National Power ICs Databook 1995

National Semiconductor

400037

National Power ICs Databook

Linear Voltage Regulators
Low Dropout Voltage Regulators
Switching Voltage Regulators
Motion Control
Surface Mount

POWER IC's
DATABOOK

1995 Edition

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Definition of Terms

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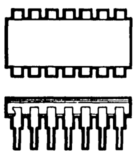
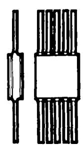
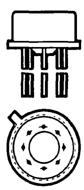
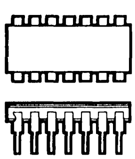
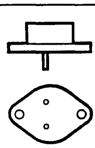
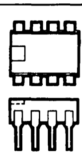
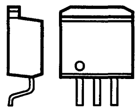
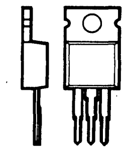
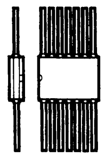
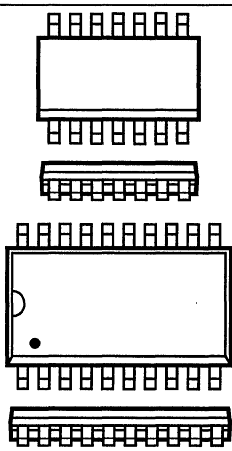
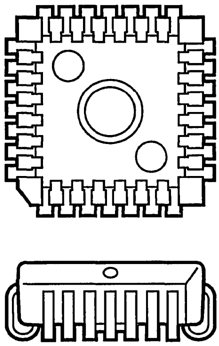
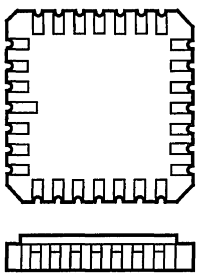
Industry Package Cross-Reference Guide

		NSC	NSC µA	Signetics	Motorola	TI	AMD	Sprague
	4/16 Lead Glass/Metal DIP	D	D	I	L		D	R
	Glass/Metal Flat Pack	F	F	Q	F	F, S	F	
	TO-99, TO-100, TO-5	H	H	T, K, L, DB	G	L	H	
	8-, 14- and 16-Lead Low Temperature Ceramic DIP	J	R, D	F	U	J	D	H
	TO-3 (Steel)	K			KS			
	TO-3 (Aluminum)	KC	K	DA	K	K		
	8-, 14- and 16-Lead Plastic DIP	N	T, P	N, V	P	P, N	P	A, B, M

		NSC	NSC μA	Signetics	Motorola	TI	AMD	Sprague
	TO-263 3- & 5-Lead	S						
	TO-220 3- & 5-Lead	T	U	U		KC		
	TO-220 11-, 15- & 23-Lead	T						
	Low Temperature Glass Hermetic Flat Pack	W	F		F	W	F	
	TO-92 (Plastic)	Z	W	S	P	LP		
	SO (Narrow Body)	M	S	S, D	D	D		L
	(Wide Body)	WM				DW		LW
	SOT-23 5-Lead	M5						

		NSC	NSC μA	Signetics	Motorola	TI	AMD	Sprague
	PCC	V	Q	A	FN	FN	L	EP
	LCC Leadless Ceramic Chip Carrier	E	L1	G	U	FK/ FG/FH	L	EK

Section 1

Linear Voltage Regulators

1

Section 1 Contents

Voltage Regulators Definition of Terms

Current-Limit Sense Voltage: The voltage across the current limit terminals required to cause the regulator to current-limit with a short circuited output. This voltage is used to determine the value of the external current-limit resistor when external booster transistors are used.

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reductions in input voltage.

Feedback Sense Voltage: The voltage, referred to ground, on the feedback terminal of the regulator while it is operating in regulation.

Input Voltage Range: The range of dc input voltages over which the regulator will operate within specifications.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions at 125°C with maximum rated voltages and power dissipation for 1000 hours.

Maximum Power Dissipation: The maximum total device dissipation for which the regulator will operate within specifications.

Output-Input Voltage Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate within specifications.

Output Noise Voltage: The RMS ac voltage at the output with constant load and no input ripple, measured over a specified frequency range.

Output Voltage Range: The range of regulated output voltages over which the specifications apply.

Output Voltage Scale Factor: The output voltage obtained for a unit value of resistance between the adjustment terminal and ground.

Quiescent Current: That part of input current to the regulator that is not delivered to the load.

Ripple Rejection: The line regulation for ac input signals at or above a given frequency with a specified value of bypass capacitor on the reference bypass terminal.

Standby Current Drain: That part of the operating current of the regulator which does not contribute to the load current. (See Quiescent Current)

Temperature Stability: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Thermal Regulation: Percentage change in output voltage for a given change in power dissipation over a specified time period.

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Linear Voltage Regulators Selection Guide

Adjustable Positive Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Input Voltage (V)*	Operating Temperature (Tj °C)	Package Availability**	Page No.
5.0	LM138	1.2 to 32	Diff. ≤ 40	−55 to +150	K2	1-83
	LM338	1.2 to 32	Diff. ≤ 40	0 to +125	K2, T3	1-83
3.0	LM150	1.2 to 32	Diff. ≤ 35	−55 to +150	K2	1-114
	LM350	1.2 to 32	Diff. ≤ 35	0 to +125	K2, T3	1-114
	LM350A	1.2 to 32	Diff. ≤ 35	−40 to +125	T3	1-114
1.5	LM117	1.2 to 37	Diff. ≤ 40	−55 to +150	K2	1-20
	LM117A	1.2 to 37	Diff. ≤ 40	−55 to +150	K2***	1-20
	LM117HV	1.2 to 57	Diff. ≤ 60	−55 to +150	K2***	1-32
	LM317	1.2 to 37	Diff. ≤ 40	0 to +125	K2, S3, T3	1-20
	LM317A	1.2 to 37	Diff. ≤ 40	−40 to +125	T3	1-20
	LM317HV	1.2 to 57	Diff. ≤ 60	0 to +125	K2, T3	1-32
0.5	LM117	1.2 to 37	Diff. ≤ 40	−55 to +150	H3, E20***	1-20
	LM117A	1.2 to 37	Diff. ≤ 40	−55 to +150	H3***	1-20
	LM117HV	1.2 to 57	Diff. ≤ 60	−55 to +150	H3	1-32
	LM317	1.2 to 37	Diff. ≤ 40	0 to +125	H3	1-20
	LM317A	1.2 to 37	Diff. ≤ 40	−40 to +125	H3	1-20
	LM317HV	1.2 to 57	Diff. ≤ 60	0 to +125	H3	1-32
0.1	LM317L	1.2 to 37	Diff. ≤ 40	−40 to +125	M8, Z3	1-20

*In cases where the regulator is "floating" the maximum input-to-output voltage differential is listed.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.
E: Leadless Ceramic Chip Carrier
H: Metal Can (TO-39, TO-99)
K: Metal Can (TO-3)
M: Small Outline Molded Package (Surface Mount)
S: TO-263 (Power Surface Mount)
T: TO-220
Z: TO-92

***Available in indicated package only as a military specified device.

Adjustable Negative Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Input Voltage (V)*	Operating Temperature (Tj °C)	Package Availability**	Page No.
3.0	LM133	−1.2 to −32	Diff. ≤ 35	−55 to +150	K2	1-64
	LM333	−1.2 to −32	Diff. ≤ 35	−40 to +125	K2, T3	1-64
1.5	LM137	−1.2 to −37	Diff. ≤ 40	−55 to +150	K2***	1-71
	LM137A	−1.2 to −37	Diff. ≤ 40	−55 to +150	K2***	1-77
	LM137HV	−1.2 to −47	Diff. ≤ 50	−55 to +150	K2***	1-71
	LM337	−1.2 to −37	Diff. ≤ 40	0 to +125	K2, T3	1-71
	LM337HV	−1.2 to −47	Diff. ≤ 50	0 to +125	K2	1-77
0.5	LM137	−1.2 to −37	Diff. ≤ 40	−55 to +150	H3	1-71
	LM137A	−1.2 to −37	Diff. ≤ 40	−55 to +150	H3***	1-71
	LM137HV	−1.2 to −47	Diff. ≤ 50	−55 to +150	H3***	1-77
	LM337	−1.2 to −37	Diff. ≤ 40	0 to +125	H3	1-71
	LM337HV	−1.2 to −47	Diff. ≤ 50	0 to +125	H3	1-77
0.1	LM337L	−1.2 to −37	Diff. ≤ 40	−25 to +125	M8, Z3	1-71

*In cases where the regulator is "floating" the maximum input-to-output voltage differential is listed.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.
H: Metal Can (TO-39, TO-99)
K: Metal Can (TO-3)
M: Small Outline Molded Package (Surface Mount)
T: TO-220
Z: TO-92

***Available in indicated package only as a military specified device.

Building Block Adjustable Positive and Negative Voltage Regulators

Output Current (mA)	Device	Output Voltage (V)	Input Voltage (V)	Operating Temperature (Tj °C)	Package Availability*	Page No.
150	LM723	2 to 37	9.5 to 40	−55 to +150	H10, J14**, E20**	1-149
	LM723C	2 to 37	9.5 to 40	0 to +150	H10, N14	1-149
45	LM105	4.5 to 40	8.5 to 50	−55 to +150	H8	1-8
	LM305	4.5 to 40	8.5 to 50	0 to +85	H8	1-8
	LM305A	4.5 to 40	8.5 to 50	0 to +150	H8	1-8

*Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.
E: Leadless Ceramic Chip Carrier
H: Metal Can (TO-99, TO-100)
J: Ceramic Dual-In-Line Package
N: Molded Dual-In-Line Package

**Available in indicated package only as a military specified device.

Fixed Positive Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Max. Input Voltage (V)	Operating Temperature (Tj °C)	Package Availability*	Page No.
3.0	LM123	5	20	−55 to +150	K2	1-51
	LM323	5	20	0 to +125	K2	1-51
	LM323A	5	20	−40 to +125	K2	1-51
1.0	LM140	5, 12, 15	35	−55 to +150	K2	1-95
	LM140A	5, 12, 15	35	−55 to +150	K2**	1-95
	LM340	5, 12	35	0 to +150	K2, S3, T3	1-95
		15	35	0 to +150	K2, T3	1-95
	LM340A	5	35	0 to +150	K2, T3	1-95
		12, 15	35	0 to +150	T3	1-95
	LM78XX	5, 12, 15	35	−55 to +150	K2	1-168
	LM78XXC	5, 6, 8, 12, 15, 18, 24	35	0 to +150	T3	1-168
	LM109	5	35	−55 to +150	K2	1-14
	LM309	5	35	0 to +125	K2	1-14
0.5	LM140	5, 6, 8, 12, 15, 24	35	−55 to +150	H3**	1-95
	LM140A	15	35	−55 to +150	H3**	1-95
	LM341	5, 12, 15	35	−40 to +125	T3	1-143
	LM78MXXC	5, 12, 15	35	−40 to +125	H3	1-143
0.2	LM109	5	35	−55 to +150	H3	1-14
	LM309	5	35	0 to +125	H3	1-14
0.1	LM140LA	5, 12, 15	35	−55 to +150	H3	1-106
	LM340LA	5, 12, 15	35	0 to +150	H3, Z3	1-106
	LM78LXXAC	5, 12, 15	35	0 to +125	H3, M8	1-158
	LM78LXXAC	5, 6.2, 8.2, 9, 12, 15	35	0 to +125	Z3	1-158

*Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.
H: Metal Can (TO-39)
K: Metal Can (TO-3)
M: Small Outline Molded Package (Surface Mount)
S: TO-263 (Power Surface Mount)
T: TO-220
Z: TO-92

**Available in indicated package only as a military specified device.

Fixed Negative Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Min. Input Voltage (V)	Operating Temperature (Tj °C)	Package Availability*	Page No.
3.0	LM145	−5, −5.2	−20	−55 to +150	K2**	1-110
	LM345	−5	−20	0 to +125	K2	1-110
1.5	LM120	−5	−25	−55 to +150	K2**	1-42
		−12, −15	−35	−55 to +150	K2**	1-42
	LM320	−5	−25	0 to +125	K2, T3	1-42
		−12, −15	−35	0 to +125	K2, T3	1-42
	LM79XXC	−5	−35	0 to +125	T3	1-178
		−12, −15	−40	0 to +125	T3	1-178
0.5	LM120	−5	−25	−55 to +150	H3	1-42
	LM320	−5	−25	0 to +125	H3	1-42
	LM79MXXC	−5	−25	0 to +125	T3	1-171
		−12, −15	−35	0 to +125	T3	1-171
0.2	LM120	−12, −15	−35	−55 to +150	H3	1-42
	LM320	−12, −15	−35	0 to +125	H3	1-42
0.1	LM320L	−5, −12, −15	−35	0 to +125	Z3	1-137
	LM79LXXAC	−5, −12, −15	−35	0 to +125	M8, Z3	1-158

Shunt Voltage Regulators

Output Current (A)	Device	Output Voltage (V)	Max. Input Voltage (V)	Operating Temperature (Tj °C)	Package Availability*	Page No.
0.15	LM431AI	2.5 to 36	37	−40 to +150	Z3	3-188
	LM431AC	2.5 to 36	37	0 to +150	M8, Z3	3-188

*Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: T5 = 5-Lead TO-220, and M8 = 8-Lead Surface Mount.
H: Metal Can (TO-39)
K: Metal Can (TO-3)
M: Small Outline Molded Package (Surface Mount)
T: TO-220
Z: TO-92

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National Semiconductor

LM105/LM205/LM305/LM305A, LM376 Voltage Regulators

General Description

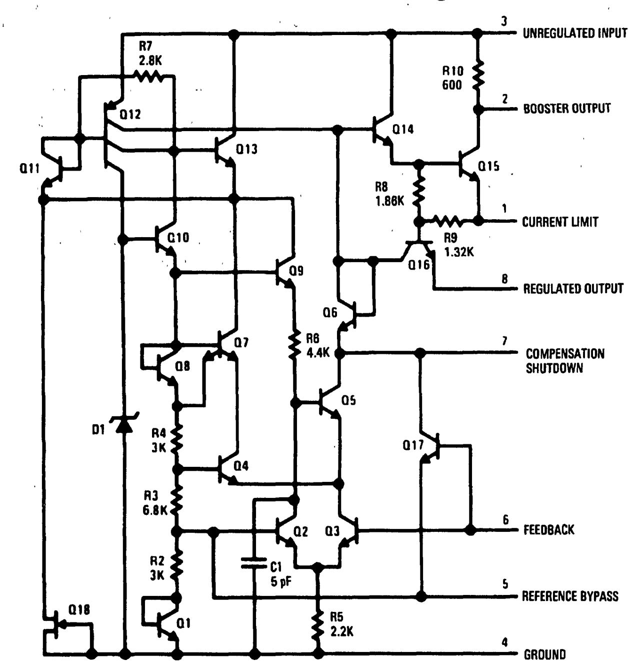
The LM105 series are positive voltage regulators similar to the LM100, except that an extra gain stage has been added for improved regulation. A redesign of the biasing circuitry removes any minimum load current requirement and at the same time reduces standby current drain, permitting higher voltage operation. They are direct, plug-in replacements for the LM100 in both linear and switching regulator circuits with output voltages greater than 4.5V. Important characteristics of the circuits are:

- Output voltage adjustable from 4.5V to 40V
- Output currents in excess of 10A possible by adding external transistors
- Load regulation better than 0.1%, full load with current limiting
- DC line regulation guaranteed at 0.03%/V
- Ripple rejection on 0.01%V
- 45 mA output current without external pass transistor (LM305A)

Like the LM100, they also feature fast response to both load and line transients, freedom from oscillations with varying resistive and reactive loads and the ability to start reliably on any load within rating. The circuits are built on a single silicon chip and are supplied in a TO-99 metal can.

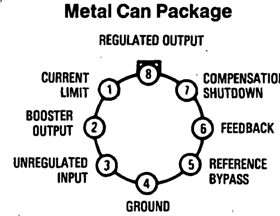
The LM105 is specified for operation for $-55^{\circ}C \leq T_A \leq +125^{\circ}C$, and the LM305/LM305A is specified for $0^{\circ}C \leq T_A \leq +70^{\circ}C$.

Schematic and Connection Diagrams



TL/H/7755-1

Metal Can Package



TL/H/7755-3

Top View

Order Number LM105H, LM105H/883, SMD #5962-8958801, LM305H or LM305AH
See NS Package Number H08C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.
(Note 5)

	LM105	LM305	LM305A
Input Voltage	50V	40V	50V
Input-Output Differential	40V	40V	40V
Power Dissipation (Note 1)	800 mW	800 mW	800 mW
Operating Temperature Range	−55°C to +125°C	−0°C to +70°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C	300°C	300°C

Electrical Characteristics (Note 2)

Parameter	Conditions	LM105			LM305			LM305A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Voltage Range		8.5		50	8.5		40	8.5		50	V
Output Voltage Range		4.5		40	4.5		30	4.5		40	V
Input-Output Voltage Differential		3.0		30	3.0		30	3.0		30	V
Load Regulation (Note 3)	$R_{SC} = 10\Omega$, $T_A = 25°C$		0.02	0.05		0.02	0.05				%
	$R_{SC} = 10\Omega$, $T_A = T_{A(MAX)}$		0.03	0.1		0.03	0.1				%
	$R_{SC} = 10\Omega$, $T_A = T_{A(MIN)}$		0.03	0.1		0.03	0.1				%
		$0 \le I_O \le 12$ mA			$0 \le I_O \le 12$ mA						
	$R_{SC} = 0\Omega$, $T_A = 25°C$								0.02	0.2	%
	$R_{SC} = 0\Omega$, $T_A = 70°C$								0.03	0.4	%
	$R_{SC} = 0\Omega$, $T_A = 0°C$								0.03	0.4	%
								$0 \le I_O \le 45$ mA			
Line Regulation	$T_A = 25°C$										%/V
	$0°C \le T_A \le +70°C$										%/V
	$V_{IN} - V_{OUT} \le 5V$, $T_A = 25°C$		0.025	0.06		0.025	0.06		0.025	0.06	%/V
	$V_{IN} - V_{OUT} \ge 5V$, $T_A = 25°C$		0.015	0.03		0.015	0.03		0.015	0.03	%/V
Temperature Stability	$T_{A(MIN)} \le T_A \le T_{A(MAX)}$		0.3	1.0		0.3	1.0		0.3	1.0	%

1

Electrical Characteristics (Note 2) (Continued)

Parameter	Conditions	LM105			LM305			LM305A			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Feedback Sense Voltage		1.63	1.7	1.81	1.63	1.7	1.81	1.55	1.7	1.85	V
Output Noise Voltage	$10\ Hz \leq f \leq 10\ kHz$										
	$C_{REF} = 0$		0.005			0.005			0.005		%
	$C_{REF} = 0.1\ \mu F$		0.002			0.002			0.002		%
Standby Current Drain	$V_{IN} = 30V, T_A = 25°C$										mA
	$V_{IN} = 40V$					0.8	2.0				mA
	$V_{IN} = 50V$		0.8	2.0					0.8	2.0	mA
Current Limit Sense Voltage	$T_A = 25°C, R_{SC} = 10\Omega$, $V_{OUT} = 0V$, (Note 4)	225	300	375	225	300	375	225	300	375	mV
Long Term Stability			0.1			0.1			0.1		%
Ripple Rejection	$C_{REF} = 10\ \mu F, f = 120\ Hz$		0.003			0.003			0.003		%/V
θ_{JA}	TO-99 Board Mount in Still Air		230			230			230		°C/W
θ_{JA}	TO-99 Board Mount in 400 LF/Min Air Flow		92			92			92		°C/W
θ_{JC}	TO-99		25			25			25		°C/W

Note 1: The maximum junction temperature of the LM105 and LM305A is 150°C, and the LM305 is 85°C. For operation at elevated temperatures, devices in the H08C package must be derated based on a thermal resistance of 168°C/W junction to ambient, or 25°C/W junction to case. Peak dissipations to 1W are allowable providing the dissipation rating is not exceeded with the power average over a five second interval for the LM105 and averaged over a two second interval for the LM305.

Note 2: Unless otherwise specified, these specifications apply for temperatures within the operating temperature range, for input and output voltages within the range given, and for a divider impedance seen by the feedback terminal of 2 kΩ. Load and line regulation specifications are for a constant junction temperature. Temperature drift effects must be taken into account separately when the unit is operating under conditions of high dissipation.

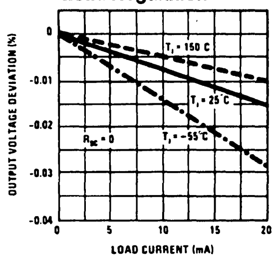
Note 3: The output currents given, as well as the load regulation, can be increased by the addition of external transistors. The improvement factor will be roughly equal to the composite current gain of the added transistors.

Note 4: With no external pass transistor.

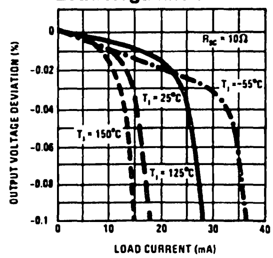
Note 5: Refer to RETS105X Drawing for military specifications for the LM105.

Typical Performance Characteristics LM105/LM305/LM305A

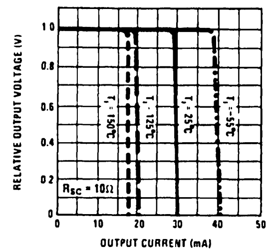
Load Regulation



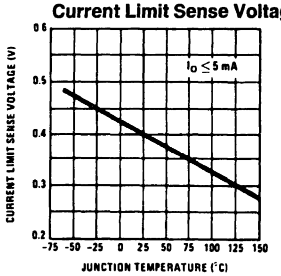
Load Regulation



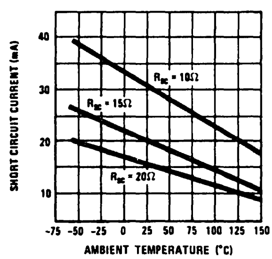
Current Limiting Characteristics



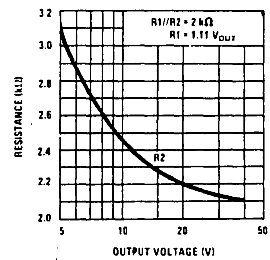
Current Limit Sense Voltage



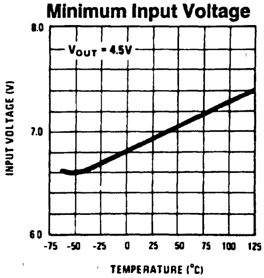
Short Circuit Current



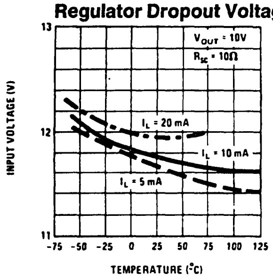
Optimum Divider Resistance Values



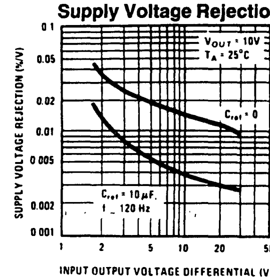
Minimum Input Voltage



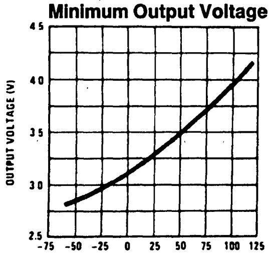
Regulator Dropout Voltage



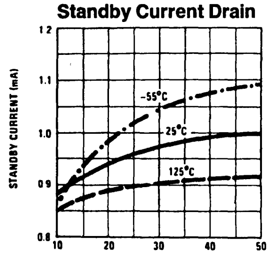
Supply Voltage Rejection



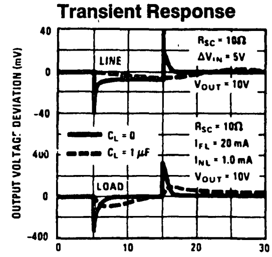
Minimum Output Voltage



Standby Current Drain



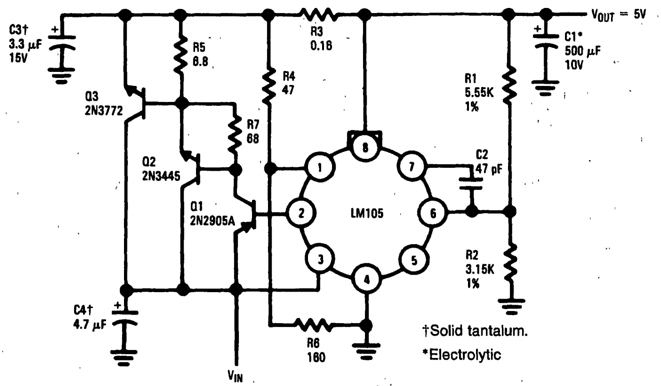
Transient Response



TL/H/7755-6

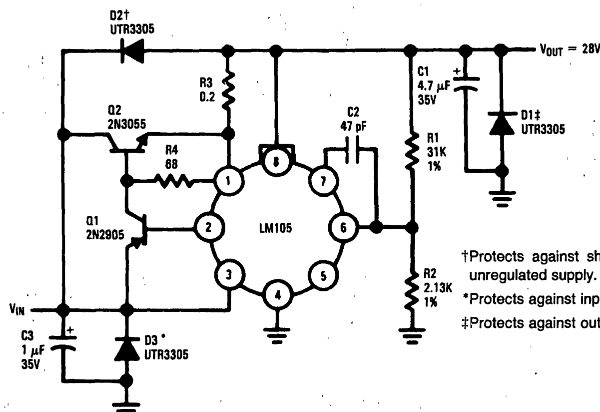
Typical Applications

10A Regulator with Foldback Current Limiting



TL/H/7755-4

1.0A Regulator with Protective Diodes



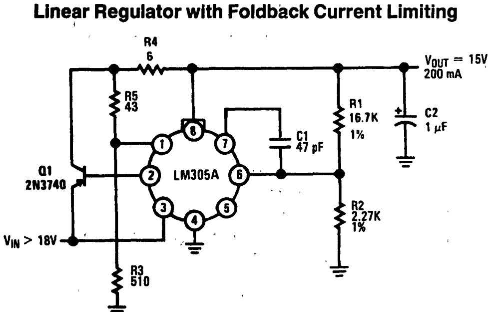
†Protects against shorted input or inductive leads on unregulated supply.

*Protects against input voltage reversal.

‡Protects against output voltage reversal.

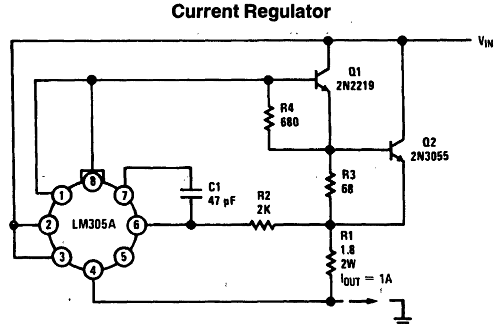
TL/H/7755-5

Linear Regulator with Foldback Current Limiting



TL/H/7755-8

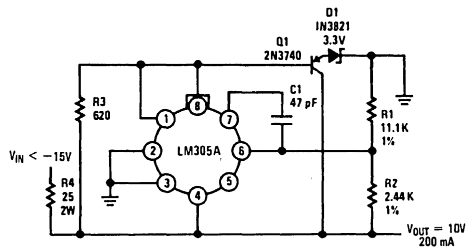
Current Regulator



TL/H/7755-9

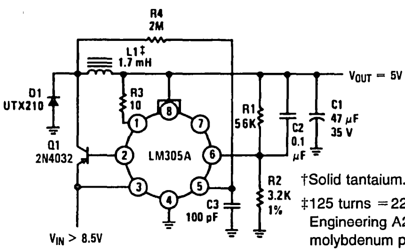
Typical Applications (Continued)

Shunt Regulator



TL/H/7755-10

Switching Regulator

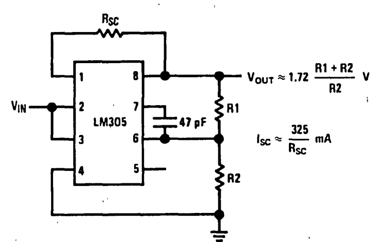


†Solid tantaium.

‡125 turns = 22 on Arnold Engineering A262123-2 molybdenum permally core.

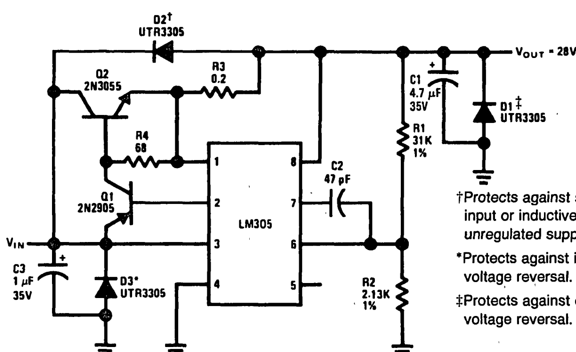
TL/H/7755-11

Basic Positive Regulator with Current Limiting



TL/H/7755-12

1.0A Regulator with Protective Diodes



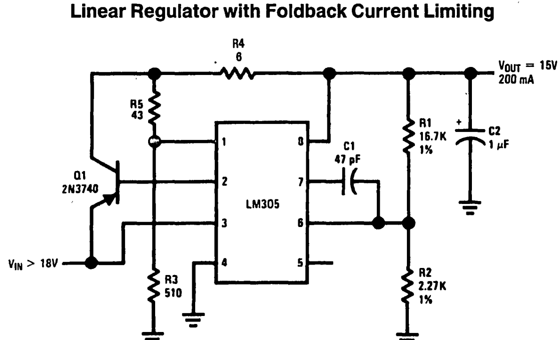
†Protects against shorted input or inductive loads on unregulated supply.

*Protects against input voltage reversal.

‡Protects against output voltage reversal.

TL/H/7755-13

Linear Regulator with Foldback Current Limiting



TL/H/7755-14

National Semiconductor

LM109/LM309 5-Volt Regulator

General Description

The LM109 series are complete 5V regulators fabricated on a single silicon chip. They are designed for local regulation on digital logic cards, eliminating the distribution problems association with single-point regulation. The devices are available in two standard transistor packages. In the solid-kovar TO-5 header, it can deliver output currents in excess of 200 mA, if adequate heat sinking is provided. With the TO-3 power package, the available output current is greater than 1A.

The regulators are essentially blowout proof. Current limiting is included to limit the peak output current to a safe value. In addition, thermal shutdown is provided to keep the IC from overheating. If internal dissipation becomes too great, the regulator will shut down to prevent excessive heating.

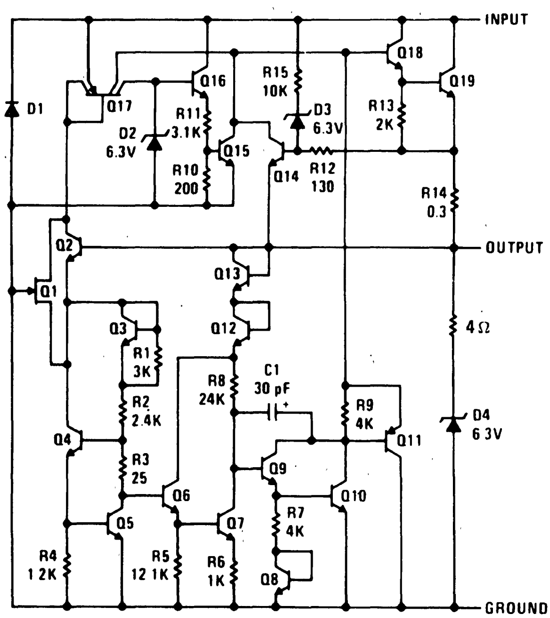
Considerable effort was expended to make these devices easy to use and to minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response somewhat. Input bypassing is needed, however, if the regulator is located very far from the filter capacitor of the power supply. Stability is also achieved by methods that provide very good rejection of load or line transients as are usually seen with TTL logic.

Although designed primarily as a fixed-voltage regulator, the output of the LM109 series can be set to voltages above 5V, as shown. It is also possible to use the circuits as the control element in precision regulators, taking advantage of the good current-handling capability and the thermal overload protection.

Features

- Specified to be compatible, worst case, with TTL and DTL
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required

Schematic Diagram



TL/H/7138-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 3)

Input Voltage	35V
Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM109	−55°C to +150°C
LM309	0°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics (Note 1)

Parameter	Conditions	LM109			LM309			Units
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_j = 25°C$	4.7	5.05	5.3	4.8	5.05	5.2	V
Line Regulation	$T_j = 25°C$ $7.10V \leq V_{IN} \leq 25V$		4.0	50		4.0	50	mV
Load Regulation TO-39 Package TO-3 Package	$T_j = 25°C$ $5\ mA \leq I_{OUT} \leq 0.5A$ $5\ mA \leq I_{OUT} \leq 1.5A$		 15 15	 50 100		 15 15	 50 100	 mV mV
Output Voltage	$7.40V \leq V_{IN} \leq 25V$, $5\ mA \leq I_{OUT} \leq I_{MAX}$, $P < P_{MAX}$	4.6		5.4	4.75		5.25	V
Quiescent Current	$7.40V \leq V_{IN} \leq 25V$		5.2	10		5.2	10	mA
Quiescent Current Change	$7.40V \leq V_{IN} \leq 25V$ $5\ mA \leq I_{OUT} \leq I_{MAX}$			0.5 0.8			0.5 0.8	mA mA
Output Noise Voltage	$T_A = 25°C$ $10\ Hz \leq f \leq 100\ kHz$		40			40		μV
Long Term Stability			10			20		mV
Ripple Rejection	$T_j = 25°C$	50			50			dB
Thermal Resistance, Junction to Case TO-39 Package TO-3 Package	(Note 2)		 15 2.5			 15 2.5		 °C/W °C/W

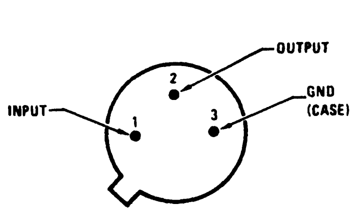
Note 1: Unless otherwise specified, these specifications apply $-55°C \leq T_j \leq +150°C$ for the LM109 and $0°C \leq T_j \leq +125°C$ for the LM309; $V_{IN} = 10V$; and $I_{OUT} = 0.1A$ for the TO-39 package or $I_{OUT} = 0.5A$ for the TO-3 package. For the TO-39 package, $I_{MAX} = 0.2A$ and $P_{MAX} = 2.0W$. For the TO-3 package, $I_{MAX} = 1.0A$ and $P_{MAX} = 20W$.

Note 2: Without a heat sink, the thermal resistance of the TO-39 package is about 150°C/W, while that of the TO-3 package is approximately 35°C/W. With a heat sink, the effective thermal resistance can only approach the values specified, depending on the efficiency of the sink.

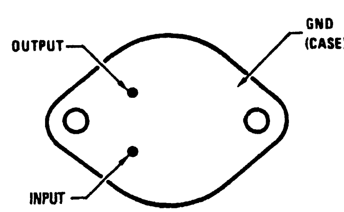
Note 3: Refer to RETS109H drawing for LM109H or RETS109K drawing for LM109K military specifications.

Connection Diagrams

Metal Can Packages



Order Number LM109H, LM109H/883 or LM309H
See NS Package Number H03A



TL/H/7138-3

Order Number LM109K STEEL or LM309K STEEL
See NS Package Number K02A
Order Number LM109K/883
See NS Package Number K02C

Application Hints

a. Bypass the input of the LM109 to ground with ≥ 0.2 μF ceramic or solid tantalum capacitor if main filter capacitor is more than 4 inches away.

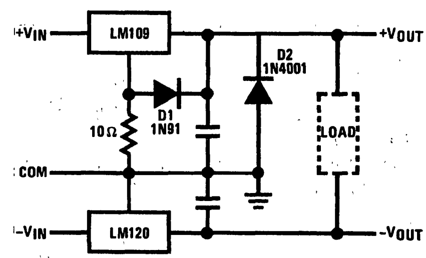
b. Avoid insertion of regulator into "live" socket if input voltage is greater than 10V. The output will rise to within 2V of the unregulated input if the ground pin does not make contact, possibly damaging the load. The LM109 may also be damaged if a large output capacitor is charged up, then discharged through the internal clamp zener when the ground pin makes contact.

c. The output clamp zener is designed to absorb transients only. It will not clamp the output effectively if a failure occurs in the internal power transistor structure. Zener dynamic impedance is ≈ 4Ω. Continuous RMS current into the zener should not exceed 0.5A.

d. Paralleling of LM109s for higher output current is not recommended. Current sharing will be almost nonexistent, leading to a current limit mode operation for devices with the highest initial output voltage. The current limit devices may also heat up to the thermal shutdown point (≈ 175°C). Long term reliability cannot be guaranteed under these conditions.

e. Preventing latchoff for loads connected to negative voltage:

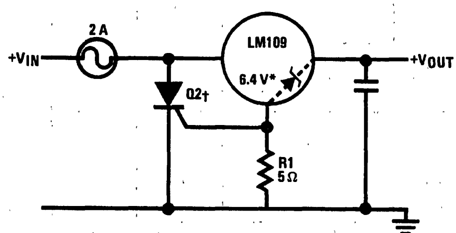
If the output of the LM109 is pulled negative by a high current supply so that the output pin is more than 0.5V negative with respect to the ground pin, the LM109 can latch off. This can be prevented by clamping the ground pin to the output pin with a germanium or Schottky diode as shown. A silicon diode (1N4001) at the output is also needed to keep the positive output from being pulled too far negative. The 10Ω resistor will raise $+V_{OUT}$ by ≈ 0.05V.



TL/H/7138–7

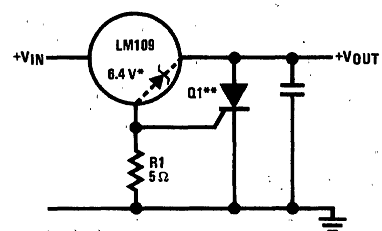
Crowbar Overvoltage Protection

Input Crowbar



TL/H/7138–8

Output Crowbar



TL/H/7138–9

*Zener is internal to LM109.

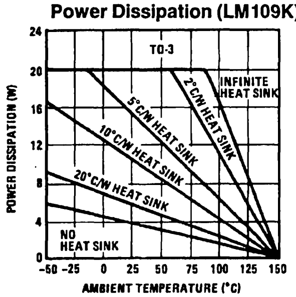
**Q1 must be able to withstand 7A continuous current if fusing is not used at regulator input. LM109 bond wires will fuse at currents above 7A.

†Q2 is selected for surge capability. Consideration must be given to filter capacitor size, transformer impedance, and fuse blowing time.

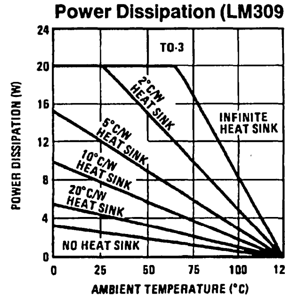
††Trip point is ≈ 7.5V.

Typical Performance Characteristics

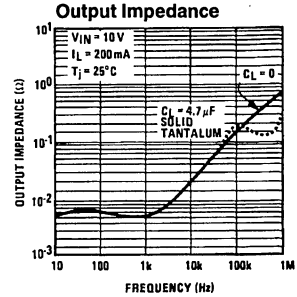
Maximum Average Power Dissipation (LM109K)



Maximum Average Power Dissipation (LM309K)

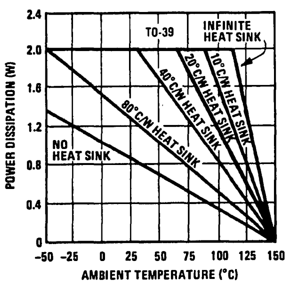


Output Impedance

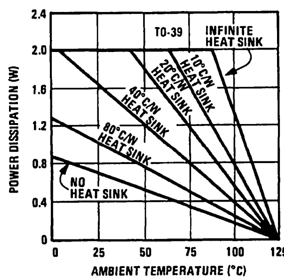


TL/H/7138–10

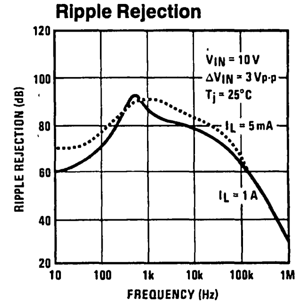
Maximum Average Power Dissipation (LM109H)



Maximum Average Power Dissipation (LM309H)

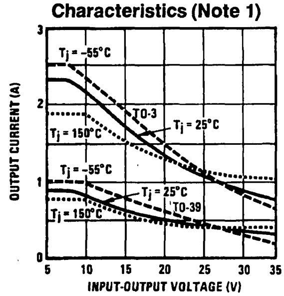


Ripple Rejection

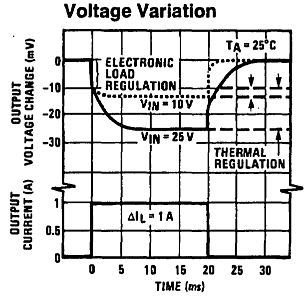


TL/H/7138–11

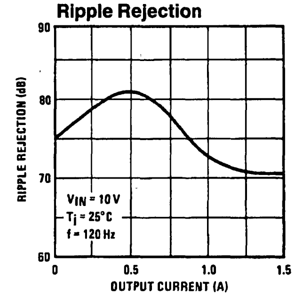
Current Limit Characteristics (Note 1)



Thermally Induced Output Voltage Variation



Ripple Rejection

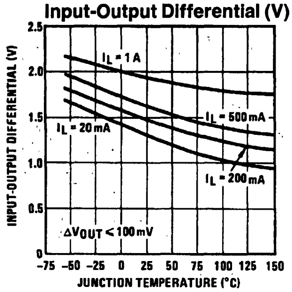


TL/H/7138–12

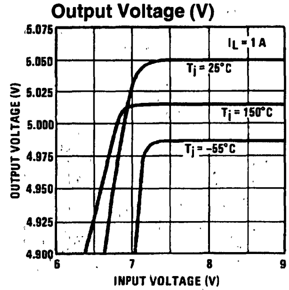
Note 1: Current limiting foldback characteristics are determined by input output differential, not by output voltage.

Typical Performance Characteristics (Continued)

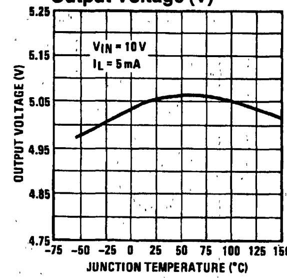
Input-Output Differential (V)



Output Voltage (V)

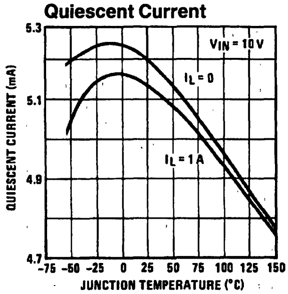


Output Voltage (V)

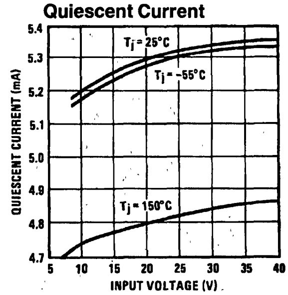


TL/H/7138–13

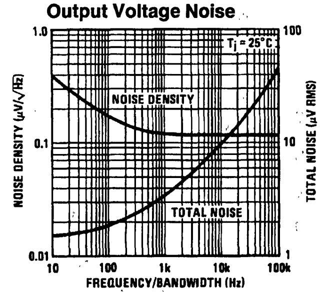
Quiescent Current



Quiescent Current

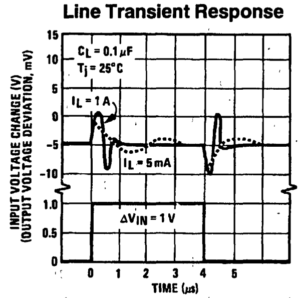


Output Voltage Noise

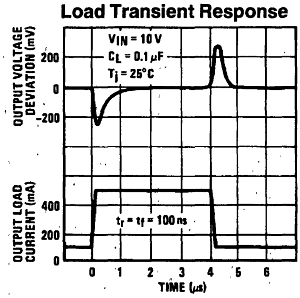


TL/H/7138–14

Line Transient Response



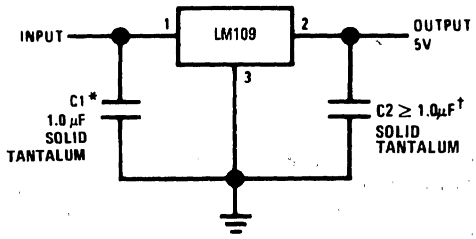
Load Transient Response



TL/H/7138–15

Typical Applications

Fixed 5V Regulator



TL/H/7138-2

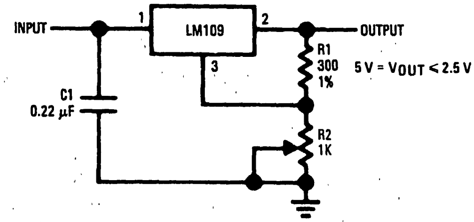
*Required if regulator is located more than 4″ from power supply filter capacitor.

†Although no output capacitor is needed for stability, it does improve transient response.

C2 should be used whenever long wires are used to connect to the load, or when transient response is critical.

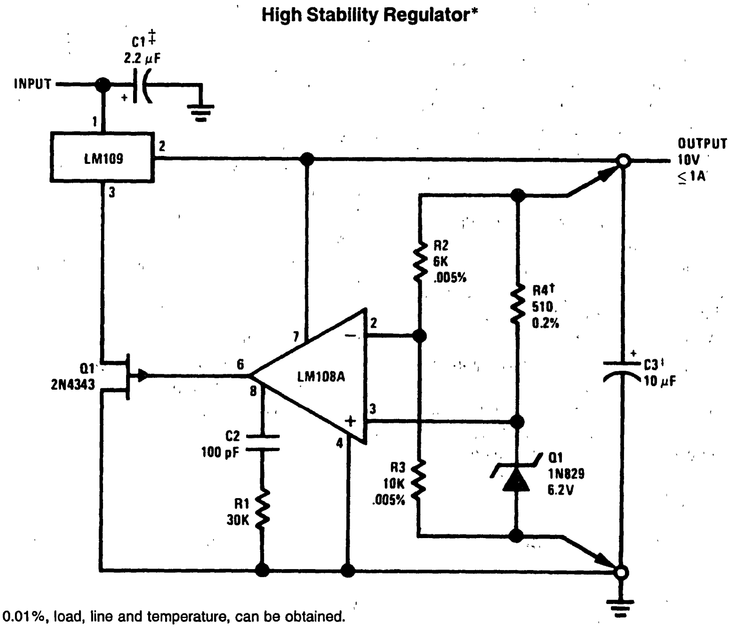
Note: Pin 3 electrically connected to case.

Adjustable Output Regulator



TL/H/7138-4

High Stability Regulator*



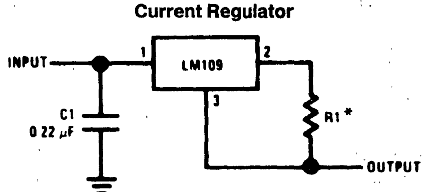
*Regulation better than 0.01%, load, line and temperature, can be obtained.

†Determines zener current. May be adjusted to minimize thermal drift.

‡Solid tantalum.

TL/H/7138-5

Current Regulator



TL/H/7138-6

*Determines output current. If wirewound resistor is used, bypass with 0.1 µF.

1

National Semiconductor

LM117/LM317A/LM317 3-Terminal Adjustable Regulator

General Description

The LM117 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 1.5A over a 1.2V to 37V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment pin and output, the LM117 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

For applications requiring greater output current, see LM150 series (3A) and LM138 series (5A) data sheets. For the negative complement, see LM137 series data sheet.

LM117 Series Packages and Power Capability

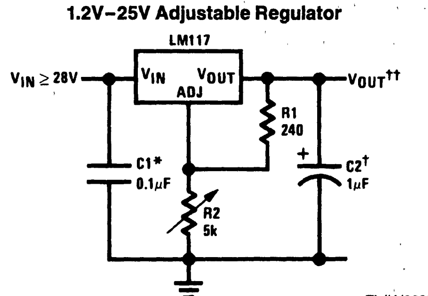
Part Number Suffix	Package	Rated Power Dissipation	Design Load Current
K	TO-3	20W	1.5A
H	TO-39	2W	0.5A
T	TO-220	20W	1.5A
E	LCC	2W	0.5A
S	TO-263	4W	1.5A

Features

- Guaranteed 1% output voltage tolerance (LM317A)
- Guaranteed max. 0.01%/V line regulation (LM317A)
- Guaranteed max. 0.3% load regulation (LM117)
- Guaranteed 1.5A output current
- Adjustable output down to 1.2V
- Current limit constant with temperature
- P+ Product Enhancement tested
- 80 dB ripple rejection
- Output is short-circuit protected

Typical Applications

1.2V–25V Adjustable Regulator



TL/H/9063-1

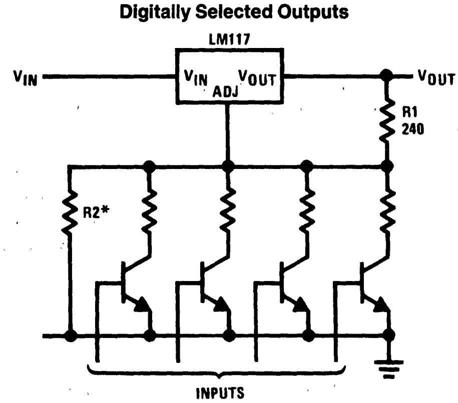
Full output current not available at high input-output voltages

*Needed if device is more than 6 inches from filter capacitors.

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

$$††V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

Digitally Selected Outputs



TL/H/9063-2

*Sets maximum V_{OUT}

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 2)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300°C
Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance (Note 5)	3 kV

Operating Temperature Range

LM117	$-55°C \le T_J \le +150°C$
LM317A	$-40°C \le T_J \le +125°C$
LM317	$0°C \le T_J \le +125°C$

Preconditioning

Thermal Limit Burn-In	All Devices 100%

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT} = 5V$, and $I_{OUT} = 10$ mA. (Note 3)

Parameter	Conditions	LM117 (Note 2)			Units
		Min	Typ	Max	
Reference Voltage					V
	$3V \le (V_{IN} - V_{OUT}) \le 40V$, $10\text{ mA} \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	**1.20**	**1.25**	**1.30**	V
Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 40V$ (Note 4)		0.01	0.02	%/V
			0.02	**0.05**	%/V
Load Regulation	$10\text{ mA} \le I_{OUT} \le I_{MAX}$ (Note 4)		0.1	0.3	%
			0.3	**1**	%
Thermal Regulation	20 ms Pulse		0.03	0.07	%/W
Adjustment Pin Current			**50**	**100**	μA
Adjustment Pin Current Change	$10\text{ mA} \le I_{OUT} \le I_{MAX}$ $3V \le (V_{IN} - V_{OUT}) \le 40V$		**0.2**	**5**	μA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 40V$		**3.5**	**5**	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$ K Package H, K Packages	 **1.5** **0.5**	 **2.2** **0.8**	 **3.4** **1.8**	 A A
	$(V_{IN} - V_{OUT}) = 40V$ K Package H, K Packages	 0.3 0.15	 0.4 0.2		 A A
RMS Output Noise, % of V_{OUT}	$10\text{ Hz} \le f \le 10\text{ kHz}$		0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10V$, f = 120 Hz, $C_{ADJ} = 0\ \mu F$		**65**		dB
	$V_{OUT} = 10V$, f = 120 Hz, $C_{ADJ} = 10\ \mu F$	**66**	**80**		dB
Long-Term Stability	$T_J = 125°C$, 1000 hrs		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package H Package E Package		2.3 12	3 15	°C/W °C/W °C/W
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package H Package E Package		35 140		°C/W °C/W °C/W

Electrical Characteristics (Continued)

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} - V_{OUT} = 5V$, and $I_{OUT} = 10$ mA. (Note 3)

Parameter	Conditions	LM317A			LM317			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage		1.238	1.250	1.262				V
	$3V \le (V_{IN} - V_{OUT}) \le 40V$, $10\text{ mA} \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	**1.225**	**1.250**	**1.270**	**1.20**	**1.25**	**1.30**	V
Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 40V$ (Note 4)		0.005	0.01		0.01	0.04	%/V
			0.01	**0.02**		**0.02**	**0.07**	%/V
Load Regulation	$10\text{ mA} \le I_{OUT} \le I_{MAX}$ (Note 4)		0.1	0.5		0.1	0.5	%
			0.3	**1**		**0.3**	**1.5**	%
Thermal Regulation	20 ms Pulse		0.04	0.07		0.04	0.07	%/W
Adjustment Pin Current			**50**	**100**		**50**	**100**	μA
Adjustment Pin Current Change	$10\text{ mA} \le I_{OUT} \le I_{MAX}$ $3V \le (V_{IN} - V_{OUT}) \le 40V$		**0.2**	**5**		**0.2**	**5**	μA
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**			**1**		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 40V$		**3.5**	**10**		**3.5**	**10**	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$ K, T Packages H, P Packages	 **1.5** **0.5**	 **2.2** **0.8**	 **3.4** **1.8**	 **1.5** **0.5**	 **2.2** **0.8**	 **3.4** **1.8**	 A A
	$(V_{IN} - V_{OUT}) = 40V$ K, T Packages H, P Packages	 0.15 0.075	 0.4 0.2		 0.15 0.075	 0.4 0.2		 A A
RMS Output Noise, % of V_{OUT}	$10\text{ Hz} \le f \le 10\text{ kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10V$, $f = 120$ Hz, $C_{ADJ} = 0\ \mu F$		**65**			**65**		dB
	$V_{OUT} = 10V$, $f = 120$ Hz, $C_{ADJ} = 10\ \mu F$	**66**	**80**		**66**	**80**		dB
Long-Term Stability	$T_J = 125°C$, 1000 hrs		0.3	1		0.3	1	%
Thermal Resistance, Junction-to-Case	K Package H Package T Package P Package		 12 4 	 15 5 		2.3 12 4 	3 15 	°C/W °C/W °C/W °C/W
Thermal Resistance, Junction-to-Ambient (No Heat Sink)	K Package H Package T Package P Package (Note 6)		35 140 50 			35 140 50 50		°C/W °C/W °C/W °C/W

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed.

Note 2: Refer to RETS117H drawing for the LM117H, or the RETS117K for the LM117K military specifications.

Note 3: Although power dissipation is internally limited, these specifications are applicable for maximum power dissipations of 2W for the TO-39 and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 packages and 0.5A for the TO-39 package. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 4: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

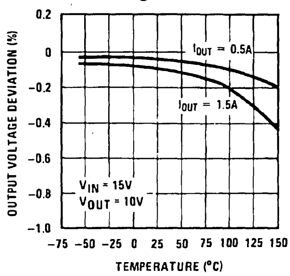
Note 5: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 6: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package: Using 0.5 square inches of copper area. θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

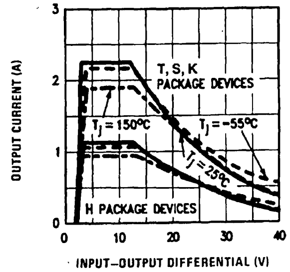
Typical Performance Characteristics

Output Capacitor = 0 μF unless otherwise noted

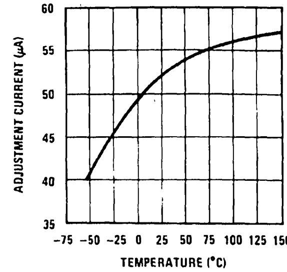
Load Regulation



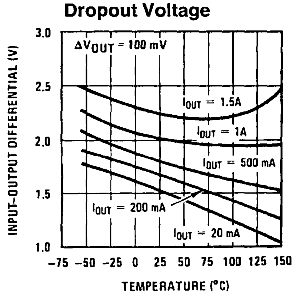
Current Limit



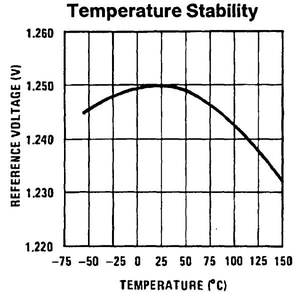
Adjustment Current



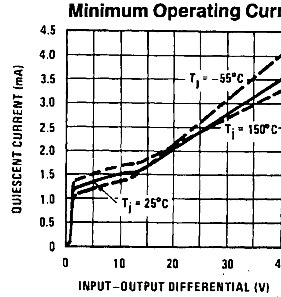
Dropout Voltage



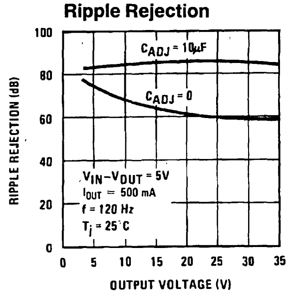
Temperature Stability



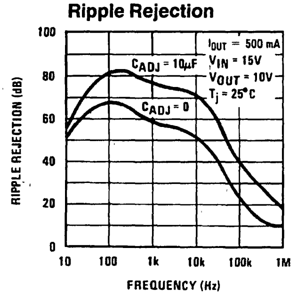
Minimum Operating Current



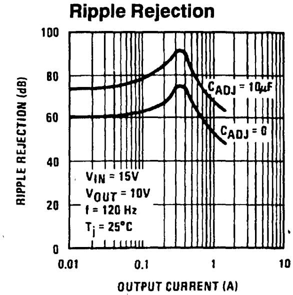
Ripple Rejection



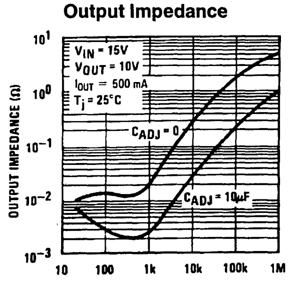
Ripple Rejection



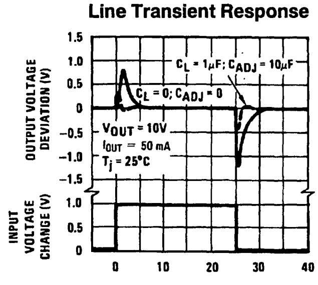
Ripple Rejection



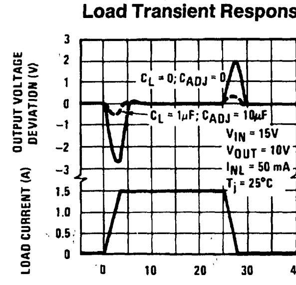
Output Impedance



Line Transient Response



Load Transient Response

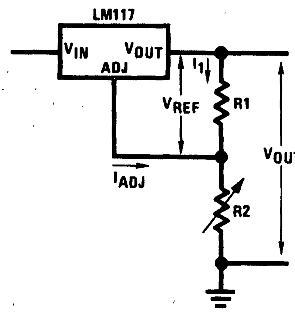


TL/H/9063–4

Application Hints

In operation, the LM117 develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$



TL/H/9063-5

FIGURE 1

Since the 100 μA current from the adjustment terminal represents an error term, the LM117 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μF disc or 1 μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM117 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μF bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

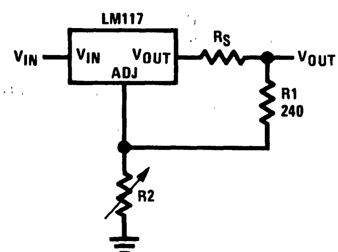
In general, the best type of capacitors to use is solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1 μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μF disc may seem to work better than a 0.1 μF disc as a bypass.

Although the LM117 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μF solid tantalum (or 25 μF aluminum electrolytic) on the output swamps this effect and insures stability. Any increase of the load capacitance larger than 10 μF will merely improve the loop stability and output impedance.

Load Regulation

The LM117 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output (case) of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω $\times$ I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.



TL/H/9063-6

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

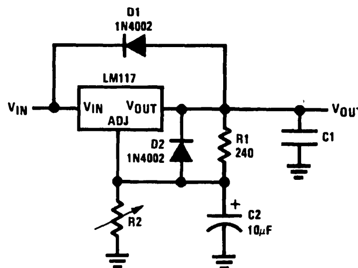
Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM117, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, there is no need to use diodes.

Application Hints (Continued)

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM117 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM117 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.



$$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

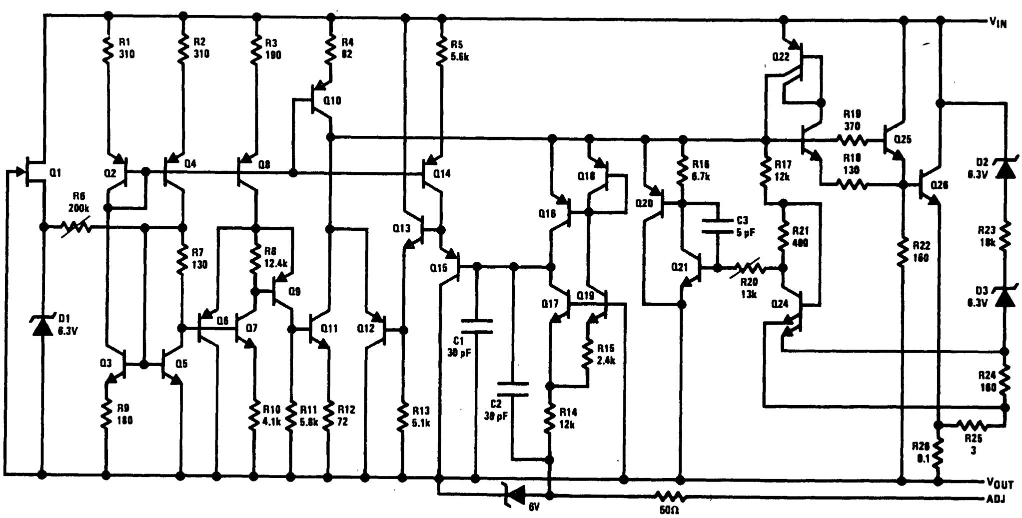
D1 protects against C1

D2 protects against C2

TL/H/9063-7

FIGURE 3. Regulator with Protection Diodes

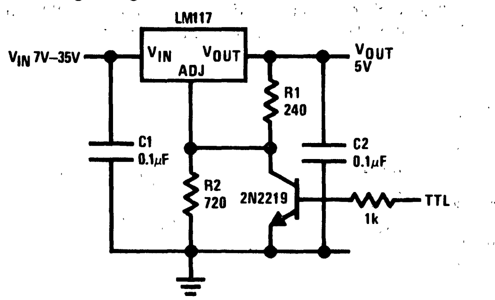
Schematic Diagram



TL/H/9063-8

Typical Applications (Continued)

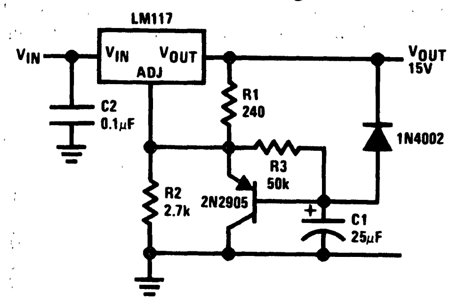
5V Logic Regulator with Electronic Shutdown*



*Min. output ≈ 1.2V

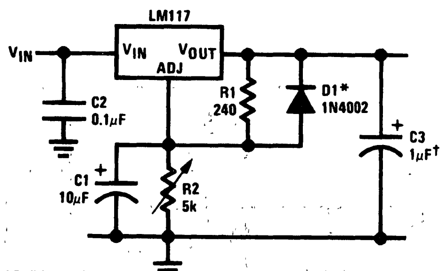
TL/H/9063-3

Slow Turn-On 15V Regulator



TL/H/9063-9

Adjustable Regulator with Improved Ripple Rejection

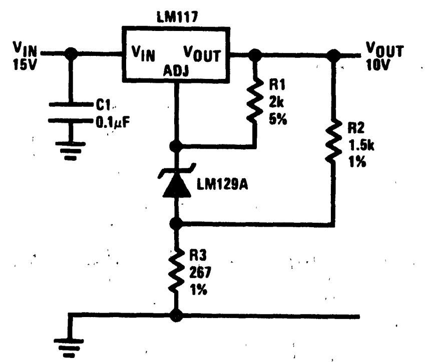


†Solid tantalum

*Discharges C1 if output is shorted to ground

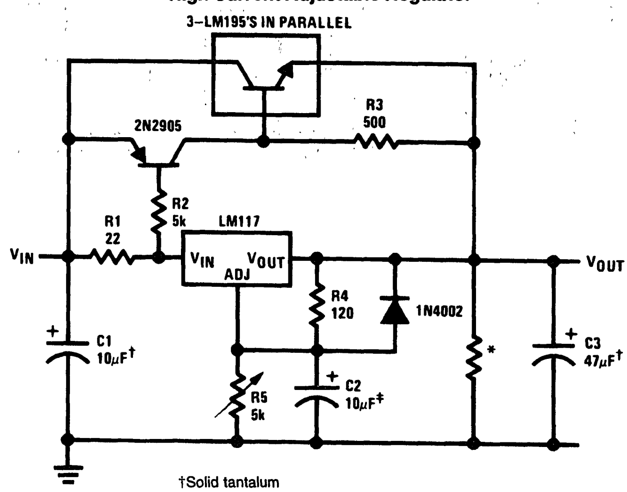
TL/H/9063-10

High Stability 10V Regulator



TL/H/9063-11

High Current Adjustable Regulator



†Solid tantalum

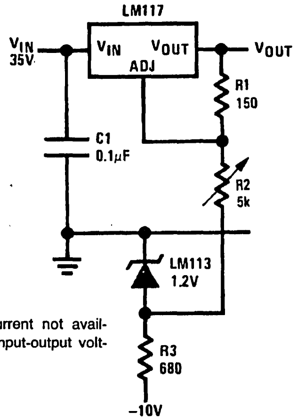
*Minimum load current = 30 mA

‡Optional—improves ripple rejection

TL/H/9063-12

Typical Applications (Continued)

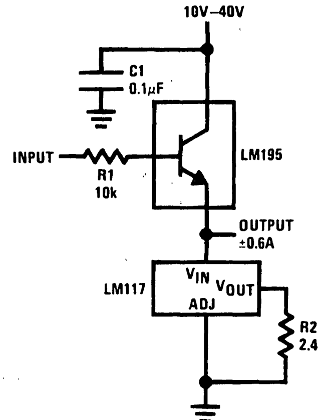
0 to 30V Regulator



Full output current not available at high input-output voltages

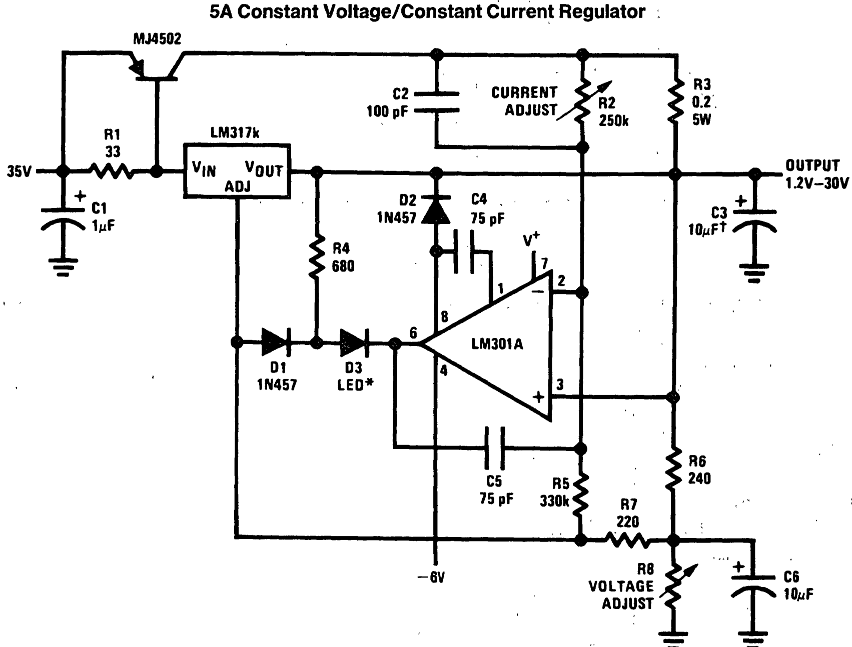
TL/H/9063–13

Power Follower



TL/H/9063–14

5A Constant Voltage/Constant Current Regulator



†Solid tantalum

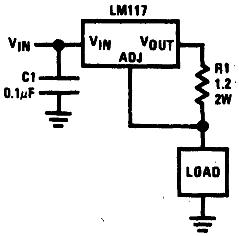
*Lights in constant current mode

TL/H/9063–15

1

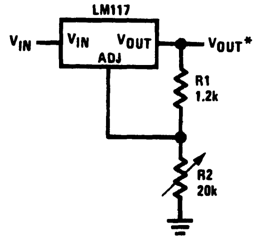
Typical Applications (Continued)

1A Current Regulator



TL/H/9063-16

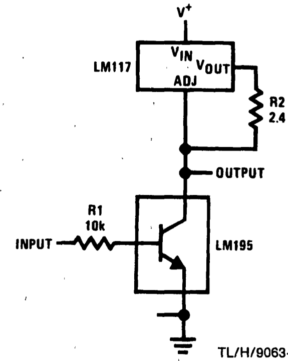
1.2V–20V Regulator with Minimum Program Current



TL/H/9063-17

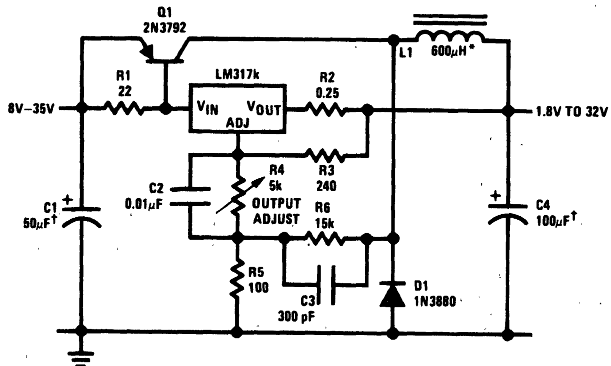
*Minimum load current ≈ 4 mA

High Gain Amplifier



TL/H/9063-18

Low Cost 3A Switching Regulator

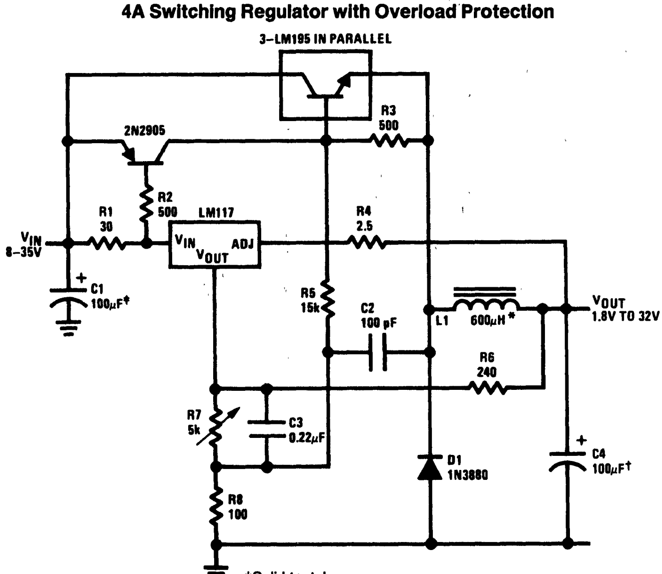


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9063-19

4A Switching Regulator with Overload Protection

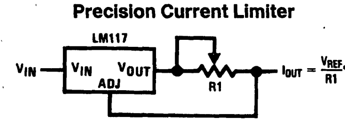


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9063-20

Precision Current Limiter

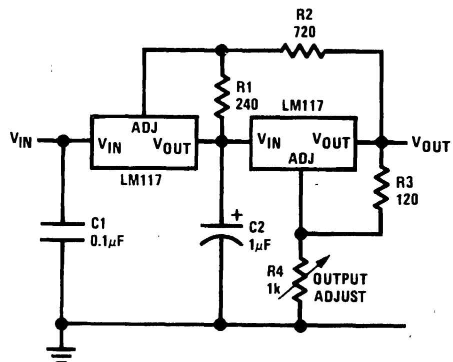


$*0.8\Omega \leq R1 \leq 120\Omega$

TL/H/9063-21

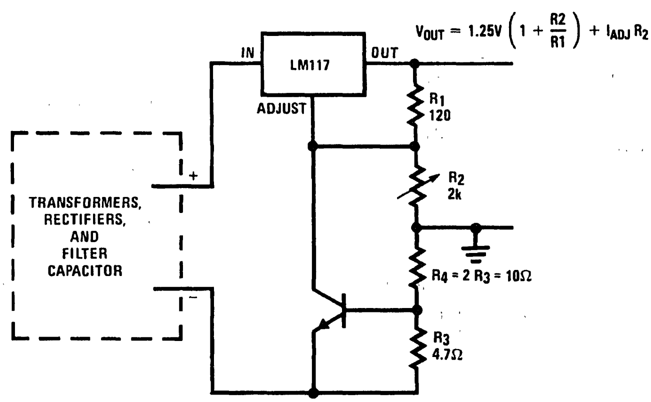
Typical Applications (Continued)

Tracking Preregulator



TL/H/9063-22

Current Limited Voltage Regulator



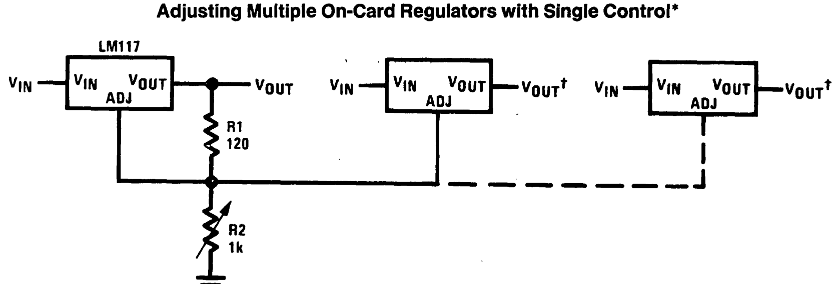
TL/H/9063-23

—Short circuit current is approximately $\frac{600\text{ mV}}{R3}$, or 120 mA

(Compared to LM117's higher current limit)

—At 50 mA output only ¾ volt of drop occurs in R_3 and R_4

Adjusting Multiple On-Card Regulators with Single Control*



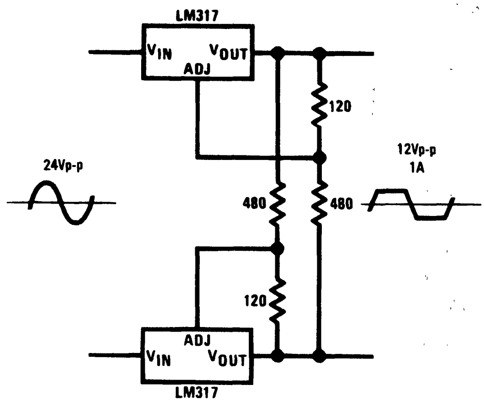
*All outputs within ±100 mV

†Minimum load—10 mA

TL/H/9063-24

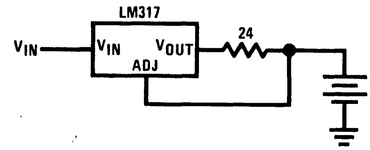
Typical Applications (Continued)

AC Voltage Regulator



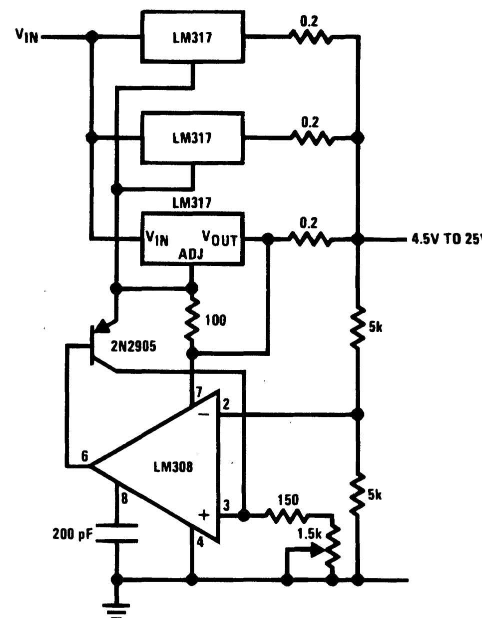
TL/H/9063-25

50 mA Constant Current Battery Charger



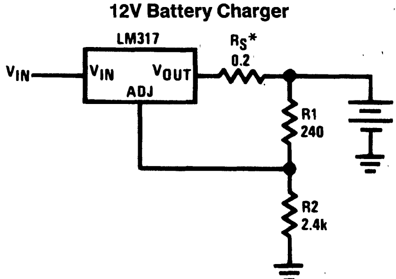
TL/H/9063-27

Adjustable 4A Regulator



TL/H/9063-28

12V Battery Charger

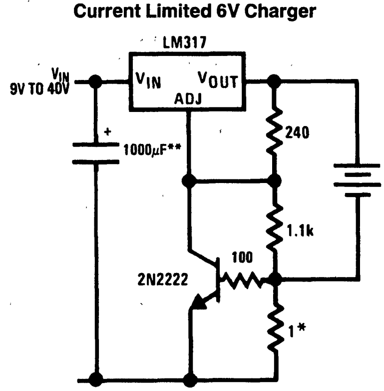


TL/H/9063-26

*R_S—sets output impedance of charger: $Z_{OUT} = R_S \left(1 + \frac{R2}{R1}\right)$

Use of R_S allows low charging rates with fully charged battery.

Current Limited 6V Charger



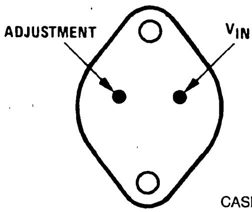
TL/H/9063-29

*Sets peak current (0.6A for 1Ω)

**The 1000 μF is recommended to filter out input transients

Connection Diagrams

(TO-3)
Metal Can Package



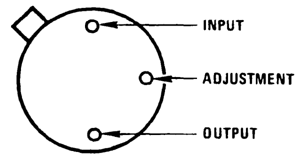
CASE IS OUTPUT

TL/H/9063–30

Bottom View

Steel Package
Order Number LM117K STEEL
or LM317K STEEL
See NS Package Number K02A
Order Number LM117K/883
See NS Package Number K02C

(TO-39)
Metal Can Package



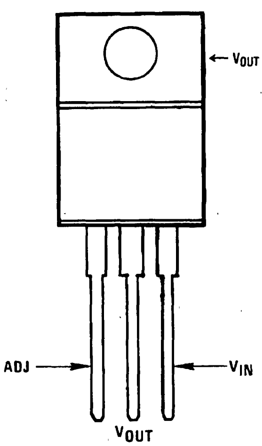
CASE IS OUTPUT

TL/H/9063–31

Bottom View

Order Number LM117H, LM117H/883,
LM317AH or LM317H
See NS Package Number H03A

(TO-220)
Plastic Package

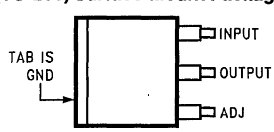


TL/H/9063–32

Front View

Order Number LM317AT or LM317T
See NS Package Number T03B

(TO-263) Surface-Mount Package



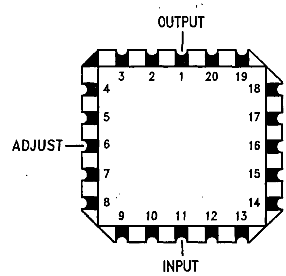
TL/H/9063–35

Top View

TL/H/9063–36

Side View

Order Number LM317S
See NS Package Number TS3B



TL/H/9063–34

Top View

Order Number LM117E/883
See NS Package Number E20A

National Semiconductor

LM117HV/LM317HV 3-Terminal Adjustable Regulator

General Description

The LM117HV/LM317HV are adjustable 3-terminal positive voltage regulators capable of supplying in excess of 1.5A over a 1.2V to 57V output range. They are exceptionally easy to use and require only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM117HV is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM117HV series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejections ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM117HV is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e. do not short the output to ground.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM117HV can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

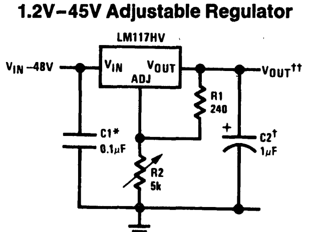
The LM117HVK STEEL and LM317HVK STEEL are packaged in standard TO-3 transistor packages, while the LM117HVH and LM317HVH are packaged in a solid Kovar base TO-39 transistor package. The LM317HVT uses a TO-220 plastic package. The LM117HV is rated for operation from −55°C to +150°C, and the LM317HV from 0°C to +125°C.

Features

- Adjustable output down to 1.2V
- Guaranteed 1.5A output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- 100% electrical burn-in
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short-circuit protected
- P+ Product Enhancement tested

Typical Applications

1.2V–45V Adjustable Regulator



TL/H/9062–1

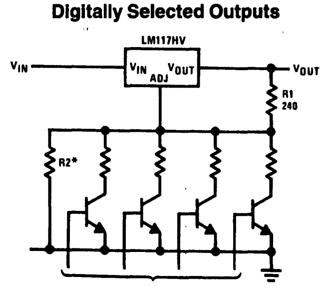
Full output current not available at high input-output voltages

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

$$\dagger\dagger V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ} R_2$$

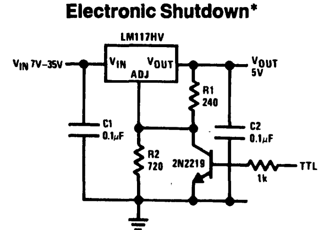
Digitally Selected Outputs



TL/H/9062–2

*Sets maximum V_{OUT}

5V Logic Regulator with Electronic Shutdown*



TL/H/9062–3

*Min. output ≈ 1.2V

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

(Note 3)

Power Dissipation	Internally limited
Input—Output Voltage Differential	+60V, −0.3V
Operating Junction Temperature Range	
LM117HV	−55°C to +150°C
LM317HV	0°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
ESD Tolerance (Note 4)	2000V

Electrical Characteristics (Note 1)

Parameter	Conditions	LM117HV			LM317HV			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$T_J = 25°C$, $3V \le V_{IN} - V_{OUT} \le 60V$ (Note 2) $I_L = 10$ mA		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_J = 25°C$, $10\text{ mA} \le I_{OUT} \le I_{MAX}$		0.1	0.3		0.1	0.5	%
Thermal Regulation	$T_J = 25°C$, 20 ms Pulse		0.03	0.07		0.04	0.07	%/W
Adjustment Pin Current			50	100		50	100	μA
Adjustment Pin Current Change	$10\text{ mA} \le I_L \le I_{MAX}$ $3.0\text{ V} \le (V_{IN} - V_{OUT}) \le 60V$		0.2	5		0.2	5	μA
Reference Voltage	$3.0\text{ V} \le (V_{IN} - V_{OUT}) \le 60V$, (Note 3) $10\text{ mA} \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	1.20	1.25	1.30	1.20	1.25	1.30	V
Line Regulation	$3.0V \le (V_{IN} - V_{OUT}) \le 60V$, $I_L = 10$ mA, (Note 2)		0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\text{ mA} \le I_{OUT} \le I_{MAX}$ (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		1			1		%
Minimum Load Current	$(V_{IN} - V_{OUT}) = 60V$		3.5	7		3.5	12	mA
Current Limit	$(V_{IN} - V_{OUT}) \le 15V$							
	K, T Packages	1.5	2.2	3.5	1.5	2.2	3.7	A
	H Package	0.5	0.8	1.8	0.5	0.8	1.9	A
	$(V_{IN} - V_{OUT}) \le 60V$							
	K, T Packages		0.3			0.3		A
	H Package		0.03			0.03		A
RMS Output Noise, % of V_{OUT}	$T_J = 25°C$, $10\text{ Hz} \le f \le 10\text{ kHz}$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = 10V$, $f = 120$ Hz		65			65		dB
	$C_{ADJ} = 10\ \mu F$	66	80		66	80		dB
Long-Term Stability	$T_J = 125°C$		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package		12	15		12	15	°C/W
	T Package					4	5	°C/W
	K Package		2.3	3		2.3	3	°C/W
Thermal Resistance, Junction to Ambient (no heat sink)	H Package		140			140		°C/W
	T Package					50		°C/W
	K Package		35			35		°C/W

Note 1: Unless otherwise specified, these specifications apply: $-55°C \le T_J \le +150°C$ for the LM117HV, and $0°C \le T_J \le +125°C$ for the LM317HV; $V_{IN} - V_{OUT} = 5V$ and $I_{OUT} = 0.1A$ for the TO-39 package and $I_{OUT} = 0.5A$ for the TO-3 and TO-220 packages. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 and 0.5A for the TO-39 package.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. Pulse testing with low duty cycle is used.

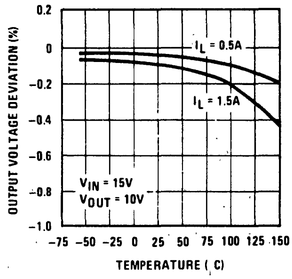
Note 3: Refer to RETS117HVH for LM117HVH or RETS117HVK for LM117HVK military specificatioins.

Note 4: Human body model, 1.5 kΩ in series with 100 pF.

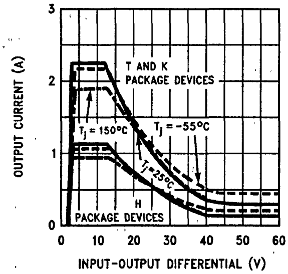
Typical Performance Characteristics

Output capacitor = 0 μF unless otherwise noted.

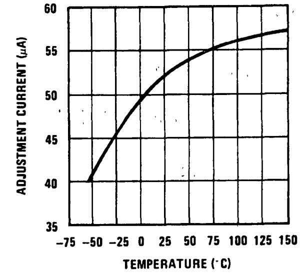
Load Regulation



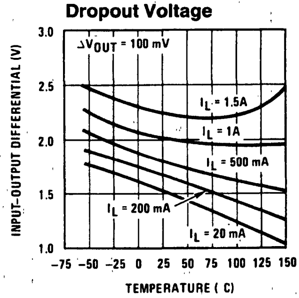
Current Limit



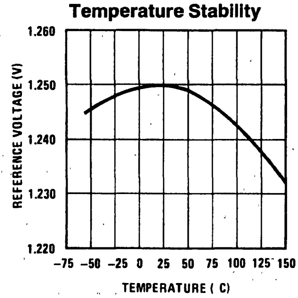
Adjustment Current



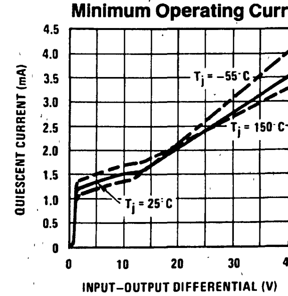
Dropout Voltage



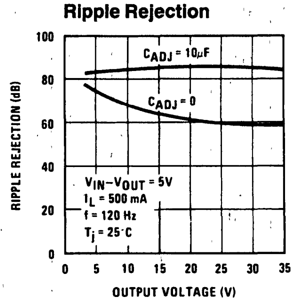
Temperature Stability



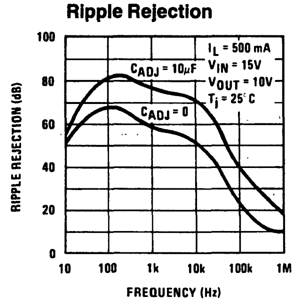
Minimum Operating Current



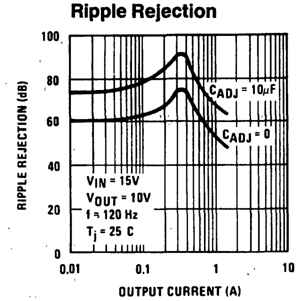
Ripple Rejection



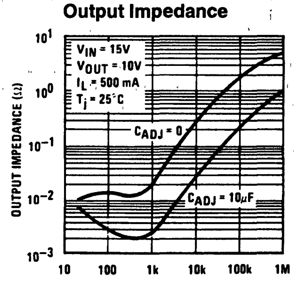
Ripple Rejection



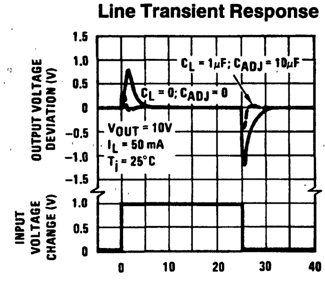
Ripple Rejection



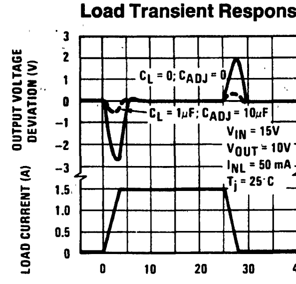
Output Impedance



Line Transient Response



Load Transient Response

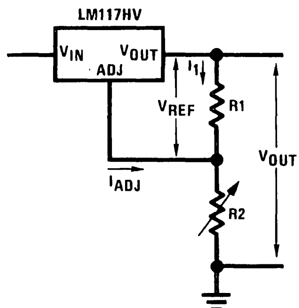


TL/H/9062–4

Application Hints

In operation, the LM117HV develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$



TL/H/9062-5

FIGURE 1

Since the 100 μA current from the adjustment terminal represents an error term, the LM117HV was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μF disc or 1 μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possiblity of problems.

The adjustment terminal can be bypassed to ground on the LM117HV to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μF bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

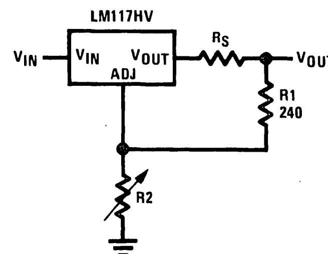
In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1 μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μF disc may seem to work better than a 0.1 μF disc as a bypass.

Although the LM117HV is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μF solid tantalum (or 25 μF aluminum electrolytic) on the output swamps this effect and insures stability. Any increase of load capacitance larger than 10 μF will merely improve the loop stability and output impedance.

Load Regulation

The LM117HV is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω × I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.



TL/H/9062-6

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. However, with the TO-5 package, care should be taken to minimize the wire length of the output lead. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

Protection Diodes

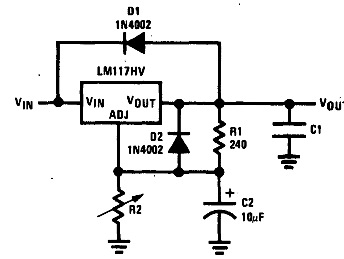
When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM117HV, this discharge path is through a large junction that is able to sustain 15A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM117HV is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM117HV with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Current Limit

Internal current limit will be activated whenever the output current exceeds the limit indicated in the Typical Performance Characteristics. However, if during a short circuit condition the regulator's differential voltage exceeds the Absolute Maximum Rating of 60V (e.g. $V_{IN} \geq 60V$, $V_{OUT} = 0V$), internal junctions in the regulator may break down and the device may be damaged or fail. Failure modes range from an apparent open or short from input to output of the regulator, to a destroyed package (most common with the TO-220 package). To protect the regulator, the user is advised to be aware of voltages that may be applied to the regulator during fault conditions, and to avoid violating the Absolute Maximum Ratings.



TL/H/9062-7

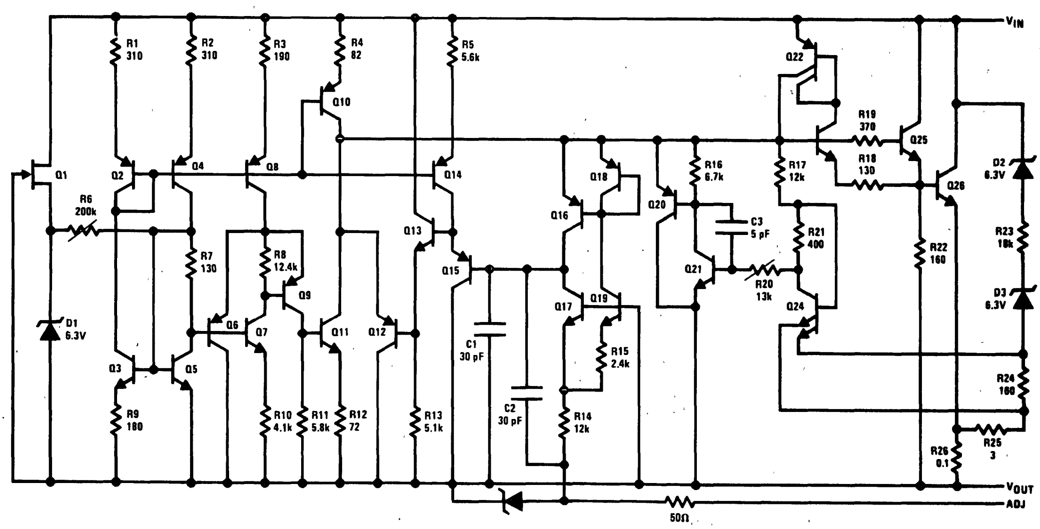
FIGURE 3. Regulator with Protection Diodes

$$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

D1 protects against C1

D2 protects against C2

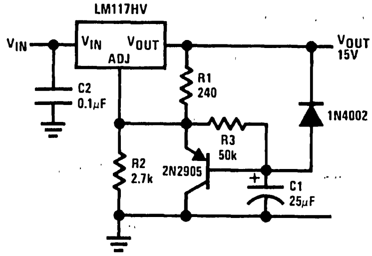
Schematic Diagram



TL/H/9062-8

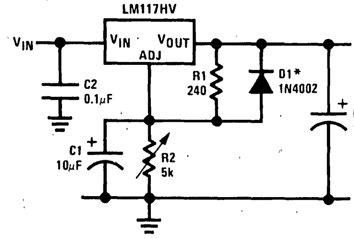
Typical Applications (Continued)

Slow Turn-On 15V Regulator



TL/H/9062-9

Adjustable Regulator with Improved Ripple Rejection

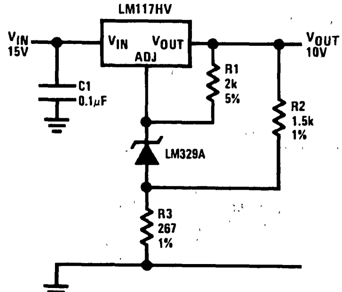


TL/H/9062-10

†Solid tantalum

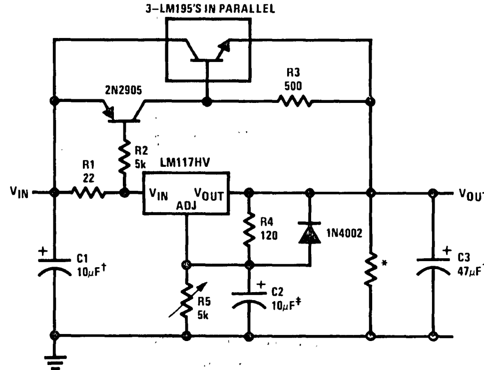
*Discharges C1 if output is shorted to ground

High Stability 10V Regulator



TL/H/9062-11

High Current Adjustable Regulator



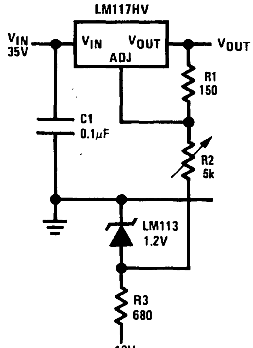
TL/H/9062-12

†Solid tantalum

*Minimum load current = 30 mA

‡Optional—improves ripple rejection

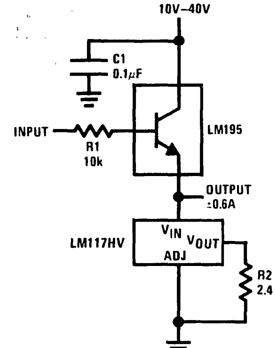
0 to 30V Regulator



TL/H/9062-13

Full output current not available at high input-output voltages

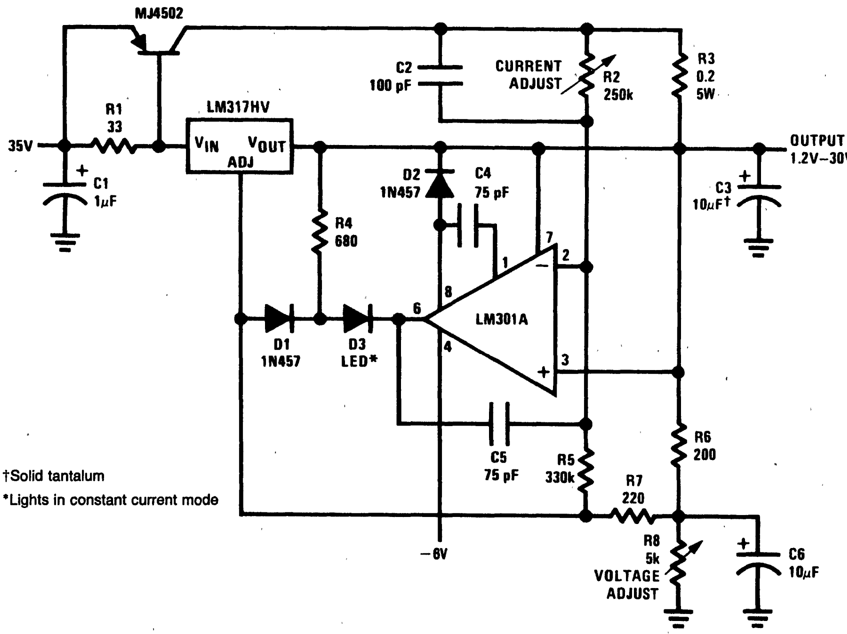
Power Follower



TL/H/9062-14

Typical Applications (Continued)

5A Constant Voltage/Constant Current Regulator

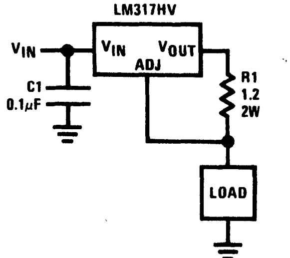


†Solid tantalum

*Lights in constant current mode

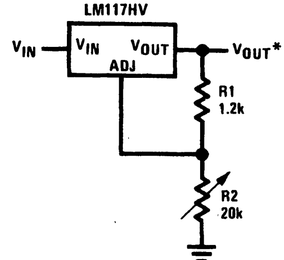
TL/H/9062–15

1A Current Regulator



TL/H/9062–16

1.2V–20V Regulator with Minimum Program Current

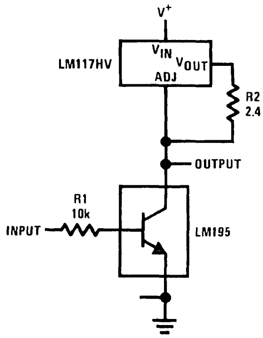


TL/H/9062–17

*Minimum load current ≈ 4 mA

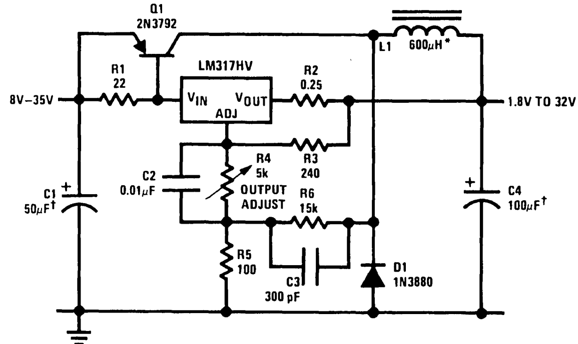
Typical Applications (Continued)

High Gain Amplifier



TL/H/9062-18

Low Cost 3A Switching Regulator

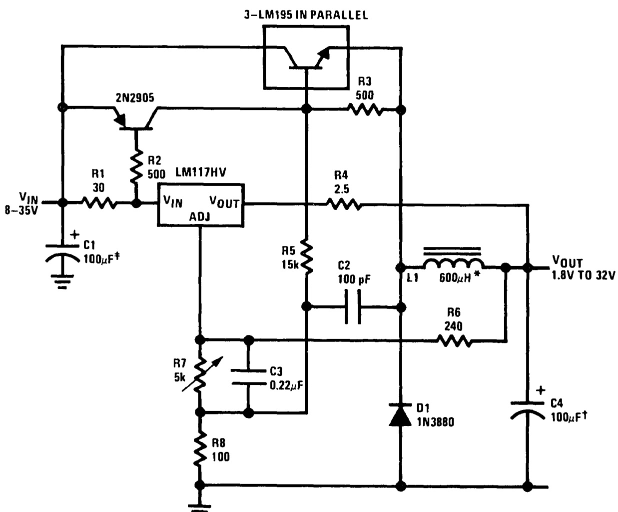


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9062-19

4A Switching Regulator with Overload Protection

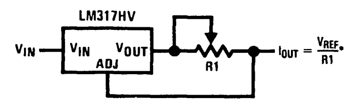


†Solid tantalum

*Core—Arnold A-254168-2 60 turns

TL/H/9062-20

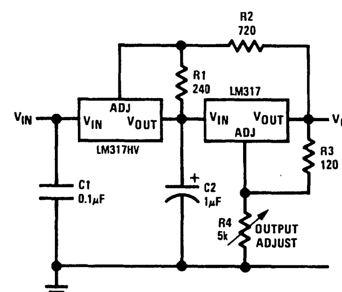
Precision Current Limiter



TL/H/9062-21

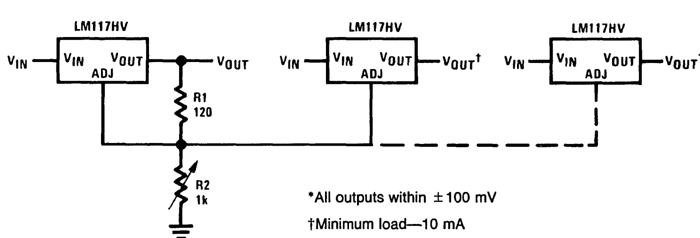
*0.8Ω ≤ R1 ≤ 120Ω

Tracking Preregulator



TL/H/9062-22

Adjustable Multiple On-Card Regulators with Single Control*



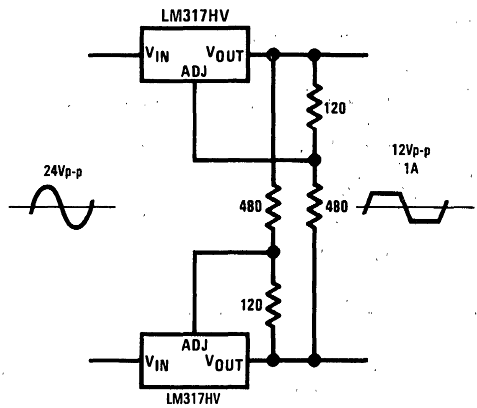
*All outputs within ±100 mV

†Minimum load—10 mA

TL/H/9062-23

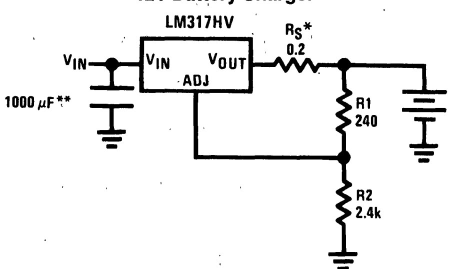
Typical Applications (Continued)

AC Voltage Regulator



TL/H/9062-24

12V Battery Charger



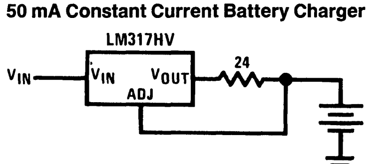
TL/H/9062-25

*R_S—sets output impedance of charger $Z_{OUT} = R_S \left(1 + \frac{R2}{R1}\right)$

Use of R_S allows low charging rates with fully charged battery.

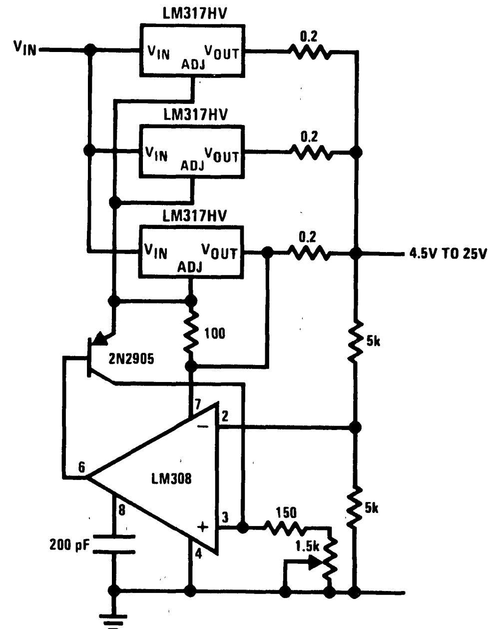
**The 1000 μF is recommended to filter out input transients

50 mA Constant Current Battery Charger



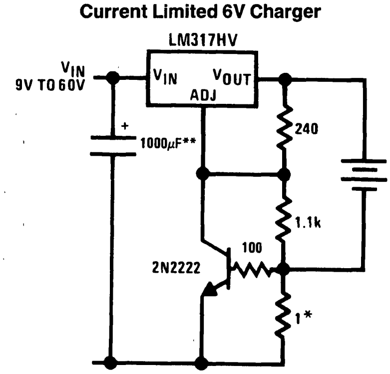
TL/H/9062-26

Adjustable 4A Regulator



TL/H/9062-27

Current Limited 6V Charger



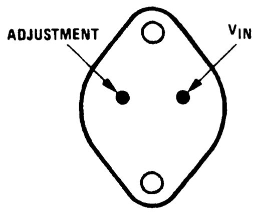
TL/H/9062-28

*Sets peak current (0.6A for 1Ω)

**The 1000 μF is recommended to filter out input transients

Connection Diagrams (See Physical Dimension section for further information)

(TO-3 Steel)
Metal Can Package



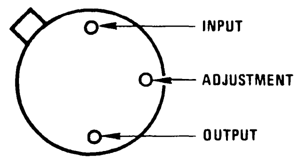
TL/H/9062–29

Case Is Output
Bottom View

Order Number LM117HVKSTL/883,
or SMD #7703402
See NS Package Number K02C

Order Number LM317HVK STEEL
See NS Package Number K02A

(TO-39)
Metal Can Package

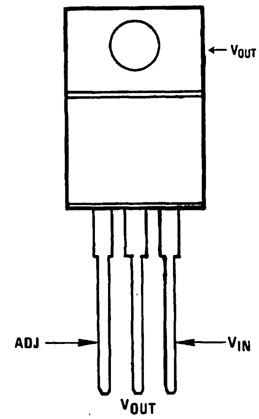


TL/H/9062–30

Case Is Output
Bottom View

Order Number LM117HVH,
LM117HVH/883, SMD #7703402
or LM317HVH
See NS Package Number H03A

(TO-220)
Plastic Package



TL/H/9062–31

Front View

Order Number LM317HVT
See NS Package Number T03B

1

National Semiconductor

LM120/LM320 Series 3-Terminal Negative Regulators

General Description

The LM120 series are three-terminal negative regulators with a fixed output voltage of −5V, −12V, and −15V, and up to 1.5A load current capability. Where other voltages are required, the LM137 and LM137HV series provide an output voltage range of −1.2V to −47V.

The LM120 need only one external component—a compensation capacitor at the output, making them easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM120 Series immune to overload conditions. The regulators have current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

Although primarily intended for fixed output voltage applications, the LM120 Series may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain current of the devices allows this technique to be used with good regulation.

Features

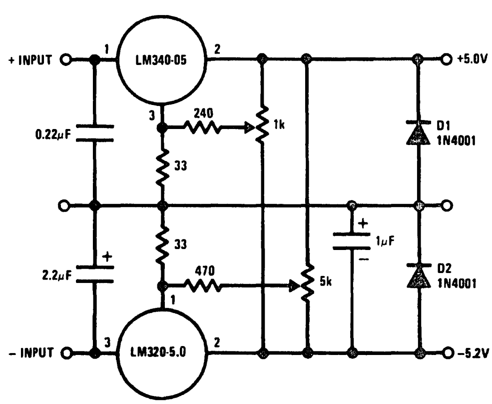
- Preset output voltage error less than ±3%
- Preset current limit
- Internal thermal shutdown
- Operates with input-output voltage differential down to 1V
- Excellent ripple rejection
- Low temperature drift
- Easily adjustable to higher output voltage

LM120 Series Packages and Power Capability

Device	Package	Rated Power Dissipation	Design Load Current
LM120/LM320	TO-3 (K)	20W	1.5A
	TO-39 (H)	2W	0.5A
LM320	TO-220 (T)	15W	1.5A
LM320M	TO-202 (P)	7.5W	0.5A

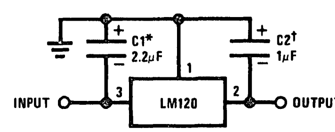
Typical Applications

Dual Trimmed Supply



TL/H/7767-3

Fixed Regulator



TL/H/7767-2

*Required if regulator is separated from filter capacitor by more than 3". For value given, capacitor must be solid tantalum. 25 µF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 µF aluminum electrolytic may substituted. Values given may be increased without limit.

For output capacitance in excess of 100 µF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

−5 Volt Regulators (Note 3)

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Power Dissipation	Internally Limited
Input Voltage	−25V
Input-Output Voltage Differential	25V
Junction Temperatures	See Note 1
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
Plastic	260°C

Electrical Characteristics

Order Numbers		Metal Can Package												Power Plastic Package			Units
		LM120K-5.0 (TO-3)			LM320K-5.0 (TO-3)			LM120H-5.0 (TO-39)			LM320H-5.0 (TO-39)			LM320T-5.0 (TO-220)			
Design Output Current (I_D) Device Dissipation (P_D)		1.5A 20W			1.5A 20W			0.5A 2W			0.5A 2W			1.5A 15W			
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_J = 25°C$, $V_{IN} = 10V$, $I_{LOAD} = 5$ mA	−5.1	−5	−4.9	−5.2	−5	−4.8	−5.1	−5	−4.9	−5.2	−5	−4.8	−5.2	−5	−4.8	V
Line Regulation	$T_J = 25°C$, $I_{LOAD} = 5$ mA, $V_{MIN} \le V_{IN} \le V_{MAX}$		10	25		10	40		10	25		10	40		10	40	mV
Input Voltage		−25		−7	−25		−7	−25		−7	−25		−7	−25		−7.5	V
Ripple Rejection	f = 120 Hz	54	64		54	64		54	64		54	64		54	64		dB
Load Regulation, (Note 2)	$T_J = 25°C$, $V_{IN} = 10V$, 5 mA $\le I_{LOAD} \le I_D$		50	75		60	100		30	50		30	50		50	100	mV
Output Voltage, (Note 1)	$-7.5V \le V_{IN} \le V_{MAX}$, 5 mA $\le I_{LOAD} \le I_D$, $P \le P_D$	−5.20		−4.80	−5.25		−4.75	−5.20		−4.80	−5.25		−4.75	−5.25		−4.75	V
Quiescent Current	$V_{MIN} \le V_{IN} \le V_{MAX}$		1	2		1	2		1	2		1	2		1		mA
Quiescent Current Change	$T_J = 25°C$ $V_{MIN} \le V_{IN} \le V_{MAX}$ 5 mA $\le I_{LOAD} \le I_D$		0.1 0.1	0.4 0.4		0.1 0.1	0.4 0.4		0.05 0.04	0.4 0.4		0.05 0.04	0.4 0.4		0.1 0.1	0.4 0.4	mA mA
Output Noise Voltage	$T_A = 25°C$, $C_L = 1\ \mu F$, $I_L = 5$ mA, $V_{IN} = 10V$, 10 Hz $\le f \le$ 100 kHz		150			150			150			150			150		µV
Long Term Stability			5	50		5	50		5	50		5	50		10		mV
Thermal Resistance Junction to Case Junction to Ambient				3 35			3 35			Note 4 Note 4			Note 4 Note 4		4 50		°C/W °C/W

Note 1: This specification applies over $-55°C \le T_J \le +150°C$ for the LM120 and $0°C \le T_J \le +125°C$ for the LM320.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: For −5V 3 amp regulators, see LM145 data sheet.

Note 4: Thermal resistance of typically 85°C/W (in 400 linear feet air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

Note 5: Refer to RETS120-5H drawing for LM120H-5.0 or RETS120-5K drawing for LM120-5K military specifications.

−12 Volt Regulators

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation	Internally Limited
Input Voltage	−35V
Input-Output Voltage Differential	30V
Junction Temperatures	See Note 1
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics

Order Numbers		Metal Can Package												Power Plastic Package			Units
		LM120K-12 (TO-3)			LM320K-12 (TO-3)			LM120H-12 (TO-39)			LM320H-12 (TO-39)			LM320T-12 (TO-220)			
Design Output Current (I_D) Device Dissipation (P_D)		1A 20W			1A 20W			0.2A 2W			0.2A 2W			1A 15W			
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_J = 25°C$, $V_{IN} = 17V$, $I_{LOAD} = 5\ mA$	−12.3	−12	−11.7	−12.4	−12	−11.6	−12.3	−12	−11.7	−12.4	−12	−11.6	−12.4	−12	−11.6	V
Line Regulation	$T_J = 25°C$, $I_{LOAD} = 5\ mA$, $V_{MIN} \leq V_{IN} \leq V_{MAX}$		4	10		4	20		4	10		4	20		4	20	mV
Input Voltage		−32		−14	−32		−14	−32		−14	−32		−14	−32		−14.5	V
Ripple Rejection	f = 120 Hz	56	80		56	80		56	80		56	80		56	80		dB
Load Regulation, (Note 2)	$T_J = 25°C$, $V_{IN} = 17V$, $5\ mA \leq I_{LOAD} \leq I_D$		30	80		30	80		10	25		10	40		30	80	mV
Output Voltage, (Note 1)	$14.5V \leq V_{IN} \leq V_{MAX}$, $5\ mA \leq I_{LOAD} \leq I_D$, $P \leq P_D$	−12.5		−11.5	−12.6		−11.4	−12.5		−11.5	−12.6		−11.4	−12.6		−11.4	V
Quiescent Current	$V_{MIN} \leq V_{IN} \leq V_{MAX}$		2	4		2	4		2	4		2	4		2	4	mA
Quiescent Current Change	$T_J = 25°C$ $V_{MIN} \leq V_{IN} \leq V_{MAX}$ $5\ mA \leq I_{LOAD} \leq I_D$		0.1 0.1	0.4 0.4		0.1 0.1	0.4 0.4		0.05 0.03	0.4 0.4		0.05 0.03	0.4 0.4		0.1 0.1	0.4 0.4	mA mA
Output Noise Voltage	$T_A = 25°C$, $C_L = 1\ \mu F$, $I_L = 5\ mA$, $V_{IN} = 17V$, $10\ Hz \leq f \leq 100\ kHz$		400			400			400			400			400		μV
Long Term Stability			12	120		12	120		12	120		12	120		24		mV
Thermal Resistance Junction to Case Junction to Ambient				3 35			3 35			Note 3 Note 3			Note 3 Note 3		4 50		°C/W °C/W

Note 1: This specification applies over $-55°C \leq T_J \leq +150°C$ for the LM120 and $0°C \leq T_J \leq +125°C$ for the LM320.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: Thermal resistance of typically 85°C/W (in 400 linear feet/min air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

Note 4: Refer to RETS120H-12 drawing for LM120H-12 or RETS120-12K drawing for LM120K-12 military specifications.

−15 Volt Regulators

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation	Internally Limited
Input Voltage	
LM120/LM320	−40V
LM320T	−35V
Input-Output Voltage Differential	30V
Junction Temperatures	See Note 1
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics

Order Numbers		Metal Can Package												Power Plastic Package			Units
		LM120K-15 (TO-3)			LM320K-15 (TO-3)			LM120H-15 (TO-39)			LM320H-15 (TO-39)			LM320T-15 (TO-220)			
Design Output Current (I_D) Device Dissipation (P_D)		1A 20W			1A 20W			0.2A 2W			0.2A 2W			1A 15W			
Parameter	Conditions (Note 1)	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage	T_J = 25°C, V_{IN} = 20V, I_{LOAD} = 5 mA	−15.3	−15	−14.7	−15.4	−15	−14.6	−15.3	−15	−14.7	−15.4	−15	−14.6	−15.5	−15	−14.5	V
Line Regulation	T_J = 25°C, I_{LOAD} = 5 mA, $V_{MIN} \le V_{IN} \le V_{MAX}$		5	10		5	20		5	10		5	20		5	20	mV
Input Voltage		−35		−17	−35		−17	−35		−17	−35		−17	−35		−17.5	V
Ripple Rejection	f = 120 Hz	56	80		56	80		56	80		56	80		56	80		dB
Load Regulation, (Note 2)	T_J = 25°C, V_{IN} = 20V, 5 mA ≤ I_{LOAD} ≤ I_D		30	80		30	80		10	25		10	40		30	80	mV
Output Voltage, (Note 1)	17.5V ≤ V_{IN} ≤ V_{MAX}, 5 mA ≤ I_{LOAD} ≤ I_D, P ≤ P_D	−15.5		−14.5	−15.6		−14.4	−15.5		−14.5	−15.6		−14.4	−15.7		−14.3	V
Quiescent Current	$V_{MIN} \le V_{IN} \le V_{MAX}$		2	4		2	4		2	4		2	4		2	4	mA
Quiescent Current Change	T_J = 25°C $V_{MIN} \le V_{IN} \le V_{MAX}$ 5 mA ≤ I_{LOAD} ≤ I_D		0.1 0.1	0.4 0.4		0.1 0.1	0.4 0.4		0.05 0.03	0.4 0.4		0.05 0.03	0.4 0.4		0.1 0.1	0.4 0.4	mA mA
Output Noise Voltage	T_A = 25°C, C_L = 1 μF, I_L = 5 mA, V_{IN} = 20V, 10 Hz ≤ f ≤ 100 kHz		400			400			400			400			400		μV
Long Term Stability			15	150		15	150		15	150		15	150		30		mV
Thermal Resistance Junction to Case Junction to Ambient				3 35			3 35			Note 3 Note 3			Note 3 Note 3		4 50		°C/W °C/W

Note 1: This specification applies over −55°C ≤ T_J ≤ +150°C for the LM120 and 0°C ≤ T_J ≤ +125°C for the LM320.

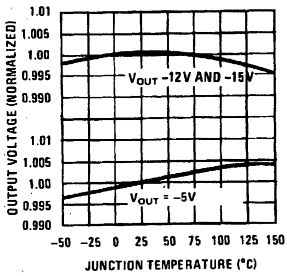
Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, low duty cycle, pulse testing is used. The LM120/LM320 series does have low thermal feedback, improving line and load regulation. On all other tests, even though power dissipation is internally limited, electrical specifications apply only up to P_D.

Note 3: Thermal resistance of typically 85°C/W (in 400 linear feet/min air flow), 224°C/W (in static air) junction to ambient, of typically 21°C/W junction to case.

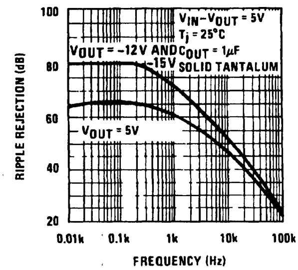
Note 4: Refer to RETS120-15H drawing for LM120H-15 or RETS120-15K drawing for LM120K-15 military specifications.

Typical Performance Characteristics

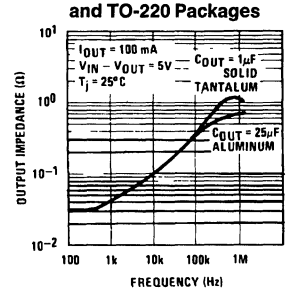
Output Voltage vs Temperature



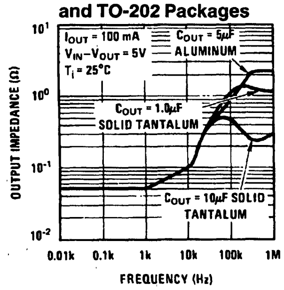
Ripple Rejection (All Types)



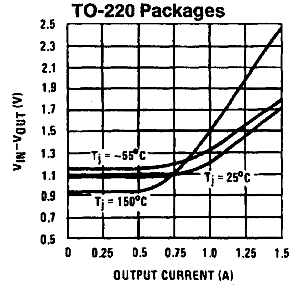
Output Impedance TO-3 and TO-220 Packages



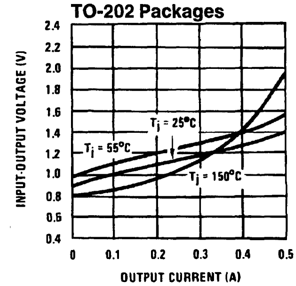
Output Impedance TO-5 and TO-202 Packages



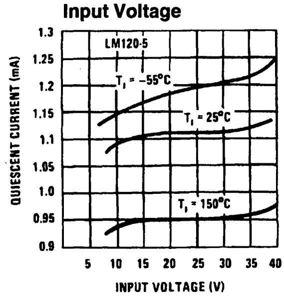
Minimum Input-Output Differential TO-3 and TO-220 Packages



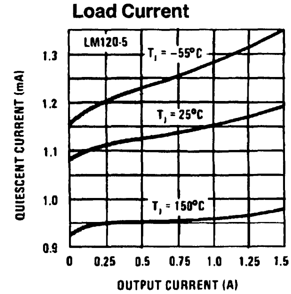
Minimum Input-Output Differential TO-5 and TO-202 Packages



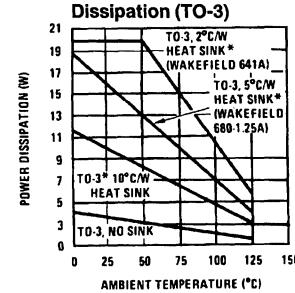
Quiescent Current vs Input Voltage



Quiescent Current vs Load Current



Maximum Average Power Dissipation (TO-3)

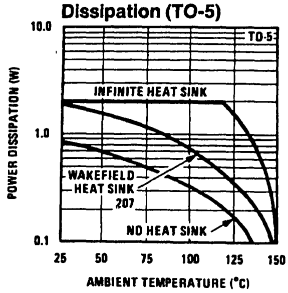


TL/H/7767–4

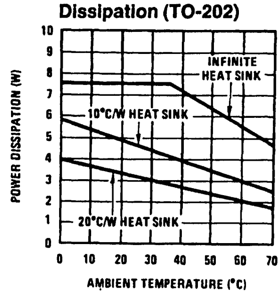
*These curves for LM120.
Derate 25°C further for LM320.

Typical Performance Characteristics (Continued)

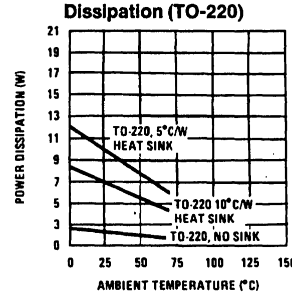
Maximum Average Power Dissipation (TO-5)



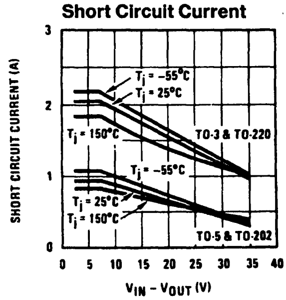
Maximum Average Power Dissipation (TO-202)



Maximum Average Power Dissipation (TO-220)



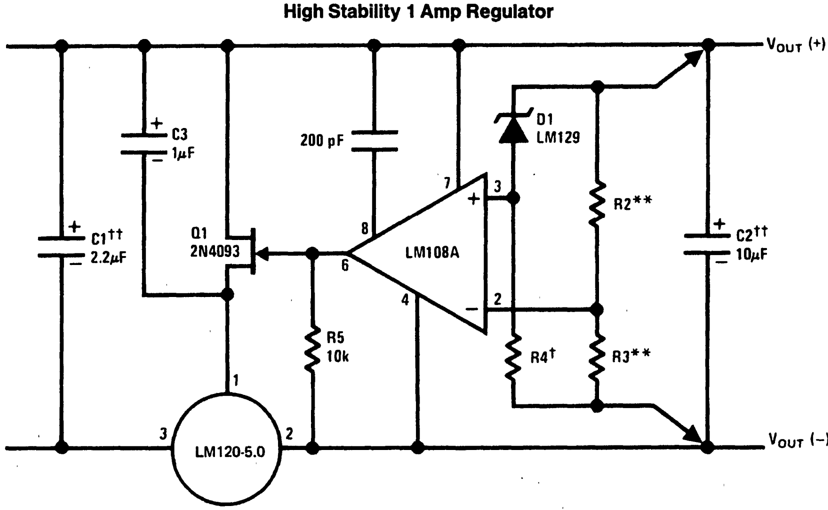
Short Circuit Current



TL/H/7767-5

Typical Applications (Continued)

High Stability 1 Amp Regulator



TL/H/7767-6

Lead and line regulation — 0.01% temperature stability — 0.2%

†Determines Zener current.

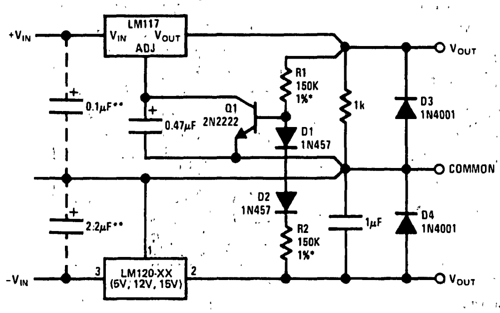
††Solid tantalum.

An LM120-12 or LM120-15 may be used to permit higher input voltages, but the regulated output voltage must be at least −15V when using the LM120-12 and −18V for the LM120-15.

**Select resistors to set output voltage. 2 ppm/°C tracking suggested.

Typical Applications (Continued)

Wide Range Tracking Regulator



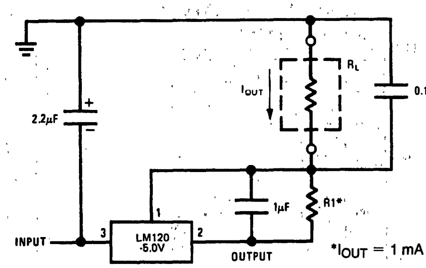
TL/H/7767-7

*Resistor tolerance of R1 and R2 determine matching of (+) and (−) inputs.

**Necessary only if raw supply capacitors are more than 3″ from regulators

An LM3086N array may substitute for Q1, D1 and D2 for better stability and tracking. In the array diode transistors Q5 and Q4 (in parallel) make up D2; similarly, Q1 and Q2 become D1 and Q3 replaces the 2N2222.

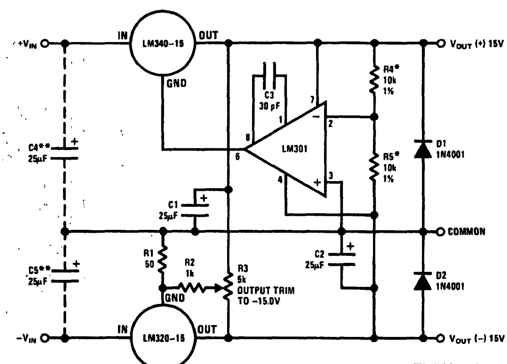
Current Source



$$^{*}I_{OUT} = 1\text{ mA} + \frac{5.0V}{R1}$$

TL/H/7767-8

±15V, 1 Amp Tracking Regulators



TL/H/7767-12

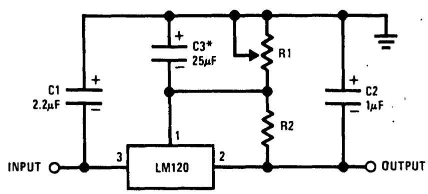
Performance (Typical)

Load Regulation at $\Delta I_L = 1A$	10 mV	1 mV
Output Ripple, $C_{IN} = 3000\ \mu F$, $I_L = 1A$	100 μVrms	100 μVrms
Temperature Stability	+50 mV	+50 mV
Output Noise 10 Hz ≤ f ≤ 10 kHz	150 μVrms	150 μVrms

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.

**Necessary only if raw supply filter capacitors are more than 2″ from regulators.

Variable Output



TL/H/7767-9

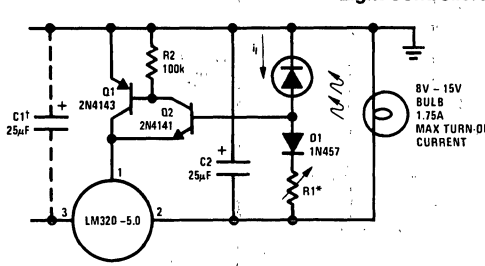
*Optional. Improves transient response and ripple rejection.

$$V_{OUT} = V_{SET}\frac{R1+R2}{R2}$$

SELECT R2 AS FOLLOWS:

LM120-5	**−300Ω**
LM120-12	**−750Ω**
LM120-15	**−1k**

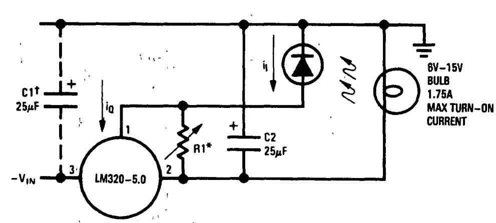
Light Controllers Using Silicon Photo Cells



TL/H/7767-10

*Lamp brightness increases until $i_l = 5V/R1$ (i_l can be set as low as 1 μA).

†Necessary only of raw supply filter capacitor is more than 2″ from LM320MP.

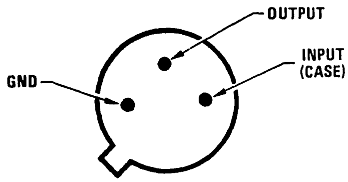


TL/H/7767-11

*Lamp brightness increases until $i_l = i_Q$ (1 mA) + 5V/R1.

†Necessary only if raw supply filter capacitor is more than 2″ from LM320.

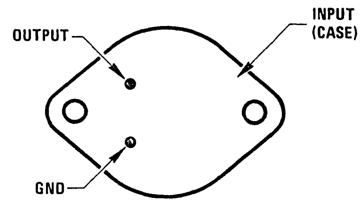
Connection Diagrams



TL/H/7767-13

Bottom View

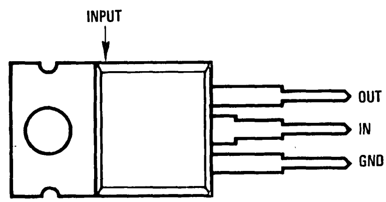
Metal Can Package TO-39 (H)
Order Number LM120H-5.0, LM120H-12, LM120H-15, LM120H-5.0/883, LM120H-12/883, LM120H-15/883, LM320H-5.0, LM320H-12 or LM320H-15
See NS Package Number H03A



TL/H/7767-14

Bottom View

Steel Metal Can Package TO-3 (K)
Order Number LM120K-5.0/883, LM120K-12/883, LM120K-15/883, LM320K-5.0, LM320K-12 or LM320K-15
See NS Package Number K02A

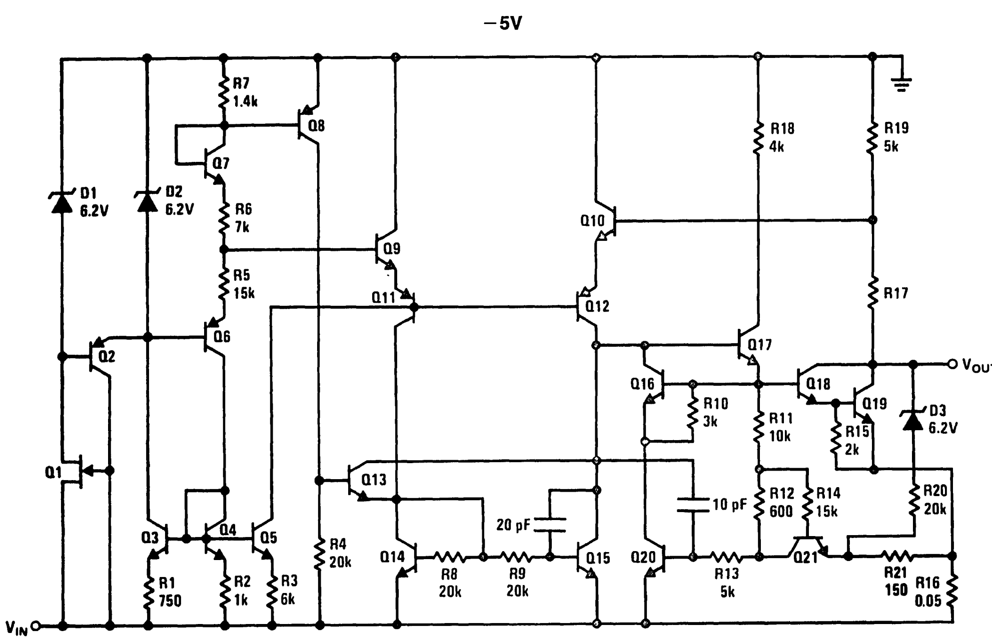


TL/H/7767-17

Front View

Power Package TO-220 (T)
Order Number LM320T-5.0, LM320T-12 or LM320T-15
See NS Package Number T03B

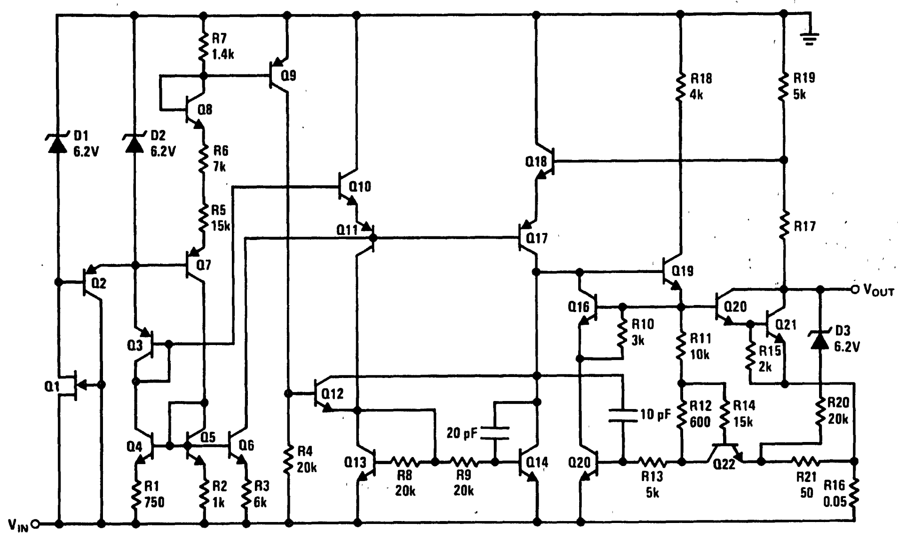
Schematic Diagrams



TL/H/7767-18

Schematic Diagrams (Continued)

−12V and −15V



TL/H/7767–19

National Semiconductor

LM123/LM323A/LM323
3-Amp, 5-Volt Positive Regulator

General Description

The LM123 is a three-terminal positive regulator with a preset 5V output and a load driving capability of 3 amps. New circuit design and processing techniques are used to provide the high output current without sacrificing the regulation characteristics of lower current devices.

The LM323A offers improved precision over the standard LM323. Parameters with tightened specifications include output voltage tolerance, line regulation, and load regulation.

The 3 amp regulator is virtually blowout proof. Current limiting, power limiting, and thermal shutdown provide the same high level of reliability obtained with these techniques in the LM109 1 amp regulator.

No external components are required for operation of the LM123. If the device is more than 4 inches from the filter capacitor, however, a 1 μF solid tantalum capacitor should be used on the input. A 0.1 μF or larger capacitor may be used on the output to reduce load transient spikes created by fast switching digital logic, or to swamp out stray load capacitance.

An overall worst case specification for the combined effects of input voltage, load currents, ambient temperature, and power dissipation ensure that the LM123 will perform satisfactorily as a system element.

For applications requiring other voltages, see LM150 series adjustable regulator data sheet.

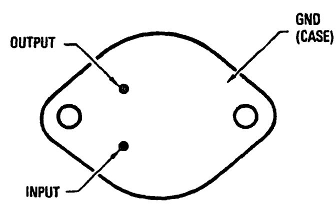
Operation is guaranteed over the junction temperature range -55°C to $+150^\circ$C for LM123, -40°C to $+125^\circ$C for LM323A, and 0°C to $+125^\circ$C for LM323. A hermetic TO-3 package is used for high reliability and low thermal resistance.

Features

- Guaranteed 1% initial accuracy (A version)
- 3 amp output current
- Internal current and thermal limiting
- 0.01Ω typical output impedance
- 7.5V minimum input voltage
- 30W power dissipation
- P+ Product Enhancement tested

Connection Diagram

Metal Can Package



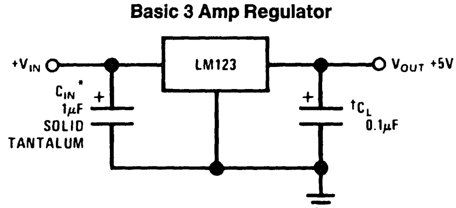
TL/H/7771-2

Order Number LM123K STEEL, LM323AK STEEL or LM323K STEEL
See NS Package Number K02A

Order Number LM123K/883
See NS Package Number K02C

Typical Applications

Basic 3 Amp Regulator



TL/H/7771-3

*Required if LM123 is more than 4″ from filter capacitor.

†Regulator is stable with no load capacitor into resistive loads.

1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Input Voltage	20V
Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM123	−55°C to +150°C
LM323A	−40°C to +125°C
LM323	0°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
ESD Tolerance (Note 5)	2000V

LM123 Electrical Characteristics (Note 1)

Parameter	Conditions	LM123			Units
		Min	Typ	Max	
Output Voltage	$T_j = 25°C$ $V_{IN} = 7.5V, I_{OUT} = 0A$	4.7	5	5.3	V
	$7.5V \le V_{IN} \le 15V$ $0A \le I_{OUT} \le 3A, P \le 30W$	4.6		5.4	V
Line Regulation (Note 3)	$T_j = 25°C$ $7.5V \le V_{IN} \le 15V$		5	25	mV
Load Regulation (Note 3)	$T_j = 25°C, V_{IN} = 7.5V,$ $0A \le I_{OUT} \le 3A$		25	100	mV
Quiescent Current	$7.5V \le V_{IN} \le 15V,$ $0A \le I_{OUT} \le 3A$		12	20	mA
Output Noise Voltage	$T_j = 25°C$ $10\ Hz \le f \le 100\ kHz$		40		μVrms
Short Circuit Current Limit	$T_j = 25°C$ $V_{IN} = 15V$ $V_{IN} = 7.5V$		 3 4	 4.5 5	 A A
Long Term Stability				35	mV
Thermal Resistance Junction to Case (Note 2)			2		°C/W

LM323A/LM323 Electrical Characteristics (Note 1)

Parameter	Conditions	LM323A Min	LM323A Typ	LM323A Max	LM323 Min	LM323 Typ	LM323 Max	Units
Output Voltage	$T_j = 25°C$ $V_{IN} = 7.5V$, $I_{OUT} = 0A$	4.95	5	5.05	4.8	5	5.2	V
	$7.5V \leq V_{IN} \leq 15V$ $0A \leq I_{OUT} \leq 3A$, $P \leq 30W$	4.85		5.15	4.75		5.25	V
Line Regulation (Note 3)	$T_j = 25°C$ $7.5V \leq V_{IN} \leq 15V$		5	10		5	25	mV
Load Regulation (Note 3)	$T_j = 25°C$, $V_{IN} = 7.5V$, $0A \leq I_{OUT} \leq 3A$		25	50		25	100	mV
Quiescent Current	$7.5V \leq V_{IN} \leq 15V$, $0A \leq I_{OUT} \leq 3A$		12	20		12	20	mA
Output Noise Voltage	$T_j = 25°C$ $10\ Hz \leq f \leq 100\ kHz$		40			40		μVrms
Short Circuit Current Limit	$T_j = 25°C$ $V_{IN} = 15V$ $V_{IN} = 7.5V$		 3 4	 4.5 6		 3 4	 4.5 5	 A A
Long Term Stability				35			35	mV
Thermal Resistance Junction to Case (Note 2)			2			2		°C/W

Note 1: Unless otherwise noted, specifications apply for $-55°C \leq T_j \leq +150°C$ for the LM123, $-40°C \leq T_j \leq +125°C$ for the LM323A, and $0°C \leq T_j \leq +125°C$ for the LM323. Although power dissipation is internally limited, specifications apply only for $P \leq 30W$.

Note 2: Without a heat sink, the thermal resistance of the TO-3 package is about 35°C/W. With a heat sink, the effective thermal resistance can only approach the specified values of 2°C/W, depending on the efficiency of the heat sink.

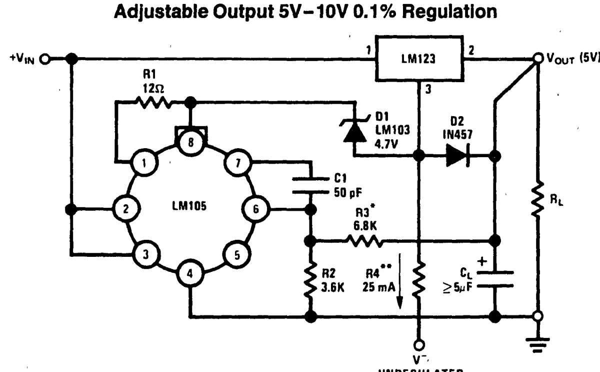
Note 3: Load and line regulation are specified at constant junction temperature. Pulse testing is required with a pulse width ≤ 1 ms and a duty cycle ≤ 5%.

Note 4: Refer to RETS123K drawing for LM123K military specifications.

Note 5: Human body model, 1.5 kΩ in series with 100 pF.

Typical Applications (Continued)

Adjustable Output 5V–10V 0.1% Regulation



*Select to Set Output Voltage

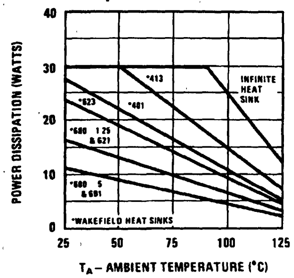
**Select to Draw 25 mA from V−

TL/H/7771-4

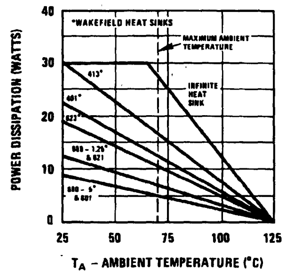
1

Typical Performance Characteristics

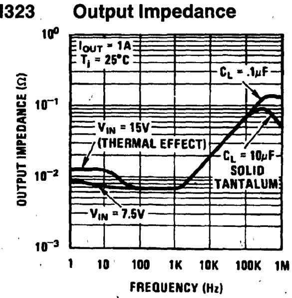
Maximum Average Power Dissipation for LM123



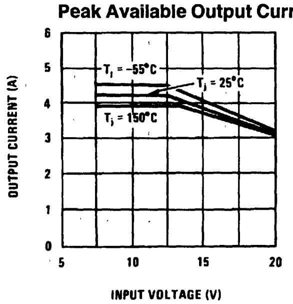
Maximum Average Power Dissipation for LM323A, LM323



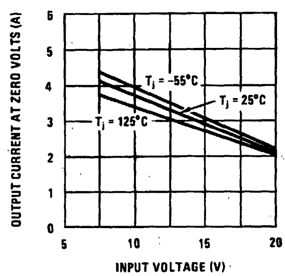
Output Impedance



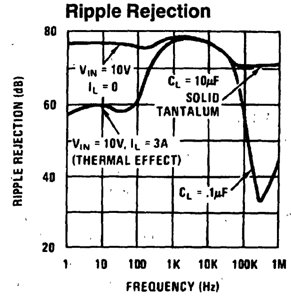
Peak Available Output Current



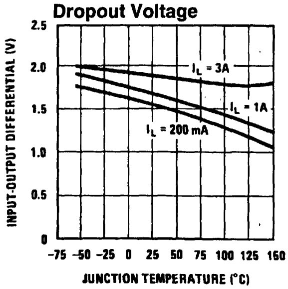
Short Circuit Current



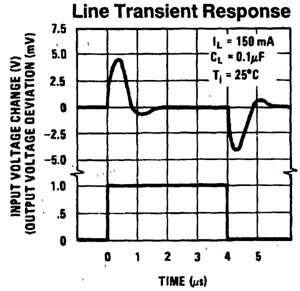
Ripple Rejection



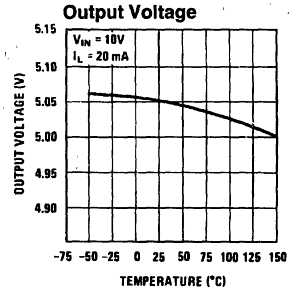
Dropout Voltage



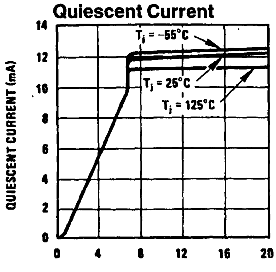
Line Transient Response



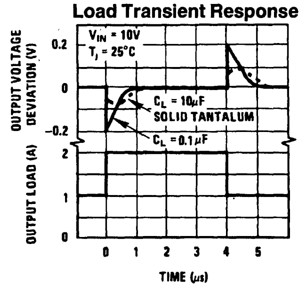
Output Voltage



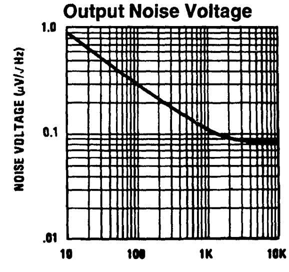
Quiescent Current



Load Transient Response



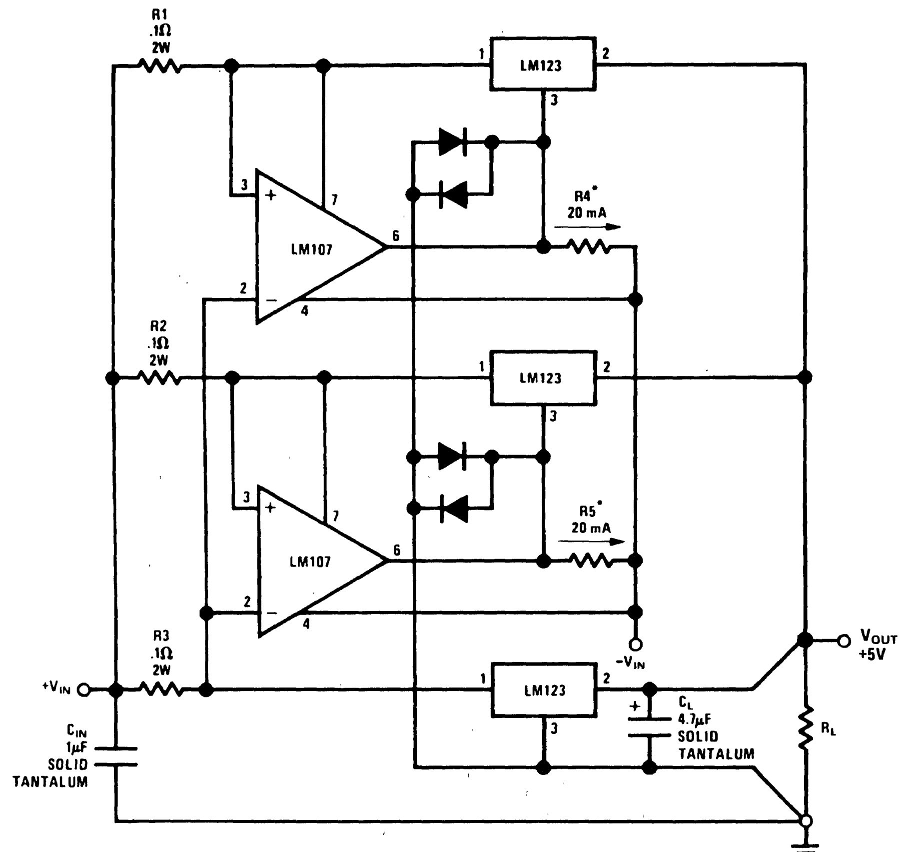
Output Noise Voltage



TL/H/7771–5

Typical Applications (Continued)

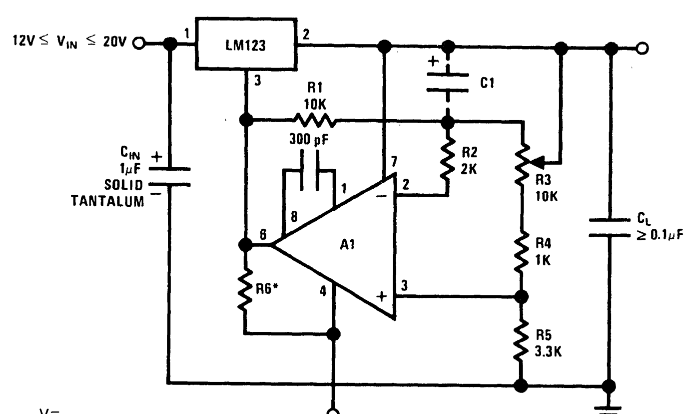
10 Amp Regulator with Complete Overload Protection



*Select for 20 mA Current from Unregulated Negative Supply

TL/H/7771-6

Adjustable Regulator 0V–10V @ 3A



$$*R6 = \frac{V^-}{12\ mA}$$

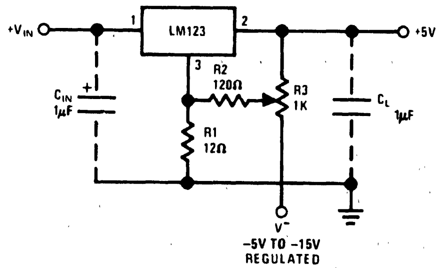
A_1—LM101A

C_1—2 μF Optional—Improves Ripple Rejection, Noise, and Transient Response

TL/H/7771-7

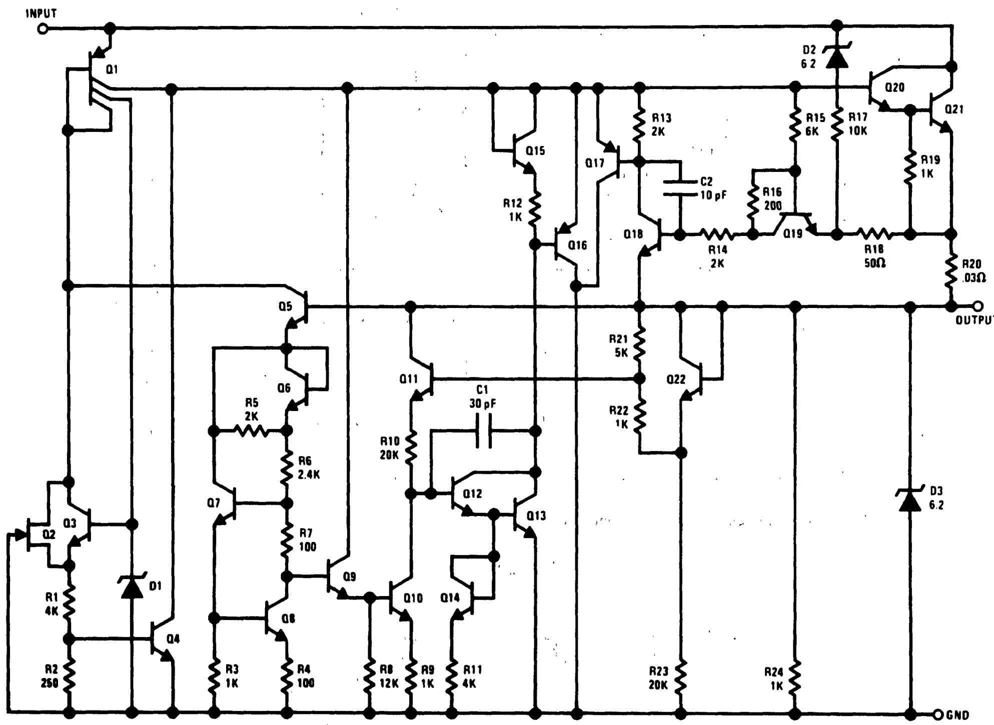
Typical Applications (Continued)

Trimming Output to 5V



TL/H/7771-8

Schematic Diagram



TL/H/7771-1

National Semiconductor

LM125/LM325 Dual Voltage Regulators

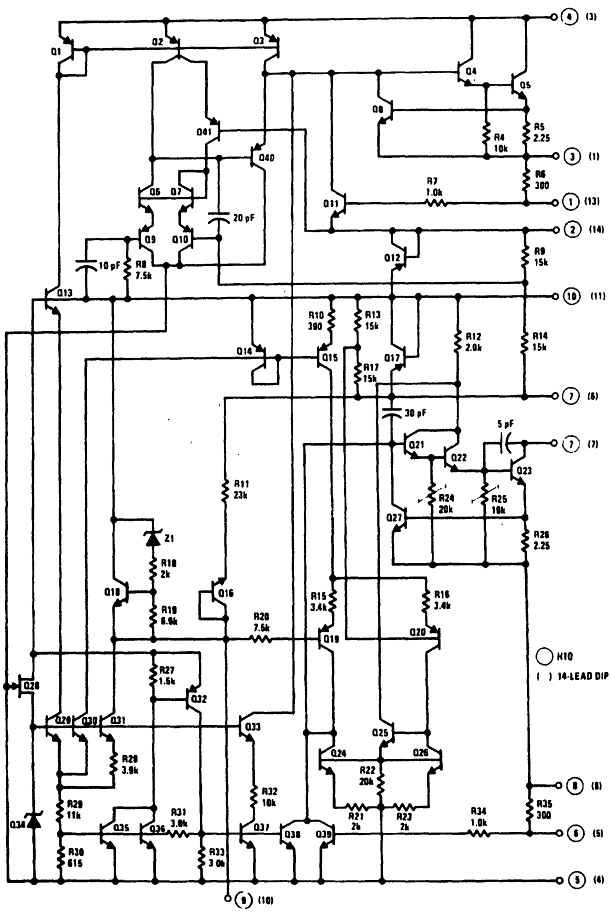
General Description

These dual polarity tracking regulators are designed to provide balanced positive and negative output voltages at current up to 100 mA, and are set for ±15V outputs. Input voltages up to ±30V can be used and there is provision for adjustable current limiting. These devices are available in two package types to accommodate various power requirements and temperature ranges.

Features

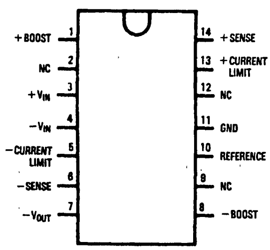
- ±15V tracking outputs
- Output current to 100 mA
- Output voltage balanced to within 2%
- Line and load regulation of 0.06%
- Internal thermal overload protection
- Standby current drain of 3 mA
- Externally adjustable current limit
- Internal current limit

Schematic and Connection Diagrams



TL/H/7776–1

Dual-In-Line Package

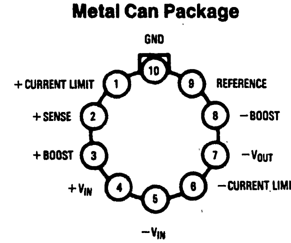


TL/H/7776–2

Top View

Order Number LM325N
See NS Package Number N14A

Metal Can Package



Case connected to $-V_{IN}$ TL/H/7776–3

Top View

Order Number
LM125H/883 or LM325H
See NS Package Number H10C

1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

Input Voltage	±30V
Forced V_O^+ (Min) (Note 1)	−0.5V
Forced V_O^- (Max) (Note 1)	+0.5V
Power Dissipation (Note 2)	P_{MAX}
Output Short-Circuit Duration (Note 3)	Continuous

Operating Conditions

Operating Free Temperature Range	
LM125	−55°C to +125°C
LM325	0°C to +70°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics LM125/LM325 (Note 2)

Parameter	Conditions	Min	Typ	Max	Units
Output Voltage	T_j = 25°C				
LM125		14.8	15	15.2	V
LM325		14.5	15	15.5	V
Input-Output Differential		2.0			V
Line Regulation	V_{IN} = 18V to 30V, I_L = 20 mA, T_j = 25°C		2.0	10	mV
Line Regulation Over Temperature Range	V_{IN} = 18V to 30V, I_L = 20 mA,		2.0	20	mV
Load Regulation	I_L = 0 to 50 mA, V_{IN} = ±30V, T_j = 25°C				
V_O^+			3.0	10	mV
V_O^-			5.0	10	mV
Load Regulation Over Temperature Range	I_L = 0 to 50 mA, V_{IN} = ±30V				
V_O^+			4.0	20	mV
V_O^-			7.0	20	mV
Output Voltage Balance	T_j = 25°C				
LM125				±150	mV
LM325				±300	mV
Output Voltage Over Temperature Range	$P \le P_{MAX}$, $0 \le I_O \le 50$ mA, $18V \le \lvert V_{IN}\rvert \le 30$				
LM125		14.65		15.35	V
LM325		14.27		15.73	V
Temperature Stability of V_O			±0.3		%
Short Circuit Current Limit	T_j = 25°C		260		mA
Output Noise Voltage	T_j = 25°C, BW = 100 − 10 kHz		150		μVrms
Positive Standby Current	T_j = 25°C		1.75	3.0	mA
Negative Standby Current	T_j = 25°C		3.1	5.0	mA
Long Term Stability			0.2		%/kHr
Thermal Resistance Junction to Case (Note 4)					
LM125H, LM325H			20		°C/W
Junction to Ambient	(Still Air)		215		°C/W
Junction to Ambient	(400 Lf/min Air Flow)		82		°C/W
Junction to Ambient LM325N	(Still Air)		90		°C/W

Note 1: That voltage to which the output may be forced without damage to the device.

Note 2: Unless otherwise specified these specifications apply for T_j = 55°C to +150°C on LM125, T_j = 0°C to +125°C on LM325A, T_j = 0°C to +125°C on LM325, V_{IN} = ±20V, I_L = 0 mA, I_{MAX} = 100 mA, P_{MAX} = 2.0W for the H10 Package. I_{MAX} = 100 mA. I_{MAX} = 100 mA, P_{MAX} = 1.0W for the DIP N Package.

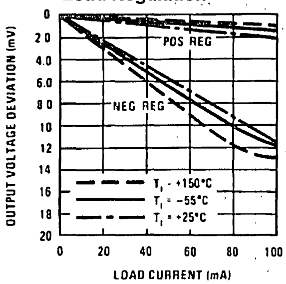
Note 3: If the junction temperature exceeds 150°C, the output short circuit duration is 60 seconds.

Note 4: Without a heat sink, the thermal resistance junction to ambient of the H10 Package is about 155°C/W. With a heat sink, the effective thermal resistance can only approach the junction to case values specified, depending on the efficiency of the sink.

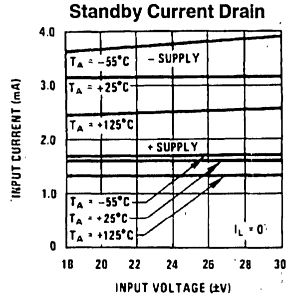
Note 5: Refer to RETS125X drawing for military specification of LM125.

Typical Performance Characteristics

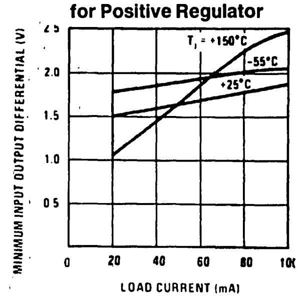
Load Regulation



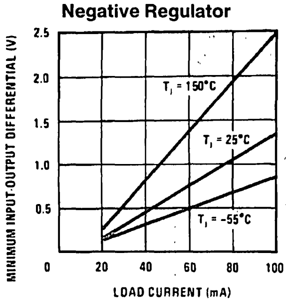
Standby Current Drain



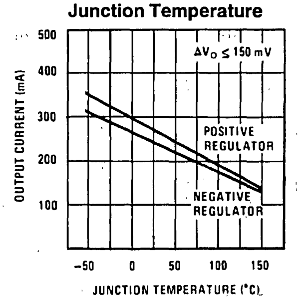
Regulator Dropout Voltage for Positive Regulator



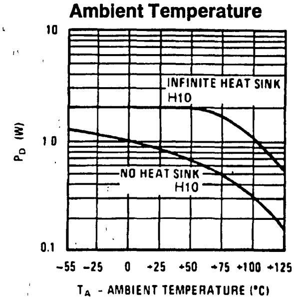
Regulator Dropout Voltage for Negative Regulator



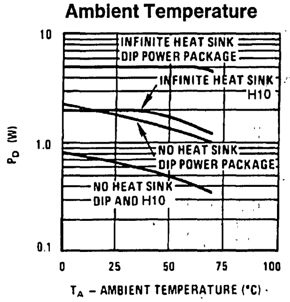
Peak Output Current vs Junction Temperature



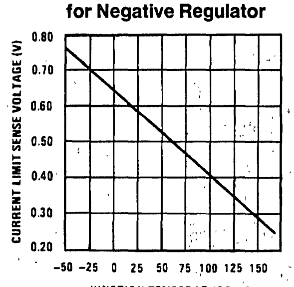
LM125 Maximum Average Power Dissipation vs Ambient Temperature



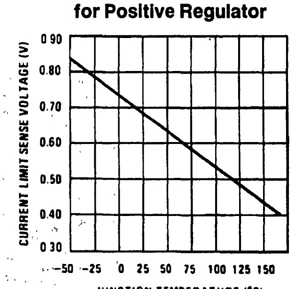
LM325 Maximum Average Power Dissipation vs Ambient Temperature



LM125 Current Limit Sense Voltage vs Temperature for Negative Regulator



LM125 Current Limit Sense Voltage vs Temperature for Positive Regulator



TL/H/7776-4

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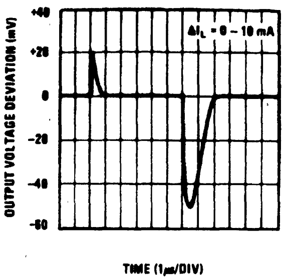
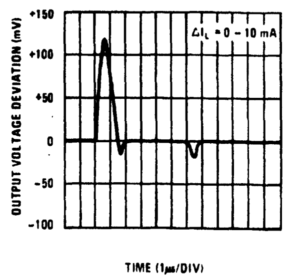
Typical Performance Characteristics (Continued)

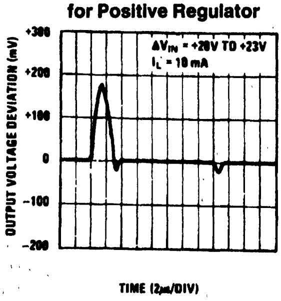
Load Transient Response for Positive Regulator



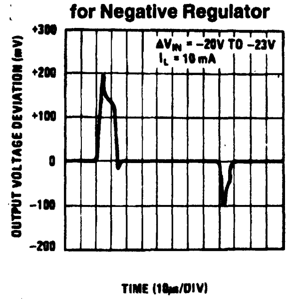
Load Transient Response for Negative Regulator



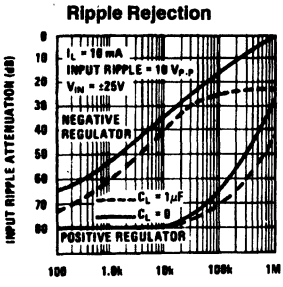
Line Transient Response for Positive Regulator



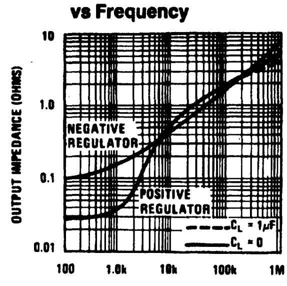
Line Transient Response for Negative Regulator



Ripple Rejection



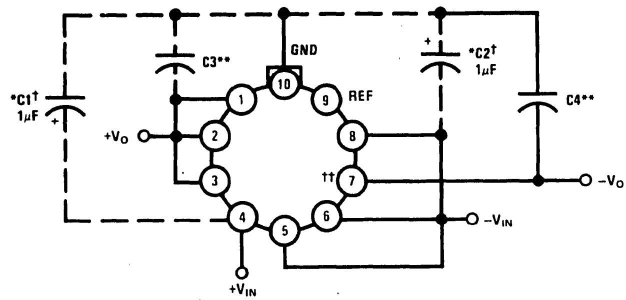
Output Impedance vs Frequency



TL/H/7776–5

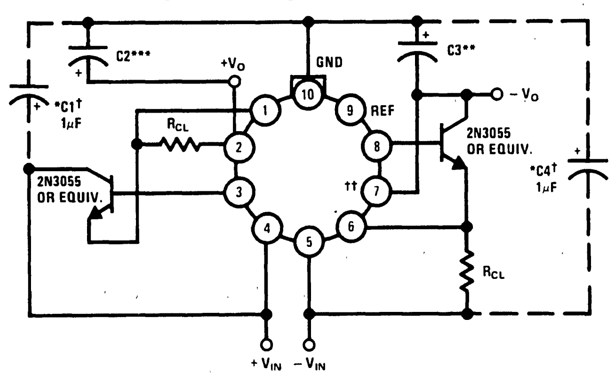
Typical Applications

Basic Regulator†††



TL/H/7776-6

2.0 Amp Boosted Regulator With Current Limit



TL/H/7776-7

Note: Metal can (H) packages shown.

$$I_{CL} = \frac{\text{Current Limit Sense Voltage (See Curve)}}{R_{CL}}$$

†Solid tantalum

††Short pins 6 and 7 on dip

†††R_{CL} can be added to the basic regulator between pins 6 and 5, 1 and 2 to reduce current limit.

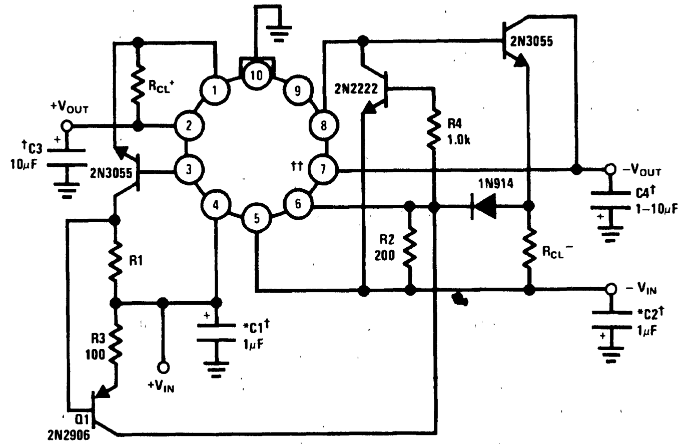
*Required if regulator is located an appreciable distance from power supply filter.

**Although no capacitor is needed for stability, it does help transient response. (If needed use 1 μF electrolytic).

***Although no capacitor is needed for stability, it does help transient response. (If needed use 10 μF electrolytic).

Typical Applications (Continued)

Positive Current Dependent Simultaneous Current Limiting



TL/H/7776-8

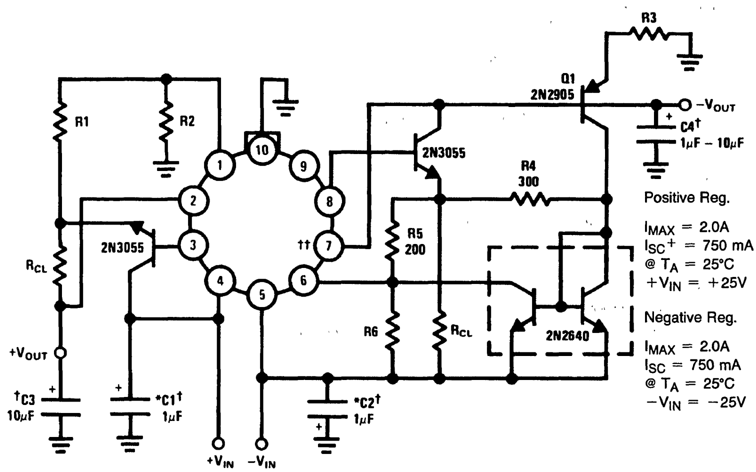
$$I_{CL}^{+} = \frac{\frac{V_{SENSE\,NEG}}{2} + V_{BEQ1}}{R1}$$

$$I_{CL}^{+} = \frac{V_{SENSE\,NEG} + V_{DIODE}}{R_{CL}^{-}}$$

$$R_{CL}^{+} = \frac{V_{SENSE}^{+}}{1.1\ I_{CL}^{+}}$$

I_{CL}^{+} Controls Both Sides of the Regulator.

Boosted Regulator With Foldback Current Limit



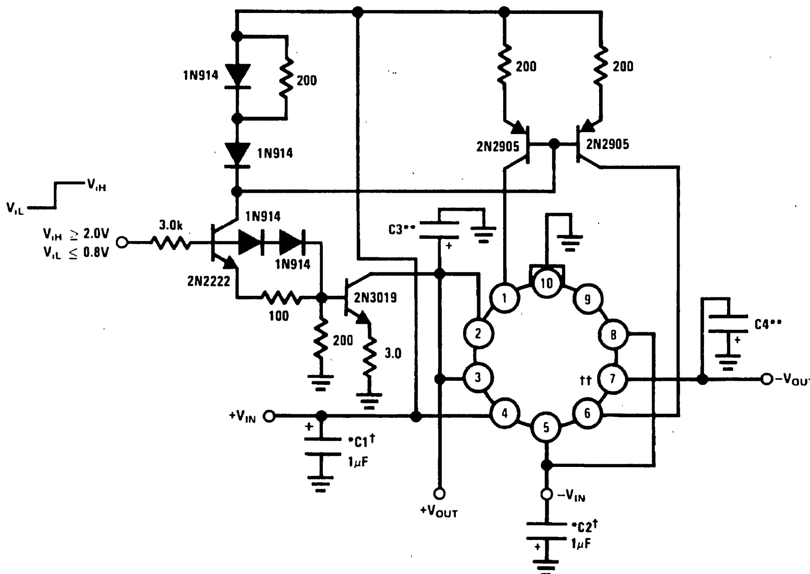
Resistor Values

	125	126
R1	18	20
R2	310	180
R3	2.4k	1.35k
R6	300	290
R_{CL}	0.7	0.9

TL/H/7776-9

Typical Applications (Continued)

Electric Shutdown



TL/H/7776-10

†Solid tantalum

††Short pins 6 and 7 on dip

*Required if regulator is located an appreciable distance from power supply filter.

**Although no capacitor is needed for stability, it does help transient response. (If needed use 1 μF electrolytic).

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National Semiconductor

LM133/LM333 3-Ampere Adjustable Negative Regulators

General Description

The LM133/LM333 are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −3.0A over an output voltage range of −1.2V to −32V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM133 series features internal current limiting, thermal shutdown and safe-area compensation, making them substantially immune to failure from overloads.

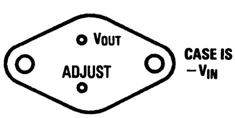
The LM133/LM333 serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM133/LM333 are ideal complements to the LM150/LM350 adjustable positive regulators.

Features

- Output voltage adjustable from −1.2V to −32V
- 3.0A output current guaranteed, −55°C to +150°C
- Line regulation typically 0.01%/V
- Load regulation typically 0.2%
- Excellent rejection of thermal transients
- 50 ppm/°C temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P+ Product Enhancement tested
- Standard 3-lead transistor package
- Output is short circuit protected

Connection Diagrams

TO-3
Metal Can Package

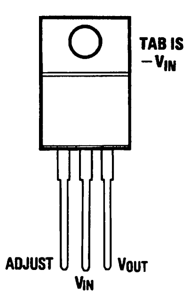


TL/H/9065-1

Bottom View

Steel TO-3 Metal Can Package (K STEEL)
Order Number LM133K STEEL or LM333K STEEL
See NS Package Number K02A

TO-220
Plastic Package



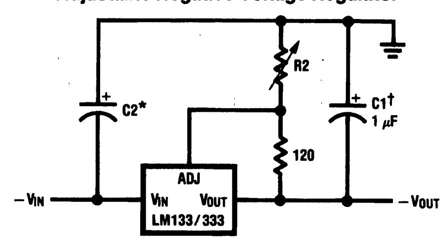
TL/H/9065-2

Front View

3-Lead TO-220 Plastic Package (T)
Order Number LM333T
See NS Package Number T03B

Typical Applications

Adjustable Negative Voltage Regulator



TL/H/9065-3

$$-V_{OUT} = -1.25V\left(1+\frac{R2}{120\Omega}\right) + \left(-I_{ADJ}\times R2\right)$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability.

*C2 = 1 μF solid tantalum is required only if regulator is more than 4" from power supply filter capacitor.

Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide lower output impedance and improved transient response.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	35V
Operating Junction Temperature Range	T_{MIN} to T_{MAX}
LM133	−55°C to +150°C
LM333	−40°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package	300°C
TO-220 Package	260°C
ESD Susceptibility	TBD

Electrical Characteristics LM133

Specifications with standard typeface are for T_J = 25°C, and those with **boldface type** apply over the full operating temperature range. (Note 3)

Parameter	Conditions	Typical	Min (Note 2)	Max (Note 2)	Units
Reference Voltage	I_L = 10 mA	−1.250	−1.238	−1.262	V
	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$ $10\ mA \le I_L \le 3A, P \le P_{MAX}$	**−1.250**	**−1.225**	**−1.275**	V
Line Regulation	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$ I_{OUT} = 50 mA (Note 4)	0.01 **0.02**		0.02 **0.05**	% /V
Load Regulation	$10\ mA \le I_{OUT} \le 3A, P \le P_{MAX}$ (Notes 4, 5)	0.2 **0.4**		0.5 **1.0**	%
Thermal Regulation	10 ms Pulse	0.002		0.01	% /W
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$	**0.4**			%
Long Term Stability	T_J = 125°C, 1000 Hours	0.15			%
Adjust Pin Current		65 **70**		90 **100**	μA
Adjust Pin Current Change	$10\ mA \le I_L \le 3A$ $3.0V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$	2		**6**	μA
Minimum Load Current	$\lvert V_{IN} - V_{OUT} \rvert \le 35V$	**2.5**		**5.0**	mA
	$\lvert V_{IN} - V_{OUT} \rvert \le 10V$	**1.2**		**2.5**	mA
Current Limit (Note 5)	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 10V$	**3.9**	**3.0**		A
	$\lvert V_{IN} - V_{OUT} \rvert = 20V$	**2.4**	**1.25**		A
	$\lvert V_{IN} - V_{OUT} \rvert = 30V$	**0.4**	**0.3**		A
Output Noise (% of V_{OUT})	10 Hz to 10 kHz	0.003			% (rms)
Ripple Rejection	V_{OUT} = 10V, f = 120 Hz C_{ADJ} = 0 μF C_{ADJ} = 10 μF	 60 77			dB
Thermal Resistance Junction-to-Case	TO-3 Package (K STEEL)	1.2		1.8	°C/W
Thermal Shutdown Temperature		163	150	190	°C

Electrical Characteristics LM333

Specifications with standard typeface are for $T_J = 25°C$, and those with **boldface type** apply over the full operating temperature range. (Note 3)

Parameter	Conditions	Typical	Min (Note 2)	Max (Note 2)	Units
Reference Voltage	$I_L = 10$ mA	−1.250	−1.225	−1.275	V
	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$ $10\text{ mA} \le I_L \le 3A$, $P \le P_{MAX}$	**−1.250**	**−1.213**	**−1.287**	
Line Regulation	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$ $I_{OUT} = 50$ mA (Note 4)	0.01 **0.02**		0.04 **0.07**	% /V
Load Regulation	$10\text{ mA} \le I_L \le 3A$, $P \le P_{MAX}$ (Notes 4 and 5)	0.2 **0.4**		1.0 **1.5**	%
Thermal Regulation	10 ms Pulse	0.002		0.02	% /W
Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$	**0.5**			%
Long Term Stability	$T_J = 125°C$, 1000 Hours	0.2			%
Adjust Pin Current		65 **70**		95 **100**	μA
Adjust Pin Current Change	$10\text{ mA} \le I_L \le 3A$ $3.0V \le \lvert V_{IN} - V_{OUT} \rvert \le 35V$	2.5		**8**	μA
Minimum Load Current	$\lvert V_{IN} - V_{OUT} \rvert \le 35V$	**2.5**		**10**	mA
	$\lvert V_{IN} - V_{OUT} \rvert \le 10V$	**1.5**		**5.0**	
Current Limit (Note 5)	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 10V$	**3.9**	3.0		A
	$\lvert V_{IN} - V_{OUT} \rvert = 20V$	**2.4**	1.0		
	$\lvert V_{IN} - V_{OUT} \rvert = 30V$	**0.4**	0.20		
Output Noise (% of V_{OUT})	10 Hz to 10 kHz	0.003			% (rms)
Ripple Rejection	$V_{OUT} = 10V$, $f = 120$ Hz $C_{ADJ} = 0$ μF $C_{ADJ} = 10$ μF	 60 77			dB
Thermal Resistance Junction to Case	TO-3 Package (K STEEL)	1.2		1.8	°C/W
	TO-220 Package (T)	3		4	
Thermal Shutdown Temperature		163			°C
Thermal Resistance Junction to Ambient (No Heatsink)	K Package	35			°C/W
	T Package	50			

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its stated operating conditions.

Note 2: All limits are guaranteed at either room temperature (standard type face) or at **temperature extremes (bold typeface)** by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods.

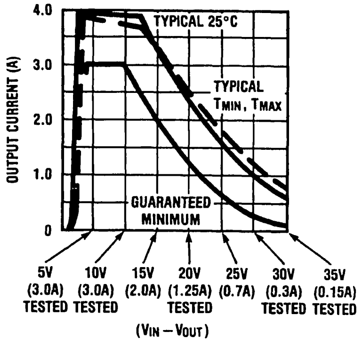
Note 3: Unless otherwise specified: $\lvert V_{IN} - V_{OUT} \rvert = 5V$, $I_{OUT} = 0.5A$, $P_{DISS} \le 30W$.

Note 4: Load and line regulation are measured at constant junction temperature, using low duty cycle pulse testing (output voltage changes due to heating effects are covered by the Thermal Regulation specification). For the TO-3 package, load regulation is measured on the output pin, ⅛" below the base of the package.

Note 5: The output current of the LM333 is guaranteed to be ≥ 3A in the range $3V \le \lvert V_{IN} - V_{OUT} \rvert \le 10V$. For the range $10V \le \lvert V_{IN} - V_{OUT} \rvert \le 15V$, the guaranteed minimum output current is equal to: $30/(V_{IN} - V_{OUT})$. Refer to graphs for guaranteed output currents at other voltages.

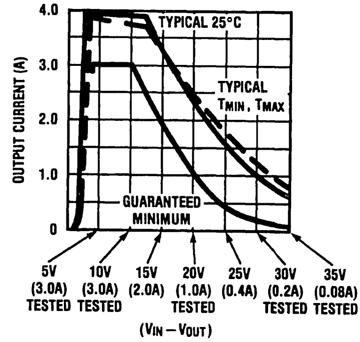
Guaranteed Performance Characteristics

LM133 Guaranteed Output Current



TL/H/9065–4

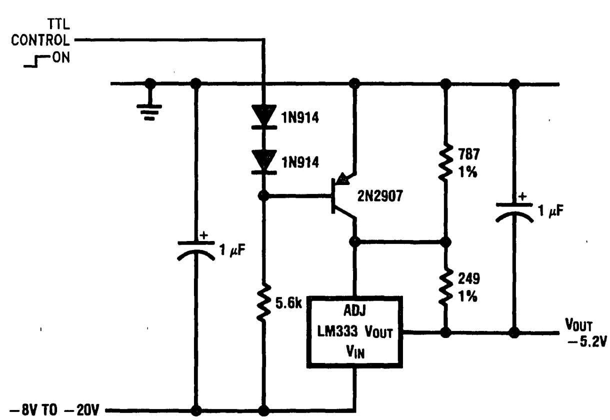
LM333 Guaranteed Output Current



TL/H/9065–5

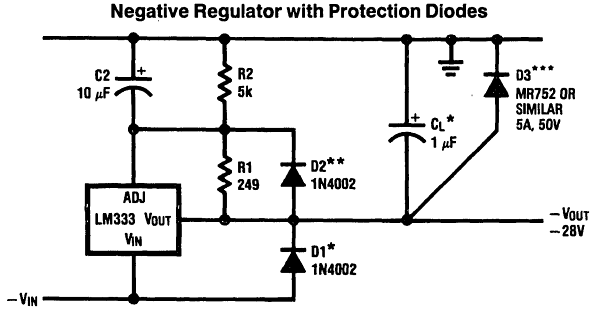
Typical Applications (Continued)

−5.2V Regulator with Electronic Shutdown



TL/H/9065–6

Negative Regulator with Protection Diodes



TL/H/9065–7

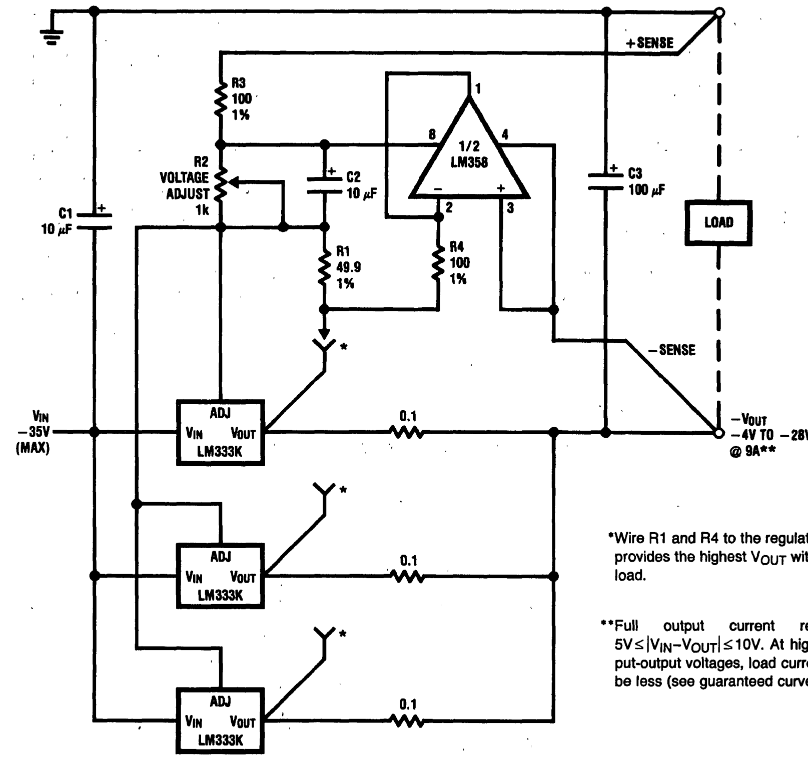
*When C_L is larger than 20 µF, D1 protects the LM133 in case the input supply is shorted.

**When C2 is larger than 10 µF and $-V_{OUT}$ is larger than −25V, D2 protects the LM133 in case the output is shorted.

***In case V_{OUT} is shorted to a positive supply, D3 protects the LM133 from overvoltage, and protects the load from reversed voltage.

Typical Applications (Continued)

High-Performance 9-Ampere Adjustable Regulator

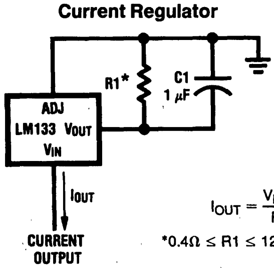


*Wire R1 and R4 to the regulator that provides the highest V_{OUT} with a 3A load.

**Full output current requires $5V \leq |V_{IN}-V_{OUT}| \leq 10V$. At higher input-output voltages, load current will be less (see guaranteed curves)

TL/H/9065-8

Current Regulator

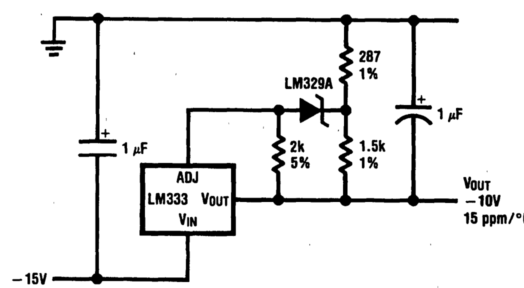


$$I_{OUT} = \frac{V_{REF}}{R1}$$

$*0.4\Omega \leq R1 \leq 120\Omega$

TL/H/9065-9

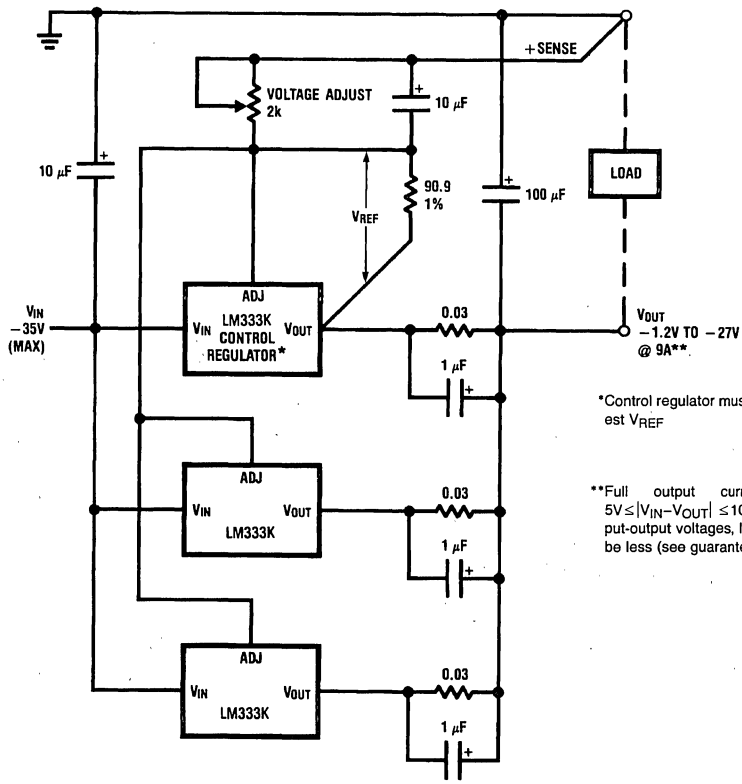
High Stability 10V Regulator



TL/H/9065-10

Typical Applications (Continued)

High-Current Adjustable Regulator

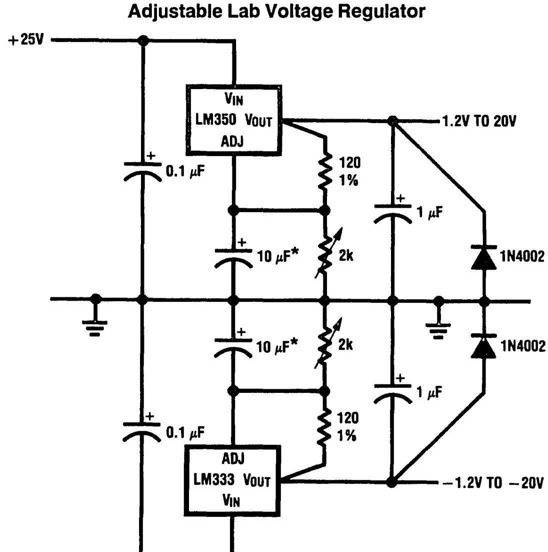


*Control regulator must have the largest V_{REF}

**Full output current requires $5V \leq |V_{IN}-V_{OUT}| \leq 10V$. At higher input-output voltages, load current will be less (see guaranteed curves)

TL/H/9065-11

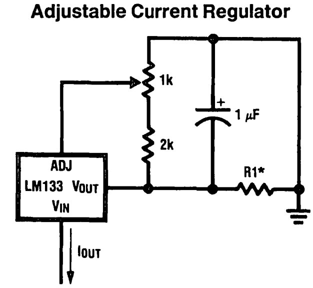
Adjustable Lab Voltage Regulator



TL/H/9065-12

*The 10 μF capacitors are optional to improve ripple rejection.

Adjustable Current Regulator



TL/H/9065-13

$$I_{OUT} = \left(\frac{1.5V}{R1}\right) \pm 15\% \text{ adjustable}$$

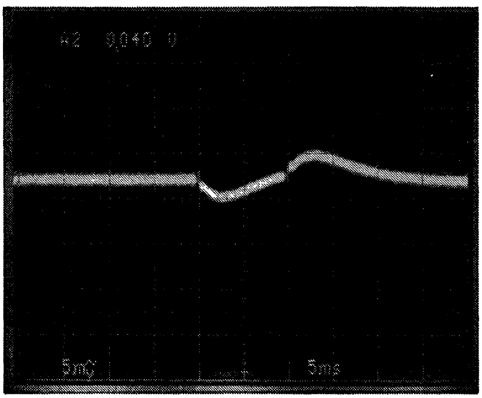
$^*0.5\Omega \leq R1 \leq 24\Omega$

Typical Applications (Continued)

THERMAL REGULATION

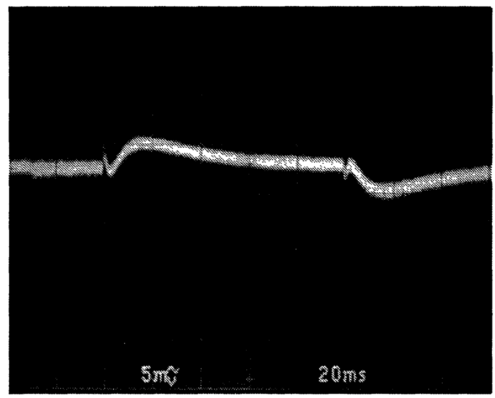
When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since the power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT}, per watt, within the first 10 ms after a step of power is applied. The LM133's specification is 0.01%/W, max.

In *Figure 1*, a typical LM133's output drifts only 2 mV (or 0.02% of $V_{OUT} = -10V$) when a 20W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.01%/W$\times$20W = 0.2% max. When the 20W pulse is ended, the thermal regulation again shows a 2 mV step as the LM133 chip cools off. Note that the load regulation error of about 1 mV (0.01%) is additional to the thermal regulation error. In *Figure 2*, when the 20W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



TL/H/9065–14

FIGURE 1



TL/H/9065–15

FIGURE 2

National Semiconductor

LM137/LM337
3-Terminal Adjustable Negative Regulators

General Description

The LM137/LM337 are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −1.5A over an output voltage range of −1.2V to −37V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137 series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

The LM137/LM337 serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137/LM337 are ideal complements to the LM117/LM317 adjustable positive regulators.

Features

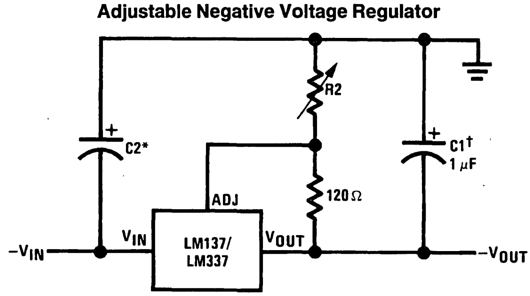
- Output voltage adjustable from −1.2V to −37V
- 1.5A output current guaranteed, −55°C to +150°C
- Line regulation typically 0.01%/V
- Load regulation typically 0.3%
- Excellent thermal regulation, 0.002%/W
- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/°C temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P^+ Product Enhancement tested
- Standard 3-lead transistor package
- Output is short circuit protected

LM137 Series Packages and Power Capability

Device	Package	Rated Power Dissipation	Design Load Current
LM137/337	TO-3 (K) TO-39 (H)	20W 2W	1.5A 0.5A
LM337	TO-220 (T)	15W	1.5A

Typical Applications

Adjustable Negative Voltage Regulator



TL/H/9067–1

Full output current not available at high input-output voltages

$$-V_{OUT} = -1.25V\left(1 + \frac{R2}{120\Omega}\right) + \left(-I_{ADJ} \times R2\right)$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability

*C2 = 1 μF solid tantalum is required only if regulator is more than 4″ from power-supply filter capacitor

Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	40V
Operating Junction Temperature Range	
LM137	−55°C to +150°C
LM337	0°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C
Plastic Package (Soldering, 4 sec.)	260°C
ESD Rating	2k Volts

Electrical Characteristics (Note 1)

Parameter	Conditions	LM137			LM337			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	$T_j = 25°C$, $3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$ (Note 2) $I_L = 10\ mA$		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_j = 25°C$, $10\ mA \le I_{OUT} \le I_{MAX}$		0.3	0.5		0.3	1.0	%
Thermal Regulation	$T_j = 25°C$, 10 ms Pulse		0.002	0.02		0.003	0.04	%/W
Adjustment Pin Current			65	100		65	100	μA
Adjustment Pin Current Charge	$10\ mA \le I_L \le I_{MAX}$ $3.0V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, $T_A = 25°C$		2	5		2	5	μA
Reference Voltage	$T_j = 25°C$ (Note 3)	−1.225	−1.250	−1.275	−1.213	−1.250	−1.287	V
	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, (Note 3) $10\ mA \le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	−1.200	−1.250	−1.300	−1.200	−1.250	−1.300	V
Line Regulation	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, (Note 2)		0.02	0.05		0.02	0.07	%/V
Load Regulation	$10\ mA \le I_{OUT} \le I_{MAX}$, (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \le T_j \le T_{MAX}$		0.6			0.6		%
Minimum Load Current	$\lvert V_{IN} - V_{OUT} \rvert \le 40V$		2.5	5		2.5	10	mA
	$\lvert V_{IN} - V_{OUT} \rvert \le 10V$		1.2	3		1.5	6	mA
Current Limit	$\lvert V_{IN} - V_{OUT} \rvert \le 15V$							
	K and T Package	1.5	2.2	3.5	1.5	2.2	3.7	A
	H Package	0.5	0.8	1.8	0.5	0.8	1.9	A
	$\lvert V_{IN} - V_{OUT} \rvert = 40V$, $T_j = 25°C$							
	K and T Package	0.24	0.4		0.15	0.4		A
	H Package	0.15	0.17		0.10	0.17		A
RMS Output Noise, % of V_{OUT}	$T_j = 25°C$, $10\ Hz \le f \le 10\ kHz$		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = -10V$, $f = 120\ Hz$		60			60		dB
	$C_{ADJ} = 10\ \mu F$	66	77		66	77		dB
Long-Term Stability	$T_j = 125°C$, 1000 Hours		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package		12	15		12	15	°C/W
	K Package		2.3	3		2.3	3	°C/W
	T Package					4		°C/W
Thermal Resistance, Junction to Ambient (No Heat Sink)	H Package		140			140		°C/W
	K Package		35			35		°C/W
	T Package					50		°C/W

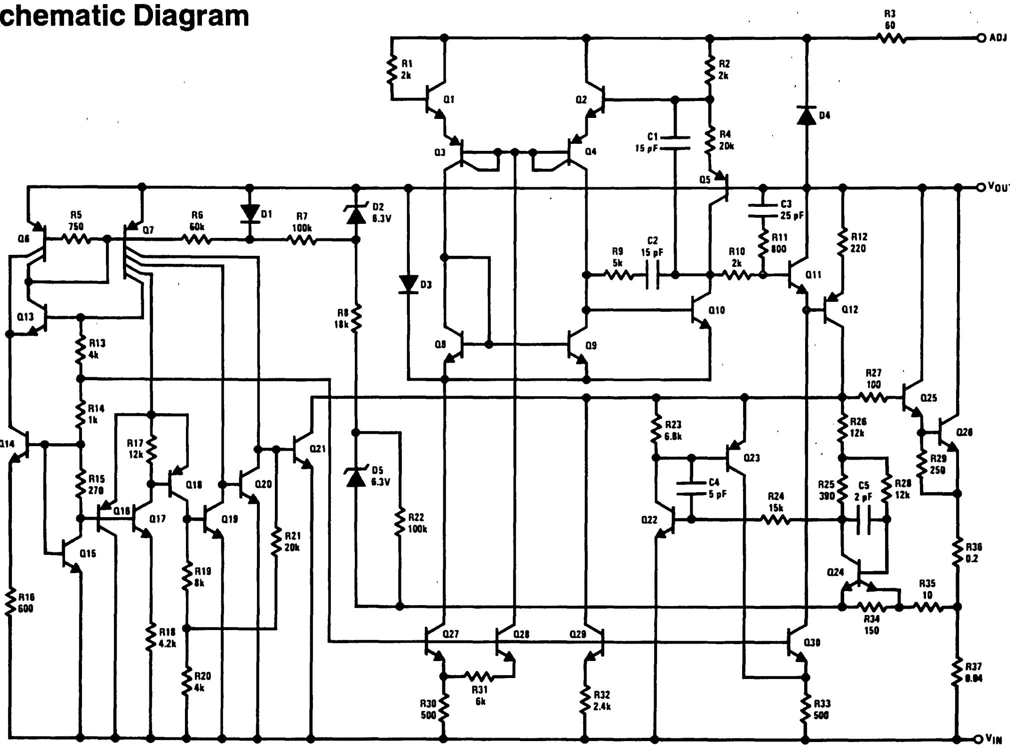
Note 1: Unless otherwise specified, these specifications apply $-55°C \le T_j \le +150°C$ for the LM137, $0°C \le T_j \le +125°C$ for the LM337; $V_{IN} - V_{OUT} = 5V$; and $I_{OUT} = 0.1A$ for the TO-39 package and $I_{OUT} = 0.5A$ for the TO-3 and TO-220 packages. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and 20W for the TO-3 and TO-220. I_{MAX} is 1.5A for the TO-3 and TO-220 packages, and 0.2A for the TO-39 package.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation. Load regulation is measured on the output pin at a point ⅛" below the base of the TO-3 and TO-39 packages.

Note 3: Selected devices with tightened tolerance reference voltage available.

Note 4: Refer to RETS137H drawing for LM137H or RETS137K drawing for LM137K military specifications.

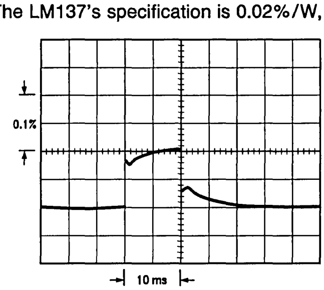
Schematic Diagram



TL/H/9067–2

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT}, per Watt, within the first 10 ms after a step of power is applied. The LM137's specification is 0.02%/W, max.

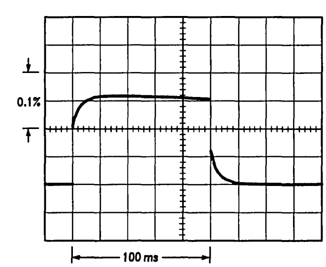


TL/H/9067–3

LM137, $V_{OUT} = -10V$
$V_{IN} - V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Vertical sensitivity, 5 mV/div

FIGURE 1

In *Figure 1*, a typical LM137's output drifts only 3 mV (or 0.03% of $V_{OUT} = -10V$) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.02%/W × 10W = 0.2% max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step at the LM137 chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In *Figure 2*, when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



TL/H/9067–4

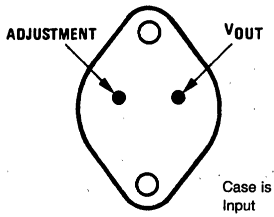
LM137, $V_{OUT} = -10V$
$V_{IN} - V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Horizontal sensitivity, 20 ms/div

FIGURE 2

1

Connection Diagrams

TO-3
Metal Can Package

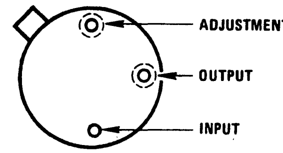


TL/H/9067-5

Bottom View
Order Number LM137K/883
See NS Package Number K02C

Order Number LM337K STEEL
See NS Package Number K02A

TO-39
Metal Can Package



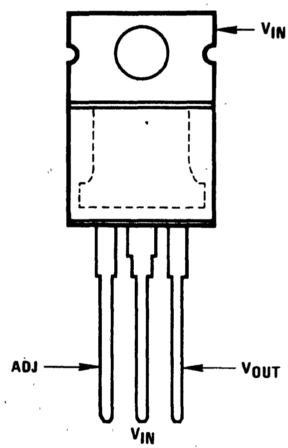
Case Is Input

TL/H/9067-6

Bottom View

Order Number LM137H, LM137H/883 or LM337H
See NS Package Number H03A

TO-220
Plastic Package



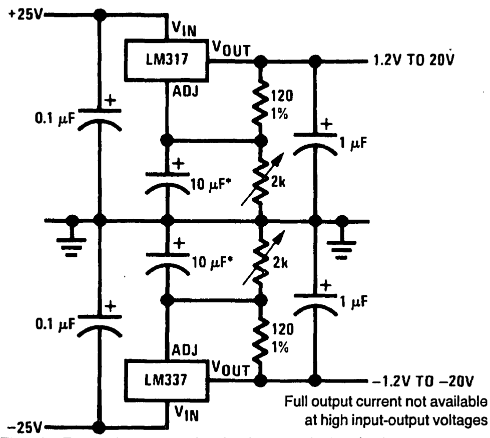
TL/H/9067-7

Front View

Order Number LM337T
See NS Package Number T03B

Typical Applications (Continued)

Adjustable Lab Voltage Regulator

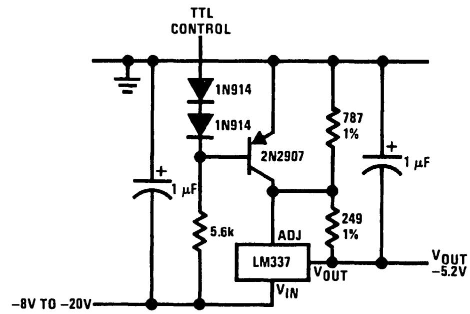


Full output current not available at high input-output voltages

*The 10 µF capacitors are optional to improve ripple rejection

TL/H/9067–9

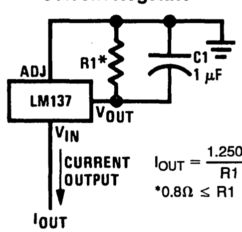
−5.2V Regulator with Electronic Shutdown*



TL/H/9067–10

*Minimum output ≅ −1.3V when control input is low

Current Regulator

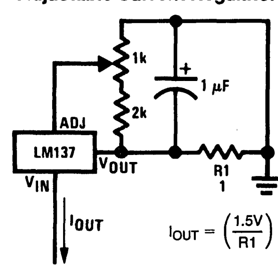


$I_{OUT} = \frac{1.250V}{R1}$

$*0.8\Omega \le R1 \le 120\Omega$

TL/H/9067–11

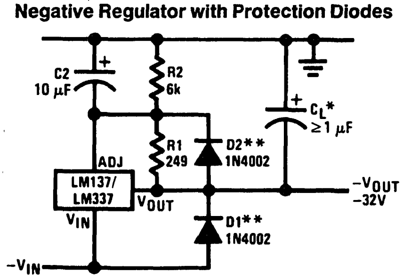
Adjustable Current Regulator



$I_{OUT} = \left(\frac{1.5V}{R1}\right)$ ±15% adjustable

TL/H/9067–12

Negative Regulator with Protection Diodes

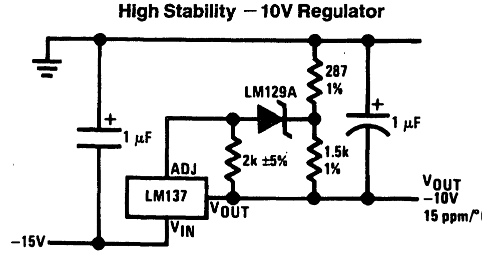


TL/H/9067–13

*When C_L is larger than 20 µF, D1 protects the LM137 in case the input supply is shorted

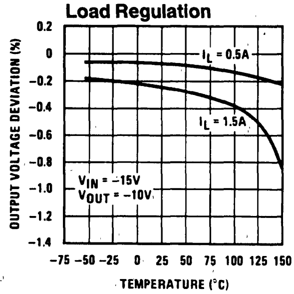
**When C2 is larger than 10 µF and $-V_{OUT}$ is larger than −25V, D2 protects the LM137 in case the output is shorted

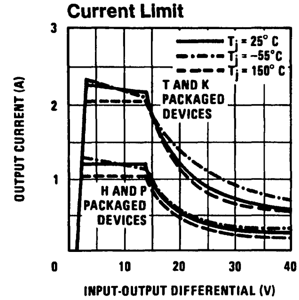
High Stability −10V Regulator

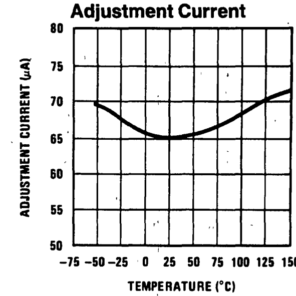


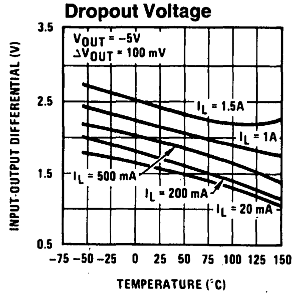
TL/H/9067–14

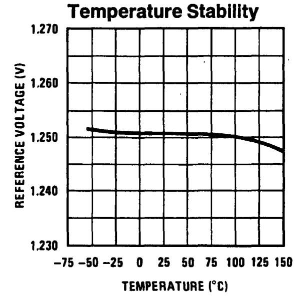
Typical Performance Characteristics (K Steel and T Packages)

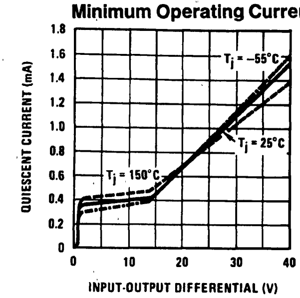
Load Regulation


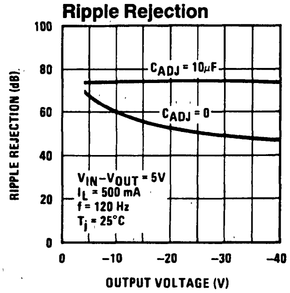
Current Limit


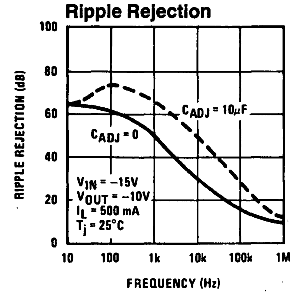
Adjustment Current


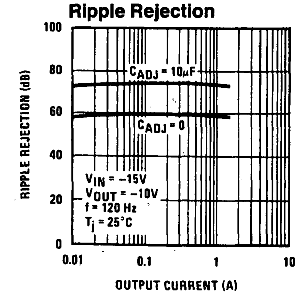
Dropout Voltage


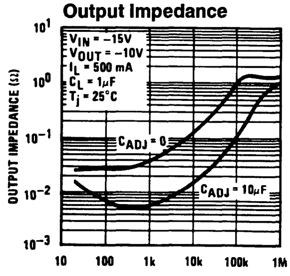
Temperature Stability


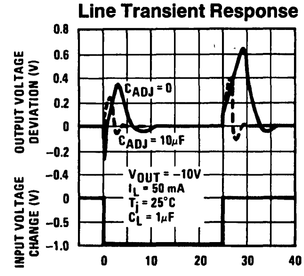
Minimum Operating Current


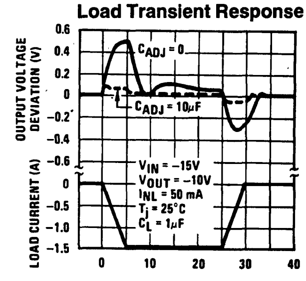
Ripple Rejection


Ripple Rejection


Ripple Rejection


Output Impedance


Line Transient Response


Load Transient Response


TL/H/9067–15

National Semiconductor

LM137HV/LM337HV 3-Terminal Adjustable Negative Regulators (High Voltage)

General Description

The LM137HV/LM337HV are adjustable 3-terminal negative voltage regulators capable of supplying in excess of −1.5A over an output voltage range of −1.2V to −47V. These regulators are exceptionally easy to apply, requiring only 2 external resistors to set the output voltage and 1 output capacitor for frequency compensation. The circuit design has been optimized for excellent regulation and low thermal transients. Further, the LM137HV series features internal current limiting, thermal shutdown and safe-area compensation, making them virtually blowout-proof against overloads.

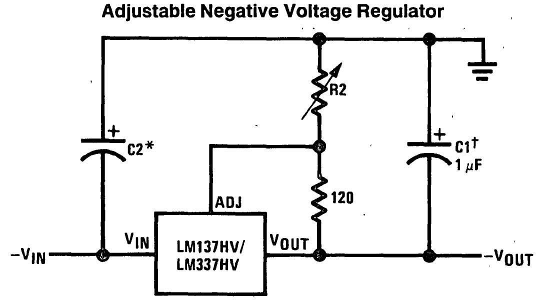
The LM137HV/LM337HV serve a wide variety of applications including local on-card regulation, programmable-output voltage regulation or precision current regulation. The LM137HV/LM337HV are ideal complements to the LM117HV/LM317HV adjustable positive regulators.

Features

- Output voltage adjustable from −1.2V to −47V
- 1.5A output current guaranteed, −55°C to +150°C
- Line regulation typically 0.01%/V
- Load regulation typically 0.3%
- Excellent thermal regulation, 0.002%/W
- 77 dB ripple rejection
- Excellent rejection of thermal transients
- 50 ppm/°C temperature coefficient
- Temperature-independent current limit
- Internal thermal overload protection
- P+ Product Enhancement tested
- Standard 3-lead transistor package
- Output short circuit protected

Typical Applications

Adjustable Negative Voltage Regulator



TL/H/9066-1

$$-V_{OUT} = -1.25V\left(1 + \frac{R2}{120\Omega}\right) + \left[-I_{Adj}(R_2)\right]$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*C2 = 1 μF solid tantalum is required only if regulator is more than 4″ from power-supply filter capacitor.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 3)

Power Dissipation	Internally limited
Input—Output Voltage Differential	50V
Operating Junction Temperature Range	
LM137HV	−55°C to +150°C
LM337HV	0°C to +125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°

ESD rating is to be determined.

Electrical Characteristics (Note 1)

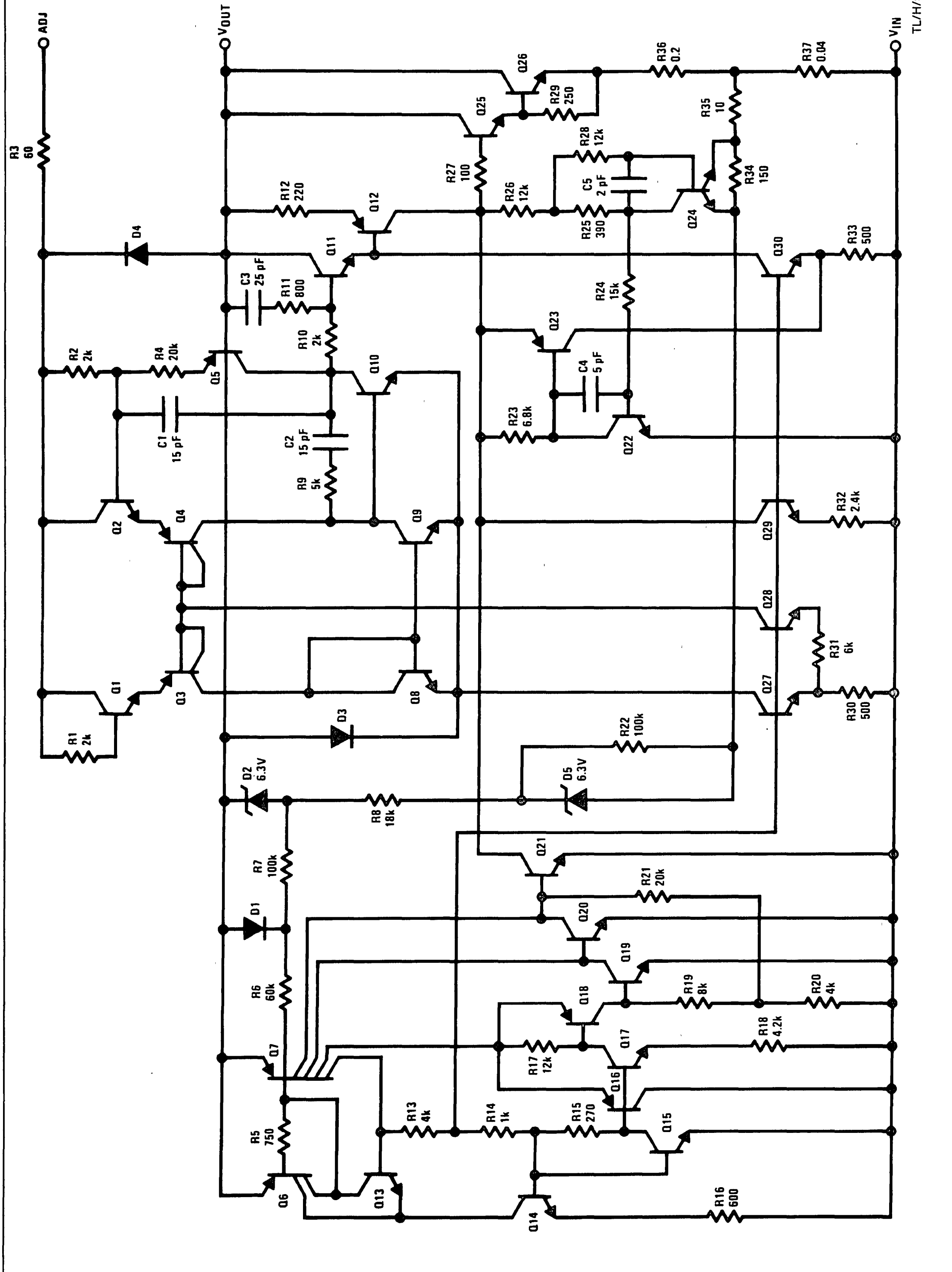
Parameter	Conditions	LM137HV Min	LM137HV Typ	LM137HV Max	LM337HV Min	LM337HV Typ	LM337HV Max	Units
Line Regulation	$T_J = 25°C$, $3V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 2) $I_L = 10$ mA		0.01	0.02		0.01	0.04	%/V
Load Regulation	$T_J = 25°C$, 10 mA $\le I_{OUT} \le I_{MAX}$		0.3	0.5		0.3	1.0	%
Thermal Regulation	$T_J = 25°C$, 10 ms Pulse		0.002	0.02		0.003	0.04	%/W
Adjustment Pin Current			65	100		65	100	μA
Adjustment Pin Current Change	10 mA $\le I_L \le I_{MAX}$		2	5		2	5	μA
	$3.0V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, $T_J = 25°$		4	6		3	6	μA
Reference Voltage	$T_J = 25°C$, (Note 3)	−1.225	−1.250	−1.275	−1.213	−1.250	−1.287	V
	$3V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 3) 10 mA $\le I_{OUT} \le I_{MAX}$, $P \le P_{MAX}$	−1.200	−1.250	−1.300	−1.200	−1.250	−1.300	V
Line Regulation	$3V \le \lvert V_{IN}-V_{OUT}\rvert \le 50V$, (Note 2) $I_L = 10$ mA		0.02	0.05		0.02	0.07	%/V
Load Regulation	10 mA $\le I_{OUT} \le I_{MAX}$, (Note 2)		0.3	1		0.3	1.5	%
Temperature Stability	$T_{MIN} \le T_j \le T_{MAX}$		0.6			0.6		%
Minimum Load Current	$\lvert V_{IN}-V_{OUT}\rvert \le 50V$		2.5	5		2.5	10	mA
	$\lvert V_{IN}-V_{OUT}\rvert \le 10V$		1.2	3		1.5	6	mA
Current Limit	$\lvert V_{IN}-V_{OUT}\rvert \le 13V$							
	K Package	1.5	2.2	3.2	1.5	2.2	3.5	A
	H Package	0.5	0.8	1.6	0.5	0.8	1.8	A
	$\lvert V_{IN}-V_{OUT}\rvert = 50V$							
	K Package	0.2	0.4	0.8	0.1	0.4	0.8	A
	H Package	0.1	0.17	0.5	0.050	0.17	0.5	A
RMS Output Noise, % of V_{OUT}	$T_J = 25°C$, 10 Hz $\le f \le$ 10 kHz		0.003			0.003		%
Ripple Rejection Ratio	$V_{OUT} = -10V$, f = 120 Hz		60			60		dB
	$C_{ADJ} = 10\ \mu F$	66	77		66	77		dB
Long-Term Stability	$T_A = 125°C$, 1000 Hours		0.3	1		0.3	1	%
Thermal Resistance, Junction to Case	H Package		12	15		12	15	°C/W
	K Package		2.3	3		2.3	3	°C/W
Thermal Resistance, Junction to Ambient	H Package		140			140		°C/W
	K Package		35			35		°C/W

Note 1: Unless otherwise specified, these specifications apply: $-55°C \le T_j \le +150°C$ for the LM137HV, $0°C \le T_j \le +125°C$ for the LM337HV; $V_{IN}-V_{OUT} = 5V$; and $I_{OUT} = 0.1A$ for the TO-39 package and $I_{OUT} = 0.5A$ for the TO-3 package. Although power dissipation is internally limited, these specifications are applicable for power dissipations of 2W for the TO-39 and 20W for the TO-3. I_{MAX} is 1.5A for the TO-3 package and 0.2A for the TO-39 package.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulations. Load regulation is measured on the output pin at a point ⅛″ below the base of the TO-3 and TO-39 packages.

Note 3: Refer to RETS137HVH drawing for LM137HVH or RETS137HVK for LM137HVK military specifications.

Schematic Diagram



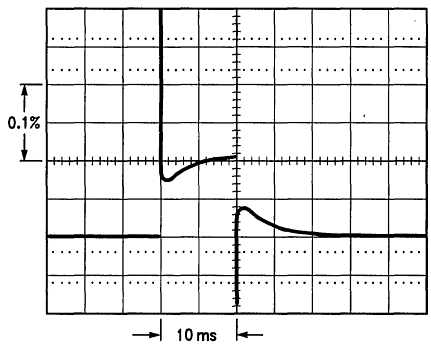
TL/H/9066–2

1

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per Watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT}, per Watt, within the first 10 ms after a step of power is applied. The LM137HV's specification is 0.02%/W, max.

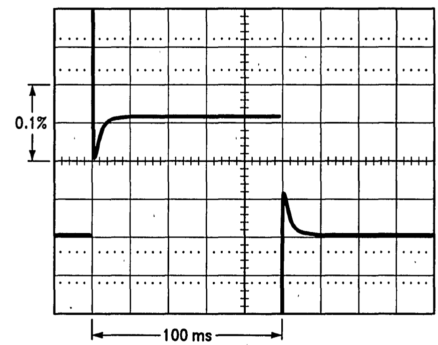
In *Figure 1,* a typical LM137HV's output drifts only 3 mV (or 0.03% of $V_{OUT} = -10V$) when a 10W pulse is applied for 10 ms. This performance is thus well inside the specification limit of 0.02%/W x 10W = 0.2% max. When the 10W pulse is ended, the thermal regulation again shows a 3 mV step as the LM137HV chip cools off. Note that the load regulation error of about 8 mV (0.08%) is additional to the thermal regulation error. In *Figure 2,* when the 10W pulse is applied for 100 ms, the output drifts only slightly beyond the drift in the first 10 ms, and the thermal error stays well within 0.1% (10 mV).



TL/H/9066-3

LM137HV, $V_{OUT} = -10V$
$V_{IN}-V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Vertical sensitivity, 5 mV/div

FIGURE 1



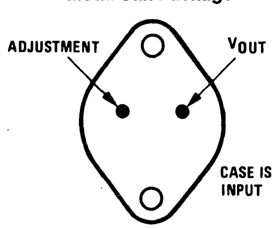
TL/H/9066-4

LM137HV, $V_{OUT} = -10V$
$V_{IN}-V_{OUT} = -40V$
$I_L = 0A \rightarrow 0.25A \rightarrow 0A$
Horizontal sensitivity, 20 ms/div

FIGURE 2

Connection Diagram (See Physical Dimensions section for further information)

TO-3
Metal Can Package



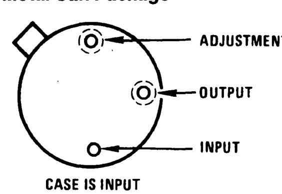
TL/H/9066-5

Bottom View

Order Number LM137HVK/883 or SMD #7703404
See NS Package Number K02C

Order Number LM337HVK STEEL
See NS Package Number K02A

TO-39
Metal Can Package



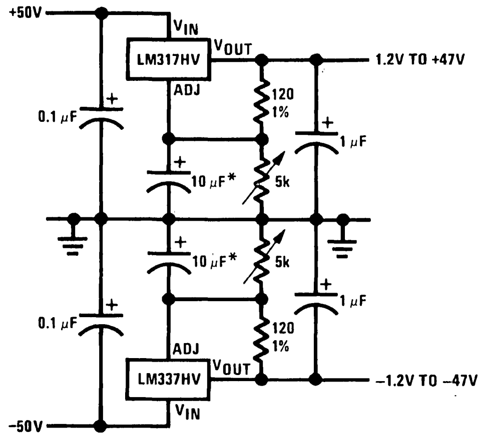
TL/H/9066-6

Bottom View

Order Number LM137HVH/883, SMD #7703404 or LML337HVH
See NS Package Number H03A

Typical Applications (Continued)

Adjustable High Voltage Regulator

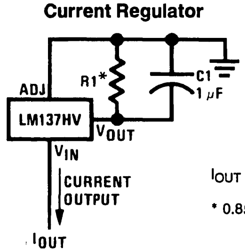


TL/H/9066–7

Full output current not available
at high input-output voltages

*The 10 μF capacitors are optional to improve ripple rejection

Current Regulator

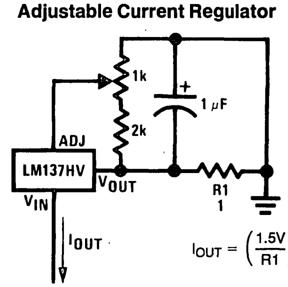


$I_{OUT} = \frac{V_{REF}}{R1}$

* $0.8\Omega \le R1 \le 120\Omega$

TL/H/9066–8

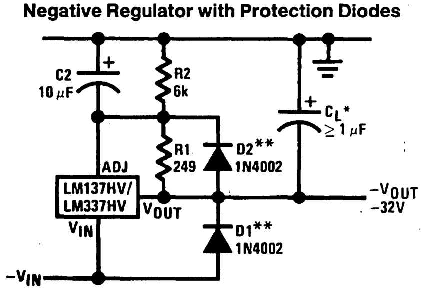
Adjustable Current Regulator



$I_{OUT} = \left(\frac{1.5V}{R1}\right)$ ±15% adjustable

TL/H/9066–9

Negative Regulator with Protection Diodes

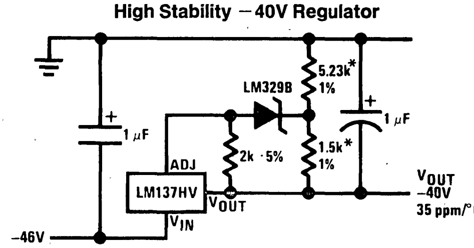


TL/H/9066–10

*When C_L is larger than 20 μF, D1 protects the LM137HV in case the input supply is shorted

**When C2 is larger than 10 μF and $-V_{OUT}$ is larger than −25V, D2 protects the LM137HV is case the output is shorted

High Stability −40V Regulator



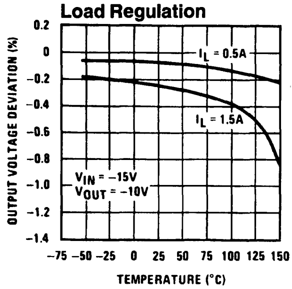
TL/H/9066–11

* Use resistors with good tracking TC < 25 ppm/°C

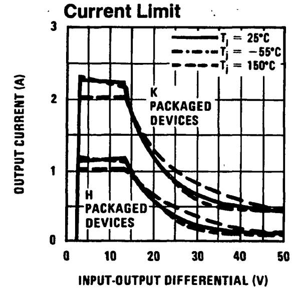
1

Typical Performance Characteristics (H and K-STEEL Package)

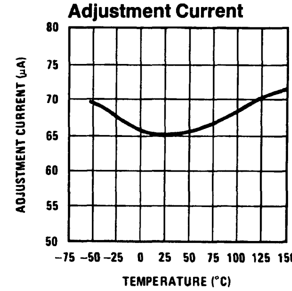
Load Regulation



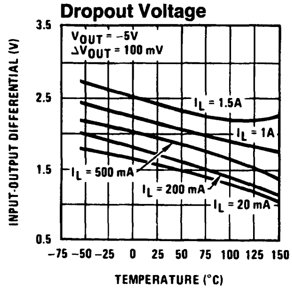
Current Limit



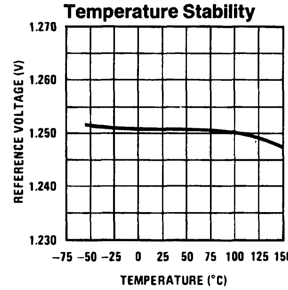
Adjustment Current



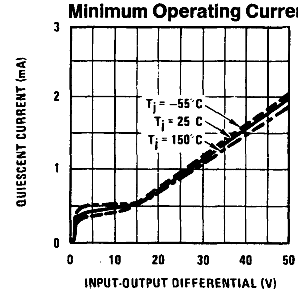
Dropout Voltage



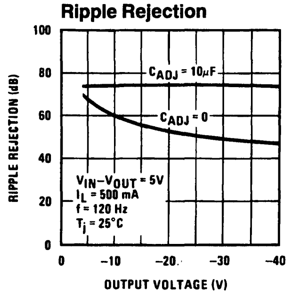
Temperature Stability



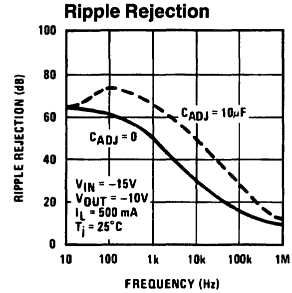
Minimum Operating Current



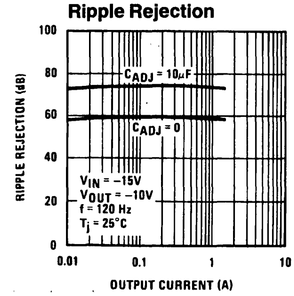
Ripple Rejection



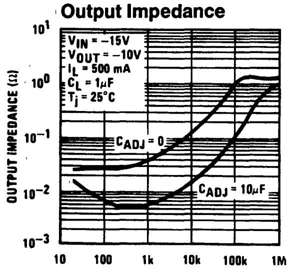
Ripple Rejection



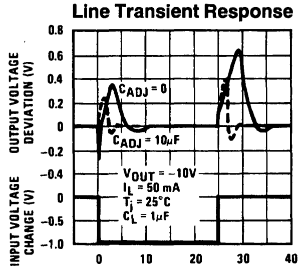
Ripple Rejection



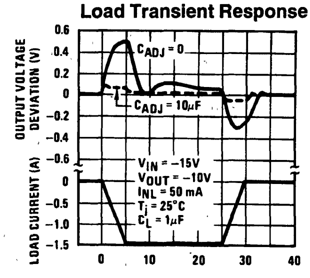
Output Impedance



Line Transient Response



Load Transient Response



TL/H/9066–12

National Semiconductor

LM138, LM338 5-Amp Adjustable Regulators

General Description

The LM138 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 5A over a 1.2V to 32V output range. They are exceptionally easy to use and require only 2 resistors to set the output voltage. Careful circuit design has resulted in outstanding load and line regulation—comparable to many commercial power supplies. The LM138 family is supplied in a standard 3-lead transistor package.

A unique feature of the LM138 family is time-dependent current limiting. The current limit circuitry allows peak currents of up to 12A to be drawn from the regulator for short periods of time. This allows the LM138 to be used with heavy transient loads and speeds start-up under full-load conditions. Under sustained loading conditions, the current limit decreases to a safe value protecting the regulator. Also included on the chip are thermal overload protection and safe area protection for the power transistor. Overload protection remains functional even if the adjustment pin is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM138 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., do not short-circuit output to ground. The part numbers in the LM138 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM138 is rated for $-55°C \leq T_J \leq +150°C$, and the LM338 is rated for $0°C \leq T_J \leq +125°C$.

Features

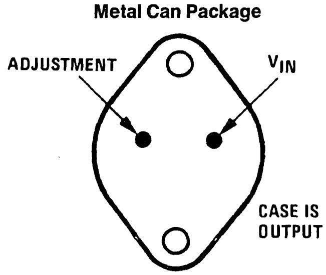
- Guaranteed 7A peak output current
- Guaranteed 5A output current
- Adjustable output down to 1.2V
- Guaranteed thermal regulation
- Current limit constant with temperature
- P^+ Product Enhancement tested
- Output is short-circuit protected

Applications

- Adjustable power supplies
- Constant current regulators
- Battery chargers

Connection Diagrams (See Physical Dimension section for further information)

(TO-3 STEEL)
Metal Can Package

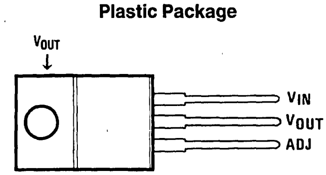


TL/H/9060-30

Bottom View

Order Number LM138K STEEL or LM338K STEEL
See NS Package Number K02A

(TO-220)
Plastic Package



TL/H/9060-31

Front View

Order Number LM338T
See NS Package Number T03B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation	Internally limited
Input/Output Voltage Differential	+40V, −0.3V
Storage Temperature	−65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 seconds)	300°C
Plastic Package (Soldering, 4 seconds)	260°C
ESD Tolerance	TBD

Operating Temperature Range

LM138	$-55°C \le T_J \le +150°C$
LM338	$0°C \le T_J \le +125°C$

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} - V_{OUT} = 5V$; and $I_{OUT} = 10$ mA. (Note 2)

Symbol	Parameter	Conditions	LM138			Units
			Min	Typ	Max	
V_{REF}	Reference Voltage	$3V \le (V_{IN} - V_{OUT}) \le 35V$, 10 mA $\le I_{OUT} \le$ 5A, P $\le$ 50W	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 35V$ (Note 3)		0.005	0.01	%/V
				0.02	**0.04**	%/V
V_{RLOAD}	Load Regulation	10 mA $\le I_{OUT} \le$ 5A (Note 3)		0.1	0.3	%
				0.3	**0.6**	%
	Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	μA
ΔI_{ADJ}	Adjustment Pin Current Change	10 mA $\le I_{OUT} \le$ 5A, $3V \le (V_{IN} - V_{OUT}) \le 35V$		**0.2**	**5**	μA
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**		%
I_{LOAD}(Min)	Minimum Load Current	$V_{IN} - V_{OUT} = 35V$		**3.5**	**5**	mA
I_{CL}	Current Limit	$V_{IN} - V_{OUT} \le 10V$				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} - V_{OUT} = 30V$		1		A
V_N	RMS Output Noise, % of V_{OUT}	10 Hz $\le$ f $\le$ 10 kHz		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 μF		**60**		dB
		V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 μF	**60**	**75**		dB
	Long-Term Stability	T_J = 125°C, 1000 Hrs		0.3	1	%
θ_{JC}	Thermal Resistance, Junction to Case	K Package			1	°C/W
θ_{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		°C/W

Electrical Characteristics (Continued)

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} - V_{OUT} = 5V$; and $I_{OUT} = 10$ mA. (Note 2)

Symbol	Parameter	Conditions	LM338 Min	LM338 Typ	LM338 Max	Units
V_{REF}	Reference Voltage	$3V \le (V_{IN} - V_{OUT}) \le 35V$, $10\ mA \le I_{OUT} \le 5A$, $P \le 50W$	**1.19**	**1.24**	**1.29**	V
V_{RLINE}	Line Regulation	$3V \le (V_{IN} - V_{OUT}) \le 35V$ (Note 3)		0.005	0.03	%/V
				0.02	**0.06**	%/V
V_{RLOAD}	Load Regulation	$10\ mA \le I_{OUT} \le 5A$ (Note 3)		0.1	0.5	%
				0.3	**1**	%
	Thermal Regulation	20 ms Pulse		0.002	0.02	%/W
I_{ADJ}	Adjustment Pin Current			**45**	**100**	μA
ΔI_{ADJ}	Adjustment Pin Current Change	$10\ mA \le I_{OUT} \le 5A$, $3V \le (V_{IN} - V_{OUT}) \le 35V$		**0.2**	**5**	μA
$\Delta V_{R/T}$	Temperature Stability	$T_{MIN} \le T_J \le T_{MAX}$		**1**		%
$I_{LOAD}(Min)$	Minimum Load Current	$V_{IN} - V_{OUT} = 35V$		**3.5**	**10**	mA
I_{CL}	Current Limit	$V_{IN} - V_{OUT} \le 10V$				
		DC	**5**	**8**		A
		0.5 ms Peak	**7**	**12**		A
		$V_{IN} - V_{OUT} = 30V$			1	A
V_N	RMS Output Noise, % of V_{OUT}	$10\ Hz \le f \le 10\ kHz$		0.003		%
$\frac{\Delta V_R}{\Delta V_{IN}}$	Ripple Rejection Ratio	$V_{OUT} = 10V$, $f = 120\ Hz$, $C_{ADJ} = 0\ \mu F$		**60**		dB
		$V_{OUT} = 10V$, $f = 120\ Hz$, $C_{ADJ} = 10\ \mu F$	**60**	**75**		dB
	Long-Term Stability	$T_J = 125°C$, 1000 hrs		0.3	1	%
θ_{JC}	Thermal Resistance Junction to Case	K Package			1	°C/W
		T Package			4	°C/W
θ_{JA}	Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		°C/W
		T Package		50		°C/W

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

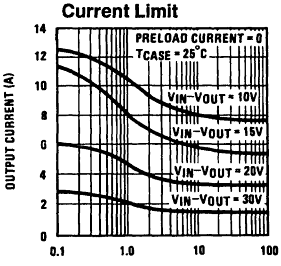
Note 2: These specifications are applicable for power dissipations up to 50W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 3: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

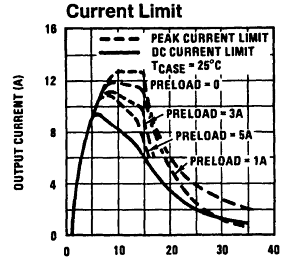
Note 4: Refer to RETS138K drawing for military specifications of LM138K.

Typical Performance Characteristics

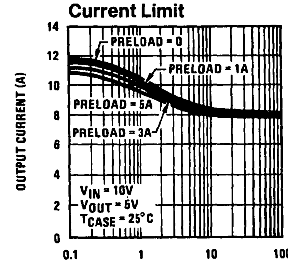
Current Limit



Current Limit



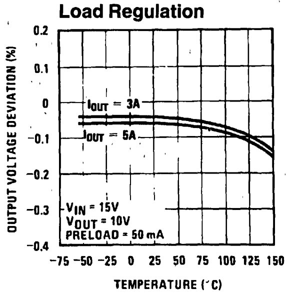
Current Limit



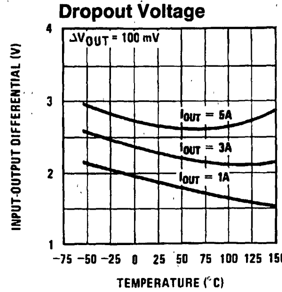
TL/H/9060–4

Typical Performance Characteristics (Continued)

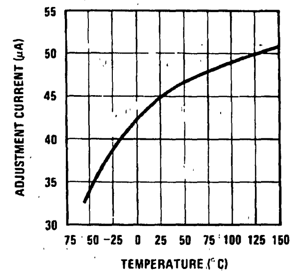
Load Regulation



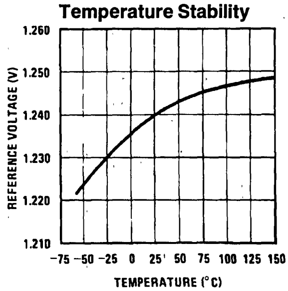
Dropout Voltage



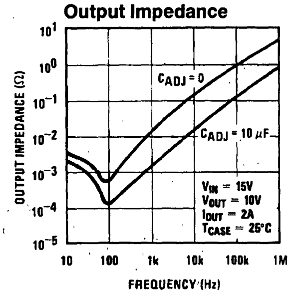
Adjustment Current



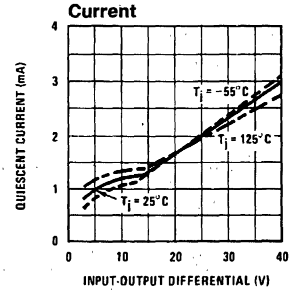
Temperature Stability



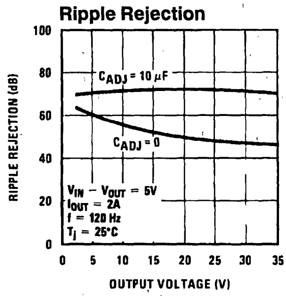
Output Impedance



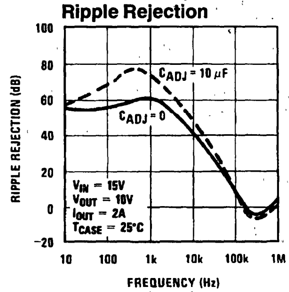
Minimum Operating Current



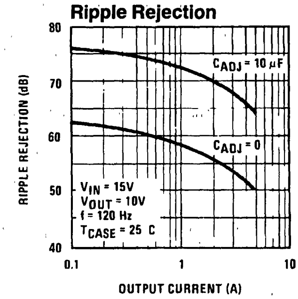
Ripple Rejection



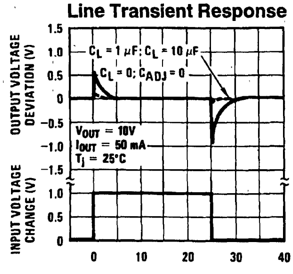
Ripple Rejection



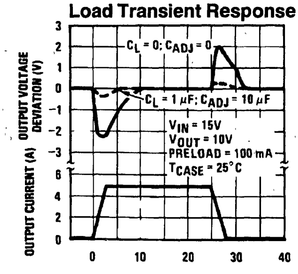
Ripple Rejection



Line Transient Response



Load Transient Response

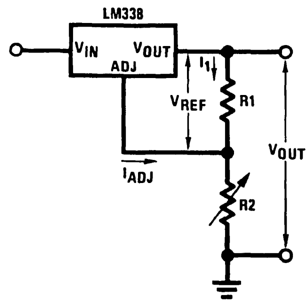


TL/H/9060–5

Application Hints

In operation, the LM138 develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2.$$



TL/H/9060-6

FIGURE 1

Since the 50 μA current from the adjustment terminal represents an error term, the LM138 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

External Capacitors

An input bypass capacitor is recommended. A 0.1 μF disc or 1 μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassiing when adjustment or output capacitors are used but the above values will eliminate the possiblity of problems.

The adjustment terminal can be bypassed to ground on the LM138 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μF bypass capacitor 75 dB ripple rejection is obtainable at any output level. Increases over 20 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

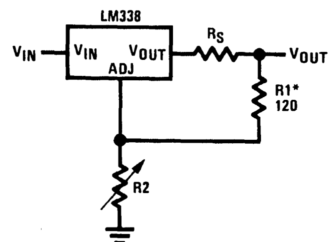
In general, the best type of capacitors to use are solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1 μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μF disc may seem to work better than a 0.1 μF disc as a bypass.

Although the LM138 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μF solid tantalum (or 25 μF aluminum electrolytic) on the output swamps this effect and insures stability.

Load Regulation

The LM138 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output of the regulator (case) rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω × I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.



TL/H/9060-7

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using 2 separate leads to the case. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

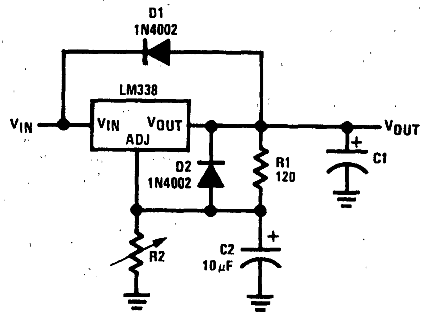
Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 20 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM138 this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 100 μF or less at output of 15V or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM138 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM138 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Application Hints (Continued)



TL/H/9060-8

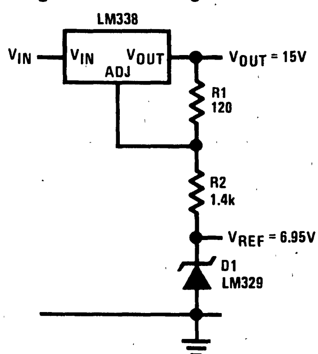
D1 protects against C1
D2 protects against C2

$$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

FIGURE 3. Regulator with Protection Diodes

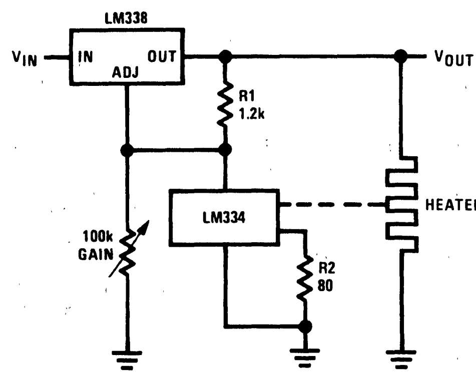
Typical Applications

Regulator and Voltage Reference



TL/H/9060-3

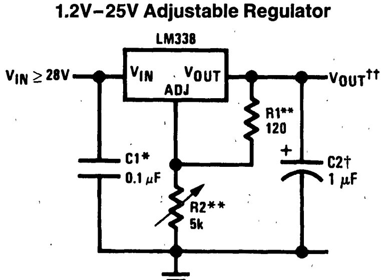
Temperature Controller



TL/H/9060-10

Full output current not available at high input-output voltages

1.2V–25V Adjustable Regulator



TL/H/9060-1

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

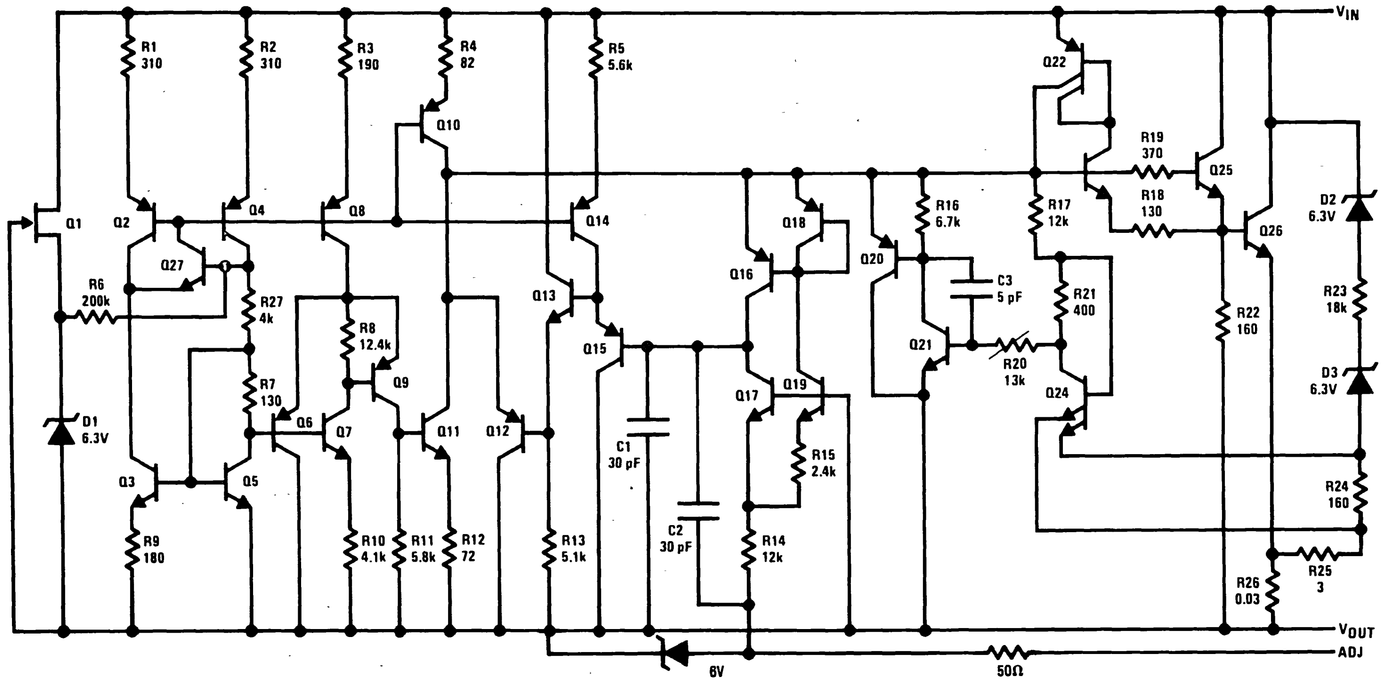
$$††V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

**R1 = 240Ω for LM138. R1, R2 as an assembly can be ordered from Bourns:

MIL part no. 7105A-AT2-502

COMM part no. 7105A-AT7-502

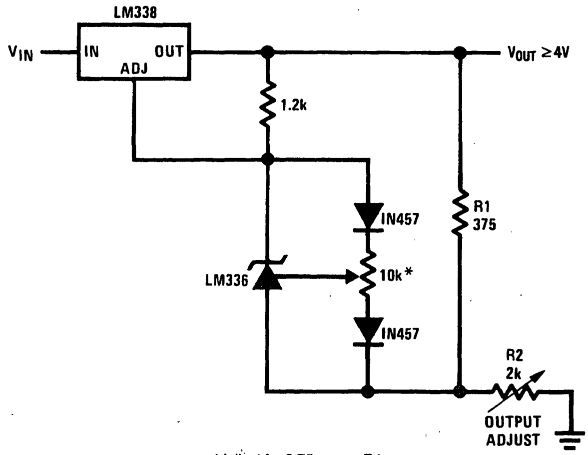
Schematic Diagram



TL/H/9060-9

Typical Applications (Continued)

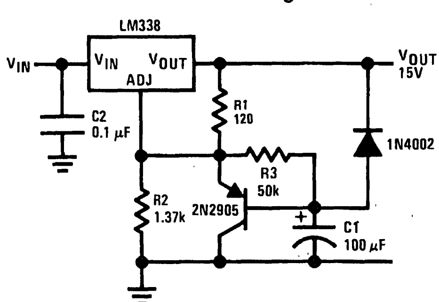
Precision Power Regulator with Low Temperature Coefficient



*Adjust for 3.75 across R1

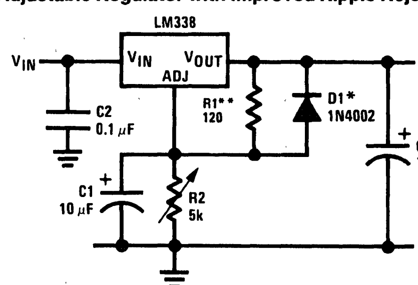
TL/H/9060-12

Slow Turn-On 15V Regulator



TL/H/9060-13

Adjustable Regulator with Improved Ripple Rejection



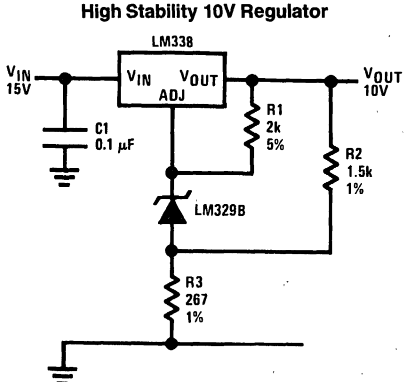
TL/H/9060-14

†Solid tantalum

*Discharges C1 if output is shorted to ground

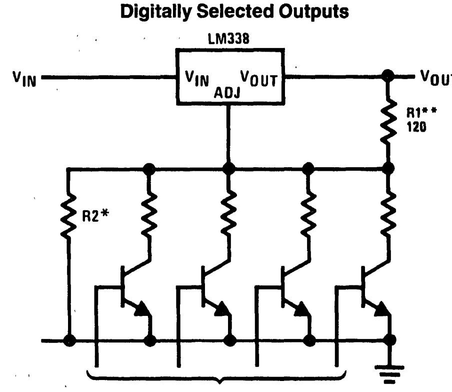
**R1 = 240Ω for LM138

High Stability 10V Regulator



TL/H/9060-15

Digitally Selected Outputs



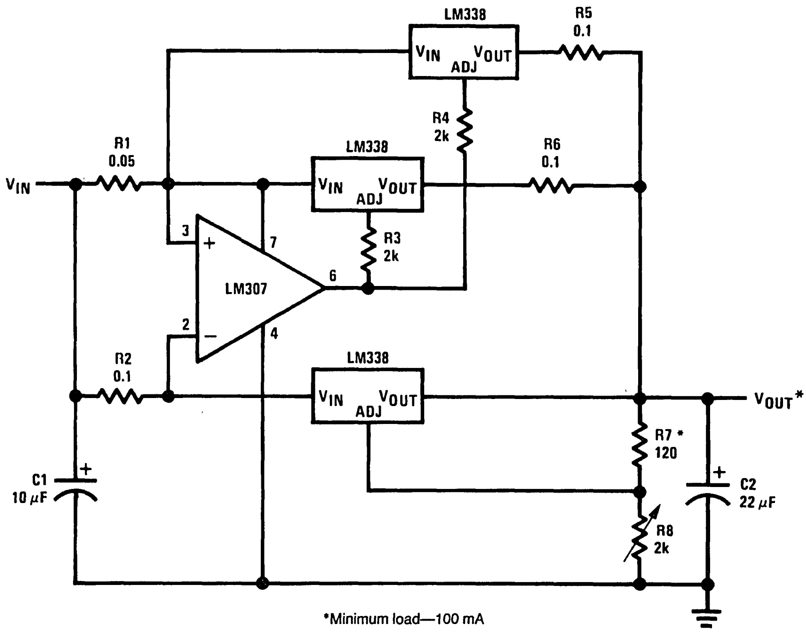
TL/H/9060-16

*Sets maximum V_{OUT}

**R1 = 240Ω for LM138

Typical Applications (Continued)

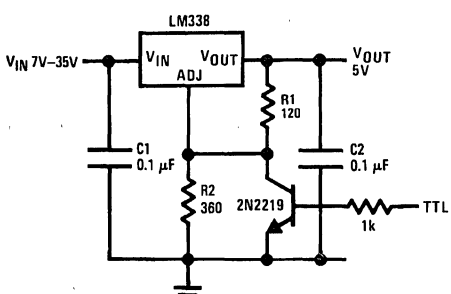
15A Regulator



*Minimum load—100 mA

TL/H/9060-17

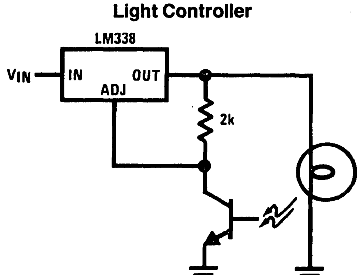
5V Logic Regulator with Electronic Shutdown**



**Minimum output ≈ 1.2V

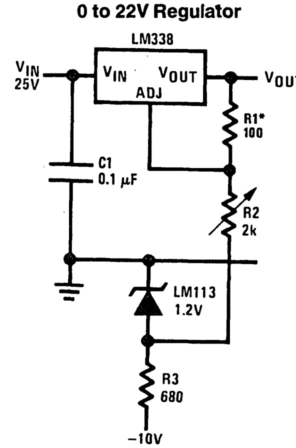
TL/H/9060-18

Light Controller



TL/H/9060-11

0 to 22V Regulator

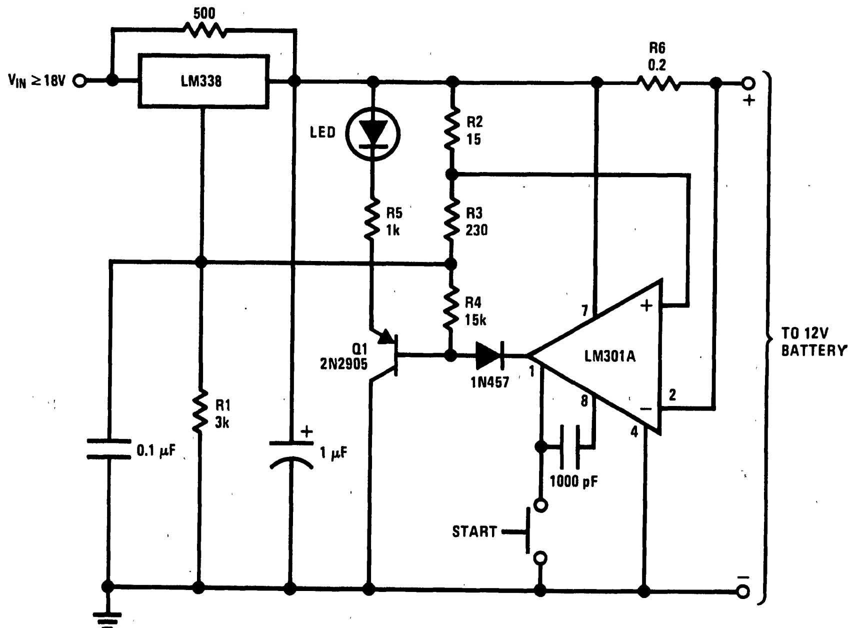


TL/H/9060-19

*R1 = 240Ω, R2 = 5k for LM138
Full output current not available at high input-output voltages

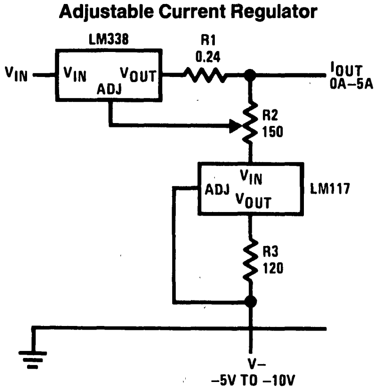
Typical Applications (Continued)

12V Battery Charger



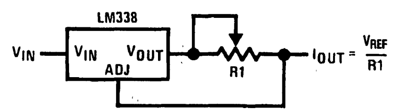
TL/H/9060-20

Adjustable Current Regulator



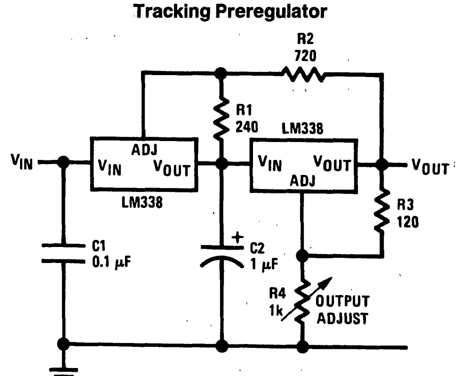
TL/H/9060-21

Precision Current Limiter



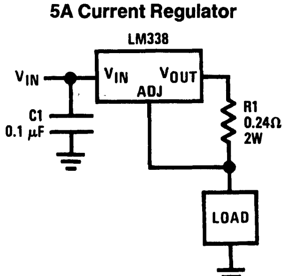
TL/H/9060-22

Tracking Preregulator



TL/H/9060-24

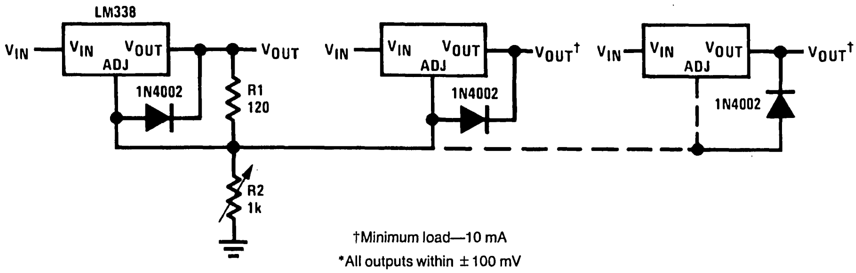
5A Current Regulator



TL/H/9060-23

Typical Applications (Continued)

Adjusting Multiple On-Card Regulators with Single Control*

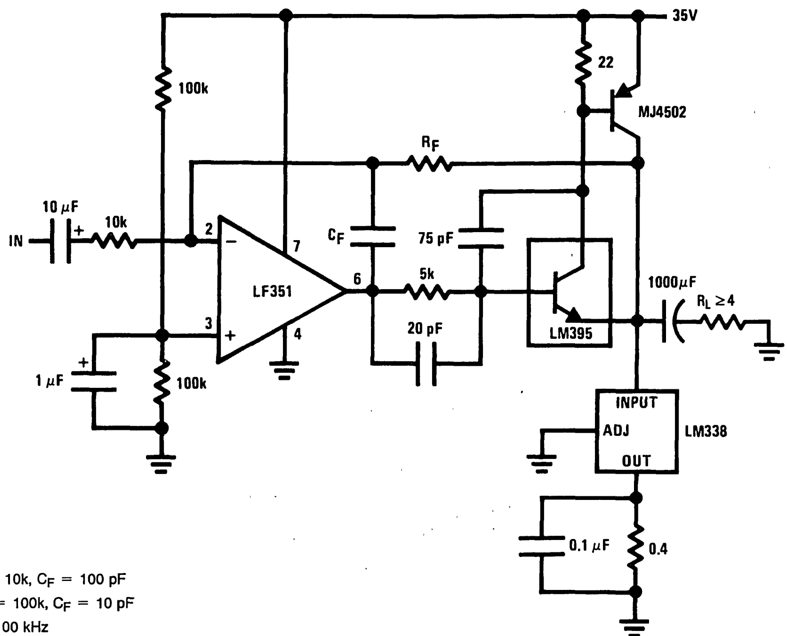


†Minimum load—10 mA

*All outputs within ±100 mV

TL/H/9060-25

Power Amplifier



$A_V = 1$, $R_F = 10k$, $C_F = 100$ pF

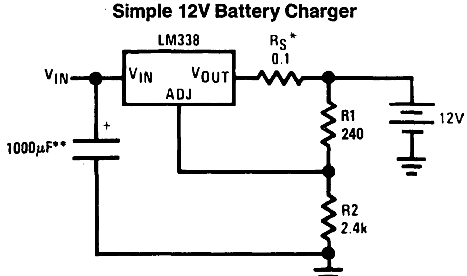
$A_V = 10$, $R_F = 100k$, $C_F = 10$ pF

Bandwidth ≥ 100 kHz

Distortion ≤ 0.1%

TL/H/9060-27

Simple 12V Battery Charger



TL/H/9060-28

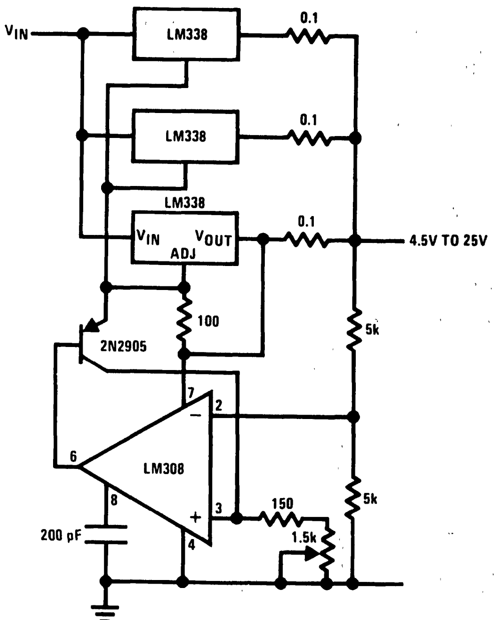
*R_S—sets output impedance of charger $Z_{OUT} = R_S\left(1 + \frac{R2}{R1}\right)$

Use of R_S allows low charging rates with fully charged battery.

**The 1000 µF is recommended to filter out input transients

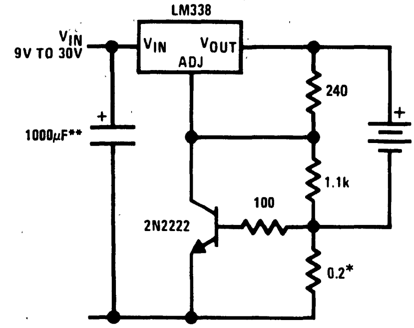
Typical Applications (Continued)

Adjustable 15A Regulator



TL/H/9060-26

Current Limited 6V Charger

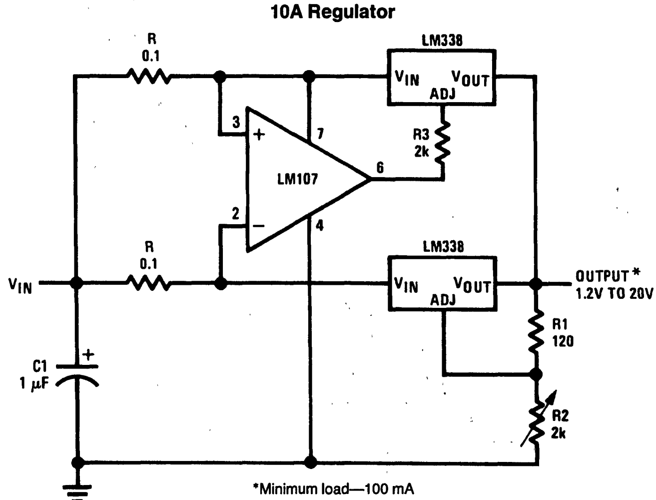


TL/H/9060-29

*Set max charge current to 3A

**The 1000 µF is recommended to filter out input transients.

10A Regulator



*Minimum load—100 mA

TL/H/9060-2

National Semiconductor

LM140A/LM140/LM340A/LM340/LM7800C Series 3-Terminal Positive Regulators

General Description

The LM140A/LM140/LM340A/LM340/LM7800C monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

The 5V, 12V, and 15V regulator options are available in the steel TO-3 power package. The LM340A/LM340/LM7800C series is available in the TO-220 plastic power package, and the LM7805 and LM7812 are also available in the surface-mount TO-263 package.

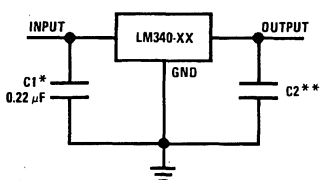
Features

- Complete specifications at 1A load
- Output voltage tolerances of $\pm 2\%$ at $T_j = 25°C$ and $\pm 4\%$ over the temperature range (LM140A/LM340A)
- Line regulation of 0.01% of V_{OUT}/V of ΔV_{IN} at 1A load (LM140A/LM340A)
- Load regulation of 0.3% of V_{OUT}/A (LM140A/LM340A)
- Internal thermal overload protection
- Internal short-circuit current limit
- Output transistor safe area protection
- P+ Product Enhancement tested

Device	Output Voltages	Packages
LM140A/LM140	5, 12, 15	TO-3 (K)
LM340A/LM340	5, 12, 15	TO-3 (K), TO-220 (T)
LM7800C	5, 6, 8, 12, 15, 18, 24	TO-220 (T), TO-263 (S) (5V and 12V only)

Typical Applications

Fixed Output Regulator

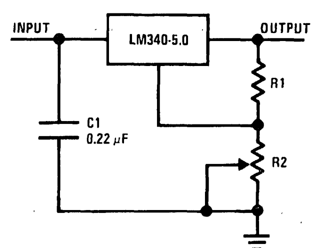


TL/H/7781-1

*Required if the regulator is located far from the power supply filter.

**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1 µF, ceramic disc).

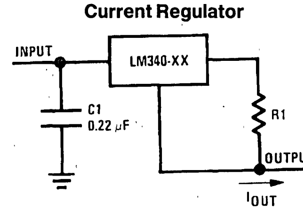
Adjustable Output Regulator



TL/H/7781-2

$V_{OUT} = 5V + (5V/R1 + I_Q)\ R2\ 5V/R1 > 3\ I_Q$, load regulation $(L_r) \approx [(R1 + R2)/R1]$ (L_r of LM340-5).

Current Regulator



TL/H/7781-3

$I_{OUT} = \frac{V2\text{-}3}{R1} + I_Q$

$\Delta I_Q = 1.3$ mA over line and load changes.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 5)

DC Input Voltage	
All Devices except LM7824/LM7824C	35V
LM7824/LM7824C	40V
Internal Power Dissipation (Note 2)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package (K)	300°C
TO-220 Package (T), TO-263 Package (S)	230°C
ESD Susceptibility (Note 3)	2 kV

Operating Conditions (Note 1)

Temperature Range (T_A) (Note 2)	
LM140A, LM140	−55°C to +125°C
LM340A, LM340, LM7805C, LM7812C, LM7815C	0°C to +70°C
LM7806C, LM7808C, LM7818C, LM7824C	0°C to +125°C

LM140A/LM340A

Electrical Characteristics

I_{OUT} = 1A, −55°C ≤ T_J ≤ +150°C (LM140A), or 0°C ≤ T_J ≤ +125°C (LM340A) unless otherwise specified (Note 4)

Symbol	Output Voltage		5V			12V			15V			Units
	Input Voltage (unless otherwise noted)		10V			19V			23V			
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	T_J = 25°C	4.9	5	5.1	11.75	12	12.25	14.7	15	15.3	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A	4.8		5.2	11.5		12.5	14.4		15.6	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA			10			18			22	mV
		ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		T_J = 25°C		3	10		4	18		4	22	mV
		ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
		T_J = 25°C			4			9			10	mV
		Over Temperature			12			30			30	mV
		ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	T_J = 25°C, 5 mA ≤ I_O ≤ 1.5A		10	25		12	32		12	35	mV
		T_J = 25°C, 250 mA ≤ I_O ≤ 750 mA			15			19			21	mV
		Over Temperature, 5 mA ≤ I_O ≤ 1A			25			60			75	mV
I_Q	Quiescent Current	T_J = 25°C			6			6			6	mA
		Over Temperature			6.5			6.5			6.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A			0.5			0.5			0.5	mA
		T_J = 25°C, I_O = 1A			0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O = 500 mA			0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(8 ≤ V_{IN} ≤ 25)			(15 ≤ V_{IN} ≤ 30)			(17.9 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz		40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	T_J = 25°C, f = 120 Hz, I_O = 1A	68	80		61	72		60	70		dB
		or f = 120 Hz, I_O = 500 mA, Over Temperature,	68			61			60			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	T_J = 25°C, I_O = 1A		2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz		8			18			19		mΩ
	Short-Circuit Current	T_J = 25°C		2.1			1.5			1.2		A
	Peak Output Current	T_J = 25°C		2.4			2.4			2.4		A
	Average TC of V_O	Min, T_J = 0°C, I_O = 5 mA		−0.6			−1.5			−1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	T_J = 25°C	7.5			14.5			17.5			V

LM140

Electrical Characteristics (Note 4) $-55°C \le T_J \le +150°C$ unless otherwise specified

Symbol	Output Voltage			5V			12V			15V			Units
	Input Voltage (unless otherwise noted)			10V			19V			23V			
	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_J = 25°C$, $5\ mA \le I_O \le 1A$		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		$P_D \le 15W$, $5\ mA \le I_O \le 1A$		4.75		5.25	11.4		12.6	14.25		15.75	V
		$V_{MIN} \le V_{IN} \le V_{MAX}$			$(8 \le V_{IN} \le 20)$			$(15.5 \le V_{IN} \le 27)$			$(18.5 \le V_{IN} \le 30)$		V
ΔV_O	Line Regulation	$I_O = 500\ mA$	$T_J = 25°C$		3	50		4	120		4	150	mV
			ΔV_{IN}		$(7 \le V_{IN} \le 25)$			$(14.5 \le V_{IN} \le 30)$			$(17.5 \le V_{IN} \le 30)$		V
			$-55°C \le T_J \le +150°C$			50			120			150	mV
			ΔV_{IN}		$(8 \le V_{IN} \le 20)$			$(15 \le V_{IN} \le 27)$			$(18.5 \le V_{IN} \le 30)$		V
		$I_O \le 1A$	$T_J = 25°C$			50			120			150	mV
			ΔV_{IN}		$(7.5 \le V_{IN} \le 20)$			$(14.6 \le V_{IN} \le 27)$			$(17.7 \le V_{IN} \le 30)$		V
			$-55°C \le T_J \le +150°C$			25			60			75	mV
			ΔV_{IN}		$(8 \le V_{IN} \le 12)$			$(16 \le V_{IN} \le 22)$			$(20 \le V_{IN} \le 26)$		V
ΔV_O	Load Regulation	$T_J = 25°C$	$5\ mA \le I_O \le 1.5A$		10	50		12	120		12	150	mV
			$250\ mA \le I_P \le 750\ mA$			25			60			75	mV
		$-55°C \le T_J \le +150°C$, $5\ mA \le I_O \le 1A$				50			120			150	mV
I_Q	Quiescent Current	$I_O \le 1A$	$T_J = 25°C$			6			6			6	mA
			$-55°C \le T_J \le +150°C$			7			7			7	mA
ΔI_Q	Quiescent Current Change	$5\ mA \le I_O \le 1A$				0.5			0.5			0.5	mA
		$T_J = 25°C$, $I_O \le 1A$				0.8			0.8			0.8	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			$(8 \le V_{IN} \le 20)$			$(15 \le V_{IN} \le 27)$			$(18.5 \le V_{IN} \le 30)$		V
		$I_O = 500\ mA$, $-55°C \le T_J \le +150°C$				0.8			0.8			0.8	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$			$(8 \le V_{IN} \le 25)$			$(15 \le V_{IN} \le 30)$			$(18.5 \le V_{IN} \le 30)$		V
V_N	Output Noise Voltage	$T_A = 25°C$, $10\ Hz \le f \le 100\ kHz$			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120\ Hz$	$I_O \le 1A$, $T_J = 25°C$ or	68	80		61	72		60	70		dB
			$I_O \le 500\ mA$, $-55°C \le T_J \le +150°C$	68			61			60			dB
		$V_{MIN} \le V_{IN} \le V_{MAX}$			$(8 \le V_{IN} \le 18)$			$(15 \le V_{IN} \le 25)$			$(18.5 \le V_{IN} \le 28.5)$		V
R_O	Dropout Voltage	$T_J = 25°C$, $I_O = 1A$			2.0			2.0			2.0		V
	Output Resistance	$f = 1\ kHz$			8			18			19		mΩ
	Short-Circuit Current	$T_J = 25°C$			2.1			1.5			1.2		A
	Peak Output Current	$T_J = 25°C$			2.4			2.4			2.4		A
	Average TC of V_{OUT}	$0°C \le T_J \le +150°C$, $I_O = 5\ mA$			−0.6			−1.5			−1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	$T_J = 25°C$, $I_O \le 1A$		7.5			14.6			17.7			V

LM340/LM7800C

Electrical Characteristics (Note 4) 0°C ≤ T_J ≤ +125°C unless otherwise specified

Symbol	Output Voltage			5V			12V			15V			Units
	Input Voltage (unless otherwise noted)			10V			19V			23V			
	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	T_J = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ T_J ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	T_J = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ T_J ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ T_J ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	T_J = 25°C			8			8			8	mA
			0°C ≤ T_J ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		T_J = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0°C ≤ T_J ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, T_J = 25°C	62	80		55	72		54	70		dB
			or I_O ≤ 500 mA, 0°C ≤ T_J ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	T_J = 25°C, I_O = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ
	Short-Circuit Current	T_J = 25°C			2.1			1.5			1.2		A
	Peak Output Current	T_J = 25°C			2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ T_J ≤ +125°C, I_O = 5 mA			−0.6			−1.5			−1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	T_J = 25°C, I_O ≤ 1A		7.5			14.6			17.7			V

Note 1: Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Conditions are conditions under which the device functions but the specifications might not be guaranteed. For guaranteed specifications and test conditions see the Electrical Characteristics.

Note 2: The maximum allowable power dissipation at any ambient temperature is a function of the maximum junction temperature for operation (T_{JMAX} = 125°C or 150°C), the junction-to-ambient thermal resistance (θ_{JA}), and the ambient temperature (T_A). $P_{DMAX} = (T_{JMAX} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above T_{JMAX} and the electrical specifications do not apply. If the die temperature rises above 150°C, the device will go into thermal shutdown. For the TO-3 package (K, KC), the junction-to-ambient thermal resistance (θ_{JA}) is 39°C/W. When using a heatsink, θ_{JA} is the sum of the 4°C/W junction-to-case thermal resistance (θ_{JC}) of the TO-3 package and the case-to-ambient thermal resistance of the heatsink. For the TO-220 package (T), θ_{JA} is 54°C/W and θ_{JC} is 4°C/W.

If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°G/W; and with 1.6 or more inches of copper area, θ_{JA} is 32°C/W.

Note 3: ESD rating is based on the human body model, 100 pF discharged through 1.5 kΩ.

Note 4: All characteristics are measured with a 0.22 μF capacitor from input to ground and a 0.1 μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 5: A military RETS specification is available on request. At the time of printing, the military RETS specifications for the LM140AK-5.0/883, LM140AK-12/883, and LM140AK-15/883 complied with the min and max limits for the respective versions of the LM140A. At the time of printing, the military RETS specifications for the LM140K-5.0/883, LM140K-12/883, and LM140K-15/883 complied with the min and max limits for the respective versions of the LM140. The LM140H/883, LM140K/883, and LM140AK/883 may also be procured as a Standard Military Drawing.

LM7806C
Electrical Characteristics

0°C ≤ T_J ≤ +150°C, V_I = 11V, I_O = 500 mA, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified

Symbol	Parameter		Conditions (Note 4)		Min	Typ	Max	Units
V_O	Output Voltage		T_J = 25°C		5.75	6.0	6.25	V
ΔV_O	Line Regulation		T_J = 25°C	8.0V ≤ V_I ≤ 25V		5.0	120	mV
				9.0V ≤ V_I ≤ 13V		1.5	60	
ΔV_O	Load Regulation		T_J = 25°C	5.0 mA ≤ I_O ≤ 1.5A		14	120	mV
				250 mA ≤ I_O ≤ 750 mA		4.0	60	
V_O	Output Voltage		8.0V ≤ V_I ≤ 21V, 5.0 mA ≤ I_O ≤ 1.0A, P ≤ 15W		5.7		6.3	V
I_Q	Quiescent Current		T_J = 25°C			4.3	8.0	mA
ΔI_Q	Quiescent Current Change	With Line	8.0V ≤ V_I ≤ 25V				1.3	mA
		With Load	5.0 mA ≤ I_O ≤ 1.0A				0.5	
V_N	Noise		T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			45		μV
$\Delta V_I/\Delta V_O$	Ripple Rejection		f = 120 Hz, I_O = 350 mA, T_J = 25°C		59	75		dB
V_{DO}	Dropout Voltage		I_O = 1.0A, T_J = 25°C			2.0		V
R_O	Output Resistance		f = 1.0 kHz			9		mΩ
I_{OS}	Output Short Circuit Current		T_J = 25°C, V_I = 35V			550		mA
I_{PK}	Peak Output Current		T_J = 25°C			2.2		A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage		I_O = 5.0 mA, 0°C ≤ T_A ≤ +125°C			0.8		mV/°C

LM7808C
Electrical Characteristics

0°C ≤ T_J ≤ +150°C, V_I = 14V, I_O = 500 mA, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified

Symbol	Parameter		Conditions (Note 4)		LM7808C			Units
					Min	Typ	Max	
V_O	Output Voltage		T_J = 25°C		7.7	8.0	8.3	V
ΔV_O	Line Regulation		T_J = 25°C	10.5V ≤ V_I ≤ 25V		6.0	160	mV
				11.0V ≤ V_I ≤ 17V		2.0	80	
ΔV_O	Load Regulation		T_J = 25°C	5.0 mA ≤ I_O ≤ 1.5A		12	160	mV
				250 mA ≤ I_O ≤ 750 mA		4.0	80	
V_O	Output Voltage		11.5V ≤ V_I ≤ 23V, 5.0 mA ≤ I_O ≤ 1.0A, P ≤ 15W		7.6		8.4	V
I_Q	Quiescent Current		T_J = 25°C			4.3	8.0	mA
ΔI_Q	Quiescent Current Change	With Line	11.5V ≤ V_I ≤ 25V				1.0	mA
		With Load	5.0 mA ≤ I_O ≤ 1.0A				0.5	
V_N	Noise		T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			52		μV
$\Delta V_I/\Delta V_O$	Ripple Rejection		f = 120 Hz, I_O = 350 mA, T_J = 25°C		56	72		dB
V_{DO}	Dropout Voltage		I_O = 1.0A, T_J = 25°C			2.0		V
R_O	Output Resistance		f = 1.0 kHz			16		mΩ
I_{OS}	Output Short Circuit Current		T_J = 25°C, V_I = 35V			0.45		A
I_{PK}	Peak Output Current		T_J = 25°C			2.2		A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage		I_O = 5.0 mA			0.8		mV/°C

Note 4: All characteristics are measured with a 0.22 μF capacitor from input to ground and a 0.1 μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

LM7818C
Electrical Characteristics

0°C ≤ T_J ≤ +150°C, V_I = 27V, I_O = 500 mA, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified

Symbol	Parameter		Conditions (Note 4)		LM7818C			Units
					Min	Typ	Max	
V_O	Output Voltage		T_J = 25°C		17.3	18.0	18.7	V
ΔV_O	Line Regulation		T_J = 25°C	21V ≤ V_I ≤ 33V		15	360	mV
				24V ≤ V_I ≤ 30V		5.0	180	
ΔV_O	Load Regulation		T_J = 25°C	5.0 mA ≤ I_O ≤ 1.5A		12	360	mV
				250 mA ≤ I_O ≤ 750 mA		4.0	180	
V_O	Output Voltage		22V ≤ V_I ≤ 33V, 5.0 mA ≤ I_O ≤ 1.0A, P ≤ 15W		17.1		18.9	V
I_Q	Quiescent Current		T_J = 25°C			4.5	8.0	mA
ΔI_Q	Quiescent Current Change	With Line	22V ≤ V_I ≤ 33V				1.0	mA
		With Load	5.0 mA ≤ I_O ≤ 1.0A				0.5	
V_N	Noise		T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			110		μV
$\Delta V_I/\Delta V_O$	Ripple Rejection		f = 120 Hz, I_O = 350 mA, T_J = 25°C		53	69		dB
V_{DO}	Dropout Voltage		I_O = 1.0A, T_J = 25°C			2.0		V
R_O	Output Resistance		f = 1.0 kHz			22		mΩ
I_{OS}	Output Short Circuit Current		T_J = 25°C, V_I = 35V			0.20		A
I_{PK}	Peak Output Current		T_J = 25°C			2.1		A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage		I_O = 5.0 mA			1.0		mV/°C

LM7824C
Electrical Characteristics

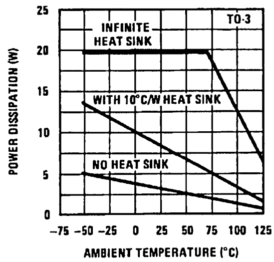
0°C ≤ T_J ≤ +150°C, V_I = 33V, I_O = 500 mA, C_I = 0.33 μF, C_O = 0.1 μF, unless otherwise specified

Symbol	Parameter		Conditions (Note 4)		LM7824C			Units
					Min	Typ	Max	
V_O	Output Voltage		T_J = 25°C		23.0	24.0	25.0	V
ΔV_O	Line Regulation		T_J = 25°C	27V ≤ V_I ≤ 38V		18	480	mV
				30V ≤ V_I ≤ 36V		6.0	240	
ΔV_O	Load Regulation		T_J = 25°C	5.0 mA ≤ I_O ≤ 1.5A		12	480	mV
				250 mA ≤ I_O ≤ 750 mA		4.0	240	
V_O	Output Voltage		28V ≤ V_I ≤ 38V, 5.0 mA ≤ I_O ≤ 1.0A, P ≤ 15W		22.8		25.2	V
I_Q	Quiescent Current		T_J = 25°C			4.6	8.0	mA
ΔI_Q	Quiescent Current Change	With Line	28V ≤ V_I ≤ 38V				1.0	mA
		With Load	5.0 mA ≤ I_O ≤ 1.0A				0.5	
V_N	Noise		T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			170		μV
$\Delta V_I/\Delta V_O$	Ripple Rejection		f = 120 Hz, I_O = 350 mA, T_J = 25°C		50	66		dB
V_{DO}	Dropout Voltage		I_O = 1.0A, T_J = 25°C			2.0		V
R_O	Output Resistance		f = 1.0 kHz			28		mΩ
I_{OS}	Output Short Circuit Current		T_J = 25°C, V_I = 35V			0.15		A
I_{PK}	Peak Output Current		T_J = 25°C			2.1		A
$\Delta V_O/\Delta T$	Average Temperature Coefficient of Output Voltage		I_O = 5.0 mA			1.5		mV/°C

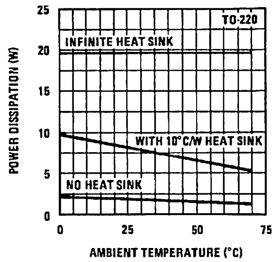
Note 4: All characteristics are measured with a 0.22 μF capacitor from input to ground and a 0.1 μF capacitor from output to ground. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_W ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Typical Performance Characteristics

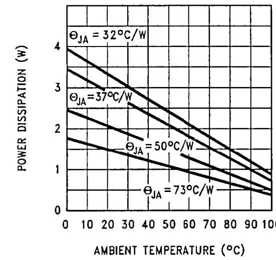
Maximum Average Power Dissipation



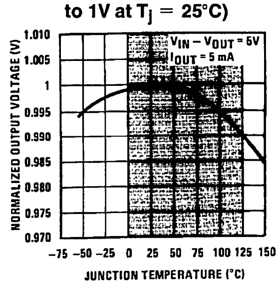
Maximum Average Power Dissipation



Maximum Power Dissipation (TO-263) (See Note 2)

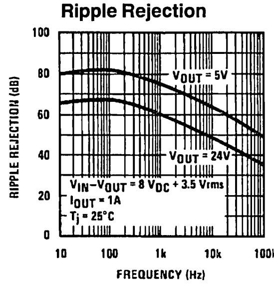


Output Voltage (Normalized to 1V at T_J = 25°C)

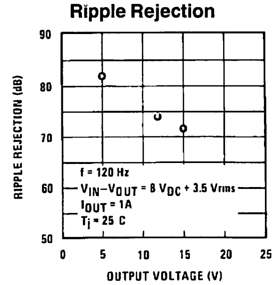


Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.

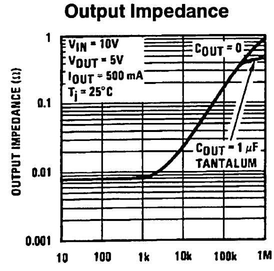
Ripple Rejection



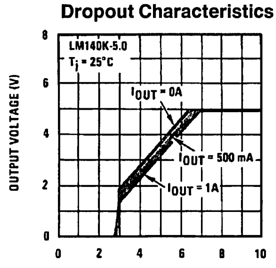
Ripple Rejection



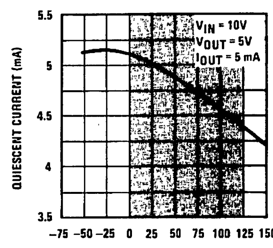
Output Impedance



Dropout Characteristics

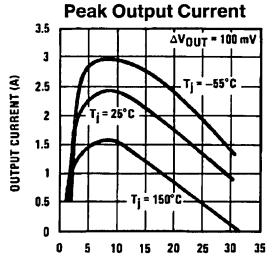


Quiescent Current

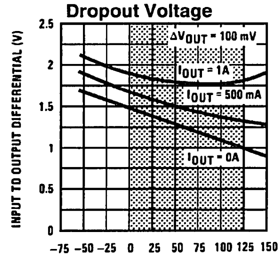


Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.

Peak Output Current

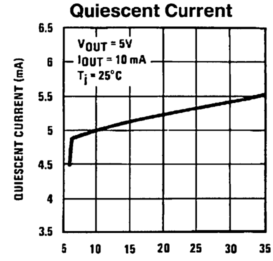


Dropout Voltage



Note: Shaded area refers to LM340A/LM340, LM7805C, LM7812C and LM7815C.

Quiescent Current



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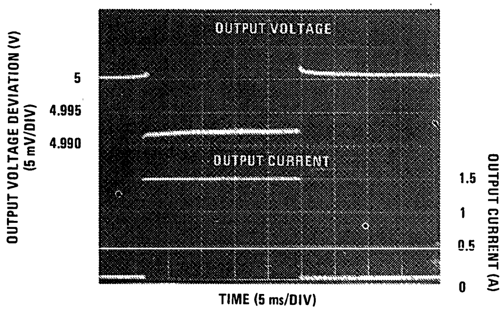
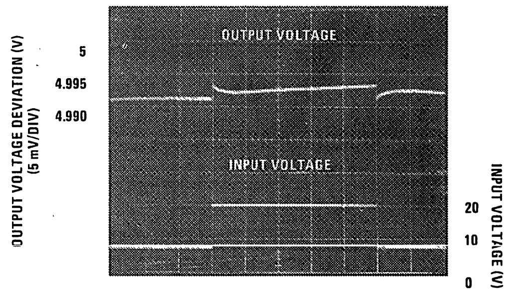
Typical Performance Characteristics (Continued)

Load Regulation
140AK-5.0, V_{IN} = 10V, T_A = 25°C



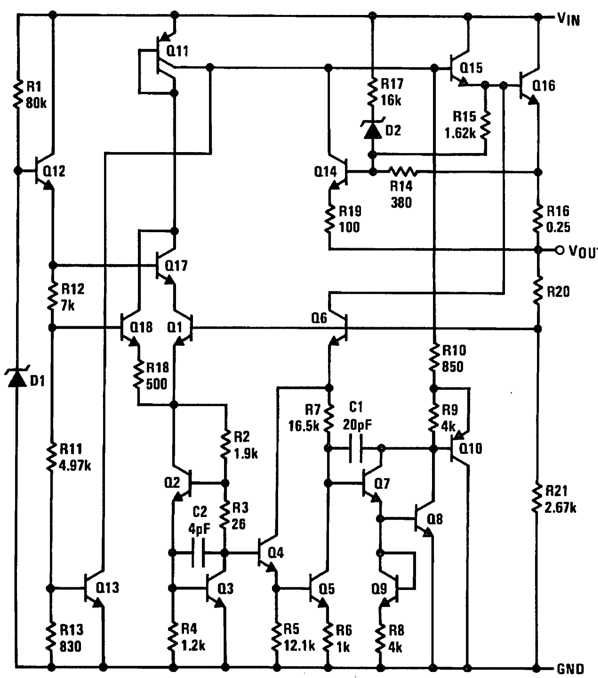
TL/H/7781–5

Line Regulation
140AK-5.0, I_{OUT} = 1A, T_A = 25°C



TL/H/7781–6

Equivalent Schematic



TL/H/7781–7

Application Hints

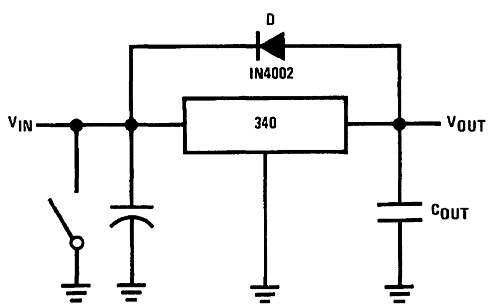
The LM340/LM78XX series is designed with thermal protection, output short-circuit protection and output transistor safe area protection. However, as with *any* IC regulator, it becomes necessary to take precautions to assure that the regulator is not inadvertently damaged. The following describes possible misapplications and methods to prevent damage to the regulator.

Shorting the Regulator Input: When using large capacitors at the output of these regulators, a protection diode connected input to output *(Figure 1)* may be required if the input is shorted to ground. Without the protection diode, an input short will cause the input to rapidly approach ground potential, while the output remains near the initial V_{OUT} because of the stored charge in the large output capacitor. The capacitor will then discharge through a large internal input to output diode and parasitic transistors. If the energy released by the capacitor is large enough, this diode, low current metal and the regulator will be destroyed. The fast diode in *Figure 1* will shunt most of the capacitors discharge current around the regulator. Generally no protection diode is required for values of output capacitance $\leq$ 10 μF.

Raising the Output Voltage above the Input Voltage: Since the output of the device does not sink current, forcing the output high can cause damage to internal low current paths in a manner similar to that just described in the "Shorting the Regulator Input" section.

Regulator Floating Ground *(Figure 2)*: When the ground pin alone becomes disconnected, the output approaches the unregulated input, causing possible damage to other circuits connected to V_{OUT}. If ground is reconnected with power "ON", damage may also occur to the regulator. This fault is most likely to occur when plugging in regulators or modules with on card regulators into powered up sockets. Power should be turned off first, thermal limit ceases operating, or ground should be connected first if power must be left on.

Transient Voltages: If transients exceed the maximum rated input voltage of the device, or reach more than 0.8V below ground and have sufficient energy, they will damage the regulator. The solution is to use a large input capacitor, a series input breakdown diode, a choke, a transient suppressor or a combination of these.



TL/H/7781-8

FIGURE 1. Input Short

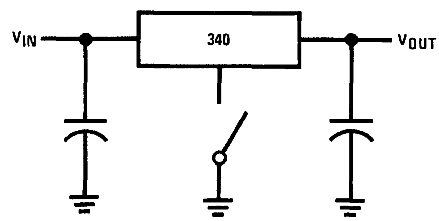


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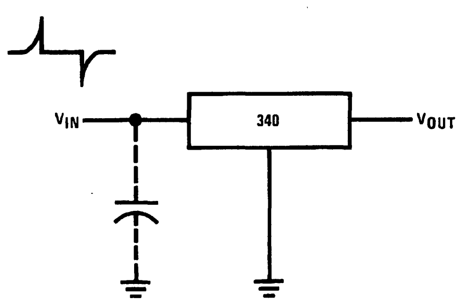
FIGURE 2. Regulator Floating Ground



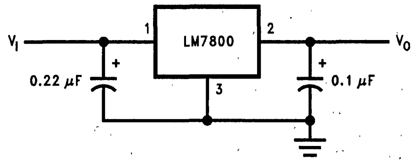
TL/H/7781-10

FIGURE 3. Transients

1

Typical Applications

Fixed Output Regulator



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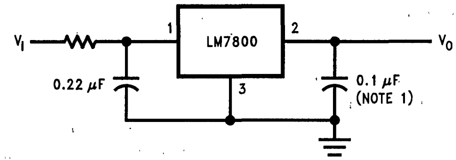
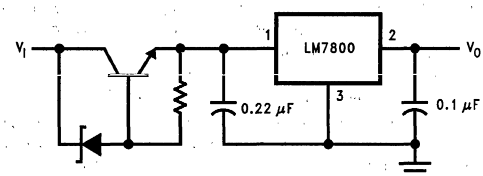
Note 1: Bypass capacitors are recommended for optimum stability and transient response, and should be located as close as possible to the regulator.

High Input Voltage Circuits



TL/H/7781-14



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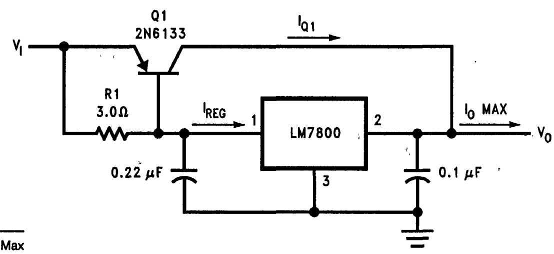
High Current Voltage Regulator



$$\beta(Q1) \geq \frac{I_{O\,Max}}{I_{REG\,Max}}$$

$$R1 = \frac{0.9}{I_{REG}} = \frac{\beta(Q1)\,V_{BE(Q1)}}{I_{REG\,Max}\,(\beta + 1) - I_{O\,Max}}$$

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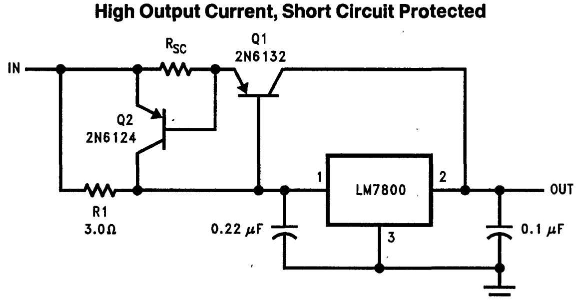
High Output Current, Short Circuit Protected



$$R_{SC} = \frac{0.8}{I_{SC}}$$

$$R1 = \frac{\beta V_{BE(Q1)}}{I_{REG\,Max}\,(\beta + 1) - I_{O\,Max}}$$

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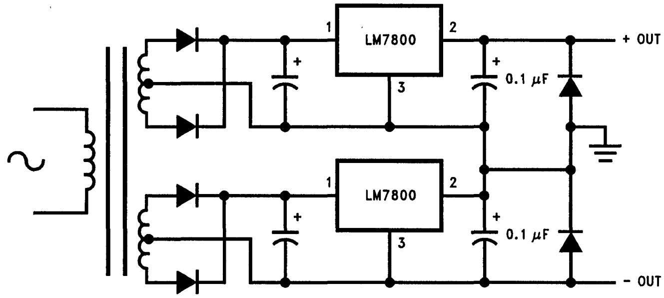
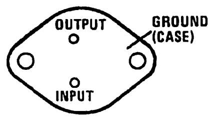
Positive and Negative Regulator



TL/H/7781-18

Connection Diagrams and Ordering Information

TO-3 Metal Can Package (K)



TL/H/7781-11

Bottom View

Steel Package Order Numbers:

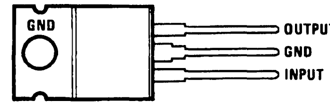
LM140K-5.0 LM140K-12 LM140K-15
LM340AK-5.0 LM340K-12 LM340K-15
LM340K-5.0

See Package Number K02A

LM140AK-5.0/883 LM140AK-12/883 LM140AK-15/883
LM140K-5.0/883 LM140K-12/883 LM140K-15/883

See Package Number K02C

TO-220 Power Package (T)



TL/H/7781-12

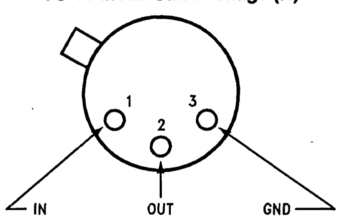
Top View

Plastic Package Order Numbers:

LM340AT-5.0 LM340T-5.0
LM340AT-12 LM340T-12
LM340AT-15 LM340T-15
LM7805CT LM7812CT
LM7815CT LM7806CT
LM7808CT LM7818CT
LM7824CT

See Package Number T03B

TO-39 Metal Can Package (H)



TL/H/7781-19

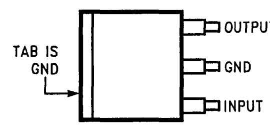
Top View

Metal Can Order Numbers†:

LM140H-5.0/883 LM140H-6.0/883
LM140H-8.0/883 LM140H-12/883
LM140H-15/883 LM140H-24/883

See Package Number H03A

TO-263 Surface-Mount Package (S)



TL/H/7781-20

Top View

TL/H/7781-21

Side View

Surface-Mount Package Order Numbers:

LM7805S LM7812S

See Package Number TS3B

†The specifications for the LM140H/883 devices are not contained in this datasheet. If specifications for these devices are required, contact the National Semiconductor Sales Office/Distributors.

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National Semiconductor

LM140L/LM340L Series 3-Terminal Positive Regulators

General Description

The LM140L series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. The LM140LA is an improved version of the LM78LXX series with a tighter output voltage tolerance (specified over the full military temperature range), higher ripple rejection, better regulation and lower quiescent current. The LM140LA regulators have ±2% V_{OUT} specification, 0.04%/V line regulation, and 0.01%/mA load regulation. When used as a zener diode/resistor combination replacement, the LM140LA usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM140LA to be used in logic systems, instrumentation, Hi-Fi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.

The LM140LA/LM340LA are available in the low profile metal three lead TO-39 (H) and the LM340LA are also available in the plastic TO-92 (Z). With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shut-down circuit takes over, preventing the IC from overheating.

For applications requiring other voltages, see LM117L Data Sheet.

Features

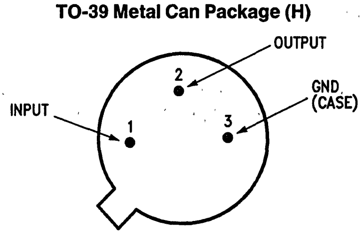
- Line regulation of 0.04%/V
- Load regulation of 0.01%/mA
- Output voltage tolerances of ±2% at T_j = 25°C and ±4% over the temperature range (LM140LA) ±3% over the temperature range (LM340LA)
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in metal TO-39 low profile package (LM140LA/LM340LA) and plastic TO-92 (LM340LA)

Output Voltage Options

LM140LA-5.0	5V	LM340LA-5.0	5V
LM140LA-12	12V	LM340LA-12	12V
LM140LA-15	15V	LM340LA-15	15V

Connection Diagrams

TO-39 Metal Can Package (H)

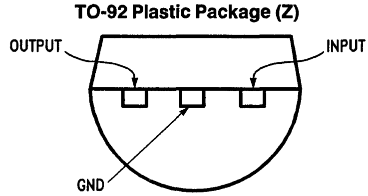


TL/H/7782-2

Bottom View

Order Number LM140LAH-5.0, LM140LAH-5.0/883, LM140LAH-12, LM140LAH-12/883, LM140LAH-15, LM140LAH-15/883, LM340LAH-5.0, LM340LAH-12 or LM340LAH-15
See NS Package Number H03A

TO-92 Plastic Package (Z)



TL/H/7782-3

Bottom View

Order Number LM340LAZ-5.0, LM340LAZ-12 or LM340LAZ-15
See NS Package Number Z03A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Input Voltage	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	
LM140LA	−55°C to +125°C
LM340LA	0°C to +70°C
Maximum Junction Temperature	+150°C
Storage Temperature Range	
Metal Can (H package)	−65°C to +150°C
Molded TO-92	−55°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
Metal Can	+300°C
Plastic TO-92	+230°C

Electrical Characteristics

Test conditions unless otherwise specified. $T_A = -55°C$ to $+125°C$ (LM140LA), $T_A = 0°C$ to $+70°C$ (LM340LA), $I_O = 40$ mA, $C_{IN} = 0.33\ \mu F$, $C_O = 0.01\ \mu F$.

Output Voltage Option				5.0V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	$T_j = 25°C$		4.9	5	5.1	11.75	12	12.25	14.7	15	15.3	V
	Output Voltage Over Temp. (Note 3)	LM140LA	$I_O = 1 - 100$ mA	4.8		5.2	11.5		12.5	14.4		15.6	V
				(7.2–20)			(14.5–27)			(17.6–30)			V
		LM340LA	$I_O = 1 - 100$ mA or $I_O = 1 - 40$ mA and $V_{IN} = ()V$	4.85		5.15	11.65		12.35	14.55		15.45	V
				(7–20)			(14.3–27)			(17.5–30)			V
ΔV_O	Line Regulation	$T_j = 25°C$	$I_O = 40$ mA, $V_{IN} = ()V$		18	30		30	65		37	70	mV
				(7–25)			(14.2–30)			(17.3–30)			mV
			$I_O = 100$ mA, $V_{IN} = ()V$		18	30		30	65		37	70	mV
				(7.5–25)			(14.5–30)			(17.5–30)			mV
	Load Regulation	$T_j = 25°C$	$I_O = 1 - 40$ mA		5	20		10	40		12	50	mV
			$I_O = 1 - 100$ mA		20	40		30	80		35	100	mV
	Long Term Stability				12			24			30		mV 1000 hrs
I_O	Quiescent Current	$T_j = 25°C$			3	4.5		3	4.5		3.1	4.5	mA
		$T_j = 125°C$				4.2			4.2			4.2	mA
ΔI_Q	Quiescent Current Change	$T_j = 25°C$	ΔLoad $I_O = 1 - 40$ mA			0.1			0.1			0.1	mA
			ΔLine $V_{IN} = ()V$			0.5			0.5			0.5	mA
				(7.5–25)			(14.3–30)			(17.5–30)			mA
V_N	Output Noise Voltage	$T_j = 25°C$ (Note 2) $f = 10$ Hz–10 kHz			40			80			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	$f = 120$ Hz, $V_{IN} = ()V$		55	62		47	54		45	52		dB
				(7.5–18)			(14.5–25)			(17.5–28.5)			dB
	Input Voltage Required to Maintain Line Regulation	$T_j = 25°C$, $I_O = 40$ mA		7			14.2			17.3			V

Note 1: Thermal resistance of H-package is typically 26°C/W θ_{jC}, 250°C/W θ_{jA} still air, and 94°C/W θ_{jA} 400 lf/min of air. For the Z-package is 60°C/W θ_{jC}, 232°C/W θ_{jA} still air, and 88°C/W θ_{jA} at 400 lf/min of air. The maximum junction temperature shall not exceed 125°C on electrical parameters.

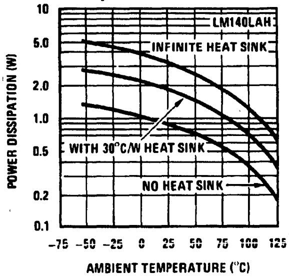
Note 2: It is recommended that a minimum load capacitor of 0.01 μF be used to limit the high frequency noise bandwidth.

Note 3: The temperature coefficient of V_{OUT} is typically within 0.01% V_O/°C.

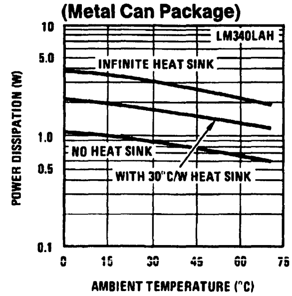
Note 4: A military RETS specification is available upon request. At the time of printing, the LM140LA-5.0, -12, and -15 RETS specifications complied with the Min and Max limits in this table. The LM140LAH-5.0, LM140LAH-12, and LM140LAH-15 may also be procured as Standard Military Drawings.

Typical Performance Characteristics

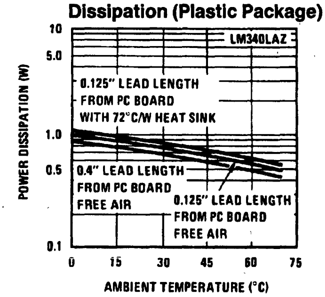
Maximum Average Power Dissipation



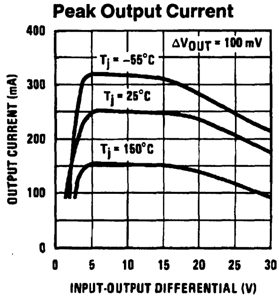
Maximum Average Power Dissipation (Metal Can Package)



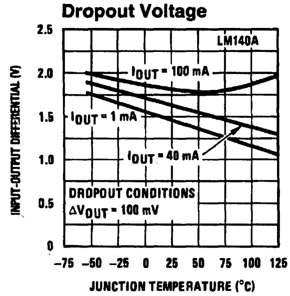
Maximum Average Power Dissipation (Plastic Package)



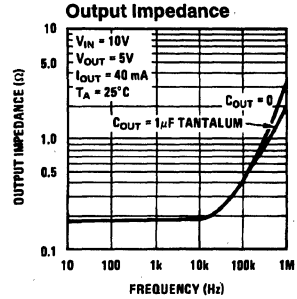
Peak Output Current



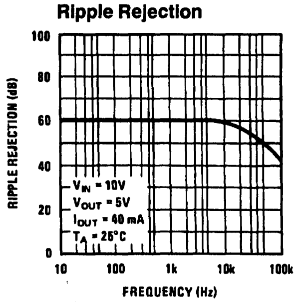
Dropout Voltage



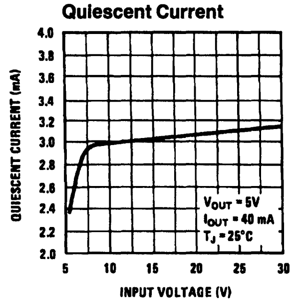
Output Impedance



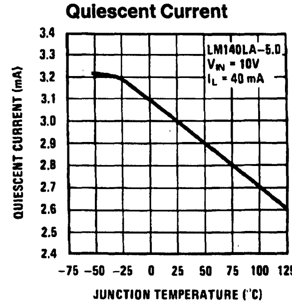
Ripple Rejection



Quiescent Current



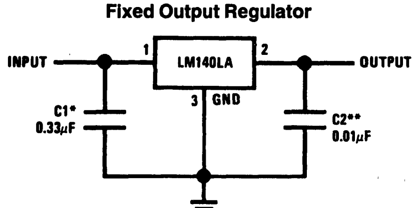
Quiescent Current



TL/H/7782-4

Typical Applications

Fixed Output Regulator

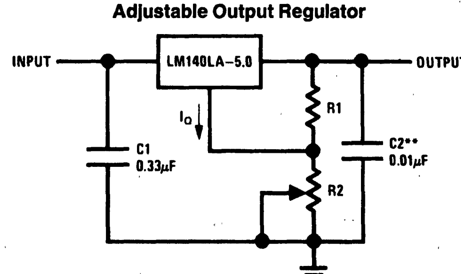


TL/H/7782-5

*Required if the regulator is located far from the power supply filter.

**See note 3 in the electrical characteristics table.

Adjustable Output Regulator

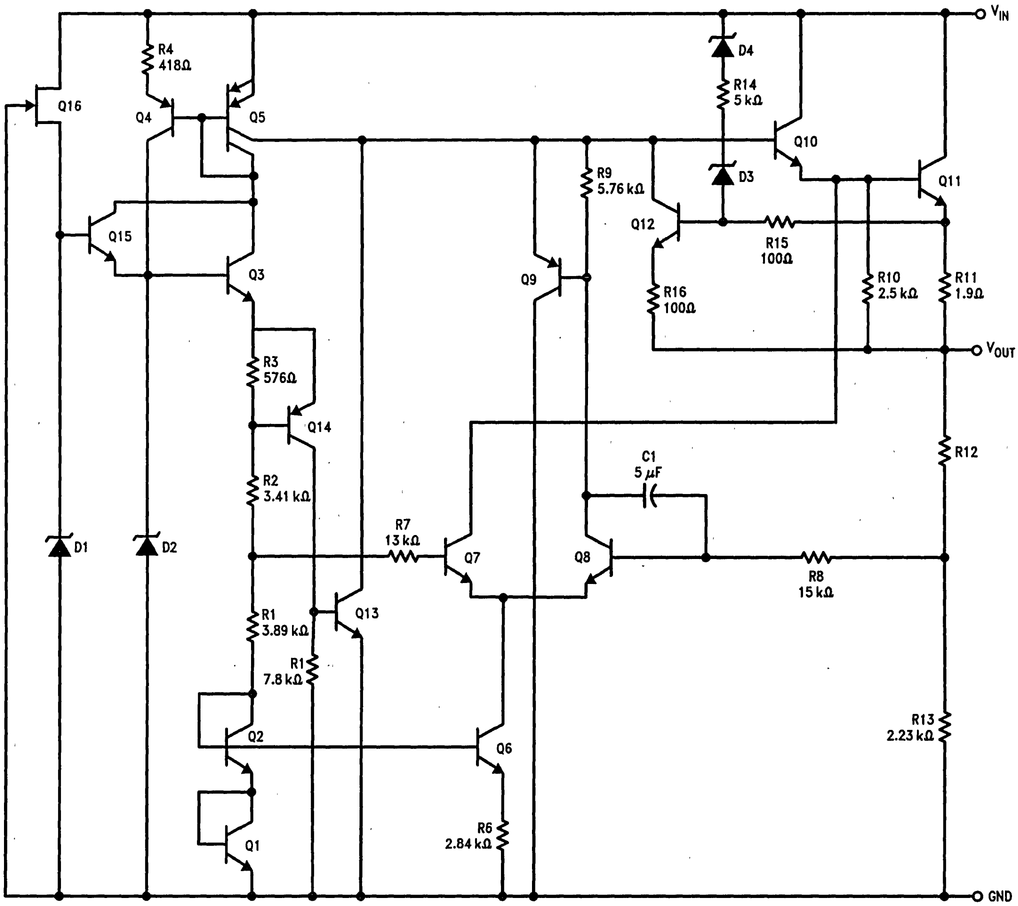


$V_{OUT} = 5V + (5V/R1 + I_O)\ R2$

TL/H/7782-6

$5V/R1 = 3\ I_O$ load regulation (L_r) [(R1 + R2)/R1] (L_r of LM140LA-5.0)

Equivalent Circuit



TL/H/7782-1

National Semiconductor

LM145/LM345 Negative Three Amp Regulator

General Description

The LM145 is a three-terminal negative regulator with a fixed output voltage of −5V and up to 3A load current capability. This device needs only one external component—a compensation capacitor at the output, making it easy to apply. Worst case guarantees on output voltage deviation due to any combination of line, load or temperature variation assure satisfactory system operation.

Exceptional effort has been made to make the LM145 immune to overload conditions. The regulator has current limiting which is independent of temperature, combined with thermal overload protection. Internal current limiting protects against momentary faults while thermal shutdown prevents junction temperatures from exceeding safe limits during prolonged overloads.

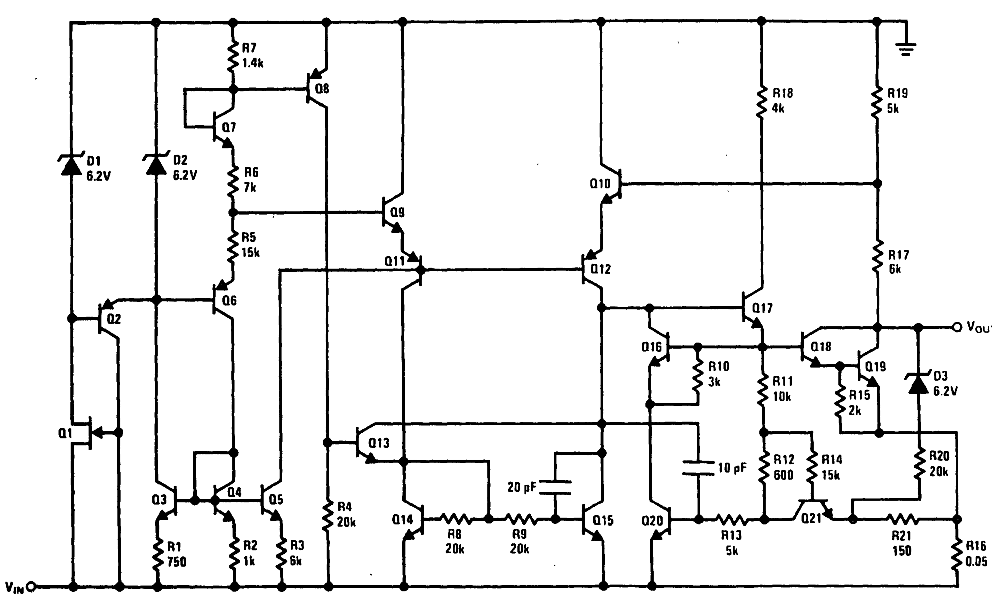
Although primarily intended for fixed output voltage applications, the LM145 may be programmed for higher output voltages with a simple resistive divider. The low quiescent drain current of the device allows this technique to be used with good regulation.

The LM145 comes in a hermetic TO-3 package rated at 25W. A reduced temperature range part LM345 is also available.

Features

- Output voltage accurate to better than ±2%
- Current limit constant with temperature
- Internal thermal shutdown protection
- Operates with input-output voltage differential of 2.8V at full rated load over full temperature range
- Regulation guaranteed with 25W power dissipation
- 3A output current guaranteed
- Only one external component needed
- P+ Product Enhancement tested

Schematic Diagram



TL/H/7785-1

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 3)

Input Voltage	20V
Input-Output Differential	20V
Power Dissipation	Internally Limited
Operating Junction Temperature Range	
LM145	−55°C to +150°C
LM345	0°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Electrical Characteristics (Note 1)

Parameter	Conditions	Limits						Units
		LM145			LM345			
		Min	Typ	Max	Min	Typ	Max	
Output Voltage	$T_j = 25°C$, $I_{OUT} = 5$ mA, $V_{IN} = -7.5$	−5.1	−5.0	−4.9	−5.2	−5.0	−4.8	V
Line Regulation (Note 2)	$T_j = 25°C$ $-20V \le V_{IN} \le -7.5V$		5	15		5	25	mV
Load Regulation (Note 2)	$T_j = 25°C$, $V_{IN} = -7.5V$ $5\text{ mA} \le I_{OUT} \le 3A$		30	75		30	100	mV
Output Voltage	$-20V \le V_{IN} \le -7.8V$ $5\text{ mA} \le I_{OUT} \le 3A$ $P \le 25W$ $T_{MIN} \le T_j \le T_{MAX}$	−5.20		−4.80	−5.25		−4.75	V
Quiescent Current	$-20V \le V_{IN} \le -7.5V$ $5\text{ mA} \le I_{OUT} \le 3A$		1.0	3.0		1.0	3.0	mA
Short Circuit Current	$V_{IN} = -7.5V$, $T_j = +25°C$ $V_{IN} = -20V$, $T_j = +25°C$		4 2	5.5 3.5		4 2	5.5 3.5	A A
Output Noise Voltage	$T_A = 25°C$, $C_L = 4.7\ \mu F$ $10\text{ Hz} \le f \le 100\text{ kHz}$		150			150		μV
Long Term Stability			5	50		5	50	mV
Thermal Resistance Junction to Case			2			2		°C/W

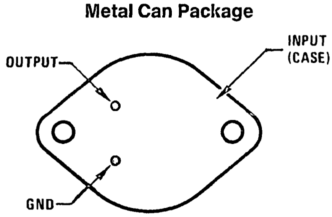
Note 1: Unless otherwise specified, these specifications apply: $-55°C \le T_j \le +150°C$ for the LM145 and $0°C \le T_j \le +125°C$ for the LM345. $V_{IN} = 7.5V$ and $I_{OUT} = 5$ mA. Although power dissipation is internally limited, electrical specifications apply only for power levels up to 25W. For calculations of junction temperature rise due to power dissipation, use a thermal resistance of 35°C/W for the TO-3 with no heat sink. With a heat sink, use 2°C/W for junction to case thermal resistance.

Note 2: Regulation is measured at constant junction temperature. Changes in output voltage due to heating effects must be taken into account separately. To ensure constant junction temperature, pulse testing with a low duty cycle is used.

Note 3: Refer to RETS145K-5V for LM145K-5.0 military specifications.

Connection Diagram

Metal Can Package

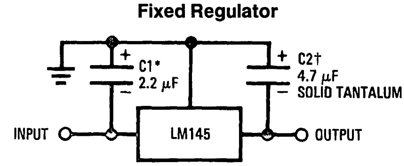


TL/H/7785–2

Bottom View
Order Number LM345K-5.0
See NS Package Number K02A
Order Number LM145K-5.0/883 or SMD #5962-9064501
See NS Package Number K02C

Typical Applications

Fixed Regulator



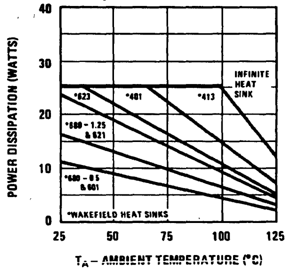
TL/H/7785–3

†Required for stability. For value given, capacitor must be solid tantalum. 50 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

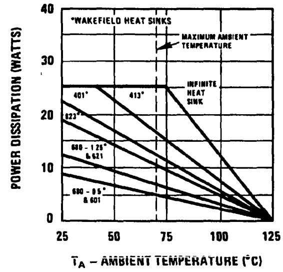
*Required if regulator is separated from filter capacitor. For value given, capacitor must be solid tantulum. 50 μF aluminum electrolytic may be substituted.

Typical Performance Characteristics

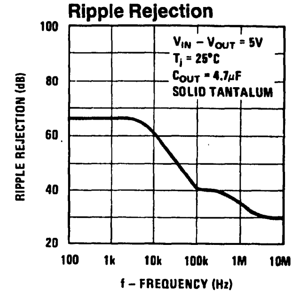
Maximum Average Power Dissipation for LM145



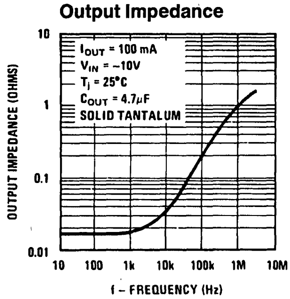
Maximum Average Power Dissipation for LM345



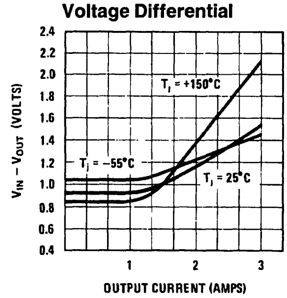
Ripple Rejection



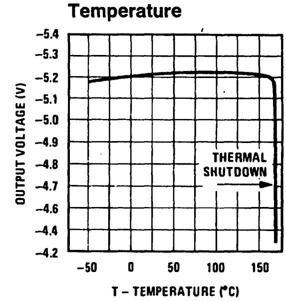
Output Impedance



Minimum Input-Output Voltage Differential

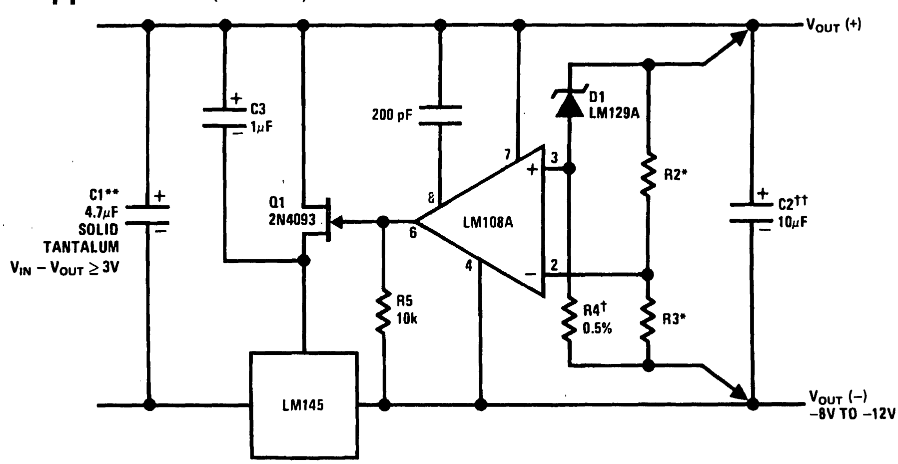


Output Voltage vs Temperature



TL/H/7785–4

Typical Applications (Continued)



TL/H/7785–5

*Select resistors to set output voltage. 1 ppm/C tracking suggested.

**C1 is not needed if power supply filter capacitor is within 3″ of regulator.

†Determines zener current. May be adjusted to minimize temperature drift.

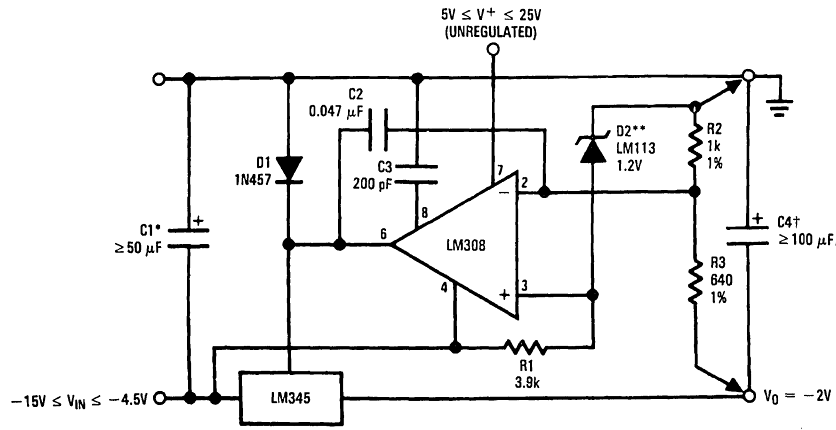
††Solid tantalum.

Load and line regulation < 0.01%

Temperature drift < 0.001%/C

Typical Applications (Continued)

High Stability Regulator



TL/H/7785-6

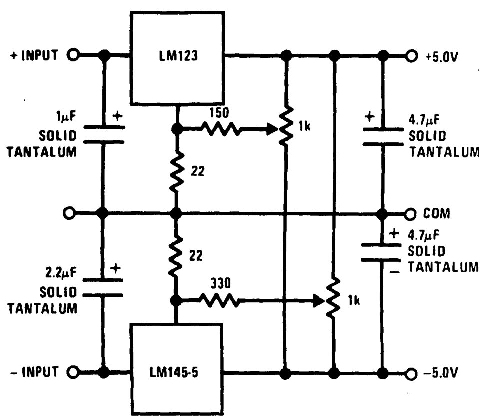
**C1 is not needed if power supply filter capacitor is within 3″ of regulator.

†Keep C4 within 2″ of LM345.

**D2 sets initial output voltage accuracy. The LM113 is available in −5, −2, and −1% tolerance.

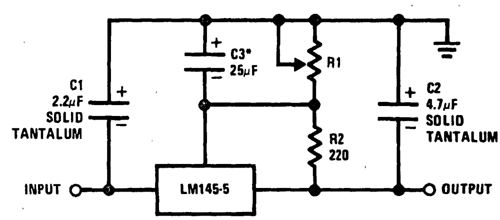
−2V ECL Termination Regulator

Dual 3 Amp Trimmed Supply



TL/H/7785-7

Variable Output (−5.0V to −15V)



TL/H/7785-8

*Optional. Improves transient response and ripple rejection.

$$V_{OUT} = -5V\left(\frac{R1 + R2}{R2}\right)$$

National Semiconductor

LM150, LM350A/LM350 3-Amp Adjustable Regulators

General Description

The LM150 series of adjustable 3-terminal positive voltage regulators is capable of supplying in excess of 3A over a 1.2V to 33V output range. They are exceptionally easy to use and require only 2 external resistors to set the output voltage. Further, both line and load regulation are comparable to discrete designs. Also, the LM150 is packaged in standard transistor packages which are easily mounted and handled.

In addition to higher performance than fixed regulators, the LM150 series offers full overload protection available only in IC's. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is accidentally disconnected.

Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An output capacitor can be added to improve transient response, while bypassing the adjustment pin will increase the regulator's ripple rejection.

Besides replacing fixed regulators or discrete designs, the LM150 is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input to output differential is not exceeded, i.e., avoid short-circuiting the output.

By connecting a fixed resistor between the adjustment pin and output, the LM150 can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

The part numbers in the LM150 series which have a K suffix are packaged in a standard Steel TO-3 package, while those with a T suffix are packaged in a TO-220 plastic package. The LM150 is rated for $-55°C \le T_J \le +150°C$, while the LM350A is rated for $-40°C \le T_J \le +125°C$, and the LM350 is rated for $0°C \le T_J \le +125°C$.

Features

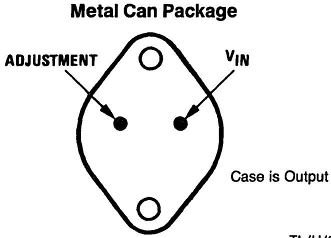
- Adjustable output down to 1.2V
- Guaranteed 3A output current
- Guaranteed thermal regulation
- Output is short circuit protected
- Current limit constant with temperature
- P^+ Product Enhancement tested
- 86 dB ripple rejection
- Guaranteed 1% output voltage tolerance (LM350A)
- Guaranteed max. 0.01%/V line regulation (LM350A)
- Guaranteed max. 0.3% load regulation (LM350A)

Applications

- Adjustable power supplies
- Constant current regulators
- Battery chargers

Connection Diagrams

(TO-3 STEEL)
Metal Can Package



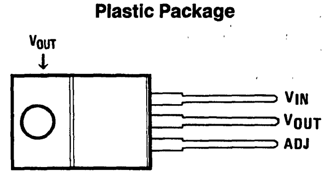
TL/H/9061–4

Bottom View

Order Number LM150K STEEL or LM350K STEEL
See NS Package Number K02A

Order Number LM150K/883
See NS Package Number K02C

(TO-220)
Plastic Package



TL/H/9061–5

Front View

Order Number LM350AT or LM350T
See NS Package Number T03B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 4)

Power Dissipation	Internally Limited
Input-Output Voltage Differential	+35V
Storage Temperature	−65°C to +150°C
Lead Temperature	
Metal Package (Soldering, 10 sec.)	300°C
Plastic Package (Soldering, 4 sec.)	260°C
ESD Tolerance	TBD
Operating Temperature Range	
LM150	$-55°C \leq T_J \leq +150°C$
LM350A	$-40°C \leq T_J \leq +125°C$
LM350	$0°C \leq T_J \leq +125°C$

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} - V_{OUT} = 5V$, and $I_{OUT} = 10$ mA. (Note 2)

Parameter	Conditions	LM150 Min	LM150 Typ	LM150 Max	Units
Reference Voltage	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$, $10\ mA \leq I_{OUT} \leq 3A$, $P \leq 30W$	**1.20**	**1.25**	**1.30**	V
Line Regulation	$3V \leq (V_{IN} - V_{OUT}) \leq 35V$ (Note 3)		0.005	0.01	%/V
			0.02	**0.05**	%/V
Load Regulation	$10\ mA \leq I_{OUT} \leq 3A$ (Note 3)		0.1	0.3	%
			0.3	**1**	%
Thermal Regulation	20 ms Pulse		0.002	0.01	%/W
Adjustment Pin Current			**50**	**100**	μA
Adjustment Pin Current Change	$10\ mA \leq I_{OUT} \leq 3A$, $3V \leq (V_{IN} - V_{OUT}) \leq 35V$		**0.2**	**5**	μA
Temperature Stability	$T_{MIN} \leq T_J \leq T_{MAX}$		**1**		%
Minimum Load Current	$V_{IN} - V_{OUT} = 35V$		**3.5**	**5**	mA
Current Limit	$V_{IN} - V_{OUT} \leq 10V$	**3.0**	**4.5**		A
	$V_{IN} - V_{OUT} = 30V$	0.3	1		A
RMS Output Noise, % of V_{OUT}	$10\ Hz \leq f \leq 10\ kHz$		0.001		%
Ripple Rejection Ratio	$V_{OUT} = 10V$, $f = 120$ Hz, $C_{ADJ} = 0\ \mu F$		**65**		dB
	$V_{OUT} = 10V$, $f = 120$ Hz, $C_{ADJ} = 10\ \mu F$	**66**	**86**		dB
Long-Term Stability	$T_J = 125°C$, 1000 hrs		0.3	1	%
Thermal Resistance, Junction to Case	K Package		1.2	1.5	°C/W
Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package		35		°C/W

Electrical Characteristics (Continued)

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range.** Unless otherwise specified, $V_{IN} - V_{OUT}$ = 5V, and I_{OUT} = 10 mA. (Note 2) (Continued)

Parameter	Conditions	LM350A			LM350			Units
		Min	Typ	Max	Min	Typ	Max	
Reference Voltage	I_{OUT} = 10 mA, T_J = 25°C	1.238	1.250	1.262				V
	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 35V, 10 mA ≤ I_{OUT} ≤ 3A, P ≤ 30W	**1.225**	**1.250**	**1.270**	**1.20**	**1.25**	**1.30**	V
Line Regulation	3V ≤ ($V_{IN} - V_{OUT}$) ≤ 35V (Note 3)		0.005	0.01		0.005	0.03	%/V
			0.02	**0.05**		**0.02**	**0.07**	%/V
Load Regulation	10 mA ≤ I_{OUT} ≤ 3A (Note 3)		0.1	0.3		0.1	0.5	%
			0.3	**1**		**0.3**	**1.5**	%
Thermal Regulation	20 ms Pulse		0.002	0.01		0.002	0.03	%/W
Adjustment Pin Current			**50**	**100**		**50**	**100**	μA
Adjustment Pin Current Change	10 mA ≤ I_{OUT} ≤ 3A, 3V ≤ ($V_{IN} - V_{OUT}$) ≤ 35V		**0.2**	**5**		**0.2**	**5**	μA
Temperature Stability	T_{MIN} ≤ T_J ≤ T_{MAX}		**1**			**1**		%
Minimum Load Current	$V_{IN} - V_{OUT}$ = 35V		**3.5**	**10**		**3.5**	**10**	mA
Current Limit	$V_{IN} - V_{OUT}$ ≤ 10V	**3.0**	**4.5**		**3.0**	**4.5**		A
	$V_{IN} - V_{OUT}$ = 30V	0.3	1		0.25	1		A
RMS Output Noise, % of V_{OUT}	10 Hz ≤ f ≤ 10 kHz		0.001			0.001		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 μF		**65**			**65**		dB
	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 10 μF	**66**	**86**		**66**	**86**		dB
Long-Term Stability	T_J = 125°C, 1000 hrs		0.25	1		0.25	1	%
Thermal Resistance, Junction to Case	K Package					1.2	1.5	°C/W
	T Package		3	4		3	4	°C/W
Thermal Resistance, Junction to Ambient (No Heat Sink)	K Package					35		°C/W
	T Package		50			50		°C/W

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

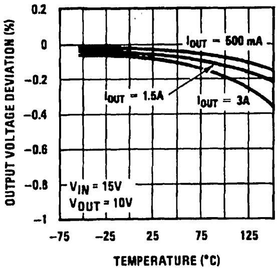
Note 2: These specifications are applicable for power dissipations up to 30W for the TO-3 (K) package and 25W for the TO-220 (T) package. Power dissipation is guaranteed at these values up to 15V input-output differential. Above 15V differential, power dissipation will be limited by internal protection circuitry. All limits (i.e., the numbers in the Min. and Max. columns) are guaranteed to National's AOQL (Average Outgoing Quality Level).

Note 3: Regulation is measured at a constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specifications for thermal regulation.

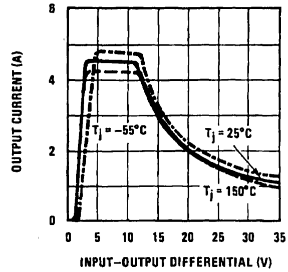
Note 4: Refer to RETS150K drawing for military specifications of the LM150K.

Typical Performance Characteristics

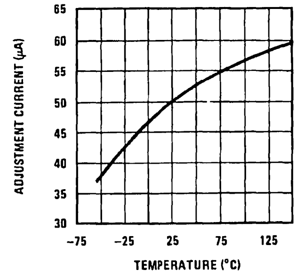
Load Regulation



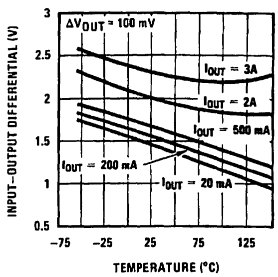
Current Limit



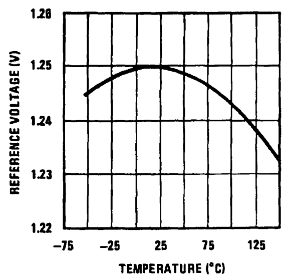
Adjustment Current



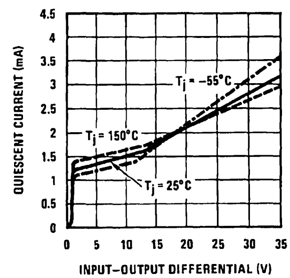
Dropout Voltage



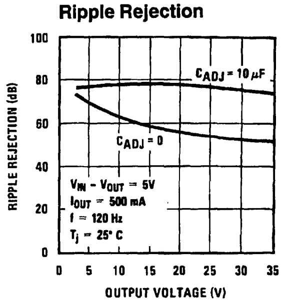
Temperature Stability



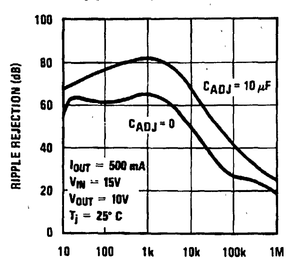
Minimum Operating Current



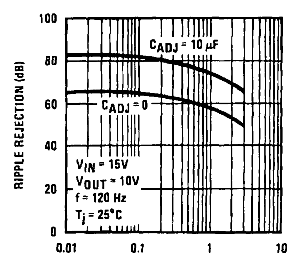
Ripple Rejection



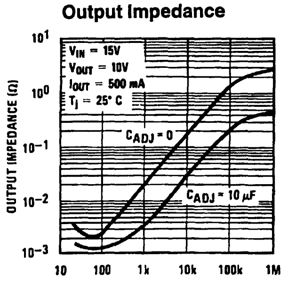
Ripple Rejection



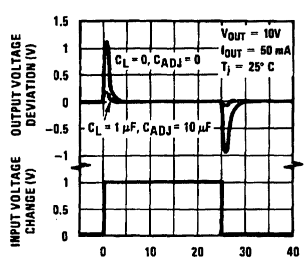
Ripple Rejection



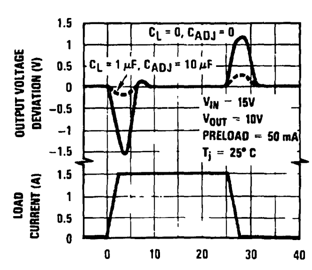
Output Impedance



Line Transient Response



Load Transient Response



TL/H/9061-6

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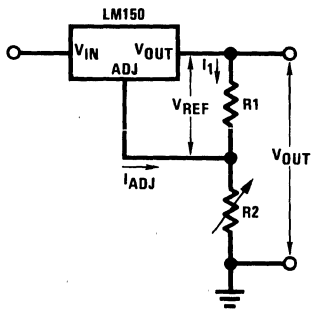
Application Hints

In operation, the LM150 develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}\,R2.$$



TL/H/9061-7

FIGURE 1

Since the 50 μA current from the adjustment terminal represents an error term, the LM150 was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.

EXTERNAL CAPACITORS

An input bypass capacitor is recommended. A 0.1 μF disc or 1 μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used but the above values will eliminate the possibility of problems.

The adjustment terminal can be bypassed to ground on the LM150 to improve ripple rejection. This bypass capacitor prevents ripple from being amplified as the output voltage is increased. With a 10 μF bypass capacitor 86 dB ripple rejection is obtainable at any output level. Increases over 10 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

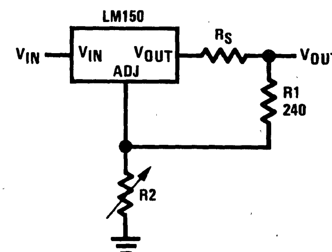
In general, the best type of capacitors to use is solid tantalum. Solid tantalum capacitors have low impedance even at high frequencies. Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1 μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies, but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, 0.01 μF disc may seem to work better than a 0.1 μF disc as a bypass.

Although the LM150 is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μF solid tantalum (or 25 μF aluminum electrolytic) on the output swamps this effect and insures stability.

LOAD REGULATION

The LM150 is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output (case) of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω × I_{OUT}. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.



TL/H/9061-8

FIGURE 2. Regulator with Line Resistance in Output Lead

With the TO-3 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the case. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.

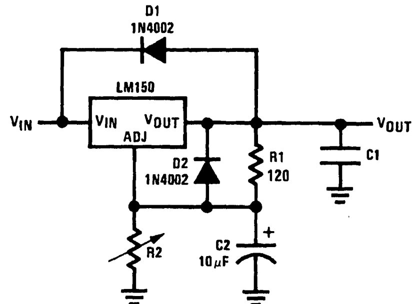
PROTECTION DIODES

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM150, this discharge path is through a large junction that is able to sustain 25A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, there is no need to use diodes.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM150 is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM150 with protection diodes included for use with outputs greater than 25V and high values of output capacitance.

Application Hints (Continued)



D1 protects against C1

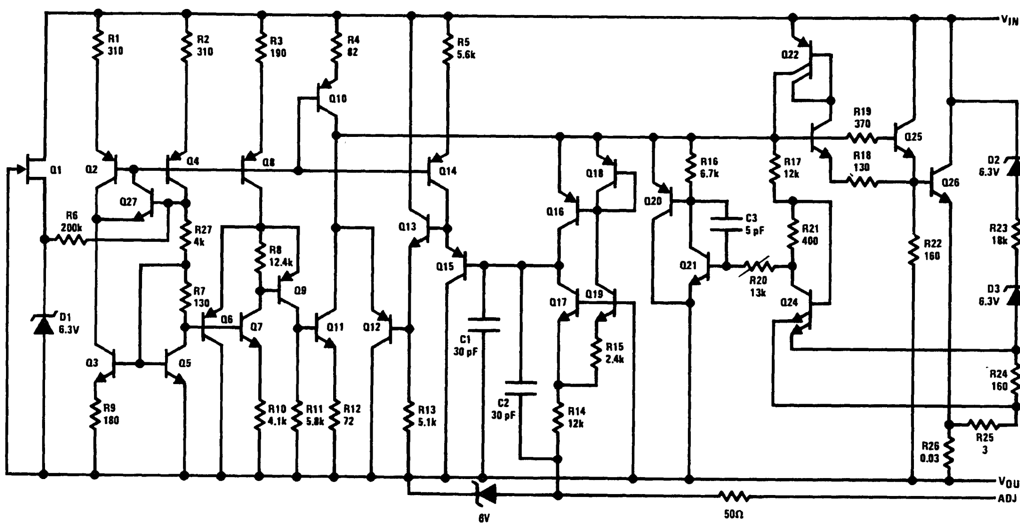
D2 protects against C2

$$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}R2$$

TL/H/9061-9

FIGURE 3. Regulator with Protection Diodes

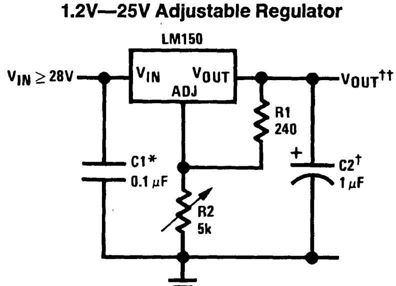
Schematic Diagram



TL/H/9061-10

Typical Applications

1.2V—25V Adjustable Regulator



TL/H/9061-1

Full output current not available at high input-output voltages.

†Optional—improves transient response. Output capacitors in the range of 1 μF to 1000 μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

*Needed if device is more than 6 inches from filter capacitors.

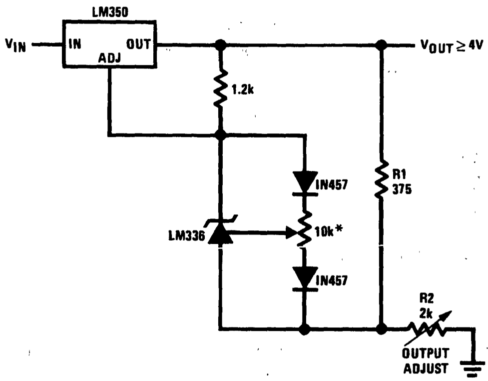
$$††V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R2)$$

Note: Usually R1 = 240Ω for LM150 and R1 = 120Ω for LM350.

1

Typical Applications (Continued)

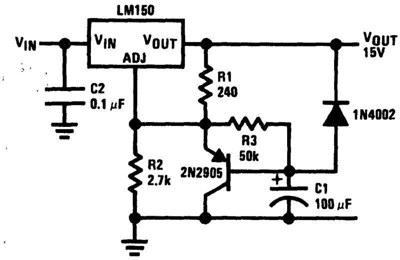
Precision Power Regulator with Low Temperature Coefficient



*Adjust for 3.75V across R1

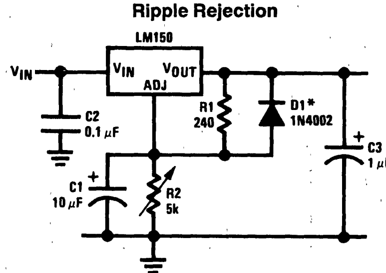
TL/H/9061–13

Slow Turn-ON 15V Regulator



TL/H/9061–14

Adjustable Regulator with Improved Ripple Rejection

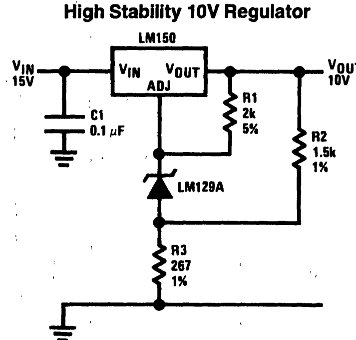


†Solid tantalum

*Discharges C1 if output is shorted to ground

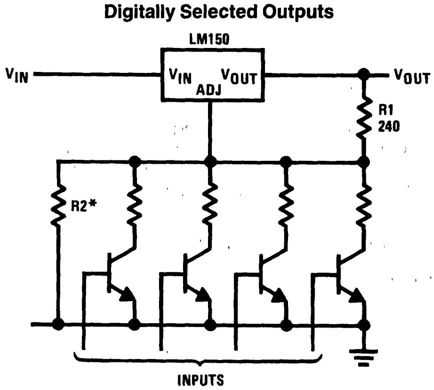
TL/H/9061–15

High Stability 10V Regulator



TL/H/9061–16

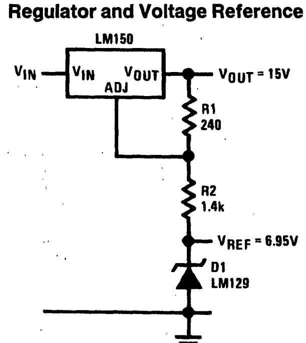
Digitally Selected Outputs



TL/H/9061–17

*Sets maximum V_{OUT}

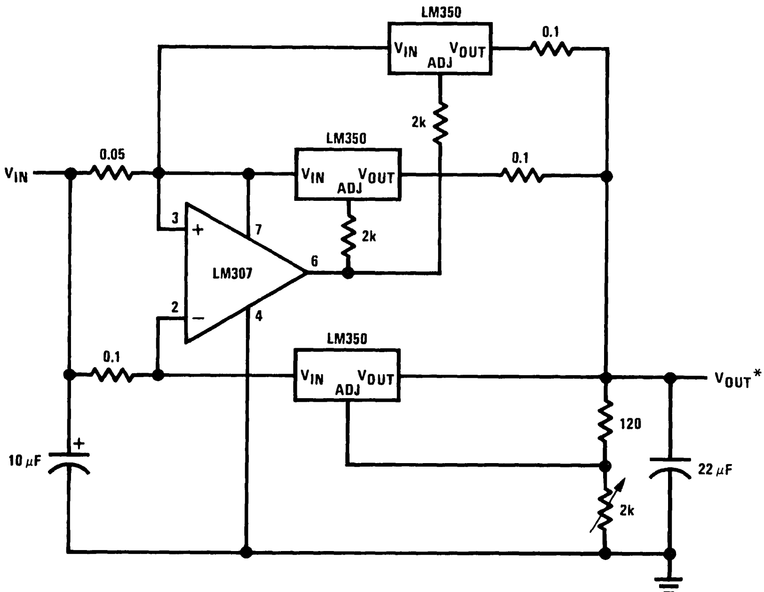
Regulator and Voltage Reference



TL/H/9061–3

Typical Applications (Continued)

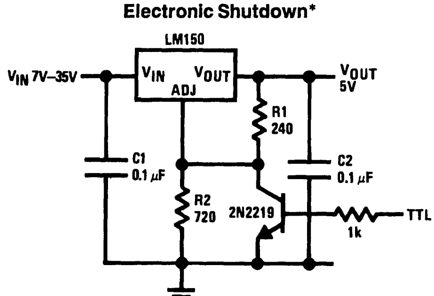
10A Regulator



*Minimum load current 50 mA

TL/H/9061–18

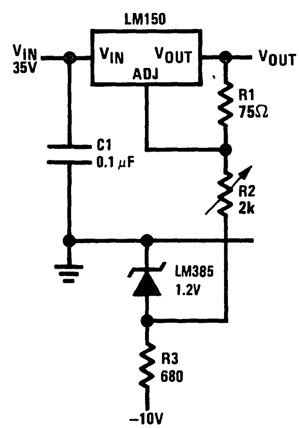
5V Logic Regulator with Electronic Shutdown*



TL/H/9061–19

*Min output ≈ 1.2V

0 to 30V Regulator

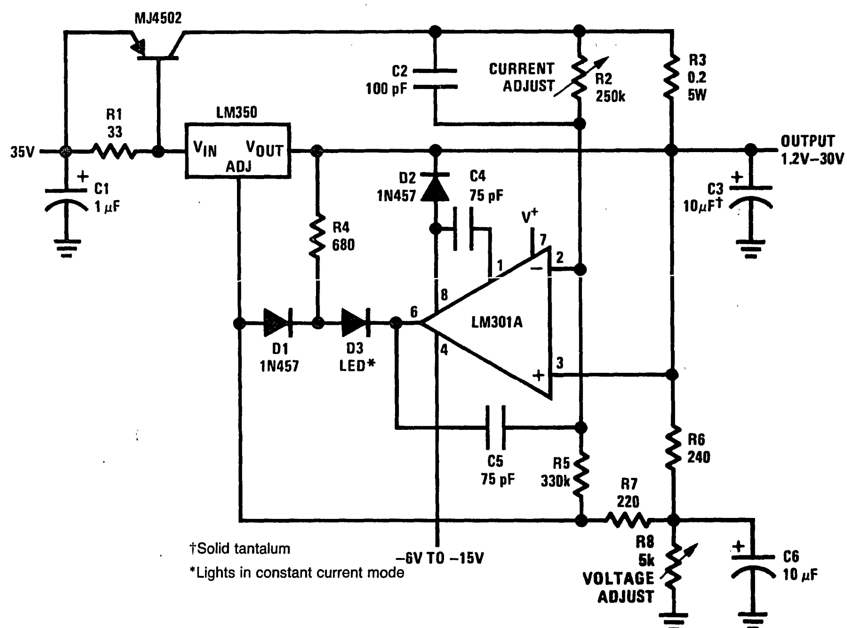


TL/H/9061–20

Full output current not available at high input-output voltages

Typical Applications (Continued)

5A Constant Voltage/Constant Current Regulator

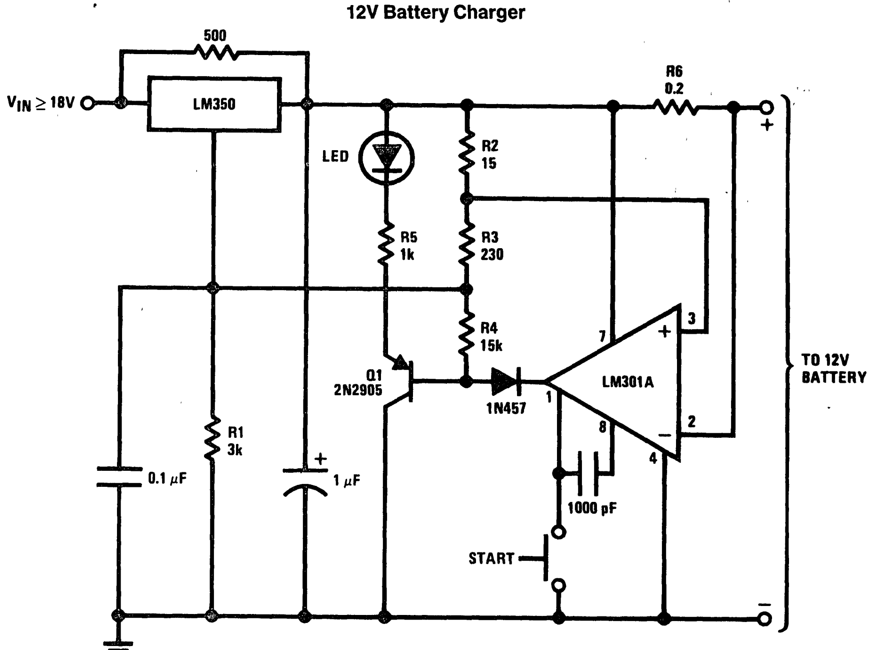


†Solid tantalum

*Lights in constant current mode

TL/H/9061-21

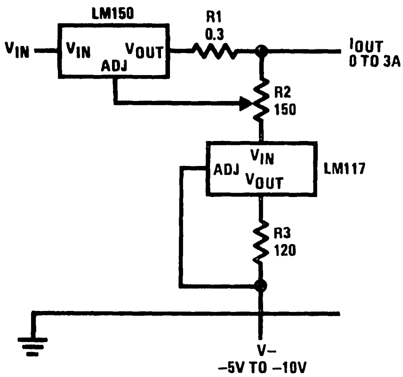
12V Battery Charger



TL/H/9061-22

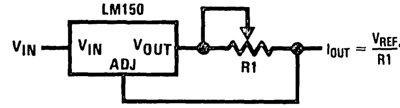
Typical Applications (Continued)

Adjustable Current Regulator



TL/H/9061–23

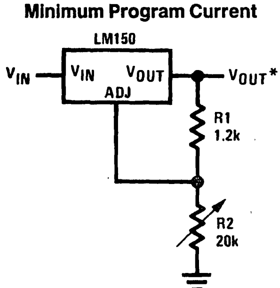
Precision Current Limiter



TL/H/9061–24

*$0.4 \leq R_1 \leq 120\Omega$

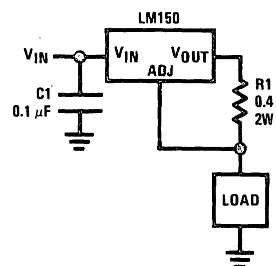
1.2V–20V Regulator with Minimum Program Current



TL/H/9061–25

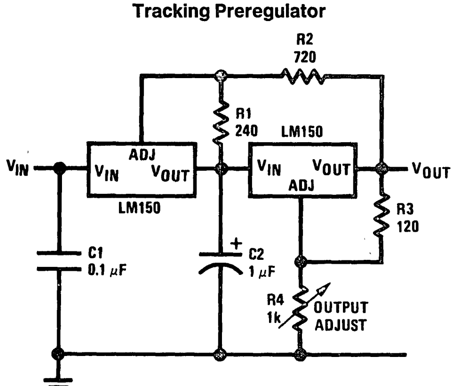
*Minimum output current ≈ 4 mA

3A Current Regulator



TL/H/9061–26

Tracking Preregulator



TL/H/9061–27

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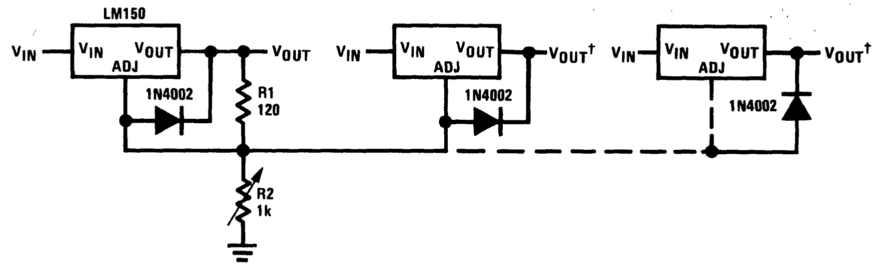
Typical Applications (Continued)

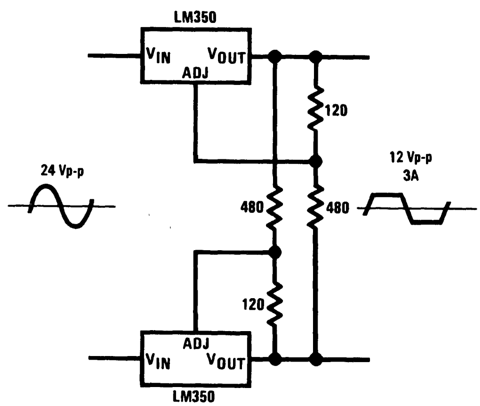
Adjusting Multiple On-Card Regulators with Single Control*



TL/H/9061-28

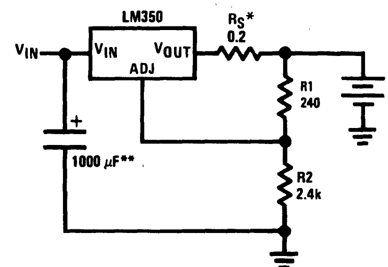
†Minimum load—10 mA
*All outputs within ±100 mV

AC Voltage Regulator



TL/H/9061-29

Simple 12V Battery Charger



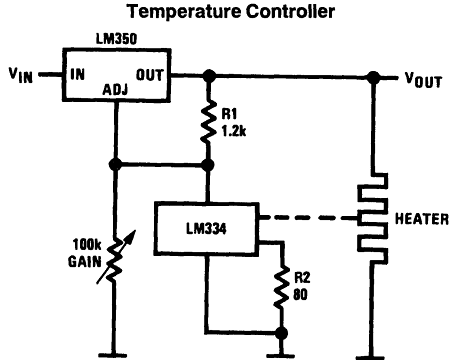
TL/H/9061-30

*R_S—sets output impedance of charger: $Z_{OUT} = R_S\left(1 + \frac{R2}{R1}\right)$

Use of R_S allows low charging rates with fully charged battery.

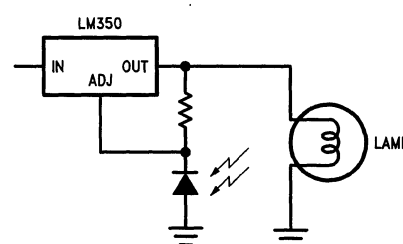
**1000 μF is recommended to filter out any input transients

Temperature Controller



TL/H/9061-11

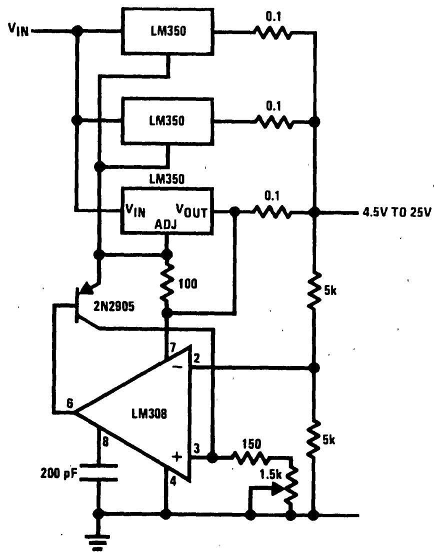
Light Controller



TL/H/9061-12

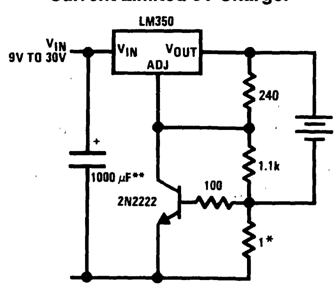
Typical Applications (Continued)

Adjustable 10A Regulator



TL/H/9061-31

Current Limited 6V Charger

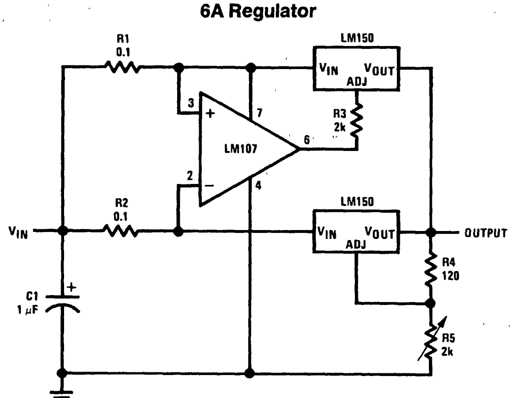


TL/H/9061-32

*Sets peak current (2A for 0.3Ω)

**1000 μF is recommended to filter out any input transients.

6A Regulator



TL/H/9061-2

National Semiconductor

LM317L 3-Terminal Adjustable Regulator

General Description

The LM317L is an adjustable 3-terminal positive voltage regulator capable of supplying 100 mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Further, both line and load regulation are better than standard fixed regulators. Also, the LM317L is available packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM317L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Features

- Adjustable output down to 1.2V
- Guaranteed 100 mA output current
- Line regulation typically 0.01%V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short circuit protected

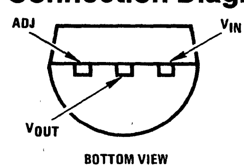
Normally, no capacitors are needed unless the device is situated more than 6 inches from the input filter capacitors in which case an input bypass is needed. An optional output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM317L is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM317L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

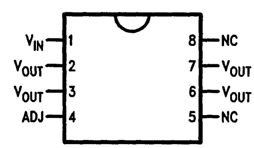
The LM317L is available in a standard TO-92 transistor package and the SO-8 package. The LM317L is rated for operation over a −25°C to 125°C range.

Connection Diagram



TL/H/9064-4

Order Number LM317LZ
See NS Package
Number Z03A

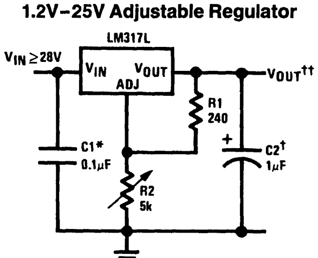


TL/H/9064-5

Order Number LM317LM
See NS Package
Number M08A

Typical Applications

1.2V–25V Adjustable Regulator



TL/H/9064-1

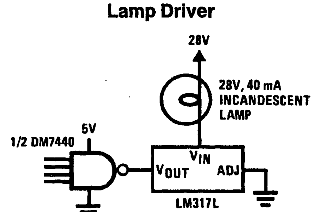
Full output current not available at high input-output voltages

†Optional—improves transient response

*Needed if device is more than 6 inches from filter capacitors

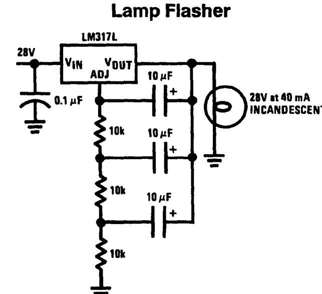
$$††V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R_2)$$

Fully Protected (Bulletproof) Lamp Driver



TL/H/9064-2

Lamp Flasher



TL/H/9064-3

Output rate—4 flashes per second at 10% duty cycle

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	40V
Operating Junction Temperature Range	−40°C to +125°C
Storage Temperature	−55°C to +150°C
Lead Temperature (Soldering, 4 seconds)	260°C

Output is Short Circuit Protected

ESD rating to be determined.

Electrical Characteristics (Note 1)

Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	T_j = 25°C, 3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, I_L ≤ 20 mA (Note 2)		0.01	0.04	%/V
Load Regulation	T_j = 25°C, 5 mA ≤ I_{OUT} ≤ I_{MAX}, (Note 2)		0.1	0.5	%
Thermal Regulation	T_j = 25°C, 10 ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	5 mA ≤ I_L ≤ 100 mA 3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, P ≤ 625 mW		0.2	5	μA
Reference Voltage	3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, (Note 3) 5 mA ≤ I_{OUT} ≤ 100 mA, P ≤ 625 mW	1.20	1.25	1.30	V
Line Regulation	3V ≤ (V_{IN} − V_{OUT}) ≤ 40V, I_L ≤ 20 mA (Note 2)		0.02	0.07	%/V
Load Regulation	5 mA ≤ I_{OUT} ≤ 100 mA, (Note 2)		0.3	1.5	%
Temperature Stability	T_{MIN} ≤ T_j ≤ T_{Max}		0.65		%
Minimum Load Current	(V_{IN} − V_{OUT}) ≤ 40V 3V ≤ (V_{IN} − V_{OUT}) ≤ 15V		3.5 1.5	5 2.5	mA
Current Limit	3V ≤ (V_{IN} − V_{OUT}) ≤ 13V (V_{IN} − V_{OUT}) = 40V	100 25	200 50	300 150	mA mA
Rms Output Noise, % of V_{OUT}	T_j = 25°C, 10 Hz ≤ f ≤ 10 kHz		0.003		%
Ripple Rejection Ratio	V_{OUT} = 10V, f = 120 Hz, C_{ADJ} = 0 C_{ADJ} = 10 μF	 66	65 80		dB dB
Long-Term Stability	T_j = 125°C, 1000 Hours		0.3	1	%
Thermal Resistance Junction to Ambient	Z Package 0.4″ Leads Z Package 0.125 Leads SO-8 Package		180 160 165		°C/W °C/W °C/W
Thermal Rating of SO Package			165		°C/W

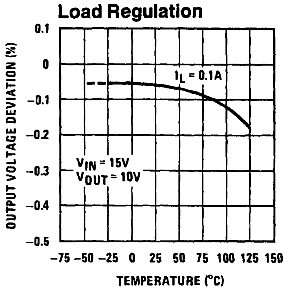
Note 1: Unless otherwise noted, these specifications apply: −25°C ≤ T_j ≤ 125°C for the LM317L; V_{IN} − V_{OUT} = 5V and I_{OUT} = 40 mA. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100 mA.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

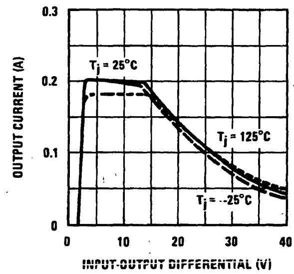
Note 3: Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4″ leads from a PC board and 160°C/W junction to ambient with 0.125″ lead length to PC board.

Typical Performance Characteristics (Output capacitor = 0 μF unless otherwise noted.)

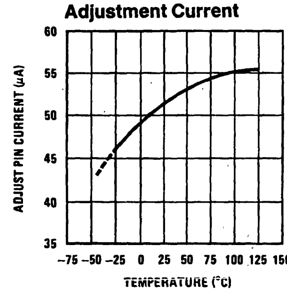
Load Regulation



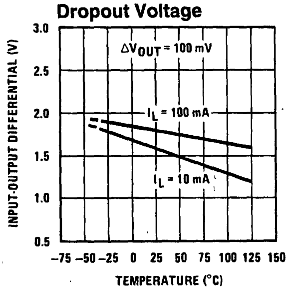
Current Limit



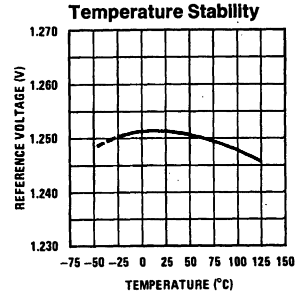
Adjustment Current



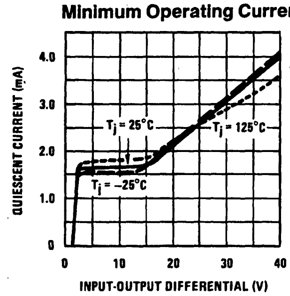
Dropout Voltage



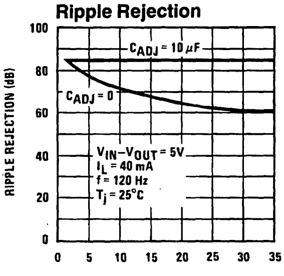
Reference Voltage Temperature Stability



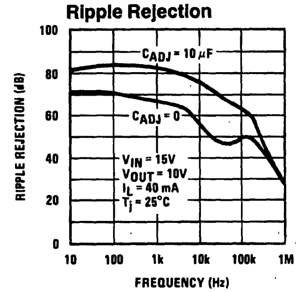
Minimum Operating Current



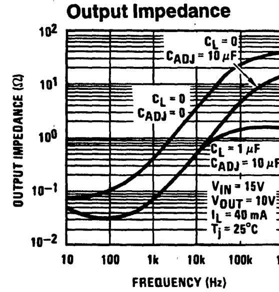
Ripple Rejection



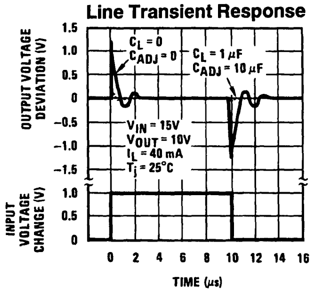
Ripple Rejection



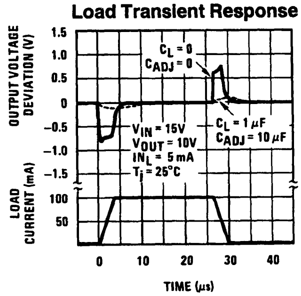
Output Impedance



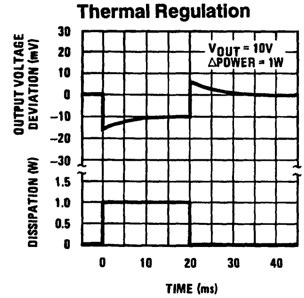
Line Transient Response



Load Transient Response



Thermal Regulation



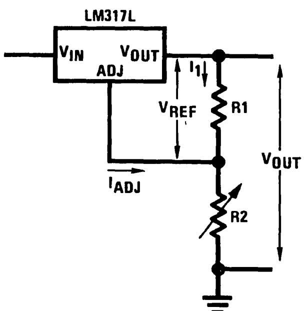
TL/H/9064-6

Application Hints

In operation, the LM317L develops a nominal 1.25V reference voltage, V_{REF}, between the output and adjustment terminal. The reference voltage is impressed across program resistor R1 and, since the voltage is constant, a constant current I_1 then flows through the output set resistor R2, giving an output voltage of

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) + I_{ADJ}(R2)$$

Since the 100 μA current from the adjustment terminal represents an error term, the LM317L was designed to minimize I_{ADJ} and make it very constant with line and load changes. To do this, all quiescent operating current is returned to the output establishing a minimum load current requirement. If there is insufficient load on the output, the output will rise.



TL/H/9064-7

FIGURE 1

External Capacitors

An input bypass capacitor is recommended in case the regulator is more than 6 inches away from the usual large filter capacitor. A 0.1 μF disc or 1 μF solid tantalum on the input is suitable input bypassing for almost all applications. The device is more sensitive to the absence of input bypassing when adjustment or output capacitors are used, but the above values will eliminate the possiblity of problems.

The adjustment terminal can be bypassed to ground on the LM317L to improve ripple rejection and noise. This bypass capacitor prevents ripple and noise from being amplified as the output voltage is increased. With a 10 μF bypass capacitor 80 dB ripple rejection is obtainable at any output level. Increases over 10 μF do not appreciably improve the ripple rejection at frequencies above 120 Hz. If the bypass capacitor is used, it is sometimes necessary to include protection diodes to prevent the capacitor from discharging through internal low current paths and damaging the device.

In general, the best type of capacitors to use is solid tantalum. *Solid tantalum capacitors have low impedance even at high frequencies.* Depending upon capacitor construction, it takes about 25 μF in aluminum electrolytic to equal 1 μF solid tantalum at high frequencies. Ceramic capacitors are also good at high frequencies; but some types have a large decrease in capacitance at frequencies around 0.5 MHz. For this reason, a 0.01 μF disc may seem to work better than a 0.1 μF disc as a bypass.

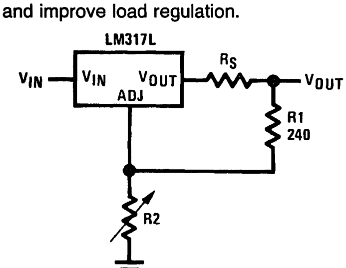
Although the LM317L is stable with no output capacitors, like any feedback circuit, certain values of external capacitance can cause excessive ringing. This occurs with values between 500 pF and 5000 pF. A 1 μF solid tantalum (or 25 μF aluminum electrolytic) on the output swamps this effect and insures stability.

Load Regulation

The LM317L is capable of providing extremely good load regulation but a few precautions are needed to obtain maximum performance. The current set resistor connected between the adjustment terminal and the output terminal (usually 240Ω) should be tied directly to the output of the regulator rather than near the load. This eliminates line drops from appearing effectively in series with the reference and degrading regulation. For example, a 15V regulator with 0.05Ω resistance between the regulator and load will have a load regulation due to line resistance of 0.05Ω × I_L. If the set resistor is connected near the load the effective line resistance will be 0.05Ω (1 + R2/R1) or in this case, 11.5 times worse.

Figure 2 shows the effect of resistance between the regulator and 240Ω set resistor.

With the TO-92 package, it is easy to minimize the resistance from the case to the set resistor, by using two separate leads to the output pin. The ground of R2 can be returned near the ground of the load to provide remote ground sensing and improve load regulation.



TL/H/9064-8

FIGURE 2. Regulator with Line Resistance in Output Lead

1

Application Hints (Continued)

Thermal Regulation

When power is dissipated in an IC, a temperature gradient occurs across the IC chip affecting the individual IC circuit components. With an IC regulator, this gradient can be especially severe since power dissipation is large. Thermal regulation is the effect of these temperature gradients on output voltage (in percentage output change) per watt of power change in a specified time. Thermal regulation error is independent of electrical regulation or temperature coefficient, and occurs within 5 ms to 50 ms after a change in power dissipation. Thermal regulation depends on IC layout as well as electrical design. The thermal regulation of a voltage regulator is defined as the percentage change of V_{OUT}, per watt, within the first 10 ms after a step of power is applied. The LM317L specification is 0.2%/W, maximum.

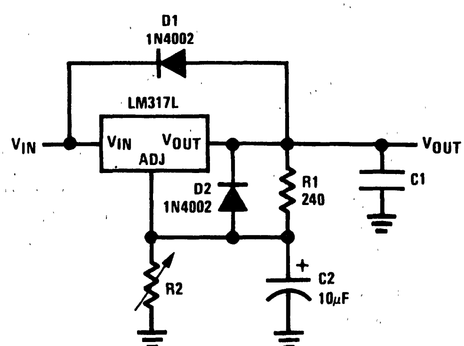
In the Thermal Regulation curve at the bottom of the Typical Performance Characteristics page, a typical LM317L's output changes only 7 mV (or 0.07% of $V_{OUT} = -10V$) when a 1W pulse is applied for 10 ms. This performance is thus well inside the specification limit of $0.2\%/W \times 1W = 0.2\%$ maximum. When the 1W pulse is ended, the thermal regulation again shows a 7 mV change as the gradients across the LM317L chip die out. Note that the load regulation error of about 14 mV (0.14%) is additional to the thermal regulation error.

Protection Diodes

When external capacitors are used with *any* IC regulator it is sometimes necessary to add protection diodes to prevent the capacitors from discharging through low current points into the regulator. Most 10 μF capacitors have low enough internal series resistance to deliver 20A spikes when shorted. Although the surge is short, there is enough energy to damage parts of the IC.

When an output capacitor is connected to a regulator and the input is shorted, the output capacitor will discharge into the output of the regulator. The discharge current depends on the value of the capacitor, the output voltage of the regulator, and the rate of decrease of V_{IN}. In the LM317L, this discharge path is through a large junction that is able to sustain a 2A surge with no problem. This is not true of other types of positive regulators. For output capacitors of 25 μF or less, the LM317L's ballast resistors and output structure limit the peak current to a low enough level so that there is no need to use a protection diode.

The bypass capacitor on the adjustment terminal can discharge through a low current junction. Discharge occurs when *either* the input or output is shorted. Internal to the LM317L is a 50Ω resistor which limits the peak discharge current. No protection is needed for output voltages of 25V or less and 10 μF capacitance. *Figure 3* shows an LM317L with protection diodes included for use with outputs greater than 25V and high values of output capacitance.



TL/H/9064–9

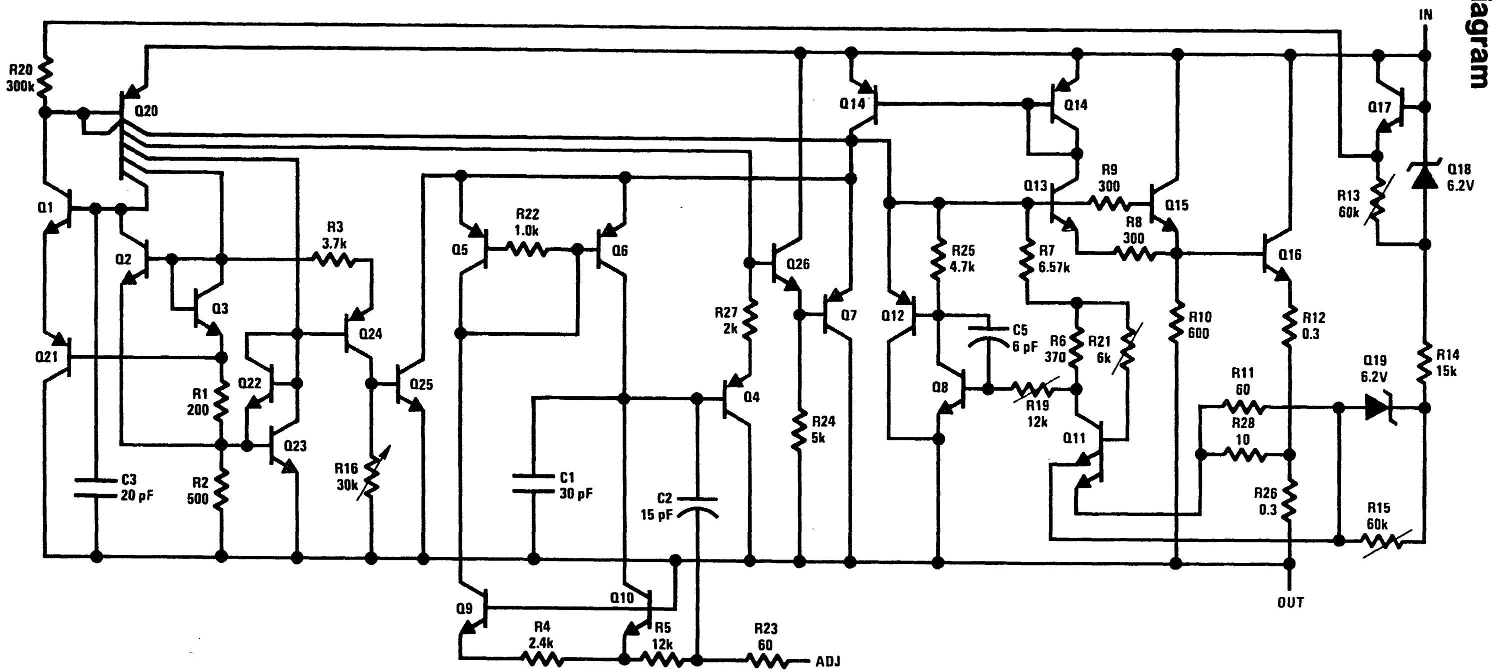
FIGURE 3. Regulator with Protection Diodes

$V_{OUT} = 1.25V\left(1 + \frac{R2}{R1}\right) I_{ADJ} R2$

D1 protects against C1

D2 protects against C2

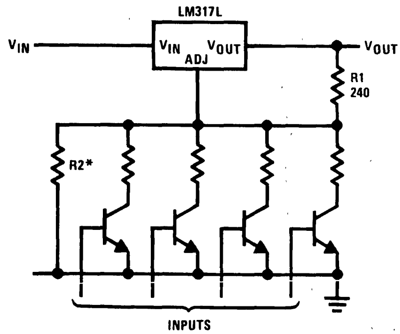
Schematic Diagram



TL/H/9064-10

Typical Applications (Continued)

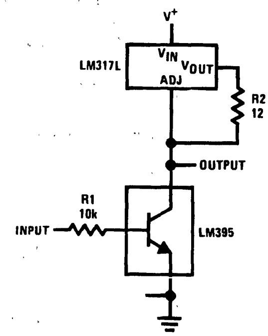
Digitally Selected Outputs



TL/H/9064–11

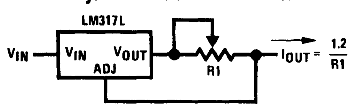
*Sets maximum V_{OUT}

High Gain Amplifier



TL/H/9064–12

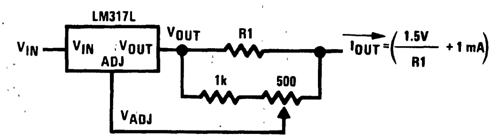
Adjustable Current Limiter



TL/H/9064–13

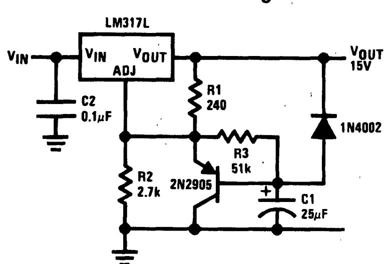
$12 \leq R1 \leq 240$

Precision Current Limiter



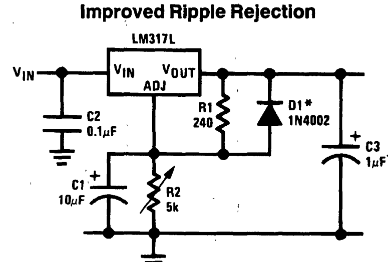
TL/H/9064–14

Slow Turn-On 15V Regulator



TL/H/9064–15

Adjustable Regulator with Improved Ripple Rejection

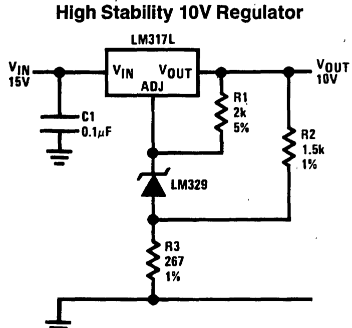


†Solid tantalum

TL/H/9064–16

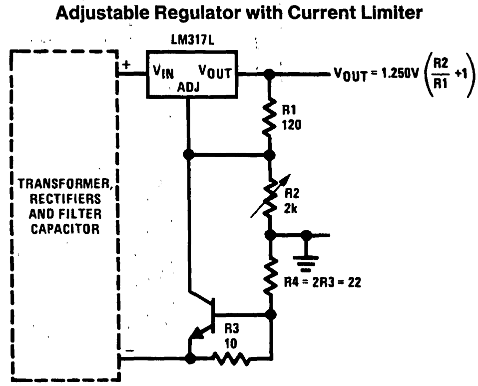
*Discharges C1 if output is shorted to ground

High Stability 10V Regulator



TL/H/9064–17

Adjustable Regulator with Current Limiter



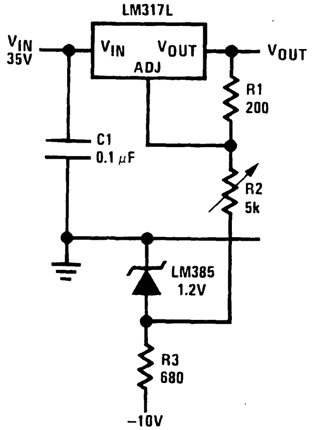
TL/H/9064–18

Short circuit current is approximately 600 mV/R3, or 60 mA (compared to LM317LZ's 200 mA current limit).

At 25 mA output only 3/4V of drop occurs in R3 and R4.

Typical Applications (Continued)

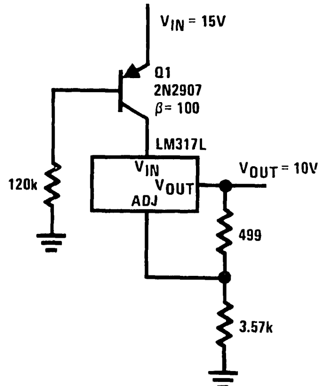
0V–30V Regulator



TL/H/9064–19

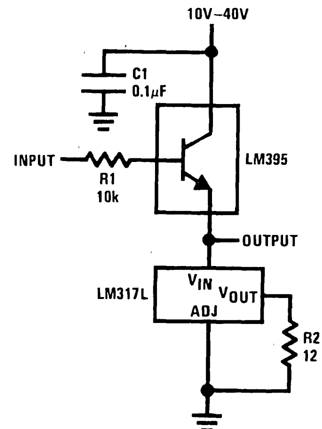
Full output current not available at high input-output voltages

Regulator With 15 mA Short Circuit Current



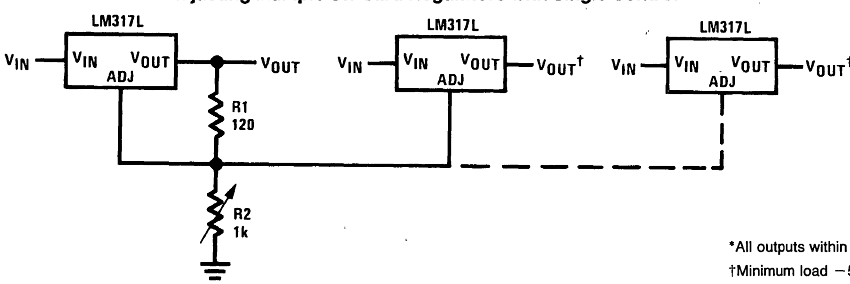
TL/H/9064–20

Power Follower



TL/H/9064–21

Adjusting Multiple On-Card Regulators with Single Control*

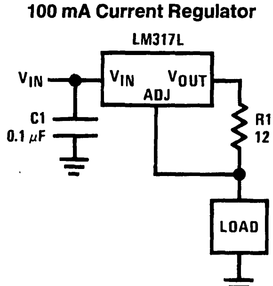


*All outputs within ± 100 mV

†Minimum load −5mA

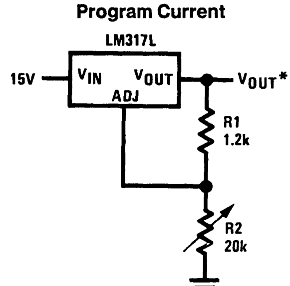
TL/H/9064–22

100 mA Current Regulator



TL/H/9064–23

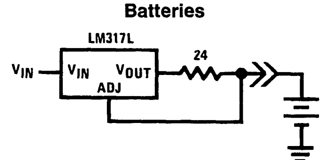
1.2V–12V Regulator with Minimum Program Current



*Minimum load current ≈ 2 mA

TL/H/9064–24

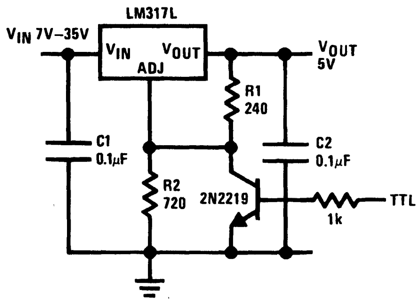
50 mA Constant Current Battery Charger for Nickel-Cadmium Batteries



TL/H/9064–25

Typical Applications (Continued)

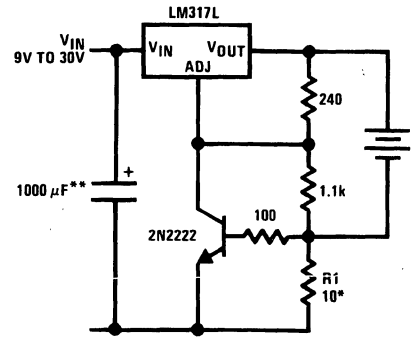
5V Logic Regulator with Electronic Shutdown*



TL/H/9064–26

*Minimum output ≈ 1.2V

Current Limited 6V Charger

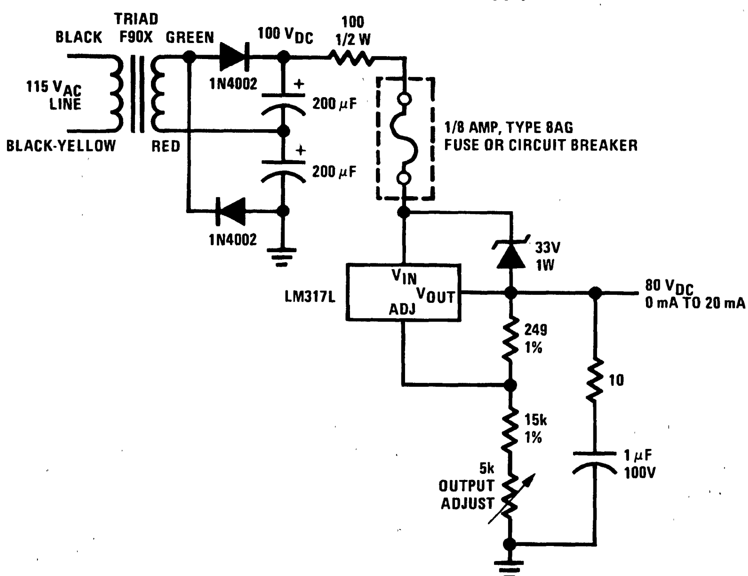


TL/H/9064–27

*Sets peak current, I_{PEAK} = 0.6V/R1

**1000 µF is recommended to filter out any input transients.

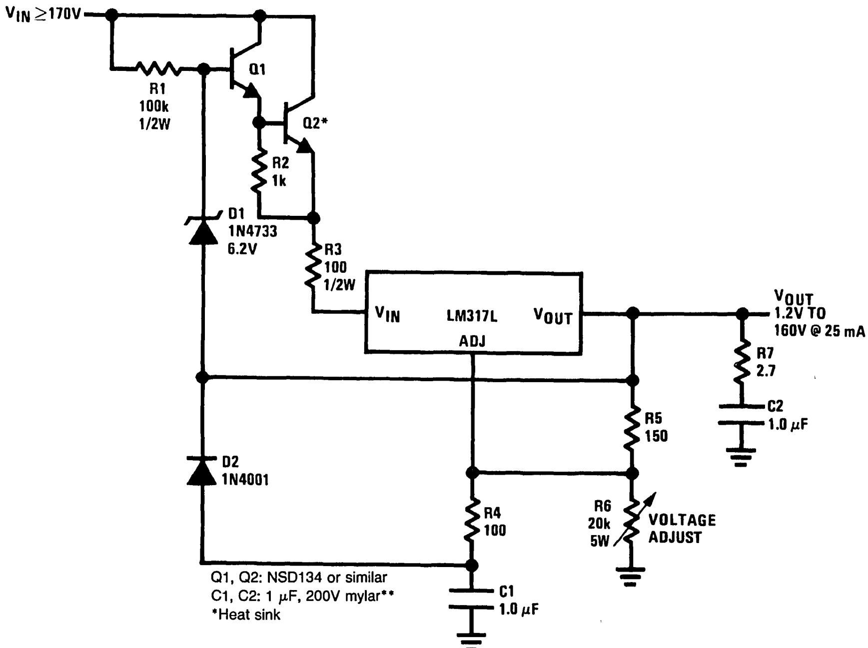
Short Circuit Protected 80V Supply



TL/H/9064–28

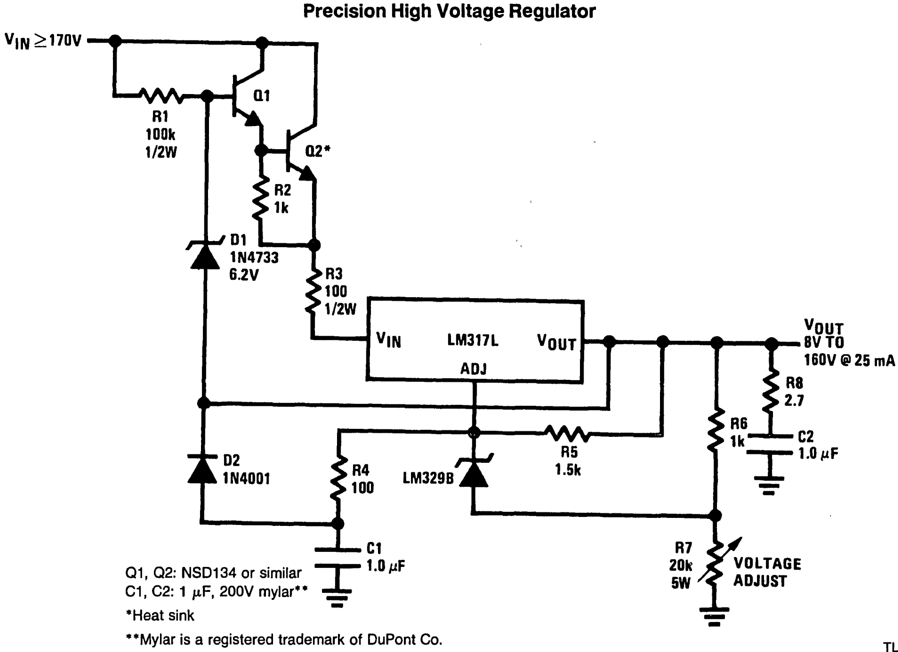
Typical Applications (Continued)

Basic High Voltage Regulator



TL/H/9064–29

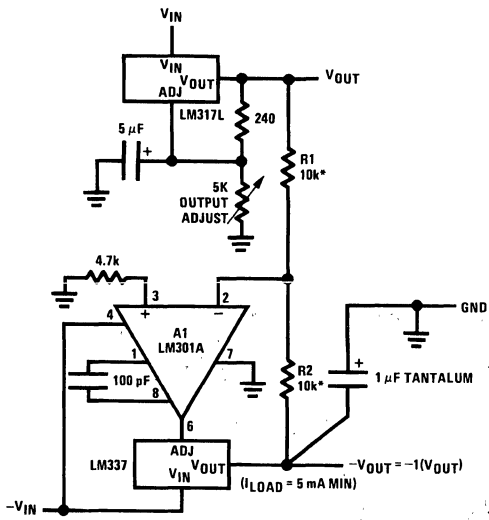
Precision High Voltage Regulator



TL/H/9064–30

Typical Applications (Continued)

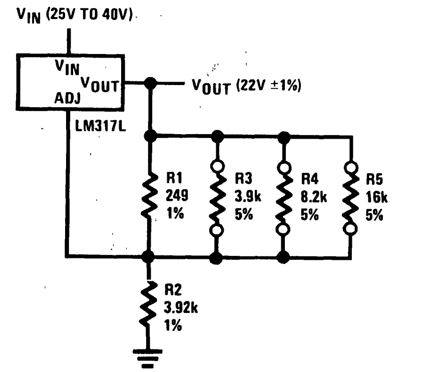
Tracking Regulator



TL/H/9064–31

A1 = LM301A, LM307, or LF13741 only
R1, R2 = matched resistors with good TC tracking

Regulator With Trimmable Output Voltage



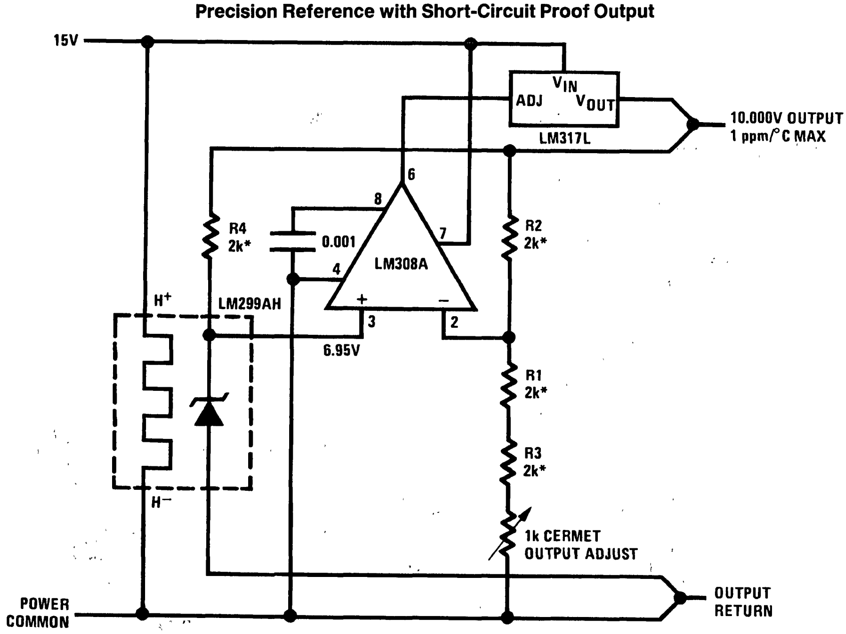
TL/H/9064–32

Trim Procedure:

— If V_{OUT} is 23.08V or higher, cut out R3 (if lower, don't cut it out).
— Then if V_{OUT} is 22.47V or higher, cut out R4 (if lower, don't).
— Then if V_{OUT} is 22.16V or higher, cut out R5 (if lower, don't).

This will trim the output to well within ±1% of 22.00 V_{DC}, without any of the expense or uncertainty of a trim pot (see LB-46). Of course, this technique can be used at any output voltage level.

Precision Reference with Short-Circuit Proof Output



TL/H/9064–33

*R1–R4 from thin-film network, Beckman 694-3-R2K-D or similar

National Semiconductor

LM320L, LM79LXXAC Series 3-Terminal Negative Regulators

General Description

The LM320L/LM79LXXAC series of 3-terminal negative voltage regulators features fixed output voltages of −5V, −12V, and −15V with output current capabilities in excess of 100 mA. These devices were designed using the latest computer techniques for optimizing the packaged IC thermal/electrical performance. The LM79LXXAC series, even when combined with a minimum output compensation capacitor of 0.1 μF, exhibits an excellent transient response, a maximum line regulation of 0.07% V_O/V, and a maximum load regulation of 0.01% V_O/mA.

The LM320L/LM79LXXAC series also includes, as self-protection circuitry: safe operating area circuitry for output transistor power dissipation limiting, a temperature independent short circuit current limit for peak output current limiting, and a thermal shutdown circuit to prevent excessive junction temperature. Although designed primarily as fixed voltage regulators, these devices may be combined with simple external circuitry for boosted and/or adjustable voltages and currents. The LM79LXXAC series is available in the 3-lead TO-92 package, and SO-8; 8 lead package. The LM320L series is available in the 3-lead TO-92 package.

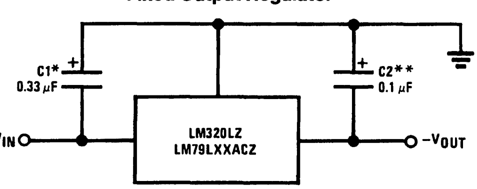
For output voltage other than −5V, −12V and −15V the LM137L series provides an output voltage range from 1.2V to 47V.

Features

- Preset output voltage error is less than ±5% overload, line and temperature
- Specified at an output current of 100 mA
- Easily compensated with a small 0.1 μF output capacitor
- Internal short-circuit, thermal and safe operating area protection
- Easily adjustable to higher output voltages
- Maximum line regulation less than 0.07% V_{OUT}/V
- Maximum load regulation less than 0.01% V_{OUT}/mA

Typical Applications

Fixed Output Regulator

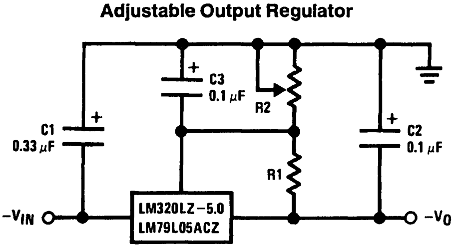


TL/H/7748–1

*Required if the regulator is located far from the power supply filter. A 1 μF aluminum electrolytic may be substituted.

**Required for stability. A 1 μF aluminum electrolytic may be substituted.

Adjustable Output Regulator

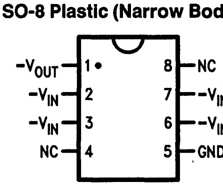


TL/H/7748–3

$$-V_O = -5V - (5V/R1 + I_Q) \bullet R2,$$
$$5V/R1 > 3\,I_Q$$

Connection Diagrams

SO-8 Plastic (Narrow Body)

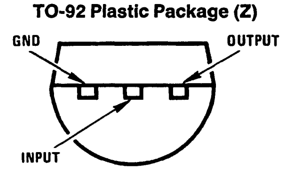


TL/H/7748–4

Top View

Order Number LM79L05ACM, LM79L12ACM or LM79L15ACM
See NS Package Number M08A

TO-92 Plastic Package (Z)



TL/H/7748–2

Bottom View

Order Number LM320LZ-5.0, LM79L05ACZ, LM320LZ-12, LM79L12ACZ, LM320LZ-15 or LM79L15ACZ
See NS Package Number Z03A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
V_O = −5V, −12V, −15V	−35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	0°C to +70°C
Maximum Junction Temperature	+125°C
Storage Temperature Range	−55°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Electrical Characteristics (Note 2) T_A = 0°C to +70°C unless otherwise noted.

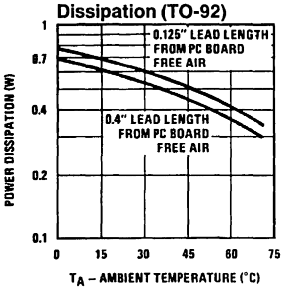
Output Voltage			−5V			−12V			−15V			Units
Input Voltage (unless otherwise noted)			**−10V**			**−17V**			**−20V**			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	Tj = 25°C, I_O = 100 mA	−5.2	−5	−4.8	−12.5	−12	−11.5	−15.6	−15	−14.4	V
		1 mA ≤ I_O ≤ 100 mA $V_{MIN} \le V_{IN} \le V_{MAX}$	−5.25 (−20 ≤ V_{IN} ≤ −7.5)		−4.75	−12.6 (−27 ≤ V_{IN} ≤ −14.8)		−11.4	−15.75 (−30 ≤ V_{IN} ≤ −18)		−14.25	V
		1 mA ≤ I_O ≤ 40 mA $V_{MIN} \le V_{IN} \le V_{MAX}$	−5.25 (−20 ≤ V_{IN} ≤ −7)		−4.75	(−27 ≤ V_{IN} ≤ −14.5)	−12.6	−11.4	−15.75 (−30 ≤ V_{IN} ≤ −17.5)		−14.25	V
ΔV_O	Line Regulation	Tj = 25°C, I_O = 100 mA $V_{MIN} \le V_{IN} \le V_{MAX}$	(−20 ≤ V_{IN} ≤ −7.3)		60	(−27 ≤ V_{IN} ≤ −14.6)		45	(−30 ≤ V_{IN} ≤ −17.7)		45	mV V
		Tj = 25°C, I_O = 40 mA $V_{MIN} \le V_{IN} \le V_{MAX}$	(−20 ≤ V_{IN} ≤ −7)		60	(−27 ≤ V_{IN} ≤ −14.5)		45	(−30 ≤ V_{IN} ≤ −17.5)		45	mV V
ΔV_O	Load Regulation	Tj = 25°C 1 mA ≤ I_O ≤ 100 mA			50			100			125	mV
ΔV_O	Long Term Stability	I_O = 100 mA		20			48			60		mV/khrs
I_Q	Quiescent Current	I_O = 100 mA		2	6		2	6		2	6	mA
ΔI_Q	Quiescent Current Change	1 mA ≤ I_O ≤ 100 mA			0.3			0.3			0.3	mA
		1 mA ≤ I_O ≤ 40 mA			0.1			0.1			0.1	mA
		I_O = 100 mA			0.25			0.25			0.25	mA
		$V_{MIN} \le V_{IN} \le V_{MAX}$	(−20 ≤ V_{IN} ≤ −7.5)			(−27 ≤ V_{IN} ≤ −14.8)			(−30 ≤ V_{IN} ≤ −18)			V
V_n	Output Noise Voltage	Tj = 25°C, I_O = 100 mA f = 10 Hz − 10 kHz		40			96			120		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	Tj = 25°C, I_O = 100 mA f = 120 Hz	50			52			50			dB
	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O = 100 mA I_O = 40 mA			−7.3 −7.0			−14.6 −14.5			−17.7 −17.5	V V

Note 1: Thermal resistance of Z package is 60°C/W θ_{jc}, 232°C/W θ_{ja} at still air, and 88°C/W at 400 ft/min of air. The M package θ_{ja} is 180°C/W in still air. The maximum junction temperature shall not exceed 125°C on electrical parameters.

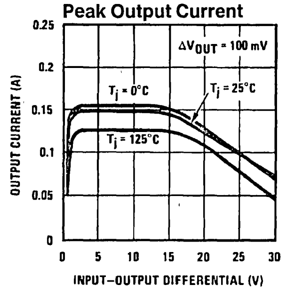
Note 2: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Performance Characteristics

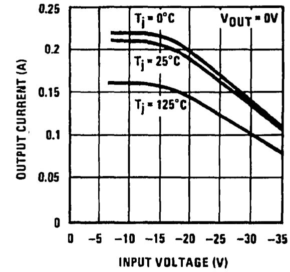
Maximum Average Power Dissipation (TO-92)



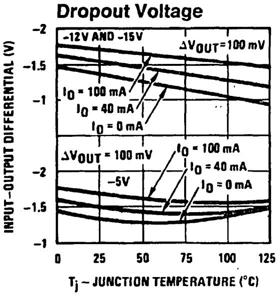
Peak Output Current



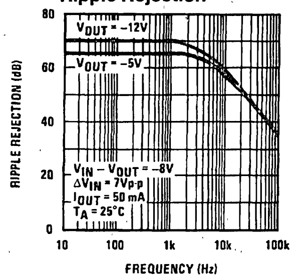
Short Circuit Output Current



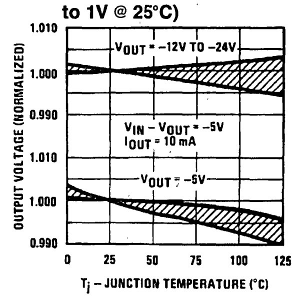
Dropout Voltage



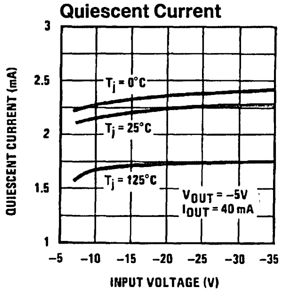
Ripple Rejection



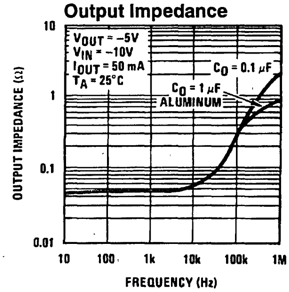
Output Voltage vs. Temperature (Normalized to 1V @ 25°C)



Quiescent Current



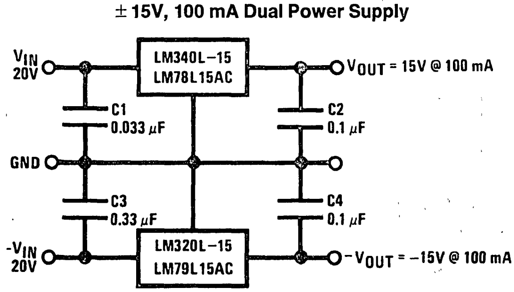
Output Impedance



TL/H/7748–5

Typical Applications (Continued)

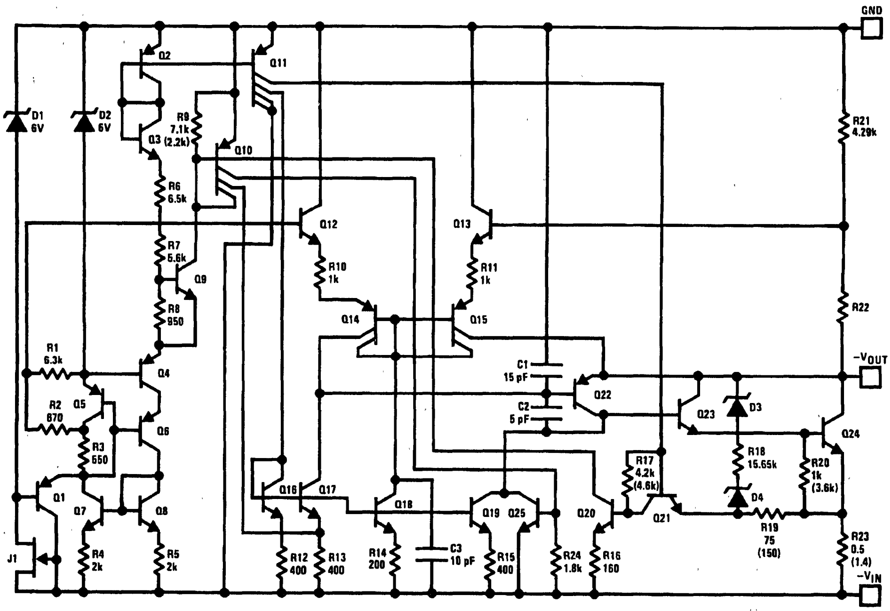
± 15V, 100 mA Dual Power Supply



TL/H/7748–6

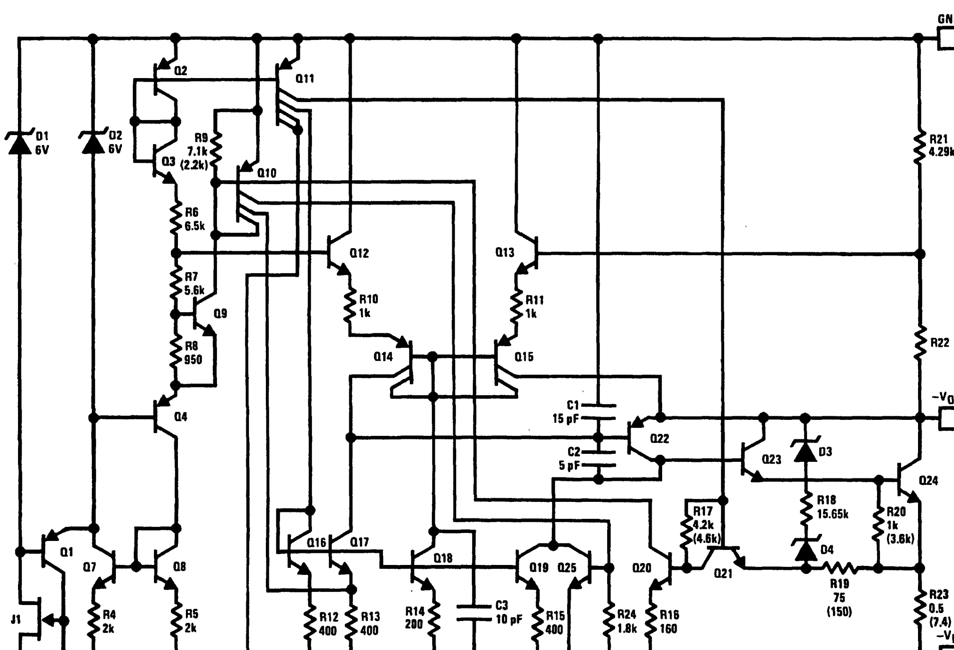
Schematic Diagrams

−5V



TL/H/7748-9

−12V and −15V



TL/H/7748-10

National Semiconductor

LM337L 3-Terminal Adjustable Regulator

General Description

The LM337L is an adjustable 3-terminal negative voltage regulator capable of supplying 100 mA over a 1.2V to 37V output range. It is exceptionally easy to use and requires only two external resistors to set the output voltage. Furthermore, both line and load regulation are better than standard fixed regulators. Also, the LM337L is packaged in a standard TO-92 transistor package which is easy to use.

In addition to higher performance than fixed regulators, the LM337L offers full overload protection. Included on the chip are current limit, thermal overload protection and safe area protection. All overload protection circuitry remains fully functional even if the adjustment terminal is disconnected.

Normally, only a single 1 μF solid tantalum output capacitor is needed unless the device is situated more than 6 inches from the input filter capacitors, in which case an input bypass is needed. A larger output capacitor can be added to improve transient response. The adjustment terminal can be bypassed to achieve very high ripple rejection ratios which are difficult to achieve with standard 3-terminal regulators.

Besides replacing fixed regulators, the LM337L is useful in a wide variety of other applications. Since the regulator is "floating" and sees only the input-to-output differential voltage, supplies of several hundred volts can be regulated as long as the maximum input-to-output differential is not exceeded.

Also, it makes an especially simple adjustable switching regulator, a programmable output regulator, or by connecting a fixed resistor between the adjustment and output, the LM337L can be used as a precision current regulator. Supplies with electronic shutdown can be achieved by clamping the adjustment terminal to ground which programs the output to 1.2V where most loads draw little current.

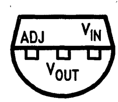
The LM337L is available in a standard TO-92 transistor package and a SO-8 surface mount package. The LM337L is rated for operation over a −25°C to +125°C range.

For applications requiring greater output current in excess of 0.5A and 1.5A, see LM137 series data sheets. For the positive complement, see series LM117 and LM317L data sheets.

Features

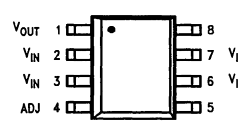
- Adjustable output down to 1.2V
- Guaranteed 100 mA output current
- Line regulation typically 0.01%/V
- Load regulation typically 0.1%
- Current limit constant with temperature
- Eliminates the need to stock many voltages
- Standard 3-lead transistor package
- 80 dB ripple rejection
- Output is short circuit protected

Connection Diagram



TL/H/9134-1

Bottom View



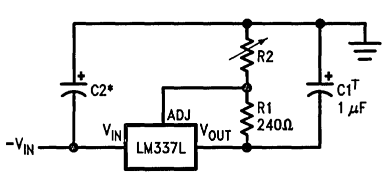
TL/H/9134-2

Top View

Order Number LM337LM or LM337LZ
See NS Package Number M08A or Z03A

Typical Applications

1.2V–25V Adjustable Regulator



TL/H/9134-3

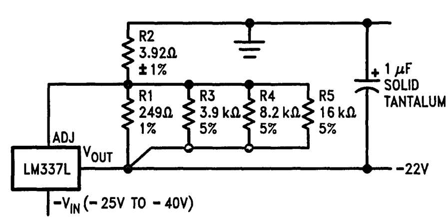
Full output current not available at high input-output voltages

$$-V_{OUT} = -1.25V\left(1 + \frac{R2}{240\Omega}\right)$$

†C1 = 1 μF solid tantalum or 10 μF aluminum electrolytic required for stability

*C2 = 1 μF solid tantalum is required only if regulator is more than 4" from power supply filter capacitor

Regulator with Trimmable Output Voltage



TL/H/9134-4

Trim Procedure:

—If V_{OUT} is −23.08V or bigger, cut out R3 (if smaller, don't cut it out).

—Then if V_{OUT} is −22.47V or bigger, cut out R4 (if smaller, don't).

—Then if V_{OUT} is −22.16V or bigger, cut out R5 (if smaller, don't).

This will trim the output to well within 1% of −22.00 V_{DC}, without any of the expense or trouble of a trim pot (see LB-46). Of course, this technique can be used at any output voltage level.

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Input-Output Voltage Differential	40V
Operating Junction Temperature Range	$-25°C$ to $+125°C$
Storage Temperature	$-55°C$ to $+150°C$
Lead Temperature (Soldering, 10 sec.)	300°C
Plastic Package (Soldering 4 sec.)	260°C

ESD rating to be determined.

Electrical Characteristics (Note 1)

Parameter	Conditions	Min	Typ	Max	Units
Line Regulation	$T_A = 25°C$, $3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, (Note 2)		0.01	0.04	%/V
Load Regulation	$T_A = 25°C$, $5\ mA \le I_{OUT} \le I_{MAX}$, (Note 2)		0.1	0.5	%
Thermal Regulation	$T_A = 25°C$, 10 ms Pulse		0.04	0.2	%/W
Adjustment Pin Current			50	100	μA
Adjustment Pin Current Change	$5\ mA \le I_L \le 100\ mA$ $3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$		0.2	5	μA
Reference Voltage	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, (Note 3) $10\ mA \le I_{OUT} \le 100\ mA$, $P \le 625\ mW$	1.20	1.25	1.30	V
Line Regulation	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 40V$, (Note 2)		0.02	0.07	%/V
Load Regulation	$5\ mA \le I_{OUT} \le 100\ mA$, (Note 2)		0.3	1.5	%
Temperature Stability	$T_{MIN} \le T_j \le T_{MAX}$		0.65		%
Minimum Load Current	$\lvert V_{IN} - V_{OUT} \rvert \le 40V$ $3V \le \lvert V_{IN} - V_{OUT} \rvert \le 15V$		3.5 2.2	5 3.5	mA mA
Current Limit	$3V \le \lvert V_{IN} - V_{OUT} \rvert \le 13V$ $\lvert V_{IN} - V_{OUT} \rvert = 40V$	100 25	200 50	320 120	mA mA
Rms Output Noise, % of V_{OUT}	$T_A = 25°C$, $10\ Hz \le f \le 10\ kHz$		0.003		%
Ripple Rejection Ratio	$V_{OUT} = -10V$, F = 120 Hz, $C_{ADJ} = 0$ $C_{ADJ} = 10\ \mu F$	 66	65 80		dB dB
Long-Term Stability	$T_A = 125°C$		0.3	1	%

Note 1: Unless otherwise specified, these specifications apply $-25°C \le T_j \le +125°C$ for the LM337L; $\lvert V_{IN} - V_{OUT} \rvert = 5V$ and $I_{OUT} = 40$ mA. Although power dissipation is internally limited, these specifications are applicable for power dissipations up to 625 mW. I_{MAX} is 100 mA.

Note 2: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

Note 3: Thermal resistance of the TO-92 package is 180°C/W junction to ambient with 0.4″ leads from a PC board and 160°C/W junction to ambient with 0.125″ lead length to PC board. The M package θ_{JA} is 180°C/W in still air.

National Semiconductor

LM341, LM78MXX Series 3-Terminal Positive Voltage Regulators

General Description

The LM341 and LM78MXX series of three-terminal positive voltage regulators employ built-in current limiting, thermal shutdown, and safe-operating area protection which makes them virtually immune to damage from output overloads.

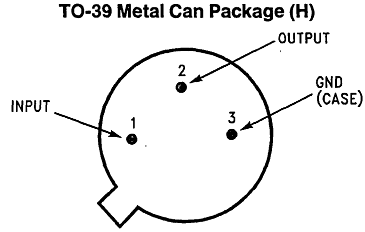
With adequate heatsinking, they can deliver in excess of 0.5A output current. Typical applications would include local (on-card) regulators which can eliminate the noise and degraded performance associated with single-point regulation.

Features

- Output current in excess of 0.5A
- No external components
- Internal thermal overload protection
- Internal short circuit current-limiting
- Output transistor safe-area compensation
- Available in TO-220 and TO-39 packages
- Output voltages of 5V, 12V, and 15V

Connection Diagrams

TO-39 Metal Can Package (H)

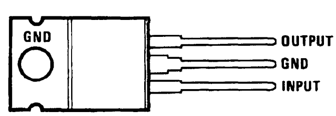


TL/H/10484–5

Bottom View

Order Number LM78M05CH, LM78M12CH or LM78M15CH
See NS Package Number H03A

TO-220 Power Package (T)



TL/H/10484–6

Top View

Order Number LM341T-5.0, LM341T-12 or LM341T-15
See NS Package Number T03B

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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Lead Temperature (Soldering, 10 seconds)	
TO-39 Package (H)	300°C
TO-220 Package (T)	260°C
Storage Temperature Range	−65°C to +150°C
Operating Junction Temperature Range	−40°C to +125°C
Power Dissipation (Note 2)	Internally Limited
Input Voltage	
$5V \leq V_O \leq 15V$	35V
ESD Susceptibility	TBD

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the −40°C to +125°C operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods.

LM341-5.0, LM78M05C Unless otherwise specified: V_{IN} = 10V, C_{IN} = 0.33 μF, C_O = 0.1 μF

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	I_L = 500 mA		4.8	5.0	5.2	V
		$5 mA \leq I_L \leq 500 mA$ $P_D \leq 7.5W$, $7.5V \leq V_{IN} \leq 20V$		**4.75**	**5.0**	**5.25**	
$V_{R LINE}$	Line Regulation	$7.2V \leq V_{IN} \leq 25V$	I_L = 100 mA			50	mV
			I_L = 500 mA			100	
$V_{R LOAD}$	Load Regulation	$5 mA \leq I_L \leq 500 mA$				100	
I_Q	Quiescent Current	I_L = 500 mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	$5 mA \leq I_L \leq 500 mA$				0.5	
		$7.5V \leq V_{IN} \leq 25V$, I_L = 500 mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			40		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, I_L = 500 mA			78		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	I_L = 500 mA		7.2			V
ΔV_O	Long Term Stability	I_L = 500 mA				**20**	mV/khrs

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, and limits in **boldface type** apply over the $-40°C$ to $+125°C$ operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. (Continued)

LM341-12, LM78M12C Unless otherwise specified: $V_{IN} = 19V$, $C_{IN} = 0.33\ \mu F$, $C_O = 0.1\ \mu F$

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 500$ mA		11.5	12	12.5	V
		$5\ mA \leq I_L \leq 500\ mA$ $P_D \leq 7.5W$, $14.8V \leq V_{IN} \leq 27V$		**11.4**	**12**	**12.6**	
$V_{R\ LINE}$	Line Regulation	$14.5V \leq V_{IN} \leq 30V$	$I_L = 100$ mA			120	mV
			$I_L = 500$ mA			240	
$V_{R\ LOAD}$	Load Regulation	$5\ mA \leq I_L \leq 500\ mA$				240	
I_Q	Quiescent Current	$I_L = 500$ mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	$5\ mA \leq I_L \leq 500\ mA$				0.5	
		$14.8V \leq V_{IN} \leq 30V$, $I_L = 500$ mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			75		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, $I_L = 500$ mA			71		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 500$ mA		14.5			V
ΔV_O	Long Term Stability	$I_L = 500$ mA				**48**	mV/khrs

LM341-15, LM78M15C Unless otherwise specified: $V_{IN} = 23V$, $C_{IN} = 0.33\ \mu F$, $C_O = 0.1\ \mu F$

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	$I_L = 500$ mA		14.4	15	15.6	V
		$5\ mA \leq I_L \leq 500\ mA$ $P_D \leq 7.5W$, $18V \leq V_{IN} \leq 30V$		**14.25**	**15**	**15.75**	
$V_{R\ LINE}$	Line Regulation	$17.6V \leq V_{IN} \leq 30V$	$I_L = 100$ mA			150	mV
			$I_L = 500$ mA			300	
$V_{R\ LOAD}$	Load Regulation	$5\ mA \leq I_L \leq 500\ mA$				300	
I_Q	Quiescent Current	$I_L = 500$ mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	$5\ mA \leq I_L \leq 500\ mA$				0.5	
		$18V \leq V_{IN} \leq 30V$, $I_L = 500$ mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			90		μV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, $I_L = 500$ mA			69		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	$I_L = 500$ mA		17.6			V
ΔV_O	Long Term Stability	$I_L = 500$ mA				**60**	mV/khrs

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The typical thermal resistance of the three package types is:

T (TO-220) package: $\theta_{(J-A)} = 60\ °C/W$, $\theta_{(J-C)} = 5\ °C/W$
H (TO-39) package: $\theta_{(J-A)} = 120\ °C/W$, $\theta_{(J-C)} = 18\ °C/W$

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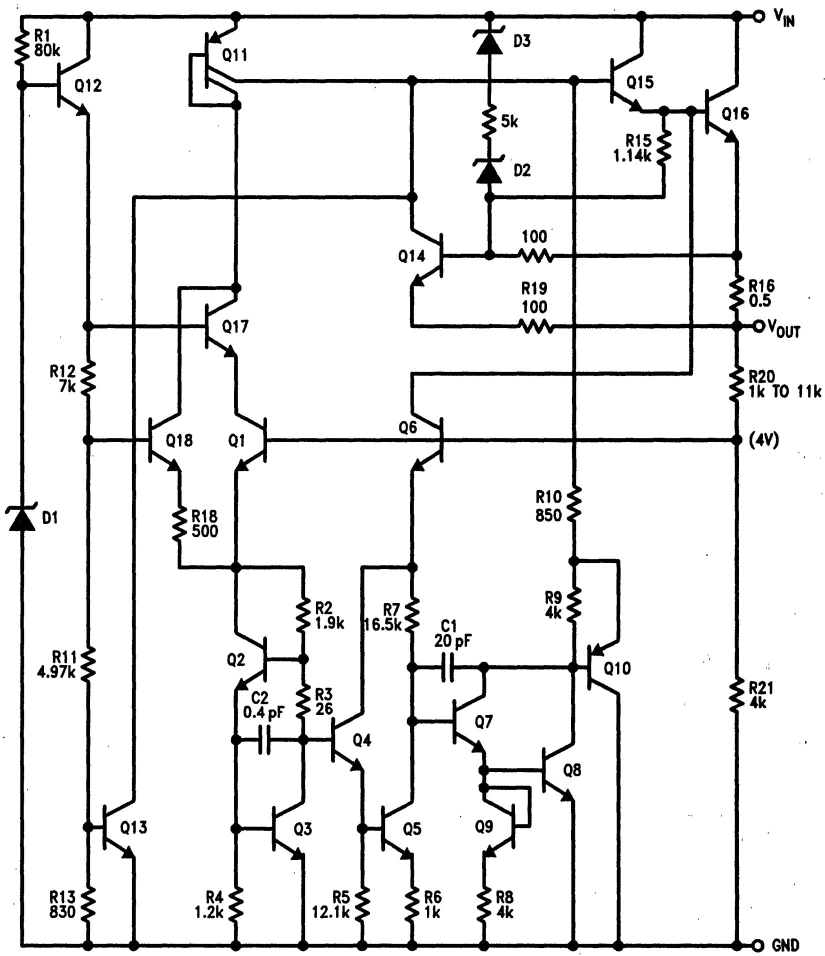
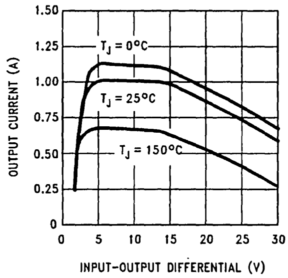
Schematic Diagram



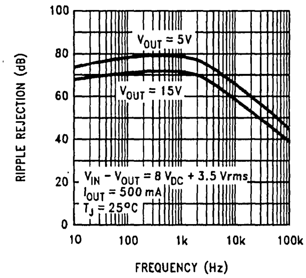
TL/H/10484-1

Typical Performance Characteristics

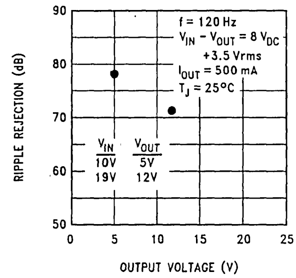
Peak Output Current



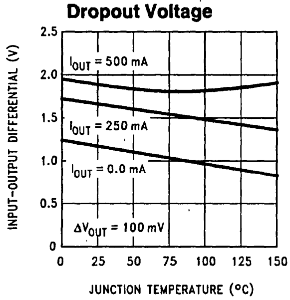
Ripple Rejection



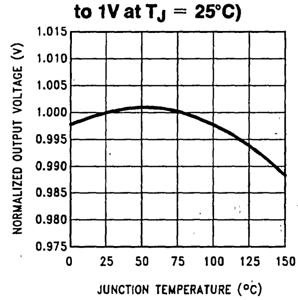
Ripple Rejection



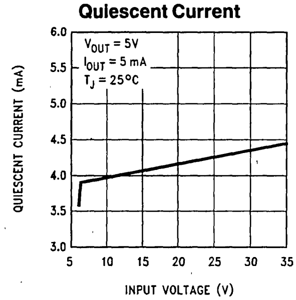
Dropout Voltage



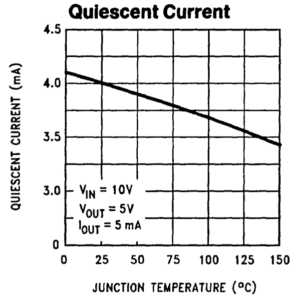
Output Voltage (Normalized to 1V at T_J = 25°C)



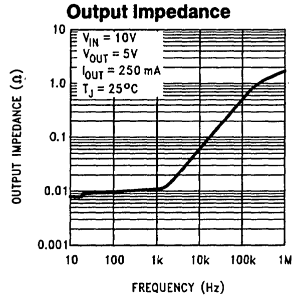
Quiescent Current



Quiescent Current



Output Impedance



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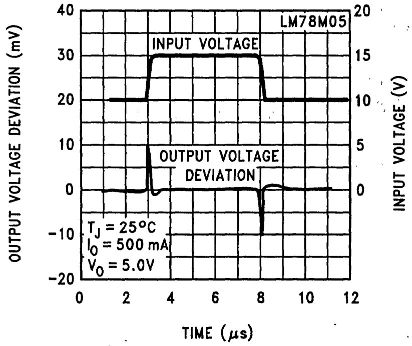
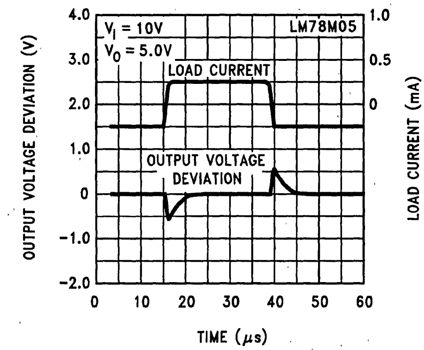
Typical Performance Characteristics (Continued)

Line Transient Response



TL/H/10484-7

Load Transient Response



TL/H/10484-8

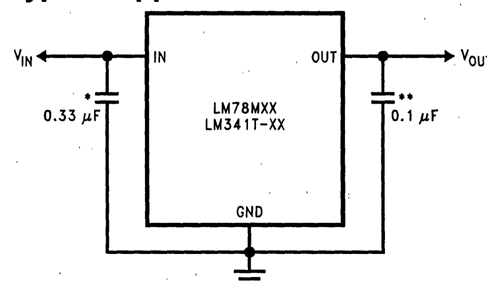
Design Considerations

The LM78MXX/LM341XX fixed voltage regulator series has built-in thermal overload protection which prevents the device from being damaged due to excessive junction temperature.

The regulators also contain internal short-circuit protection which limits the maximum output current, and safe-area protection for the pass transistor which reduces the short-circuit current as the voltage across the pass transistor is increased.

Although the internal power dissipation is automatically limited, the maximum junction temperature of the device must be kept below +125°C in order to meet data sheet specifications. An adequate heatsink should be provided to assure this limit is not exceeded under worst-case operating conditions (maximum input voltage and load current) if reliable performance is to be obtained.

Typical Application



TL/H/10484-9

*Required if regulator input is more than 4 inches from input filter capacitor (or if no input filter capacitor is used).

**Optional for improved transient response.

National Semiconductor

LM723/LM723C Voltage Regulator

General Description

The LM723/LM723C is a voltage regulator designed primarily for series regulator applications. By itself, it will supply output currents up to 150 mA; but external transistors can be added to provide any desired load current. The circuit features extremely low standby current drain, and provision is made for either linear or foldback current limiting.

The LM723/LM723C is also useful in a wide range of other applications such as a shunt regulator, a current regulator or a temperature controller.

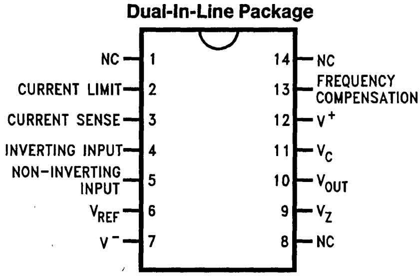
The LM723C is identical to the LM723 except that the LM723C has its performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Features

- 150 mA output current without external pass transistor
- Output currents in excess of 10A possible by adding external transistors
- Input voltage 40V max
- Output voltage adjustable from 2V to 37V
- Can be used as either a linear or a switching regulator

Connection Diagrams

Dual-In-Line Package

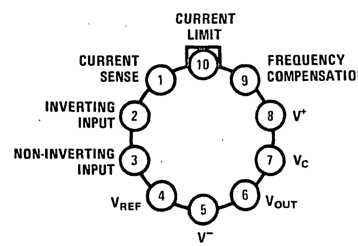


TL/H/8563-2

Top View

Order Number LM723J/883 or LM723CN
See NS Package J14A or N14A

Metal Can Package



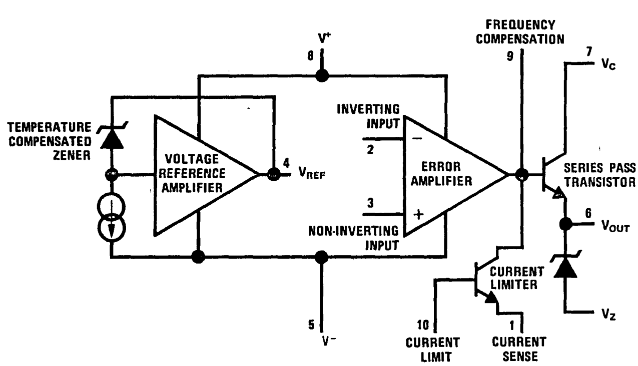
TL/H/8563-3

Note: Pin 5 connected to case.

Top View

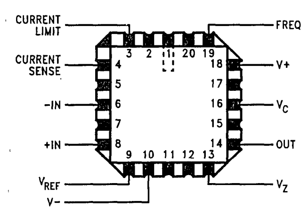
Order Number LM723H, LM723H/883 or LM723CH
See NS Package H10C

Equivalent Circuit*



TL/H/8563-4

*Pin numbers refer to metal can package.



TL/H/8563-20

Top View

Order Number LM723E/883
See NS Package E20A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 9)

Pulse Voltage from V^+ to V^- (50 ms)	50V
Continuous Voltage from V^+ to V^-	40V
Input-Output Voltage Differential	40V
Maximum Amplifier Input Voltage (Either Input)	8.5V
Maximum Amplifier Input Voltage (Differential)	5V
Current from V_Z	25 mA
Current from V_{REF}	15 mA
Internal Power Dissipation Metal Can (Note 1)	800 mW
Cavity DIP (Note 1)	900 mW
Molded DIP (Note 1)	660 mW
Operating Temperature Range LM723	−55°C to +150°C
LM723C	0°C to +70°C
Storage Temperature Range Metal Can	−65°C to +150°C
Molded DIP	−55°C to +150°C
Lead Temperature (Soldering, 4 sec. max.)	
Hermetic Package	300°C
Plastic Package	260°C
ESD Tolerance	1200V
(Human body model, 1.5 kΩ in series with 100 pF)	

Electrical Characteristics (Notes 2, 9)

Parameter	Conditions	LM723			LM723C			Units
		Min	Typ	Max	Min	Typ	Max	
Line Regulation	V_{IN} = 12V to V_{IN} = 15V		0.01	0.1		0.01	0.1	% V_{OUT}
	$-55°C \le T_A \le +125°C$			0.3				% V_{OUT}
	$0°C \le T_A \le +70°C$						0.3	% V_{OUT}
	V_{IN} = 12V to V_{IN} = 40V		0.02	0.2		0.1	0.5	% V_{OUT}
Load Regulation	I_L = 1 mA to I_L = 50 mA		0.03	0.15		0.03	0.2	% V_{OUT}
	$-55°C \le T_A \le +125°C$			0.6				% V_{OUT}
	$0°C \le T_A \le +70°C$						0.6	% V_{OUT}
Ripple Rejection	f = 50 Hz to 10 kHz, C_{REF} = 0		74			74		dB
	f = 50 Hz to 10 kHz, C_{REF} = 5 μF		86			86		dB
Average Temperature Coefficient of Output Voltage (Note 8)	$-55°C \le T_A \le +125°C$		0.002	0.015				%/°C
	$0°C \le T_A \le +70°C$					0.003	0.015	%/°C
Short Circuit Current Limit	R_{SC} = 10Ω, V_{OUT} = 0		65			65		mA
Reference Voltage		6.95	7.15	7.35	6.80	7.15	7.50	V
Output Noise Voltage	BW = 100 Hz to 10 kHz, C_{REF} = 0		86			86		μVrms
	BW = 100 Hz to 10 kHz, C_{REF} = 5 μF		2.5			2.5		μVrms
Long Term Stability			0.05			0.05		%/1000 hrs
Standby Current Drain	I_L = 0, V_{IN} = 30V		1.7	3.5		1.7	4.0	mA
Input Voltage Range		9.5		40	9.5		40	V
Output Voltage Range		2.0		37	2.0		37	V
Input-Output Voltage Differential		3.0		38	3.0		38	V
θ_{JA}	Molded DIP					105		°C/W
θ_{JA}	Cavity DIP		150					°C/W
θ_{JA}	H10C Board Mount in Still Air		165			165		°C/W
θ_{JA}	H10C Board Mount in 400 LF/Min Air Flow		66			66		°C/W
θ_{JC}			22			22		°C/W

Note 1: See derating curves for maximum power rating above 25°C.

Note 2: Unless otherwise specified, T_A = 25°C, $V_{IN} = V^+ = V_C$ = 12V, V^- = 0, V_{OUT} = 5V, I_L = 1 mA, R_{SC} = 0, C_1 = 100 pF, C_{REF} = 0 and divider impedance as seen by error amplifier ≤ 10 kΩ connected as shown in *Figure 1*. Line and load regulation specifications are given for the condition of constant chip temperature. Temperature drifts must be taken into account separately for high dissipation conditions.

Note 3: L_1 is 40 turns of No. 20 enameled copper wire wound on Ferroxcube P36/22-3B7 pot core or equivalent with 0.009 in. air gap.

Note 4: Figures in parentheses may be used if R1/R2 divider is placed on opposite input of error amp.

Note 5: Replace R1/R2 in figures with divider shown in *Figure 13.*

Note 6: V^+ and V_{CC} must be connected to a +3V or greater supply.

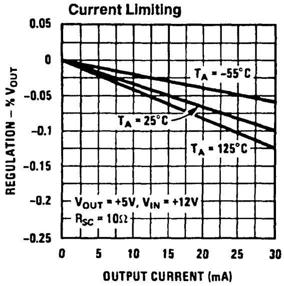
Note 7: For metal can applications where V_Z is required, an external 6.2V zener diode should be connected in series with V_{OUT}.

Note 8: Guaranteed by correlation to other tests.

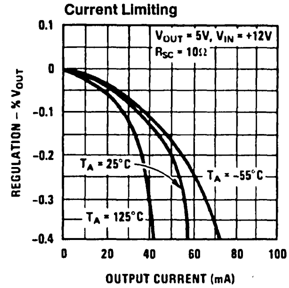
Note 9: A military RETS specification is available on request. At the time of printing, the LM723 RETS specification complied with the Min and Max limits in this table. The LM723E, H, and J may also be procured as a Standard Military Drawing.

Typical Performance Characteristics

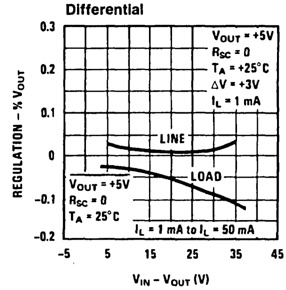
Load Regulation Characteristics with Current Limiting



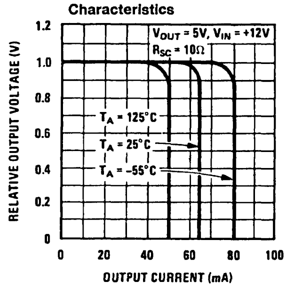
Load Regulation Characteristics with Current Limiting



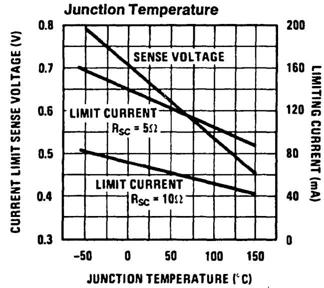
Load & Line Regulation vs Input-Output Voltage Differential



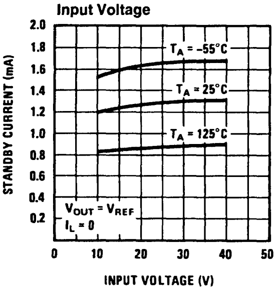
Current Limiting Characteristics



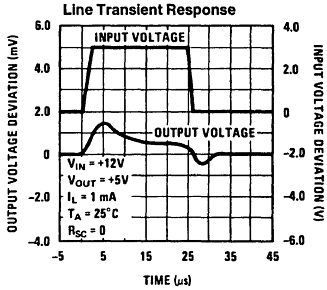
Current Limiting Characteristics vs Junction Temperature



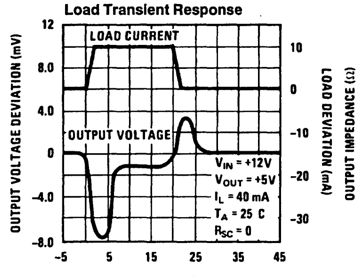
Standby Current Drain vs Input Voltage



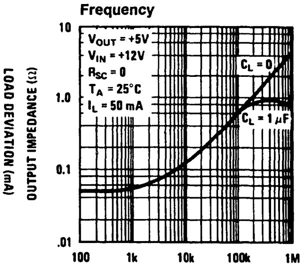
Line Transient Response



Load Transient Response



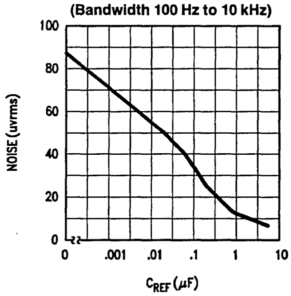
Output Impedence vs Frequency



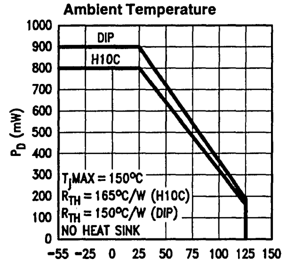
TL/H/8563–6

Maximum Power Ratings

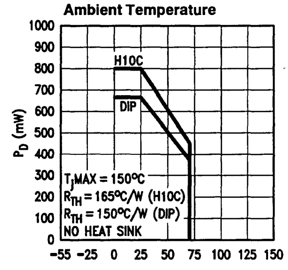
Noise vs Filter Capacitor (CREF in Circuit of *Figure 1*) (Bandwidth 100 Hz to 10 kHz)



LM723 Power Dissipation vs Ambient Temperature



LM723C Power Dissipation vs Ambient Temperature



TL/H/8563–7

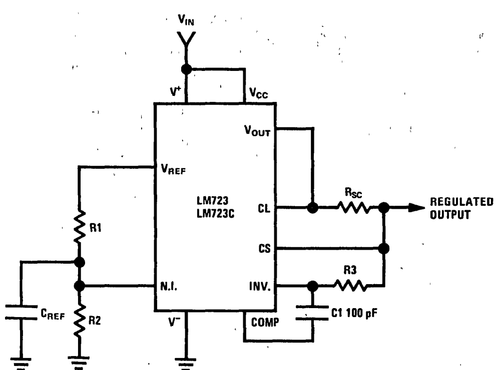
TABLE I. Resistor Values (kΩ) for Standard Output Voltage

Positive Output Voltage	Applicable Figures	Fixed Output ±5%		Output Adjustable ±10% (Note 5)			Negative Output Voltage	Applicable Figures	Fixed Output ±5%		5% Output Adjustable ±10%		
	(Note 4)	R1	R2	R1	P1	R2			R1	R2	R1	P1	R2
+3.0	1, 5, 6, 9, 12 (4)	4.12	3.01	1.8	0.5	1.2	+100	7	3.57	102	2.2	10	91
+3.6	1, 5, 6, 9, 12 (4)	3.57	3.65	1.5	0.5	1.5	+250	7	3.57	255	2.2	10	240
+5.0	1, 5, 6, 9, 12 (4)	2.15	4.99	0.75	0.5	2.2	−6 (Note 6)	3, (10)	3.57	2.43	1.2	0.5	0.75
+6.0	1, 5, 6, 9, 12 (4)	1.15	6.04	0.5	0.5	2.7	−9	3, 10	3.48	5.36	1.2	0.5	2.0
+9.0	2, 4, (5, 6, 9, 12)	1.87	7.15	0.75	1.0	2.7	−12	3, 10	3.57	8.45	1.2	0.5	3.3
+12	2, 4, (5, 6, 9, 12)	4.87	7.15	2.0	1.0	3.0	−15	3, 10	3.65	11.5	1.2	0.5	4.3
+15	2, 4, (5, 6, 9, 12)	7.87	7.15	3.3	1.0	3.0	−28	3, 10	3.57	24.3	1.2	0.5	10
+28	2, 4, (5, 6, 9, 12)	21.0	7.15	5.6	1.0	2.0	−45	8	3.57	41.2	2.2	10	33
+45	7	3.57	48.7	2.2	10	39	−100	8	3.57	97.6	2.2	10	91
+75	7	3.57	78.7	2.2	10	68	−250	8	3.57	249	2.2	10	240

TABLE II. Formulae for Intermediate Output Voltages

Outputs from +2 to +7 volts (*Figures 1, 5, 6, 9, 12, [4]*) $V_{OUT} = \left(V_{REF} \times \frac{R2}{R1 + R2}\right)$	**Outputs from +4 to +250 volts** (*Figure 7*) $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R2 - R1}{R1}\right)$; R3 = R4	**Current Limiting** $I_{LIMIT} = \frac{V_{SENSE}}{R_{SC}}$
Outputs from +7 to +37 volts (*Figures 2, 4, [5, 6, 9, 12]*) $V_{OUT} = \left(V_{REF} \times \frac{R1 + R2}{R2}\right)$	**Outputs from −6 to −250 volts** (*Figures 3, 8, 10*) $V_{OUT} = \left(\frac{V_{REF}}{2} \times \frac{R1 + R2}{R1}\right)$; R3 = R4	**Foldback Current Limiting** $I_{KNEE} = \left(\frac{V_{OUT}\,R3}{R_{SC}\,R4} + \frac{V_{SENSE}\,(R3 + R4)}{R_{SC}\,R4}\right)$ $I_{SHORT\,CKT} = \left(\frac{V_{SENSE}}{R_{SC}} \times \frac{R3 + R4}{R4}\right)$

Typical Applications



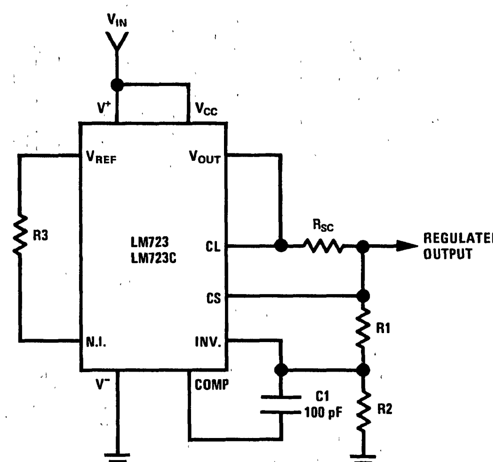
TL/H/8563-8

Note: $R3 = \frac{R1\,R2}{R1 + R2}$ for minimum temperature drift.

Typical Performance

Regulated Output Voltage	5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 50 mA)	1.5 mV

FIGURE 1. Basic Low Voltage Regulator (V_{OUT} = 2 to 7 Volts)



TL/H/8563-9

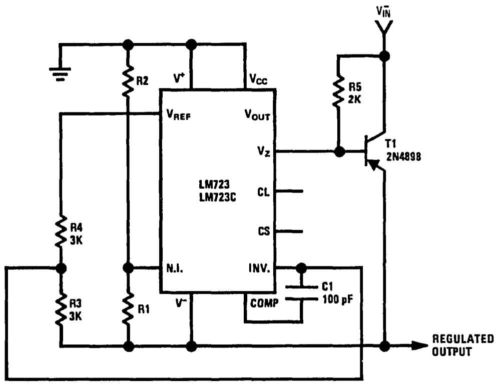
Note: $R3 = \frac{R1\,R2}{R1 + R2}$ for minimum temperature drift. R3 may be eliminated for minimum component count.

Typical Performance

Regulated Output Voltage	15V
Line Regulation (ΔV_{IN} = 3V)	1.5 mV
Load Regulation (ΔI_L = 50 mA)	4.5 mV

FIGURE 2. Basic High Voltage Regulator (V_{OUT} = 7 to 37 Volts)

Typical Applications (Continued)

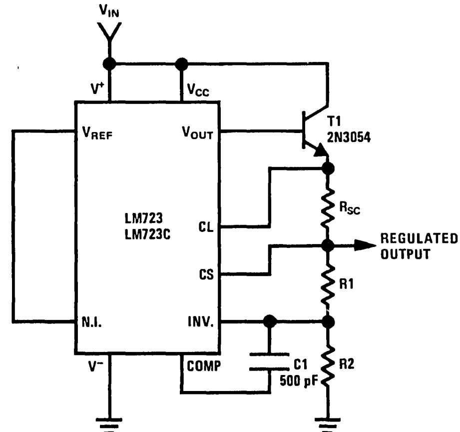


TL/H/8563-10

Typical Performance

Regulated Output Voltage	−15V
Line Regulation (ΔV_{IN} = 3V)	1 mV
Load Regulation (ΔI_L = 100 mA)	2 mV

FIGURE 3. Negative Voltage Regulator

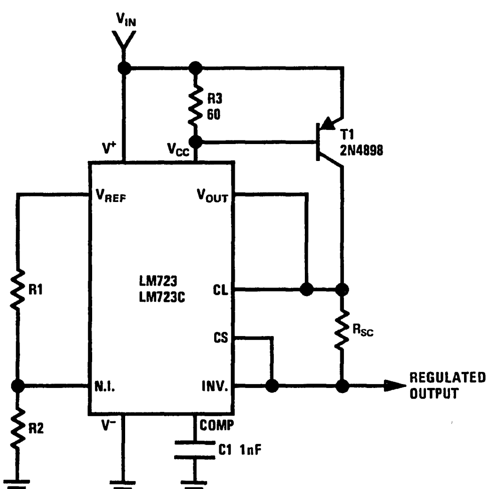


TL/H/8563-11

Typical Performance

Regulated Output Voltage	+15V
Line Regulation (ΔV_{IN} = 3V)	1.5 mV
Load Regulation (ΔI_L = 1A)	15 mV

FIGURE 4. Positive Voltage Regulator (External NPN Pass Transistor)

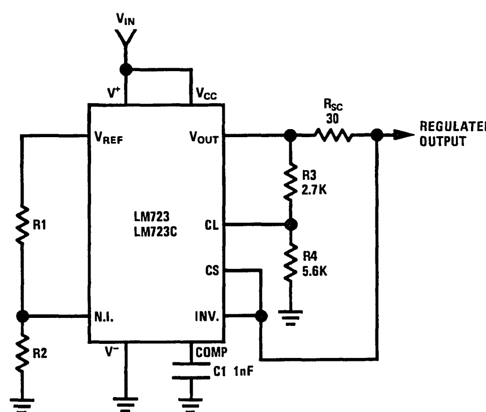


TL/H/8563-12

Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 1A)	5 mV

FIGURE 5. Positive Voltage Regulator (External PNP Pass Transistor)



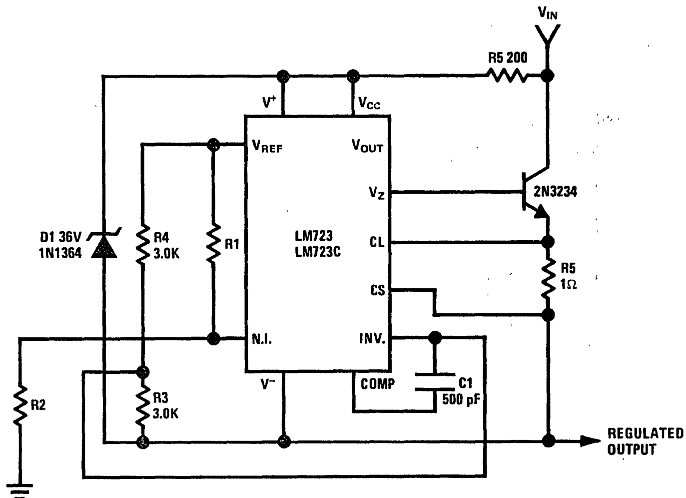
TL/H/8563-13

Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 10 mA)	1 mV
Short Circuit Current	20 mA

FIGURE 6. Foldback Current Limiting

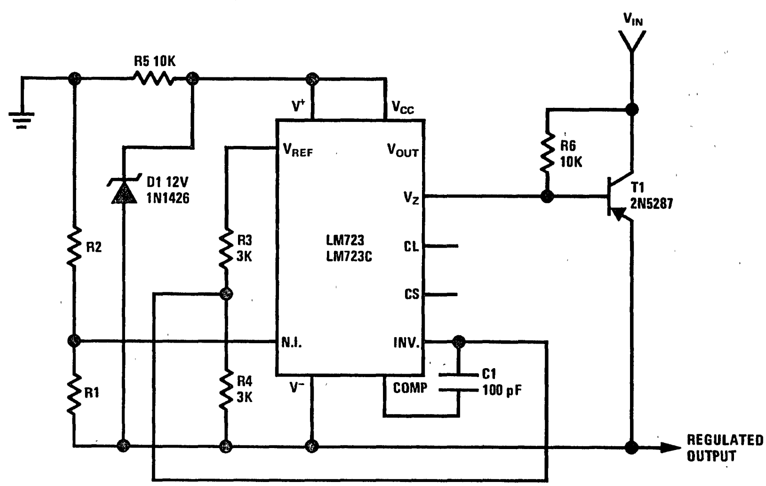
Typical Applications (Continued)



Typical Performance

Regulated Output Voltage	+50V
Line Regulation (ΔV_{IN} = 20V)	15 mV
Load Regulation (ΔI_L = 50 mA)	20 mV

FIGURE 7. Positive Floating Regulator

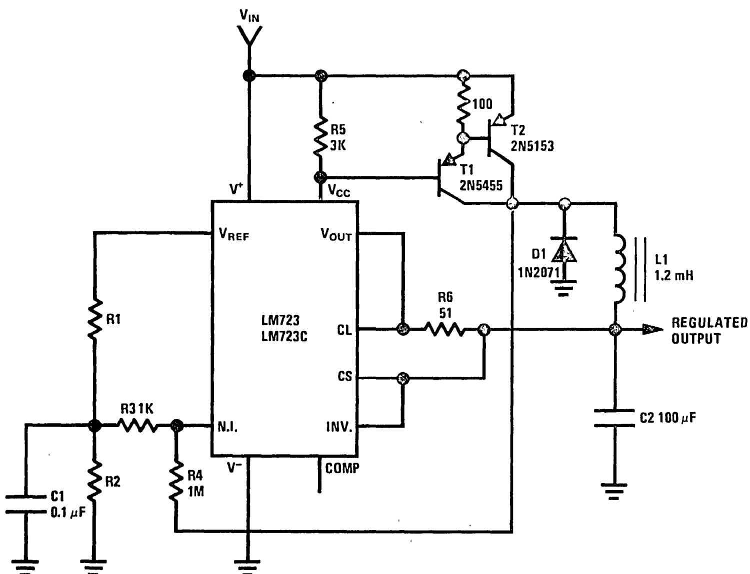


Typical Performance

Regulated Output Voltage	−100V
Line Regulation (ΔV_{IN} = 20V)	30 mV
Load Regulation (ΔI_L = 100 mA)	20 mV

FIGURE 8. Negative Floating Regulator

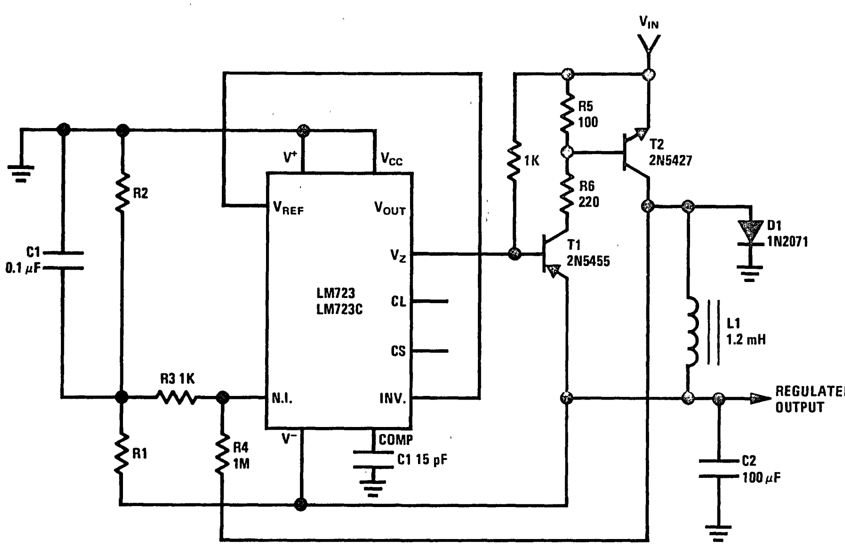
Typical Applications (Continued)



TL/H/8563-16

Typical Performance	
Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 30V)	10 mV
Load Regulation (ΔI_L = 2A)	80 mV

FIGURE 9. Positive Switching Regulator

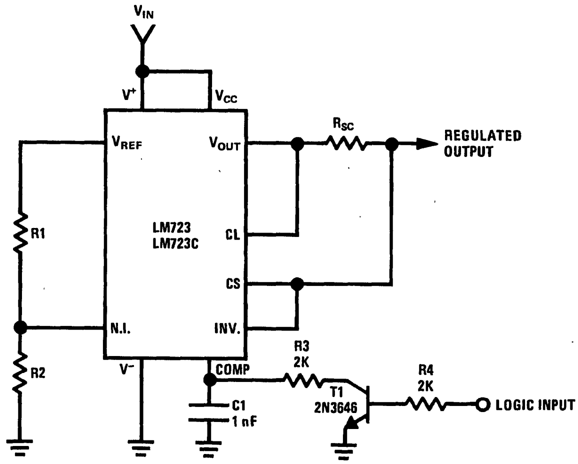


TL/H/8563-17

Typical Performance	
Regulated Output Voltage	−15V
Line Regulation (ΔV_{IN} = 20V)	8 mV
Load Regulation (ΔI_L = 2A)	6 mV

FIGURE 10. Negative Switching Regulator

Typical Applications (Continued)



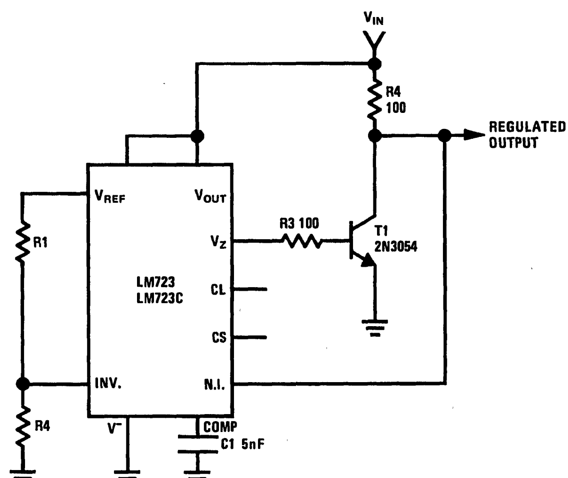
TL/H/8563-18

Note: Current limit transistor may be used for shutdown if current limiting is not required.

Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 3V)	0.5 mV
Load Regulation (ΔI_L = 50 mA)	1.5 mV

FIGURE 11. Remote Shutdown Regulator with Current Limiting



TL/H/8563-19

Typical Performance

Regulated Output Voltage	+5V
Line Regulation (ΔV_{IN} = 10V)	0.5 mV
Load Regulation (ΔI_L = 100 mA)	1.5 mV

FIGURE 12. Shunt Regulator

Typical Applications (Continued)

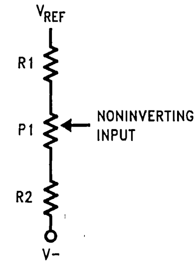
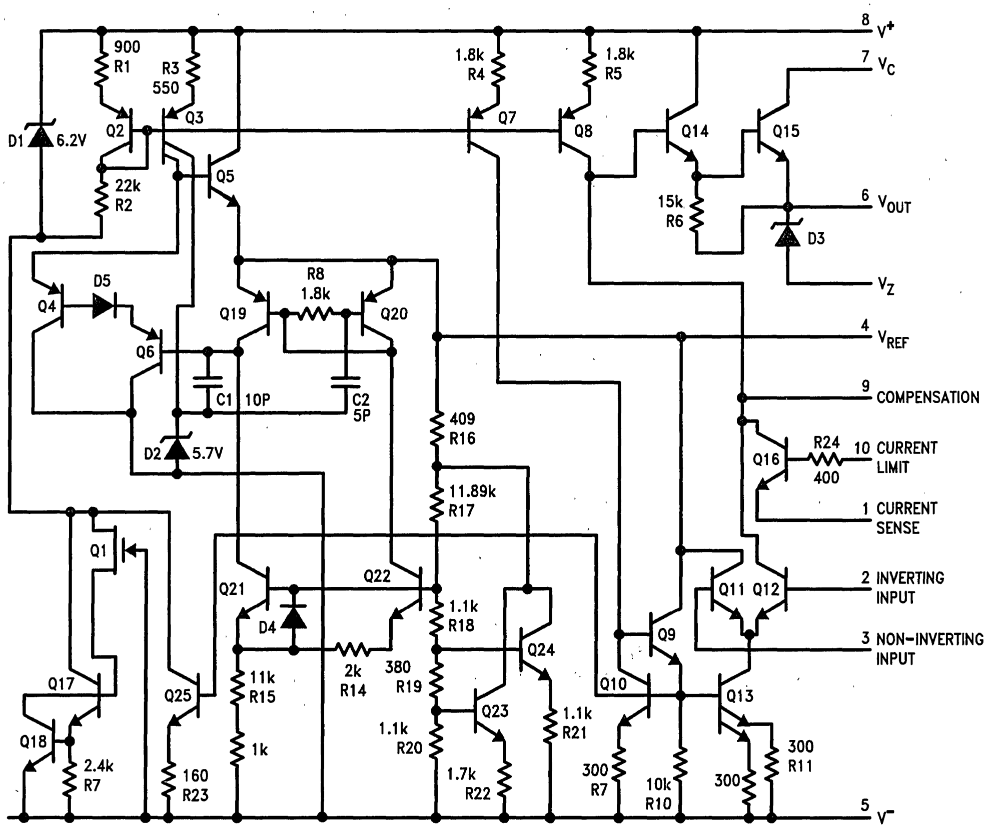


FIGURE 13. Output Voltage Adjust (See Note 5)

Schematic Diagram



National Semiconductor

LM78LXX Series 3-Terminal Positive Regulators

General Description

The LM78LXX series of three terminal positive regulators is available with several fixed output voltages making them useful in a wide range of applications. When used as a zener diode/resistor combination replacement, the LM78LXX usually results in an effective output impedance improvement of two orders of magnitude, and lower quiescent current. These regulators can provide local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow the LM78LXX to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment.

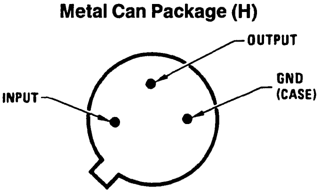
The LM78LXX is available in the metal three-lead TO-39(H) package, the plastic TO-92 (Z) package, and the plastic SO-8 (M) package. With adequate heat sinking the regulator can deliver 100 mA output current. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistors is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Features

- Output voltage tolerances of ±5% (LM78LXXAC) over the temperature range
- Output current of 100 mA
- Internal thermal overload protection
- Output transistor safe area protection
- Internal short circuit current limit
- Available in plastic TO-92 and metal TO-39 and plastic SO-8 low profile packages
- No external components
- Output voltages of 5.0V, 6.2V, 8.2V, 9.0V, 12V, 15V

Connection Diagrams

(TO-39)
Metal Can Package (H)

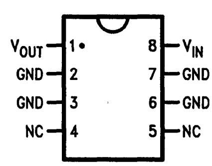


TL/H/7744–1

Bottom View

Order Number LM78L05ACH, LM78L12ACH or LM78L15ACH
See NS Package Number H03A

SO-8 Plastic (M)
(Narrow Body)

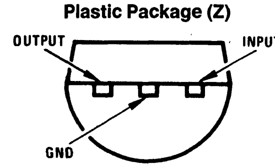


TL/H/7744–2

Top View

Order Number LM78L05ACM, LM78L12ACM or LM78L15ACM
See NS Package Number M08A

(TO-92)
Plastic Package (Z)



TL/H/7744–3

Bottom View

Order Number
LM78L05ACZ, LM78L09ACZ, LM78L12ACZ, LM78L15ACZ, LM78L62ACZ or LM78L82ACZ
See NS Package Number Z03A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation (Note 5)	Internally Limited
Input Voltage	35V
Storage Temperature	−65°C to +150°C
Operating Junction Temperature	0°C to +125°C
Lead Temperature (Soldering, 10 seconds)	265°C
ESD Susceptibility (Note 2)	2 kV

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to +125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33\ \mu F$, $C_O = 0.1\ \mu F$.

LM78L05AC Unless otherwise specified, $V_{IN} = 10V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		4.8	5	5.2	V
		$7V \le V_{IN} \le 20V$ $1\ mA \le I_O \le 40\ mA$ (Note 3)	**4.75**		**5.25**	
		$1\ mA \le I_O \le 70\ mA$ (Note 3)	**4.75**		**5.25**	
ΔV_O	Line Regulation	$7V \le V_{IN} \le 20V$		18	75	mV
		$8V \le V_{IN} \le 20V$		10	54	
ΔV_O	Load Regulation	$1\ mA \le I_O \le 100\ mA$		20	60	
		$1\ mA \le I_O \le 40\ mA$		5	30	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$8V \le V_{IN} \le 20V$			**1.0**	
		$1\ mA \le I_O \le 40\ mA$			**0.1**	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz (Note 4)		40		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $8V \le V_{IN} \le 16V$	47	62		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5\ mA$		−0.65		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			6.7	7	V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to +125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33\ \mu F$, $C_O = 0.1\ \mu F$. (Continued)

LM78L62AC Unless otherwise specified, $V_{IN} = 12V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		5.95	6.2	6.45	V
		$8.5V \le V_{IN} \le 20V$ $1\ mA \le I_O \le 40\ mA$ (Note 3)	**5.9**		**6.5**	
		$1\ mA \le I_O \le 70\ mA$ (Note 3)	**5.9**		**6.5**	
ΔV_O	Line Regulation	$8.5V \le V_{IN} \le 20V$		65	175	mV
		$9V \le V_{IN} \le 20V$		55	125	
ΔV_O	Load Regulation	$1\ mA \le I_O \le 100\ mA$		13	80	
		$1\ mA \le I_O \le 40\ mA$		6	40	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$8V \le V_{IN} \le 20V$			**1.5**	
		$1\ mA \le I_O \le 40\ mA$			**0.1**	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz (Note 4)		50		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $10V \le V_{IN} \le 20V$	40	46		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5$ mA		−0.75		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			7.9		V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to +125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33$ µF, $C_O = 0.1$ µF. (Continued)

LM78L82AC Unless otherwise specified, $V_{IN} = 14V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		7.87	8.2	8.53	V
		$11V \leq V_{IN} \leq 23V$ $1\text{ mA} \leq I_O \leq 40\text{ mA}$ (Note 3)	**7.8**		**8.6**	
		$1\text{ mA} \leq I_O \leq 70\text{ mA}$ (Note 3)	**7.8**		**8.6**	
ΔV_O	Line Regulation	$11V \leq V_{IN} \leq 23V$		80	175	mV
		$12V \leq V_{IN} \leq 23V$		70	125	
ΔV_O	Load Regulation	$1\text{ mA} \leq I_O \leq 100\text{ mA}$		15	80	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$		8	40	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$12V \leq V_{IN} \leq 23V$			**1.5**	
		$1\text{ mA} \leq I_O \leq 40\text{ mA}$			**0.1**	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz (Note 4)		60		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $12V \leq V_{IN} \leq 22V$	39	45		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5$ mA		−0.8		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			9.9		V

1

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to + 125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33$ μF, $C_O = 0.1$ μF. (Continued)

LM78L09AC Unless otherwise specified, $V_{IN} = 15V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		8.64	9.0	9.36	V
		$11.5V \le V_{IN} \le 24V$ $1\ mA \le I_O \le 40\ mA$ (Note 3)	**8.55**		**9.45**	
		$1\ mA \le I_O \le 70\ mA$ (Note 3)	**8.55**		**9.45**	
ΔV_O	Line Regulation	$11.5V \le V_{IN} \le 24V$		100	200	mV
		$13V \le V_{IN} \le 24V$		90	150	
ΔV_O	Load Regulation	$1\ mA \le I_O \le 100\ mA$		20	90	
		$1\ mA \le I_O \le 40\ mA$		10	45	
I_Q	Quiescent Current			2	5.5	mA
ΔI_Q	Quiescent Current Change	$11.5V \le V_{IN} \le 24V$			**1.5**	
		$1\ mA \le I_O \le 40\ mA$			**0.1**	
V_n	Output Noise Voltage			70		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $15V \le V_{IN} \le 25V$	38	44		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5$ mA		−0.9		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			10.7		V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to +125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33$ μF, $C_O = 0.1$ μF. (Continued)

LM78L12AC Unless otherwise specified, $V_{IN} = 19V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		11.5	12	12.5	V
		$14.5V \le V_{IN} \le 27V$ $1 mA \le I_O \le 40 mA$ (Note 3)	**11.4**		**12.6**	
		$1 mA \le I_O \le 70 mA$ (Note 3)	**11.4**		**12.6**	
ΔV_O	Line Regulation	$14.5V \le V_{IN} \le 27V$		30	180	mV
		$16V \le V_{IN} \le 27V$		20	110	
ΔV_O	Load Regulation	$1 mA \le I_O \le 100 mA$		30	100	
		$1 mA \le I_O \le 40 mA$		10	50	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$16V \le V_{IN} \le 27V$			**1**	
		$1 mA \le I_O \le 40 mA$			**0.1**	
V_n	Output Noise Voltage			80		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $15V \le V_{IN} \le 25V$	40	54		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5$ mA		−1.0		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			13.7	14.5	V

LM78LXXAC Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface applies over the 0°C to +125°C temperature range.** Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $I_O = 40$ mA, $C_I = 0.33$ μF, $C_O = 0.1$ μF. (Continued)

LM78L15AC Unless otherwise specified, $V_{IN} = 23V$

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage		14.4	15.0	15.6	V
		$17.5V \le V_{IN} \le 30V$ $1 mA \le I_O \le 40 mA$ (Note 3)	**14.25**		**15.75**	
		$1 mA \le I_O \le 70 mA$ (Note 3)	**14.25**		**15.75**	
ΔV_O	Line Regulation	$17.5V \le V_{IN} \le 30V$		37	250	mV
		$20V \le V_{IN} \le 30V$		25	140	
ΔV_O	Load Regulation	$1 mA \le I_O \le 100 mA$		35	150	
		$1 mA \le I_O \le 40 mA$		12	75	
I_Q	Quiescent Current			3	5	mA
ΔI_Q	Quiescent Current Change	$20V \le V_{IN} \le 30V$			**1**	
		$1 mA \le I_O \le 40 mA$			**0.1**	
V_n	Output Noise Voltage			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz $18.5V \le V_{IN} \le 28.5V$	37	51		dB
I_{PK}	Peak Output Current			140		mA
$\frac{\Delta V_O}{\Delta T}$	Average Output Voltage Tempco	$I_O = 5 mA$		−1.3		mV/°C
V_{IN} (Min)	Minimum Value of Input Voltage Required to Maintain Line Regulation			16.7	17.5	V

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its stated operating conditions.

Note 2: Human body model, 1.5 kΩ in series with 100 pF.

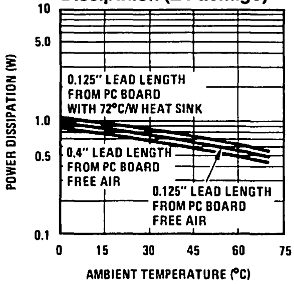
Note 3: Power dissipation ≤ 0.75W.

Note 4: Recommended minimum load capacitance of 0.01 μF to limit high frequency noise.

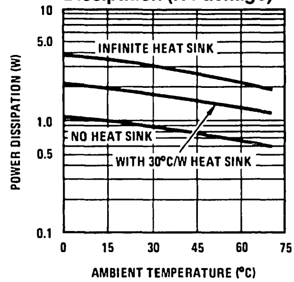
Note 5: Typical thermal resistance values for the packages are:
- **H** Package: Rth(J-C) = 26 °C/W, Rth(J-A) = 120 °C/W
- **Z** Package: Rth(J-C) = 60 °C/W, Rth(J-A) = 230 °C/W
- **M** Package: Rth(J-A) = 180 °C/W

Typical Performance Characteristics

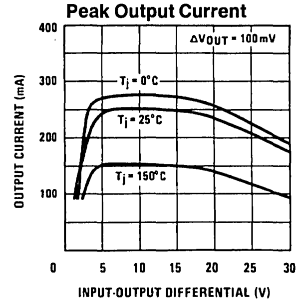
Maximum Average Power Dissipation (Z Package)



Maximum Average Power Dissipation (H Package)

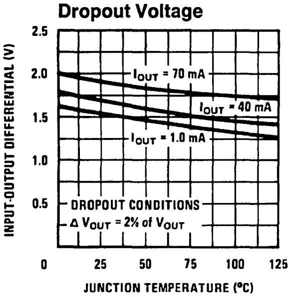


Peak Output Current

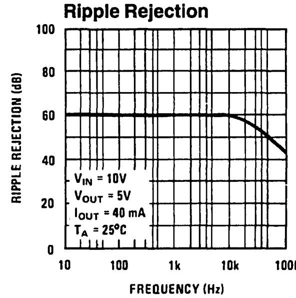


TL/H/7744–4

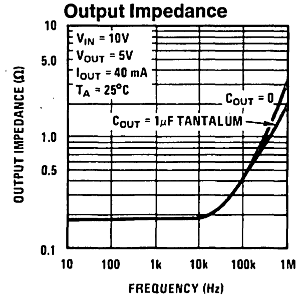
Dropout Voltage



Ripple Rejection

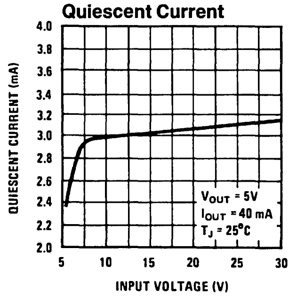


Output Impedance

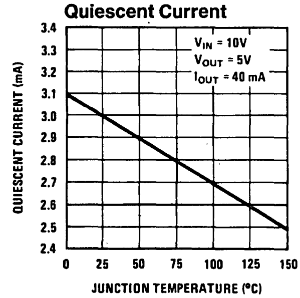


TL/H/7744–5

Quiescent Current



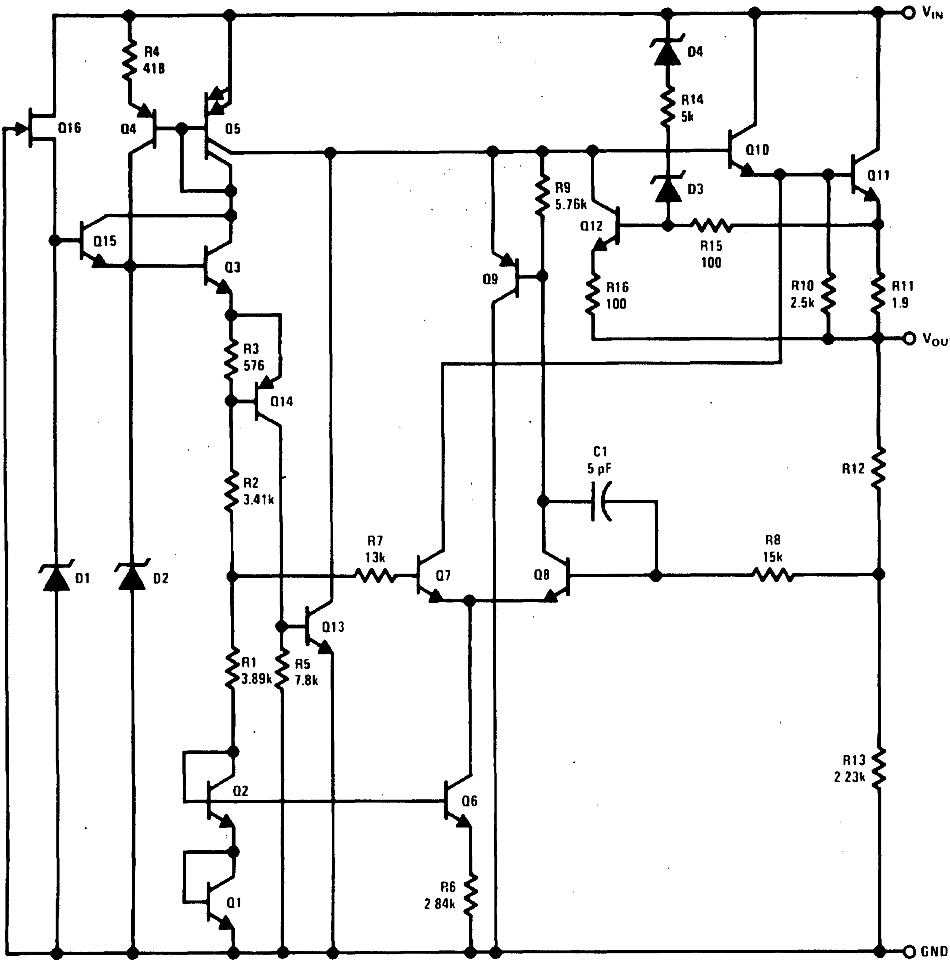
Quiescent Current



TL/H/7744–6

Equivalent Circuit

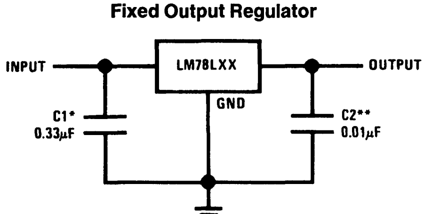
LM78LXX



TL/H/7744–7

Typical Applications

Fixed Output Regulator

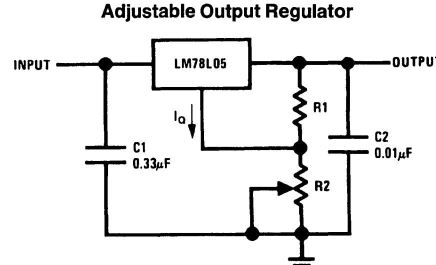


TL/H/7744–8

*Required if the regulator is located more than 3″ from the power supply filter.

**See Note 4 in the electrical characteristics table.

Adjustable Output Regulator



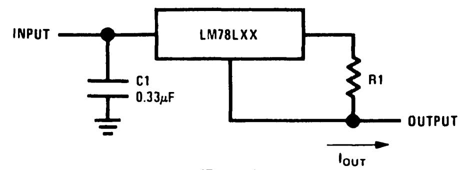
TL/H/7744–9

$V_{OUT} = 5V + (5V/R1 + I_Q)\ R2$

$5V/R1 > 3\ I_Q$, load regulation $(L_r) \approx [(R1 + R2)/R1]$ (L_r of LM78L05)

Typical Applications (Continued)

Current Regulator

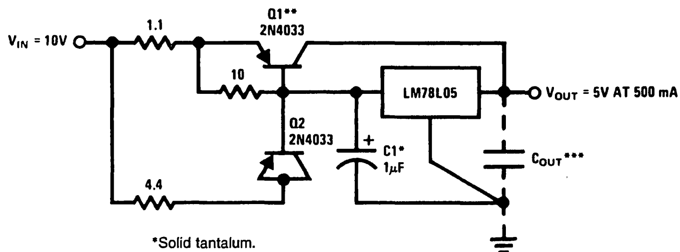


$I_{OUT} = (V_{OUT}/R1) + I_Q$

$>I_Q$ = 1.5 mA over line and load changes

TL/H/7744–10

5V, 500 mA Regulator with Short Circuit Protection



*Solid tantalum.

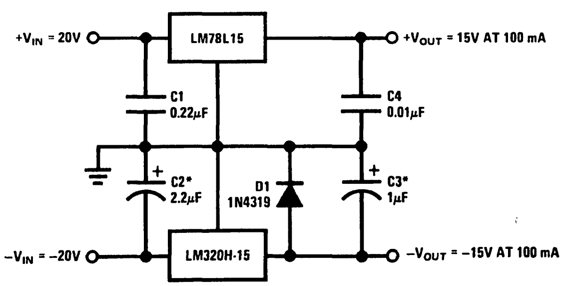
**Heat sink Q1.

***Optional: Improves ripple rejection and transient response.

Load Regulation: 0.6% $0 \le I_L \le 250$ mA pulsed with t_{ON} = 50 ms.

TL/H/7744–11

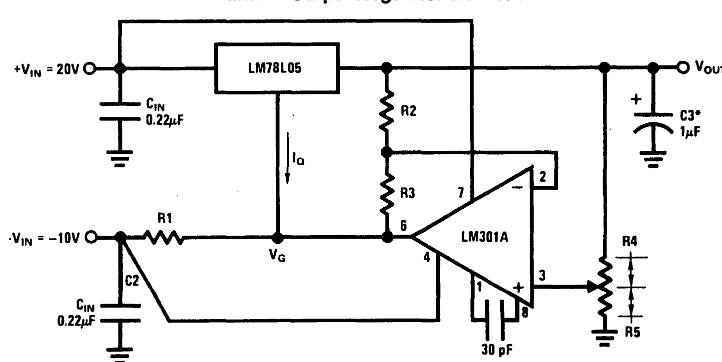
±15V, 100 mA Dual Power Supply



*Solid tantalum.

TL/H/7744–12

Variable Output Regulator 0.5V-18V



*Solid tantalum.

$V_{OUT} = V_G + 5V$, $R1 = (-V_{IN}/I_{Q\ LM78L05})$

$V_{OUT} = 5V\ (R2/R4)$ for $(R2 + R3) = (R4 + R5)$

A 0.5V output will correspond to $(R2/R4) = 0.1$ $(R3/R4) = 0.9$

TL/H/7744–13

National Semiconductor

LM78XX Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and mininize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

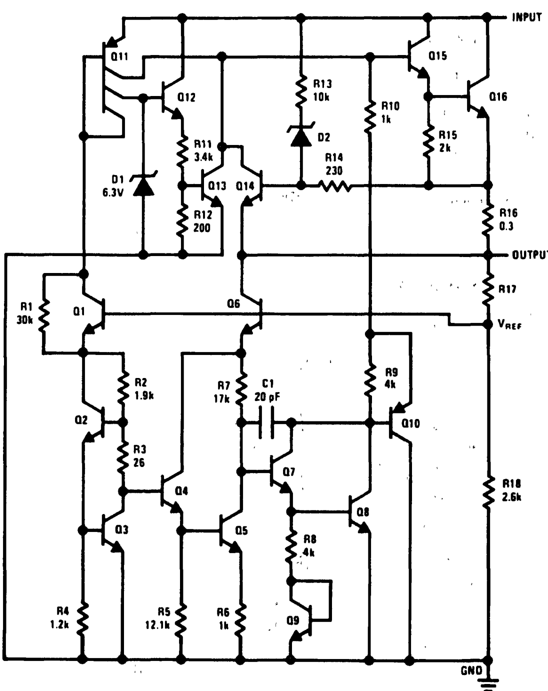
Features

- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

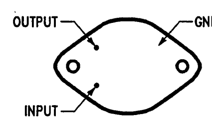
LM7805C	5V
LM7812C	12V
LM7815C	15V

Schematic and Connection Diagrams



TL/H/7746–1

Metal Can Package
TO-3 (K)
Aluminum

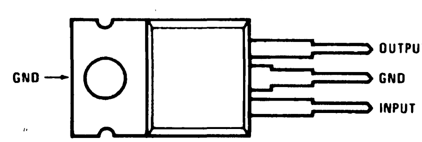


TL/H/7746–2

Bottom View

Order Number LM7805CK, LM7812CK or LM7815CK
See NS Package Number KC02A

Plastic Package
TO-220 (T)



TL/H/7746–3

Top View

Order Number LM7805CT, LM7812CT or LM7815CT
See NS Package Number T03B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2) 0°C ≤ Tj ≤ 125°C unless otherwise noted.

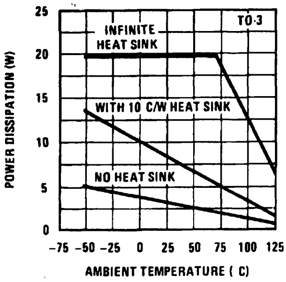
Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)		V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}		(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}		(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)		V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}		(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)		V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)		V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)		V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}			(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)		V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ
	Short-Circuit Current	Tj = 25°C			2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C			2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ Tj ≤ +125°C, I_O = 5 mA			0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	Tj = 25°C, I_O ≤ 1A			7.5		14.6			17.7			V

Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

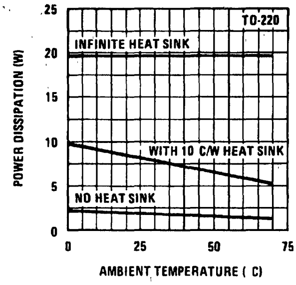
Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques (t_w ≤ 10 ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Typical Performance Characteristics

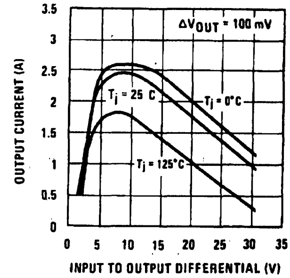
Maximum Average Power Dissipation



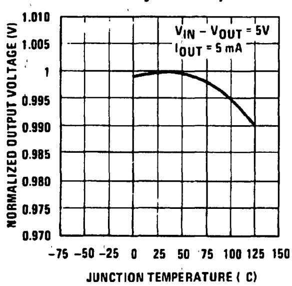
Maximum Average Power Dissipation



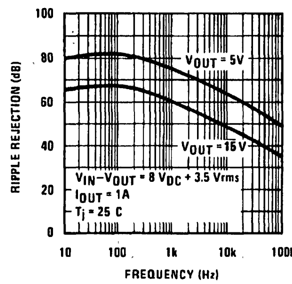
Peak Output Current



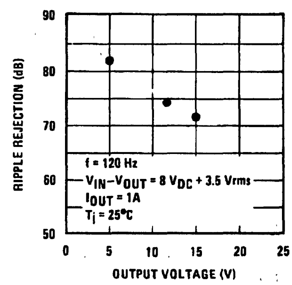
Output Voltage (Normalized to 1V at Tj = 25°C)



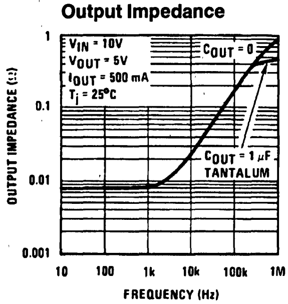
Ripple Rejection



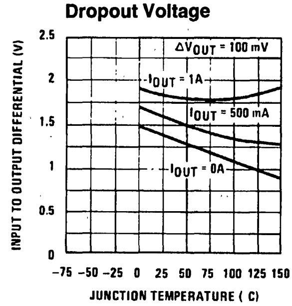
Ripple Rejection



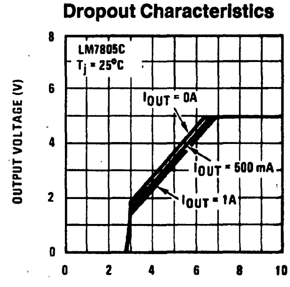
Output Impedance



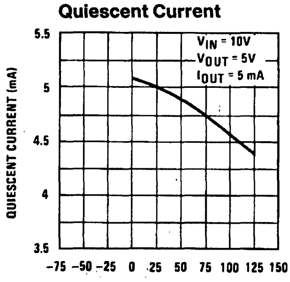
Dropout Voltage



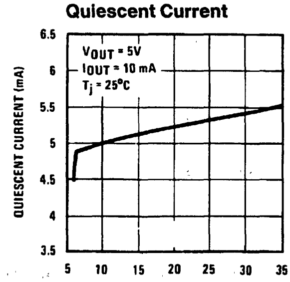
Dropout Characteristics



Quiescent Current



Quiescent Current



TL/H/7746–4

National Semiconductor

LM79MXX Series
3-Terminal Negative Regulators

General Description

The LM79MXX series of 3-terminal regulators is available with fixed output voltages of −5V, −12V, and −15V. These devices need only one external component—a compensation capacitor at the output. The LM79MXX series is packaged in the TO-220 power package, and is capable of supplying 0.5A of output current.

These regulators employ internal current limiting, safe area protection, and thermal shotdown for protection against virtually all overload conditions.

Low ground pin current of the LM79MXX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

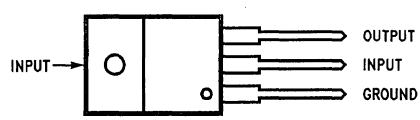
For output voltage other than −5V, −12V, and −15V the LM137 series provides an output voltage range from −1.2V to −57V.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 0.5A output current
- 4% tolerance on preset output voltage

Connection Diagram

TO-220 Plastic Package (T)



TL/H/10483-7

Front View

Order Number LM79M05CT, LM79M12CT or LM79M15CT
See NS Package Number T03B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
$V_O = -5V$	−25V
$V_O = -12V, -15V$	−35V
Input/Output Differential	
$V_O = -5V$	25V
$V_O = -12V, -15V$	30V
Power Dissipation (Note 2)	Internally Limited
Operating Junction Temperature Range	0°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C
ESD Susceptability	TBD

Electrical Characteristics LM79M05C

Conditions unless otherwise noted: I_{OUT} = 350 mA, C_{IN} = 2.2 μF, C_{OUT} = 1 μF, 0°C ≤ T_J ≤ +125°C

Part Number			**LM79M05C**			**Units**
Output Voltage			**−5V**			
Input Voltage (Unless Otherwise Specified)			**−10V**			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25°C	−4.8	−5.0	−5.2	V
		5 mA ≤ I_{OUT} ≤ 350 mA	−4.75	(−25 ≤ V_{IN} ≤ −7)	−5.25	V
ΔV_O	Line Regulation	T_J = 25°C (Note 3)		8 (−25 ≤ V_{IN} ≤ −7)	50	mV
				2 (−18 ≤ V_{IN} ≤ −8)	30	mV
ΔV_O	Load Regulation	T_J = 25°C, (Note 3) 5 mA ≤ I_{OUT} ≤ 0.5A		30	100	mV
I_Q	Quiescent Current	T_J = 25°C		1	2	mA
ΔI_Q	Quiescent Current Change	With Input Voltage		(−25 ≤ V_{IN} ≤ −8)	0.4	mA
		With Load, 5 mA ≤ I_{OUT} ≤ 350 mA			0.4	mA
V_n	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 Hz		150		μV
	Ripple Rejection	f = 120 Hz	54	66 (−18 ≤ V_{IN} ≤ −8)		dB
	Dropout Voltage	T_J = 25°C, I_{OUT} = 0.5A		1.1		V
I_{OMAX}	Peak Output Current	T_J = 25°C		800		mA
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5 mA, 0°C ≤ T_J ≤ 100°C		−0.4		mV/°C

Electrical Characteristics LM79M12C, LM79M15C

Conditions unless otherwise noted: I_{OUT} = 350 mA, C_{IN} = 2.2 μF, C_{OUT} = 1 μF, 0°C ≤ T_J ≤ +125°C

Part Number			**LM79M12C**			**LM79M15C**			**Units**
Output Voltage				**−12V**			**−15V**		
Input Voltage (Unless Otherwise Specified)				**−19V**			**−23V**		
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25°C	−11.5	−12.0	−12.5	−14.4	−15.0	−15.6	V
		5 mA ≤ I_{OUT} ≤ 350 mA	−11.4		−12.6	−14.25		−15.75	V
				(−27 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −10.5)		
ΔV_O	Line Regulation	T_J = 25°C (Note 3)		5	80		5	80	mV
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)		
				3	50		3	50	mV
				(−25 ≤ V_{IN} ≤ −15)			(−28 ≤ V_{IN} ≤ −18)		
ΔV_O	Load Regulation	T_J = 25°C, (Note 3) 5 mA ≤ I_{OUT} ≤ 0.5A		30	240		30	240	mV
I_Q	Quiescent Current	T_J = 25°C		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Input Voltage			0.4			0.4	mA
				(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −27)		
		With Load, 5 mA ≤ I_{OUT} ≤ 350 mA			0.4			0.4	mA
V_n	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 Hz		400			400		μV
	Ripple Rejection	f = 120 Hz	54	70		54	70		dB
				(−25 ≤ V_{IN} ≤ −15)			(−30 ≤ V_{IN} ≤ −17.5)		
	Dropout Voltage	T_J = 25°C, I_{OUT} = 0.5A		1.1			1.1		V
I_{OMAX}	Peak Output Current	T_J = 25°C		800			800		mA
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5 mA, 0°C ≤ T_J ≤ 100°C		−0.8			−1.0		mV/°C

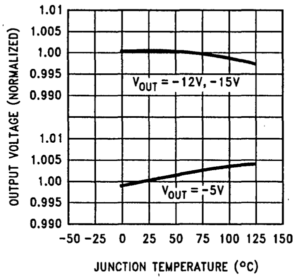
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

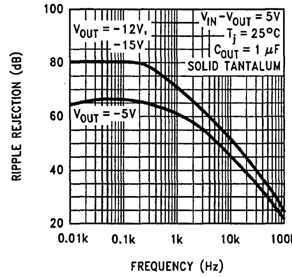
Note 3: Regulation is measued at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Typical Performance Characteristics

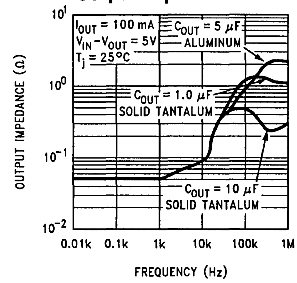
Output Voltage vs Temperature



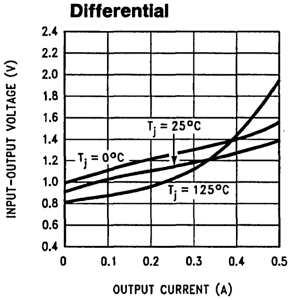
Ripple Rejection



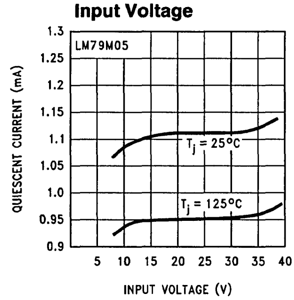
Output Impedance



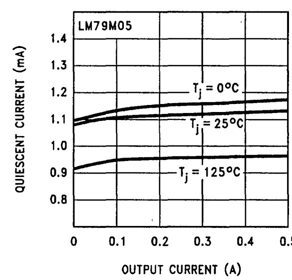
Minimum Input-Output Differential



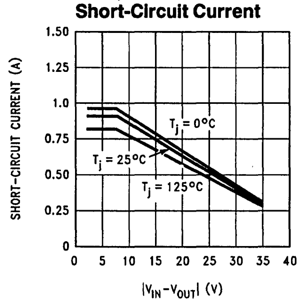
Quiescent Current vs Input Voltage



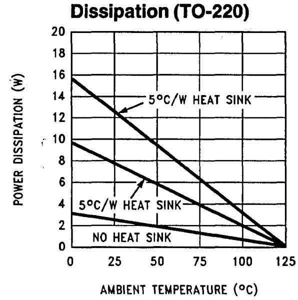
Quiescent Current vs Load Current



Short-Circuit Current



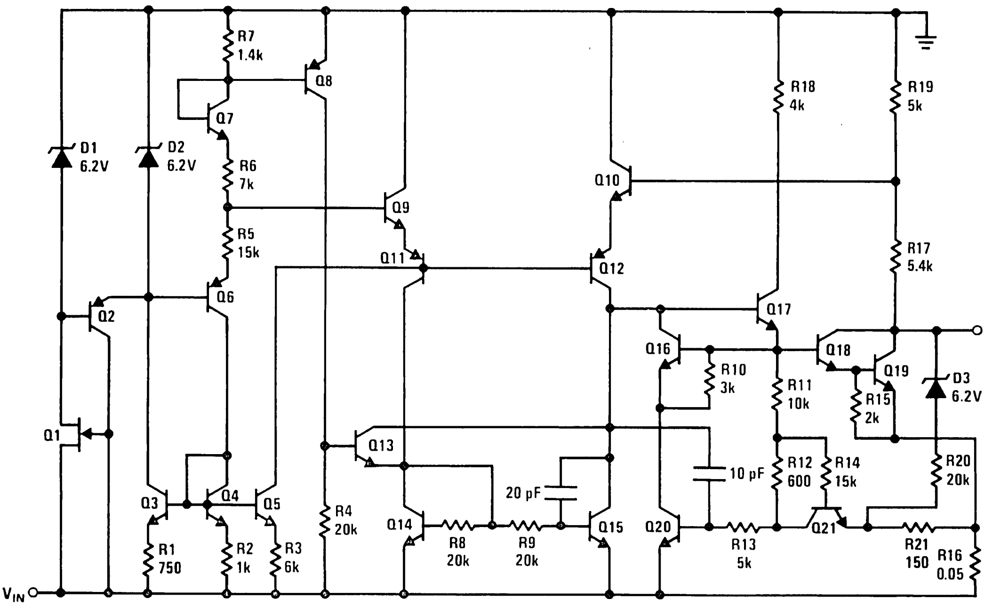
Maximum Average Power Dissipation (TO-220)



TL/H/10483-10

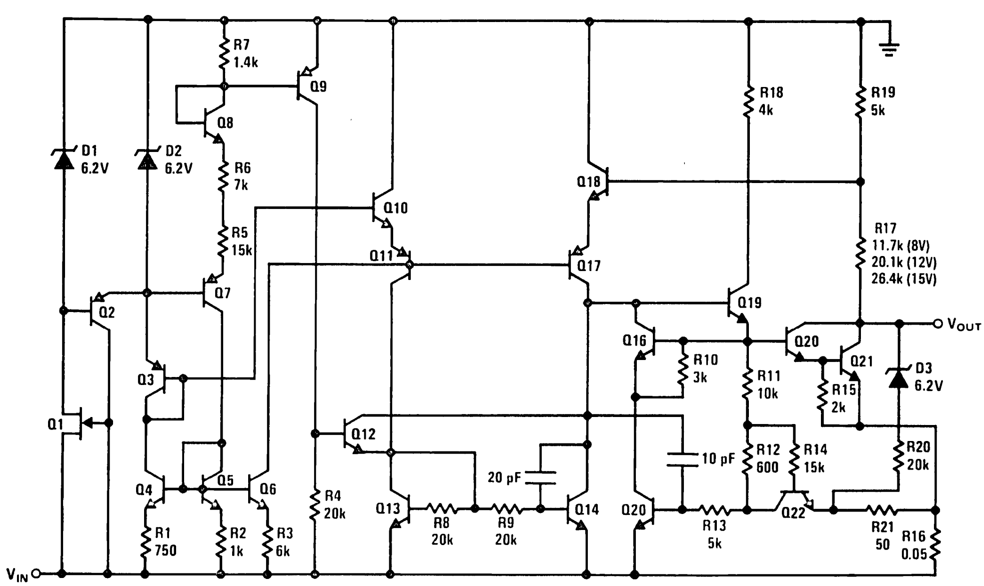
Schematic Diagrams

−5V



TL/H/10483-8

−12V and −15V



TL/H/10483-9

Design Considerations

The LM79MXX fixed voltage regulator series have thermal-overload protection from excessive power, internal short-circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	θ_{JC} (°C/W)	θ_{JA} (°C/W)
TO-220	3	40

$$P_{DMAX} = \frac{T_{JMax} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or} \quad (1)$$

$$= \frac{T_{JMax} - T_A}{\theta_{JA}} \text{ (Without a Heat Sink)}$$

$\theta_{CA} = \theta_{CS} + \theta_{SA}$

Solving for T_J:

$T_J = T_A + P_D (\theta_{JC} + \theta_{CA})$ or

$= T_A = + P_D\theta_{JA}$ (Without a Heat Sink)

Where

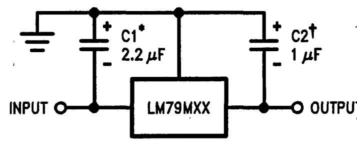
T_J = Junction Temperature
T_A = Ambient Temperature
P_D = Power Dissipation
θ_{JC} = Junction-to-Case Thermal Resistance
θ_{CA} = Case-to-Ambient Thermal Resistance
θ_{CS} = Case-to-Heat Sink Thermal Resistance
θ_{SA} = Heat Sink-to-Ambient Thermal Resistance
θ_{JA} = Junction-to-Ambient Thermal Resistance

Typical Applications

Bypass capacitors are necessary for stable operation of the LM79MXX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response of the regulator.

The bypass capacitors (2.2 μF on the input, 1.0 μF on the output), should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10 μF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

Fixed Regulator



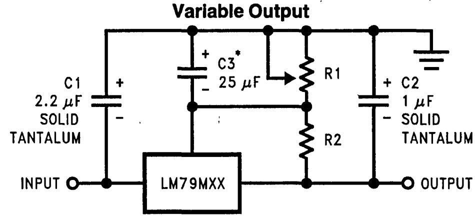
TL/H/10483-2

*Required if regulator is separated from filter capacitor by more than 3″. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100 μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

Variable Output



TL/H/10483-3

*Improves transient response and ripple rejection. Do not increase beyond 50 μF.

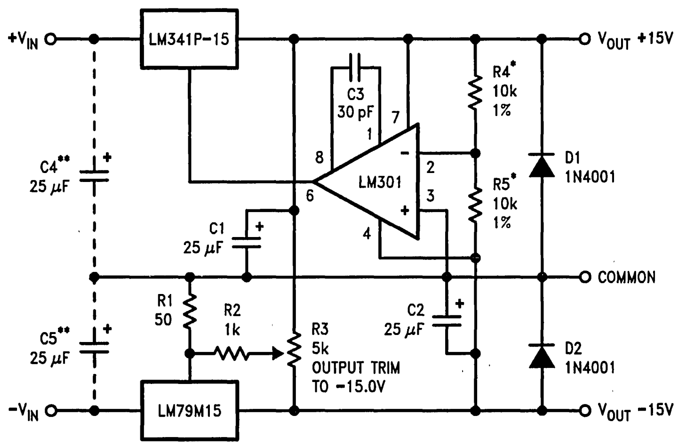
$$V_{OUT} = V_{SET} \left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows:

LM79M05C	300Ω
LM79M12C	750Ω
LM79M15C	1k

Typical Applications (Continued)

±15V, 1 Amp Tracking Regulators



TL/H/10483-1

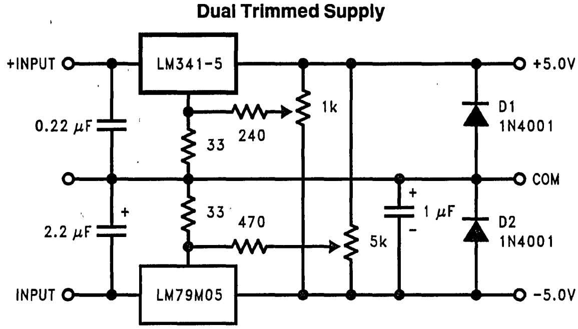
Performance (Typical)

	(−15)	(+15)
Load Regulation at 0.5A	40 mV	2 mV
Output Ripple, C_{IN} = 3000 μF, I_L = 0.5A	100 μVrms	100 μVrms
Temperature Stability	50 mV	50 mV
Output Noise 10 Hz ≤ f ≤ 10 kHz	150 μVrms	150 μVrms

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.

**Necessary only if raw supply filter capacitors are more than 3″ from regulators.

Dual Trimmed Supply



TL/H/10483-4

National Semiconductor

LM79XX Series 3-Terminal Negative Regulators

General Description

The LM79XX series of 3-terminal regulators is available with fixed output voltages of −5V, −8V, −12V, and −15V. These devices need only one external component—a compensation capacitor at the output. The LM79XX series is packaged in the TO-220 power package and is capable of supplying 1.5A of output current.

These regulators employ internal current limiting safe area protection and thermal shutdown for protection against virtually all overload conditions.

Low ground pin current of the LM79XX series allows output voltage to be easily boosted above the preset value with a resistor divider. The low quiescent current drain of these devices with a specified maximum change with line and load ensures good regulation in the voltage boosted mode.

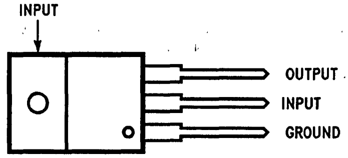
For applications requiring other voltages, see LM137 data sheet.

Features

- Thermal, short circuit and safe area protection
- High ripple rejection
- 1.5A output current
- 4% tolerance on preset output voltage

Connection Diagrams

TO-220 Package



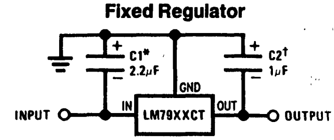
TL/H/7340–14

Front View

Order Number LM7905CT, LM7912CT or LM7915CT
See NS Package Number TO3B

Typical Applications

Fixed Regulator



TL/H/7340–3

*Required if regulator is separated from filter capacitor by more than 3″. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted.

†Required for stability. For value given, capacitor must be solid tantalum. 25 μF aluminum electrolytic may be substituted. Values given may be increased without limit.

For output capacitance in excess of 100 μF, a high current diode from input to output (1N4001, etc.) will protect the regulator from momentary input shorts.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
($V_o = -5V$)	−25V
($V_o = -12V$ and $-15V$)	−35V
Input-Output Differential	
($V_o = -5V$)	25V
($V_o = -12V$ and $-15V$)	30V
Power Dissipation (Note 2)	Internally Limited
Operating Junction Temperature Range	0°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C

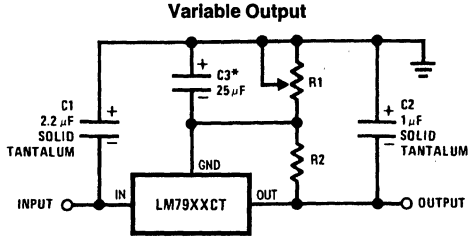
Electrical Characteristics

Conditions unless otherwise noted: $I_{OUT} = 500$ mA, $C_{IN} = 2.2\ \mu F$, $C_{OUT} = 1\ \mu F$, $0°C \le T_J \le +125°C$, Power Dissipation $\le$ 1.5W.

Part Number			LM7905C			Units
Output Voltage			−5V			
Input Voltage (unless otherwise specified)			−10V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	$T_J = 25°C$	−4.8	−5.0	−5.2	V
		$5\ mA \le I_{OUT} \le 1A$,	−4.75		−5.25	V
		$P \le 15W$		$(-20 \le V_{IN} \le -7)$		V
ΔV_O	Line Regulation	$T_J = 25°C$, (Note 3)		8	50	mV
				$(-25 \le V_{IN} \le -7)$		V
				2	15	mV
				$(-12 \le V_{IN} \le -8)$		V
ΔV_O	Load Regulation	$T_J = 25°C$, (Note 3)				
		$5\ mA \le I_{OUT} \le 1.5A$		15	100	mV
		$250\ mA \le I_{OUT} \le 750\ mA$		5	50	mV
I_Q	Quiescent Current	$T_J = 25°C$		1	2	mA
ΔI_Q	Quiescent Current Change	With Line			0.5	mA
				$(-25 \le V_{IN} \le -7)$		V
		With Load, $5\ mA \le I_{OUT} \le 1A$			0.5	mA
V_n	Output Noise Voltage	$T_A = 25°C$, $10\ Hz \le f \le 100\ Hz$		125		µV
	Ripple Rejection	f = 120 Hz	54	66		dB
				$(-18 \le V_{IN} \le -8)$		V
	Dropout Voltage	$T_J = 25°C$, $I_{OUT} = 1A$		1.1		V
I_{OMAX}	Peak Output Current	$T_J = 25°C$		2.2		A
	Average Temperature Coefficient of Output Voltage	$I_{OUT} = 5\ mA$, $0\ C \le T_J \le 100°C$		0.4		mV/°C

Typical Applications (Continued)

Variable Output



TL/H/7340–2

*Improves transient response and ripple rejection. Do not increase beyond 50 µF.

$$V_{OUT} = V_{SET}\left(\frac{R1 + R2}{R2}\right)$$

Select R2 as follows:

LM7905CT	300Ω
LM7912CT	750Ω
LM7915CT	1k

Electrical Characteristics (Continued) Conditions unless otherwise noted: I_{OUT} = 500 mA, C_{IN} = 2.2 μF, C_{OUT} = 1 μF, 0°C ≤ T_J ≤ +125°C, Power Dissipation = 1.5W.

Part Number			LM7912C			LM7915C			Units
Output Voltage			−12V			−15V			
Input Voltage (unless otherwise specified)			−19V			−23V			
Symbol	**Parameter**	**Conditions**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	T_J = 25°C	−11.5	−12.0	−12.5	−14.4	−15.0	−15.6	V
		5 mA ≤ I_{OUT} ≤ 1A,	−11.4		−12.6	−14.25		−15.75	V
		P ≤ 15W	(−27 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)			V
ΔV_O	Line Regulation	T_J = 25°C, (Note 3)		5	80		5	100	mV
			(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)			V
				3	30		3	50	mV
			(−22 ≤ V_{IN} ≤ −16)			(−26 ≤ V_{IN} ≤ −20)			V
ΔV_O	Load Regulation	T_J = 25°C, (Note 3)							
		5 mA ≤ I_{OUT} ≤ 1.5A		15	200		15	200	mV
		250 mA ≤ I_{OUT} ≤ 750 mA		5	75		5	75	mV
I_Q	Quiescent Current	T_J = 25°C		1.5	3		1.5	3	mA
ΔI_Q	Quiescent Current Change	With Line			0.5			0.5	mA
			(−30 ≤ V_{IN} ≤ −14.5)			(−30 ≤ V_{IN} ≤ −17.5)			V
		With Load, 5 mA ≤ I_{OUT} ≤ 1A			0.5			0.5	mA
V_n	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 Hz		300			375		μV
	Ripple Rejection	f = 120 Hz	54	70		54	70		dB
			(−25 ≤ V_{IN} ≤ −15)			(−30 ≤ V_{IN} ≤ −17.5)			V
	Dropout Voltage	T_J = 25°C, I_{OUT} = 1A		1.1			1.1		V
I_{OMAX}	Peak Output Current	T_J = 25°C		2.2			2.2		A
	Average Temperature Coefficient of Output Voltage	I_{OUT} = 5 mA, 0 C ≤ T_J ≤ 100°C		−0.8			−1.0		mV/°C

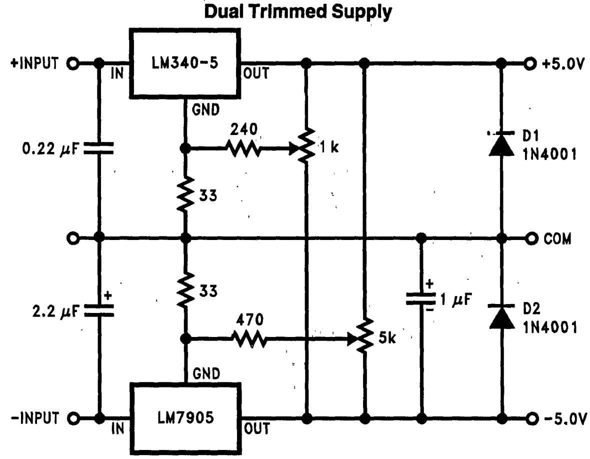
Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee Specific Performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Refer to Typical Performance Characteristics and Design Considerations for details.

Note 3: Regulation is measured at a constant junction temperature by pulse testing with a low duty cycle. Changes in output voltage due to heating effects must be taken into account.

Typical Applications (Continued)

Dual Trimmed Supply



TL/H/7340-4

Design Considerations

The LM79XX fixed voltage regulator series has thermal overload protection from excessive power dissipation, internal short circuit protection which limits the circuit's maximum current, and output transistor safe-area compensation for reducing the output current as the voltage across the pass transistor is increased.

Although the internal power dissipation is limited, the junction temperature must be kept below the maximum specified temperature (125°C) in order to meet data sheet specifications. To calculate the maximum junction temperature or heat sink required, the following thermal resistance values should be used:

Package	Typ θ_{JC} °C/W	Max θ_{JC} °C/W	Typ θ_{JA} °C/W	Max θ_{JA} °C/W
TO-220	3.0	5.0	60	40

$$P_{D\,MAX} = \frac{T_{J\,Max} - T_A}{\theta_{JC} + \theta_{CA}} \text{ or } \frac{T_{J\,Max}\,T_A}{\theta_{JA}}$$

$\theta_{CA} = \theta_{CS} + \theta_{SA}$ (without heat sink)

Solving for T_J:

$T_J = T_A + P_D(\theta_{JC} + \theta_{CA})$ or

$= T_A + P_D\theta_{JA}$ (without heat sink)

Where:

T_J = Junction Temperature

T_A = Ambient Temperature

P_D = Power Dissipation

θ_{JA} = Junction-to-Ambient Thermal Resistance

θ_{JC} = Junction-to-Case Thermal Resistance

θ_{CA} = Case-to-Ambient Thermal Resistance

θ_{CS} = Case-to-Heat Sink Thermal Resistance

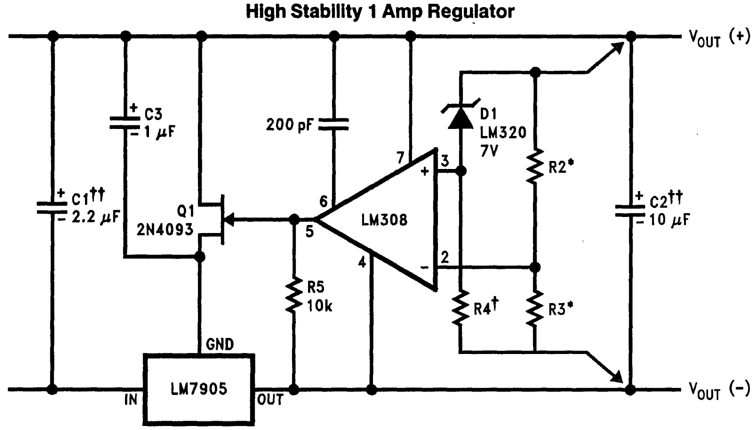
θ_{SA} = Heat Sink-to-Ambient Thermal Resistance

Typical Applications (Continued)

Bypass capacitors are necessary for stable operation of the LM79XX series of regulators over the input voltage and output current ranges. Output bypass capacitors will improve the transient response by the regulator.

The bypass capacitors, (2.2 μF on the input, 1.0 μF on the output) should be ceramic or solid tantalum which have good high frequency characteristics. If aluminum electrolytics are used, their values should be 10 μF or larger. The bypass capacitors should be mounted with the shortest leads, and if possible, directly across the regulator terminals.

High Stability 1 Amp Regulator



TL/H/7340-5

Load and line regulation < 0.01% temperature stability ≤ 0.2%

†Determine Zener current

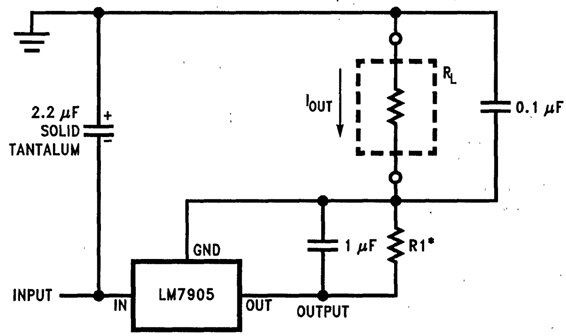
††Solid tantalum

*Select resistors to set output voltage. 2 ppm/°C tracking suggested

1

Typical Applications (Continued)

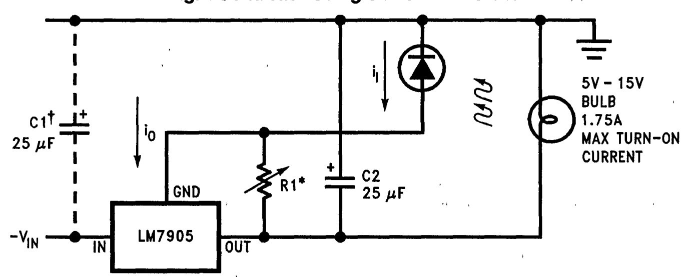
Current Source



$^{*}I_{OUT} = 1\ mA + \frac{5V}{R1}$

TL/H/7340–7

Light Controller Using Silicon Photo Cell



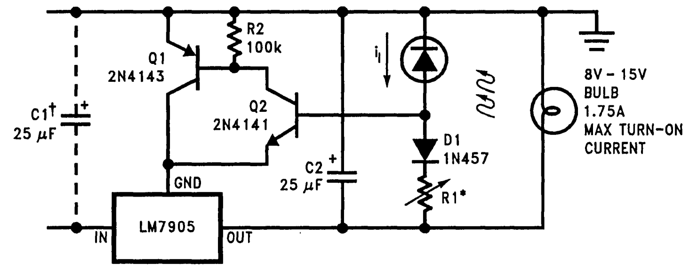
TL/H/7340–8

*Lamp brightness increase until $i_l = i_Q$ (≈ 1 mA) + 5V/R1.

†Necessary only if raw supply filter capacitor is more than 2″ from LM7905CT

Typical Applications (Continued)

High-Sensitivity Light Controller

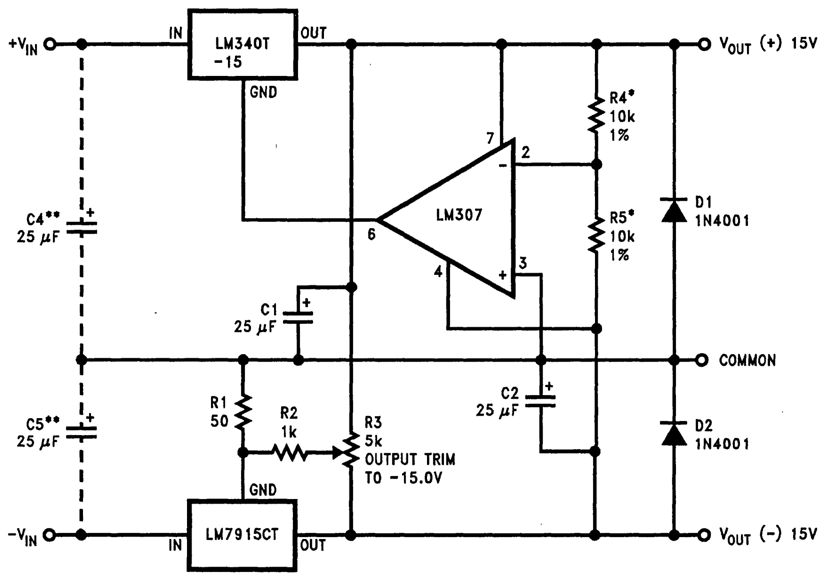


TL/H/7340-9

*Lamp brightness increases until $i_l = 5V/R1$ (I_l can be set as low as 1 μA)

†Necessary only if raw supply filter capacitor is more than 2" from LM7905

±15V, 1 Amp Tracking Regulators



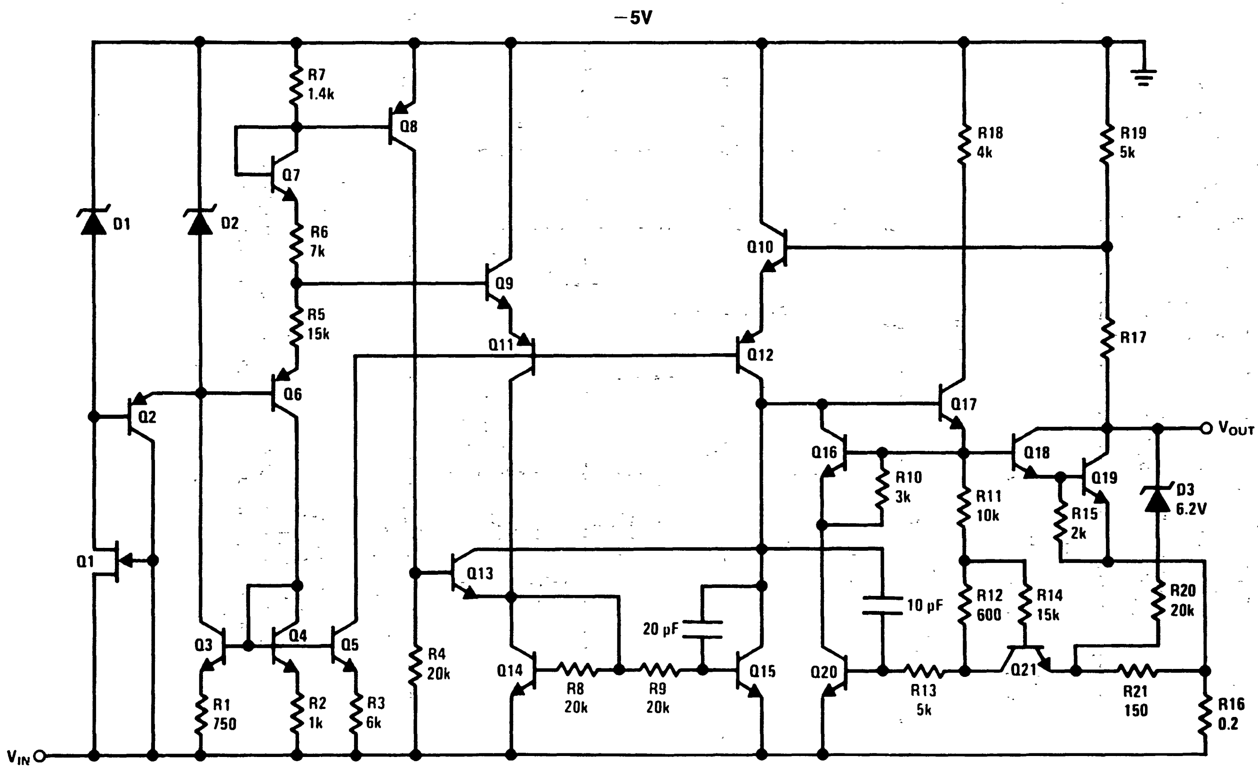
TL/H/7340-1

	(−15)	(+15)
Load Regulation at $\Delta I_L = 1A$	40 mV	2 mV
Output Ripple, $C_{IN} = 3000\ \mu F$, $I_L = 1A$	100 μVrms	100 μVrms
Temperature Stability	50 mV	50 mV
Output Noise 10 Hz ≤ f ≤ 10 kHz	150 μVrms	150 μVrms

*Resistor tolerance of R4 and R5 determine matching of (+) and (−) outputs.

**Necessary only if raw supply filter capacitors are more than 3" from regulators.

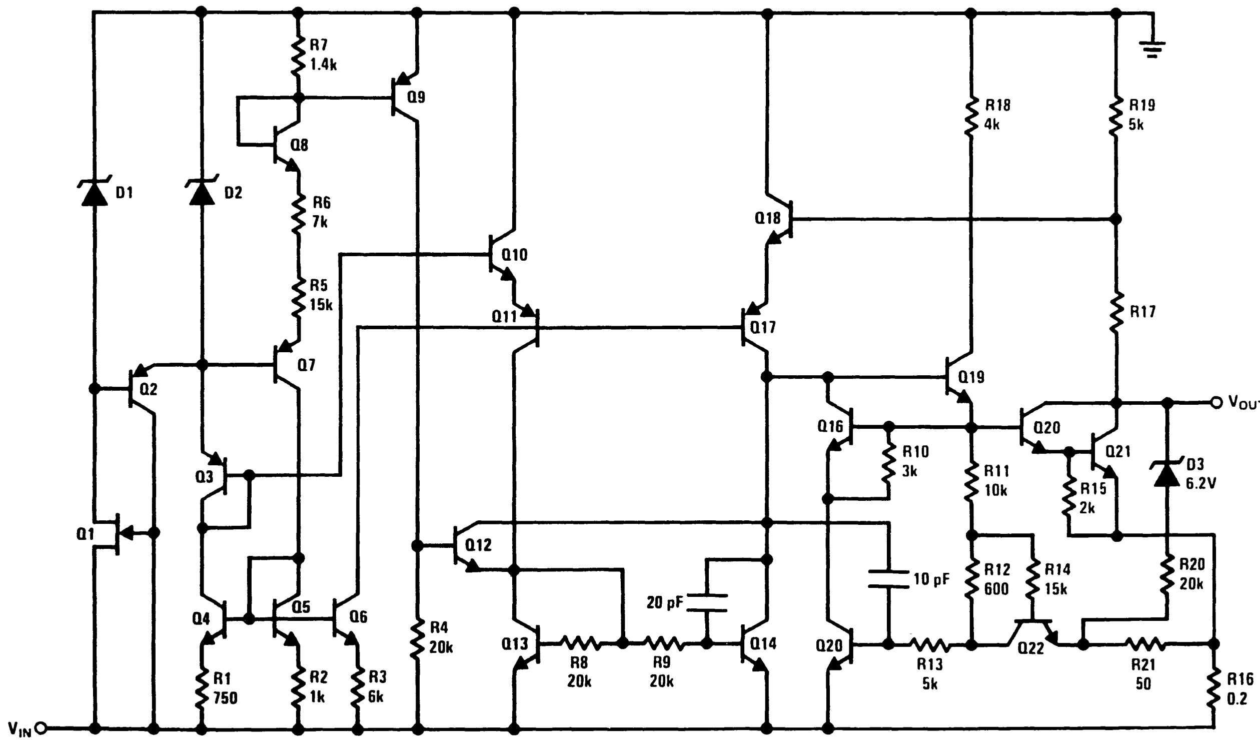
Schematic Diagrams



TL/H/7340–12

Schematic Diagrams (Continued)

−12V and −15V



TL/H/7340–13

Section 2
Low Dropout Voltage Regulators

Section 2 Contents

National Semiconductor

Low-Dropout Voltage Regulators Definition of Terms

Dropout Voltage: The input-voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at (V_{OUT} + 5V) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Low Dropout Regulators Selection Guide

Output Current (A)	Device	Output Voltage (V)	Typical Dropout Voltage (V)*	Maximum Input Voltage (V)	Typical Quiescent Current (mA)	Reverse Polarity Protection (V)	Transient Protection (V)	Operating Temperature (Tj °C)	Page No.
1.0	LM2940	5, 8, 12, 15	0.50	26	10	−15	+60**/−50	−55 to +150	2-55
	LM2940C	5, 9, 12, 15	0.50	26	10	−15	+45/−45	0 to +150	2-55
0.75	LM2925	5	0.82	26	3	−15	+60**/−50	−40 to +150	2-9
	LM2935	Two 5V Outputs	0.82	26	3	−15	+60**/−50	−40 to +150	2-37
0.5	LM2926	5	0.35	26	2	−18	+80**/−50	−40 to +125	2-15
	LM2927	5	0.35	26	2	−18	+80**/−50	−40 to +125	2-15
	LM2937	5, 8, 10, 12, 15	0.50	26	2	−15	+60**/−50	−40 to +125	2-50
	LM2984	Three 5V Outputs	0.53	26	14	−15	+60**/−35	−40 to +150	2-72
0.1	LM2931	5	0.30	24	0.400	−15	+60**/−50	−40 to +125	2-29
	LM2931C	Adj. (3 to 29)	0.30	24	0.400	−15	+60**/−50	−40 to +125	2-29
	LP2950C	5	0.38	30	0.075			−40 to +125	2-116
	LP2950AC	5	0.38	30	0.075			−40 to +125	2-116
	LP2951	5, Adj. (1.24V to 29)	0.38	30	0.075			−55 to +150	2-116
	LP2951C	3.0, 3.3, 5, Adj. (1.24V to 29)	0.38	30	0.075			−40 to +125	2-116
	LP2951AC	3.0, 3.3, 5, Adj. (1.24V to 29)	0.38	30	0.075			−40 to +125	2-116
0.05	LM2936	5	0.4	40	0.009	−15	+60/−50	−40 to +125	2-45

*Guaranteed maximum dropout voltage at full load over temperature.

**Positive transient protection value also indicates the regulator's load dump capability.

Low Dropout Regulators Selection Guide

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LM330 3-Terminal Positive Regulator

General Description

The LM330 5V 3-terminal positive voltage regulator features an ability to source 150 mA of output current with an input-output differential of 0.6V or less. Familiar regulator features such as current limit and thermal overload protection are also provided.

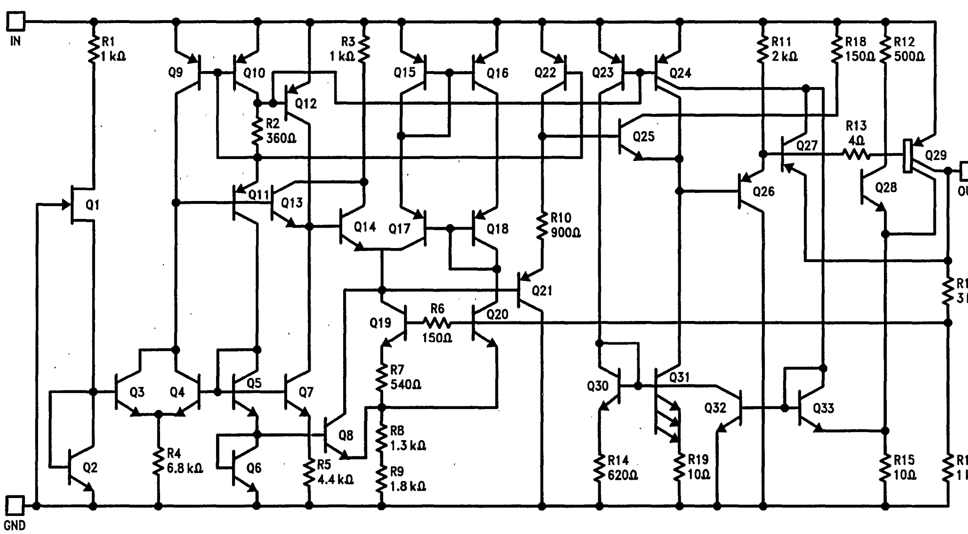
The low dropout voltage makes the LM330 useful for certain battery applications since this feature allows a longer battery discharge before the output falls out of regulation. For example, a battery supplying the regulator input voltage may discharge to 5.6V and still properly regulate the system and load voltage. Supporting this feature, the LM330 protects both itself and regulated systems from negative voltage inputs resulting from reverse installations of batteries.

Other protection features include line transient protection up to 26V, when the output actually shuts down to avoid damaging internal and external circuits. Also, the LM330 regulator cannot be harmed by a temporary mirror-image insertion.

Features

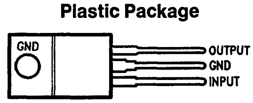
- Input-output differential less than 0.6V
- Output current of 150 mA
- Reverse battery protection
- Line transient protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection
- P^+ Product Enhancement tested

Schematic and Connection Diagrams



TL/H/9306-1

(TO-220)
Plastic Package



TL/H/9306-2

Front View

Order Number LM330T-5.0
See NS Package Number T03B

2

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Line Transient Protection (1000 ms)	40V
Internal Power Dissipation	Internally Limited
Operating Temperature Range	0°C to +70°C
Maximum Junction Temperature	+125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	+300°C

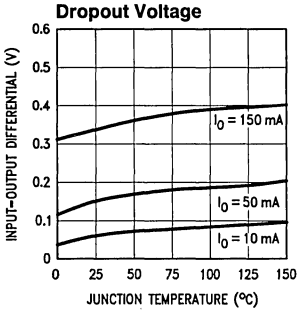
Electrical Characteristics (Note 1)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_O	Output Voltage	$T_j = 25°C$	4.8	5	5.2	V
	Output Voltage Over Temp	$5 < I_O < 150$ mA $6 < V_{IN} < 26V$; $0°C \leq T_j \leq 100°C$	4.75		5.25	
ΔV_O	Line Regulation	$9 < V_{IN} < 16V$, $I_O = 5$ mA $6 < V_{IN} < 26V$, $I_O = 5$ mA		7 30	25 60	mV
	Load Regulation	$5 < I_O < 150$ mA		14	50	
	Long Term Stability			20		mV/1000 hrs
I_Q	Quiescent Current	$I_O = 10$ mA $I_O = 50$ mA $I_O = 150$ mA		3.5 5 18	7 11 40	mA
	Line Transient Reverse Polarity	$V_{IN} = 40V$, $R_L = 100\Omega$, 1s $V_{IN} = -6V$, $R_L = 100\Omega$		14 −80		
ΔI_Q	Quiescent Current Change	$6 < V_{IN} < 26V$		10		%
V_{IN}	Overvoltage Shutdown Voltage		26	38		V
	Max Line Transient			60		
		1s, $V_O \leq 5.5V$		50		
	Reverse Polarity Input Voltage			−30		
		DC $V_O > -0.3V$, $R_L = 100\Omega$		−12		
	Output Noise Voltage	10 Hz–100 kHz		50		μV
	Output Impedance	$I_O = 100$ mADC + 10 mArms		200		mΩ
	Ripple Rejection			56		dB
	Current Limit		150	400	700	mA
	Dropout Voltage	$I_O = 150$ mA		0.32	0.6	V
	Thermal Resistance	Junction to Case Junction to Ambient		4 50		°C/W

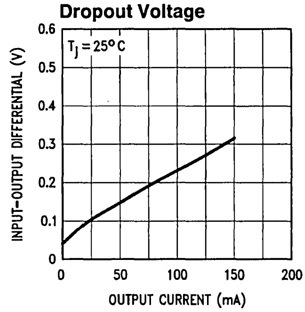
Note 1: Unless otherwise specified: $V_{IN} = 14V$, $I_O = 150$ mA, $T_j = 25°C$, C1 = 0.1 μF, C2 = 10 μF. All characteristics except noise voltage and ripple rejection are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle ≤ 5%). Output voltage changes due to changes in internal temperature must be taken into account separately.

Typical Performance Characteristics

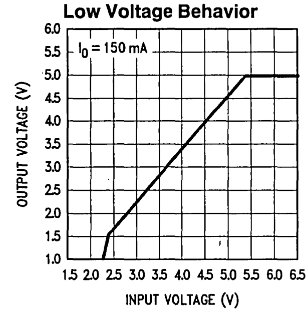
Dropout Voltage



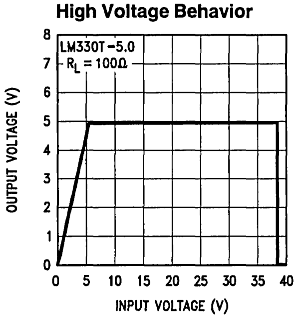
Dropout Voltage



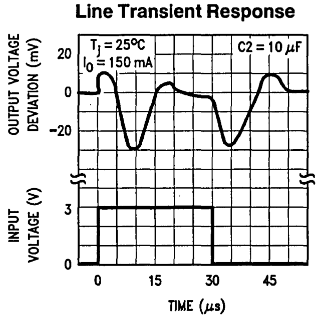
Low Voltage Behavior



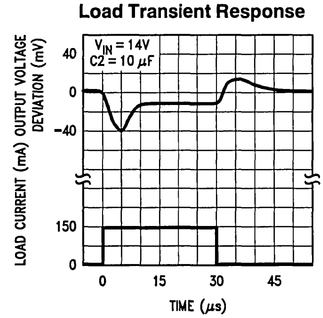
High Voltage Behavior



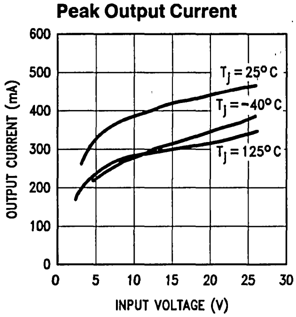
Line Transient Response



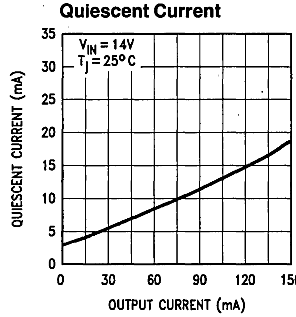
Load Transient Response



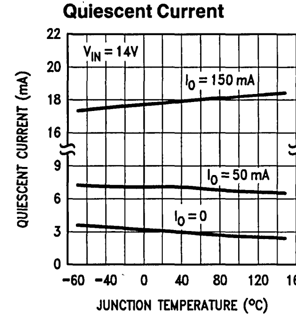
Peak Output Current



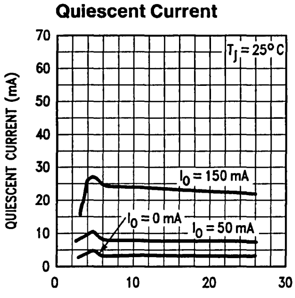
Quiescent Current



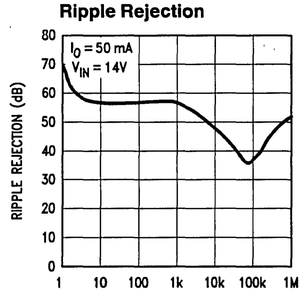
Quiescent Current



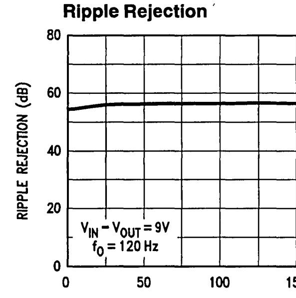
Quiescent Current



Ripple Rejection



Ripple Rejection

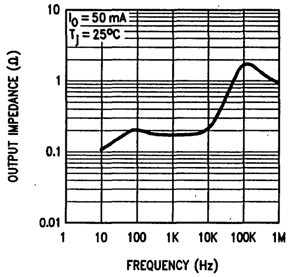


TL/H/9306-3

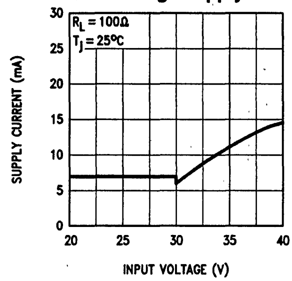
2

Typical Performance Characteristics (Continued)

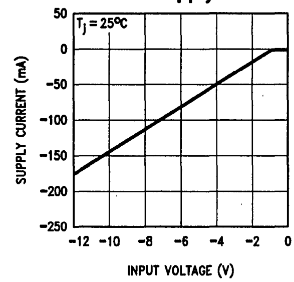
Output Impedance



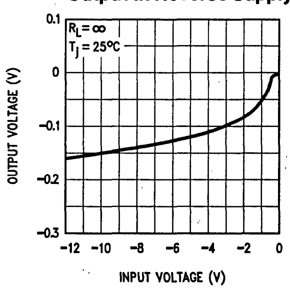
Overvoltage Supply Current



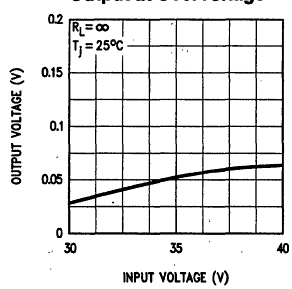
Reverse Supply Current



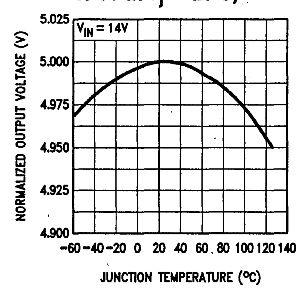
Output at Reverse Supply



Output at Overvoltage



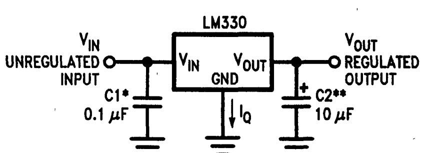
Output Voltage (Normalized to 5V at T_J = 25°C)



TL/H/9306-4

Typical Applications

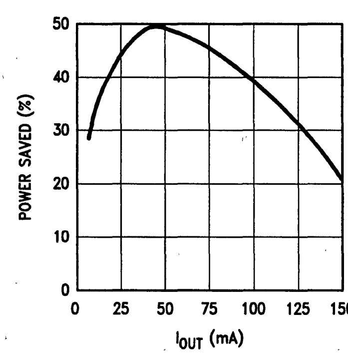
The LM330 is designed specifically to operate at lower input to output voltages. The device is designed utilizing a power lateral PNP transistor which reduces dropout voltage from 2.0V to 0.3V when compared to IC regulators using NPN pass transistors. Since the LM330 can operate at a much lower input voltage, the device power dissipation is reduced, heat sinking can be simpler and device reliability improved through lower chip operating temperature. Also, a cost savings can be utilized through use of lower power/voltage components. In applications utilizing battery power, the LM330 allows the battery voltage to drop to within 0.3V of output voltage prior to the voltage regulator dropping out of regulation.



TL/H/9306-5

* Required if regulator is located far from power supply filter.

** C2 may be either an Aluminum or Tantalum type capacitor but must be rated to operate at −40°C to guarantee regulator stability to that temperature extreme. 10 μF is the minimum value required for stability and may be increased without bound. Locate as close as possible to the regulation.



TL/H/9306-6

Note: Compared to IC regulator with 2.0V dropout voltage and I_{Qmax} = 6.0 mA.

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LM2925 Low Dropout Regulator with Delayed Reset

General Description

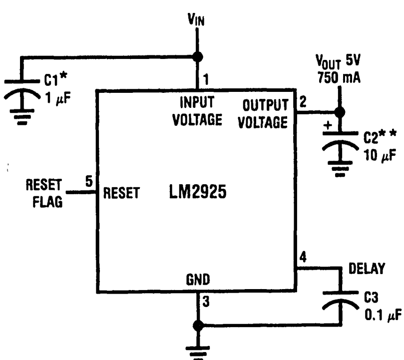
The LM2925 features a low dropout, high current regulator. Also included on-chip is a reset function with an externally set delay time. Upon power up, or after the detection of any error in the regulated output, the reset pin remains in the active low state for the duration of the delay. Types of errors detected include any that cause the output to become unregulated: low input voltage, thermal shutdown, short circuit, input transients, etc. No external pull-up resistor is necessary. The current charging the delay capacitor is very low, allowing long delay times.

Designed primarily for automotive applications, the LM2925 and all regulated circuitry are protected from reverse battery installations or two-battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the 0.75A regulator will automatically shut down to protect both internal circuits and the load. The LM2925 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- 5V, 750 mA output
- Externally set delay for reset
- Input-output differential less than 0.6V at 0.5A
- Reverse battery protection
- 60V load dump protection
- −50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Available in plastic TO-220
- Long delay times available
- P+ Product Enhancement tested

Typical Application Circuit



*Required if regulator is located far from power supply filter.

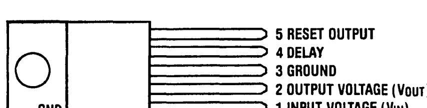
**C_{OUT} must be at least 10 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

TL/H/5268–1

FIGURE 1. Test and Application Circuit

Connection Diagram

TO-220 5-Lead



FRONT VIEW

TL/H/5268–2

Order Number LM2925T
See NS Package Number T05A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overvoltage Protection	60V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	−40°C to + 125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	−65°C to + 150°C
Lead Temperature (Soldering, 10 seconds)	260°C

ESD rating is to be determined

Electrical Characteristics for V_{OUT}

V_{IN} = 14V, C2 = 10 μf, I_O = 500 mA, T_J = 25°C (Note 3) (unless otherwise specified)

Parameter	Conditions	Min	Typ	Max	Units
		Note 2			
Output Voltage	6V ≤ V_{IN} ≤ 26V, I_O ≤ 500 mA, −40°C ≤ T_J ≤ +125°C	4.75	5.00	5.25	V
Line Regulation	9V ≤ V_{IN} ≤ 16V, I_O = 5 mA 6V ≤ V_{IN} ≤ 26V, I_O = 5 mA		4 10	25 50	mV mV
Load Regulation	5 mA ≤ I_O ≤ 500 mA		10	50	mV
Output Impedance	500 mA_{DC} and 10 mArms, 100 Hz-10 kHz		200		mΩ
Quiescent Current	I_O ≤ 10 mA I_O = 500 mA I_O = 750 mA		3 40 90	 100 	mA mA mA
Output Noise Voltage	10 Hz-100 kHz		100		μVrms
Long Term Stability			20		mV/1000 hr
Ripple Rejection	f_o = 120 Hz		66		dB
Dropout Voltage	I_O = 500 mA I_O = 750 mA		0.45 0.82	0.6 	V V
Current Limit		0.75	1.2		A
Maximum Operational Input Voltage		26	31		V
Maximum Line Transient	V_O ≤ 5.5V	60	70		V
Reverse Polarity Input Voltage, DC	V_O ≥ − 0.6V, 10Ω Load	−15	−30		V
Reverse Polarity Input Voltage, Transient	1% Duty Cycle, τ ≤ 100 ms, 10Ω Load	−50	−80		V

Electrical Characteristics for Reset Output

V_{IN} = 14V, C3 = 0.1 μF, T_A = 25°C (Note 3) (unless otherwise specified)

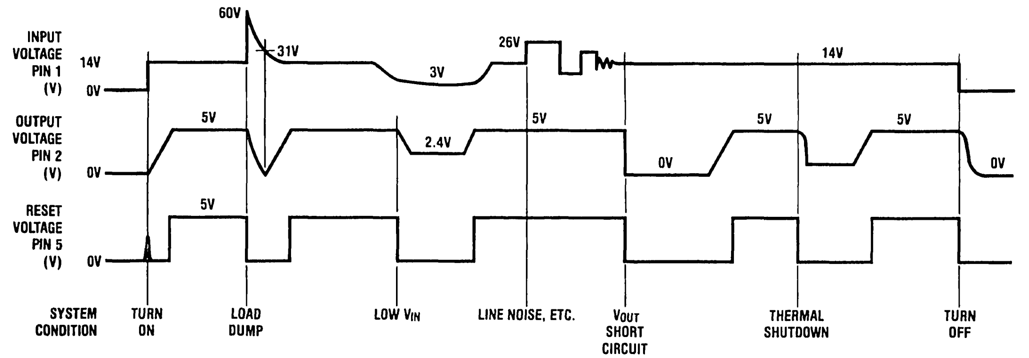
Parameter	Conditions	Min	Typ	Max	Units
		Note 2			
Reset Voltage Output Low Output High	 I_{SINK} = 1.6 mA, V_{IN} = 35V I_{SOURCE} = 0	 4.5	 0.3 5.0	 0.6 5.5	 V V
Reset Internal Pull-up Resistor			30		kΩ
Reset Output Current Limit	V_{RESET} = 1.2 V		5		mA
V_{OUT} Threshold			4.5		V
Delay Time	C_3 = .005 μF C_3 = 0.1 μF C_3 = 4.7 μF tantalum	 150 	12 250 12	 300 	ms ms s
Delay Current	Pin 4	1.2	1.95	2.5	μA

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W (TO-220). Thermal resistance for TO-220 case to ambient temperature is 50°C/W.

Note 2: These parameters are guaranteed and 100% production tested.

Note 3: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Circuit Waveforms

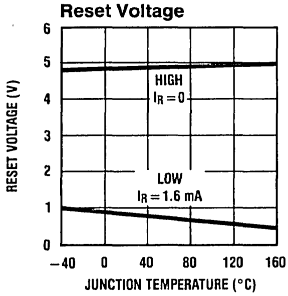


TL/H/5268-3

FIGURE 2

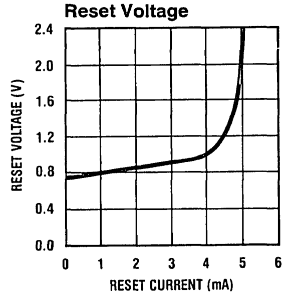
Typical Performance Characteristics

Reset Voltage



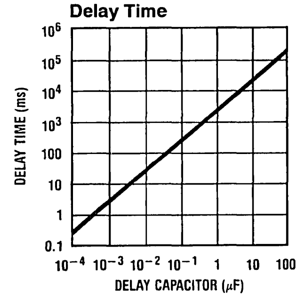
TL/H/5268-4

Reset Voltage



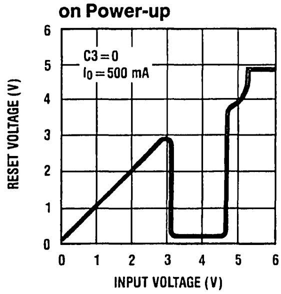
TL/H/5268-5

Delay Time



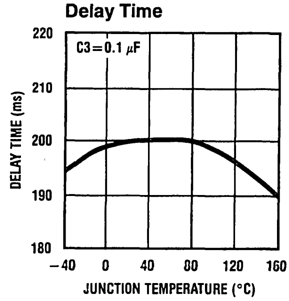
TL/H/5268-6

Reset Voltage on Power-up



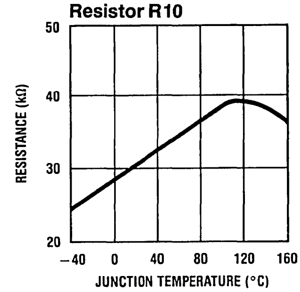
TL/H/5268-7

Delay Time



TL/H/5268-8

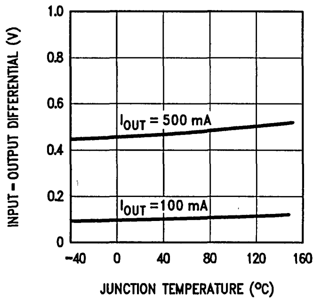
Reset Pull-up Resistor R10



TL/H/5268-9

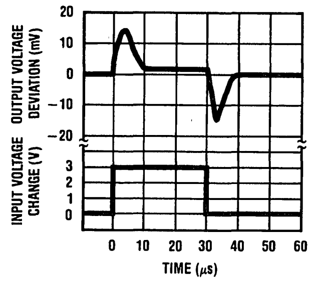
Typical Performance Characteristics (Continued)

Dropout Voltage



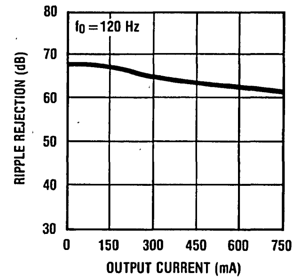
TL/H/5268–10

Line Transient Response



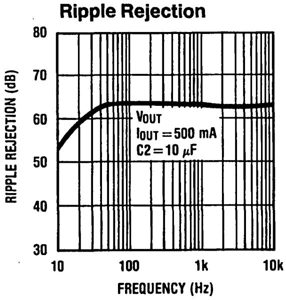
TL/H/5268–11

Ripple Rejection



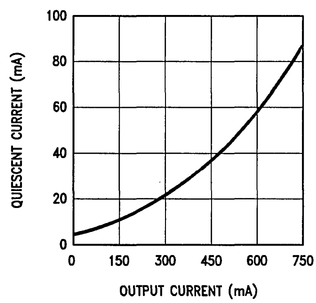
TL/H/5268–12

Ripple Rejection



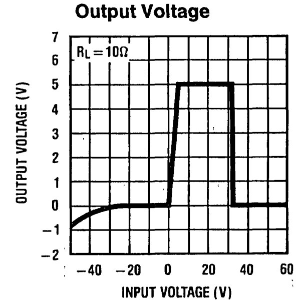
TL/H/5268–13

Quiescent Current



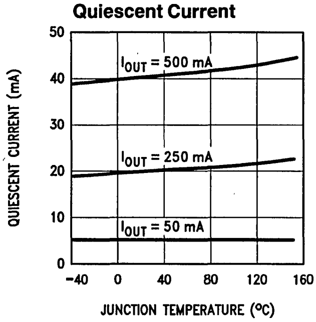
TL/H/5268–14

Output Voltage



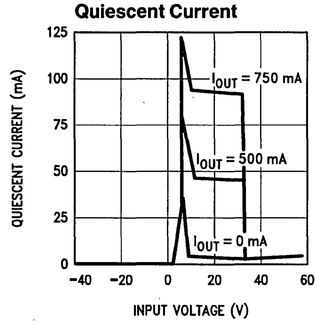
TL/H/5268–15

Quiescent Current



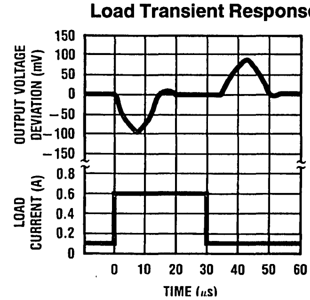
TL/H/5268–19

Quiescent Current



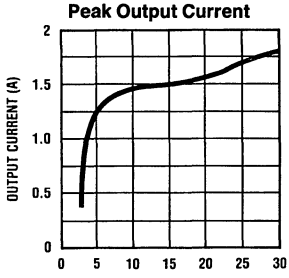
TL/H/5268–17

Load Transient Response



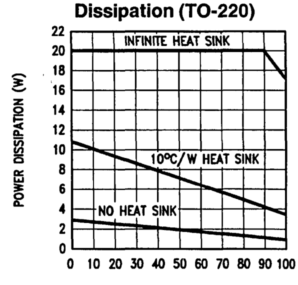
TL/H/5268–18

Peak Output Current



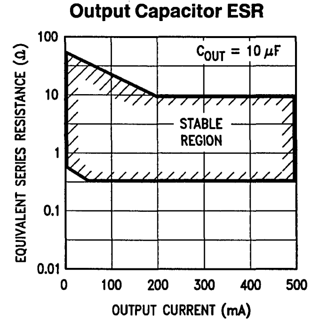
TL/H/5268–20

Maximum Power Dissipation (TO-220)



TL/H/5268–21

Output Capacitor ESR



TL/H/5268–22

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: The part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O: The percentage change in ouput voltage for a thermal variation from room temperature to either temperature extreme.

Application Hints

EXTERNAL CAPACITORS

The LM2925 output capacitor is required for stability. Without it, the regulator output will oscillate, sometimes by many volts. Though the 10 μF shown is the minimum recommended value, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also effects the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst-case is usually determined at the minimum junction and ambient temperature and maximum load expected.

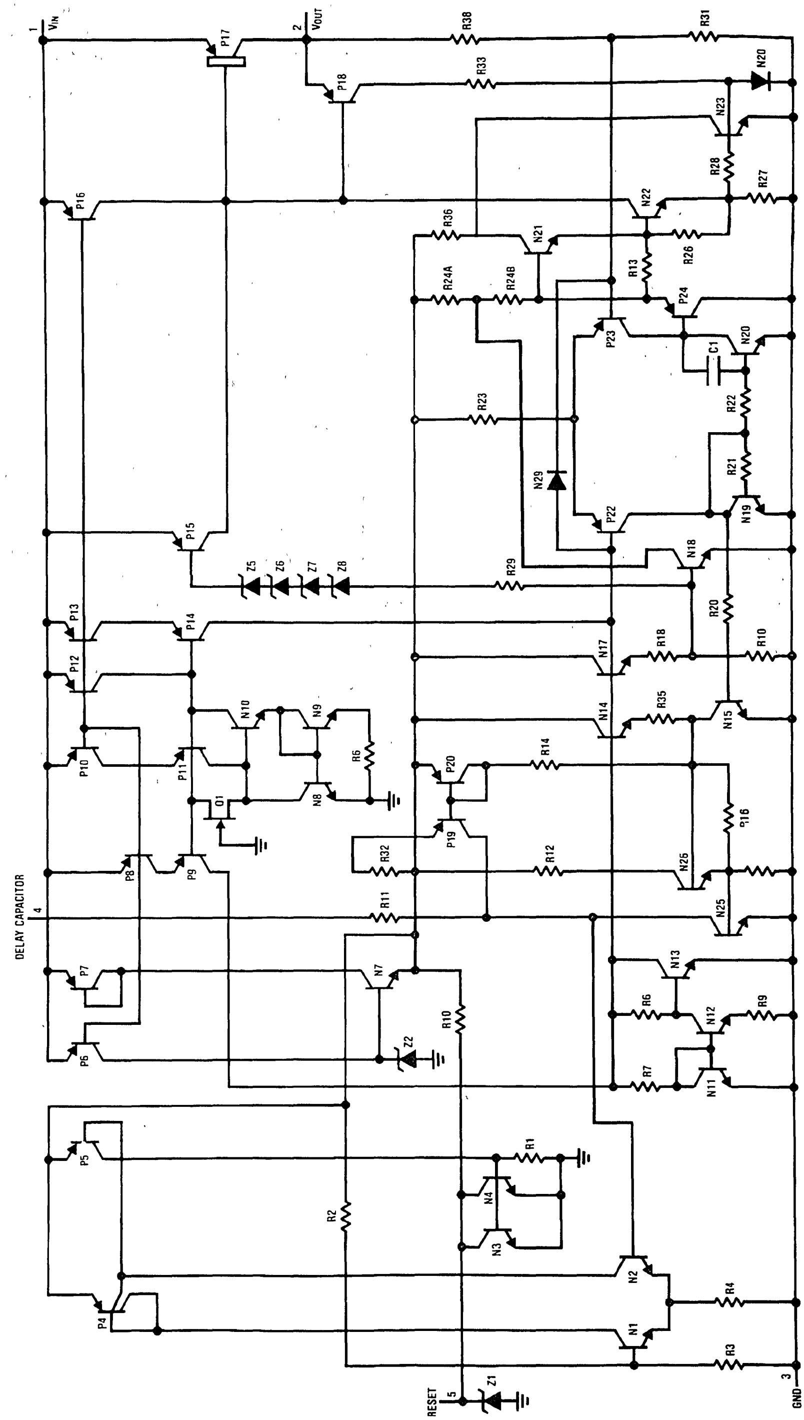
Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltages during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than −30°C, reducing their effective capacitance to zero. To maintain regulator stability down to −40°C, capacitors rated at that temperature (such as tantalums) must be used.

RESET OUTPUT

The range of values for the delay capacitor is limited only by stray capacitances on the lower extreme and capacitance leakage on the other. Thus, delay times from microseconds to seconds are possible. The low charging current, typically 2.0 microamps, allows the use of small, inexpensive disc capacitors for the nominal range of 100 to 500 milliseconds. This is the time required in many microprocessor systems for the clock oscillator to stabilize when initially powered up. The RESET output of the regulator will thus prevent erroneous data and/or timing functions to occur during this part of operation. The same delay is incorporated after any other fault condition in the regulator output is corrected.

Circuit Schematic



TL/H/5268-23

FIGURE 3

National Semiconductor

LM2926/LM2927 Low Dropout Regulator with Delayed Reset

General Description

The LM2926 is a 5V, 500 mA, low dropout regulator with delayed reset. The microprocessor reset flag is set low by thermal shutdown, short circuits, overvoltage conditions, dropout, and power-up. After the fault condition is corrected, the reset flag remains low for a delay time determined by the delay capacitor. Hysteresis is included in the reset circuit to prevent oscillations, and a reset output is guaranteed down to 3.2V supply input. A latching comparator is used to discharge the delay capacitor, which guarantees a full reset pulse even when triggered by a relatively short fault condition. A patented quiescent current reduction circuit drops the ground pin current to 8 mA at full load when the input-output differential is 3V or more.

Familiar PNP regulator features such as reverse battery protection, transient protection, and overvoltage shutdown are included in the LM2926 making it suitable for use in automotive and battery operated equipment.

The LM2927 is electrically identical to the LM2926 but has a different pin-out. The LM2927 is pin-for-pin compatible with the L4947 and TLE4260 alternatives. The LM2926 is pin-for-pin compatible with the LM2925.

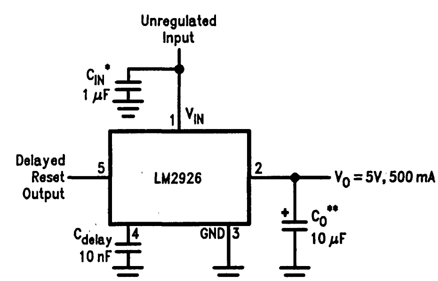
Features

- 5% output accuracy over entire operating range
- Dropout voltage typically 350 mV at 500 mA output
- Externally programmed reset delay
- Short circuit proof
- Reverse battery proof
- Thermally protected
- LM2926 is pin-for-pin compatible with the LM2925
- P^+ Product Enhancement tested

Applications

- Battery operated equipment
- Microprocessor-based systems
- Portable instruments

Typical Application



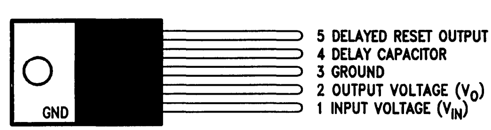
TL/H/10759-1

*Required if regulator is located far (>2″) from power supply filter.

C_O must be at least 10 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor msut be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve under **Typical Performance Characteristics.

Connection Diagrams and Ordering Information

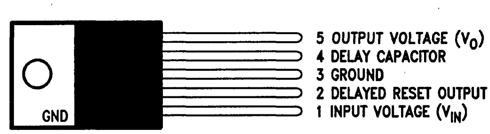
5-Lead TO-220



TL/H/10759-2

Front View
Order Number LM2926T
See NS Package Number TO5A

5-Lead TO-220



TL/H/10759-14

Front View
Order Number LM2927T
See NS Package Number TO5A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Survival	
t = 100 ms	80V
t = 1 ms	−50V
Continuous	−18V to +26V
Reset Output Sink Current	10 mA
ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited
Junction Temperature (T_{JMAX})	150°C
Storage Temperature Range	−40°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	−40°C to +125°C
Maximum Input Voltage	26V

Electrical Characteristics V_{IN} = 14.4V, C_O = 10 μF, −40°C ≤ T_J ≤ 125°C, unless otherwise specified.

Parameter	Conditions	Typ (Note 4)	Limit (Note 5)	Units (Limit)
REGULATOR OUTPUT				
Output Voltage	5 mA ≤ I_O ≤ 500 mA, T_J = 25°C	5	4.85 5.15	V (min) V V (max)
	5 mA ≤ I_O ≤ 500 mA	5	4.75 5.25	V (min) V V (max)
Line Regulation	I_O = 5 mA, 9V ≤ V_{IN} ≤ 16V	1	25	mV mV (max)
	I_O = 5 mA, 7V ≤ V_{IN} ≤ 26V	3	50	mV mV (max)
Load Regulation	5 mA ≤ I_O ≤ 500 mA	5	60	mV mV (max)
Quiescent Current	I_O = 5 mA	2	3	mA mA (max)
	I_O = 500 mA	8	30	mA mA (max)
Quiescent Current at Low V_{IN}	I_O = 5 mA, V_{IN} = 5V	3	10	mA mA (max)
	I_O = 500 mA, V_{IN} = 6V	25	60	mA mA (max)
Dropout Voltage (Note 6)	I_O = 5 mA, T_J = 25°C	60	200	mV mV (max)
	I_O = 5 mA		300	mV (max)
	I_O = 500 mA, T_J = 25°C	350	600	mV mV (max)
	I_O = 500 mA		700	mV (max)
Short Circuit Current	V_{IN} = 8V, R_L = 1Ω	2	800 3	mA (min) A A (max)
Ripple Rejection	f_{RIPPLE} = 120 Hz, V_{RIPPLE} = 1 Vrms, I_O = 50 mA		60	dB (min)
Output Impedance	I_O = 50 mAdc and 10 mArms @ 1 kHz	100		mΩ
Output Noise	10 Hz to 100 kHz, I_O = 50 mA	1		mVrms
Long Term Stability		20		mV/1000 Hr
Maximum Operational Input Voltage	Continuous		26	V (min)

Electrical Characteristics

V_{IN} = 14.4V, C_O = 10 μF, −40°C ≤ T_J ≤ 125°C, unless otherwise specified (Continued)

Parameter	Conditions	Typ (Note 4)	Limit (Note 5)	Units (Limit)
REGULATOR OUTPUT (Continued)				
Peak Transient Input Voltage	V_O ≤ 7V, R_L = 100Ω, t_f = 100 ms		80	V (min)
Reverse DC Input Voltage	V_O ≥ −0.6V, R_L = 100Ω		−18	V (min)
Reverse Transient Input Voltage	t_r = 1 ms, R_L = 100Ω		−50	V (min)
RESET OUTPUT				
Threshold	ΔV_O Required for Reset Condition (Note 7)	 −250	−80 −400	mV (min) mV mV (max)
Output Low Voltage	I_{SINK} = 1.6 mA, V_{IN} = 3.2V	0.15	0.4	V (max)
Internal Pull-Up Resistance		30		kΩ
Delay Time	C_{DELAY} = 10 nF (See Timing Curve)	19		ms
Minimum Operational V_{IN} on Power Up	Delayed Reset Output ≤ 0.8V, I_{SINK} = 1.6 mA, R_L = 100Ω	2.2	3.2	V V (min)
Minimum Operational V_O on Power Down	Delay Reset Output ≤ 0.8V, I_{SINK} = 10 μA, V_{IN} = 0V	0.7		V
DELAY CAPACITOR PIN				
Threshold Difference (ΔV_{DELAY})	Change in Delay Capacitor Voltage Required for Reset Output to Return High	 3.75	3.5 4.1	V (min) V V (max)
Charging Current (I_{DELAY})		 2.0	1.0 3.0	μA (min) μA μA (max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. **Operating Ratings** indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the **Electrical Characteristics.**

Note 2: Human body model; 100 pF discharged through a 1.5 kΩ resistor.

Note 3: The maximum power dissipation is a function of T_{JMAX}, and θ_{JA}, and T_A, and is limited by thermal shutdown. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{JMAX}-T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the device will go into thermal shutdown. For the LM2926 and LM2927, the junction-to-ambient thermal resistance is 53°C/W, and the junction-to-case thermal resistance is 3°C/W.

Note 4: Typicals are at T_J = 25°C and represent the most likely parametric norm.

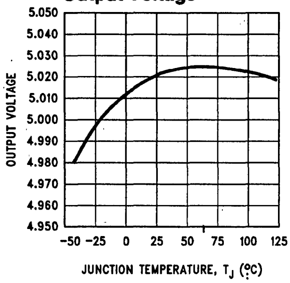
Note 5: Limits are 100% guaranteed by production testing.

Note 6: Dropout voltage is the input-output differential at which the circuit ceases to regulate against any further reduction in input voltage. Dropout voltage is measured when the output voltage (V_O) has dropped 100 mV from the nominal value measured at V_{IN} = 14.4V.

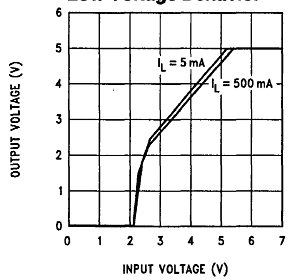
Note 7: The reset flag is set LOW when the output voltage has dropped an amount, ΔV_O, from the nominal value measured at V_{IN} = 14.4V.

Typical Performance Characteristics

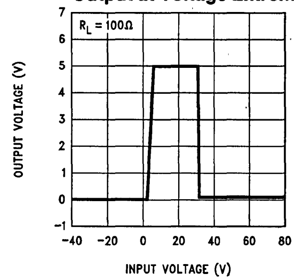
Output Voltage



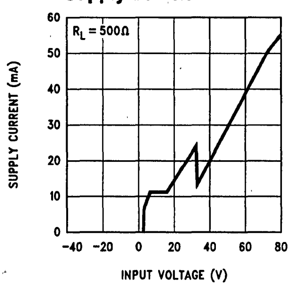
Low Voltage Behavior



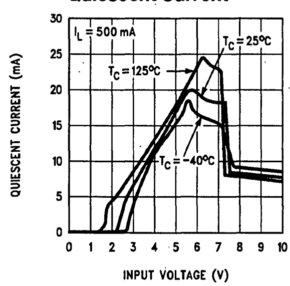
Output at Voltage Extremes



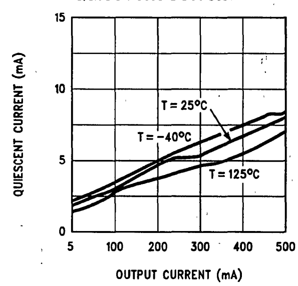
Supply Current



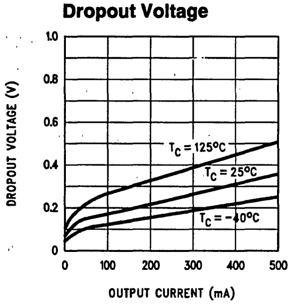
Quiescent Current



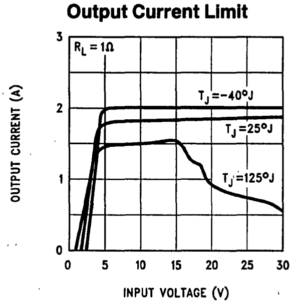
Quiescent Current



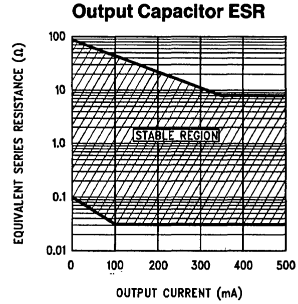
Dropout Voltage



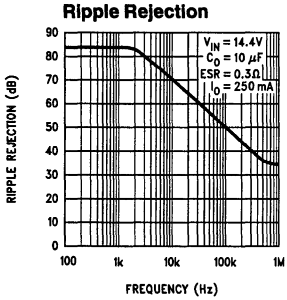
Output Current Limit



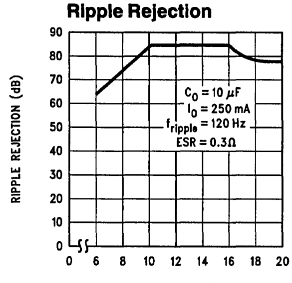
Output Capacitor ESR



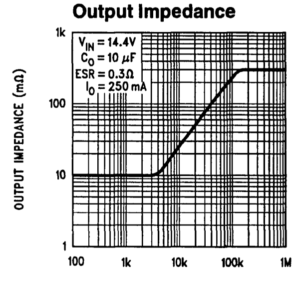
Ripple Rejection



Ripple Rejection

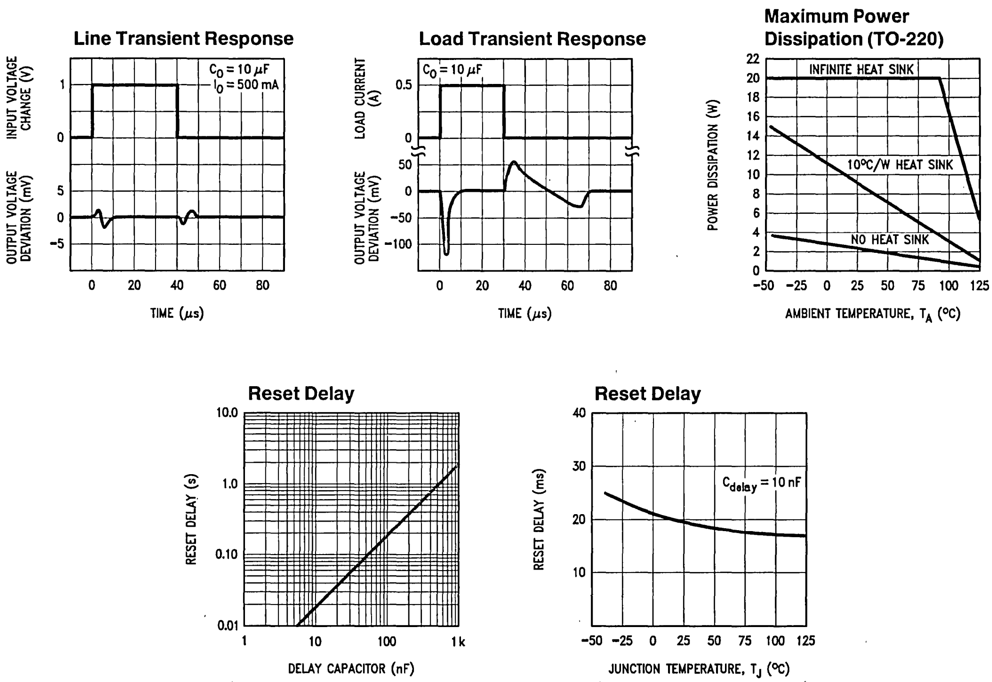


Output Impedance



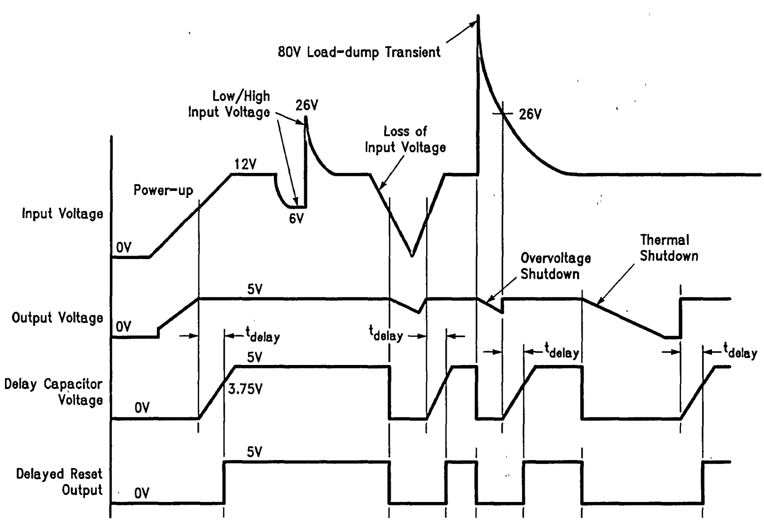
TL/H/10759-3

Typical Performance Characteristics (Continued)



TL/H/10759-4

Typical Circuit Waveforms



TL/H/10759-5

Applications Information

EXTERNAL CAPACITORS

The LM2926/7 output capacitor is required for stability. Without it, the regulator output will oscillate at amplitudes as high as several volts peak-to-peak at frequencies up to 500 kHz. Although 10 μF is the minimum recommended value, the actual size and type may vary depending upon the application load and temperature range. Capacitor equivalent series resistance (ESR) also affects stability. The region of stable operation is shown in the **Typical Performance Characteristics** (Output Capacitor ESR curve).

Output capacitors can be increased in size to any desired value above 10 μF. One possible purpose of this would be to maintain the output voltage during brief conditions of input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum electrolytics freeze at temperatures below $-30°C$, reducing their effective capacitance to zero. To maintain regulator stability down to $-40°C$, capacitors rated at that temperature (such as tantalums) must be used.

DELAYED RESET

The delayed reset output is designed to hold a microprocessor in a reset state on system power-up for a programmable time interval to allow the system clock and other powered circuitry to stabilize. A full reset interval is also generated whenever the output voltage falls out of regulation. The circuit is tripped whenever the output voltage of the regulator is out of regulation by the Reset Threshold value. This can be caused by low input voltages, over current conditions, over-voltage shutdown, thermal shutdown, and by both power-up and power-down sequences. When the reset circuit detects one of these conditions, the delay capacitor is discharged by an SCR and held in a discharged state by a saturated NPN switch. As long as the delay capacitor is held low, the reset output is also held low. Because of the action of the SCR, the reset output cannot glitch on noise or transient fault conditions. A full reset pulse is obtained for any fault condition that trips the reset circuit.

When the output regains regulation, the SCR is switched off and a small current ($I_{DELAY} = 2\ \mu A$) begins charging the delay capacitor. When the capacitor voltage increases 3.75V (ΔV_{DELAY}) from its discharged value, the reset output is again set HIGH. The delay time is calculated by:

$$\text{delay time} = \frac{C_{DELAY}\,\Delta V_{DELAY}}{I_{DELAY}} \quad (1)$$

or

$$\text{delay time} \approx 1.9 \times 10^6\, C_{DELAY} \quad (2)$$

The constant, 1.9×10^6, has a $\pm 20\%$ tolerance from device to device. The total delay time error budget is the sum of the 20% device tolerance and the tolerance of the external capacitor. For a 20% timing capacitor tolerance, the worst case total timing variation would amount to $\pm 40\%$, or a ratio of 2.33:1. In most applications the minimum expected reset pulse is of interest. This occurs with minimum C_{DELAY}, minimum ΔV_{DELAY}, and maximum I_{DELAY}. ΔV_{DELAY} and I_{DELAY} are fully specified in the **Electrical Characteristics.** Graphs showing the relationship between delay time and both temperature and C_{DELAY} are shown in the **Typical Performance Characteristics.**

As shown in *Figure 1,* the delayed reset output is pulled low by an NPN transistor (Q2), and pulled high to V_O by an internal 30 kΩ resistor (R3) and PNP transistor (Q3). The reset output will operate when V_O is sufficient to bias Q2 (0.7V or more). At lower voltages the reset output will be in a high impedance condition. Because of differences in the V_{BE} of Q2 and Q3 and the values of R1 and R2, Q2 is guaranteed by design to bias *before* Q3, providing a smooth transition from the high impedance state when $V_O < 0.7V$, to the active low state when $V_O > 0.7V$.

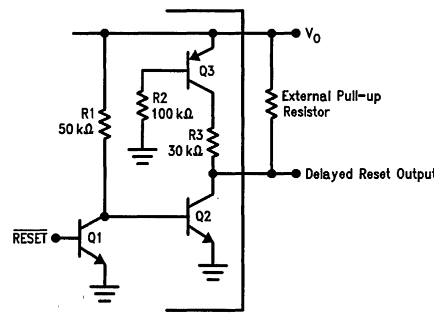


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FIGURE 1. Delay Reset Output

The static reset characteristics are shown in *Figure 2.* This shows the relationship between the input voltage, the regultor output and reset output. Plots are shown for various external pull-up resistors ranging in value from 3 kΩ to an open circuit. Any external pull-up resistance causes the reset output to follow the regulator output until Q2 is biased ON. C_{DELAY} has no effect on this characteristic.

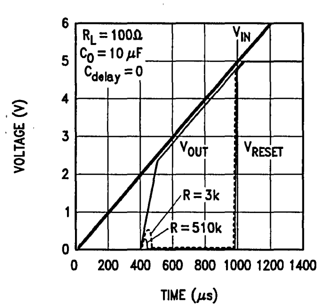

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FIGURE 2. Reset Output Behavior during Power-Up

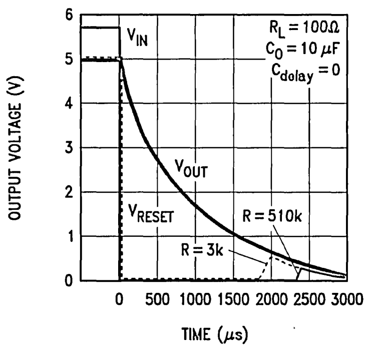
Figure 2 is useful for determing reset performance at any particular input voltage. Dynamic performance at power-up will closely follow the characteristics illustrated in *Figure 2,* except for the delay added by C_{DELAY} when V_O reaches 5V.

The dynamic reset characteristics at power-down are illustrated by the curve shown in *Figure 3.* At time t=0 the input voltage is instantaneously brought to 0V, leaving the output powered by C_O. As the voltage on C_O decays (discharged by a 100Ω load resistor), the reset output is held low. As V_O drops below 0.7V, the reset rises up slightly should there be any external pull-up resistance. With no external resistance, the reset line stays low throughout the entire power down cycle. If the input voltage does not fall instantaneously, the reset signal will tend to follow the performance characteristics shown in *Figure 2.*

Applications Information (Continued)

SYSTEM DESIGN CONSIDERATIONS

Many microprocessors are specified for operation at 5V ±10%, although they often continue operating well outside this range. Others, such as certain members of the COPS family of microcontrollers, are specified for operation as low as 2.4V.



TL/H/10759-8

FIGURE 3. Reset Output Behavior during Power-Down

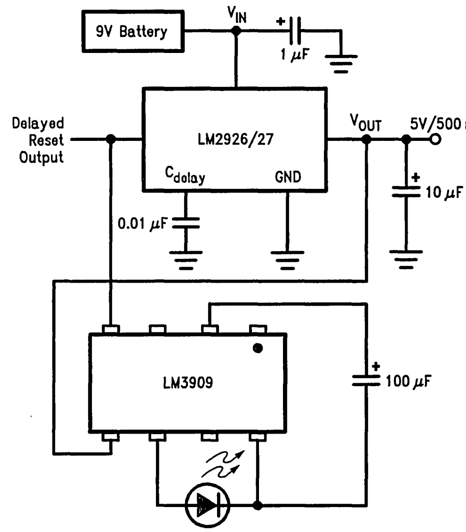
Of particular concern is low voltage operation, which occurs in battery operated systems when the battery reaches the end of its discharge cycle. Under this condition, when the supply voltage is outside the guaranteed operating range, the clock may continue to run and the microprocessor will attempt to execute instructions. If the supply voltage is outside the guaranteed operating range, the instructions may not execute properly and a hardware reset such as is supplied by the LM 2926/7 may fail to bring the processor under control. The LM2926/7 reset output may be more efficiently employed in certain applications as a means of defeating memory WRITE lines, clocks, or external loads, rather than depending on unspecified microprocessor operating conditions.

In critical applications the microprocessor reset input should be fully characterized and guaranteed to operate until the clock ceases oscillating.

INPUT TRANSIENTS

The LM2926/7 are guaranteed to withstand positive input transients to 80V followed by an exponential decay of τ = 20 ms (t_f = 100 ms, or 5 time constants) while maintaining an output of less than 7V. The regulator remains operational to 26 V_{DC}, and shuts down if this value is exceeded.

Battery Powered Regulator with Flashing LED for Low Battery Indication



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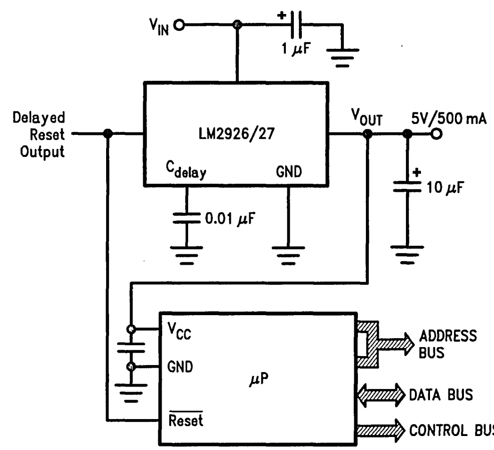
General Microprocessor Configuration



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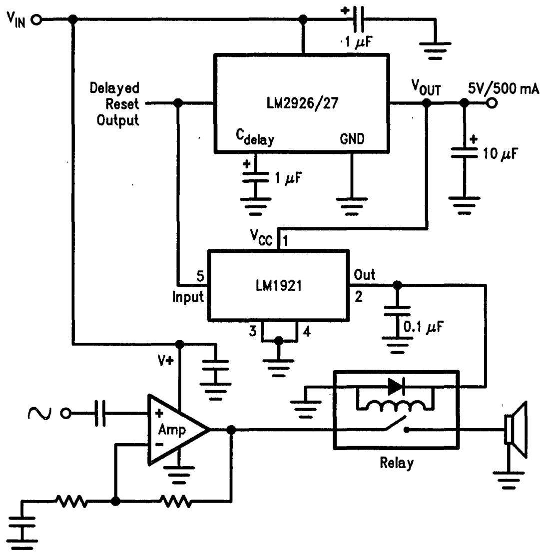
Applications Information (Continued)

Using the Reset to De-Activate Power Loads. The LM1921 is a Fully Protected 1 Amp High-Side Driver.



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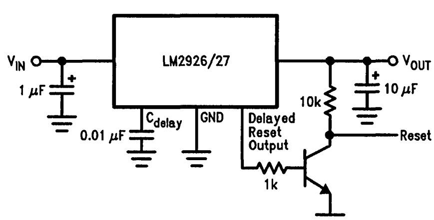
Generating an Active High Reset Signal



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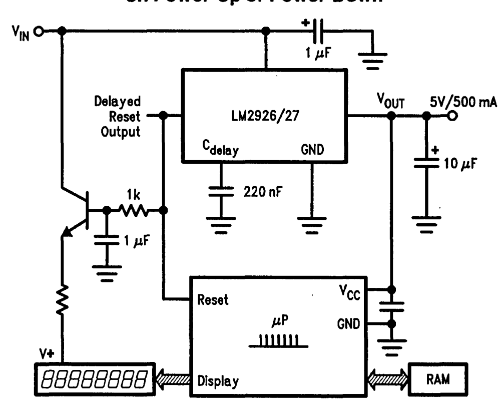
Using the Reset to Ensure an Accurate Display on Power-Up or Power-Down



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National Semiconductor

LM2930 3-Terminal Positive Regulator

General Description

The LM2930 3-terminal positive regulator features an ability to source 150 mA of output current with an input-output differential of 0.6V or less. Efficient use of low input voltages obtained, for example, from an automotive battery during cold crank conditions, allows 5V circuitry to be properly powered with supply voltages as low as 5.6V. Familiar regulator features such as current limit and thermal overload protection are also provided.

Designed originally for automotive applications, the LM2930 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (40V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both internal circuits and the load. The LM2930 cannot be harmed by temporary mirror-image insertion.

Fixed outputs of 5V and 8V are available in the plastic TO-220 and TO-263 power packages.

Features

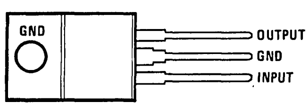
- Input-output differential less than 0.6V
- Output current in excess of 150 mA
- Reverse battery protection
- 40V load dump protection
- Internal short circuit current limit
- Internal thermal overload protection
- Mirror-image insertion protection
- P+ Product Enhancement tested

Voltage Range

LM2930T-5.0	5V
LM2930T-8.0	8V
LM2930S-5.0	5V
LM2930S-8.0	8V

Connection Diagrams

(TO-220)
Plastic Package



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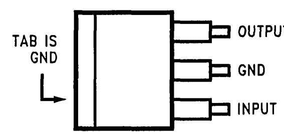
Front View

Order Number LM2930T-5.0 or LM2930T-8.0
See NS Package Number T03B

(TO-263)
Plastic Surface-Mount Package



TL/H/5539–7

Top View

TL/H/5539–8

Side View

Order Number LM2930S-5.0 or LM2930S-8.0
See NS Package Number TS3B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overvoltage Protection	40V
Reverse Voltage (100 ms)	−12V
Reverse Voltage (DC)	−6V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	−40°C to +85°C
Maximum Junction Temperature	125°C
Storage Temperature Range	−65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	230°C

Electrical Characteristics (Note 2)

LM2930-5.0 $V_{IN}=14V$, $I_O=150$ mA, $T_j=25°C$ (Note 5), C2 = 10 μF, unless otherwise specified

Parameter	Conditions	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Unit
Output Voltage		5	5.3 4.7		V_{MAX} V_{MIN}
	$6V \leq V_{IN} \leq 26V$, $5\ mA \leq I_O \leq 150\ mA$ $-40°C \leq T_J \leq 125°C$			5.5 4.5	V_{MAX} V_{MIN}
Line Regulation	$9V \leq V_{IN} \leq 16V$, $I_O=5$ mA $6V \leq V_{IN} \leq 26V$, $I_O=5$ mA	7 30	25 80		mV_{MAX} mV_{MAX}
Load Regulation	$5\ mA \leq I_O \leq 150\ mA$	14	50		mV_{MAX}
Output Impedance	100 mA_{DC} & 10 mA_{rms}, 100 Hz−10 kHz	200			mΩ
Quiescent Current	$I_O=10$ mA $I_O=150$ mA	4 18	7 40		mA_{MAX} mA_{MAX}
Output Noise Voltage	10 Hz−100 kHz	140			μV_{rms}
Long Term Stability		20			mV/1000 hr
Ripple Rejection	$f_O=120$ Hz	56			dB
Current Limit		400	700 150		mA_{MAX} mA_{MIN}
Dropout Voltage	$I_O=150$ mA	0.32	0.6		V_{MAX}
Output Voltage Under Transient Conditions	$-12V \leq V_{IN} \leq 40V$, $R_L=100\Omega$		5.5 −0.3		V_{MAX} V_{MIN}

Electrical Characteristics (Note 2)

LM2930-8.0 ($V_{IN}=14V$, $I_O=150$ mA, $T_j=25°C$ (Note 5), C2 = 10 μF, unless otherwise specified)

Parameter	Conditions	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Unit
Output Voltage		8	8.5 7.5		V_{MAX} V_{MIN}
	$9.4V \leq V_{IN} \leq 26V$, $5\ mA \leq I_O \leq 150\ mA$, $-40°C \leq T_J \leq 125°C$			8.8 7.2	V_{MAX} V_{MIN}
Line Regulation	$9.4V \leq V_{IN} \leq 16V$, $I_O=5$ mA $9.4V \leq V_{IN} \leq 26V$, $I_O=5$ mA	12 50	50 100		mV_{MAX} mV_{MAX}
Load Regulation	$5\ mA \leq I_O \leq 150\ mA$	25	50		mV_{MAX}
Output Impedance	100 mA_{DC} & 10 mA_{rms}, 100 Hz−10 kHz	300			mΩ
Quiescent Current	$I_O=10$ mA $I_O=150$ mA	4 18	7 40		mA_{MAX} mA_{MAX}
Output Noise Voltage	10 Hz−100 kHz	170			μV_{rms}
Long Term Stability		30			mV/1000 hr
Ripple Rejection	$f_O=120$ Hz	52			dB
Current Limit		400	700 150		mA_{MAX} mA_{MIN}
Dropout Voltage	$I_O=150$ mA	0.32	0.6		V_{MAX}
Output Voltage Under Transient Conditions	$-12V \leq V_{IN} \leq 40V$, $R_L=100\Omega$		8.8 −0.3		V_{MAX} V_{MIN}

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W and for case to ambient temperature is 50°C/W for the TO-220, 73°C/W for the TO-263. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

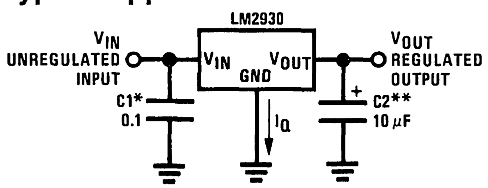
Note 2: All characteristics are measured with a capacitor across the input of 0.1 μF and a capacitor across the output of 10 μF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_W \leq 10$ ms, duty cycle $\leq 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed (but not 100% production tested) over the operating temperature and input current ranges. These limits are not used to calculate outgoing quality levels.

Note 5: To ensure constant junction temperature, low duty cycle pulse testing is used.

Typical Application



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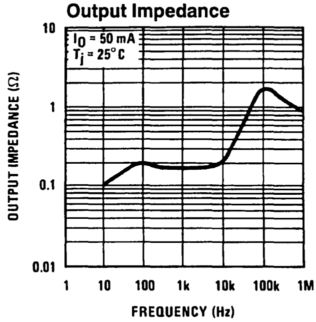
*Required if regulator is located far from power supply filter.

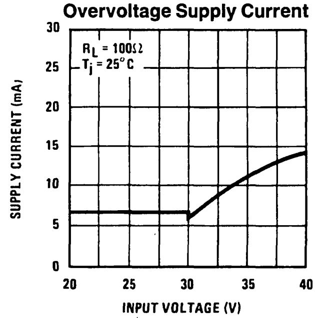
**C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor should be less than 1Ω over the expected operating temperature range.

Typical Performance Characteristics

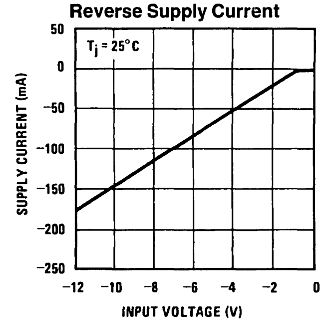
Output Impedance



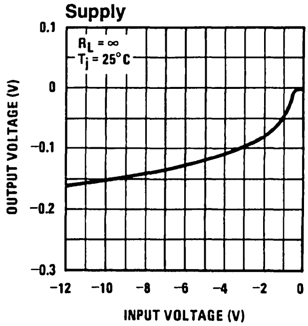
Overvoltage Supply Current



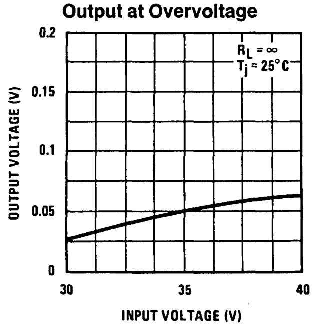
Reverse Supply Current



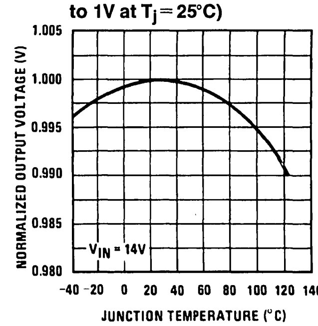
Output at Reverse Supply



Output at Overvoltage



Output Voltage (Normalized to 1V at $T_j = 25°C$)



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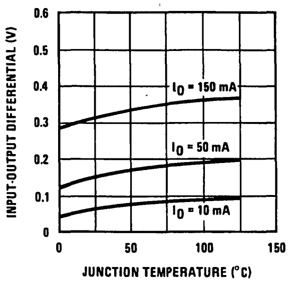
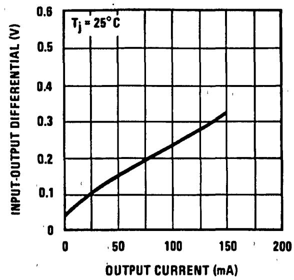
Typical Performance Characteristics (Continued)

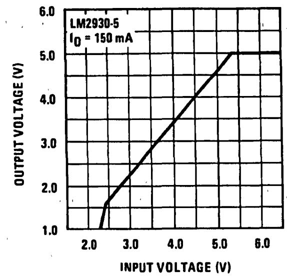
Dropout Voltage



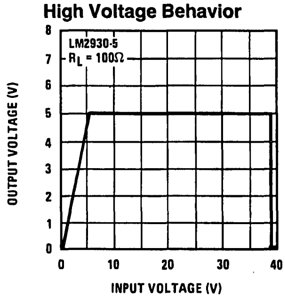
Dropout Voltage



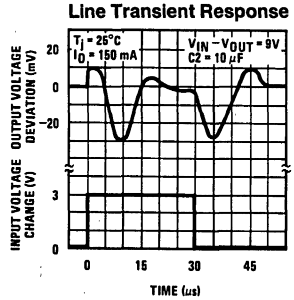
Low Voltage Behavior



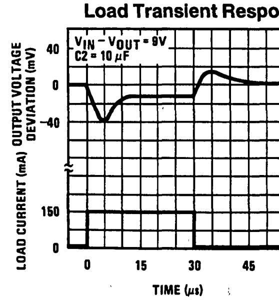
High Voltage Behavior



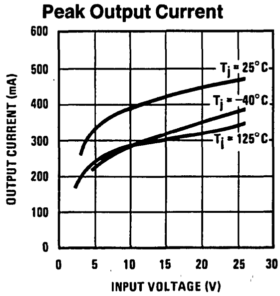
Line Transient Response



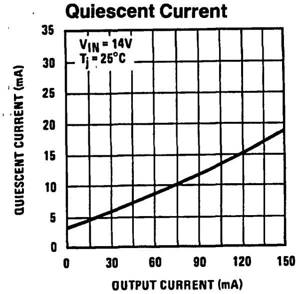
Load Transient Response



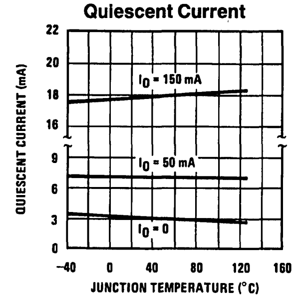
Peak Output Current



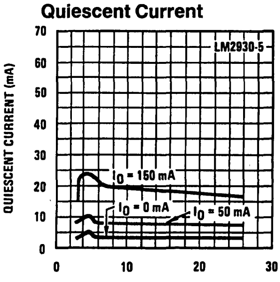
Quiescent Current



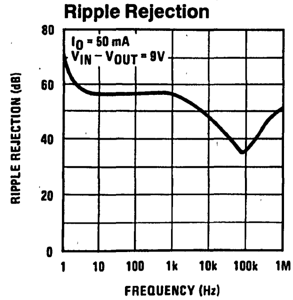
Quiescent Current



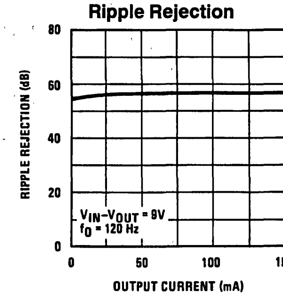
Quiescent Current



Ripple Rejection



Ripple Rejection



TL/H/5539–2

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

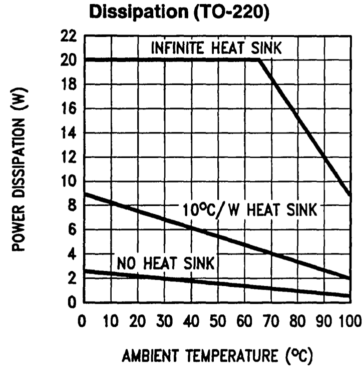
Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

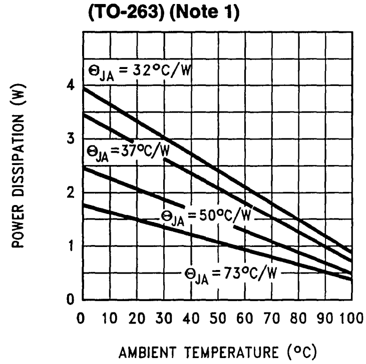
Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Maximum Power Dissipation (TO-220)



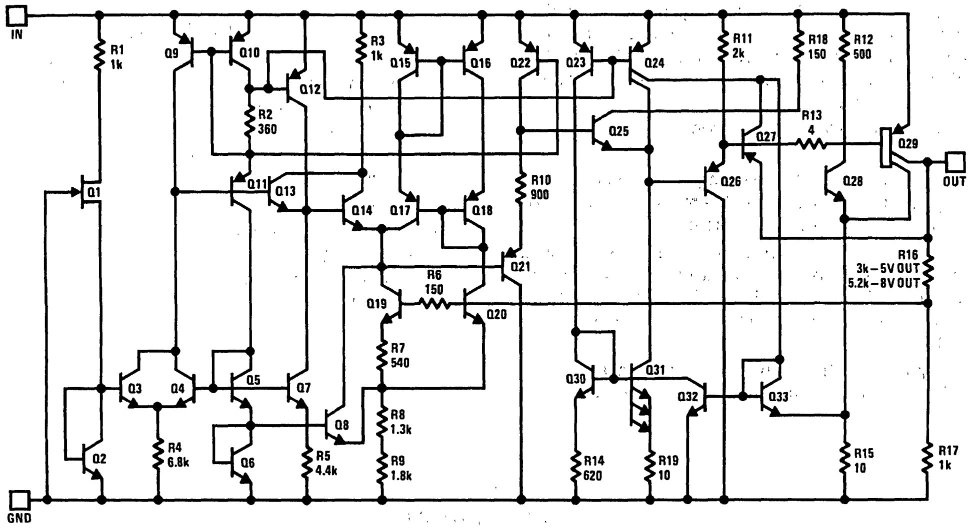
TL/H/5539–6

Maximum Power Dissipation (TO-263) (Note 1)



TL/H/5539–9

Schematic Diagram



TL/H/5539–10

National Semiconductor

LM2931 Series Low Dropout Regulators

General Description

The LM2931 positive voltage regulator features a very low quiescent current of 1 mA or less when supplying 10 mA loads. This unique characteristic and the extremely low input-output differential required for proper regulation (0.2V for output currents of 10 mA) make the LM2931 the ideal regulator for standby power systems. Applications include memory standby circuits, CMOS and other low power processor power supplies as well as systems demanding as much as 100 mA of output current.

Designed originally for automotive applications, the LM2931 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both internal circuits and the load. The LM2931 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

The LM2931 family includes a fixed 5V output (±3.8% tolerance for A grade) or an adjustable output with ON/OFF pin. Both versions are available in a TO-220 power package, TO-263 surface mount package, and an 8-lead surface mount package. The fixed output version is also available in the TO-92 plastic package.

Features

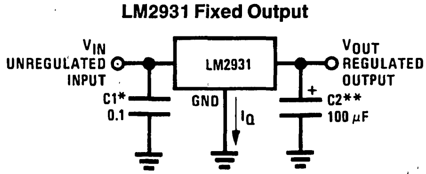
- Very low quiescent current
- Output current in excess of 100 mA
- Input-output differential less than 0.6V
- Reverse battery protection
- 60V load dump protection
- −50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Mirror-image insertion protection
- Available in TO-220, TO-92, TO-263 or SO-8 packages
- Available as adjustable with TTL compatible switch

Output Voltage Options

Output Number	Part Number	Package Type
5V	LM2931T-5.0, LM2931AT-5.0	3-Lead TO-220
	LM2931S-5.0, LM2931AS-5.0	3-Lead TO-263
	LM2931Z-5.0, LM2931AZ-5.0	TO-92
	LM2931M-5.0, LM2931AM-5.0	8-Lead SO
Adjustable, 3V to 24V	LM2931CT	5-Lead TO-220
	LM2931CS	5-Lead TO-263
	LM2931CM	8-Lead SO

Typical Applications

LM2931 Fixed Output

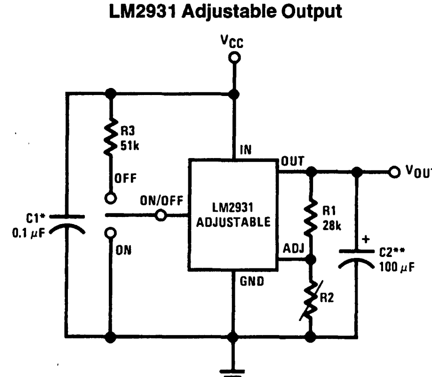


TL/H/5254–4

*Required if regulator is located far from power supply filter.

**C2 must be at least 100 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

LM2931 Adjustable Output



TL/H/5254–5

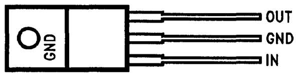
$$V_{OUT} = \text{Reference Voltage} \times \frac{R1 + R2}{R1}$$

Note: Using 27k for R1 will automatically compensate for errors in V_{OUT} due to the input bias current of the ADJ pin (approximately 1 µA).

Connection Diagrams and Ordering Information

FIXED 5V OUTPUT

TO-220 3-Lead Power Package

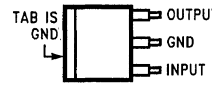


TL/H/5254-6

Front View

Order Number LM2931T-5.0 or LM2931AT-5.0
See NS Package Number T03B

TO-263 Surface-Mount Package



TL/H/5254-11

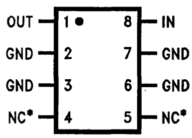
Top View

TL/H/5254-12

Side View

Order Number LM2931S-5.0 or LM2931AS-5.0
See NS Package Number TS3B

8-Pin Surface Mount



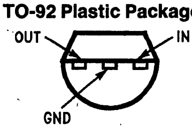
TL/H/5254-7

*NC = Not internally connected

Top View

Order Number LM2931M-5.0 or LM2931AM-5.0
See NS Package Number M08A

TO-92 Plastic Package



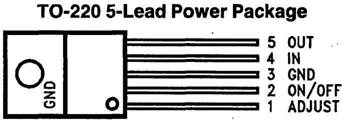
TL/H/5254-8

Bottom View

Order Number LM2931Z-5.0 or LM2931AZ-5.0
See NS Package Number Z03A

ADJUSTABLE OUTPUT VOLTAGE

TO-220 5-Lead Power Package

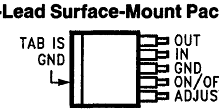


TL/H/5254-9

Front View

Order Number LM2931CT
See NS Package Number T05A

TO-263
5-Lead Surface-Mount Package



TL/H/5254-13

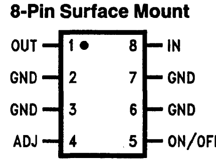
Top View

TL/H/5254-14

Side View

Order Number LM2931CS
See NS Package Number TS5B

8-Pin Surface Mount



TL/H/5254-10

Top View

Order Number LM2931CM
See NS Package Number M08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overvoltage Protection	
LM2931A, LM2931CT, LM2931CS Adjustable	60V
LM2931	50V
Internal Power Dissipation (Notes 1 and 3)	Internally Limited
Operating Ambient Temperature Range	−40°C to +85°C
Maximum Junction Temperature	125°C
Storage Temperature Range	−65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	230°C
ESD Tolerance (Note 4)	2000V

Electrical Characteristics for Fixed 5V Version

V_{IN} = 14V, I_O = 10 mA, T_J = 25°C, C2 = 100 μF (unless otherwise specified) (Note 1)

Parameter	Conditions	LM2931A-5.0 Typ	LM2931A-5.0 Limit (Note 2)	LM2931-5.0 Typ	LM2931-5.0 Limit (Note 2)	Units Limit
Output Voltage		5	5.19 4.81		5.25 4.75	V_{MAX} V_{MIN}
	6.0V ≤ V_{IN} ≤ 26V, I_O = 100 mA −40°C ≤ T_j ≤ 125°C		**5.25** **4.75**		**5.5** **4.5**	V_{MAX} V_{MIN}
Line Regulation	9V ≤ V_{IN} ≤ 16V 6V ≤ V_{IN} ≤ 26V	2 4	10 30	2 4	10 30	mV_{MAX} mV_{MAX}
Load Regulation	5 mA ≤ I_O ≤ 100 mA	14	50	14	50	mV_{MAX}
Output Impedance	100 mA_{DC} and 10 mA_{rms}, 100 Hz–10 kHz	200		200		$m\Omega_{MAX}$
Quiescent Current	I_O ≤ 10 mA, 6V ≤ V_{IN} ≤ 26V −40°C ≤ T_j ≤ 125°C I_O = 100 mA, V_{IN} = 14V, T_j = 25°C	0.4 15	**1.0** 30 5	0.4 15	**1.0**	mA_{MAX} mA_{MAX} mA_{MIN}
Output Noise Voltage	10 Hz–100 kHz, C_{OUT} = 100 μF	500		500		$\mu V_{rms MAX}$
Long Term Stability		20		20		mV/1000 hr
Ripple Rejection	f_O = 120 Hz	80	**55**	80		dB_{MIN}
Dropout Voltage	I_O = 10 mA I_O = 100 mA	0.05 0.3	0.2 0.6	0.05 0.3	0.2 0.6	V_{MAX} V_{MAX}
Maximum Operational Input Voltage		33	 26	33	 26	V_{MAX} V_{MIN}
Maximum Line Transient	R_L = 500Ω, V_O ≤ 5.5V, T = 1 ms, τ ≤ 100 ms	70	60	70	50	V_{MIN}
Reverse Polarity Input Voltage, DC	V_O ≥ −0.3V, R_L = 500Ω	−30	−15	−30	−15	V_{MIN}
Reverse Polarity Input Voltage, Transient	T = 1 ms, τ ≤ 100 ms, R_L = 500Ω	−80	−50	−80	−50	V_{MIN}

Note 1: See circuit in Typical Applications. To ensure constant junction temperature, low duty cycle pulse testing is used.

Note 2: All limits are guaranteed for T_J = 25°C (standard type face) or over the full operating junction temperature range of −40°C to +125°C **(bold type face).**

Note 3: The maximum power dissipation is a function of maximum junction temperature T_{Jmax}, total thermal resistance θ_{JA}, and ambient temperature T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2931 will go into thermal shutdown. For the LM2931 in the TO-92 package, θ_{JA} is 195°C/W; in the SO-8 package, θ_{JA} is 160°C/W, and in the TO-220 package, θ_{JA} is 50°C/W; and in the TO-263 package, θ_{JA} is 73°C/W. If the TO-220 package is used with a heat sink, θ_{JA} is the sum of the package thermal resistance junction-to-case of 3°C/W and the thermal resistance added by the heat sink and thermal interface.

If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Note 4: Human body model, 100 pF discharged through 1.5 kΩ.

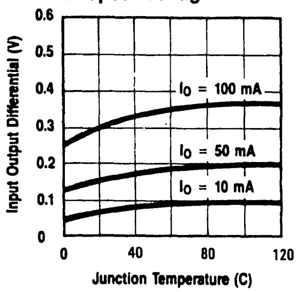
Electrical Characteristics for Adjustable Version

V_{IN} = 14V, V_{OUT} = 3V, I_O = 10 mA, T_J = 25°C, R1 = 27k, C2 = 100 μF (unless otherwise specified) (Note 1)

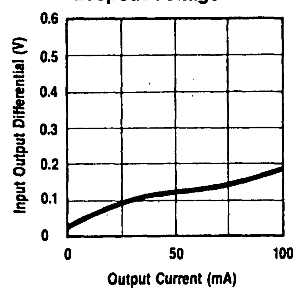
Parameter	Conditions	Typ	Limit	Units Limit
Reference Voltage		1.20	1.26 1.14	V_{MAX} V_{MIN}
	$I_O \le$ 100 mA, $-40°C \le T_j \le 125°C$, R1 = 27k Measured from V_{OUT} to Adjust Pin		**1.32** **1.08**	V_{MAX} V_{MIN}
Output Voltage Range			24 3	V_{MAX} V_{MIN}
Line Regulation	V_{OUT} + 0.6V $\le V_{IN} \le$ 26V	0.2	1.5	mV/V_{MAX}
Load Regulation	5 mA $\le I_O \le$ 100 mA	0.3	1	$\%_{MAX}$
Output Impedance	100 mA_{DC} and 10 mA_{rms}, 100 Hz–10 kHz	40		mΩ/V
Quiescent Current	I_O = 10 mA I_O = 100 mA During Shutdown R_L = 500Ω	0.4 15 0.8	1 1	mA_{MAX} mA mA_{MAX}
Output Noise Voltage	10 Hz–100 kHz	100		μV_{rms}/V
Long Term Stability		0.4		%/1000 hr
Ripple Rejection	f_O = 120 Hz	0.02		%/V
Dropout Voltage	$I_O \le$ 10 mA I_O = 100 mA	0.05 0.3	0.2 0.6	V_{MAX} V_{MAX}
Maximum Operational Input Voltage		33	26	V_{MIN}
Maximum Line Transient	I_O = 10 mA, Reference Voltage $\le$ 1.5V T = 1 ms, $\tau \le$ 100 ms	70	60	V_{MIN}
Reverse Polarity Input Voltage, DC	$V_O \ge -0.3V$, R_L = 500Ω	−30	−15	V_{MIN}
Reverse Polarity Input Voltage, Transient	T = 1 ms, $\tau \le$ 100 ms, R_L = 500Ω	−80	−50	V_{MIN}
On/Off Threshold Voltage On Off	V_O=3V	 2.0 2.2	 1.2 3.25	 V_{MAX} V_{MIN}
On/Off Threshold Current		20	50	μA_{MAX}

Typical Performance Characteristics

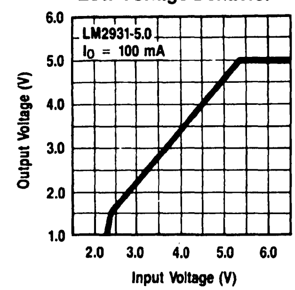
Dropout Voltage



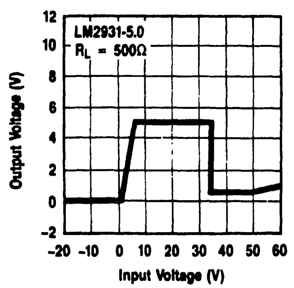
Dropout Voltage



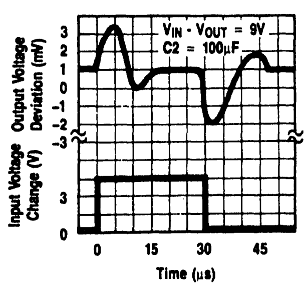
Low Voltage Behavior



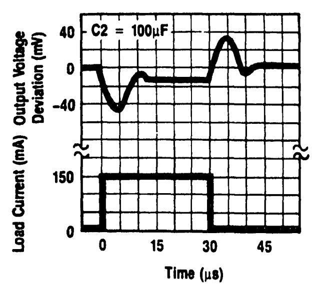
Output at Voltage Extremes



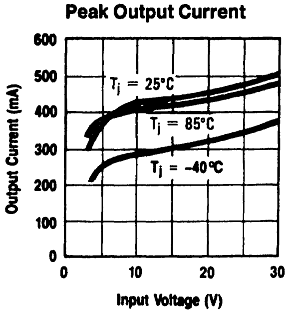
Line Transient Response



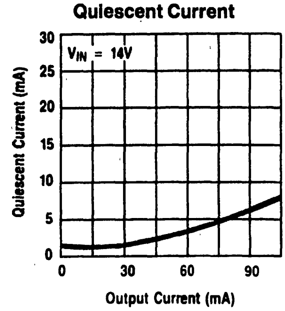
Load Transient Response



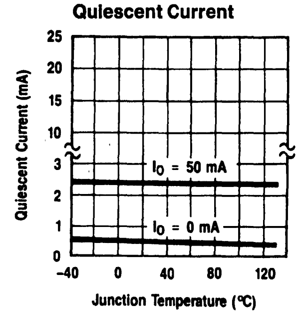
Peak Output Current



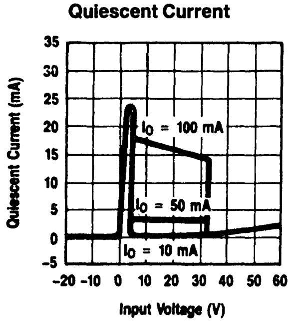
Quiescent Current



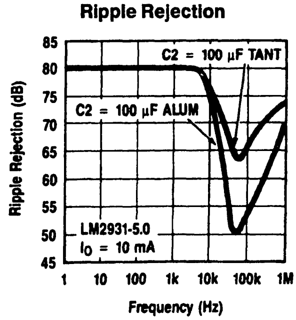
Quiescent Current



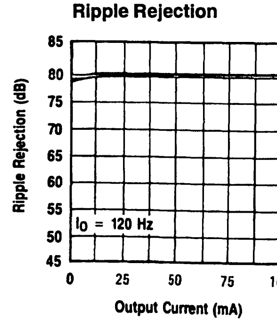
Quiescent Current



Ripple Rejection



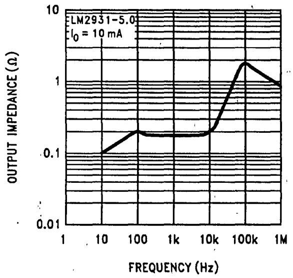
Ripple Rejection



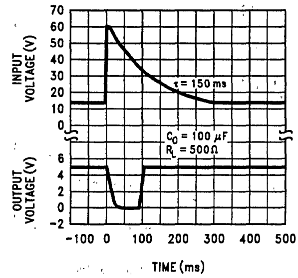
TL/H/5254–2

Typical Performance Characteristics

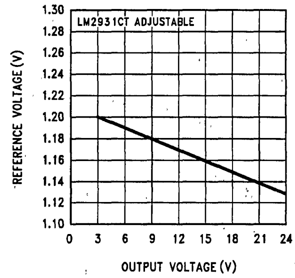
Output Impedance



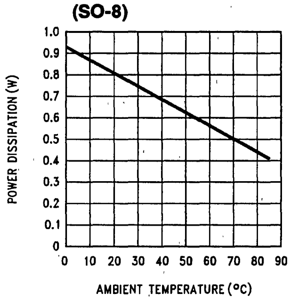
Operation During Load Dump



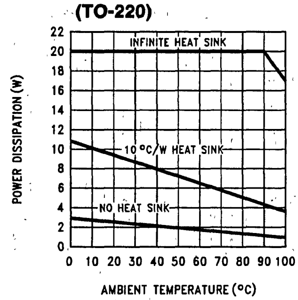
Reference Voltage



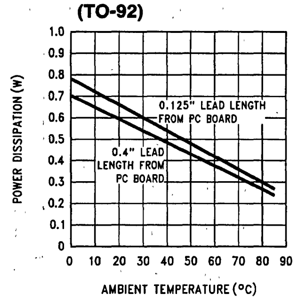
Maximum Power Dissipation (SO-8)



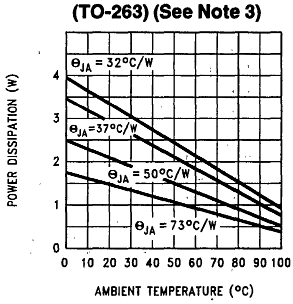
Maximum Power Dissipation (TO-220)



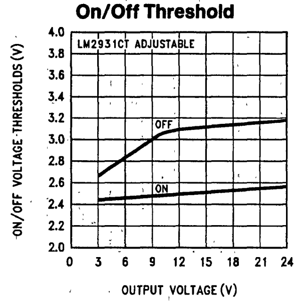
Maximum Power Dissipation (TO-92)



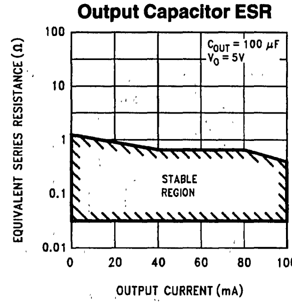
Maximum Power Dissipation (TO-263) (See Note 3)



On/Off Threshold

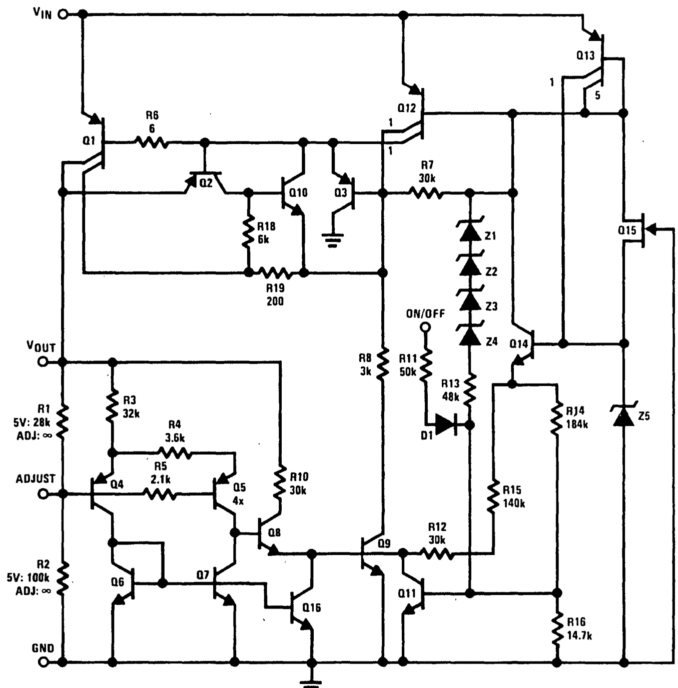


Output Capacitor ESR



TL/H/5254-3

Schematic Diagram



TL/H/5254-1

2

Application Hints

One of the distinguishing factors of the LM2931 series regulators is the requirement of an output capacitor for device stability. The value required varies greatly depending upon the application circuit and other factors. Thus some comments on the characteristics of both capacitors and the regulator are in order.

High frequency characteristics of electrolytic capacitors depend greatly on the type and even the manufacturer. As a result, a value of capacitance that works well with the LM2931 for one brand or type may not necessary be sufficient with an electrolytic of different origin. Sometimes actual bench testing, as described later, will be the only means to determine the proper capacitor type and value. Experience has shown that, as a rule of thumb, the more expensive and higher quality electrolytics generally allow a smaller value for regulator stability. As an example, while a high-quality 100 μF aluminum electrolytic covers all general application circuits, similar stability can be obtained with a tantalum electrolytic of only 47 μF. This factor of two can generally be applied to any special application circuit also.

Another critical characteristic of electrolytics is their performance over temperature. While the LM2931 is designed to operate to $-40°C$, the same is not always true with all electrolytics (hot is generally not a problem). The electrolyte in many aluminum types will freeze around $-30°C$, reducing their effective value to zero. Since the capacitance is needed for regulator stability, the natural result is oscillation (and lots of it) at the regulator output. For all application circuits where cold operation is necessary, the output capacitor must be rated to operate at the minimum temperature. By coincidence, worst-case stability for the LM2931 also occurs at minimum temperatures. As a result, in applications where the regulator junction temperature will never be less than 25°C, the output capacitor can be reduced approximately by a factor of two over the value needed for the entire temperature range. To continue our example with the tantalum electrolytic, a value of only 22 μF would probably thus suffice. For high-quality aluminum, 47 μF would be adequate in such an application.

Another regulator characteristic that is noteworthy is that stability decreases with higher output currents. This sensible fact has important connotations. In many applications, the LM2931 is operated at only a few milliamps of output current or less. In such a circuit, the output capacitor can be further reduced in value. As a rough estimation, a circuit that is required to deliver a maximum of 10 mA of output current from the regulator would need an output capacitor of only half the value compared to the same regulator required to deliver the full output current of 100 mA. If the example of the tantalum capacitor in the circuit rated at 25°C junction temperature and above were continued to include a maximum of 10 mA of output current, then the 22 μF output capacitor could be reduced to only 10 μF.

In the case of the LM2931CT adjustable regulator, the minimum value of output capacitance is a function of the output voltage. As a general rule, the value decreases with higher output voltages, since internal loop gain is reduced.

At this point, the procedure for bench testing the minimum value of an output capacitor in a special application circuit should be clear. Since worst-case occurs at minimum operating temperatures and maximum operating currents, the entire circuit, including the electrolytic, should be cooled to the minimum temperature. The input voltage to the regulator should be maintained at 0.6V above the output to keep internal power dissipation and die heating to a minimum. Worst-case occurs just after input power is applied and before the die has had a chance to heat up. Once the minimum value of capacitance has been found for the brand and type of electrolytic in question, the value should be doubled for actual use to account for production variations both in the capacitor and the regulator. (All the values in this section and the remainder of the data sheet were determined in this fashion.)

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage at a specified frequency.

Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

National Semiconductor

LM2935 Low Dropout Dual Regulator

General Description

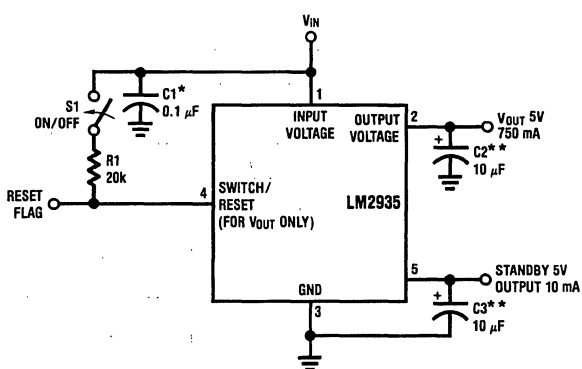
The LM2935 dual 5V regulator provides a 750 mA output as well as a 10 mA standby output. It features a low quiescent current of 3 mA or less when supplying 10 mA loads from the 5V standby regulator output. This unique characteristic and the extremely low input-output differential required for proper regulation (0.55V for output currents of 10 mA) make the LM2935 the ideal regulator for power systems that include standby memory. Applications include microprocessor power supplies demanding as much as 750 mA of output current.

Designed for automotive applications, the LM2935 and all regulated circuitry are protected from reverse battery installations or 2 battery jumps. During line transients, such as a load dump (60V) when the input voltage to the regulator can momentarily exceed the specified maximum operating voltage, the 0.75A regulator will automatically shut down to protect both internal circuits and the load while the standby regulator will continue to power any standby load. The LM2935 cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- Two 5V regulated outputs
- Output current in excess of 750 mA
- Low quiescent current standby regulator
- Input-output differential less than 0.6V at 0.5A
- Reverse battery protection
- 60V load dump protection
- −50V reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- Available in 5-lead TO-220
- ON/OFF switch controls high current output
- Reset error flag
- P+ Product Enhancement tested

Typical Application Circuit



*Required if regulator is located far from power supply filter.

**C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

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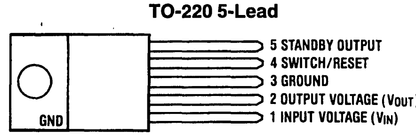
FIGURE 1. Test and Application Circuit

Connection Diagram

TO-220 5-Lead



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Front View

Order Number LM2935T
See NS Package Number T05A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Operating Range	26V
Overvoltage Protection	60V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range	−40°C to + 125°C
Maximum Junction Temperature	150°C
Storage Temperature Range	−65°C to + 150°C
Lead Temp. (Soldering, 10 seconds)	230°C

Electrical Characteristics for V_{OUT}

V_{IN} = 14V, I_O = 500 mA, T_J = 25°C (Note 4), C2 = 10 μF (unless otherwise specified)

Parameter	Conditions	Typ	Tested Limit (Note 3)	Units Limit
Output Voltage	$6V \le V_{IN} \le 26V$, $5\ mA \le I_O \le 500\ mA$, $-40°C \le T_J \le 125°C$ (Note 2)	5.00	5.25 4.75	V_{MAX} V_{MIN}
Line Regulation	$9V \le V_{IN} \le 16V$, $I_O = 5\ mA$ $6V \le V_{IN} \le 26V$, $I_O = 5\ mA$	4 10	25 50	mV_{MAX} mV_{MAX}
Load Regulation	$5\ mA \le I_O \le 500\ mA$	10	50	mV_{MAX}
Output Impedance	500 mA_{DC} and 10 mA_{rms}, 100 Hz–10 kHz	200		mΩ
Quiescent Current	$I_O \le 10\ mA$, No Load on Standby $I_O = 500\ mA$, No Load on Standby $I_O = 750\ mA$, No Load on Standby	3 40 90	 100 	mA mA_{MAX} mA
Output Noise Voltage	10 Hz–100 kHz	100		μV_{rms}
Long Term Stability		20		mV/1000 hr
Ripple Rejection	$f_O = 120\ Hz$	66		dB
Dropout Voltage	$I_O = 500\ mA$ $I_O = 750\ mA$	0.45 0.82	0.6	V_{MAX}
Current Limit		1.2	0.75	A_{MIN}
Maximum Operational Input Voltage		31	26	V_{MIN}
Maximum Line Transient	$V_O \le 5.5V$	70	60	V
Reverse Polarity Input Voltage, DC		−30	−15	V
Reverse Polarity Input Voltage, Transient	1% Duty Cycle, $\tau \le 100$ ms, 10Ω Load	−80	−50	V
Reset Output Voltage Low High	 $R1 = 20k$, $V_{IN} = 4.0V$ $R1 = 20k$, $V_{IN} = 14V$	 0.9 5.0	 1.2 6.0 4.5	 V_{MAX} V_{MAX} V_{MIN}
Reset Output Current	Reset = 1.2V	5		mA
ON/OFF Resistor	R1 (± 10% Tolerance)		20	$k\Omega_{MAX}$

Note 1: Thermal resistance without a heat sink for junction to case temperature is 3°C/W(TO-220). Thermal resistance for TO-220 case to ambient temperature is 50° C/W.

Note 2: The temperature extremes are guaranteed but not 100% production tested. This parameter is not used to calculate outgoing AQL.

Note 3: Tested Limits are guaranteed and 100% tested in production.

Note 4: To ensure constant junction temperature, low duty cycle pulse testing is used.

Electrical Characteristics for Standby Output

$I_O = 10$ mA, $V_{IN} = 14V$, S1 open, $C_{OUT} = 10$ µF, $T_J = 25°C$ (Note 4), (unless otherwise specified)

Parameter	Standby Output Conditions	Typ	Tested Limit	Units Limit
Output Voltage	$I_O \leq 10$ mA, $6V \leq V_{IN} \leq 26V$, $-40°C \leq T_J \leq 125°C$	5.00	5.25 4.75	V_{MAX} V_{MIN}
Tracking	V_{OUT}–Standby Output Voltage	50	200	mV_{MAX}
Line Regulation	$6V \leq V_{IN} \leq 26V$	4	50	mV_{MAX}
Load Regulation	1 mA $\leq I_O \leq$ 10 mA	10	50	mV_{MAX}
Output Impedance	10 mA_{DC} and 1 mA_{rms}, 100 Hz–10 kHz	1		Ω
Quiescent Current	$I_O \leq 10$ mA, V_{OUT} OFF (Note 2)	2	3	mA_{MAX}
Output Noise Voltage	10 Hz–100 kHz	300		µV
Long Term Stability		20		mV/1000 hr
Ripple Rejection	$f_O = 120$ Hz	66		dB
Dropout Voltage	$I_O \leq 10$ mA	0.55	0.7	V_{MAX}
Current Limit		70	25	mA_{MIN}
Maximum Operational Input Voltage	$V_O \leq 6V$	70	60	V_{MIN}
Reverse Polarity Input Voltage, DC	$V_O \geq -0.3V$, 510Ω Load	−30	−15	V_{MIN}
Reverse Polarity Input Voltage, Transient	1% Duty Cycle T ≤ 100 ms 500Ω Load	−80	−50	V_{MIN}

Typical Circuit Waveforms

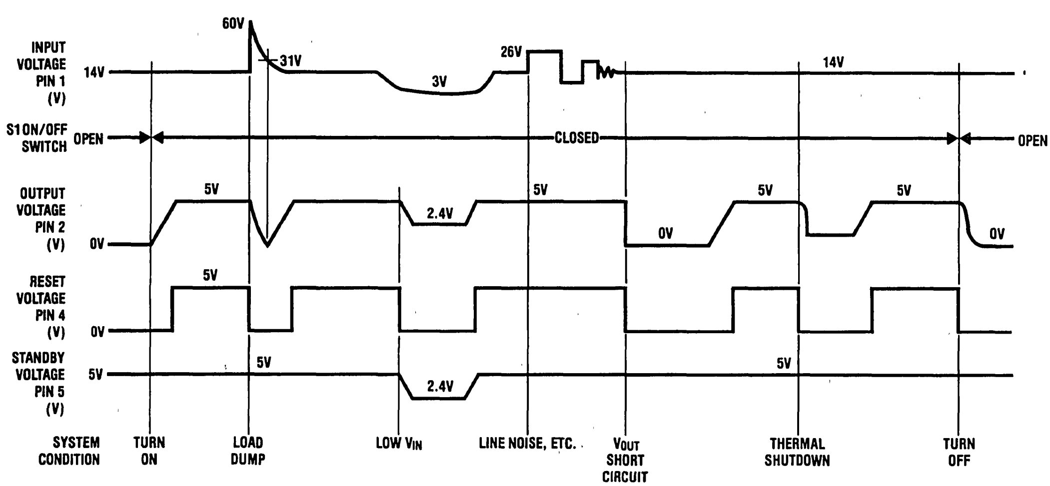
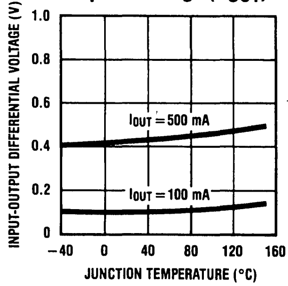


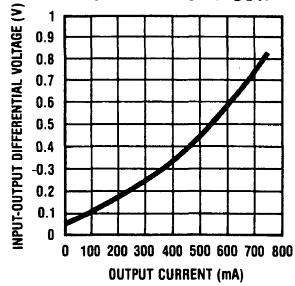
FIGURE 2

Typical Performance Characteristics

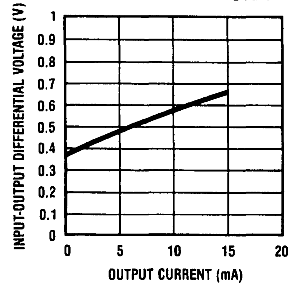
Dropout Voltage (V_{OUT})



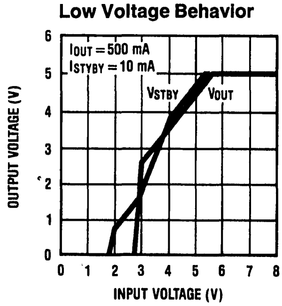
Dropout Voltage (V_{OUT})



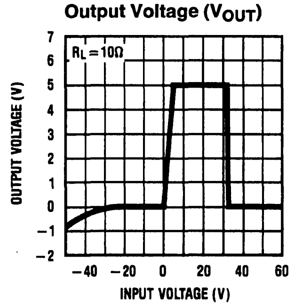
Dropout Voltage (V_{STBY})



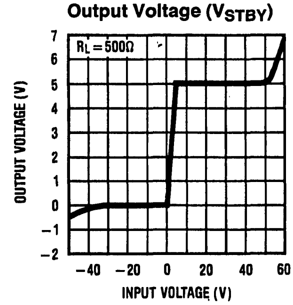
Low Voltage Behavior



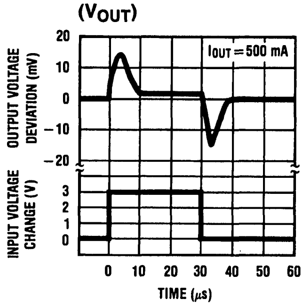
Output Voltage (V_{OUT})



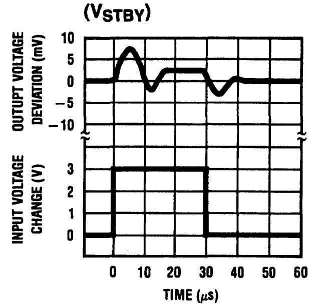
Output Voltage (V_{STBY})



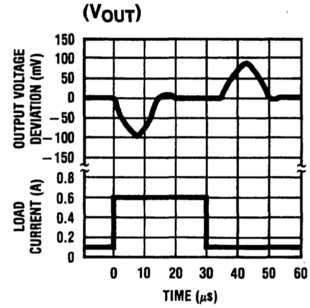
Line Transient Response (V_{OUT})



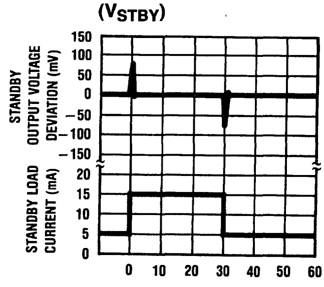
Line Transient Response (V_{STBY})



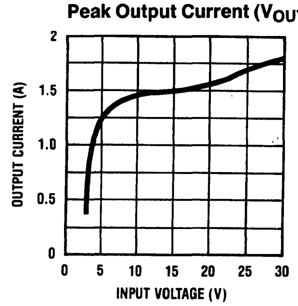
Load Transient Response (V_{OUT})



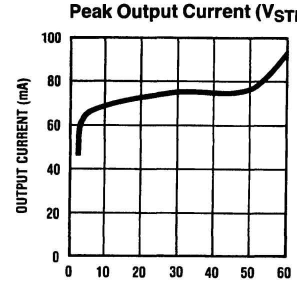
Load Transient Response (V_{STBY})



Peak Output Current (V_{OUT})



Peak Output Current (V_{STBY})



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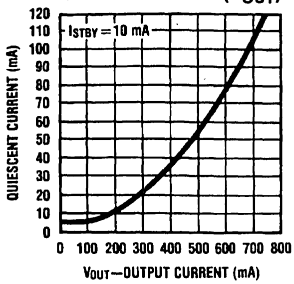
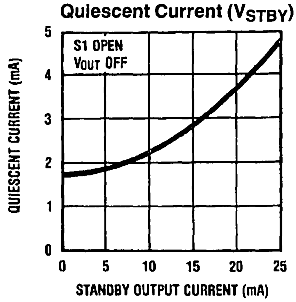
Typical Performance Characteristics (Continued)

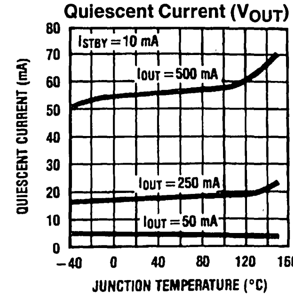
Quiescent Current (V_{OUT})



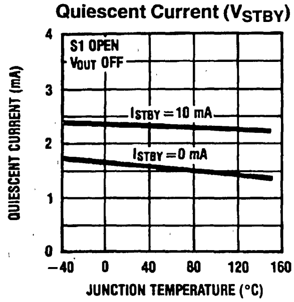
Quiescent Current (V_{STBY})



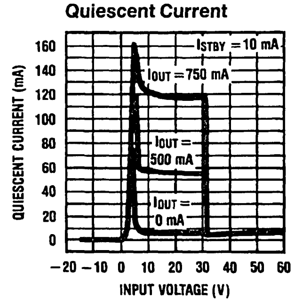
Quiescent Current (V_{OUT})



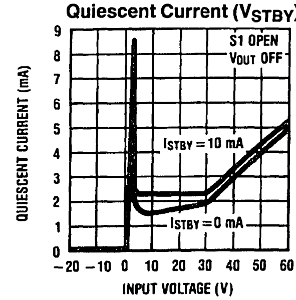
Quiescent Current (V_{STBY})



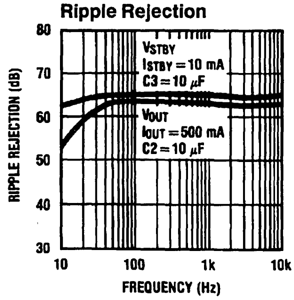
Quiescent Current



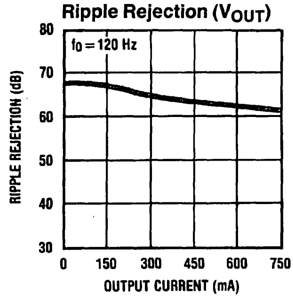
Quiescent Current (V_{STBY})



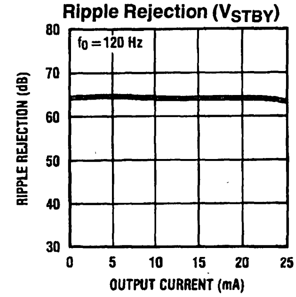
Ripple Rejection



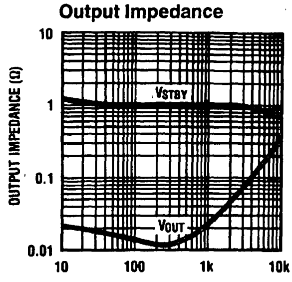
Ripple Rejection (V_{OUT})



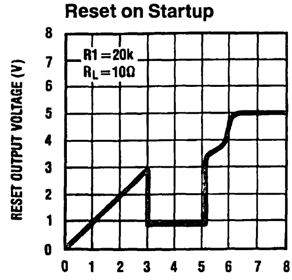
Ripple Rejection (V_{STBY})



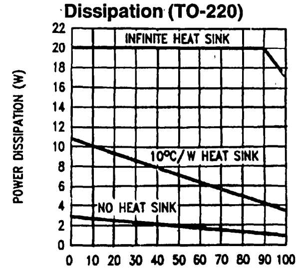
Output Impedance



Reset on Startup



Maximum Power Dissipation (TO-220)



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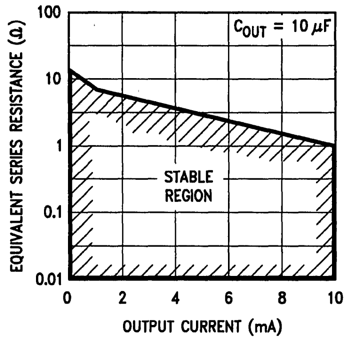
Typical Performance Characteristics (Continued)

Output Capacitor ESR (Standby Output, Pin 5)



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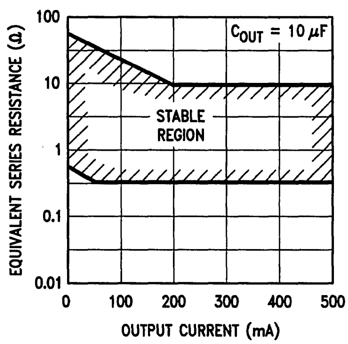
Output Capacitor ESR (Main Output, Pin 2)



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Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at 14V input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

Quiescent Current: The part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Application Hints

EXTERNAL CAPACITORS

The LM2935 output capacitors are required for stability. Without them, the regulator outputs will oscillate, sometimes by many volts. Though the 10µF shown are the minimum recommended values, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also factors in the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst-case is usually determined at the minimum ambient temperature and maximum load expected.

Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltage during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than −30°C, reducing their effective capacitance to zero. To maintain regulator stability down to −40°C, capacitors rated at that temperature (such as tantalums) must be used.

No capacitor must be attached to the ON/OFF and ERROR FLAG pin. Due to the internal circuits of the IC, oscillation on this pin could result.

STANDBY OUTPUT

The LM2935 differs from most fixed voltage regulators in that it is equipped with two regulator outputs instead of one. The additional output is intended for use in systems requiring standby memory circuits. While the high current regulator output can be controlled with the ON/OFF pin described below, the standby output remains on under all conditions as long as sufficient input voltage is applied to the IC. Thus, memory and other circuits powered by this output remain unaffected by positive line transients, thermal shutdown, etc.

The standby regulator circuit is designed so that the quiescent current to the IC is very low (<3 mA) when the other regulator output is off.

Application Hints (Continued)

In applications where the standby output is not needed, it may be disabled by connecting a resistor from the standby output to the supply voltage. This eliminates the need for a more expensive capacitor on the output to prevent unwanted oscillations. The value of the resistor depends upon the minimum input voltage expected for a given system. Since the standby output is shunted with an internal 5.7V zener (*Figure 3*), the current through the external resistor should be sufficient to bias R2 and R3 up to this point. Approximately 60 μA will suffice, resulting in a 10k external resistor for most applications (*Figure 4*).

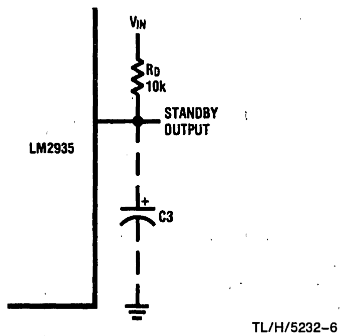

FIGURE 4. Disabling Standby Output to Eliminate C3

HIGH CURRENT OUTPUT

Unlike the standby regulated output, which must remain on whenever possible, the high current regulated output is fault protected against overvoltage and also incorporates thermal shutdown. If the input voltage rises above approximately 30V (e.g., load dump), this output will automatically shutdown. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. Thermal shutdown is effective against die overheating since the high current output is the dominant source of power dissipation in the IC.

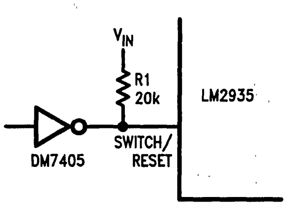

FIGURE 5. Controlling ON/OFF Terminal with a Typical Open Collector Logic Gate

ON/OFF AND ERROR FLAG PIN

This pin has the ability to serve a dual purpose if desired. When controlled in the manner shown in *Figure 1* (common in automotive systems where S1 is the ignition switch), the pin also serves as an output flag that is active low whenever a fault condition is detected with the high current regulated output. In other words, under normal operating conditions, the output voltage of this pin is high (5V). This is set by an internal clamp. If the high current output becomes unregulated for any reason (line transients, short circuit, thermal shutdown, low input voltage, etc.) the pin switches to the active low state, and is capable of sinking several milliamps. This output signal can be used to initiate any reset or start-up procedure that may be required of the system.

The ON/OFF pin can also be driven directly from open collector logic circuits. The only requirement is that the 20k pull-up resistor remain in place *(Figure 5)*. This will not affect the logic gate since the voltage on this pin is limited by the internal clamp in the LM2935 to 5V.

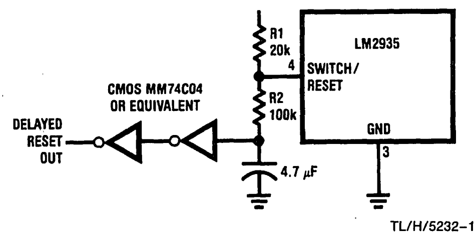

FIGURE 6. Reset Pulse on Power-Up (with approximately 300 ms delay)

Circuit Schematic

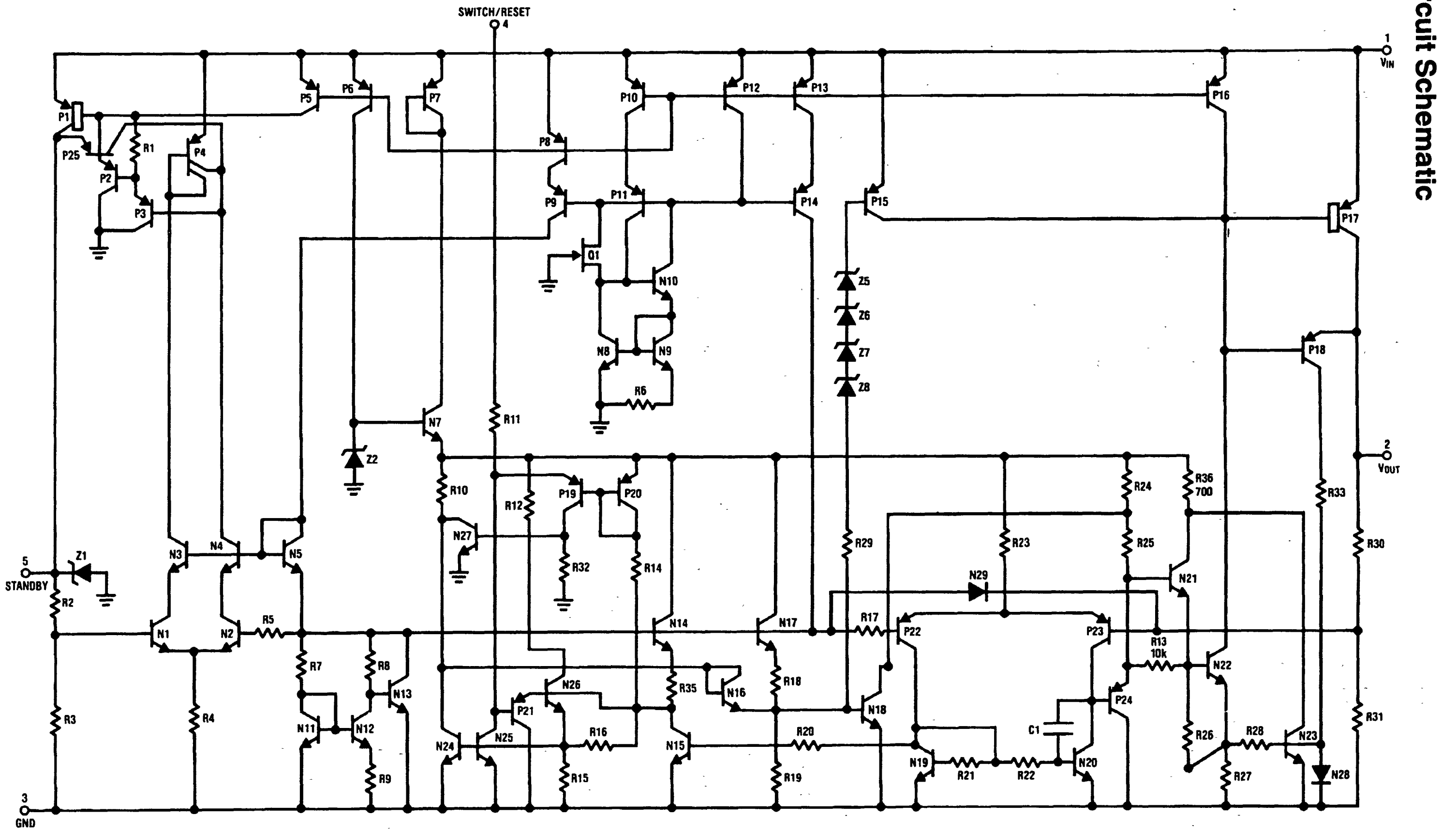

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FIGURE 3

National Semiconductor

LM2936 Ultra-Low Quiescent Current 5V Regulator

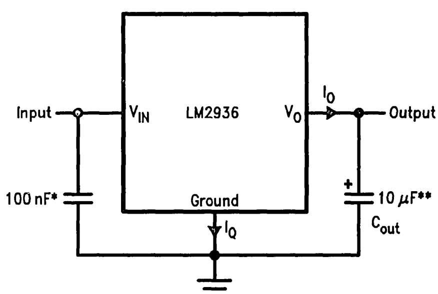
General Description

The LM2936 ultra-low quiescent current regulator features low dropout voltage and low current in the standby mode. With less than 15 μA quiescent current at a 100 μA load, the LM2936 is ideally suited for automotive and other battery operated systems. The LM2936 retains all of the features that are common to low dropout regulators including a low dropout PNP pass device, short circuit protection, reverse battery protection, and thermal shutdown. The LM2936 has a 40V operating voltage limit, −40°C to +125°C operating temperature range, and ±3% output voltage tolerance over the entire output current, input voltage, and temperature range. The LM2936 is available in both a TO-92 package and an 8-pin surface mount package with a fixed 5V output.

Features

- Ultra low quiescent current ($I_Q \leq 15\ \mu A$ for $I_O \leq 100\ \mu A$)
- Fixed 5V, 50 mA output
- Output tolerance ±3% over line, load, and temperature
- Dropout voltage typically 200 mV @ I_O = 50 mA
- Reverse battery protection
- −50V reverse transient protection
- Internal short circuit current limit
- Internal thermal shutdown protection
- 40V operating voltage limit

Typical Application



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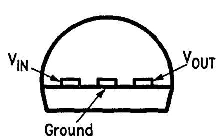
* Required if regulator is located more than 2″ from power supply filter capacitor.

** Required for stability. Must be rated for 10 μF minimum over intended operating temperature range. Effective series resistance (ESR) is critical, see curve. Locate capacitor as close as possible to the regulator output and ground pins. Capacitance may be increased without bound.

Connection Diagrams

TO-92 Plastic Package (Z)



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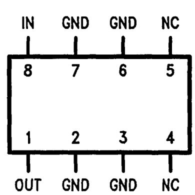
Bottom View

Order Number LM2936Z-5.0
See NS Package Number Z03A

8-Pin SO (M)



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Top View

Order Number LM2936M-5.0
See NS Package Number M08A

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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (Survival)	+60V, −50V
ESD Susceptability (Note 2)	1900V
Power Dissipation (Note 3)	Internally limited
Junction Temperature (T_{Jmax})	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings

Operating Temperature Range	−40°C to +125°C
Maximum Input Voltage (Operational)	40V

Electrical Characteristics

V_{IN} = 14V, I_O = 10 mA, T_J = 25°C, unless otherwise specified. **Boldface** limits apply over entire operating temperature range

Parameter	Conditions	Typical (Note 4)	Tested Limit (Note 5)	Units
Output Voltage	5.5V ≤ V_{IN} ≤ 26V, I_O ≤ 50 mA (Note 6)		**4.85**	V_{min}
		5		V
			5.15	V_{max}
Line Regulation	9V ≤ V_{IN} ≤ 16V	5	10	mV_{max}
	6V ≤ V_{IN} ≤ 40V, I_O = 1 mA	10	30	
Load Regulation	100 μA ≤ I_O ≤ 5 mA	10	30	mV_{max}
	5 mA ≤ I_O ≤ 50 mA	10	30	
Output Impedance	I_O = 30 mAdc and 10 mArms, f = 1000 Hz	450		mΩ
Quiescent Current	I_O = 100 μA, 8V ≤ V_{IN} ≤ 24V	9	15	μA_{max}
	I_O = 10 mA, 8V ≤ V_{IN} ≤ 24V	0.20	0.50	mA_{max}
	I_O = 50 mA, 8V ≤ V_{IN} ≤ 24V	1.5	2.5	mA_{max}
Output Noise Voltage	10 Hz–100 kHz	500		μV_{rms}
Long Term Stability		20		mV/1000 Hr
Ripple Rejection	V_{ripple} = 1 V_{rms}, f_{ripple} = 120 Hz	60	40	dB_{min}
Dropout Voltage	I_O = 100 μA	0.05	0.10	V_{max}
	I_O = 50 mA	0.20	0.40	V_{max}
Reverse Polarity DC Input Voltage	R_L = 500Ω, V_O ≥ −0.3V		−15	V_{min}
Reverse Polarity Transient Input Voltage	R_L = 500Ω, T = 1 ms	−80	−50	V_{min}
Output Leakage with Reverse Polarity Input	V_{IN} = −15V, R_L = 500Ω	−0.1	−600	μA_{max}
Maximum Line Transient	R_L = 500Ω, V_O ≤ 5.5V, T = 40 ms		60	V_{min}
Short Circuit Current	V_O = 0V	120	250	mA_{max}
			65	mA_{min}

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its specified operating ratings.

Note 2: Human body model, 100 pF discharge through a 1.5 kΩ resistor.

Note 3: The maximum power dissipation is a function of T_{Jmax}, Θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\Theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2936 will go into thermal shutdown. For the LM2936Z, the junction-to-ambient thermal resistance (Θ_{JA}) is 195°C/W. For the LM2936M, θja is 160°C/W.

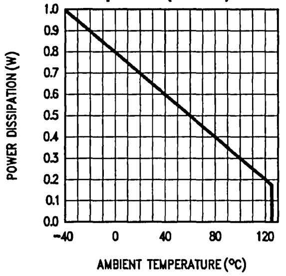
Note 4: Typicals are at 25°C (unless otherwise specified) and represent the most likely parametric norm.

Note 5: Tested limits are guaranteed to National's AOQL (Average Outgoing Quality Level) and 100% tested.

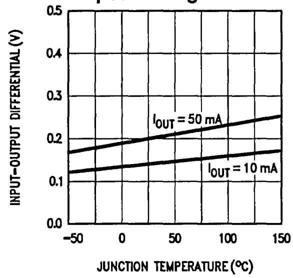
Note 6: To ensure constant junction temperature, pulse testing is used.

Typical Performance Characteristics

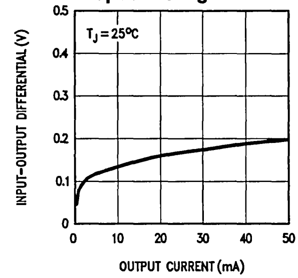
Maximum Power Dissipation (TO-92)



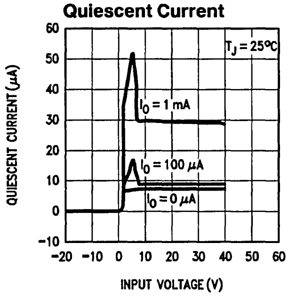
Dropout Voltage



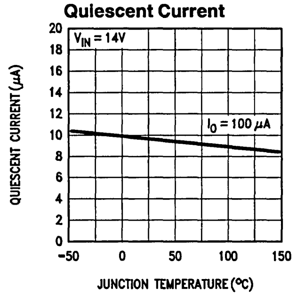
Dropout Voltage



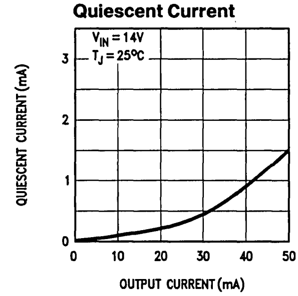
Quiescent Current



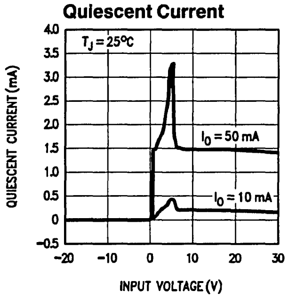
Quiescent Current



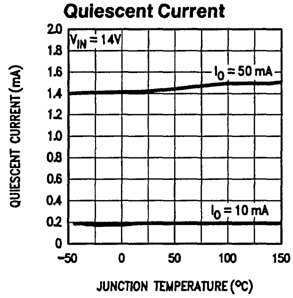
Quiescent Current



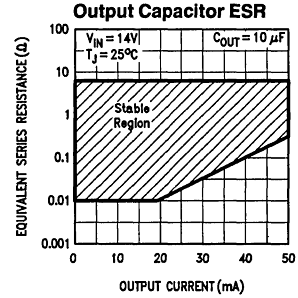
Quiescent Current



Quiescent Current



Output Capacitor ESR



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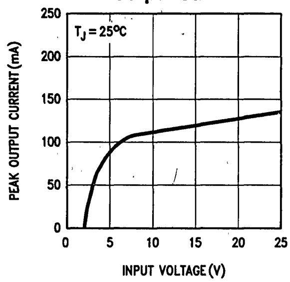
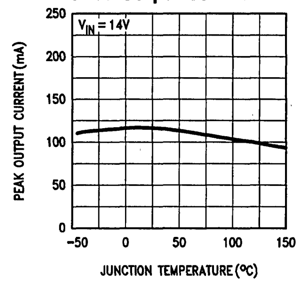
2

Typical Performance Characteristics (Continued)

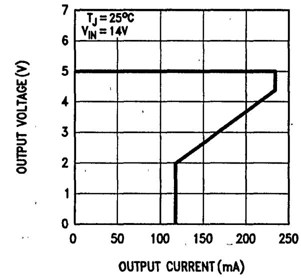
Peak Output Current



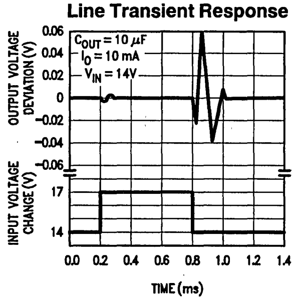
Peak Output Current



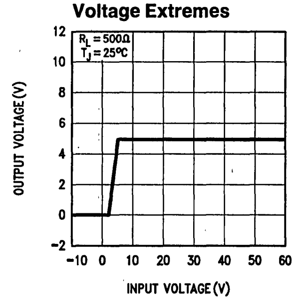
Current Limit



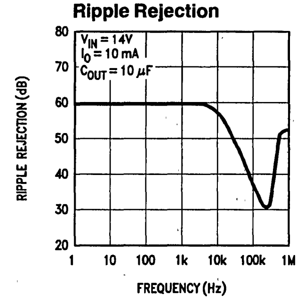
Line Transient Response



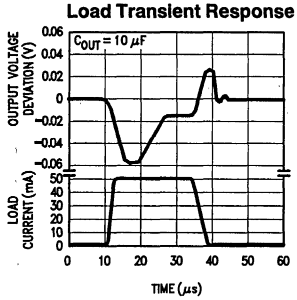
Output at Voltage Extremes



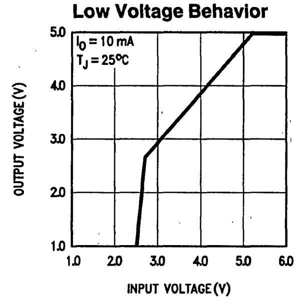
Ripple Rejection



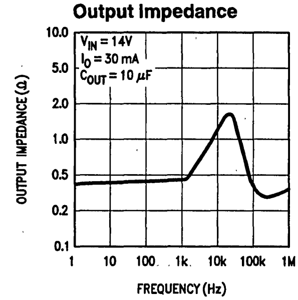
Load Transient Response



Low Voltage Behavior



Output Impedance



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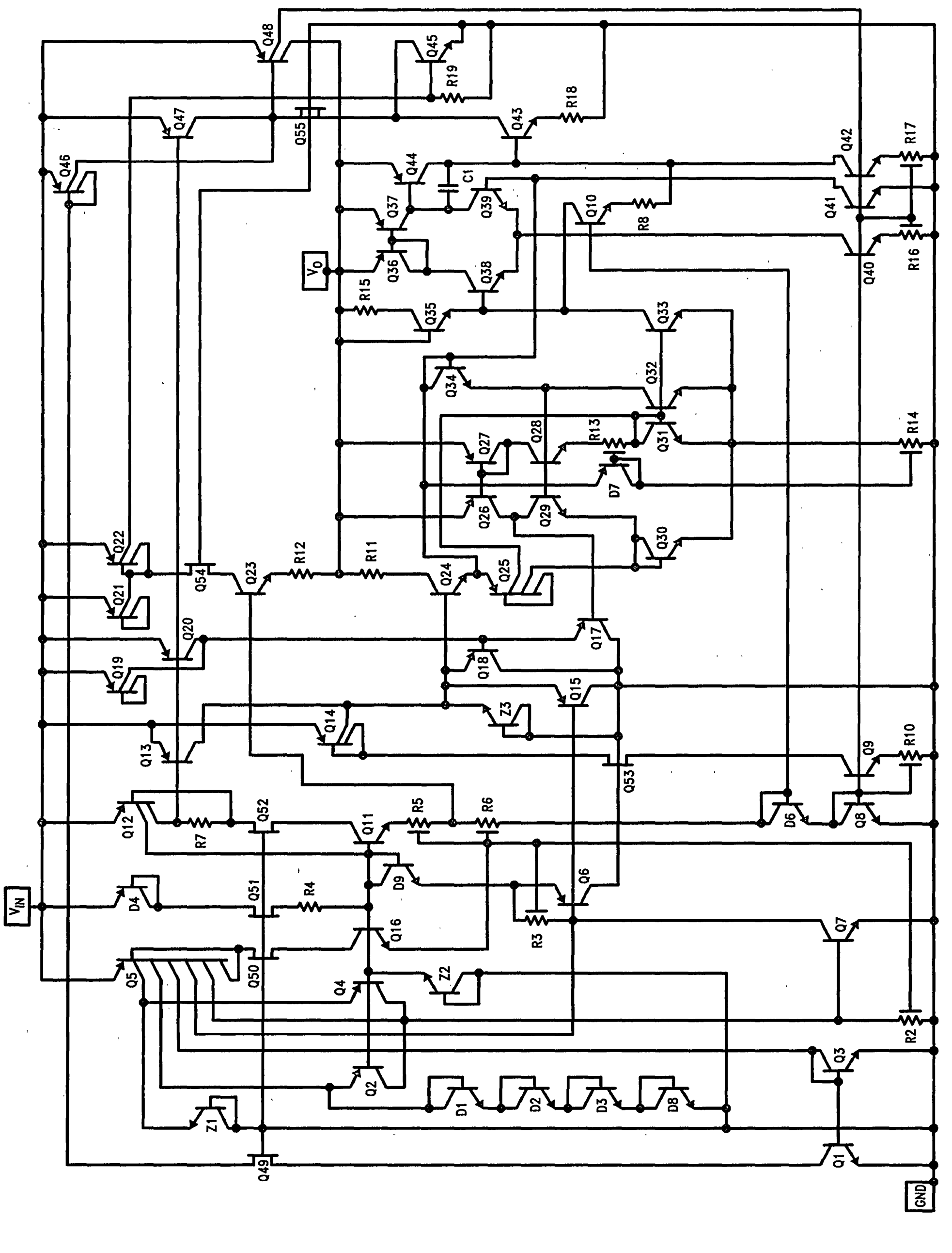
Applications Information

Unlike other PNP low dropout regulators, the LM2936 remains fully operational to 40V. Owing to power dissipation characteristics of the TO-92 package, full output current cannot be guaranteed for all combinations of ambient temperature and input voltage. As an example, consider an LM2936 operating at 25°C ambient. Using the formula for maximum allowable power dissipation given in Note 3, we find that P_{Dmax} = 641 mW at 25°C. Including the small contribution of the quiescent current to total power dissipation the maximum input voltage (while still delivering 50 mA output current) is 17.3V. The device will go into thermal shutdown if it attempts to deliver full output current with an input voltage of more than 17.3V. Similarly, at 40V input and 25°C ambient the LM2936 can deliver 18 mA maximum.

Under conditions of higher ambient temperatures, the voltage and current calculated in the previous examples will drop. For instance, at the maximum ambient of 125°C the LM2936 can only dissipate 128 mW, limiting the input voltage to 7.34V for a 50 mA load, or 3.5 mA output current for a 40V input.

While the LM2936 maintains regulation to 60V, it will not withstand a short circuit above 40V because of safe operating area limitations in the internal PNP pass device. Above 60V the LM2936 will break down with catastrophic effects on the regulator and possibly the load as well. Do not use this device in a design where the input operating voltage may exceed 40V, or where transients are likely to exceed 60V.

Equivalent Schematic Diagram



TL/H/9759–5

National Semiconductor

LM2937 500 mA Low Dropout Regulator

General Description

The LM2937 is a positive voltage regulator capable of supplying up to 500 mA of load current. The use of a PNP power transistor provides a low dropout voltage characteristic. With a load current of 500 mA the minimum input to output voltage differential required for the output to remain in regulation is typically 0.5V (1V guaranteed maximum over the full operating temperature range). Special circuitry has been incorporated to minimize the quiescent current to typically only 10 mA with a full 500 mA load current when the input to output voltage differential is greater than 3V.

The LM2937 requires an output bypass capacitor for stability. As with most low dropout regulators, the ESR of this capacitor remains a critical design parameter, but the LM2937 includes special compensation circuitry that relaxes ESR requirements. The LM2937 is stable for all ESR below 3Ω. This allows the use of low ESR chip capacitors.

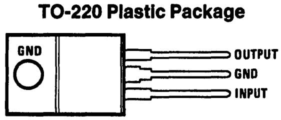
Ideally suited for automotive applications, the LM2937 will protect itself and any load circuitry from reverse battery connections, two-battery jumps and up to +60V/−50V load dump transients. Familiar regulator features such as short circuit and thermal shutdown protection are also built in.

Features

- Fully specified for operation over −40°C to +125°C
- Output current in excess of 500 mA
- Output trimmed for 5% tolerance under all operating conditions
- Typical dropout voltage of 0.5V at full rated load current
- Wide output capacitor ESR range, up to 3Ω
- Internal short circuit and thermal overload protection
- Reverse battery protection
- 60V input transient protection
- Mirror image insertion protection

Connection Diagram and Ordering Information

TO-220 Plastic Package



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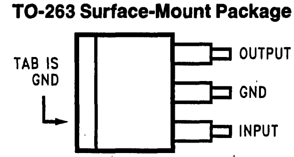
Front View

Order Number LM2937ET-5.0, LM2937ET-8.0, LM2937ET-10, LM2937ET-12 or LM2937ET-15
See NS Package Number T03B

TO-263 Surface-Mount Package



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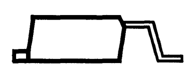
Top View



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Side View

Order Number LM2937ES-5.0, LM2937ES-8.0, LM2937ES-10, LM2937ES-12 or LM2937ES-15
See NS Package Number TS3B

Temperature Range	Output Voltage					NSC Package Drawing	Package
	5.0	8.0	10	12	15		
−40°C ≤ T_A ≤ 125°C	LM2937ES-5.0	LM2937ES-8.0	LM2937ES-10	LM2937ES-12	LM2937ES-15	TS3B	TO-263
	LM2537ET-5.0	LM2537ET-8.0	LM2537ET-10	LM2537ET-12	LM2537ET-15	T03B	TO-220

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Continuous	26V
Transient ($t \leq 100$ ms)	60V
Internal Power Dissipation (Note 2)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	230°C
ESD Susceptibility (Note 3)	2 kV

Operating Conditions (Note 1)

Temperature Range (T_J) (Note 2)	−40°C to +125°C
Maximum Input Voltage	26V

Electrical Characteristics

$V_{IN} = V_{NOM} + 5V$ (Note 4), $I_{OUT} = 500$ mA, $C_{OUT} = 10\ \mu F$ unless otherwise indicated. **Boldface limits apply over the entire operating temperature range, $-40°C \leq T_J \leq +125°C$**, all other specifications are for $T_A = T_J = 25°C$.

Output Voltage (V_{OUT})		5V		8V		10V		Units
Parameter	Conditions	Typ	Limit	Typ	Limit	Typ	Limit	
Output Voltage	$5\ mA \leq I_{OUT} \leq 0.5A$	5.00	4.85 **4.75** 5.15 **5.25**	8.00	7.76 **7.60** 8.24 **8.40**	10.00	9.70 **9.50** 10.30 **10.50**	V(Min) V(Min) V(Max) V(Max)
Line Regulation	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5$ mA	15	**50**	24	**80**	30	**100**	mV(Max)
Load Regulation	$5\ mA \leq I_{OUT} \leq 0.5A$	5	**50**	8	**80**	10	**100**	mV(Max)
Quiescent Current	$(V_{OUT} + 2V) \leq V_{IN} \leq 26V$, $I_{OUT} = 5$ mA	2	**10**	2	**10**	2	**10**	mA(Max)
	$V_{IN} = (V_{OUT} + 5V)$, $I_{OUT} = 0.5A$	10	**20**	10	**20**	10	**20**	mA(Max)
Output Noise Voltage	10 Hz–100 kHz, $I_{OUT} = 5$ mA	150		240		300		μVrms
Long Term Stability	1000 Hrs.	20		32		40		mV
Dropout Voltage	$I_{OUT} = 500$ mA	0.5	**1.0**	0.5	**1.0**	0.5	**1.0**	V(Max)
	$I_{OUT} = 50$ mA	110	**250**	110	**250**	110	**250**	mV(Max)
Short-Circuit Current		1.0	**0.6**	1.0	**0.6**	1.0	**0.6**	A(Min)
Peak Line Transient Voltage	$t_f < 100$ ms, $R_L = 100\Omega$	75	**60**	75	**60**	75	**60**	V(Min)
Maximum Operational Input Voltage			**26**		**26**		**26**	V(Min)
Reverse DC Input Voltage	$V_{OUT} \geq -0.6V$, $R_L = 100\Omega$	−30	**−15**	−30	**−15**	−30	**−15**	V(Min)
Reverse Transient Input Voltage	$t_r < 1$ ms, $R_L = 100\Omega$	−75	**−50**	−75	**−50**	−75	**−50**	V(Min)

Electrical Characteristics

$V_{IN} = V_{NOM} + 5V$ (Note 4), I_{OUT} = 500 mA, C_{OUT} = 10 μF unless otherwise indicated. **Boldface limits apply over the entire operating temperature range, −40°C ≤ T_J ≤ +125°C**, all other specifications are for $T_A = T_J$ = 25°C.

Output Voltage (V_{OUT})		12V		15V		Units
Parameter	**Conditions**	**Typ**	**Limit**	**Typ**	**Limit**	
Output Voltage	5 mA ≤ I_{OUT} ≤ 0.5A	12.00	11.64 **11.40** 12.36 **12.60**	15.00	14.55 **14.25** 15.45 **15.75**	V (Min) V(Min) V(Max) V(Max)
Line Regulation	(V_{OUT} + 2V) ≤ V_{IN} ≤ 26V, I_{OUT} = 5 mA	36	**120**	45	**150**	mV(Max)
Load Regulation	5 mA ≤ I_{OUT} ≤ 0.5A	12	**120**	15	**150**	mV(Max)
Quiescent Current	(V_{OUT} + 2V) ≤ V_{IN} ≤ 26V, I_{OUT} = 5 mA	2	**10**	2	**10**	mA(Max)
	V_{IN} = (V_{OUT} + 5V), I_{OUT} = 0.5A	10	**20**	10	**20**	mA(Max)
Output Noise Voltage	10 Hz–100 kHz, I_{OUT} = 5 mA	360		450		μVrms
Long Term Stability	1000 Hrs.	44		56		mV
Dropout Voltage	I_{OUT} = 500 mA	0.5	**1.0**	0.5	**1.0**	V(Max)
	I_{OUT} = 50 mA	110	**250**	110	**250**	mV(Max)
Short-Circuit Current		1.0	**0.6**	1.0	**0.6**	A(Min)
Peak Line Transient Voltage	t_f < 100 ms, R_L = 100Ω	75	**60**	75	**60**	V(Min)
Maximum Operational Input Voltage			**26**		**26**	V(Min)
Reverse DC Input Voltage	V_{OUT} ≥ −0.6V, R_L = 100Ω	−30	**−15**	−30	**−15**	V(Min)
Reverse Transient Input Voltage	t_r < 1 ms, R_L = 100Ω	−75	**−50**	−75	**−50**	V(Min)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside of its rated Operating Conditions.

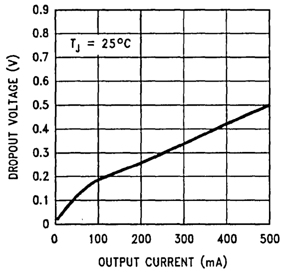
Note 2: The maximum allowable power dissipation at any ambient temperature is $P_{MAX} = (125 - T_A)/\theta_{JA}$, where 125 is the maximum junction temperature for operation, T_A is the ambient temperature, and θ_{JA} is the junction-to-ambient thermal resistance. If this dissipation is exceeded, the die temperature will rise above 125°C and the electrical specifications do not apply. If the die temperature rises above 150°C, the LM2937 will go into thermal shutdown. For the LM2937, the junction-to-ambient thermal resistance θ_{JA} is 65°C/W, for the TO-220, and 73°C/W for the TO-263. When used with a heatsink, θ_{JA} is the sum of the LM2937 junction-to-case thermal resistance θ_{JC} of 3°C/W and the heatsink case-to-ambient thermal resistance. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package. Using 0.5 Square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more sqaure inches of copper area, θ_{JA} is 32°C/W.

Note 3: ESD rating is based on the human body model, 100 pF discharged through 1.5 kΩ.

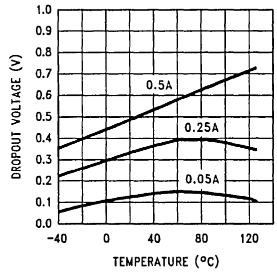
Note 4: Typicals are at T_J = 25°C and represent the most likely parametric norm.

Typical Performance Characteristics

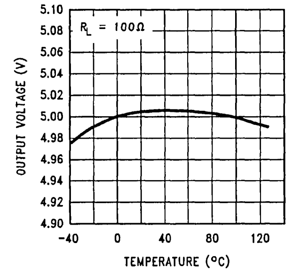
Dropout Voltage vs Output Current



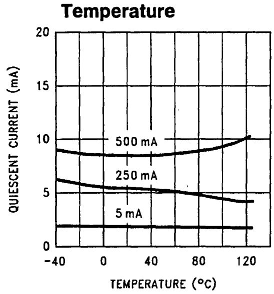
Dropout Voltage vs Temperature



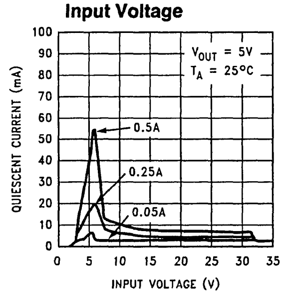
Output Voltage vs Temperature



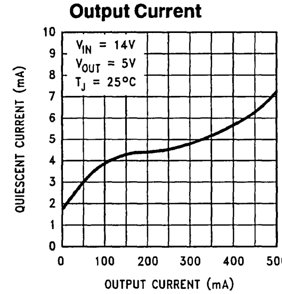
Quiescent Current vs Temperature



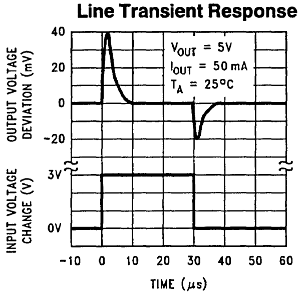
Quiescent Current vs Input Voltage



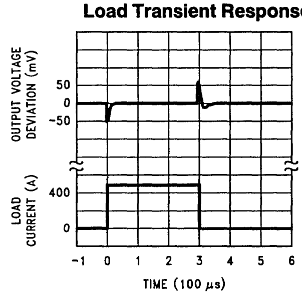
Quiescent Current vs Output Current



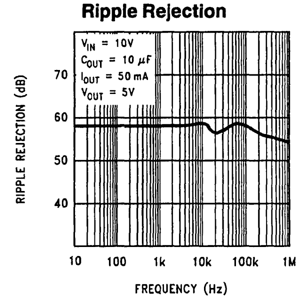
Line Transient Response



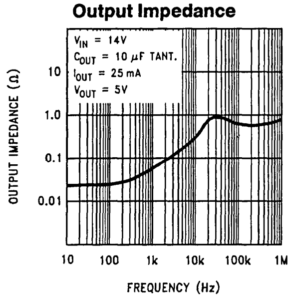
Load Transient Response



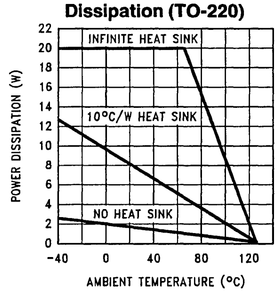
Ripple Rejection



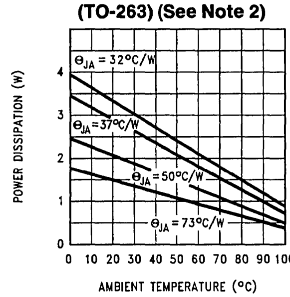
Output Impedance



Maximum Power Dissipation (TO-220)



Maximum Power Dissipation (TO-263) (See Note 2)



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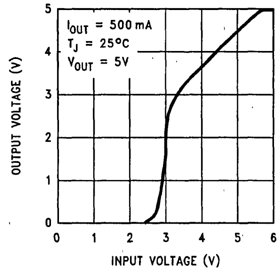
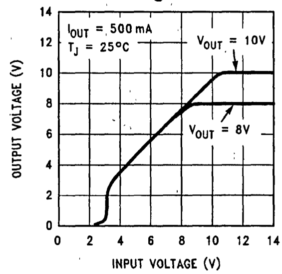
Typical Performance Characteristics (Continued)

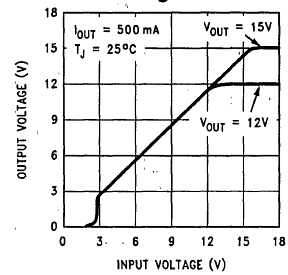
Low Voltage Behavior



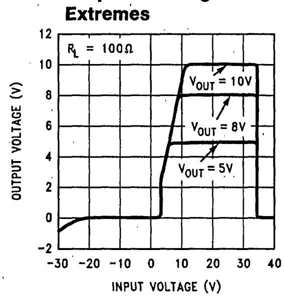
Low Voltage Behavior



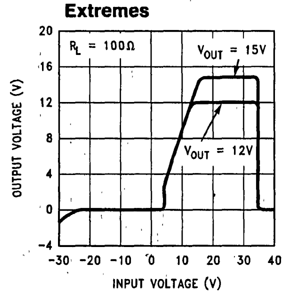
Low Voltage Behavior



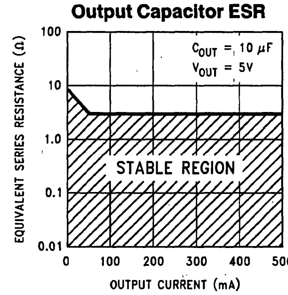
Output at Voltage Extremes



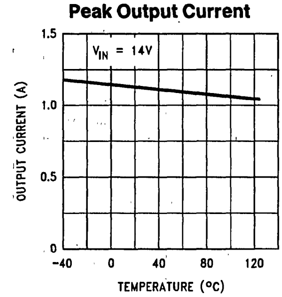
Output at Voltage Extremes



Output Capacitor ESR

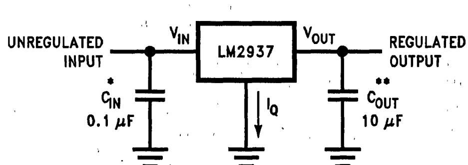


Peak Output Current



TL/H/11280–4

Typical Application



TL/H/11280–1

*Required if the regulator is located more than 3 inches from the power supply filter capacitors.

**Required for stability. C_{out} must be at least 10 μF (over the full expected operating temperature range) and located as close as possible to the regulator. The equivalent series resistance, ESR, of this capacitor may be as high as 3Ω.

National Semiconductor

LM2940/LM2940C 1A Low Dropout Regulator

General Description

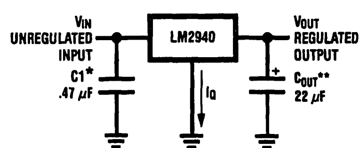
The LM2940/LM2940C positive voltage regulator features the ability to source 1A of output current with a dropout voltage of typically 0.5V and a maximum of 1V over the entire temperature range. Furthermore, a quiescent current reduction circuit has been included which reduces the ground current when the differential between the input voltage and the output voltage exceeds approximately 3V. The quiescent current with 1A of output current and an input-output differential of 5V is therefore only 30 mA. Higher quiescent currents only exist when the regulator is in the dropout mode ($V_{IN} - V_{OUT} \leq 3V$).

Designed also for vehicular applications, the LM2940/LM2940C and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. During line transients, such as load dump when the input voltage can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both the internal circuits and the load. The LM2940/LM2940C cannot be harmed by temporary mirror-image insertion. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- Dropout voltage typically 0.5V @I_O = 1A
- Output current in excess of 1A
- Output voltage trimmed before assembly
- Reverse battery protection
- Internal short circuit current limit
- Mirror image insertion protection
- P^+ Product Enhancement tested

Typical Application



TL/H/8822-3

*Required if regulator is located far from power supply filter.

**C_{OUT} must be at least 22 µF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

Ordering Information

Temperature Range	Output Voltage						Package
	5.0	8.0	9.0	10	12	15	
$0°C \leq T_A \leq 125°C$	LM2940CT-5.0		LM2940CT-9.0		LM2940CT-12	LM2940CT-15	TO-220
	LM2940CS-5.0		LM2940CS-9.0		LM2940CS-12	LM2940CS-15	TO-263
$-40°C \leq T_A \leq 125°C$	LM2940T-5.0	LM2940T-8.0	LM2940T-9.0	LM2940T-10	LM2940T-12		TO-220
	LM2940S-5.0	LM2940S-8.0	LM2940S-9.0	LM2940S-10	LM2940S-12		TO-263
$-55°C \leq T_A \leq 125°C$	LM2940K-5.0/883	LM2940K-8.0/883			LM2940K-12/883	LM2940K-15/883	TO-3

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications. (Note 2)

LM2940S, T ≤ 100 ms	60V
LM2940T, T ≤ 100 ms	60V
LM2940K/883, T ≤ 20 ms	40V
LM2940CT, T ≤ 1 ms	45V
LM2940CS, T ≤ 1 ms	45V
Internal Power Dissipation (Note 3)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	$-65°C \le T_J \le +150°C$

Lead Temperature (Soldering, 10 seconds)	
TO-3 (K) Package	300°C
TO-220 (T) Package	260°C
TO-263 (S) Package	260°C
ESD Susceptibility (Note 4)	2 kV

Operating Conditions (Note 1)

Input Voltage	26V
Temperature Range	
LM2940K/883	$-55°C \le T_A \le 125°C$
LM2940T, LM2940S	$-40°C \le T_A \le 125°C$
LM2940CT, LM2940CS	$0°C \le T_A \le 125°C$

Electrical Characteristics

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22\ \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25°C$

Output Voltage (V_O)		5V			8V			Units
Parameter	Conditions	Typ	LM2940 Limit (Note 5)	LM2940/883 Limit (Note 6)	Typ	LM2940 Limit (Note 5)	LM2940/883 Limit (Note 6)	
		$6.25V \le V_{IN} \le 26V$			$9.4V \le V_{IN} \le 26V$			
Output Voltage	$5\ mA \le I_O \le 1A$	5.00	4.85/**4.75** 5.15/**5.25**	4.85/**4.75** 5.15/**5.25**	8.00	7.76/**7.60** 8.24/**8.40**	7.76/**7.60** 8.24/**8.40**	V_{MIN} V_{MAX}
Line Regulation	$V_O + 2V \le V_{IN} \le 26V$, $I_O = 5\ mA$	20	50	40/**50**	20	80	50/**80**	mV_{MAX}
Load Regulation	$50\ mA \le I_O \le 1A$ LM2940, LM2940/883 LM2940C	 35 35	 50/**80** 50	 50/**100**	 55 55	 80/**130** 80	 80/**130**	mV_{MAX}
Output Impedance	100 mADC and 20 mArms, $f_O = 120$ Hz	35		1000/**1000**	55		1000/**1000**	mΩ
Quiescent Current	$V_O + 2V \le V_{IN} \le 26V$, $I_O = 5\ mA$ LM2940, LM2940/883 LM2940C	 10 10	 15/**20** 15	 15/**20**	 10	 15/**20**	 15/**20**	mA_{MAX}
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/**60**	50/**60**	30	45/**60**	50/**60**	mA_{MAX}
Output Noise Voltage	10 Hz − 100 kHz, $I_O = 5\ mA$	150		700/**700**	240		1000/**1000**	μV_{rms}
Ripple Rejection	$f_O = 120$ Hz, 1 V_{rms}, $I_O = 100\ mA$ LM2940 LM2940C	 72 72	 60/**54** 60		 66 66	 54/**48** 54		dB_{MIN}
	$f_O = 1$ kHz, 1 V_{rms}, $I_O = 5\ mA$			60/**50**			54/**48**	dB_{MIN}
Long Term Stability		20			32			mV/ 1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/**1.0**	0.7/**1.0**	0.5	0.8/**1.0**	0.7/**1.0**	V_{MAX}
	$I_O = 100\ mA$	110	150/**200**	150/**200**	110	150/**200**	150/**200**	mV_{MAX}

Electrical Characteristics

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22\ \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25°C$ (Continued)

Output Voltage (V_O)		5V			8V			Units
Parameter	Conditions	Typ	LM2940 Limit (Note 5)	LM2940/883 Limit (Note 6)	Typ	LM2940 Limit (Note 5)	LM2940/883 Limit (Note 6)	
Short Circuit Current	(Note 7)	1.9	1.6	1.5/**1.3**	1.9	1.6	1.6/**1.3**	A_{MIN}
Maximum Line Transient	$R_O = 100\Omega$ LM2940, $T \leq 100$ ms LM2940/883, $T \leq 20$ ms LM2940C, $T \leq 1$ ms	 75 55	 60/**60** 45	 40/**40** 	 75 55	 60/**60** 45	 40/**40** 	V_{MIN}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$ LM2940, LM2940/883 LM2940C	 −30 −30	 −15/**−15** −15	 −15/**−15** 	 −30 −30	 −15/**−15** −15	 −15/**−15** 	V_{MIN}
Reverse Polarity Transient Input Voltage	$R_O = 100\Omega$ LM2940, $T \leq 100$ ms LM2940/883, $T \leq 20$ ms LM2940C, $T \leq 1$ ms	 −75 −55	 −50/**−50** −45/**−45**	 −45/**−45** 	 −75 	 −50/**−50** 	 −45/**−45** 	V_{MIN}

2

Electrical Characteristics $V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22\ \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25°C$ (Continued)

Output Voltage (V_O)		9V		10V		
Parameter	**Conditions**	**Typ**	**LM2940 Limit (Note 5)**	**Typ**	**LM2940 Limit (Note 5)**	**Units**
		$10.5V \le V_{IN} \le 26V$		$11.5V \le V_{IN} \le 26V$		
Output Voltage	$5\ mA \le I_O \le 1A$	9.00	8.73/**8.55** 9.27/**9.45**	10.00	9.70/**9.50** 10.30/**10.50**	V_{MIN} V_{MAX}
Line Regulation	$V_O + 2V \le V_{IN} \le 26V$, $I_O = 5\ mA$	20	90	20	100	mV_{MAX}
Load Regulation	$50\ mA \le I_O \le 1A$ LM2940 LM2940C	 60 60	 90/**150** 90	 65	 100/**165**	mV_{MAX}
Output Impedance	100 mADC and 20 mArms, $f_O = 120\ Hz$	60		65		$m\Omega$
Quiescent Current	$V_O + 2V \le V_{IN} < 26V$, $I_O = 5\ mA$ LM2940 LM2940C	 10 10	 15/**20** 15	 10	 15/**20**	mA_{MAX}
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/**60**	30	45/**60**	mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz, $I_O = 5\ mA$	270		300		μV_{rms}
Ripple Rejection	$f_O = 120\ Hz$, $1\ V_{rms}$, $I_O = 100\ mA$ LM2940 LM2940C	 64 64	 52/**46** 52	 63	 51/**45**	dB_{MIN}
Long Term Stability		34		36		mV/ 1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/**1.0**	0.5	0.8/**1.0**	V_{MAX}
	$I_O = 100\ mA$	110	150/**200**	110	150/**200**	mV_{MAX}
Short Circuit Current	(Note 7)	1.9	1.6	1.9	1.6	A_{MIN}
Maximum Line Transient	$R_O = 100\Omega$ $T \le 100\ ms$ LM2940 LM2940C	 75 55	 60/**60** 45	 75	 60/**60**	V_{MIN}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$ LM2940 LM2940C	 −30 −30	 −15/**−15** −15	 −30	 −15/**−15**	V_{MIN}
Reverse Polarity Transient Input Voltage	$R_O = 100\Omega$ $T \le 100\ ms$ LM2940 LM2940C	 −75 −55	 −50/**−50** −45/**−45**	 −75	 −50/**−50**	V_{MIN}

Electrical Characteristics

$V_{IN} = V_O + 5V$, $I_O = 1A$, $C_O = 22\ \mu F$, unless otherwise specified. **Boldface limits apply over the entire operating temperature range of the indicated device.** All other specifications apply for $T_A = T_J = 25°C$ (Continued)

Output Voltage (V_O)		12V			15V			
Parameter	**Conditions**	**Typ**	**LM2940 Limit (Note 5)**	**LM2940/833 Limit (Note 6)**	**Typ**	**LM2940 Limit (Note 5)**	**LM2940/833 Limit (Note 6)**	**Units**
		13.6V ≤ V_{IN} ≤ 26V			**16.75V ≤ V_{IN} ≤ 26V**			
Output Voltage	5 mA ≤ I_O ≤1A	12.00	11.64/**11.40** 12.36/**12.60**	11.64/**11.40** 12.36/**12.60**	15.00	14.55/**14.25** 15.45/**15.75**	14.55/**14.25** 15.45/**15.75**	V_{MIN} V_{MAX}
Line Regulation	V_O + 2V ≤ V_{IN} ≤ 26V, I_O = 5 mA	20	120	75/**120**	20	150	95/**150**	mV_{MAX}
Load Regulation	50 mA ≤ I_O ≤ 1A LM2940, LM2940/883 LM2940C	 55 55	 120/**200** 120	 120/**190** 	 70	 150	 150/**240** 	mV_{MAX}
Output Impedance	100 mADC and 20 mArms, f_O = 120 Hz	80		1000/**1000**	100		1000/**1000**	mΩ
Quiescent Current	V_O +2V ≤ V_{IN} ≤ 26V, I_O = 5 mA LM2940, LM2940/883 LM2940C	 10 10	 15/**20** 15	 15/**20** 	 10	 15	 15/**20** 	mA_{MAX}
	V_{IN} = V_O + 5V, I_O = 1A	30	45/**60**	50/**60**	30	45/**60**	50/**60**	mA_{MAX}
Output Noise Voltage	10 Hz – 100 kHz, I_O = 5 mA	360		1000/**1000**	450		1000/**1000**	μV_{rms}
Ripple Rejection	f_O = 120 Hz, 1 V_{rms}, I_O = 100 mA LM2940 LM2940C	 66 66	 54/**48** 54		 64	 52		dB_{MIN}
	f_O = 1 kHz, 1 V_{rms}, I_O = 5 mA			52/**46**			48/**42**	dB_{MIN}
Long Term Stability		48			60			mV/ 1000 Hr
Dropout Voltage	I_O = 1A	0.5	0.8/**1.0**	0.7/**1.0**	0.5	0.8/**1.0**	0.7/**1.0**	V_{MAX}
	I_O = 100 mA	110	150/**200**	150/**200**	110	150/**200**	150/**200**	mV_{MAX}
Short Circuit Current	(Note 7)	1.9	1.6	1.6/**1.3**	1.9	1.6	1.6/**1.3**	A_{MIN}
Maximum Line Transient	R_O = 100Ω LM2940, T ≤ 100 ms LM2940/883, T ≤ 20 ms LM2940C, T ≤ 1 ms	 75 55	 60/**60** 45	 40/**40** 	 55	 45	 40/**40** 	V_{MIN}
Reverse Polarity DC Input Voltage	R_O = 100Ω LM2940, LM2940/883 LM2940C	 −30 −30	 −15/**−15** −15	 −15/**−15** 	 −30	 −15	 −15/**−15** 	V_{MIN}
Reverse Polarity Transient Input Voltage	R_O = 100Ω LM2940, T ≤ 100 ms LM2940/883, T ≤ 20 ms LM2940C, T ≤ 1 ms	 −75 −55	 −50/**−50** −45/**−45**	 −45/**−45** 	 −55	 −45/**−45**	 −45/**−45** 	V_{MIN}

Note 1: Absolute Maximum Ratings are limits beyond which damage to the device may occur. Operating Conditions are conditions under which the device functions but the specifications might not be guaranteed. For guaranteed specifications and test conditions see the Electrical Characteristics.

Note 2: Military specifications complied with RETS/SMD at the time of printing. For current specifications refer to RETS LM2940K-5.0, LM2940K-8.0, LM2940K-12, and LM2940K-15. SMD numbers are 5962-8958701YA(5V), 5962-9083301YA(8V), 5962-9088401YA(12V), and 5962-9088501YA(15V).

Note 3: The maximum power dissipation is a function of the maximum junction temperature, $T_J = 150°C$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is $P_{DMAX} = (150 - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2940 will go into thermal shutdown. For the LM2940T and LM2940CT, the junction-to-ambient thermal resistance (θ_{JA}) is 53°C/W. When using a heatsink, θ_{JA} is the sum of the 3°C/W junction-to-case thermal resistance (θ_{JC}) of the LM2940T or LM2940CT and the case-to-ambient thermal resistance of the heatsink. If the TO-263 package is used, the thermal resistance can be used by increasing the P.C. board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area , θ_{JA} is 32°C/W. For the LM2940K, θ_{JA} is 39°C/W and θ_{JC} is 4°C/W.

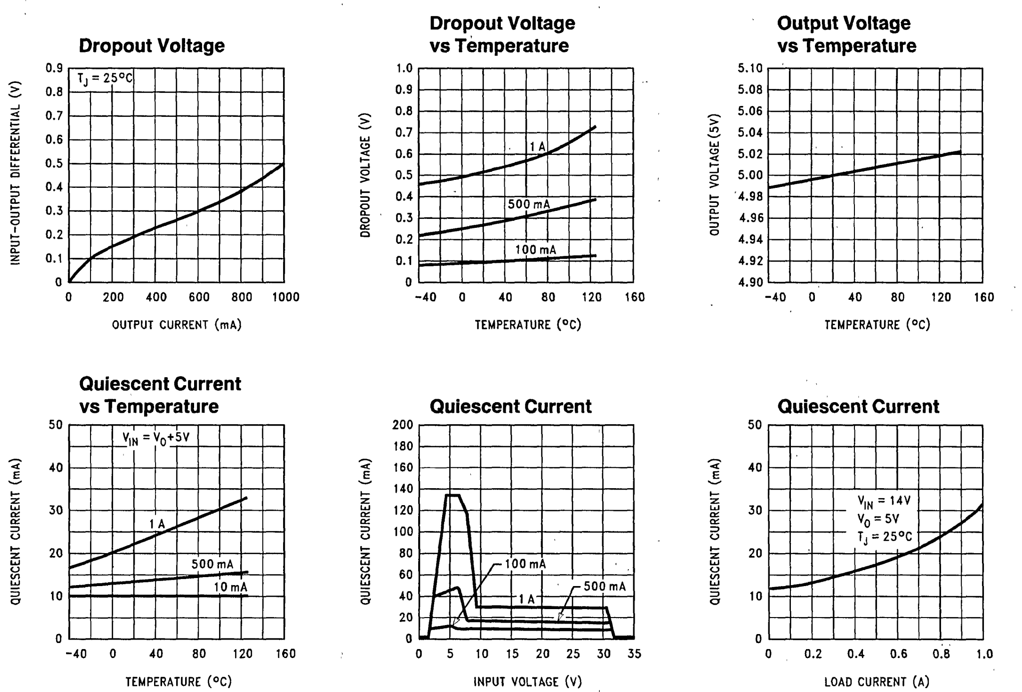
Note 4: ESD rating is based on the human body model, 100 pF discharged through 1.5 kΩ.

Note 5: All limits are guaranteed at $T_A = T_J = 25°C$ only (standard typeface) or over the entire operating temperature range of the indicated device (**boldface type**). All limits at $T_A = T_J = 25°C$ are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control methods.

Note 6: All limits are guaranteed at $T_A = T_J = 25°C$ only (standard typeface) or over the entire operating temperature range of the indicated device (**boldface type**). All limits are 100% production tested and are used to calculate Outgoing Quality Levels.

Note 7: Output current will decrease with increasing temperature but will not drop below 1A at the maximum specified temperature.

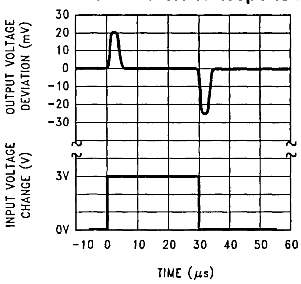
Typical Performance Characteristics



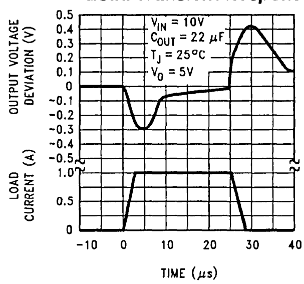
TL/H/8822-9

Typical Performance Characteristics (Continued)

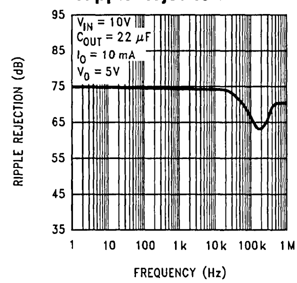
Line Transient Response



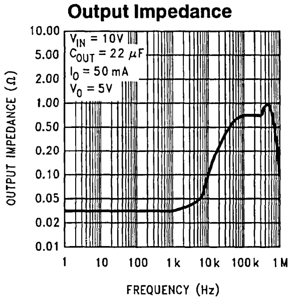
Load Transient Response



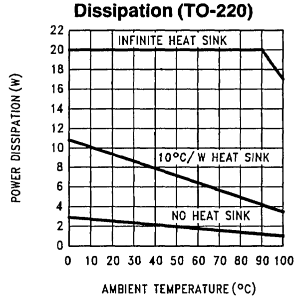
Ripple Rejection



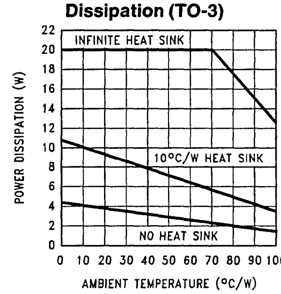
Output Impedance



Maximum Power Dissipation (TO-220)

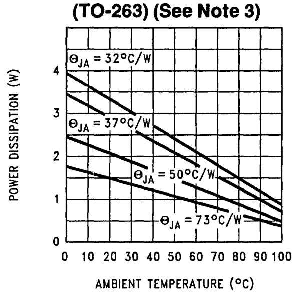


Maximum Power Dissipation (TO-3)



TL/H/8822-4

Maximum Power Dissipation (TO-263) (See Note 3)



TL/H/8822-10

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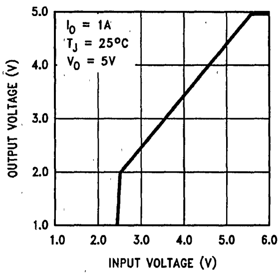
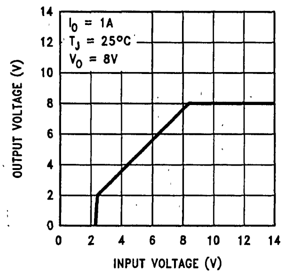
Typical Performance Characteristics (Continued)

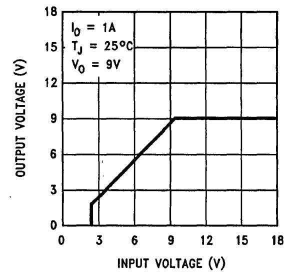
Low Voltage Behavior



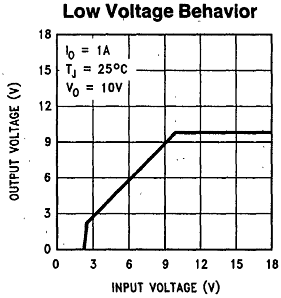
Low Voltage Behavior



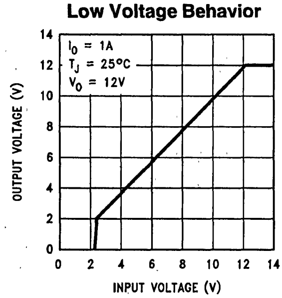
Low Voltage Behavior



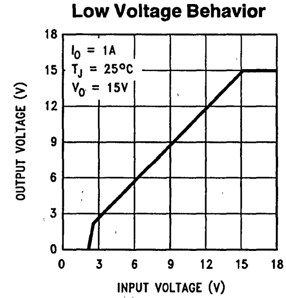
Low Voltage Behavior



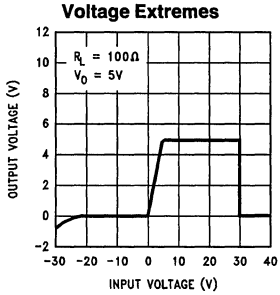
Low Voltage Behavior



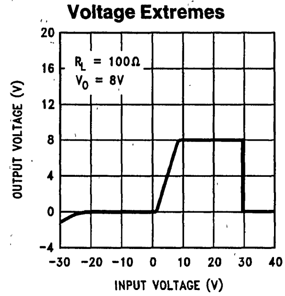
Low Voltage Behavior



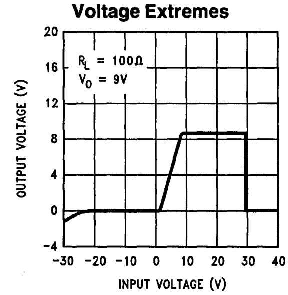
Output at Voltage Extremes



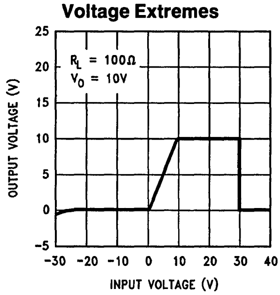
Output at Voltage Extremes



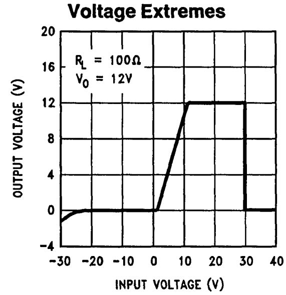
Output at Voltage Extremes



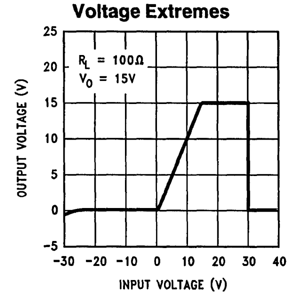
Output at Voltage Extremes



Output at Voltage Extremes



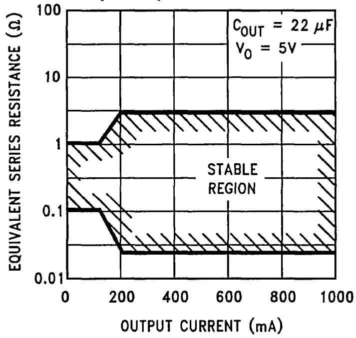
Output at Voltage Extremes



TL/H/8822-5

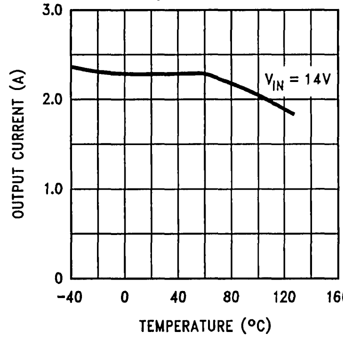
Typical Performance Characteristics (Continued)

Output Capacitor ESR



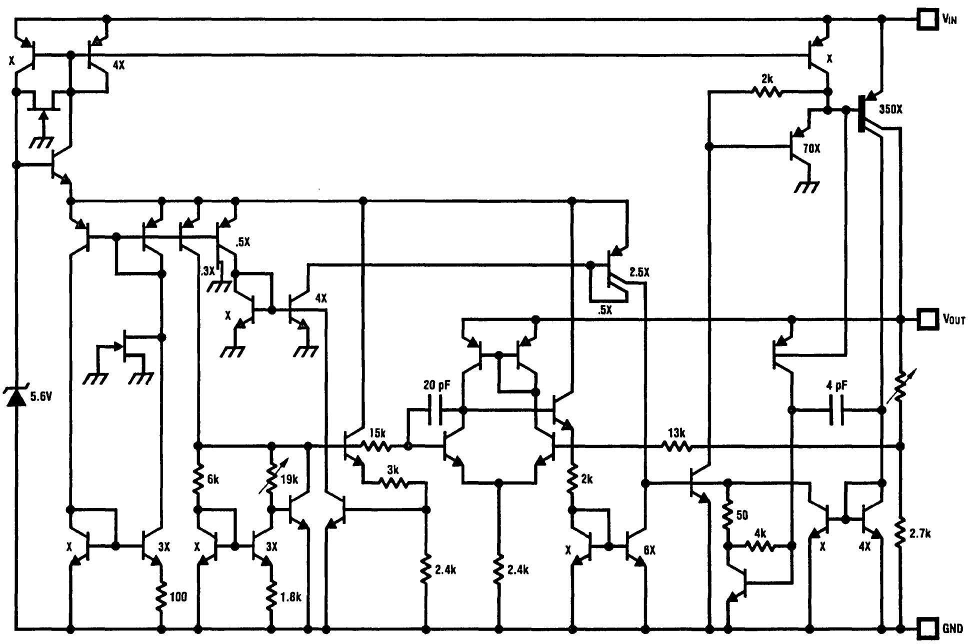
TL/H/8822-6

Peak Output Current



TL/H/8822-8

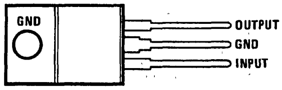
Equivalent Schematic Diagram



TL/H/8822-1

Connection Diagrams

(TO-220) Plastic Package

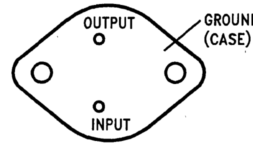


TL/H/8822-2

Front View

Order Number LM2940CT-5.0, LM2940CT-9.0, LM2940CT-12, LM2940CT-15, LM2940T-5.0, LM2940T-8.0, LM2940T-9.0, LM2940T-10 or LM2940T-12
See NS Package Number T03B

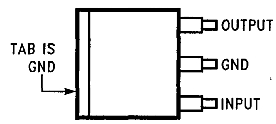
TO-3 Metal Can Package (K)



TL/H/8822-7

Bottom View
Order Number LM2940K-5.0/883, LM2940K-8.0/883, LM2940K-12/883, LM2940K-15/883
See NS Package Number K02A

(TO-263) Surface-Mount Package



TL/H/8822-11

Top View

TL/H/8822-12

Side View

Order Number LM2940CS-5.0, LM2940CS-9.0, LM2940CS-12, LM2940CS-15, LM2940S-5.0, LM2940S-8.0, LM2940S-9.0, LM2940S-10 or LM2940S-12
See NS Package Number TS3B

National Semiconductor

LM2941/LM2941C 1A Low Dropout Adjustable Regulator

General Description

The LM2941 positive voltage regulator features the ability to source 1A of output current with a typical dropout voltage of 0.5V and a maximum of 1V over the entire temperature range. Furthermore, a quiescent current reduction circuit has been included which reduces the ground pin current when the differential between the input voltage and the output voltage exceeds approximately 3V. The quiescent current with 1A of output current and an input-output differential of 5V is therefore only 30 mA. Higher quiescent currents only exist when the regulator is in the dropout mode ($V_{IN} - V_{OUT} \leq 3V$).

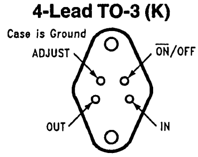
Designed also for vehicular applications, the LM2941 and all regulated circuitry are protected from reverse battery installations or two-battery jumps. During line transients, such as load dump when the input voltage can momentarily exceed the specified maximum operating voltage, the regulator will automatically shut down to protect both the internal circuits and the load. Familiar regulator features such as short circuit and thermal overload protection are also provided.

Features

- Output voltage adjustable from 5V to 20V
- Dropout voltage typically 0.5V @ I_O = 1A
- Output current in excess of 1A
- Trimmed reference voltage
- Reverse battery protection
- Internal short circuit current limit
- Mirror image insertion protection
- P+ Product Enhancement tested
- TTL, CMOS compatible ON/OFF switch

Connection Diagram and Ordering Information

4-Lead TO-3 (K)

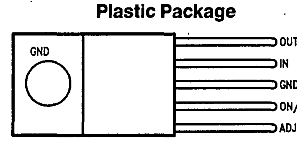


TL/H/8823-7

Bottom View

Order Number LM2941K/883
See NS Package Number K04A

(TO-220)
Plastic Package

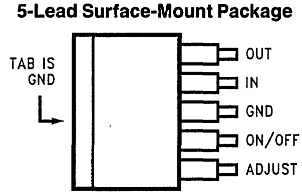


TL/H/8823-2

Front View

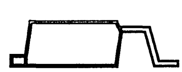
Order Number LM2941T or LM2941CT
See NS Package Number TO5A

(TO-263)
5-Lead Surface-Mount Package



TOP VIEW

TL/H/8823-8



SIDE VIEW

TL/H/8823-9

Order Number LM2941S or LM2941CS
See NS Package Number TS5B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage (Survival Voltage, ≤ 100 ms)	
LM2941K, LM2941T, LM2941S	60V
LM2941CT, LM2941CS	45V
Internal Power Dissipation (Note 3)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	$-65°C \le T_J \le +150°C$
Lead Temperature (Soldering, 10 seconds)	
TO-3 (K) Package	300°C
TO-220 (T) Package	260°C
TO-263 (S) Package	260°C

ESD susceptibility to be determined.

Operating Ratings

Maximum Input Voltage	26V
Temperature Range	
LM2941K	$-55°C \le T_J \le 150°C$
LM2941T	$-40°C \le T_J \le 125°C$
LM2941CT	$-0°C \le T_J \le 125°C$
LM2941S	$-40°C \le T_J \le 125°C$
LM2941CS	$-0°C \le T_J \le 125°C$

Electrical Characteristics—LM2941K, LM2941T, LM2941S

$5V \le V_O \le 20V$, $V_{IN} = V_O + 5V$, $C_O = 22\ \mu F$, unless otherwise specified. Specifications in standard typeface apply for T_J = 25°C, while those in **boldface type** apply over the full **Operating Temperature Range.**

Parameter	Conditions	Typ	LM2941K Limit (Notes 2, 4)	LM2941T LM2941S Limit (Note 5)	Units (Limits)
Reference Voltage	$5\ mA \le I_O \le 1A$ (Note 6)	1.275	1.237/**1.211** 1.313/**1.339**	1.237/**1.211** 1.313/**1.339**	V(min) V(max)
Line Regulation	$V_O + 2V \le V_{IN} \le 26V$, $I_O = 5\ mA$	4	10/**10**	10/**10**	mV/V(max)
Load Regulation	$50\ mA \le I_O \le 1A$	7	10/**10**	10/**10**	mV/V(max)
Output Impedance	100 mADC and 20 mArms $f_O = 120\ Hz$	7			mΩ/V
Quiescent Current	$V_O + 2V \le V_{IN} < 26V$, $I_O = 5\ mA$	10	15/**20**	15/**20**	mA(max)
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/**60**	45/**60**	mA(max)
RMS Output Noise, % of V_{OUT}	10 Hz–100 kHz $I_O = 5\ mA$	0.003			%
Ripple Rejection	$f_O = 120\ Hz$, 1 Vrms, $I_L = 100\ mA$	0.005	0.02/**0.04**	0.02/**0.04**	%/V(max)
Long Term Stability		0.4			%/1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/**1.0**	0.8/**1.0**	V(max)
	$I_O = 100\ mA$	110	200/**200**	200/**200**	mV(max)
Short Circuit Current	V_{IN} max = 26V (Note 7)	1.9	1.6/**1.3**	1.6	A(min)
Maximum Line Transient	V_O max 1V above nominal V_O $R_O = 100\Omega$, $T \le 100\ ms$	75	60/**60**	60/**60**	V(min)
Maximum Operational Input Voltage		31	26/**26**	26/**26**	V_{DC}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$, $V_O \ge -0.6V$	−30	−15/**−15**	−15/**−15**	V(min)
Reverse Polarity Transient Input Voltage	$T \le 100\ ms$, $R_O = 100\Omega$	−75	−50/**−50**	−50/**−50**	V(min)
ON/OFF Threshold Voltage ON	$I_O \le 1A$	1.30	0.80/**0.80**	0.80/**0.80**	V(max)
ON/OFF Threshold Voltage OFF	$I_O \le 1A$	1.30	2.00/**2.00**	2.00/**2.00**	V(min)
ON/OFF Threshold Current	$V_{ON/OFF} = 2.0V$, $I_O \le 1A$	50	100/**300**	100/**300**	µA(max)

Electrical Characteristics—LM2941CT,LM2941CS

$5V \le V_O \le 20V$, $V_{IN} = V_O + 5V$, $C_O = 22\ \mu F$, unless otherwise specified. Specifications in standard typeface apply for T_J = 25°C, while those in **boldface type** apply over the full **Operating Temperature Range**.

Parameter	Conditions	Typ	Limit (Note 5)	Units (Limits)
Reference Voltage	$5\ mA \le I_O \le 1A$ (Note 6)	1.275	1.237/**1.211** 1.313/**1.339**	V(min) V(max)
Line Regulation	$V_O + 2V \le V_{IN} \le 26V$, $I_O = 5\ mA$	4	10	mV/V(max)
Load Regulation	$50\ mA \le I_O \le 1A$	7	10	mV/V(max)
Output Impedance	100 mADC and 20 mArms $f_O = 120\ Hz$	7		mΩ/V
Quiescent Current	$V_O + 2V \le V_{IN} < 26V$, $I_O = 5\ mA$	10	15	mA(max)
	$V_{IN} = V_O + 5V$, $I_O = 1A$	30	45/**60**	mA(max)
RMS Output Noise, % of V_{OUT}	10 Hz–100 kHz $I_O = 5\ mA$	0.003		%
Ripple Rejection	$f_O = 120\ Hz$, 1 Vrms, $I_L = 100\ mA$	0.005	0.02	%/V(max)
Long Term Stability		0.4		%/1000 Hr
Dropout Voltage	$I_O = 1A$	0.5	0.8/**1.0**	V(max)
	$I_O = 100\ mA$	110	200/**200**	mV(max)
Short Circuit Current	V_{IN} max = 26V (Note 7)	1.9	1.6	A(min)
Maximum Line Transient	V_O max 1V above nominal V_O $R_O = 100\Omega$, $T \le 100\ ms$	55	45	V(min)
Maximum Operational Input Voltage		31	26	V_{DC}
Reverse Polarity DC Input Voltage	$R_O = 100\Omega$, $V_O \ge -0.6V$	−30	−15	V(min)
Reverse Polarity Transient Input Voltage	$T \le 100\ ms$, $R_O = 100\Omega$	−55	−45	V(min)
ON/OFF Threshold Voltage ON	$I_O \le 1A$	1.30	0.80	V(max)
ON/OFF Threshold Voltage OFF	$I_O \le 1A$	1.30	2.00	V(min)
ON/OFF Threshold Current	$V_{ON/OFF} = 2.0V$, $I_O \le 1A$	50	100	µA(max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions for which the device is intended to be functional, but device parameter specifications may not be guaranteed under these conditions. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: A military RETS specification available upon request. At the time of printing, the LM2941/883 RETS specification complied with the boldface limits in this column. The LM2941K/883 may also be procured to a Standard Military Drawing.

Note 3: The maximum power dissipation is a function of $T_J(max)$, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_J(max) - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 150°C and the LM2941 will go into thermal shutdown. For the LM2941T and LM2941CT, the junction-to-ambient thermal resistance (θ_{JA}) is 53°C/W, and the junction-to-case thermal resistance (θ_{JC}) is 3°C/W. For the LM2941K, θ_{JA} is 35°C/W and θ_{JC} is 4°C/W. The junction-to-ambient thermal resistance of the TO-263 is 73°C/W, and junction-to-case thermal resistance, θ_{JC} is 3°C. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Note 4: All limits guaranteed at room temperature (standard typeface) and at temperature extremes (boldface type). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.

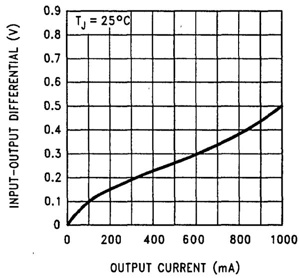
Note 5: All limits guaranteed at room temperature (standard typeface) and at temperature extremes (boldface type). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 6: The output voltage range is 5V to 20V and is determined by the two external resistors, R1 and R2. See Typical Application Circuit.

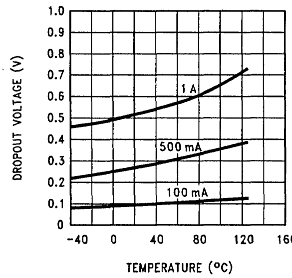
Note 7: Output current capability will decrease with increasing temperature, but will not go below 1A at the maximum specified temperatures.

Typical Performance Characteristics

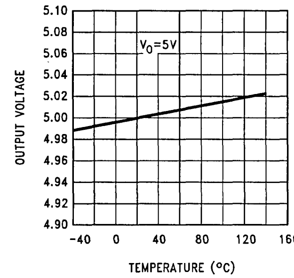
Dropout Voltage



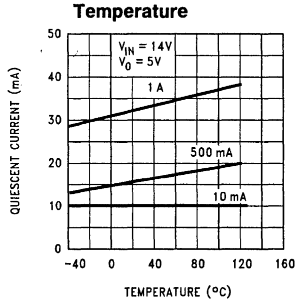
Dropout Voltage vs Temperature



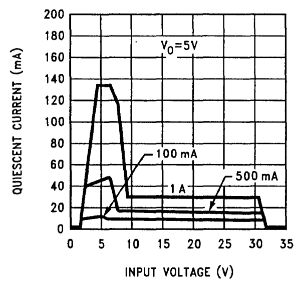
Output Voltage



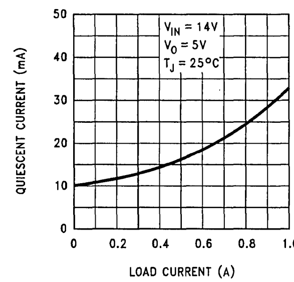
Quiescent Current vs Temperature



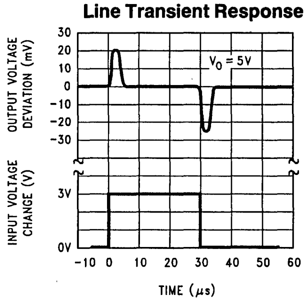
Quiescent Current



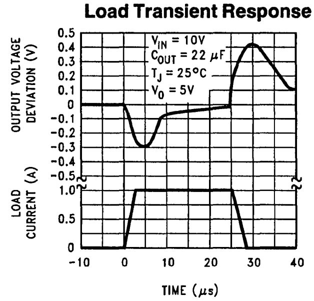
Quiescent Current



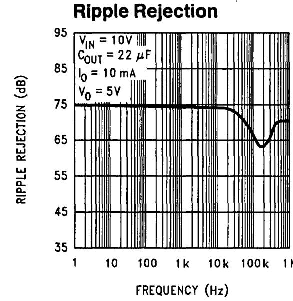
Line Transient Response



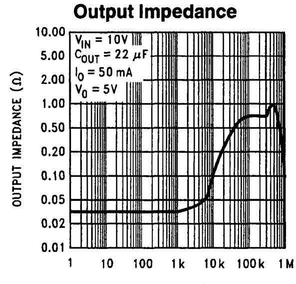
Load Transient Response



Ripple Rejection



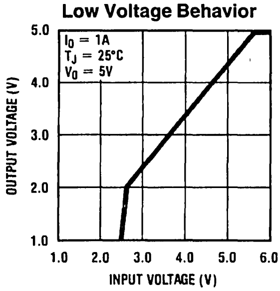
Output Impedance



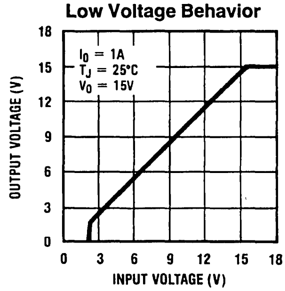
TL/H/8823–4

Typical Performance Characteristics (Continued)

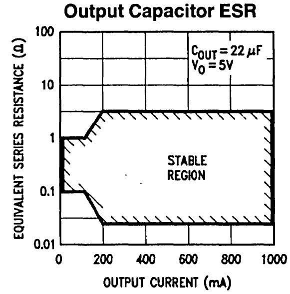
Low Voltage Behavior



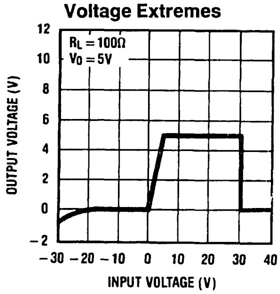
Low Voltage Behavior



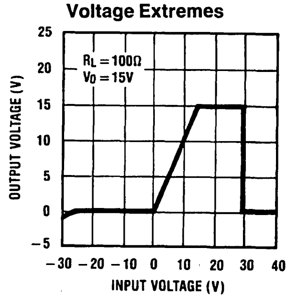
Output Capacitor ESR



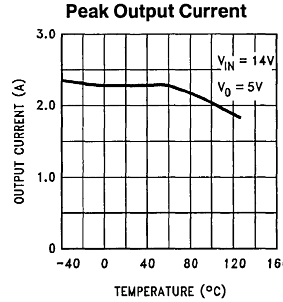
Output at Voltage Extremes



Output at Voltage Extremes

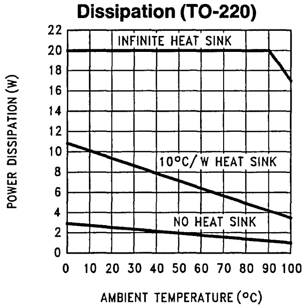


Peak Output Current

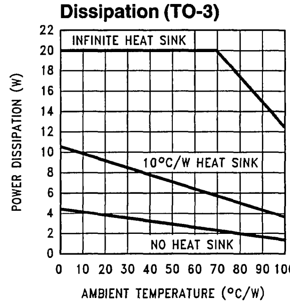


TL/H/8823-5

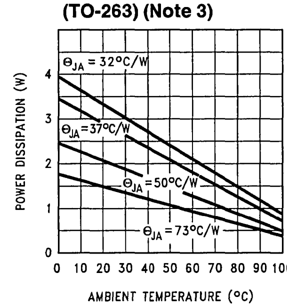
Maximum Power Dissipation (TO-220)



Maximum Power Dissipation (TO-3)



Maximum Power Dissipation (TO-263) (Note 3)



TL/H/8823-10

Definition of Terms

Dropout Voltage: The input-voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at (V_{OUT} + 5V) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accelerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

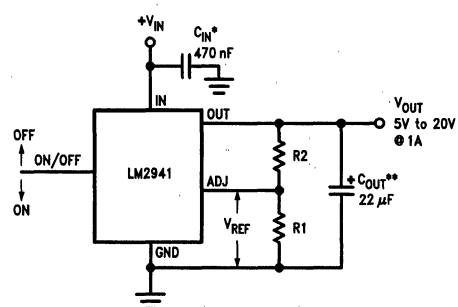
Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Typical Applications

5V to 20V Adjustable Regulator



TL/H/8823-3

V_{OUT} = Reference voltage $\times \frac{R1 + R2}{R1}$ where V_{REF} = 1.275 typical

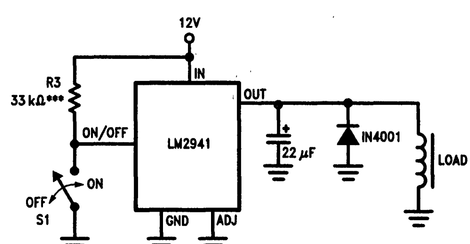
Solving for R2: $R2 = R1 \left(\frac{V_O}{V_{REF}} - 1\right)$

Note: Using 1k for R1 will ensure that the input bias current error of the adjust pin will be negligible. Do not bypass R1 or R2. This will lead to instabilities.

*Required if regulator is located far from power supply filter.

**C_{OUT} must be at least 22 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator and the ESR is critical; see curve.

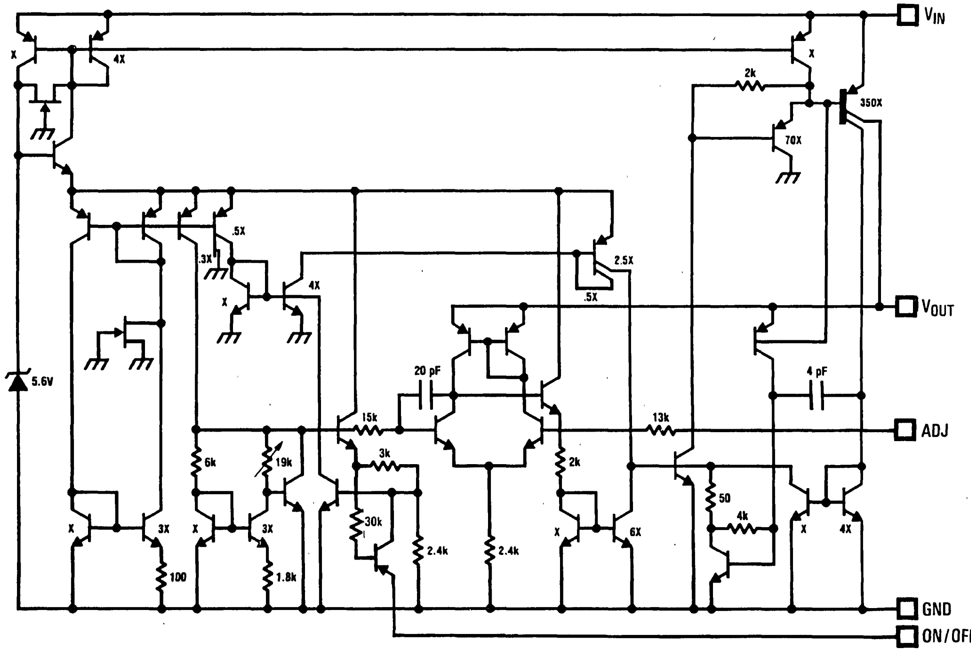
1A Switch



TL/H/8823-6

***To assure shutdown, select Resistor R3 to guarantee at least 300 μA of pull-up current when S1 is open. (Assume 2V at the ON/OFF pin.)

Equivalent Schematic Diagram



TL/H/8823-1

National Semiconductor

LM2984 Microprocessor Power Supply System

General Description

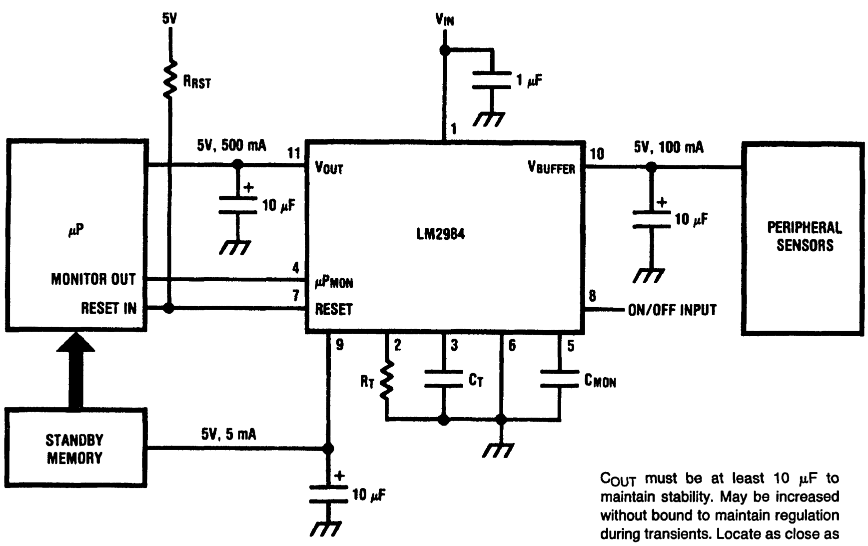
The LM2984 positive voltage regulator features three independent and tracking outputs capable of delivering the power for logic circuits, peripheral sensors and standby memory in a typical microprocessor system. The LM2984 includes circuitry which monitors both its own high-current output and also an external μP. If any error conditions are sensed in either, a reset error flag is set and maintained until the malfunction terminates. Since these functions are included in the same package with the three regulators, a great saving in board space can be realized in the typical microprocessor system. The LM2984 also features very low dropout voltages on each of its three regulator outputs (0.6V at the rated output current). Furthermore, the quiescent current can be reduced to 1 mA in the standby mode.

Designed also for vehicular applications, the LM2984 and all regulated circuitry are protected from reverse battery installations or 2-battery jumps. Familiar regulator features such as short circuit and thermal overload protection are also provided. Fixed outputs of 5V are available in the plastic TO-220 power package.

Features

- Three low dropout tracking regulators
- Output current in excess of 500 mA
- Fully specified for −40°C to +125°C operation
- Low quiescent current standby regulator
- Microprocessor malfunction RESET flag
- Delayed RESET on power-up
- Accurate pretrimmed 5V outputs
- Reverse battery protection
- Overvoltage protection
- Reverse transient protection
- Short circuit protection
- Internal thermal overload protection
- ON/OFF switch for high current outputs
- P+ Product Enhancement tested

Typical Application Circuit



C_{OUT} must be at least 10 μF to maintain stability. May be increased without bound to maintain regulation during transients. Locate as close as possible to the regulator. This capacitor must be rated over the same operating temperature range as the regulator. The equivalent series resistance (ESR) of this capacitor is critical; see curve.

TL/H/11252-1

Order Number LM2984T
See NS Package Number TA11B

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	
Survival Voltage (<100 ms)	60V
Operational Voltage	26V
Internal Power Dissipation	Internally Limited
Operating Temperature Range (T_A)	−40°C to +125°C
Maximum Junction Temperature (Note 1)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C
ESD Susceptability (Note 3)	2000V

Electrical Characteristics

V_{IN} = 14V, I_{OUT} = 5 mA, C_{OUT} = 10 μF, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, −40°C ≤ T_A ≤ +125°C, all other limits are for $T_A = T_j$ = 25°C (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{OUT} (Pin 11)				
Output Voltage	5 mA ≤ I_O ≤ 500 mA 6V ≤ V_{IN} ≤ 26V	5.00	4.85/**4.75** 5.15/**5.25**	V_{min} V_{max}
Line Regulation	9V ≤ V_{IN} ≤ 16V	2	25/**25**	mV_{max}
	7V ≤ V_{IN} ≤ 26V	5	50/**50**	mV_{max}
Load Regulation	5 mA ≤ I_{OUT} ≤ 500 mA	12	50/**50**	mV_{max}
Output Impedance	250 mA_{dc} and 10 mA_{rms}, f_o = 120 Hz	24		mΩ
Quiescent Current	I_{OUT} = 500 mA	38	100/**100**	mA_{max}
	I_{OUT} = 250 mA	14	50/**50**	mA_{max}
Output Noise Voltage	10 Hz–100 kHz, I_{OUT} = 100 mA	100		μV
Long Term Stability		20		mV/1000 hr
Ripple Rejection	f_o = 120 Hz	70	60/**50**	dB_{min}
Dropout Voltage	I_{OUT} = 500 mA	0.53	0.80/**1.1**	V_{max}
	I_{OUT} = 250 mA	0.28	0.50/**0.70**	V_{max}
Current Limit		0.92	0.75/**0.60**	A_{min}
Maximum Operational Input Voltage	Continuous DC	32	26/**26**	V_{min}
Maximum Line Transient	V_{OUT} ≤ 6V, R_{OUT} = 100Ω, T ≤ 100 ms	65	60/**60**	V_{min}
Reverse Polarity Input Voltage DC	V_{OUT} ≥ −0.6V, R_{OUT} = 100Ω	−30	−15/**−15**	V_{min}
Reverse Polarity Input Voltage Transient	T ≤ 100 ms, R_{OUT} = 100Ω	−55	−35/**−35**	V_{min}

Electrical Characteristics (Continued)

V_{IN} = 14V, I_{buf} = 5 mA, C_{buf} = 10 μF, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40°C \leq T_A \leq +125°C$, all other limits are for $T_A = T_j = 25°C$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
V_{buffer} (Pin 10)				
Output Voltage	$5\ mA \leq I_O \leq 100\ mA$ $6V \leq V_{IN} \leq 26V$	5.00	4.85/**4.75** 5.15/**5.25**	V_{min} V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	25/**25**	mV_{max}
	$7V \leq V_{IN} \leq 26V$	5	50/**50**	mV_{max}
Load Regulation	$5\ mA \leq I_{buf} \leq 100\ mA$	15	50/**50**	mV_{max}
Output Impedance	50 mA_{dc} and 10 mA_{rms}, f_O = 120 Hz	200		mΩ
Quiescent Current	I_{buf} = 100 mA	8.0	15/**15**	mA_{max}
Output Noise Voltage	10 Hz–100 kHz, I_{OUT} = 100 mA	100		μV
Long Term Stability		20		mV/1000 hr
Ripple Rejection	f_o = 120 Hz	70	60/**50**	dB_{min}
Dropout Voltage	I_{buf} = 100 mA	0.35	0.50/**0.80**	V_{max}
Current Limit		0.23	0.15/**0.15**	A_{min}
Maximum Operational Input Voltage	Continuous DC	32	26/**26**	V_{min}
Maximum Line Transient	$V_{buf} \leq 6V$, R_{buf} = 100Ω, $T \leq 100$ ms	65	60/**60**	V_{min}
Reverse Polarity Input Voltage DC	$V_{buf} \geq -0.6V$, R_{buf} = 100Ω	−30	−15/**−15**	V_{min}
Reverse Polarity Input Voltage Transient	$T \leq 100$ ms, R_{buf} = 100Ω	−55	−35/**−35**	V_{min}

Electrical Characteristics

V_{IN} = 14V, I_{stby} = 1 mA, C_{stby} = 10 μF, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, $-40°C \leq T_A \leq +125°C$, all other limits are for $T_A = T_j = 25°C$ (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
$V_{standby}$ (Pin 9)				
Output Voltage	$1\ mA \leq I_O \leq 7.5\ mA$ $6V \leq V_{IN} \leq 26V$	5.00	4.85/**4.75** 5.15/**5.25**	V_{min} V_{max}
Line Regulation	$9V \leq V_{IN} \leq 16V$	2	25/**25**	mV_{max}
	$7V \leq V_{IN} \leq 26V$	5	50/**50**	mV_{max}
Load Regulation	$0.5\ mA \leq I_{OUT} \leq 7.5\ mA$	6	50/**50**	mV_{max}
Output Impedance	5 mA_{dc} and 1 mA_{rms}, f_o = 120 Hz	0.9		Ω
Quiescent Current	I_{stby} = 7.5 mA	1.2	2.0/**4.0**	mA_{max}
	I_{stby} = 2 mA	0.9	1.5/**4.0**	mA_{max}

Electrical Characteristics (Continued)

V_{IN} = 14V, I_{stby} = 1 mA, C_{stby} = 10 μF, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, −40°C ≤ T_A ≤ +125°C, all other limits are for T_A = T_j = 25°C (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
$V_{standby}$ (Pin 9) (Continued)				
Output Noise Voltage	10 Hz–100 kHz, I_{stby} = 1 mA	100		μV
Long Term Stability		20		mV/1000 hr
Ripple Rejection	f_o = 120 Hz	70	60/**50**	dB_{min}
Dropout Voltage	I_{stby} = 1 mA	0.26	0.50/**0.60**	V_{max}
	I_{stby} = 7.5 mA	0.38	0.60/**0.70**	V_{max}
Current Limit		15	12/**12**	mA_{min}
Maximum Operational Input Voltage	4.5V ≤ V_{stby} ≤ 6V, R_{stby} = 1000Ω	65	60/**60**	V_{min}
Maximum Line Transient	V_{stby} ≤ 6V, T ≤ 100 ms, R_{stby} = 1000Ω	65	60/**60**	V_{min}
Reverse Polarity Input Voltage DC	V_{stby} ≥ −0.6V, R_{stby} = 1000Ω	−30	−15/**−15**	V_{min}
Reverse Polarity Input Voltage Transient	T ≤ 100 ms, R_{stby} = 1000Ω	−55	−35/**−35**	V_{min}

Electrical Characteristics

V_{IN} = 14V, C_{OUT} = 10 μF, C_{buf} = 10 μF, C_{stby} = 10 μF, unless otherwise indicated. **Boldface** type refers to limits over the entire operating temperature range, −40°C ≤ T_A ≤ +125°C, all other limits are for T_A = T_j = 25°C (Note 6).

Parameter	Conditions	Typical	Limit (Note 2)	Units
Tracking and Isolation				
Tracking $V_{OUT}-V_{stby}$	I_{OUT} ≤ 500 mA, I_{buf} = 5 mA, I_{stby} ≤ 7.5 mA	±30	±100/**±100**	mV_{max}
Tracking $V_{buf}-V_{stby}$	I_{OUT} = 5 mA, I_{buf} ≤ 100 mA, I_{stby} ≤ 7.5 mA	±30	±100/**±100**	mV_{max}
Tracking $V_{OUT}-V_{buf}$	I_{OUT} ≤ 500 mA, I_{buf} ≤ 100 mA, I_{stby} = 1 mA	±30	±100/**±100**	mV_{max}
Isolation* V_{buf} from V_{OUT}	R_{OUT} = 1Ω, I_{buf} ≤ 100 mA	5.00	4.50/**4.50** 5.50/**5.50**	V_{min} V_{max}
Isolation* V_{stby} from V_{OUT}	R_{OUT} = 1Ω, I_{stby} ≤ 7.5 mA	5.00	4.50/**4.50** 5.50/**5.50**	V_{min} V_{max}
Isolation* V_{OUT} from V_{buf}	R_{buf} = 1Ω, I_{OUT} ≤ 500 mA	5.00	4.50/**4.50** 5.50/**5.50**	V_{min} V_{max}
Isolation* V_{stby} from V_{buf}	R_{buf} = 1Ω, I_{stby} ≤ 7.5 mA	5.00	4.50/**4.50** 5.50/**5.50**	V_{min} V_{max}

*Isolation refers to the ability of the specified output to remain within the tested limits when the other output is shorted to ground.

Electrical Characteristics (Continued)

V_{IN} = 14V, I_{OUT} = 5 mA, I_{buf} = 5 mA, I_{stby} = 5 mA, R_t = 130 kΩ, C_t = 0.33 μF, C_{mon} = 0.47 μF, unless otherwise indicated, **Boldface** type refers to limits over the entire operating temperature range, −40°C ≤ T_A ≤ +125°C, all other limits are for T_A = T_J = 25°C (Note 6)

Parameter	Conditions	Typical	Limit (Note 2)	Units
Computer Monitor/Reset Functions				
I_{reset} Low	V_{IN} = 4V, V_{rst} = 0.4V	5	2/**0.50**	mA_{min}
V_{reset} Low	V_{IN} = 4V, I_{rst} = 1 mA	0.10	0.40/**0.40**	V_{max}
R_t voltage	(Pin 2)	1.22	1.15/**0.75**	V_{min}
		1.22	1.30/**2.00**	V_{max}
Power On Reset Delay	$V\mu P_{mon}$ = 5V (T_{dly} = 1.2 R_t C_t)	50	45/**17.0**	ms_{min}
		50	55/**80.0**	ms_{max}
ΔV_{OUT} Low Reset Threshold	(Note 4)	−350	−225/**−175**	mV_{min}
			−500/**−550**	mV_{max}
ΔV_{OUT} High Reset Threshold	(Note 4)	600	225/**175**	mV_{min}
			750/**800**	mV_{max}
Reset Output Leakage	$V\mu P_{mon}$ = 5V, V_{rst} = 12V	0.01	1/**5.0**	μA_{max}
μP_{mon} Input Current (Pin 4)	$V\mu P_{mon}$ = 2.4V	7.5	25/**25**	μA_{max}
	$V\mu P_{mon}$ = 0.4V	0.01	10/**15**	μA_{max}
μP_{mon} Input Threshold Voltage		1.22	0.80/**0.80**	V_{min}
		1.22	2.00/**2.00**	V_{max}
μP Monitor Reset Oscillator Period	$V\mu P_{mon}$ = 0V (T_{window} = 0.82 R_tC_{mon})	50	45/**30**	ms_{min}
		50	55/**70**	ms_{max}
μP Monitor Reset Oscillator Pulse Width	$V\mu P_{mon}$ = 0V ($RESET_{pw}$ = 2000 C_{mon})	1.0	0.7/**0.4**	ms_{min}
		1.0	1.3/**2.10**	ms_{max}
Minimum μP Monitor Input Pulse Width	(Note 5)	2		μs
Reset Fall Time	R_{rst} = 10k, V_{rst} = 5V, C_{rst} ≤ 10 pF	0.20	1.00/**1.00**	μs_{max}
Reset Rise Time	R_{rst} = 10k, V_{rst} = 5V, C_{rst} ≤ 10 pF	0.60	1.00/**1.50**	μs_{max}
On/Off Switch Input Current (Pin 8)	V_{ON} = 2.4V	7.5	25/**25**	μA_{max}
	V_{ON} = 0.4V	0.01	10/**10**	μA_{max}
On/Off Switch Input Threshold Voltage		1.22	0.80/**0.80**	V_{min}
		1.22	2.00/**2.00**	V_{max}

Note 1: Thermal resistance without a heatsink for junction-to-case temperature is 3°C/W. Thermal resistance case-to-ambient is 40°C/W.

Note 2: Tested Limits are guaranteed and 100% production tested.

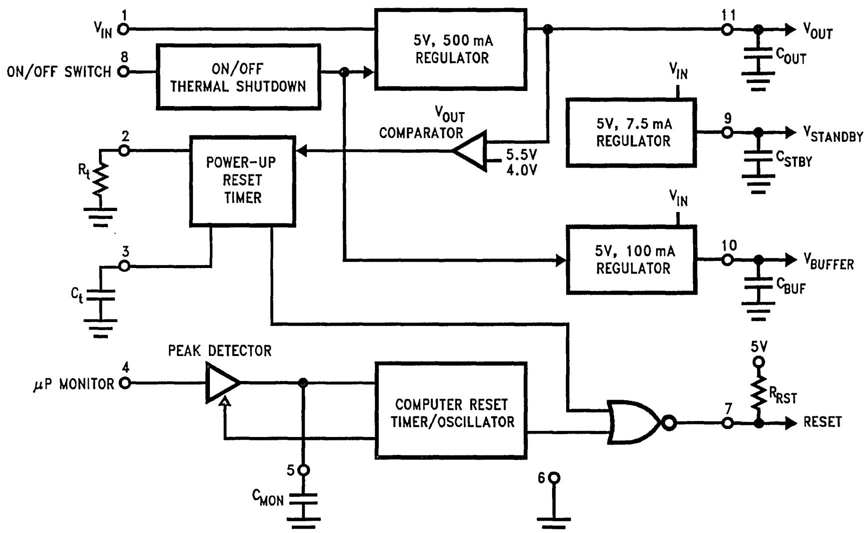
Note 3: Human body model, 100 pF capacitor discharged through a 1500Ω resistor.

Note 4: Internal comparators detect when the main regulator output (V_{OUT}) changes from the measured output voltage (with V_{IN} = 14V) by the specified amount, ΔV_{OUT} High or ΔV_{OUT} Low, and set the Reset Error Flag low. The Reset Error Flag is held low until V_{OUT} returns to regulation. The Reset Error Flag is then allowed to go high again after a delay set by R_t and C_t. (see application section).

Note 5: This parameter is a measure of how short a pulse can be detected at the μP Monitor Input. This parameter is primarily influenced by the value of C_{mon}. (See Application Hints Section.)

Note 6: To ensure constant junction temperature, low duty cycle pulse testing is used.

Block Diagram



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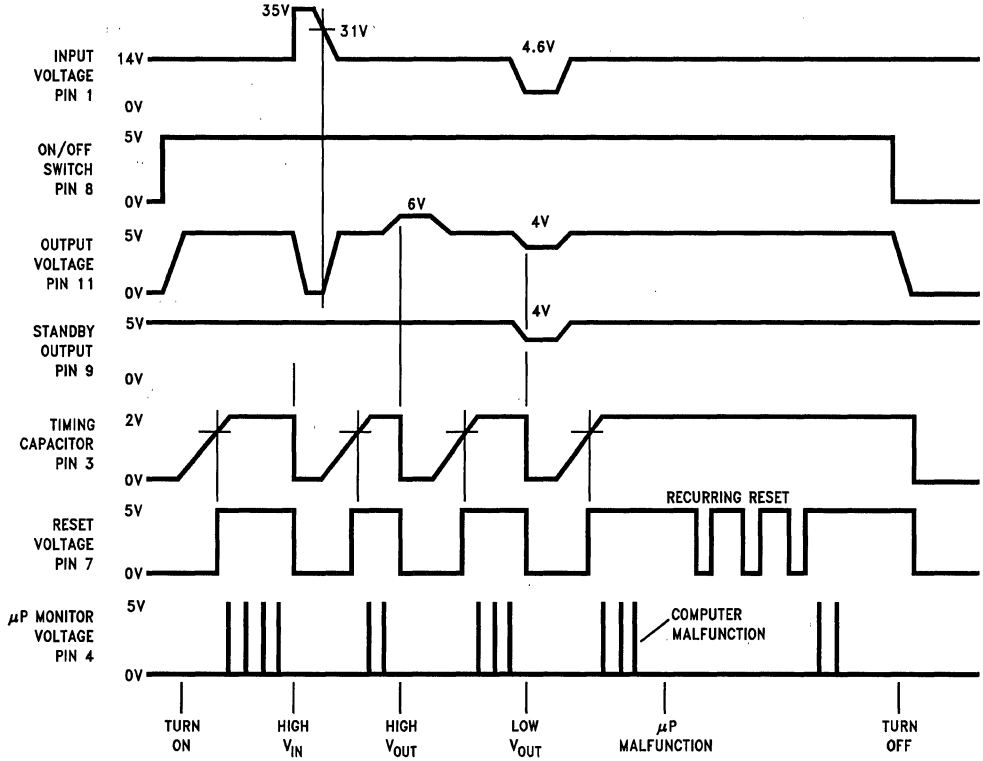
Pin Description

Pin No.	Pin Name	Comments
1	V_{IN}	Positive supply input voltage
2	R_t	Sets internal timing currents
3	C_t	Sets power-up reset delay timing
4	μP_{mon}	Microcomputer monitor input
5	C_{mon}	Sets μC monitor timing
6	Ground	Regulator ground
7	Reset	Reset error flag output
8	ON/OFF	Enables/disables high current regulators
9	$V_{standby}$	Standby regulator output (7.5 mA)
10	V_{buffer}	Buffer regulator output (100 mA)
11	V_{OUT}	Main regulator output (500 mA)

External Components

Component	Typical Value	Component Range	Comments
C_{IN}	1 μF	0.47 μF–10 μF	Required if device is located far from power supply filter.
R_t	130k	24k–510k	Sets internal timing currents.
C_t	0.33 μF	0.033 μF–3.3 μF	Sets power-up reset delay.
C_{tc}	0.01 μF	0.001 μF–0.1 μF	Establishes time constant of AC coupled computer monitor.
R_{tc}	10k	1k–100k	Establishes time constant of AC coupled computer monitor. (See applications section.)
C_{mon}	0.47 μF	0.047 μF–4.7 μF	Sets time window for computer monitor. Also determines period and pulse width of computer malfunction reset. (See applications section.)
R_{rst}	10k	5k–100k	Load for open collector reset output. Determined by computer reset input requirements.
C_{stby}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.
C_{buf}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.
C_{OUT}	10 μF	10 μF–no bound	A 10 μF is required for stability but larger values can be used to maintain regulation during transient conditions.

Typical Circuit Waveforms



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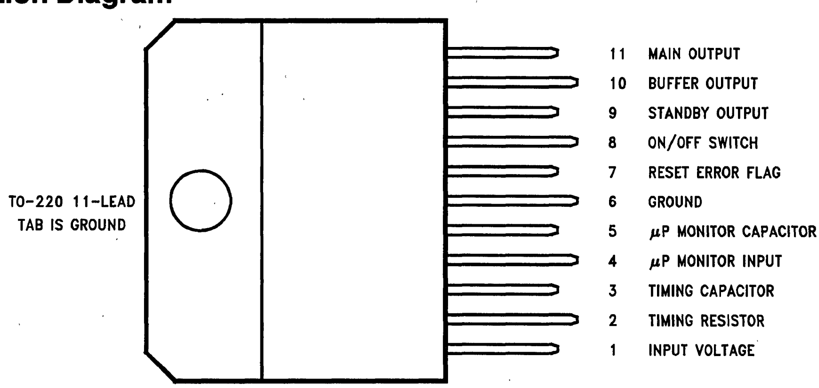
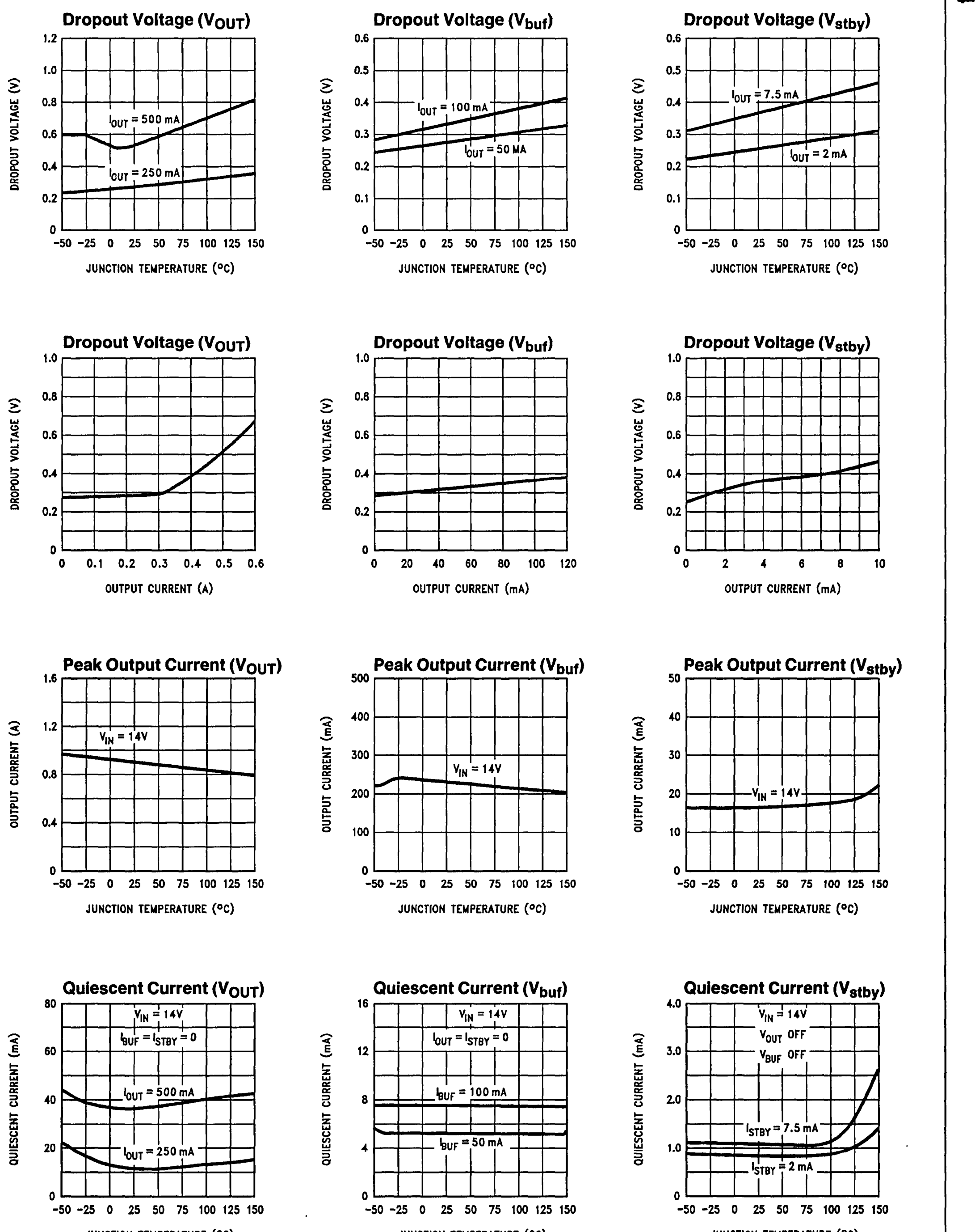
Connection Diagram



TL/H/11252-4

Order Number LM2984T
See NS Package Number TA11B

Typical Performance Characteristics



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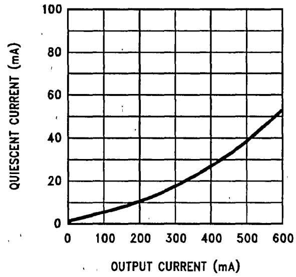
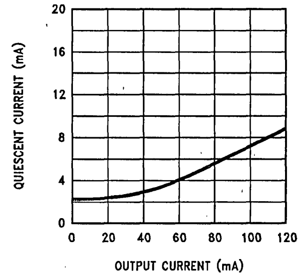
2

Typical Performance Characteristics (Continued)

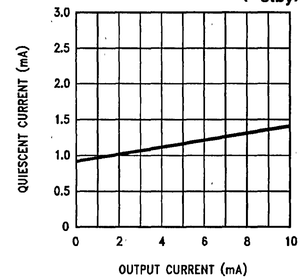
Quiescent Current (V_{OUT})



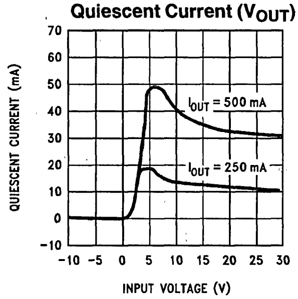
Quiescent Current (V_{buf})



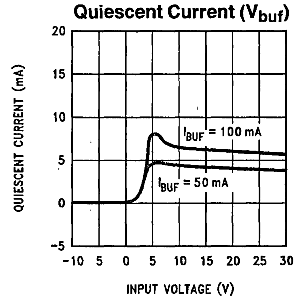
Quiescent Current (V_{stby})



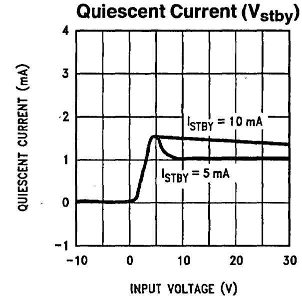
Quiescent Current (V_{OUT})



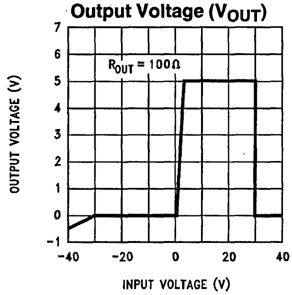
Quiescent Current (V_{buf})



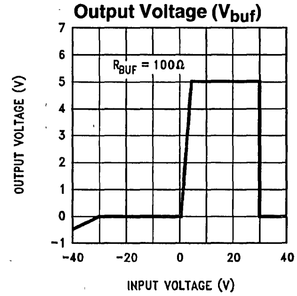
Quiescent Current (V_{stby})



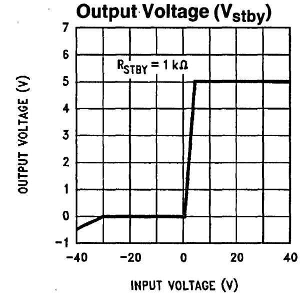
Output Voltage (V_{OUT})



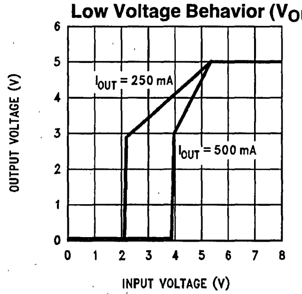
Output Voltage (V_{buf})



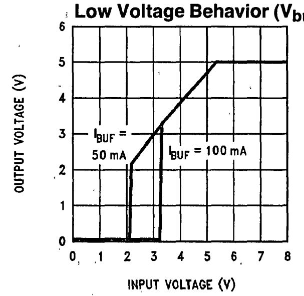
Output Voltage (V_{stby})



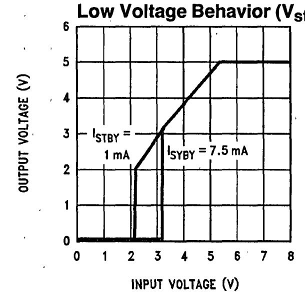
Low Voltage Behavior (V_{OUT})



Low Voltage Behavior (V_{buf})



Low Voltage Behavior (V_{stby})



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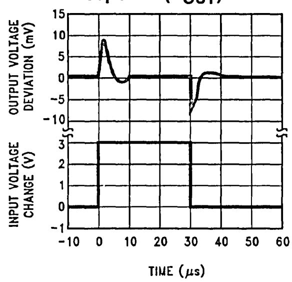
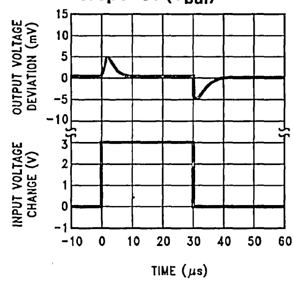
Typical Performance Characteristics (Continued)

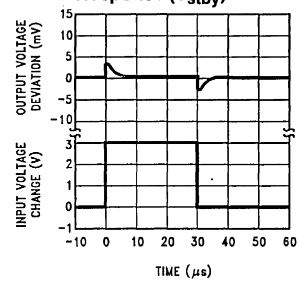
Line Transient Response (V_{OUT})



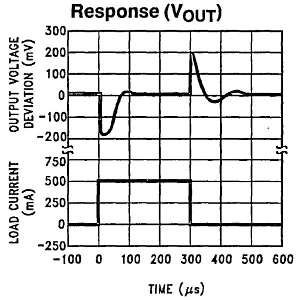
Line Transient Response (V_{buf})



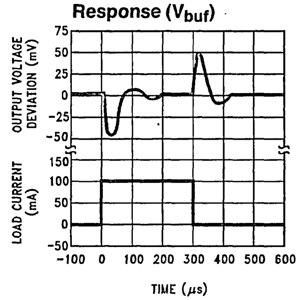
Line Transient Response (V_{stby})



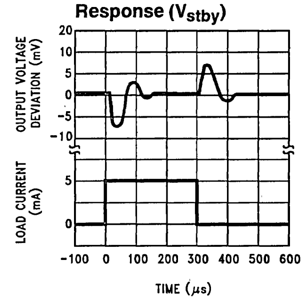
Load Transient Response (V_{OUT})



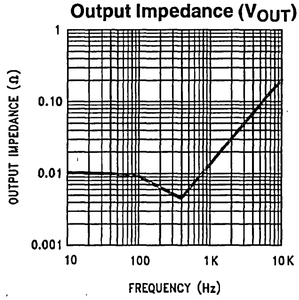
Load Transient Response (V_{buf})



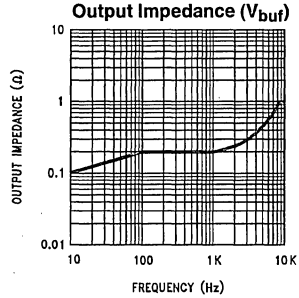
Load Transient Response (V_{stby})



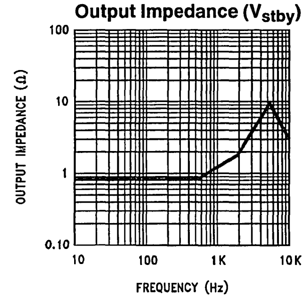
Output Impedance (V_{OUT})



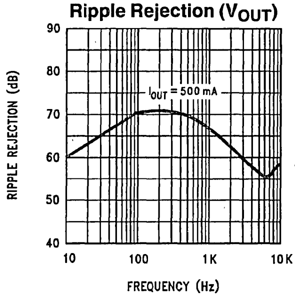
Output Impedance (V_{buf})



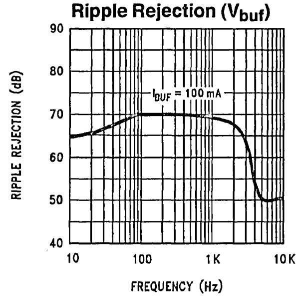
Output Impedance (V_{stby})



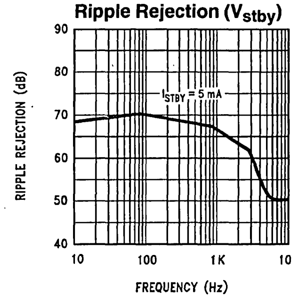
Ripple Rejection (V_{OUT})



Ripple Rejection (V_{buf})



Ripple Rejection (V_{stby})

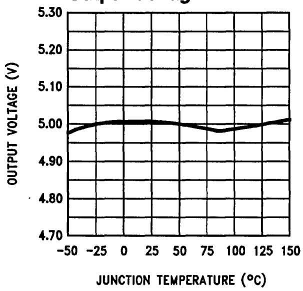


TL/H/11252–7

2

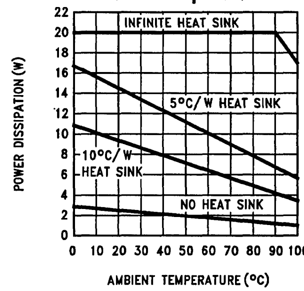
Typical Performance Characteristics (Continued)

Output Voltage



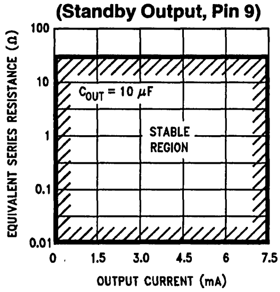
TL/H/11252-8

Device Dissipation vs Ambient Temperature



TL/H/11252-9

Output Capacitor ESR (Standby Output, Pin 9)



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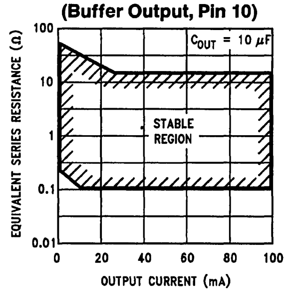
Output Capacitor ESR (Buffer Output, Pin 10)



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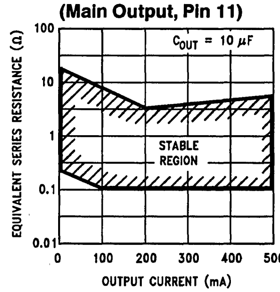
Output Capacitor ESR (Main Output, Pin 11)



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Application Hints

OUTPUT CAPACITORS

The LM2984 output capacitors are required for stability. Without them, the regulator outputs will oscillate, sometimes by many volts. Though the 10 μF shown are the minimum recommended values, actual size and type may vary depending upon the application load and temperature range. Capacitor effective series resistance (ESR) also affects the IC stability. Since ESR varies from one brand to the next, some bench work may be required to determine the minimum capacitor value to use in production. Worst case is usually determined at the minimum ambient temperature and the maximum load expected.

Output capacitors can be increased in size to any desired value above the minimum. One possible purpose of this would be to maintain the output voltages during brief conditions of negative input transients that might be characteristic of a particular system.

Capacitors must also be rated at all ambient temperatures expected in the system. Many aluminum type electrolytics will freeze at temperatures less than −30°C, reducing their effective capacitance to zero. To maintain regulator stability down to −40°C, capacitors rated at that temperature (such as tantalums) must be used.

Each output **must** be terminated by a capacitor, even if it is not used.

STANDBY OUTPUT

The standby output is intended for use in systems requiring standby memory circuits. While the high current regulator outputs are controlled with the ON/OFF pin described later, the standby output remains on under all conditions as long as sufficient input voltage is supplied to the IC. Thus, memory and other circuits powered by this output remain unaffected by positive line transients, thermal shutdown, etc.

The standby regulator circuit is designed so that the quiescent current to the IC is very low (<1.5 mA) when the other regulator outputs are off.

The capacitor on the output of this regulator can be increased without bound. This will help maintain the output voltage during negative input transients and will also help to reduce the noise on all three outputs. Because the other two track the standby output: therefore any noise reduction here will also reduce the other two noise voltages.

BUFFER OUTPUT

The buffer output is designed to drive peripheral sensor circuitry in a μP system. It will track the standby and main regulator within a few millivolts in normal operation. Therefore, a peripheral sensor can be powered off this supply and have the same operating voltage as the μP system. This is important if a ratiometric sensor system is being used.

The buffer output can be short circuited while the other two outputs are in normal operation. This protects the μP system from disruption of power when a sensor wire, etc. is temporarily shorted to ground, i.e. only the sensor signal would be interrupted, while the μP and memory circuits would remain operational.

The buffer output is similar to the main output in that it is controlled by the ON/OFF switch in order to save power in

Application Hints (Continued)

the standby mode. It is also fault protected against overvoltage and thermal overload. If the input voltage rises above approximately 30V (e.g. load dump), this output will automatically shut down. This protects the internal circuitry and enables the IC to survive higher voltage transients than would otherwise be expected. Thermal shutdown is necessary since this output is one of the dominant sources of power dissipation in the IC.

MAIN OUTPUT

The main output is designed to power relatively large loads, i.e. approximately 500 mA. It is therefore also protected against overvoltage and thermal overload.

This output will track the other two within a few millivolts in normal operation. It can therefore be used as a reference voltage for any signal derived from circuitry powered off the standby or buffer outputs. This is important in a ratiometric sensor system or any system requiring accurate matching of power supply voltages.

ON/OFF SWITCH

The ON/OFF switch controls the main output and the buffer output. The threshold voltage is compatible with most logic families and has about 20 mV of hysteresis to insure 'clean' switching from the standby mode to the active mode and vice versa. This pin can be tied to the input voltage through a 10 kΩ resistor if the regulator is to be powered continuously.

POWER DOWN OVERRIDE

Another possible approach is to use a diode in series with the ON/OFF signal and another in series with the main output in order to maintain power for some period of time after the ON/OFF signal has been removed (see *Figure 1*). When the ON/OFF switch is initially pulled high through diode D1, the main output will turn on and supply power through diode D2 to the ON/OFF switch effectively latching the main output. An open collector transistor Q1 is connected to the ON/OFF pin along with the two diodes and forces the regulators off after a period of time determined by the μP. In this way, the μP can override a power down command and store data, do housekeeping, etc. before reverting back to the standby mode.

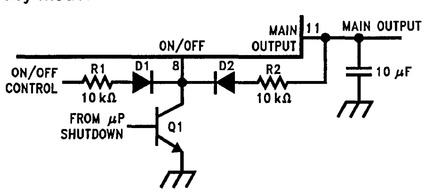

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FIGURE 1. Power Down Override

RESET OUTPUT

This output is an open collector NPN transistor which is forced low whenever an error condition is present at the main output or when a μP error is sensed (see μP Monitor section). If the main output voltage drops by 350 mV or rises out of regulation by 600 mV typically, the RESET output is forced low and held low for a period of time set by two external components, R_t and C_t. There is a slight amount of hysteresis in these two threshold voltages so that the RESET output has a fast rise and fall time compatible with the requirements of most μP RESET inputs.

DELAYED RESET

Resistor R_t and capacitor C_t set the period of time that the RESET output is held low after a main output error condition has been sensed. The delay is given by the formula:

$$T_{dly} = 1.2\, R_t C_t \text{ (seconds)}$$

The delayed RESET will be initiated any time the main output is out of regulation, i.e. during power-up, short circuit, overvoltage, low line, thermal shutdown or power-down. The μP is therefore RESET whenever the output voltage is out of regulation. (It is important to note that a RESET is only initiated when the main output is in error. The buffer and standby outputs are not directly monitored for error conditions.)

μP MONITOR RESET

There are two distinct and independent error monitoring systems in the LM2984. The one described above monitors the main regulator output and initiates a delayed RESET whenever this output is in error. The other error monitoring system is the μP watchdog. These two systems are OR'd together internally and both force the RESET output low when either type of error occurs.

This watchdog circuitry continuously monitors a pin on the μP that generates a positive going pulse during normal operation. The period of this pulse is typically on the order of milliseconds and the pulse width is typically on the order of 10's of microseconds. If this pulse ever disappears, the watchdog circuitry will time out and a RESET low will be sent to the μP. The time out period is determined by two external components, R_t and C_{mon}, according to the formula:

$$T_{window} = 0.82\, R_t C_{mon} \text{ (seconds)}$$

The width of the RESET pulse is set by C_{mon} and an internal resistor according to the following:

$$RESET_{pw} = 2000\, C_{mon} \text{ (seconds)}$$

A square wave signal can also be monitored for errors by filtering the C_{mon} input such that only the positive edges of the signal are detected. *Figure 2* is a schematic diagram of a typical circuit used to differentiate the input signal. Resistor R_{tc} and capacitor C_{tc} pass only the rising edge of the square wave and create a short positive pulse suitable for the μP monitor input. If the incoming signal continues in a high state or in a low state for too long a period of time, a RESET low will be generated.

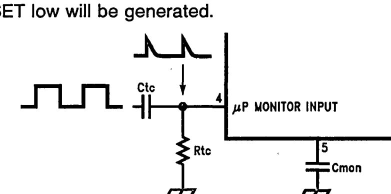

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FIGURE 2. Monitoring Square Wave μP Signals

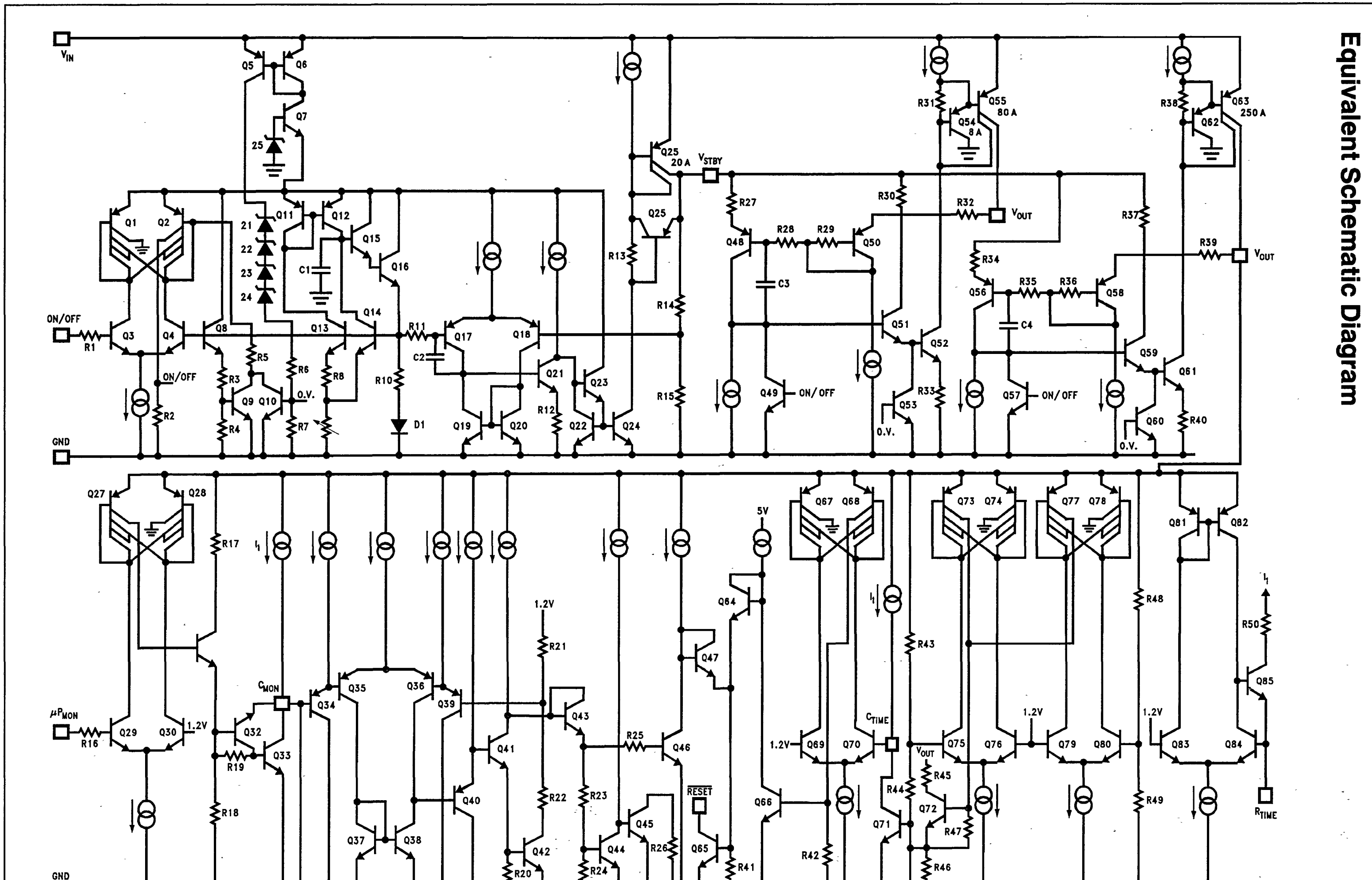
The threshold voltage and input characteristics of this pin are compatible with nearly all logic families.

There is a limit on the width of a pulse that can be reliably detected by the watchdog circuit. This is due to the output resistance of the transistor which discharges C_{mon} when a high state is detected at the input. The minimum detectable pulse width can be determined by the following formula:

$$PW_{min} = 20\, C_{mon} \text{ (seconds)}$$

2

Equivalent Schematic Diagram



TL/H/11252–15

National Semiconductor

LM2990 Negative Low Dropout Regulator

General Description

The LM2990 is a three-terminal, low dropout, 1 ampere negative voltage regulator available with fixed output voltages of −5, −5.2, −12, and −15V.

The LM2990 uses new circuit design techniques to provide low dropout and low quiescent current. The dropout voltage at 1A load current is typically 0.6V and a guaranteed worst-case maximum of 1V over the entire operating temperature range. The quiescent current is typically 1 mA with 1A load current and an input-output voltage differential greater than 3V. A unique circuit design of the internal bias supply limits the quiescent current to only 9 mA (typical) when the regulator is in the dropout mode ($V_{OUT} - V_{IN} \leq 3V$). Output voltage accuracy is guaranteed to ±5% over load, and temperature extremes.

The LM2990 is short-circuit proof, and thermal shutdown includes hysteresis to enhance the reliability of the device when overloaded for an extended period of time. The LM2990 is available in a 3-lead TO-220 package and is rated for operation over the automotive temperature range of −40°C to +125°C.

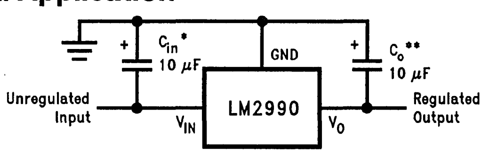
Features

- 5% output accuracy over entire operating range
- Output current in excess of 1A
- Dropout voltage typically 0.6V at 1A load
- Low quiescent current
- Internal short circuit current limit
- Internal thermal shutdown with hysteresis
- Functional complement to the LM2940 series

Applications

- Post switcher regulator
- Local, on-card, regulation
- Battery operated equipment

Typical Application



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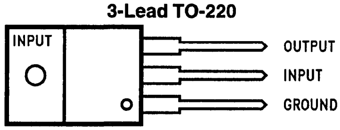
*Required if the regulator is located further than 6 inches from the power supply filter capacitors. A 1 µF solid tantalum or a 10 µF aluminum electrolytic capacitor is recommended.

**Required for stability. Must be at least a 10 µF aluminum electrolytic or a 1 µF solid tantalum to maintain stability. May be increased without bound to maintain regulation during transients. Locate the capacitor as close as possible to the regulator. The equivalent series resistance (ESR) is critical, and should be less than 10Ω over the same operating temperature range as the regulator.

Connection Diagram and Ordering Information

3-Lead TO-220

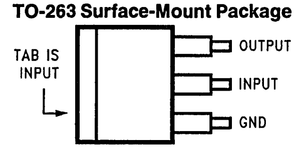


TL/H/10801-2

Front View

Order Number LM2990T-5.0, LM2990T-5.2, LM2990T-12 or LM2990T-15
See NS Package Number T03B

TO-263 Surface-Mount Package



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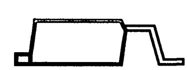
Top View



TL/H/10801-12

Side View

Order Number LM2990S-5.0, LM2990S-12 or LM2990S-15
See NS Package Number TS3B

Temperature Range	Output Voltage				Package
	-5.0	-5.2	-12	-15	
−40°C to +125°C	LM2990T-5.0	LM2990T-5.2	LM2990T-12	LM2990T-15	TO-220
	LM2990S-5.0		LM2990S-12	LM2990S-15	TO-263

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	−26V to +0.3V
ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited
Junction Temperature (T_{Jmax})	125°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	−40°C to +125°C
Maximum Input Voltage (Operational)	−26V

Electrical Characteristics $V_{IN} = -5V + V_{O(NOM)}$ (Note 6), $I_O = 1A$, $C_O = 47\ \mu F$, unless otherwise specified.

Boldface limits apply over the entire operating temperature range, $-40°C \le T_J \le 125°C$, all other limits apply for $T_J = 25°C$.

Parameter	Conditions	LM2990-5.0 Typ (Note 4)	LM2990-5.0 Limit (Note 5)	LM2990-5.2 Typ (Note 4)	LM2990-5.2 Limit (Note 5)	Units (Limit)
Output Voltage (V_O)	$5\ mA \le I_O \le 1A$	−5	−4.90 −5.10	−5.2	−5.10 −5.30	V (max) V (min) V
	$5\ mA \le I_O \le 1A$		**−4.75** **−5.25**		**−4.94** **−5.46**	V (max) V (min)
Line Regulation	$I_O = 5\ mA$, $V_{O(NOM)} - 1V > V_{IN} > -26V$	4	40	4	40	mV (max)
Load Regulation	$50\ mA \le I_O \le 1A$	1	40	1	40	mV (max)
Dropout Voltage	$I_O = 0.1A$, $\Delta V_O \le 100\ mV$	0.1	**0.3**	0.1	**0.3**	V (max)
	$I_O = 1A$, $\Delta V_O \le 100\ mV$	0.6	**1**	0.6	**1**	V (max)
Quiescent Current (I_q)	$I_O \le 1A$	1	5	1	5	mA (max)
	$I_O = 1A$, $V_{IN} = V_{O(NOM)}$	9	50	9	50	mA (max)
Short Circuit Current	$R_L = 1\Omega$ (Note 7)	1.8	1.5	1.8	1.5	A (min)
Maximum Output Current	(Note 7)	1.8	1.5	1.8	1.5	A (min)
Ripple Rejection	$V_{ripple} = 1\ V_{rms}$, $f_{ripple} = 1\ kHz$, $I_O = 5\ mA$	58	50	58	50	dB (min)
Output Noise Voltage	10 Hz–100 kHz, $I_O = 5\ mA$	250	750	250	750	μV (max)
Long Term Stability	1000 Hours	2000		2000		ppm

Electrical Characteristics $V_{IN} = -5V + V_{O(NOM)}$ (Note 6), $I_O = 1A$, $C_O = 47\ \mu F$, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40°C \le T_J \le 125°C$, all other limits apply for $T_J = 25°C$. (Continued)

Parameter	Conditions	LM2990-12		LM2990-15		Units (Limit)
		Typ (Note 4)	Limit (Note 5)	Typ (Note 4)	Limit (Note 5)	
Output Voltage (V_O)	5 mA ≤ I_O ≤ 1A	−12	−11.76 −12.24	−15	−14.70 −15.30	V (max) V (min) V
	5 mA ≤ I_O ≤ 1A		**−11.40** **−12.60**		**−14.25** **−15.75**	V (max) V (min)
Line Regulation	I_O = 5 mA, $V_{O(NOM)} -1V > V_{IN} > -26V$	6	60	6	60	mV (max)
Load Regulation	50 mA ≤ I_O ≤ 1A	3	50	3	50	mV (max)
Dropout Voltage	I_O = 0.1A, ΔV_O ≤ 100 mV	0.1	**0.3**	0.1	**0.3**	V (max)
	I_O = 1A, ΔV_O ≤ 100 mV	0.6	**1**	0.6	**1**	V (max)
Quiescent Current (I_q)	I_O ≤ 1A	1	5	1	5	mA (max)
	I_O = 1A, $V_{IN} = V_{O(NOM)}$	9	50	9	50	mA (max)
Short Circuit Current	R_L = 1Ω (Note 7)	1.2	0.9	1.0	0.75	A (min)
Maximum Output Current	(Note 7)	1.8	1.4	1.8	1.4	A (min)
Ripple Rejection	V_{ripple} = 1 V_{rms}, f_{ripple} = 1 kHz, I_O = 5 mA	52	42	52	42	dB (min)
Output Noise Voltage	10 Hz–100 kHz, I_O = 5 mA	500	1500	600	1800	µV (max)
Long Term Stability	1000 Hours	2000		2000		ppm

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 3: The maximum power dissipation is a function of T_{Jmax}, θ_{JA}, and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 125°C, and the LM2990 will eventually go into thermal shutdown at a T_J of approximately 160°C. For the LM2990, the junction-to-ambient thermal resistance, is 53°C/W, 73°C/W for the TO-263, and the junction-to-case thermal resistance is 3°C. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Note 4: Typicals are at T_J = 25°C and represent the most likely parametric norm.

Note 5: Limits are guaranteed and 100% production tested.

Note 6: $V_{O(NOM)}$ is the nominal (typical) regulator output voltage, −5V, −5.2V, −12V or −15V.

Note 7: The short circuit current is less than the maximum output current with the −12V and −15V versions due to internal foldback current limiting. The −5V and −5.2V versions, tested with a lower input voltage, does not reach the foldback current limit and therefore conducts a higher short circuit current level. If the LM2990 output is pulled above ground, the maximum allowed current sunk back into the LM2990 is 1.5A.

Definition of Terms

Dropout Voltage: The input-output voltage differential at which the circuit ceases to regulate against further reduction in input voltage. Measured when the output voltage has dropped 100 mV from the nominal value obtained at (V_O + 5V) input, dropout voltage is dependent upon load current and junction temperature.

Input Voltage: The DC voltage applied to the input terminals with respect to ground.

Input-Output Differential: The voltage difference between the unregulated input voltage and the regulated output voltage for which the regulator will operate.

Line Regulation: The change in output voltage for a change in the input voltage. The measurement is made under conditions of low dissipation or by using pulse techniques such that the average chip temperature is not significantly affected.

Load Regulation: The change in output voltage for a change in load current at constant chip temperature.

Long Term Stability: Output voltage stability under accellerated life-test conditions after 1000 hours with maximum rated voltage and junction temperature.

Output Noise Voltage: The rms AC voltage at the output, with constant load and no input ripple, measured over a specified frequency range.

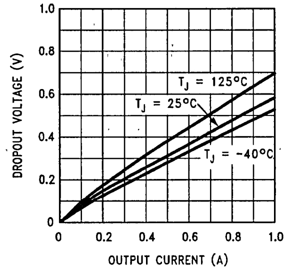
Quiescent Current: That part of the positive input current that does not contribute to the positive load current. The regulator ground lead current.

Ripple Rejection: The ratio of the peak-to-peak input ripple voltage to the peak-to-peak output ripple voltage.

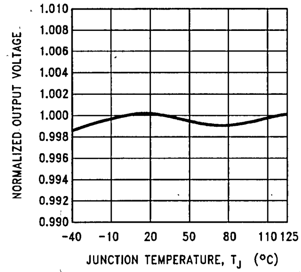
Temperature Stability of V_O: The percentage change in output voltage for a thermal variation from room temperature to either temperature extreme.

Typical Performance Characteristics

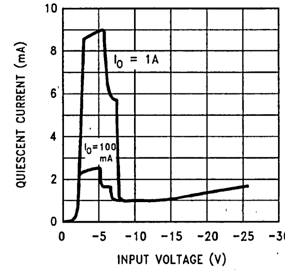
Dropout Voltage



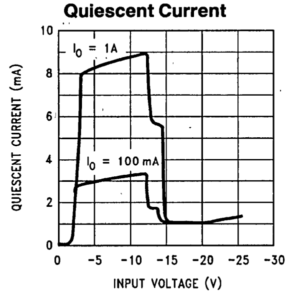
Normalized Output Voltage



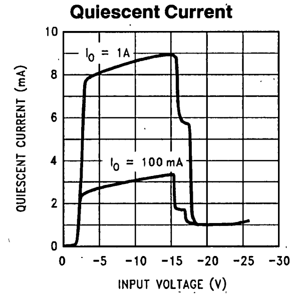
LM2990-5.0 and LM2990-5.2 Quiescent Current



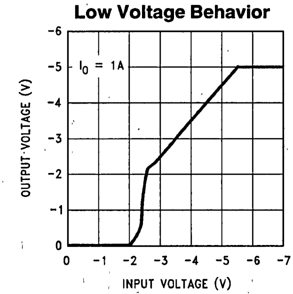
LM2990-12 Quiescent Current



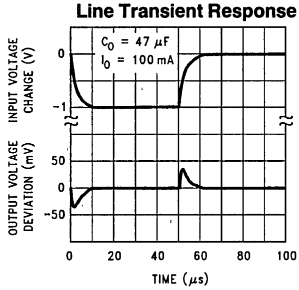
LM2990-15 Quiescent Current



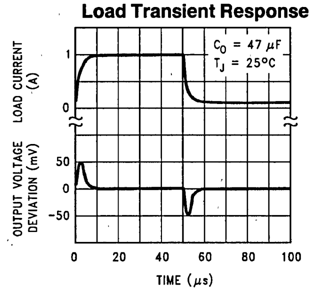
LM2990-5 and LM2990-5.2 Low Voltage Behavior



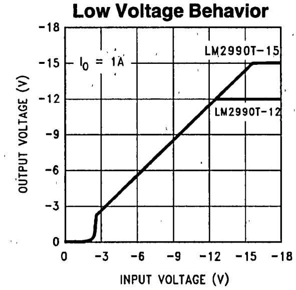
LM2990-5 and LM2990-5.2 Line Transient Response



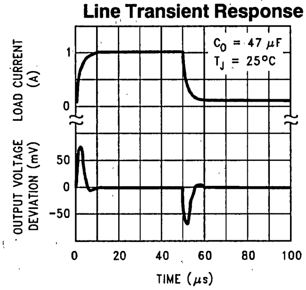
LM2990-5 and LM2990-5.2 Load Transient Response



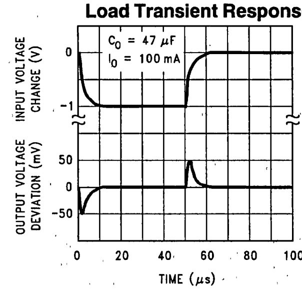
LM2990-12 and LM2990-15 Low Voltage Behavior



LM2990-12 and LM2990-15 Line Transient Response



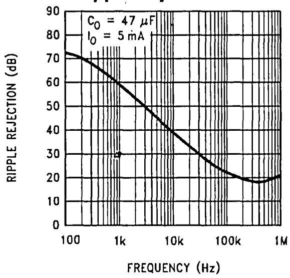
LM2990-12 and LM2990-15 Load Transient Response



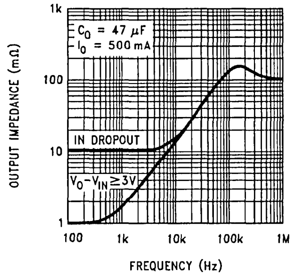
TL/H/10801–3

Typical Performance Characteristics (Continued)

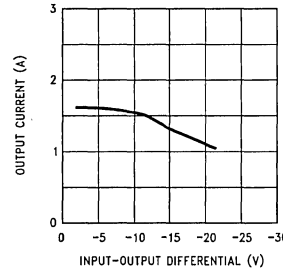
LM2990-5 and LM2990-5.2 Ripple Rejection



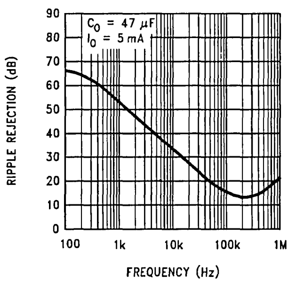
LM2990-5 and LM2990-5.2 Output Impedance



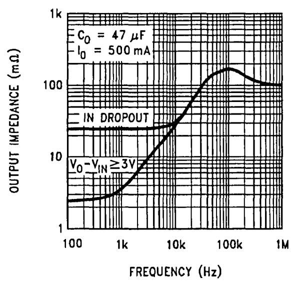
Maximum Output Current



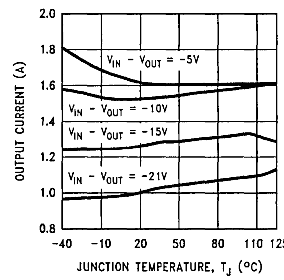
LM2990-12 and LM2990-15 Ripple Rejection



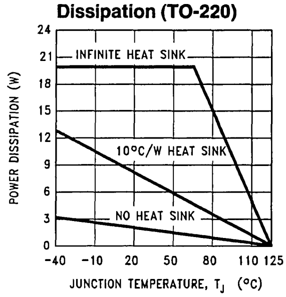
LM2990-12 and LM2990-15 Output Impedance



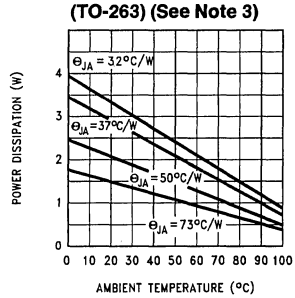
Maximum Output Current



Maximum Power Dissipation (TO-220)



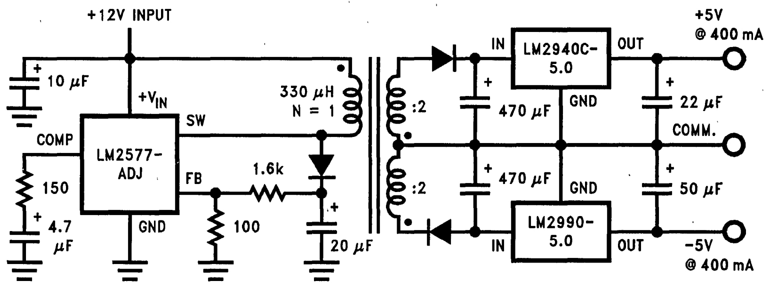
Maximum Power Dissipation (TO-263) (See Note 3)



TL/H/10801-4

Typical Applications

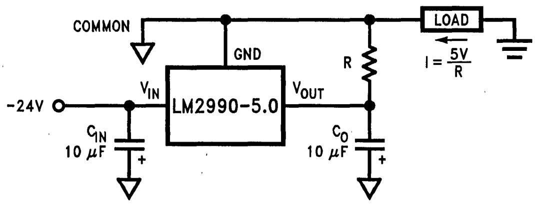
Post Regulator for an Isolated Switching Power Supply



TL/H/10801-5

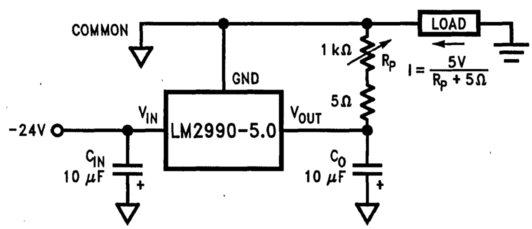
The LM2490 is a positive 1A low dropout regulator; refer to its datasheet for further information.

Fixed Current Sink



TL/H/10801-7

Adjustable Current Sink



TL/H/10801-10

Application Hints

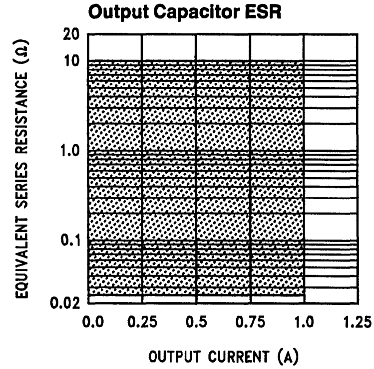
EXTERNAL CAPACITORS

The LM2990 regulator requires an output capacitor to maintain stability. The capacitor must be at least 10 µF aluminum electrolytic or 1 µF solid tantalum. The output capacitor's ESR must be less than 10Ω, or the zero added to the regulator frequency response by the ESR could reduce the phase margin, creating oscillations (refer to the graph on the right). An input capacitor, of at least 1 µF solid tantalum or 10 µF aluminum electrolytic, is also needed if the regulator is situated more than 6″ from the input power supply filter.

FORCING THE OUTPUT POSITIVE

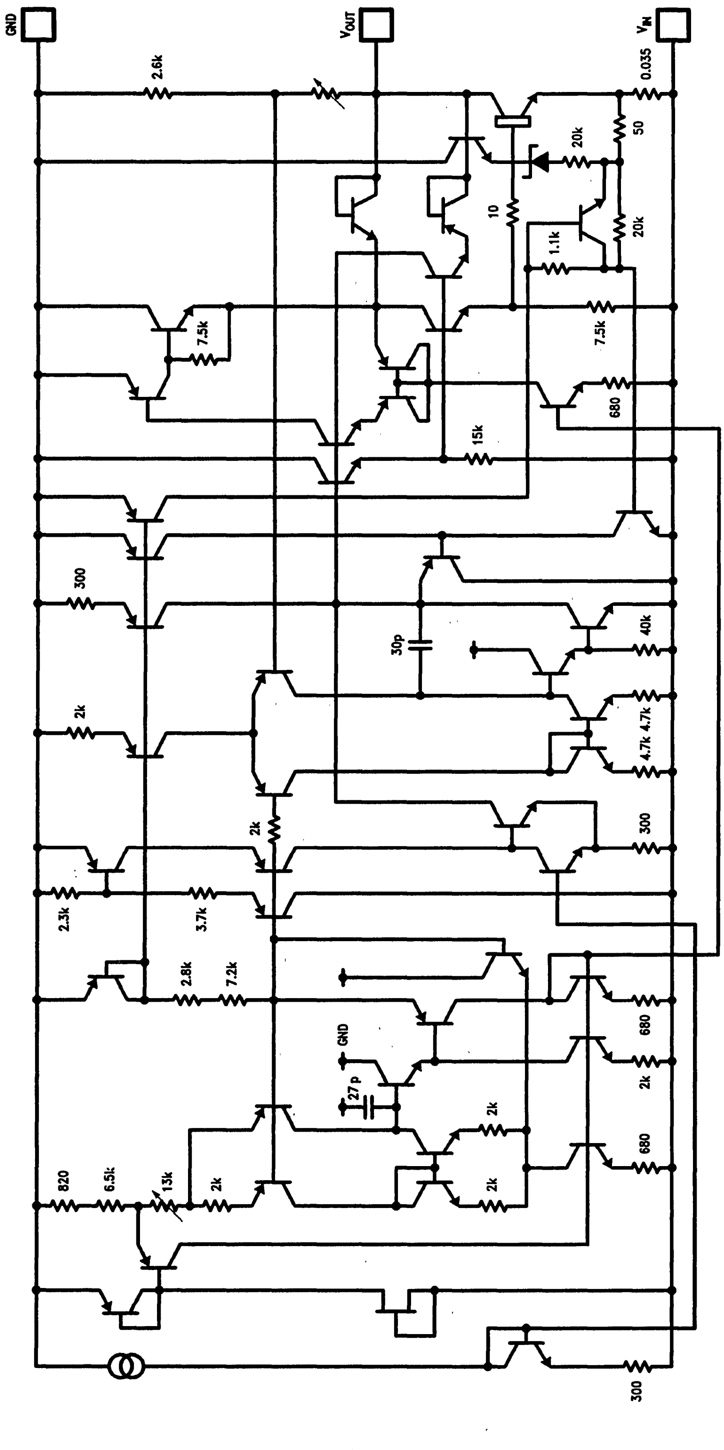
Due to an internal clamp circuit, the LM2990 can withstand positive voltages on its output. If the voltage source pulling the output positive is DC, the current must be limited to 1.5A. A current over 1.5A fed back into the LM2990 could damage the device. The LM2990 output can also withstand fast positive voltage transients up to 26V, without any current limiting of the source. However, if the transients have a duration of over 1 ms, the output should be clamped with a Schottky diode to ground.

Output Capacitor ESR



TL/H/10801-9

Equivalent Schematic



TL/H/10801-8

National Semiconductor

LM2991 Negative Low Dropout Adjustable Regulator

General Description

The LM2991 is a low dropout adjustable negative regulator with a output voltage range between −2V to −25V. The LM2991 provides up to 1A of load current and features a $\overline{\text{On}}$/Off pin for remote shutdown capability.

The LM2991 uses new circuit design techniques to provide a low dropout voltage, low quiescent current and low temperature coefficient precision reference. The dropout voltage at 1A load current is typically 0.6V and a guaranteed worst-case maximum of 1V over the entire operating temperature range. The quiescent current is typically 1 mA with a 1A load current and an input-output voltage differential greater than 3V. A unique circuit design of the internal bias supply limits the quiescent current to only 9 mA (typical) when the regulator is in the dropout mode ($V_{OUT} - V_{IN} \leq 3V$).

The LM2991 is short-circuit proof, and thermal shutdown includes hysteresis to enhance the reliability of the device when inadvertently overloaded for extended periods. The LM2991 is available in a 5-lead TO-220, TO-263, and is rated for operation over the automotive temperature range of −40°C to +125°C.

Features

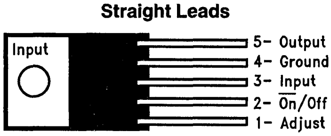
- Output voltage adjustable from −2V to −25V
- Output current in excess of 1A
- Dropout voltage typically 0.6V at 1A load
- Low quiescent current
- Internal short circuit current limit
- Internal thermal shutdown with hysteresis
- TTL, CMOS compatible $\overline{\text{ON}}$/OFF switch
- Functional complement to the LM2941 series

Applications

- Post switcher regulator
- Local, on-card, regulation
- Battery operated equipment

Connection Diagrams and Ordering Information

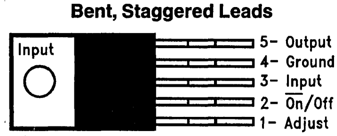
5-Lead TO-220
Straight Leads



TL/H/11260-9

Front View
Order Number LM2991T
See NS Package Number T05A

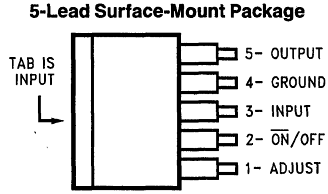
5-Lead TO-220
Bent, Staggered Leads



TL/H/11260-2

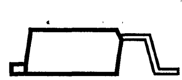
Front View
Order Number LM2991T Flow LB03
See NS Package Number T05D

TO263
5-Lead Surface-Mount Package



TL/H/11260-11

Top View



TL/H/11260-12

Side View
Order Number LM2991S
See NS Package Number TS5B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	−26V to +0.3V
ESD Susceptibility (Note 2)	2 kV
Power Dissipation (Note 3)	Internally limited
Junction Temperature (T_{Jmax})	125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	230°C

Operating Ratings (Note 1)

Junction Temperature Range (T_J)	−40°C to +125°C
Maximum Input Voltage (Operational)	−26V

Electrical Characteristics

$V_{IN} = -10V$, $V_O = -3V$, $I_O = 1A$, $C_O = 47\ \mu F$, $R1 = 2.7k$, $T_J = 25°C$, unless otherwise specified. **Boldface** limits apply over the entire operating junction temperature range.

Parameter	Conditions	Typical (Note 4)	Min	Max	Units
Reference Voltage	$5\ mA \le I_O \le 1A$	−1.210	−1.234	−1.186	V
	$5\ mA \le I_O \le 1A$, $V_O - 1V \ge V_{IN} \ge -26V$		**−1.27**	**−1.15**	V
Output Voltage Range		−2		−3	V
	$V_{IN} = -26V$	−25	−24		V
Line Regulation	$I_O = 5\ mA$, $V_O - 1V \ge V_{IN} \ge -26V$	0.004		0.04	%/V
Load Regulation	$50\ mA \le I_O \le 1A$	0.04		0.4	%
Dropout Voltage	$I_O = 0.1A$, $\Delta V_O \le 100\ mV$	0.1		0.2 **0.3**	V
	$I_O = 1A$, $\Delta V_O \le 100\ mV$	0.6		0.8 **1**	V
Quiescent Current	$I_O \le 1A$	0.7		**5**	mA
Dropout Quiescent Current	$V_{IN} = V_O$, $I_O \le 1A$	16		50	mA
Ripple Rejection	$V_{ripple} = 1$ Vrms, $f_{ripple} = 1$ kHz, $I_O = 5\ mA$	60	50		dB
Output Noise	10 Hz − 100 kHz, $I_O = 5\ mA$	200		450	μV
$\overline{ON}$/OFF Input Voltage	(V_{OUT}: ON) (V_{OUT}: OFF)	1.2 1.3	 **2.4**	**0.8** 	V
$\overline{ON}$/OFF Input Current	$V_{\overline{ON}/OFF} = 0.8V$ (V_{OUT}: ON) $V_{\overline{ON}/OFF} = 2.4V$ (V_{OUT}: OFF)	0.1 40		10 100	μA
Output Leakage Current	$V_{IN} = -26V$, $V_{\overline{ON}/OFF} = 2.4V$ $V_{OUT} = 0V$	60		250	μA
Current Limit	$V_{OUT} = 0V$	2	1.5		A

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the deivce is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

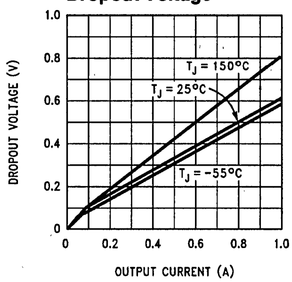
Note 2: Human body model, 100 pF discharged through a 1.5 kΩ resistor.

Note 3: The maximum power dissipation is a function of T_{Jmax}, θ_{JA} and T_A. The maximum allowable power dissipation at any ambient temperature is $P_D = (T_{Jmax} - T_A)/\theta_{JA}$. If this dissipation is exceeded, the die temperature will rise above 125°C and the LM2991 will go into thermal shutdown. For the LM2991, the junction-to-ambient thermal resistance is 53°C/W for the TO-220, 73°C/W for the TO-263, and junction-to-case thermal resistance is 3°C. If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

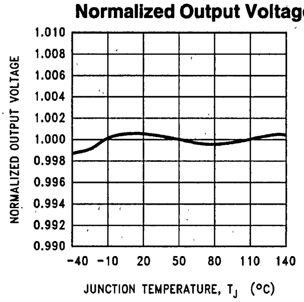
Note 4: Typicals are at $T_J = 25°C$ and represent the most likely parametric norm.

Typical Performance Characteristics

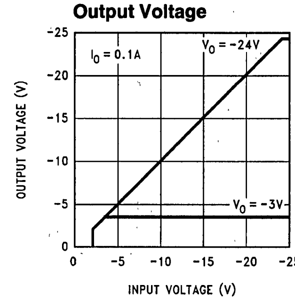
Dropout Voltage



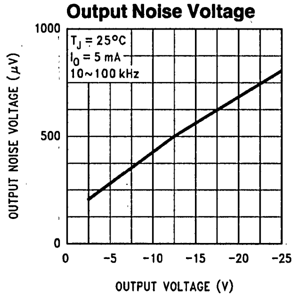
Normalized Output Voltage



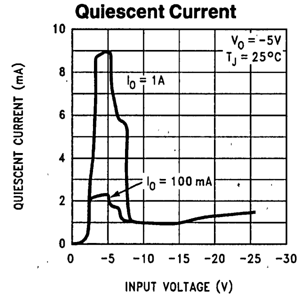
Output Voltage



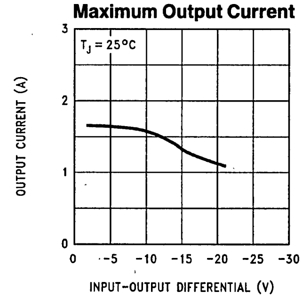
Output Noise Voltage



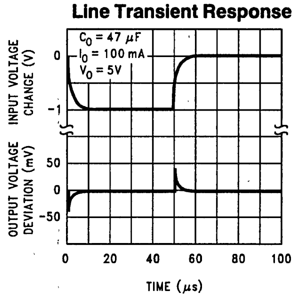
Quiescent Current



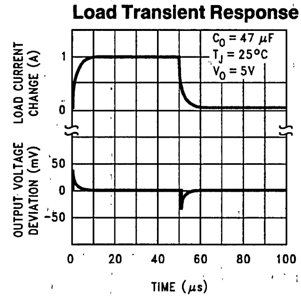
Maximum Output Current



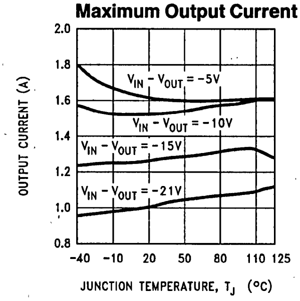
Line Transient Response



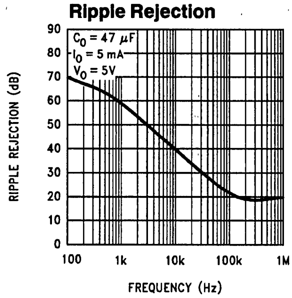
Load Transient Response



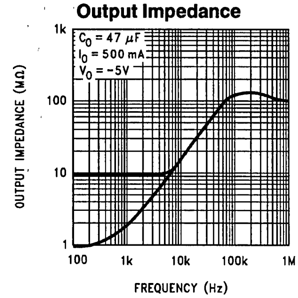
Maximum Output Current



Ripple Rejection

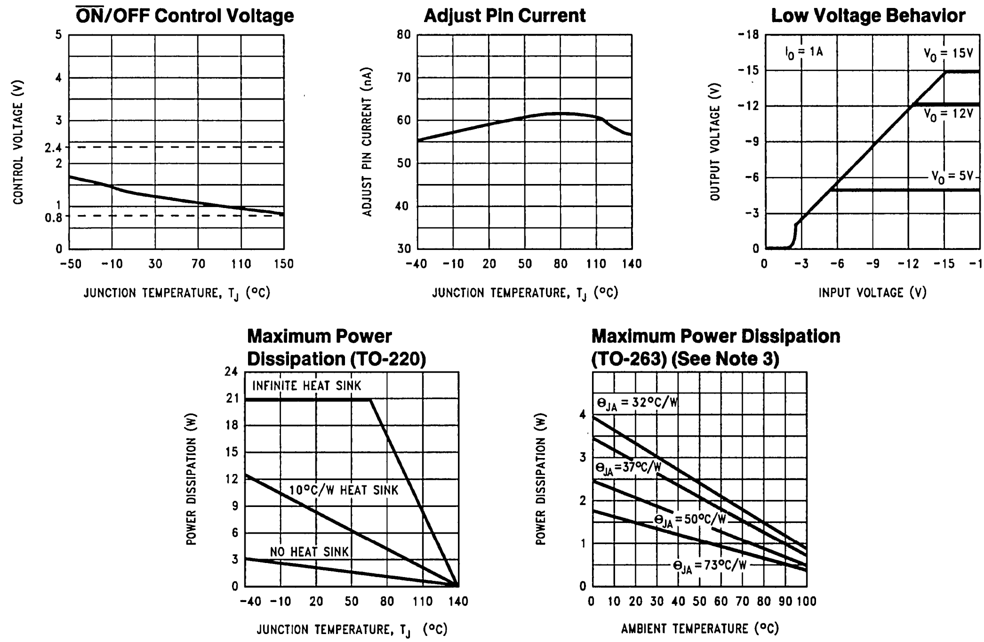


Output Impedance



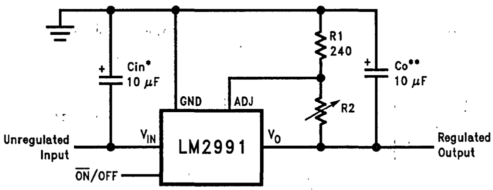
TL/H/11260-3

Typical Performance Characteristics (Continued)



TL/H/11260-4

Typical Applications



TL/H/11260-1

$V_{OUT} = V_{REF} (1 + R2/R1)$

*Required if the regulator is located further than 6 inches from the power supply filter capacitors. A 1 µF solid tantalum or a 10 µF aluminum electrolytic capacitor is recommended.

**Required for stability. Must be at least a 10 µF aluminum electrolytic or a 1 µF solid tantalum to maintain stability. May be increased without bound to maintain regulation during transients. Locate the capacitor as close as possible to the regulator. The equivalent series resistance (ESR) is critical, and should be less than 10Ω over the same operating temperature range as the regulator.

Application Hints

EXTERNAL CAPACITORS

The LM2991 regulator requires an output capacitor to maintain stability. The capacitor must be at least 10 µF aluminum electrolytic or 1 µF solid tantalum. The output capacitor's ESR must be less than 10Ω, or the zero added to the regulator frequency response by the ESR could reduce the phase margin, creating oscillations. The shaded area in the Output Capacitor ESR graph indicates the recommended ESR range. An input capacitor, of at least 1 µF solid tantalum or 10 µF aluminum electrolytic, is also needed if the regulator is situated more than 6 inches from the input power supply filter.

MINIMUM LOAD

A minimum load current of 500 µA is required for proper operation. The external resistor divider can provide the minimum load, with the resistor from the adjust pin to ground set to 2.4 kΩ.

SETTING THE OUTPUT VOLTAGE

The output voltage of the LM2991 is set externally by a resistor divider and the adjust pin current using the following equation:

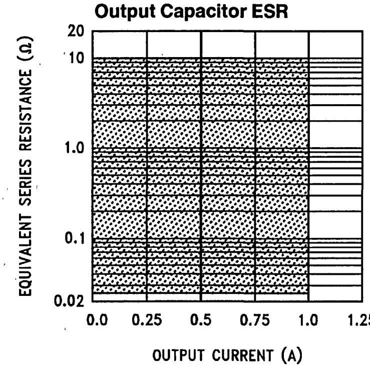
$$V_{OUT} = V_{REF} * (1 + R_2/R_1) - I_{ADJ} * R_2$$

where $V_{REF} = -1.21V$. The output voltage can be programmed within the range of −2V to −25V. The adjust pin current is about 60 nA, causing a slight error in the output voltage. However, using resistors lower than 100 kΩ makes the adjust pin current negligible. For example, neglecting the adjust pin current, and setting R2 to 100 kΩ and V_{OUT} to −5V, results in an output voltage error of only 0.16%.

ON/OFF PIN

The LM2991 regulator can be turned off by applying a TTL or CMOS level high signal to the ON/OFF pin (see Current Sink Application).

Output Capacitor ESR



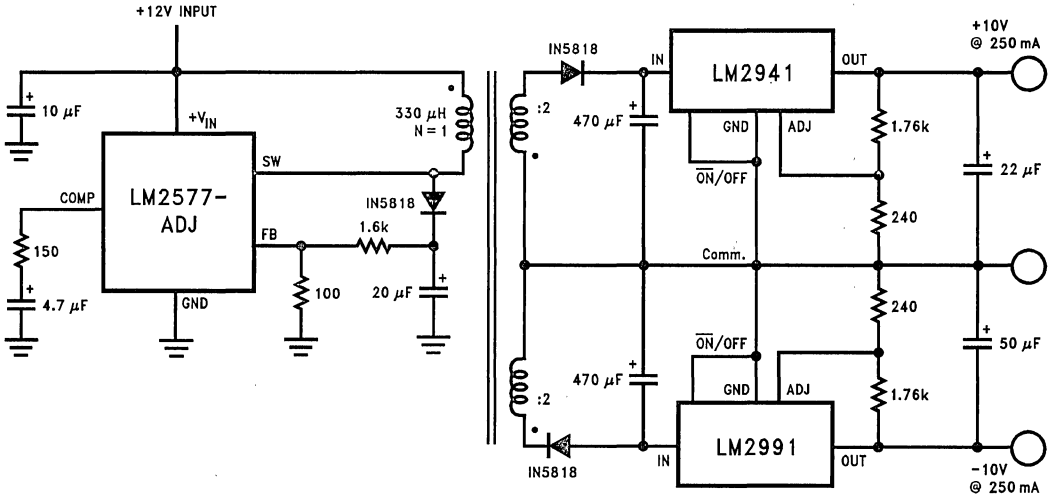
TL/H/11260-5

FORCING THE OUTPUT POSITIVE

Due to an internal clamp circuit, the LM2991 can withstand positive voltages on its output. If the voltage source pulling the output positive is DC, the current must be limited to 1.5A. A current over 1.5A fed back into the LM2991 could damage the device. The LM2991 output can also withstand fast positive voltage transients up to 26V, without any current limiting of the source. However, if the transients have a duration of over 1 ms, the output should be clamped with a Schottky diode to ground.

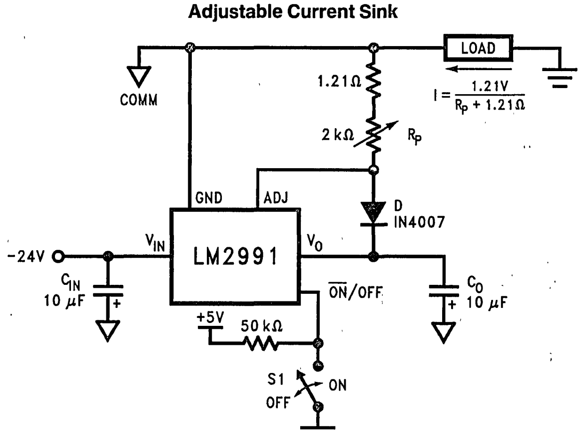
Typical Applications (Continued)

Fully Isolated Post-Switcher Regulater



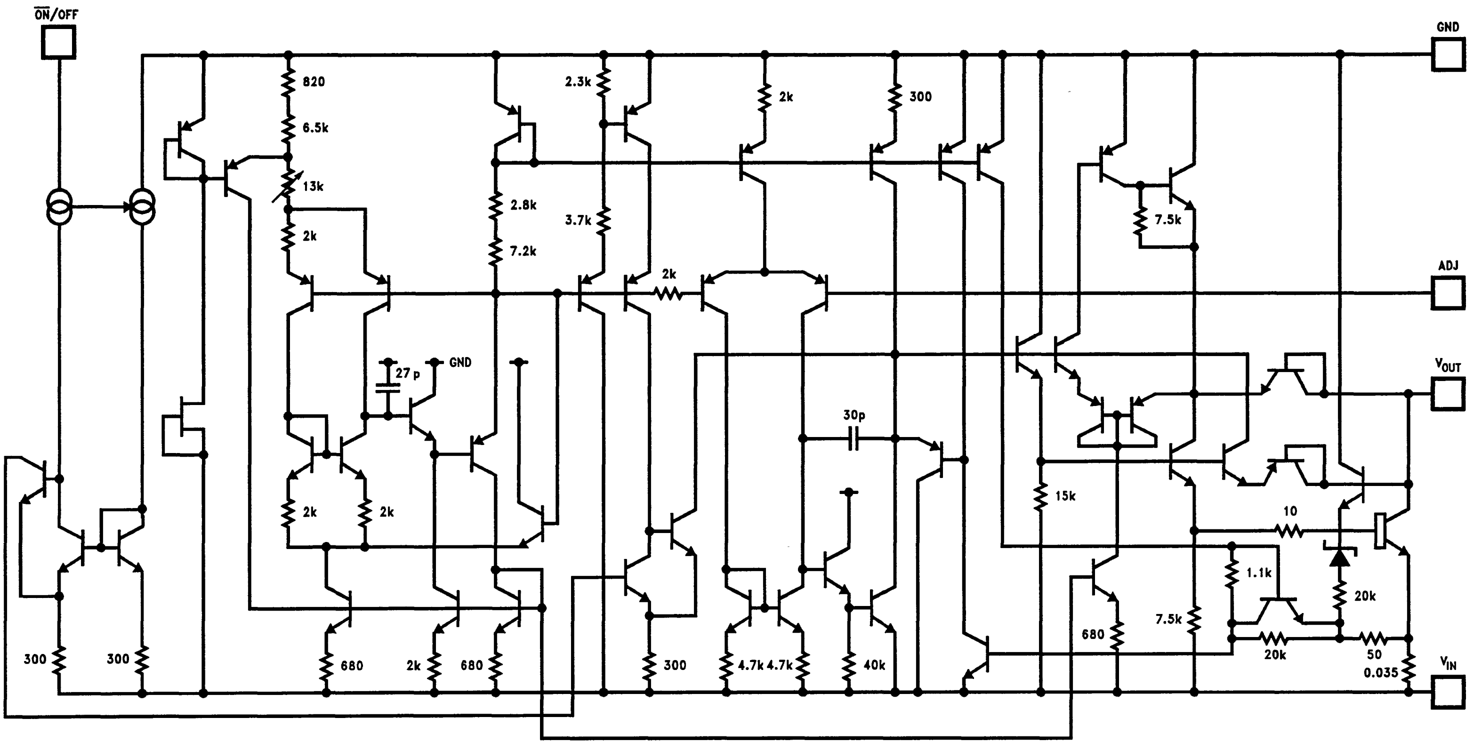
TL/H/11260-6

Adjustable Current Sink



TL/H/11260-10

Equivalent Schematic



TL/H/11260-8

National Semiconductor

LM3420-4.2, -8.4, -12.6 Lithium-Ion Battery Charge Controller

General Description

The LM3420 series of controllers are monolithic integrated circuits designed for charging and end-of-charge control for Lithium-Ion rechargeable batteries. The LM3420 is available in three fixed voltage versions for one, two, or three cell charger applications (4.2V, 8.4V, and 12.6V respectively).

Included in a very small package is an (internally compensated) op amp, a bandgap reference, an NPN output transistor, and voltage setting resistors. The amplifier's inverting input is externally accessible for loop frequency compensation. The output is an open-emitter NPN transistor capable of driving up to 15 mA of output current into external circuitry.

A trimmed precision bandgap reference utilizes temperature drift curvature correction for excellent voltage stability over the operating temperature range. Available with an initial tolerance of 0.5% for the A grade version, and 1% for the standard version, the LM3420 allows for precision end-of-charge control for Lithium-Ion rechargeable batteries.

The LM3420 is available in a sub-miniature 5-lead SOT23-5 surface mount package thus allowing very compact designs.

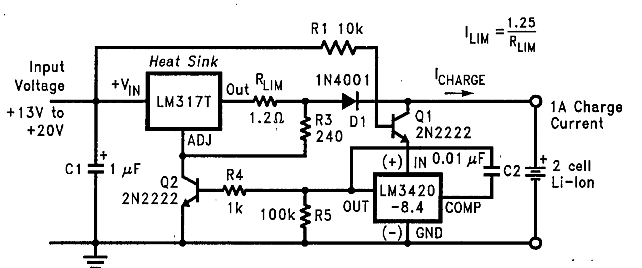
Features

- Voltage options for charging 1, 2, or 3 cells
- Tiny SOT23-5 package
- Precision (0.5%) end-of-charge control
- Drive capability for external power stage
- Low quiescent current, 85 μA (typ.)

Applications

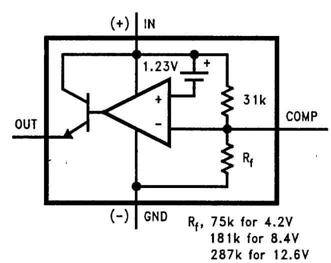
- Lithium-Ion battery charging
- Suitable for linear and switching regulator charger designs

Typical Application and Functional Diagram



TL/H/12359-1

Typical Constant Current/Constant Voltage Li-Ion Battery Charger

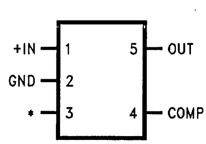


TL/H/12359-2

LM3420 Functional Diagram

Connection Diagrams and Order Information

5-Lead Small Outline Package (M5)



Top View

TL/H/12359-3

Actual Size

TL/H/12359-4

*No internal connection, but should be soldered to PC board for best heat transfer.

For Ordering Information
See *Figure 1* in this Data Sheet
See NS Package Number MA05A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage V(IN)	20V
Output Current	20 mA
Junction Temperature	150°C
Storage Temperature	−65°C to +150°C
Lead Temperature	
Vapor Phase (60 seconds)	+215°C
Infrared (15 seconds)	+220°C
Power Dissipation (T_A = 25°C) (Note 2)	300 mW
ESD Susceptibility (Note 3)	
Human Body Model	1500V

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for methods on soldering surface-mount devices.

Operating Ratings (Notes 1 and 2)

Ambient Temperature Range	$-40°C \leq T_A \leq +85°C$
Junction Temperature Range	$-40°C \leq T_J \leq +125°C$
Output Current	15 mA

LM3420-4.2
Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, V(IN) = V_{REG}, V_{OUT} = 1.5V.

Symbol	Parameter	Conditions	Typical (Note 4)	LM3420A-4.2 Limit (Note 5)	LM3420-4.2 Limit (Note 5)	Units (Limits)
V_{REG}	Regulation Voltage	I_{OUT} = 1 mA	4.2			V
				4.221/**4.242**	4.242/**4.284**	V(max)
				4.179/**4.158**	4.158/**4.116**	V(min)
	Regulation Voltage Tolerance	I_{OUT} = 1 mA		±0.5/±**1**	±1/±**2**	%(max)
I_q	Quiescent Current	I_{OUT} = 1 mA	85			μA
				110/**115**	125/**150**	μA(max)
G_m	Transconductance $\Delta I_{OUT}/\Delta V_{REG}$	20 μA ≤ I_{OUT} ≤ 1 mA, V_{OUT} = 2V	3.3			mA/mV
				1.3/**0.75**	1.0/**0.50**	mA/mV(min)
		1 mA ≤ I_{OUT} ≤ 15 mA, V_{OUT} = 2V	6.0			mA/mV
				3.0/**1.5**	2.5/**1.4**	mA/mV(min)
A_V	Voltage Gain $\Delta V_{OUT}/\Delta V_{REG}$	1V ≤ V_{OUT} ≤ V_{REG} − 1.2V (**−1.3**), R_L = 200Ω (Note 6)	1000			V/V
				550/**250**	450/**200**	V/V(min)
		1V ≤ V_{OUT} ≤ V_{REG} − 1.2V (**−1.3**), R_L = 2 kΩ	3500			V/V
				1500/**900**	1000/**700**	V/V(min)
V_{SAT}	Output Saturation (Note 7)	V(IN) = V_{REG} +100 mV, I_{OUT} = 15 mA	1.0			V
				1.2/**1.3**	1.2/**1.3**	V(max)
I_L	Output Leakage Current	V(IN) = V_{REG} −100 mV, V_{OUT} = 0V	0.1			μA
				0.5/**1.0**	0.5/**1.0**	μA(max)
R_f	Internal Feedback Resistor (Note 8)		75			kΩ
				94	94	kΩ(max)
				56	56	kΩ(min)
E_n	Output Noise Voltage	I_{OUT} = 1 mA, 10 Hz ≤ f ≤ 10 kHz	70			μV_{RMS}

LM3420-8.4
Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V(IN) = V_{REG}$, $V_{OUT} = 1.5V$.

Symbol	Parameter	Conditions	Typical (Note 4)	LM3420A-8.4 Limit (Note 5)	LM3420-8.4 Limit (Note 5)	Units (Limits)
V_{REG}	Regulation Voltage	$I_{OUT} = 1$ mA	8.4			V
				8.442/**8.484**	8.484/**8.568**	V(max)
				8.358/**8.316**	8.316/**8.232**	V(min)
	Regulation Voltage Tolerance	$I_{OUT} = 1$ mA		±0.5/±**1**	±1/±**2**	%(max)
I_q	Quiescent Current	$I_{OUT} = 1$ mA	85			μA
				110/**115**	125/**150**	μA(max)
G_m	Transconductance $\Delta I_{OUT}/\Delta V_{REG}$	$20\ \mu A \le I_{OUT} \le 1$ mA	3.3			mA/mV
		$V_{OUT} = 6V$		1.3/**0.75**	1.0/**0.50**	mA/mV(min)
		$1\ mA \le I_{OUT} \le 15$ mA	6.0			mA/mV
		$V_{OUT} = 6V$		3.0/**1.5**	2.5/**1.4**	mA/mV(min)
A_V	Voltage Gain $\Delta V_{OUT}/\Delta V_{REG}$	$1V \le V_{OUT} \le V_{REG} - 1.2V$ **(−1.3)**	1000			V/V
		$R_L = 470\Omega$ (Note 6)		550/**250**	450/**200**	V/V(min)
		$1V \le V_{OUT} \le V_{REG} - 1.2V$ **(−1.3)**	3500			V/V
		$R_L = 5\ k\Omega$		1500/**900**	1000/**700**	V/V(min)
V_{SAT}	Output Saturation (Note 7)	$V(IN) = V_{REG} + 100$ mV	1.0			V
		$I_{OUT} = 15$ mA		1.2/**1.3**	1.2/**1.3**	V(max)
I_L	Output Leakage Current	$V(IN) = V_{REG} - 100$ mV	0.1			μA
		$V_{OUT} = 0V$		0.5/**1.0**	0.5/**1.0**	μA(max)
R_f	Internal Feedback Resistor (Note 8)		181			kΩ
				227	227	kΩ(max)
				135	135	kΩ(min)
E_n	Output Noise Voltage	$I_{OUT} = 1$ mA, $10\ Hz \le f \le 10\ kHz$	140			μV_{RMS}

LM3420-12.6
Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V(IN) = V_{REG}$, $V_{OUT} = 1.5V$.

Symbol	Parameter	Conditions	Typical (Note 4)	LM3420A-12.6 Limit (Note 5)	LM3420-12.6 Limit (Note 5)	Units (Limits)
V_{REG}	Regulation Voltage	$I_{OUT} = 1$ mA	12.6	12.663/**12.726** 12.537/**12.474**	12.726/**12.852** 12.474/**12.348**	V V(max) V(min)
	Regulation Voltage Tolerance	$I_{OUT} = 1$ mA		±0.5/±**1**	±1/±**2**	%(max)
I_q	Quiescent Current	$I_{OUT} = 1$ mA	85	110/**115**	125/**150**	μA μA(max)
G_m	Transconductance $\Delta I_{OUT}/\Delta V_{REG}$	$20\ \mu A \le I_{OUT} \le 1$ mA $V_{OUT} = 10V$	3.3	1.3/**0.75**	1.0/**0.5**	mA/mV mA/mV(min)
		$1\ mA \le I_{OUT} \le 15$ mA $V_{OUT} = 10V$	6.0	3.0/**1.5**	2.5/**1.4**	mA/mV mA/mV(min)
A_V	Voltage Gain $\Delta V_{OUT}/\Delta V_{REG}$	$1V \le V_{OUT} \le V_{REG} - 1.2V$ (**−1.3**) $R_L = 750\Omega$ (Note 6)	1000	550/**250**	450/**200**	V/V V/V(min)
		$1V \le V_{OUT} \le V_{REG} - 1.2V$ (**−1.3**) $R_L = 10\ k\Omega$	3500	1500/**900**	1000/**700**	V/V V/V(min)
V_{SAT}	Output Saturation (Note 7)	$V(IN) = V_{REG} + 100$ mV $I_{OUT} = 15$ mA	1.0	1.2/**1.3**	1.2/**1.3**	V V(max)
I_L	Output Leakage Current	$V(IN) = V_{REG} - 100$ mV $V_{OUT} = 0V$	0.1	0.5/**1.0**	0.5/**1.0**	μA μA(max)
R_f	Internal Feedback Resistor (Note 8)		287	359 215	359 215	kΩ kΩ(max) kΩ(min)
E_n	Output Noise Voltage	$I_{OUT} = 1$ mA, 10 Hz ≤ f ≤ 10 kHz	210			μV_{RMS}

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{Jmax} (maximum junction temperature), θ_{JA} (junction to ambient thermal resistance), and T_A (ambient temperature). The maximum allowable power dissipation at any temperature is $P_{Dmax} = (T_{Jmax} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. The typical thermal resistance (θ_{JA}) when soldered to a printed circuit board is approximately 306°C/W for the M5 package.

Note 3: The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

Note 4: Typical numbers are at 25°C and represent the most likely parametric norm.

Note 5: Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Averaging Outgoing Quality Level (AOQL).

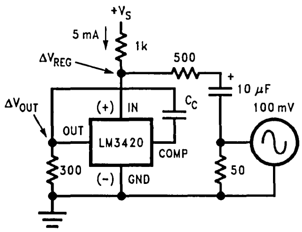
Note 6: Actual test is done using equivalent current sink instead of a resistor load.

Note 7: $V_{SAT} = V(IN) - V_{OUT}$, when the voltage at the IN pin is forced 100 mV above the nominal regulating voltage (V_{REG}).

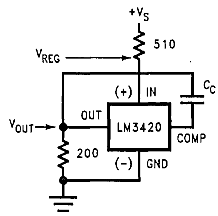
Note 8: See Applications and Curves sections for information on this resistor.

Typical Performance Characteristics

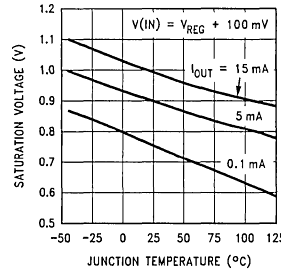
Circuit Used for Bode Plots



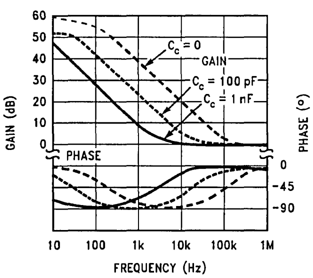
Circuit Used for Response Time



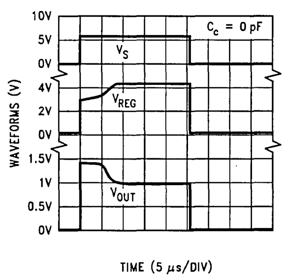
Output Saturation Voltage (V_{SAT})



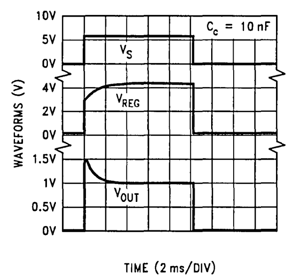
4.2V Bode Plot



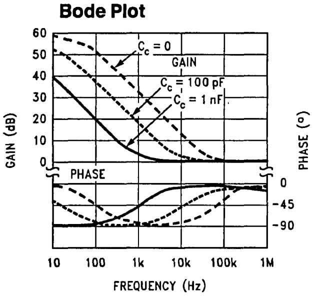
Response Time for 4.2V Version



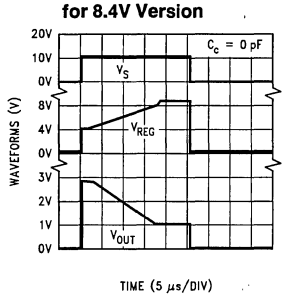
Response Time for 4.2V Version



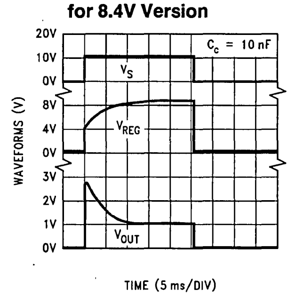
8.4V Bode Plot



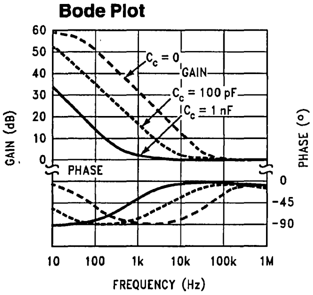
Response Time for 8.4V Version



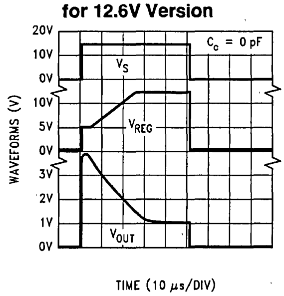
Response Time for 8.4V Version



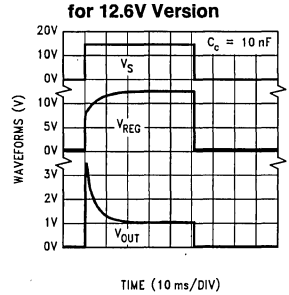
12.6V Bode Plot



Response Time for 12.6V Version



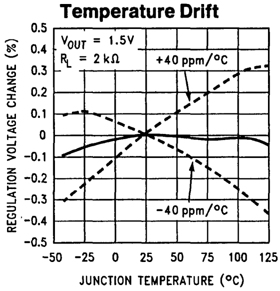
Response Time for 12.6V Version



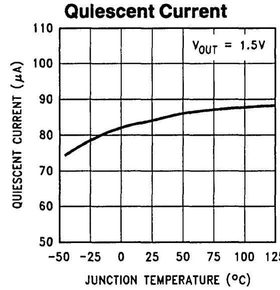
TL/H/12359-5

Typical Performance Characteristics (Continued)

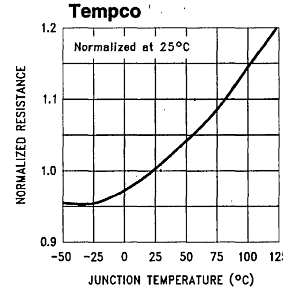
Normalized Temperature Drift



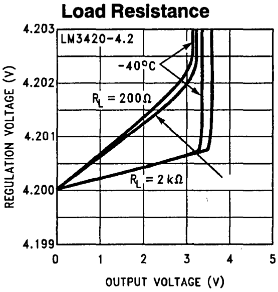
Quiescent Current



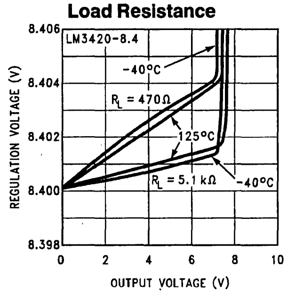
Internal Feedback Resistor (Rf) Tempco



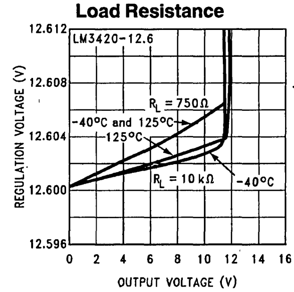
Regulation Voltage vs Output Voltage and Load Resistance



Regulation Voltage vs Output Voltage and Load Resistance



Regulation Voltage vs Output Voltage and Load Resistance



TL/H/12359-6

Five Lead Surface Mount Package Information

The small SOT23-5 package allows only 4 alphanumeric characters to identify the product. The table below contains the field information marked on the package.

Voltage	Grade	Order Information	Package Marking	Supplied as
4.2V	A (Prime)	LM3420AM5-4.2	D02A	250 unit increments on tape and reel
4.2V	A (Prime)	LM3420AM5X-4.2	D02A	3k unit increments on tape and reel
4.2V	B (Standard)	LM3420M5-4.2	D02B	250 unit increments on tape and reel
4.2V	B (Standard)	LM3420M5X-4.2	D02B	3k unit increments on tape and reel
8.4V	A (Prime)	LM3420AM5-8.4	D03A	250 unit increments on tape and reel
8.4V	A (Prime)	LM3420AM5X-8.4	D03A	3k unit increments on tape and reel
8.4V	B (Standard)	LM3420M5-8.4	D03B	250 unit increments on tape and reel
8.4V	B (Standard)	LM3420M5X-8.4	D03B	3k unit increments on tape and reel
12.6V	A (Prime)	LM3420AM5-12.6	D04A	250 unit increments on tape and reel
12.6V	A (Prime)	LM3420AM5X-12.6	D04A	3k unit increments on tape and reel
12.6V	B (Standard)	LM3420M5-12.6	D04B	250 unit increments on tape and reel
12.6V	B (Standard)	LM3420M5X-12.6	D04B	3k unit increments on tape and reel

FIGURE 1. SOT23-5 Marking

The first letter "D" identifies the part as a Driver, the next two numbers indicate the voltage, "02" for a 4.2V part, "03" for a 8.4V part and "04" for a 12.6V part. The fourth letter indicates the grade, "B" for standard grade, "A" for the prime grade.

The SOT23-5 surface mount package is only available on tape in quantity increments of 250 on tape and reel (indicated by the letters "M5" in the part number), or in quantity increments of 3000 on tape and reel (indicated by the letters "M5X" in the part number).

Product Description

The LM3420 is a shunt regulator specifically designed to be the reference and control section in an overall feedback loop of a Lithium-Ion battery charger. The regulated output voltage is sensed between the IN pin and GROUND pin of the LM3420. If the voltage at the IN pin is less than the LM3420 regulating voltage (V_{REG}), the OUT pin sources no current. As the voltage at the IN pin approaches the V_{REG} voltage, the OUT pin begins sourcing current. This current is then used to drive a feedback device, (opto-coupler) or a power device, (linear regulator, switching regulator, etc.) which servos the output voltage to be the same value as V_{REG}.

In some applications, (even under normal operating conditions) the voltage on the IN pin can be forced above the V_{REG} voltage. In these instances, the maximum voltage applied to the IN pin should not exceed 20V. In addition, an external resistor may be required on the OUT pin to limit the maximum current to 20 mA.

Compensation

The inverting input of the error amplifier is brought out to allow overall closed-loop compensation. In many of the applications circuits shown here, compensation is provided by a single capacitor (C_C) connected from the compensation pin to the out pin of the LM3420. The capacitor values shown in the schematics are adequate under most conditions, but they can be increased or decreased depending on the desired loop response. Applying a load pulse to the output of a regulator circuit and observing the resultant output voltage response is an easy method of determining the stability of the control loop.

Analyzing more complex feedback loops requires additional information.

The formula for AC gain at a frequency (f) is as follows;

$$\text{Gain (f)} = 1 + \frac{Z_f(f)}{R_f}$$

$$\text{where } Z_f\text{ (f)} = \frac{1}{j \bullet 2\pi \bullet f \bullet C_C}$$

where $R_f \approx$ 75 kΩ for the 4.2V part, $R_f \approx$ 181 kΩ for the 8.4V part and $R_f \approx$ 287 kΩ for the 12.6V part.

The resistor (R_f) in the formula is an internal resistor located on the die. Since this resistor value will affect the phase margin, the worst case maximum and minimum values are important when analyzing closed loop stability. The minimum and maximum room temperature values of this resistor are specified in the Electrical Characteristics section of this data sheet, and a curve showing the temperature coefficient is shown in the curves section. Minimum values of R_f result in lower phase margins.

Test Circuit

The test circuit shown in *Figure 2* can be used to measure and verify various LM3420 parameters. Test conditions are set by forcing the appropriate voltage at the V_{OUT} Set test point and selecting the appropriate R_L or I_{OUT} as specified in the Electrical Characteristics section. Use a DVM at the "measure" test points to read the data.

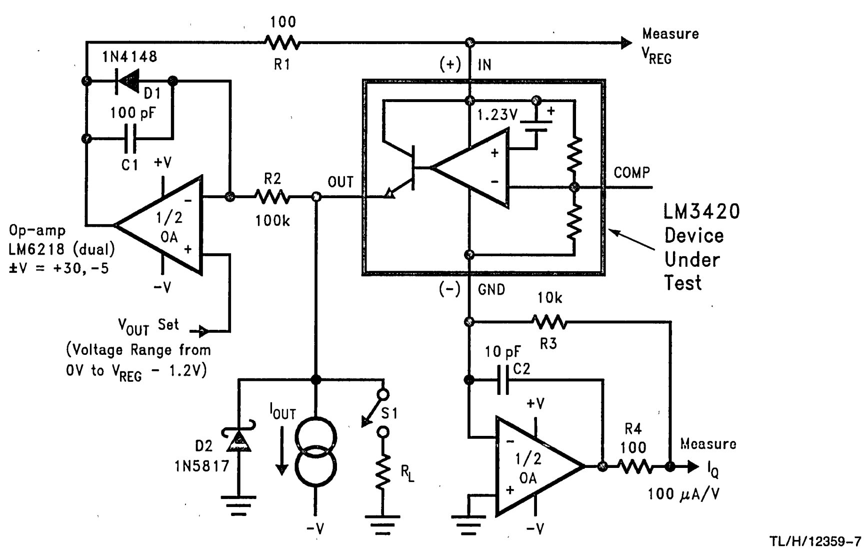
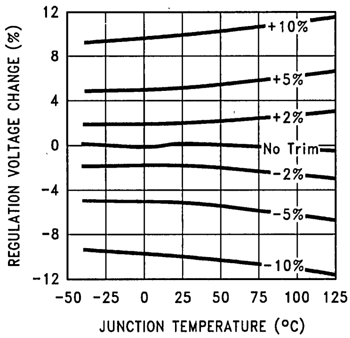


FIGURE 2. LM3420 Test Circuit

V_{REG} External Voltage Trim

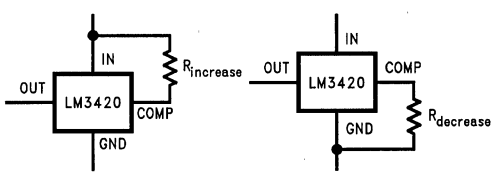
The regulation voltage (V_{REG}) of the LM3420 can be externally trimmed by adding a single resistor from the COMP. pin to the +IN pin or from the COMP. pin to the GND pin, depending on the desired trim direction. Trim adjustments up to ±10% of V_{REG} can be realized, with only a small increase in the temperature coefficient. (See temperature coefficient curve shown below)

Normalized Temperature Drift with Output Externally Trimmed



TL/H/12359-8

FIGURE 3



TL/H/12359-9 TL/H/12359-10

Increasing V_{REG} **Decreasing V_{REG}**

FIGURE 4

Formulas for selecting trim resistor values are shown below.

For LM3420-4.2

$$R_{increase} = \frac{22 \times 10^5}{\%\ increase},$$

$$R_{decrease} = \frac{53 \times 10^5}{\%\ decrease} - 75 \times 10^3$$

For LM3420-8.4

$$R_{increase} = \frac{26 \times 10^5}{\%\ increase},$$

$$R_{decrease} = \frac{154 \times 10^5}{\%\ decrease} - 181 \times 10^3$$

For LM3420-12.6

$$R_{increase} = \frac{28 \times 10^5}{\%\ increase},$$

$$R_{decrease} = \frac{259 \times 10^5}{\%\ decrease} - 287 \times 10^3$$

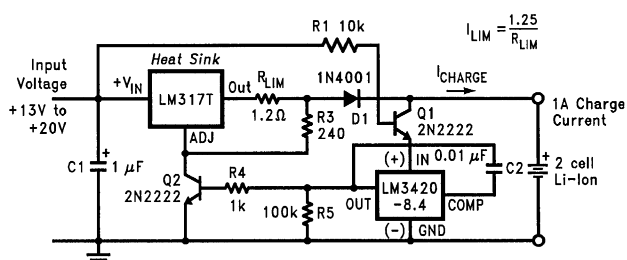
Application Information

The LM3420 regulator/driver provides the reference and feedback drive functions for a Lithium-Ion battery charger. It can be used in many different charger configurations using both linear and switching topologies to provide the precision needed for charging Lithium-Ion batteries safely and efficiently. Output voltage tolerances better than 0.5% are possible without using trim pots or precision resistors. The circuits shown are designed for 2 cell operation, but they can readily be changed for either 1 or 3 cell charging applications.

Application Circuits

The circuit shown in *Figure 5* performs constant-current, constant-voltage charging of two Li-Ion cells. At the beginning of the charge cycle, when the battery voltage is less than 8.4V, the LM3420 sources no current from the OUT pin, keeping Q2 off, thus allowing the LM317 Adjustable voltage regulator to operate as a constant-current source. (The LM317 is rated for currents up to 1.5A, and the LM350 and LM338 can be used for higher currents.) The LM317 forces a constant 1.25V across R_{LIM}, thus generating a constant current of

$$I_{LIM} = \frac{1.25V}{R_{LIM}}$$



TL/H/12359-1

FIGURE 5. Constant Current/Constant Voltage Li-Ion Battery Charger

Application Circuits (Continued)

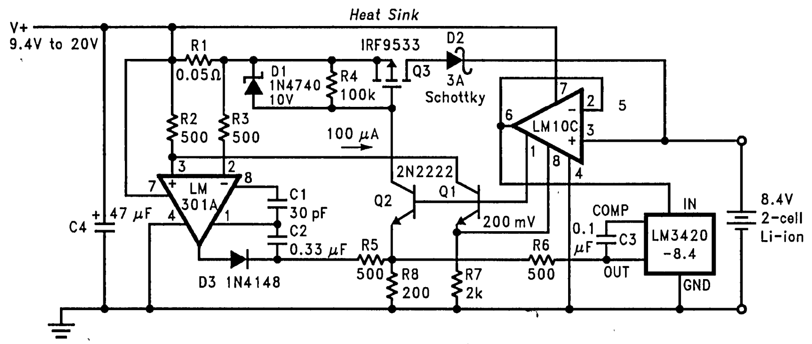


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FIGURE 6. Low Drop-Out Constant Current/Constant Voltage 2-Cell Charger

Transistor Q1 provides a disconnect between the battery and the LM3420 when the input voltage is removed. This prevents the 85 µA quiescent current of the LM3420 from eventually discharging the battery. In this application Q1 is used as a low offset saturated switch, with the majority of the base drive current flowing through the collector and crossing over to the emitter as the battery becomes fully charged. It provides a very low collector to emitter saturation voltage (approximately 5 mV). Diode D1 is also used to prevent the battery current from flowing through the LM317 regulator from the output to the input when the DC input voltage is removed.

As the battery charges, its voltage begins to rise, and is sensed at the IN pin of the LM3420. Once the battery voltage reaches 8.4V, the LM3420 begins to regulate and starts sourcing current to the base of Q2. Transistor Q2 begins controlling the ADJ. pin of the LM317 which begins to regulate the voltage across the battery and the constant voltage portion of the charging cycle starts. Once the charger is in the constant voltage mode, the charger maintains a regulated 8.4V across the battery and the charging current is dependent on the state of charge of the battery. As the cells approach a fully charged condition, the charge current falls to a very low value.

Figure 6 shows a Li-Ion battery charger that features a dropout voltage of less than one volt. This charger is a constant-current, constant-voltage charger (it operates in constant-current mode at the beginning of the charge cycle and switches over to a constant-voltage mode near the end of the charging cycle). The circuit consists of two basic feedback loops. The first loop controls the constant charge current delivered to the battery, and the second determines the final voltage across the battery.

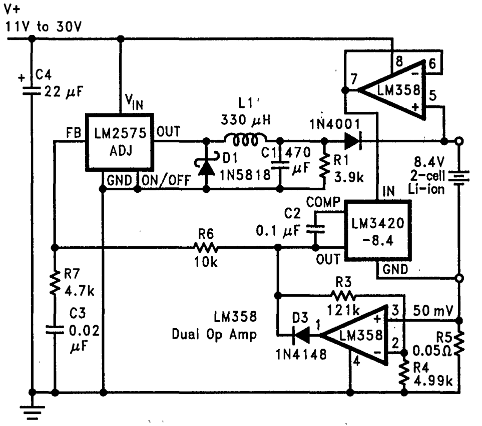
With a discharged battery connected to the charger, (battery voltage is less than 8.4V) the circuit begins the charge cycle with a constant charge current. The value of this current is set by using the reference section of the LM10C to force 200 mV across R7 thus causing approximately 100 µA of emitter current to flow through Q1, and approximately 1 mA of emitter current to flow through Q2. The collector current of Q1 is also approximately 100 µA, and this current flows through R2 developing 50 mV across it. This 50 mV is used as a reference to develop the constant charge current through the current sense resistor R1.

The constant current feedback loop operates as follows. Initially, the emitter and collector current of Q2 are both approximately 1 mA, thus providing gate drive to the MOSFET Q3, turning it on. The output of the LM301A op-amp is low. As Q3's current reaches 1A, the voltage across R1 approaches 50 mV, thus canceling the 50 mV drop across R2, and causing the op-amp's output to start going positive, and begin sourcing current into R8. As more current is forced into R8 from the op-amp, the collector current of Q2 is reduced by the same amount, which decreases the gate drive to Q3, to maintain a constant 50 mV across the 0.05Ω current sensing resistor, thus maintaining a constant 1A of charge current.

The current limit loop is stabilized by compensating the LM301A with C1 (the standard frequency compensation used with this op-amp) and C2, which is additional compensation needed when D3 is forward biased. This helps speed up the response time during the reverse bias of D3. When the LM301A output is low, diode D3 reverse biases and prevents the op-amp from pulling more current through the emitter of Q2. This is important when the battery voltage reaches 8.4V, and the 1A charge current is no longer needed. Resistor R5 isolates the LM301A feedback node at the emitter of Q2.

The battery voltage is sensed and buffered by the op-amp section of the LM10C, connected as a voltage follower driving the LM3420. When the battery voltage reaches 8.4V, the LM3420 will begin regulating by sourcing current into R8, which controls the collector current of Q2, which in turn reduces the gate voltage of Q3 and becomes a constant voltage regulator for charging the battery. Resistor R6 isolates the LM3420 from the common feedback node at the emitter of Q2. If R5 and R6 are omitted, oscillations could occur during the transition from the constant-current to the constant-voltage mode. D2 and the PNP transistor input stage of the LM10C will disconnect the battery from the charger circuit when the input supply voltage is removed to prevent the battery from discharging.

Application Circuits (Continued)



TL/H/12359–12

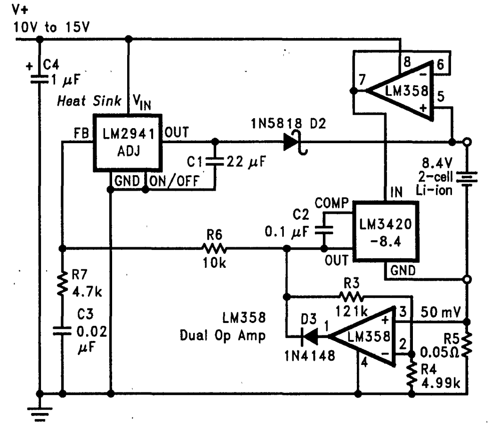
FIGURE 7. High Efficiency Switching Regulator Constant Current/Constant Voltage 2-Cell Charger

A switching regulator, constant-current, constant-voltage two-cell Li-Ion battery charging circuit is shown in *Figure 7.* This circuit provides much better efficiency, especially over a wide input voltage range than the linear topologies. For a 1A charger an LM2575-ADJ. switching regulator IC is used in a standard buck topology. For other currents, or other packages, other members of the SIMPLE SWITCHER® buck regulator family may be used.

Circuit operation is as follows. With a discharged battery connected to the charger, the circuit operates as a constant current source. The constant-current portion of the charger is formed by the loop consisting of one half of the LM358 op amp along with gain setting resistors R3 and R4, current sensing resistor R5, and the feedback reference voltage of 1.23V. Initially the LM358's output is low causing the output of the LM2575-ADJ. to rise thus causing some charging current to flow into the battery. When the current reaches 1A, it is sensed by resistor R5 (50 mΩ), and produces 50 mV. This 50 mV is amplified by the op-amps gain of 25 to produce 1.23V, which is applied to the feedback pin of the LM2575-ADJ. to satisfy the feedback loop.

Once the battery voltage reaches 8.4V, the LM3420 takes over and begins to control the feedback pin of the LM2575-ADJ. The LM3420 now regulates the voltage across the battery, and the charger becomes a constant-voltage charger. Loop compensation network R6, R7, and C3 ensure stable operation of the charger circuit under both constant-current and constant-voltage conditions. If the input supply voltage is removed, diode D2 and the PNP input stage of the LM358 become reversed biased and disconnects the battery to ensure that the battery is not discharged. Diode D3 reverse biases to prevent the op-amp from sinking current when the charger changes to constant voltage mode.

The minimum supply voltage for this charger is approximately 11V, and the maximum is around 30V (limited by the 32V maximum operating voltage of the LM358). If another op-amp is substituted for the LM358, make sure that the input common-mode range of the op-amp extends down to ground so that it can accurately sense 50 mV. R1 is included to provide a minimum load for the switching regulator to assure that switch leakage current will not cause the output to rise when the battery is removed.

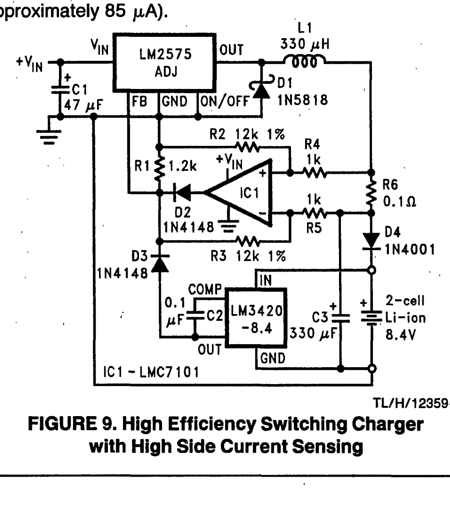


TL/H/12359–13

FIGURE 8. Low Dropout Constant Current/Constant Voltage Li-Ion Battery Charger

The circuit in *Figure 8* is very similar to *Figure 7,* except the switching regulator has been replaced with a low dropout linear regulator, allowing the input voltage to be as low as 10V. The constant current and constant voltage control loops are the same as the previous circuit. Diode D2 has been changed to a Schottky diode to provide a reduction in the overall dropout voltage of this circuit, but Schottky diodes typically have higher leakage currents than a standard silicon diode. This leakage current could discharge the battery if the input voltage is removed for an extended period of time.

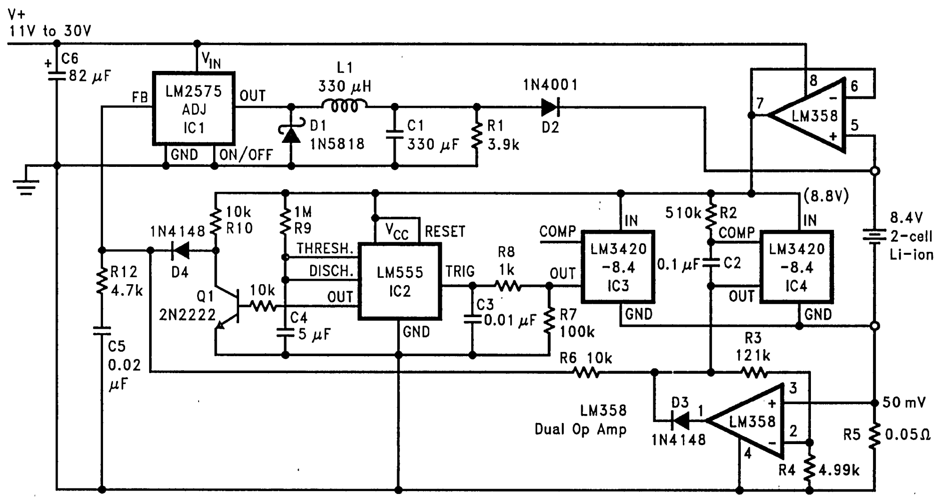
Another variation of a constant current/constant voltage switch mode charger is shown in *Figure 9.* The basic feedback loops for current and voltage are similar to the previous circuits. This circuit has the current sensing resistor, for the constant current part of the feedback loop, on the positive side of the battery, thus allowing a common ground between the input supply and the battery. Also, the LMC7101 op-amp is available in a very small SOT23-5 package thus allowing a very compact pc board design. Diode D4 prevents the battery from discharging through the charger circuitry if the input voltage is removed, although the quiescent current of the LM3420 will still be present (approximately 85 μA).



TL/H/12359–14

FIGURE 9. High Efficiency Switching Charger with High Side Current Sensing

Application Circuits (Continued)



TL/H/12359-15

FIGURE 10. (Fast) Pulsed Constant Current 2-Cell Charger

A rapid charge Lithium-Ion battery charging circuit is shown in *Figure 10.* This configuration uses a switching regulator to deliver the charging current in a series of constant current pulses. At the beginning of the charge cycle (constant-current mode), this circuit performs identically to the previous LM2575 charger by charging the battery at a constant current of 1A. As the battery voltage reaches 8.4V, this charger changes from a constant continuous current of 1A to a 5 second pulsed 1A. This allows the total battery charge time to be reduced considerably. This is different from the other charging circuits that switch from a constant current charge to a constant voltage charge once the battery voltage reaches 8.4V. After charging the battery with 1A for 5 seconds, the charge stops, and the battery voltage begins to drop. When it drops below 8.4V, the LM555 timer again starts the timing cycle and charges the battery with 1A for another 5 seconds. This cycling continues with a constant 5 second charge time, and a variable off time. In this manner, the battery will be charged with 1A for 5 seconds, followed by an off period (determined by the battery's state of charge), setting up a periodic 1A charge current. The off time is determined by how long it takes the battery voltage to decrease back down to 8.4V. When the battery first reaches 8.4V, the off time will be very short (1 ms or less), but when the battery approaches full charge, the off time will begin increasing to tens of seconds, then minutes, and eventually hours.

The constant-current loop for this charger and the method used for programming the 1A of constant current is identical to the previous LM2575-ADJ. charger. In this circuit, a second LM3420-8.4 has its V_{REG} increased by approximately 400 mV (via R2), and is used to limit the output voltage of the charger to 8.8V in the event of a bad battery connection, or the battery is removed or possibly damaged.

The LM555 timer is connected as a one-shot, and is used to provide the 5 second charging pulses. As long as the battery voltage is less than the 8.4V, the output of IC3 will be held low, and the LM555 one-shot will never fire (the output of the LM555 will be held high) and the one-shot will have no effect on the charger. Once the battery voltage exceeds the 8.4V regulation voltage of IC3, the trigger pin of the LM555 is pulled high, enabling the one shot to begin timing. The charge current will now be pulsed into the battery at a 5 second rate, with the off time determined by the battery's state of charge. The LM555 output will go high for 5 seconds (pulling down the collector of Q1) which allows the 1A constant-current loop to control the circuit.

2

Application Circuits (Continued)

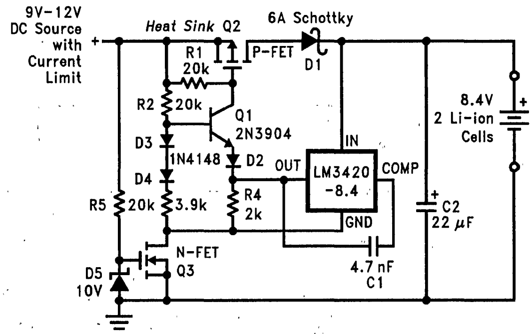


FIGURE 11. MOSFET Low Dropout Charger

Figure 11 shows a low dropout constant voltage charger using a MOSFET as the pass element, but this circuit does not include current limiting. This circuit uses Q3 and a Schottky diode to isolate the battery from the charging circuitry when the input voltage is removed, to prevent the battery from discharging. Q2 should be a high current (0.2Ω) FET, while Q3 can be a low current (2Ω) device.

Note: Although the application circuits shown here have been built and tested, they should be thoroughly evaluated with the same type of battery the charger will eventually be used with.

Different battery manufacturers may use a slightly different battery chemistry which may require different charging characteristics. Always consult the battery manufacturer for information on charging specifications and battery details, and always observe the manufacturers precautions when using their batteries. Avoid overcharging or shorting Lithium-Ion batteries.

National Semiconductor

LM3940
1A Low Dropout Regulator for 5V to 3.3V Conversion

General Description

The LM3940 is a 1A low dropout regulator designed to provide 3.3V from a 5V supply.

The LM3940 is ideally suited for systems which contain both 5V and 3.3V logic, with prime power provided from a 5V bus.

Because the LM3940 is a true low dropout regulator, it can hold its 3.3V output in regulation with input voltages as low as 4.5V.

The T0-220 package of the LM3940 means that in most applications the full 1A of load current can be delivered without using an additional heatsink.

The surface mount TO-263 package uses minimum board space, and gives excellent power dissipation capability when soldered to a copper plane on the PC board.

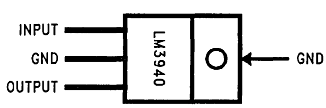
Features

- Output voltage specified over temperature
- Excellent load regulation
- Guaranteed 1A output current
- Requires only one external component
- Built-in protection against excess temperature
- Short circuit protected

Applications

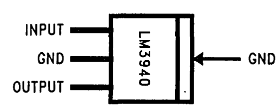
- Laptop/Desktop Computers
- Logic Systems

Connection Diagram/Ordering Information



TL/H/12080-2

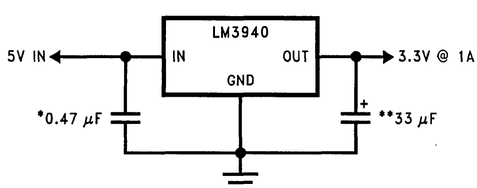
3-Lead TO-220 Package (Front View)
Order Part Number LM3940IT-3.3
NSC Drawing Number TO3B



TL/H/12080-3

3-Lead TO-263 Package (Front View)
Order Part Number LM3940IS-3.3
NSC Drawing Number TS3B

Typical Application



TL/H/12080-1

*Required if regulator is located more that 1″ from the power supply filter capacitor or if battery power is used.

**See Application Hints.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	$-65°C$ to $+150°C$
Operating Junction Temperature Range	$-40°C$ to $+125°C$
Lead Temperature (Soldering, 5 seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	7.5V
ESD Rating (Note 3)	2 kV

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: $V_{IN} = 5V$, $I_L = 1A$, $C_{OUT} = 33\ \mu F$.

Symbol	Parameter	Conditions	Typical	LM3940 (Note 4)		Units
				min	max	
V_O	Output Voltage	$5\ mA \le I_L \le 1A$	3.3	3.20 **3.13**	3.40 **3.47**	V
$\frac{\Delta V_O}{\Delta V_I}$	Line Regulation	$I_L = 5\ mA$ $4.5V \le V_O \le 5.5V$	20		40	mV
$\frac{\Delta V_O}{I_L}$	Load Regulation	$50\ mA \le I_L \le 1A$	35		50 **80**	mV
Z_O	Output Impedance	I_L (DC) = 100 mA I_L (AC) = 20 mA (rms) f = 120 Hz	35			mΩ
I_Q	Quiescent Current	$4.5V \le V_{IN} \le 5.5V$ $I_L = 5\ mA$	10		15 **20**	mA
		$V_{IN} = 5V$ $I_L = 1A$	110		200 **250**	mA
e_n	Output Noise Voltage	BW = 10 Hz–100 kHz $I_L = 5\ mA$	150			μV (rms)
$V_O - V_{IN}$	Dropout Voltage (Note 5)	$I_L = 1A$	0.5		0.8 **1.0**	V
		$I_L = 100\ mA$	110		150 **200**	mV
I_L(SC)	Short Circuit Current	$R_L = 0$	1.7	1.2		A

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, T_J, the junction-to-ambient thermal resistance, θ_{J-A}, and the ambient temperature, T_A. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. The value of θ_{J-A} (for devices in still air with no heatsink) is 60°C/W for the "T" package, and 80°C/W for the "S" package. The effective value of θ_{J-A} can be reduced by using a heatsink (see Application Hints for specific information on heatsinking).

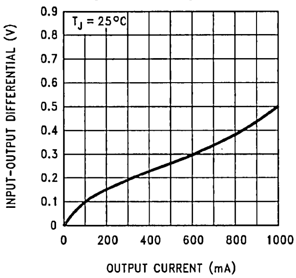
Note 3: ESD rating is based on the human body model: 100 pF discharged through 1.5 kΩ.

Note 4: All limits guaranteed for $T_J = 25°C$ are 100% tested and are used to calculate Outgoing Quality Levels. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

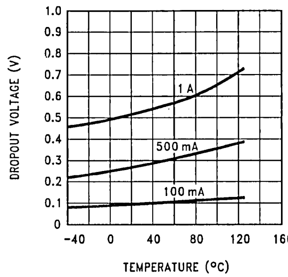
Note 5: Dropout voltage is defined as the input-output differential voltage where the regulator output drops to a value that is 100 mV below the value that is measured at $V_{IN} = 5V$.

Typical Performance Characteristics

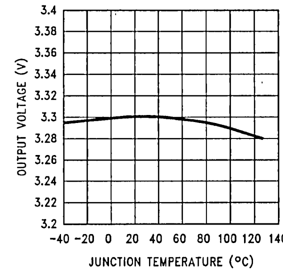
Dropout Voltage



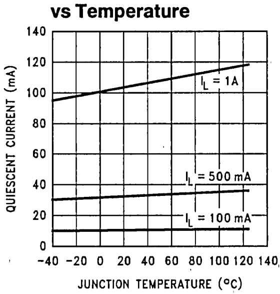
Dropout Voltage vs Temperature



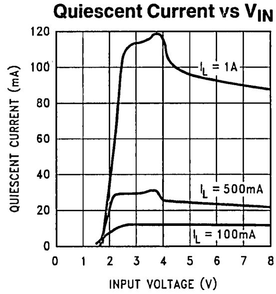
Output Voltage vs Temperature



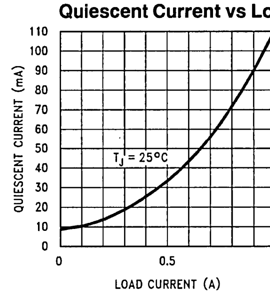
Quiescent Current vs Temperature



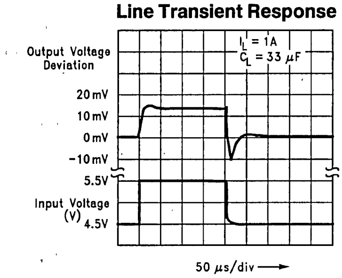
Quiescent Current vs V_{IN}



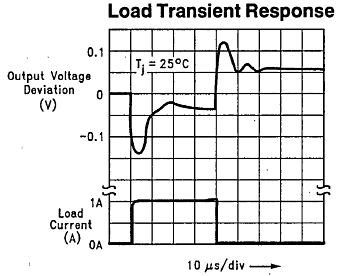
Quiescent Current vs Load



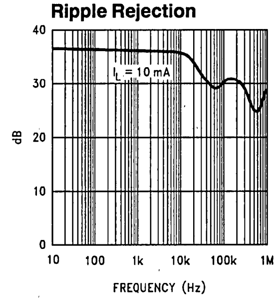
Line Transient Response



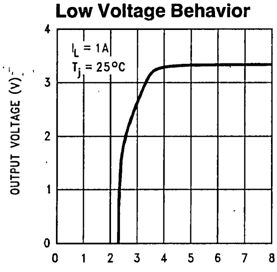
Load Transient Response



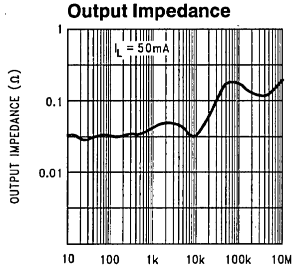
Ripple Rejection



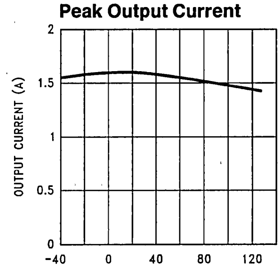
Low Voltage Behavior



Output Impedance



Peak Output Current



TL/H/12080-4

Application Hints

EXTERNAL CAPACITORS

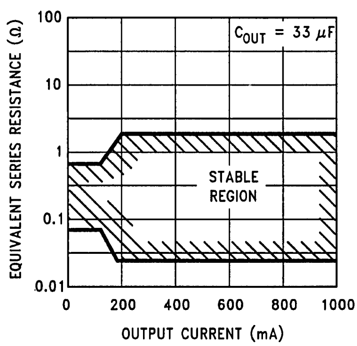
The output capacitor is critical to maintaining regulator stability, and must meet the required conditions for both ESR (Equivalent Series Resistance) and minimum amount of capacitance.

MINIMUM CAPACITANCE:

The minimum output capacitance required to maintain stability is 33 μF (this value may be increased without limit). Larger values of output capacitance will give improved transient response.

ESR LIMITS:

The ESR of the output capacitor will cause loop instability if it is too high or too low. The acceptable range of ESR plotted versus load current is shown in the graph below. ***It is essential that the output capacitor meet these requirements, or oscillations can result.***



TL/H/12080-5

FIGURE 1. ESR Limits

It is important to note that for most capacitors, ESR is specified only at room temperature. However, the designer must ensure that the ESR will stay inside the limits shown over the entire operating temperature range for the design.

For aluminum electrolytic capacitors, ESR will increase by about 30X as the temperature is reduced from 25°C to −40°C. This type of capacitor is not well-suited for low temperature operation.

Solid tantalum capacitors have a more stable ESR over temperature, but are more expensive than aluminum electrolytics. A cost-effective approach sometimes used is to parallel an aluminum electrolytic with a solid Tantalum, with the total capacitance split about 75/25% with the Aluminum being the larger value.

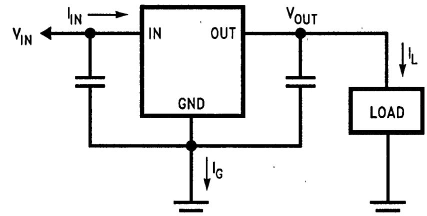
If two capacitors are paralleled, the effective ESR is the parallel of the two individual values. The "flatter" ESR of the Tantalum will keep the effective ESR from rising as quickly at low temperatures.

HEATSINKING

A heatsink may be required depending on the maximum power dissipation and maximum ambient temperature of the application. Under all possible operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the power dissipated by the regulator, P_D, must be calculated.

The figure below shows the voltages and currents which are present in the circuit, as well as the formula for calculating the power dissipated in the regulator:



TL/H/12080-6

$I_{IN} = I_L + I_G$

$P_D = (V_{IN} - V_{OUT})\, I_L + (V_{IN})\, I_G$

FIGURE 2. Power Dissipation Diagram

The next parameter which must be calculated is the maximum allowable temperature rise, T_R (max). This is calculated by using the formula:

$$T_R\,(\text{max}) = T_J\,(\text{max}) - T_A\,(\text{max})$$

where: T_J (max) is the maximum allowable junction temperature, which is 125°C for commercial grade parts.

T_A (max) is the maximum ambient temperature which will be encountered in the application.

Using the calculated values for T_R(max) and P_D, the maximum allowable value for the junction-to-ambient thermal resistance, $\theta_{(J-A)}$, can now be found:

$$\theta_{(J-A)} = T_R\,(\text{max})/P_D$$

IMPORTANT: If the maximum allowable value for $\theta_{(J-A)}$ is found to be ≥ 60°C/W for the "T" package, or ≥ 80°/W for the "S" package, no heatsink is needed since the package alone will dissipate enough heat to satisfy these requirements.

If the calculated value for $\theta_{(J-A)}$ falls below these limits, a heatsink is required. Methods for heatsinking the TO-220 and TO-263 packages will be addressed separately:

HEATSINKING TO-220 PACKAGE PARTS

The TO-220 can be attached to a typical heatsink, or secured to a copper plane on a PC board. If a copper plane is to be used, the values of $\theta_{(J-A)}$ will be the same as shown in the next section for the TO-263.

If a manufactured heatsink is to be selected, the value of heatsink-to-ambient thermal resistance, $\theta_{(H-A)}$, must first be calculated:

$$\theta_{(H-A)} = \theta_{(J-A)} - \theta_{(C-H)} - \theta_{(J-C)}$$

Where: $\theta_{(J-C)}$ is defined as the thermal resistance from the junction to the surface of the case. A value of 4°C/W can be assumed for $\theta_{(J-C)}$ for this calculation.

$\theta_{(C-H)}$ is defined as the thermal resistance between the case and the surface of the heatsink. The value of $\theta_{(C-H)}$ will vary from about 1.5°C/W to about 2.5°C/W (depending on method of attachment, insulator, etc.). If the exact value is unknown, 2°C/W should be assumed for $\theta_{(C-H)}$.

Application Hints (Continued)

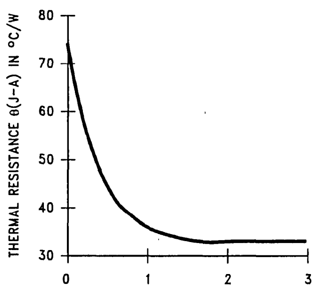
When a value for $\theta_{(H-A)}$ is found using the equation shown, *a heatsink must be selected that has a value that is less than or equal to this number.*

$\theta_{(H-A)}$ is specified numerically by the heatsink manufacturer in the catalog, or shown in a curve that plots temperature rise vs power dissipation for the heatsink.

HEATSINKING TO-263 PACKAGE PARTS

Heat is conducted away from the TO-263 by soldering the tab of the device to a copper plane on the PC board.

The graph below shows the measured values of $\theta_{(J-A)}$ for different copper area sizes using a typical P.C. board with 1 ounce copper *and no solder mask over the copper area used for heatsinking:*

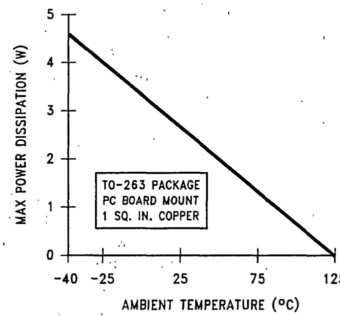


TL/H/12080-7

FIGURE 3. $\theta_{(J-A)}$ vs Copper Area

As shown in the figure, increasing the copper area beyond 1 square inch produces very little improvement. It should also be observed that the minimum value of $\theta_{(J-A)}$ for the TO-263 package mounted to a P.C. board is 32°C/W.

As a design aid, a plot is shown below which illustrates the maximum allowable power dissipation compared to ambient temperature for the TO-263 device (assuming $\theta_{(J-A)}$ is 35°C/W and the maximum junction temperature is 125°C):



TL/H/12080-8

FIGURE 4. Maximum Power Dissipation vs T_{AMB}

National Semiconductor

LP2950/A-XX and LP2951/A-XX Series of Adjustable Micropower Voltage Regulators

General Description

The LP2950 and LP2951 are micropower voltage regulators with very low quiescent current (75 μA typ.) and very low dropout voltage (typ. 40 mV at light loads and 380 mV at 100 mA). They are ideally suited for use in battery-powered systems. Furthermore, the quiescent current of the LP2950/LP2951 increases only slightly in dropout, prolonging battery life.

The LP2950-5.0 in the popular 3-pin TO-92 package is pin-compatible with older 5V regulators. The 8-lead LP2951 is available in plastic, ceramic dual-in-line, or metal can packages and offers additional system functions.

One such feature is an error flag output which warns of a low output voltage, often due to falling batteries on the input. It may be used for a power-on reset. A second feature is the logic-compatible shutdown input which enables the regulator to be switched on and off. Also, the part may be pin-strapped for a 5V, 3V, or 3.3V output (depending on the version), or programmed from 1.24V to 29V with an external pair of resistors.

Careful design of the LP2950/LP2951 has minimized all contributions to the error budget. This includes a tight initial tolerance (.5% typ.), extremely good load and line regulation (.05% typ.) and a very low output voltage temperature coefficient, making the part useful as a low-power voltage reference.

Features

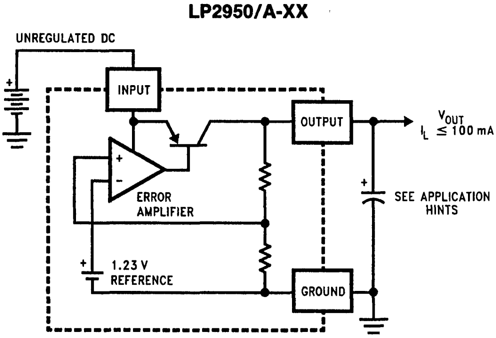
- 5V, 3V, and 3.3V versions available
- High accuracy output voltage
- Guaranteed 100 mA output current
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight load and line regulation
- Very low temperature coefficient
- Use as Regulator or Reference
- Needs minimum capacitance for stability
- Current and Thermal Limiting

LP2951 versions only

- Error flag warns of output dropout
- Logic-controlled electronic shutdown
- Output programmable from 1.24 to 29V

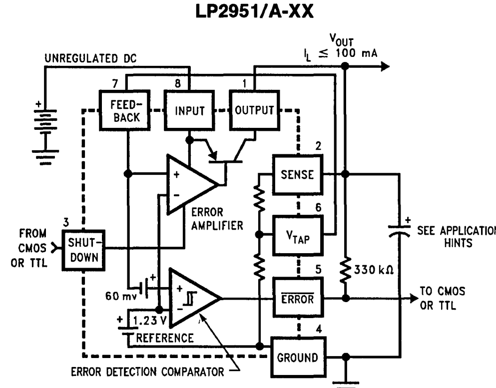
Block Diagram and Typical Applications

LP2950/A-XX



TL/H/8546-25

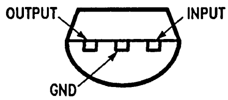
LP2951/A-XX



TL/H/8546-1

Connection Diagrams

TO-92 Plastic Package (Z)

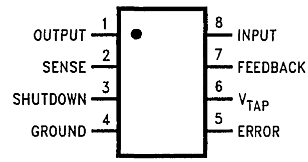


TL/H/8546-2

Bottom View

Order Number LP2950ACZ-3.0, LP2950CZ-3.0, LP2950ACZ-3.3, LP2950CZ-3.3 LP2950ACZ-5.0 or LP2950CZ-5.0
See NS Package Number Z03A

Dual-In-Line Packages (N, J)
Surface-Mount Package (M)



TL/H/8546-26

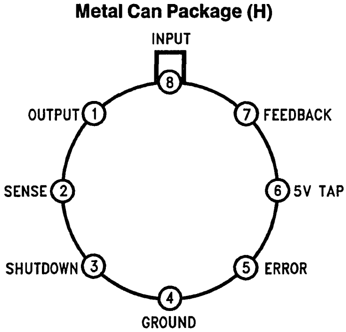
Top View

Order Number LP2951CJ, LP2951ACJ, LP2951J, LP2951J/883 or 5962-3870501MPA
See NS Package Number J08A

Order Number LP2951ACN, LP2951CN, LP2951ACN-3.0, LP2951CN-3.0, LP2951ACN-3.3 or LP2951CN-3.3
See NS Package Number N08E

Order Number LP2951ACM, LP2951CM, LP2951ACM-3.0, LP2951CM-3.0, LP2951ACM-3.3 or LP2951CM-3.3
See NS Package Number M08A

Metal Can Package (H)

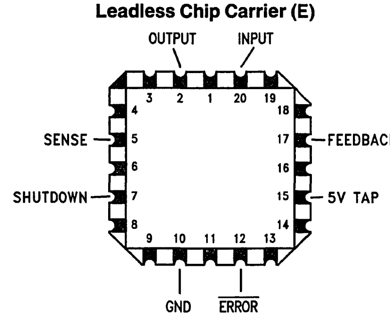


TL/H/8546-19

Top View

Order Number LP2951H/883 or 5962-3870501MGA
See NS Package Number H08C

Leadless Chip Carrier (E)



TL/H/8546-24

Top View

Order Number LP2951E/883 or 5962-3870501M2A
See NS Package Number E20A

2

Ordering Information

Package	Output Voltage			Temperature (°C)
	3.0V	3.3V	5.0V	
TO-92 (Z)	LP2950ACZ-3.0 LP2950CA-3.0	LP2950ACZ-3.3 LP2950CZ-3.3	LP2950ACZ-5.0 LP2950CZ-5.0	$-40 < T_J < 125$
N (N-08E)	LP2951ACN-3.0 LP2951CN-3.0	LP2951ACN-3.3 LP2951CN-3.3	LP2951ACN LP2950CN	$-40 < T_J < 125$
M (M08A)	LP2951ACM-3.0 LP2951CM-3.0	LP2951ACM-3.3 LP2951CM-3.3	LP2951ACM LP2951CM	$-40 < T_J < 125$
J (J08A)			LP2951ACJ LP2951CJ	$-40 < T_J < 125$
			LP2951J LP2951J/883 5926-3870501MPA	$-55 < T_J < 150$
H (H08C)			LP2951H/883 5962-3870501MGA	$-55 < T_J < 150$
E (E20A)			LP2951E/883 5962-3870501M2A	$-55 < T_J < 150$

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Power Dissipation	Internally Limited
Lead Temp. (Soldering, 5 seconds)	260°C
Storage Temperature Range	−65° to +150°C
Operating Junction Temperature Range (Note 8)	
LP2951	−55° to +150°C
LP2950AC-XX, LP2950C-XX, LP2951AC-XX, LP2951C-XX	−40° to +125°C
Input Supply Voltage	−0.3 to +30V
Feedback Input Voltage (Notes 9 and 10)	−1.5 to +30V
Shutdown Input Voltage (Note 9)	−0.3 to +30V
Error Comparator Output Voltage (Note 9)	−0.3 to +30V

ESD Rating is to be determined.

Electrical Characteristics (Note 1)

Parameter	Conditions (Note 2)	LP2951		LP2950AC-XX LP2951AC-XX			LP2950C-XX LP2951C-XX			Units
		Typ	Tested Limit (Notes 3, 16)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
3V VERSIONS (Note 17)										
Output Voltage	$T_J = 25°C$	3.0	3.015 2.985	3.0	3.015 2.985		3.0	3.030 2.970		V max V min
	$-25°C \le T_J \le 85°C$	3.0		3.0		3.030 2.970	3.0		3.045 2.955	V max V min
	Full Operating Temperature Range	3.0	**3.036** **2.964**	3.0		**3.036** **2.964**	3.0		**3.060** **2.940**	V max V min
Output Voltage	$100\ \mu A \le I_L \le 100\ mA$ $T_J \le T_{JMAX}$	3.0	**3.045** **2.955**	3.0		**3.042** **2.958**	3.0		**3.072** **2.928**	V max V min
3.3V VERSIONS (Note 17)										
Output Voltage	$T_J = 25°C$	3.3	3.317 3.284	3.3	3.317 3.284		3.3	3.333 3.267		V max V min
	$-25°C \le T_J \le 85°C$	3.3		3.3		3.333 3.267	3.3		3.350 3.251	V max V min
	Full Operating Temperature Range	3.3	**3.340** **3.260**	3.3		**3.340** **3.260**	3.3		**3.366** **3.234**	V max V min
Output Voltage	$100\ \mu A \le I_L \le 100\ mA$ $T_J \le T_{JMAX}$	3.3	**3.350** **3.251**	3.3		**3.346** **3.254**	3.3		**3.379** **3.221**	V max V min
5V VERSIONS (Note 17)										
Output Voltage	$T_J = 25°C$	5.0	5.025 4.975	5.0	5.025 4.975		5.0	5.05 4.95		V max V min
	$-25°C \le T_J \le 85°C$	5.0		5.0		5.05 4.95	5.0		5.075 4.925	V max V min
	Full Operating Temperature Range	5.0	**5.06** **4.94**	5.0		**5.06** **4.94**	5.0		**5.1** **4.9**	V max V min
Output Voltage	$100\ \mu A \le I_L \le 100\ mA$ $T_J \le T_{JMAX}$	5.0	**5.075** **4.925**	5.0		**5.075** **4.925**	5.0		**5.12** **4.88**	V max V min
ALL VOLTAGE OPTIONS										
Output Voltage Temperature Coefficient	(Note 12)	**20**	**120**	**20**		**100**	**50**		**150**	ppm/°C
Line Regulation (Note 14)	$(V_ONOM + 1)V \le V_{in} \le 30V$ (Note 15)	0.03	0.1 **0.5**	0.03	0.1	 **0.2**	0.04	0.2	 **0.4**	% max % max
Load Regulation (Note 14)	$100\ \mu A \le I_L \le 100\ mA$	0.04	0.1 **0.3**	0.04	0.1	 **0.2**	0.1	0.2	 **0.3**	% max % max

Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions (Note 2)	LP2951 Typ	LP2951 Tested Limit (Notes 3, 16)	LP2950AC-XX LP2951AC-XX Typ	LP2950AC-XX LP2951AC-XX Tested Limit (Note 3)	LP2950AC-XX LP2951AC-XX Design Limit (Note 4)	LP2950C-XX LP2951C-XX Typ	LP2950C-XX LP2951C-XX Tested Limit (Note 3)	LP2950C-XX LP2951C-XX Design Limit (Note 4)	Units
ALL VOLTAGE OPTIONS (Continued)										
Dropout Voltage (Note 5)	I_L = 100 μA	50	80 **150**	50	80	**150**	50	80	**150**	mV max mV max
	I_L = 100 mA	380	450 **600**	380	450	**600**	380	450	**600**	mV max mV max
Ground Current	I_L = 100 μA	75	120 **140**	75	120	**140**	75	120	**140**	μA max μA max
	I_L = 100 mA	8	12 **14**	8	12	**14**	8	12	**14**	mA max mA max
Dropout Ground Current	V_{in} = (V_ONOM − 0.5)V I_L = 100 μA	110	170 **200**	110	170	**200**	110	170	**200**	μA max μA max
Current Limit	V_{out} = 0	160	200 **220**	160	200	**220**	160	200	**220**	mA max mA max
Thermal Regulation	(Note 13)	0.05	0.2	0.05	0.2		0.05	0.2		%/W max
Output Noise, 10 Hz to 100 KHz	C_L = 1 μF (5V Only)	430		430			430			μV rms
	C_L = 200 μF	160		160			160			μV rms
	C_L = 3.3 μF (Bypass = 0.01 μF Pins 7 to 1 (LP2951))	100		100			100			μV rms
8-PIN VERSIONS ONLY		**LP2951**		**LP2951AC-XX**			**LP2951C-XX**			
Reference Voltage		1.235	1.25 **1.26** 1.22 **1.2**	1.235	1.25 1.22	**1.26** **1.2**	1.235	1.26 1.21	**1.27** **1.2**	V max V max V min V min
Reference Voltage	(Note 7)		**1.27** **1.19**			**1.27** **1.19**			**1.285** **1.185**	V max V min
Feedback Pin Bias Current		20	40 **60**	20	40	**60**	20	40	**60**	nA max nA max
Reference Voltage Temperature Coefficient	(Note 12)	20		20			50			ppm/°C
Feedback Pin Bias Current Temperature Coefficient		0.1		0.1			0.1			nA/°C
Error Comparator										
Output Leakage Current	V_{OH} = 30V	0.01	1 **2**	0.01	1	**2**	0.01	1	**2**	μA max μA max
Output Low Voltage	V_{in} = (V_ONOM − 0.5)V I_{OL} = 400 μA	150	250 **400**	150	250	**400**	150	250	**400**	mV max mV max
Upper Threshold Voltage	(Note 6)	60	40 **25**	60	40	**25**	60	40	**25**	mV min mV min
Lower Threshold Voltage	(Note 6)	75	95 **140**	75	95	**140**	75	95	**140**	mV max mV max
Hysteresis	(Note 6)	15		15			15			mV

Electrical Characteristics (Note 1) (Continued)

Parameter	Conditions (Note 2)	LP2951 Typ	LP2951 Tested Limit (Notes 3, 16)	LP2951AC-XX Typ	LP2951AC-XX Tested Limit (Note 3)	LP2951AC-XX Design Limit (Note 4)	LP2951C-XX Typ	LP2951C-XX Tested Limit (Note 3)	LP2951C-XX Design Limit (Note 4)	Units
8-PIN VERSIONS ONLY (Continued)										
Shutdown Input										
Input Logic Voltage		1.3		1.3			1.3			V
	Low (Regulator ON)		**0.6**			**0.7**			**0.7**	V max
	High (Regulator OFF)		**2.0**			**2.0**			**2.0**	V min
Shutdown Pin Input Current	$V_{shutdown}$ = 2.4V	30	50	30	50		30	50		μA max
			100			**100**			**100**	μA max
	$V_{shutdown}$ = 30V	450	600	450	600		450	600		μA max
			750			**750**			**750**	μA max
Regulator Output Current in Shutdown	(Note 11)	3	10	3	10		3	10		μA max
			20			**20**			**20**	μA max

Note 1: Boldface limits apply at temperature extremes.

Note 2: Unless otherwise specified all limits guaranteed for T_J = 25°C, V_{in} = (V_ONOM + 1)V, I_L = 100 μA and C_L = 1 μF for 5V versions, and 2.2 μF for 3V and 3.3V versions. Additional conditions for the 8-pin versions are Feedback tied to V_{TAP}, Output tied to Output Sense and $V_{shutdown} \leq 0.8V$.

Note 3: Guaranteed and 100% production tested.

Note 4: Guaranteed but not 100% production tested. These limits are not used to calculate outgoing AQL levels.

Note 5: Dropout Voltage is defined as the input to output differential at which the output voltage drops 100 mV below its nominal value measured at 1V differential. At very low values of programmed output voltage, the minimum input supply voltage of 2V **(2.3V over temperature)** must be taken into account.

Note 6: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at V_{in} = (V_ONOM + 1)V. To express these thresholds in terms of output voltage change, multiply by the error amplifier gain = V_{out}/V_{ref} = (R1 + R2)/R2. For example, at a programmed output voltage of 5V, the Error output is guaranteed to go low when the output drops by 95 mV × 5V/1.235V = 384 mV. Thresholds remain constant as a percent of V_{out} as V_{out} is varied, with the dropout warning occurring at typically 5% below nominal, 7.5% guaranteed.

Note 7: $V_{ref} \leq V_{out} \leq (V_{in} - 1V)$, 2.3V $\leq V_{in} \leq$ 30V, 100 μA $\leq I_L \leq$ 100 mA, $T_J \leq T_{JMAX}$.

Note 8: The junction-to-ambient thermal resistance of the TO-92 package is 180°C/W with 0.4″ leads and 160°C/W with 0.25″ leads to a PC board. The thermal resistance of the 8-pin DIP packages is 105°C/W for the molded plastic (N) and 130°C/W for the cerdip (J) junction to ambient when soldered directly to a PC board. Thermal resistance for the metal can (H) is 160°C/W junction to ambient and 20°C/W junction to case. Junction to ambient thermal resistance for the S.O. (M) package is 160°C/W. Thermal resistance for the leadless chip carrier (E) package is 95°C/W junction to ambient and 24°C/W junction to case.

Note 9: May exceed input supply voltage.

Note 10: When used in dual-supply systems where the output terminal sees loads returned to a negative supply, the output voltage should be diode-clamped to ground.

Note 11: $V_{shutdown} \geq 2V$, $V_{in} \leq 30V$, V_{out} = 0, Feedback pin tied to V_{TAP}.

Note 12: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 13: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 50 mA load pulse at V_{IN} = 30V (1.25W pulse) for T = 10 ms.

Note 14: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output voltage due to heating effects are covered under the specification for thermal regulation.

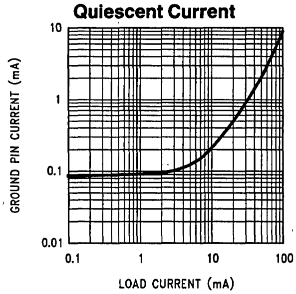
Note 15: Line regulation for the LP2951 is tested at 150°C for I_L = 1 mA. For I_L = 100 μA and T_J = 125°C, line regulation is guaranteed by design to 0.2%. See Typical Performance Characteristics for line regulation versus temperature and load current.

Note 16: A Military RETS spec is available on request. At time of printing, the LP2951 RETS spec complied with the boldface limits in this column. The LP2951H, E, or J may also be procured as Standard Military Drawing Spec #5962-3870501MGA, M2A, or MPA.

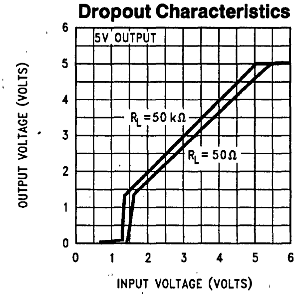
Note 17: All LP2950 devices have the nominal output voltage coded as the last two digits of the part number. In the LP2951 products, the 3.0V and 3.3V versions are designated by the last two digits, but the 5V version is denoted with no code at this location of the part number (refer to ordering information table).

Typical Performance Characteristics

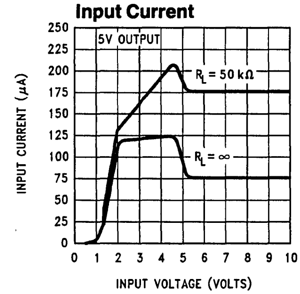
Quiescent Current



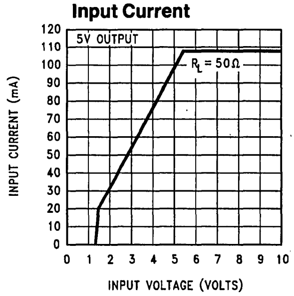
Dropout Characteristics



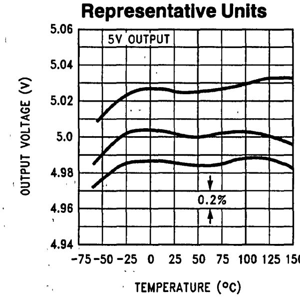
Input Current



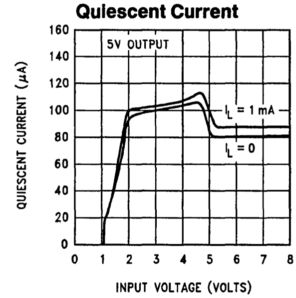
Input Current



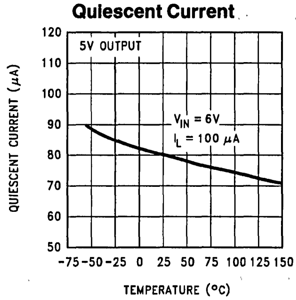
Output Voltage vs. Temperature of 3 Representative Units



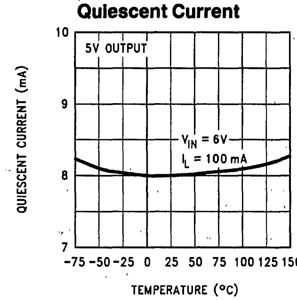
Quiescent Current



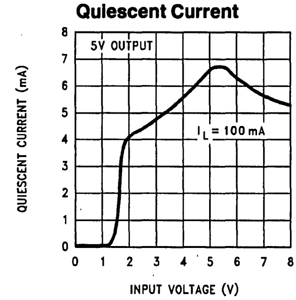
Quiescent Current



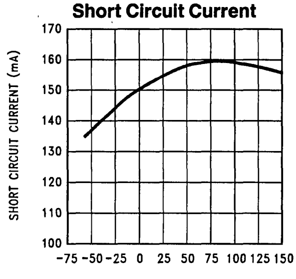
Quiescent Current



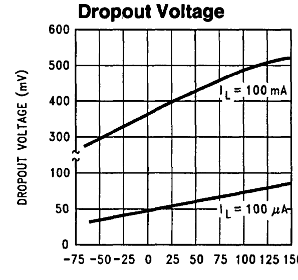
Quiescent Current



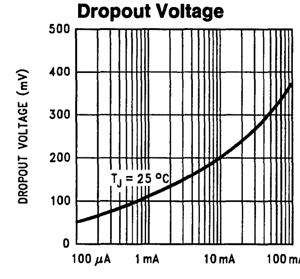
Short Circuit Current



Dropout Voltage



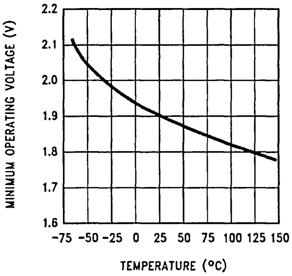
Dropout Voltage



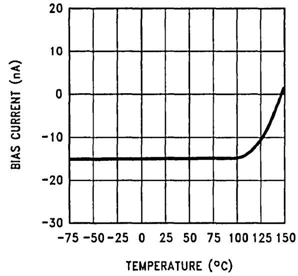
TL/H/8546-3

Typical Performance Characteristics (Continued)

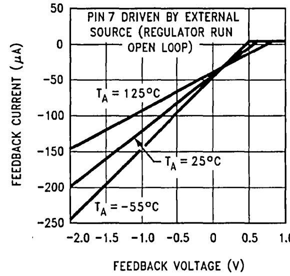
LP2951
Minimum Operating Voltage



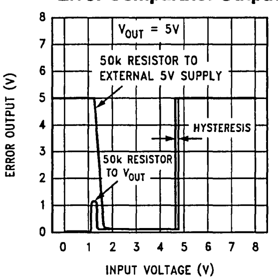
LP2951
Feedback Bias Current



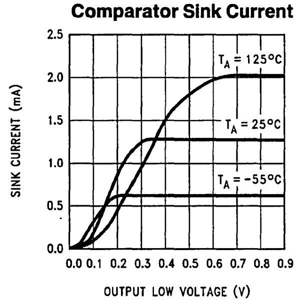
LP2951
Feedback Pin Current



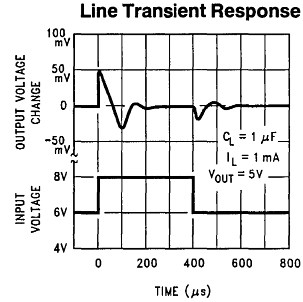
LP2951
Error Comparator Output



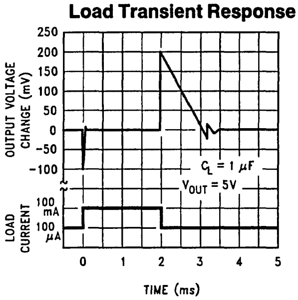
LP2951
Comparator Sink Current



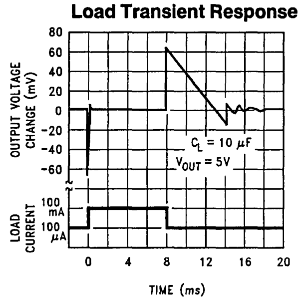
Line Transient Response



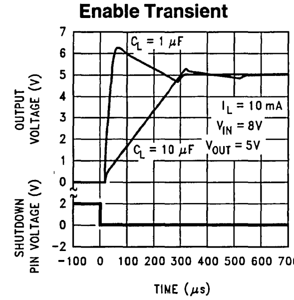
Load Transient Response



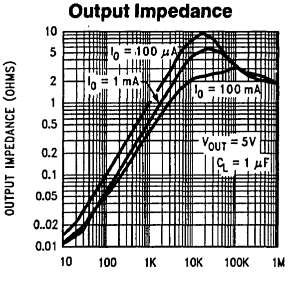
Load Transient Response



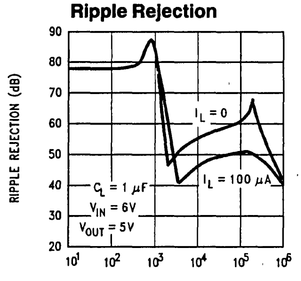
LP2951
Enable Transient



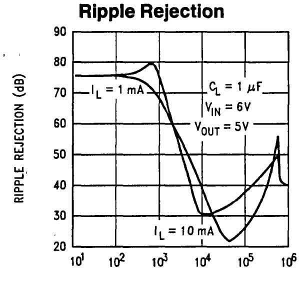
Output Impedance



Ripple Rejection



Ripple Rejection

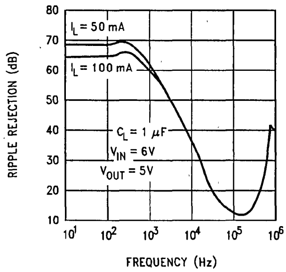


TL/H/8546-4

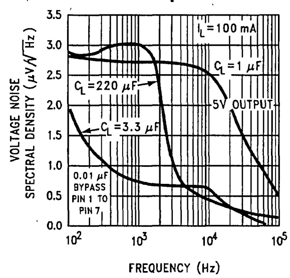
2

Typical Performance Characteristics (Continued)

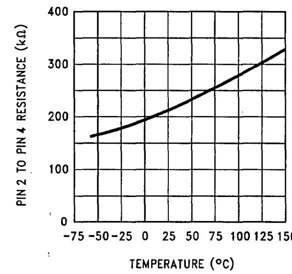
Ripple Rejection



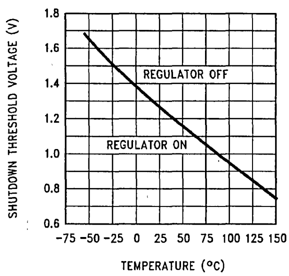
LP2951 Output Noise



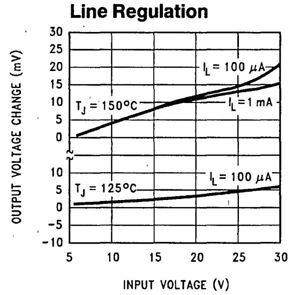
LP2951 Divider Resistance



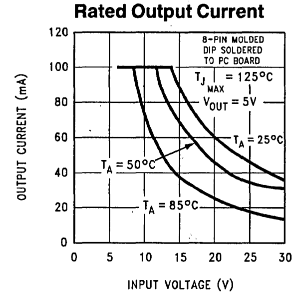
Shutdown Threshold Voltage



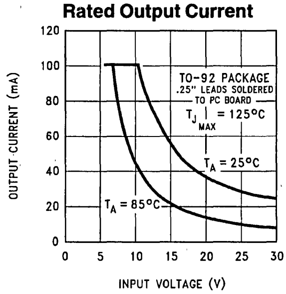
Line Regulation



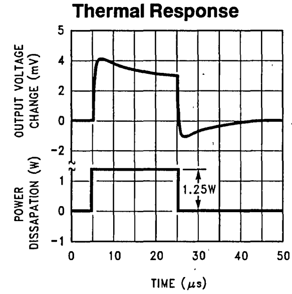
LP2951 Maximum Rated Output Current



LP2950 Maximum Rated Output Current



Thermal Response



TL/H/8546–5

Application Hints

EXTERNAL CAPACITORS

A 1.0 μF (or greater) capacitor is required between the output and ground for stability at output voltages of 5V or more. At lower output voltages, more capacitance is required (2.2 μF or more is recommended for 3V and 3.3V versions). Without this capacitor the part will oscillate. Most types of tantalum or aluminum electrolytics work fine here; even film types work but are not recommended for reasons of cost. Many aluminum electrolytics have electrolytes that freeze at about −30°C, so solid tantalums are recommended for operation below −25°C. The important parameters of the capacitor are an ESR of about 5 Ω or less and a resonant frequency above 500 kHz. The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.33 μF for currents below 10 mA or 0.1 μF for currents below 1 mA. Using the adjustable versions at voltages below 5V runs the error amplifier at lower gains so that *more* output capacitance is needed. For the worst-case situation of a 100 mA load at 1.23V output (Output shorted to Feedback) a 3.3 μF (or greater) capacitor should be used.

Unlike many other regulators, the LP2950 will remain stable and in regulation with no load in addition to the internal voltage divider. This is especially important in CMOS RAM keep-alive applications. When setting the output voltage of the LP2951 versions with external resistors, a minimum load of 1 μA is recommended.

A 1 μF tantalum or aluminum electrolytic capacitor should be placed from the LP2950/LP2951 input to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery is used as the input.

Application Hints (Continued)

Stray capacitance to the LP2951 Feedback terminal can cause instability. This may especially be a problem when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between Output and Feedback and increasing the output capacitor to at least 3.3 μF will fix this problem.

ERROR DETECTION COMPARATOR OUTPUT

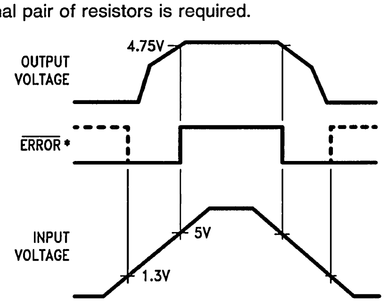
The comparator produces a logic low output whenever the LP2951 output falls out of regulation by more than approximately 5%. This figure is the comparator's built-in offset of about 60 mV divided by the 1.235 reference voltage. (Refer to the block diagram in the front of the datasheet.) This trip level remains "5% below normal" regardless of the programmed output voltage of the 2951. For example, the error flag trip level is typically 4.75V for a 5V output or 11.4V for a 12V output. The out of regulation condition may be due either to low input voltage, current limiting, or thermal limiting.

Figure 1 below gives a timing diagram depicting the $\overline{\text{ERROR}}$ signal and the regulated output voltage as the LP2951 input is ramped up and down. For 5V versions, the $\overline{\text{ERROR}}$ signal becomes valid (low) at about 1.3V input. It goes high at about 5V input (the input voltage at which $V_{OUT} = 4.75$). Since the LP2951's dropout voltage is load-dependent (see curve in typical performance characteristics), the **input** voltage trip point (about 5V) will vary with the load current. The **output** voltage trip point (approx. 4.75V) does not vary with load.

The error comparator has an open-collector output which requires an external pullup resistor. This resistor may be returned to the output or some other supply voltage depending on system requirements. In determining a value for this resistor, note that while the output is rated to sink 400 μA, this sink current adds to battery drain in a low battery condition. Suggested values range from 100k to 1 MΩ. The resistor is not required if this output is unused.

PROGRAMMING THE OUTPUT VOLTAGE (LP2951)

The LP2951 may be pin-strapped for the nominal fixed output voltage using its internal voltage divider by tying the output and sense pins together, and also tying the feedback and V_{TAP} pins together. Alternatively, it may be programmed for any output voltage between its 1.235V reference and its 30V maximum rating. As seen in *Figure 2*, an external pair of resistors is required.



TL/H/8546-20

*When $V_{IN} \le 1.3V$, the error flag pin becomes a high impedance, and the error flag voltage rises to its pull-up voltage. Using V_{OUT} as the pull-up voltage (see *Figure 2*), rather than an external 5V source, will keep the error flag voltage under 1.2V (typ.) in this condition. The user may wish to divide down the error flag voltage using equal-value resistors (10 kΩ suggested), to ensure a low-level logic signal during any fault condition, while still allowing a valid high logic level during normal operation.

FIGURE 1. $\overline{\text{ERROR}}$ Output Timing

The complete equation for the output voltage is

$$V_{OUT} = V_{REF} \bullet \left(1 + \frac{R_1}{R_2}\right) + I_{FB}R_1$$

where V_{REF} is the nominal 1.235 reference voltage and I_{FB} is the feedback pin bias current, nominally −20 nA. The minimum recommended load current of 1 μA forces an upper limit of 1.2 MΩ on the value of R_2, if the regulator must work with no load (a condition often found in CMOS in standby). I_{FB} will produce a 2% typical error in V_{OUT} which may be eliminated at room temperature by trimming R_1. For better accuracy, choosing R_2 = 100k reduces this error to 0.17% while increasing the resistor program current to 12 μA. Since the LP2951 typically draws 60 μA at no load with Pin 2 open-circuited, this is a small price to pay.

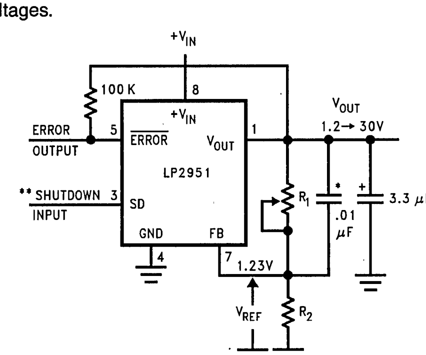
REDUCING OUTPUT NOISE

In reference applications it may be advantageous to reduce the AC noise present at the output. One method is to reduce the regulator bandwidth by increasing the size of the output capacitor. This is the only way noise can be reduced on the 3 lead LP2950 but is relatively inefficient, as increasing the capacitor from 1 μF to 220 μF only decreases the noise from 430 μV to 160 μV rms for a 100 kHz bandwidth at 5V output.

Noise can be reduced fourfold by a bypass capacitor across R_1, since it reduces the high frequency gain from 4 to unity. Pick

$$C_{BYPASS} \cong \frac{1}{2\pi R_1 \bullet 200\text{ Hz}}$$

or about 0.01 μF. When doing this, the output capacitor must be increased to 3.3 μF to maintain stability. These changes reduce the output noise from 430 μV to 100 μV rms for a 100 kHz bandwidth at 5V output. With the bypass capacitor added, noise no longer scales with output voltage so that improvements are more dramatic at higher output voltages.



TL/H/8546-7

FIGURE 2. Adjustable Regulator

*See Application Hints

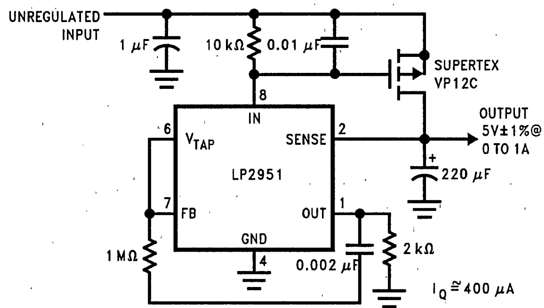
$$V_{out} = V_{Ref}\left(1 + \frac{R_1}{R_2}\right)$$

**Drive with TTL-high to shut down. Ground or leave open if shutdown feature is not to be used.

Note: Pins 2 and 6 are left open.

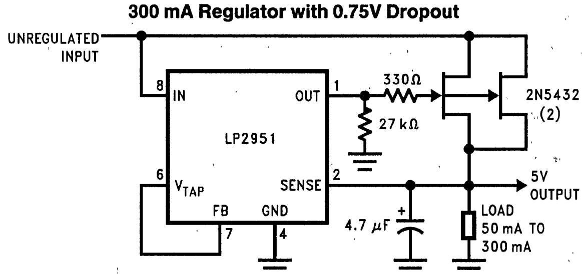
Typical Applications

1A Regulator with 1.2V Dropout



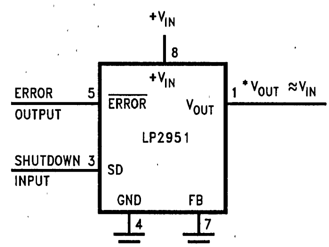
TL/H/8546-22

300 mA Regulator with 0.75V Dropout



TL/H/8546-21

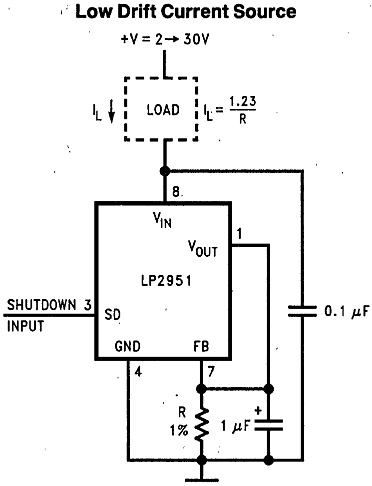
Wide Input Voltage Range Current Limiter



TL/H/8546-9

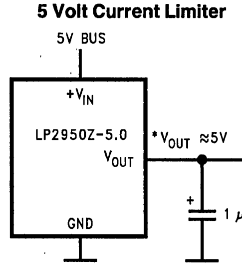
*Minimum input-output voltage ranges from 40 mV to 400 mV, depending on load current. Current limit is typically 160 mA.

Low Drift Current Source



TL/H/8546-8

5 Volt Current Limiter

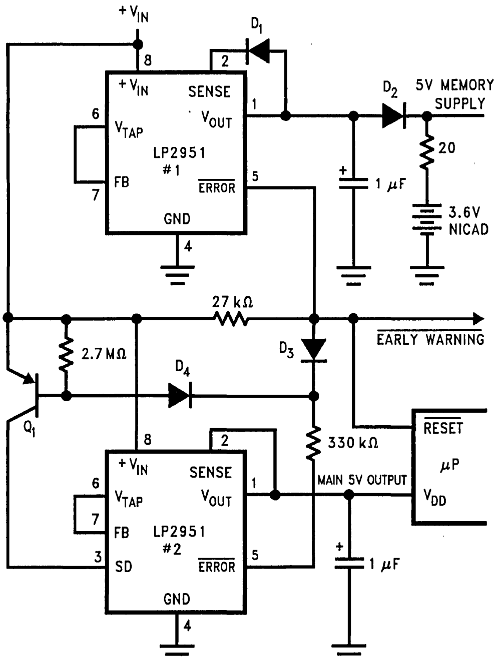


TL/H/8546-10

*Minimum input-output voltage ranges from 40 mV to 400 mV, depending on load current. Current limit is typically 160 mA.

Typical Applications (Continued)

Regulator with Early Warning and Auxiliary Output

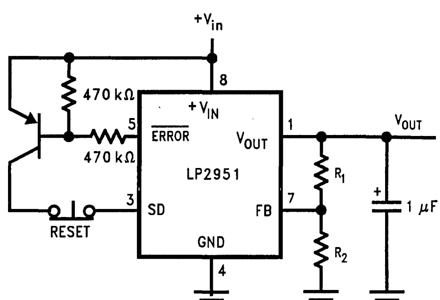


TL/H/8546–11

- Early warning flag on low input voltage
- Main output latches off at lower input voltages
- Battery backup on auxiliary output

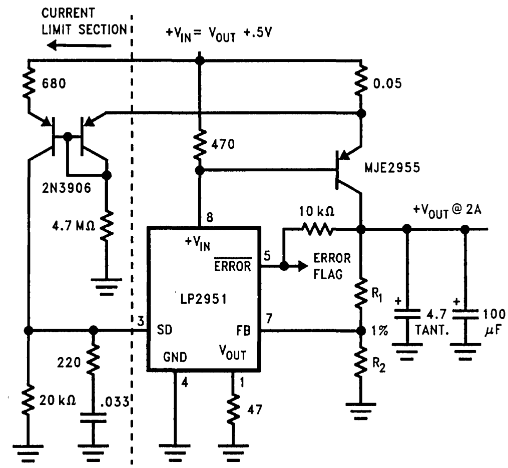
Operation: Reg. #1's V_{out} is programmed one diode drop above 5V. Its error flag becomes active when $V_{in} \leq 5.7V$. When V_{in} drops below 5.3V, the error flag of Reg. #2 becomes active and via Q1 latches the main output off. When V_{in} again exceeds 5.7V Reg. #1 is back in regulation and the early warning signal rises, unlatching Reg. #2 via D3.

Latch Off When Error Flag Occurs



TL/H/8546–12

2 Ampere Low Dropout Regulator

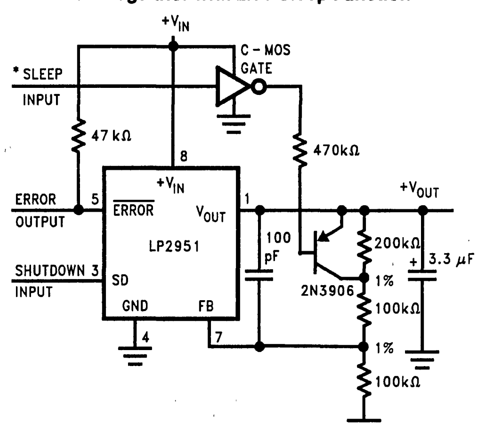


TL/H/8546–13

$$V_{out} = 1.23V\left(1 + \frac{R_1}{R_2}\right)$$

For $5V_{out}$, use internal resistors. Wire pin 6 to 7, & wire pin 2 to $+V_{out}$ Buss.

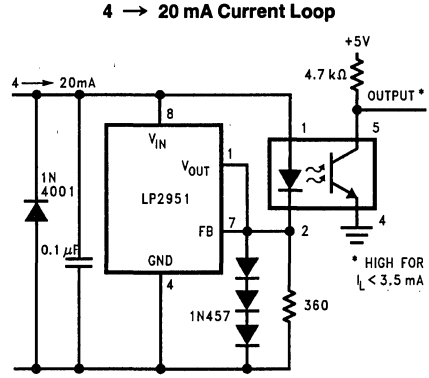
5V Regulator with 2.5V Sleep Function



*High input lowers V_{out} to 2.5V

TL/H/8546–14

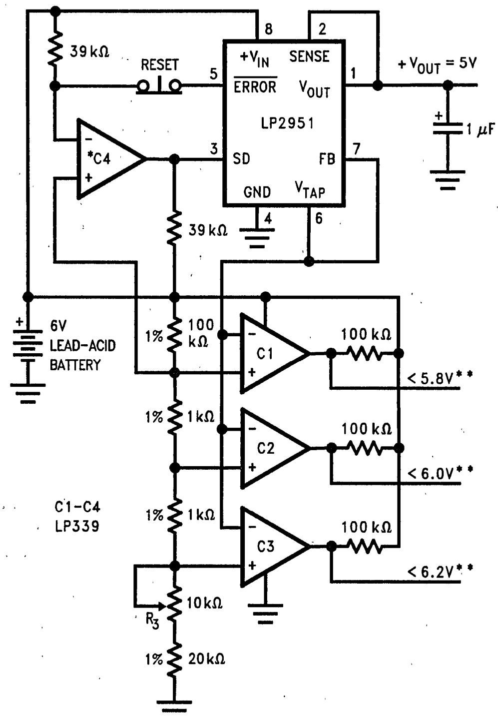
Open Circuit Detector for 4 → 20 mA Current Loop



TL/H/8546–15

Typical Applications (Continued)

Regulator with State-of-Charge Indicator



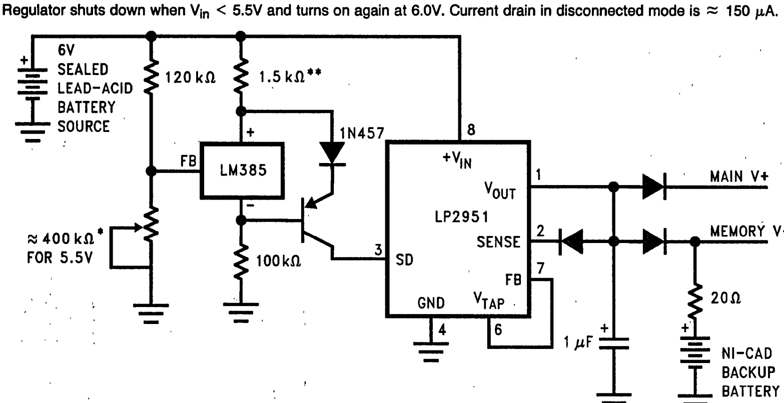
TL/H/8546-16

*Optional Latch off when drop out occurs. Adjust R3 for C2 Switching when V_{in} is 6.0V.

**Outputs go low when V_{in} drops below designated thresholds.

Low Battery Disconnect

For values shown, Regulator shuts down when V_{in} < 5.5V and turns on again at 6.0V. Current drain in disconnected mode is ≈ 150 μA.



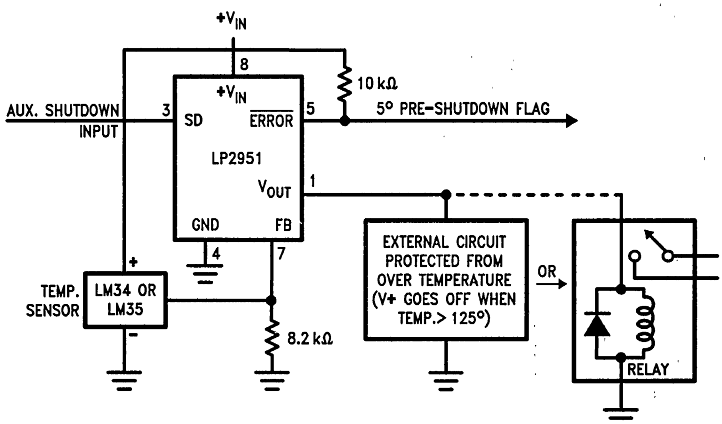
*Sets disconnect Voltage

**Sets disconnect Hysteresis

TL/H/8546-17

Typical Applications (Continued)

System Overtemperature Protection Circuit

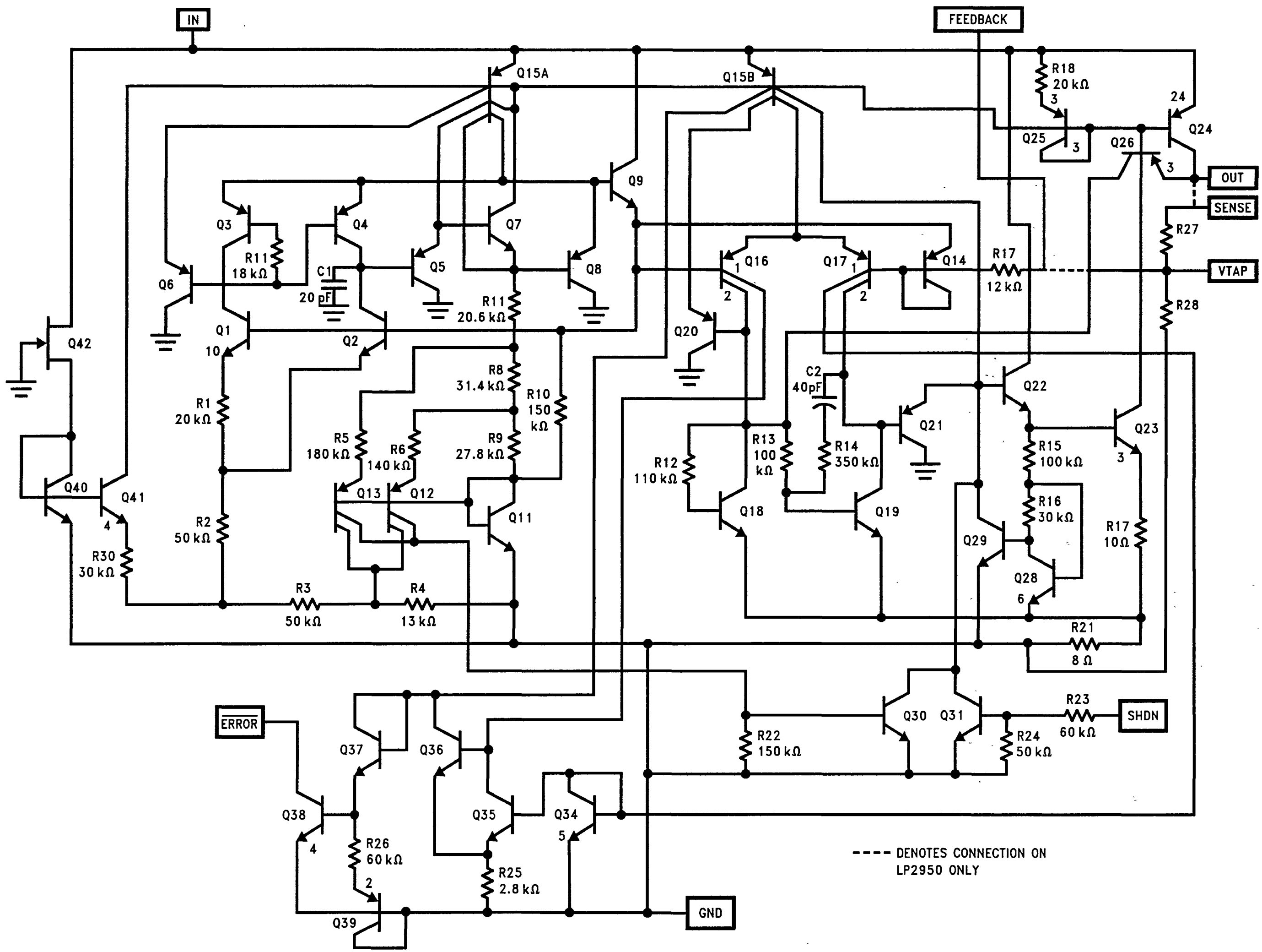


TL/H/8546-18

LM34 for 125°F Shutdown

LM35 for 125°C Shutdown

Schematic Diagram



TL/H/8546-23

National Semiconductor

LP2952/LP2952A/LP2953/LP2953A Adjustable Micropower Low-Dropout Voltage Regulators

General Description

The LP2952 and LP2953 are micropower voltage regulators with very low quiescent current (130 μA typical at 1 mA load) and very low dropout voltage (typ. 60 mV at light load and 470 mV at 250 mA load current). They are ideally suited for battery-powered systems. Furthermore, the quiescent current increases only slightly at dropout, which prolongs battery life.

The LP2952 and LP2953 retain all the desirable characteristics of the LP2951, but offer increased output current, additional features, and an improved shutdown function.

The internal crowbar pulls the output down quickly when the shutdown is activated.

The error flag goes low if the output voltage drops out of regulation.

Reverse battery protection is provided.

The internal voltage reference is made available for external use, providing a low-T.C. reference with very good line and load regulation.

The parts are available in DIP and surface mount packages.

Features

- Output voltage adjusts from 1.23V to 29V
- Guaranteed 250 mA output current
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse battery protection
- 50 mA (typical) output pulldown crowbar
- 5V and 3.3V versions available

LP2953 Versions Only

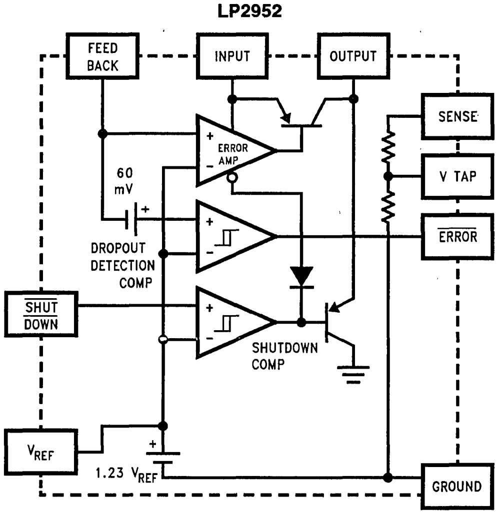
- Auxiliary comparator included with CMOS/TTL compatible output levels. Can be used for fault detection, low input line detection, etc.

Applications

- High-efficiency linear regulator
- Regulator with under-voltage shutdown
- Low dropout battery-powered regulator
- Snap-ON/Snap-OFF regulator

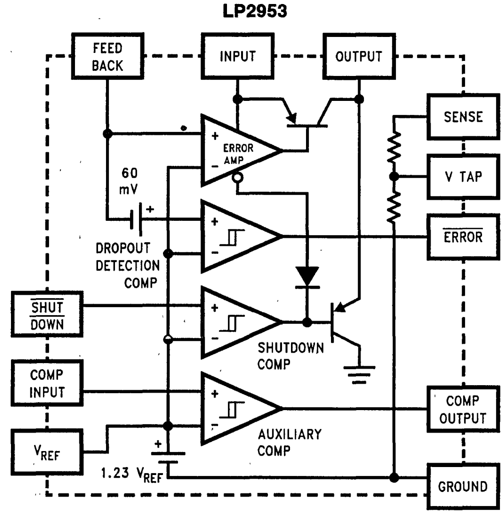
Block Diagrams

LP2952



TL/H/11127-1

LP2953



TL/H/11127-2

2

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	$-65°C \le T_A \le +150°C$
Operating Temperature Range	
LP2952I, LP2953I, LP2952AI, LP2953AI, LP2952I-3.3, LP2953I-3.3, LP2952AI-3.3, LP2953AI-3.3	$-40°C \le T_J \le +125°C$
LP2953AM	$-55°C \le T_A \le +125°C$
Maximum Junction Temperature	
LP2952I, LP2953I, LP2952AI, LP2953AI, LP2952I-3.3, LP2953I-3.3, LP2952AI-3.3, LP2953AI-3.3	+125°C
LP2953AM	+150°C
Lead Temp. (Soldering, 5 seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	−20V to +30V
Feedback Input Voltage (Note 3)	−0.3V to +5V
Comparator Input Voltage (Note 4)	−0.3V to +30V
Shutdown Input Voltage (Note 4)	−0.3V to +30V
Comparator Output Voltage (Note 4)	−0.3V to +30V
ESD Rating (Note 15)	2 kV

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface** applies over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = V_O(NOM) + 1V$, $I_L = 1$ mA, $C_L = 2.2\ \mu F$ for 5V parts and $4.7\mu F$ for 3.3V parts. Feedback pin is tied to V Tap pin, Output pin is tied to Output Sense pin.

3.3V Versions

Symbol	Parameter	Conditions	Typical	LP2952AI-3.3, LP2953AI-3.3		LP2952I-3.3, LP2953I-3.3		Units
				Min	Max	Min	Max	
V_O	Output Voltage		3.3	3.284 **3.260**	3.317 **3.340**	3.267 **3.234**	3.333 **3.366**	V
		$1\text{ mA} \le I_L \le 250\text{ mA}$	3.3	**3.254**	**3.346**	**3.221**	**3.379**	

5V Versions

Symbol	Parameter	Conditions	Typical	LP2952AI, LP2953AI, LP2953AM (Note 17)		LP2952I, LP2953I		Units
				Min	Max	Min	Max	
V_O	Output Voltage		5.0	4.975 **4.940**	5.025 **5.060**	4.950 **4.900**	5.050 **5.100**	V
		$1\text{ mA} \le I_L \le 250\text{ mA}$	5.0	**4.930**	**5.070**	**4.880**	**5.120**	

All Voltage Options

Symbol	Parameter	Conditions	Typical	LP2952AI, LP2953AI, LP2952AI-3.3, LP2953AI-3.3, LP2953AM (Note 17)		LP2952I, LP2953I, LP2952I-3.3, LP2953I-3.3		Units
				Min	Max	Min	Max	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temp. Coefficient	(Note 5)	**20**		**100**		**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Output Voltage Line Regulation	$V_{IN} = V_O(NOM) + 1V$ to 30V	0.03		0.1 **0.2**		0.2 **0.4**	%
$\frac{\Delta V_O}{V_O}$	Output Voltage Load Regulation (Note 6)	$I_L = 1$ mA to 250 mA $I_L = 0.1$ mA to 1 mA	0.04		0.16 **0.20**		0.20 **0.30**	%
$V_{IN}-V_O$	Dropout Voltage (Note 7)	$I_L = 1$ mA	60		100 **150**		100 **150**	mV
		$I_L = 50$ mA	240		300 **420**		300 **420**	
		$I_L = 100$ mA	310		400 **520**		400 **520**	
		$I_L = 250$ mA	470		600 **800**		600 **800**	

Electrical Characteristics Limits in standard typeface are for T_J = 25°C, **bold typeface** applies over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = V_O(NOM) + 1V$, I_L = 1 mA, C_L = 2.2 μF for 5V parts and 4.7μF for 3.3V parts. Feedback pin is tied to V Tap pin, Output pin is tied to Output Sense pin. (Continued)

All Voltage Options (Continued)

Symbol	Parameter	Conditions	Typical	LP2952AI, LP2953AI, LP2952AI-3.3, LP2953AI-3.3, LP2953AM (Note 17)		LP2952I, LP2953I, LP2952I-3.3, LP2953I-3.3		Units
				Min	Max	Min	Max	
I_{GND}	Ground Pin Current (Note 8)	I_L = 1 mA	130		170 **200**		170 **200**	μA
		I_L = 50 mA	1.1		2 **2.5**		2 **2.5**	mA
		I_L = 100 mA	4.5		6 **8**		6 **8**	mA
		I_L = 250 mA	21		28 **33**		28 **33**	mA
I_{GND}	Ground Pin Current at Dropout (Note 8)	$V_{IN} = V_O(NOM) - 0.5V$ I_L = 100 μA	165		210 **240**		210 **240**	μA
I_{GND}	Ground Pin Current at Shutdown (Note 8)	(Note 9)	105		140		140	μA
I_{LIMIT}	Current Limit	V_{OUT} = 0	380		500 **530**		500 **530**	mA
$\frac{\Delta V_O}{\Delta Pd}$	Thermal Regulation	(Note 10)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 kHz) I_L = 100 mA	C_L = 4.7 μF	400					μV RMS
		C_L = 33 μF	260					
		C_L = 33 μF (Note 11)	80					
V_{REF}	Reference Voltage	(Note 12)	1.230	1.215 **1.205**	1.245 **1.255**	1.205 **1.190**	1.255 **1.270**	V
$\frac{\Delta V_{REF}}{V_{REF}}$	Reference Voltage Line Regulation	V_{IN} = 2.5V to $V_O(NOM)$ + 1V $V_{IN} = V_O(NOM)$ + 1V to 30V (Note 13)	0.03		0.1 **0.2**		0.2 **0.4**	%
$\frac{\Delta V_{REF}}{V_{REF}}$	Reference Voltage Load Regulation	I_{REF} = 0 to 200 μA	0.25		0.4 **0.6**		0.8 **1.0**	%
$\frac{\Delta V_{REF}}{\Delta T}$	Reference Voltage Temp. Coefficient	(Note 5)	**20**					ppm/°C
$I_B(FB)$	Feedback Pin Bias Current		20		40 **60**		40 **60**	nA
I_O (SINK)	Output "OFF" Pulldown Current	(Note 9)	50	30 **20**		30 **20**		mA

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, **bold typeface** applies over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: $V_{IN} = V_O(NOM) + 1V$, $I_L = 1$ mA, $C_L = 2.2$ μF for 5V parts and 4.7μF for 3.3V parts. Feedback pin is tied to V Tap pin, Output pin is tied to Output Sense pin. (Continued)

Symbol	Parameter	Conditions	Typical	LP2952AI, LP2953AI, LP2952AI-3.3, LP2953AI-3.3, LP2953AM (Note 17)		LP2952I, LP2953I, LP2952I-3.3, LP2953I-3.3		Units
				Min	Max	Min	Max	
DROPOUT DETECTION COMPARATOR								
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 30V$	0.01		1 **2**		1 **2**	μA
V_{OL}	Output "LOW" Voltage	$V_{IN} = V_O(NOM) - 0.5V$ $I_O(COMP) = 400$ μA	150		250 **400**		250 **400**	mV
V_{THR} (MAX)	Upper Threshold Voltage	(Note 14)	−60	−80 **−95**	−35 **−25**	−80 **−95**	−35 **−25**	mV
V_{THR} (MIN)	Lower Threshold Voltage	(Note 14)	−85	−110 **−160**	−55 **−40**	−110 **−160**	−55 **−40**	mV
HYST	Hysteresis	(Note 14)	15					mV
$\overline{\text{SHUTDOWN}}$ INPUT (Note 16)								
V_{OS}	Input Offset Voltage	(Referred to V_{REF})	±3	−7.5 **−10**	7.5 **10**	−7.5 **−10**	7.5 **10**	mV
HYST	Hysteresis		6					mV
I_B	Input Bias Current	$V_{IN}(S/D) = 0V$ to $5V$	10	−30 **−50**	30 **50**	−30 **−50**	−30 **50**	nA
		LP2953AM	10	−30 **−75**	30 **75**			
AUXILIARY COMPARATOR (LP2953 Only)								
V_{OS}	Input Offset Voltage	(Referred to V_{REF})	±3	−7.5 **−10**	7.5 **10**	−7.5 **−10**	7.5 **10**	mV
		LP2953AM	±3	−7.5 **−12**	7.5 **12**			
HYST	Hysteresis		6					mV
I_B	Input Bias Current	$V_{IN}(COMP) = 0V$ to $5V$	10	−30 **−50**	30 **50**	−30 **−50**	30 **50**	nA
		LP2953AM	10	−30 **−75**	30 **75**			
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 30V$ $V_{IN}(COMP) = 1.3V$	0.01		1 **2**		1 **2**	μA
		LP2953AM	0.01		1 **2.2**			
V_{OL}	Output "LOW" Voltage	$V_{IN}(COMP) = 1.1V$ $I_O(COMP) = 400$ μA	150		250 **400**		250 **400**	mV
		LP2953AM	150		250 **420**			

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, $T_J(MAX)$, the junction-to-ambient thermal resistance, θ_{J-A}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P\ (MAX) = \frac{T_J(MAX) - T_A}{\theta_{J-A}}$.

Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. See APPLICATION HINTS for additional information on heatsinking and thermal resistance.

Note 3: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

Note 4: May exceed the input supply voltage.

Note 5: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 6: Load regulation is measured at constant junction temperature using low duty cycle pulse testing. Two separate tests are performed, one for the range of 100 μA to 1 mA and one for the 1 mA to 250 mA range. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 7: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential. At very low values of programmed output voltage, the input voltage minimum of 2V **(2.3V over temperature)** must be observed.

Note 8: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the ground pin current, output load current, and current through the external resistive divider (if used).

Note 9: $V_{SHUTDOWN} \leq 1.1V$, $V_{OUT} = V_O(NOM)$.

Note 10: Thermal regulation is the change in output voltage at a time T after a change in power dissipation, excluding load or line regulation effects. Specifications are for a 200 mA load pulse at $V_{IN} = V_O(NOM) + 15V$ (3W pulse) for T = 10 ms.

Note 11: Connect a 0.1 μF capacitor from the output to the feedback pin.

Note 12: $V_{REF} \leq V_{OUT} \leq (V_{IN} - 1V)$, $2.3V \leq V_{IN} \leq 30V$, $100\ \mu A \leq I_L \leq 250$ mA.

Note 13: Two separate tests are performed, one covering $2.5V \leq V_{IN} \leq V_O(NOM) + 1V$ and the other test for $V_O(NOM) + 1V \leq V_{IN} \leq 30V$.

Note 14: Comparator thresholds are expressed in terms of a voltage differential at the Feedback terminal below the nominal reference voltage measured at $V_{IN} = V_O(NOM) + 1V$. To express these thresholds in terms of output voltage change, multiply by the Error amplifier gain, which is $V_{OUT}/V_{REF} = (R1 + R2)/R2$ (refer to Figure 4).

Note 15: Human body model, 200 pF discharged through 1.5 kΩ.

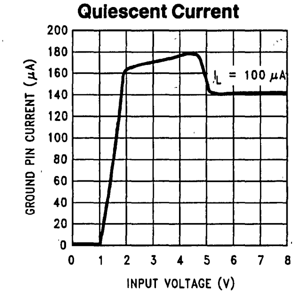
Note 16: Drive $\overline{\text{Shutdown}}$ pin with TTL or CMOS-low level to shut regulator OFF, high level to turn regulator ON.

Note 17: A military RETS specification is available upon request. At the time of printing, the LP2953AMJ/883C RETS specification complied with the **boldface** limits in this column.

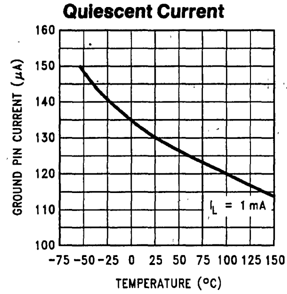
Typical Performance Characteristics

Unless otherwise specified: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF, V_{SD} = 3V, T_A = 25°C, V_{OUT} = 5V.

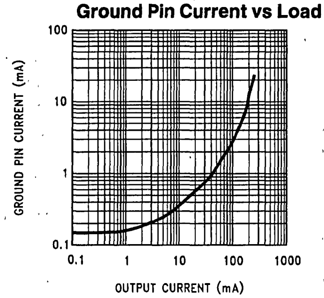
Quiescent Current



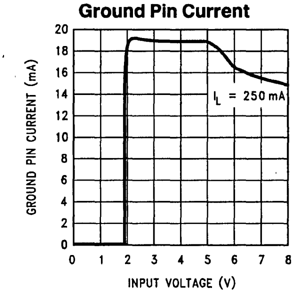
Quiescent Current



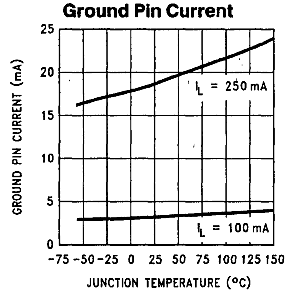
Ground Pin Current vs Load



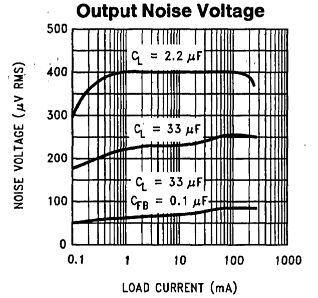
Ground Pin Current



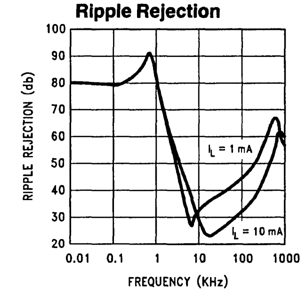
Ground Pin Current



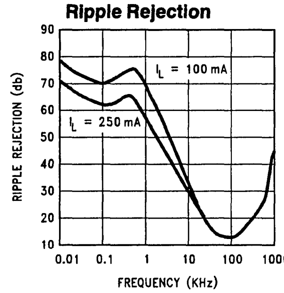
Output Noise Voltage



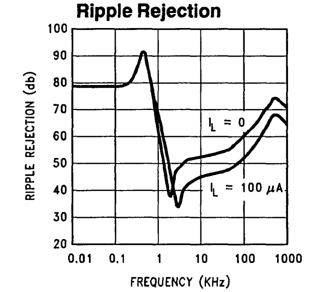
Ripple Rejection



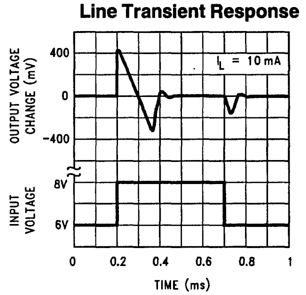
Ripple Rejection



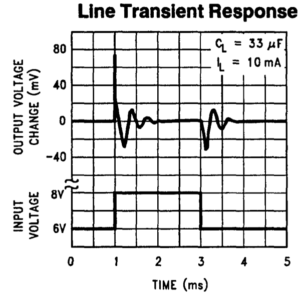
Ripple Rejection



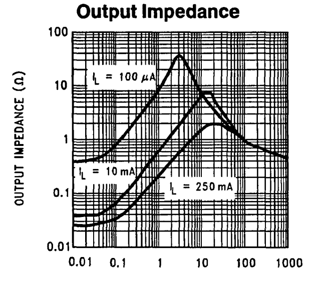
Line Transient Response



Line Transient Response



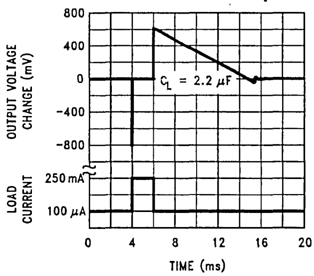
Output Impedance



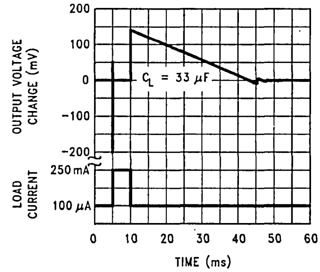
TL/H/11127-3

Typical Performance Characteristics Unless otherwise specified: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF, V_{SD} = 3V, T_A = 25°C, V_{OUT} = 5V. (Continued)

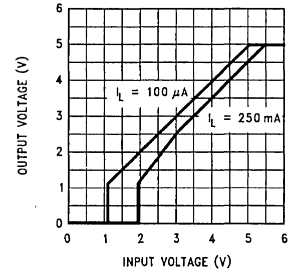
Load Transient Response



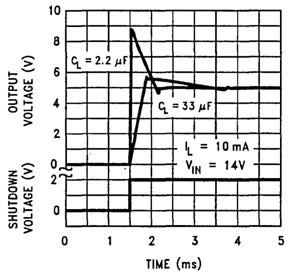
Load Transient Response



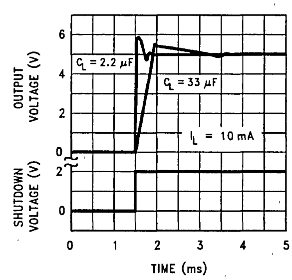
Dropout Characteristics



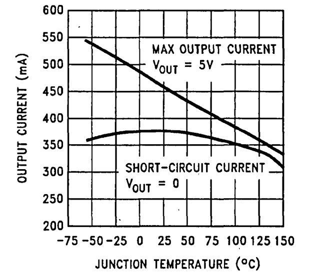
Enable Transient



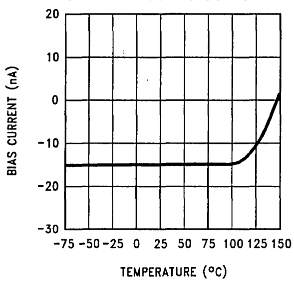
Enable Transient



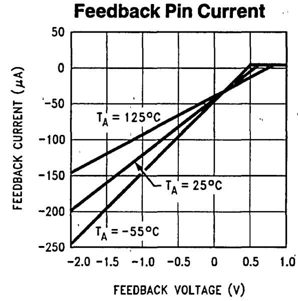
Short-Circuit Output Current and Maximum Output Current



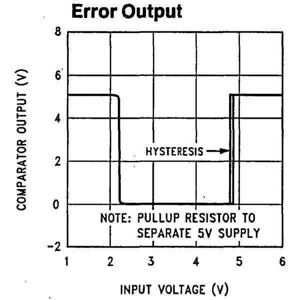
Feedback Bias Current



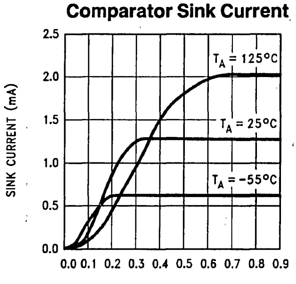
Feedback Pin Current



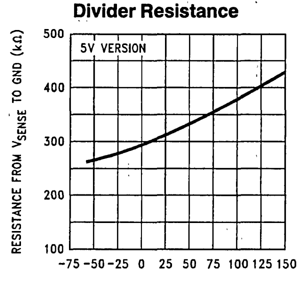
Error Output



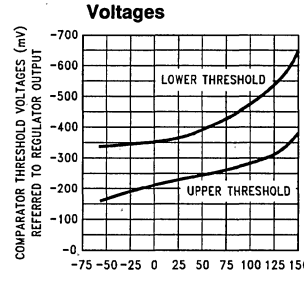
Comparator Sink Current



Divider Resistance



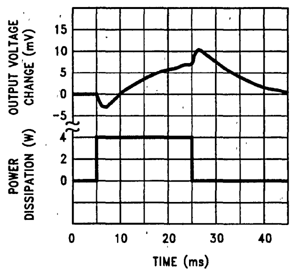
Dropout Detection Comparator Threshold Voltages



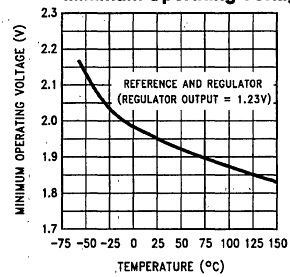
TL/H/11127-4

Typical Performance Characteristics Unless otherwise specified: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF, V_{SD} = 3V, T_A = 25°C, V_{OUT} = 5V. (Continued)

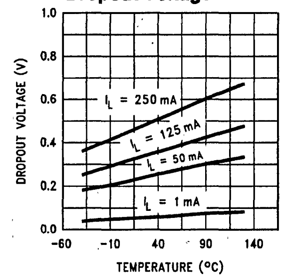
Thermal Regulation



Minimum Operating Voltage



Dropout Voltage



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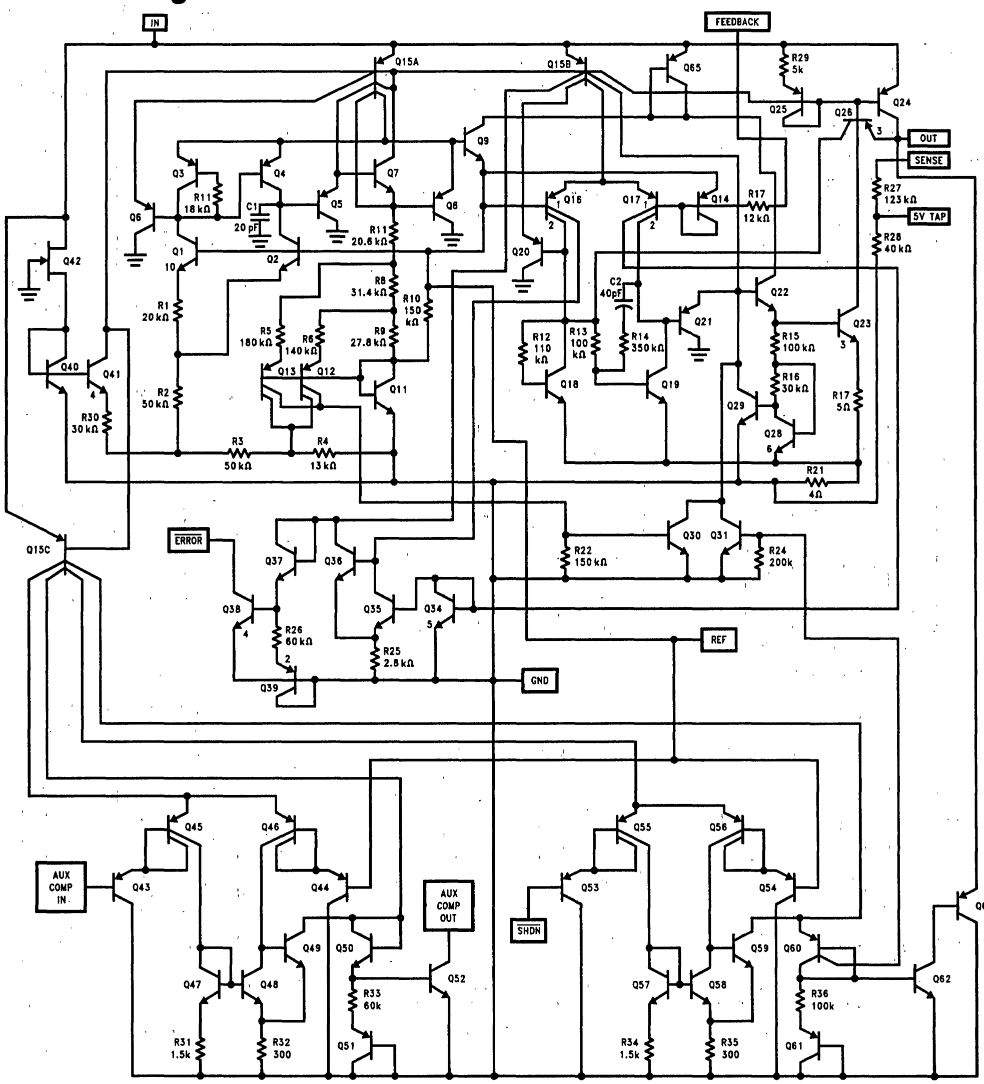
Schematic Diagram



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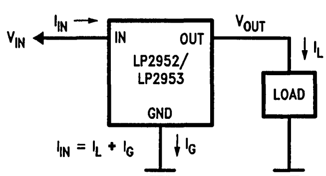
Application Hints

HEATSINK REQUIREMENTS (Industrial Temperature Range Devices)

The maximum allowable power dissipation for the LP2952/LP2953 is limited by the maximum junction temperature (+125°C) and the external factors that determine how quickly heat flows away from the part: the *ambient temperature* and the *junction-to-ambient thermal resistance* for the specific application.

The industrial temperature range ($-40°C \leq T_J \leq +125°C$) parts are manufactured in plastic DIP and surface mount packages which contain a copper lead frame that allows heat to be effectively conducted away from the die, through the ground pins of the IC, and into the copper of the PC board. Details on heatsinking using PC board copper are covered later.

To determine if a heatsink is required, the maximum power dissipated by the regulator, P(max), must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator). *Figure 1* shows the voltages and currents which are present in the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1*:



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$$P_{TOTAL} = (V_{IN} - V_{OUT})\, I_L + (V_{IN})\, I_G$$

FIGURE 1. Current/Voltage Diagram

The next parameter which must be calculated is the maximum allowable temperature rise, T_R(max). This is calculated by using the formula:

$$T_R(\text{max}) = T_J(\text{max}) - T_A(\text{max})$$

where: T_J(max) is the maximum allowable junction temperature

T_A(max) is the maximum ambient temperature

Using the calculated values for T_R(max) and P(max), the required value for junction-to-ambient thermal resistance, $\theta_{(J-A)}$, can now be found:

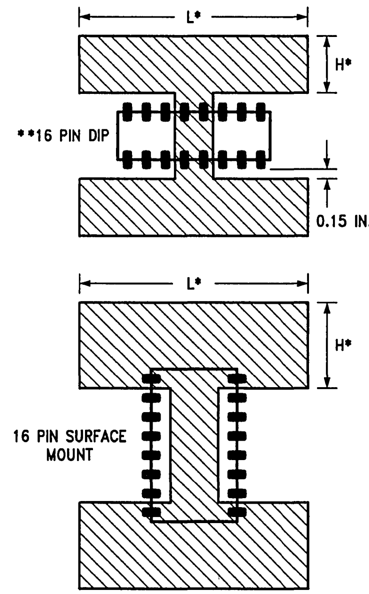
$$\theta_{(J-A)} = T_R(\text{max})/P(\text{max})$$

The heatsink is made using the PC board copper. The heat is conducted from the die, through the lead frame (inside the part), and out the pins which are soldered to the PC board. The pins used for heat conduction are:

TABLE I

Part	Package	Pins
LP2952IN, LP2952AIN, LP2952IN-3.3, LP2952AIN-3.3	14-Pin DIP	3, 4, 5, 10, 11, 12
LP2953IN, LP2953AIN, LP2953IN-3.3, LP2953AIN-3.3	16-Pin DIP	4, 5, 12, 13
LP2952IM, LP2952AIM, LP2952IM-3.3, LP2952AIM-3.3, LP2953IM, LP2953AIM, LP2953IM-3.3, LP2953AIM-3.3	16-Pin Surface Mount	1, 8, 9, 16

Figure 2 shows copper patterns which may be used to dissipate heat from the LP2952 and LP2953:



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*For best results, use L = 2H

**14-Pin DIP is similar, refer to Table I for pins designated for heatsinking.

FIGURE 2. Copper Heatsink Patterns

Table II shows some values of junction-to-ambient thermal resistance (θ_{J-A}) for values of L and W for 1 oz. copper:

TABLE II

Package	L (in.)	H (in.)	θ_{J-A} (°C/W)
16-Pin DIP	1	0.5	70
	2	1	60
	3	1.5	58
	4	0.19	66
	6	0.19	66
14-Pin DIP	1	0.5	65
	2	1	51
	3	1.5	49
Surface Mount	1	0.5	83
	2	1	70
	3	1.5	67
	6	0.19	69
	4	0.19	71
	2	0.19	73

Application Hints (Continued)

HEATSINK REQUIREMENTS (Military Temperature Range Devices)

The maximum allowable power dissipation for the LP2953AMJ is limited by the maximum junction temperature (+150°C) and the two parameters that determine how quickly heat flows away from the die: *the ambient temperature and the junction-to-ambient thermal resistance of the part.*

The military temperature range ($-55°C \le T_J \le +150°C$) parts are manufactured in ceramic DIP packages which contain a KOVAR lead frame (unlike the industrial parts, which have a copper lead frame). The KOVAR material is necessary to attain the hermetic seal required in military applications.

The KOVAR lead frame does not conduct heat as well as copper, which means that the PC board copper can not be used to significantly reduce the overall junction-to-ambient thermal resistance in applications using the LP2953AMJ part.

The power dissipation calculations for military applications are done exactly the same as was detailed in the previous section, with one important exception: the value for $\theta_{(J-A)}$, the junction-to-ambient thermal resistance, is fixed at 95°C/W and can not be changed by adding copper foil patterns to the PC board. This leads to an important fact: The *maximum allowable power dissipation in any application using the LP2953AMJ is dependent only on the ambient temperature:*

$$P(max) = T_{R(max)} / \theta_{(J-A)}$$

$$P(max) = \frac{T_{J(max)} - T_{A(max)}}{\theta_{(J-A)}}$$

$$P(max) = \frac{150 - T_{A(max)}}{95}$$

Figure 3 shows a graph of maximum allowable power dissipation vs. ambient temperature for the LP2953AMJ, made using the 95°C/W value for $\theta_{(J-A)}$ and assuming a maximum junction temperature of 150°C (caution: the *maximum* ambient temperature which will be reached in a given application must always be used to calculate maximum allowable power dissipation).

EXTERNAL CAPACITORS

A 2.2 µF (or greater) capacitor is required between the output pin and ground to assure stability when the output is set to 5V. Without this capacitor, the part will oscillate. Most type of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at −30°C, which requires the use of solid tantalums below −25°C. The important parameters of the capacitor are an ESR of about 5Ω or less and a resonant frequency above 500 kHz (the ESR may increase by a factor of **20** or **30** as the temperature is reduced from 25°C to −30°C). The value of this capacitor may be increased without limit.

At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.68 µF for currents below 10 mA or 0.22 µF for currents below 1 mA.

Programming the output for voltages below 5V runs the error amplifier at lower gains requiring *more* output capacitance for stability. At 3.3V output, a minimum of 4.7 µF is required. For the worst-case condition of 1.23V output and 250 mA of load current, a 6.8 µF (or larger) capacitor should be used.

A 1 µF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used.

Stray capacitance to the Feedback terminal can cause instability. This problem is most likely to appear when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between the Output and Feedback pins and increasing the output capacitance to 6.8 µF (or greater) will cure the problem.

MINIMUM LOAD

When setting the output voltage using an external resistive divider, a minimum current of 1 µA is recommended through the resistors to provide a minimum load.

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so this value must be used to obtain correlation on these tested limits.

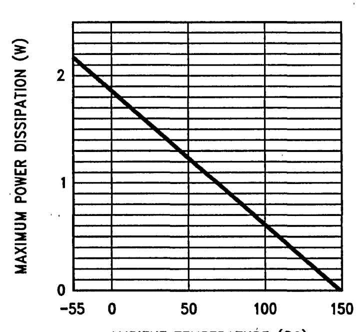

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FIGURE 3. Power Derating Curve for LP2953AMJ

Application Hints (Continued)

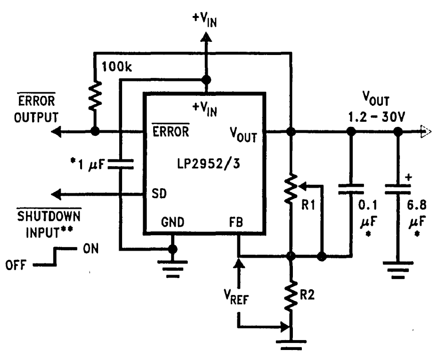
PROGRAMMING THE OUTPUT VOLTAGE

The regulator may be pin-strapped for 5V operation using its internal resistive divider by tying the Output and Sense pins together and also tying the Feedback and 5V Tap pins together.

Alternatively, it may be programmed for any voltage between the 1.23V reference and the 30V maximum rating using an external pair of resistors (see *Figure 4*). The complete equation for the output voltage is:

$$V_{OUT} = V_{REF} \times \left(1 + \frac{R1}{R2}\right) + (I_{FB} \times R1)$$

where V_{REF} is the 1.23V reference and I_{FB} is the Feedback pin bias current (−20 nA typical). The minimum recommended load current of 1 µA sets an upper limit of 1.2 MΩ on the value of R2 in cases where the regulator must work with no load (see **MINIMUM LOAD**). I_{FB} will produce a typical 2% error in V_{OUT} which can be eliminated at room temperature by trimming R1. For better accuracy, choosing R2 = 100 kΩ will reduce this error to 0.17% while increasing the resistor program current to 12 µA. Since the typical quiescent current is 120 µA, this added current is negligible.



TL/H/11127-9

FIGURE 4. Adjustable Regulator

*See Application Hints

**Drive with TTL-low to shut down

DROPOUT VOLTAGE

The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltage is independent of the programmed output voltage.

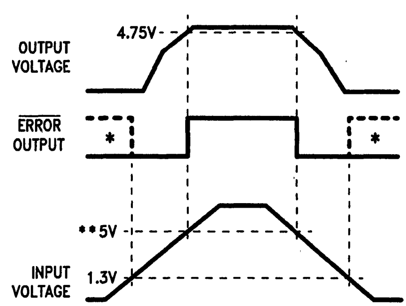
DROPOUT DETECTION COMPARATOR

This comparator produces a logic "LOW" whenever the output falls out of regulation by more than about 5%. This figure results from the comparator's built-in offset of 60 mV divided by the 1.23V reference (refer to block diagrams on page 1). The 5% low trip level remains constant regardless of the programmed output voltage. An out-of-regulation condition can result from low input voltage, current limiting, or thermal limiting.

Figure 5 gives a timing diagram showing the relationship between the output voltage, the $\overline{\text{ERROR}}$ output, and input voltage as the input voltage is ramped up and down to a regulator programmed for 5V output. The $\overline{\text{ERROR}}$ signal becomes low at about 1.3V input. It goes high at about 5V input, where the output equals 4.75V. Since the dropout voltage is load dependent, the **input** voltage trip points will vary with load current. The **output** voltage trip point does not vary.

The comparator has an open-collector output which requires an external pull-up resistor. This resistor may be connected to the regulator output or some other supply voltage. Using the regulator output prevents an invalid "HIGH" on the comparator output which occurs if it is pulled up to an external voltage while the regulator input voltage is reduced below 1.3V. In selecting a value for the pull-up resistor, note that while the output can sink 400 µA, this current adds to battery drain. Suggested values range from 100 kΩ to 1 MΩ. This resistor is not required if the output is unused.

When $V_{IN} \leq 1.3V$, the error flag pin becomes a high impedance, allowing the error flag voltage to rise to its pull-up voltage. Using V_{OUT} as the pull-up voltage (rather than an external 5V source) will keep the error flag voltage below 1.2V (typical) in this condition. The user may wish to divide down the error flag voltage using equal-value resistors (10 kΩ suggested) to ensure a low-level logic signal during any fault condition, while still allowing a valid high logic level during normal operation.



TL/H/11127-10

FIGURE 5. $\overline{\text{ERROR}}$ Output Timing

*In shutdown mode, $\overline{\text{ERROR}}$ will go high if it has been pulled up to an external supply. To avoid this invalid response, pull up to regulator output.

**Exact value depends on dropout voltage. (See Application Hints)

OUTPUT ISOLATION

The regulator output can be left connected to an active voltage source (such as a battery) with the regulator input power shut off, **as long as the regulator ground pin is connected to ground.** If the ground pin is left floating, **damage to the regulator can occur** if the output is pulled up by an external voltage source.

Application Hints (Continued)

REDUCING OUTPUT NOISE

In reference applications it may be advantageous to reduce the AC noise present on the output. One method is to reduce regulator bandwidth by increasing output capacitance. This is relatively inefficient, since large increases in capacitance are required to get significant improvement.

Noise can be reduced more effectively by a bypass capacitor placed across R1 (refer to *Figure 4*). The formula for selecting the capacitor to be used is:

$$C_B = \frac{1}{2\pi \text{ R1} \times 20 \text{ Hz}}$$

This gives a value of about 0.1 μF. When this is used, the output capacitor must be 6.8 μF (or greater) to maintain stability. The 0.1 μF capacitor reduces the high frequency gain of the circuit to unity, lowering the output noise from 260 μV to 80 μV using a 10 Hz to 100 kHz bandwidth. Also, noise is no longer proportional to the output voltage, so improvements are more pronounced at high output voltages.

AUXILIARY COMPARATOR (LP2953 only)

The LP2953 contains an auxiliary comparator whose inverting input is connected to the 1.23V reference. The auxiliary comparator has an open-collector output whose electrical characteristics are similar to the dropout detection comparator. The non-inverting input and output are brought out for external connections.

SHUTDOWN INPUT

A logic-level signal will shut off the regulator output when a "LOW" (<1.2V) is applied to the $\overline{\text{Shutdown}}$ input.

To prevent possible mis-operation, the $\overline{\text{Shutdown}}$ input must be actively terminated. If the input is driven from open-collector logic, a pull-up resistor (20 kΩ to 100 kΩ recommended) should be connected from the $\overline{\text{Shutdown}}$ input to the regulator input.

If the $\overline{\text{Shutdown}}$ input is driven from a source that actively pulls high and low (like an op-amp), the pull-up resistor is not required, but may be used.

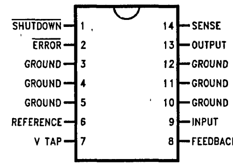
If the shutdown function is not to be used, the cost of the pull-up resistor can be saved by simply tying the $\overline{\text{Shutdown}}$ input directly to the regulator input.

IMPORTANT: Since the Absolute Maximum Ratings state that the $\overline{\text{Shutdown}}$ input can not go more than 0.3V below ground, the reverse-battery protection feature which protects the regulator input is sacrificed if the $\overline{\text{Shutdown}}$ input is tied directly to the regulator input.

If reverse-battery protection is required in an application, *the pull-up resistor between the $\overline{\text{Shutdown}}$ input and the regulator input must be used.*

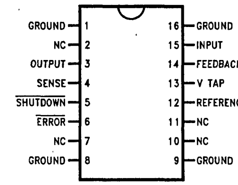
Pinout Drawings

LP2952
14-Pin DIP



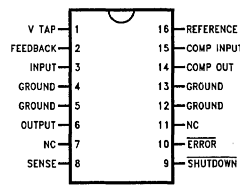
TL/H/11127–11

LP2952
16-Pin SO



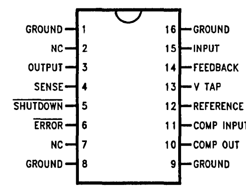
TL/H/11127–12

LP2953
16-Pin DIP



TL/H/11127–13

LP2953
16-Pin SO



TL/H/11127–14

Ordering Information

LP2952

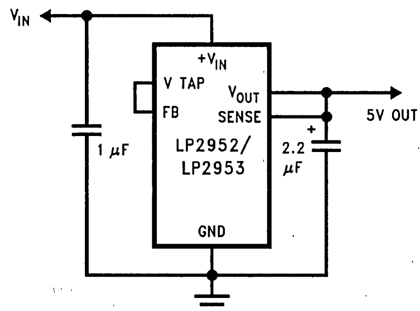
Order Number	Temp. Range (T_J) °C	Package	NSC Drawing Number
LP2952IN, LP2952AIN, LP2952IN-3.3, LP2952AIN-3.3	−40 to +125	14-Pin Molded DIP	N14A
LP2952IM, LP2952AIM, LP2952IM-3.3, LP2952AIM-3.3	−40 to +125	16-Pin Surface Mount	M16A

LP2953

Order Number	Temp. Range (T_J) °C	Package	NSC Drawing Number
LP2953IN, LP2953AIN, LP2953IN-3.3, LP2953AIN-3.3	−40 to +125	16-Pin Molded DIP	N16A
LP2953IM, LP2953AIM, LP2953IM-3.3, LP2953AIM-3.3	−40 to +125	16-Pin Surface Mount	M16A
LP2953AMJ/883	−55 to +150	16-Pin Ceramic DIP	J16A

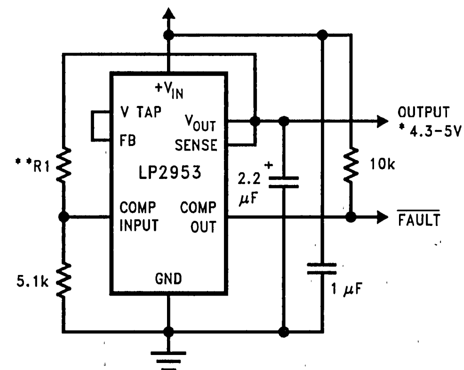
Typical Applications

Basic 5V Regulator



TL/H/11127-15

5V Current Limiter with Load Fault Indicator

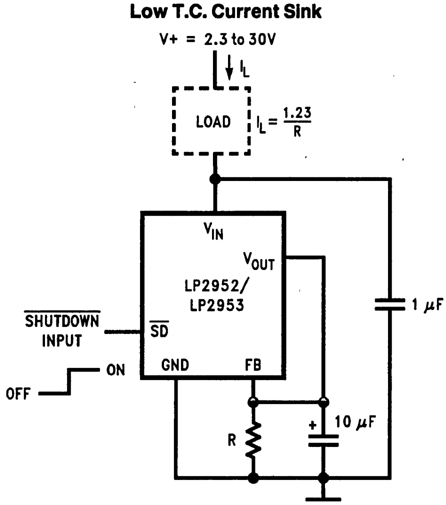


TL/H/11127-16

*Output voltage equals $+V_{IN}$ minum dropout voltage, which varies with output current. Current limits at a maximum of 380 mA (typical).

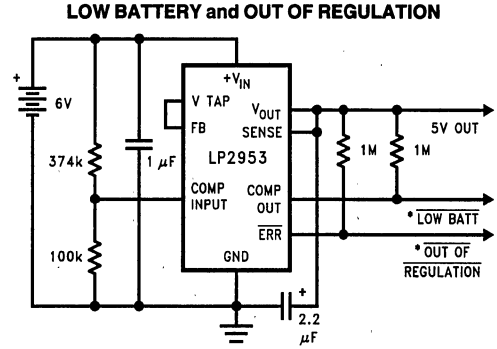
**Select R1 so that the comparator input voltage is 1.23V at the output voltage which corresponds to the desired fault current value.

Low T.C. Current Sink



TL/H/11127-17

5V Regulator with Error Flags for LOW BATTERY and OUT OF REGULATION



TL/H/11127-18

*Connect to Logic or μP control inputs.

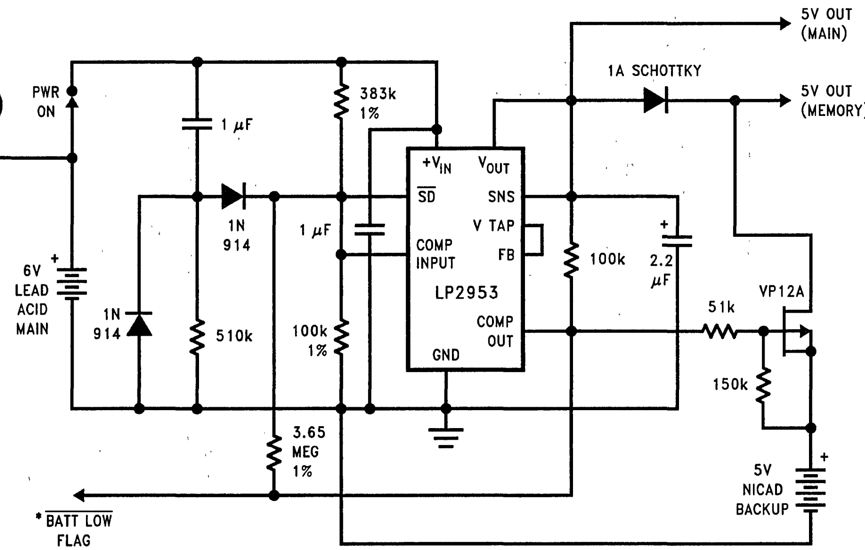
LOW BATT flag warns the user that the battery has discharged down to about 5.8V, giving the user time to recharge the battery or power down some hardware with high power requirements. The output is still in regulation at this time.

OUT OF REGULATION flag indicates when the battery is almost completely discharged, and can be used to initiate a power-down sequence.

2

Typical Applications (Continued)

5V Battery Powered Supply with Backup and Low Battery Flag



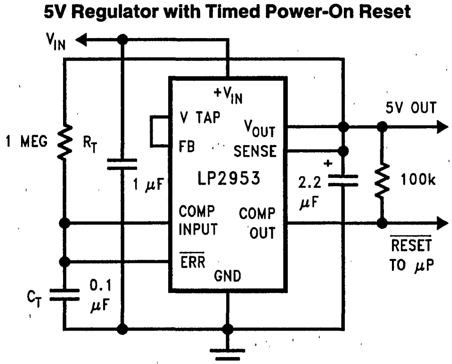
The circuit switches to the NI-CAD backup battery when the main battery voltage drops below about 5.6V, and returns to the main battery when its voltage is recharged to about 6V.

The 5V MAIN output powers circuitry which requires no backup, and the 5V MEMORY output powers critical circuitry which can not be allowed to lose power.

*The $\overline{\text{BATTERY LOW}}$ flag goes low whenever the circuit switches to the NI-CAD backup battery.

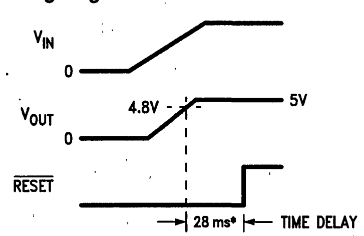
TL/H/11127-19

5V Regulator with Timed Power-On Reset



TL/H/11127-20

Timing Diagram for Timed Power-On Reset

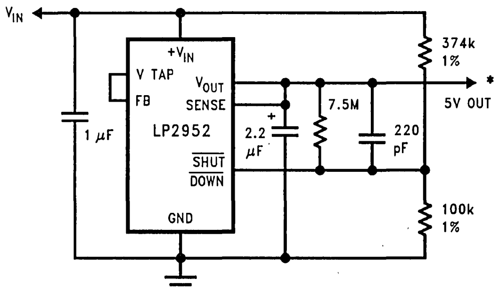


TL/H/11127-21

$^*R_T = 1$ MEG, $C_T = 0.1\ \mu F$

Typical Applications (Continued)

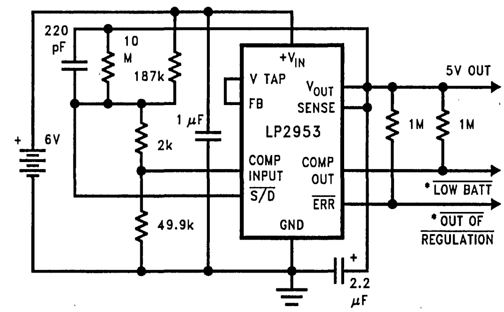
5V Regulator with Snap-On/Snap-Off Feature and Hysteresis



TL/H/11127-22

*Turns ON at V_{IN} = 5.87V
Turns OFF at V_{IN} = 5.64V
(for component values shown)

5V Regulator with Error Flags for LOW BATTERY and OUT OF REGULATION with SNAP-ON/SNAP-OFF Output



TL/H/11127-23

*Connect to Logic or µP control inputs.

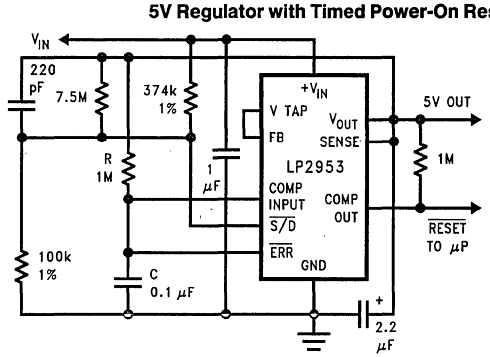
OUTPUT has SNAP-ON/SNAP-OFF feature.

LOW BATT flag warns the user that the battery has discharged down to about 5.8V, giving the user time to recharge the battery or shut down hardware with high power requirements. The output is still in regulation at this time.

OUT OF REGULATION flag goes low if the output goes below about 4.7V, which could occur from a load fault.

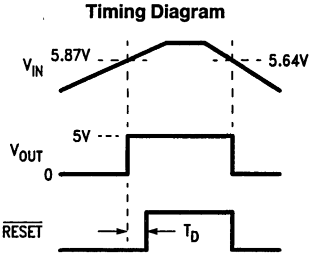
OUTPUT has SNAP-ON/SNAP-OFF feature. Regulator snaps ON at about 5.7V input, and OFF at about 5.6V.

5V Regulator with Timed Power-On Reset, Snap-On/Snap-Off Feature and Hysteresis



TL/H/11127-24

Timing Diagram



TL/H/11127-25

Td = (0.28) RC = 28 ms for components shown.

National Semiconductor

LP2954/LP2954A
5V Micropower Low-Dropout Voltage Regulators

General Description

The LP2954 is a three-terminal, 5V micropower voltage regulator with very low quiescent current (90 μA typical at 1 mA load) and very low dropout voltage (typically 60 mV at light loads and 470 mV at 250 mA load current).

The quiescent current increases only slightly at dropout (120 μA typical), which prolongs battery life.

The LP2954 is available in the three-lead TO-220 and TO-263 packages.

Reverse battery protection is provided.

The tight line and load regulation (0.04% typical), as well as very low output temperature coefficient make the LP2954 well suited for use as a low-power voltage reference.

The accuracy of the 5V output is guaranteed at both room temperature and over the entire operating temperature range.

Features

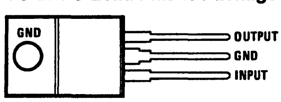
- 5V output within 1.2% over temperature (A grade)
- Guaranteed 250 mA output current
- Extremely low quiescent current
- Low dropout voltage
- Reverse battery protection
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Pin compatible with LM2940 and LM340

Applications

- High-efficiency linear regulator
- Low dropout battery-powered regulator

Package Outline and Ordering Information

TO-220 3-Lead Plastic Package

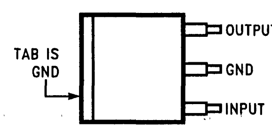


TL/H/11128-2

Front View

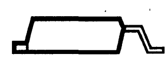
Order Number LP2954AIT or LP2954IT
See NS Package T03B

TO-263 3-Lead Plastic Surface-Mount Package



TL/H/11128-9

Top View



TL/H/11128-10

Side View

Order Number LP2954AIS or LP2954IS
See NS Package TS3B

Ordering Information

Order Number	Temp. Range (T_J) °C	Package (JEDEC)	NS Package Number
LP2954AIT	−40 to +125	TO-220	TO3B
LP2954IT			
LP2954AIS	−40 to +125	TO-263	TS3B
LP2954IS			

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Operating Junction Temperature Range	
LP2954AI/LP2954I	−40°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature	
(Soldering, 5 seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	−20V to +30V
ESD Rating	2 kV

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, **bold typeface applies over the −40°C to +125°C temperature range**. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise noted: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF.

Symbol	Parameter	Conditions	Typical	2954AI		2954I		Units
				Min	Max	Min	Max	
V_O	Output Voltage		5.0	4.975 **4.940**	5.025 **5.060**	4.950 **4.900**	5.050 **5.100**	V
		1 mA ≤ I_L ≤ 250 mA	5.0	**4.930**	**5.070**	**4.880**	**5.120**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temp. Coefficient	(Note 3)	**20**		**100**		**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	V_{IN} = 6V to 30V	0.03		0.10 **0.20**		0.20 **0.40**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 1 to 250 mA I_L = 0.1 to 1 mA (Note 4)	0.04		0.16 **0.20**		0.20 **0.30**	%
$V_{IN}-V_O$	Dropout Voltage (Note 5)	I_L = 1 mA	60		100 **150**		100 **150**	mV
		I_L = 50 mA	240		300 **420**		300 **420**	
		I_L = 100 mA	310		400 **520**		400 **520**	
		I_L = 250 mA	470		600 **800**		600 **800**	
I_{GND}	Ground Pin Current (Note 6)	I_L = 1 mA	90		150 **180**		150 **180**	μA
		I_L = 50 mA	1.1		2 **2.5**		2 **2.5**	mA
		I_L = 100 mA	4.5		6 **8**		6 **8**	
		I_L = 250 mA	21		28 **33**		28 **33**	
I_{GND}	Ground Pin Current at Dropout (Note 6)	V_{IN} = 4.5V	120		170 **210**		170 **210**	μA
I_{LIMIT}	Current Limit	V_{OUT} = 0V	380		500 **530**		500 **530**	mA
$\frac{\Delta V_O}{\Delta Pd}$	Thermal Regulation	(Note 7)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 kHz) I_L = 100 mA	C_L = 2.2 μF	400					μV RMS
		C_L = 33 μF	260					

Electrical Characteristics (Continued)

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, T_J (MAX), the junction-to-ambient thermal resistance, $\theta_{J\text{-}A}$, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P(MAX) = \frac{T_J(MAX) - T_A}{\theta_{J\text{-}A}}$.

Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction-to-ambient thermal resistance of the TO-220 (without heatsink) is 60°C/W and 73°C/W for the TO-263. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W. The junction-to-case thermal resistance is 3°C/W. If an external heatsink is used, the effective junction-to-ambient thermal resistance is the **sum** of the junction-to-case resistance (3°C/W), the specified thermal resistance of the heatsink selected, and the thermal resistance of the interface between the heatsink and the LP2954. Some typical values are listed for interface materials used with TO-220:

Typical Values of Case-to-Heatsink Thermal Resistance (°C/W)

TABLE I. (Data from AAVID Eng.)

Silicone grease	1.0
Dry interface	1.3
Mica with grease	1.4

TABLE II. (Data from Thermalloy)

Thermasil III	1.3
Thermasil II	1.5
Thermalfilm (0.002) with grease	2.2

Note 3: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 4: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested separately for load regulation in the load ranges 0.1 mA–1 mA and 1 mA–250 mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 5: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential.

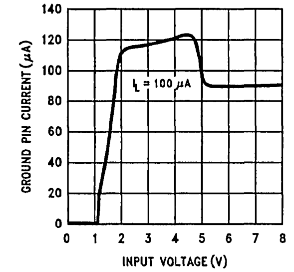
Note 6: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for 200 mA load pulse at V_{IN} = 20V (3W pulse) for T = 10 ms.

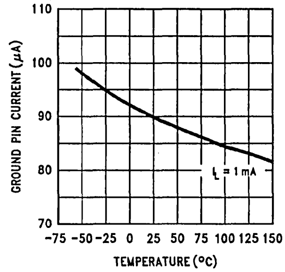
Note 8: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

Typical Performance Characteristics

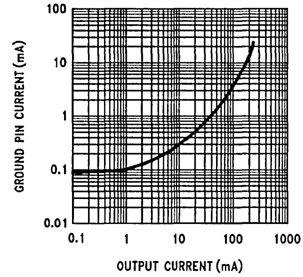
Quiescent Current



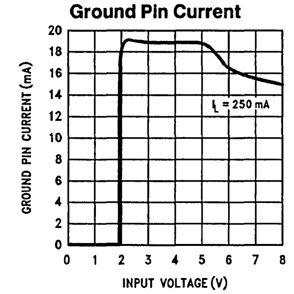
Quiescent Current



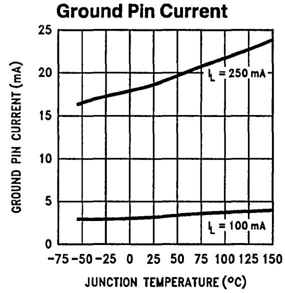
Ground Pin Current vs Load



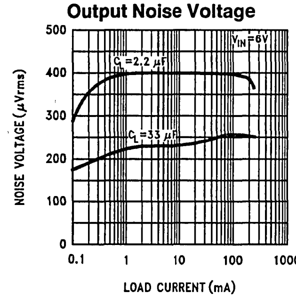
Ground Pin Current



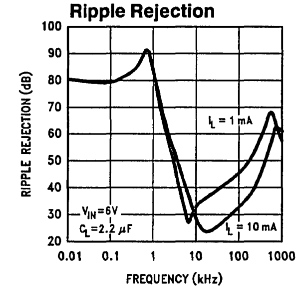
Ground Pin Current



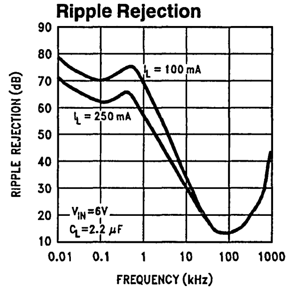
Output Noise Voltage



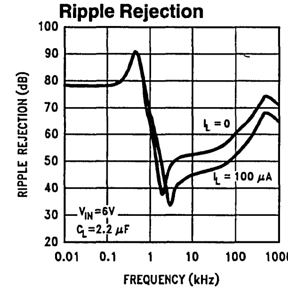
Ripple Rejection



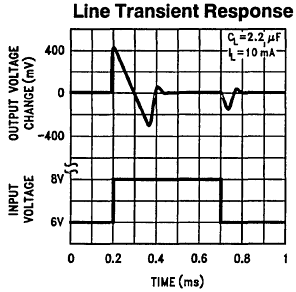
Ripple Rejection



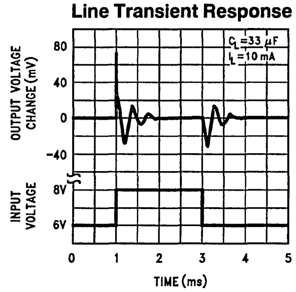
Ripple Rejection



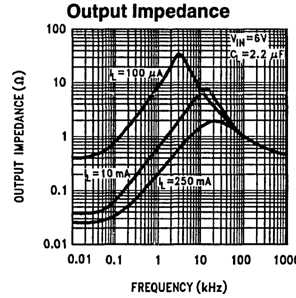
Line Transient Response



Line Transient Response



Output Impedance



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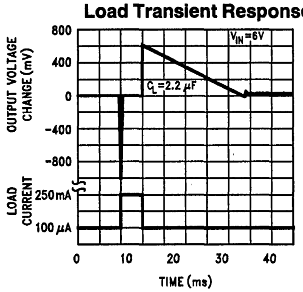
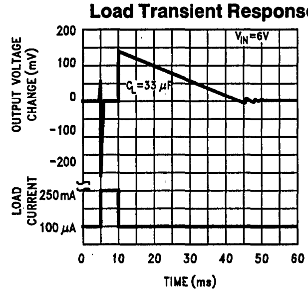
2

Typical Performance Characteristics (Continued)

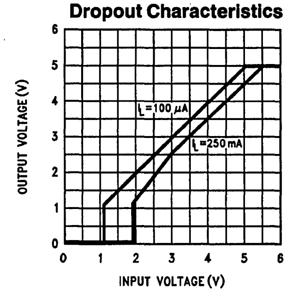
Load Transient Response



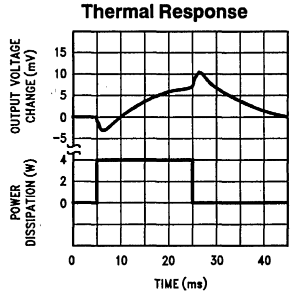
Load Transient Response



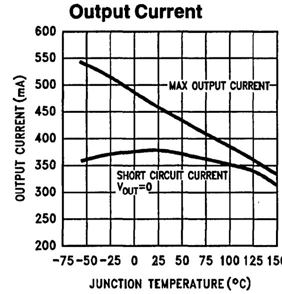
Dropout Characteristics



Thermal Response



Short-Circuit Output Current and Maximum Output Current



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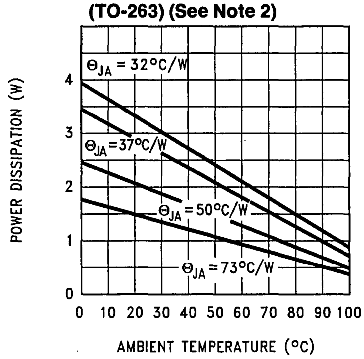
Maximum Power Dissipation (TO-263) (See Note 2)



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Application Hints

EXTERNAL CAPACITORS

A 2.2 μF (or greater) capacitor is **required** between the output pin and the ground to assure stability (refer to *Figure 1*). Without this capacitor, the part may oscillate. Most types of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at −30°C, which requires the use of solid tantalums below −25°C. The important parameters of the capacitor are an ESR of about 5Ω or less and a resonant frequency above 500 kHz (the ESR may increase by a factor of **20** or **30** as the temperature is reduced from 25°C to −30°C). The value of this capacitor may be increased without limit. At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.68 μF for currents below 10 mA or 0.22 μF for currents below 1 mA.

A 1 μF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used.

MINIMUM LOAD

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so this value must be used to obtain correlation on these tested limits. The part is parametrically tested down to 100 μA, but is functional with no load.

DROPOUT VOLTAGE

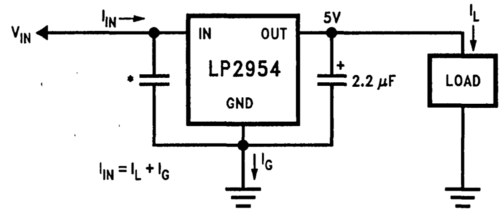
The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltages for various values of load current are listed under Electrical Characteristics.

If the regulator is powered from a rectified AC source with a capacitive filter, the minimum AC line voltage and maximum load current must be used to calculate the minimum voltage at the input of the regulator. The minimum input voltage, **including AC ripple on the filter capacitor,** must not drop below the voltage required to keep the LP2954 in regulation. It is also advisable to verify operating at **minimum** operating ambient temperature, since the increasing ESR of the filter capacitor makes this a worst-case test for dropout voltage due to increased ripple amplitude.

HEATSINK REQUIREMENTS

A heatsink may be required with the LP2954 depending on the maximum power dissipation and maximum ambient temperature of the application. Under all possible operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the maximum power dissipated by the regulator, P(max), must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator). *Figure 1* shows the voltages and currents which are present in



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*See External Capacitors

$P_{Total} = (V_{IN} - 5)\, I_L + (V_{IN})\, I_G$

FIGURE 1. Basic 5V Regulator Circuit

the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1*.

The next parameter which must be calculated is the maximum allowable temperature rise, $T_R(max)$. This is calculated by using the formula:

$$T_R(max) = T_J(max) - T_A(max)$$

where: $T_J(max)$ is the maximum allowable junction temperature

$T_A(max)$ is the maximum ambient temperature

Using the calculated values for $T_R(max)$ and P(max), the required value for junction-to-ambient thermal resistance, $\theta_{(J\text{-}A)}$, can now be found:

$$\theta_{(J\text{-}A)} = T_R(max)/P(max)$$

If the calculated value is 60° C/W **or higher,** the regulator may be operated without an external heatsink. If the calculated value is **below** 60° C/W, an external heatsink is required. The required thermal resistance for this heatsink can be calculated using the formula:

$$\theta_{(H\text{-}A)} = \theta_{(J\text{-}A)} - \theta_{(J\text{-}C)} - \theta_{(C\text{-}H)}$$

where:

$\theta_{(J\text{-}C)}$ is the junction-to-case thermal resistance, which is specified as 3° C/W maximum for the LP2954.

$\theta_{(C\text{-}H)}$ is the case-to-heatsink thermal resistance, which is dependent on the interfacing material (if used). For details and typical values, refer to Note 2 listed at the end of the ELECTRICAL CHARACTERISTICS section.

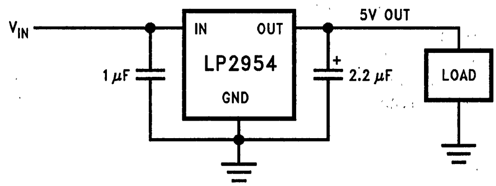
$\theta_{(H\text{-}A)}$ is the heatsink-to-ambient thermal resistance. It is this specification (listed on the heatsink manufacturers data sheet) which defines the effectiveness of the heatsink. The heatsink selected must have a thermal resistance which is **equal to or lower** than the value of $\theta_{(H\text{-}A)}$ calculated from the above listed formula.

OUTPUT ISOLATION

The regulator output can be left connected to an active voltage source (such as a battery) with the regulator input power turned off, **as long as the regulator ground pin is connected to ground.** If the ground pin is left floating, **damage to the regulator can occur** if the output is pulled up by an external voltage source.

Typical Applications

Typical Application Circuit



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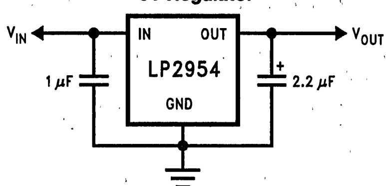
5V Regulator



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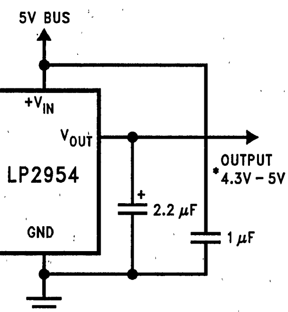
5V Current Limiter



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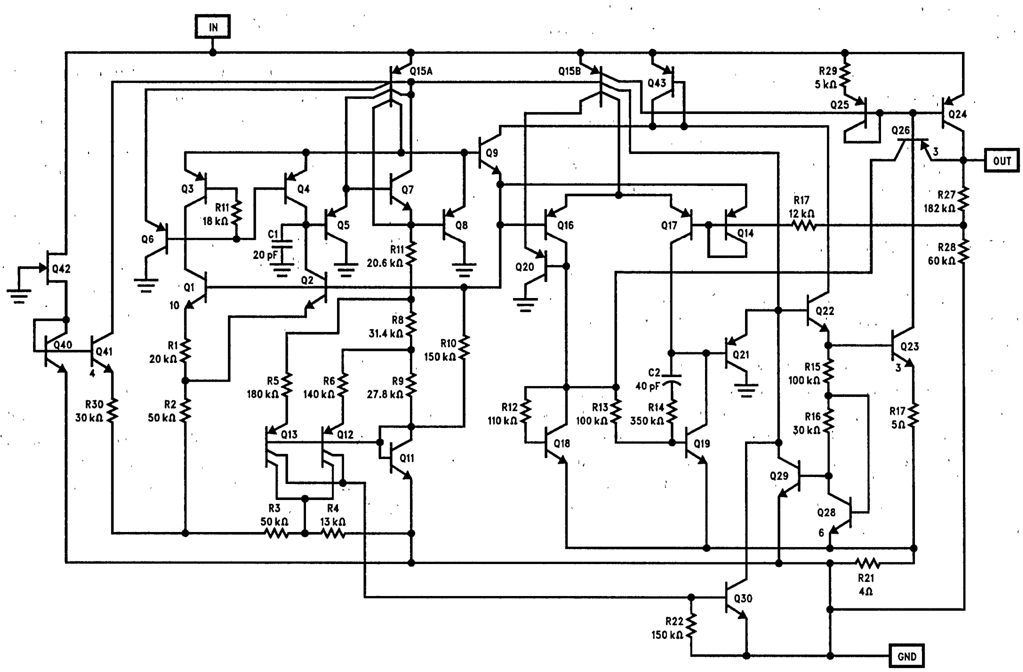
*Output voltage equals $+V_{IN}$ minus dropout voltage, which varies with output current. Current limits at 380 mA (typical).

Schematic Diagram



TL/H/11128–8

National Semiconductor

LP2956/LP2956A
Dual Micropower Low-Dropout Voltage Regulators

General Description

The LP2956 is a micropower voltage regulator with very low quiescent current (170 μA typical at light loads) and very low dropout voltage (typically 60 mV at 1 mA load current and 470 mV at 250 mA load current on the main output).

The LP2956 retains all the desirable characteristics of the LP2951, but offers increased output current (main output), an auxiliary LDO adjustable regulated output (75 mA), and additional features.

The auxiliary output is always on (regardless of main output status), so it can be used to power memory circuits.

Quiescent current increases only slightly at dropout, which prolongs battery life.

The error flag goes low if the main output voltage drops out of regulation.

An open-collector auxiliary comparator is included, whose inverting input is tied to the 1.23V reference.

Reverse battery protection is provided.

The parts are available in plastic DIP and surface mount packages.

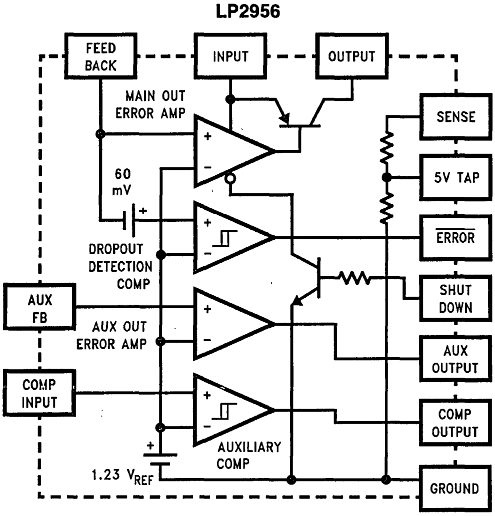
Features

- Output voltage adjusts from 1.23V to 29V
- Guaranteed 250 mA current (main output)
- Auxiliary LDO (75 mA) adjustable output
- Auxiliary comparator with open-collector output
- Shutdown pin for main output
- Extremely low quiescent current
- Low dropout voltage
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Reverse battery protection

Applications

- High-efficiency linear regulator
- Low dropout battery-powered regulator
- μP system regulator with switchable high-current V_{CC}

Block Diagram



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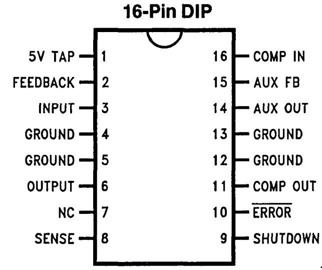
Connection Diagrams

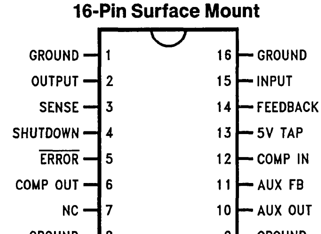
16-Pin DIP



TL/H/11339-2

Order Number LP2956IN or LP2956AIN
See NS Package Number N16A

16-Pin Surface Mount



TL/H/11339-3

Order Number LP2956IM or LP2956AIM
See NS Package Number M16A

2

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	−65°C to +150°C
Operating Junction Temperature Range	−40°C to +125°C
Lead Temperature (Soldering, 5 seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	−20V to +30V
Feedback Input Voltage (Note 3)	−0.3V to +5V
Aux. Feedback Input Voltage (Note 3)	−0.3V to +5V
Shutdown Input Voltage (Note 3)	−0.3V to +30V
Comparator Input Voltage (Notes 3, 4)	−0.3V to +30V
Comparator Output Voltage (Notes 3, 4)	−0.3V to +30V
ESD Rating (Note 16)	2 kV

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 µF (Main Output) and 10 µF (Auxiliary Output), Feedback pin is tied to 5V Tap pin, C_{IN} = 1 µF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary regulator output has a 100 µA load.

Symbol	Parameter	Conditions	Typical	LP2956AI		LP2956I		Units
				Min	Max	Min	Max	
MAIN OUTPUT								
V_O	Output Voltage		5.0	4.975 **4.940**	5.025 **5.060**	4.950 **4.900**	5.050 **5.100**	V
		1 mA ≤ I_L ≤ 250 mA	5.0	**4.930**	**5.070**	**4.880**	**5.120**	V
$\frac{\Delta V_O}{\Delta T}$	Temperature Coefficient	(Note 5)	**20**		**100**		**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	V_{IN} = 6V to 30V	0.03		0.1 **0.2**		0.2 **0.4**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 1 mA to 250 mA I_L = 0.1 mA to 1 mA (Note 6)	0.04		0.16 **0.20**		0.20 **0.30**	%
$V_{IN}-V_O$	Dropout Voltage (Note 7)	I_L = 1 mA	60		100 **150**		100 **150**	mV
		I_L = 50 mA	240		300 **420**		300 **420**	mV
		I_L = 100 mA	310		400 **520**		400 **520**	mV
		I_L = 250 mA	470		600 **800**		600 **800**	mV
I_{LIMIT}	Current Limit	R_L = 1Ω	380		500 **530**		500 **530**	mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 8)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 KHz) I_L = 100 mA	C_L = 2.2 µF	400					µV RMS
		C_L = 33 µF	260					µV RMS
		C_L = 33 µF (Note 9)	80					µV RMS

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 µF (Main Output) and 10 µF (Auxiliary Output), Feedback pin is tied to 5V Tap pin, C_{IN} = 1 µF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary regulator output has a 100 µA load. (Continued)

Symbol	Parameter	Conditions	Typical	LP2956AI		LP2956I		Units
				Min	Max	Min	Max	
MAIN OUTPUT (Continued)								
V_{FB}	Feedback Pin Voltage		1.23	1.215	1.245	1.205	1.255	V
I_{FB}	Feedback Pin Bias Current		20		40 **60**		40 **60**	nA
I_O (OFF)	Output Leakage In Shutdown	$I_{(SD\ IN)} \geq 1$ µA V_{IN} = 30V, V_{OUT} = 0V	3		10 **20**		10 **20**	µA
AUXILIARY OUTPUT								
V_{FB}	Feedback Pin Voltage		1.23	1.22 **1.21**	1.25 **1.26**	1.21 **1.20**	1.26 **1.27**	V
$\frac{\Delta V_{FB}}{\Delta T}$	Feedback Voltage Temperature Coefficient		**20**					ppm/°C
I_{FB}	Feedback Pin Bias Current		10		20 **30**		20 **30**	nA
$\frac{\Delta V_O}{V_O}$	Line Regulation	6V ≤ V_{IN} ≤ 30V	0.07		0.3 **0.5**		0.4 **0.6**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 0.1 mA to 1 mA I_L = 1 mA to 75 mA (Note 10)	0.1		0.3 **0.6**		0.4 **1.0**	%
$V_{IN}-V_O$	Dropout Voltage	I_L = 1 mA	100		200 **300**		200 **300**	mV
		I_L = 50 mA	400		600 **700**		600 **700**	mV
		I_L = 75 mA	500		700 **850**		700 **850**	mV
e_n	Output Noise (10 Hz–100 KHz) I_L = 10 mA	C_L = 10 µF	300					µV RMS
		C_L = 33 µF (Note 9)	100					
I_{LIM}	Current Limit	V_{OUT} = 0V (Note 13)	80		200 **250**		200 **250**	mA
$\frac{\Delta V_O}{\Delta P_D}$	Thermal Regulation	(Note 8)	0.2		0.5		0.5	%/W
DROPOUT DETECTION COMPARATOR								
I_{OH}	Output "HIGH" Leakage	V_{OH} = 30V	0.01		1 **2**		1 **2**	µA
V_{OL}	Output "LOW" Voltage	V_{IN} = 4V I_O (COMP) = 400 µA	150		250 **400**		250 **400**	mV
V_{THR} (max)	Upper Threshold Voltage	(Note 11)	−240	−320 **−380**	−150 **−100**	−320 **−380**	−150 **−100**	mV

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 μF (Main Output) and 10 μF (Auxiliary Output), Feedback pin is tied to 5V Tap pin, C_{IN} = 1 μF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary regulator output has a 100 μA load. (Continued)

Symbol	Parameter	Conditions	Typical	LP2956AI		LP2956I		Units
				Min	Max	Min	Max	
DROPOUT DETECTION COMPARATOR (Continued)								
V_{THR} (min)	Lower Threshold Voltage	(Note 11)	−350	−450 **−640**	−230 **−160**	−450 **−640**	−230 **−160**	mV
HYST	Hysteresis	(Note 11)	110					mV
SHUTDOWN INPUT								
I_{IN}	Input Current to Disable Output	(Note 12)	0.03		**0.5**		**0.5**	μA
V_{IH}	Shutdown Input High Threshold	$I_{(SD\ IN)} \geq 1\ \mu A$		900 **1200**		900 **1200**		mV
V_{IL}	Shutdown Input Low Threshold	$V_O \geq 4.5V$			400 **200**		400 **200**	mV
AUXILIARY COMPARATOR								
V_T(high)	Upper Trip Point	(Note 14)	1.236	1.20 **1.19**	1.28 **1.29**	1.20 **1.19**	1.28 **1.29**	V
V_T(low)	Lower Trip Point	(Note 14)	1.230	1.19 **1.18**	1.27 **1.28**	1.19 **1.18**	1.27 **1.28**	V
HYST	Hysteresis		6					mV
I_{OH}	Output "HIGH" Leakage	V_{OH} = 30V V_{IN} (COMP) = 1.3V	0.01		1 **2**		1 **2**	μA
V_{OL}	Output "LOW" Voltage	V_{IN} (COMP) = 1.1V I_O(COMP) = 400 μA	150		250 **400**		250 **400**	mV
I_B	Input Bias Current	$0 \leq V_{IN}$ (COMP) $\leq 5V$	10	−30 **−50**	30 **50**	−30 **−50**	30 **50**	nA
GROUND PIN CURRENT								
I_{GND}	Ground Pin Current (Note 15)	I_L (Main Out) = 1 mA I_L (Aux. Out) = 0.1 mA	170		250 **280**		250 **280**	μA
		I_L (Main Out) = 50 mA I_L (Aux. Out) = 1 mA	1.1		2 **2.5**		2 **2.5**	mA
		I_L (Main Out) = 100 mA I_L (Aux. Out) = 1 mA	3		6 **8**		6 **8**	mA
		I_L (Main Out) = 250 mA I_L (Aux. Out) = 1 mA	16		28 **33**		28 **33**	mA
		I_L (Main Out) = 1 mA I_L (Aux. Out) = 50 mA	3		6 **8**		6 **8**	mA
		I_L (Main Out) = 1 mA I_L (Aux. Out) = 75 mA	6		8 **10**		8 **10**	mA

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Limits are guaranteed by production testing or correlation techniques using standard Statistical Quality Control (SQC) methods. Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 µF (Main Output) and 10 µF (Auxiliary Output), Feedback pin is tied to 5V Tap pin, C_{IN} = 1 µF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary regulator output has a 100 µA load. (Continued)

Symbol	Parameter	Conditions	Typical	LP2956AI		LP2956I		Units
				Min	Max	Min	Max	
GROUND PIN CURRENT (Continued)								
I_{GND}	Ground Pin Current at Dropout (Note 15)	V_{IN} = 4.5V I_L (Main Out) = 0.1 mA I_L (Aux. Out) = 0.1 mA	270		325 **350**		325 **350**	µA
I_{GND}	Ground Pin Current at Shutdown (Note 15)	No Load on Either Output $I_{(SD\ IN)} \geq 1$ µA	120		180 **200**		180 **200**	µA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, T_J(max), the junction-to-ambient thermal resistance, θ_{J-A}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using: $P(max) = \frac{T_J(max) - T_A}{\theta_{J-A}}$.

Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown. See Application Hints for additional information on heat sinking and thermal resistance.

Note 3: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

Note 4: May exceed the input supply voltage.

Note 5: Output or reference voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 6: Load regulation is measured at constant junction temperature using low duty cycle pulse testing. Two separate tests are performed, one for the range of 100 µA to 1 mA and one for the 1 mA to 250 mA range. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 7: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential. At very low values of programmed output voltage, the input voltage minimum of 2V **(2.3V over temperature)** must be observed.

Note 8: Thermal regulation is the change in output voltage at a time T after a change in power dissipation, excluding load or line regulation effects. Specifications are for a 200 mA load pulse at V_{IN} = 20V (3W pulse) for T = 10 ms on the Main regulator output. For the Auxiliary regulator output, specifications are for a 66 mA load pulse at V_{IN} = 20V (1W pulse) for T = 10 ms.

Note 9: Connect a 0.1 µF capacitor from the output to the feedback pin.

Note 10: Load regulation is measured at constant junction temperature using low duty cycle pulse testing. Two separate tests are performed, one for the range of 100 µA to 1 mA and one for the 1 mA to 75 mA range. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 11: Dropout dectection comparator thresholds are expressed as changes in a 5V output. To express the threshold voltages in terms of a differential at the Feedback terminal, divide by the error amplifier gain = V_{OUT}/V_{REF}.

Note 12: The shutdown input equivalent circuit is the base of a grounded-emitter NPN transistor in series with a current-limiting resistor. Pulling the shutdown input high turns off the main regulator. For more details, see Application Hints.

Note 13: The auxiliary regulator output has foldback limiting, which means the output current reduces with output voltage. The tested limit is for V_{OUT} = 0V, so the output current will be higher at higher output voltages.

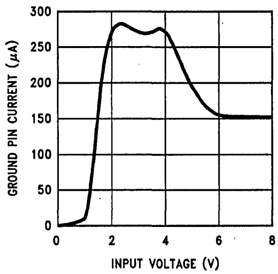
Note 14: This test is performed with the auxiliary comparator output sinking 400 µA of current. At the upper trip point, the comparator output must be ≥2.4V. At the low trip point, the comparator output must be ≤ 0.4V.

Note 15: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the ground pin current, output load current, and current through the external resistive dividers (if used).

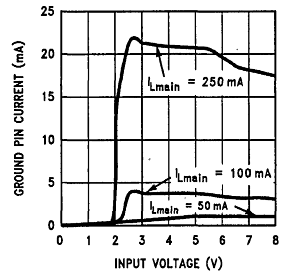
Note 16: All pins are rated for 2 kV, except for the auxiliary feedback pin which is rated for 1.2 kV (human body model, 100 pF discharged through 1.5 kΩ).

Typical Performance Characteristics Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 μF (Main Output) and 10 μF (Auxiliary Output), Feedback is tied to 5V Tap pin, C_{IN} = 1 μF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary output has a 100 μA load.

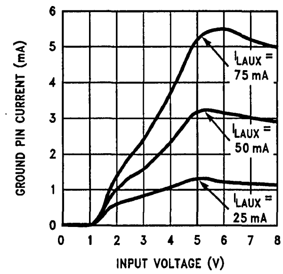
Ground Pin Current



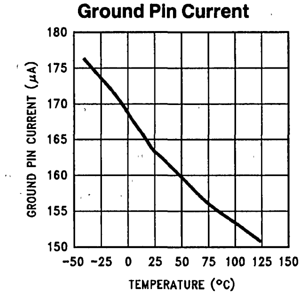
Ground Pin Current



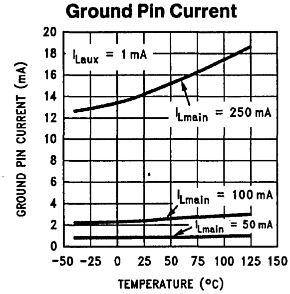
Ground Pin Current



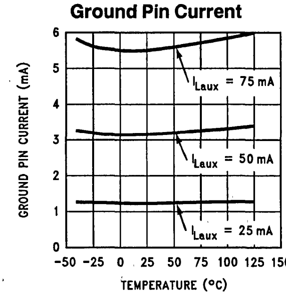
Ground Pin Current



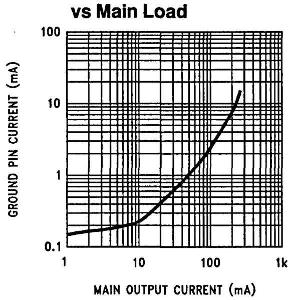
Ground Pin Current



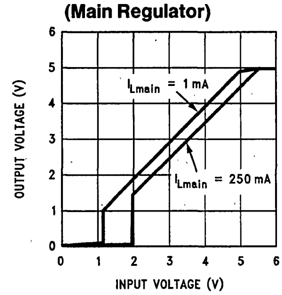
Ground Pin Current



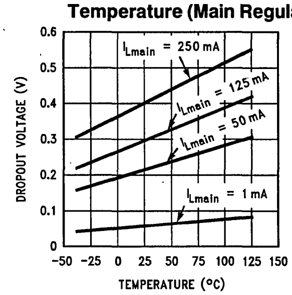
Ground Pin Current vs Main Load



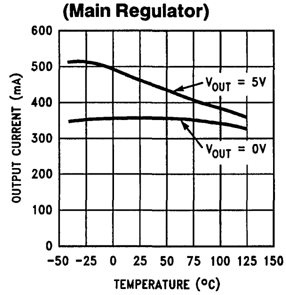
Dropout Characteristics (Main Regulator)



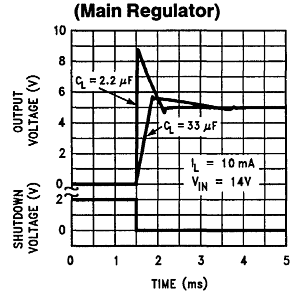
Dropout Voltage vs Temperature (Main Regulator)



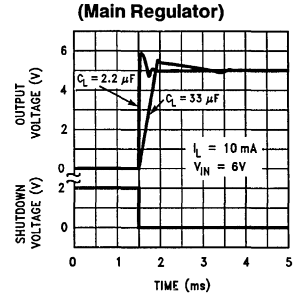
Current Limit vs Regulator (Main Regulator)



Enable Transient (Main Regulator)



Enable Transient (Main Regulator)



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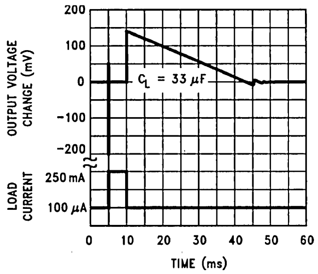
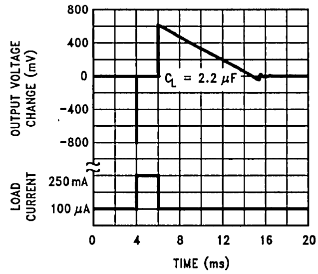
Typical Performance Characteristics Unless otherwise specified: V_{IN} = 6V, C_L = 2.2 μF (Main Output) and 10 μF (Auxiliary Output), Feedback is tied to 5V Tap pin, C_{IN} = 1 μF, V_{SD} = 0V, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary output has a 100 μA load. (Continued)

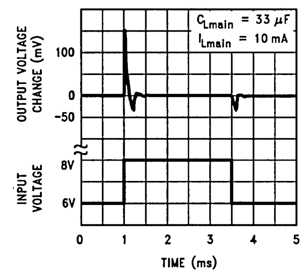
Load Transient Response (Main Regulator)



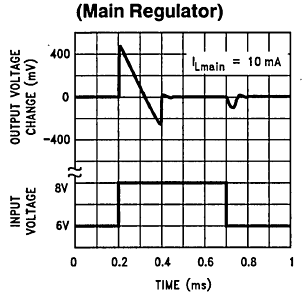
Load Transient Response (Main Regulator)



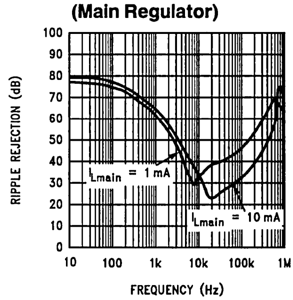
Line Transient Response (Main Regulator)



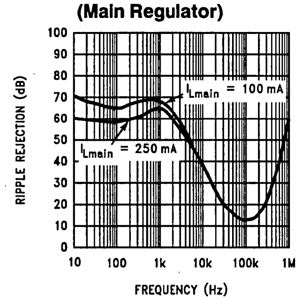
Line Transient Response (Main Regulator)



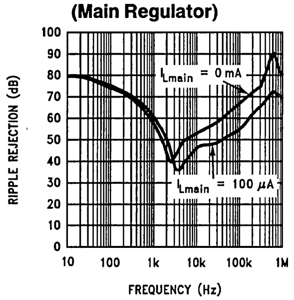
Ripple Rejection (Main Regulator)



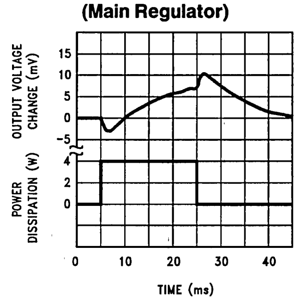
Ripple Rejection (Main Regulator)



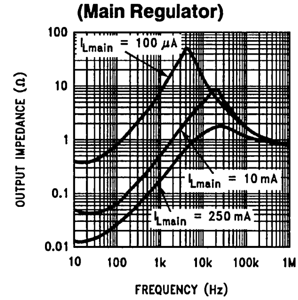
Ripple Rejection (Main Regulator)



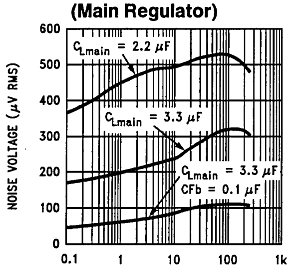
Thermal Regulation (Main Regulator)



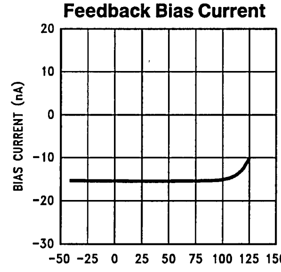
Output Impedance (Main Regulator)



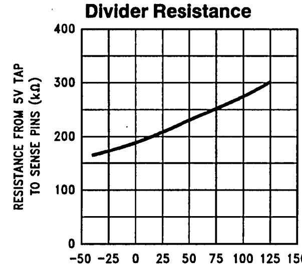
Output Noise Voltage (Main Regulator)



Feedback Bias Current



Divider Resistance



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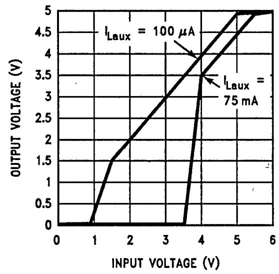
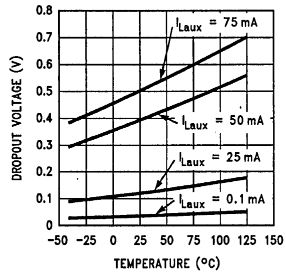
2

Typical Performance Characteristics Unless otherwise specified: $V_{IN} = 6V$, $C_L = 2.2\ \mu F$ (Main Output) and 10 μF (Auxiliary Output), Feedback is tied to 5V Tap pin, $C_{IN} = 1\ \mu F$, $V_{SD} = 0V$, Main Output pin is tied to Output Sense pin, Auxiliary Output is programmed for 5V. The main regulator output has a 1 mA load, the auxiliary output has a 100 μA load. (Continued)

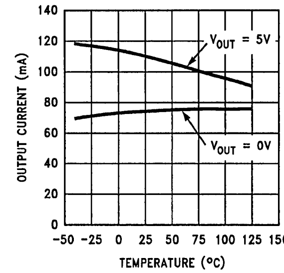
Dropout Characteristics (Auxiliary Regulator)



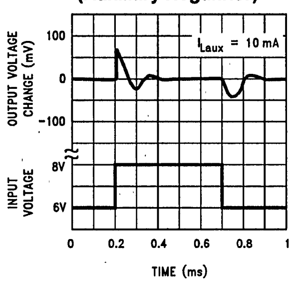
Dropout vs Temperature (Auxiliary Regulator)



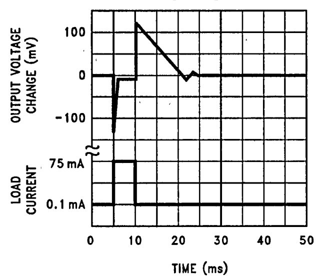
Current Limit vs Temperature (Auxiliary Regulator)



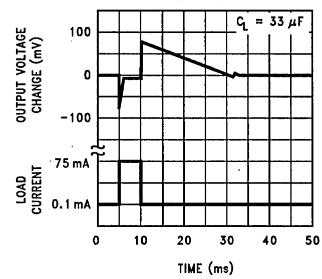
Line Transient Response (Auxiliary Regulator)



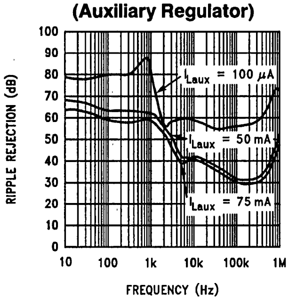
Load Transient Response (Auxiliary Regulator)



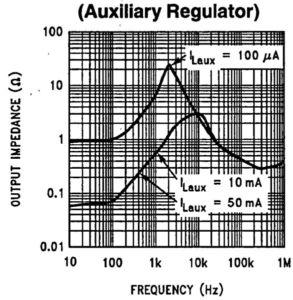
Load Transient Response (Auxiliary Regulator)



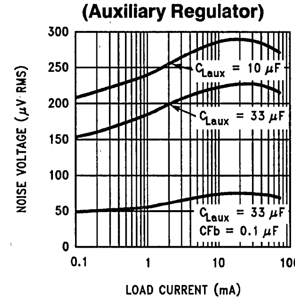
Ripple Rejection (Auxiliary Regulator)



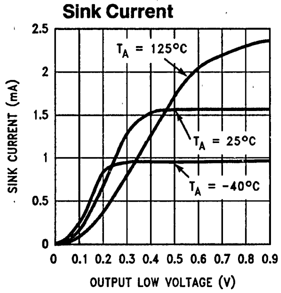
Output Impedance (Auxiliary Regulator)



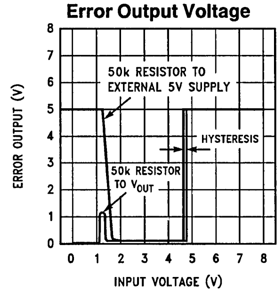
Output Noise Voltage (Auxiliary Regulator)



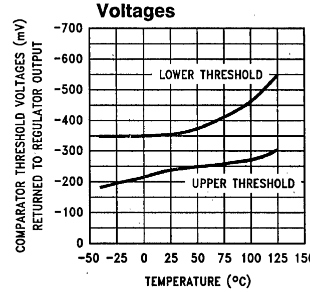
Auxiliary Comparator Sink Current



Error Output Voltage



Dropout Detection Comparator Threshold Voltages



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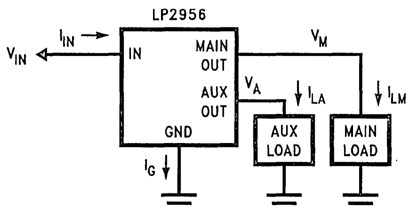
Application Hints

HEATSINK REQUIREMENTS

A heatsink may be required with the LP2956 depending on the maximum power dissipation and maximum ambient temperature of the application. Under all expected operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the maximum power dissipated by the regulator, P(max), must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator). *Figure 1* shows the voltages and currents which are present in the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1* (the currents and power due to external resistive dividers are not included, and are typically negligible).



$$P_{TOTAL} = (V_{IN} - V_M) I_{LM} + (V_{IN} - V_A) I_{LA} + (V_{IN}) I_G$$

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FIGURE 1. Current/Voltage Diagram

The next parameter which must be calculated is the maximum allowable temperature rise, T_R(max). This is calculated by using the formula:

$$T_R(\text{max}) = T_J(\text{max}) - T_A(\text{max})$$

where: T_J(max) is the maximum allowable junction temperature

T_A(max) is the maximum ambient temperature

Using the calculated values for T_R(max) and P(max), the required value for junction-to-ambient thermal resistance, $\theta_{(J\text{-}A)}$, can now be found:

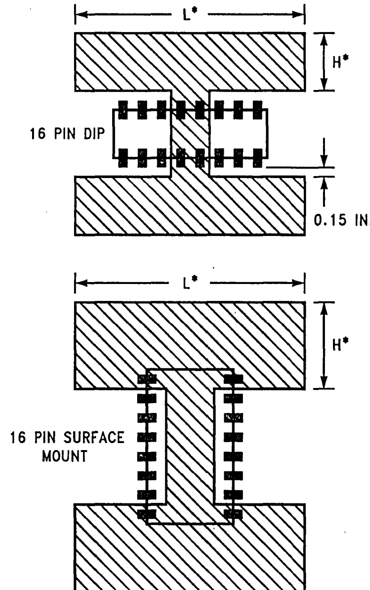
$$\theta_{(J\text{-}A)} = T_R(\text{max})/P(\text{max})$$

The heatsink for the LP2956 is made using the PC board copper. The heat is conducted from the die, through the lead frame (inside the part), and out the pins which are soldered to the PC board. The pins used for heat conduction are shown in Table I.

TABLE I

Part	Package	Pins
LP2956IN	16-Pin DIP	4, 5, 12, 13
LP2956AIN	16-Pin DIP	4, 5, 12, 13
LP2956IM	16-Pin Surface Mt.	1, 8, 9, 16
LP2956AIM	16-Pin Surface Mt.	1, 8, 9, 16

Figure 2 shows copper patterns which may be used to dissipate heat from the LP2956:



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*For best results, use L = 2H

FIGURE 2. Copper Heatsink Patterns

Table II shows some typical values of junction-to-ambient thermal resistance ($\theta_{J\text{-}A}$) for values of L and W (1 oz. copper).

TABLE II

Package	L (In.)	H (In.)	$\theta_{J\text{-}A}$ (°C/W)
16-Pin DIP	1	0.5	70
	2	1	60
	3	1.5	58
	4	0.19	66
	6	0.19	66
16-Pin Surface Mount	1	0.5	83
	2	1	70
	3	1.5	67
	6	0.19	69
	4	0.19	71
	2	0.19	73

Application Hints (Continued)

EXTERNAL CAPACITORS

A 2.2 µF (or greater) capacitor is required between the main output pin and ground to assure stability. The auxiliary output requires 10 µF to ground. Without these capacitors, the part may oscillate. Most types of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at −30°C, which requires the use of solid tantalums below −25°C. The important characteristic of the capacitors is an ESR of 5Ω (or less) on the main regulator output and an ESR of 1Ω (or less) on the auxiliary regulator output (the ESR may increase by a factor of **20** or **30** as the temperature is reduced from +25°C to −30°C). The value of these capacitors may be increased without limit.

The main output requires less capacitance at lighter load currents. This capacitor can be reduced to 0.68 µF for currents below 10 mA or 0.22 µF for currents below 1 mA.

Programming the main output for voltages below 5V requires *more* output capacitance for stability. For the worst-case condition of 1.23V output and 250 mA of load current, a 6.8 µF (or larger) capacitor should be used.

A 1 µF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used.

Stray capacitance to the Feedback terminal can cause instability. This problem is most likely to appear when using high value external resistors to set the output voltage. Adding a 100 pF capacitor between the Output and Feedback pins and increasing the output capacitance to 6.8 µF (or greater) will cure the problem.

MINIMUM LOAD ON MAIN OUTPUT

When setting the main output voltage using an external resistive divider, a minimum current of 10 µA is recommended through the resistors to provide a minimum load.

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so the specified value must be used to obtain test limit correlation.

PROGRAMMING THE MAIN OUTPUT VOLTAGE

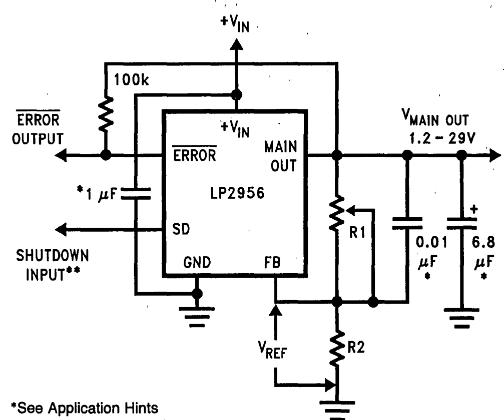
The main output may be pin-strapped for 5V operation using its internal resistive divider by tying the Output and Sense pins together and also tying the Feedback and 5V Tap pins together.

Alternatively, it may be programmed for any voltage between the 1.23V reference and the 29V maximum rating using an external pair of resistors (see *Figure 3*). The complete equation for the output voltage is:

$$V_{MAIN\ OUT} = V_{REF} \times \left(1 + \frac{R1}{R2}\right) + (I_{FB} \times R1)$$

where V_{REF} is the 1.23V reference and I_{FB} is the Feedback pin bias current (−20 nA typical). The minimum recommended load current of 1 µA sets an upper limit of 1.2 MΩ on the value of R2 in cases where the regulator must work with no load (see **MINIMUM LOAD**).

If I_{FB} is ignored in the calculation of the output voltage, it will produce a small error in $V_{MAIN\ OUT}$. Choosing R2 = 100 kΩ will reduce this error to 0.16% (typical) while increasing the resistor program current to 12 µA. Since the typical quiescent current is 130 µA, this added current is negligible.



*See Application Hints

**Drive with high to shut down

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FIGURE 3. Adjustable Regulator

DROPOUT VOLTAGE

The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltage is independent of the programmed output voltage.

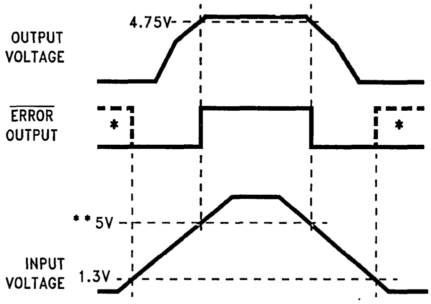
DROPOUT DETECTION COMPARATOR

This comparator produces a logic "LOW" whenever the main output falls out of regulation by more than about 5%. This figure results from the comparator's built-in offset of 60 mV divided by the 1.23V reference (refer to block diagram). The 5% low trip level remains constant regardless of the programmed output voltage. An out-of-regulation condition can result from low input voltage, current limiting, or thermal limiting.

Figure 4 gives a timing diagram showing the relationship between the main output voltage, the $\overline{\text{ERROR}}$ output, and input voltage as the input voltage is ramped up and down to a regulator whose main output is programmed for 5V. The $\overline{\text{ERROR}}$ signal becomes low at about 1.3V input. It goes high at about 5V input, where the main output equals 4.75V. Since the dropout voltage is load dependent, the **input** voltage trip points will vary with load current. The **main output** voltage trip point does not vary.

The comparator has an open-collector output which requires an external pull-up resistor. This resistor may be connected to the regulator main output or some other supply voltage. Using the main output prevents an invalid "HIGH" on the comparator output which occurs if it is pulled up to an external voltage while the regulator input voltage is reduced below 1.3V. In selecting a value for the pull-up resistor, note that while the output can sink 400 µA, this current adds to battery drain. Suggested values range from 100 kΩ to 1 MΩ. The resistor is not required if the output is unused.

Application Hints (Continued)



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*In shutdown mode, $\overline{\text{ERROR}}$ will go high if it has been pulled up to an external supply. To avoid this invalid response, pull up to regulator output.

**Exact value depends on dropout voltage. (See Application Hints)

FIGURE 4. $\overline{\text{ERROR}}$ Output Timing

If a single pull-up resistor is used to the regulator output, the error flag may briefly rise up to about 1.3V as the input voltage ramps up or down through the 0V to 1.3V region.

In some cases, this 1.3V signal may be mis-interpreted as a false high by a μP which is still "alive" with 1.3V applied to it.

To prevent this, the user may elect to use **two** resistors which are equal in value on the error output (one connected to ground and the other connected to the regulator output).

If this two-resistor divider is used, the error output will only be pulled up to about 0.6V (not 1.3V) during power-up or power-down, so it can not be interpreted as a high signal. When the regulator output is at 5V, the error output will be 2.5V, which is still clearly a high signal.

OUTPUT ISOLATION

The regulator outputs can be left connected to an active voltage source (such as a battery) with the regulator input power shut off, as long as the regulator ground pin is connected to ground. If the ground pin is left floating, damage to the regulator can occur if the output is pulled up by an external voltage source.

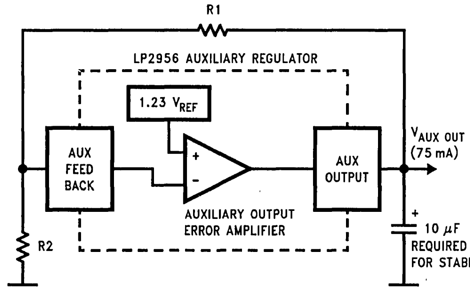
REDUCING MAIN OUTPUT NOISE

In reference applications it may be advantageous to reduce the AC noise present on the main output. One method is to reduce regulator bandwidth by increasing output capacitance. This is relatively inefficient, since large increases in capacitance are required to get significant improvement.

Noise can be reduced more effectively by a bypass capacitor placed across R1 (refer to *Figure 3*). The formula for selecting the capacitor to be used is:

$$CB = \frac{1}{2\pi\, R1 \times 20\ \text{Hz}}$$

This gives a value of about 0.1 μF. When this is used, the output capacitor must be 6.8 μF (or greater) to maintain stability. The 0.1 μF capacitor reduces the high frequency noise gain of the circuit to unity, lowering the output noise from 260 μV to 80 μV using a 10 Hz to 100 kHz bandwidth. Also, noise is no longer proportional to the output voltage, so improvements are more pronounced at higher output voltages.



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$$V_{AUX\,OUT} = V_{REF}\left(1 + \frac{R1}{R2}\right) + (I_{FB} \times R1)$$

where: V_{REF} = 1.23V and I_{FB} = −10 nA (typical)

FIGURE 5. Auxiliary Adjustable Regulator

AUXILIARY LDO OUTPUT

The LP2956 has an auxiliary LDO regulator output (which can source up to 75 mA) that is adjustable for voltages from 1.23V to 29V.

The output voltage is set by an external resistive divider, as shown in *Figure 5*. The maximum output current is 75 mA, and the output requires 10 μF from the output to ground for stability, regardless of load current.

SHUTDOWN INPUT

The shutdown input equivalent circuit is shown in *Figure 6*. The main regulator output is shut down when the NPN transistor is turned ON.

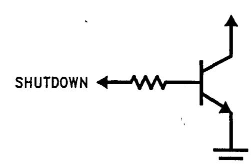

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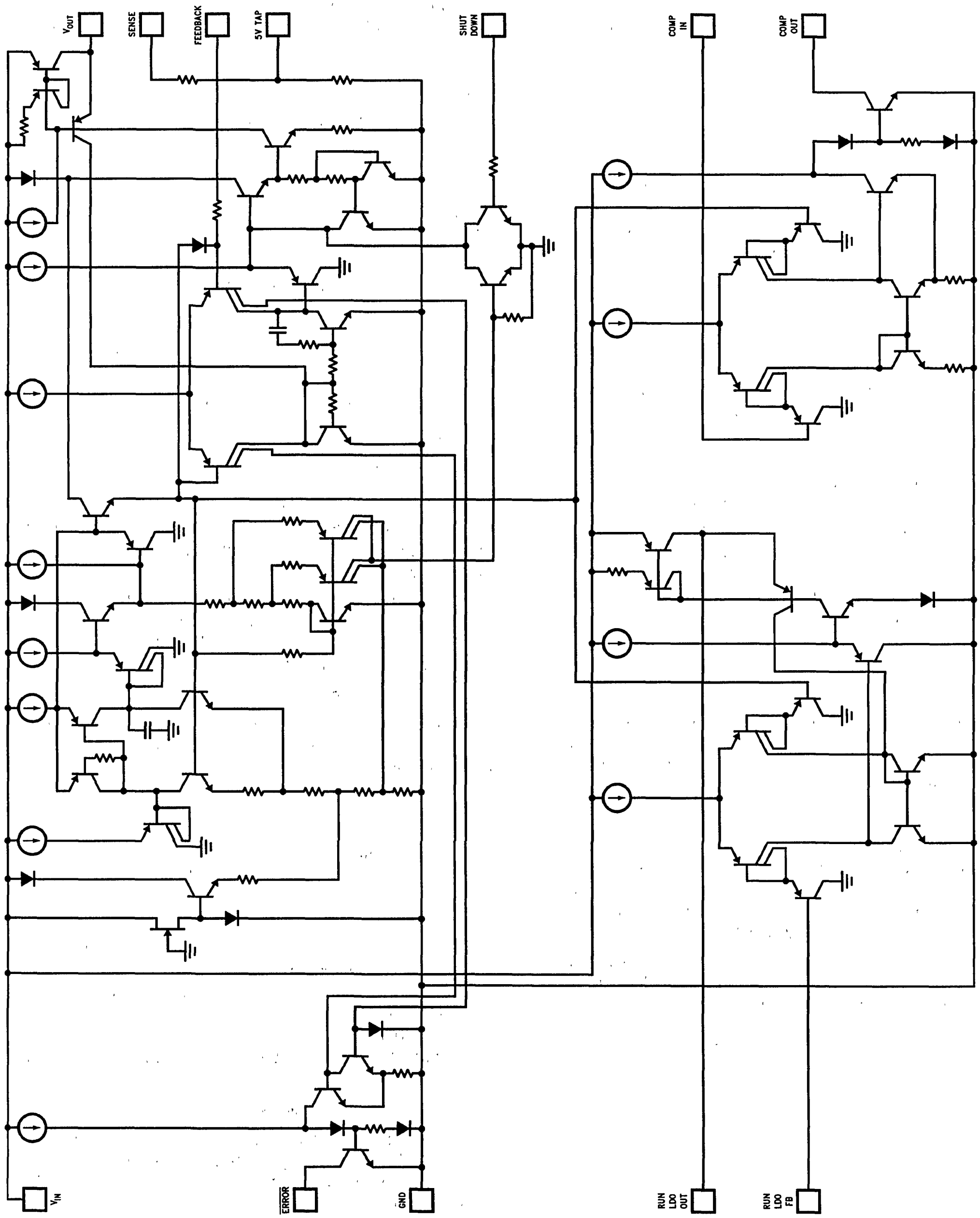
FIGURE 6. Shutdown Circuitry

The current into the input should be at least 0.5 μA to assure the output shutdown function. A resistor may be placed in series with the input to minimize current draw in shutdown mode, provided this minimum input current requirement is met.

IMPORTANT:

The shutdown input must not be left floating: a pull-down resistor (10 kΩ to 50 kΩ recommended) must be connected between the shutdown input and ground in cases where the input is not actively pulled low.

Schematic Diagram



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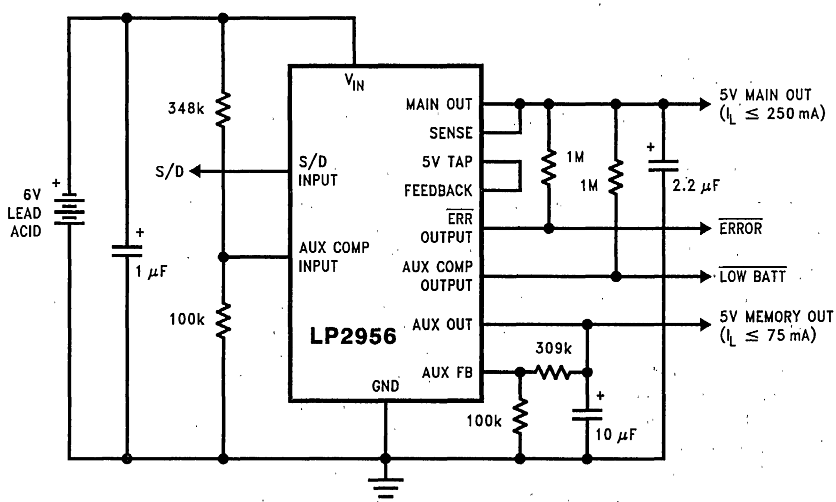
Typical Applications



TL/H/11339-16

National Semiconductor

LP2957/LP2957A
5V Low-Dropout Regulator for μP Applications

General Description

The LP2957 is a 5V micropower voltage regulator with electronic shutdown, error flag, very low quiescent current (150 μA typical at 1 mA load), and very low dropout voltage (470 mV typical at 250 mA load current).

Output can be wired for snap-on/snap-off operation to eliminate transition voltage states where μP operation may be unpredictable.

Output crowbar (50 mA typical pull-down current) will bring down the output quickly when the regulator snaps off or when the shutdown function is activated.

The part has tight line and load regulation (0.04% typical) and low output temperature coefficient (20 ppm/°C typical).

The accuracy of the 5V output is guaranteed at room temperature and over the full operating temperature range.

The LP2957 is available in the five-lead TO-220 and TO-263 packages.

Features

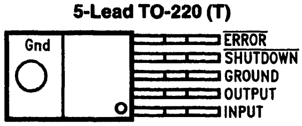
- 5V output within 1.4% over temperature (A grade)
- Easily programmed for snap-on/snap-off output
- Guaranteed 250 mA output current
- Extremely low quiescent current
- Low Input-Output voltage required for regulation
- Reverse battery protection
- Extremely tight line and load regulation
- Very low temperature coefficient
- Current and thermal limiting
- Error flag signals when output is out of regulation

Applications

- High-efficiency linear regulator
- Battery-powered regulator

Package Outline

Bent, Staggered Leads
5-Lead TO-220 (T)

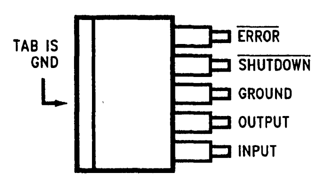


TL/H/11340-16

Top View

Order Number LP2957AIT or LP2957IT
See NS Package Number T05D

Plastic Surface Mount Package
5-Lead TO-263 (S)



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Top View

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Side View

Order Number LP2957AIS or LP2957IS
See NS Package Number TS5B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Operating Junction Temperature Range	−40°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 5 Seconds)	260°C
Power Dissipation (Note 2)	Internally Limited
Input Supply Voltage	−20V to +30V
$\overline{\text{Shutdown}}$ Input	−0.3V to +30V
ESD Rating	2 kV

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF, V_{SD} = 3V.

Symbol	Parameter	Conditions	Typical	LP2957AI		LP2957I		Units
				Min	Max	Min	Max	
V_O	Output Voltage (Note 9)		5.0	4.975 **4.940**	5.025 **5.060**	4.950 **4.900**	5.050 **5.100**	V
		1 mA ≤ I_L ≤ 250 mA	5.0	**4.930**	**5.070**	**4.880**	**5.120**	
$\frac{\Delta V_O}{\Delta T}$	Output Voltage Temperature Coefficient	(Note 3)	**20**		**100**		**150**	ppm/°C
$\frac{\Delta V_O}{V_O}$	Line Regulation	V_{IN} = 6V to 30V	0.03		0.10 **0.20**		0.20 **0.40**	%
$\frac{\Delta V_O}{V_O}$	Load Regulation	I_L = 1 mA to 250 mA I_L = 0.1 mA to 1 mA (Note 4)	0.04		0.16 **0.20**		0.20 **0.30**	%
$V_{IN}-V_O$	Dropout Voltage (Note 5)	I_L = 1 mA	60		100 **150**		100 **150**	mV
		I_L = 50 mA	240		300 **420**		300 **420**	
		I_L = 100 mA	310		400 **520**		400 **520**	
		I_L = 250 mA	470		600 **800**		600 **800**	
I_{GND}	Ground Pin Current (Note 6)	I_L = 1 mA	150		200 **230**		200 **230**	μA
		I_L = 50 mA	1.1		2 **2.5**		2 **2.5**	mA
		I_L = 100 mA	3		6 **8**		6 **8**	
		I_L = 250 mA	16		28 **33**		28 **33**	
I_{GND}	Ground Pin Current in Shutdown (Note 6)	I_L = 0 V_{SD} = 0.4V	130		180 **200**		180 **200**	μA
I_{GND}	Ground Pin Current at Dropout (Note 6)	V_{IN} = 4.5V I_L = 0.1 mA	180		230 **250**		230 **250**	μA
I_O (Sink)	Off-State Output Pulldown Current	V_{IN} = 5.3V V_O = 5V, V_{SD} = 0.4V	50	30 **20**		30 **20**		mA
I_O (Off)	Output Leakage in Shutdown	$I_{(SD\ IN)}$ ≥ 1 μA V_{IN} = 30V, V_{OUT} = 0V	3		10 **20**		10 **20**	μA

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: $V_{IN} = 6V$, $I_L = 1$ mA, $C_L = 2.2$ µF, $V_{SD} = 3V$. (Continued)

Symbol	Parameter	Conditions	Typical	LP2957AI		LP2957I		Units
				Min	Max	Min	Max	
I_{LIMIT}	Current Limit	$R_L = 1\Omega$	400		500 **530**		500 **530**	mA
$\frac{\Delta V_O}{\Delta Pd}$	Thermal Regulation	(Note 7)	0.05		0.2		0.2	%/W
e_n	Output Noise Voltage (10 Hz to 100 kHz) $I_L = 100$ mA	$C_L = 2.2$ µF	500					µV RMS
		$C_L = 33$ µF	320					
$\overline{\text{SHUTDOWN}}$ INPUT								
V_{SD} (ON)	Output Turn-On Threshold Voltage			1.155 **1.140**	1.305 **1.320**	1.155 **1.140**	1.305 **1.320**	V
HYST	Hysteresis		6					mV
I_B	Input Bias Current	$V_{IN(SD)} = 0V$ to 5V	10	−30 **−50**	30 **50**	−30 **−50**	30 **50**	nA
DROPOUT DETECTION COMPARATOR								
I_{OH}	Output "HIGH" Leakage	$V_{OH} = 30V$	0.01		1 **2**		1 **2**	µA
V_{OL}	Output "LOW" Voltage	$V_{IN} = 4V$ $I_O(COMP) = 400$ µA	150		250 **400**		250 **400**	mV
V_{THR} (Max)	Upper Threshold Voltage	(Note 8)	−240	−320 **−380**	−150 **−100**	−320 **−380**	−150 **−100**	mV
V_{THR} (Min)	Lower Threshold Voltage	(Note 8)	−350	−450 **−640**	−230 **−160**	−450 **−640**	−230 **−160**	mV
HYST	Hysteresis	(Note 8)	60					mV

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The maximum allowable power dissipation is a function of the maximum junction temperature, $T_J(MAX)$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using:

$$P(MAX) = \frac{T_J(MAX) - T_A}{\theta_{JA}}$$

Exceeding the maximum allowable power dissipation will result in excessive die temperature, and the regulator will go into thermal shutdown. The junction-to-ambient thermal resistance of the TO-220 (without heatsink) is 60°C/W and 73°C/W for the TO-263. If the TO-263 package is used, the thermal resistance can be reduced by increasing the P.C. board copper area thermally connected to the package: Using 0.5 Square inches of copper area, θ_{JA} is 50°C/W, with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W. The junction-to-case thermal resistance is 3°C/W. If an external heatsink is used, the effective junction-to-ambient thermal resistance is the **sum** of the junction-to-case resistance (3°C/W), the specified thermal resistance of the heatsink selected, and the thermal resistance of the interface between the heatsink and the LP2957 (see **Application Hints**).

Note 3: Output voltage temperature coefficient is defined as the worst case voltage change divided by the total temperature range.

Note 4: Regulation is measured at constant junction temperature using low duty cycle pulse testing. Parts are tested separately for load regulation in the load ranges 0.1 mA–1 mA and 1 mA–250 mA. Changes in output voltage due to heating effects are covered by the thermal regulation specification.

Note 5: Dropout voltage is defined as the input to output voltage differential at which the output voltage drops 100 mV below the value measured with a 1V input to output differential.

Note 6: Ground pin current is the regulator quiescent current. The total current drawn from the source is the sum of the load current plus the ground pin current.

Note 7: Thermal regulation is defined as the change in output voltage at a time T after a change in power dissipation is applied, excluding load or line regulation effects. Specifications are for a 200 mA load pulse at $V_{IN} = 20V$ (3W pulse) for T = 10 ms.

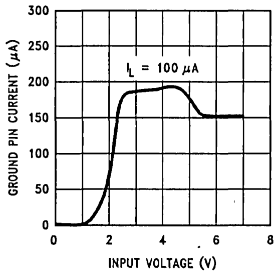
Note 8: Voltages are referenced to the nominal regulated output voltage.

Note 9: When used in dual-supply systems where the regulator load is returned to a negative supply, the output voltage must be diode-clamped to ground.

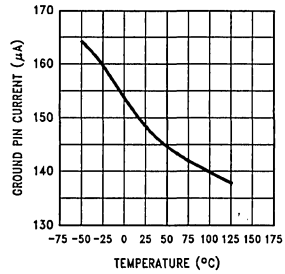
Typical Performance Characteristics

Unless otherwise specified: $V_{IN} = 6V$, $I_L = 1$ mA, $C_L = 2.2\ \mu F$, $V_{SD} = 3V$, $T_A = 25°C$

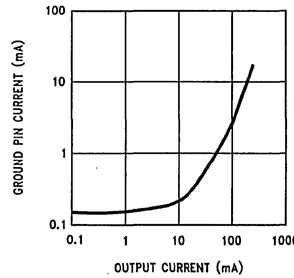
Ground Pin Current



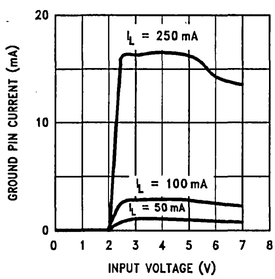
Ground Pin Current



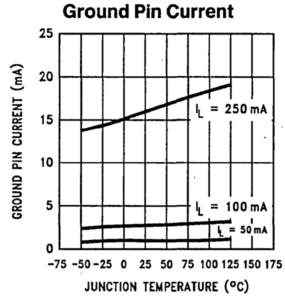
Ground Pin Current vs Load



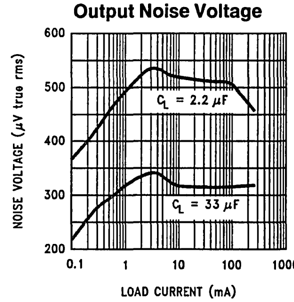
Ground Pin Current



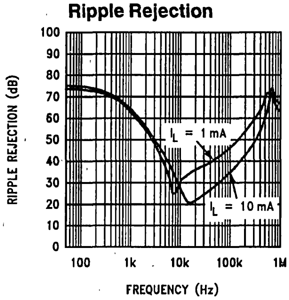
Ground Pin Current



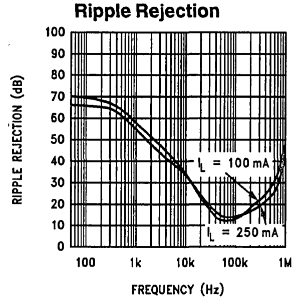
Output Noise Voltage



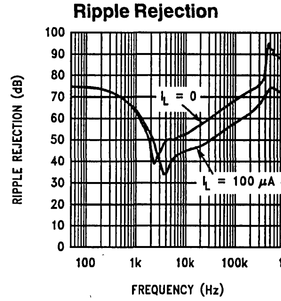
Ripple Rejection



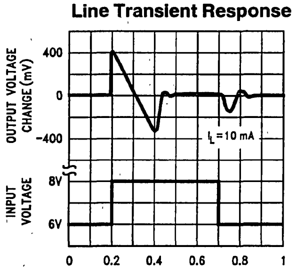
Ripple Rejection



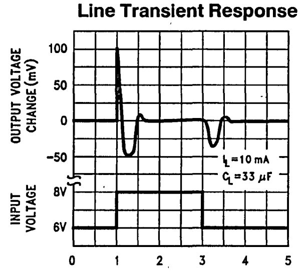
Ripple Rejection



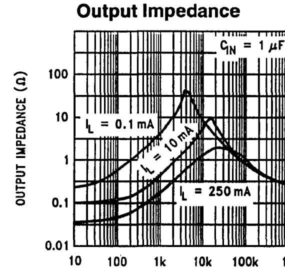
Line Transient Response



Line Transient Response



Output Impedance



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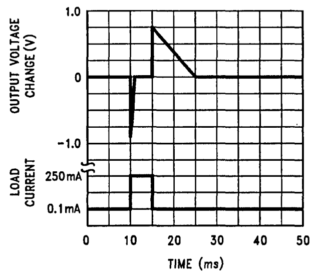
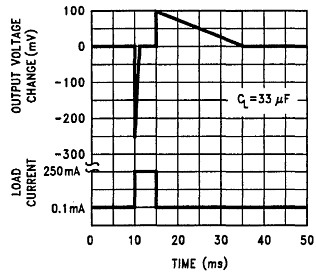
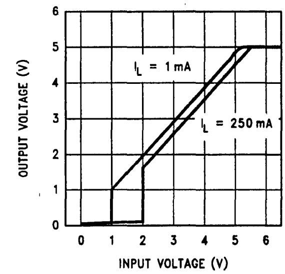
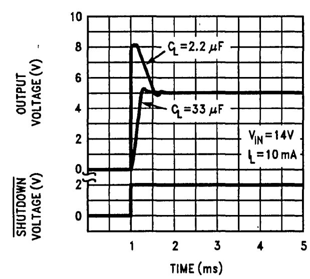
2

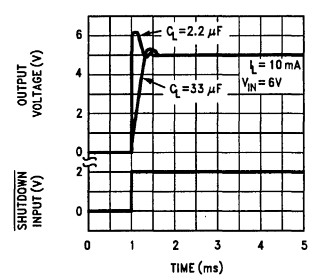
Typical Performance Characteristics
Unless otherwise specified: V_{IN} = 6V, I_L = 1 mA, C_L = 2.2 μF, V_{SD} = 3V, T_A = 25°C (Continued)

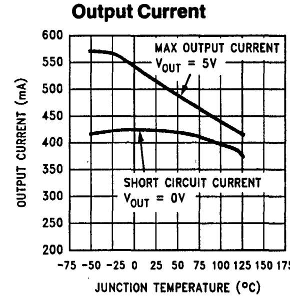
Load Transient Response


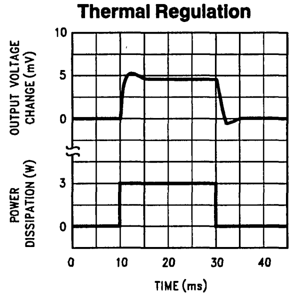
Load Transient Response


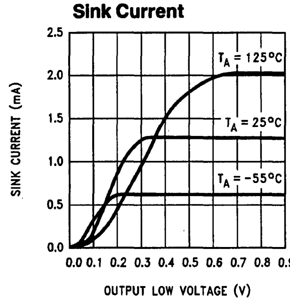
Dropout Characteristics


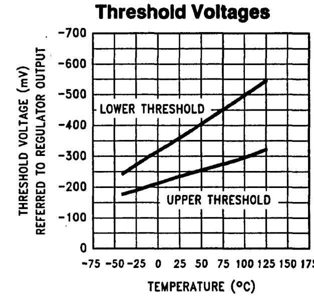
Enable Transient


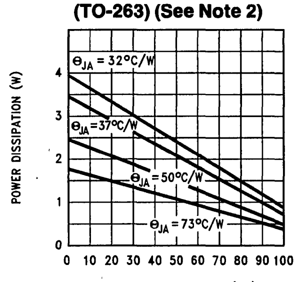
Enable Transient


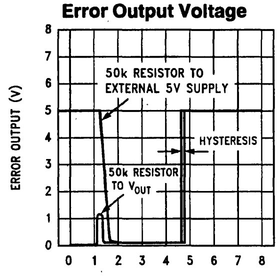
Short-Circuit Output Current and Maximum Output Current


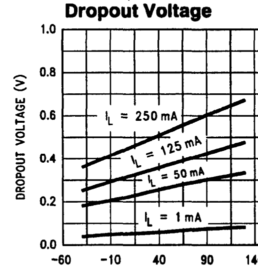
Thermal Regulation


Error Output Sink Current


Dropout Detection Threshold Voltages


Maximum Power Dissipation (TO-263) (See Note 2)


Error Output Voltage


Dropout Voltage


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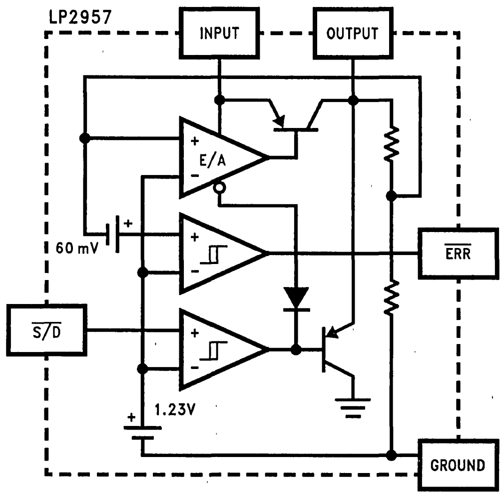
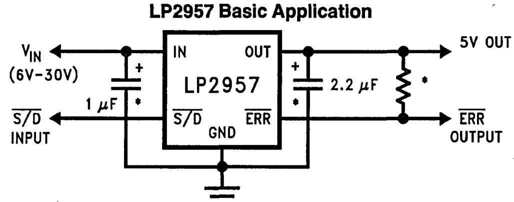
Block Diagram



TL/H/11340-1

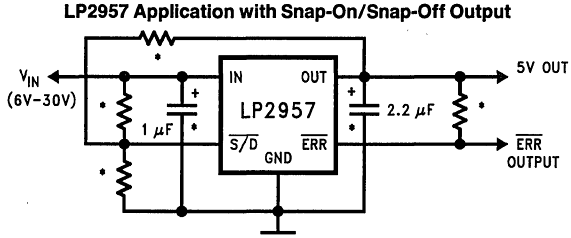
Typical Application Circuits

LP2957 Basic Application



TL/H/11340-2

LP2957 Application with Snap-On/Snap-Off Output



*See Application Hints

TL/H/11340-4

Application Hints

EXTERNAL CAPACITORS

A 2.2 µF (or greater) capacitor is required between the output pin and ground to assure stability (refer to *Figure 1*). Without this capacitor, the part may oscillate. Most type of tantalum or aluminum electrolytics will work here. Film types will work, but are more expensive. Many aluminum electrolytics contain electrolytes which freeze at −30°C, which requires the use of solid tantalums below −25°C. The important parameters of the capacitor are an ESR of about 5Ω or less and a resonant frequency above 500 kHz (the ESR may increase by a factor of **20** or **30** as the temperature is reduced from 25°C to −30°C). The value of this capacitor may be increased without limit. At lower values of output current, less output capacitance is required for stability. The capacitor can be reduced to 0.68 µF for currents below 10 mA or 0.22 µF for currents below 1 mA.

A 1 µF capacitor should be placed from the input pin to ground if there is more than 10 inches of wire between the input and the AC filter capacitor or if a battery input is used. This **capacitor may have to be increased if the regulator is wired for snap-on/snap-off output and the source impedance is high** (see ***Snap-On/Snap-Off Operation*** section).

SHUTDOWN INPUT

A logic-level signal will shut off the regulator output when a "LOW" (< 1.2V) is applied to the $\overline{\text{Shutdown}}$ input.

To prevent possible mis-operation, the $\overline{\text{Shutdown}}$ input must be actively terminated. If the input is driven from open-collector logic, a pull-up resistor (20 kΩ to 100 kΩ recommended) must be connected from the $\overline{\text{Shutdown}}$ input to the regulator input.

If the $\overline{\text{Shutdown}}$ input is driven from a source that actively pulls high and low (like an op-amp), the pull-up resistor is not required, but may be used.

If the shutdown function is not to be used, the cost of the pull-up resistor can be saved by tying the $\overline{\text{Shutdown}}$ input directly to the regulator input.

IMPORTANT: Since the Absolute Maximum Ratings state that the $\overline{\text{Shutdown}}$ input can not go more than 0.3V below ground, the reverse-battery protection feature which protects the regulator input is sacrificed if the $\overline{\text{Shutdown}}$ input is tied directly to the regulator input.

If reverse-battery protection is required in an application, the pull-up resistor between the $\overline{\text{Shutdown}}$ input and the regulator input must be used.

MINIMUM LOAD

It should be noted that a minimum load current is specified in several of the electrical characteristic test conditions, so the value listed must be used to obtain correlation on these tested limits. The part is parametrically tested down to 100 µA, but is functional with no load.

DROPOUT VOLTAGE

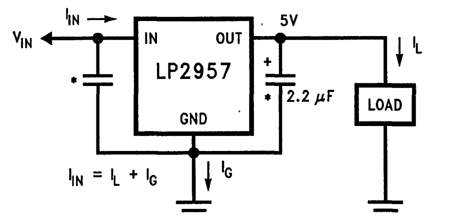
The dropout voltage of the regulator is defined as the minimum input-to-output voltage differential required for the output voltage to stay within 100 mV of the output voltage measured with a 1V differential. The dropout voltages for various values of load current are listed under Electrical Characteristics.

If the regulator is powered from a transformer connected to the AC line, the **minimum AC line voltage** and **maximum load current** must be used to measure the minimum voltage at the input of the regulator. The minimum input voltage is the lowest voltage level **including ripple on the filter capacitor.** It is also advisable to verify operation at **minimum operating ambient temperature**, since the increasing ESR of the filter capacitor makes this a worst-case test due to increased ripple amplitude.

HEATSINK REQUIREMENTS

A heatsink may be required with the LP2957 depending on the maximum power dissipation and maximum ambient temperature of the application. Under all possible operating conditions, the junction temperature must be within the range specified under Absolute Maximum Ratings.

To determine if a heatsink is required, the maximum power dissipated by the regulator, P(max), must be calculated. It is important to remember that if the regulator is powered from a transformer connected to the AC line, the **maximum specified AC input voltage** must be used (since this produces the maximum DC input voltage to the regulator), and the **maximum load current** must also be used. *Figure 1* shows the voltages and currents which are present in the circuit. The formula for calculating the power dissipated in the regulator is also shown in *Figure 1*.



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*See EXTERNAL CAPACITORS

$P_{TOTAL} = (V_{IN} - 5)I_L + (V_{IN})I_G$

FIGURE 1. Basic 5V Regulator Circuit

The next parameter which must be calculated is the maximum allowable temperature rise, T_R(Max). This is calculated by using the formula:

$$T_R(\text{Max}) = T_J(\text{Max}) - T_A(\text{Max})$$

where: T_J(Max) is the maximum allowable junction temperature

T_A(Max) is the maximum ambient temperature

Using the calculated values for T_R(Max) and P(Max), the required value for junction-to-ambient thermal resistance, $\theta_{(JA)}$, can now be found:

$$\theta_{(JA)} = T_R(\text{Max})/P(\text{Max})$$

If the calculated value is 60°C/W **or higher,** the regulator may be operated without an external heatsink. If the calculated value is **below** 60°C/W, an external heatsink is required. The required thermal resistance for this heatsink, $\theta_{(HA)}$, can be calculated using the formula:

$$\theta_{(HA)} = \theta_{(JA)} - \theta_{(JC)} - \theta_{(CH)}$$

where:

$\theta_{(JC)}$ is the junction-to-case thermal resistance, which is specified as 3°C/W for the LP2957.

$\theta_{(CH)}$ is the case-to-heatsink thermal resistance, which is dependent on the interfacing material (see Tables I and II).

Application Hints (Continued)

Typical TO-220 Case-To-Heatsink Thermal Resistances in °C/W

TABLE I. (From AAVID)

Silicone Grease	1.0
Dry Interface	1.3
Mica with Grease	1.4

TABLE II. (From Thermalloy)

Thermasil III	1.3
Thermasil II	1.5
Thermalfilm (0.002) with Grease	2.2

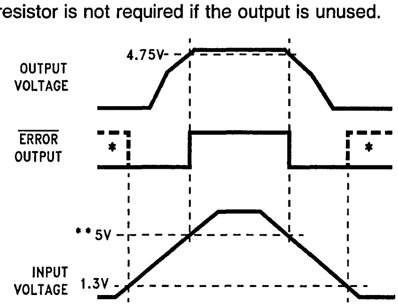
$\theta_{(HA)}$ is the heatsink-to-ambient thermal resistance. It is this specification (listed on the heatsink manufacturers data sheet) which defines the effectiveness of the heatsink. The heatsink selected must have a thermal resistance which is **equal to or lower** than the value of $\theta_{(HA)}$ calculated from the above listed formula.

ERROR COMPARATOR

This comparator produces a logic "LOW" whenever the output falls out of regulation by more than about 5%. This figure results from the comparator's built-in offset of 60 mV divided by the 1.23V reference. An out-of-regulation condition can result from low input voltage, current limiting, or thermal limiting.

Figure 2 gives a timing diagram showing the relationship between the output voltage, the $\overline{\text{ERROR}}$ output, and input voltage as the input voltage is ramped up and down to the regulator **without snap-on/snap-off output**. The $\overline{\text{ERROR}}$ signal becomes low at about 1.3V input. It goes high at about 5V input, where the output equals 4.75V. Since the dropout voltage is load dependent, the **input** voltage trip points will vary with load current. The **output** voltage trip point does not vary.

The comparator has an open-collector output which requires an external pull-up resistor. This resistor may be connected to the regulator output or some other supply voltage. Using the regulator output prevents an invalid "HIGH" on the comparator output which occurs if it is pulled up to an external voltage while the regulator input voltage is reduced below 1.3V. In selecting a value for the pull-up resistor, note that while the output can sink 400 μA, this current adds to battery drain. Suggested values range from 100k to 1 MΩ. The resistor is not required if the output is unused.



*In shutdown mode, $\overline{\text{ERROR}}$ will go high if it has been pulled up to an external supply. To avoid this invalid response, pull up to regulator output.

**Exact value depends on dropout voltage, which varies with load current.

FIGURE 2. $\overline{\text{ERROR}}$ Output Timing

If a single pull-up resistor is connected to the regulator output, the error flag may briefly rise up to about 1.3V as the input voltage ramps up or down through the 0V to 1.3V region.

In some cases, this 1.3V signal may be mis-interpreted as a false high by a μP which is still "alive" with 1.3V applied to it.

To prevent this, the user may elect to use **two** resistors which are equal in value on the error output (one connected to ground and the other connected to the regulator output).

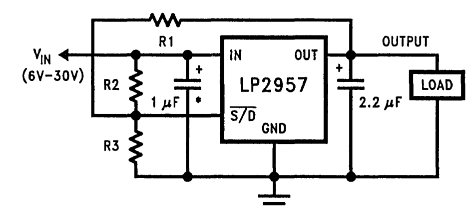
If this two-resistor divider is used, the error output will only be pulled up to about 0.6V (not 1.3V) during power-up or power-down, so it can not be interpreted as a high signal. When the regulator output is in regulation (4.8V to 5V), the error output voltage will be 2.4V to 2.5V, which is clearly a high signal.

OUTPUT ISOLATION

The regulator output can be connected to an active voltage source (such as a battery) with the regulator input turned off, **as long as the regulator ground pin is connected to ground**. If the ground pin is left floating, **damage to the regulator can occur** if the output is pulled up by an external voltage source.

SNAP-ON/SNAP-OFF OPERATION

The LP2957 output can be wired for snap-on/snap-off operation using three external resistors:



*Minimum value (increase as required for smooth turn-on characteristic).

FIGURE 3. Snap-On/Snap-Off Output

When connected as shown, the shutdown input holds the regulator off until the input voltage rises up to the turn-on threshold (V_{ON}), at which point the output "snaps on".

When the input power is shut off (and the input voltage starts to decay) the output voltage will snap off when the input voltage reaches the turn-off threshold, V_{OFF}.

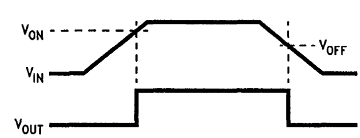


FIGURE 4. Snap-On/Snap-Off Input and Output Voltage Diagram

It is important to note that the voltage V_{OFF} must always be lower than V_{ON} (the difference in these voltage levels is called the hysteresis).

Application Hints (Continued)

Hysteresis is **required** when using snap-on/snap-off output, with the minimum amount of hysteresis required for a specific application being dependent on the source impedance of whatever is supplying V_{IN}.

Caution: A type of **low-frequency oscillation** can occur if V_{ON} and V_{OFF} are too close together **(insufficient hysteresis)**. When the output snaps on, the regulator must draw sufficient current to power the load and charge up the output capacitor (in most cases, the regulator will briefly draw the maximum current allowed by its internal limiter).

For this reason, it is best to assume the LP2957 may pull a peak current of about **600 mA** from the source (which is the listed maximum short-circuit load current of **530 mA** plus the ground pin current of **70 mA**).

This high peak current causes V_{IN} to drop by an amount equal to the source impedance multiplied by the current. If V_{IN} drops below V_{OFF}, the regulator will turn off and stop drawing current from the source. This will allow V_{IN} to rise back up above V_{ON}, and the cycle will start over. The regulator will stay in this oscillating mode and never come into regulation.

HYSTERESIS IN TRANSFORMER-POWERED APPLICATIONS:

If the unregulated DC input voltage to the regulator comes from a transformer, the required hysteresis is easily measured by loading the source with a resistive load.

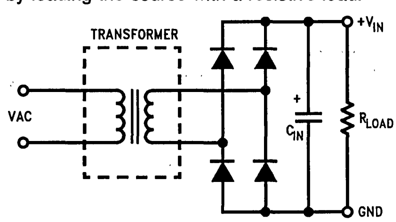


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FIGURE 5. Transformer Powered Input Supply

If the regulator is powered from a battery, the source impedance will probably be low enough that other considerations will determine the optimum values for hysteresis (see Design Example #2).

For best results, the load resistance used to test the transformer should be selected to draw about **600 mA** for the maximum load current test, since this is the maximum peak current the LP2957 could be expected to draw from the source.

The difference in input voltage measured at no load and full load defines the amount of hysteresis required for proper snap-on/snap-off operation (the programmed hysteresis must be **greater** than the difference in voltages).

CALCULATING RESISTOR VALUES:

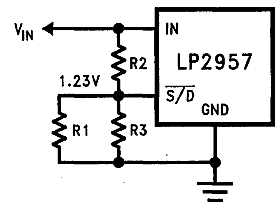
The values of R1, R2 and R3 can be calculated assuming the designer knows the hysteresis.

In most transformer-powered applications, it can be assumed that V_{OFF} (the input voltage at turn-off) **should be set for about 5.5V,** since this allows about 500 mV across the LP2957 to keep the output in regulation until it snaps off. V_{ON} (the input voltage at turn on) is found by **adding the hysteresis voltage to V_{OFF}.**

R1, R2 and R3 are found by solving the node equations for the currents entering the node nearest the shutdown pin (written at the turn-on and turn-off thresholds).

The shutdown pin bias current (10 nA typical) is not included in the calculations:

Turn-ON Transition



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Turn-OFF Transition

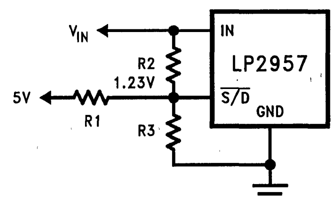

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FIGURE 6. Equivalent Circuits

$$\left(\frac{V_{ON} - 1.23}{R2}\right) = \frac{1.23}{R1} + \frac{1.23}{R3} \qquad \text{(TURN-ON)}$$

$$\frac{V_{OFF} - 1.23}{R2} + \frac{5 - 1.23}{R1} = \frac{1.23}{R3} \qquad \text{(TURN-OFF)}$$

Since these **two** equations contain **three** unknowns (R1, R2 and R3) one resistor value must be assumed and then the remaining two values can be obtained by solving the equations.

The node equations will be simplified by solving both equations for R2, and then equating the two to generate an expression in terms of R1 and R3.

$$R2 = \frac{(R1 \times R3) \times (V_{ON} - 1.23)}{1.23 \times (R1 + R3)} \qquad \text{(TURN-ON)}$$

$$R2 = \frac{(R1 \times R3) \times (V_{OFF} - 1.23)}{(1.23R1 - 3.77R3)} \qquad \text{(TURN-OFF)}$$

Setting these equal to each other and solving for R1 yields:

$$R1 = \frac{R3 \times (V_{OFF} + 3.07V_{ON} - 5)}{V_{ON} - V_{OFF}}$$

The same equation solved for R3 is:

$$R3 = \frac{R1 \times (V_{ON} - V_{OFF})}{V_{OFF} + 3.07V_{ON} - 5}$$

A value for R1 or R3 can be derived using either one of the above equations, if the designer assumes a value for one of the resistors.

The simplest approach is to assume a value for R3. Best results will typically be obtained using values between about **20 kΩ and 100 kΩ** (this keeps the current drain low, but also generates realistic values for the other resistors).

There is no limit on the **minimum value** of R3, but current should be minimized as it generates power that drains the source and does not power the load.

Application Hints (Continued)

SUMMARY: TO SOLVE FOR R1, R2 AND R3:

1. Assume a value for either R1 or R3.
2. Solve for the other variable using the equation for R1 or R3.
3. Take the values for R1 and R3 and plug them back into **either** equation for R2 and solve for this value.

DESIGN EXAMPLE #1:

A 5V regulated output is to be powered from a transformer secondary which is rectified and filtered. The voltage V_{IN} is measured at zero current and maximum current (600 mA) to determine the minimum allowable hysteresis.

V_{IN} is measured using an oscilloscope (both traces are shown on the same grid for clarity):

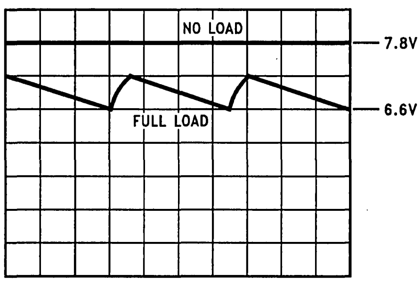

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FIGURE 7. V_{IN} VOLTAGE WAVEFORMS

The full-load voltage waveform from a transformer-powered supply will have ripple voltage as shown. The correct point to measure is the **lowest** value of the waveform.

The 1.2V differential between no-load and full-load conditions means that **at least 1.2V** of hysteresis is required for proper snap-on/snap-off operation (for this example, **we will use 1.5V**).

As a starting point, we will assume:

$$\mathbf{V_{OFF} = 5.5V}$$

$$\mathbf{V_{ON} = V_{OFF} + HYST = 5.5 + 1.5 = 7V}$$

$$\mathbf{R3 = 49.9k}$$

Solving for R1:

$$R1 = \frac{R3 \times (V_{OFF} + 3.07V_{ON} - 5)}{V_{ON} - V_{OFF}}$$

$$R1 = \frac{49.9k \times (5.5 + (3.07 \times 7) - 5)}{7 - 5.5}$$

$$\mathbf{R1 = 731k\ (standard\ size\ 732k)}$$

Solving for R2:

$$R2 = \frac{(R1 \times R3) \times V_{ON} - 1.23)}{1.23 \times (R1 + R3)}$$

$$R2 = \frac{(732k \times 49.9k) \times (7 - 1.23)}{1.23 \times (732k + 49.9k}$$

$$\mathbf{R2 = 219k\ (standard\ size\ 221k)}$$

DESIGN EXAMPLE #2:

A 5V regulated output is to be powered from a battery made up of six NiCad cells. The cell data is:

cell voltage (full charged): 1.4V

cell voltage (90% discharged): 1.0V

The internal impedance of a typical battery is low enough that source loading during regulator turn-on is not usually a problem.

In a battery-powered application, the turn-off voltage V_{OFF} should be selected so that the regulator is shut down when the batteries are about 90% discharged (over discharge can damage rechargeable batteries).

In this case, the battery voltage will be **6.0V** at the 90% discharge point (since there are six cells at 1.0V each). That means for this application, V_{OFF} will be set to 6.0V.

Selecting the optimum voltage for V_{ON} requires understanding battery behavior. If a Ni-Cad battery is nearly discharged (cell voltage 1.0V) **and the load is removed,** the cell voltage will drift back up. The voltage where the regulator turns on must be set high enough to keep the regulator from restarting during this time, or an on-off pulsing mode can occur.

If the regulator restarts when the discharged cell voltage drifts up, the load on the battery will cause the cell voltage to fall below the turn-off level, which causes the regulator to shut down. The cell voltage will again float up and the on-off cycling will continue.

For NiCad batteries, a good cell voltage to use to calculate V_{ON} is about 1.2V per cell. In this application, this will yield a value for V_{ON} of 7.2V.

We can now find R1, R2 and R3 assuming:

$$\mathbf{V_{OFF} = 6.0V \quad V_{ON} = 7.2V \quad R3 = 49.9k}$$

Solving for R1:

$$R1 = \frac{R3 \times (V_{OFF} + 3.07V_{ON} - 5)}{V_{ON} - V_{OFF}}$$

$$R1 = \frac{49.9k \times (6 + (3.07 \times 7.2) - 5)}{7.2 - 6}$$

$$\mathbf{R1 = 961k\ (standard\ size\ 953k)}$$

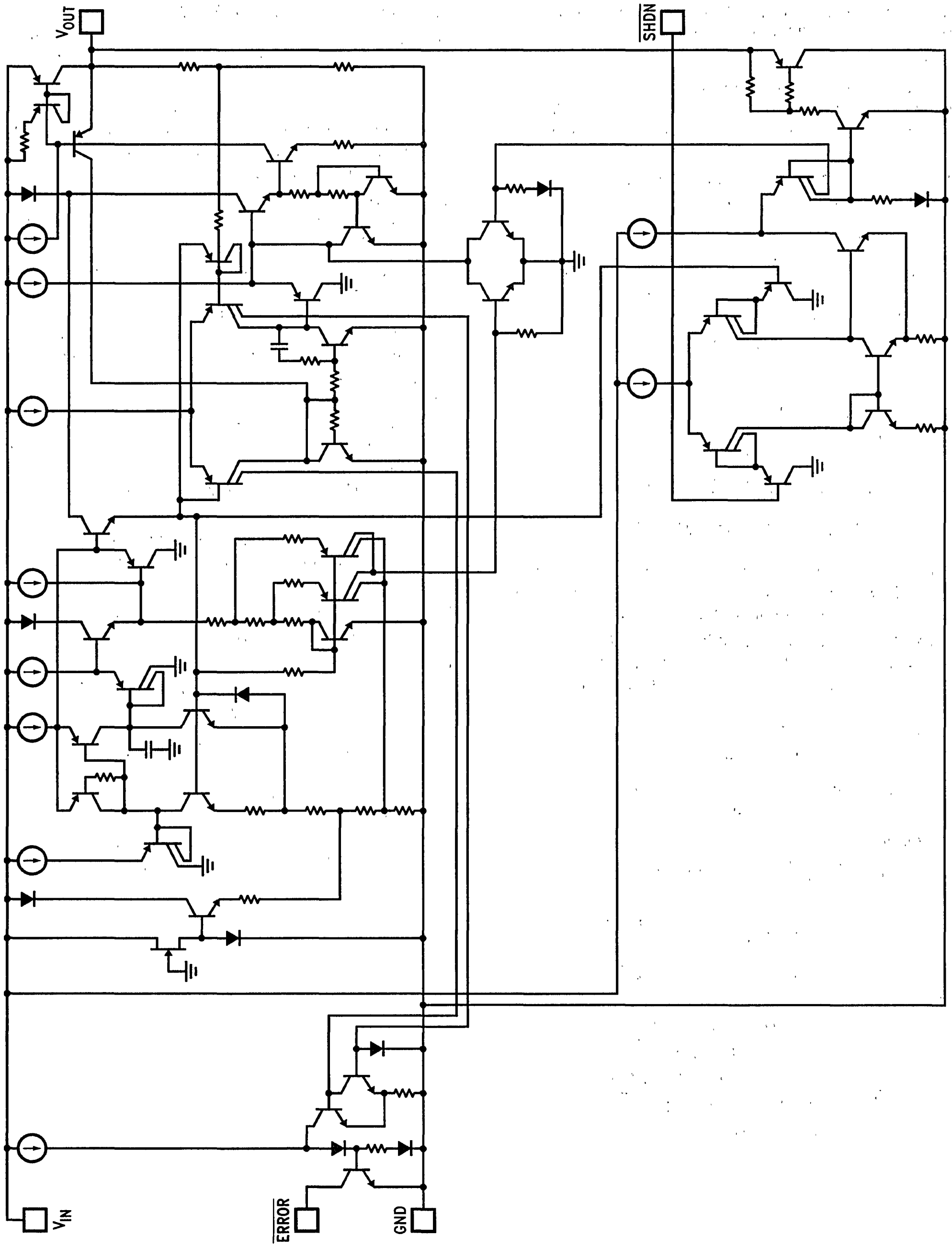
Solving for R2:

$$R2 = \frac{(R1 \times R3) \times (V_{ON} - 1.23)}{1.23 \times (R1 + R3)}$$

$$R2 = \frac{(953k \times 49.9k) \times (7.2 - 1.23)}{1.23 \times (953k + 49.9k)}$$

$$\mathbf{R2 = 230k\ (standard\ size\ 232k)}$$

Schematic Diagram



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National Semiconductor

LP2980
Micropower SOT, 50 mA Ultra Low-Dropout Regulator

General Description

The LP2980 is a 50 mA, fixed-output voltage regulator designed specifically to meet the requirements of battery-powered applications.

Using an optimized VIP™ (Vertically Integrated PNP) process, the LP2980 delivers unequaled performance in all specifications critical to battery-powered designs:

Dropout Voltage. Typically 120 mV @ 50 mA load, and 7 mV @ 1 mA load.

Ground Pin Current. Typically 375 μA @ 50 mA load, and 80 μA @ 1 mA load.

Sleep Mode. Less than 1 μA quiescent current when ON/OFF pin is pulled low.

Smallest Possible Size. SOT-23 package uses an absolute minimum of board space.

Minimum Part Count. Requires only 1 μF of external capacitance on the regulator output.

Precision Output. 0.5% tolerance output voltages available (A grade).

5.0V, 3.3V, and 3.0V versions available as standard products.

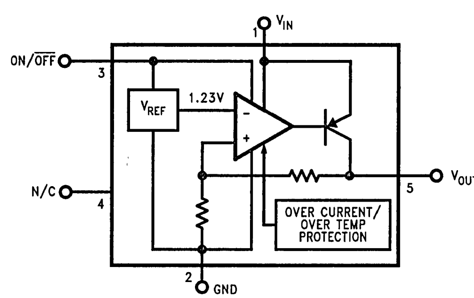
Features

- Ultra low dropout voltage
- Output voltage accuracy 0.5% (A Grade)
- Guaranteed 50 mA output current
- Smallest possible size (SOT-23 Package)
- Requires only 1 μF external capacitance
- < 1 μA quiescent current when shutdown
- Low ground pin current at all load currents
- High peak current capability (150 mA typical)
- Wide supply voltage range (16V max)
- Fast dynamic response to line and load
- Low Z_{OUT} over wide frequency range
- Overtemperature/overcurrent protection
- −40°C to +125°C junction temperature range

Applications

- Cellular Phone
- Palmtop/Laptop Computer
- Personal Digital Assistant (PDA)
- Camcorder, Personal Stereo, Camera

Block Diagram



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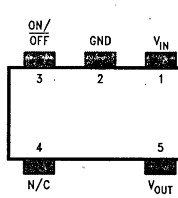
Connection Diagram and Ordering Information

5-Lead Small Outline Package (M5)



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Top View

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Actual Size

For Ordering Information See Table I in this Datasheet
See NS Package Number MA05A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	−65°C to +150°C
Operating Junction Temperature Range	−40°C to +125°C
Lead Temperature (Soldering, 5 sec.)	260°C
ESD Rating (Note 2)	2 kV
Power Dissipation (Note 3)	Internally Limited
Input Supply Voltage (Survival)	−0.3V to +16V
Input Supply Voltage (Operating)	2.1V to +16V
Shutdown Input Voltage (Survival)	−0.3V to +16V
Output Voltage (Survival, Note 4)	−0.3V to +9V
I_{OUT} (Survival)	Short Circuit Protected
Input-Output Voltage (Survival, Note 5)	−0.3V to +16V

Electrical Characteristics

Limits in standard typeface are for T_J = 25°C, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: V_{IN} = $V_{O(NOM)}$ + 1V, I_L = 1 mA, C_{OUT} = 1 µF, $V_{ON/OFF}$ = 2V.

Symbol	Parameter	Conditions	Typ	LP2980AI-XX (Note 6)		LP2980I-XX (Note 6)		Units
				Min	Max	Min	Max	
V_O	Output Voltage (5.0V Versions)	V_{IN} = $V_{O(NOM)}$ + 1V	5.0	4.975	5.025	4.950	5.050	V
		1 mA < I_L < 50 mA	5.0	4.962 **4.875**	5.038 **5.125**	4.925 **4.825**	5.075 **5.175**	
	Output Voltage (3.3V Versions)	V_{IN} = $V_{O(NOM)}$ + 1V	3.3	3.283	3.317	3.267	3.333	
		1 mA < I_L < 50 mA	3.3	3.275 **3.217**	3.325 **3.383**	3.250 **3.184**	3.350 **3.416**	
	Output Voltage (3.0V Versions)	V_{IN} = $V_{O(NOM)}$ + 1V	3.0	2.985	3.015	2.970	3.030	
		1 mA < I_L < 50 mA	3.0	2.977 **2.925**	3.023 **3.075**	2.955 **2.895**	3.045 **3.105**	
$\frac{\Delta V_O}{\Delta V_{IN}}$	Output Voltage Line Regulation	$V_{O(NOM)}$ + 1V ≤ V_{IN} ≤ 16V	0.007		0.014 **0.032**		0.014 **0.032**	%/V
V_{IN}−V_O	Dropout Voltage (Note 7)	I_L = 0	1		3 **5**		3 **5**	mV
		I_L = 1 mA	7		10 **15**		10 **15**	
		I_L = 10 mA	40		60 **90**		60 **90**	
		I_L = 50 mA	120		150 **225**		150 **225**	
I_{GND}	Ground Pin Current	I_L = 0	65		95 **125**		95 **125**	µA
		I_L = 1 mA	80		110 **170**		110 **170**	
		I_L = 10 mA	140		220 **460**		220 **460**	
		I_L = 50 mA	375		600 **1200**		600 **1200**	
		$V_{ON/OFF}$ < 0.18V	0		**1**		**1**	
$V_{ON/OFF}$	ON/OFF Input Voltage (Note 8)	High = O/P ON	1.4	**2.0**		**2.0**		V
		Low = O/P OFF	0.55		**0.18**		**0.18**	
$I_{ON/OFF}$	ON/OFF Input Current	$V_{ON/OFF}$ = 0	0		**−1**		**−1**	µA
		$V_{ON/OFF}$ = 5V	5		**15**		**15**	

Electrical Characteristics

Limits in standard typeface are for $T_J = 25°C$, and limits in **boldface type** apply over the full operating temperature range. Unless otherwise specified: $V_{IN} = V_{O(NOM)} + 1V$, $I_L = 1$ mA, $C_{OUT} = 1\ \mu F$, $V_{ON/OFF} = 2V$. (Continued)

Symbol	Parameter	Conditions	Typ	LP2980AI-XX (Note 6)		LP2980I-XX (Note 6)		Units
				Min	Max	Min	Max	
$I_{O(PK)}$	Peak Output Current	$V_{OUT} \geq V_{O(NOM)} - 5\%$	150	100		100		mA
e_n	Output Noise Voltage (RMS)	BW = 300 Hz–50 kHz, $C_{OUT} = 10\ \mu F$	160					μV
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Ripple Rejection	f = 1 kHz, $C_{OUT} = 10\ \mu F$	63					dB
$I_{O(MAX)}$	Short Circuit Current	$R_L = 0$ (Steady State) (Note 9)	150					mA

Note 1: Absolute maximum ratings indicate limits beyond which damage to the component may occur. Electrical specifications do not apply when operating the device outside of its rated operating conditions.

Note 2: The ESD rating of pins 3 and 4 is 1 kV.

Note 3: The maximum allowable power dissipation is a function of the maximum junction temperature, $T_{J(MAX)}$, the junction-to-ambient thermal resistance, θ_{JA}, and the ambient temperature, T_A. The maximum allowable power dissipation at any ambient temperature is calculated using:

$$P\,(MAX) = \frac{T_{J(MAX)} - T_A}{\theta_{JA}}$$

The value of θ_{JA} for the SOT-23 package is 300°C/W. Exceeding the maximum allowable power dissipation will cause excessive die temperature, and the regulator will go into thermal shutdown.

Note 4: If used in a dual-supply system where the regulator load is returned to a negative supply, the LP2980 output must be diode-clamped to ground.

Note 5: The output PNP structure contains a diode between the V_{IN} and V_{OUT} terminals that is normally reverse-biased. Reversing the polarity from V_{IN} to V_{OUT} will turn on this diode (see Application Hints).

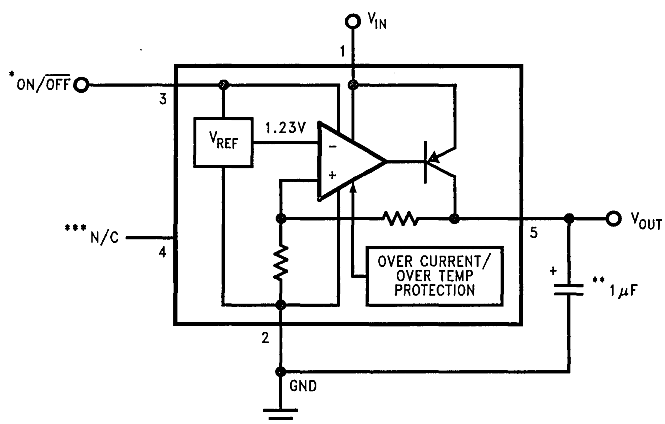
Note 6: Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Averaging Outgoing Level (AOQL).

Note 7: Dropout voltage is defined as the input to output differential at which the output voltage drops 100 mV below the value measured with a 1V differential.

Note 8: The ON/OFF inputs must be properly driven to prevent misoperation. For details, refer to Application Hints.

Note 9: See Typical Performance Characteristics curves.

Basic Application Circuit



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*ON/$\overline{\text{OFF}}$ input must be actively terminated. Tie to V_{IN} if this function is not to be used.

**Minimum Output Capacitance is 1 μF to insure stability over full load current range. More capacitance provides superior dynamic performance and additional stability margin (see Application Hints).

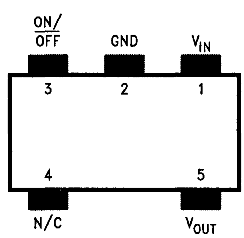
***Do not make connections to this pin.

Ordering Information

TABLE I. Package Marking and Order Information

Output Voltage (V)	Grade	Order Information	Package Marking	Supplied as:
5.0	A	LP2980AIM5X-5.0	L01A	3k Units on Tape and Reel
5.0	A	LP2980AIM5-5.0	L01A	250 Units on Tape and Reel
5.0	STD	LP2980IM5X-5.0	L01B	3k Units on Tape and Reel
5.0	STD	LP2980IM5-5.0	L01B	250 Units on Tape and Reel
3.3	A	LP2980AIM5X-3.3	L00A	3k Units on Tape and Reel
3.3	A	LP2980AIM5-3.3	L00A	250 Units on Tape and Reel
3.3	STD	LP2980IM5X-3.3	L00B	3k Units on Tape and Reel
3.3	STD	LP2980IM5-3.3	L00B	250 Units on Tape and Reel
3.0	A	LP2980AIM5X-3.0	L02A	3k Units on Tape and Reel
3.0	A	LP2980AIM5-3.0	L02A	250 Units on Tape and Reel
3.0	STD	LP2980IM5X-3.0	L02B	3k Units on Tape and Reel
3.0	STD	LP2980IM5-3.0	L02B	250 Units on Tape and Reel

Connection Diagram



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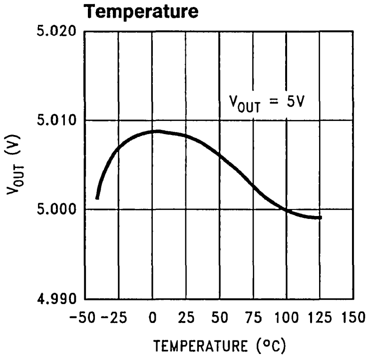
Top View

See NS Package Number MA05A

Typical Performance Characteristics

Unless otherwise specified: T_A = 25°C, V_{IN} = $V_{O(NOM)}$ + 1V, C_{OUT} = 2.2 μF, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

Output Voltage vs Temperature



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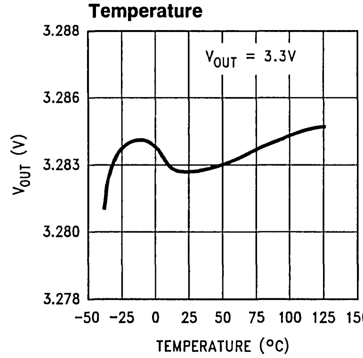
Output Voltage vs Temperature



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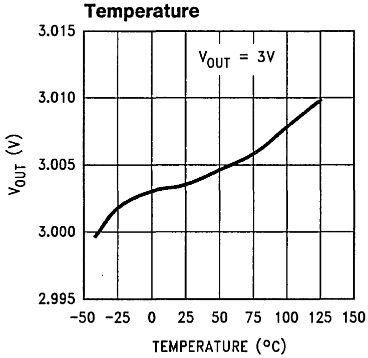
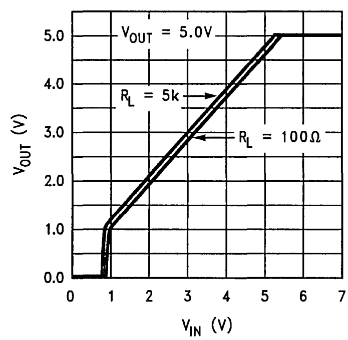
Output Voltage vs Temperature



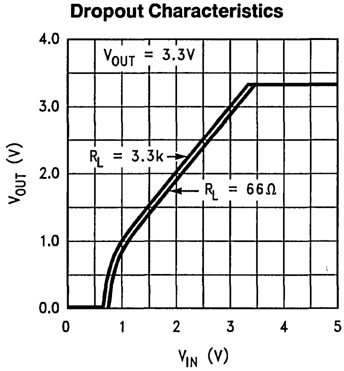
TL/H/12078-40

Dropout Characteristics



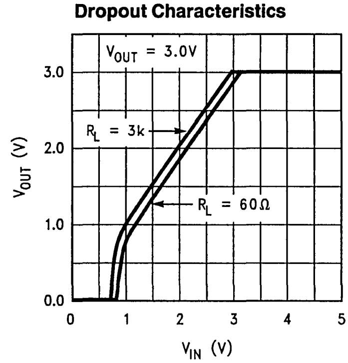
TL/H/12078-16

Dropout Characteristics



TL/H/12078-15

Dropout Characteristics

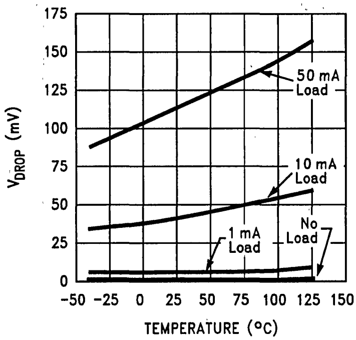


TL/H/12078-14

Typical Performance Characteristics (Continued)

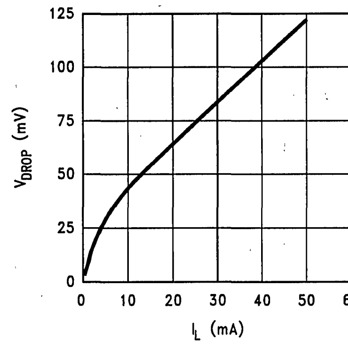
Unless otherwise specified: $T_A = 25°C$, $V_{IN} = V_{O(NOM)} + 1V$, $C_{OUT} = 2.2\ \mu F$, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

Dropout Voltage vs Temperature



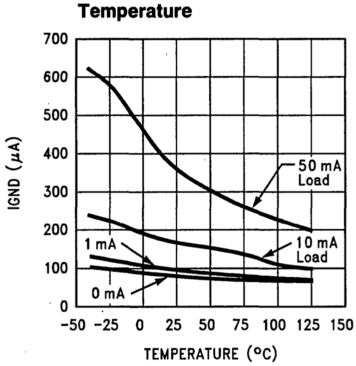
TL/H/12078-11

Dropout Voltage vs Load Current



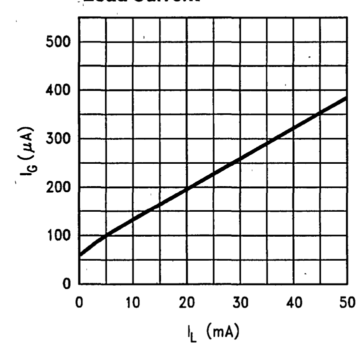
TL/H/12078-20

Ground Pin Current vs Temperature



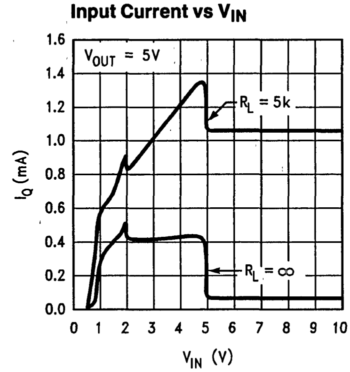
TL/H/12078-10

Ground Pin Current vs Load Current



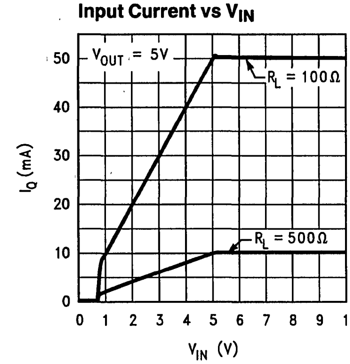
TL/H/12078-19

Input Current vs V_{IN}



TL/H/12078-17

Input Current vs V_{IN}

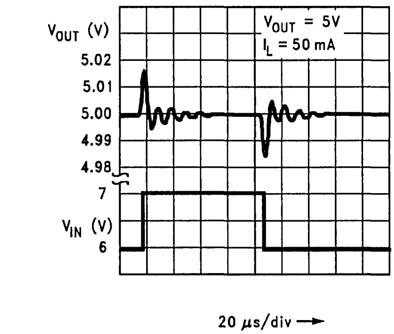


TL/H/12078-18

Typical Performance Characteristics (Continued)

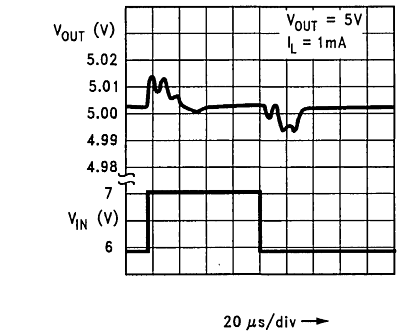
Unless otherwise specified: $T_A = 25°C$, $V_{IN} = V_{O(NOM)} + 1V$, $C_{OUT} = 2.2\ \mu F$, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

Line Transient Response



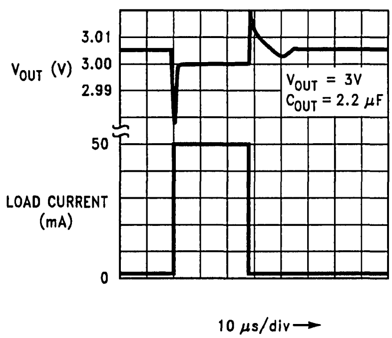
TL/H/12078-21

Line Transient Response



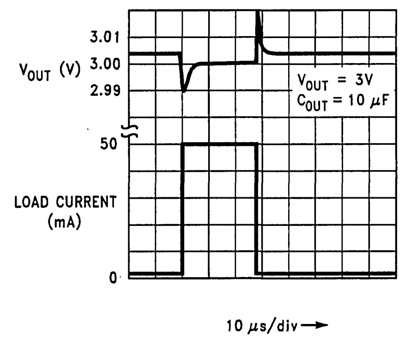
TL/H/12078-22

Load Transient Response



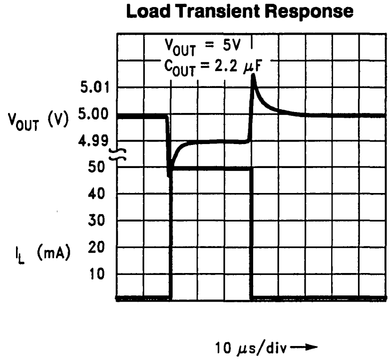
TL/H/12078-41

Load Transient Response



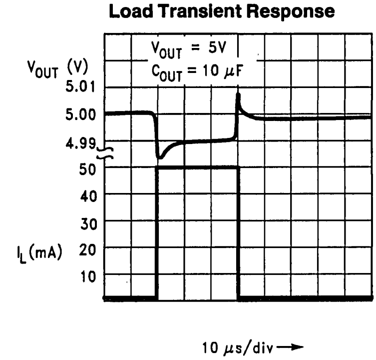
TL/H/12078-42

Load Transient Response



TL/H/12078-23

Load Transient Response



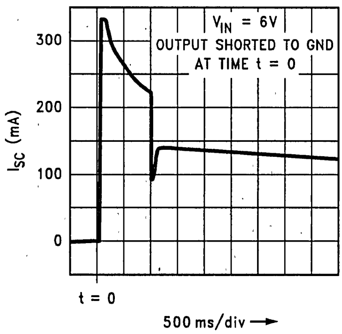
TL/H/12078-24

2

Typical Performance Characteristics (Continued)

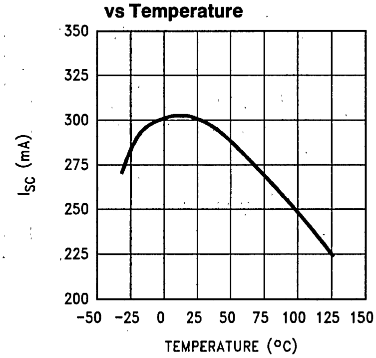
Unless otherwise specified: T_A = 25°C, V_{IN} = $V_{O(NOM)}$ + 1V, C_{OUT} = 2.2 μF, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

Short Circuit Current



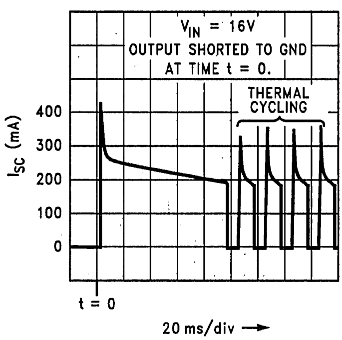
TL/H/12078-32

Instantaneous Short Circuit Current vs Temperature



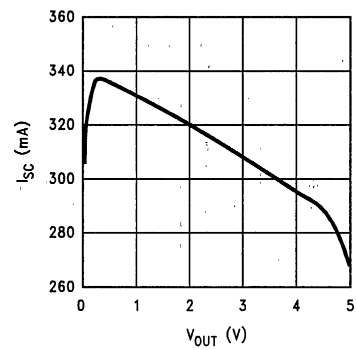
TL/H/12078-12

Short Circuit Current



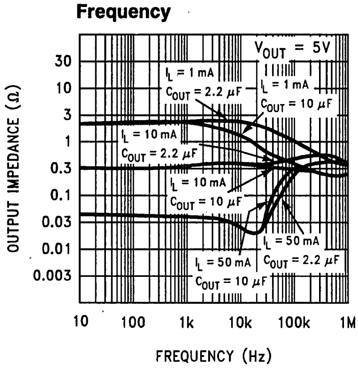
TL/H/12078-33

Instantaneous Short Circuit Current vs Output Voltage



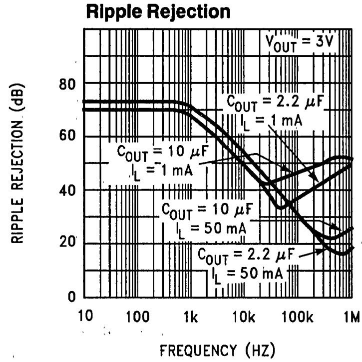
TL/H/12078-43

Output Impedance vs Frequency



TL/H/12078-44

Ripple Rejection

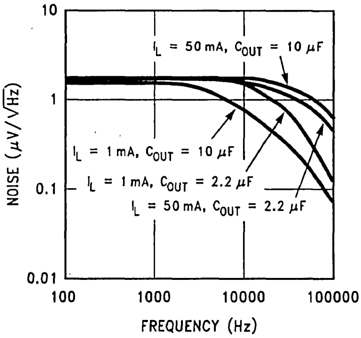


TL/H/12078-25

Typical Performance Characteristics (Continued)

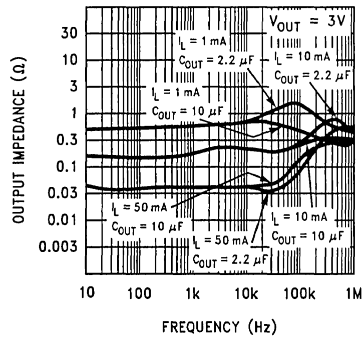
Unless otherwise specified: $T_A = 25°C$, $V_{IN} = V_{O(NOM)} + 1V$, $C_{OUT} = 2.2\ \mu F$, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

Output Noise Density



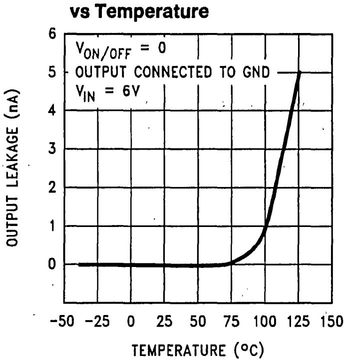
TL/H/12078-27

Output Impedance vs Frequency



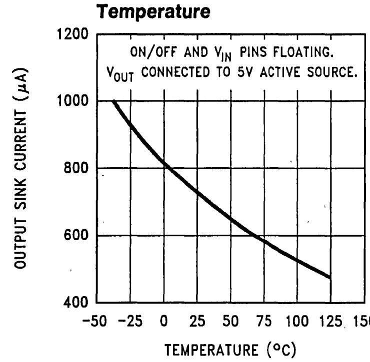
TL/H/12078-26

Input to Output Leakage vs Temperature



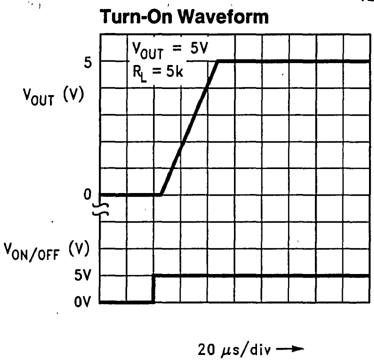
TL/H/12078-28

Output Reverse Leakage vs Temperature



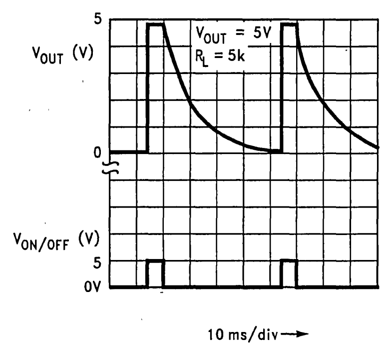
TL/H/12078-29

Turn-On Waveform



TL/H/12078-30

Turn-Off Waveform

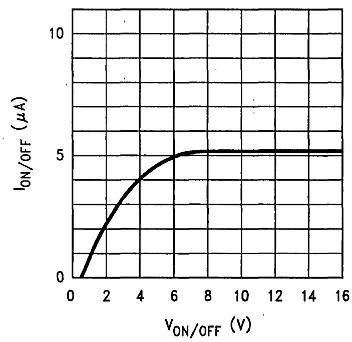


TL/H/12078-31

Typical Performance Characteristics (Continued)

Unless otherwise specified:
$T_A = 25°C$, $V_{IN} = V_{O(NOM)} + 1V$, $C_{OUT} = 2.2\ \mu F$, all voltage options, ON/$\overline{OFF}$ pin tied to V_{IN}.

ON/OFF Pin Current vs $V_{ON/OFF}$



TL/H/12078–45

Application Hints

OUTPUT CAPACITOR

Like any low-dropout regulator, the LP2980 requires an output capacitor to maintain regulator loop stability. This capacitor must be selected to meet the requirements of minimum capacitance and equivalent series resistance (ESR) range. It is not difficult to find capacitors which meet the criteria of the LP2980, as the acceptable capacitance and ESR ranges are wider than for most other LDOs.

In general, the capacitor value must be at least 1 μF (over the actual ambient operating temperature), and the ESR must be within the range indicated in *Figures 1, 2,* and *3*. It should be noted that, although a maximum ESR is shown in these Figures, it is very unlikely to find a capacitor with ESR that high.

Tantalum Capacitors

Surface-mountable solid tantalum capacitors offer a good combination of small physical size for the capacitance value, and ESR in the range needed by the LP2980.

The results of testing the LP2980 stability with surface-mount solid tantalum capacitors show good stability with values of at least 1 μF. The value can be increased to 2.2 μF (or more) for even better performance, including transient response and noise.

Small value tantalum capacitors that have been verified as suitable for use with the LP2980 are shown in Table II. Capacitance values can be increased without limit.

Aluminum Electrolytic Capacitors

Although probably not a good choice for a production design, because of relatively large physical size, an aluminum electrolytic capacitor can be used in the design prototype for an LP2980 regulator. A value of at least 1 μF should be used, and the ESR must meet the conditions of *Figures 1, 2,* and *3*. If the operating temperature drops below 0°C, the regulator may not remain stable, as the ESR of the aluminum electrolytic capacitor will increase, and may exceed the limits indicated in the Figures.

TABLE II. Surface-Mount Tantalum Capacitor Selection Guide

1 μF Surface-Mount Tantalums	
Manufacturer	**Part Number**
Kemet	T491A105M010AS
NEC	NRU105M10
Siemens	B45196-E3105-K
Nichicon	F931C105MA
Sprague	293D105X0016A2T
2.2 μF Surface-Mount Tantalums	
Manufacturer	**Part Number**
Kemet	T491A225M010AS
NEC	NRU225M06
Siemens	B45196/2.2/10/10
Nichicon	F930J225MA
Sprague	293D225X0010A2T

Multilayer Ceramic Capacitors

Surface-mountable multilayer ceramic capacitors may be an attractive choice because of their relatively small physical size and excellent RF characteristics. However, they sometimes have ESR values lower than the minimum required by the LP2980, and relatively large capacitance change with temperature. The manufacturer's datasheet for the capacitor should be consulted before selecting a value.

Test results of LP2980 stability using multilayer ceramic capacitors show that a minimum value of 2.2 μF is usually needed for the 5V regulator. For the lower output voltages, or for better performance, a higher value should be used, such as 4.7 μF.

Multilayer ceramic capacitors that have been verified as suitable for use with the LP2980 are shown in Table III.

TABLE III. Surface-Mount Multilayer Ceramic Capacitor Selection Guide

2.2 μF Surface-Mount Ceramic	
Manufacturer	**Part Number**
Tokin	1E225ZY5U-C203
Murata	GRM42-6Y5V225Z16
4.7 μF Surface-Mount Ceramic	
Manufacturer	**Part Number**
Tokin	1E475ZY5U-C304

Application Hints (Continued)

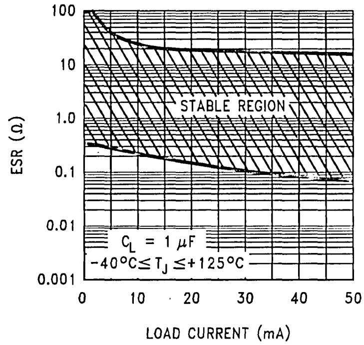


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FIGURE 1. 1 µF ESR Range

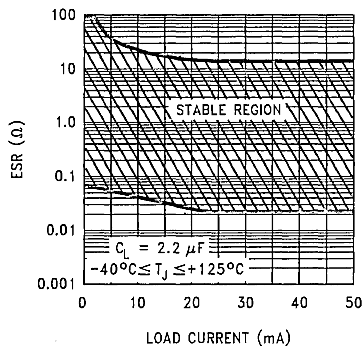

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FIGURE 2. 2.2 µF ESR Range

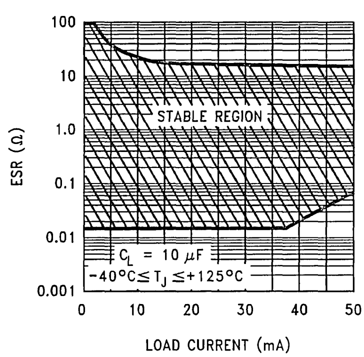

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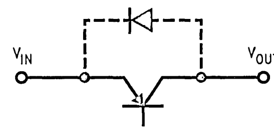
FIGURE 3. 10 µF ESR Range

REVERSE CURRENT PATH

The power transistor used in the LP2980 has an inherent diode connected between the regulator input and output (see below).



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If the output is forced above the input by more than a V_{BE}, this diode will become forward biased and current will flow from the V_{OUT} terminal to V_{IN}. No damage to the LP2980 will occur under these conditions as long as the current flowing into the output pin does not exceed 100 mA.

ON/OFF INPUT OPERATION

The LP2980 is shut off by pulling the ON/OFF input low, and turned on by driving the input high. If this feature is not to be used, the ON/OFF input should be tied to V_{IN} to keep the regulator on at all times (the ON/OFF input must **not** be left floating).

To ensure proper operation, the signal source used to drive the ON/OFF input must be able to swing above and below the specified turn-on/turn-off voltage thresholds which guarantee an ON or OFF state (see Electrical Characteristics).

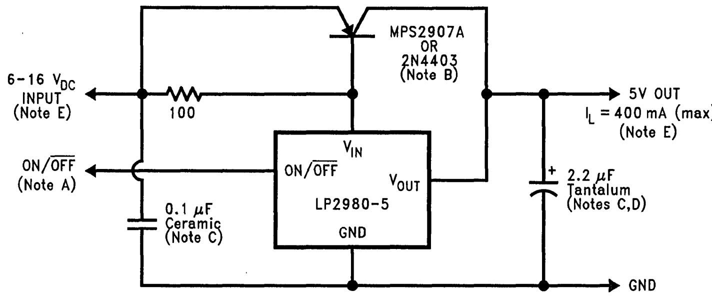
The ON/OFF signal may come from either a totem-pole output, or an open-collector output with pull-up resistor to the LP2980 input voltage or another logic supply. The high-level voltage may exceed the LP2980 input voltage, but must remain within the Absolute Maximum Ratings for the ON/OFF pin.

It is also important that the turn-on/turn-off voltage signals applied to the ON/OFF input have a slew rate which is greater than 40 mV/µs.

Important: the regulator shutdown function will operate incorrectly if a slow-moving signal is applied to the ON/OFF input.

Typical Applications

5V/400 mA Regulator



TL/H/12078-51

The LP2980 can be used to control higher-current regulators, by adding an external PNP pass device. With the PNP transistors shown, the output current can be as high as 400 mA, as long as the input voltage is held within the Safe Operation Boundary Curves shown below.

To ensure regulation, the minimum input voltage of this regulator is 6V. This "headroom" is the sum of the V_{BE} of the external transistor and the dropout voltage of the LP2980.

Notes:

A. Drive this input with a logic signal (see Application Hints). If the shutdown function is not to be used, tie the ON/OFF pin directly to the V_{IN} pin.

B. Recommended devices (other PNP transistors can be used if the current gain and voltage ratings are similar).

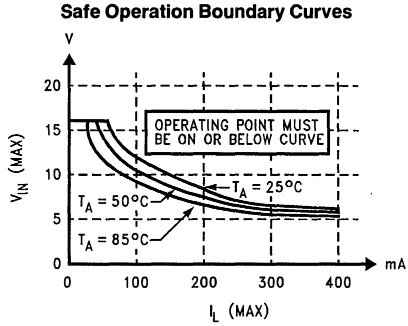
C. Capacitor is required for regulator stability. Minimum size is shown, and may be increased without limit.

D. Increasing the output capacitance improves transient response and increases phase margin.

E. Maximum safe input voltage and load current are limited by power dissipation in the PNP pass transistor and the maximum ambient temperature for the specific application. If a TO-92 transistor such as the MPS2907A is used, the thermal resistance from junction-to-ambient is 180°C/W in still air.

Assuming a maximum allowable junction temperature of 150°C for the MPS2907A device, the following curves show the maximum V_{IN} and I_L values that may be safely used for several ambient temperatures.

Safe Operation Boundary Curves



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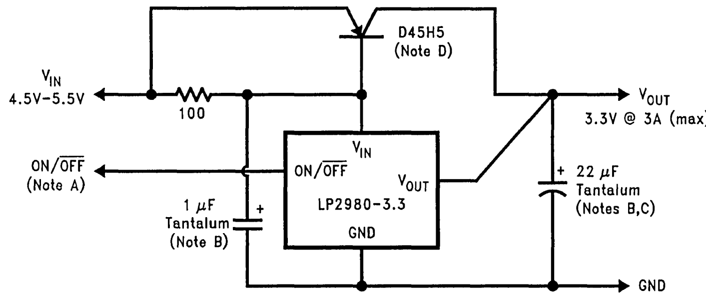
Typical Applications (Continued)

5V to 3.3V @ 3A Converter



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With limited input voltage range, the LP2980 can control a 3.3V, 3A regulator with the use of a high current-gain external PNP pass transistor. If the regulator is to be loaded with the full 3A, heat sinking will be required on the pass transistor to keep it within its rated temperature range. Refer to the Heatsink Thermal Resistance Requirements, below. For best load regulation at the high load current, the LP2980 output voltage connection should be made as close to the load as possible.

Although this regulator can handle a much higher load current than can the LP2980 alone, it can be shut down in the same manner as the LP2980. When the ON/OFF control is brought low, the converter will be in shutdown, and will draw less than 1 μA from the source.

Notes:

A. Drive this input with a logic signal (see Application Hints). If the shutdown function is not to be used, tie the ON/OFF pin directly to the V_{IN} pin.

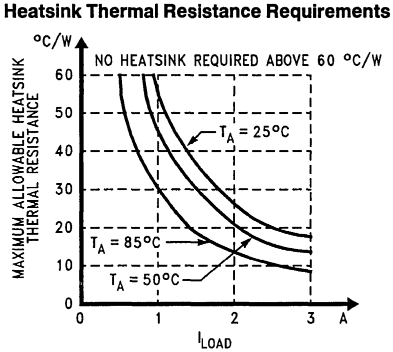
B. Capacitor is required for regulator stability. Minimum size is shown, and may be increased without limit.

C. Increasing the output capacitance improves transient response and increases phase margin.

D. A heatsink may be required for this transistor. The maximum allowable value for thermal resistance of the heatsink is dependent on ambient temperature and load current (see curves below). Once the value is obtained from the graph, a heatsink must be selected which has a thermal resistance equal to or lower than this value. If the value is above 60°C/W, no heatsink is required (the TO-220 package alone will safely dissipate this).

For these curves, a maximum junction temperature of 150°C is assumed for the pass transistor. The case-to-heatsink attachment thermal resistance is assumed to be 1.5°C/W. All calculations are for 5.5V input voltage (which is worst-case for power dissipation).

Heatsink Thermal Resistance Requirements



TL/H/12078–54

Section 3

Switching Voltage Regulators

Section 3 Contents

National Semiconductor

Switching Regulators Definition of Terms

Boost Regulator: A switching regulator topology in which a lower DC voltage is converted to a higher DC voltage. Also known as a *Step-Up Regulator*.

Buck Regulator: A switching regulator topology in which a higher DC voltage is converted to a lower DC voltage. Also known as a *Step-Down Regulator*.

Buck-Boost Regulator: A switching regulator topology in which a positive DC voltage is converted to a negative DC voltage without the use of a transformer. A variation of this topology produces a positive DC output voltage which is between the positive DC input voltage maximum and minimum limits, i.e., providing both buck and boost functions.

Burst Mode: The mode of operation in a switching regulator that results when the load current is reduced to the point where the minimum duty cycle of each pulse provides more energy than the load demands, thus causing the controller to "skip" pulses (or sets of pulses) to maintain the output voltage at its correct value.

Duty Cycle (D): The ratio of the period of time the output switch is ON to the total oscillator period.

$$D = t_{ON}/T$$

Capacitor Ripple Current: The RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature. This parameter is specified by the capacitor manufacturer, and must be considered when a capacitor is used as part of a switching regulator input or output filter.

Catch Diode: The diode which provides a return path for the load current when the regulator switch is OFF. For switching regulators, the types of diodes normally used include Schottky-barrier, fast-recovery, and ultra-fast recovery. Also known as a *steering diode* or *free-wheeling diode*.

Collector Saturation Voltage: With the emitter grounded and the switch ON, the collector-to-emitter voltage of an NPN transistor switch at a specified collector current.

Compensation: The circuitry required to provide adequate stability for the regulator control loop.

Continuous Mode Operation: Relates to the inductor current. In the continuous mode, the inductor current is always greater than zero. In discontinuous mode, the inductor current falls to zero before the end of each switching cycle.

Current Limit Sense Voltage: For regulator ICs that have externally-controlled current limit, the current limit sense voltage is the voltage that must be applied (between two specified pins) to turn the output transistor OFF and start other current limit functions within the IC.

Current-Mode Control: A method of feedback control used in switching regulators where both the output voltage and the switch current are used to control the switching element.

Diode Recovery Time: The period of time it takes the current through a diode to return to zero after the forward voltage is removed (i.e., the diode is turned OFF).

Discontinuous Mode Operation: See *Continuous Mode Operation*.

Efficiency (η): The proportion of input power actually delivered to the load.

$$n = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

Electromagnetic Interference (EMI): A generic term which is used to refer to any type of unwanted electromagnetic radiation coming from a system such as a switching regulator.

Emitter Saturation Voltage: With the collector pulled up to the DC input voltage and the switch ON, the collector-to-emitter voltage of a NPN transistor switch at a specified emitter current.

Error Amplifier (or Comparator): An amplifier (or comparator) which is used to detect the difference between a feedback voltage (usually proportional to the output voltage) and a DC reference voltage. The resulting error voltage is used in the regulator control circuitry to adjust the switch on-time. This error amplifier may be either a transconductance-type or an operational amplifier.

ESR: A parasitic element of every capacitor, the ESR (equivalent series resistance) is the purely resistive component of a real capacitor's impedance. It is modeled as a resistor in series with the capacitive element, and its value is usually determined by the device construction.

ESL: A parasitic element of every capacitor, which limits its effectiveness at high frequencies. The ESL (equivalent series inductance) is the pure inductance component of a device. Its value is usually determined by the device construction, especially its leads. It is modeled as an inductor in series with the capacitive element.

$E \bullet T_{OP}$: See *Operating Volt-Microsecond Constant*.

Flyback Regulator: A switching regulator topology in which a DC voltage is converted to another DC voltage by means of a transformer which stores energy delivered by a switch during the switch ON time, and transfers the energy to an output storage capacitor during the switch OFF time.

Inductor Ripple Current (ΔI_{IND}): The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode.

Inductor Saturation: The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, its inductance appears to decrease and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

Inverting Regulator: A switching regulator which converts a positive DC voltage to a negative DC voltage. The *buck-boost* topology is often used for this function.

Magnetic Flux Interference: Unwanted interference emitted by magnetic components (transformers and inductors) in the form of magnetic flux. Magnetic flux interference can be minimized by the use of magnetic cores (such as toroid or pot core) which contain the flux, or by shielding with materials such as steel or mu-metal. Aluminum and copper are not effective in shielding flux.

Operating Volt-Microsecond Constant: The product (in Volts $\times$ microseconds) of the voltage applied to the switching regulator inductor and the period of time the voltage is applied. Abbreviated as $E \bullet T_{OP}$, this constant is a measure of the energy-handling capability of an inductor, and is dependent upon the type of core used, its core area, the number of turns of wire used, and the applied duty cycle.

Oscillator Frequency: The frequency of the internal oscillator used in the control of the switching regulator. Generally the same as the *switching frequency*, for most regulators the oscillator frequency is fixed, either internally or by an external resistor and/or capacitor.

Output Ripple Voltage: The AC component of the switching regulator output voltage. it is usually dominated by the output capacitor ESR multiplied by the applied ripple current, but may have high-frequency spikes caused by effects of output capacitor ESL.

Pulse-Width Modulation (PWM): A method of control used in a switching regulator where the duty cycle of the switching element is used to control the output voltage.

Radio Frequency Interference (RFI): High-frequency electromagnetic radiation resulting from the high switching speeds of switching transistors and rectifiers, often causing problems in nearby circuitry that is sensitive to the large noise "spikes" that are often associated with it. RFI can be easily shielded by a good electrical conductor such as copper or aluminum.

Snubber: A network used to limit the voltage developed across a component. The network usually consists of a zener diode, or a diode in series with a parallel resistor and capacitor. In a switching regulator, the snubber is most often used to limit the switch voltage of a flyback regulator.

Soft Start: In a switching regulator, a soft start limits the duty cycle of the regulator during startup. This in turn limits the energy the regulator demands from its source while building up the output voltage from its initial condition of 0V.

Standby Quiescent Current: For a regulator with an ON/OFF pin, this is the supply current (or ground pin current) required by the regulator IC when in the standby (OFF) mode.

Switch: In a switching regulator, a transistor or MOSFET used to deliver energy, in pulses, into energy storage devices (such as inductors, transformers, or capacitors) for use by a load.

Switching Frequency: See *Oscillator Frequency*.

Step Response: The transient response of a regulator output after the load current is "stepped" from one value to another. This test is often used for evaluating the loop stability of a regulator.

Transient Response Time: The period of time it takes the output of a regulator to return to a steady-state value after a change in line voltage or load current. See also *Step Response*.

Voltage Mode Control: A method of control used in a switching regulator where feedback from the output voltage is used to provide control of the switching element.

National Semiconductor

Switching Voltage Regulators Selection Guide

DC/DC Voltage Converters

Output Current (A)	Device	Standard Operating Modes	Input Voltage (V)	Output Voltage (V)	Switching Frequency (kHz)	Efficiency (%)	Operating Temperature (Tj °C)	Package Availability**	Page No.
3.0	LM1577*	Step-Up, Flyback	3.5 to 40	12, 15, Adjustable	52	80	−55 to +150	K4***	3-80
	LM2577*	Step-Up, Flyback	3.5 to 40	12, 15, Adjustable	52	80	−40 to +125	M24, N16, S5, T5	3-80
	LM2576	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	−40 to +125	S5, T5	3-63
	LM2576HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	−40 to +125	T5	3-63
1.0	LM1575	Step-Down	4 to 40	5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	−55 to +150	K4***	3-45
	LM2575	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	−40 to +125	M24, N16, S5, T5	3-45
	LM2575HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	−40 to +125	M24, N16, S5, T5	3-45
0.5	LM2574	Step-Down	4 to 40	3.3, 5, 12, 15, Adj. (1.23 to 37)	52	77 to 88	−40 to +125	M14, N8	3-27
	LM2574HV	Step-Down	4 to 60	3.3, 5, 12, 15, Adj. (1.23 to 57)	52	77 to 88	−40 to +125	M14, N8	3-27
0.05	LMC7660I	Invert	1.5 to 10	−1.5 to −10	10	90	−40 to +125	N8	3-202

*The 3.0A specification indicates the rated operating switch current of the LM1577, and LM2577.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: TS = 5-Lead TO-220, and M14 = 14-Lead Surface Mount.

K: Metal Can (TO-3)
M: Small Outline Molded Package (Surface Mount)
N: Molded Dual-In-Line Package
S: TO-263 (Power Surface Mount)
T: TO-220

***Available in indicated package only as a military specified device.

Switching Voltage Regulators

Switch Current (A)	Device	Standard Operating Modes	Input Voltage (V)	Output Voltage (V)	Switching Frequency (kHz)	Operating Temperature (Tj °C)	Package Availability**	Page No.
5.0	LH1605	Step-Down	8 to 35	3 to 30	6 to 100	−55 to +150	K8	3-7
	LH1605C	Step-Down	8 to 35	3 to 30	6 to 100	−25 to +150	K8	3-7
1.5	LM78S40	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	−55 to +150	J16***	3-195
	LM78S40	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	−40 to +125	N16	3-195
	LM78S40C	Step-Up, Step-Down, Invert	2.5 to 50	Adjustable	0.1 to 100	0 to +125	N16	3-195
0.75	LM1578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	−55 to +150	H8***	3-102
	LM2578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	−40 to +125	M8, N8	3-102
	LM3578A	Step-Up, Step-Down, Flyback, Invert	2 to 40	Adjustable	0.001 to 100	0 to +125	M8, N8	3-102
0.2*	LM2524D	Step-Up, Step-Down, Flyback, Invert	5 to 40	Adjustable	1 to 550	−40 to +125	N16	3-10
	LM3524D	Step-Up, Step-Down, Flyback, Invert	5 to 40	Adjustable	1 to 350	0 to +125	M16, N16	3-10

*Switch current specification is the maximum capability for each of the dual internal NPN transistors.

**Under Package Availability the letter identifies the type of package available and the number indicates the number of leads of the package.
For example: TS = 5-Lead TO-220, and M14 = 14-Lead Surface Mount.

H: Metal Can (TO-99)
J: Ceramic Dual-In-Line Package
K: Metal Can (TQ-3)
M: Small Outline Molded Package (Surface Mount)
N: Molded Dual-In-Line Package

***Available in indicated package only as a military specified device.

National Semiconductor

LH1605/LH1605C
5 Amp, High Efficiency Switching Regulator

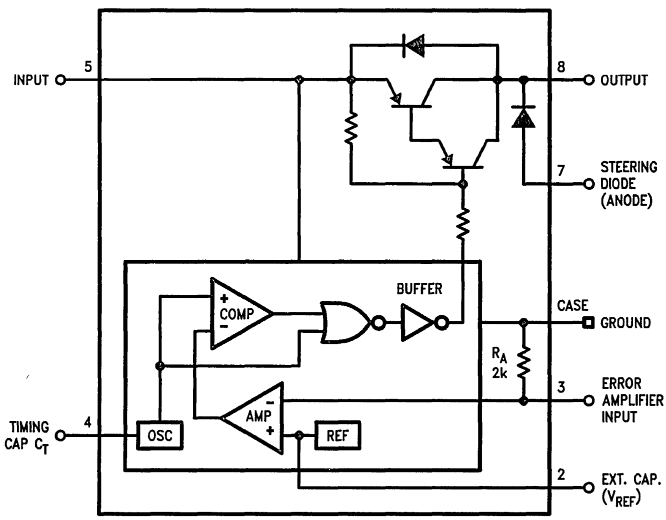
General Description

The LH1605 is a hybrid switching regulator with high output current capabilities. It incorporates a temperature-compensated voltage reference, a duty cycle modulator with the oscillator frequency programmable, error amplifier, high current-high voltage output switch, and a power diode. The LH1605 can supply up to 5A of output current over a wide range of regulated output voltage.

Features

- Step down switching regulator
- Output adjustable from 3.0V to 30V
- 5A output current
- High efficiency
- Frequency adjustable to 100 kHz
- Standard 8-pin TO-3 package

Block and Connection Diagrams



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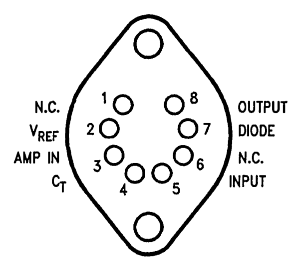
Case is Ground



TL/K/10114-2

Top View

Order Number LH1605K or LH1605CK
See NS Package Number K08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

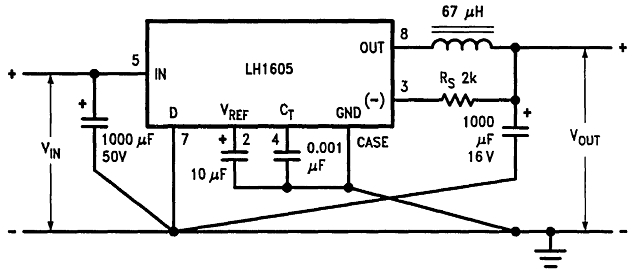
Input Voltage (V_{IN})	35V max
Output Current (I_O)	6A
Operating Temperature (T_J)	150°C
Internal Power Dissipation (P_D) (Note 1)	20W
Operating Temperature (T_A)	
LH1605C	−25°C to +85°C
LH1605	−55°C to +125°C
Storage Temperature Range (T_{STG})	−65°C to +150°C
Duty Cycle (D.C.)	20% to 80%
Steering Diode Reverse Voltage (V_R) (V_{8-7})	60V
Steering Diode Forward Current (I_D) (I_{7-8})	6A

Electrical Characteristics $T_C = 25°C, V_{IN} = 15V, V_{OUT} = 10V$ unless otherwise specified

Symbol	Characteristics	Conditions	LH1605			LH1605C			Units
			Min	Typ	Max	Min	Typ	Max	
V_{OUT}	Output Voltage Range	$V_{IN} \geq V_O + 5V$ $I_O = 2A$ (Note 2)	3.0		30	3.0		30	V
V_S	Switch Saturation Voltage	$I_C = 5.0A$ $I_C = 2.0A$		1.6 1.0	2.0 1.2		1.6 1.0	2.0 1.2	V
V_F	Steering Diode On Voltage	$I_D = 5.0A$ $I_D = 2.0A$		1.2 1.0	2.8 2.0		1.2 1.0	2.8 2.0	V
V_{IN}	Supply Voltage Range		10		35	10		35	V
I_R	Steering Diode Reverse Current	$V_R = 25V$		0.1	5.0		0.1	5.0	μA
I_Q	Quiescent Current	$I_{OUT} = 0.2A$		20			20		mA
V_2	Voltage on Pin 2			2.5			2.5		V
$\Delta V_2/\Delta T$	V_2 Temperature Coeff.			100			100		ppm/°C
V_4	Voltage Swing—Pin 4			3.0			3.0		V
I_4	Charging Current—Pin 4			70			70		μA
R_A	Resistance Pin 3 to GND			2.0			2.0		kΩ
$\Delta R_A/\Delta T$	Resistance Temp. Coeff.			75			75		ppm/°C
t_r	Voltage Rise Time	$I_{OUT} = 2.0A$ $I_{OUT} = 5.0A$		350 500			350 500		ns
t_f	Voltage Fall Time	$I_{OUT} = 2.0A$ $I_{OUT} = 5.0A$		300 400			300 400		ns
t_s	Storage Time	$I_{OUT} = 5.0A$		1.5			1.5		μs
t_d	Delay Time			100			100		ns
P_D	Power Dissipation	$V_{OUT} = 10V$ $I_{OUT} = 5.0A$		16			16		W
η	Efficiency			75			75		%
θ_{JC}	Thermal Resistance (Note 1)			5.0			5.0		°C/W

Note 1: θ_{JA} is typically 30°C/W for natural convection cooling.

Note 2: V_{OUT} refers to the output voltage range of switching supply after the output LC filter as shown in the Typical Application circuit.



TL/K/10114–3

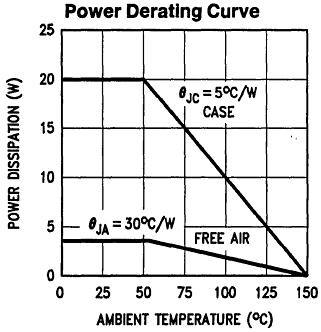
Minimum $V_{IN} - V_{OUT} = 5V$ for Proper Operation

$$R_S = \frac{2 \times 10^3 (V_{OUT} - 2.5)}{2.5}$$

$V_{IN} = 10 - 18V$
$V_{OUT} = 5V$
$I_{OUT} = 3A$ (Max)
$I_{OUT} = 1A$ (Min)
$\eta \cong 70\%$

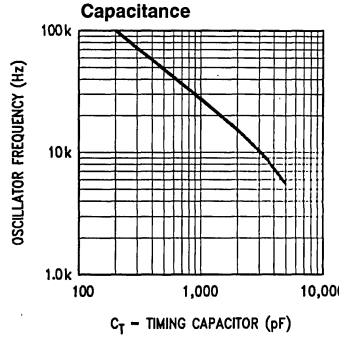
Load Reg. = 50 mV
Line Reg. = 10 mV
Ripple = 20 mV

Power Derating Curve



TL/K/10114–4

Frequency vs Timing Capacitance



TL/K/10114–5

Design Equations

$$\text{Efficiency } (\eta) = \frac{P_{OUT} \times 100}{P_{IN}}$$

$$\text{Transistor DC Losses } (P_T) = I_{OUT} \times V_S \left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right)$$

$$\text{Diode DC Losses } (P_D) = I_{OUT} \times V_F \left(\frac{t_{OFF}}{t_{ON} + t_{OFF}}\right)$$

$$\text{Drive Circuit Losses } (D_L) = \frac{V_{IN}^2}{300} \times \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

$$\text{Switching Losses Transistor } (P_S) = V_{IN} \times I_{OUT} \times \frac{t_r + t_f}{2(t_{ON} + t_{OFF})}$$

$$\text{Transistor Duty Cycle} = \frac{t_{ON}}{t_{ON} + t_{OFF}} = \frac{V_{OUT}}{V_{IN}}$$

$$\text{Diode Duty Cycle} = \frac{t_{OFF}}{t_{ON} + t_{OFF}} = 1 - \frac{V_{OUT}}{V_{IN}}$$

$$\text{Power Inductor } (P_L) = I_{OUT}^2 \times R_L \text{ (Winding Resistance)}$$

$$\text{Efficiency } (\eta) = \frac{V_{OUT} I_{OUT}}{V_{OUT} I_{OUT} + P_T + P_D + D_L + P_S + P_L} \times 100\%$$

3

National Semiconductor

LM2524D/LM3524D Regulating Pulse Width Modulator

General Description

The LM3524D family is an improved version of the industry standard LM3524. It has improved specifications and additional features yet is pin for pin compatible with existing 3524 families. New features reduce the need for additional external circuitry often required in the original version.

The LM3524D has a ±1% precision 5V reference. The current carrying capability of the output drive transistors has been raised to 200 mA while reducing V_{CEsat} and increasing V_{CE} breakdown to 60V. The common mode voltage range of the error-amp has been raised to 5.5V to eliminate the need for a resistive divider from the 5V reference.

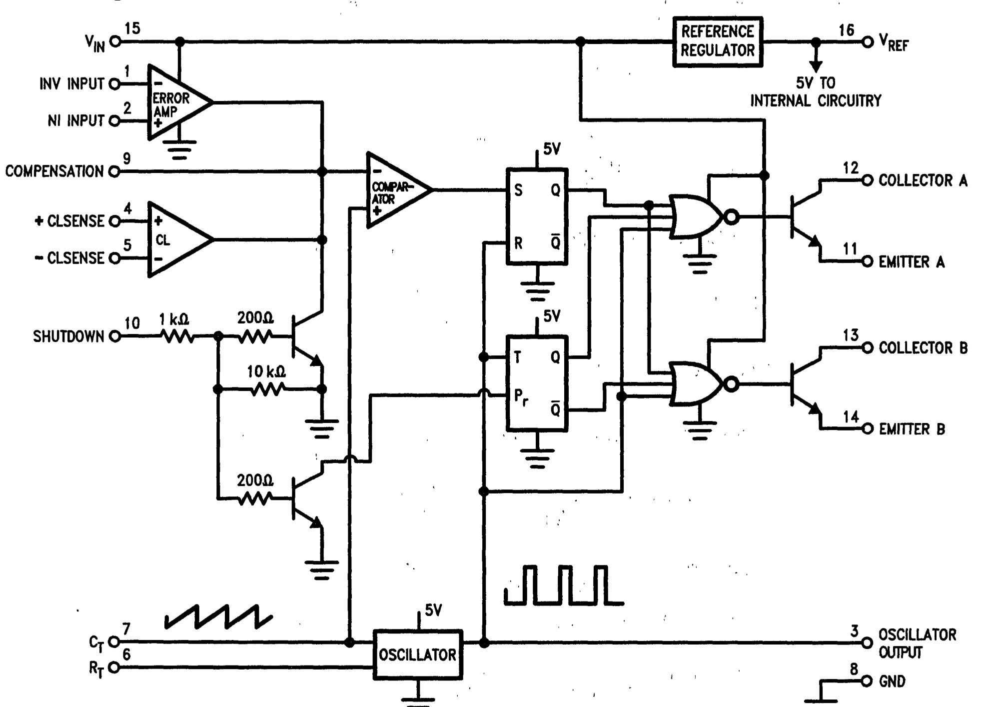
In the LM3524D the circuit bias line has been isolated from the shut-down pin. This prevents the oscillator pulse amplitude and frequency from being disturbed by shut-down. Also at high frequencies (≅300 kHz) the max. duty cycle per output has been improved to 44% compared to 35% max. duty cycle in other 3524s.

In addition, the LM3524D can now be synchronized externally, through pin 3. Also a latch has been added to insure one pulse per period even in noisy environments. The LM3524D includes double pulse suppression logic that insures when a shut-down condition is removed the state of the T-flip-flop will change only after the first clock pulse has arrived. This feature prevents the same output from being pulsed twice in a row, thus reducing the possibility of core saturation in push-pull designs.

Features

- Fully interchangeable with standard LM3524 family
- ±1% precision 5V reference with thermal shut-down
- Output current to 200 mA DC
- 60V output capability
- Wide common mode input range for error-amp
- One pulse per period (noise suppression)
- Improved max. duty cycle at high frequencies
- Double pulse suppression
- Synchronize through pin 3

Block Diagram



TL/H/8650-1

Absolute Maximum Ratings (Note 5)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	40V
Collector Supply Voltage	
(LM2524D)	55V
(LM3524D)	40V
Output Current DC (each)	200 mA
Oscillator Charging Current (Pin 7)	5 mA
Internal Power Dissipation	1W
Operating Junction Temperature Range (Note 2)	
LM2524D	−40°C to +125°C
LM3524D	0°C to +125°C
Maximum Junction Temperature	150°
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering 4 sec.) M, N Pkg.	260°C

Electrical Characteristics (Note 1)

Symbol	Parameter	Conditions	LM2524D			LM3524D			Units
			Typ	Tested Limit (Note 3)	Design Limit (Note 4)	Typ	Tested Limit (Note 3)	Design Limit (Note 4)	
REFERENCE SECTION									
V_{REF}	Output Voltage		5	4.85	**4.80**	5	4.75		V_{Min}
				5.15	**5.20**		5.25		V_{Max}
V_{RLine}	Line Regulation	V_{IN} = 8V to 40V	10	15	**30**	10	25	50	mV_{Max}
V_{RLoad}	Load Regulation	I_L = 0 mA to 20 mA	10	15	**25**	10	25	50	mV_{Max}
$\frac{\Delta V_{IN}}{\Delta V_{REF}}$	Ripple Rejection	f = 120 Hz	66			66			dB
I_{OS}	Short Circuit Current	V_{REF} = 0	50	25		50	25		mA Min
				180			200		mA Max
N_O	Output Noise	10 Hz ≤ f ≤ 10 kHz	40		100	40		100	$\mu V_{rms\ Max}$
	Long Term Stability	T_A = 125°C	20			20			mV/kHr
OSCILLATOR SECTION									
f_{OSC}	Max. Freq.	R_T = 1k, C_T = 0.001 μF (Note 7)	550		500	350			kHz_{Min}
f_{OSC}	Initial Accuracy	R_T = 5.6k, C_T = 0.01 μF (Note 7)	20	17.5		20	17.5		kHz_{Min}
				22.5			22.5		kHz_{Max}
		R_T = 2.7k, C_T = 0.01 μF (Note 7)	38	34		38	30		kHz_{Min}
				42			46		kHz_{Max}
Δf_{OSC}	Freq. Change with V_{IN}	V_{IN} = 8 to 40V	0.5	1		0.5	1.0		$\%_{Max}$
Δf_{OSC}	Freq. Change with Temp.	T_A = −55°C to +125°C at 20 kHz R_T = 5.6k, C_T = 0.01 μF	5			5			%
V_{OSC}	Output Amplitude (Pin 3) (Note 8)	R_T = 5.6k, C_T = 0.01 μF	3	2.4		3	2.4		V_{Min}
t_{PW}	Output Pulse Width (Pin 3)	R_T = 5.6k, C_T = 0.01 μF	0.5	1.5		0.5	1.5		μs_{Max}

3

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	LM2524D Typ	LM2524D Tested Limit (Note 3)	LM2524D Design Limit (Note 4)	LM3524D Typ	LM3524D Tested Limit (Note 3)	LM3524D Design Limit (Note 4)	Units
OSCILLATOR SECTION (Continued)									
	Sawtooth Peak Voltage	R_T = 5.6k, C_T = 0.01 μF	3.4	3.6	**3.8**		3.8		V_{Max}
	Sawtooth Valley Voltage	R_T = 5.6k, C_T = 0.01 μF	1.1	0.8	**0.6**		0.6		V_{Min}
ERROR-AMP SECTION									
V_{IO}	Input Offset Voltage	V_{CM} = 2.5V	2	8	**10**	2	10		mV_{Max}
I_{IB}	Input Bias Current	V_{CM} = 2.5V	1	8	**10**	1	10		μA_{Max}
I_{IO}	Input Offset Current	V_{CM} = 2.5V	0.5	1.0	**1**	0.5	1		μA_{Max}
I_{COSI}	Compensation Current (Sink)	$V_{IN(I)} - V_{IN(NI)}$ = 150 mV	95	65 125		95	65 125		μA_{Min} μA_{Max}
I_{COSO}	Compensation Current (Source)	$V_{IN(NI)} - V_{IN(I)}$ = 150 mV	−95	−125 −65		−95	−125 −65		μA_{Min} μA_{Max}
A_{VOL}	Open Loop Gain	$R_L = \infty$, V_{CM} = 2.5 V	80	74	**60**	80	70	60	dB_{Min}
VCMR	Common Mode Input Voltage Range			1.5 5.5	**1.4** **5.4**		1.5 5.5		V_{Min} V_{Max}
CMRR	Common Mode Rejection Ratio		90	80		90	80		dB_{Min}
G_{BW}	Unity Gain Bandwidth	A_{VOL} = 0 dB, V_{CM} = 2.5V	3			2			MHz
V_O	Output Voltage Swing	$R_L = \infty$		0.5 5.5			0.5 5.5		V_{Min} V_{Max}
PSRR	Power Supply Rejection Ratio	V_{IN} = 8 to 40V	80		70	80	65		db_{Min}
COMPARATOR SECTION									
$\frac{t_{ON}}{t_{OSC}}$	Minimum Duty Cycle	Pin 9 = 0.8V, [R_T = 5.6k, C_T = 0.01 μF]	0	0		0	0		$\%_{Max}$
$\frac{t_{ON}}{t_{OSC}}$	Maximum Duty Cycle	Pin 9 = 3.9V, [R_T = 5.6k, C_T = 0.01 μF]	49	45		49	45		$\%_{Min}$
$\frac{t_{ON}}{t_{OSC}}$	Maximum Duty Cycle	Pin 9 = 3.9V, [R_T = 1k, C_T = 0.001 μF]	44	35		44	35		$\%_{Min}$
V_{COMPZ}	Input Threshold (Pin 9)	Zero Duty Cycle	1			1			V
V_{COMPM}	Input Threshold (Pin 9)	Maximum Duty Cycle	3.5			3.5			V
I_{IB}	Input Bias Current		−1			−1			μA

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	LM2524D Typ	LM2524D Tested Limit (Note 3)	LM2524D Design Limit (Note 4)	LM3524D Typ	LM3524D Tested Limit (Note 3)	LM3524D Design Limit (Note 4)	Units
CURRENT LIMIT SECTION									
V_{SEN}	Sense Voltage	$V_{(Pin\ 2)} - V_{(Pin\ 1)} \geq$ 150 mV	200	180 220		200	180 220		mV_{Min} mV_{Max}
TC-V_{sense}	Sense Voltage T.C.		0.2			0.2			mV/°C
	Common Mode Voltage Range	$V_5 - V_4 = 300$ mV	−0.7 1			−0.7 1			V_{Min} V_{Max}
SHUT DOWN SECTION									
V_{SD}	High Input Voltage	$V_{(Pin\ 2)} - V_{(Pin\ 1)} \geq$ 150 mV	1	0.5 1.5		1	0.5 1.5		V_{Min} V_{Max}
I_{SD}	High Input Current	$I_{(pin\ 10)}$	1			1			mA
OUTPUT SECTION (EACH OUTPUT)									
V_{CES}	Collector Emitter Voltage Breakdown	$I_C \leq 100\ \mu A$		55			40		V_{Min}
I_{CES}	Collector Leakage Current	$V_{CE} = 60V$							
		$V_{CE} = 55V$	0.1	50					μA_{Max}
		$V_{CE} = 40V$				0.1	50		
V_{CESAT}	Saturation Voltage	$I_E = 20$ mA	0.2	0.5		0.2	0.7		V_{Max}
		$I_E = 200$ mA	1.5	2.2		1.5	2.5		
V_{EO}	Emitter Output Voltage	$I_E = 50$ mA	18	17		18	17		V_{Min}
t_R	Rise Time	$V_{IN} = 20V$, $I_E = -250\ \mu A$ $R_C = 2k$	200			200			ns
t_F	Fall Time	$R_C = 2k$	100			100			ns
SUPPLY CHARACTERISTICS SECTION									
V_{IN}	Input Voltage Range	After Turn-on		8 40			8 40		V_{Min} V_{Max}
T	Thermal Shutdown Temp.	(Note 2)	160			160			°C
I_{IN}	Stand By Current	$V_{IN} = 40V$ (Note 6)	5	10		5	10		mA

Note 1: Unless otherwise stated, these specifications apply for $T_A = T_J = 25°C$. Boldface numbers apply over the rated temperature range: LM2524D is −40° to 85°C and LM3524D is 0°C to 70°C. $V_{IN} = 20V$ and $f_{OSC} = 20$ kHz.

Note 2: For operation at elevated temperatures, devices in the N package must be derated based on a thermal resistance of 86°C/W, junction to ambient. Devices in the M package must be derated at 125°C/W, junction to ambient.

Note 3: Tested limits are guaranteed and 100% tested in production.

Note 4: Design limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage range. These limits are not used to calculate outgoing quality level.

Note 5: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

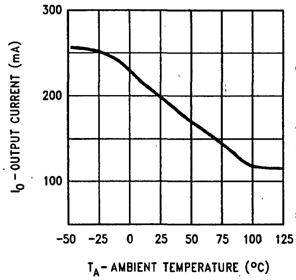
Note 6: Pins 1, 4, 7, 8, 11, and 14 are grounded; Pin 2 = 2V. All other inputs and outputs open.

Note 7: The value of a C_t capacitor can vary with frequency. Careful selection of this capacitor must be made for high frequency operation. Polystyrene was used in this test. NPO ceramic or polypropylene can also be used.

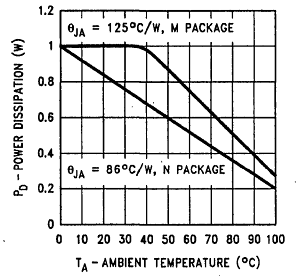
Note 8: OSC amplitude is measured open circuit. Available current is limited to 1 mA so care must be exercised to limit capacitive loading of fast pulses.

Typical Performance Characteristics

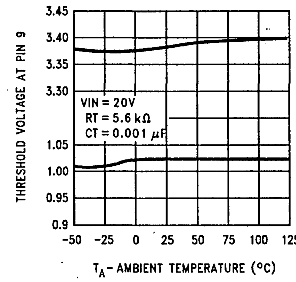
Switching Transistor Peak Output Current vs Temperature



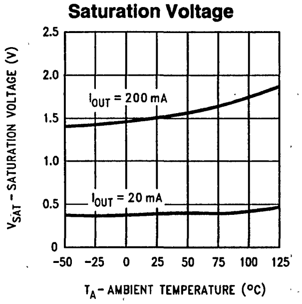
Maximum Average Power Dissipation (N, M Packages)



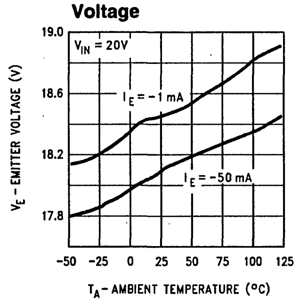
Maximum & Minimum Duty Cycle Threshold Voltage



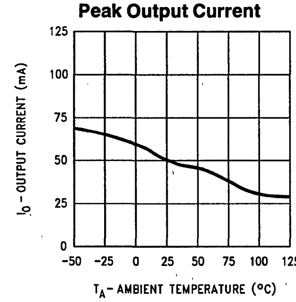
Output Transistor Saturation Voltage



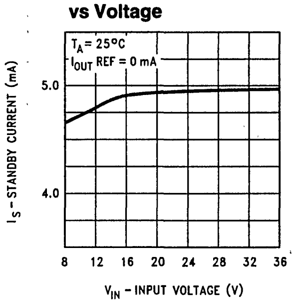
Output Transistor Emitter Voltage



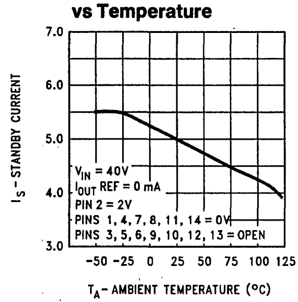
Reference Transistor Peak Output Current



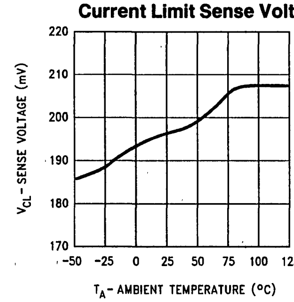
Standby Current vs Voltage



Standby Current vs Temperature

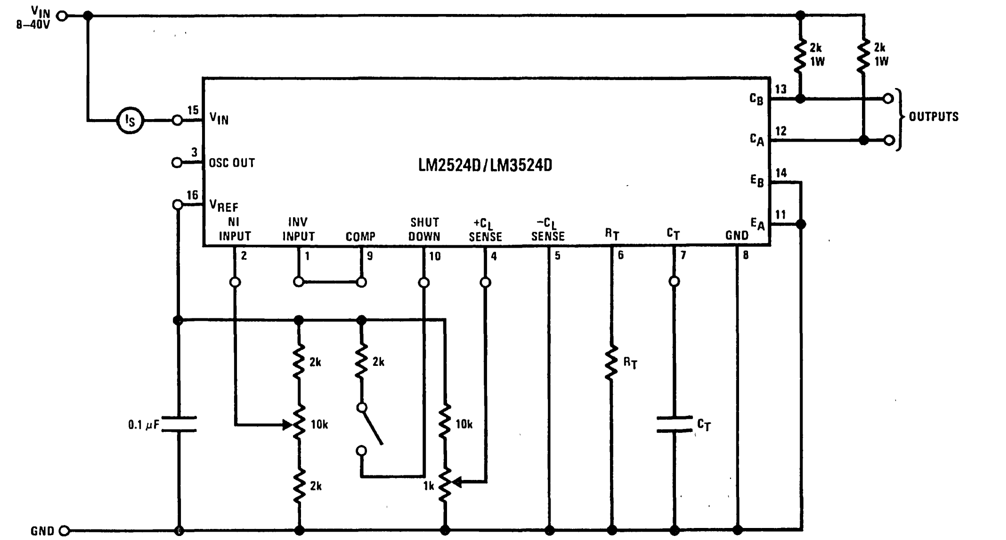


Current Limit Sense Voltage



TL/H/8650-3

Test Circuit



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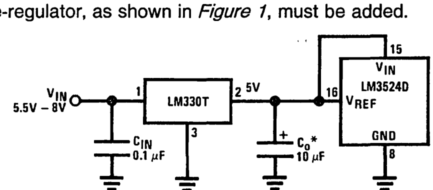
Functional Description

INTERNAL VOLTAGE REGULATOR

The LM3524D has an on-chip 5V, 50 mA, short circuit protected voltage regulator. This voltage regulator provides a supply for all internal circuitry of the device and can be used as an external reference.

For input voltages of less than 8V the 5V output should be shorted to pin 15, V_{IN}, which disables the 5V regulator. With these pins shorted the input voltage must be limited to a maximum of 6V. If input voltages of 6V–8V are to be used, a pre-regulator, as shown in *Figure 1*, must be added.



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*Minimum C_O of 10 μF required for stability.

FIGURE 1

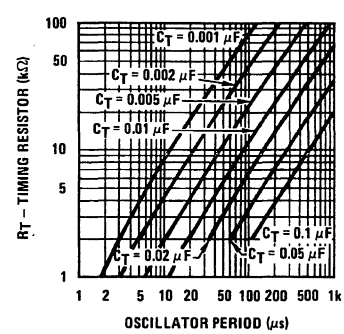
OSCILLATOR

The LM3524D provides a stable on-board oscillator. Its frequency is set by an external resistor, R_T and capacitor, C_T. A graph of R_T, C_T vs oscillator frequency is shown is *Figure 2*. The oscillator's output provides the signals for triggering an internal flip-flop, which directs the PWM information to the outputs, and a blanking pulse to turn off both outputs during transitions to ensure that cross conduction does not occur. The width of the blanking pulse, or dead time, is controlled by the value of C_T, as shown in *Figure 3*. The recommended values of R_T are 1.8 kΩ to 100 kΩ, and for C_T, 0.001 μF to 0.1 μF.

If two or more LM3524D's must be synchronized together, the easiest method is to interconnect all pin 3 terminals, tie all pin 7's (together) to a single C_T, and leave all pin 6's open except one which is connected to a single R_T. This method works well unless the LM3524D's are more than 6″ apart.

A second synchronization method is appropriate for any circuit layout. One LM3524D, designated as master, must have its R_TC_T set for the correct period. The other slave LM3524D(s) should each have an R_TC_T set for a 10% longer period. All pin 3's must then be interconnected to allow the master to properly reset the slave units.

The oscillator may be synchronized to an external clock source by setting the internal free-running oscillator frequency 10% slower than the external clock and driving pin 3 with a pulse train (approx. 3V) from the clock. Pulse width should be greater than 50 ns to insure full synchronization.



TL/H/8650-5

FIGURE 2

Functional Description (Continued)

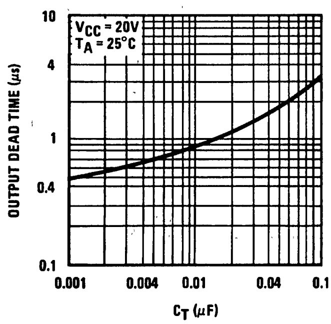


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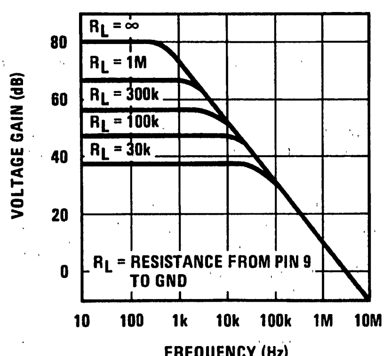
FIGURE 3

ERROR AMPLIFIER

The error amplifier is a differential input, transconductance amplifier. Its gain, nominally 86 dB, is set by either feedback or output loading. This output loading can be done with either purely resistive or a combination of resistive and reactive components. A graph of the amplifier's gain vs output load resistance is shown in *Figure 4*.



TL/H/8650-7

FIGURE 4

The output of the amplifier, or input to the pulse width modulator, can be overridden easily as its output impedance is very high ($Z_O \cong 5\ M\Omega$). For this reason a DC voltage can be applied to pin 9 which will override the error amplifier and force a particular duty cycle to the outputs. An example of this could be a non-regulating motor speed control where a variable voltage was applied to pin 9 to control motor speed. A graph of the output duty cycle vs the voltage on pin 9 is shown in *Figure 5*.

The duty cycle is calculated as the percentage ratio of each output's ON-time to the oscillator period. Paralleling the outputs doubles the observed duty cycle.

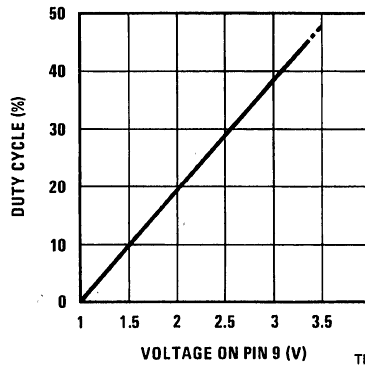


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FIGURE 5

The amplifier's inputs have a common-mode input range of 1.5V–5.5V. The on board regulator is useful for biasing the inputs to within this range.

CURRENT LIMITING

The function of the current limit amplifier is to override the error amplifier's output and take control of the pulse width. The output duty cycle drops to about 25% when a current limit sense voltage of 200 mV is applied between the $+C_L$ and $-C_L$ sense terminals. Increasing the sense voltage approximately 5% results in a 0% output duty cycle. Care should be taken to ensure the −0.7V to +1.0V input common-mode range is not exceeded.

In most applications, the current limit sense voltage is produced by a current through a sense resistor. The accuracy of this measurement is limited by the accuracy of the sense resistor, and by a small offset current, typically 100 µA, flowing from +CL to −CL.

OUTPUT STAGES

The outputs of the LM3524D are NPN transistors, capable of a maximum current of 200 mA. These transistors are driven 180° out of phase and have non-committed open collectors and emitters as shown in *Figure 6*.

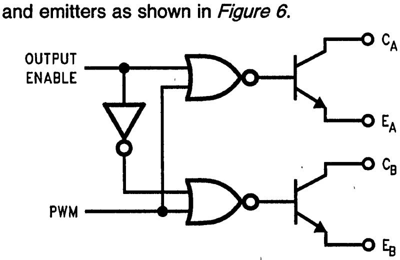

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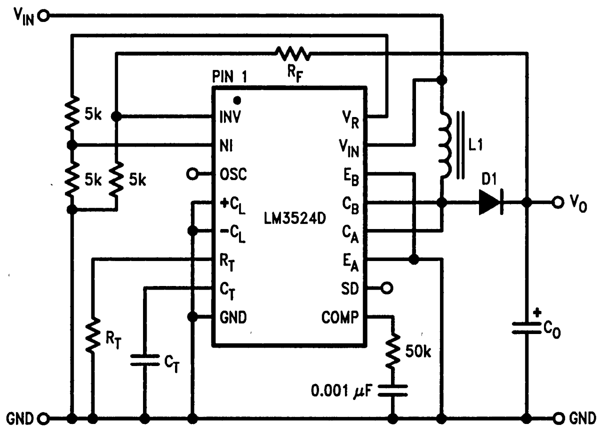
FIGURE 6

Typical Applications



Design Equations

$$R_F = 5k\left(\frac{V_o}{2.5} - 1\right)$$

$$f_{OSC} \cong \frac{1}{R_T C_T}$$

$$L1 = \frac{2.5 V_{IN}^2 (V_o - V_{IN})}{f_{OSC} I_o V_o^2}$$

$$C_o = \frac{I_o (V_o - V_{IN})}{f_{OSC}\, \Delta V_o\, V_o}$$

$$I_{o(MAX)} = I_{IN} \frac{V_{IN}}{V_o}$$

TL/H/8650-11

FIGURE 7. Positive Regulator, Step-Up Basic Configuration ($I_{IN(MAX)}$ = 80 mA)

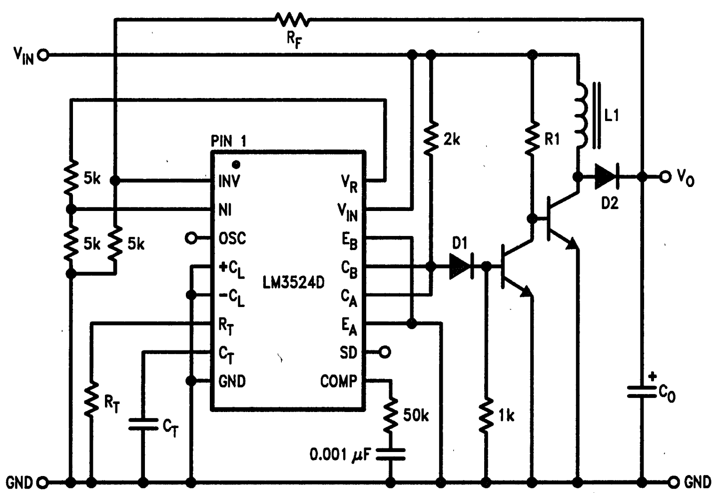


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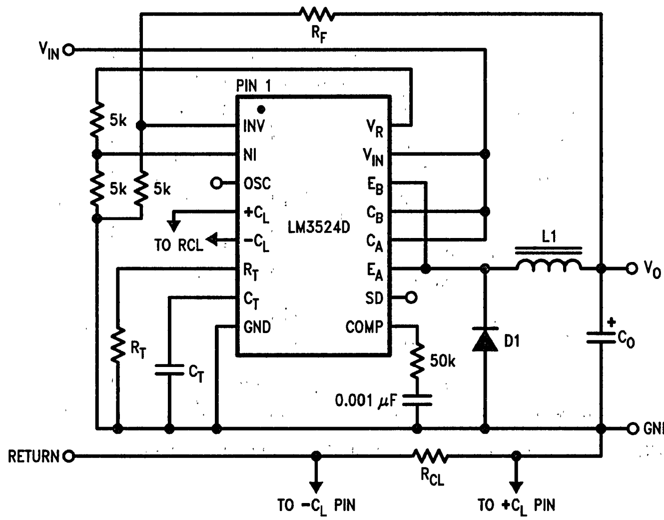
FIGURE 8. Positive Regulator, Step-Up Boosted Current Configuration

3

Typical Applications (Continued)



Design Equations

$$R_F = 5\ k\Omega \left(\frac{V_o}{2.5} - 1\right)$$

$$R_{CL} = \frac{\text{Current Limit Sense Volt}}{I_{o(MAX)}}$$

$$f_{OSC} \cong \frac{1}{R_T C_T}$$

$$L1 = \frac{2.5 V_o (V_{IN} - V_o)}{I_o V_{IN} f_{OSC}}$$

$$C_o = \frac{(V_{IN} - V_o) V_o T^2}{8\ \Delta V_o V_{IN} L1}$$

$$I_{o(MAX)} = I_{IN} \frac{V_{IN}}{V_o}$$

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FIGURE 9. Positive Regulator, Step-Down Basic Configuration ($I_{IN(MAX)}$ = 80 mA)

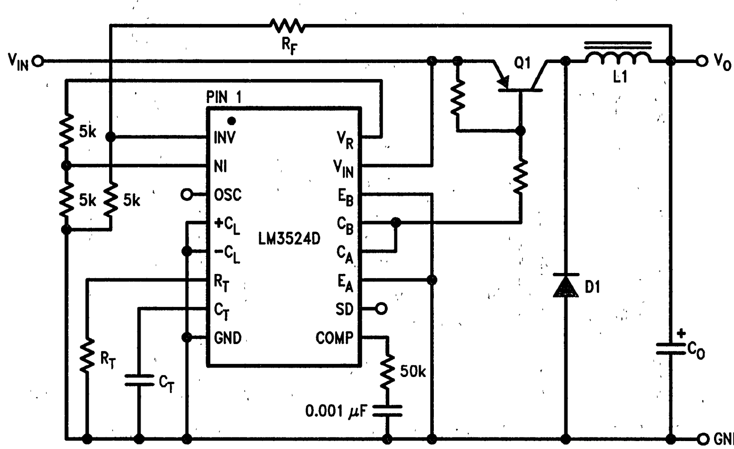

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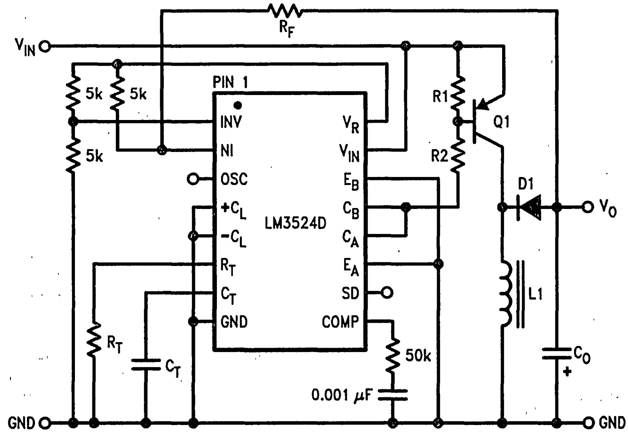
FIGURE 10. Positive Regulator, Step-Down Boosted Current Configuration

Typical Applications (Continued)



Design Equations

$R_F = 5k\left(1 - \frac{V_o}{2.5}\right)$

$f_{OSC} \cong \frac{1}{R_T C_T}$

$L1 = \frac{2.5 V_{IN} V_o}{f_{OSC} (V_o + V_{IN}) I_o}$

$C_o = \frac{I_o V_o}{\Delta V_o f_{OSC} (V_o + V_{IN})}$

TL/H/8650-15

FIGURE 11. Boosted Current Polarity Inverter

BASIC SWITCHING REGULATOR THEORY AND APPLICATIONS

The basic circuit of a step-down switching regulator circuit is shown in *Figure 12*, along with a practical circuit design using the LM3524D in *Figure 15*.

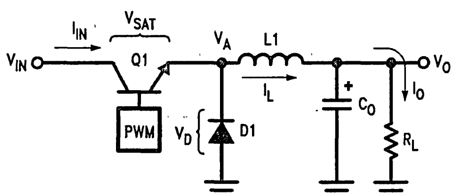


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FIGURE 12. Basic Step-Down Switching Regulator

The circuit works as follows: Q1 is used as a switch, which has ON and OFF times controlled by the pulse width modulator. When Q1 is ON, power is drawn from V_{IN} and supplied to the load through L1; V_A is at approximately V_{IN}, D1 is reverse biased, and C_o is charging. When Q1 turns OFF the inductor L1 will force V_A negative to keep the current flowing in it, D1 will start conducting and the load current will flow through D1 and L1. The voltage at V_A is smoothed by the L1, C_O filter giving a clean DC output. The current flowing through L1 is equal to the nominal DC load current plus some ΔI_L which is due to the changing voltage across it. *A good rule of thumb is to set $\Delta I_{LP\text{-}P} \cong 40\% \times I_o$.*

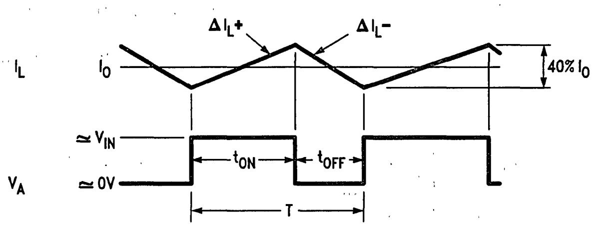

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FIGURE 13

Typical Applications (Continued)

From the relation $V_L = L\frac{d_i}{d_t}, \Delta I_L \cong \frac{V_L T}{L1}$

$$\Delta I_L{+} = \frac{(V_{IN} - V_O)\, t_{ON}}{L1};\ \Delta I_L{-} = \frac{V_O\, t_{OFF}}{L1}$$

Neglecting V_{SAT}, V_D, and settling $\Delta I_L{+} = \Delta I_L{-}$;

$$\boxed{V_O \cong V_{IN}\left(\frac{t_{ON}}{t_{OFF} + t_{ON}}\right)} = V_{IN}\left(\frac{t_{ON}}{T}\right);$$

where T = Total Period

The above shows the relation between V_{IN}, V_O and duty cycle.

$$I_{IN(DC)} = I_{OUT(DC)}\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right),$$

as Q1 only conducts during t_{ON}.

$$P_{IN} = I_{IN(DC)}\, V_{IN} = (I_{O(DC)})\left(\frac{t_{ON}}{t_{ON} + t_{OFF}}\right) V_{IN}$$

$$P_O = I_O V_O$$

The efficiency, η, of the circuit is:

$$\eta MAX = \frac{P_O}{P_{IN}} = \frac{I_O V_O}{I_O \frac{(t_{ON})}{T} V_{IN} + \frac{(V_{SAT}\, t_{ON} + V_{D1} t_{OFF})}{T} I_O}$$

$$= \boxed{\frac{V_O}{V_O + 1}} \text{ for } V_{SAT} = V_{D1} = 1V.$$

ηMAX will be further decreased due to switching losses in Q1. For this reason Q1 should be selected to have the maximum possible f_T, which implies very fast rise and fall times.

CALCULATING INDUCTOR L1

$$t_{ON} \cong \frac{(\Delta I_L{+}) \times L1}{(V_{IN} - V_O)},\ t_{OFF} = \frac{(\Delta I_L{-}) \times L1}{V_O}$$

$$t_{ON} + t_{OFF} = T = \frac{(\Delta I_L{+}) \times L1}{(V_{IN} - V_Q)} + \frac{(\Delta I_L{-}) \times L1}{V_O}$$

$$= \frac{0.4 I_O L1}{(V_{IN} - V_O)} + \frac{0.4 I_O L1}{V_O}$$

Since $\Delta I_L{+} = \Delta I_L{-} = 0.4 I_O$

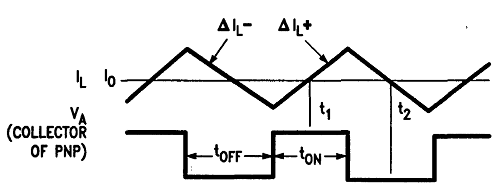

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FIGURE 14

Solving the above for L1

$$\boxed{L1 = \frac{2.5\, V_O\, (V_{IN} - V_O)}{I_O\, V_{IN}\, f}}$$

where: L1 is in Henrys

f is switching frequency in Hz

Also, see LM1578 data sheet for graphical methods of inductor selection.

CALCULATING OUTPUT FILTER CAPACITOR C_O:

Figure 14 shows L1's current with respect to Q1's t_{ON} and t_{OFF} times. This curent must flow to the load and C_O. C_O's current will then be the difference between I_L, and I_O.

$$I_{C_O} = I_L - I_O$$

From *Figure 14* it can be seen that current will be flowing into C_O for the second half of t_{ON} through the first half of t_{OFF}, or a time, $t_{ON}/2 + t_{OFF}/2$. The current flowing for this time is $\Delta I_L/4$. The resulting ΔV_C or ΔV_O is described by:

$$\Delta V_{op\text{-}p} = \frac{1}{C} \times \frac{\Delta I_L}{4} \times \left(\frac{t_{ON}}{2} + \frac{t_{OFF}}{2}\right)$$

$$= \frac{\Delta I_L}{4C}\left(\frac{t_{ON} + t_{OFF}}{2}\right)$$

Since $\Delta I_L = \frac{V_O(T - t_{ON})}{L1}$ and $t_{ON} = \frac{V_O T}{V_{IN}}$

$$\Delta V_{op\text{-}p} = \frac{V_O\left(T - \frac{V_O T}{V_{IN}}\right)}{4C\, L1}\left(\frac{T}{2}\right) = \frac{(V_{IN} - V_O)\, V_O T^2}{8 V_{IN} C_O L1} \text{ or}$$

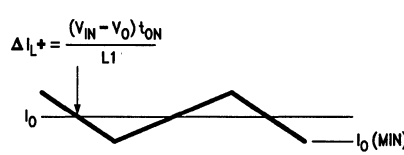
$$\boxed{C_O = \frac{(V_{IN} - V_O)\, V_O\, T^2}{8 \Delta V_O V_{IN} L1}}$$

where: C is in farads, T is $\frac{1}{\text{switching frequency}}$

ΔV_O is p-p output ripple

For best regulation, the inductor's current cannot be allowed to fall to zero. Some minimum load current I_O, and thus inductor current, is required as shown below:

$$I_{O(MIN)} = \frac{(V_{IN} - V_O)\, t_{ON}}{2L1} = \boxed{\frac{(V_{IN} - V_O)\, V_O}{2f V_{IN} L1}}$$



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Typical Applications (Continued)

A complete step-down switching regulator schematic, using the LM3524D, is illustrated in *Figure 15.* Transistors Q1 and Q2 have been added to boost the output to 1A. The 5V regulator of the LM3524D has been divided in half to bias the error amplifier's non-inverting input to within its common-mode range. Since each output transistor is on for half the period, actually 45%, they have been paralleled to allow longer possible duty cycle, up to 90%. This makes a lower possible input voltage. The output voltage is set by:

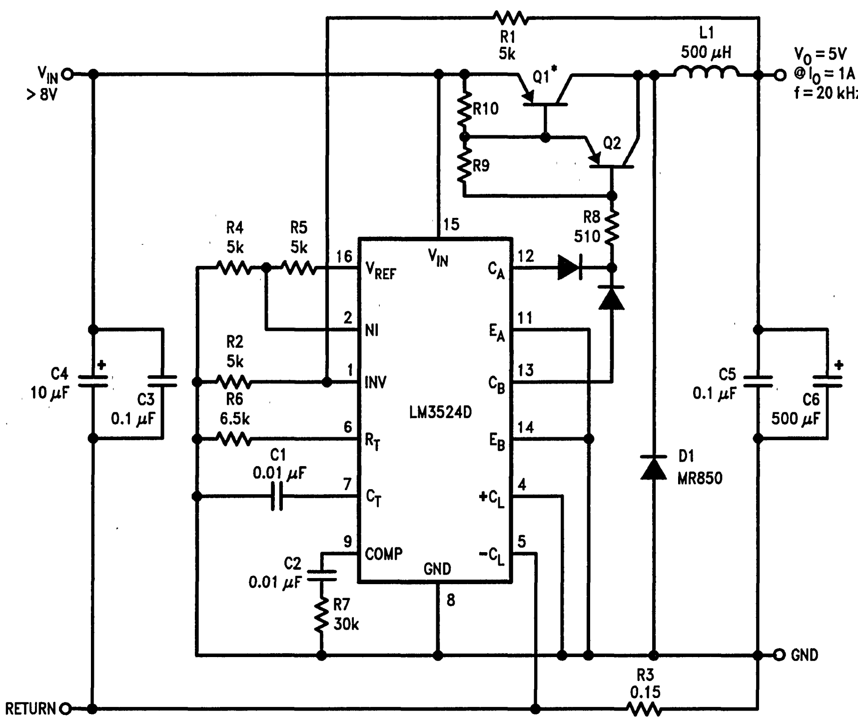
$$V_O = V_{NI}\left(1 + \frac{R1}{R2}\right),$$

where V_{NI} is the voltage at the error amplifier's non-inverting input.

Resistor R3 sets the current limit to:

$$\frac{200\text{ mV}}{R3} = \frac{200\text{ mV}}{0.15} = 1.3\text{A}.$$

Figure 16 and *17* show a PC board layout and stuffing diagram for the 5V, 1A regulator of *Figure 15.* The regulator's performance is listed in Table I.



*Mounted to Staver Heatsink No. V5-1.

Q1 = BD344

Q2 = 2N5023

L1 = >40 turns No. 22 wire on Ferroxcube No. K300502 Torroid core.

FIGURE 15. 5V, 1 Amp Step-Down Switching Regulator

Typical Applications (Continued)

TABLE I

Parameter	Conditions	Typical Characteristics
Output Voltage	$V_{IN} = 10V, I_o = 1A$	5V
Switching Frequency	$V_{IN} = 10V, I_o = 1A$	20 kHz
Short Circuit Current Limit	$V_{IN} = 10V$	1.3A
Load Regulation	$V_{IN} = 10V$ $I_o = 0.2 - 1A$	3 mV
Line Regulation	$\Delta V_{IN} = 10 - 20V,$ $f_o = 1A$	6 mV
Efficiency	$V_{IN} = 10V, I_o = 1A$	80%
Output Ripple	$V_{IN} = 10V, I_o = 1A$	10 mVp-p

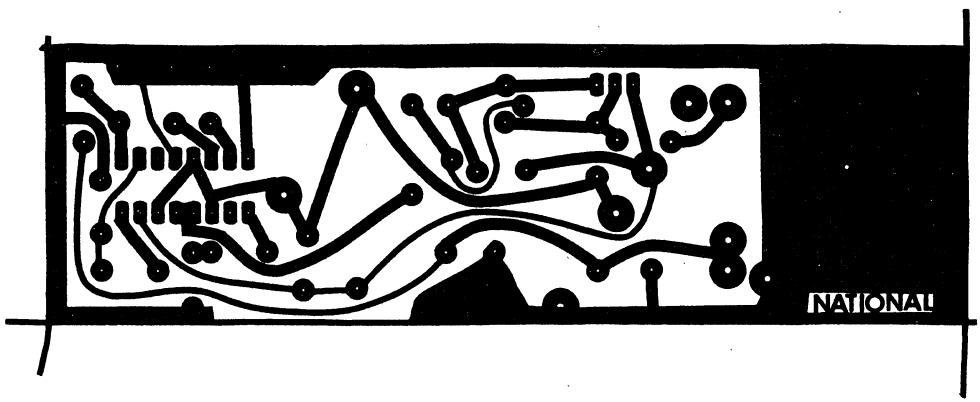


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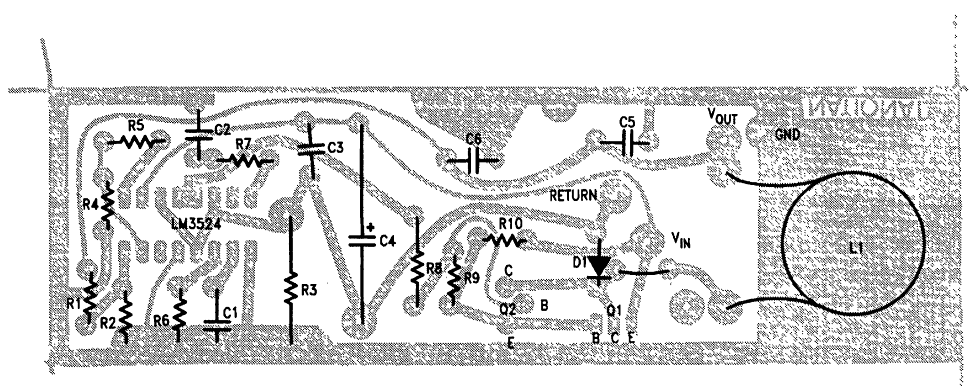
FIGURE 16. 5V, 1 Amp Switching Regulator, Foil Side



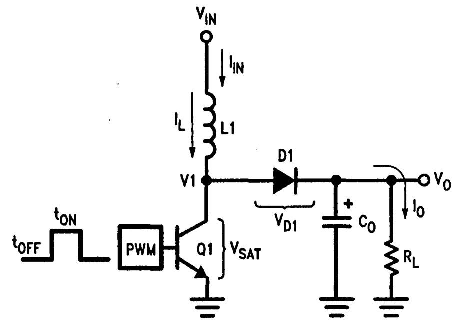
TL/H/8650–22

FIGURE 17. Stuffing Diagram, Component Side

Typical Applications (Continued)

THE STEP-UP SWITCHING REGULATOR

Figure 18 shows the basic circuit for a step-up switching regulator. In this circuit Q1 is used as a switch to alternately apply V_{IN} across inductor L1. During the time, t_{ON}, Q1 is ON and energy is drawn from V_{IN} and stored in L1; D1 is reverse biased and I_O is supplied from the charge stored in C_O. When Q1 opens, t_{OFF}, voltage V1 will rise positively to the point where D1 turns ON. The output current is now supplied through L1, D1 to the load and any charge lost from C_O during t_{ON} is replenished. Here also, as in the step-down regulator, the current through L1 has a DC component plus some ΔI_L. ΔI_L is again selected to be approximately 40% of I_L. *Figure 19* shows the inductor's current in relation to Q1's ON and OFF times.



TL/H/8650-23

FIGURE 18. Basic Step-Up Switching Regulator

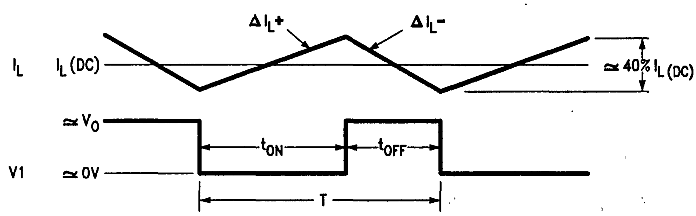


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FIGURE 19

Typical Applications (Continued)

From $\Delta I_L = \frac{V_L T}{L}$, $\Delta I_L^{+} \cong \frac{V_{IN} t_{ON}}{L1}$

and $\Delta I_L^{-} \cong \frac{(V_o - V_{IN})\, t_{OFF}}{L1}$

Since $\Delta I_L^{+} = \Delta I_L^{-}$, $V_{IN} t_{ON} = V_o t_{OFF} - V_{IN} t_{OFF}$, and neglecting V_{SAT} and V_{D1}

$$\boxed{V_o \cong V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)}$$

The above equation shows the relationship between V_{IN}, V_o and duty cycle.

In calculating input current $I_{IN(DC)}$, which equals the inductor's DC current, assume first 100% efficiency:

$$P_{IN} = I_{IN(DC)}\, V_{IN}$$

$$P_{OUT} = I_o V_o = I_o\, V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$$

for $\eta = 100\%$, $P_{OUT} = P_{IN}$

$$I_o\, V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right) = I_{IN(DC)}\, V_{IN}$$

$$I_{IN(DC)} = I_o\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$$

This equation shows that the input, or inductor, current is larger than the output current by the factor $(1 + t_{ON}/t_{OFF})$. Since this factor is the same as the relation between V_o and V_{IN}, $I_{IN(DC)}$ can also be expressed as:

$$\boxed{I_{IN(DC)} = I_o\left(\frac{V_o}{V_{IN}}\right)}$$

So far it is assumed $\eta = 100\%$, where the actual efficiency or η_{MAX} will be somewhat less due to the saturation voltage of Q1 and forward on voltage of D1. The internal power loss due to these voltages is the average I_L current flowing, or I_{IN}, through either V_{SAT} or V_{D1}. For $V_{SAT} = V_{D1} = 1V$ this power loss becomes $I_{IN(DC)}$ (1V). η_{MAX} is then:

$$\Delta_{MAX} = \frac{P_o}{P_{IN}} = \frac{V_o I_o}{V_o I_o + I_{IN}\,(1V)} = \frac{V_o I_o}{V_o I_o + I_o\left(1 + \frac{t_{ON}}{t_{OFF}}\right)}$$

From $V_o = V_{IN}\left(1 + \frac{t_{ON}}{t_{OFF}}\right)$

$$\boxed{\eta_{max} = \frac{V_{IN}}{V_{IN} + 1}}$$

This equation assumes only DC losses, however η_{MAX} is further decreased because of the switching time of Q1 and D1.

In calculating the output capacitor C_o it can be seen that C_o supplies I_o during t_{ON}. The voltage change on C_o during this time will be some $\Delta V_c = \Delta V_o$ or the output ripple of the regulator. Calculation of C_o is:

$$\Delta V_o = \frac{I_o t_{ON}}{C_o} \text{ or } C_o = \frac{I_o t_{ON}}{\Delta V_o}$$

From $V_o = V_{IN}\left(\frac{T}{t_{OFF}}\right)$; $t_{OFF} = \frac{V_{IN}}{V_o} T$

where $T = t_{ON} + t_{OFF} = \frac{1}{f}$

$$t_{ON} = T - \frac{V_{IN}}{V_o} T = T\left(\frac{V_o - V_{IN}}{V_o}\right) \text{ therefore:}$$

$$C_o = \frac{I_o T\left(\frac{V_o - V_{IN}}{V_o}\right)}{\Delta V_o} = \boxed{\frac{I_o\,(V_o - V_{IN})}{f \Delta V_o V_o}}$$

where: C_o is in farads, f is the switching frequency,
ΔV_o is the p-p output ripple

Calculation of inductor L1 is as follows:

$$L1 = \frac{V_{IN} t_{ON}}{\Delta I_L^{+}}, \text{ since during } t_{ON},$$

V_{IN} is applied across L1

$$\Delta I_{Lp\text{-}p} = 0.4\, I_L = 0.41\, I_{IN} = 0.4\, I_o\left(\frac{V_o}{V_{IN}}\right), \text{ therefore:}$$

$$L1 = \frac{V_{IN} t_{ON}}{0.4\, I_o\left(\frac{V_o}{V_{IN}}\right)} \text{ and since } t_{ON} = \frac{T\,(V_o - V_{IN})}{V_o}$$

$$\boxed{L1 = \frac{2.5\, V_{IN}^2\,(V_o - V_{IN})}{f\, I_o V_o^2}}$$

where: L1 is in henrys, f is the switching frequency in Hz

Typical Applications (Continued)

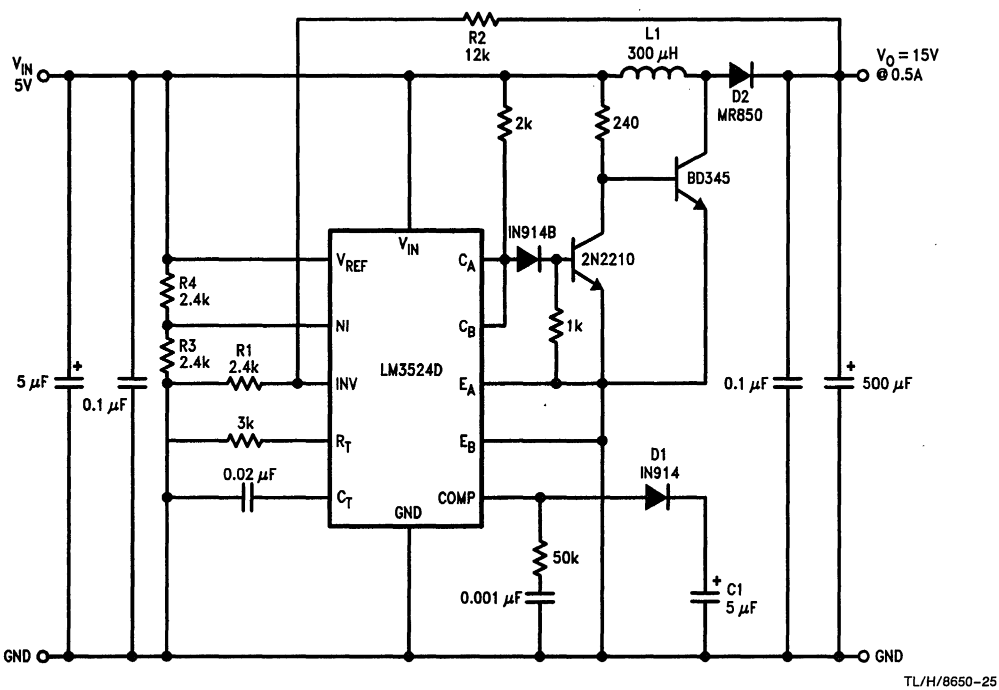
To apply the above theory, a complete step-up switching regulator is shown in *Figure 20.* Since V_{IN} is 5V, V_{REF} is tied to V_{IN}. The input voltage is divided by 2 to bias the error amplifier's inverting input. The output voltage is:

$$V_{OUT} = \left(1 + \frac{R2}{R1}\right) \times V_{INV} = 2.5 \times \left(1 + \frac{R2}{R1}\right)$$

The network D1, C1 forms a slow start circuit.

This holds the output of the error amplifier initially low thus reducing the duty-cycle to a minimum. Without the slow start circuit the inductor may saturate at turn-on because it has to supply high peak currents to charge the output capacitor from 0V. It should also be noted that this circuit has no supply rejection. By adding a reference voltage at the non-inverting input to the error amplifier, see *Figure 21*, the input voltage variations are rejected.

The LM3524D can also be used in inductorless switching regulators. *Figure 22* shows a polarity inverter which if connected to *Figure 20* provides a −15V unregulated output.



L1 = > 25 turns No. 24 wire on Ferroxcube No. K300502 Torroid core.

FIGURE 20. 15V, 0.5A Step-Up Switching Regulator

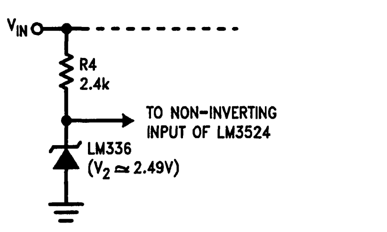


FIGURE 21

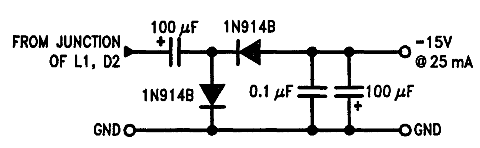
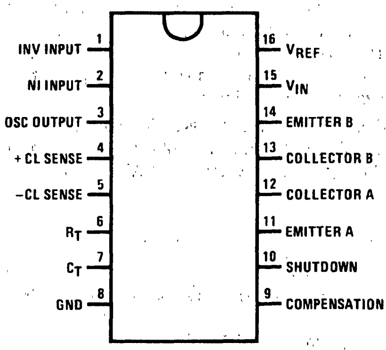


FIGURE 22

3

Connection Diagram



TL/H/8650–2

Top View

Order Number LM2524DN or LM3524DN
See NS Package Number N16E

Order Number LM3524DM
See NS Package Number M16A

National Semiconductor

LM2574/LM2574HV Series
SIMPLE SWITCHER™ 0.5A Step-Down Voltage Regulator

General Description

The LM2574 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 0.5A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2574 series offers a high-efficiency replacement for popular three-terminal linear regulators. Because of its high efficiency, the copper traces on the printed circuit board are normally the only heat sinking needed.

A standard series of inductors optimized for use with the LM2574 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

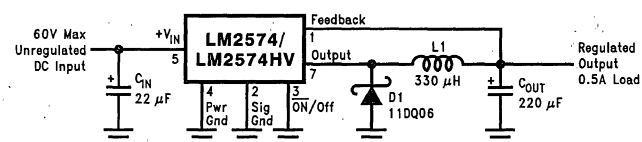
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 0.5A output current
- Wide input voltage range, 40V, up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive-to negative converter (Buck-Boost)

Typical Application (Fixed Output Voltage Versions)



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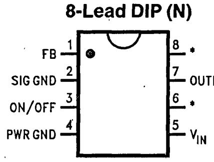
Note: Pin numbers are for 8-pin DIP package.

Connection Diagrams

8-Lead DIP (N)



Top View

*No internal connection, but should be soldered to PC board for best heat transfer.

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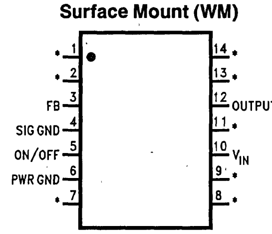
Order Number LM2574-3.3HVN, LM2574HVN-5.0, LM2574HVN-12, LM2574HVN-15, LM2574HVN-ADJ, LM2574N-3.3, LM2574N-5.0, LM2574N-12, LM2574N-15 or LM2574N-ADJ
See NS Package Number N08A

14-Lead Wide Surface Mount (WM)



Top View

TL/H/11394–3

Order Number LM2574HVM-3.3, LM2574HVM-5.0, LM2574HVM-12, LM2574HVM-15, LM2574HVM-ADJ, LM2574M-3.3 LM2574M-5.0, LM2574M-12, LM2574M-15 or LM2574M-ADJ
See NS Package Number M14B

Patent Pending

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM2574	45V
LM2574HV	63V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	−1V
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV
Lead Temperature (Soldering, 10 seconds)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM2574/LM2574HV	$-40°C \leq T_J \leq +125°C$
Supply Voltage	
LM2574	40V
LM2574HV	60V

LM2574-3.3, LM2574HV-3.3

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-3.3 LM2574HV-3.3 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	V_{IN} = 12V, I_{LOAD} = 100 mA	3.3	 3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$4.75V \leq V_{IN} \leq 40V$, $0.1A \leq I_{LOAD} \leq 0.5A$	3.3	 3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$4.75V \leq V_{IN} \leq 60V$, $0.1A \leq I_{LOAD} \leq 0.5A$	3.3	3.168/**3.135** 3.450/**3.482**	V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 0.5A	72		%

LM2574-5.0, LM2574HV-5.0

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-5.0 LM2574HV-5.0 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	V_{IN} = 12V, I_{LOAD} = 100 mA	5	 4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$7V \leq V_{IN} \leq 40V$, $0.1A \leq I_{LOAD} \leq 0.5A$	5	 4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$7V \leq V_{IN} \leq 60V$, $0.1A \leq I_{LOAD} \leq 0.5A$	5	4.800/**4.750** 5.225/**5.275**	V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 0.5A	77		%

LM2574-12, LM2574HV-12

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-12 LM2574HV-12 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 25V$, $I_{LOAD} = 100$ mA	10	11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$15V \leq V_{IN} \leq 40V$, $0.1A \leq I_{LOAD} \leq 0.5A$	12	11.52/**11.40** 12.48/**12.60**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$15V \leq V_{IN} \leq 60V$, $0.1A \leq I_{LOAD} \leq 0.5A$	12	11.52/**11.40** 12.54/**12.66**	V(Min) V(Max)
η	Efficiency	$V_{IN} = 15V$, $I_{LOAD} = 0.5A$	88		%

LM2574-15, LM2574HV-15

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	LM2574-15 LM2574HV-15 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 30V$, $I_{LOAD} = 100$ mA	15	14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574	$18V \leq V_{IN} \leq 40V$, $0.1A \leq I_{LOAD} \leq 0.5A$	15	14.40/**14.25** 15.60/**15.75**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2574HV	$18V \leq V_{IN} \leq 60V$, $0.1A \leq I_{LOAD} \leq 0.5A$	15	14.40/**14.25** 15.68/**15.83**	V(Min) V(Max)
η	Efficiency	$V_{IN} = 18V$, $I_{LOAD} = 0.5A$	88		%

LM2574-ADJ, LM2574HV-ADJ

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$, $I_{LOAD} = 100$ mA.

Symbol	Parameter	Conditions	LM2574-ADJ LM2574HV-ADJ Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{FB}	Feedback Voltage	$V_{IN} = 12V$, $I_{LOAD} = 100$ mA	1.230	 1.217 1.243	V V(Min) V(Max)
V_{FB}	Feedback Voltage LM2574	$7V \le V_{IN} \le 40V$, $0.1A \le I_{LOAD} \le 0.5A$ V_{OUT} Programmed for 5V. Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{FB}	Feedback Voltage LM2574HV	$7V \le V_{IN} \le 60V$, $0.1A \le I_{LOAD} \le 0.5A$ V_{OUT} Programmed for 5V. Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.273/**1.286**	 V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $V_{OUT} = 5V$, $I_{LOAD} = 0.5A$	77		%

All Output Voltage Versions

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25V$ for the 12V version, and $V_{IN} = 30V$ for the 15V version. $I_{LOAD} = 100$ mA.

Symbol	Parameter	Conditions	LM2574-XX LM2574HV-XX Typ	Limit (Note 2)	Units (Limits)
DEVICE PARAMETERS					
I_b	Feedback Bias Current	Adjustable Version Only, $V_{OUT} = 5V$	50	100/**500**	nA
f_O	Oscillator Frequency	(see Note 10)	52	 47/**42** 58/**63**	kHz kHz(Min) kHz(Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 0.5A$ (Note 4)	0.9	 1.2/**1.4**	V V(max)
DC	Max Duty Cycle (ON)	(Note 5)	98	 93	% %(Min)
I_{CL}	Current Limit	Peak Current, (Notes 4, 10)	1.0	 0.7/**0.65** 1.6/**1.8**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6, 7) Output = 0V Output = −1V Output = −1V	 7.5 	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$/OFF Pin = 5V (OFF)	50	 200	μA μA(Max)
θ_{JA} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	N Package, Junction to Ambient (Note 8) N Package, Junction to Ambient (Note 9) M Package, Junction to Ambient (Note 8) M Package, Junction to Ambient (Note 9)	92 72 102 78		°C/W
$\overline{ON}$/OFF CONTROL Test Circuit *Figure 2*					
V_{IH}	$\overline{ON}$/OFF Pin Logic Input Level	$V_{OUT} = 0V$	1.4	2.2/**2.4**	V(Min)
V_{IL}		V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	V(Max)
I_H	$\overline{ON}$/OFF Pin Input Current	$\overline{ON}$/OFF Pin = 5V (OFF)	12	 30	μA μA(Max)
I_{IL}		$\overline{ON}$/OFF Pin = 0V (ON)	0	 10	μA μA(Max)

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (Standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate Average Outgoing Quality Level.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2574 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output pin.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

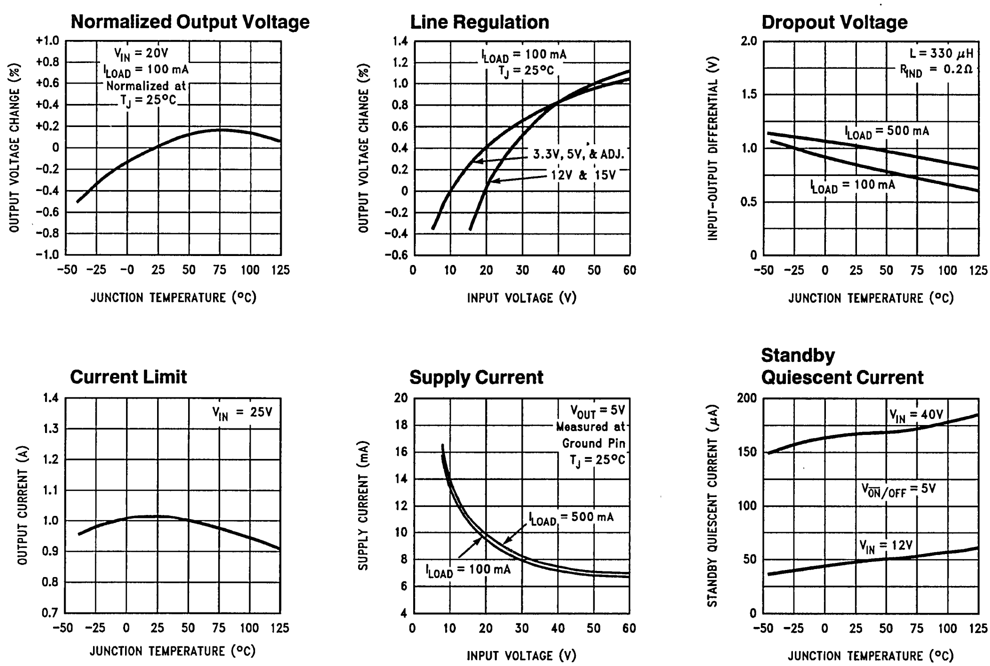
Note 7: V_{IN} = 40V (60V for high voltage version).

Note 8: Junction to ambient thermal resistance with approximately 1 square inch of printed circuit board copper surrounding the leads. Additional copper area will lower thermal resistance further. See application hints in this data sheet and the thermal model in ***Switchers Made Simple*** software.

Note 9: Junction to ambient thermal resistance with approximately 4 square inches of 1 oz. (0.0014 in. thick) printed circuit board copper surrounding the leads. Additional copper area will lower thermal resistance further. (See Note 8.)

Note 10: The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics (Circuit of *Figure 2*)



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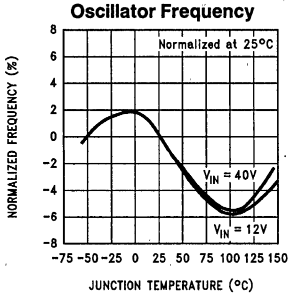
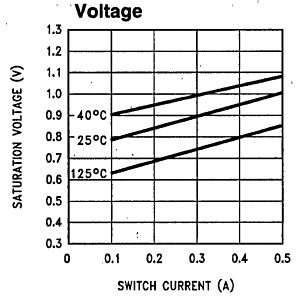
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

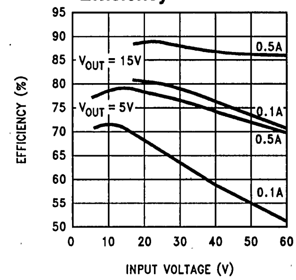
Oscillator Frequency



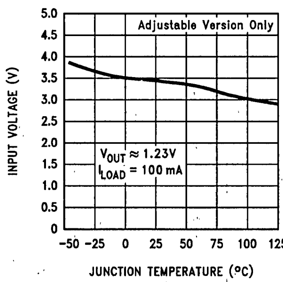
Switch Saturation Voltage



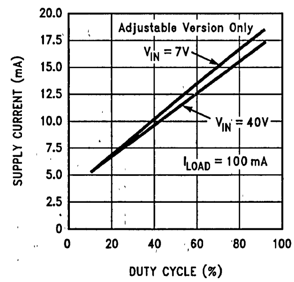
Efficiency



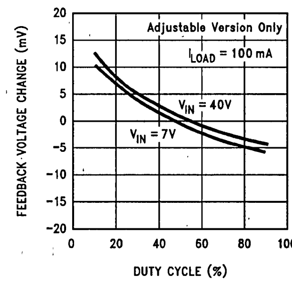
Minimum Operating Voltage



Supply Current vs Duty Cycle



Feedback Voltage vs Duty Cycle



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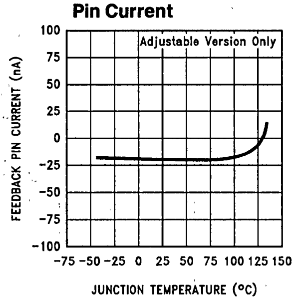
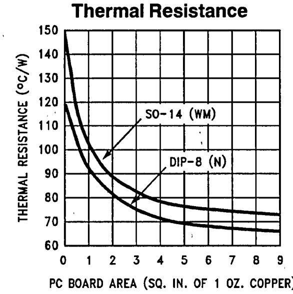
Feedback Pin Current



Junction to Ambient Thermal Resistance



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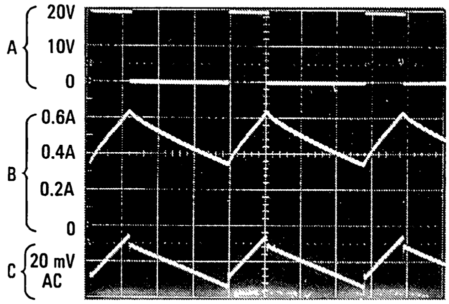
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Continuous Mode Switching Waveforms
V_{OUT} = 5V, 500 mA Load Current, L = 330 µH



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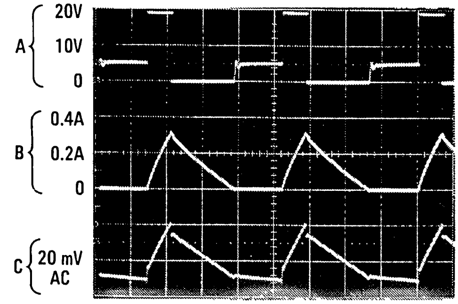
A: Output Pin Voltage, 10V/div
B: Inductor Current, 0.2 A/div
C: Output Ripple Voltage, 20 mV/div, AC-Coupled
Horizontal Time Base: 5µs/div

Discontinuous Mode Switching Waveforms
V_{OUT} = 5V, 100 mA Load Current, L = 100 µH



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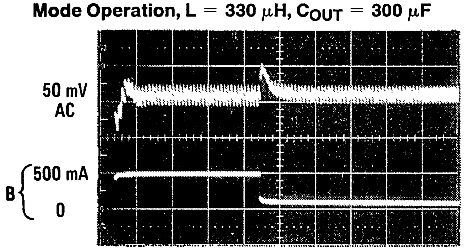
A: Output Pin Voltage, 10V/div
B: Inductor Current, 0.2 A/div
C: Output Ripple Voltage, 20 mV/div, AC-Coupled
Horizontal Time Base: 5 µs/div

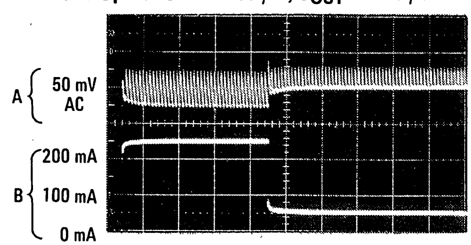
500 mA Load Transient Response for Continuous Mode Operation, L = 330 µH, C_{OUT} = 300 µF



TL/H/11394-8

A: Output Voltage, 50 mV/div. AC Coupled
B: 100 mA to 500 mA Load Pulse
Horizontal Time Base: 200 µs/div

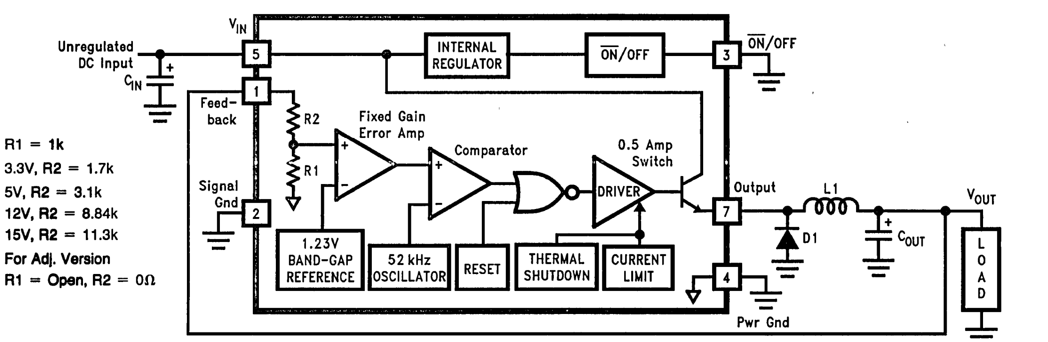
250 mA Load Transient Response for Discontinuous Mode Operation. L = 68 µH, C_{OUT} = 470 µF



TL/H/11394-9

A: Output Voltage, 50 mV/div. AC Coupled
B: 50 mA to 250 mA Load Pulse
Horizontal Time Base: 200 µs/div

Block Diagram



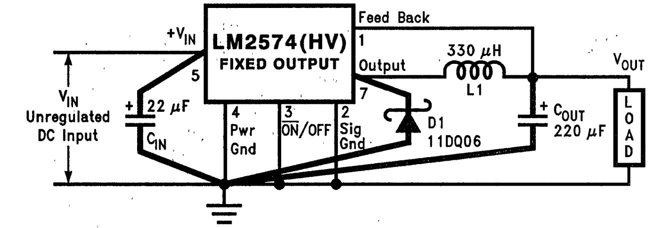
Note: Pin numbers are for the 8-pin DIP package.

TL/H/11394-10

FIGURE 1

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



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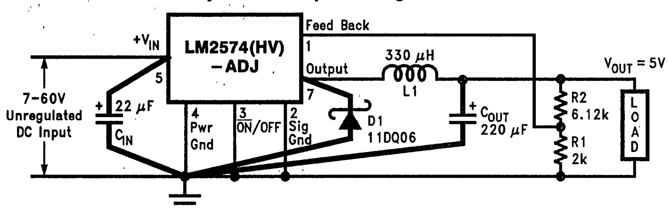
C_{IN}— 22 µF, 75V Aluminum Electrolytic
C_{OUT}— 220 µF, 25V Aluminum Electrolytic
D1— Schottky, 11DQ06
L1— 330 µH, 52627 (for 5V in, 3.3V out, use 100 µH, RL-1284-100)
R1— 2k, 0.1%
R2— 6.12k, 0.1%

Adjustable Output Voltage Version



TL/H/11394–12

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where V_{REF} = 1.23V,
R1 between 1k & 5k.

FIGURE 2

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by **heavy lines should be kept as short as possible**. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Inductor Value	Pulse Eng. (Note 1)	Renco (Note 2)	NPI (Note 3)
68 µH	*	RL-1284-68	NP5915
100 µH	*	RL-1284-100	NP5916
150 µH	52625	RL-1284-150	NP5917
220 µH	52626	RL-1284-220	NP5918/5919
330 µH	52627	RL-1284-330	NP5920/5921
470 µH	52628	RL-1284-470	NP5922
680 µH	52629	RL-1283-680	NP5923
1000 µH	52631	RL-1283-1000	*
1500 µH	*	RL-1283-1500	*
2200 µH	*	RL-1283-2200	*

FIGURE 3. Inductor Selection by Manufacturer's Part Number

U.S. Source

Note 1: Pulse Engineering, (619) 674-8100
P.O. Box 12236, San Diego, CA 92112

Note 2: Renco Electronics Inc., (516) 586-5566
60 Jeffryn Blvd. East, Deer Park, NY 11729

*Contact Manufacturer

European Source

Note 3: NPI/APC +44 (0) 634 290588
47 Riverside, Medway City Estate
Strood, Rochester, Kent ME2 4DP. UK

*Contact Manufacturer

LM2574 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(Max) = 15V I_{LOAD}(Max) = 0.4A
1. Inductor Selection (L1) **A.** Select the correct Inductor value selection guide from *Figures 4, 5, 6* or *7*. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by V_{IN}(Max) and I_{LOAD}(Max). **C.** Select an appropriate inductor from the table shown in *Figure 3*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2574 switching frequency (52 kHz) and for a current rating of 1.5 × I_{LOAD}. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1)** **A.** Use the selection guide shown in *Figure 5*. **B.** From the selection guide, the inductance area intersected by the 15V line and 0.4A line is 330. **C.** Inductor value required is 330 μH. From the table in *Figure 3*, choose Pulse Engineering PE-52627, Renco RL-1284-330, or NPI NP5920/5921.
2. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT})** **A.** C_{OUT} = 100 μF to 470 μF standard aluminum electrolytic. **B.** Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.5 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2574. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1)** **A.** For this example, a 1A current rating is adequate. **B.** Use a 20V 1N5817 or SR102 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 9*.
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 22 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

LM2574 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

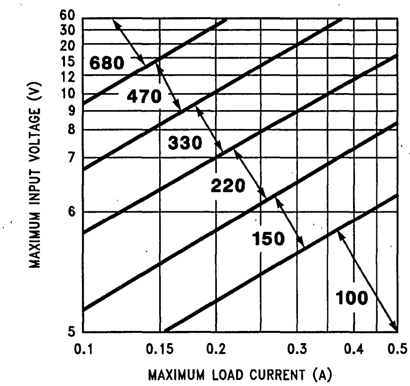


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FIGURE 4. LM2574HV-3.3 Inductor Selection Guide

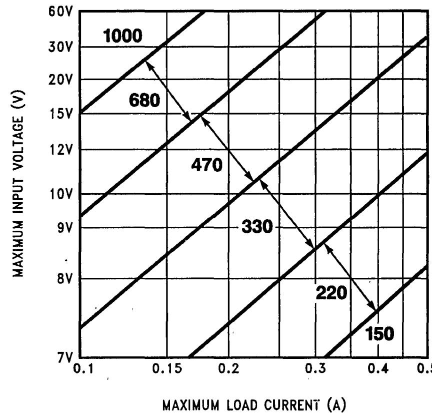

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FIGURE 5. LM2574HV-5.0 Inductor Selection Guide

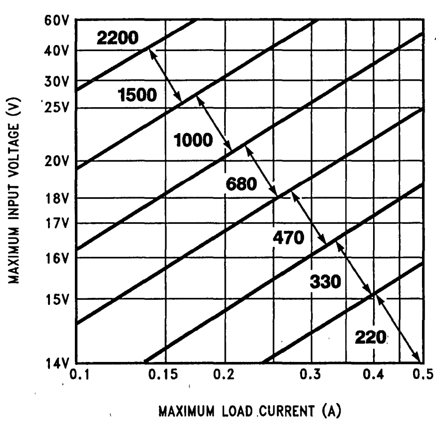

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FIGURE 6. LM2574HV-12 Inductor Selection Guide

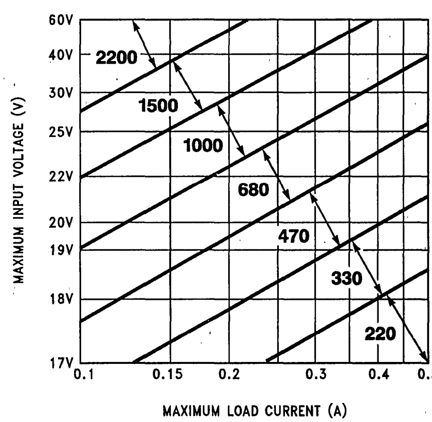

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FIGURE 7. LM2574HV-15 Inductor Selection Guide

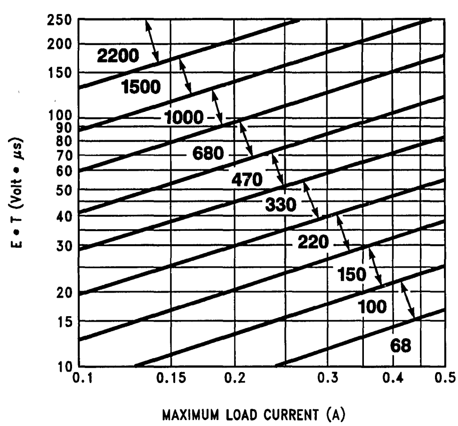

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FIGURE 8. LM2574HV-ADJ Inductor Selection Guide

LM2574 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
$V_{IN}(Max)$ = Maximum Input Voltage
$I_{LOAD}(Max)$ = Maximum Load Current
F = Switching Frequency *(Fixed at 52 kHz)*

1. **Programming Output Voltage** *(Selecting R1 and R2, as shown in Figure 2)*

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)*

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. **Inductor Selection (L1)**

A. Calculate the inductor Volt • microsecond constant, E • T (V • μs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT})\frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (in\ kHz)}\ (V \bullet \mu s)$$

B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 8*.

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor value for that region.

E. Select an appropriate inductor from the table shown in *Figure 3*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2574 switching frequency (52 kHz) and for a current rating of 1.5 × I_{LOAD}. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. **Output Capacitor Selection (C_{OUT})**

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 13{,}300 \frac{V_{IN}(Max)}{V_{OUT} \bullet L(\mu H)}\ (\mu F)$$

The above formula yields capacitor values between 5 μF and 1000 μF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 24V regulator, a rating of at least 35V is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = 24V
$V_{IN}(Max)$ = 40V
$I_{LOAD}(Max)$ = 0.4A
F = 52 kHz

1. **Programming Output Voltage** *(Selecting R1 and R2)*

$$V_{OUT} = 1.23\left(1 + \frac{R_2}{R_1}\right) \quad \text{Select R1} = 1k$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{24V}{1.23V} - 1\right)$$

R_2 = 1k (19.51 − 1) = 18.51k, closest 1% value is 18.7k

2. **Inductor Selection (L1)**

A. Calculate E • T (V • μs)

$$E \bullet T = (40 - 24) \bullet \frac{24}{40} \bullet \frac{1000}{52} = 185\ V \bullet \mu s$$

B. E • T = 185 V • μs

C. $I_{LOAD}(Max)$ = 0.4A

D. Inductance Region = 1000

E. Inductor Value = 1000 μH *Choose from* ***Pulse Engineering*** *Part #PE-52631, or* ***Renco*** *Part #RL-1283-1000.*

3. **Output Capacitor Selection (C_{OUT})**

A. $C_{OUT} > 13{,}300 \frac{40}{24 \bullet 1000} = 22.2\ \mu F$

However, for acceptable output ripple voltage select

$C_{OUT} \geq 100\ \mu F$

C_{OUT} = 100 μF electrolytic capacitor

LM2574 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
4. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.5 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2574. The most stressful condition for this diode is an overload or shorted output condition. Suitable diodes are shown in the selection guide of *Figure 9*. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1)** **A.** For this example, a 1A current rating is adequate. **B.** Use a 50V MBR150 or 11DQ05 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 9*.
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 22 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

V_R	1 Amp Diodes	
	Schottky	Fast Recovery
20V	1N5817 SR102 MBR120P	The following diodes are all rated to 100V 11DF1 10JF1 MUR110 HER102
30V	1N5818 SR103 11DQ03 MBR130P 10JQ030	
40V	1N5819 SR104 11DQ04 11JQ04 MBR140P	
50V	MBR150 SR105 11DQ05 11JQ05	
60V	MBR160 SR106 11DQ06 11JQ06	
90V	11DQ09	

FIGURE 9. Diode Selection Guide

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. ***Switchers Made Simple*** *(version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 22 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below $-25°C$, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

where $\frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$ for a buck regulator

and $\frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}}$ for a buck-boost regulator.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2574 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

In many cases the preferred mode of operation is in the continuous mode. It offers better load regulation, lower peak switch, inductor and diode currents, and can have lower output ripple voltage. But it does require relatively large inductor values to keep the inductor current flowing continuously, especially at low output load currents.

To simplify the inductor selection process, an inductor selection guide (nomograph) was designed (see *Figures 4* through *8*). This guide assumes continuous mode operation, and selects an inductor that will allow a peak-to-peak inductor ripple current (ΔI_{IND}) to be a certain percentage of the maximum design load current. In the LM2574 SIMPLE SWITCHER, the peak-to-peak inductor ripple current percentage (of load current) is allowed to change as different design load currents are selected. By allowing the percentage of inductor ripple current to increase for lower current applications, the inductor size and value can be kept relatively low.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

The curve shown in *Figure 10* illustrates how the peak-to-peak inductor ripple current (ΔI_{IND}) is allowed to change as different maximum load currents are selected, and also how it changes as the operating point varies from the upper border to the lower border within an inductance region (see Inductor Selection guides).

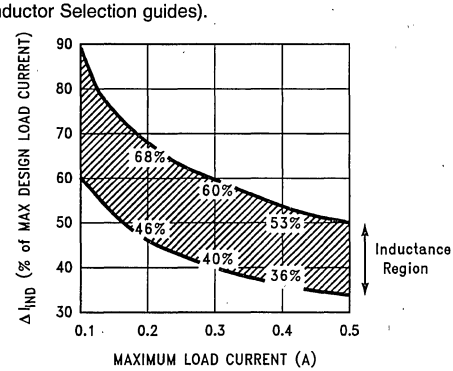

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FIGURE 10. Inductor Ripple Current (ΔI_{IND}) Range Based on Selection Guides from *Figures 4–8.*

Consider the following example:

V_{OUT} = 5V @ 0.4A

V_{IN} = 10V minimum up to 20V maximum

The selection guide in *Figure 5* shows that for a 0.4A load current, and an input voltage range between 10V and 20V, the inductance region selected by the guide is 330 μH. This value of inductance will allow a peak-to-peak inductor ripple current (ΔI_{IND}) to flow that will be a percentage of the maximum load current. For this inductor value, the ΔI_{IND} will also vary depending on the input voltage. As the input voltage increases to 20V, it approaches the upper border of the inductance region, and the inductor ripple current increases. Referring to the curve in *Figure 10*, it can be seen that at the 0.4A load current level, and operating near the upper border of the 330 μH inductance region, the ΔI_{IND} will be 53% of 0.4A, or 212 mA p-p.

This ΔI_{IND} is important because from this number the peak inductor current rating can be determined, the minimum load current required before the circuit goes to discontinuous operation, and also, knowing the ESR of the output capacitor, the output ripple voltage can be calculated, or conversely, measuring the output ripple voltage and knowing the ΔI_{IND}, the ESR can be calculated.

Application Hints (Continued)

From the previous example, the Peak-to-peak Inductor Ripple Current (ΔI_{IND}) = 212 mA p-p. Once the Δ_{IND} value is known, the following three formulas can be used to calculate additional information about the switching regulator circuit:

1. Peak Inductor or peak switch current

$$= \left(I_{LOAD} + \frac{\Delta I_{IND}}{2}\right) = \left(0.4A + \frac{212}{2}\right) = 506\text{ mA}$$

2. Mimimum load current before the circuit becomes discontinuous

$$= \frac{\Delta I_{IND}}{2} = \frac{212}{2} = 106\text{ mA}$$

3. Output Ripple Voltage = (ΔI_{IND}) × (ESR of C_{OUT})

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toroid, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This can cause the inductor current to rise very rapidly and will affect the energy storage capabilities of the inductor and could cause inductor overheating. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor. The inductor manufacturers' data sheets include current and energy limits to avoid inductor saturation.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2574 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (100 μF– 330 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

Output Ripple Voltage = (ΔI_{IND}) (ESR of C_{OUT})

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2574 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 9* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μH & 100 μF) can be added to the output (as shown in *Figure 16*) to further reduce the amount of output ripple and transients. A 10 × reduction in output ripple voltage and transients is possible with this filter.

Application Hints (Continued)

FEEDBACK CONNECTION

The LM2574 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2574 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$/OFF INPUT

For normal operation, the $\overline{\text{ON}}$/OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$/OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$/OFF pin should not be left open.

GROUNDING

The 8-pin molded DIP and the 14-pin surface mount package have separate power and signal ground pins. Both ground pins should be soldered directly to wide printed circuit board copper traces to assure low inductance connections and good thermal properties.

THERMAL CONSIDERATIONS

The 8-pin DIP (N) package and the 14-pin Surface Mount (M) package are molded plastic packages with solid copper lead frames. The copper lead frame conducts the majority of the heat from the die, through the leads, to the printed circuit board copper, which acts as the heat sink. For best thermal performance, wide copper traces should be used, and all ground and unused pins should be soldered to generous amounts of printed circuit board copper, such as a ground plane. Large areas of copper provide the best transfer of heat (lower thermal resistance) to the surrounding air, and even double-sided or multilayer boards provide better heat paths to the surrounding air. Unless the power levels are small, using a socket for the 8-pin package is not recommended because of the additional thermal resistance it introduces, and the resultant higher junction temperature.

Because of the 0.5A current rating of the LM2574, the total package power dissipation for this switcher is quite low, ranging from approximately 0.1W up to 0.75W under varying conditions. In a carefully engineered printed circuit board, both the N and the M package can easily dissipate up to 0.75W, even at ambient temperatures of 60°C, and still keep the maximum junction temperature below 125°C.

A curve displaying thermal resistance vs. pc board area for the two packages is shown in the Typical Performance Characteristics curves section of this data sheet.

These thermal resistance numbers are approximate, and there can be many factors that will affect the final thermal resistance. Some of these factors include board size, shape, thickness, position, location, and board temperature. Other factors are, the area of printed circuit copper, copper thickness, trace width, multi-layer, single- or double-sided, and the amount of solder on the board. The effectiveness of the pc board to dissipate heat also depends on the size, number and spacing of other components on the board. Furthermore, some of these components, such as the catch diode and inductor will generate some additional heat. Also, the thermal resistance decreases as the power level increases because of the increased air current activity at the higher power levels, and the lower surface to air resistance coefficient at higher temperatures.

The data sheet thermal resistance curves and the thermal model in ***Switchers Made Simple*** software (version 3.3) can estimate the maximum junction temperature based on operating conditions. In addition, the junction temperature can be estimated in actual circuit operation by using the following equation.

$$T_j = T_{cu} + (\theta_{j\text{-}cu} \times P_D)$$

With the switcher operating under worst case conditions and all other components on the board in the intended enclosure, measure the copper temperature (T_{cu}) near the IC. This can be done by temporarily soldering a small thermocouple to the pc board copper near the IC, or by holding a small thermocouple on the pc board copper using thermal grease for good thermal conduction.

The thermal resistance ($\theta_{j\text{-}cu}$) for the two packages is:

$\theta_{j\text{-}cu}$ = 42°C/W for the N-8 package

$\theta_{j\text{-}cu}$ = 52°C/W for the M-14 package

The power dissipation (P_D) for the IC could be measured, or it can be estimated by using the formula:

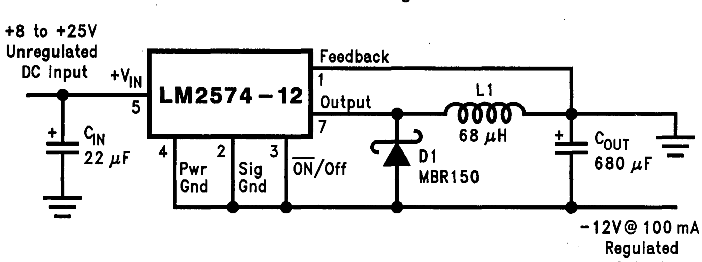
$$P_D = (V_{IN})(I_S) + \left(\frac{V_O}{V_{IN}}\right)(I_{LOAD})(V_{SAT})$$

Where I_S is obtained from the typical supply current curve (adjustable version use the supply current vs. duty cycle curve).

Additional Applications

INVERTING REGULATOR

Figure 11 shows a LM2574-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.



Note: Pin numbers are for the 8-pin DIP package.

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FIGURE 11. Inverting Buck-Boost Develops −12V

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Additional Applications (Continued)

For an input voltage of 8V or more, the maximum available output current in this configuration is approximately 100 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 0.6A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μH and 220 μH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_P \approx \frac{I_{LOAD}(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}|V_O|}{V_{IN}+|V_O|} \times \frac{1}{2L_1 f_{osc}}$$

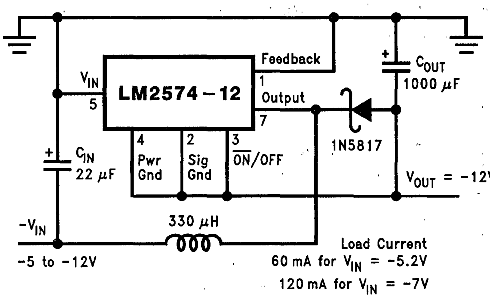
Where f_{osc} = 52 kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2574 is +28V, or +48V for the LM2574HV.

The ***Switchers Made Simple*** (version 3.3) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 12* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.



TL/H/11394–20

Note: Pin numbers are for 8-pin DIP package.

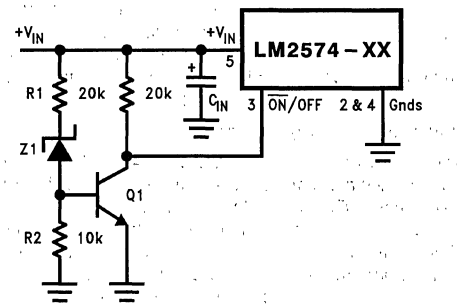
FIGURE 12. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 13*, while *Figure 14* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

$$V_{TH} \approx V_{Z1} + 2V_{BE}\,(Q1)$$

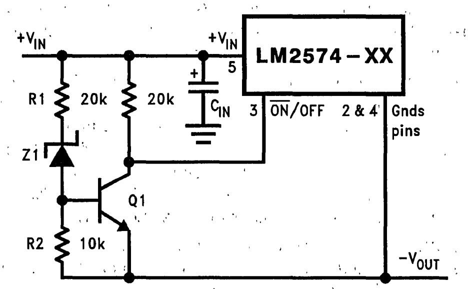


TL/H/11394–21

Note: Complete circuit not shown.

Note: Pin numbers are for 8-pin DIP package.

FIGURE 13. Undervoltage Lockout for Buck Circuit



TL/H/11394–22

Note: Complete circuit not shown (see Figure 11).

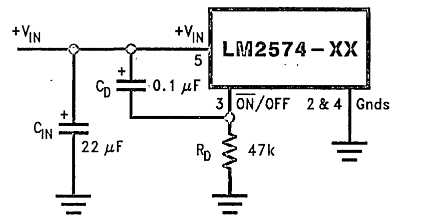
Note: Pin numbers are for 8-pin DIP package.

FIGURE 14. Undervoltage Lockout for Buck-Boost Circuit

Additional Applications (Continued)

DELAYED STARTUP

The $\overline{\text{ON}}$/OFF pin can be used to provide a delayed startup feature as shown in *Figure 15*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{\text{ON}}$/OFF pin.



TL/H/11394-23

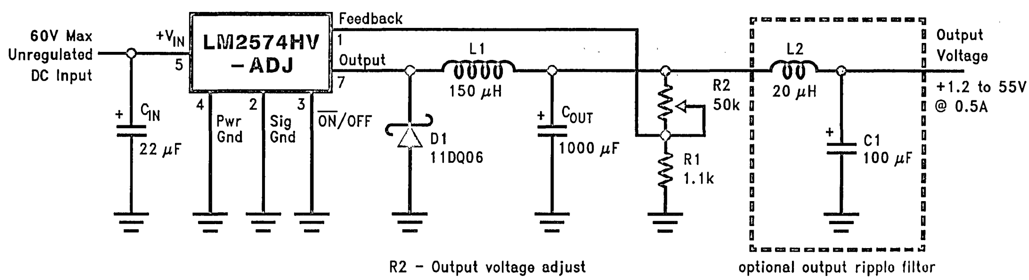
Note: Complete circuit not shown.

Note: Pin numbers are for 8-pin DIP package.

FIGURE 15. Delayed Startup

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 500 mA power supply that features an adjustable output voltage is shown in *Figure 16*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.



TL/H/11394-24

Note: Pin numbers are for 8-pin DIP package.

FIGURE 16. 1.2V to 55V Adjustable 500 mA Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator $$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$$

for buck-boost regulator $$D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2574 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 17*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

TL/H/11394-25

FIGURE 17. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 µF–1000 µF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 100 µF–1000 µF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 17*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

Definition of Terms (Continued)

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2574 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

OPERATING VOLT MICROSECOND CONSTANT ($E \bullet T_{op}$)

The product (in Volt•μs) of the voltage applied to the inductor and the time the voltage is applied. This $E \bullet T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

National Semiconductor

LM1575/LM1575HV/LM2575/LM2575HV Series SIMPLE SWITCHER® 1A Step-Down Voltage Regulator

General Description

The LM2575 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving a 1A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2575 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in many cases no heat sink is required.

A standard series of inductors optimized for use with the LM2575 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

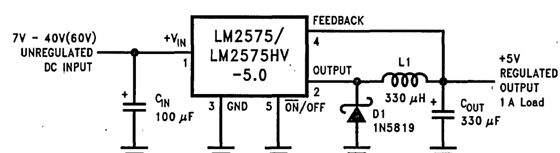
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 1A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regualtor for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

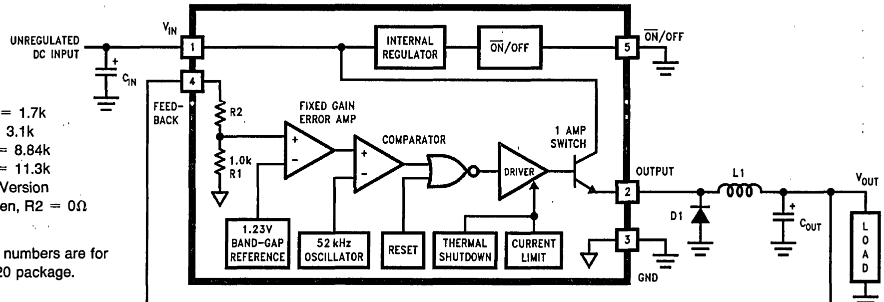
Typical Application (Fixed Output Voltage Versions)



TL/H/11475-1

Note: Pin numbers are for the TO-220 package.

Block Diagram and Typical Application



3.3V, R2 = 1.7k
5V, R2 = 3.1k
12V, R2 = 8.84k
15V, R2 = 11.3k
For ADJ. Version
R1 = Open, R2 = 0Ω

Note: Pin numbers are for the TO-220 package.

TL/H/11475-2

FIGURE 1

Patent Pending

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM1575/LM2575	45V
LM1575HV/LM2575HV	63V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3V \le V \le +V_{IN}$
Output Voltage to Ground (Steady State)	−1V
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Minimum ESD Rating ($C = 100\ pF$, $R = 1.5\ k\Omega$)	2 kV
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM1575/LM1575HV	$-55°C \le T_J \le +150°C$
LM2575/LM2575HV	$-40°C \le T_J \le +125°C$
Supply Voltage	
LM1575/LM2575	40V
LM1575HV/LM2575HV	60V

LM1575-3.3, LM1575HV-3.3, LM2575-3.3, LM2575HV-3.3

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-3.3 LM1575HV-3.3 Limit (Note 2)	LM2575-3.3 LM2575HV-3.3 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	3.3	 3.267 3.333	 3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$4.75V \le V_{IN} \le 40V$, $0.2A \le I_{LOAD} \le 1A$ Circuit of *Figure 2*	3.3	 3.200/**3.168** 3.400/**3.432**	 3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$4.75V \le V_{IN} \le 60V$, $0.2A \le I_{LOAD} \le 1A$ Circuit of *Figure 2*	3.3	 3.200/**3.168** 3.416/**3.450**	 3.168/**3.135** 3.450/**3.482**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	75			%

LM1575-5.0, LM1575HV-5.0, LM2575-5.0, LM2575HV-5.0

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-5.0 LM1575HV-5.0 Limit (Note 2)	LM2575-5.0 LM2575HV-5.0 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.2A$ Circuit of *Figure 2*	5.0	 4.950 5.050	 4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	$0.2A \le I_{LOAD} \le 1A$, $8V \le V_{IN} \le 40V$ Circuit of *Figure 2*	5.0	 4.850/**4.800** 5.150/**5.200**	 4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	$0.2A \le I_{LOAD} \le 1A$, $8V \le V_{IN} \le 60V$ Circuit of *Figure 2*	5.0	 4.850/**4.800** 5.175/**5.225**	 4.800/**4.750** 5.225/**5.275**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 1A$	77			%

LM1575-12, LM1575HV-12, LM2575-12, LM2575HV-12

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-12 LM1575HV-12 Limit (Note 2)	LM2575-12 LM2575HV-12 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	V_{IN} = 25V, I_{LOAD} = 0.2A Circuit of *Figure 2*	12	 11.88 12.12	 11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	0.2A ≤ I_{LOAD} ≤ 1A, 15V ≤ V_{IN} ≤ 40V Circuit of *Figure 2*	12	 11.64/**11.52** 12.36/**12.48**	 11.52/**11.40** 12.48/**12.60**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	0.2A ≤ I_{LOAD} ≤ 1A, 15V ≤ V_{IN} ≤ 60V Circuit of *Figure 2*	12	 11.64/**11.52** 12.42/**12.54**	 11.52/**11.40** 12.54/**12.66**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 15V, I_{LOAD} = 1A	88			%

LM1575-15, LM1575HV-15, LM2575-15, LM2575HV-15

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-15 LM1575HV-15 Limit (Note 2)	LM2575-15 LM2575HV-15 Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Output Voltage	V_{IN} = 30V, I_{LOAD} = 0.2A Circuit of *Figure 2*	15	 14.85 15.15	 14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575/LM2575	0.2A ≤ I_{LOAD} ≤ 1A, 18V ≤ V_{IN} ≤ 40V Circuit of *Figure 2*	15	 14.55/**14.40** 15.45/**15.60**	 14.40/**14.25** 15.60/**15.75**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM1575HV/LM2575HV	0.2A ≤ I_{LOAD} ≤ 1A, 18V ≤ V_{IN} ≤ 60V Circuit of *Figure 2*	15	 14.55/**14.40** 15.525/**15.675**	 14.40/**14.25** 15.68/**15.83**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 18V, I_{LOAD} = 1A	88			%

LM1575-ADJ, LM1575HV-ADJ, LM2575-ADJ, LM2575HV-ADJ

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**.

Symbol	Parameter	Conditions	Typ	LM1575-ADJ LM1575HV-ADJ Limit (Note 2)	LM2575-ADJ LM2575HV-ADJ Limit (Note 3)	Units (Limits)
SYSTEM PARAMETERS (Note 4) Test Circuit *Figure 2*						
V_{OUT}	Feedback Voltage	V_{IN} = 12V, I_{LOAD} = 0.2A V_{OUT} = 5V Circuit of *Figure 2*	1.230	 1.217 1.243	 1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575/LM2575	0.2A ≤ I_{LOAD} ≤ 1A, 8V ≤ V_{IN} ≤ 40V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.205/**1.193** 1.255/**1.267**	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM1575HV/LM2575HV	0.2A ≤ I_{LOAD} ≤ 1A, 8V ≤ V_{IN} ≤ 60V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.205/**1.193** 1.261/**1.273**	 1.193/**1.180** 1.273/**1.286**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 1A, V_{OUT} = 5V	77			%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 12V$ for the 3.3V, 5V, and Adjustable version, $V_{IN} = 25V$ for the 12V version, and $V_{IN} = 30V$ for the 15V version. $I_{LOAD} = 200$ mA.

Symbol	Parameter	Conditions	Typ	LM1575-XX LM1575HV-XX Limit (Note 2)	LM2575-XX LM2575HV-XX Limit (Note 3)	Units (Limits)
DEVICE PARAMETERS						
I_b	Feedback Bias Current	$V_{OUT} = 5V$ (Adjustable Version Only)	50	100/**500**	100/**500**	nA
f_O	Oscillator Frequency	(Note 13)	52	 47/**43** 58/**62**	 47/**42** 58/**63**	kHz kHz(Min) kHz(Max)
V_{SAT}	Saturation Voltage	$I_{OUT} = 1A$ (Note 5)	0.9	 1.2/**1.4**	 1.2/**1.4**	V V(Max)
DC	Max Duty Cycle (ON)	(Note 6)	98	 93	 93	% %(Min)
I_{CL}	Current Limit	Peak Current (Notes 5 and 13)	2.2	 1.7/**1.3** 3.0/**3.2**	 1.7/**1.3** 3.0/**3.2**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 7 and 8) Output = 0V Output = −1V Output = −1V	 7.5 	2 30	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 7)	5	 10/**12**	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$/OFF Pin = 5V (OFF)	50	 200/**500**	 200	μA μA(Max)
θ_{JA} θ_{JC} θ_{JA} θ_{JA} θ_{JC} θ_{JA} θ_{JA} θ_{JA}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case T Package, Junction to Ambient (Note 9) T Package, Junction to Ambient (Note 10) T Package, Junction to Case N Package, Junction to Ambient (Note 11) M Package, Junction to Ambient (Note 11) S Package, Junction to Ambient (Note 12)	35 1.5 65 45 2 85 100 37			°C/W
$\overline{ON}$/OFF CONTROL Test Circuit *Figure 2*						
V_{IH}	$\overline{ON}$/OFF Pin Logic	$V_{OUT} = 0V$	1.4	2.2/**2.4**	2.2/**2.4**	V(Min)
V_{IL}	Input Level	V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	1.0/**0.8**	V(Max)
I_{IH}	$\overline{ON}$/OFF Pin Input Current	$\overline{ON}$/OFF Pin = 5V (OFF)	12	 30	 30	μA μA(Max)
I_{IL}		$\overline{ON}$/OFF Pin = 0V (ON)	0	 10	 10	μA μA(Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All limts are used to calculate Average Outgoing Quality Leel, and all are 100% production tested.

Note 3: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face)**. All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 4: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM1575/LM2575 is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 5: Output (pin 2) sourcing current. No diode, inductor or capacitor connected to output pin.

Note 6: Feedback (pin 4) removed from output and connected to 0V.

Note 7: Feedback (pin 4) removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 8: $V_{IN} = 40V$ (60V for the high voltage version).

Electrical Characteristics (Notes) (Continued)

Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

Note 10: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

Note 11: Junction to ambient thermal resistance with approxmiately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in Switchers made Simple software.

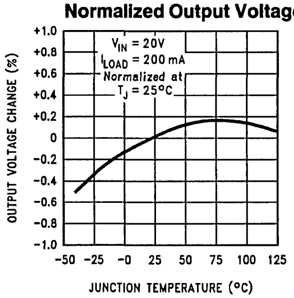
Note 12: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package: Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Note 13: The oscillator frequency reduces to approximately 18 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

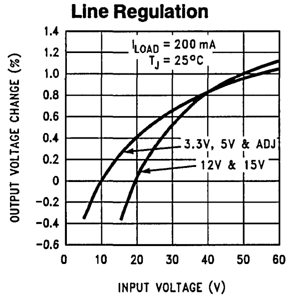
Note 14: Refer to RETS LM1575K, LM1575HVK for current revision of military RETS/SMD.

Typical Performance Characteristics (Circuit of *Figure 2*)

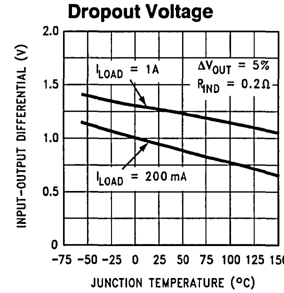
Normalized Output Voltage



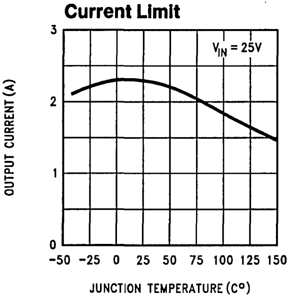
Line Regulation



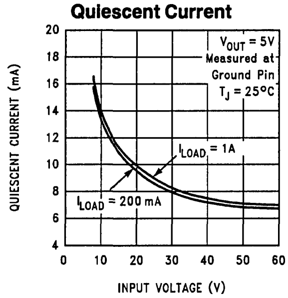
Dropout Voltage



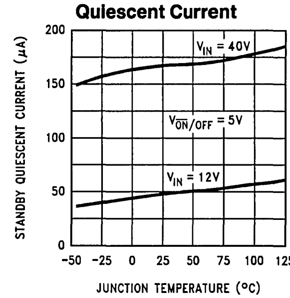
Current Limit



Quiescent Current

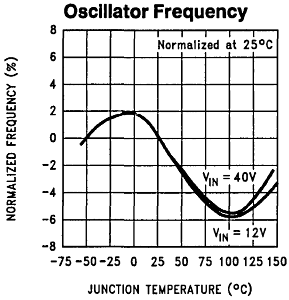


Standby Quiescent Current

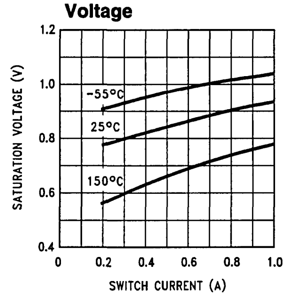


TL/H/11475–3

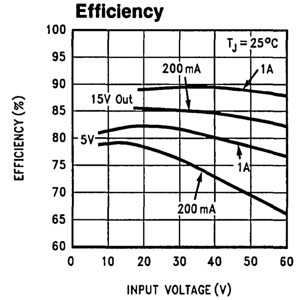
Oscillator Frequency



Switch Saturation Voltage



Efficiency

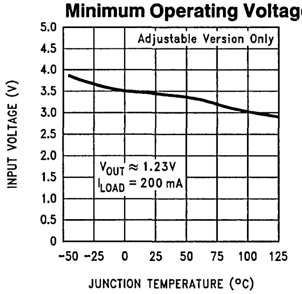


TL/H/11475–31

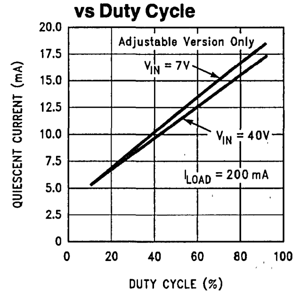
3

Typical Performance Characteristics (Continued)

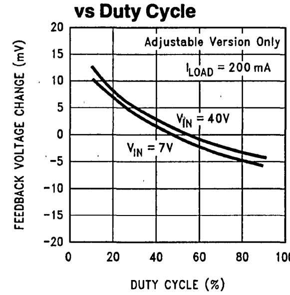
Minimum Operating Voltage



Quiescent Current vs Duty Cycle

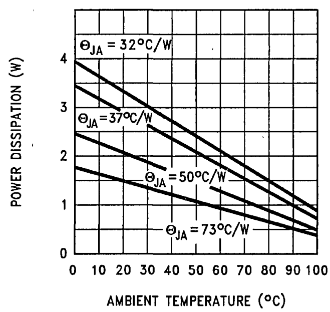


Feedback Voltage vs Duty Cycle



TL/H/11475–4

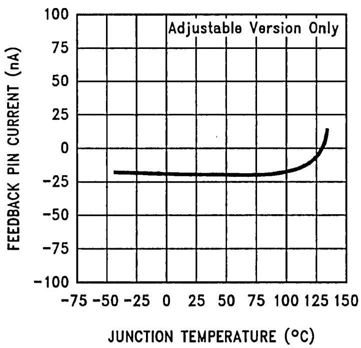
Maximum Power Dissipation (TO-263) (See Note 12)



TL/H/11475–28

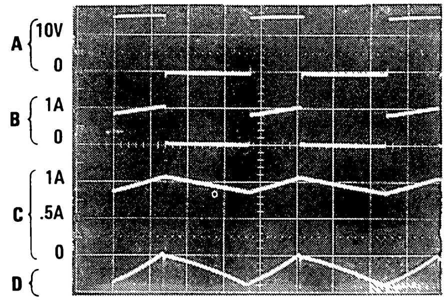
Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Feedback Pin Current



TL/H/11475-5

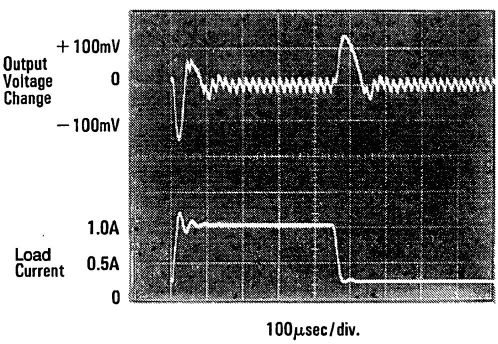
Switching Waveforms



TL/H/11475-6

V_{OUT} = 5V
A: Output Pin Voltage, 10V/div
B: Output Pin Current, 1A/div
C: Inductor Current, 0.5A/div
D: Output Ripple Voltage, 20 mV/div, AC-Coupled
Horizontal Time Base: 5 μs/div

Load Transient Response

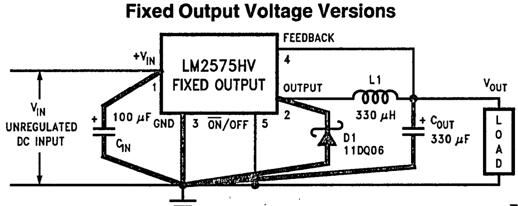


TL/H/11475-7

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

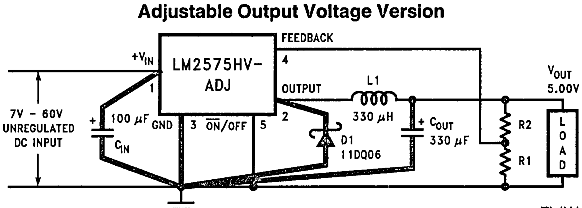
Fixed Output Voltage Versions



TL/H/11475-8

C_{IN} — 100 μF, 75V, Aluminum Electrolytic
C_{OUT} — 330 μF, 25V, Aluminum Electrolytic
D1 — Schottky, 11DQ06
L1 — 330 μH, PE-52627 (for 5V in, 3.3V out, use 100 μH, PE-92108)

Adjustable Output Voltage Version



TL/H/11475-9

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right)$$

$$R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where V_{REF} = 1.23V, R1 between 1k and 5k.
R1 — 2k, 0.1%
R2 — 6.12k, 0.1%

Note: Pin numbers are for the TO-220 package.

FIGURE 2

LM2575 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) V_{IN}(Max) = Maximum Input Voltage I_{LOAD}(Max) = Maximum Load Current	**Given:** V_{OUT} = 5V V_{IN}(Max) = 20V I_{LOAD}(Max) = 0.8A
1. Inductor Selection (L1) **A.** Select the correct Inductor value selection guide from *Figures 3, 4, 5,* or *6.* (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by V_{IN}(Max) and I_{LOAD}(Max), and note the inductor code for that region. **C.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9.* Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of 1.15 × I_{LOAD}. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1)** **A.** Use the selection guide shown in *Figure 4.* **B.** From the selection guide, the inductance area intersected by the 20V line and 0.8A line is L330. **C.** Inductor value required is 330 μH. From the table in *Figure 9,* choose AIE 415-0926, Pulse Engineering PE-52627, or RL1952.
2. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT})** **A.** C_{OUT} = 100 μF to 470 μF standard aluminum electrolytic. **B.** Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1)** **A.** For this example, a 1A current rating is adequate. **B.** Use a 30V 1N5818 or SR103 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 8.*
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 47 μF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

LM2575 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

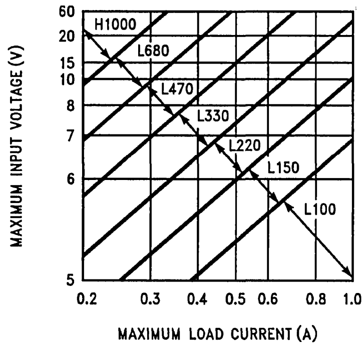


FIGURE 3. LM2575(HV)-3.3

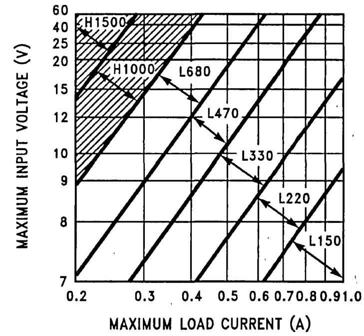


FIGURE 4. LM2575(HV)-5.0

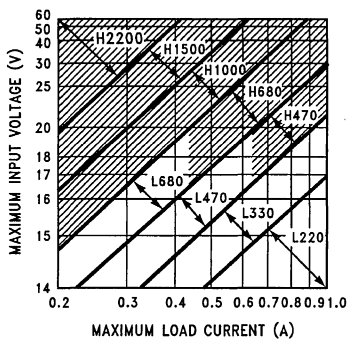


FIGURE 5. LM2575(HV)-12

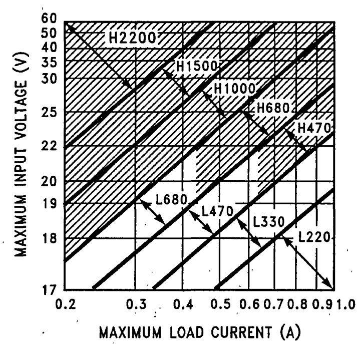


FIGURE 6. LM2575(HV)-15

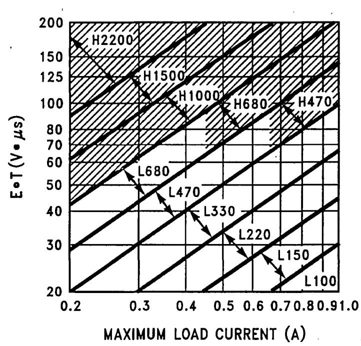


FIGURE 7. LM2575(HV)-ADJ

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
$V_{IN}(Max)$ = Maximum Input Voltage
$I_{LOAD}(Max)$ = Maximum Load Current
F = Switching Frequency *(Fixed at 52 kHz)*

1. **Programming Output Voltage** *(Selecting R1 and R2, as shown in Figure 2)*

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R2}{R1}\right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)*

$$R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. **Inductor Selection (L1)**

A. Calculate the inductor Volt • microsecond constant, E • T (V • µs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT})\frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (in\ kHz)}\ (V \bullet \mu s)$$

B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 7.*

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor code for that region.

E. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9.* Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2575 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. **Output Capacitor Selection (C_{OUT})**

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 7{,}785\frac{V_{IN}(Max)}{V_{OUT} \bullet L(\mu H)}\ (\mu F)$$

The above formula yields capacitor values between 10 µF and 2000 µF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reasion it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = 10V
$V_{IN}(Max)$ = 25V
$I_{LOAD}(Max)$ = 1A
F = 52 kHz

1. **Programming Output Voltage** *(Selecting R1 and R2)*

$$V_{OUT} = 1.23\left(1 + \frac{R2}{R1}\right) \quad \text{Select R1} = 1k$$

$$R2 = R1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$$

R2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k

2. **Inductor Selection (L1)**

A. Calculate E • T (V • µs)

$$E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115\ V \bullet \mu s$$

B. E • T = 115 V • µs
C. $I_{LOAD}(Max)$ = 1A
D. Inductance Region = H470
E. Inductor Value = 470 µH *Choose from* ***AIE*** *part #430-0634,* ***Pulse Engineering*** *part #PE-53118, or* ***Renco*** *part #RL-1961.*

3. **Output Capacitor Selection (C_{OUT})**

A. $C_{OUT} > 7{,}785\frac{25}{10 \bullet 150} = 130\ \mu F$

However, for acceptable output ripple voltage select

$C_{OUT} \geq 220\ \mu F$

C_{OUT} = 220 µF electrolytic capacitor

LM2575 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
4. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2575. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8.* **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1)** **A.** For this example, a 3A current rating is adequate. **B.** Use a 40V MBR340 or 31DQ04 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8.*
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 100 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the Simple Switcher line of switching regulators. ***Switchers Made Simple*** *(version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

V_R	Schottky		Fast Recovery	
	1A	3A	1A	3A
20V	1N5817 MBR120P SR102	1N5820 MBR320 SR302	The following diodes are all rated to 100V 11DF1 MUR110 HER102	The following diodes are all rated to 100V 31DF1 MURD310 HER302
30V	1N5818 MBR130P 11DQ03 SR103	1N5821 MBR330 31DQ03 SR303		
40V	1N5819 MBR140P 11DQ04 SR104	IN5822 MBR340 31DQ04 SR304		
50V	MBR150 11DQ05 SR105	MBR350 31DQ05 SR305		
60V	MBR160 11DQ06 SR106	MBR360 31DQ06 SR306		

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	Schott (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L100	100 μH	67127000	PE-92108	RL2444
L150	150 μH	67127010	PE-53113	RL1954
L220	220 μH	67127020	PE-52626	RL1953
L330	330 μH	67127030	PE-52627	RL1952
L470	470 μH	67127040	PE-53114	RL1951
L680	680 μH	67127050	PE-52629	RL1950
H150	150 μH	67127060	PE-53115	RL2445
H220	220 μH	67127070	PE-53116	RL2446
H330	330 μH	67127080	PE-53117	RL2447
H470	470 μH	67127090	PE-53118	RL1961
H680	680 μH	67127100	PE-53119	RL1960
H1000	1000 μH	67127110	PE-53120	RL1959
H1500	1500 μH	67127120	PE-53121	RL1958
H2200	2200 μH	67127130	PE-53122	RL2448

Note 1: Schott Corp., (612) 475-1173, 1000 Parkers Lake Rd., Wayzata, MN 55391.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12236, San Diego, CA 92112.

Note 3: Renco Electronics Inc., (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 47 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below −25°C, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

where $\frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$ for a buck regulator

and $\frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}}$ for a buck-boost regulator.

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2575 (or any of the Simple Switcher family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figures 3* through *7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 200 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toriod, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2575 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF–680 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND})(\text{ESR of } C_{OUT})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.05Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2575 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μH & 100 μF) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 × reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2575 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2575 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$/OFF INPUT

For normal operation, the $\overline{\text{ON}}$/OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$/OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$/OFF pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the TO-3 style package, the case is ground. For the 5-lead TO-220 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

With the N or M packages, all the pins labeled ground, power ground, or signal ground should be soldered directly to wide printed circuit board copper traces. This assures both low inductance connections and good thermal properties.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, no heat sink is required to keep the LM2575 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (150°C for the LM1575 or 125°C for the LM2575). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperature should be selected.
4. LM2575 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2575 can be estimated as follows:

$$P_D = (V_{IN})\ (I_Q) + (V_O/V_{IN})\ (I_{LOAD})\ (V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

Application Hints (Continued)

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)(\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

When using the LM2575 in the plastic DIP (N) or surface mount (M) packages, several items about the thermal properties of the packages should be understood. The majority of the heat is conducted out of the package through the leads, with a minor portion through the plastic parts of the package. Since the lead frame is solid copper, heat from the die is readily conducted through the leads to the printed circuit board copper, which is acting as a heat sink.

For best thermal performance, the ground pins and all the unconnected pins should be soldered to generous amounts of printed circuit board copper, such as a ground plane. Large areas of copper provide the best transfer of heat to the surrounding air. Copper on both sides of the board is also helpful in getting the heat away from the package, even if there is no direct copper contact between the two sides. Thermal resistance numbers as low as 40°C/W for the SO package, and 30°C/W for the N package can be realized with a carefully engineered pc board.

Included on the ***Switchers Made Simple*** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2575-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 0.35A. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 1.5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 µH and 220 µH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2 L_1 f_{osc}}$$

Where f_{osc} = 52 kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2575 is +28V, or +48V for the LM2575HV.

The ***Switchers Made Simple*** (version 3.3) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

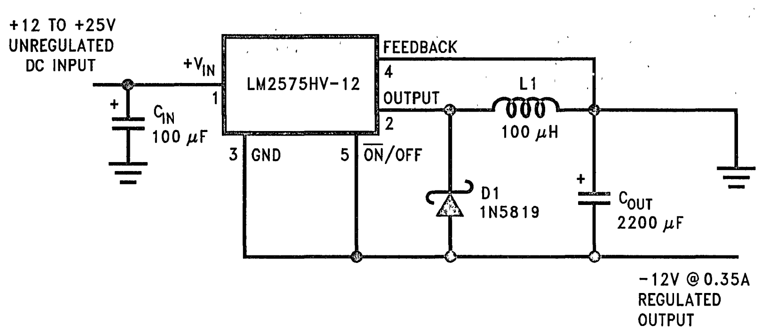


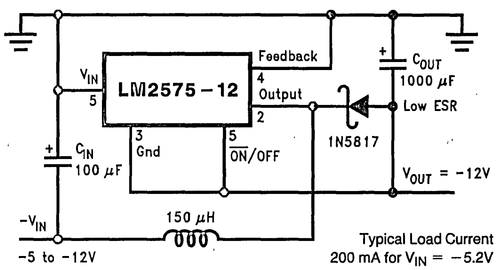
FIGURE 10. Inverting Buck-Boost Develops −12V

Additional Applications (Continued)

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.



TL/H/11475–16

Note: Pin numbers are for TO-220 package.

FIGURE 11. Negative Boost

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

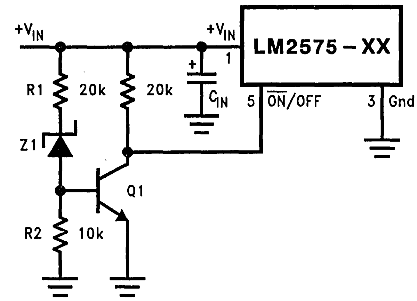
$$V_{TH} \approx V_{Z1} + 2V_{BE} (Q1)$$

DELAYED STARTUP

The $\overline{ON}$/OFF pin can be used to provide a delayed startup feature as shown in *Figure 14*. With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{ON}$/OFF pin.

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 1A power supply that features an adjustable output voltage is shown in *Figure 15*. An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.

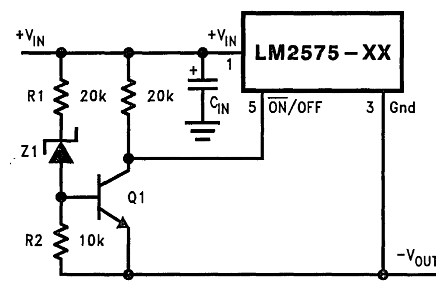


TL/H/11475–17

Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

FIGURE 12. Undervoltage Lockout for Buck Circuit

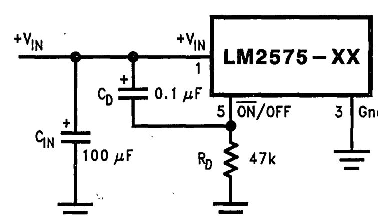


TL/H/11475–18

Note: Complete circuit not shown (see *Figure 10*).

Note: Pin numbers are for the TO-220 package.

FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit



TL/H/11475–19

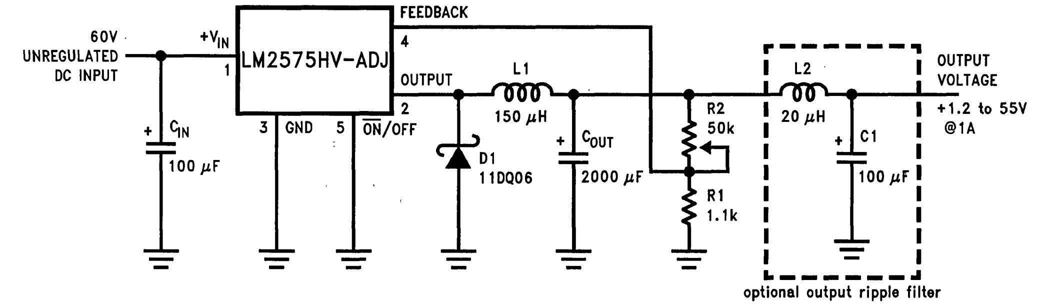
Note: Complete circuit not shown.

Note: Pin numbers are for the TO-220 package.

FIGURE 14. Delayed Startup

3

Additional Applications (Continued)



TL/H/11475–20

Note: Pin numbers are for the TO-220 package.

FIGURE 15. 1.2V to 55V Adjustable 1A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator $D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$

for buck-boost regulator $D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2575 switch is OFF.

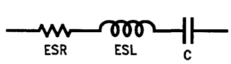
EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.



TL/H/11475–21

FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 µF–1000 µF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance"') in the 100 µF–1000 µF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2575 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

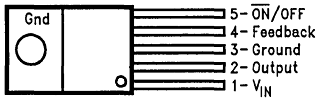
OPERATING VOLT MICROSECOND CONSTANT ($E \bullet T_{op}$)

The product (in Volt•µs) of the voltage applied to the inductor and the time the voltage is applied. This $E \bullet T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

(XX indicates output voltage option. See ordering information table for complete part number.)

Straight Leads
5-Lead TO-220 (T)

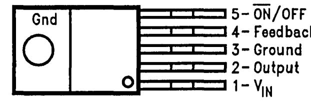


TL/H/11475-22

Top View

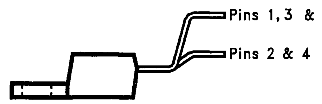
LM2575T-XX or LM2575HVT-XX
See NS Package Number T05A

Bent, Staggered Leads
5-Lead TO-220 (T)



TL/H/11475-23

Top View

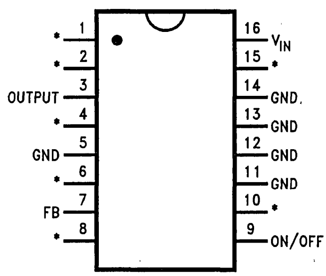


TL/H/11475-24

Side View

LM2575T-XX Flow LB03 or LM2575HVT-XX Flow LB03
See NS Package Number T05D

16-Lead DIP (N)



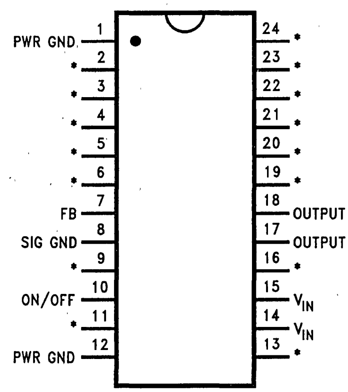
TL/H/11475-25

*No Internal Connection

Top View

LM2575N-XX or LM2575HVN-XX
See NS Package Number N16A

24-Lead Surface Mount (M)



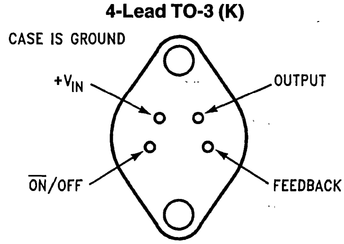
TL/H/11475-26

*No Internal Connection

Top View

LM2575M-XX or LM2575HVM-XX
See NS Package Number M24B

4-Lead TO-3 (K)



TL/H/11475-27

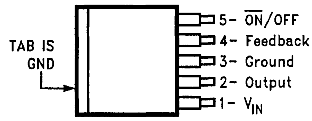
Bottom View

LM1575K-XX or LM1575HVK-XX/883
See NS Package Number K04A

Connection Diagrams (Continued)

(XX indicates output voltage option. See ordering information table for complete part number.)

TO-263(S)
5-Lead Surface-Mount Package



TL/H/11475-29

Top View

TL/H/11475-30

Side View
LM2575S-XX or LM2575HVS-XX
See NS Package Number S05A

Ordering Information

Package Type	NSC Package Number	Standard Voltage Rating (40V)	High Voltage Rating (60V)	Temperature Range
5-Lead TO-220 Straight Leads	T05A	LM2575T-3.3 LM2575T-5.0 LM2575T-12 LM2575T-15 LM2575T-ADJ	LM2575HVT-3.3 LM2575HVT-5.0 LM2575HVT-12 LM2575HVT-15 LM2575HVT-ADJ	$-40°C \leq T_J \leq +125°C$
5-Lead TO-220 Bent and Staggered Leads	T05D	LM2575T-3.3 Flow LB03 LM2575T-5.0 Flow LB03 LM2575T-12 Flow LB03 LM2575T-15 Flow LB03 LM2575T-ADJ Flow LB03	LM2575HVT-3.3 Flow LB03 LM2575HVT-5.0 Flow LB03 LM2575HVT-12 Flow LB03 LM2575HVT-15 Flow LB03 LM2575HVT-ADJ Flow LB03	
16-Pin Molded DIP	N16A	LM2575N-5.0 LM2575N-12 LM2575N-15 LM2575N-ADJ	LM2575HVN-5.0 LM2575HVN-12 LM2575HVN-15 LM2575HVN-ADJ	
24-Pin Surface Mount	M24B	LM2575M-5.0 LM2575M-12 LM2575M-15 LM2575M-ADJ	LM2575HVM-5.0 LM2575HVM-12 LM2575HVM-15 LM2575HVM-ADJ	
5-Lead TO-236 Surface Mount	S05A	LM2575S-3.3 LM2575S-5.0 LM2575S-12 LM2575S-15 LM2575S-ADJ	LM2575HVS-3.3 LM2575HVS-5.0 LM2575HVS-12 LM2575HVS-15 LM2575HVS-ADJ	
4-Pin TO-3	K04A	LM1575K-3.3/883 LM1575K-5.0/883 LM1575K-12/883 LM1575K-15/883 LM1575K-ADJ/883	LM1575HVK-3.3/883 LM1575HVK-5.0/883 LM1575HVK-12/883 LM1575HVK-15/883 LM1575HVK-ADJ/883	$-55°C \leq T_J \leq +150°C$

National Semiconductor

LM2576/LM2576HV Series SIMPLE SWITCHER® 3A Step-Down Voltage Regulator

General Description

The LM2576 series of regulators are monolithic integrated circuits that provide all the active functions for a step-down (buck) switching regulator, capable of driving 3A load with excellent line and load regulation. These devices are available in fixed output voltages of 3.3V, 5V, 12V, 15V, and an adjustable output version.

Requiring a minimum number of external components, these regulators are simple to use and include internal frequency compensation and a fixed-frequency oscillator.

The LM2576 series offers a high-efficiency replacement for popular three-terminal linear regulators. It substantially reduces the size of the heat sink, and in some cases no heat sink is required.

A standard series of inductors optimized for use with the LM2576 are available from several different manufacturers. This feature greatly simplifies the design of switch-mode power supplies.

Other features include a guaranteed ±4% tolerance on output voltage within specified input voltages and output load conditions, and ±10% on the oscillator frequency. External shutdown is included, featuring 50 μA (typical) standby current. The output switch includes cycle-by-cycle current limiting, as well as thermal shutdown for full protection under fault conditions.

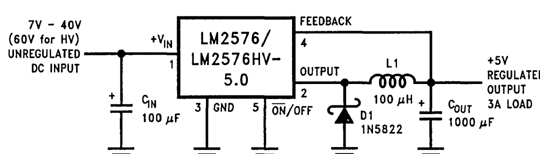
Features

- 3.3V, 5V, 12V, 15V, and adjustable output versions
- Adjustable version output voltage range, 1.23V to 37V (57V for HV version) ±4% max over line and load conditions
- Guaranteed 3A output current
- Wide input voltage range, 40V up to 60V for HV version
- Requires only 4 external components
- 52 kHz fixed frequency internal oscillator
- TTL shutdown capability, low power standby mode
- High efficiency
- Uses readily available standard inductors
- Thermal shutdown and current limit protection
- P+ Product Enhancement tested

Applications

- Simple high-efficiency step-down (buck) regulator
- Efficient pre-regulator for linear regulators
- On-card switching regulators
- Positive to negative converter (Buck-Boost)

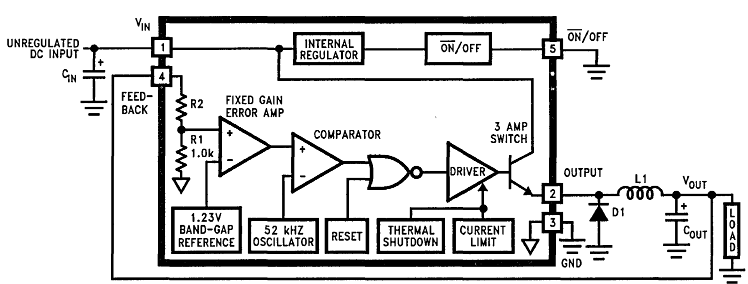
Typical Application (Fixed Output Voltage Versions)



TL/H/11476–1

FIGURE 1

Block Diagram



3.3V R2 = 1.7k
5V, R2 = 3.1k
12V, R2 = 8.84k
15V, R2 = 11.3k
For ADJ. Version
R1 = Open, R2 = 0Ω

TL/H/11476–2

Patent Pending

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Maximum Supply Voltage	
LM2576	45V
LM2576HV	63V
$\overline{ON}$/OFF Pin Input Voltage	$-0.3V \leq V \leq +V_{IN}$
Output Voltage to Ground (Steady State)	−1V
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV
Lead Temperature (Soldering, 10 Seconds)	260°C
Maximum Junction Temperature	150°C

Operating Ratings

Temperature Range	
LM2576/LM2576HV	$-40°C \leq T_J \leq +125°C$
Supply Voltage	
LM2576	40V
LM2576HV	60V

LM2576-3.3, LM2576HV-3.3

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-3.3 LM2576HV-3.3 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	3.3	 3.234 3.366	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$6V \leq V_{IN} \leq 40V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.432/**3.465**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$6V \leq V_{IN} \leq 60V$, $0.5A \leq I_{LOAD} \leq 3A$ Circuit of *Figure 2*	3.3	 3.168/**3.135** 3.450/**3.482**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	75		%

LM2576-5.0, LM2576HV-5.0

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-5.0 LM2576HV-5.0 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	$V_{IN} = 12V$, $I_{LOAD} = 0.5A$ Circuit of *Figure 2*	5.0	 4.900 5.100	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 40V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.200/**5.250**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	$0.5A \leq I_{LOAD} \leq 3A$, $8V \leq V_{IN} \leq 60V$ Circuit of *Figure 2*	5.0	 4.800/**4.750** 5.225/**5.275**	V V(Min) V(Max)
η	Efficiency	$V_{IN} = 12V$, $I_{LOAD} = 3A$	77		%

LM2576-12, LM2576HV-12

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-12 LM2576HV-12 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	V_{IN} = 25V, I_{LOAD} = 0.5A Circuit of *Figure 2*	12	 11.76 12.24	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	0.5A ≤ I_{LOAD} ≤ 3A, 15V ≤ V_{IN} ≤ 40V Circuit of *Figure 2*	12	 11.52/**11.40** 12.48/**12.60**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	0.5A ≤ I_{LOAD} ≤ 3A, 15V ≤ V_{IN} ≤ 60V Circuit of *Figure 2*	12	 11.52/**11.40** 12.54/**12.66**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 15V, I_{LOAD} = 3A	88		%

LM2576-15, LM2576HV-15

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-15 LM2576HV-15 Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Output Voltage	V_{IN} = 25V, I_{LOAD} = 0.5A Circuit of *Figure 2*	15	 14.70 15.30	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576	0.5A ≤ I_{LOAD} ≤ 3A, 18V ≤ V_{IN} ≤ 40V Circuit of *Figure 2*	15	 14.40/**14.25** 15.60/**15.75**	V V(Min) V(Max)
V_{OUT}	Output Voltage LM2576HV	0.5A ≤ I_{LOAD} ≤ 3A, 18V ≤ V_{IN} ≤ 60V Circuit of *Figure 2*	15	 14.40/**14.25** 15.68/**15.83**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 18V, I_{LOAD} = 3A	88		%

LM2576-ADJ, LM2576HV-ADJ

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over full Operating Temperature Range.

Symbol	Parameter	Conditions	LM2576-ADJ LM2576HV-ADJ Typ	Limit (Note 2)	Units (Limits)
SYSTEM PARAMETERS (Note 3) Test Circuit *Figure 2*					
V_{OUT}	Feedback Voltage	V_{IN} = 12V, I_{LOAD} = 0.5A V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.217 1.243	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576	0.5A ≤ I_{LOAD} ≤ 3A, 8V ≤ V_{IN} ≤ 40V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.267/**1.280**	V V(Min) V(Max)
V_{OUT}	Feedback Voltage LM2576HV	0.5A ≤ I_{LOAD} ≤ 3A, 8V ≤ V_{IN} ≤ 60V V_{OUT} = 5V, Circuit of *Figure 2*	1.230	 1.193/**1.180** 1.273/**1.286**	V V(Min) V(Max)
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 3A, V_{OUT} = 5V	77		%

All Output Voltage Versions

Electrical Characteristics Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over full Operating Temperature Range. Unless otherwise specified, V_{IN} = 12V for the 3.3V, 5V, and Adjustable version, V_{IN} = 25V for the 12V version, and V_{IN} = 30V for the 15V version. I_{LOAD} = 500 mA.

Symbol	Parameter	Conditions	LM2576-XX LM2576HV-XX Typ	Limit (Note 2)	Units (Limits)
DEVICE PARAMETERS					
I_b	Feedback Bias Current	V_{OUT} = 5V (Adjustable Version Only)	50	100/**500**	nA
f_O	Oscillator Frequency	(Note 11)	52	 47/**42** 58/**63**	kHz kHz (Min) kHz (Max)
V_{SAT}	Saturation Voltage	I_{OUT} = 3A (Note 4)	1.4	 1.8/**2.0**	V V(Max)
DC	Max Duty Cycle (ON)	(Note 5)	98	 93	% %(Min)
I_{CL}	Current Limit	(Notes 4 and 11)	5.8	 4.2/**3.5** 6.9/**7.5**	A A(Min) A(Max)
I_L	Output Leakage Current	(Notes 6 and 7) Output = 0V Output = −1V Output = −1V	 7.5	2 30	mA(Max) mA mA(Max)
I_Q	Quiescent Current	(Note 6)	5	 10	mA mA(Max)
I_{STBY}	Standby Quiescent Current	$\overline{ON}$/OFF Pin = 5V (OFF)	50	 200	μA μA(Max)
θ_{JA} θ_{JA} θ_{JC} θ_{JA}	Thermal Resistance	T Package, Junction to Ambient (Note 8) T Package, Junction to Ambient (Note 9) T Package, Junction to Case S Package, Junction to Ambient (Note 10)	65 45 2 50		°C/W
$\overline{ON}$/OFF CONTROL Test Circuit *Figure 2*					
V_{IH}	$\overline{ON}$/OFF Pin Logic Input Level	V_{OUT} = 0V	1.4	2.2/**2.4**	V(Min)
V_{IL}		V_{OUT} = Nominal Output Voltage	1.2	1.0/**0.8**	V(Max)
I_{IH}	$\overline{ON}$/OFF Pin Input Current	$\overline{ON}$/OFF Pin = 5V (OFF)	12	 30	μA μA(Max)
I_{IL}		$\overline{ON}$/OFF Pin = 0V (ON)	0	 10	μA μA(Max)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face).** All room temperature limits are 100% production tested. All limits at **temperature extremes** are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 3: External components such as the catch diode, inductor, input and output capacitors can affect switching regulator system performance. When the LM2576/LM2576HV is used as shown in the *Figure 2* test circuit, system performance will be as shown in system parameters section of Electrical Characteristics.

Note 4: Output pin sourcing current. No diode, inductor or capacitor connected to output.

Note 5: Feedback pin removed from output and connected to 0V.

Note 6: Feedback pin removed from output and connected to +12V for the Adjustable, 3.3V, and 5V versions, and +25V for the 12V and 15V versions, to force the output transistor OFF.

Note 7: V_{IN} = 40V (60V for high voltage version).

Note 8: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

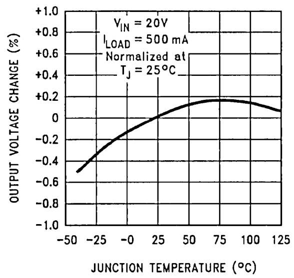
Note 9: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ¼ inch leads soldered to a PC board containing approximately 4 square inches of copper area surrounding the leads.

Note 10: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W, with 1 square inch of copper area, θ_{JA} is 37°C/W, and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

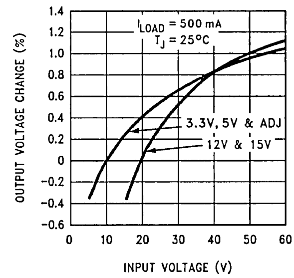
Note 11: The oscillator frequency reduces to approximately 11 kHz in the event of an output short or an overload which causes the regulated output voltage to drop approximately 40% from the nominal output voltage. This self protection feature lowers the average power dissipation of the IC by lowering the minimum duty cycle from 5% down to approximately 2%.

Typical Performance Characteristics (Circuit of *Figure 2*)

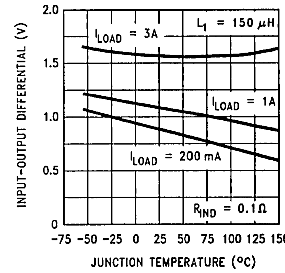
Normalized Output Voltage



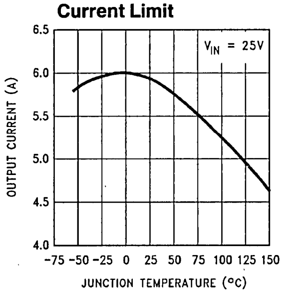
Line Regulation



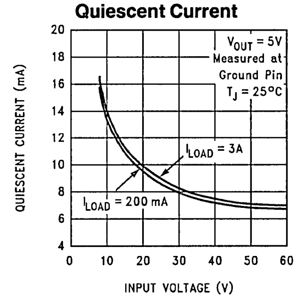
Dropout Voltage



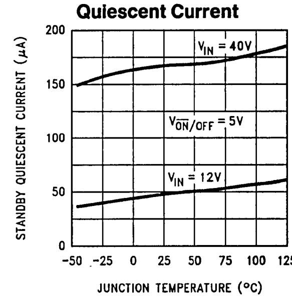
Current Limit



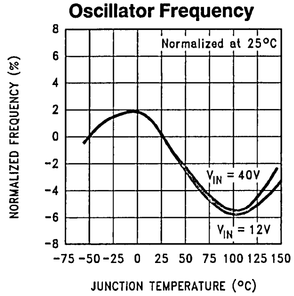
Quiescent Current



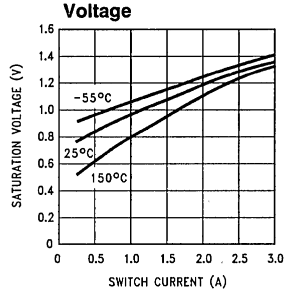
Standby Quiescent Current



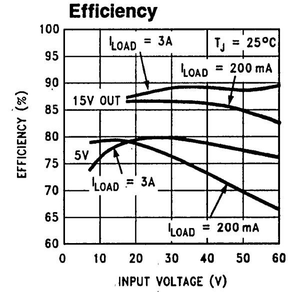
Oscillator Frequency



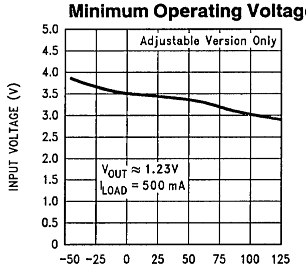
Switch Saturation Voltage



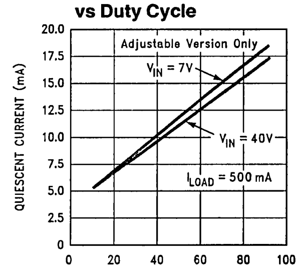
Efficiency



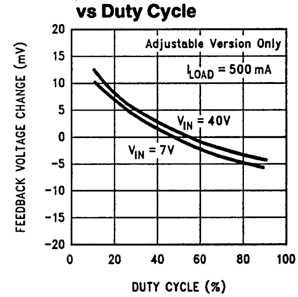
Minimum Operating Voltage



Quiescent Current vs Duty Cycle



Feedback Voltage vs Duty Cycle



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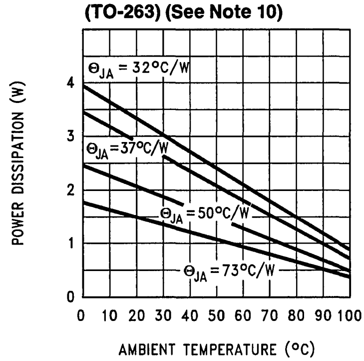
3

Typical Performance Characteristics (Circuit of *Figure 2*) (Continued)

Maximum Power Dissipation (TO-263) (See Note 10)



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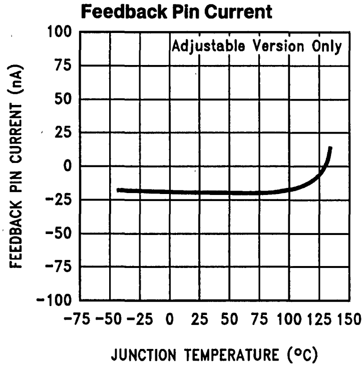
Feedback Pin Current



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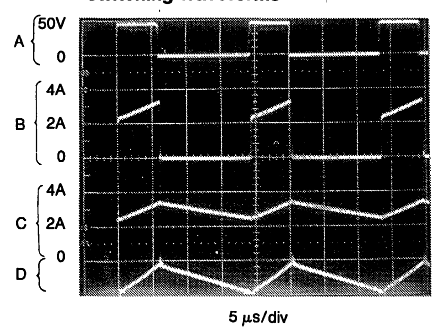
Switching Waveforms



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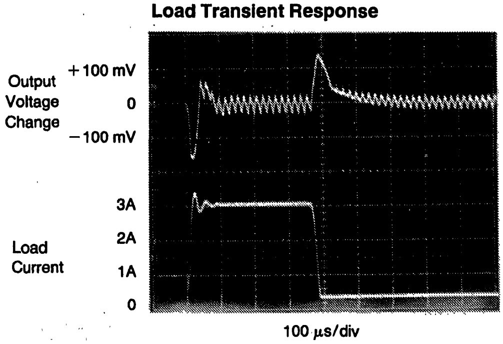
V_{OUT} = 15V
A: Output Pin Voltage, 50V/div
B: Output Pin Current, 2A/div
C: Inductor Current, 2A/div
D: Output Ripple Voltage, 50 mV/div, AC-Coupled
Horizontal Time Base: 5 μs/div

Load Transient Response



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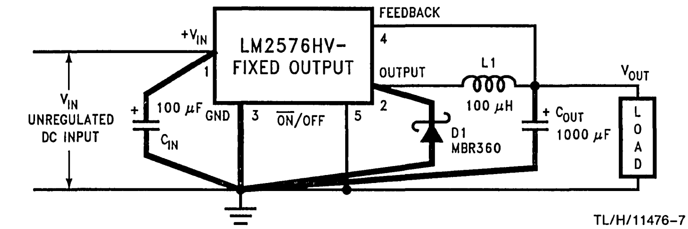
As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, the length of the leads indicated by heavy lines should be kept as short as possible. Single-point grounding (as indicated) or ground plane construction should be used for best results. When using the Adjustable version, physically locate the programming resistors near the regulator, to keep the sensitive feedback wiring short.

Test Circuit and Layout Guidelines

Fixed Output Voltage Versions



C_{IN} — 100 μF, 75V, Aluminum Electrolytic

C_{OUT} — 1000 μF, 25V, Aluminum Electrolytic

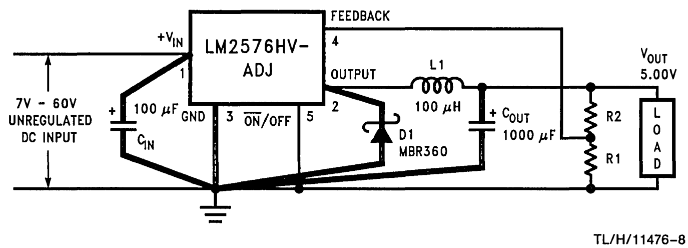
D_1 — Schottky, MBR360

L_1 — 100 μH, Pulse Eng. PE-92108

R_1 — 2k, 0.1%

R_2 — 6.12k, 0.1%

Adjustable Output Voltage Version



$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right)$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

where V_{REF} = 1.23V, R1 between 1k and 5k.

FIGURE 2

LM2576 Series Buck Regulator Design Procedure

PROCEDURE (Fixed Output Voltage Versions)	EXAMPLE (Fixed Output Voltage Versions)
Given: V_{OUT} = Regulated Output Voltage (3.3V, 5V, 12V, or 15V) $V_{IN}(Max)$ = Maximum Input Voltage $I_{LOAD}(Max)$ = Maximum Load Current	**Given:** V_{OUT} = 5V $V_{IN}(Max)$ = 15V $I_{LOAD}(Max)$ = 3A
1. Inductor Selection (L1) **A.** Select the correct Inductor value selection guide from *Figures 3, 4, 5,* or *6*. (Output voltages of 3.3V, 5V, 12V or 15V respectively). For other output voltages, see the design procedure for the adjustable version. **B.** From the inductor value selection guide, identify the inductance region intersected by $V_{IN}(Max)$ and $I_{LOAD}(Max)$, and note the inductor code for that region. **C.** Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 3*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of $1.15 \times I_{LOAD}$. For additional inductor information, see the inductor section in the Application Hints section of this data sheet.	**1. Inductor Selection (L1)** **A.** Use the selection guide shown in *Figure 4*. **B.** From the selection guide, the inductance area intersected by the 15V line and 3A line is L100. **C.** Inductor value required is 100 μH. From the table in *Figure 3*. Choose AIE 415-0930, Pulse Engineering PE92108, or Renco RL2444.
2. Output Capacitor Selection (C_{OUT}) **A.** The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation and an acceptable output ripple voltage, (approximately 1% of the output voltage) a value between 100 μF and 470 μF is recommended. **B.** The capacitor's voltage rating should be at least 1.5 times greater than the output voltage. For a 5V regulator, a rating of at least 8V is appropriate, and a 10V or 15V rating is recommended. Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rated for a higher voltage than would normally be needed.	**2. Output Capacitor Selection (C_{OUT})** **A.** C_{OUT} = 680 μF to 2000 μF standard aluminum electrolytic. **B.** Capacitor voltage rating = 20V.
3. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output condition. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**3. Catch Diode Selection (D1)** **A.** For this example, a 3A current rating is adequate. **B.** Use a 20V 1N5823 or SR302 Schottky diode, or any of the suggested fast-recovery diodes shown in *Figure 8*.
4. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**4. Input Capacitor (C_{IN})** A 100 μF, 25V aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

LM2576 Series Buck Regulator Design Procedure (Continued)

INDUCTOR VALUE SELECTION GUIDES (For Continuous Mode Operation)

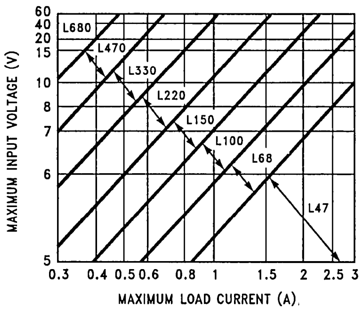


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FIGURE 3. LM2576(HV)-3.3

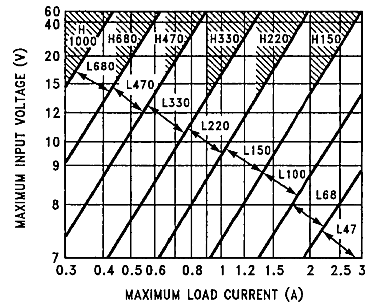

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FIGURE 4. LM2576(HV)-5.0

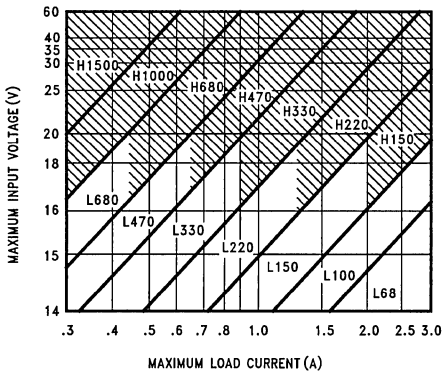

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FIGURE 5. LM2576(HV)-12

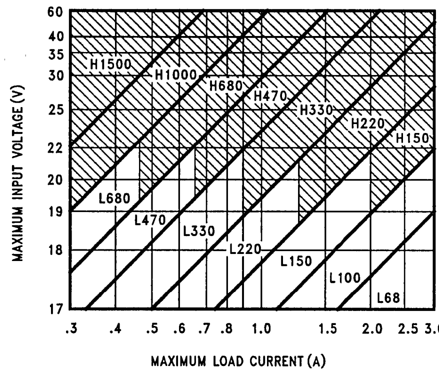

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FIGURE 6. LM2576(HV)-15

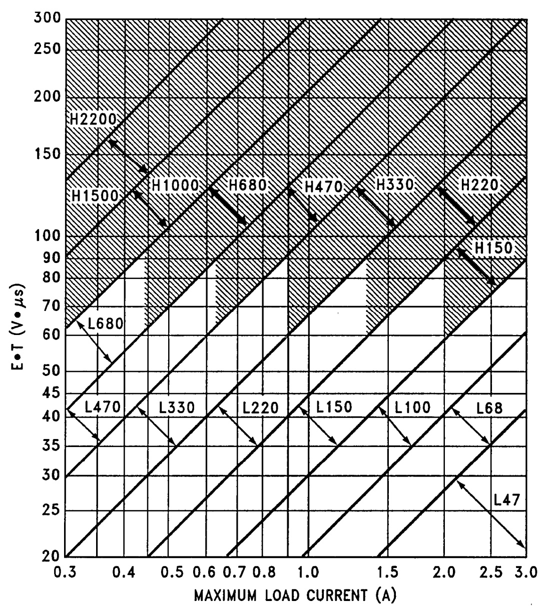

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FIGURE 7. LM2576(HV)-ADJ

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = Regulated Output Voltage
$V_{IN}(Max)$ = Maximum Input Voltage
$I_{LOAD}(Max)$ = Maximum Load Current
F = Switching Frequency *(Fixed at 52 kHz)*

1. Programming Output Voltage *(Selecting R1 and R2, as shown in Figure 2)*

Use the following formula to select the appropriate resistor values.

$$V_{OUT} = V_{REF}\left(1 + \frac{R_2}{R_1}\right) \quad \text{where } V_{REF} = 1.23V$$

R_1 can be between 1k and 5k. *(For best temperature coefficient and stability with time, use 1% metal film resistors)*

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right)$$

2. Inductor Selection (L1)

A. Calculate the inductor Volt • microsecond constant, E • T (V • µs), from the following formula:

$$E \bullet T = (V_{IN} - V_{OUT})\frac{V_{OUT}}{V_{IN}} \bullet \frac{1000}{F\ (in\ kHz)}\ (V \bullet \mu s)$$

B. Use the E • T value from the previous formula and match it with the E • T number on the vertical axis of the **Inductor Value Selection Guide** shown in *Figure 7*.

C. On the horizontal axis, select the maximum load current.

D. Identify the inductance region intersected by the E • T value and the maximum load current value, and note the inductor code for that region.

E. Identify the inductor value from the inductor code, and select an appropriate inductor from the table shown in *Figure 9*. Part numbers are listed for three inductor manufacturers. The inductor chosen must be rated for operation at the LM2576 switching frequency (52 kHz) and for a current rating of 1.15 × I_{LOAD}. For additional inductor information, see the inductor section in the application hints section of this data sheet.

3. Output Capacitor Selection (C_{OUT})

A. The value of the output capacitor together with the inductor defines the dominate pole-pair of the switching regulator loop. For stable operation, the capacitor must satisfy the following requirement:

$$C_{OUT} \geq 13{,}300\frac{V_{IN}(Max)}{V_{OUT} \bullet L(\mu H)}\ (\mu F)$$

The above formula yields capacitor values between 10 µF and 2200 µF that will satisfy the loop requirements for stable operation. But to achieve an acceptable output ripple voltage, (approximately 1% of the output voltage) and transient response, the output capacitor may need to be several times larger than the above formula yields.

B. The capacitor's voltage rating should be at last 1.5 times greater than the output voltage. For a 10V regulator, a rating of at least 15V or more is recommended.

Higher voltage electrolytic capacitors generally have lower ESR numbers, and for this reason it may be necessary to select a capacitor rate for a higher voltage than would normally be needed.

EXAMPLE (Adjustable Output Voltage Versions)

Given:

V_{OUT} = 10V
$V_{IN}(Max)$ = 25V
$I_{LOAD}(Max)$ = 3A
F = 52 kHz

1. Programming Output Voltage *(Selecting R1 and R2)*

$$V_{OUT} = 1.23\left(1 + \frac{R_2}{R_1}\right) \quad \text{Select R1} = 1k$$

$$R_2 = R_1\left(\frac{V_{OUT}}{V_{REF}} - 1\right) = 1k\left(\frac{10V}{1.23V} - 1\right)$$

R_2 = 1k (8.13 − 1) = 7.13k, closest 1% value is 7.15k

2. Inductor Selection (L1)

A. Calculate E • T (V • µs)

$$E \bullet T = (25 - 10) \bullet \frac{10}{25} \bullet \frac{1000}{52} = 115\ V \bullet \mu s$$

B. E • T = 115 V • µs

C. $I_{LOAD}(Max)$ = 3A

D. Inductance Region = H150

E. Inductor Value = 150 µH *Choose from* ***AIE*** *part #415-0936* ***Pulse Engineering*** *part #*PE-531115, or ***Renco*** *part #RL2445.*

3. Output Capacitor Selection (C_{OUT})

A. $C_{OUT} > 13{,}300\dfrac{25}{10 \bullet 150} = 22.2\ \mu F$

However, for acceptable output ripple voltage select

$C_{OUT} \geq 680\ \mu F$

C_{OUT} = 680 µF electrolytic capacitor

LM2576 Series Buck Regulator Design Procedure (Continued)

PROCEDURE (Adjustable Output Voltage Versions)	EXAMPLE (Adjustable Output Voltage Versions)
4. Catch Diode Selection (D1) **A.** The catch-diode current rating must be at least 1.2 times greater than the maximum load current. Also, if the power supply design must withstand a continuous output short, the diode should have a current rating equal to the maximum current limit of the LM2576. The most stressful condition for this diode is an overload or shorted output. See diode selection guide in *Figure 8*. **B.** The reverse voltage rating of the diode should be at least 1.25 times the maximum input voltage.	**4. Catch Diode Selection (D1)** **A.** For this example, a 3.3A current rating is adequate. **B.** Use a 30V 31DQ03 Schottky diode, or any of the suggested fast-recovery diodes in *Figure 8*.
5. Input Capacitor (C_{IN}) An aluminum or tantalum electrolytic bypass capacitor located close to the regulator is needed for stable operation.	**5. Input Capacitor (C_{IN})** A 100 μF aluminum electrolytic capacitor located near the input and ground pins provides sufficient bypassing.

V_R	Schottky		Fast Recovery	
	3A	4A–6A	3A	4A–6A
20V	1N5820 MBR320P SR302	1N5823	The following diodes are all rated to 100V 31DF1 HER302	The following diodes are all rated to 100V 50WF10 MUR410 HER602
30V	1N5821 MBR330 31DQ03 SR303	50WQ03 1N5824		
40V	1N5822 MBR340 31DQ04 SR304	MBR340 50WQ04 1N5825		
50V	MBR350 31DQ05 SR305	50WQ05		
60V	MBR360 DQ06 SR306	50WR06 50SQ060		

To further simplify the buck regulator design procedure, National Semiconductor is making available computer design software to be used with the SIMPLE SWITCHER line of switching regulators. ***Switchers Made Simple*** *(Version 3.3) is available on a (3½") diskette for IBM compatible computers from a National Semiconductor sales office in your area.*

FIGURE 8. Diode Selection Guide

Inductor Code	Inductor Value	Schott (Note 1)	Pulse Eng. (Note 2)	Renco (Note 3)
L47	47 μH	671 26980	PE-53112	RL2442
L68	68 μH	671 26990	PE-92114	RL2443
L100	100 μH	671 27000	PE-92108	RL2444
L150	150 μH	671 27010	PE-53113	RL1954
L220	220 μH	671 27020	PE-52626	RL1953
L330	330 μH	671 27030	PE-52627	RL1952
L470	470 μH	671 27040	PE-53114	RL1951
L680	680 μH	671 27050	PE-52629	RL1950
H150	150 μH	671 27060	PE-53115	RL2445
H220	220 μH	671 27070	PE-53116	RL2446
H330	330 μH	671 27080	PE-53117	RL2447
H470	470 μH	671 27090	PE-53118	RL1961
H680	680 μH	671 27100	PE-53119	RL1960
H1000	1000 μH	671 27110	PE-53120	RL1959
H1500	1500 μH	671 27120	PE-53121	RL1958
H2200	2200 μH	671 27130	PE-53122	RL2448

Note 1: Schott Corporation, (612) 475-1173, 1000 Parkers Lake Road, Wayzata, MN 55391.

Note 2: Pulse Engineering, (619) 674-8100, P.O. Box 12235, San Diego, CA 92112.

Note 3: Renco Electronics Incorporated, (516) 586-5566, 60 Jeffryn Blvd. East, Deer Park, NY 11729.

FIGURE 9. Inductor Selection by Manufacturer's Part Number

Application Hints

INPUT CAPACITOR (C_{IN})

To maintain stability, the regulator input pin must be bypassed with at least a 100 μF electrolytic capacitor. The capacitor's leads must be kept short, and located near the regulator.

If the operating temperature range includes temperatures below $-25°C$, the input capacitor value may need to be larger. With most electrolytic capacitors, the capacitance value decreases and the ESR increases with lower temperatures and age. Paralleling a ceramic or solid tantalum capacitor will increase the regulator stability at cold temperatures. For maximum capacitor operating lifetime, the capacitor's RMS ripple current rating should be greater than

$$1.2 \times \left(\frac{t_{ON}}{T}\right) \times I_{LOAD}$$

$$\text{where } \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}} \text{ for a buck regulator}$$

$$\text{and } \frac{t_{ON}}{T} = \frac{|V_{OUT}|}{|V_{OUT}| + V_{IN}} \text{ for a buck-boost regulator.}$$

INDUCTOR SELECTION

All switching regulators have two basic modes of operation: continuous and discontinuous. The difference between the two types relates to the inductor current, whether it is flowing continuously, or if it drops to zero for a period of time in the normal switching cycle. Each mode has distinctively different operating characteristics, which can affect the regulator performance and requirements.

The LM2576 (or any of the SIMPLE SWITCHER family) can be used for both continuous and discontinuous modes of operation.

The inductor value selection guides in *Figure 3* through *Figure 7* were designed for buck regulator designs of the continuous inductor current type. When using inductor values shown in the inductor selection guide, the peak-to-peak inductor ripple current will be approximately 20% to 30% of the maximum DC current. With relatively heavy load currents, the circuit operates in the continuous mode (inductor current always flowing), but under light load conditions, the circuit will be forced to the discontinuous mode (inductor current falls to zero for a period of time). This discontinuous mode of operation is perfectly acceptable. For light loads (less than approximately 300 mA) it may be desirable to operate the regulator in the discontinuous mode, primarily because of the lower inductor values required for the discontinuous mode.

The selection guide chooses inductor values suitable for continuous mode operation, but if the inductor value chosen is prohibitively high, the designer should investigate the possibility of discontinuous operation. The computer design software ***Switchers Made Simple*** will provide all component values for discontinuous (as well as continuous) mode of operation.

Inductors are available in different styles such as pot core, toriod, E-frame, bobbin core, etc., as well as different core materials, such as ferrites and powdered iron. The least expensive, the bobbin core type, consists of wire wrapped on a ferrite rod core. This type of construction makes for an inexpensive inductor, but since the magnetic flux is not completely contained within the core, it generates more electromagnetic interference (EMI). This EMI can cause problems in sensitive circuits, or can give incorrect scope readings because of induced voltages in the scope probe.

The inductors listed in the selection chart include ferrite pot core construction for AIE, powdered iron toroid for Pulse Engineering, and ferrite bobbin core for Renco.

An inductor should not be operated beyond its maximum rated current because it may saturate. When an inductor begins to saturate, the inductance decreases rapidly and the inductor begins to look mainly resistive (the DC resistance of the winding). This will cause the switch current to rise very rapidly. Different inductor types have different saturation characteristics, and this should be kept in mind when selecting an inductor.

The inductor manufacturer's data sheets include current and energy limits to avoid inductor saturation.

INDUCTOR RIPPLE CURRENT

When the switcher is operating in the continuous mode, the inductor current waveform ranges from a triangular to a sawtooth type of waveform (depending on the input voltage). For a given input voltage and output voltage, the peak-to-peak amplitude of this inductor current waveform remains constant. As the load current rises or falls, the entire sawtooth current waveform also rises or falls. The average DC value of this waveform is equal to the DC load current (in the buck regulator configuration).

If the load current drops to a low enough level, the bottom of the sawtooth current waveform will reach zero, and the switcher will change to a discontinuous mode of operation. This is a perfectly acceptable mode of operation. Any buck switching regulator (no matter how large the inductor value is) will be forced to run discontinuous if the load current is light enough.

OUTPUT CAPACITOR

An output capacitor is required to filter the output voltage and is needed for loop stability. The capacitor should be located near the LM2576 using short pc board traces. Standard aluminum electrolytics are usually adequate, but low ESR types are recommended for low output ripple voltage and good stability. The ESR of a capacitor depends on many factors, some which are: the value, the voltage rating, physical size and the type of construction. In general, low value or low voltage (less than 12V) electrolytic capacitors usually have higher ESR numbers.

The amount of output ripple voltage is primarily a function of the ESR (Equivalent Series Resistance) of the output capacitor and the amplitude of the inductor ripple current (ΔI_{IND}). See the section on inductor ripple current in Application Hints.

The lower capacitor values (220 μF–1000 μF) will allow typically 50 mV to 150 mV of output ripple voltage, while larger-value capacitors will reduce the ripple to approximately 20 mV to 50 mV.

$$\text{Output Ripple Voltage} = (\Delta I_{IND})\ (\text{ESR of } C_{OUT})$$

Application Hints (Continued)

To further reduce the output ripple voltage, several standard electrolytic capacitors may be paralleled, or a higher-grade capacitor may be used. Such capacitors are often called "high-frequency," "low-inductance," or "low-ESR." These will reduce the output ripple to 10 mV or 20 mV. However, when operating in the continuous mode, reducing the ESR below 0.03Ω can cause instability in the regulator.

Tantalum capacitors can have a very low ESR, and should be carefully evaluated if it is the only output capacitor. Because of their good low temperature characteristics, a tantalum can be used in parallel with aluminum electrolytics, with the tantalum making up 10% or 20% of the total capacitance.

The capacitor's ripple current rating at 52 kHz should be at least 50% higher than the peak-to-peak inductor ripple current.

CATCH DIODE

Buck regulators require a diode to provide a return path for the inductor current when the switch is off. This diode should be located close to the LM2576 using short leads and short printed circuit traces.

Because of their fast switching speed and low forward voltage drop, Schottky diodes provide the best efficiency, especially in low output voltage switching regulators (less than 5V). Fast-Recovery, High-Efficiency, or Ultra-Fast Recovery diodes are also suitable, but some types with an abrupt turn-off characteristic may cause instability and EMI problems. A fast-recovery diode with soft recovery characteristics is a better choice. Standard 60 Hz diodes (e.g., 1N4001 or 1N5400, etc.) are also **not suitable.** See *Figure 8* for Schottky and "soft" fast-recovery diode selection guide.

OUTPUT VOLTAGE RIPPLE AND TRANSIENTS

The output voltage of a switching power supply will contain a sawtooth ripple voltage at the switcher frequency, typically about 1% of the output voltage, and may also contain short voltage spikes at the peaks of the sawtooth waveform.

The output ripple voltage is due mainly to the inductor sawtooth ripple current multiplied by the ESR of the output capacitor. (See the inductor selection in the application hints.)

The voltage spikes are present because of the the fast switching action of the output switch, and the parasitic inductance of the output filter capacitor. To minimize these voltage spikes, special low inductance capacitors can be used, and their lead lengths must be kept short. Wiring inductance, stray capacitance, as well as the scope probe used to evaluate these transients, all contribute to the amplitude of these spikes.

An additional small LC filter (20 μH & 100 μF) can be added to the output (as shown in *Figure 15*) to further reduce the amount of output ripple and transients. A 10 × reduction in output ripple voltage and transients is possible with this filter.

FEEDBACK CONNECTION

The LM2576 (fixed voltage versions) feedback pin must be wired to the output voltage point of the switching power supply. When using the adjustable version, physically locate both output voltage programming resistors near the LM2576 to avoid picking up unwanted noise. Avoid using resistors greater than 100 kΩ because of the increased chance of noise pickup.

$\overline{\text{ON}}$/OFF INPUT

For normal operation, the $\overline{\text{ON}}$/OFF pin should be grounded or driven with a low-level TTL voltage (typically below 1.6V). To put the regulator into standby mode, drive this pin with a high-level TTL or CMOS signal. The $\overline{\text{ON}}$/OFF pin can be safely pulled up to $+V_{IN}$ without a resistor in series with it. The $\overline{\text{ON}}$/OFF pin should not be left open.

GROUNDING

To maintain output voltage stability, the power ground connections must be low-impedance (see *Figure 2*). For the 5-lead TO-220 and TO-263 style package, both the tab and pin 3 are ground and either connection may be used, as they are both part of the same copper lead frame.

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, only a small heat sink is required to keep the LM2576 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1. Maximum ambient temperature (in the application).
2. Maximum regulator power dissipation (in application).
3. Maximum allowed junction temperature (125°C for the LM2576). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum temperatures should be selected.
4. LM2576 package thermal resistances θ_{JA} and θ_{JC}.

Total power dissipated by the LM2576 can be estimated as follows:

$$P_D = (V_{IN})(I_Q) + (V_O/V_{IN})(I_{LOAD})(V_{SAT})$$

where I_Q (quiescent current) and V_{SAT} can be found in the Characteristic Curves shown previously, V_{IN} is the applied minimum input voltage, V_O is the regulated output voltage, and I_{LOAD} is the load current. The dynamic losses during turn-on and turn-off are negligible if a Schottky type catch diode is used.

When no heat sink is used, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\,(\theta_{JA})$$

To arrive at the actual operating junction temperature, add the junction temperature rise to the maximum ambient temperature.

$$T_J = \Delta T_J + T_A$$

If the actual operating junction temperature is greater than the selected safe operating junction temperature determined in step 3, then a heat sink is required.

When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = (P_D)\,(\theta_{JC} + \theta_{interface} + \theta_{Heat\ sink})$$

The operating junction temperature will be:

$$T_J = T_A + \Delta T_J$$

As above, if the actual operating junction temperature is greater than the selected safe operating junction temperature, then a larger heat sink is required (one that has a lower thermal resistance).

Included on the **Switcher Made Simple** design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulators junction temperature below the maximum operating temperature.

Additional Applications

INVERTING REGULATOR

Figure 10 shows a LM2576-12 in a buck-boost configuration to generate a negative 12V output from a positive input voltage. This circuit bootstraps the regulator's ground pin to the negative output voltage, then by grounding the feedback pin, the regulator senses the inverted output voltage and regulates it to −12V.

For an input voltage of 12V or more, the maximum available output current in this configuration is approximately 700 mA. At lighter loads, the minimum input voltage required drops to approximately 4.7V.

The switch currents in this buck-boost configuration are higher than in the standard buck-mode design, thus lowering the available output current. Also, the start-up input current of the buck-boost converter is higher than the standard buck-mode regulator, and this may overload an input power source with a current limit less than 5A. Using a delayed turn-on or an undervoltage lockout circuit (described in the next section) would allow the input voltage to rise to a high enough level before the switcher would be allowed to turn on.

Because of the structural differences between the buck and the buck-boost regulator topologies, the buck regulator design procedure section can not be used to to select the inductor or the output capacitor. The recommended range of inductor values for the buck-boost design is between 68 μH and 220 μH, and the output capacitor values must be larger than what is normally required for buck designs. Low input voltages or high output currents require a large value output capacitor (in the thousands of micro Farads).

The peak inductor current, which is the same as the peak switch current, can be calculated from the following formula:

$$I_p \approx \frac{I_{LOAD}(V_{IN} + |V_O|)}{V_{IN}} + \frac{V_{IN}|V_O|}{V_{IN} + |V_O|} \times \frac{1}{2L_1 f_{osc}}$$

Where f_{osc} = 52 kHz. Under normal continuous inductor current operating conditions, the minimum V_{IN} represents the worst case. Select an inductor that is rated for the peak current anticipated.

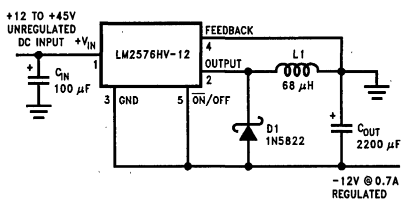

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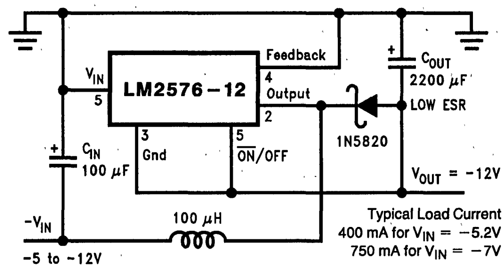
FIGURE 10. Inverting Buck-Boost Develops −12V

Also, the maximum voltage appearing across the regulator is the absolute sum of the input and output voltage. For a −12V output, the maximum input voltage for the LM2576 is +28V, or +48V for the LM2576HV.

The ***Switchers Made Simple*** (version 3.0) design software can be used to determine the feasibility of regulator designs using different topologies, different input-output parameters, different components, etc.

NEGATIVE BOOST REGULATOR

Another variation on the buck-boost topology is the negative boost configuration. The circuit in *Figure 11* accepts an input voltage ranging from −5V to −12V and provides a regulated −12V output. Input voltages greater than −12V will cause the output to rise above −12V, but will not damage the regulator.



Note: Heat sink may be required.

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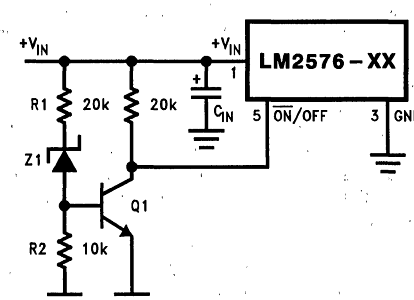
FIGURE 11. Negative Boost

Because of the boosting function of this type of regulator, the switch current is relatively high, especially at low input voltages. Output load current limitations are a result of the maximum current rating of the switch. Also, boost regulators can not provide current limiting load protection in the event of a shorted load, so some other means (such as a fuse) may be necessary.

UNDERVOLTAGE LOCKOUT

In some applications it is desirable to keep the regulator off until the input voltage reaches a certain threshold. An undervoltage lockout circuit which accomplishes this task is shown in *Figure 12*, while *Figure 13* shows the same circuit applied to a buck-boost configuration. These circuits keep the regulator off until the input voltage reaches a predetermined level.

$$V_{TH} \approx V_{Z1} + 2V_{BE}(Q1)$$



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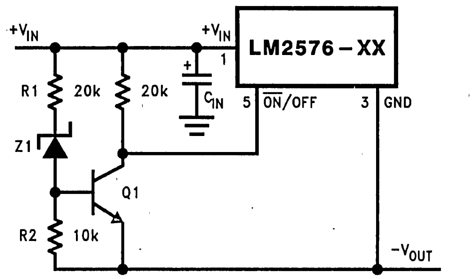
Note: Complete circuit not shown.

FIGURE 12. Undervoltage Lockout for Buck Circuit

Additional Applications (Continued)



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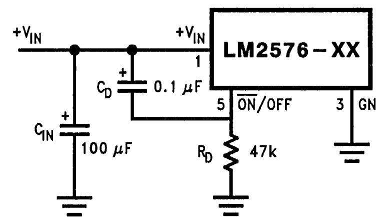
Note: Complete circuit not shown (see Figure 10).

FIGURE 13. Undervoltage Lockout for Buck-Boost Circuit

DELAYED STARTUP

The $\overline{\text{ON}}$/OFF pin can be used to provide a delayed startup feature as shown in *Figure 14.* With an input voltage of 20V and for the part values shown, the circuit provides approximately 10 ms of delay time before the circuit begins switching. Increasing the RC time constant can provide longer delay times. But excessively large RC time constants can cause problems with input voltages that are high in 60 Hz or 120 Hz ripple, by coupling the ripple into the $\overline{\text{ON}}$/OFF pin.



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Note: Complete circuit not shown.

FIGURE 14. Delayed Startup

ADJUSTABLE OUTPUT, LOW-RIPPLE POWER SUPPLY

A 3A power supply that features an adjustable output voltage is shown in *Figure 15.* An additional L-C filter that reduces the output ripple by a factor of 10 or more is included in this circuit.

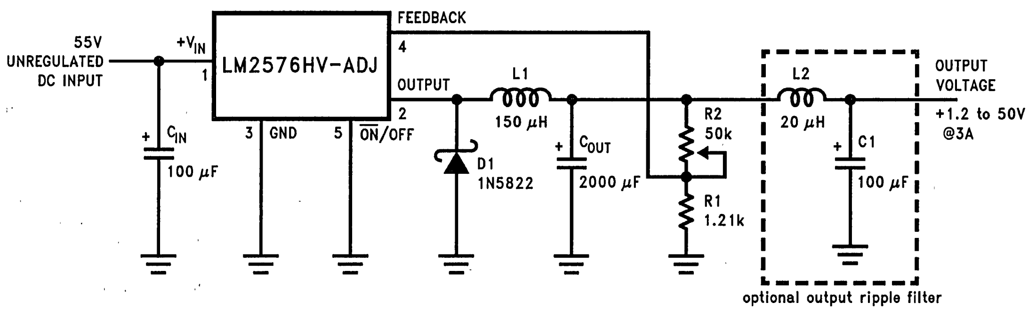

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FIGURE 15. 1.2V to 55V Adjustable 3A Power Supply with Low Output Ripple

Definition of Terms

BUCK REGULATOR

A switching regulator topology in which a higher voltage is converted to a lower voltage. Also known as a step-down switching regulator.

BUCK-BOOST REGULATOR

A switching regulator topology in which a positive voltage is converted to a negative voltage without a transformer.

DUTY CYCLE (D)

Ratio of the output switch's on-time to the oscillator period.

for buck regulator $$D = \frac{t_{ON}}{T} = \frac{V_{OUT}}{V_{IN}}$$

for buck-boost regulator $$D = \frac{t_{ON}}{T} = \frac{|V_O|}{|V_O| + V_{IN}}$$

CATCH DIODE OR CURRENT STEERING DIODE

The diode which provides a return path for the load current when the LM2576 switch is OFF.

EFFICIENCY (η)

The proportion of input power actually delivered to the load.

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{P_{OUT}}{P_{OUT} + P_{LOSS}}$$

CAPACITOR EQUIVALENT SERIES RESISTANCE (ESR)

The purely resistive component of a real capacitor's impedance (see *Figure 16*). It causes power loss resulting in capacitor heating, which directly affects the capacitor's operating lifetime. When used as a switching regulator output filter, higher ESR values result in higher output ripple voltages.

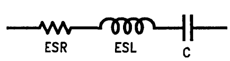

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FIGURE 16. Simple Model of a Real Capacitor

Most standard aluminum electrolytic capacitors in the 100 μF–1000 μF range have 0.5Ω to 0.1Ω ESR. Higher-grade capacitors ("low-ESR", "high-frequency", or "low-inductance") in the 100 μF–1000 μF range generally have ESR of less than 0.15Ω.

EQUIVALENT SERIES INDUCTANCE (ESL)

The pure inductance component of a capacitor (see *Figure 16*). The amount of inductance is determined to a large extent on the capacitor's construction. In a buck regulator, this unwanted inductance causes voltage spikes to appear on the output.

OUTPUT RIPPLE VOLTAGE

The AC component of the switching regulator's output voltage. It is usually dominated by the output capacitor's ESR multiplied by the inductor's ripple current (ΔI_{IND}). The peak-to-peak value of this sawtooth ripple current can be determined by reading the Inductor Ripple Current section of the Application hints.

CAPACITOR RIPPLE CURRENT

RMS value of the maximum allowable alternating current at which a capacitor can be operated continuously at a specified temperature.

STANDBY QUIESCENT CURRENT (I_{STBY})

Supply current required by the LM2576 when in the standby mode ($\overline{ON}$/OFF pin is driven to TTL-high voltage, thus turning the output switch OFF).

INDUCTOR RIPPLE CURRENT (ΔI_{IND})

The peak-to-peak value of the inductor current waveform, typically a sawtooth waveform when the regulator is operating in the continuous mode (vs. discontinuous mode).

CONTINUOUS/DISCONTINUOUS MODE OPERATION

Relates to the inductor current. In the continuous mode, the inductor current is always flowing and never drops to zero, vs. the discontinuous mode, where the inductor current drops to zero for a period of time in the normal switching cycle.

INDUCTOR SATURATION

The condition which exists when an inductor cannot hold any more magnetic flux. When an inductor saturates, the inductor appears less inductive and the resistive component dominates. Inductor current is then limited only by the DC resistance of the wire and the available source current.

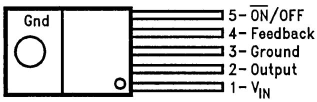
OPERATING VOLT MICROSECOND CONSTANT ($E \bullet T_{op}$)

The product (in Volt•μs) of the voltage applied to the inductor and the time the voltage is applied. This $E \bullet T_{op}$ constant is a measure of the energy handling capability of an inductor and is dependent upon the type of core, the core area, the number of turns, and the duty cycle.

Connection Diagrams

(XX indicates output voltage option. See ordering information table for complete part number.)

Straight Leads
5-Lead TO-220 (T)
Top View



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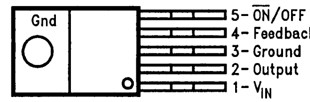
LM2576T-XX or LM2576HVT-XX
NS Package Number T05A

Bent, Staggered Leads
5-Lead TO-220 (T)
Top View



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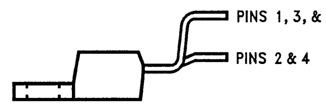
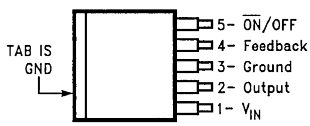
Side View



TL/H/11476–23

LM2576T-XX Flow LB03
or LM2576HVT-XX Flow LB03
NS Package Number T05D

TO-263 (S)
5-Lead Surface-Mount Package
Top View



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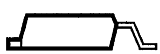
Side View



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LM2576S-XX
NS Package Number TS5B

Ordering Information

Temperature Range	Output Voltage					NS Package	Package
	3.3	5.0	12	15	ADJ		
$-40°C \leq T_A \leq 125°C$	LM2576S-3.3	LM2576S-5.0	LM2576S-12	LM2576S-15	LM2576S-ADJ	TS5B	TO-263
	LM2576HVT-3.3	LM2576HVT-5.0	LM2576HVT-12	LM2576HVT-15	LM2576HVT-ADJ	T05A	TO-220
	LM2576T-3.3	LM2576T-5.0	LM2576T-12	LM2576T-15	LM2576T-ADJ	T05A	TO-220
	LM2576HVT-3.3	LM2576HVT-5.0	LM2576HVT-12	LM2576HVT-15	LM2576HVT-ADJ	T05D	TO-220
	LM2576T-3.3	LM2576T-5.0	LM2576T-12	LM2576T-15	LM2576T-ADJ	T05D	TO-220

National Semiconductor

LM1577/LM2577 Series SIMPLE SWITCHER® Step-Up Voltage Regulator

General Description

The LM1577/LM2577 are monolithic integrated circuits that provide all of the power and control functions for step-up (boost), flyback, and forward converter switching regulators. The device is available in three different output voltage versions: 12V, 15V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Listed in this data sheet are a family of standard inductors and flyback transformers designed to work with these switching regulators.

Included on the chip is a 3.0A NPN switch and its associated protection circuitry, consisting of current and thermal limiting, and undervoltage lockout. Other features include a 52 kHz fixed-frequency oscillator that requires no external components, a soft start mode to reduce in-rush current during start-up, and current mode control for improved rejection of input voltage and output load transients.

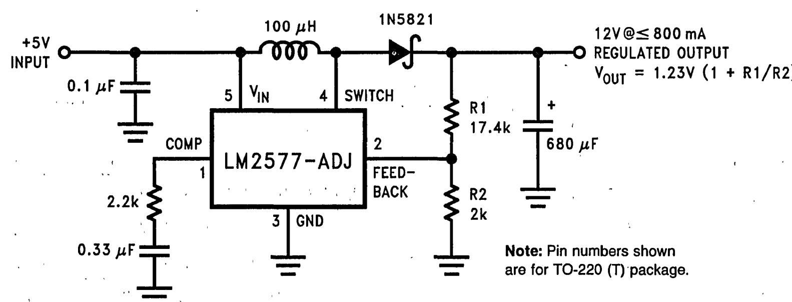
Features

- Requires few external components
- NPN output switches 3.0A, can stand off 65V
- Wide input voltage range: 3.5V to 40V
- Current-mode operation for improved transient response, line regulation, and current limit
- 52 kHz internal oscillator
- Soft-start function reduces in-rush current during start-up
- Output switch protected by current limit, under-voltage lockout, and thermal shutdown

Typical Applications

- Simple boost regulator
- Flyback and forward regulators
- Multiple-output regulator

Typical Application



Note: Pin numbers shown are for TO-220 (T) package.

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Ordering Information

Temperature Range	Package Type	Output Voltage 12V	Output Voltage 15V	Output Voltage ADJ	NSC Package Drawing	Package
$-40°C \leq T_A \leq +125°C$	24-Pin Surface Mount	LM2577M-12	LM2577M-15	LM2577M-ADJ	M24B	SO
	16-Pin Molded DIP	LM2577N-12	LM2577N-15	LM2577N-ADJ	N16A	N
	5-Lead Surface Mount	LM2577S-12	LM2577S-15	LM2577S-ADJ	TS5B	TO-263
	5-Straight Leads	LM2577T-12	LM2577T-15	LM2577T-ADJ	T05A	TO-220
	5-Bent Staggered Leads	LM2577T-12 Flow LB03	LM2577T-15 Flow LB03	LM2577T-ADJ Flow LB03	T05D	TO-220
$-55°C \leq T_A \leq +150°C$	4-Pin TO-3	LM1577K-12/883	LM1577K-15/883	LM1577K-ADJ/883	K04A	TO-3

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	45V
Output Switch Voltage	65V
Output Switch Current (Note 2)	6.0A
Power Dissipation	Internally Limited
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature	150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV

Operating Ratings

Supply Voltage	$3.5V \le V_{IN} \le 40V$
Output Switch Voltage	$0V \le V_{SWITCH} \le 60V$
Output Switch Current	$I_{SWITCH} \le 3.0A$
Junction Temperature Range	
LM1577	$-55°C \le T_J \le +150°C$
LM2577	$-40°C \le T_J \le +125°C$

Electrical Characteristics—LM1577-12, LM2577-12

Specifications with standard type face are for T_J = 25°C, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, V_{IN} = 5V, and I_{SWITCH} = 0.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit (Notes 3, 4)	LM2577-12 Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of *Figure 1* (Note 6)						
V_{OUT}	Output Voltage	V_{IN} = 5V to 10V I_{LOAD} = 100 mA to 800 mA (Note 3)	12.0	11.60/**11.40** 12.40/**12.60**	11.60/**11.40** 12.40/**12.60**	V V(min) V(max)
$\frac{\Delta V_{OUT}}{\Delta V_{IN}}$	Line Regulation	V_{IN} = 3.5V to 10V I_{LOAD} = 300 mA	20	50/**100**	50/**100**	mV mV(max)
$\frac{\Delta V_{OUT}}{\Delta_{LOAD}}$	Load Regulation	V_{IN} = 5V I_{LOAD} = 100 mA to 800 mA	20	50/**100**	50/**100**	mV mV(max)
η	Efficiency	V_{IN} = 5V, I_{LOAD} = 800 mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK}$ = 14V (Switch Off)	7.5	10.0/**14.0**	10.0/**14.0**	mA mA(max)
		I_{SWITCH} = 2.0A V_{COMP} = 2.0V (Max Duty Cycle)	25	50/**85**	50/**85**	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	I_{SWITCH} = 100 mA	2.90	2.70/**2.65** 3.10/**3.15**	2.70/**2.65** 3.10/**3.15**	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin I_{SWITCH} = 100 mA	52	48/**42** 56/**62**	48/**42** 56/**62**	kHz kHz(min) kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin V_{IN} = 3.5V to 40V V_{COMP} = 1.0V	12	11.76/**11.64** 12.24/**12.36**	11.76/**11.64** 12.24/**12.36**	V V(min) V(max)
$\frac{\Delta V_{REF}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulator	V_{IN} = 3.5V to 40V	7			mV
R_{FB}	Feedback Pin Input Resistance		9.7			kΩ
G_M	Error Amp Transconductance	I_{COMP} = −30 μA to +30 μA V_{COMP} = 1.0V	370	225/**145** 515/**615**	225/**145** 515/**615**	μmho μmho(min) μmho(max)
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 1.1V to 1.9V R_{COMP} = 1.0 MΩ (Note 7)	80	50/**25**	50/**25**	V/V V/V(min)

Electrical Characteristics—LM1577-12, LM2577-12 (Continued)

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-12 Limit (Notes 3, 4)	LM2577-12 Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 10.0V$	2.4	2.2/**2.0**	2.2/**2.0**	V V(min)
		Lower Limit $V_{FEEDBACK} = 15.0V$	0.3	0.40/**0.55**	0.40/**0.55**	V V(max)
	Error Amplifier Output Current	$V_{FEEDBACK} = 10.0V$ to $15.0V$ $V_{COMP} = 1.0V$	±200	±130/±**90** ±300/±**400**	±130/±**90** ±300/±**400**	μA μA(min) μA(max)
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 10.0V$ $V_{COMP} = 0V$	5.0	2.5/**1.5** 7.5/**9.5**	2.5/**1.5** 7.5/**9.5**	μA μA(min) μA(max)
D	Maximum Duty Cycle	$V_{COMP} = 1.5V$ $I_{SWITCH} = 100$ mA	95	93/**90**	93/**90**	% %(min)
$\frac{\Delta I_{SWITCH}}{\Delta V_{COMP}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65V$ $V_{FEEDBACK} = 15V$ (Switch Off)	10	300/**600**	300/**600**	μA μA(max)
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	0.5	0.7/**0.9**	0.7/**0.9**	V V(max)
	NPN Switch Current Limit		4.5	3.7/**3.0** 5.3/**6.0**	3.7/**3.0** 5.3/**6.0**	A A(min) A(max)

Electrical Characteristics—LM1577-15, LM2577-15

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit (Notes 3, 4)	LM2577-15 Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of *Figure 2* (Note 6)						
V_{OUT}	Output Voltage	$V_{IN} = 5V$ to 12V $I_{LOAD} = 100$ mA to 600 mA (Note 3)	15.0	 14.50/**14.25** 15.50/**15.75**	 14.50/**14.25** 15.50/**15.75**	V V(min) V(max)
$\frac{\Delta V_{OUT}}{V_{IN}}$	Line Regulation	$V_{IN} = 3.5V$ to 12V $I_{LOAD} = 300$ mA	20	 50/**100**	 50/**100**	mV mV(max)
$\frac{\Delta V_{OUT}}{\Delta I_{LOAD}}$	Load Regulation	$V_{IN} = 5V$ $I_{LOAD} = 100$ mA to 600 mA	20	 50/**100**	 50/**100**	mV mV(max)
η	Efficiency	$V_{IN} = 5V$, $I_{LOAD} = 600$ mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK} = 18.0V$ (Switch Off)	7.5	 10.0/**14.0**	 10.0/**14.0**	mA mA(max)
		$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	25	 50/**85**	 50/**85**	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	$I_{SWITCH} = 100$ mA	2.90	 2.70/**2.65** 3.10/**3.15**	 2.70/**2.65** 3.10/**3.15**	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin $I_{SWITCH} = 100$ mA	52	 48/**42** 56/**62**	 48/**42** 56/**62**	kHz kHz(min) kHz(max)
V_{REF}	Output Reference Voltage	Measured at Feedback Pin $V_{IN} = 3.5V$ to 40V $V_{COMP} = 1.0V$	15	 14.70/**14.55** 15.30/**15.45**	 14.70/**14.55** 15.30/**15.45**	V V(min) V(max)
$\frac{\Delta V_{REF}}{\Delta V_{IN}}$	Output Reference Voltage Line Regulation	$V_{IN} = 3.5V$ to 40V	10			mV
R_{FB}	Feedback Pin Input Voltage Line Regulator		12.2			kΩ
G_M	Error Amp Transconductance	$I_{COMP} = -30\ \mu A$ to $+30\ \mu A$ $V_{COMP} = 1.0V$	300	 170/**110** 420/**500**	 170/**110** 420/**500**	µmho µmho(min) µmho(max)
A_{VOL}	Error Amp Voltage Gain	$V_{COMP} = 1.1V$ to 1.9V $R_{COMP} = 1.0\ M\Omega$ (Note 7)	65	 40/**20**	 40/**20**	V/V V/V(min)

3

Electrical Characteristics—LM1577-15, LM2577-15 (Continued)

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-15 Limit (Notes 3, 4)	LM2577-15 Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK} = 12.0V$	2.4	2.2/**2.0**	2.2/**2.0**	V V(min)
		Lower Limit $V_{FEEDBACK} = 18.0V$	0.3	0.4/**0.55**	0.40/**0.55**	V V(max)
	Error Amp Output Current	$V_{FEEDBACK} = 12.0V$ to $18.0V$ $V_{COMP} = 1.0V$	±200	±130/**±90** ±300/**±400**	±130/**±90** ±300/**±400**	μA μA(min) μA(max)
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 12.0V$ $V_{COMP} = 0V$	5.0	2.5/**1.5** 7.5/**9.5**	2.5/**1.5** 7.5/**9.5**	μA μA(min) μA(max)
D	Maximum Duty Cycle	$V_{COMP} = 1.5V$ $I_{SWITCH} = 100$ mA	95	93/**90**	93/**90**	% %(min)
$\frac{\Delta I_{SWITCH}}{\Delta V_{COMP}}$	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65V$ $V_{FEEDBACK} = 18.0V$ (Switch Off)	10	300/**600**	300/**600**	μA μA(max)
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	0.5	0.7/**0.9**	0.7/**0.9**	V V(max)
	NPN Switch Current Limit	$V_{COMP} = 2.0V$	4.3	3.7/**3.0** 5.3/**6.0**	3.7/**3.0** 5.3/**6.0**	A A(min) A(max)

Electrical Characteristics—LM1577-ADJ, LM2577-ADJ

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, $V_{IN} = 5V$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit (Notes 3, 4)	LM2577-ADJ Limit (Note 5)	Units (Limits)
SYSTEM PARAMETERS Circuit of *Figure 3* (Note 6)						
V_{OUT}	Output Voltage	V_{IN} = 5V to 10V I_{LOAD} = 100 mA to 800 mA (Note 3)	12.0	 11.60/**11.40** 12.40/**12.60**	 11.60/**11.40** 12.40/**12.60**	V V(min) V(max)
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	V_{IN} = 3.5V to 10V I_{LOAD} = 300 mA	20	 50/**100**	 50/**100**	mV mV(max)
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	V_{IN} = 5V I_{LOAD} = 100 mA to 800 mA	20	 50/**100**	 50/**100**	mV mV(max)
η	Efficiency	V_{IN} = 5V, I_{LOAD} = 800 mA	80			%
DEVICE PARAMETERS						
I_S	Input Supply Current	$V_{FEEDBACK}$ = 1.5V (Switch Off)	7.5	 10.0/**14.0**	 10.0/**14.0**	mA mA(max)
		I_{SWITCH} = 2.0A V_{COMP} = 2.0V (Max Duty Cycle)	25	 50/**85**	 50/**85**	mA mA(max)
V_{UV}	Input Supply Undervoltage Lockout	I_{SWITCH} = 100 mA	2.90	 2.70/**2.65** 3.10/**3.15**	 2.70/**2.65** 3.10/**3.15**	V V(min) V(max)
f_O	Oscillator Frequency	Measured at Switch Pin I_{SWITCH} = 100 mA	52	 48/**42** 56/**62**	 48/**42** 56/**62**	kHz kHz(min) kHz(max)
V_{REF}	Reference Voltage	Measured at Feedback Pin V_{IN} = 3.5V to 40V V_{COMP} = 1.0V	1.230	 1.214/**1.206** 1.246/**1.254**	 1.214/**1.206** 1.246/**1.254**	V V(min) V(max)
$\Delta V_{REF}/\Delta V_{IN}$	Reference Voltage Line Regulation	V_{IN} = 3.5V to 40V	0.5			mV
I_B	Error Amp Input Bias Current	V_{COMP} = 1.0V	100	 300/**800**	 300/**800**	nA nA(max)
G_M	Error Amp Transconductance	I_{COMP} = −30 μA to +30 μA V_{COMP} = 1.0V	3700	 2400/**1600** 4800/**5800**	 2400/**1600** 4800/**5800**	μmho μmho(min) μmho(max)
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 1.1V to 1.9V R_{COMP} = 1.0 MΩ (Note 7)	800	 500/**250**	 500/**250**	V/V V/V(min)
	Error Amplifier Output Swing	Upper Limit $V_{FEEDBACK}$ = 1.0V	2.4	 2.2/**2.0**	 2.2/**2.0**	V V(min)
		Lower Limit $V_{FEEDBACK}$ = 1.5V	0.3	 0.40/**0.55**	 0.40/**0.55**	V V(max)

Electrical Characteristics—LM1577-ADJ, LM2577-ADJ (Continued)

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_{IN} = 5V$, $V_{FEEDBACK} = V_{REF}$, and $I_{SWITCH} = 0$.

Symbol	Parameter	Conditions	Typical	LM1577-ADJ Limit (Notes 3, 4)	LM2577-ADJ Limit (Note 5)	Units (Limits)
DEVICE PARAMETERS (Continued)						
	Error Amp Output Current	$V_{FEEDBACK} = 1.0V$ to $1.5V$ $V_{COMP} = 1.0V$	±200	 ±130/±**90** ±300/±**400**	 ±130/±**90** ±300/±**400**	μA μA(min) μA(max)
I_{SS}	Soft Start Current	$V_{FEEDBACK} = 1.0V$ $V_{COMP} = 0V$	5.0	 2.5/**1.5** 7.5/**9.5**	 2.5/**1.5** 7.5/**9.5**	μA μA(min) μA(max)
D	Maximum Duty Cycle	$V_{COMP} = 1.5V$ $I_{SWITCH} = 100$ mA	95	 93/**90**	 93/**90**	% %(min)
$\Delta I_{SWITCH}/$ ΔV_{COMP}	Switch Transconductance		12.5			A/V
I_L	Switch Leakage Current	$V_{SWITCH} = 65V$ $V_{FEEDBACK} = 1.5V$ (Switch Off)	10	 300/**600**	 300/**600**	μA μA(max)
V_{SAT}	Switch Saturation Voltage	$I_{SWITCH} = 2.0A$ $V_{COMP} = 2.0V$ (Max Duty Cycle)	0.5	 0.7/**0.9**	 0.7/**0.9**	V V(max)
	NPN Switch Current Limit	$V_{COMP} = 2.0V$	4.3	 3.7/**3.0** 5.3/**6.0**	 3.7/**3.0** 5.3/**6.0**	A A(min) A(max)
THERMAL PARAMETERS (All Versions)						
θ_{JA} θ_{JC}	Thermal Resistance	K Package, Junction to Ambient K Package, Junction to Case	35 1.5			°C/W
θ_{JA} θ_{JC}		T Package, Junction to Ambient T Package, Junction to Case	65 2			
θ_{JA}		N Package, Junction to Ambient (Note 8)	85			
θ_{JA}		M Package, Junction to Ambient (Note 8)	100			
θ_{JA}		S Package, Junction to Ambient (Note 9)	37			

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions the device is intended to be functional, but device parameter specifications may not be guaranteed under these conditions. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Due to timing considerations of the LM1577/LM2577 current limit circuit, output current cannot be internally limited when the LM1577/LM2577 is used as a step-up regulator. To prevent damage to the switch, its current must be externally limited to 6.0A. However, output current is internally limited when the LM1577/LM2577 is used as a flyback or forward converter regulator in accordance to the Application Hints.

Note 3: All limits guaranteed at room temperature (standard type face) and at temperature extremes (**boldface type**). All limits are used to calculate Outgoing Quality Level, and are 100% production tested.

Note 4: A military RETS electrical test specification is available on request. At the time of printing, the LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 RETS specifications complied fully with the **boldface** limits in these columns. The LM1577K-12/883, LM1577K-15/883, and LM1577K-ADJ/883 may also be procured to Standard Military Drawing specifications.

Note 5: All limits guaranteed at room temperature (standard type face) and at temperature extremes (**boldface type**). All room temperature limits are 100% production tested. All limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 6: External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM1577/LM2577 is used as shown in the Test Circuit, system performance will be as specified by the system parameters.

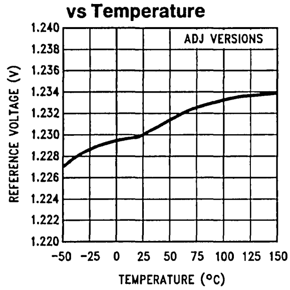
Note 7: A 1.0 MΩ resistor is connected to the compensation pin (which is the error amplifier's output) to ensure accuracy in measuring A_{VOL}. In actual applications, this pin's load resistance should be ≥10 MΩ, resulting in A_{VOL} that is typically twice the guaranteed minimum limit.

Note 8: Junction to ambient thermal resistance with approximately 1 square inch of pc board copper surrounding the leads. Additional copper area will lower thermal resistance further. See thermal model in "Switchers Made Simple" software.

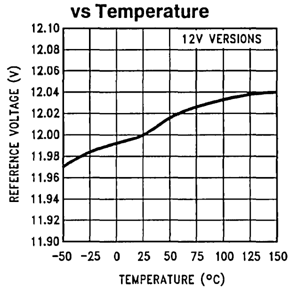
Note 9: If the TO-263 package is used, the thermal resistance can be reduced by increasing the PC board copper area thermally connected to the package. Using 0.5 square inches of copper area, θ_{JA} is 50°C/W; with 1 square inch of copper area, θ_{JA} is 37°C/W; and with 1.6 or more square inches of copper area, θ_{JA} is 32°C/W.

Typical Performance Characteristics

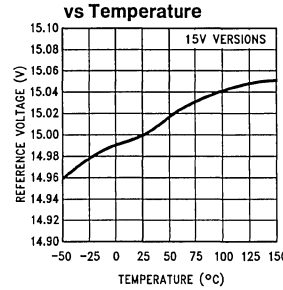
Reference Voltage vs Temperature



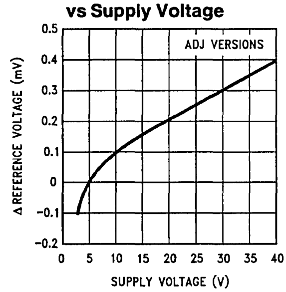
Reference Voltage vs Temperature



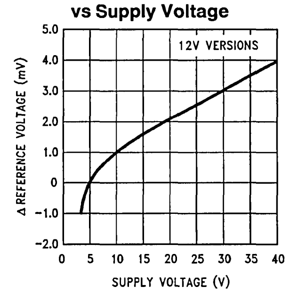
Reference Voltage vs Temperature



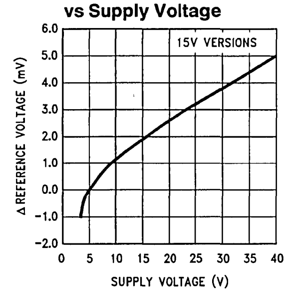
Δ Reference Voltage vs Supply Voltage



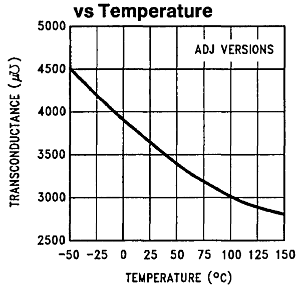
Δ Reference Voltage vs Supply Voltage



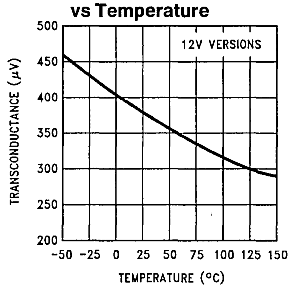
Δ Reference Voltage vs Supply Voltage



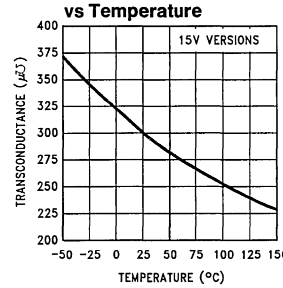
Error Amp Transconductance vs Temperature



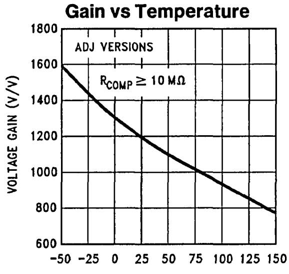
Error Amp Transconductance vs Temperature



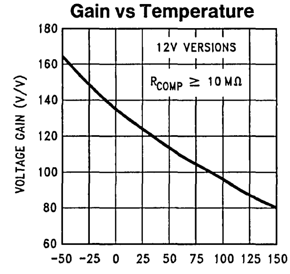
Error Amp Transconductance vs Temperature



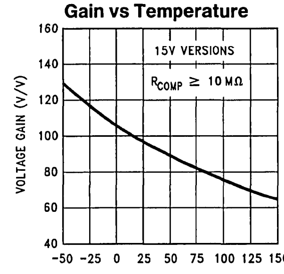
Error Amp Voltage Gain vs Temperature



Error Amp Voltage Gain vs Temperature



Error Amp Voltage Gain vs Temperature



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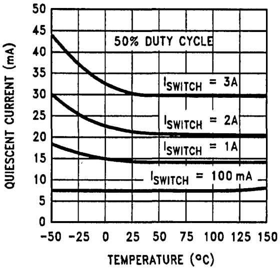
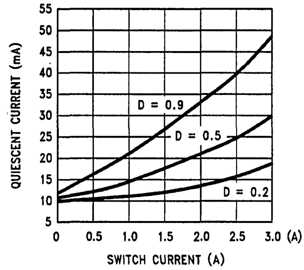
Typical Performance Characteristics (Continued)

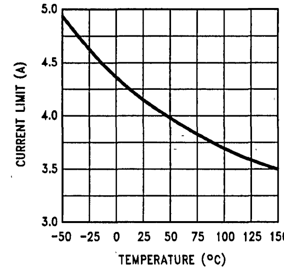
Quiescent Current vs Temperature



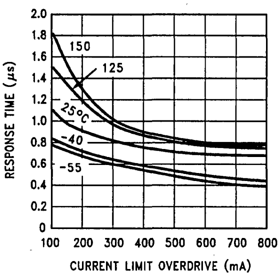
Quiescent Current vs Switch Current



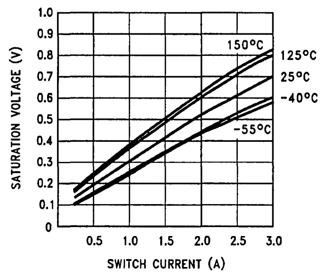
Current Limit vs Temperature



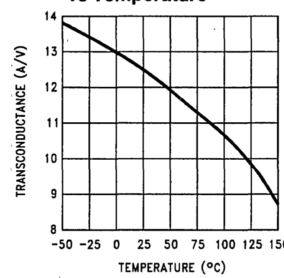
Current Limit Response Time vs Overdrive



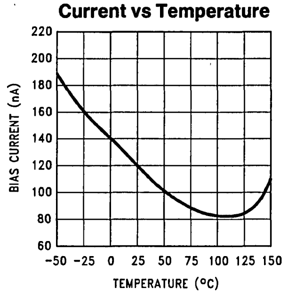
Switch Saturation Voltage vs Switch Current



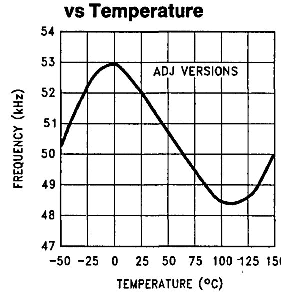
Switch Transconductance vs Temperature



Feedback Pin Bias Current vs Temperature



Oscillator Frequency vs Temperature



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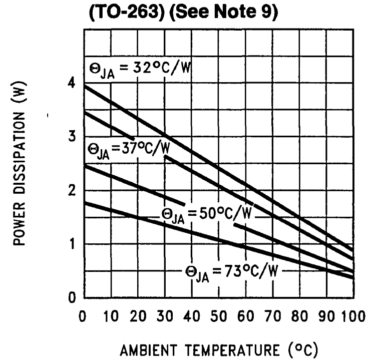
Maximum Power Dissipation (TO-263) (See Note 9)



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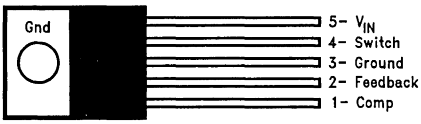
Connection Diagrams

Straight Leads
5-Lead TO-220 (T)

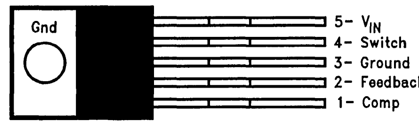


TL/H/11468-4

Top View

Order Number LM2577T-12, LM2577T-15, or LM2577T-ADJ
See NS Package Number T05A

Bent, Staggered Leads
5-Lead TO-220 (T)

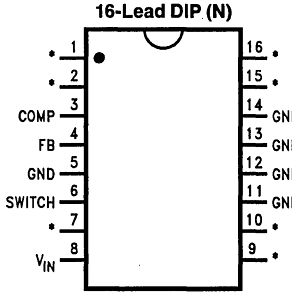


TL/H/11468-5

Top View

Order Number LM2577T-12 Flow LB03, LM2577T-15 Flow LB03, or LM2577T-ADJ Flow LB03
See NS Package Number T05D

16-Lead DIP (N)



*No internal Connection

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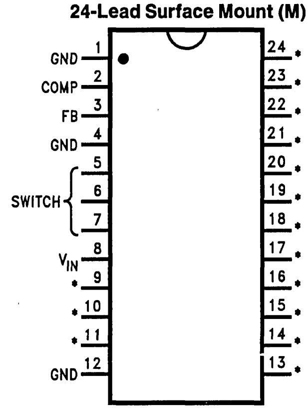
Top View

Order Number LM2577N-12, LM2577N-15, or LM2577N-ADJ
See NS Package Number N16A

24-Lead Surface Mount (M)



*No internal Connection

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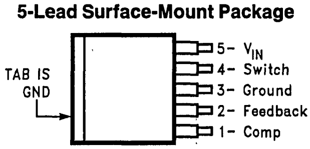
Top View

Order Number LM2577M-12, LM2577M-15, or LM2577M-ADJ
See NS Package Number M24B

TO-263 (S)
5-Lead Surface-Mount Package



TL/H/11468-32

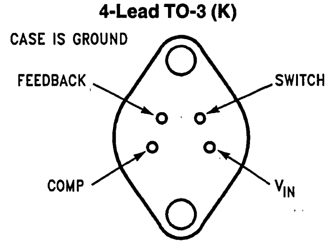
Top View

TL/H/11468-33

Side View

Order Number LM2577S-12, LM2577S-15, or LM2577S-ADJ
See NS Package Number TS5B

4-Lead TO-3 (K)



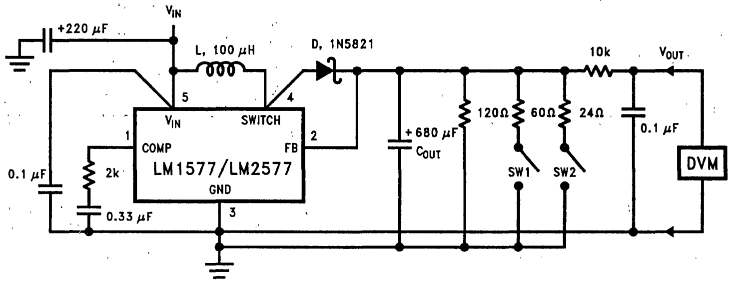
TL/H/11468-8

Bottom View

Order Number LM1577K-12/883, LM1577K-15/883, or LM1577K-ADJ/883
See NS Package Number K04A

Test Circuits

LM1577-12, LM2577-12



TL/H/11468-30

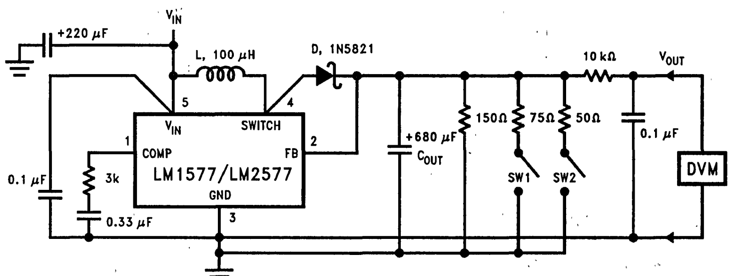
L = 415-0930 (AIE)
D = any manufacturer

C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

Note: Pin numbers shown are for TO-220 (T) package

FIGURE 1. Circuit Used to Specify System Parameters for 12V Versions

LM1577-15, LM2577-15



TL/H/11468-26

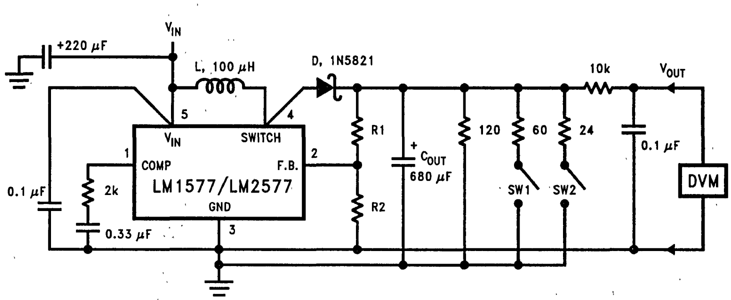
L = 415-0930 (AIE)
D = any manufacturer

C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

Note: Pin numbers shown are for TO-220 (T) package

FIGURE 2. Circuit Used to Specify System Parameters for 15V Versions

LM1577-ADJ, LM2577-ADJ



Note: Pin numbers shown are for TO-220 (T) package

TL/H/11468-9

L = 415-0930 (AIE)
D = any manufacturer

C_{OUT} = Sprague Type 673D
Electrolytic 680 μF, 20V

R1 = 48.7k in series with 511Ω (1%)
R2 = 5.62k (1%)

FIGURE 3. Circuit Used to Specify System Parameters for ADJ Versions

Application Hints

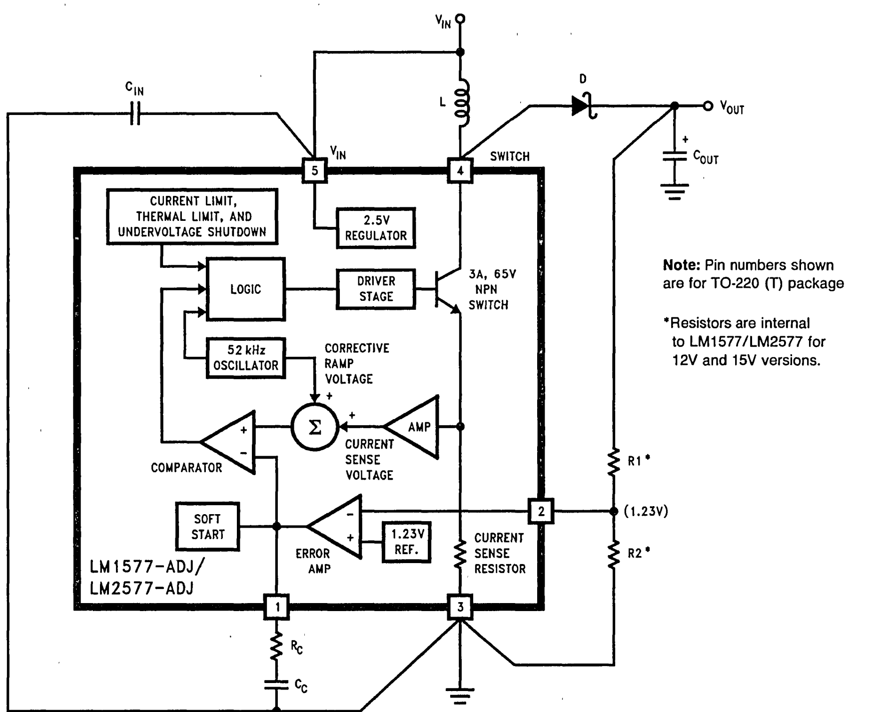


FIGURE 4. LM1577/LM2577 Block Diagram and Boost Regulator Application

STEP-UP (BOOST) REGULATOR

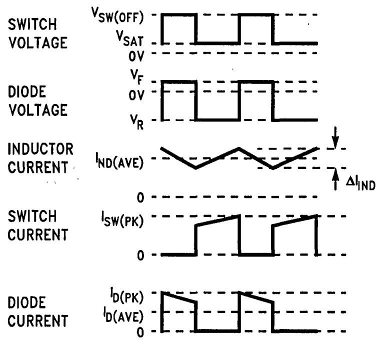
Figure 4 shows the LM1577-ADJ/LM2577-ADJ used as a Step-Up Regulator. This is a switching regulator used for producing an output voltage greater than the input supply voltage. The LM1577-12/LM2577-12 and LM1577-15/LM2577-15 can also be used for step-up regulators with 12V or 15V outputs (respectively), by tying the feedback pin directly to the regulator output.

A basic explanation of how it works is as follows. The LM1577/LM2577 turns its output switch on and off at a frequency of 52 kHz, and this creates energy in the inductor (L). When the NPN switch turns on, the inductor current charges up at a rate of V_{IN}/L, storing current in the inductor. When the switch turns off, the lower end of the inductor flies above V_{IN}, discharging its current through diode (D) into the output capacitor (C_{OUT}) at a rate of $(V_{OUT} - V_{IN})/L$. Thus, energy stored in the inductor during the switch on time is transferred to the output during the switch off time. The output voltage is controlled by the amount of energy transferred which, in turn, is controlled by modulating the peak inductor current. This is done by feeding back a portion of the output voltage to the error amp, which amplifies the difference between the feedback voltage and a 1.230V reference. The error amp output voltage is compared to a voltage proportional to the switch current (i.e., inductor current during the switch on time).

Application Hints (Continued)

The comparator terminates the switch on time when the two voltages are equal, thereby controlling the peak switch current to maintain a constant output voltage.

Voltage and current waveforms for this circuit are shown in *Figure 5*, and formulas for calculating them are given in *Figure 6*.



TL/H/11468–11

FIGURE 5. Step-Up Regulator Waveforms

Duty Cycle	D	$\frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F - V_{SAT}} \approx \frac{V_{OUT} - V_{IN}}{V_{OUT}}$
Average Inductor Current	$I_{IND(AVE)}$	$\frac{I_{LOAD}}{1 - D}$
Inductor Current Ripple	ΔI_{IND}	$\frac{V_{IN} - V_{SAT}}{L} \frac{D}{52{,}000}$
Peak Inductor Current	$I_{IND(PK)}$	$\frac{I_{LOAD(max)}}{1 - D_{(max)}} + \frac{\Delta I_{IND}}{2}$
Peak Switch Current	$I_{SW(PK)}$	$\frac{I_{LOAD(max)}}{1 - D_{(max)}} + \frac{\Delta I_{IND}}{2}$
Switch Voltage When Off	$V_{SW(OFF)}$	$V_{OUT} + V_F$
Diode Reverse Voltage	V_R	$V_{OUT} - V_{SAT}$
Average Diode Current	$I_{D(AVE)}$	I_{LOAD}
Peak Diode Current	$I_{D(PK)}$	$\frac{I_{LOAD}}{1 - D_{(max)}} + \frac{\Delta I_{IND}}{2}$
Power Dissipation of LM1577/2577	P_D	$0.25\Omega \left(\frac{I_{LOAD}}{1 - D}\right)^2 D + \frac{I_{LOAD}\, D\, V_{IN}}{50\,(1 - D)}$

V_F = Forward Biased Diode Voltage
I_{LOAD} = Output Load Current

FIGURE 6. Step-Up Regulator Formulas

STEP-UP REGULATOR DESIGN PROCEDURE

The following design procedure can be used to select the appropriate external components for the circuit in *Figure 4*, based on these system requirements.

Given:

$V_{IN\ (min)}$ = Minimum input supply voltage
V_{OUT} = Regulated output voltage
$I_{LOAD(max)}$ = Maximum output load current

Before proceeding any further, determine if the LM1577/LM2577 can provide these values of V_{OUT} and $I_{LOAD(max)}$ when operating with the minimum value of V_{IN}. The upper limits for V_{OUT} and $I_{LOAD(max)}$ are given by the following equations.

$$V_{OUT} \leq 60V$$

and $$V_{OUT} \leq 10 \times V_{IN(min)}$$

$$I_{LOAD(max)} \leq \frac{2.1A \times V_{IN(min)}}{V_{OUT}}$$

These limits must be greater than or equal to the values specified in this application.

1. Inductor Selection (L)

A. *Voltage Options:*

1. **For 12V or 15V output**

From *Figure 7a* (for 12V output) or *Figure 7b* (for 15V output), identify inductor code for region indicated by $V_{IN\ (min)}$ and $I_{LOAD\ (max)}$. The shaded region indicates conditions for which the LM1577/LM2577 output switch would be operating beyond its switch current rating. The minimum operating voltage for the LM1577/LM2577 is 3.5V.

From here, ***proceed to step C***.

2. **For Adjustable version**

Preliminary calculations:

The inductor selection is based on the calculation of the following three parameters:

$D_{(max)}$, the maximum switch duty cycle ($0 \leq D \leq 0.9$):

$$D_{(max)} = \frac{V_{OUT} + V_F - V_{IN(min)}}{V_{OUT} + V_F - 0.6V}$$

where V_F = 0.5V for Schottky diodes and 0.8V for fast recovery diodes (typically);

E•T, the product of volts × time that charges the inductor:

$$E \bullet T = \frac{D_{(max)}\,(V_{IN(min)} - 0.6V)10^6}{52{,}000\ \text{Hz}} \quad (V \bullet \mu s)$$

$I_{IND,DC}$, the average inductor current under full load;

$$I_{IND,DC} = \frac{1.05 \times I_{LOAD(max)}}{1 - D_{(max)}}$$

B. *Identify Inductor Value:*

1. From *Figure 7c*, identify the inductor code for the region indicated by the intersection of E•T and $I_{IND,DC}$. This code gives the inductor value in microhenries. The L or H prefix signifies whether the inductor is rated for a maximum E•T of 90 V•µs (L) or 250 V•µs (H).

2. If D < 0.85, go on to step C. If D ≥ 0.85, then calculate the minimum inductance needed to ensure the switching regulator's stability:

$$L_{MIN} = \frac{6.4\,(V_{IN(min)} - 0.6V)\,(2D_{(max)} - 1)}{1 - D_{(max)}} \quad (\mu H)$$

If L_{MIN} is smaller than the inductor value found in step B1, go on to step C. Otherwise, the inductor value found in step B1 is too low; an appropriate inductor code should be obtained from the graph as follows:

1. Find the lowest value inductor that is greater than L_{MIN}.
2. Find where E•T intersects this inductor value to determine if it has an L or H prefix. If E•T intersects both the L and H regions, select the inductor with an H prefix.

Application Hints (Continued)

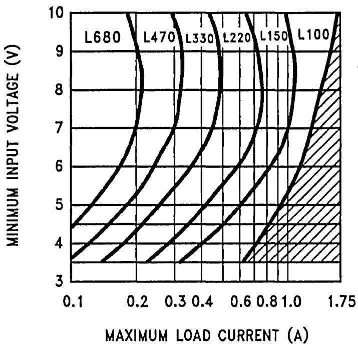


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FIGURE 7a. LM2577-12 Inductor Selection Guide

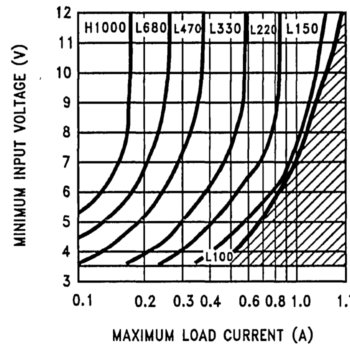

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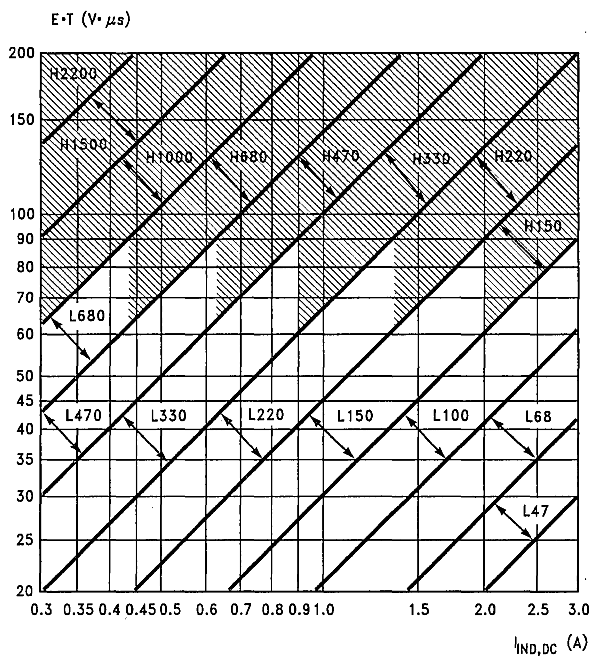
FIGURE 7b. LM2577-15 Inductor Selection Guide



TL/H/11468-12

FIGURE 7c. LM1577-ADJ/LM2577-ADJ Inductor Selection Graph

Note:

These charts assume that the inductor ripple current inductor is approximately 20% to 30% of the average inductor current (when the regulator is under full load). Greater ripple current causes higher peak switch currents and greater output ripple voltage; lower ripple current is achieved with larger-value inductors. The factor of 20 to 30% is chosen as a convenient balance between the two extremes.

Application Hints (Continued)

C. *Select an inductor* from the table of *Figure 8* which cross-references the inductor codes to the part numbers of three different manufacturers. Complete specifications for these inductors are available from the respective manufacturers. The inductors listed in this table have the following characteristics:

AIE: ferrite, pot-core inductors; Benefits of this type are low electro-magnetic interference (EMI), small physical size, and very low power dissipation (core loss). Be careful not to operate these inductors too far beyond their maximum ratings for E•T and peak current, as this will saturate the core.

Pulse: powdered iron, toroid core inductors; Benefits are low EMI and ability to withstand E•T and peak current above rated value better than ferrite cores.

Renco: ferrite, bobbin-core inductors; Benefits are low cost and best ability to withstand E•T and peak current above rated value. Be aware that these inductors generate more EMI than the other types, and this may interfere with signals sensitive to noise.

Inductor Code	Manufacturer's Part Number		
	Schott	Pulse	Renco
L47	67126980	PE - 53112	RL2442
L68	67126990	PE - 92114	RL2443
L100	67127000	PE - 92108	RL2444
L150	67127010	PE - 53113	RL1954
L220	67127020	PE - 52626	RL1953
L330	67127030	PE - 52627	RL1952
L470	67127040	PE - 53114	RL1951
L680	67127050	PE - 52629	RL1950
H150	67127060	PE - 53115	RL2445
H220	67127070	PE - 53116	RL2446
H330	67127080	PE - 53117	RL2447
H470	67127090	PE - 53118	RL1961
H680	67127100	PE - 53119	RL1960
H1000	67127110	PE - 53120	RL1959
H1500	67127120	PE - 53121	RL1958
H2200	67127130	PE - 53122	RL2448

Schott Corp., (612) 475-1173
1000 Parkers Lake Rd., Wayzata, MN 55391
Pulse Engineering, (619) 268-2400
P.O. Box 12235, San Diego, CA 92112
Renco Electronics Inc., (516) 586-5566
60 Jeffryn Blvd. East, Deer Park, NY 11729

FIGURE 8. Table of Standardized Inductors and Manufacturer's Part Numbers

2. Compensation Network (R_C, C_C) and Output Capacitor (C_{OUT}) Selection

R_C and C_C form a pole-zero compensation network that stabilizes the regulator. The values of R_C and C_C are mainly dependant on the regulator voltage gain, $I_{LOAD(max)}$, L and C_{OUT}. The following procedure calculates values for R_C, C_C, and C_{OUT} that ensure regulator stability. Be aware that this procedure doesn't necessarily result in R_C and C_C that provide optimum compensation. In order to guarantee optimum compensation, one of the standard procedures for testing loop stability must be used, such as measuring V_{OUT} transient response when pulsing I_{LOAD} (see *Figure 13*).

A. *First, calculate the maximum value for R_C.*

$$R_C \leq \frac{750 \times I_{LOAD(max)} \times V_{OUT}^2}{V_{IN(min)}^2}$$

Select a resistor less than or equal to this value, and it should also be no greater than 3 kΩ.

B. *Calculate the minimum value for* C_{OUT} using the following two equations.

$$C_{OUT} \geq \frac{0.19 \times L \times R_C \times I_{LOAD(max)}}{V_{IN(min)} \times V_{OUT}}$$

and

$$C_{OUT} \geq \frac{V_{IN(min)} \times R_C \times (V_{IN(min)} + (3.74 \times 10^5 \times L))}{487{,}800 \times V_{OUT}^3}$$

The larger of these two values is the minimum value that ensures stability.

C. *Calculate the minimum value of C_C.*

$$C_C \geq \frac{58.5 \times V_{OUT}^2 \times C_{OUT}}{R_C^2 \times V_{IN(min)}}$$

The compensation capacitor is also part of the soft start circuitry. When power to the regulator is turned on, the switch duty cycle is allowed to rise at a rate controlled by this capacitor (with no control on the duty cycle, it would immediately rise to 90%, drawing huge currents from the input power supply). In order to operate properly, the soft start circuit requires $C_C \geq 0.22\ \mu F$.

The value of the output filter capacitor is normally large enough to require the use of aluminum electrolytic capacitors. *Figure 9* lists several different types that are recommended for switching regulators, and the following parameters are used to select the proper capacitor.

Working Voltage (WVDC): Choose a capacitor with a working voltage at least 20% higher than the regulator output voltage.

Ripple Current: This is the maximum RMS value of current that charges the capacitor during each switching cycle. For step-up and flyback regulators, the formula for ripple current is

$$I_{RIPPLE(RMS)} = \frac{I_{LOAD(max)} \times D_{(max)}}{1 - D_{(max)}}$$

Choose a capacitor that is rated at least 50% higher than this value at 52 kHz.

Equivalent Series Resistance (ESR): This is the primary cause of output ripple voltage, and it also affects the values of R_C and C_C needed to stabilize the regulator. As a result, the preceding calculations for C_C and R_C are only valid if ESR doesn't exceed the maximum value specified by the following equations.

$$ESR \leq \frac{0.01 \times V_{OUT}}{I_{RIPPLE(P-P)}} \text{ and } \leq \frac{8.7 \times (10)^{-3} \times V_{IN}}{I_{LOAD(max)}}$$

where

$$I_{RIPPLE(P-P)} = \frac{1.15 \times I_{LOAD(max)}}{1 - D_{(max)}}$$

Select a capacitor with ESR, at 52 kHz, that is less than or equal to the lower value calculated. Most electrolytic capacitors specify ESR at 120 Hz which is 15% to 30% higher than at 52 kHz. Also, be aware that ESR increases by a factor of 2 when operating at −20°C.

Application Hints (Continued)

In general, low values of ESR are achieved by using large value capacitors ($C \geq 470\ \mu F$), and capacitors with high WVDC, or by paralleling smaller-value capacitors.

3. Output Voltage Selection (R1 and R2)

This section is for applications using the LM1577-ADJ/LM2577-ADJ. Skip this section if the LM1577-12/LM2577-12 or LM1577-15/LM2577-15 is being used.

With the LM1577-ADJ/LM2577-ADJ, the output voltage is given by

$$V_{OUT} = 1.23V\,(1 + R1/R2)$$

Resistors R1 and R2 divide the output down so it can be compared with the LM1577-ADJ/LM2577-ADJ internal 1.23V reference. For a given desired output voltage V_{OUT}, select R1 and R2 so that

$$\frac{R1}{R2} = \frac{V_{OUT}}{1.23V} - 1$$

4. Input Capacitor Selection (C_{IN})

The switching action in the step-up regulator causes a triangular ripple current to be drawn from the supply source. This in turn causes noise to appear on the supply voltage. For proper operation of the LM1577, the input voltage should be decoupled. Bypassing the Input Voltage pin directly to ground with a good quality, low ESR, 0.1 μF capacitor (leads as short as possible) is normally sufficient.

If the LM1577 is located far from the supply source filter capacitors, an additional large electrolytic capacitor (e.g. 47 μF) is often required.

5. Diode Selection (D)

The switching diode used in the boost regulator must withstand a reverse voltage equal to the circuit output voltage, and must conduct the peak output current of the LM2577. A suitable diode must have a minimum reverse breakdown voltage greater than the circuit output voltage, and should be rated for average and peak current greater than $I_{LOAD(max)}$ and $I_{D(PK)}$. Schottky barrier diodes are often favored for use in switching regulators. Their low forward voltage drop allows higher regulator efficiency than if a (less expensive) fast recovery diode was used. See *Figure 10* for recommended part numbers and voltage ratings of 1A and 3A diodes.

Cornell Dublier—Types 239, 250, 251, UFT, 300, or 350
P.O. Box 128, Pickens, SC 29671
(803) 878-6311

Nichicon—Types PF, PX, or PZ
927 East Parkway, Schaumburg, IL 60173
(708) 843-7500

Sprague—Types 672D, 673D, or 674D
Box 1, Sprague Road, Lansing, NC 28643
(919) 384-2551

United Chemi-Con—Types LX, SXF, or SXJ
9801 West Higgins Road, Rosemont, IL 60018
(708) 696-2000

FIGURE 9. Aluminum Electrolytic Capacitors Recommended for Switching Regulators

V_{OUT} (max)	Schottky		Fast Recovery	
	1A	3A	1A	3A
20V	1N5817 MBR120P	1N5820 MBR320P		
30V	1N5818 MBR130P 11DQ03	1N5821 MBR330P 31DQ03		
40V	1N5819 MBR140P 11DQ04	1N5822 MBR340P 31DQ04		
50V	MBR150 11DQ05	MBR350 31DQ05	1N4933 MUR105	
100V			1N4934 HER102 MUR110 10DL1	MR851 30DL1 MR831 HER302

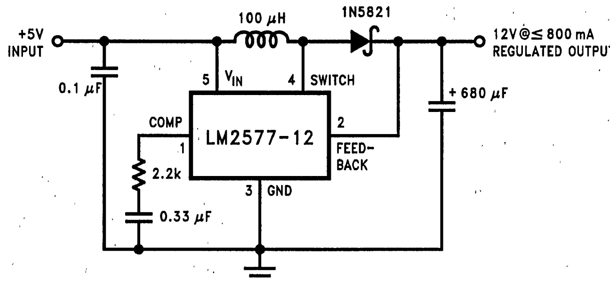
FIGURE 10. Diode Selection Chart

3

Application Hints (Continued)

BOOST REGULATOR CIRCUIT EXAMPLE

By adding a few external components (as shown in *Figure 11*), the LM2577 can be used to produce a regulated output voltage that is greater than the applied input voltage. Typical performance of this regulator is shown in *Figures 12* and *13*. The switching waveforms observed during the operation of this circuit are shown in *Figure 14*.



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Note: Pin numbers shown are for TO-220 (T) package.

FIGURE 11. Step-up Regulator Delivers 12V from a 5V Input

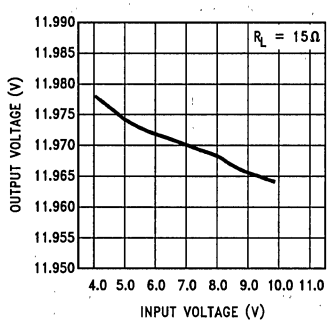

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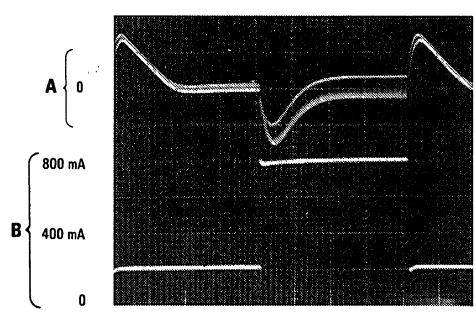
FIGURE 12. Line Regulation (Typical) of Step-Up Regulator of *Figure 11*



TL/H/11468-15

FIGURE 13. Load Transient Response of Step-Up Regulator of *Figure 11*

A: Output Voltage Change, 100 mV/div. (AC-coupled)
B: Load current, 0.2 A/div
Horizontal: 5 ms/div

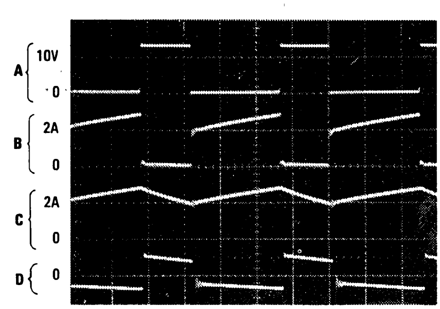


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FIGURE 14. Switching Waveforms of Step-Up Regulator of *Figure 11*

A: Switch pin voltage, 10 V/div
B: Switch pin current, 2 A/div
C: Inductor current, 2 A/div
D: Output ripple voltage, 100 mV/div (AC-coupled)
Horizontal: 5 µs/div

Application Hints (Continued)

FLYBACK REGULATOR

A Flyback regulator can produce single or multiple output voltages that are lower or greater than the input supply voltage. *Figure 15* shows the LM1577/LM2577 used as a flyback regulator with positive and negative regulated outputs. Its operation is similar to a step-up regulator, except the output switch contols the primary current of a flyback transformer. Note that the primary and secondary windings are out of phase, so no current flows through secondary when current flows through the primary. This allows the primary to charge up the transformer core when the switch is on. When the switch turns off, the core discharges by sending current through the secondary, and this produces voltage at the outputs. The output voltages are controlled by adjusting the peak primary current, as described in the step-up regulator section.

Voltage and current waveforms for this circuit are shown in *Figure 16*, and formulas for calculating them are given in *Figure 17*.

FLYBACK REGULATOR DESIGN PROCEDURE

1. Transformer Selection

A family of standardized flyback transformers is available for creating flyback regulators that produce dual output voltages, from ±10V to ±15V, as shown in *Figure 15*. *Figure 18* lists these transformers with the input voltage, output voltages and maximum load current they are designed for.

2. Compensation Network (C_C, R_C) and Output Capacitor (C_{OUT}) Selection

As explained in the Step-Up Regulator Design Procedure, C_C, R_C and C_{OUT} must be selected as a group. The following procedure is for a dual output flyback regulator with equal turns ratios for each secondary (i.e., both output voltages have the same magnitude). The equations can be used for a single output regulator by changing $\Sigma I_{LOAD(max)}$ to $I_{LOAD(max)}$ in the following equations.

A. **First, calculate the maximum value for R_C.**

$$R_C \leq \frac{750 \times \Sigma I_{LOAD(max)} \times (15V + V_{IN(min)}N)^2}{V_{IN(min)}^2}$$

Where $\Sigma I_{LOAD(max)}$ is the sum of the load current (magnitude) required from both outputs. Select a resistor less than or equal to this value, and no greater than 3 kΩ.

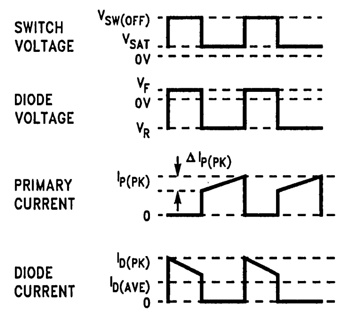
B. **Calculate the minimum value for ΣC_{OUT}** (sum of C_{OUT} at both outputs) using the following two equations.

$$C_{OUT} \geq \frac{0.19 \times R_C \times L_P \times \Sigma I_{LOAD(max)}}{15V \times V_{IN(min)}}$$

and

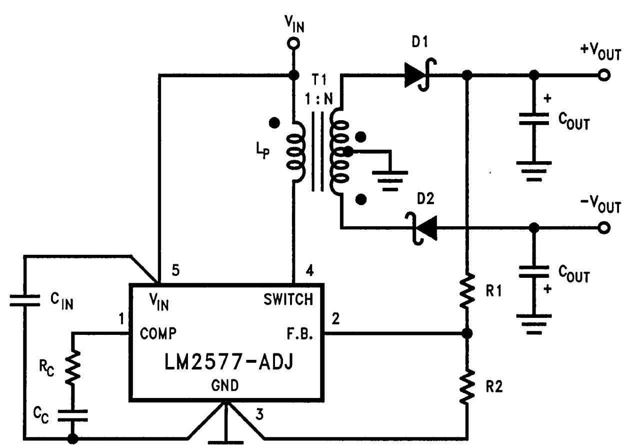
$$C_{OUT} \geq \frac{V_{IN(min)} \times R_C \times N^2 \times (V_{IN(min)} + (3.74 \times 10^5 \times L_P))}{487{,}800 \times (15V)^2 \times (15V + V_{IN(min)} \times N)}$$

The larger of these two values must be used to ensure regulator stability.



TL/H/11468-17

FIGURE 16. Flyback Regulator Waveforms



TL/H/11468-18

T1 = Pulse Engineering, PE-65300

D1, D2 = 1N5821

FIGURE 15. LM1577-ADJ/LM2577-ADJ Flyback Regulator with ± Outputs

Application Hints (Continued)

Duty Cycle	D	$\frac{V_{OUT} + V_F}{N (V_{IN} - V_{SAT}) + V_{OUT} + V_F} \approx \frac{V_{OUT}}{N (V_{IN}) + V_{OUT}}$
Primary Current Variation	ΔI_P	$\frac{D (V_{IN} - V_{SAT})}{L_P \times 52{,}000}$
Peak Primary Current	$I_{P(PK)}$	$\frac{N}{\eta} \times \frac{\Sigma I_{LOAD}}{1 - D} + \frac{\Delta I_{PK}}{2}$
Switch Voltage when Off	$V_{SW(OFF)}$	$V_{IN} + \frac{V_{OUT} + V_F}{N}$
Diode Reverse Voltage	V_R	$V_{OUT} + N (V_{IN} - V_{SAT})$
Average Diode Current	$I_{D(AVE)}$	I_{LOAD}
Peak Diode Current	$I_{D(PK)}$	$\frac{I_{LOAD}}{1 - D} + \frac{\Delta I_{IND}}{2}$
Short Circuit Diode Current		$\approx \frac{6A}{N}$
Power Dissipation of LM1577/LM2577	P_D	$0.25\Omega \left(\frac{N \Sigma I_{LOAD}}{1 - D}\right)^2 + \frac{N I_{LOAD} D}{50 (1 - D)} V_{IN}$

N = Transformer Turns Ratio = $\frac{\text{number of secondary turns}}{\text{number of primary turns}}$

η = Transformer Efficiency *(typically 0.95)*

$\Sigma I_{LOAD} = |+I_{LOAD}| + |-I_{LOAD}|$

FIGURE 17. Flyback Regulator Formulas

C. *Calculate the minimum value of C_C*

$$C_C \geq \frac{58.5 \times C_{OUT} \times V_{OUT} \times (V_{OUT} + (V_{IN(min)} \times N))}{R_C^2 \times V_{IN(min)} \times N}$$

D. *Calculate the maximum ESR* of the $+V_{OUT}$ and $-V_{OUT}$ output capacitors in parallel.

$$ESR_+ \| ESR_- \leq \frac{8.7 \times 10^{-3} \times V_{IN(min)} \times V_{OUT} \times N}{\Sigma I_{LOAD(max)} \times (V_{OUT} + (V_{IN(min)} \times N))}$$

This formula can also be used to calculate the maximum ESR of a single output regulator.

At this point, refer to this same section in the **Step-Up Regulator Design Procedure** for more information regarding the selection of C_{OUT}.

Application Hints (Continued)

3. Output Voltage Selection

This section is for applications using the LM1577-ADJ/LM2577-ADJ. Skip this section if the LM1577-12/LM2577-12 or LM1577-15/LM2577-15 is being used.

With the LM1577-ADJ/LM2577-ADJ, the output voltage is given by

$$V_{OUT} = 1.23V\,(1 + R1/R2)$$

Resistors R1 and R2 divide the output voltage down so it can be compared with the LM1577-ADJ/LM2577-ADJ internal 1.23V reference. For a desired output voltage V_{OUT}, select R1 and R2 so that

$$\frac{R1}{R2} = \frac{V_{OUT}}{1.23V} - 1$$

4. Diode Selection

The switching diode in a flyback converter must withstand the reverse voltage specified by the following equation.

$$V_R = V_{OUT} + \frac{V_{IN}}{N}$$

A suitable diode must have a reverse voltage rating greater than this. In addition it must be rated for more than the average and peak diode currents listed in *Figure 17*.

5. Input Capacitor Selection

The primary of a flyback transformer draws discontinuous pulses of current from the input supply. As a result, a flyback regulator generates more noise at the input supply than a step-up regulator, and this requires a larger bypass capacitor to decouple the LM1577/LM2577 V_{IN} pin from this noise. For most applications, a low ESR, 1.0 μF cap will be sufficient, if it is connected very close to the V_{IN} and Ground pins.

In addition to this bypass cap, a larger capacitor ($\geq$ 47 μF) should be used where the flyback transformer connects to the input supply. This will attenuate noise which may interfere with other circuits connected to the same input supply voltage.

Transformer Type		Input Voltage	Dual Output Voltage	Maximum Output Current
1	$L_P = 100\ \mu H$, $N = 1$	5V	±10V	325 mA
		5V	±12V	275 mA
		5V	±15V	225 mA
2	$L_P = 200\ \mu H$, $N = 0.5$	10V	±10V	700 mA
		10V	±12V	575 mA
		10V	±15V	500 mA
		12V	±10V	800 mA
		12V	±12V	700 mA
		12V	±15V	575 mA
3	$L_P = 250\ \mu H$, $N = 0.5$	15V	±10V	900 mA
		15V	±12V	825 mA
		15V	±15V	700 mA

Transformer Type	Manufacturers' Part Numbers		
	AIE	Pulse	Renco
1	326-0637	PE-65300	RL-2580
2	330-0202	PE-65301	RL-2581
3	330-0203	PE-65302	RL-2582

FIGURE 18. Flyback Transformer Selection Guide

6. Snubber Circuit

A "snubber" circuit is required when operating from input voltages greater than 10V, or when using a transformer with $L_P \geq 200\ \mu H$. This circuit clamps a voltage spike from the transformer primary that occurs immediately after the output switch turns off. Without it, the switch voltage may exceed the 65V maximum rating. As shown in *Figure 19*, the snubber consists of a fast recovery diode, and a parallel RC. The RC values are selected for switch clamp voltage (V_{CLAMP}) that is 5V to 10V greater than $V_{SW(OFF)}$. Use the following equations to calculate R and C;

$$C \geq \frac{0.02 \times L_P \times I_{P(PK)}^2}{(V_{CLAMP})^2 - (VSW_{(OFF)})^2}$$

$$R \leq \left(\frac{V_{CLAMP} + V_{SW(OFF)} - V_{IN}}{2}\right)^2 \times \left(\frac{19.2 \times 10^{-4}}{L_P \times I_{P(PK)}^2}\right)$$

Power dissipation (and power rating) of the resistor is;

$$P = \left(\frac{V_{CLAMP} + V_{SW(OFF)} - V_{IN}}{2}\right)^2 / R$$

The fast recovery diode must have a reverse voltage rating greater than V_{CLAMP}.

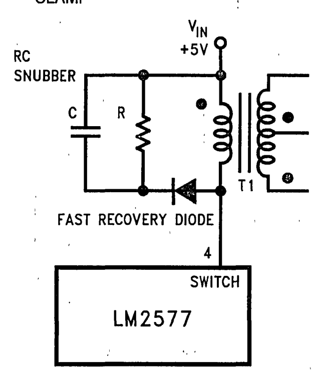


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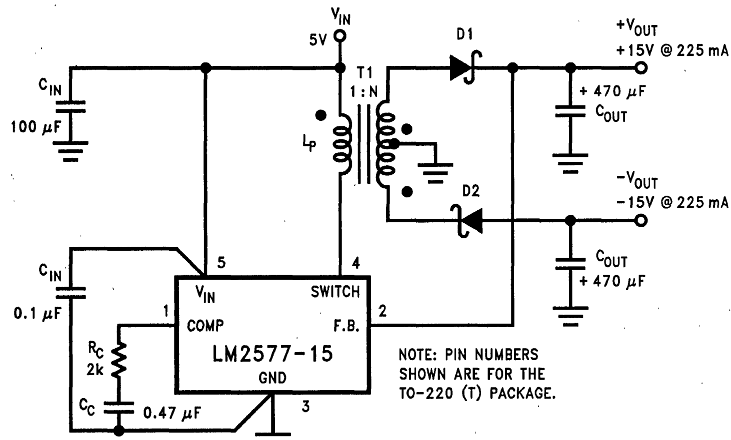
FIGURE 19. Snubber Circuit

Application Hints (Continued)

FLYBACK REGULATOR CIRCUIT EXAMPLE

The circuit of *Figure 20* produces ±15V (at 225 mA each) from a single 5V input. The output regulation of this circuit is shown in *Figures 21* and *22*, while the load transient response is shown in *Figures 23* and *24*. Switching waveforms seen in this circuit are shown in *Figure 25*.



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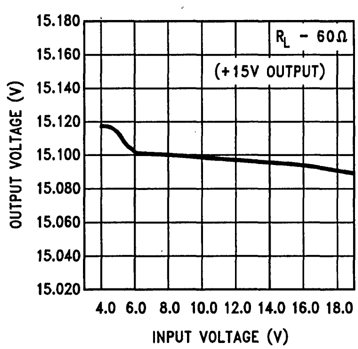
T1 = Pulse Engineering, PE-65300
D1, D2 = 1N5821

FIGURE 20. Flyback Regulator Easily Provides Dual Outputs



TL/H/11468-21

FIGURE 21. Line Regulation (Typical) of Flyback Regulator of *Figure 20*, +15V Output

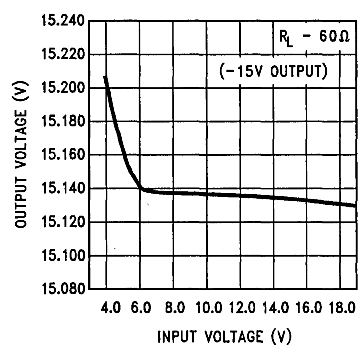


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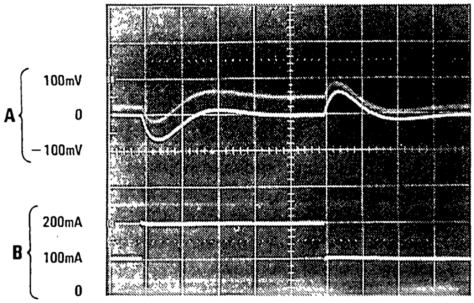
FIGURE 22. Line Regulation (Typical) of Flyback Regulator of *Figure 20*, −15V Output

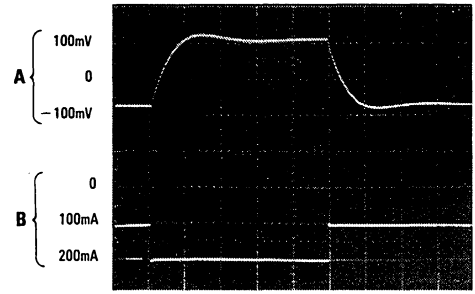
Application Hints (Continued)



TL/H/11468–23

FIGURE 23. Load Transient Response of Flyback Regulator of *Figure 20*, +15V Output

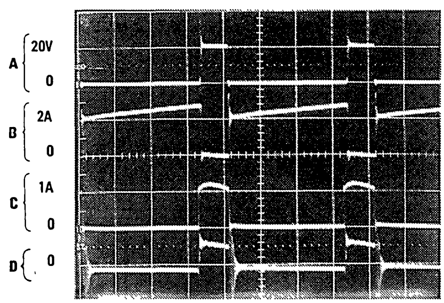
A: Output Voltage Change, 100 mV/div
B: Output Current, 100 mA/div
Horizontal: 10 ms/div



TL/H/11468–24

FIGURE 24. Load Transient Response of Flyback Regulator of *Figure 20*, −15V Output

A: Output Voltage Change, 100 mV/div
B: Output Current, 100 mA/div
Horizontal: 10 ms/div



TL/H/11468–25

FIGURE 25. Switching Waveforms of Flyback Regulator of *Figure 20*, Each Output Loaded with 60Ω

A: Switch pin voltage, 20 V/div
B: Primary current, 2 A/div
C: +15V Secondary current, 1 A/div
D: +15V Output ripple voltage, 100 mV/div
Horizontal: 5 μs/div

National Semiconductor

LM1578A/LM2578A/LM3578A Switching Regulator

General Description

The LM1578A is a switching regulator which can easily be set up for such DC-to-DC voltage conversion circuits as the buck, boost, and inverting configurations. The LM1578A features a unique comparator input stage which not only has separate pins for both the inverting and non-inverting inputs, but also provides an internal 1.0V reference to each input, thereby simplifying circuit design and p.c. board layout. The output can switch up to 750 mA and has output pins for its collector and emitter to promote design flexibility. An external current limit terminal may be referenced to either the ground or the V_{in} terminal, depending upon the application. In addition, the LM1578A has an on board oscillator, which sets the switching frequency with a single external capacitor from <1 Hz to 100 kHz (typical).

The LM1578A is an improved version of the LM1578, offering higher maximum ratings for the total supply voltage and output transistor emitter and collector voltages.

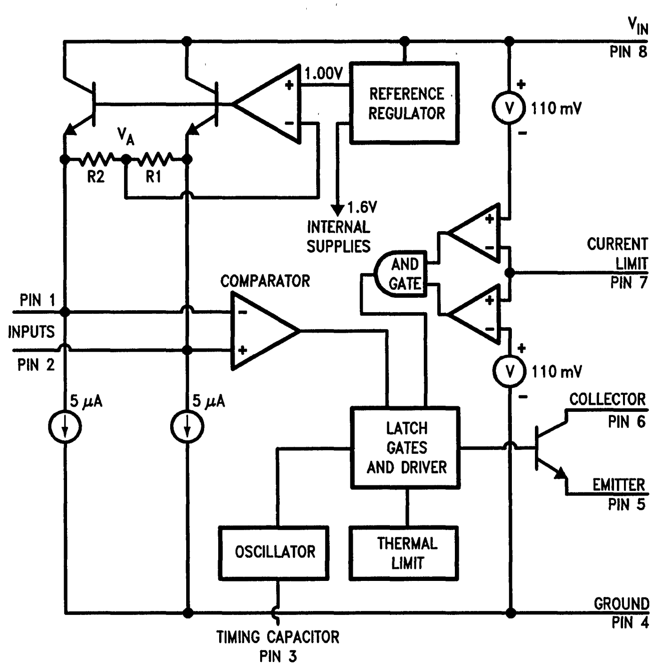
Features

- Inverting and non-inverting feedback inputs
- 1.0V reference at inputs
- Operates from supply voltages of 2V to 40V
- Output current up to 750 mA, saturation less than 0.9V
- Current limit and thermal shut down
- Duty cycle up to 90%

Applications

- Switching regulators in buck, boost, inverting, and single-ended transformer configurations
- Motor speed control
- Lamp flasher

Functional Diagram



TL/H/8711-1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage	50V
Collector Output to Ground	−0.3V to +50V
Emitter Output to Ground (Note 2)	−1V to +50V
Power Dissipation (Note 3)	Internally limited
Output Current	750 mA
Storage Temperature	−65°C to +150°C
Lead Temperature (soldering, 10 seconds)	260°C
Maximum Junction Temperature	150°C
ESD Tolerance (Note 4)	2 kV

Operating Ratings

Ambient Temperature Range	
LM1578A	$-55°C \leq T_A \leq +125°C$
LM2578A	$-40°C \leq T_A \leq +85°C$
LM3578A	$0°C \leq T_A \leq +70°C$
Junction Temperature Range	
LM1578A	$-55°C \leq T_J \leq +150°C$
LM2578A	$-40°C \leq T_J \leq +125°C$
LM3578A	$0°C \leq T_J \leq +125°C$

Electrical Characteristics

These specifications apply for $2V \leq V_{IN} \leq 40V$ ($2.2V \leq V_{IN} \leq 40V$ for $T_J \leq -25°C$), timing capacitor $C_T = 3900$ pF, and 25% ≤ duty cycle ≤ 75%, unless otherwise specified. Values in standard typeface are for $T_J = 25°C$; values in **boldface type** apply for operation over the specified operating junction temperature range.

Symbol	Parameter	Conditions	Typical (Note 5)	LM1578A Limit (Notes 6, 11)	LM2578A/ LM3578A Limit (Note 7)	Units
OSCILLATOR						
f_{OSC}	Frequency		20			kHz
				22.4	24	kHz (max)
				17.6	16	kHz (min)
$\Delta f_{OSC}/\Delta T$	Frequency Drift with Temperature		**−0.13**			%/°C
	Amplitude		550			mV_{p-p}
REFERENCE/COMPARATOR (Note 8)						
V_R	Input Reference Voltage	$I_1 = I_2 = 0$ mA and $I_1 = I_2 = 1$ mA ±1% (Note 9)	1.0			V
				1.035/**1.050**	1.050/**1.070**	V (max)
				0.965/**0.950**	0.950/**0.930**	V (min)
$\Delta V_R/\Delta V_{IN}$	Input Reference Voltage Line Regulation	$I_1 = I_2 = 0$ mA and $I_1 = I_2 = 1$ mA ±1% (Note 9)	0.003			%/V
				0.01/**0.02**	0.01/**0.02**	%/V (max)
I_{INV}	Inverting Input Current	$I_1 = I_2 = 0$ mA, duty cycle = 25%	0.5			μA
	Level Shift Accuracy	Level Shift Current = 1 mA	1.0			%
				5/**8**	10/**13**	% (max)
$\Delta V_R/\Delta t$	Input Reference Voltage Long Term Stability		100			ppm/1000h
OUTPUT						
V_C (sat)	Collector Saturation Voltage	$I_C = 750$ mA pulsed, Emitter grounded	0.7			V
				0.85/**1.2**	0.90/**1.2**	V (max)
V_E (sat)	Emitter Saturation Voltage	$I_O = 80$ mA pulsed, $V_{IN} = V_C = 40V$	1.4			V
				1.6/**2.1**	1.7/**2.0**	V (max)
I_{CES}	Collector Leakage Current	$V_{IN} = V_{CE} = 40V$, Emitter grounded, Output OFF	0.1			μA
				50/**100**	200/**250**	μA (max)
$BV_{CEO(SUS)}$	Collector-Emitter Sustaining Voltage	$I_{SUST} = 0.2A$ (pulsed), $V_{IN} = 0$	60			V
				50	50	V (min)

Electrical Characteristics (Continued)

Symbol	Parameter	Conditions	Typical (Note 5)	LM1578A Limit (Notes 6, 11)	LM2578A/ LM3578A Limit (Note 7)	Units
CURRENT LIMIT						
V_{CL}	Sense Voltage Shutdown Level	Referred to V_{IN} or Ground (Note 10)	110			mV
				95	80	mV (min)
				140	160	mV (max)
$\Delta V_{CL}/\Delta T$	Sense Voltage Temperature Drift		**0.3**			%/°C
I_{CL}	Sense Bias Current	Referred to V_{IN}	4.0			μA
		Referred to ground	0.4			μA
DEVICE POWER CONSUMPTION						
I_S	Supply Current	Output OFF, $V_E = 0V$	2.0			mA
				3.0/**3.3**	3.5/**4.0**	mA (max)
		Output ON, $I_C = 750$ mA pulsed, $V_E = 0V$	14			mA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: For $T_J \geq 100°C$, the Emitter pin voltage should not be driven more than 0.6V below ground (see Application Information).

Note 3: At elevated temperatures, devices must be derated based on package thermal resistance. The device in the TO-99 package must be derated at 150°C/W, junction to ambient, or 45°C/W, junction to case. The device in the 8-pin DIP must be derated at 95°C/W, junction to ambient. The device in the surface-mount package must be derated at 150°C/W, junction-to-ambient.

Note 4: Human body model, 1.5 kΩ in series with 100 pF.

Note 5: Typical values are for $T_J = 25°C$ and represent the most likely parametric norm.

Note 6: All limits guaranteed and 100% production tested at room temperature (standard type face) and at **temperature extremes (bold type face).** All limits are used to calculate Average Outgoing Quality Level (AOQL).

Note 7: All limits guaranteed at room temperature (standard type face) and at **temperature extremes (bold type face).** Room temperature limits are 100% production tested. Limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods. All limits are used to calculate AOQL.

Note 8: Input terminals are protected from accidental shorts to ground but if external voltages higher than the reference voltage are applied, excessive current will flow and should be limited to less than 5 mA.

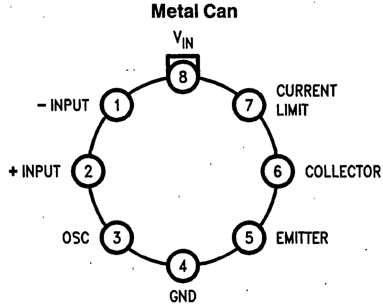
Note 9: I_1 and I_2 are the external sink currents at the inputs (refer to Test Circuit).

Note 10: Connection of a 10 kΩ resistor from pin 1 to pin 4 will drive the duty cycle to its maximum, typically 90%. Applying the minimum Current Limit Sense Voltage to pin 7 will not reduce the duty cycle to less than 50%. Applying the maximum Current Limit Sense Voltage to pin 7 is certain to reduce the duty cycle below 50%. Increasing this voltage by 15 mV may be required to reduce the duty cycle to 0%, when the Collector output swing is 40V or greater (see Ground-Referred Current Limit Sense Voltage typical curve).

Note 11: A military RETS specification is available on request. At the time of printing, the LM1578A RETS spec complied with the **boldface** limits in this column. The LM1578AH may also be procured as a Standard Military Drawing.

Connection Diagram and Ordering Information

Metal Can



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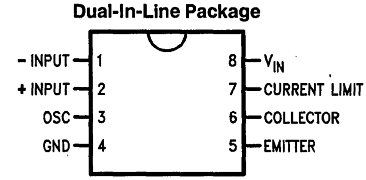
Top View

Order Number LM1578AH/883 or SMD #5962-8958602
See NS Package Number H08C

Dual-In-Line Package

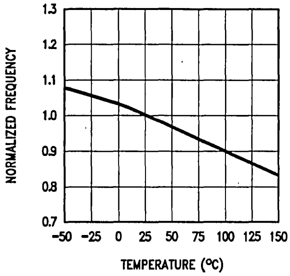


TL/H/8711–29

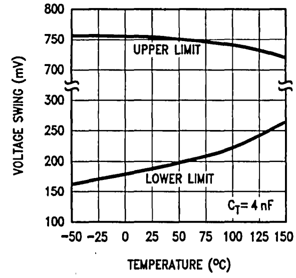
Order Number LM3578AM, LM2578AN or LM3578AN
See NS Package Number M08A or N08E

Typical Performance Characteristics

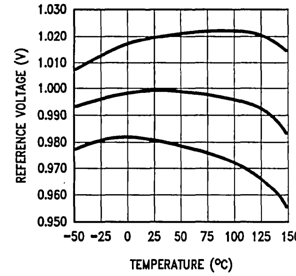
Oscillator Frequency Change with Temperature



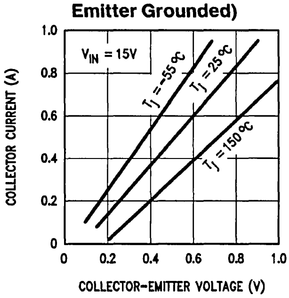
Oscillator Voltage Swing



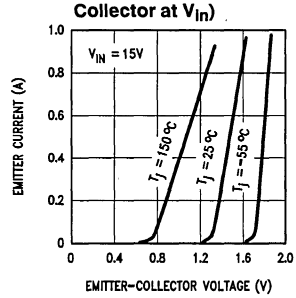
Input Reference Voltage Drift with Temperature



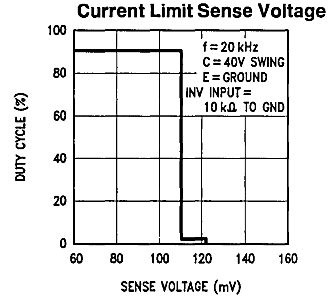
Collector Saturation Voltage (Sinking Current, Emitter Grounded)



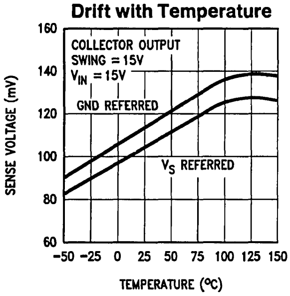
Emitter Saturation Voltage (Sourcing Current, Collector at V_{in})



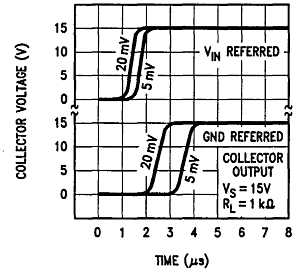
Ground Referred Current Limit Sense Voltage



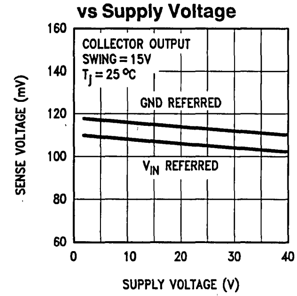
Current Limit Sense Voltage Drift with Temperature



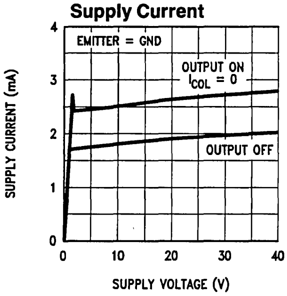
Current Limit Response Time for Various Over Drives



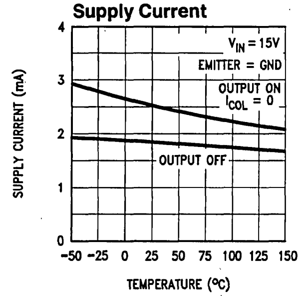
Current Limit Sense Voltage vs Supply Voltage



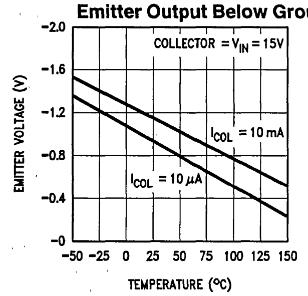
Supply Current



Supply Current



Collector Current with Emitter Output Below Ground



TL/H/8711-2

Test Circuit*

Parameter tests can be made using the test circuit shown. Select the desired V_{in}, collector voltage and duty cycle with adjustable power supplies. A digital volt meter with an input resistance greater than 100 MΩ should be used to measure the following:

Input Reference Voltage to Ground; S1 in either position.

Level Shift Accuracy (%) = (T_{P3}(V)/1V) × 100%; S1 at $I_1 = I_2 = 1$ mA

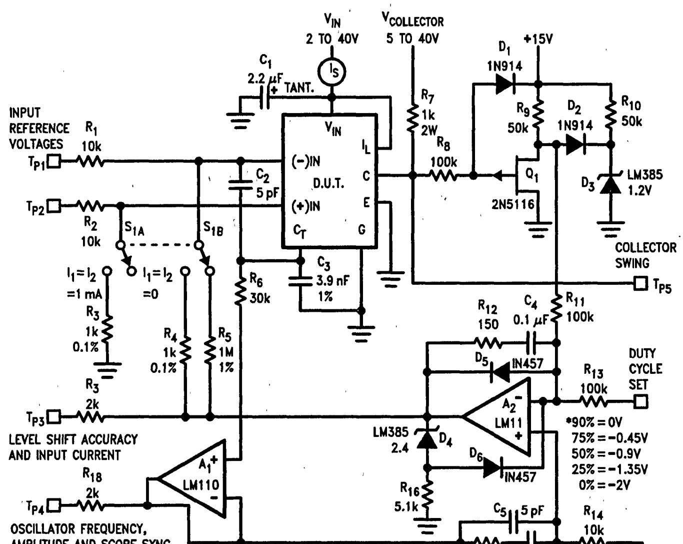
Input Current (mA) = (1V − T_{P3} (V))/1 MΩ: S1 at $I_1 = I_2 = 0$ mA.

Oscillator parameters can be measured at T_{P4} using a frequency counter or an oscilloscope.

The Current Limit Sense Voltage is measured by connecting an adjustable 0-to-1V floating power supply in series with the current limit terminal and referring it to either the ground or the V_{in} terminal. Set the duty cycle to 90% and monitor test point T_{P5} while adjusting the floating power supply voltage until the LM1578A's duty cycle just reaches 0%. This voltage is the Current Limit Sense Voltage.

The Supply Current should be measured with the duty cycle at 0% and S1 in the $I_1 = I_2 = 0$ mA position.

*LM1578A specifications are measured using automated test equipment. This circuit is provided for the customer's convenience when checking parameters. Due to possible variations in testing conditions, the measured values from these testing procedures may not match those of the factory.



Note 1: Op amp supplies are ±15V

Note 2: DVM input resistance >100 MΩ

Note 3: *LM1578 max duty cycle is 90%

TL/H/8711-3

Definition of Terms

Input Reference Voltage: The voltage (referred to ground) that must be applied to either the inverting or non-inverting input to cause the regulator switch to change state (ON or OFF).

Input Reference Current: The current that must be drawn from either the inverting or non-inverting input to cause the regulator switch to change state (ON or OFF).

Input Level Shift Accuracy: This specification determines the output voltage tolerance of a regulator whose output control depends on drawing equal currents from the inverting and non-inverting inputs (see the Inverting Regulator of *Figure 21*, and the RS-232 Line Driver Power Supply of *Figure 23*).

Level Shift Accuracy is tested by using two equal-value resistors to draw current from the inverting and non-inverting input terminals, then measuring the percentage difference in the voltages across the resistors that produces a controlled duty cycle at the switch output.

Collector Saturation Voltage: With the inverting input terminal grounded thru a 10 kΩ resistor and the output transistor's emitter connected to ground, the Collector Saturation-Voltage is the collector-to-emitter voltage for a given collector current.

Emitter Saturation Voltage: With the inverting input terminal grounded thru a 10 kΩ resistor and the output transistor's collector connected to V_{in}, the Emitter Saturation Voltage is the collector-to-emitter voltage for a given emitter current.

Collector Emitter Sustaining Voltage: The collector-emitter breakdown voltage of the output transistor, measured at a specified current.

Current Limit Sense Voltage: The voltage at the Current Limit pin, referred to either the supply or the ground terminal, which (via logic circuitry) will cause the output transistor to turn OFF and resets cycle-by-cycle at the oscillator frequency.

Definition of Terms (Continued)

Current Limit Sense Current: The bias current for the Current Limit terminal with the applied voltage equal to the Current Limit Sense Voltage.

Supply Current: The IC power supply current, excluding the current drawn through the output transistor, with the oscillator operating.

Functional Description

The LM1578A is a pulse-width modulator designed for use as a switching regulator controller. It may also be used in other applications which require controlled pulse-width voltage drive.

A control signal, usually representing output voltage, fed into the LM1578A's comparator is compared with an internally-generated reference. The resulting error signal and the oscillator's output are fed to a logic network which determines when the output transistor will be turned ON or OFF. The following is a brief description of the subsections of the LM1578A.

COMPARATOR INPUT STAGE

The LM1578A's comparator input stage is unique in that both the inverting and non-inverting inputs are available to the user, and both contain a 1.0V reference. This is accomplished as follows: A 1.0V reference is fed into a modified voltage follower circuit (see FUNCTIONAL DIAGRAM). When both input pins are open, no current flows through R1 and R2. Thus, both inputs to the comparator will have the potential of the 1.0V reference, V_A. When one input, for example the non-inverting input, is pulled ΔV away from V_A, a current of $\Delta V/R1$ will flow through R1. This same current flows through R2, and the comparator sees a total voltage of $2\Delta V$ between its inputs. The high gain of the system, through feedback, will correct for this imbalance and return both inputs to the 1.0V level.

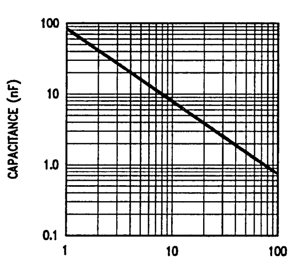
This unusual comparator input stage increases circuit flexibility, while minimizing the total number of external components required for a voltage regulator system. The inverting switching regulator configuration, for example, can be set up without having to use an external op amp for feedback polarity reversal (see TYPICAL APPLICATIONS).

OSCILLATOR

The LM1578A provides an on-board oscillator which can be adjusted up to 100 kHz. Its frequency is set by a single external capacitor, C_1, as shown in *Figure 1*, and follows the equation

$$f_{OSC} = 8\times10^{-5}/C_1$$

The oscillator provides a blanking pulse to limit maximum duty cycle to 90%, and a reset pulse to the internal circuitry.



TL/H/8711-4

FIGURE 1. Value of Timing Capacitor vs Oscillator Frequency

OUTPUT TRANSISTOR

The output transistor is capable of delivering up to 750 mA with a saturation voltage of less than 0.9V. (see *Collector Saturation Voltage* and *Emitter Saturation Voltage* curves).

The emitter must not be pulled more than 1V below ground (this limit is 0.6V for $T_J \geq 100°C$). Because of this limit, an external transistor must be used to develop negative output voltages (see the Inverting Regulator Typical Application). Other configurations may need protection against violation of this limit (see the Emitter Output section of the Applications Information).

CURRENT LIMIT

The LM1578A's current limit may be referenced to either the ground or the V_{in} pins, and operates on a cycle-by-cycle basis.

The current limit section consists of two comparators: one with its non-inverting input referenced to a voltage 110 mV below V_{in}, the other with its inverting input referenced 110 mV above ground (see FUNCTIONAL DIAGRAM). The current limit is activated whenever the current limit terminal is pulled 110 mV away from either V_{in} or ground.

Applications Information

CURRENT LIMIT

As mentioned in the functional description, the current limit terminal may be referenced to either the V_{in} or the ground terminal. Resistor R3 converts the current to be sensed into a voltage for current limit detection.

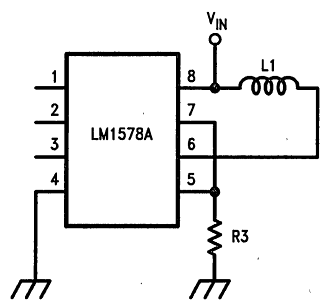


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FIGURE 2. Current Limit, Ground Referred

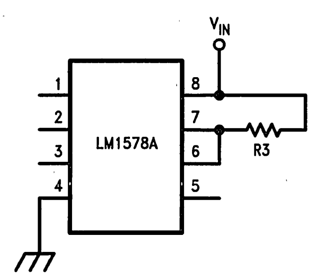

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FIGURE 3. Current Limit, V_{in} Referred

Applications Information (Continued)

CURRENT LIMIT TRANSIENT SUPPRESSION

When noise spikes and switching transients interfere with proper current limit operation, R1 and C1 act together as a low pass filter to control the current limit circuitry's response time.

Because the sense current of the current limit terminal varies according to where it is referenced, R1 should be less than 2 kΩ when referenced to ground, and less than 100Ω when referenced to V_{in}.

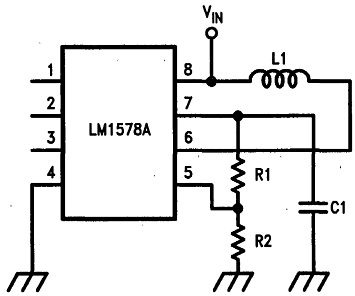

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FIGURE 4. Current Limit Transient Suppressor, Ground Referred

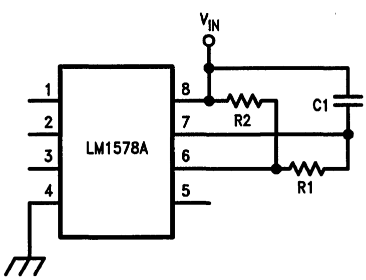

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FIGURE 5. Current Limit Transient Suppressor, V_{in} Referred

C.L. SENSE VOLTAGE MULTIPLICATION

When a larger sense resistor value is desired, the voltage divider network, consisting of R1 and R2, may be used. This effectively multiplies the sense voltage by (1 + R1/R2). Also, R1 can be replaced by a diode to increase current limit sense voltage to about 800 mV (diode V_f + 110 mV).

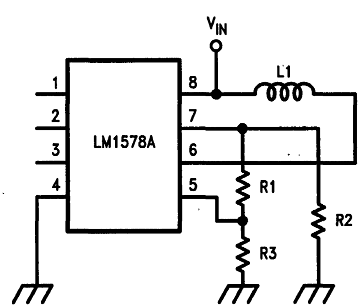

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FIGURE 6. Current Limit Sense Voltage Multiplication, Ground Referred

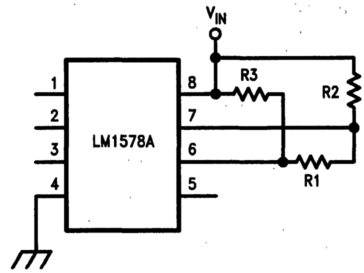

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FIGURE 7. Current Limit Sense Voltage Multiplication, V_{in} Referred

UNDER-VOLTAGE LOCKOUT

Under-voltage lockout is accomplished with few external components. When V_{in} becomes lower than the zener breakdown voltage, the output transistor is turned off. This occurs because diode D1 will then become forward biased, allowing resistor R3 to sink a greater current from the non-inverting input than is sunk by the parallel combination of R1 and R2 at the inverting terminal. R3 should be one-fifth of the value of R1 and R2 in parallel.

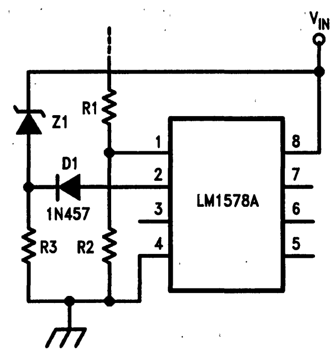

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FIGURE 8. Under-Voltage Lockout

MAXIMUM DUTY CYCLE LIMITING

The maximum duty cycle can be externally limited by adjusting the charge to discharge ratio of the oscillator capacitor with a single external resistor. Typical values are 50 μA for the charge current, 450 μA for the discharge current, and a voltage swing from 200 mV to 750 mV. Therefore, R1 is selected for the desired charging and discharging slopes and C1 is readjusted to set the oscillator frequency.

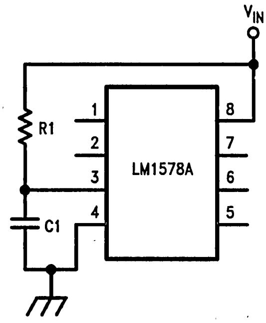

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FIGURE 9. Maximum Duty Cycle Limiting

DUTY CYCLE ADJUSTMENT

When manual or mechanical selection of the output transistor's duty cycle is needed, the cirucit shown below may be used. The output will turn on with the beginning of each oscillator cycle and turn off when the current sunk by R2 and R3 from the non-inverting terminal becomes greater than the current sunk from the inverting terminal.

With the resistor values as shown, R3 can be used to adjust the duty cycle from 0% to 90%.

When the sum of R2 and R3 is twice the value of R1, the duty cycle will be about 50%. C1 may be a large electrolytic capacitor to lower the oscillator frequency below 1 Hz.

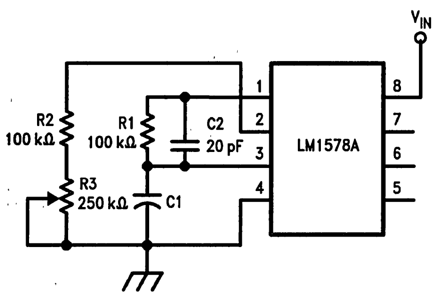

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FIGURE 10. Duty Cycle Adjustment

REMOTE SHUTDOWN

The LM1578A may be remotely shutdown by sinking a greater current from the non-inverting input than from the inverting input. This may be accomplished by selecting resistor R3 to be approximately one-half the value of R1 and R2 in parallel.

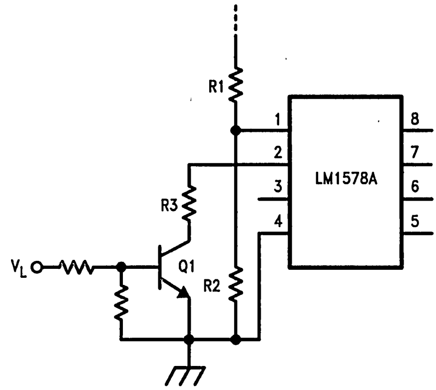

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FIGURE 11. Shutdown Occurs when V_L is High

EMITTER OUTPUT

When the LM1578A output transistor is in the OFF state, if the Emitter output swings below the ground pin voltage, the output transistor will turn ON because its base is clamped near ground. The *Collector Current with Emitter Output Below Ground* curve shows the amount of Collector current drawn in this mode, vs temperature and Emitter voltage. When the Collector-Emitter voltage is high, this current will cause high power dissipation in the output transistor and should be avoided.

This situation can occur in the high-current high-voltage buck application if the Emitter output is used and the catch diode's forward voltage drop is greater than 0.6V. A fast-recovery diode can be added in series with the Emitter output to counter the forward voltage drop of the catch diode (see *Figure 2*). For better efficiency of a high output current buck regulator, an external PNP transistor should be used as shown in *Figure 16.*

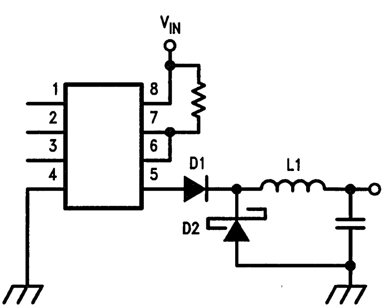

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FIGURE 12. D1 Prevents Output Transistor from Improperly Turning ON due to D2's Forward Voltage

Applications Information (Continued)

SYNCHRONIZING DEVICES

When several devices are to be operated at once, their oscillators may be synchronized by the application of an external signal. This drive signal should be a pulse waveform with a minimum pulse width of 2 μs. and an amplitude from 1.5V to 2.0V. The signal source must be capable of 1.) driving capacitive loads and 2.) delivering up to 500 μA for each LM1578A.

Capacitors C1 thru CN are to be selected for a 20% slower frequency than the synchronization frequency.

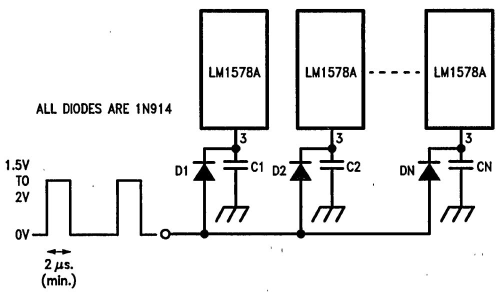

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FIGURE 13. Synchronizing Devices

Typical Applications

The LM1578A may be operated in either the continuous or the discontinuous conduction mode. The following applications (except for the Buck-Boost Regulator) are designed for continuous conduction operation. That is, the inductor current is not allowed to fall to zero. This mode of operation has higher efficiency and lower EMI characteristics than the discontinuous mode.

BUCK REGULATOR

The buck configuration is used to step an input voltage down to a lower level. Transistor Q1 in *Figure 14* chops the input DC voltage into a squarewave. This squarewave is then converted back into a DC voltage of lower magnitude by the low pass filter consisting of L1 and C1. The duty cycle, D, of the squarewave relates the output voltage to the input voltage by the following equation:

$$V_{out} = D \times V_{in} = V_{in} \times (t_{on})/(t_{on} + t_{off}).$$

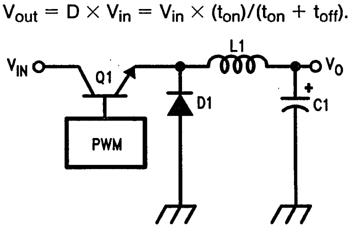

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FIGURE 14. Basic Buck Regulator

Figure 15 is a 15V to 5V buck regulator with an output current, I_o, of 350 mA. The circuit becomes discontinuous at 20% of $I_{o(max)}$, has 10 mV of output voltage ripple, an efficiency of 75%, a load regulation of 30 mV (70 mA to 350 mA) and a line regulation of 10 mV ($12 \le V_{in} \le 18V$).

Component values are selected as follows:

$R1 = (V_o - 1) \times R2$ where $R2 = 10\ k\Omega$

$R3 = V/I_{sw(max)}$

$R3 = 0.15\Omega$

where:

V is the current limit sense voltage, 0.11V

$I_{sw(max)}$ is the maximum allowable current thru the output transistor.

L1 is the inductor and may be found from the inductance calculation chart (*Figure 16*) as follows:

Given $V_{in} = 15V$ $V_o = 5V$

$I_{o(max)} = 350$ mA $f_{OSC} = 50$ kHz

Discontinuous at 20% of $I_{o(max)}$.

Note that since the circuit will become discontinuous at 20% of $I_{o(max)}$, the load current must not be allowed to fall below 70 mA.

Step 1: Calculate the maximum DC current through the inductor, $I_{L(max)}$. The necessary equations are indicated at the top of the chart and show that $I_{L(max)} = I_{o(max)}$ for the buck configuration. Thus, $I_{L(max)} = 350$ mA.

Step 2: Calculate the inductor Volts-sec product, E-T_{op}, according to the equations given from the chart. For the Buck:

$E\text{-}T_{op} = (V_{in} - V_o)\ (V_o/V_{in})\ (1000/f_{osc})$

$= (15 - 5)\ (5/15)\ (1000/50)$

$= 66V\text{-}\mu s.$

with the oscillator frequency, f_{osc}, expressed in kHz.

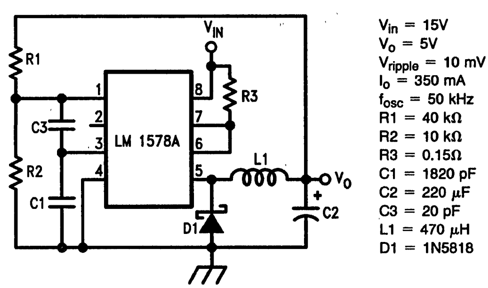

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FIGURE 15. Buck or Step-Down Regulator

Step 3: Using the graph with axis labeled "Discontinuous At % I_{OUT}" and "$I_{L(max,\ DC)}$" find the point where the desired maximum inductor current, $I_{L(max,\ DC)}$ intercepts the desired discontinuity percentage.

In this example, the point of interest is where the 0.35A line intersects with the 20% line. This is nearly the midpoint of the horizontal axis.

Step 4: This last step is merely the translation of the point found in Step 3 to the graph directly below it. This is accomplished by moving straight down the page to the point which intercepts the desired E-T_{op}. For this example, E-T_{op} is 66V-μs and the desired inductor value is 470 μH. Since this example was for 20% discontinuity, the bottom chart could have been used directly, as noted in step 3 of the chart instructions.

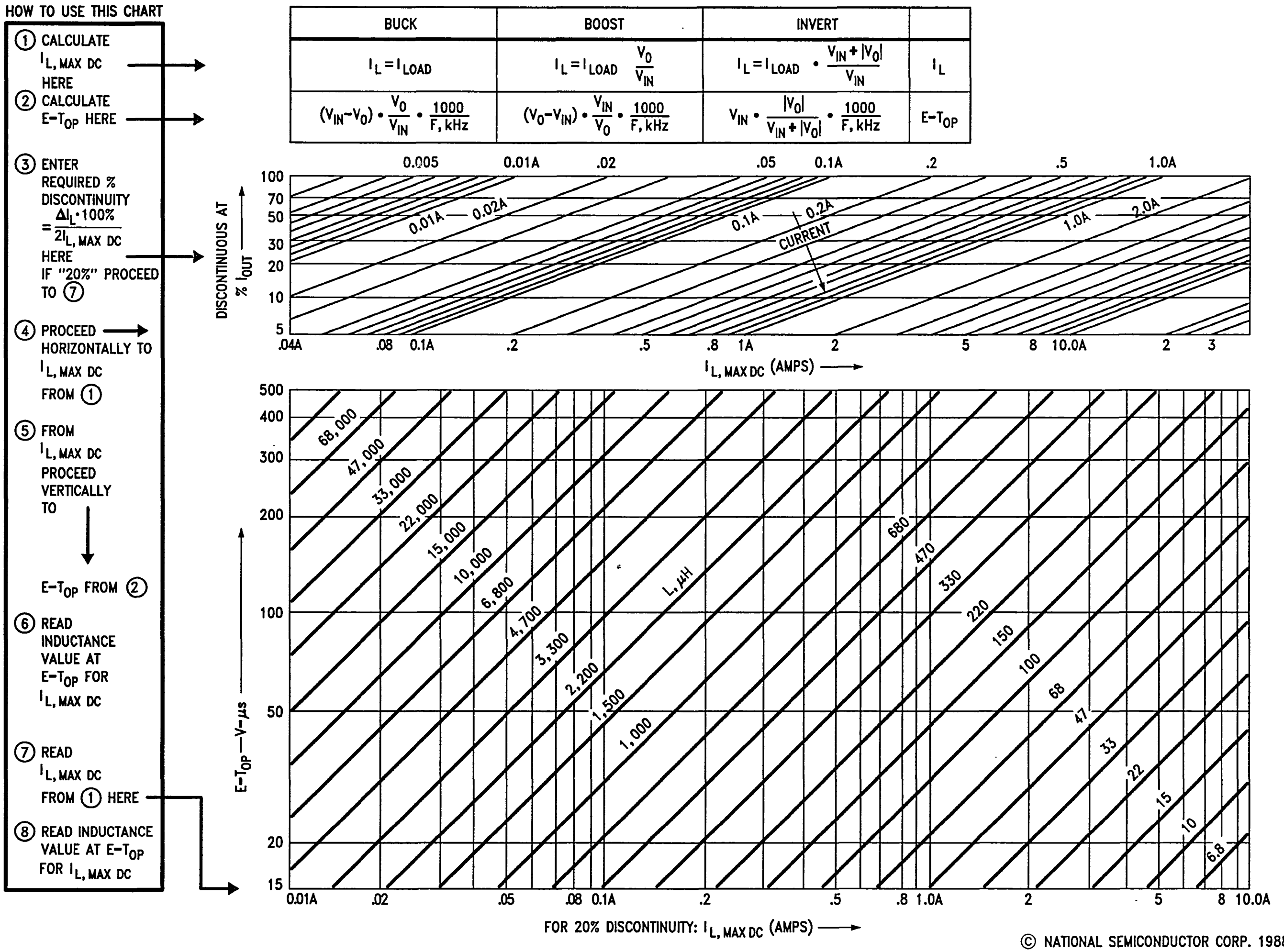

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FIGURE 16. DC/DC Inductance Calculator

Typical Applications (Continued)

For a full line of standard inductor values, contact Pulse Engineering (San Diego, Calif.) regarding their PE526XX series, or A. I. E. Magnetics (Nashville, Tenn.).

A more precise inductance value may be calculated for the Buck, Boost and Inverting Regulators as follows:

BUCK

$L = V_O (V_{in} - V_O)/(\Delta I_L V_{in} f_{osc})$

BOOST

$L = V_{in} (V_O - V_{in})/(\Delta I_L f_{osc} V_O)$

INVERT

$L = V_{in} |V_O|/[\Delta I_L(V_{in} + |V_O|)f_{osc}]$

where ΔI_L is the current ripple through the inductor. ΔI_L is usually chosen based on the minimum load current expected of the circuit. For the buck regulator, since the inductor current I_L equals the load current I_O,

$$\Delta I_L = 2 \bullet I_{O(min)}$$

ΔI_L = 140 mA for this circuit. ΔI_L can also be interpreted as

$$\Delta I_L = 2 \bullet \text{(Discontinuity Factor)} \bullet I_L$$

where the Discontinuity Factor is the ratio of the minimum load current to the maximum load current. For this example, the Discontinuity Factor is 0.2.

The remainder of the components of *Figure 15* are chosen as follows:

C1 is the timing capacitor found in *Figure 1*.

$C2 \ge V_O (V_{in} - V_O)/(8f_{osc}{}^2 V_{in} V_{ripple} L1)$

where V_{ripple} is the peak-to-peak output voltage ripple.

C3 is necessary for continuous operation and is generally in the 10 pF to 30 pF range.

D1 should be a Schottky type diode, such as the 1N5818 or 1N5819.

BUCK WITH BOOSTED OUTPUT CURRENT

For applications requiring a large output current, an external transistor may be used as shown in *Figure 17*. This circuit steps a 15V supply down to 5V with 1.5A of output current. The output ripple is 50 mV, with an efficiency of 80%, a load regulation of 40 mV (150 mA to 1.5A), and a line regulation of 20 mV ($12V \le V_{in} \le 18V$).

Component values are selected as outlined for the buck regulator with a discontinuity factor of 10%, with the addition of R4 and R5:

$R4 = 10V_{BE1}B_f/I_p$

$R5 = (V_{in} - V - V_{BE1} - V_{sat}) B_f/(I_{L(max, DC)} + I_{R4})$

where:

V_{BE1} is the V_{BE} of transistor Q1.

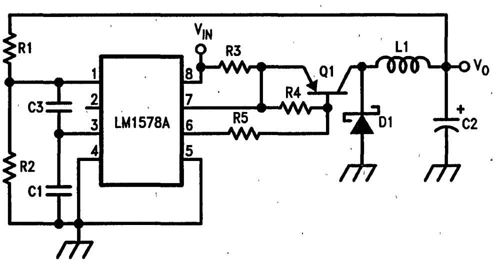
V_{sat} is the saturation voltage of the LM1578A output transistor.

V is the current limit sense voltage.

B_f is the forced current gain of transistor Q1 (B_f = 30 for *Figure 17*).

$I_{R4} = V_{BE1}/R4$

$I_p = I_{L(max, DC)} + 0.5\Delta I_L$



V_{in} = 15V	R4 = 200Ω
V_o = 5V	R5 = 330Ω
V_{ripple} = 50 mV	C1 = 1820 pF
I_o = 1.5A	C2 = 330 μF
f_{osc} = 50 kHz	C3 = 20 pF
R1 = 40 kΩ	L1 = 220 μH
R2 = 10 kΩ	D1 = 1N5819
R3 = 0.05Ω	Q1 = D45

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FIGURE 17. Buck Converter with Boosted Output Current

Typical Applications (Continued)

BOOST REGULATOR

The boost regulator converts a low input voltage into a higher output voltage. The basic configuration is shown in *Figure 18*. Energy is stored in the inductor while the transistor is on and then transferred with the input voltage to the output capacitor for filtering when the transistor is off. Thus,

$$V_O = V_{in} + V_{in}(t_{on}/t_{off}).$$

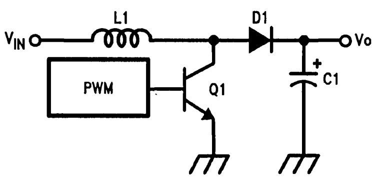

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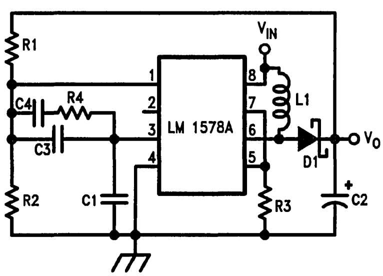
FIGURE 18. Basic Boost Regulator

The circuit of *Figure 19* converts a 5V supply into a 15V supply with 150 mA of output current, a load regulation of 14 mV (30 mA to 140 mA), and a line regulation of 35 mV ($4.5V \leq V_{in} \leq 8.5V$).



V_{in} = 5V
V_o = 15V
V_{ripple} = 10 mV
I_o = 140 mA
f_{osc} = 50 kHz
R1 = 140 kΩ
R2 = 10 kΩ
R3 = 0.15Ω
R4 = 220 kΩ
C1 = 1820 pF
C2 = 470 μF
C3 = 20 pF
C4 = 0.0022 μF
L1 = 330 μH
D1 = 1N5818

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FIGURE 19. Boost or Step-Up Regulator

$R1 = (V_O - 1)\ R2$ where $R2 = 10\ k\Omega$.

$R3 = V/(I_{L(max,\ DC)} + 0.5\ \Delta I_L)$

where:

$\Delta I_L = 2(I_{LOAD(min)})(V_o/V_{in})$

ΔI_L is 200 mA in this example.

R4, C3 and C4 are necessary for continuous operation and are typically 220 kΩ, 20 pF, and 0.0022 μF respectively.

C1 is the timing capacitor found in *Figure 1*.

$C2 \geq I_o (V_o - V_{in})/(f_{osc}\ V_o\ V_{ripple})$.

D1 is a Schottky type diode such as a IN5818 or IN5819.

L1 is found as described in the buck converter section, using the inductance chart for *Figure 16* for the boost configuration and 20% discontinuity.

INVERTING REGULATOR

Figure 20 shows the basic configuration for an inverting regulator. The input voltage is of a positive polarity, but the output is negative. The output may be less than, equal to, or greater in magnitude than the input. The relationship between the magnitude of the input voltage and the output voltage is $V_O = V_{in} \times (t_{on}/t_{off})$.

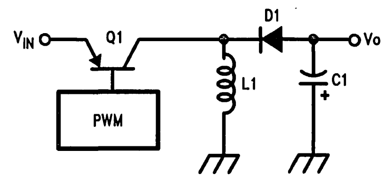

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FIGURE 20. Basic Inverting Regulator

Figure 21 shows an LM1578A configured as a 5V to −15V polarity inverter with an output current of 300 mA, a load regulation of 44 mV (60 mA to 300 mA) and a line regulation of 50 mV ($4.5V \leq V_{in} \leq 8.5V$).

$R1 = (|V_O| + 1)\ R2$ where $R2 = 10\ k\Omega$.

$R3 = V/(I_{L(max,\ DC)} + 0.5\ \Delta I_L)$.

$R4 = 10 V_{BE1} B_f/(I_{L\ (max,\ DC)} + 0.5\ \Delta I_L)$

where:

V, V_{BE1}, V_{sat}, and B_f are defined in the "Buck Converter with Boosted Output Current" section.

$\Delta I_L = 2(I_{LOAD(min)})(V_{in} + |V_o|)/V_{IN}$

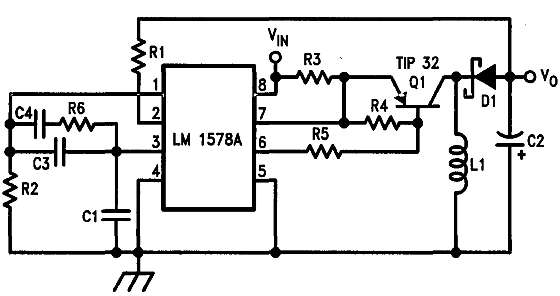
R5 is defined in the "Buck with Boosted Output Current" section.

R6 serves the same purpose as R4 in the Boost Regulator circuit and is typically 220 kΩ.

C1, C3 and C4 are defined in the "Boost Regulator" section.

$$C2 \geq I_o\ |V_o|/[f_{osc}(|V_o| + V_{in})\ V_{ripple}]$$

L1 is found as outlined in the section on buck converters, using the inductance chart of *Figure 16* for the invert configuration and 20% discontinuity.



V_{in} = 5V
V_o = −15V
V_{ripple} = 5 mV
I_o = 300 mA, I_{min} = 60 mA
f_{osc} = 50 kHz
R1 = 160 kΩ R2 = 10 kΩ
R3 = 0.01 Ω R4 = 190Ω
R5 = 82Ω R6 = 220 kΩ
C1 = 1820 pF
C2 = 1000 μF
C3 = 20 pF
C4 = 0.0022 μF
L1 = 150 μH
D1 = 1N5818

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FIGURE 21. Inverting Regulator

Typical Applications (Continued)

BUCK-BOOST REGULATOR

The Buck-Boost Regulator, shown in *Figure 22*, may step a voltage up or down, depending upon whether or not the desired output voltage is greater or less than the input voltage. In this case, the output voltage is 12V with an input voltage from 9V to 15V. The circuit exhibits an efficiency of 75%, with a load regulation of 60 mV (10 mA to 100 mA) and a line regulation of 52 mV.

$R1 = (V_O - 1)\ R2$ where $R2 = 10\ k\Omega$

$R3 = V/0.75A$

R4, C1, C3 and C4 are defined in the "Boost Regulator" section.

D1 and D2 are Schottky type diodes such as the 1N5818 or 1N5819.

$$C2 \geq \frac{(I_o/V_{ripple})\,(V_o + 2V_d)}{[f_{osc}\,(V_{in} + V_o + 2V_d - V_{sat} - V_{sat1})]}$$

where:

V_d is the forward voltage drop of the diodes.

V_{sat} is the saturation voltage of the LM1578A output transistor.

V_{sat1} is the saturation voltage of transistor Q1.

$$L1 \geq (V_{in} - V_{sat} - V_{sat1})\,(t_{on}/I_p)$$

where:

$$t_{on} = \frac{(1/f_{osc})\,(V_o + 2V_d)}{(V_o + V_{in} + 2V_d - V_{sat} - V_{sat1})}$$

$$I_p = \frac{2I_o\,(V_{in} + V_o + 2V_d - V_{sat} - V_{sat1})}{(V_{in} - V_{sat} - V_{sat1})}$$

RS-232 LINE DRIVER POWER SUPPLY

The power supply, shown in *Figure 23*, operates from an input voltage as low as 4.2V (5V nominal), and delivers an output of ±12V at ±40 mA with better than 70% efficiency. The circuit provides a load regulation of ±150 mV (from 10% to 100% of full load) and a line regulation of ±10 mV. Other notable features include a cycle-by-cycle current limit and an output voltage ripple of less than 40 mVp-p.

A unique feature of this circuit is its use of feedback from both outputs. This dual feedback configuration results in a sharing of the output voltage regulation by each output so that neither side becomes unbalanced as in single feedback systems. In addition, since both sides are regulated, it is not necessary to use a linear regulator for output regulation.

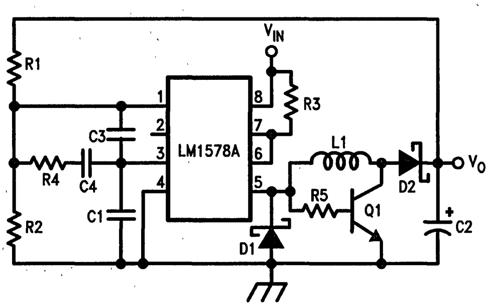
The feedback resistors, R2 and R3, may be selected as follows by assuming a value of 10 kΩ for R1;

$R2 = (V_O - 1V)/45.8\ \mu A = 240\ k\Omega$

$R3 = (|V_O| + 1V)/54.2\ \mu A = 240\ k\Omega$

Actually, the currents used to program the values for the feedback resistors may vary from 40 μA to 60 μA, as long as their sum is equal to the 100 μA necessary to establish the 1V threshold across R1. Ideally, these currents should be equal (50 μA each) for optimal control. However, as was done here, they may be mismatched in order to use standard resistor values. This results in a slight mismatch of regulation between the two outputs.

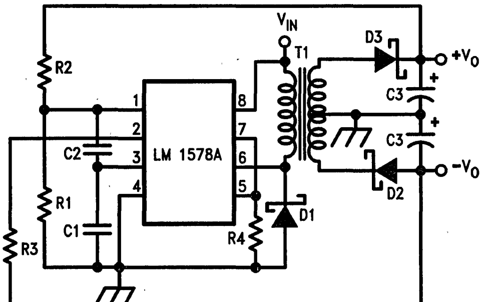
The current limit resistor, R4, is selected by dividing the current limit threshold voltage by the maximum peak current level in the output switch. For our purposes R4 = 110 mV/750 mA = 0.15Ω. A value of 0.1Ω was used.



$9V \leq V_{in} \leq 15V$
$V_o = 12V$
$I_o = 100\ mA$
$V_{ripple} = 50\ mV$
$f_{osc} = 50\ kHz$
R1 = 110 k
R2 = 10 k
R3 = 0.15
R4 = 220 k
R5 = 270
C1 = 1820 pF
C2 = 220 μF
C3 = 20 pF
C4 = 0.0022 μF
L1 = 220 μH
D1, D2 = 1N5819
Q1 = D44

TL/H/8711-13

FIGURE 22. Buck-Boost Regulator



$V_{in} = 5V$
$V_o = \pm 12V$
$I_o = \pm 40\ mA$
$f_{osc} = 80\ kHz$
R1 = 10 kΩ
R2 = 240 kΩ
R3 = 240 kΩ
R4 = 0.15 Ω
C1 = 820 pF
C2 = 10 pF
C3 = 220 μF
D1, D2, D3 = 1N5819
T1 = PE-64287

TL/H/8711-14

FIGURE 23. RS-232 Line Driver Power Supply

Typical Applications (Continued)

Capacitor C1 sets the oscillator frequency and is selected from *Figure 1*.

Capacitor C2 serves as a compensation capacitor for synchronous operation and a value of 10 to 50 pF should be sufficient for most applications.

A minimum value for an ideal output capacitor C3, could be calculated as $C = I_O \times t/\Delta V$ where I_O is the load current, t is the transistor on time (typically $0.4/f_{OSC}$), and ΔV is the peak-to-peak output voltage ripple. A larger output capacitor than this theoretical value should be used since electrolytics have poor high frequency performance. Experience has shown that a value from 5 to 10 times the calculated value should be used.

For good efficiency, the diodes must have a low forward voltage drop and be fast switching. 1N5819 Schottky diodes work well.

Transformer selection should be picked for an output transistor "on" time of $0.4/f_{OSC}$, and a primary inductance high enough to prevent the output transistor switch from ramping higher than the transistor's rating of 750 mA. Pulse Engineering (San Diego, Calif.) and Renco Electronics, Inc. (Deer Park, N.Y.) can provide further assistance in selecting the proper transformer for a specific application need. The transformer used in *Figure 23* was a Pulse Engineering PE-64287.

National Semiconductor

LM2587
SIMPLE SWITCHER® 5A Flyback Regulator

General Description

The LM2587 series of regulators are monolithic integrated circuits specifically designed for flyback, step-up (boost), and forward converter applications. The device is available in 4 different output voltage versions: 3.3V, 5.0V, 12V, and adjustable.

Requiring a minimum number of external components, these regulators are cost effective, and simple to use. Included in the datasheet are typical circuits of boost and flyback regulators. Also listed are selector guides for diodes and capacitors and a family of standard inductors and flyback transformers designed to work with these switching regulators.

The power switch is a 5.0A NPN device that can stand-off 65V. Protecting the power switch are current and thermal limiting circuits, and an undervoltage lockout circuit. This IC contains a 100 kHz fixed-frequency internal oscillator that permits the use of small magnetics. Other features include soft start mode to reduce in-rush current during start up, current mode control for improved rejection of input voltage and output load transients and cycle-by-cycle current limiting. An output voltage tolerance of ±4%, within specified input voltages and output load conditions, is guaranteed for the power supply system.

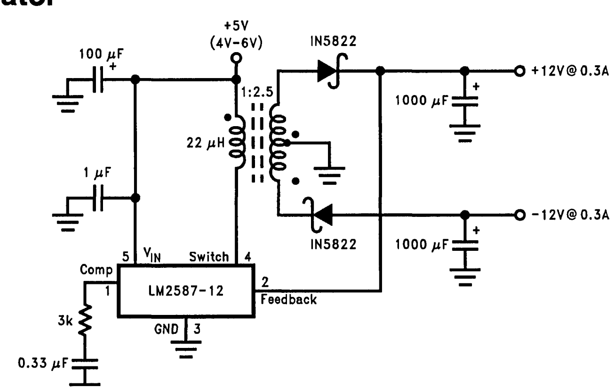
Features

- Requires few external components
- Family of standard inductors and transformers
- NPN output switches 5.0A, can stand off 65V
- Wide input voltage range: 4V to 40V
- Current-mode operation for improved transient response, line regulation, and current limit
- 100 kHz switching frequency
- Internal soft-start function reduces in-rush current during start-up
- Output transistor protected by current limit, under voltage lockout, and thermal shutdown
- System Output Voltage Tolerance of ±4% max over line and load conditions

Typical Applications

- Flyback regulator
- Multiple-output regulator
- Simple boost regulator
- Forward converter

Flyback Regulator



TL/H/12316-1

Ordering Information

Package Type	NSC Package Drawing	Order Number
5-Lead TO-220 Bent, Staggered Leads	T05D	LM2587T-3.3, LM2587T-5.0, LM2587T-12, LM2587T-ADJ
5-Lead TO-263	TS5B	LM2587S-3.3, LM2587S-5.0, LM2587S-12, LM2587S-ADJ
5-Lead TO-263 Tape and Reel	TS5B	LM2587SX-3.3, LM2587SX-5.0, LM2587SX-12, LM2587SX-ADJ

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage	$-0.4V \le V_{IN} \le 45V$
Switch Voltage	$-0.4V \le V_{SW} \le 65V$
Switch Current (Note 2)	Internally Limited
Compensation Pin Voltage	$-0.4V \le V_{COMP} \le 2.4V$
Feedback Pin Voltage	$-0.4V \le V_{FB} \le 2\ V_{OUT}$
Power Dissipation (Note 3)	Internally Limited
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	260°C
Maximum Junction Temperature (Note 3)	150°C
Minimum ESD Rating (C = 100 pF, R = 1.5 kΩ)	2 kV

Operating Ratings

Supply Voltage	$4V \le V_{IN} \le 40V$
Output Switch Voltage	$0V \le V_{SW} \le 60V$
Output Switch Current	$I_{SW} \le 5.0A$
Junction Temperature Range	$-40°C \le T_J \le +125°C$

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, V_{IN} = 5V.

LM2587-3.3

Symbol	Parameters	Conditions	Typical	Min	Max	Units
SYSTEM PARAMETERS Test Circuit of *Figure 2* (Note 4)						
V_{OUT}	Output Voltage	V_{IN} = 4V to 12V I_{LOAD} = 400 mA to 1.75A	3.3	3.17/**3.14**	3.43/**3.46**	V
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	V_{IN} = 4V to 12V I_{LOAD} = 400 mA	20		50/**100**	mV
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	V_{IN} = 12V I_{LOAD} = 400 mA to 1.75A	20		50/**100**	mV
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 1A	75			%
UNIQUE DEVICE PARAMETERS (Note 5)						
V_{REF}	Output Reference Voltage	Measured at Feedback Pin V_{COMP} = 1.0V	3.3	3.242/**3.234**	3.358/**3.366**	V
ΔV_{REF}	Reference Voltage Line Regulation	V_{IN} = 4V to 40V	2.0			mV
G_M	Error Amp Transconductance	I_{COMP} = −30 μA to +30 μA V_{COMP} = 1.0V	1.193	**0.678**	**2.259**	mmho
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 0.5V to 1.6V R_{COMP} = 1.0 MΩ (Note 6)	260	151/**75**		V/V

LM2587-5.0

Symbol	Parameters	Conditions	Typical	Min	Max	Units
SYSTEM PARAMETERS Test Circuit of *Figure 2* (Note 4)						
V_{OUT}	Output Voltage	V_{IN} = 4V to 12V I_{LOAD} = 500 mA to 1.45A	5.0	4.80/**4.75**	5.20/**5.25**	V
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	V_{IN} = 4V to 12V I_{LOAD} = 500 mA	20		50/**100**	mV
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	V_{IN} = 12V I_{LOAD} = 500 mA to 1.45A	20		50/**100**	mV
η	Efficiency	V_{IN} = 12V, I_{LOAD} = 750 mA	80			%

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, V_{IN} = 5V. (Continued)

LM2587-5.0 (Continued)

Symbol	Parameters	Conditions	Typical	Min	Max	Units
UNIQUE DEVICE PARAMETERS (Note 5)						
V_{REF}	Output Reference Voltage	Measured at Feedback Pin V_{COMP} = 1.0V	5.0	4.913/**4.900**	5.088/**5.100**	V
ΔV_{REF}	Reference Voltage Line Regulation	V_{IN} = 4V to 40V	2.8			mV
G_M	Error Amp Transconductance	I_{COMP} = −30 μA to +30 μA V_{COMP} = 1.0V	0.750	**0.447**	**1.491**	mmho
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 0.5V to 1.6V R_{COMP} = 1.0 MΩ (Note 6)	165	99/**49**		V/V

LM2587-12

Symbol	Parameters	Conditions	Typical	Min	Max	Units
SYSTEM PARAMETERS Test Circuit of *Figure 3* (Note 4)						
V_{OUT}	Output Voltage	V_{IN} = 4V to 10V I_{LOAD} = 300 mA to 1.2A	12.0	11.52/**11.40**	12.48/**12.60**	V
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	V_{IN} = 4V to 10V I_{LOAD} = 300 mA	20		100/**200**	mV
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	V_{IN} = 10V I_{LOAD} = 300 mA to 1.2A	20		100/**200**	mV
η	Efficiency	V_{IN} = 10V, I_{LOAD} = 1A	90			%
UNIQUE DEVICE PARAMETERS (Note 5)						
V_{REF}	Output Reference Voltage	Measured at Feedback Pin V_{COMP} = 1.0V	12.0	11.79/**11.76**	12.21/**12.24**	V
ΔV_{REF}	Reference Voltage Line Regulation	V_{IN} = 4V to 40V	1.0			mV
G_M	Error Amp Transconductance	I_{COMP} = −30 μA to +30 μA V_{COMP} = 1.0V	0.328	**0.186**	**0.621**	mmho
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 0.5V to 1.6V R_{COMP} = 1.0 MΩ (Note 6)	70	41/**21**		V/V

LM2587-ADJ

Symbol	Parameters	Conditions	Typical	Min	Max	Units
SYSTEM PARAMETERS Test Circuit of *Figure 3* (Note 4)						
V_{OUT}	Output Voltage	V_{IN} = 4V to 10V I_{LOAD} = 300 mA to 1.2A	12.0	11.52/**11.40**	12.48/**12.60**	V
$\Delta V_{OUT}/\Delta V_{IN}$	Line Regulation	V_{IN} = 4V to 10V I_{LOAD} = 300 mA	20		100/**200**	mV
$\Delta V_{OUT}/\Delta I_{LOAD}$	Load Regulation	V_{IN} = 10V I_{LOAD} = 300 mA to 1.2A	20		100/**200**	mV
η	Efficiency	V_{IN} = 10V, I_{LOAD} = 1A	90			%

Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, V_{IN} = 5V. (Continued)

LM2587-ADJ (Continued)

Symbol	Parameters	Conditions	Typical	Min	Max	Units
UNIQUE DEVICE PARAMETERS (Note 5)						
V_{REF}	Output Reference Voltage	Measured at Feedback Pin V_{COMP} = 1.0V	1.230	1.208/**1.205**	1.252/**1.255**	V
ΔV_{REF}	Reference Voltage Line Regulation	V_{IN} = 4V to 40V	1.5			mV
G_M	Error Amp Transconductance	I_{COMP} = −30 µA to +30 µA V_{COMP} = 1.0V	3.200	**1.800**	**6.000**	mmho
A_{VOL}	Error Amp Voltage Gain	V_{COMP} = 0.5V to 1.6V R_{COMP} = 1.0 MΩ (Note 6)	670	400/**200**		V/V
I_B	Error Amp Input Bias Current	V_{COMP} = 1.0V	125		425/**600**	nA

COMMON DEVICE PARAMETERS for all versions (Note 5)

Symbol	Parameters	Conditions	Typical	Min	Max	Units
I_S	Input Supply Current	(Switch Off) (Note 8)	11		15.5/**16.5**	mA
		I_{SWITCH} = 3.0A	85	140	**165**	mA
V_{UV}	Input Supply Undervoltage Lockout	R_{LOAD} = 100Ω	3.30	**3.05**	**3.75**	V
f_O	Oscillator Frequency	Measured at Switch Pin R_{LOAD} = 100Ω V_{COMP} = 1.0V	100	85/**75**	115/**125**	kHz
f_{SC}	Short-Circuit Frequency	Measured at Switch Pin R_{LOAD} = 100Ω $V_{FEEDBACK}$ = 1.15V	25			kHz
V_{EAO}	Error Amplifier Output Swing	Upper Limit (Note 7)	2.8	2.6/**2.4**		V
		Lower Limit (Note 8)	0.25		0.40/**0.55**	V
I_{EAO}	Error Amp Output Current (Source or Sink)	(Note 9)	165	110/**70**	260/**320**	µA
I_{SS}	Soft Start Current	$V_{FEEDBACK}$ = 0.92V V_{COMP} = 1.0V	11.0	8.0/**7.0**	17.0/**19.0**	µA
D	Maximum Duty Cycle	R_{LOAD} = 100Ω (Note 7)	98	93/**90**		%
I_L	Switch Leakage Current	Switch Off V_{SWITCH} = 60V	15		300/**600**	µA
V_{SUS}	Switch Sustaining Voltage	dV/dT = 1.5V/ns		65		V
V_{SAT}	Switch Saturation Voltage	I_{SWITCH} = 5.0A	0.7		1.1/**1.4**	V
I_{CL}	NPN Switch Current Limit		6.5	**5.0**	**9.5**	A

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range.** Unless otherwise specified, $V_{IN} = 5V$. (Continued)

COMMON DEVICE PARAMETERS (Note 4) (Continued)

Symbol	Parameters	Conditions	Typical	Min	Max	Units
θ_{JA}	Thermal Resistance	T Package, Junction to Ambient (Note 10)	65			
θ_{JA}		T Package, Junction to Ambient (Note 11)	45			
θ_{JC}		T Package, Junction to Case	2			
θ_{JA}		S Package, Junction to Ambient (Note 12)	56			°C/W
θ_{JA}		S Package, Junction to Ambient (Note 13)	35			
θ_{JA}		S Package, Junction to Ambient (Note 14)	26			
θ_{JC}		S Package, Junction to Case	2			

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating ratings indicate conditions the device is intended to be functional, but device parameter specifications may not be guaranteed under these conditions. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Note that switch current and output current are not identical in a step-up regulator. Output current cannot be internally limited when the LM2587 is used as a step-up regulator. To prevent damage to the switch, the output current must be externally limited to 5A. However, output current is internally limited when the LM2587 is used as a flyback regulator (see the Application Hints section for more information).

Note 3: The junction temperature of the device (T_J) is a function of the ambient temperature (T_A), the junction-to-ambient thermal resistance (θ_{JA}), and the power dissipation of the device (P_D). A thermal shutdown will occur if the temperature exceeds the maximum junction temperature of the device: $P_D \times \theta_{JA} + T_{A(MAX)} \geq T_{J(MAX)}$. For a safe thermal design, check that the maximum power dissipated by the device is less than: $P_D \leq [T_{J(MAX)} - T_{A(MAX)}]/\theta_{JA}$. When calculating the maximum allowable power dissipation, derate the maximum junction temperature—this ensures a margin of safety in the thermal design.

Note 4: External components such as the diode, inductor, input and output capacitors can affect switching regulator performance. When the LM2587 is used as shown in *Figures 2* and *3*, system performance will be as specified by the system parameters.

Note 5: All room temperature limits are 100% production tested, and all limits at temperature extremes are guaranteed via correlation using standard Statistical Quality Control (SQC) methods.

Note 6: A 1.0 MΩ resistor is connected to the compensation pin (which is the error amplifier output) to ensure accuracy in measuring A_{VOL}.

Note 7: To measure this parameter, the feedback voltage is set to a low value, depending on the output version of the device, to force the error amplifier output high. Adj: $V_{FB} = 1.05V$; 3.3V: $V_{FB} = 2.81V$; 5.0V: $V_{FB} = 4.25V$; 12V: $V_{FB} = 10.20V$.

Note 8: To measure this parameter, the feedback voltage is set to a high value, depending on the output version of the device, to force the error amplifier output low. Adj: $V_{FB} = 1.41V$; 3.3V: $V_{FB} = 3.80V$; 5.0V: $V_{FB} = 5.75V$; 12V: $V_{FB} = 13.80V$.

Note 9: To measure the worst-case error amplifier output current, the LM2587 is tested with the feedback voltage set to its low value (specified in Note 7) and at its high value (specified in Note 8).

Note 10: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads in a socket, or on a PC board with minimum copper area.

Note 11: Junction to ambient thermal resistance (no external heat sink) for the 5 lead TO-220 package mounted vertically, with ½ inch leads soldered to a PC board containing approximately 4 square inches of (1oz.) copper area surrounding the leads.

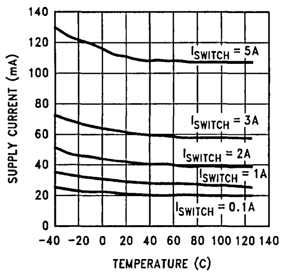
Note 12: Junction to ambient thermal resistance for the 5 lead TO-263 mounted horizontally against a PC board area of 0.136 square inches (the same size as the TO-263 package) of 1 oz. (0.0014 in. thick) copper.

Note 13: Junction to ambient thermal resistance for the 5 lead TO-263 mounted horizontally against a PC board area of 0.4896 square inches (3.6 times the area of the TO-263 package) of 1 oz. (0.0014 in. thick) copper.

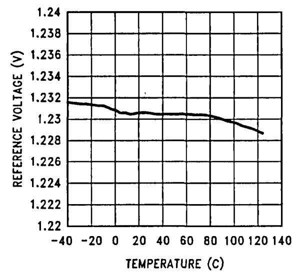
Note 14: Junction to ambient thermal resistance for the 5 lead TO-263 mounted horizontally against a PC board copper area of 1.0064 square inches (7.4 times the area of the TO-263 package) of 1 oz. (0.0014 in. thick) copper. Additional copper area will reduce thermal resistance further. See the thermal model in ***Switchers Made Simple®*** software.

Typical Performance Characteristics

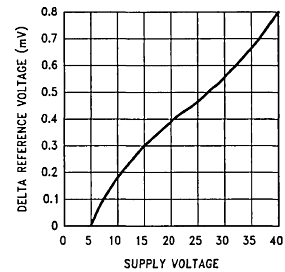
Supply Current vs Temperature



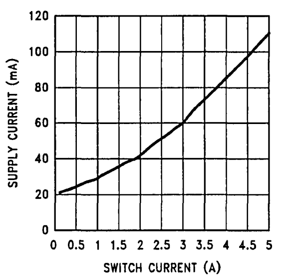
Reference Voltage vs Temperature



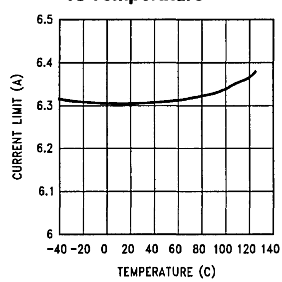
ΔReference Voltage vs Supply Voltage



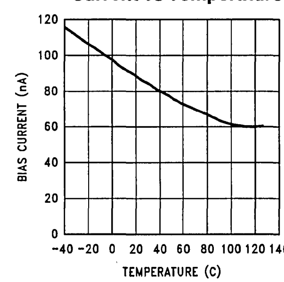
Supply Current vs Switch Current



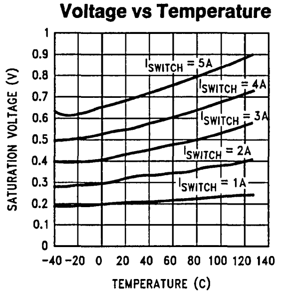
Current Limit vs Temperature



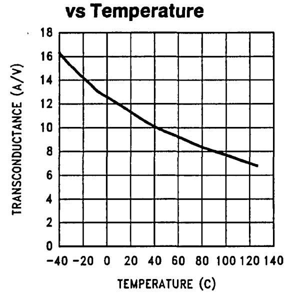
Feedback Pin Bias Current vs Temperature



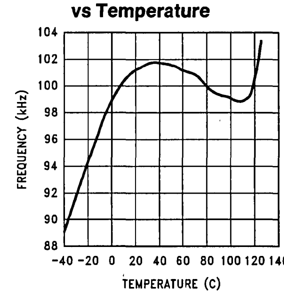
Switch Saturation Voltage vs Temperature



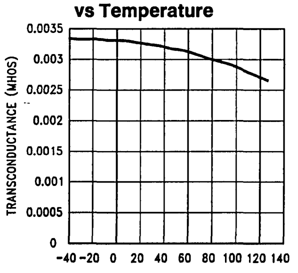
Switch Transconductance vs Temperature



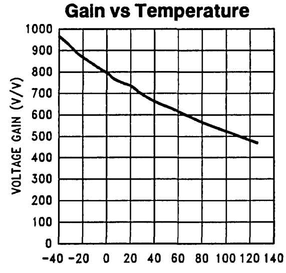
Oscillator Frequency vs Temperature



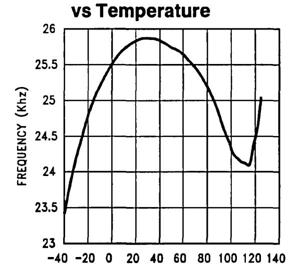
Error Amp Transconductance vs Temperature



Error Amp Voltage Gain vs Temperature



Short Circuit Frequency vs Temperature

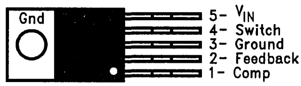


TL/H/12316–2

3

Connection Diagrams

Bent, Staggered Leads
5-Lead TO-220 (T)
Top View



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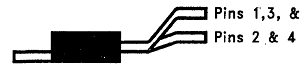
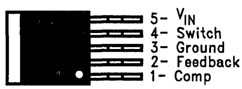
Bent, Staggered Leads
5-Lead TO-220 (T)
Side View



TL/H/12316–4

Order Number LM2587T-3.3, LM2587T-5.0,
LM2587T-12 or LM2587T-ADJ
See NS Package Number T05D

5-Lead TO-263 (S)
Top View



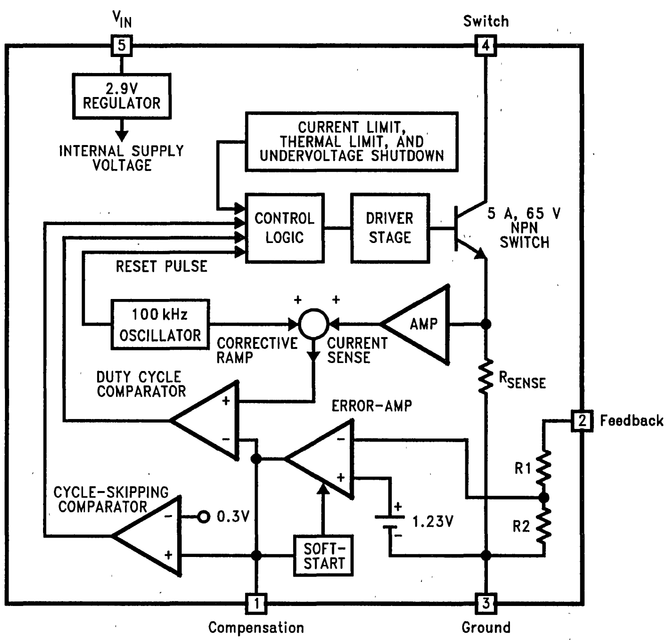
TL/H/12316–5

5-Lead TO-263 (S)
Side View

TL/H/12316–6

Order Number LM2587S-3.3, LM2587S-5.0,
LM2587S-12 or LM2587S-ADJ
See NS Package Number TS5B

Block Diagram

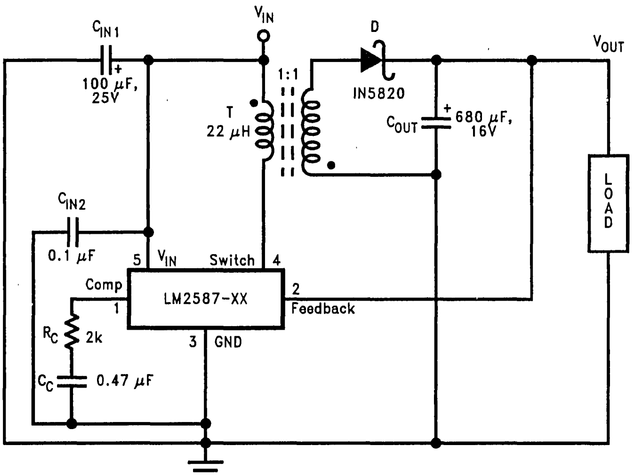


For Fixed Versions
3.3V, R1 = 3.4k, R2 = 2k
5V, R1 = 6.15k, R2 = 2k
12V, R1 = 8.73k, R2 = 1k
For Adj. Version
R1 = Short (0Ω), R2 = Open

TL/H/12316–7

FIGURE 1

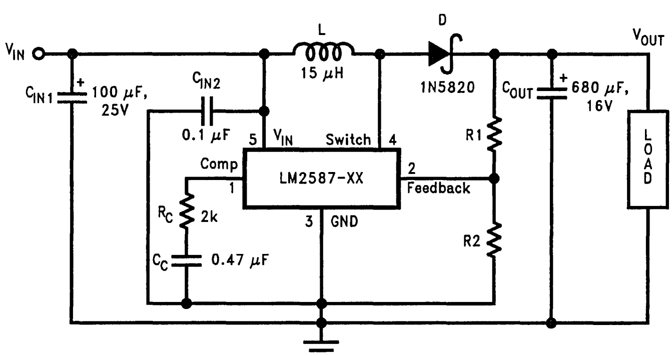
Test Circuits



C_{IN1}—100 µF, 25V Aluminum Electrolytic
C_{IN2}—0.1 µF Ceramic
T—22 µH, 1:1 Schott #67141450
D—1N5820
C_{OUT}—680 µF, 16V Aluminum Electrolytic
C_C—0.47 µF Ceramic
R_C—2k

TL/H/12316–8

FIGURE 2. LM2587-3.3 and LM2587-5.0



C_{IN1}—100 µF, 25V Aluminum Electrolytic
C_{IN2}—0.1 µF Ceramic
L—15 µH, Renco #RL-5472-5
D—1N5820
C_{OUT}—680 µF, 16V Aluminum Electrolytic
C_C—0.47 µF Ceramic
R_C—2k
For 12V Devices: R_1 = Short (0Ω) and R_2 = Open
For ADJ Devices: R_1 = 48.75k, ±0.1% and R2 = 5.62k, ±1%

TL/H/12316–9

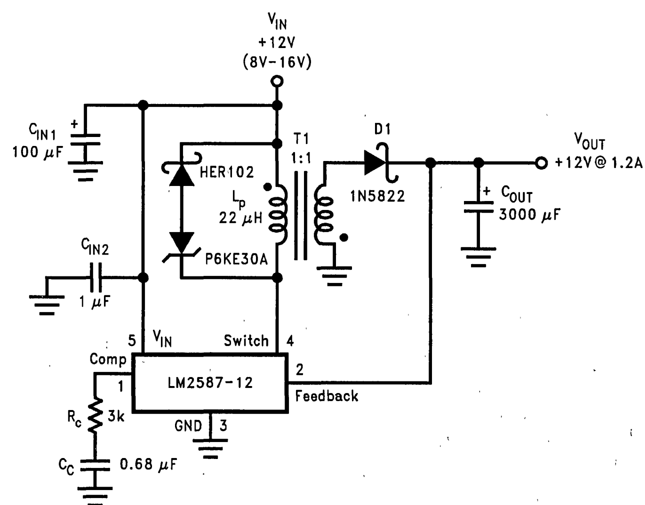
FIGURE 3. LM2587-12 and LM2587-ADJ

Flyback Regulator Operation

The LM2587 is ideally suited for use in the flyback regulator topology. The flyback regulator can produce a single output voltage, such as the one shown in *Figure 4*, or multiple output voltages. In *Figure 4*, the flyback regulator generates an output voltage that is inside the range of the input voltage. This feature is unique to flyback regulators and cannot be duplicated with buck or boost regulators.

The operation of a flyback regulator is as follows (refer to *Figure 4*): when the switch is on, current flows through the primary winding of the transformer, T1, storing energy in the magnetic field of the transformer. Note that the primary and secondary windings are out of phase, so no current flows through the secondary when current flows through the primary. When the switch turns off, the magnetic field collapses, reversing the voltage polarity of the primary and secondary windings. Now rectifier D1 is forward biased and current flows through it, releasing the energy stored in the transformer. This produces voltage at the output.

The output voltage is controlled by modulating the peak switch current. This is done by feeding back a portion of the output voltage to the error amp, which amplifies the difference between the feedback voltage and a 1.230V reference. The error amp output voltage is compared to a ramp voltage proportional to the switch current (i.e., inductor current during the switch on time). The comparator terminates the switch on time when the two voltages are equal, thereby controlling the peak switch current to maintain a constant output voltage.



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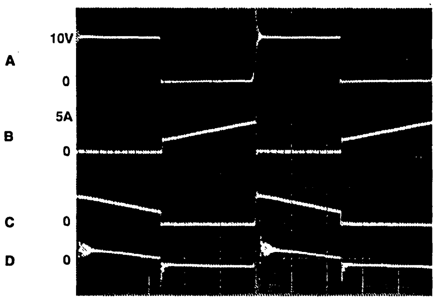
As shown in *Figure 4*, the LM2587 can be used as a flyback regulator by using a minimum number of external components. The switching waveforms of this regulator are shown in *Figure 5*. Typical Performance Characteristics observed during the operation of this circuit are shown in *Figure 6*.

FIGURE 4. 12V Flyback Regulator Design Example

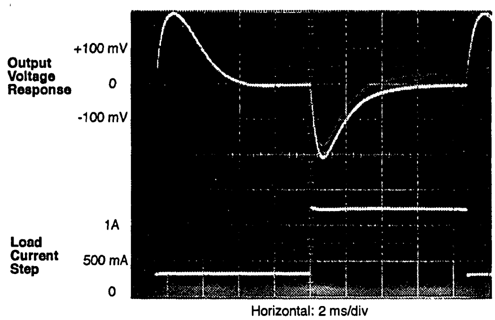
Typical Performance Characteristics



A: Switch Voltage, 10 V/div
B: Switch Current, 5 A/div
C: Output Rectifier Current, 5 A/div
D: Output Ripple Voltage, 100 mV/div AC-Coupled
Horizontal: 2 μs/div

TL/H/12316-11

FIGURE 5. Switching Waveforms



TL/H/12316-12

FIGURE 6. V_{OUT} Load Current Step Response

Typical Flyback Regulator Applications

Figures 7 through *12* show six typical flyback applications, varying from single output to triple output. Each drawing contains the part number(s) and manufacturer(s) for every component except the transformer. For the transformer part numbers and manufacturers names, see the table in *Figure 13*. For applications with different output voltages—requiring the LM2587-ADJ—or different output configurations that do not match the standard configurations, refer to the SIMPLE SWITCHER® Designer's Guide (AN-978) or ***Switchers Made Simple***® (Version 4.0) software.

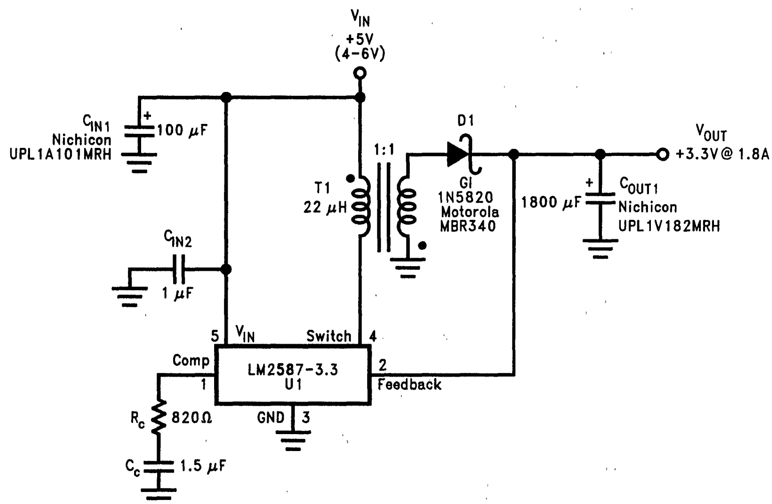


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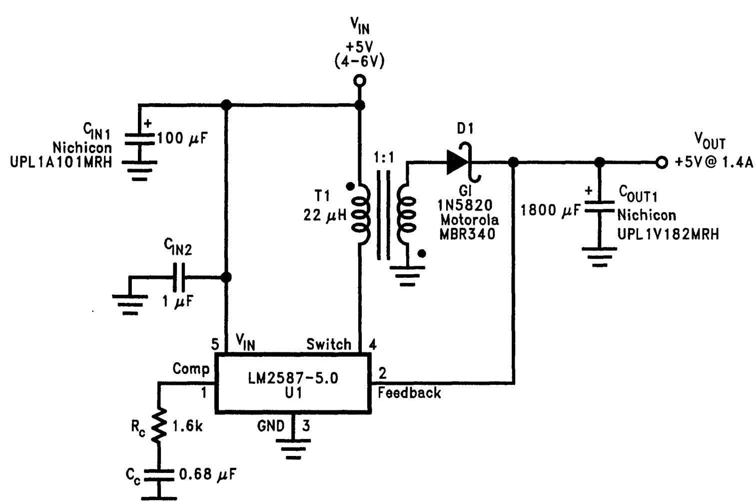
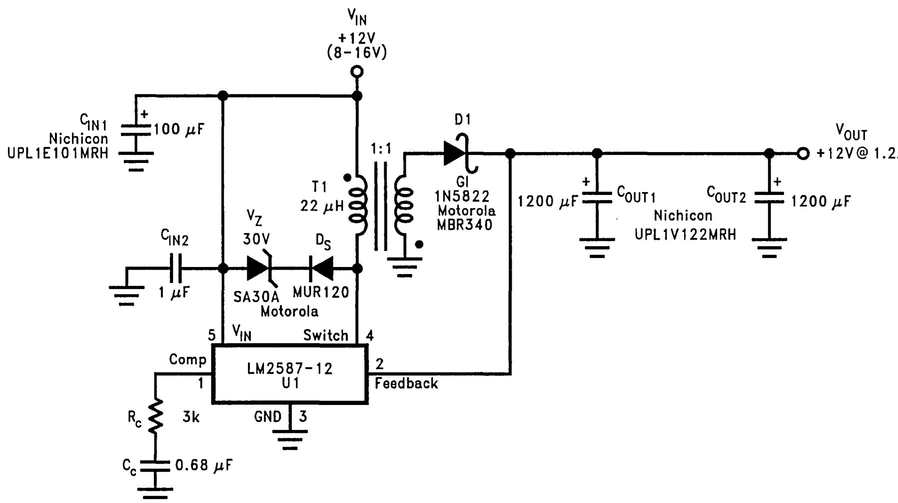
FIGURE 7. Single-Output Flyback Regulator



TL/H/12316-14

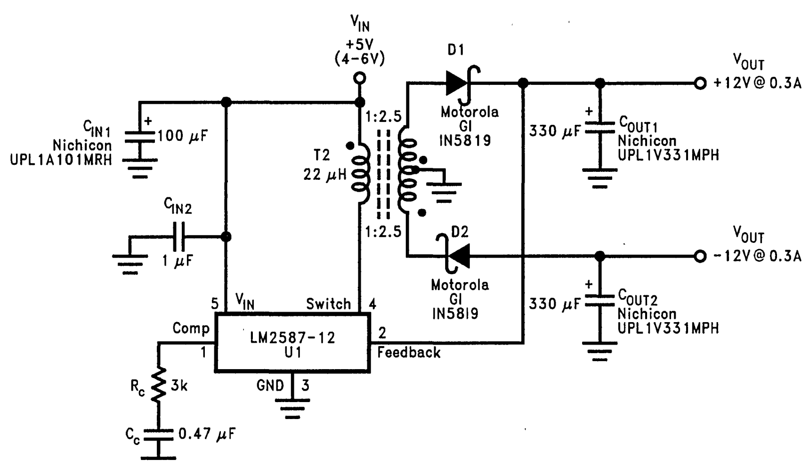
FIGURE 8. Single-Output Flyback Regulator

Typical Flyback Regulator Applications (Continued)



TL/H/12316–15

FIGURE 9. Single-Output Flyback Regulator

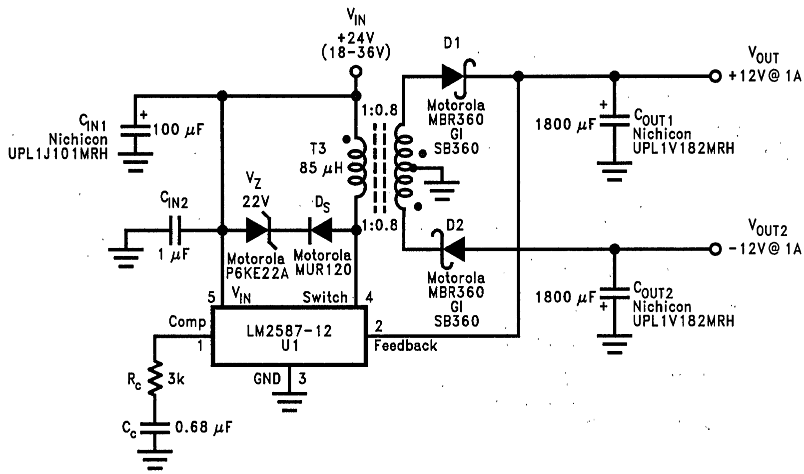


TL/H/12316–16

FIGURE 10. Dual-Output Flyback Regulator

3

Typical Flyback Regulator Applications (Continued)



TL/H/12316–17

FIGURE 11. Dual-Output Flyback Regulator

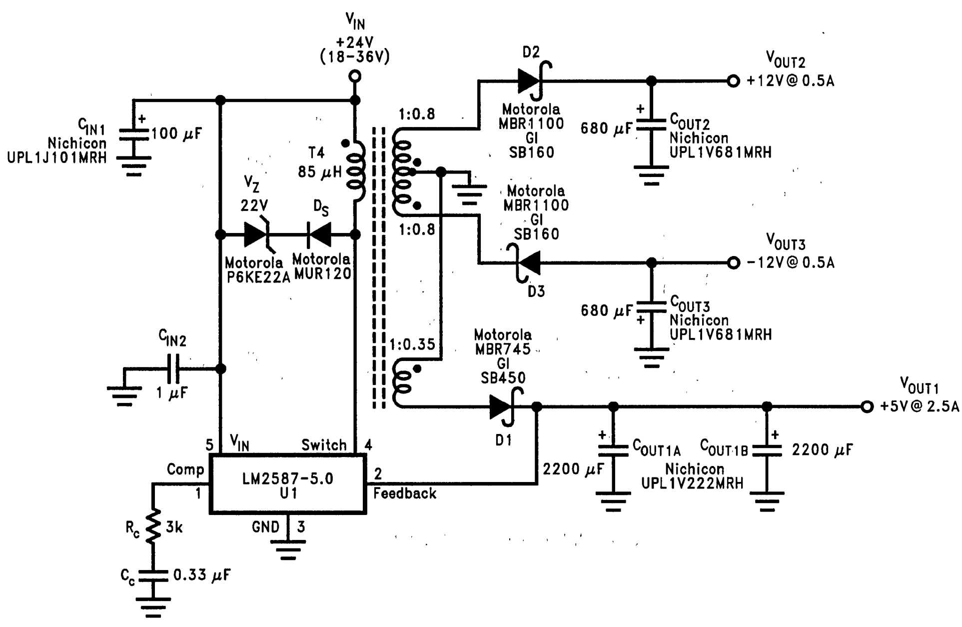


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FIGURE 12. Triple-Output Flyback Regulator

Typical Flyback Regulator Applications (Continued)

Transformer Selection (T)

Figure 13 lists the standard transformers available for flyback regulator applications. Included in the table are the turns ratio(s) for each transformer, as well as the output voltages, input voltage ranges, and the maximum load currents for each circuit.

Applications	*Figure 7*	*Figure 8*	*Figure 9*	*Figure 10*	*Figure 11*	*Figure 12*
Transformers	**T1**	**T1**	**T1**	**T2**	**T3**	**T4**
V_{IN}	4V–6V	4V–6V	8V–16V	4V–6V	18V–36V	18V–36V
V_{OUT1}	3.3V	5V	12V	12V	12V	5V
I_{OUT1} (Max)	1.8A	1.4A	1.2A	0.3A	1A	2.5A
N_1	1	1	1	2.5	0.8	0.35
V_{OUT2}				−12V	−12V	12V
I_{OUT2} (Max)				0.3A	1A	0.5A
N_2				2.5	0.8	0.8
V_{OUT3}						−12V
I_{OUT3} (Max)						0.5A
N_3						0.8

FIGURE 13. Transformer Selection Table

Transformer Type	**Manufacturers' Part Numbers**				
	Coilcraft[1]	**Coilcraft[1] Surface Mount**	**Pulse[2] Surface Mount**	**Renco[3]**	**Schott[4]**
T1	Q4434-B	Q4435-B	PE-68411	RL-5530	67141450
T2	Q4337-B	Q4436-B	PE-68412	RL-5531	67140860
T3	Q4343-B	—	PE-68421	RL-5534	67140920
T4	Q4344-B	—	PE-68422	RL-5535	67140930

Note 1: Coilcraft Inc., 1102 Silver Lake Road, Cary, IL 60013 — Phone: (800) 322-2645, Fax: (708) 639-1469

Note 2: Pulse Engineering Inc., 12220 World Trade Drive, San Diego, CA 92128 — Phone: (619) 674-8100, Fax: (619) 674-8262

Note 3: Renco Electronics Inc., 60 Jeffryn Blvd. East, Deer Park, NY 11729 — Phone: (800) 645-5828, Fax: (516) 586-5562

Note 4: Schott Corp., 1000 Parkers Lane Road, Wayzata, MN 55391 — Phone: (612) 475-1173, Fax: (612) 475-1786

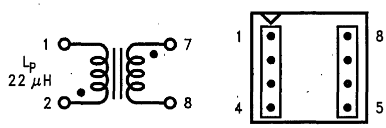
FIGURE 14. Transformer Manufacturer Guide

Typical Flyback Regulator Applications (Continued)

Transformer Footprints

Figures 15 through *32* show the footprints of each transformer, listed in *Figure 14*.

T1

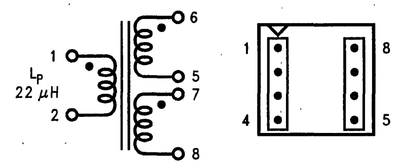


TL/H/12316–30

Top View

FIGURE 15. Coilcraft Q4434-B

T2

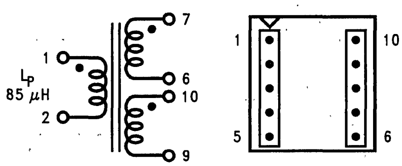


TL/H/12316–31

Top View

FIGURE 16. Coilcraft Q4337-B

T3

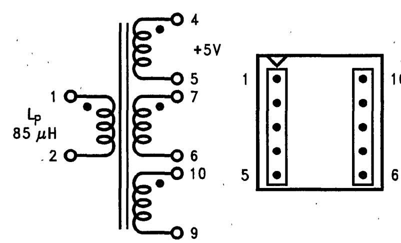


TL/H/12316–32

Top View

FIGURE 17. Coilcraft Q4343-B

T4

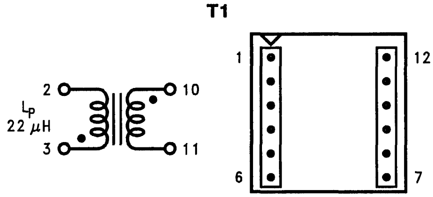


TL/H/12316–33

Top View

FIGURE 18. Coilcraft Q4344-B

T1

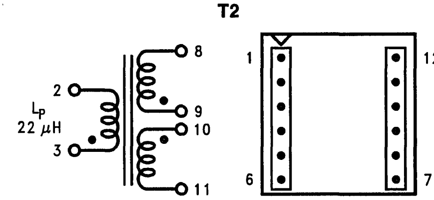


TL/H/12316–34

Top View

FIGURE 19. Coilcraft Q4435-B (Surface Mount)

T2



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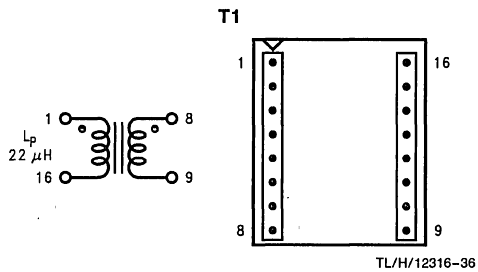
Top View

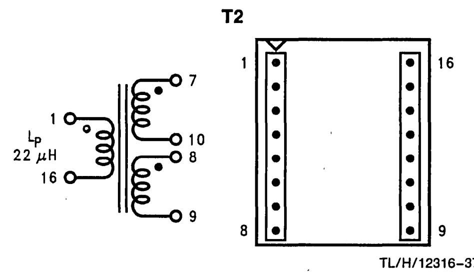
FIGURE 20. Coilcraft Q4436-B (Surface Mount)

Typical Flyback Regulator Applications (Continued)



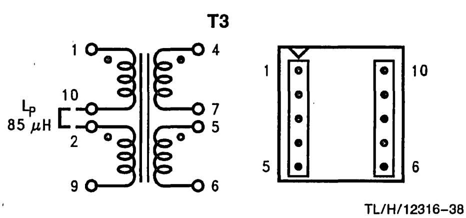
Top View

FIGURE 21. Pulse PE-68411 (Surface Mount)



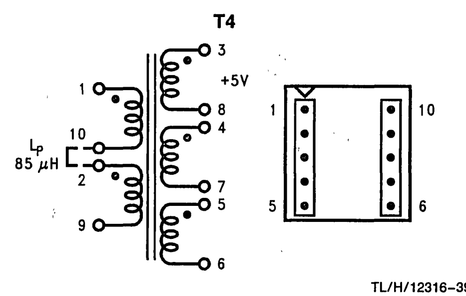
Top View

FIGURE 22. Pulse PE-68412 (Surface Mount)



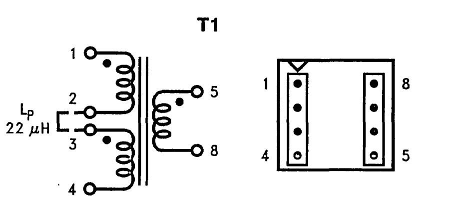
Top View

FIGURE 23. Pulse PE-68421 (Surface Mount)



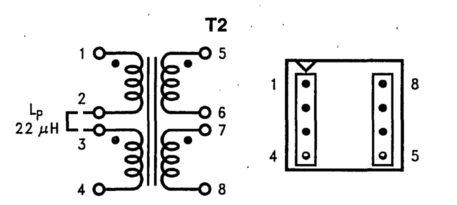
Top View

FIGURE 24. Pulse PE-68422 (Surface Mount)



Top View

FIGURE 25. Renco RL-5530



Top View

FIGURE 26. Renco RL-5531

Typical Flyback Regulator Applications (Continued)

T3

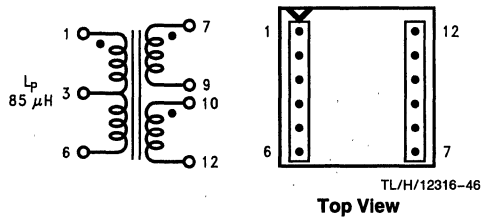


FIGURE 27. Renco RL-5534

T4

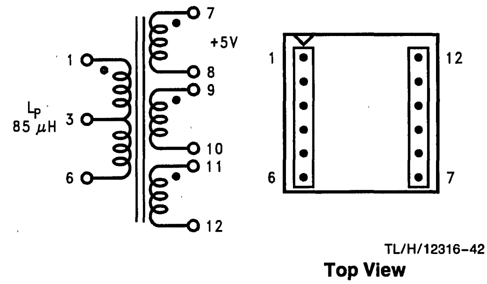


FIGURE 28. Renco RL-5535

T1

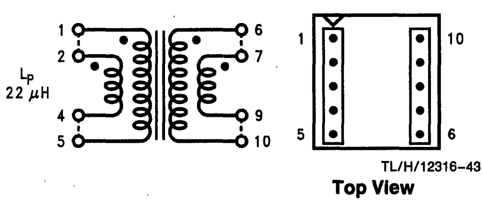


FIGURE 29. Schott 67141450

T2

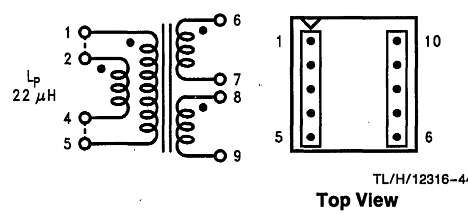


FIGURE 30. Schott 67140860

T3

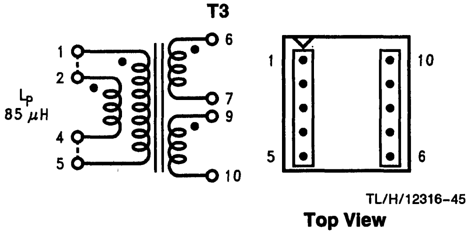


FIGURE 31. Schott 67140920

T4

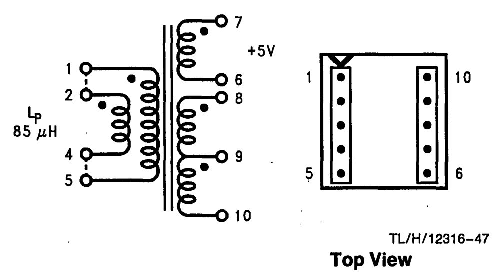
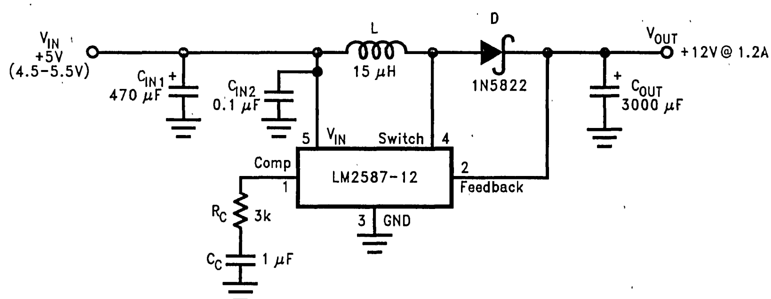


FIGURE 32. Schott 67140930

Step-Up (Boost) Regulator Operation

Figure 33 shows the LM2587 used as a step-up (boost) regulator. This is a switching regulator that produces an output voltage greater than the input supply voltage.

A brief explanation of how the LM2587 Boost Regulator works is as follows (refer to *Figure 33*). When the NPN switch turns on, the inductor current ramps up at the rate of V_{IN}/L, storing energy in the inductor. When the switch turns off, the lower end of the inductor flies above V_{IN}, discharging its current through diode (D) into the output capacitor (C_{OUT}) at a rate of $(V_{OUT} - V_{IN})/L$. Thus, energy stored in the inductor during the switch on time is transferred to the output during the switch off time. The output voltage is controlled by adjusting the peak switch current, as described in the flyback regulator section.



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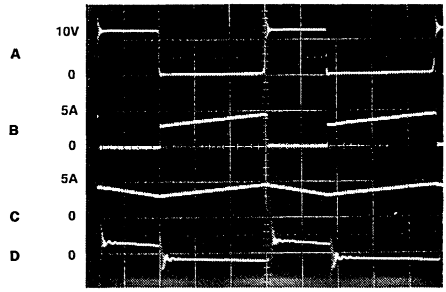
By adding a small number of external components (as shown in *Figure 33*), the LM2587 can be used to produce a regulated output voltage that is greater than the applied input voltage. The switching waveforms observed during the operation of this circuit are shown in *Figure 34*. Typical performance of this regulator is shown in *Figure 35*.

FIGURE 33. 12V Boost Regulator

Typical Performance Characteristics



A: Switch Voltage, 10 V/div
B: Switch Current, 5 A/div
C: Inductor Current, 5 A/div
D: Output Ripple Voltage, 100 mV/div, AC-Coupled
Horizontal: 2 μs/div

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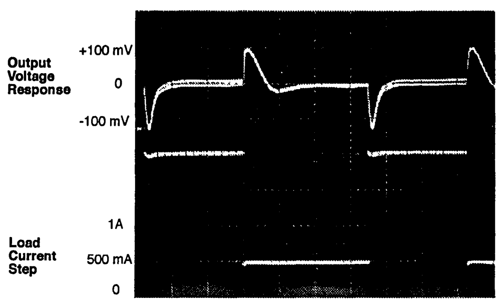
FIGURE 34. Switching Waveforms



Horizontal: 2 ms/div

TL/H/12316–21

FIGURE 35. V_{OUT} Response to Load Current Step

Typical Boost Regulator Applications

Figures 36 and *38* through *40* show four typical boost applications)—one fixed and three using the adjustable version of the LM2587. Each drawing contains the part number(s) and manufacturer(s) for every component. For the fixed 12V output application, the part numbers and manufacturers' names for the inductor are listed in a table in *Figure 40.* For applications with different output voltages, refer to the SIMPLE SWITCHER® Designer's Guide (AN-978) or ***Switchers Made Simple***® (Version 4.0) software.

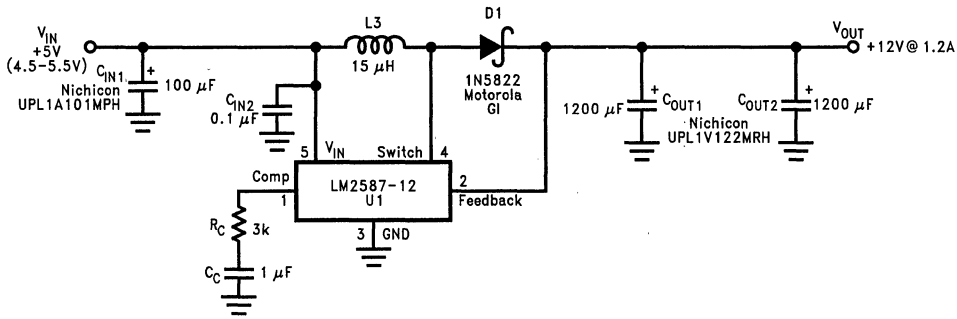


FIGURE 36. +5V to +12V Boost Regulator

Figure 37 contains a table of standard inductors, by part number and corresponding manufacturer, for the fixed output regulator of *Figure 36.*

Coilcraft[1]	Pulse[2]	Renco[3]	Schott[4]
R4793-A	PE-53900	RL-5472-5	67146520

Note 1: Coilcraft Inc., Phone: (800) 322-2645
1102 Silver Lake Road, Cary, IL 60013 Fax: (708) 639-1469

Note 2: Pulse Engineering Inc., Phone: (619) 674-8100
12220 World Trade Drive, San Diego, CA 92128 Fax: (619) 674-8262

Note 3: Renco Electronics Inc., Phone: (800) 645-5828
60 Jeffryn Blvd. East, Deer Park, NY 11729 Fax: (516) 586-5562

Note 4: Schott Corp., Phone: (612) 475-1173
1000 Parkers Lane Road, Wayzata, MN 55391 Fax: (612) 475-1786

FIGURE 37. Inductor Selection Table

Typical Boost Regulator Applications (Continued)

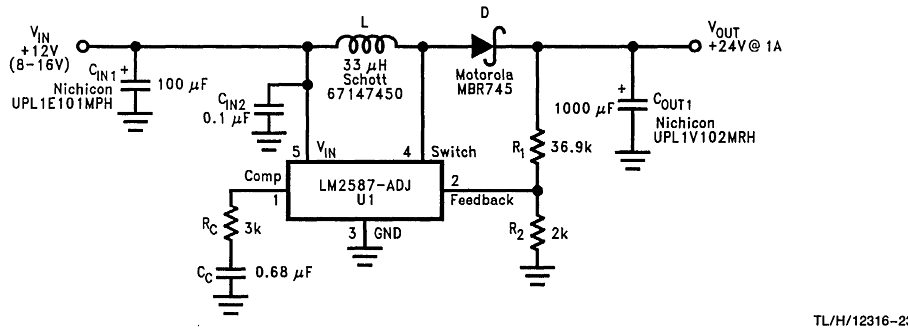


FIGURE 38. +12V to +24V Boost Regulator

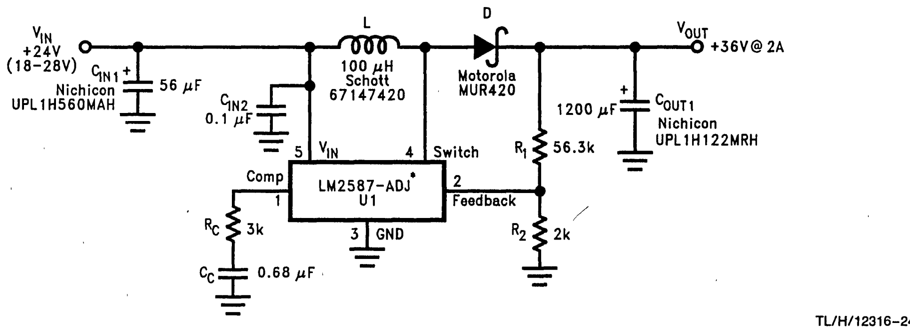


FIGURE 39. +24V to +36V Boost Regulator

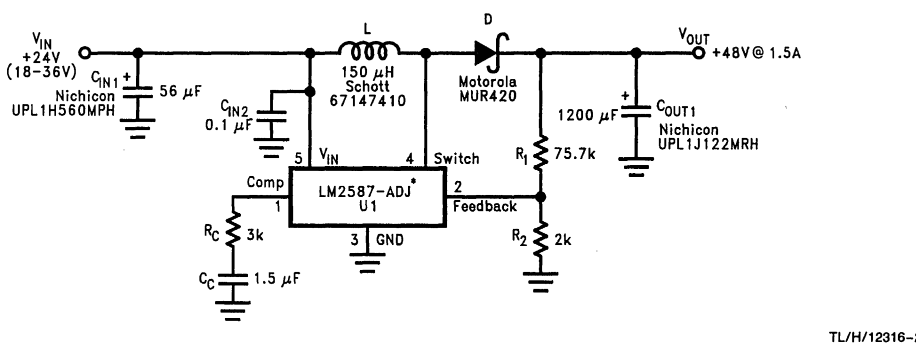


FIGURE 40. +24V to +48V Boost Regulator

*The LM2587 will require a heat sink in these applications. The size of the heat sink will depend on the maximum ambient temperature. To calculate the thermal resistance of the IC and the size of the heat sink needed, see the "Heat Sink/Thermal Considerations" section in the Application Hints.

Application Hints

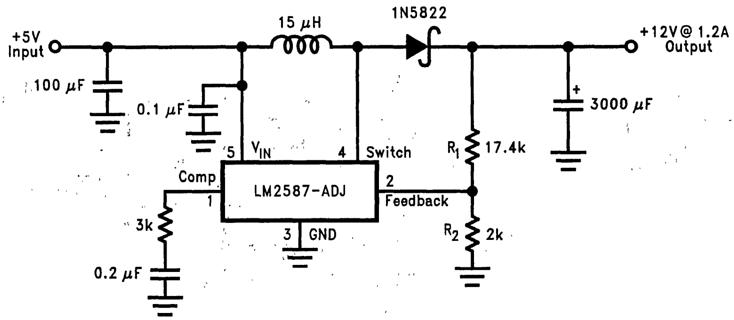


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FIGURE 41. Boost Regulator

PROGRAMMING OUTPUT VOLTAGE (SELECTING R_1 AND R_2)

Referring to the adjustable regulator in *Figure 41*, the output voltage is programmed by the resistors R_1 and R_2 by the following formula:

$V_{OUT} = V_{REF}(1 + R_1/R_2)$ where $V_{REF} = 1.23V$

Resistors R_1 and R_2 divide the output voltage down so that it can be compared with the 1.23V internal reference. With R_2 between 1k and 5k, R_1 is:

$R_1 = R_2(V_{OUT}/V_{REF} - 1)$ where $V_{REF} = 1.23V$

For best temperature coefficient and stability with time, use 1% metal film resistors.

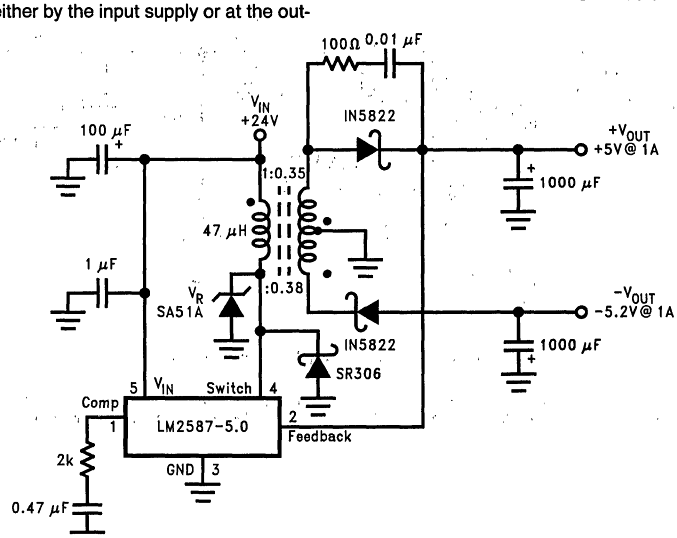
SHORT CIRCUIT CONDITION

Due to the inherent nature of boost regulators, when the output is shorted (see *Figure 41*), current flows directly from the input, through the inductor and the diode, to the output, bypassing the switch. The current limit of the switch *does not* limit the output current for the entire circuit. To protect the load and prevent damage to the switch, the current must be externally limited, either by the input supply or at the output with an external current limit circuit. The external limit should be set to the maximum switch current of the device, which is 5A.

In a flyback regulator application (*Figure 42*), using the standard transformers, the LM2587 will survive a short circuit to the main output. When the output voltage drops to 80% of its nominal value, the frequency will drop to 25 kHz. With a lower frequency, off times are larger. With the longer off times, the transformer can release all of its stored energy before the switch turns back on. Hence, the switch turns on initially with zero current at its collector. In this condition, the switch current limit will limit the peak current, saving the device.

FLYBACK REGULATOR INPUT CAPACITORS

A flyback regulator draws discontinuous pulses of current from the input supply. Therefore, there are two input capacitors needed in a flyback regulator; one for energy storage and one for filtering (see *Figure 42*). Both are required due to the inherent operation of a flyback regulator. To keep a stable or constant voltage supply to the LM2587, a stor-



TL/H/12316-27

FIGURE 42. Flyback Regulator

Application Hints (Continued)

age capacitor (≥100 μF) is required. If the input source is a recitified DC supply and/or the application has a wide temperature range, the required rms current rating of the capacitor might be very large. This means a larger value of capacitance or a higher voltage rating will be needed of the input capacitor. The storage capacitor will also attenuate noise which may interfere with other circuits connected to the same input supply voltage.

In addition, a small bypass capacitor is required due to the noise generated by the input current pulses. To eliminate the noise, insert a 1.0 μF ceramic capacitor between V_{IN} and ground as close as possible to the device.

SWITCH VOLTAGE LIMITS

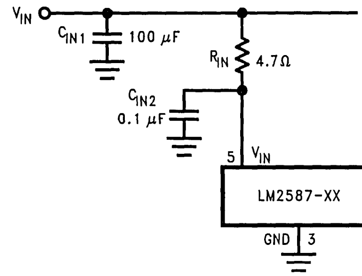
In a flyback regulator, the maximum steady-state voltage appearing at the switch, when it is off, is set by the transformer turns ratio, N, the output voltage, V_{OUT}, and the maximum input voltage, V_{IN} (Max):

$$V_{SW(OFF)} = V_{IN}\,(\text{Max}) + (V_{OUT} + V_F)/N$$

where V_F is the forward biased voltage of the output diode, and is 0.5V for Schottky diodes and 0.8V for ultra-fast recovery diodes (typically). In certain circuits, there exists a voltage spike, V_{LL}, superimposed on top of the steady-state voltage (see *Figure 5*, waveform A). Usually, this voltage spike is caused by the transformer leakage inductance and/or the output rectifier recovery time. To "clamp" the voltage at the switch from exceeding its maximum value, a transient suppressor in series with a diode is inserted across the transformer primary (as shown in the circuit on the front page and other flyback regulator circuits throughout the datasheet). The schematic in *Figure 42* shows another method of clamping the switch voltage. A single voltage transient suppressor (the SA51A) is inserted at the switch pin. This method clamps the total voltage across the switch, not just the voltage across the primary.

If poor circuit layout techniques are used (see the "Circuit Layout Guideline" section), negative voltage transients may appear on the Switch pin (pin 4). Applying a negative voltage (with respect to the IC's ground) to any monolithic IC pin causes erratic and unpredictable operation of that IC. This holds true for the LM2587 IC as well. When used in a flyback regulator, the voltage at the Switch pin (pin 4) can go negative when the switch turns on. The "ringing" voltage at the switch pin is caused by the output diode capacitance and the transformer leakage inductance forming a resonant circuit at the secondary(ies). The resonant circuit generates the "ringing" voltage, which gets reflected back through the transformer to the switch pin. There are two common methods to avoid this problem. One is to add an RC snubber around the output rectifier(s), as in *Figure 42*. The values of the resistor and the capacitor must be chosen so that the voltage at the Switch pin does not drop below −0.4V. The resistor may range in value between 10Ω and 1 kΩ, and the capacitor will vary from 0.001 μF to 0.1 μF. Adding a snubber will (slightly) reduce the efficiency of the overall circuit.

The other method to reduce or eliminate the "ringing" is to insert a Schottky diode clamp between pins 4 and 3 (ground), also shown in *Figure 42*. This prevents the voltage at pin 4 from dropping below −0.4V. The reverse voltage rating of the diode must be greater than the switch off voltage.



TL/H/12316–28

FIGURE 43. Input Line Filter

OUTPUT VOLTAGE LIMITATIONS

The maximum output voltage of a boost regulator is the maximum switch voltage minus a diode drop. In a flyback regulator, the maximum output voltage is determined by the turns ratio, N, and the duty cycle, D, by the equation:

$$V_{OUT} \approx N \times V_{IN} \times D/(1 - D)$$

The duty cycle of a flyback regulator is determined by the following equation:

$$D = \frac{V_{OUT} + V_F}{N(V_{IN} - V_{SAT}) + V_{OUT} + V_F} \approx \frac{V_{OUT}}{N(V_{IN}) + V_{OUT}}$$

Theoretically, the maximum output voltage can be as large as desired—just keep increasing the turns ratio of the transformer. However, there exists some physical limitations that prevent the turns ratio, and thus the output voltage, from increasing to infinity. The physical limitations are capacitances and inductances in the LM2587 switch, the output diode(s), and the transformer—such as reverse recovery time of the output diode (mentioned above).

NOISY INPUT LINE CONDITION)

A small, low-pass RC filter should be used at the input pin of the LM2587 if the input voltage has an unusual large amount of transient noise, such as with an input switch that bounces. The circuit in *Figure 43* demonstrates the layout of the filter, with the capacitor placed from the input pin to ground and the resistor placed between the input supply and the input pin. Note that the values of R_{IN} and C_{IN} shown in the schematic are good enough for most applications, but some readjusting might be required for a particular application. If efficiency is a major concern, replace the resistor with a small inductor (say 10 μH and rated at 100 mA).

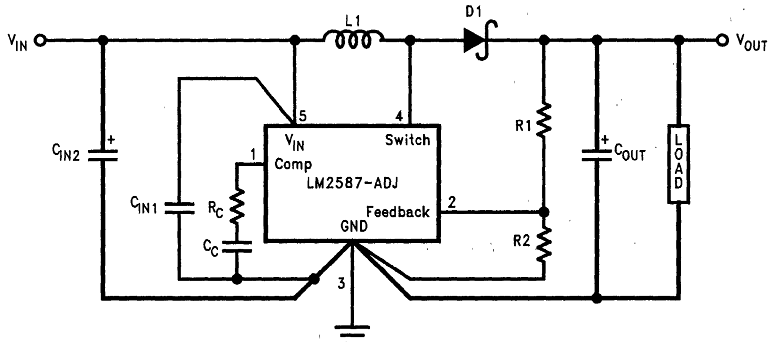
STABILITY

All current-mode controlled regulators can suffer from an instability, known as subharmonic oscillation, if they operate with a duty cycle above 50%. To eliminate subharmonic oscillations, a minimum value of inductance is required to ensure stability for all boost and flyback regulators. The minimum inductance is given by:

$$L(\text{Min}) = \frac{2.92\,[(V_{IN}(\text{Min}) - V_{SAT}) \times (2D(\text{Max}) - 1)]}{1 - D(\text{Max})}\ (\mu\text{H})$$

where V_{SAT} is the switch saturation voltage and can be found in the Characteristic Curves.

Application Hints (Continued)



TL/H/12316-29

FIGURE 44. Circuit Board Layout

CIRCUIT LAYOUT GUIDELINES

As in any switching regulator, layout is very important. Rapidly switching currents associated with wiring inductance generate voltage transients which can cause problems. For minimal inductance and ground loops, keep the length of the leads and traces as short as possible. Use single point grounding or ground plane construction for best results. Separate the signal grounds from the power grounds (as indicated in *Figure 44*). When using the Adjustable version, physically locate the programming resistors as near the regulator IC as possible, to keep the sensitive feedback wiring short. For more information on laying out a circuit board, see the SIMPLE SWITCHER® Designer's Guide (AN-978).

HEAT SINK/THERMAL CONSIDERATIONS

In many cases, no heat sink is required to keep the LM2587 junction temperature within the allowed operating range. For each application, to determine whether or not a heat sink will be required, the following must be identified:

1) Maximum ambient temperature (in the application).

2) Maximum regulator power dissipation (in the application).

3) Maximum allowed junction temperature (125°C for the LM2587). For a safe, conservative design, a temperature approximately 15°C cooler than the maximum junction temperature should be selected (110°C).

4) LM2587 package thermal resistances θ_{JA} and θ_{JC} (given in the Electrical Characteristics).

Total power dissipated (P_D) by the LM2587 can be estimated as follows:

Boost:

$$P_D = 0.15\Omega \times \left(\frac{I_{LOAD}}{1-D}\right)^2 \times D + \frac{I_{LOAD}}{50\times(1-D)} \times D \times V_{IN}$$

Flyback:

$$P_D = 0.15\Omega \times \left(\frac{N \times \Sigma I_{LOAD}}{1-D}\right)^2 \times D + \frac{N\times\Sigma I_{LOAD}}{50\times(1-D)} \times D \times V_{IN}$$

V_{IN} is the minimum input voltage, V_{OUT} is the output voltage, N is the transformer turns ratio, D is the duty cycle, and I_{LOAD} is the maximum load current (and ΣI_{LOAD} is the sum of the maximum load currents for multiple-output flyback regulators). The duty cycle is given by:

Boost:

$$D = \frac{V_{OUT} + V_F - V_{IN}}{V_{OUT} + V_F - V_{SAT}} \approx \frac{V_{OUT} - V_{IN}}{V_{OUT}}$$

Flyback:

$$D = \frac{V_{OUT} + V_F}{N(V_{IN} - V_{SAT}) + V_{OUT} + V_F} \approx \frac{V_{OUT}}{N(V_{IN}) + V_{OUT}}$$

where V_F is the forward biased voltage of the diode and is typically 0.5V for Schottky diodes and 0.8V for fast recovery diodes. V_{SAT} is the switch saturation voltage and can be found in the Characteristic Curves.

When no heat sink is used, the junction temperature rise is:

$$\Delta T_J = P_D \times \theta_{JA}.$$

Adding the junction temperature rise to the maximum ambient temperature gives the actual operating junction temperature:

$$T_J = \Delta T_J + T_A.$$

If the operating junction temperature exceeds the maximum junction temperatue in item 3 above, then a heat sink is required. When using a heat sink, the junction temperature rise can be determined by the following:

$$\Delta T_J = P_D \times (\theta_{JC} + \theta_{Interface} + \theta_{Heat\ Sink})$$

Again, the operating junction temperature will be:

$$T_J = \Delta T_J + T_A$$

Application Hints (Continued)

As before, if the maximum junction temperature is exceeded, a larger heat sink is required (one that has a lower thermal resistance).

Included in the ***Switchers Made Simple®*** *(Version 4.0)* design software is a more precise (non-linear) thermal model that can be used to determine junction temperature with different input-output parameters or different component values. It can also calculate the heat sink thermal resistance required to maintain the regulator junction temperature below the maximum operating temperature.

To further simplify the flyback regulator design procedure, National Semiconductor is making available computer design software and an application note to be used with the LM2587 SIMPLE SWITCHER® line of switching regulators. ***Switchers Made Simple®*** *(Version 4.0) software is available on a (3½") diskette for IBM compatable computers from a National Semiconductor sales office in your area or the National Semiconductor Customer Response Center (1-800-272-9959). The SIMPLE SWITCHER® Designer's Guide (AN-978) is also available from the Customer Response Center.*

European Magnetic Vendor Contacts

Please contact the following addresses for details of local distributors or representatives:

Coilcraft

21 Napier Place
Wardpark North
Cumbernauld, Scotland G68 0LL
Phone: +44 1236 730 595
Fax: +44 1236 730 627

Pulse Engineering

Dunmore Road
Tuam
Co. Galway, Ireland
Phone: +353 93 24 107
Fax: +353 93 24 459

National Semiconductor

LM3001 Primary-Side PWM Driver

General Description

The LM3001 is a primary-side PWM driver that provides all the system start-up, switch control, and protection functions needed on the primary side of an isolated offline converter. It is primarily designed for pulse communication between the primary and secondary controllers.

The LM3001 combined with the LM3101 secondary-side controller forms an offline converter chip set which allows electrical isolation between the high-power primary-side switch and the precision secondary-side control. Secondary-to-primary communication is achieved using pulse communication, via a small pulse transformer.

The primary-side driver includes a 2.5A totem-pole output switch with rise and fall times of less than 20 ns. This allows the LM3001 to operate at frequencies from below 50 kHz to beyond 1 MHz. The maximum duty cycle is programmable for each application. There are two levels of current limit within the LM3001, both of which are ground-referenced. One is a cycle-by-cycle current limit which activates at 0.38V. The other is a secondary current limit that activates at 0.6V. This current limit shuts down the LM3001 for a programmable deadtime, which is set with an external capacitor. Although the LM3001 is optimized for pulse feedback communication, it can also operate with conventional opto-coupler feedback.

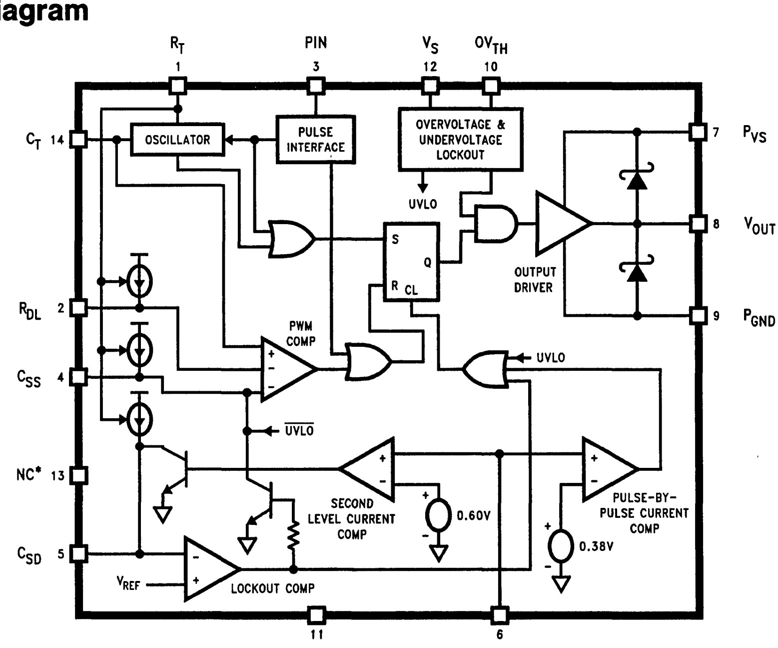
Features

- 2.5A peak high speed output driver
- Low start-up current (typ. 190 μA)
- Dual-level current limit with programmable lockout time
- Duty cycle clamp
- Operation beyond 1 MHz
- Soft-Start, undervoltage and overvoltage lockout with hysteresis
- Low output saturation voltage: Maximum of 1.5V at 400 mA sink current
- Active low output when in Undervoltage Lockout

Typical Applications

- Isolated offline switching power supplies
- Isolated Power DC/DC converters
- Flyback converter
- Forward converter

Block Diagram



TL/H/11435-1

*Internal Test Point. Leave Open.

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V_S, P_{VS})	20V
V_S–P_{VS}	±0.3V
Pulse Interface Input Current (I_{PIN})	±4 mA
ESD (Note 2)	2 kV

Operating Ratings

Supply Voltages	$8.5V \leq V_S \leq 20V$
	$8.5V \leq P_{VS} \leq 20V$
Junction Temperature Range	$-40°C \leq T_J \leq +125°C$

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_S = P_{VS} = 15V$, $C_L = 1$ nF, $R_L = 10$ kΩ, $R_T = 5.76$ kΩ, $C_T = 200$ pF ($F_O = 500$ kHz).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
OSCILLATOR SECTION						
F_O	Oscillator Frequency (Note 3)	$R_T = 5.76$ kΩ, $C_T = 200$ pF	425 **400**	500	575 **600**	kHz
		$R_T = 5.29$ kΩ, $C_T = 100$ pF	0.85 **0.80**	1.0	1.15 **1.20**	MHz
V_{PP}	Peak-to-Peak Voltage (Pin 14)			1.0		V
$I_{CT(SINK)}$	Timing Capacitor Sink Current	$V_{CT} = 3.5V$		3.0		mA
$\Delta F_O/\Delta V_S$	Line Regulation	$9.8V \leq V_S \leq 20V$		0.02	0.1	%/V
PULSE INTERFACE SECTION (Note 4)						
$I_{PIN(SINK)}$	Minimum Pulse Input Sink Current Threshold			0.16	0.25 **0.35**	mA
$I_{PIN(SOURCE)}$	Minimum Pulse Input Source Current Threshold			0.25	0.40 **0.50**	mA
t_{PW}	Minimum Pulse Width			15	30	ns
t_{dON}	Pulse Rise Delay-to-Output Time			28	42 **49**	ns
t_{dOFF}	Pulse Fall Delay-to-Output Time			26	42 **47**	ns
PULSE-WIDTH MODULATOR SECTION						
D_{MIN}	Minimum Duty Cycle			3	4.75 **5**	%
D_{MAX}	Maximum Duty Cycle	$R_{DL} = 26.1$ kΩ	78	85	91 **97**	%
		$R_{DL} = 22.6$ kΩ	42	50	58 **60**	%
CURRENT LIMIT SECTION						
V_{CL1}	Pulse-by-Pulse Current Limit Threshold Voltage		0.32 **0.28**	0.38	0.44 **0.46**	V
V_{CL2}	Secondary Current Limit Threshold Voltage		0.55 **0.50**	0.60	0.67 **0.70**	V
Δt_{dCL}	Pulse-by-Pulse Current Limit Delay Time	200 mV overdrive		50	70 **85**	ns

Electrical Characteristics

Specifications with standard type face are for $T_J = 25°C$, and those in **bold type face** apply over full **Operating Temperature Range**. Unless otherwise specified, $V_S = P_{VS} = 15V$, $C_L = 1$ nF, $R_L = 10$ kΩ, $R_T = 5.76$ kΩ, $C_T = 200$ pF ($F_O = 500$ kHz). (Continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
CURRENT LIMIT SECTION (Continued)						
I_B	Current Limit Sense Input Bias Current			−0.35		μA
I_{CSD}	Secondary Current Limit Restart Capacitor Charge Current (Pin 5)	(Note 5)	58 **42**	65	70 **84**	μA
ΔV_{SD}	Secondary Current Limit Restart Hysteresis		1.30 **1.20**	1.40	1.55 **1.65**	V
OUTPUT SECTION						
V_{OL}	Output Low Saturation Voltage	$I_{SINK} = 400$ mA		1.3	1.5 **1.8**	V
		$I_{SINK} = 20$ mA		1.0	1.2	V
V_{OH}	Output High Saturation Voltage	$I_{SOURCE} = 400$ mA		2.0	2.4	V
		$I_{SOURCE} = 20$ mA		1.6	1.9	V
t_R	Rise Time	$C_L = 1000$ pF		11	22 **25**	ns
t_F	Fall Time	$C_L = 1000$ pF		8	18 **20**	ns
OVERVOLTAGE SHUTDOWN SECTION						
V_{OVTH}	Overvoltage Shutdown Comparator Threshold Voltage		3.05 **2.80**	3.30	3.55 **3.80**	V
V_{OVH}	Overvoltage Shutdown Comparator Hysteresis		0.10 **0.06**	0.19	0.25 **0.31**	V
UNDERVOLTAGE LOCKOUT SECTION						
V_{ULTH}	Turn-On Threshold Voltage		11.0 **10.0**	11.8	12.6 **13.6**	V
V_{ULH}	Undervoltage Lockout Hysteresis		2.80 **2.40**	3.20	3.60 **3.80**	V
SOFT-START/DELAY SECTION						
I_{SS}	Soft-Start Current	(Note 5)	61 **57**	66	71 **75**	μA
V_{SS}	Soft-Start Threshold Voltage		2.10 **1.90**	2.30	2.60 **2.80**	V
V_{SI}	Initial Soft-Start Voltage	(Note 6)		0.7		V
SUPPLY AND START-UP SECTION						
I_S	Supply Current	100% Duty Cycle and No Load (Note 7)		21	28 **32**	mA
I_Q	Quiescent Current	$V_S = 9V$ (Note 7)		190	250 **300**	μA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: Pins 6 and 10, the Current Limit Input and the Overvoltage Threshold pins respectively, have an ESD rating of 1.8 kV.

Note 3: The oscillator frequency is set by R_T and C_T according to the equation:

$$\frac{1}{F_O} = T = C_T \bullet (1.5\,(R_T) + 728\Omega).$$

Note 4: The internal oscillator will synchronize to the frequency of the feedback pulse.

Note 5: These currents are set by R_T according to the equation:

$$I = 1.4V/(2 \bullet R_T).$$

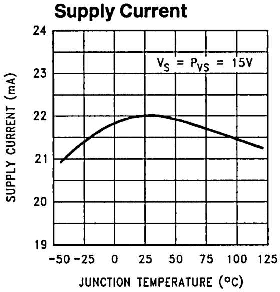
The timing resistor during these tests is set at 10.6 kΩ.

Note 6: The initial Soft-Start voltage is the voltage at the beginning of the start-up or re-start cycle.

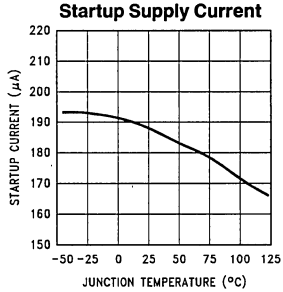
Note 7: Total supply current drawn by V_S and P_{VS} supply pins.

Typical Performance Characteristics

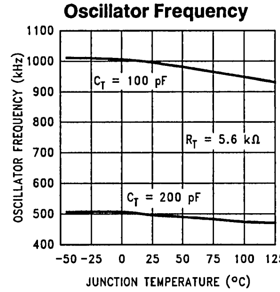
Supply Current



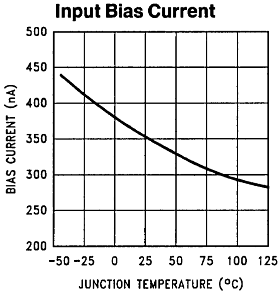
Startup Supply Current



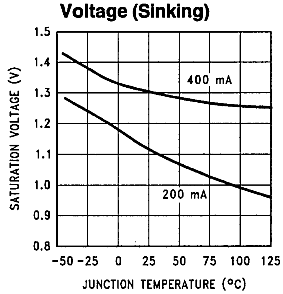
Oscillator Frequency



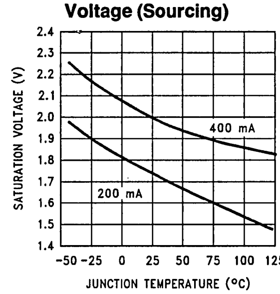
Current Sense Comparator Input Bias Current



Output Low Saturation Voltage (Sinking)



Output High Saturation Voltage (Sourcing)



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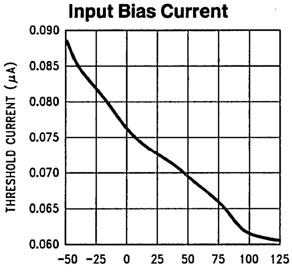
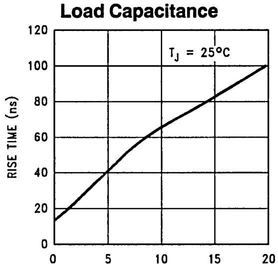
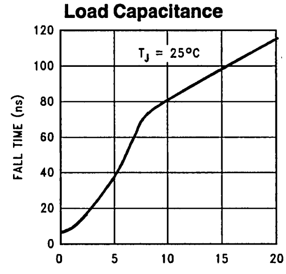
Overvoltage Comparator Input Bias Current



Rise Time vs Load Capacitance



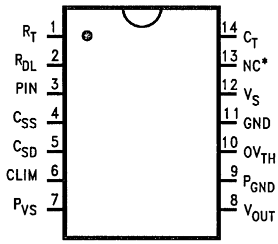
Fall Time vs Load Capacitance



TL/H/11435-3

Connection Diagram and Ordering Information

14-Lead Package



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*Do not connect to this pin.

Top View

For DIP Package
Order Number LM3001N
See NS Package Number N14A

For Surface Mount Package
Order Number LM3001M
See NS Package Number M14B

Consult your local National Semiconductor Sales Office for Availability of this Device in the Surface-Mount Package

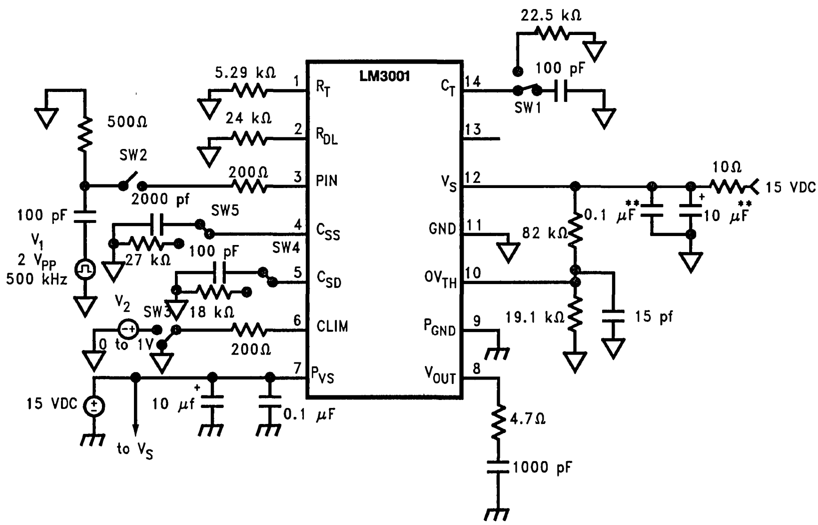
Pin-by-Pin Description

Pin No.	Symbol	Function	Description
Pin 1	R_T	Timing Resistor	A resistor from this pin to ground and a capacitor from pin 14 to ground programs the oscillator frequency by the following formula: $1/F_O = T = C_T \bullet (1.5 \bullet R_T + 728)$ [s, F, Ω]
Pin 2	R_{DL}	Duty Cycle Limit	The duty cycle limit is set by connecting a resistor, from this pin to ground, using the following formula: $R_{DL} = R_T [(D_{MAX} \bullet 1.71V) + 3.11V]$ [Ω, V] for $R_T \geq 5\ k\Omega$ and $3.37V \leq R_{DL}/R_T \leq 4.56$. An internal current source develops a voltage across this resistor which is compared to the oscillator ramp voltage (see the block diagram and the Oscillator section of the Functional Decriptions).
Pin 3	PIN	Pulse Input	Input for feedback pulses in pulse communication operating mode. The peak current of these pulses can range from 0.3 mA to 4 mA.
Pin 4	C_{SS}	Soft-Start Capacitor and Delay	A capacitor, connected from this pin to ground, programs the Soft-Start time delay. The Soft-Start time delay is made up of two parts: a time delay during which the output is turned off (zero duty cycle), and a time period in which the duty cycle goes from zero to its maximum value, set by the Duty Cycle Limit (see pin 2 description). The time delay equation is: $t_{DSS} = 2 \bullet C_{SS} \bullet R_T$ [s, F,Ω] The rate at which the duty cycle ramps up from zero to its maximum limit follows the equation: $D/t = 0.58/(C_{SS} \bullet R_T)$ [s, F,Ω]
Pin 5	C_{SD}	Shutdown Delay Capacitor	A capacitor, connected from this pin to ground. provides a time delay before the device can restart from a second level current limit shutdown (see pin 6 description). This action is governed by the formula: $t_{SD} = 2 \bullet C_{SD} \bullet R_T$ [s, F,Ω]
Pin 6	CLIM	Current Limit Input	This provides a pulse-by-pulse current limit, with a voltage threshold of 0.38V. If that is exceeded, a second level current limit, with a 0.60V threshold voltage shuts down the chip completely for a programmed time period (see pin 5 description).
Pin 7	P_{VS}	Driver Supply Voltage	Supply of the output driver.
Pin 8	V_{OUT}	Driver Output	Driver output. It can drive an external power MOSFET (in 11 ns typically) with peak source or sink currents of up to 2.5A.
Pin 9	P_{GND}	Power Ground	Power ground.

Pin-by-Pin Description (Continued)

Pin No.	Symbol	Function	Description
Pin 10	OV_{TH}	Overvoltage Threshold	This monitors the supply voltage through an external resistor divider. It shuts down the output driver if the threshold voltage is exceeded. The threshold voltage is 3.3V typical.
Pin 11	GND	Ground	Signal ground.
Pin 12	V_S	Supply Voltage	Supply voltage of the control circuit.
Pin 13	NC	No Connect	Internal Test Point. Leave Open.
Pin 14	C_T	Timing Capacitor	Inserting a capacitor from this pin to ground and a resistor from pin 1 to ground programs the oscillator frequency by the following formula: $1/F_O = T = C_T \bullet (1.5 \bullet R_T + 728)$ [s, F,Ω]

LM3001 Test Circuit



TL/H/11435–5

Initial Conditions:
SW1—Connects pin 14 to 100 pF capacitor.
SW2—Open.
SW3—Connects 200Ω to ground.
SW4—Connects pin 5 to 100 pF capacitor.
SW5—Connects pin 4 to 2000 pF capacitor.

Bench Test Procedure*

*The LM3001 specifications are measured using automated test equipment. This circuit is provided for the customer's convenience when checking parameters. Due to possible variations in testing conditions, the measured values from these testing procedures may not match those of the factory.

Required Equipment: Voltmeter, Storage Oscilloscope, Function Generator, Power Supply. Apply 15V between P_{VS} and P_{GND}. Then proceed with the following steps.

OSCILLATOR SECTION

Step 1: Measure the voltage at pin 1, across the 5.29 kΩ timing resistor R_T. It should range between 1.35 VDC and 1.55 VDC. Switch pin 14 from the 100 pF timing capacitor, C_T, to the 22.5 kΩ resistor. Measure the voltage across the resistor. It should be about 2.5V. Switch pin 14 back to the 100 pF capacitor.

Step 2: Measure the peak-to-peak voltage at pin 14 (across the timing capacitor C_T). It should be approximately 1.0V. Observe the waveform across the capacitor. The waveform frequency should measure approximately 1 MHz, and the shape of the waveform should be sawtooth.

Step 3: Measure the voltage at pin 2 (across the 24k resistor R_{DL}). It should be approximately 2.65V.

Bench Test Procedure* (Continued)

SWITCHING OUTPUT SECTION

Step 4: Observe the waveform at pin 8 (V_{OUT}). It should be a pulse-width modulated waveform with a frequency of about 1 MHz, the same frequency as the waveform of C_T (Step 2). Measure the duty cycle of the V_{OUT} waveform. It should be approximately 35%.

Step 5: Measure the rise and fall times of the V_{OUT} signal at pin 8. They each should be typically 12 ns. Measure the saturation voltage levels. The low saturation voltage level should measure about 1.5V, and the high saturation voltage level should be about 13.5V (15V−1.5V).

Step 6: Close SW2 to apply V_1, a 500 kHz $2V_{PK\text{-to-}PK}$ square wave, to pin 3 (the PIN input) through the 500Ω, 100 pF RC filter. The waveform at the V_{OUT} output should be a 500 kHz square wave. Measure the delay time from the rising edge of the input signal to the rising edge of the output waveform. The delay time should measure about 20 ns. The delay time between the falling edges of each signal should be the same.

Step 7: Open SW2 to disconnect the pulse waveform from pin 3. Observe the V_{OUT} waveform. It should also be off. Turn off the supply voltage.

INTERNAL SUPPLY OPERATIONS

Step 8: Slowly turn on the supply voltage back up toward 15V, while observing the V_{OUT} pin. Note the supply voltage when the V_{OUT} PWM waveform starts up—i.e., when the device turns on. The supply voltage should be about 11.8V. Measure the current into the supply pins P_{VS} and V_S (pins 7 and 12 respectively). The P_{VS} supply current should range from 13 mA to 23 mA, while the V_S supply current is about 12 mA. Decrease the supply voltage until the output shuts down. The supply voltage should read approximately 8.6V. Reset the supply voltage to 15V so that the device is back on.

Step 9: Increase the supply voltage until the V_{OUT} signal turns off. The voltage at the Overvoltage Threshold pin (pin 10) should be between 3.0V and 3.6V. The supply voltage should be approximately 20V. Return the supply voltage to 15V.

CURRENT LIMIT SECTION

Step 10: Connect V_2 (an adjustable voltage source set to 0V) through SW3 to the 200Ω resistor connected to pin 6, the Current Limit Input. Raise the voltage from 0V to 0.45V into the 200Ω resistor while monitoring the V_{OUT} signal. Output driver V_{OUT} should show a PWM waveform with a minimum duty cycle of approximately 3%. The minimum duty cycle waveform should start when the voltage source reaches approximately 0.38V.

Step 11: Increase the voltage at the source until the output turns off completely. The voltage should measure approximately 0.6V. The output should remain completely off until the shutdown time delay has expired and the voltage is removed.

SHUTDOWN DELAY/SOFT-START CONTROL SECTION

Step 12: Measure the shutdown time delay between when the V_2 voltage source is removed from the 200Ω resistor and when the output starts up again. It should equal the product of the following equation:

$$T_{SD} = 2 \bullet C_{SD} \bullet R_T.$$

With a 100 pF shutdown delay capacitor (C_{SD}) at pin 5 and a 5.29 kΩ timing resistor (R_T) at pin 1, the shutdown time delay should be approximately 1.3 µs.

Step 13: Switch SW4 from the shutdown delay capacitor to the 18 kΩ resistor at pin 5. Measure the voltage across the 18 kΩ. It should measure about 2.0V. Return the switch to the 100 pF capacitor.

Step 14: Switch SW5 from the 2000 pF Soft-Start delay capacitor to the 27 kΩ resistor at pin 4. Measure the voltage across the 27 kΩ resistor. It should measure about 3.0V. Return the switch to the 2000 pF capacitor. Turn off the supply voltage. End of test.

For further information on the IC operation, see the Functional Section Descriptions in the Application Section.

Functional Description

OSCILLATOR SECTION

The LM3001 oscillator can set the operating frequency from 50 kHz to over 1 MHz. The oscillator requires an external resistor and capacitor to determine the operating frequency—the equation is:

$$1/F_O = T = C_T \bullet (1.5 \bullet R_T + 728).$$

With a 6 kΩ timing resistor and a 200 pF timing capacitor, the formula calculates the operating frequency at 514 kHz. At higher operating frequencies, the oscillator frequency deviates from this equation due to switching delays. *Figure 1* shows the oscillator frequency for different combinations of timing capacitors and resistors.

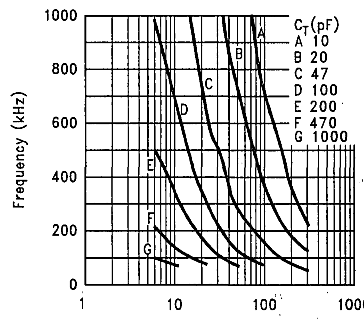


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FIGURE 1. Frequency vs R_T and C_T Graph

Functional Description (Continued)

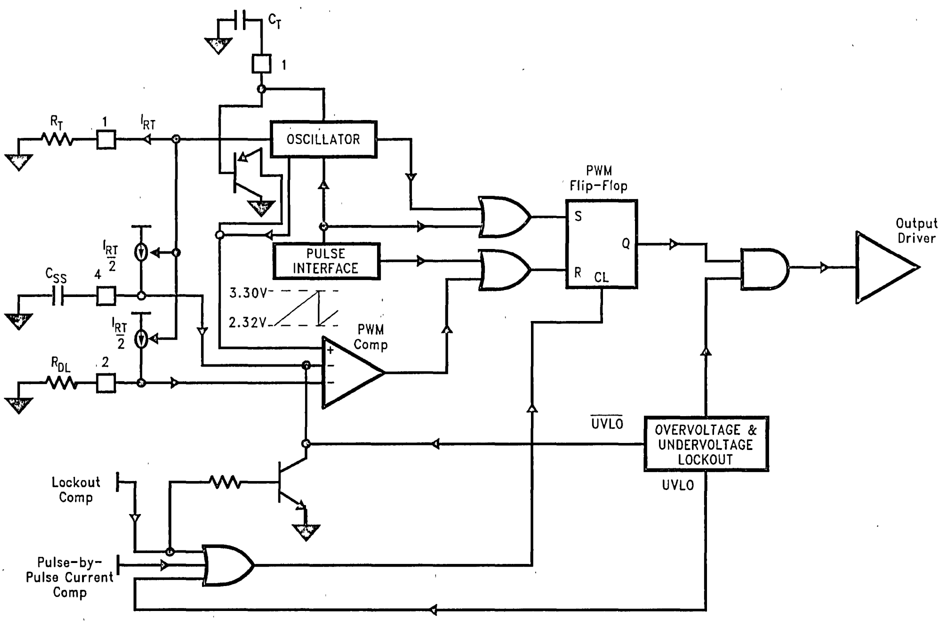

FIGURE 2. PWM Block Diagram

PULSE-WIDTH MODULATOR SECTION

The pulse-width modulator (PWM) section consists of the PWM comparator and the PWM flip-flop (see *Figure 2*). During normal pulse feedback operation, the pulse interface circuit will set or reset the PWM flip-flop, which in turn, will latch on or off the output driver (see the timing diagrams in the pulse interface section of the Application Hints section). During start-up, or opto-coupler feedback operation, the oscillator will set the PWM latch, and the PWM comparator will reset the latch.

PWM COMPARATOR CIRCUIT

The PWM Comparator is fed by several different inputs. The inverting inputs are the duty cycle limit input (R_{DL}), and the Soft-Start (C_{SS}). The non-inverting input comes from the external timing capacitor, C_T. The sawtooth waveform at C_T is adjusted up one base-emitter junction voltage, and applied to the non-inverting input. Hence, this input is a sawtooth waveform oscillating between 2.32V to 3.3V. The level-shifted oscillator ramp voltage is compared to the two inverting inputs. The lowest input determines the PWM comparator output and thus the state of PWM flip-flop. The PWM flip-flop controls the output driver, driving it on or off.

DUTY CYCLE LIMIT

Duty cycle limit can be used for either pulse or opto-coupler feedback systems. A current mirror delivers one-half of the timing resistor current to the R_{DL} input. Inserting a resistor from this pin to ground will produce a voltage, that is compared to the oscillator ramp voltage. The result limits the duty cycle of the regulator circuit. The maximum duty cycle can be calculated using the following equation:

$$D_{MAX} = [R_{DL}/(1.71 \circ R_T)] - 1.82$$

For instance, if the R_{DL} input had a 23.3 kΩ resistor connected to it, and the timing resistor was 6 kΩ, the maximum duty cycle would be approximately 45%.

Conversely, if a known maximum duty cycle was desired, the calculation for R_{DL} would be:

$$R_{DL} = R_T\,[(1.71 \circ D_{MAX}) + 3.11]$$

For example, a 30% duty cycle (and a 6 kΩ timing resistor) would result in a R_{DL} of 21.7 kΩ.

To disable the duty cycle limit, the voltage at the R_{DL} pin must be greater than 3.3V. The graph in *Figure 3* shows the maximum duty cycle for a range of R_{DL} resistor values.

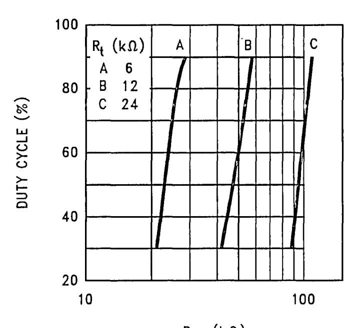

FIGURE 3. Maximum Duty Cycle vs R_{DL}

3

Functional Description (Continued)

SOFT-START

The Soft-Start function limits the duty cycle at start-up. At start-up, a current source charges the Soft-Start capacitor with a current that is half the current that flows through the timing resistor (see the PWM block diagram). Before the Soft-Start voltage reaches 2.32V, the low voltage level of the timing capacitor peak-to-peak voltage, the PWM comparator delivers a high signal to the reset input of the PWM flip-flop (see the timing diagram in *Figure 4*). This forces it and the output driver off. At the point where the Soft-Start voltage reaches 2.32V, the PWM comparator changes its output state, turning on the PWM flip-flop and the output driver. However, the Soft-Start circuit still limits the duty cycle. The duty cycle will progressively get longer with each cycle, until either the duty cycle limit is reached or the feedback signal takes control of the PWM circuit.

The formula for the Soft-Start time delay (the time the voltage at the Soft-Start pin reaches the 2.32V level) is:

$$t_D = 2 \bullet C_{SS} \bullet R_T.$$

After this time delay, the Soft-Start circuit limits the rise of the duty cycle. The amount the duty cycle rises to, and the time spent getting there, both depend on whether the duty cycle limit voltage level (V_{RDL}) or the current limit voltage level (V_{CLIM}) assumes control of the duty cycle first during start-up. Assuming the duty cycle limit voltage level is the Soft-Start voltage threshold during start-up, then the speed at which the duty cycle achieves its maximum level is:

$$D_{MAX}/t_{SS} = 0.71/(C_{SS} \bullet R_T).$$

And if the rise time is known, then the Soft-Start capacitor can be calculated as:

$$C_{SS} = (0.71 \bullet t_{SS})/(D_{MAX} \bullet R_T).$$

The Soft-Start circuit has a clamp voltage of 4.2V. Leaving the pin open will disable the Soft-Start function.

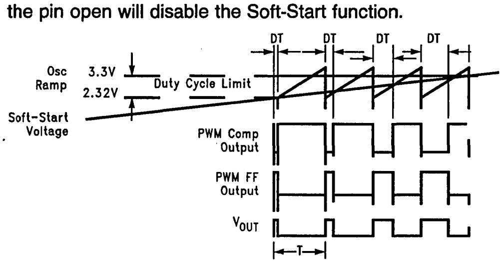

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FIGURE 4. Soft-Start Timing Diagram

PULSE INTERFACE SECTION

Figure 5 shows the block diagram of the pulse interface section. The pulse interface circuit will take AC coupled feedback pulse signals and set or reset the PWM flip-flop, depending upon whether the pulse signal is positive or negative—a positive pulse will set the flip-flop, a negative one will reset it. In turn, the flip-flop will turn on or off the output driver. Hence, the feedback signal through the pulse interface circuit will control the LM3001 operating frequency and duty cycle (in steady-state operation).

The AC-coupled current pulses can be as low as 0.3 mA (guaranteed), and as narrow as 15 ns (typical). The minimum time between pulses is approximately 10 ns. The maximum current pulse that the feedback pin can handle is 4 mA. Feedback signals beyond 4 mA can either cause improper operation or catastrophic failure of the LM3001. The time delay between when the feedback pulse signal is received and when the output gate drive signal changes state is 28 ns typically.

During start-up of an isolated offline converter, once a positive AC-coupled feedback signal is applied to the pulse interface circuit, the circuit will synchronize the internal oscillator to the feedback signal frequency. The same signal will also turn on the output driver. If, after the pulse feedback was established and for any reason it was terminated, the output would deliver the signal that was set by the last pulse sent by the feedback circuit. For example, if the output driver was set high, and the LM3001 did not receive any further feedback pulses, then the output driver would stay turned on. Either the current limit circuit or the duty cycle limit circuit would shut down the output under these circumstances.

OUTPUT DRIVER SECTION

The Output Driver is a totem pole output stage that can supply or sink 2.5A peak currents at speeds less than 20 ns. That is enough current to charge or discharge thousands of picofarads of load capacitance, which is present when driving Power MOSFETs. The saturation voltages of the internal power transistors are typically 1.5V from the rails when sourcing or sinking 400 mA.

A demonstration of the drive capability of this output stage is shown in *Figure 6*. The drawings show the output stage driving different values of load capacitance during pulse feedback operation. As shown, with a load capacitor value of 1,000 pF, the rise time is typically 11 ns, and the fall time is typically 8 ns. The supply voltage in all cases was 15V.

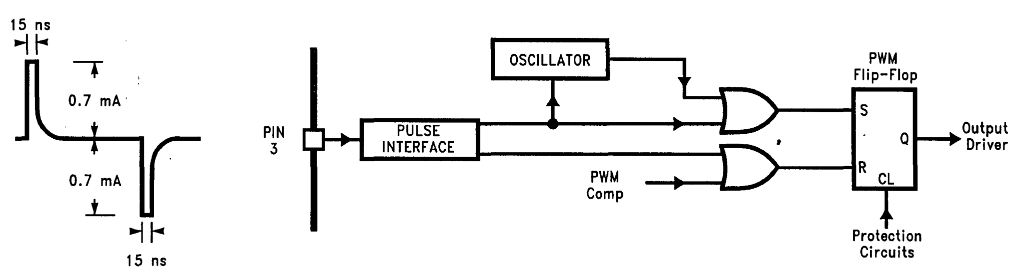

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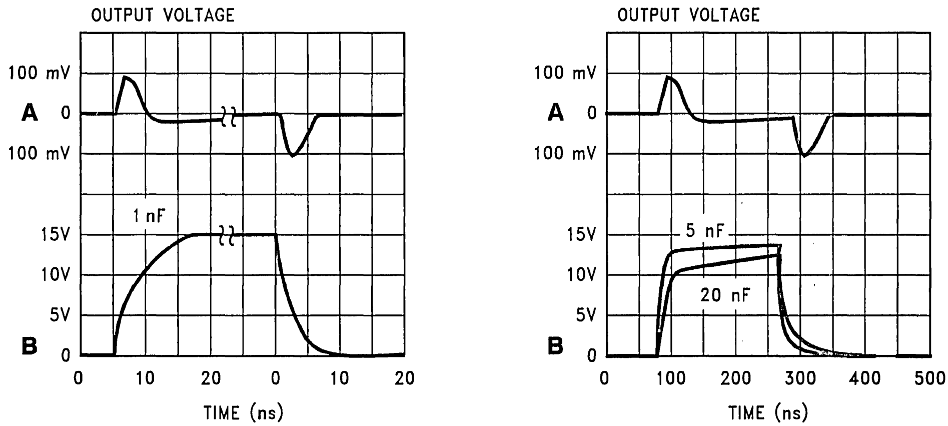
FIGURE 5. Pulse Interface Block Diagram

Functional Description (Continued)



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A: Pulse Feedback Voltage, 100 mV/div. (AC Coupled)

B: Output Voltage, 5V/div.

FIGURE 6. Output Voltage Rise and Fall Times

CURRENT LIMIT SECTION

There are two circuits in the LM3001 that limit the peak primary current. One executes pulse-by-pulse current limiting, and the other is a total shutdown current limit, which shuts down the output driver (and thus, the Power MOSFET) for a programmable amount of time. Both current limit circuits monitor the peak primary current by comparing the voltage on the CLIM input (pin 6) against two different voltage thresholds.

The voltage threshold for the pulse-by-pulse current limit is 0.38V (typical). When that threshold voltage is reached, the pulse-by-pulse current comparator turns off the present Power MOSFET gate drive by sending a high signal to the clear input of the PWM flip-flop. The current limit circuit will activate again during the next cycle, if the 0.38V threshold is exceeded again.

The voltage threshold for the total shutdown current limit is 0.6V. When that current limit comparator is activated, it forces the inverting input of the lockout comparator low (to about 0.7V) by driving a Darlington transistor into saturation. With the other input connected to a 2.1V reference voltage, the lockout comparator outputs a high signal to the PWM flip-flop clear input (via the OR gate). A high signal at its clear pin shuts down the PWM flip-flop and thus, the output driver. The output driver will remain off until the voltage level at the lockout comparator inverting input becomes larger than the voltage at its non-inverting pin (because the shutdown delay has expired and the voltage at the CLIM pin is less than 0.6V).

The shutdown delay is controlled by an external capacitor (on the C_{SD} pin—pin 5) and an internal current source connected to the inverting input of the lockout comparator (the current source delivers approximately half the current through the timing resistor). The current source will charge the capacitor until its voltage is internally clamped at about 3.0V. When the capacitor voltage reaches the reference voltage, the Lockout Comparator will change its output from a high to a low signal. This action will release the PWM flip-flop and the output driver, enabling them to resume normal operation (assuming the problem causing the current limit has been corrected. If not, normal operation will be halted again).

The time the PWM flip-flop and the output driver remain shutdown is programmable, depending on the value of the C_{SD} capacitor. Rearranging the shutdown time delay equation, giving in the pin-by-pin description section, results in a calculation of the capacitor value:

$$C_{SD} = t_{SD}/(2 \bullet R_T).$$

For example, for a desired shutdown delay time of approximately 100 μs and a R_T equal to 6 kΩ gives a C_{SD} of 8200 pF. The shutdown delay circuit is temperature compensated, so the delay time is stable over temperature. Also, after a total shutdown, the IC will repeat the Soft-Start cycle when the shutdown delay time has elapsed.

If the shutdown delay feature is not desired, leaving the pin open will disable the function (the pin voltage is internally clamped to 3V, thereby holding the lockout comparator output low).

Functional Description (Continued)

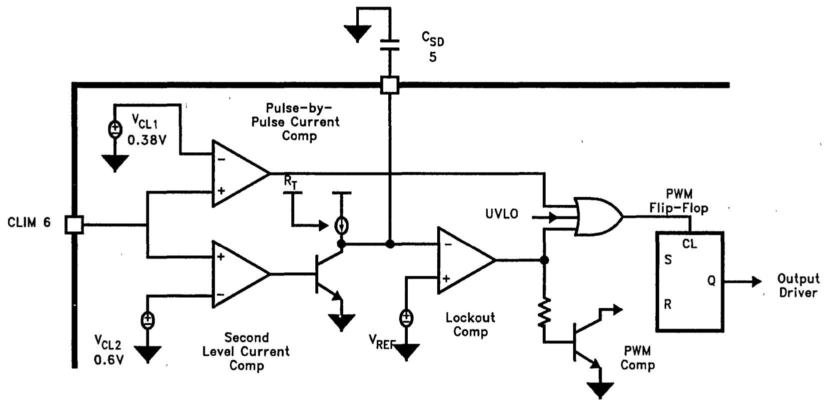

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FIGURE 7. Current Limit Block Diagram

OVERVOLTAGE/UNDERVOLTAGE SHUTDOWN SECTION

The Overvoltage and Undervoltage Lockout circuits protect the LM3001 from deviations of the supply voltage. The Overvoltage Lockout (OVL) circuit monitors the supply voltage via an external resistor divider (for more information, see the OVL section in the Application Hints section). The Overvoltage Lockout Threshold voltage is 3.30V (typically). When an overvoltage condition occurs, the OVL circuit shuts down the Output Driver (the rest of the IC stays on) until the fault causing it disappears. The Thermal Shutdown protection circuit uses the same circuitry to shut down the Output Driver and the entire regulator.

The Undervoltage Lockout (UVL) circuit monitors the supply voltage from within the IC. At start-up, the UVL is turned on when the supply voltage reaches approximately 2.0V. The UVL circuits keeps the rest of the IC off until the supply voltage reaches approximately 11.8V. The start-up supply current during this period is about 190 μA. Hysteresis (about 3.2V) is added to the circuit so that the supply voltage must decrease to 8.6V (typical) before the UVL circuit shuts down the IC. When the UVL circuit is activated, the rest of the IC and the entire regulator are turned off, and the UVL and bandgap reference voltage circuits are the only two internal circuits left on. The UVL circuit will also discharge the Soft-Start capacitor, so Soft-Start will commence at the next start-up.

SIGNAL GROUND AND POWER GROUND

The LM3001 Primary-Side PWM Driver is designed with two separate grounds inside that meet in one location—right at the pins. One ground is for small signals—hence, it is very clean (noise-free). The other ground is the power ground, used by the large signals of the Output Driver. The two grounds are internally connected at the pins; pin 9 is a power ground and pin 11 is a signal ground. The grounds should be isolated from each other on the board (see the PCB Layout section in the Application Hints section).

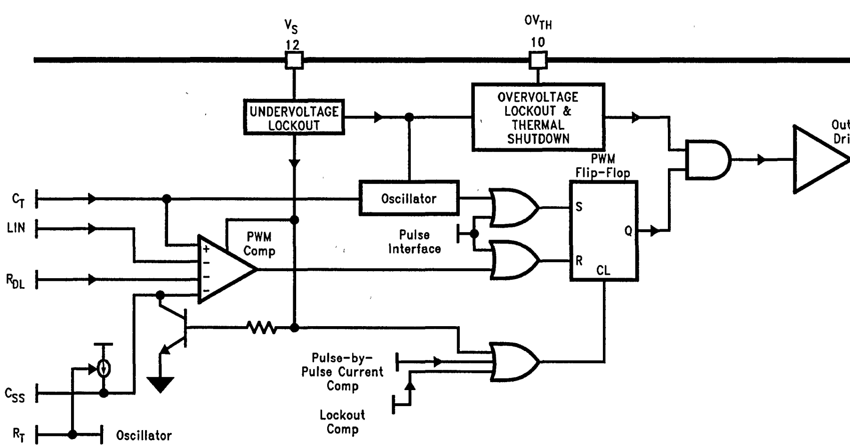

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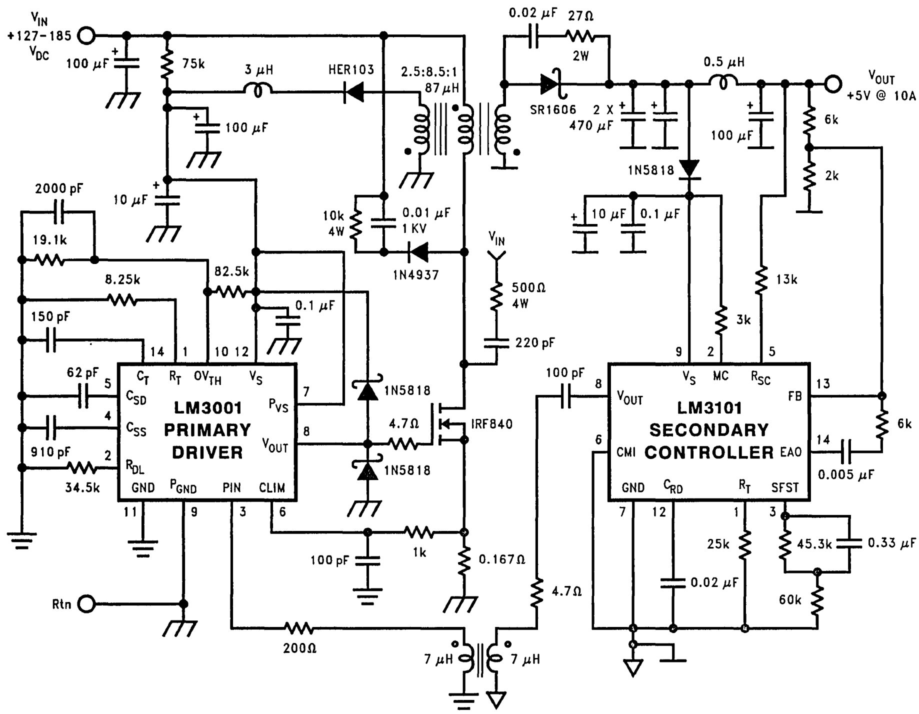
FIGURE 8. Overvoltage/Undervoltage Block Diagram

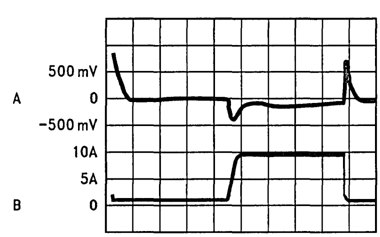
Typical Application



CAUTION: HIGH VOLTAGE
Handle with Extreme Care

FIGURE 9. Offline Voltage Mode Flyback Regulator

This 500 kHz Offline Converter delivers 50W (5V @ 10A) from an input supply ranging from 90 VAC to 130 VAC (130 VDC to 180 VDC). The regulator achieves a line regulation of 0.06% and a load regulation of 0.05%. A 0.5 μH inductor and 100 μF capacitor form an LC filter that reduces the output ripple voltage to 50 mV. As shown in *Figure 10* the regulator can respond to a "step" change in load current from 1A to 10A in about 12 μs. The efficiency of the converter is approximately 80% at full load.



TL/H/11435–15

A: Output Voltage, 500 mV/div., AC Coupled
B: Load Current, 5A/div.
Horizontal Time Base: 20 μs/div.

FIGURE 10. Load Step Response

Typical Application (Continued)

POWER STAGE OPERATION

The LM3001 Primary-Side PWM Driver sends a pulse-width-modulated signal (via pin 8) to a power switch, which in turn, drives a power transformer.

The power switch used in this case is an IRF840 Power MOSFET. It is an N-Channel enhancement mode device that has a drain-to-source voltage (V_{DSS}) rating of 500V and a pulsed drain current (I_{DM}) rating of 32A. Even though the Power MOSFET has a high V_{DSS}, snubber circuits are needed to limit the drain voltage and damp out any ringing that may occur.

The power transformer has a primary inductance of 87 μH. The primary-to-secondary turns ratio is 8.5 to 1 and the secondary-to-tertiary turns ratio is 1 to 2.5. The tertiary winding delivers the LM3001 supply voltage (pins 7 and 12) to the primary-side driver.

There is an internal Overvoltage Threshold circuit (pin 10) monitoring the input voltage via a resistor divider. The overvoltage trip point is 3.3V typically. With the resistor values shown, the maximum supply voltage is approximately 17.5V.

The output rectifier, an SR1606, delivers the secondary current to the output. The SR1606 is specified for 16A forward current, 60V reverse breakdown voltage, and comes in a TO220-AB package. Since the SR1606 dissipates 7W to 8W at full load, it requires a heatsink. An RC snubber is placed in parallel to reduce the ringing voltage caused by the output rectifier turning off during the discontinuous mode of operation.

Two Cornell Dubilier type 226 470 μF, 25V high frequency capacitors, with low ESRs of 0.25Ω, are used as the output capacitors.

OUTPUT VOLTAGE CONTROL

The output voltage is controlled by the LM3101 Secondary-Side PWM Controller. The LM3101 uses its error amplifier to compare the scaled-down output voltage against the internal precision 1.24V reference voltage. The error amplifier provides compensation for the regulator frequency response, by way of an RC feedback network.

The resulting error voltage is converted into a pulse-width-modulated waveform at the system oscillator frequency of approximately 500 kHz. This waveform is then differentiated (using an external high-pass RC filter) into a series of positive and negative pulses representing the desired switch duty cycle.

The pulses are transferred through a pulse transformer to the LM3001 Primary-Side Driver. The driver takes the feedback pulse signal and converts it into a PWM gate drive for the Power MOSFET.

FAULT RECOVERY OPERATION

A 0.15Ω resistor sets the peak primary current limits to 2.28A for the pulse-by-pulse limiting, and to 3.6A for the second-level limit. An RC network filters the current limit voltage to prevent the current limit (pin 6) from being activated by the reverse recovery spike of the output rectifier. When the second level current limit is triggered, the LM3001 shuts down and discharges the capacitor connected to pin 5 (the Shutdown Delay capacitor). After the capacitor is recharged to a voltage of approximately 2.1V, the device will try to restart. If the overcurrent condition persists, the device will shut down again.

The LM3101 provides the fault protection in case of an output short circuit. During normal operation, the operating frequency of this circuit is determined by 25 kΩ resistor connected to pin 1 of the LM3101. However, during a short circuit condition on the output, the frequency of the LM3101 (and the entire circuit operating frequency) drops, yielding a very low duty cycle. This short-circuit frequency is set by the 13 kΩ resistor connected to pin 5.

The LM3101 Mode Control and Current Mode Input pins (pins 2 and 6 respectively) are for current mode control operation. The MCR pin determines which control mode is being used—the resistor tied to the supply voltage means voltage mode control (the resistor tied to ground would indicate current mode control).

START-UP OPERATION

When power is initially applied to the regulator, the LM3001 Primary-Side PWM Driver receives its supply current through a 75 kΩ resistor connected to the input voltage (see *Figure 9*). Once the supply pin voltage reaches the threshold of 11.8V (typical), the LM3001 turns on, sending pulse signals (with an amplitude of approximately 10V) to the gate of the Power MOSFET. Because the output is driving Power MOSFETs, which need gate-to-source voltages greater than 10V for hard turn-on (low $R_{DS\ (ON)}$) the threshold voltage of 11.8V was selected to insure sufficient output voltage.

At the beginning of the start-up process, the secondary side of the regulator is still unbiased—hence the LM3001 does not receive a feedback signal from the secondary side (see the Start-Up Sequence in *Figure 11*). Before the LM3101 Secondary-Side PWM Controller is controlling the circuit, the initial operating frequency of the gate drive is determined by the LM3001 internal oscillator. The oscillator uses an external capacitor and resistor, on pins 14 and 1 respectively. The initial operating frequency in this case is approximately 500 kHz. During this time, the regulator is operating in a "free-running" state.

Also during the beginning, the LM3001 executes Soft-Start by using the Soft-Start capacitor on pin 4. The voltage across this capacitor is compared to the oscillator ramp on pin 14 (see the LM3001 block diagram). In the offline regulator, the Soft-Start time is 15 μs approximately.

During this time, as the Soft-Start capacitor charges up, the duty cycle increases with each progressive cycle, until finally the duty cycle reaches its maximum value set by the Duty Cycle Limit circuit (R_{DL}—pin 2) and the Current Limit circuit (CLIM—pin 6). The Soft-Start phase ends when the duty cycle is limited by the R_{DL} circuit. A resistor at this pin connects to an internal current source which together will generate a voltage that will be compared to the oscillator ramp voltage. This comparison will determine the maximum duty cycle during this phase of the start-up cycle. For the circuit in *Figure 9*, the duty cycle is limited to 63% by the R_{DL} circuit.

The duty cycle will reach the R_{DL} limit for several cycles, letting energy build up in the transformer—see the drain current waveform in *Figure 11*. When the residual energy builds up enough, the duty cycle starts to decrease because it is now determined by the CLIM circuit. A voltage of 0.38V or greater at this pin will toggle a pulse-by-pulse comparator on every cycle (see the LM3001 block diagram). In the ap-

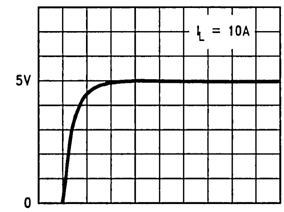
Typical Application (Continued)

plication circuit, a 0.167Ω resistor will generate the current limit threshold voltage when a 2.28A (peak) current flows through it. With the CLIM circuit in control of the duty cycle, the duty cycle will decrease with each sucessive cycle. The duty cycle will continue to shrink until the pulse feedback from the LM3101 takes control.

As the LM3001 switches the Power MOSFET on and off, the Power Transformer starts delivering power to the secondary side of the circuit. This action will cause the supply voltage of the LM3101 and the output voltage to gradually rise. When the supply voltage reaches the Undervoltage Lockout Threshold (of 3.9V), the LM3101 starts supplying a pulse train to the differentiator circuit on pin 8. The resulting PWM signals are fed back to the LM3001 via the pulse transformer. The first pulse signal to the LM3001 will cause it to disconnect its internal oscillator from its PWM and Output Driver circuits and trigger the Output Driver from the pulse feedback signals (of the LM3101). At this point, control of the frequency and the duty cycle changes from the LM3001 to the LM3101.

The LM3101 also exercises Soft-Start capability (pin 3). An RC network connected to this pin allows the LM3101 to gradually increase the duty cycle to its nominal value (in the example, the secondary Soft-Start time delay is 500 μs approximately).

The method of Soft-Start used by the LM3101 ensures that the error amplifier is in its linear region before the output voltage reaches its nominal value, thus yielding a smooth start-up of the output without any overshoot (see *Figure 12*).

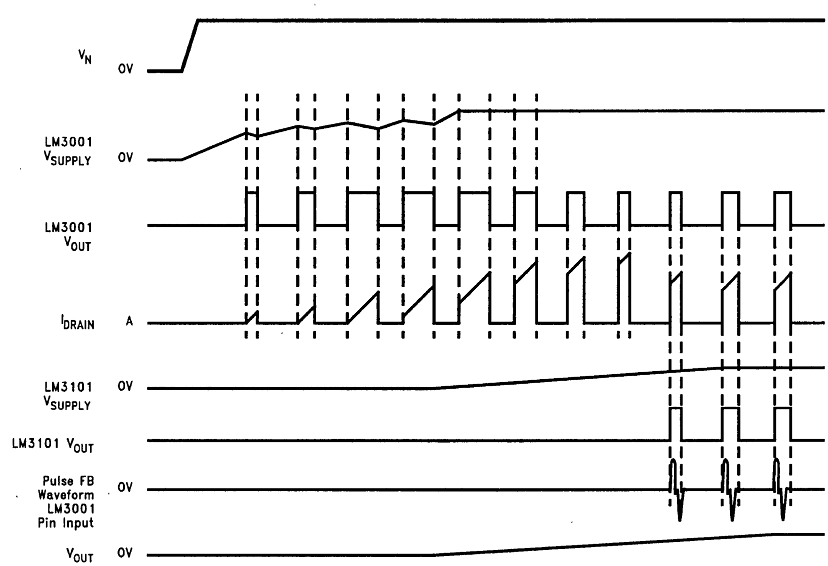


TL/H/11435-17

Output Voltage, 1V/div.
Horizontal Time Base: 500 μs/div.

FIGURE 12. Output Voltage Start-Up

At the end of the start-up sequence. the circuit is in steady-state or normal PWM operation.



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(Representative not to scale)

FIGURE 11. Start-Up Timing Sequence

Typical Applications (Continued)

DESIGN PROCEDURE

For the Offline Voltage Mode Flyback Regulator (*Figure 9*), the specifications for the power transformer, MOSFET switch, the switch snubber, and the output rectifier can be calculated based on the system specifications:

System Specifications:

$V_O = 5$ VDC

V_I Range = 90 VAC–132 VAC

I_O Range = 0.5A–10A

Efficiency (η) = 80%

$F_O = 500$ KHz

Transformer Specifications

Manipulating the transfer function of a flyback regulator results in a calculation for the turns ratio of the power transformer, involving the minimum input voltage, the output voltage, and the maximum duty cycle (D):

$$V_O + V_F = (V_{IN(MIN)} - V_{SW(ON)}) \bullet (N_S/N_P) \bullet (D_{(MAX)}/(1 - D_{(MAX)}))$$

$$\downarrow$$

$$N_S/N_P = [(V_O + V_F)/(V_{IN(MIN)} - V_{SW(ON)})] \bullet ((1 - D_{(MAX)})/D_{(MAX)}).$$

Assume that the diode forward voltage (V_F) is about 0.7V and the drain-to-source voltage when the switch is on ($V_{SW(ON)}$) is approximately 0.9V. Selecting a 28% maximum duty cycle results in a turns ratio of:

$$N_S/N_P = (5.7V/126.1V) \bullet (1 - 0.28)/0.28 = 0.12$$

$$(N_P/N_S = 8.5/1).$$

Assuming an efficiency (η) of 80%, the average input current (at the maximnum load current andd for the entire period) is:

$$I_{IN} = (V_O)(I_O)/(V_{IN(MIN)} \bullet \eta) = (50W)/(127V \bullet 0.80) = 0.49A.$$

The average current when the switch is on is the average current over the entire period divided by the duty cycle:

$$I_{IN(TON)} = I_{IN}/D = (0.49A)/(0.28) = 1.77A.$$

Selecting the primary inductance ripple current (ΔI_P) to be a certain percentage of the $I_{IN(TON)}$, and combining that with the duty cycle, the input voltage, and the operating frequency, gives the primary inductance by the equation:

$$L_P = (V_{IN(MIN)} - V_{SW(ON)}) \bullet D_{(MAX)}/(\Delta I_P \bullet F_O)$$

Assuming the percentage to be 46% in the example, then:

$$L_P = 126.1V \bullet 0.28/(0.81A \bullet 500\ kHz) \cong 87\ \mu H.$$

MOSFET Parameters

The peak current through the primary inductance and the Power MOSFET is the average current when the switch is on plus one-half the primary inductance ripple current:

$$I_{PRI(PK)} = I_{IN(TON)} + (\Delta I_P/2) = 1.77A + (0.81A/2) = 2.18A$$

Assuming ideal conditions, the maximum voltage at the drain of the Power MOSFET when the switch is off is:

$$V_{SW\,(OFF)} = (V_O + V_F)(N_P/N_S) + V_{IN(MAX)} = (5.7V)(8.5) + 185V = 233V \longrightarrow 250V.$$

However, leakage inductance exists in the transformer, causing a voltage spike immediately after the switch turns off. This voltage spike will add to the rest of the drain voltages, making $V_{SW(OFF)}$ even greater. With a leakage inductance that is 2% of the transformer primary inductance and selecting a switch which has a fall time of 2% the total off-time, the added voltage will be:

$$V_{LL} = 2\% \bullet L_P \bullet I_{PRI(PK)} \bullet F_O/[2\% \bullet (1 - D_{(MAX)})].$$

The maximum duty cycle of 28% is used for worst case purposes. Thus, the leakage inductance voltage spike is:

$$V_{LL} = 0.02 \bullet 87\ \mu H \bullet 2.18A \bullet 500\ kHz/[0.02 \bullet (1 - 0.28)] = 130V \longrightarrow 150V.$$

This means the actual peak drain voltage is approximately 400V. When choosing the Power MOSFET, add some margin to this number. A 500V MOSFET was used in this application.

Snubber Design

A "snubber" circuit, consisting of a 1N4937 fast recovery diode and a parallel RC network, is inserted around the transformer primary to clamp the voltage spike. This is to the reduce the switch voltage stress when it is off. The "snubber" components are calculated in the following manner:

$$C_{SN} \geq 0.02 \bullet L_P \bullet I_{P(PK)}{}^2/(V_{MAX}{}^2 - V_{SN}{}^2)$$

$$= 0.02 \bullet 87\ \mu H \bullet (2.18A)^2/[(255V)^2 - (250V^2] \approx 3.3\ nF$$

and

$$R_{SN} \leq [(V_{MAX} + V_{SN} - V_{IN})/2]^2 \bullet [100/F_O \bullet L_P \bullet I_{P(PK)}{}^2)] = [(255V + 250V - 185V)/2]^2 \bullet [100/(500\ kHz \bullet 87\ \mu H \bullet (2.18A)^2)] \approx 12\ k\Omega.$$

In the Offline Flyback Regulator application, a 0.01 μF capacitor and a 10 kΩ resistor are used as the snubber components. V_{MAX} is the selected maximum voltage at the drain of the MOSFET. Usually the RC values are selected so that V_{MAX} is 5V to 10V higher than V_{SN}. The power dissipation of the resistor is:

$$P = [(V_{MAX} + V_{SN} - V_{IN})/2]^2/R = [(255V + 250V - 185V)/2]^2/10\ k\Omega = 2.56W.$$

To add some margin, a 4W resistor is chosen.

The fast recovery diode must have a reverse voltage rating greater than V_{MAX}. The 1N4937 has a 600V rating.

Output Diode Parameters

The peak secondary current can be calculated using peak primary current and the turns ratio (this equation is for single output flyback regulators):

$$I_{SEC(PK)} = I_{PRI(PK)} \bullet (N_P/N_S) = 2.18 \bullet 8.5 = 18.43A \longrightarrow 20A.$$

The maximum average current through the secondary and the diode, when the switch is off, is the maximum load and current divided by the inverse of the duty cycle:

$$I_{SEC(OFF)} = I_{LOAD}/(1 - D_{(MAX)}) = 10A/0.72 = 13.90A \approx 15A.$$

Typical Application (Continued)

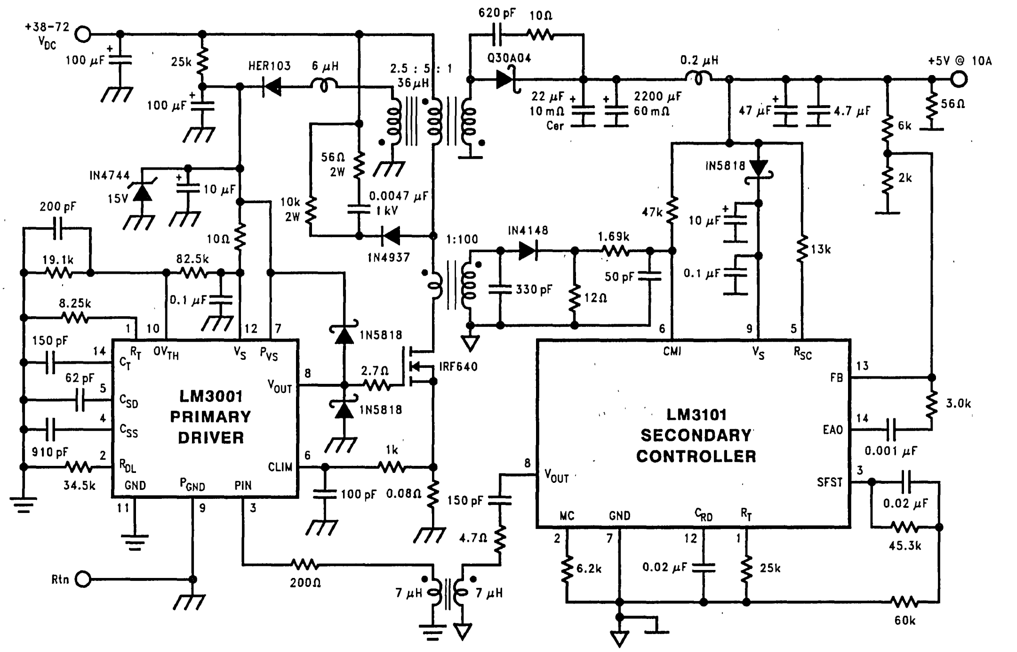

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FIGURE 13. Telecom Current Mode Flyback Regulator

The maximum average secondary current for the entire period is the maximum load current (10A).

The maximum reverse-bias voltage on the output rectifier is:

$$V_{RV} = V_{IN(MAX)} \bullet (N_S/N_P) + V_O + V_F = (185V)(1/8.5) + 5.7V = 27.42V \approx 30V.$$

A suitable diode for this circuit is the SR1606, which has a reverse voltage rating of 60V and an average current rating of 16A.

Application Hints

TELECOM CONVERTER

The schematic of a flyback regulator, used in Telecom Applications, is shown in *Figure 13*. The circuit has many of the component values that are in the offline converter. Notable exceptions are the power transformer, in which the turns-ratio and primary inductance has changed (due to the change in the input voltage range), and the Power MOSFET, which has a lower on-resistance and a lower breakdown voltage rating.

The most significant difference in the circuit design is the change in the mode of operation—from voltge mode to current mode. For current mode operation, the LM3101 Mode Control pin (MC—pin 2) is connected to ground by a 6 kΩ resistor, and the Control Mode pin (CMI—pin 6) is connected to the current sense transformer through a half-wave rectifier circuit and a low-pass filter. The filter is needed to remove the leading edge spike on the current waveform, caused by the rectifier recovery and interwinding capacitance of the power transformer.

Smaller component differences include reducing the current sensing resistor in the primary side ground path (to allow for the larger primary current), and removing a primary side snubber circuit (due to smaller peak voltages at the drain). Also, the output rectifier and Power MOSFET snubbers are modified.

Application Hints (Continued)

PULSE FEEDBACK SECTION

During steady-state operation, the LM3101 delivers pulse-width modulated signals to the feedback circuit. The feedback circuit will convert that signal into a series of AC-coupled pulse signals and apply them to the LM3001 via the pulse transformer (the first positive-edged pulse from the LM3101 will cause the LM3001 to disconnect its internal oscillator from its PWM and Output Driver circuits). The feedback pulses will trigger the LM3001 Output Driver to apply PWM drive signals to the Power MOSFET gate. The timing diagram in *Figure 14* demonstrates the feedback communication.

PULSE INTERFACE CIRCUIT

The pulse interface circuit provides isolation for the feedback circuit of the Offline Flyback Regulator. The differentiator circuit converts the PWM waveform into a pulse train. The differentiator delivers to the pulse transformer a train of 1 V_{PK}, 15 ns wide pulses. The core should have high permeability (typically 10,000) at the switching frequency to allow the transfer of energy with a very small transformer (size). This one-to-one transformer transfers the pulse train to the LM3001 via a 200Ω resistor, which is used mainly to filter noise from the system.

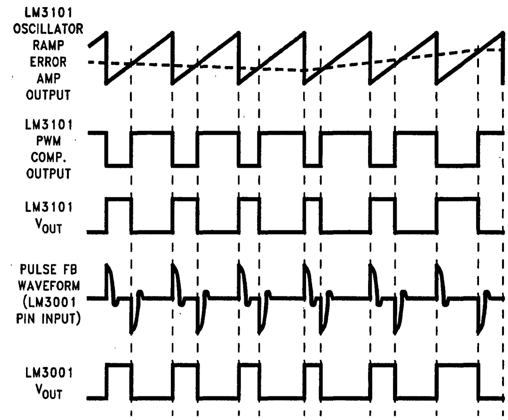

FIGURE 14. Pulse Feedback Timing Diagram

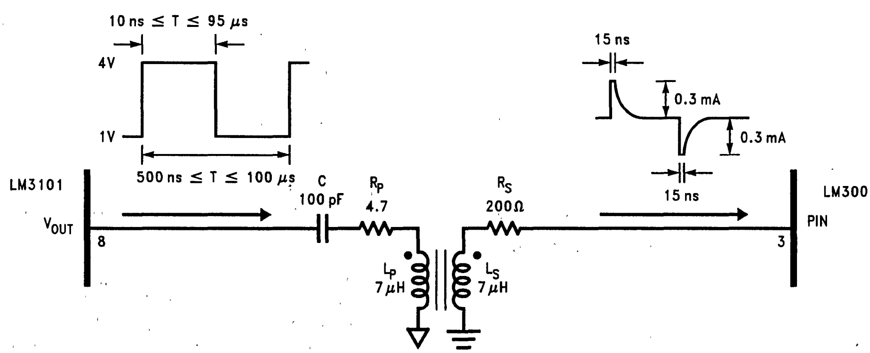

FIGURE 15. Pulse Interface Circuit

Application Hints (Continued)

CURRENT LIMIT

As previously mentioned, the primary current can be monitored by inserting a resistor between the source of the Power MOSFET and ground (See General Circuit Operation section). This generates a voltage which is compared to the reference voltages of the pulse-by-pulse current limit comparator (0.38V) or the second level current limit comparator (0.6). As an example, using a 0.1Ω will allow a peak primary current of 3.8A to activate the pulse-by-pulse current limit. A peak primary current of 6A will activate the total shutdown current limit. Also mentioned before, after the second level current limit threshold has been reached, there will be a time delay before the circuit powers up again. This shutdown delay is controlled by the Shutdown Delay capacitor (the equation for this is in the Current Limit section of the Functional Description section). In the example, a shutdown delay capacitor of 1 μF and a timing resistor of 8 kΩ produces a time delay of 10 ms before the regulator starts up again:

$$T_{SD} = 1.25 \bullet 1\ \mu F \bullet 8\ k\Omega = 10\ ms$$

The voltage generated across the current-sensing resistor needs to be filtered before it is applied to Current Limit circuit input. The filtering is needed because of current spikes, caused by the transformer leakage inductance, during the turn-on of the Power MOSFET. The filter that is used in the regulator in the General Circuit Operation section is a RC low pass filter with a 0.62 μs time constant. This filter is fast enough to allow proper operation of this function, but will screen unwanted transient signals. Note that the lower the leakage inductance the transformer has, the faster the filter can be.

Usually, it is the filter that determines the response time of the current limit activation. If the filter can be made fast enough (less than 40 ns) due to low leakage inductance, then the response time of the current limit circuit comes into play. The Current Limit Delay Time is specified at 50 ns for 100 mV of "overdrive" (the term "overdrive" means the amount of voltage over the comparator's threshold voltages). However, the speed or response time in which the current limit circuit acts and shuts down the output depends on the amount of "overdrive" caused by an excessive primary current. However, the amount of voltage driving the current limit input directly affects the speed or response time of the current limit circuit. The higher the overdrive, the faster the output is turned off. The graph below demonstrates the relationship between the overdrive voltage and the speed of the current limit circuit. An overdrive of approximately 30 mV produces a response time of 58 ns, whereas a 250 mV overdrive generates a response time of less than 50 ns.

OVERVOLTAGE THRESHOLD

The supply voltage is monitored by the Overvoltage Shutdown circuit through a resistor divider. The current needed to bias the divider is delivered by the supply voltage. It is stated in the Overvoltage/Undervoltage Shutdown section that minimum bias current to insure proper operation is approximately 10 μA. This minimum bias current sets the maximum value of the resistor in the bottom leg of the divider. While there is not a maximum bias current limit as the LM3001 is concerned, the bias current should be kept as small as possible in order that the supply current is kept small.

BYPASS CAPACITORS

Due to the high speed and currents of this IC, high frequency noise can be generated very easily, causing erratic operation of the regulator. Hence, bypass capacitors must be used to eliminate the high frequency noise from interrupting the operation of the circuit. Capacitor values of 0.1 μF and 10 μF should be selected. The bypass capacitors should be placed as near as possible to the IC.

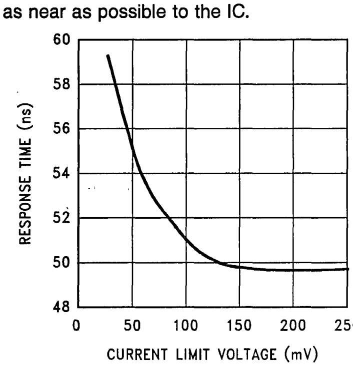

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FIGURE 16. Current Limit Response Time

Application Hints (Continued)

LM3001 WITH OPTO-COUPLER FEEDBACK

The LM3001 Primary-Side PWM Driver can also receive opto-coupler feedback as shown in *Figure 17*. A LM4041-ADJ Voltage Reference drives the opto-coupler's photodiode. The Error Amplifier of the LM4041 accepts a sample of the output voltage, from the resistor divider of R_1 and R_2, and supplies a drive current to the opto-coupler. Resistor, R_D, limits the maximum photodiode current. The RC network (C_C and $R_1 \parallel R_2$) provides compensation to the circuit.

The feedback signal from the opto-coupler is injected into the CLIM pin (pin 6). The opto-coupler's phototransistor, in an emitter follower configuration, supplies a current that produces a DC offset voltage at pin 6. A resistor, R_{CS}, generates a voltage proportional to the primary or switch current. These voltages are summed at pin 6. Referring to the LM3001 Block Diagram (on pg. 1), this summing voltage is compared to a 380 mV reference by the Pulse-by-Pulse Current Limit Comparator (see *Figure 18*). The R_F–C_F network provides filtering of the leading edge spikes.

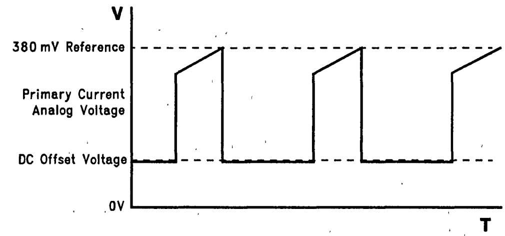

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FIGURE 18. Opto-Coupler Feedback Waveforms

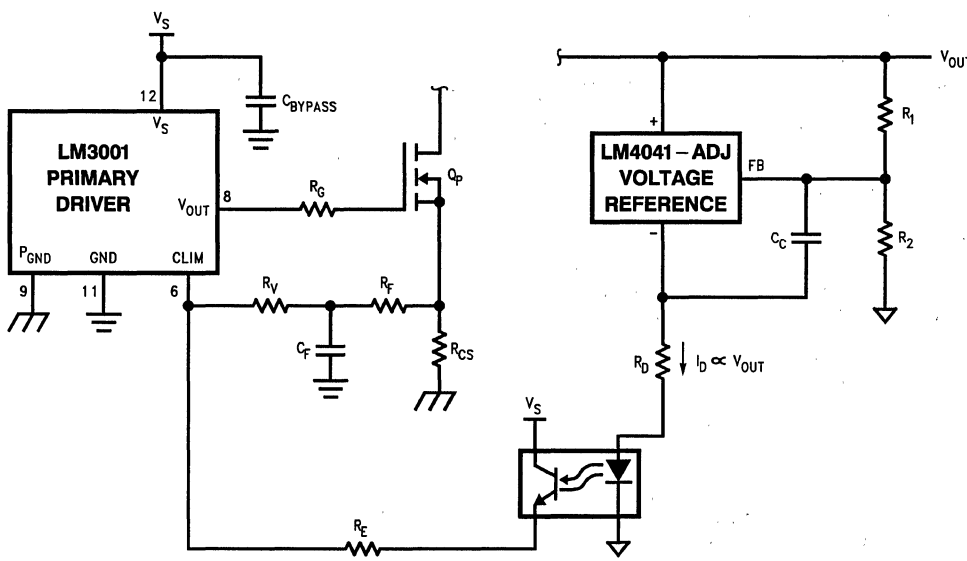

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FIGURE 17. Opto-Coupler Feedback Circuit

Application Hints (Continued)

LM3001 PCB LAYOUT

Due to the high speed of the LM3001 output driver, careful layout of the printed circuit board is essential. The ground plane should be divided into a power ground section (see *Figure 19*), connected to the PGND pin (pin 9) and an analog signal ground region, connected to the GND pin (pin 11). The separate ground sections are connected internally. The power ground region should have connected to it all paths carrying the high di/dt currents, such as the input return and the input capacitor negative lead.

High frequency bypassing is also a necessity. A 0.1 μF ceramic capacitor should be inserted between the output driver supply pin (P_{VS} − pin 7) and the P_{GND} pin. The analog signal supply pin (pin 12) should also be bypassed to Its GND pin (V_S − pin 11) wlth a 0.1 μF ceramic capacitor. The bypass capacitors should be placed as near as possible to the IC, with the shortest possible lead length.

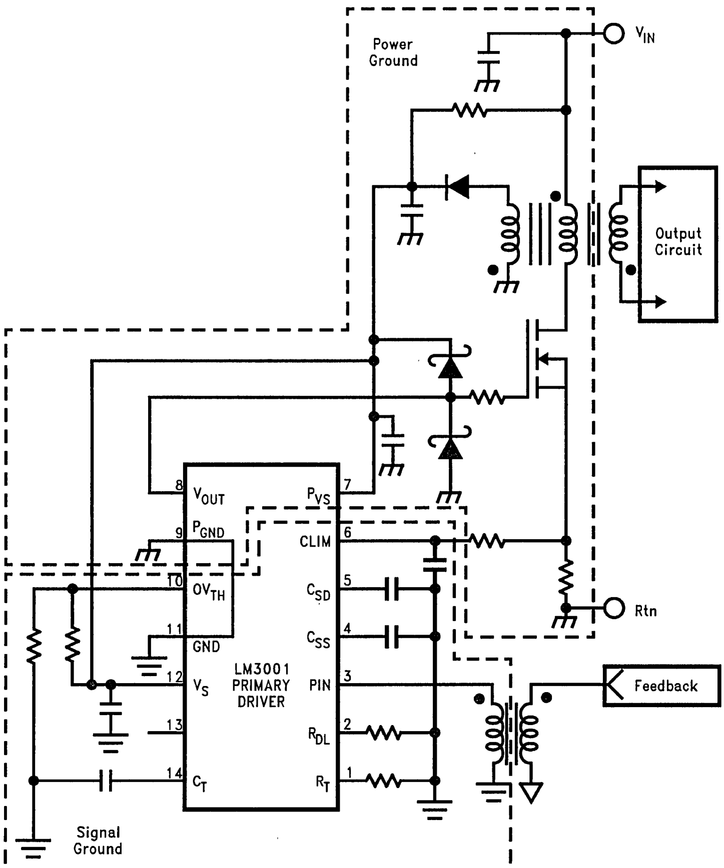

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FIGURE 19. LM3001 PCB Layout

National Semiconductor

LM3101 Secondary-Side PWM Controller

General Description

The LM3101 is a precision high-speed PWM controller. It is designed to provide secondary-side feedback for offline Switch-Mode Power Supplies (SMPS) using pulse communication to the primary-side driver. The LM3101 is applicable in all of the popular converter topologies such as flyback or forward.

The LM3101 combined with its companion LM3001 Primary-Side Driver forms a regulator chip-set that provides precision control of offline or other isolated DC/DC converters. The communication is realized between the two chips by a small pulse transformer, with one or two turns on its primary and secondary. This type of communication does not introduce any poles or zeroes in the control loop and yields the fastest possible loop response for the isolated switching regulator.

The secondary-side controller contains a precision 1.242V reference, an error amplifier, and a trimmed oscillator which is programmed with a single resistor. The LM3101 can realize voltage, current or charge mode control. Power supply monitor features include power-on reset with programmable delay and overvoltage protection.

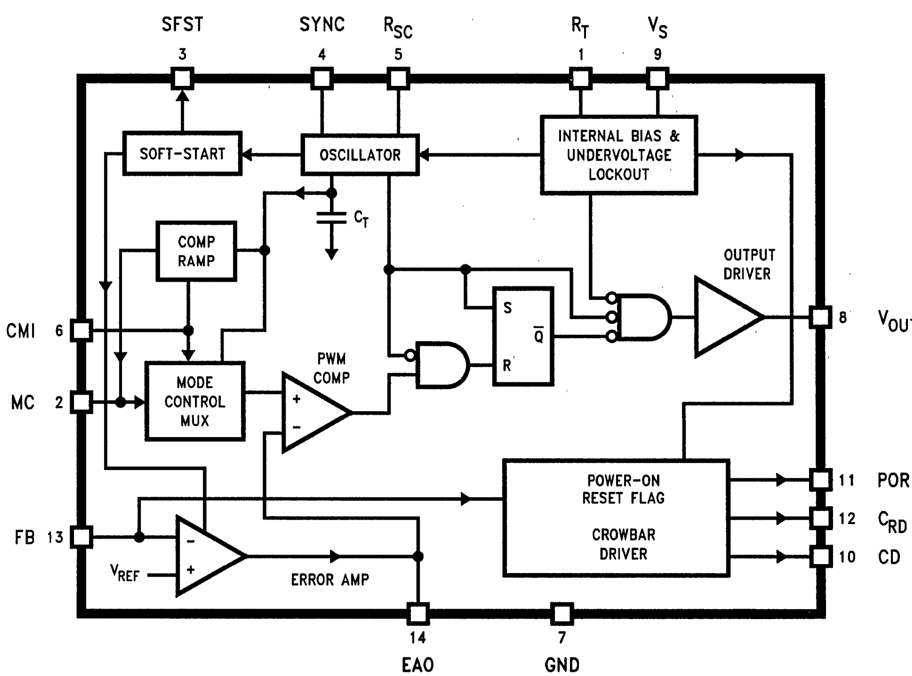
Features

- ±2% precision voltage reference
- Wide-bandwidth (8 MHz) error amplifier
- External synchronization
- Frequency shift during an output short circuit
- Power-on reset flag with programmable delay
- Overvoltage crowbar trigger circuit
- Ramped reference Soft-Start
- Operation beyond 1 MHz
- Voltage, current, or charge mode control

Typical Applications

- Isolated offline switching power supplies
- Isolated DC/DC power converters
- Flyback regulator
- Forward converter

Block Diagram



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Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V_S)	16V
Junction Temperature Range	$-65°C \leq T_J \leq +150°C$
ESD	1 kV
Lead Temperature (Soldering, 5 sec.)	260°C

Operating Ratings

Supply Voltage	$4.5V \leq V_S \leq 15V$
Junction Temperature Range	$-40°C \leq T_J \leq +125°C$

Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those in **bold typeface** apply over full **Operating Temperature Range**. Pin 2, MC, is connected to V_S by a 5 kΩ resistor—this selects voltage mode control operation. Unless otherwise specified, $T_A = 25°C$, $V_S = 5V$, $R_{FS} = 25$ kΩ ($F_O = 500$ kHz).

Symbol	Parameter	Conditions	Min	Typ	Max	Units
REFERENCE SECTION (Note 2)						
V_{REF}	Reference Voltage		1.230 **1.217**	1.242	1.254 **1.266**	V
$\Delta V_{REF}/\Delta V_S$	Line Regulation	$4.5V \leq V_S \leq 15V$		0.01	0.03	%/V
$\Delta V_{REF}/\Delta T$	Temperature Stability (Note 3)	$-40°C \leq T_J \leq +125°C$		**0.003**		%/°C
ERROR AMPLIFIER SECTION						
A_{VOL}	Open Loop Voltage Gain		75	90		dB
I_B	Input Bias Current		−1.0 **−2.0**	−0.5		μA
GBW	Gain-Bandwidth Product	$F_{TEST} = 100$ kHz	4.5	8		MHz
θ_M	Phase Margin	$A_V = 1$		52		Deg
SR	Slew Rate		2.5	6		V/μs
OSCILLATOR SECTION						
F_O	Oscillator Frequency (Note 4)	$R_T = 25$ kΩ	450 **425**	500	550 **575**	kHz
		$R_T = 12.5$ kΩ	0.88 **0.85**	1.0	1.12 **1.15**	MHz
F_{SC}	Oscillator Frequency in Output Short Circuit	$R_T = 25$ kΩ ($F_O = 500$ kHz), $R_{SC} = 13$ kΩ (Note 5)	120	187	260	kHz
		$R_T = 12.5$ kΩ ($F_O = 1$ MHz), $R_{SC} = 6.34$ kΩ (Note 5)	210	335	470	kHz
$\Delta F_O/\Delta T$	Temperature Stability	(Note 3)		**0.1**		%/°C
$\Delta F_O/\Delta V_S$	Line Stability	$4.5V \leq V_S \leq 15V$			0.9	%/V
V_{SYNC}	Synch Signal Amplitude	AC Coupled, Negative Edge Trigger (Note 6)	1.5 **2**			V_{PP}
$\Delta I_{COMP}/\Delta t$	Compensation Current Ramp Slope	$R_T = 25$ kΩ $R_{MC} = 5$ kΩ (Note 7)	155	208	260	μA/μs

Electrical Characteristics

Specifications with standard typeface are for $T_J = 25°C$, and those in **bold typeface** apply over full **Operating Temperature Range**. Pin 2, MC is connected to V_S by a 5 kΩ resistor—this selects voltage mode control operation. Unless otherwise specified, $T_A = 25°C$, $V_S = 5V$, $R_{FS} = 25\ k\Omega$ ($F_O = 500$ kHz). (Continued)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
PULSE WIDTH MODULATOR SECTION						
D_{MAX}	Maximum Duty Cycle	$F_O = 500$ kHz	88 **84**	92		%
		$F_O = 1$ MHz	84 **80**	90		%
D_{MIN}	Minimum Duty Cycle (Note 8)	$F_O = 500$ kHz		2.5	6 **8**	%
		$F_O = 1$ MHz		4	10 **12**	%
t_{dCS}	Current Sense Time Delay			75	100	ns
OUTPUT SECTION						
t_R	Rise Time	$C_L = 100$ pF		20		ns
t_F	Fall Time	$C_L = 100$ pF		30		ns
V_{OL}	Output Voltage	$I_L = 4$ mA Sinking $F_O = 100$ kHz		1.3	1.4 **1.6**	V
V_{OH}	Output Voltage	$I_L = 4$ mA Sourcing $F_O = 100$ kHz	3.6 **3.4**	3.8		V
OVER-VOLTAGE CROWBAR TRIGGER SECTION						
$\%V_{THC}$	Relative Trigger Threshold	Relative to Nominal Feedback Pin Voltage (Note 10)	18 **16**	20	22 **24**	%
I_{CD}	Crowbar Driver Output Current	$R_{CD} = 10\Omega$	170	240		mA
t_{CD}	Crowbar Delay	$R_{CD} = 10\Omega$, $V_{CD} = 1V$		400		ns
t_C	Minimum Trigger Pulse Width	(Note 11)		400		ns
POWER-ON RESET FLAG SECTION						
$\%V_{THP}$	Relative POR Trigger Threshold	Relative to Nominal Feedback Pin Voltage (Note 10)	−6 **−6.5**	−4.5	−3 **−2.5**	%
V_{POR}	POR Output Voltage	$V_{FB} = 1.11V$ $I_{POR} = 1.6$ mA		0.2	0.5	V
V_{SM}	Minimum Supply Voltage (Note 12)	$V_{POR} \le 0.5V$ $I_{POR} = 1.6$ mA		1	1.2	V
t_{DR}	Power-On Reset Delay	$C_{RD} = 2$ nF	65 **50**	120	185 **265**	μs
UNDER-VOLTAGE LOCKOUT SECTION						
V_{UV}	Start-Up Threshold	(Note 13)	3.65	3.92	4.20	V
V_{UVH}	Threshold Hysteresis			300		mV
SUPPLY SECTION						
I_S	Supply Current	$V_S = 5V$		11	16 **20**	mA
		$4.5V \le V_S \le 15V$		15	24 **28**	mA
I_{SFST}	Soft-Start Current (Note 14)	$V_{SFST} = 0V$	14.5	19.5	20.5	μA

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics.

Note 2: The reference voltage is measured at the error amplifier's output with the error amplifier connected as a non-inverting amplifier with a gain of one.

Note 3: The temperature coefficients of V_{REF} or F_O are defined as the worst-case ΔV_{REF} or ΔF_O measured at Specified Temperatures divided by the total span of the Specified Temperture Range (see graphs). There is no guarantee that the Specified Temperatures are exactly at the minimum of maximum deviation.

Note 4: The frequency of the internal oscillator is set by connecting a resistor, R_T, from pin 1 to ground. See detailed description of this feature in the Pin-by-Pin Description section or the Functional Description of this datasheet.

Note 5: A resistor, R_{SC}, is connected from pin 5 to the regulator's output. See detailed description of this feature in the Pin-by-Pin Description section or the Functional Description section of this datasheet.

Note 6: For this test, the frequency of synchronization, F_{SYNC}, is 600 kHz, C_{SYNC} is 220 pF, and R_{SYNC} is 1 kΩ. The internal oscillator will synchronize to an AC signal that is 1.1 to 1.5 times the free running oscillator frequency, F_O. See Functional Description section or Pin-by-Pin Description section for more detail on synchronization.

Note 7: I_{COMP} is sourced from pin 6 (CMI). See Functional Description section or Pin-by-Pin Description section for more detail on current mode operation.

Note 8: Minimum duty cycle is the smallest duty cycle that can be produced by the LM3101 in a given oscillator period. The controller can operate with effectively zero duty cycle—it skips cycles if the regulation cannot be maintained with the minimum duty cycle. This means that the output voltage of the switching converter is regulated down to no load.

Note 9: The current sense time delay is the time span between an input applied to the CMI pin (pin 6) and the change of state of V_{OUT} (pin 8) due to the input.

Note 10: Both these specifications, $\%V_{THC}$ and $\%V_{THP}$, are relative to the nominal feedback voltage, V_{FB}, by the factor: $[(V_{TH}-V_{FB})/V_{FB}]$.

Note 11: An internal delay circuit prevents triggering of the overvoltage crowbar circuit, for pulse widths less than 400 ns, to ensure noise immunity.

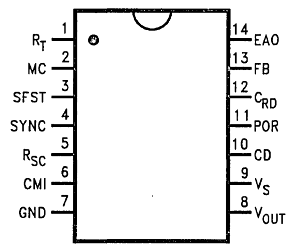
Note 12: This is the minimum supply voltage for which the power-on reset flag will continue to be valid (low).

Note 13: For $V_S < V_{UV}$, the output is off—it is in a high-impedance state.

Note 14: A resistor/capacitor circuit is normally connected from the soft start circuit, pin 3, to ground. The circuit provides a slow or "soft" start of the IC by slowly ramping the reference voltage from a lower initial value set by the resistor to its normal operating value. See detailed description of this feature in the Pin-by-Pin Description section or the Functional Description section of this datasheet.

Connection Diagram and Ordering Information

14-Lead Package
Top View



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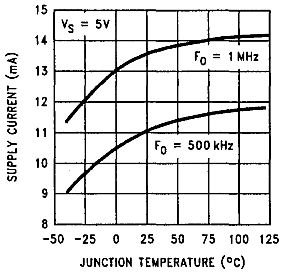
For Surface Mount Package
Order Number LM3101M
See NS Package Number M14B
For DIP Package
Order Number LM3101N
See NS Package Number N14A

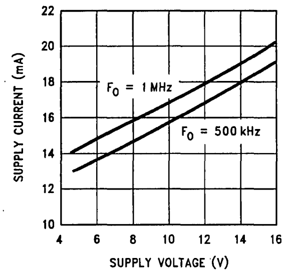
Typical Performance Characteristics

For F_O = 500 kHz, R_T = 25 kΩ
For F_O = 1 MHz, R_T = 12.5 kΩ

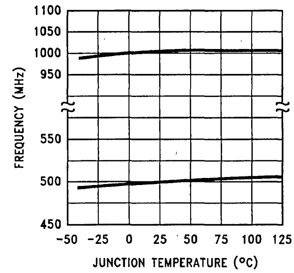
Supply Current



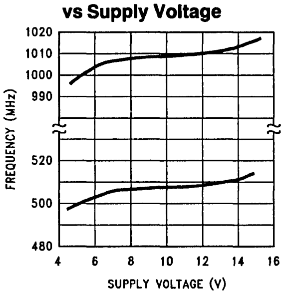
Supply Current vs Supply Voltage



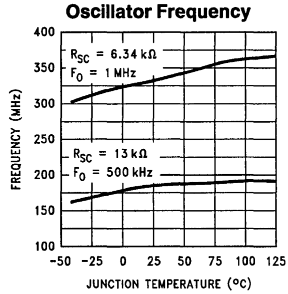
Oscillator Frequency



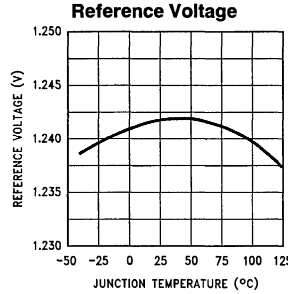
Oscillator Frequency vs Supply Voltage



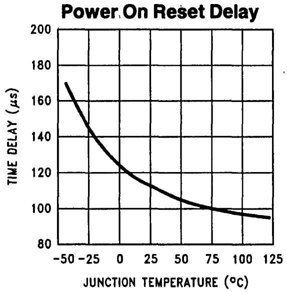
Short Circuit Oscillator Frequency



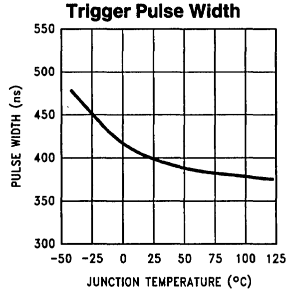
Reference Voltage



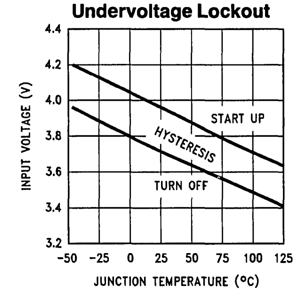
Power On Reset Delay



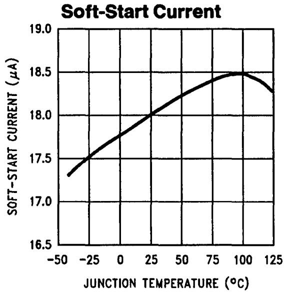
Minimum Over-Voltage Trigger Pulse Width



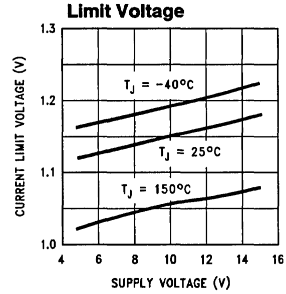
Undervoltage Lockout



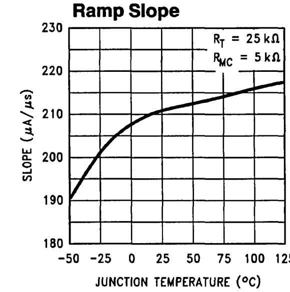
Soft-Start Current



Current Mode Input Limit Voltage



Compensation Current Ramp Slope



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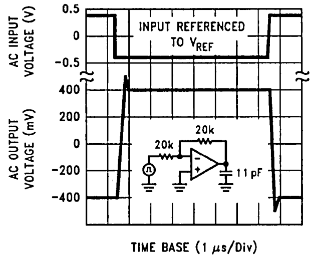
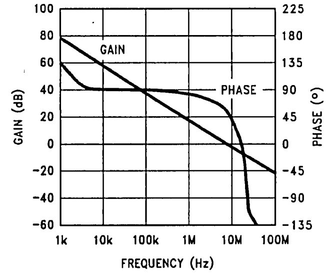
Typical Performance Characteristics (Continued)

Error Amplifier Step Response



Error Amplifier Open Loop Frequency Response



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Pin-by-Pin Description

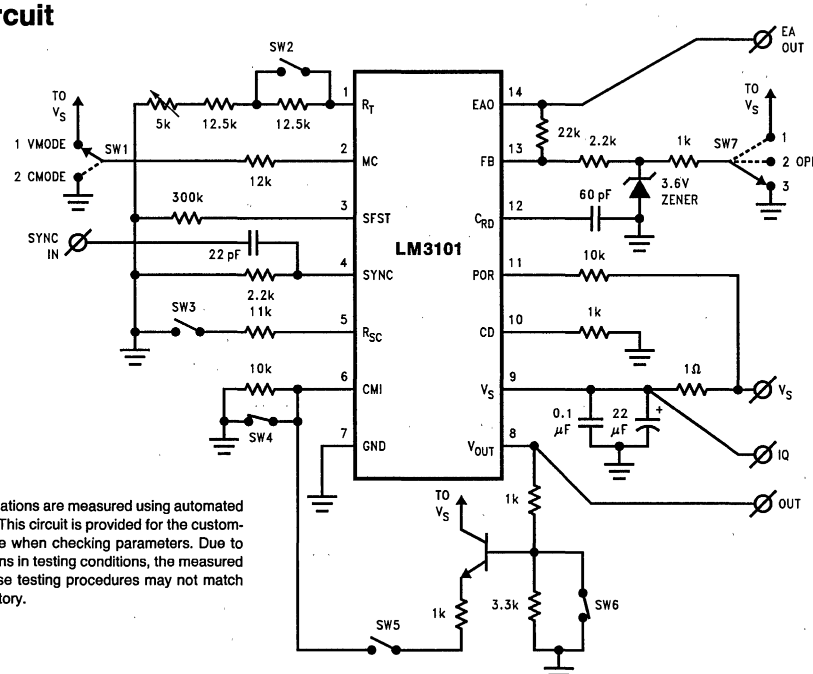
Pin #	Symbol	Function	Description
1	R_T	Frequency Setting Resistor	Connecting a resistor, R_T, between this pin and ground programs the frequency—from 50 kHz to 1 MHz—by the following equation: $R_T = 0.25/(F_O \bullet 20 \bullet 10^{-12})$ [F, Hz, Ω]. R_T also sets the internal bias current, which affects the operation of several sub-circuits within the IC.
2	MC	Mode Control	For voltage mode operation, connect a resistor, R_{MC}, from this pin to the supply voltage. For current mode operation, this pin is tied to ground via resistor R_{MC}. A current is sourced from the pin through the resistor such that it sets the slope of the compensating ramp, I_{COMP}, according to the equation: $\Delta I_{COMP}/\Delta T = 24 \bullet 10^3/(R_T \bullet R_{MC})$ [μA/μs, Ω].
3	SFST	Soft-Start Control	A series resistor-capacitor network tied from this pin to ground provides Soft-Start capability. The current charging the capacitor is: $I_{SFST} = 0.45/R_T$. [A, V, Ω]. Leave this pin open if it is not used.
4	SYNC	Synchronization Signal Input	An external negative pulse fed to this input will synchronize the internal oscillator. The frequency range of the external signal should be between 1.1 to 1.5 times the free-running frequency. Connect this pin to ground if it is not used.
5	R_{SC}	Short Circuit Frequency Shift Control	A resistor, R_{SC}, connected from this pin to the regulator output, determines the oscillator frequency during a short circuit by the formula: $R_{SC} = 0.09/[(0.267/R_T) - F_{SC} \bullet 20 \bullet^{-12}]$ [F, Hz, Ω]. or, alternately, $F_{SC} = (1/20 \bullet 10^{-12}) \bullet [(0.267/R_T) - (0.09/R_{SC})]$ [F, Hz, Ω]. The recommended minimum ratio of short circuit frequency to oscillator frequency is one-third (nominal).
6	CMI	Current Mode Input	An analog voltage signal, proportional to the transformer primary current, fed to this input results in current mode operation. Connect this pin directly to ground if selecting voltage mode operation.
7	GND	Ground	Ground.
8	V_{OUT}	Output	Output pin. It produces a PWM pulse train that is fed back to the primary side of the regulator, via a pulse transformer.
9	V_S	Supply Voltage	Supply voltage.
10	CD	Crowbar Output Driver	This pin delivers a current when an overvoltage condition occurs on the output. It can be used to fire an external SCR to crowbar the output. Leave the pin open if not used.

Pin-by-Pin Description (Continued)

Pin #	Symbol	Function	Description
11	POR	Power-On Reset Flag	This open-collector output is driven low when either the supply voltage falls below the Undervoltage Lockout Threshold Voltage or the output voltage is less than the Power-on Reset Threshold Voltage. Leave the pin open if not used.
12	C_{RD}	Reset Delay Capacitor	Adding a capacitor between this pin and ground sets the power-on reset flag delay time according to the following formula: $C_{RD} = T_{DR}/60 \bullet 10^3$ [F, s, Ω]. Leave the pin open if not used. The POR flag will still operate if this function is not used.
13	FB	Feedback Input	A sample of the output voltage, via a resistor divider, is fed back into this pin, which is the inverting input of the error amplifier.
14	EAO	Error Amplifier Output	Error Amplifier Output. The output can source 1.5 mA typically and sink 300 μA typically. This pin is primarily used for loop compensation.

Note: Pins 1, 2, 4, 5, and 10 are internally clamped by a 5.6V zener diode. Do not force a voltage larger than 5V on these pins without a resistor to limit the current to below 1 mA. All other pins are limited to the supply voltage.

Test Circuit



LM3101 specifications are measured using automated test equipment. This circuit is provided for the customer's convenience when checking parameters. Due to possible variations in testing conditions, the measured values from these testing procedures may not match those of the factory.

TL/H/11436-5

This test circuit is for exercising the LM3101 functions and measuring its specifications. With the switch positions shown, the supply current should measure 15 mA (typical) for a supply voltage of 15V. Changing the supply voltage to 5V and opening SW6 on the V_{OUT} pin should make the supply current 11 mA (typical). Changing SW7 to the supply voltage will shutdown the LM3101 output.

To test the oscillator section, adjust the 5 kΩ potentiometer at the R_T pin such that the oscillator frequency is approximately 500 kHz. Switch SW2 to obtain a 1 MHz frequency (typical). The maximum duty cycle of 92% typically can also be measured. Closing SW3 on pin R_{SC} and putting SW7 (pin FB) in the open position will change the oscillator frequency to approximately 180 kHz.

Switching the MC pin, SW1, to ground and opening SW4, the CMI pin, will put the device in current mode control. To measure the current sense time delay (typically 75 ns), close SW5 (connected to the CMI pin) and open SW6.

Functional Description

Oscillator/Synchronization Section

The operating frequency is set by a single resistor connected from the R_T pin (pin 1) to ground, according to the equation:

$$F_O = 0.25/(R_T \bullet 20\text{ pF}) \qquad [\text{kHz}, \Omega].$$

Inserting a 25 kΩ for R_T sets the oscillator frequency at 500 kHz.

The oscillator is capable of synchronizing to an external source. To synchronize the oscillator, an external source is connected to the SYNC pin (pin 4) via a differentiator (see *Figure 1*). The external source delivers a pulse train to the differentiator, which converts this signal into an AC-coupled signal. The negative-edge of this signal, applied to the SYNC pin, will control the oscillator, and thus set the operating frequency. The recommended values for R_{SYNC} and C_{SYNC} are as follows:

$$R_{SYNC} = 1\text{ k}\Omega\text{ (typical)}$$

and

$$C_{SYNC} \bullet R_{SYNC} > 1/(8 \bullet F_{SYNC}) \quad [\text{F}, \Omega, \text{kHz}].$$

To synchronize to a 600 kHz external source, and using a R_{SYNC} of 1 kΩ, the C_{SYNC} must be:

$$C_{SYNC} > 1/(8 \bullet R_{SYNC} \bullet F_{SYNC}) = 1/(8 \bullet 1\text{ k}\Omega \bullet 600\text{ kHz}) = 208\text{ pF} \approx 220\text{ pF}.$$

The oscillator frequency should range from 67% to 90% of the synchronization frequency. In the above example, the oscillator frequency can be between 400 kHz and 540 kHz.

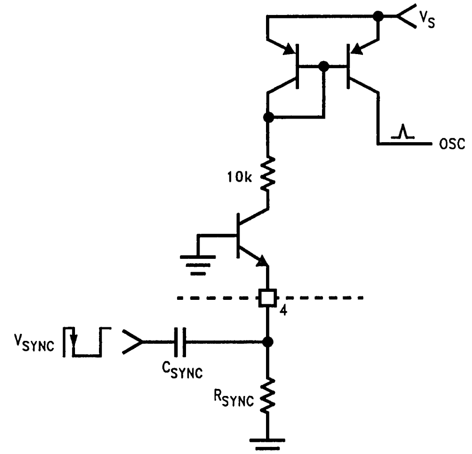


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FIGURE 1. Simplified Version of the Synchronization Circuit

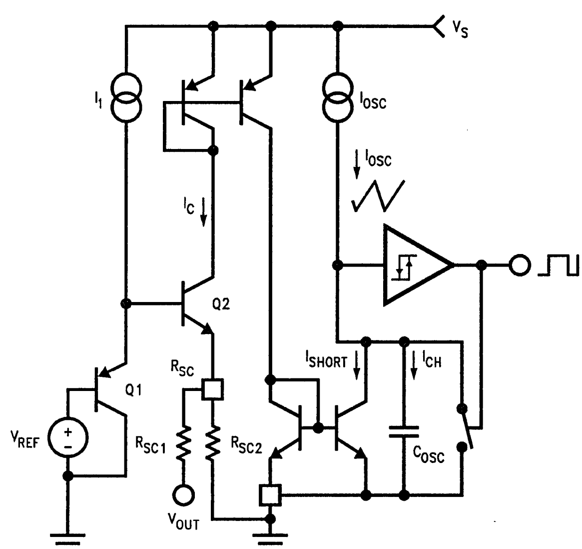

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FIGURE 2. Simplified Version of the Short Circuit Frequency Shift Circuit

Functional Description (Continued)

Frequency-Shift Circuit

The LM3101 has the ability to gradually reduce its operating frequency during an output short circuit. The amount that the frequency shifts and the output voltage threshold determining where the frequency starts to shift are both programmed by two external resistors, R_{SC1} and R_{SC2}, connected to the pin R_{SC} (pin 5).

A simplified internal schematic of the Frequency Shift Circuit is shown in *Figure 2*. The oscillator operates at its nominal frequency as long as the voltage at the emitter of the transistor Q2 is higher than the internal reference voltage, V_{REF}. Q2 emitter voltage is the output voltage, V_{OUT}, scaled down by the resistor divider:

$$V_{RSC} = V_{Q2E} = V_{OUT} \bullet R_{SC2}/(R_{SC1} + R_{SC2}) \quad [V, \Omega]$$

where $V_{Q2} > V_{REF}$ (1.24V) for normal operation.

If V_{OUT} drops, due to an overload, a current starts to flow through Q2. A cascoded current mirror causes one-tenth of this current to be subtracted from the timing capacitor charge current. Reducing the timing capacitor charge current results in decreasing the oscillator frequency. The breakpoint where the frequency-shift starts is programmed by the ratio of the two resistors:

$$V_{OUT(SC)} = 1.24V \bullet [1 + (R_{SC1}/R_{SC2})] \quad [V, \Omega].$$

The typical short circuit frequency is set by the following equations:

$$F_{SC} = [I_{OSC} - 0.1 \bullet \{((1.24V - V_{OUT(SC)})/R_{SC1}) + (1.24V/R_{SC2})\}]\ [1/(20\ pF \bullet 1.24V)] \quad [kHz, \mu A, V, \Omega]$$

where $I_{OSC} = 0.25 \bullet (1.24V/R_T)$.

For example, say 140 kΩ and 100 kΩ were selected for R_{SC1} and R_{SC2}, respectively, with R_T set to 25 kΩ. Then the output voltage level where the frequency starts to decay is:

$$V_{OUT(CL)} = 1.24V \bullet [1 + (140\ k\Omega/100\ k\Omega)] \cong 3.0V,$$

and the short circuit frequency is ($I_{OSC} = 12.4\ \mu A$ and assuming V_{OUT} is 0V during a short circuit):

$$F_{SC} = [12.4\ \mu A - 0.1 \bullet \{(1.24V/140\ k\Omega) + (1.24V/100\ k\Omega)\}]\ [1/(20\ pF \bullet 1.24V)] = 414.3\ kHz \cong 415\ kHz.$$

If R_{SC2} is omitted, the frequency starts to shift when V_{OUT} drops below V_{REF}. The short circuit frequency equation then becomes:

$$F_{SC} = (1/20\ pF) \bullet [(0.267/R_T) - (0.09/R_{SC1})] \quad [kHz, \Omega]$$

$$\downarrow$$

$$R_{SC1} = 0.09/[(0.267/R_T) - (F_{SC} \bullet 20\ pF)] \quad [\Omega, kHz].$$

Selecting a short-circuit frequency that is greater than one-third the operating frequency or 188 kHz leads to a resistor value of:

$$R_{SC1} = 0.09/[(0.267/25\ k\Omega) - (188\ kHz \bullet 20\ pF)] = 13\ k\Omega.$$

Mode Control

The LM3101 can operate in voltage mode, current mode, or charge mode control. Two multi-function pins are involved in setting the operating mode, the Mode Control pin (MC - pin 2) and the Current Mode Input pin (CMI - pin 6). *Figure 3* shows the simplified schematic diagram of the mode control circuit. To operate with voltage mode control, the MC pin is pulled high with a resistor (typically 3 kΩ), and the CMI pin is connected to ground. The mode comparator senses the MC pin voltage and sets the mode control multiplexer to voltage mode control. Notice that there is a 5.6V zener diode clamping the MC pin voltage.

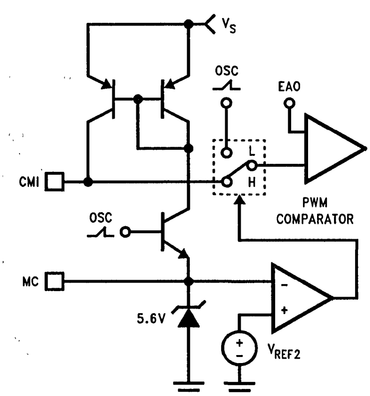

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FIGURE 3. Simplified Version of the Mode Control Circuit

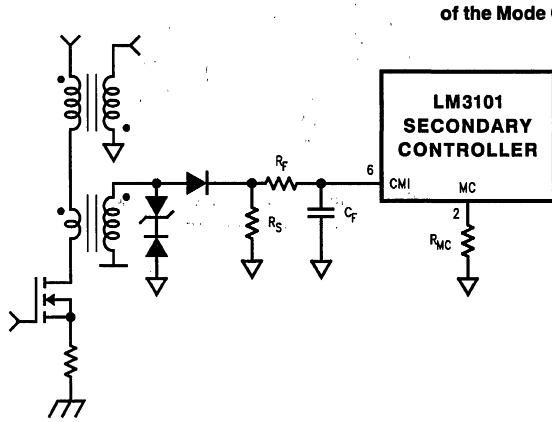

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FIGURE 4. Current Mode Sense Circuit

Functional Description (Continued)

To operate under current mode or charge mode control, insert a resistor, R_{MC}, between the MC pin and ground, and connect the CMI pin to the Current Mode Sense Circuit (see *Figure 4*). At the MC pin, a voltage, proportional to the oscillator ramp voltage, develops (see *Figure 3*). The voltage ramp applied to R_{MC} generates a current ramp, which is duplicated on the CMI pin due to the current mirror. The current ramp, which flows, out of the CMI pin to the resistor, R_F, is the compensation ramp, needed to stabilize converters operating at duty cycles above 50%. The slope of the compensating ramp can be scaled by R_F, which is connected between the CMI pin and the terminating resistor, R_S, of the current sense transformer. In all practical cases, R_F will be much greater than R_S. For both control modes, the current ramp provides slope compensation according to the equation:

$$\Delta I_{COMP}/\Delta t = 24 \bullet 10^3/(R_T \bullet R_{MC}) \quad [\mu A/\mu s, \Omega].$$

So, with R_T equal 25 kΩ and R_{MC} equal 6 kΩ, the compensation ramp slope is:

$$\Delta I_{COMP}/\Delta t = 24 \bullet 10^3/(25\ k\Omega \bullet 6\ k\Omega) = 160\ \mu A/\mu s.$$

The resistor R_F together with the capacitor C_F serves as an RC filter for the leading edge spike of the current sense waveform (the spike is caused by the output rectifier reverse recovery and/or the winding capacitance of the power transformer).

CHARGE MODE CONTROL

Under charge mode control, the current sense transformer drives a capacitor, C_1, that integrates the sensed switch current on a cycle-by-cycle basis. *Figure 5* shows the integrating current sense circuitry and the simplified details of the associated internal circuitry of the LM3101. Transistor Q_1 discharges the integrating capacitor C_1 once every switch cycle—during the switch off-time (Q1 can provide up to 20 mA of discharge current). Charge mode control yields the fastest average current control loop.

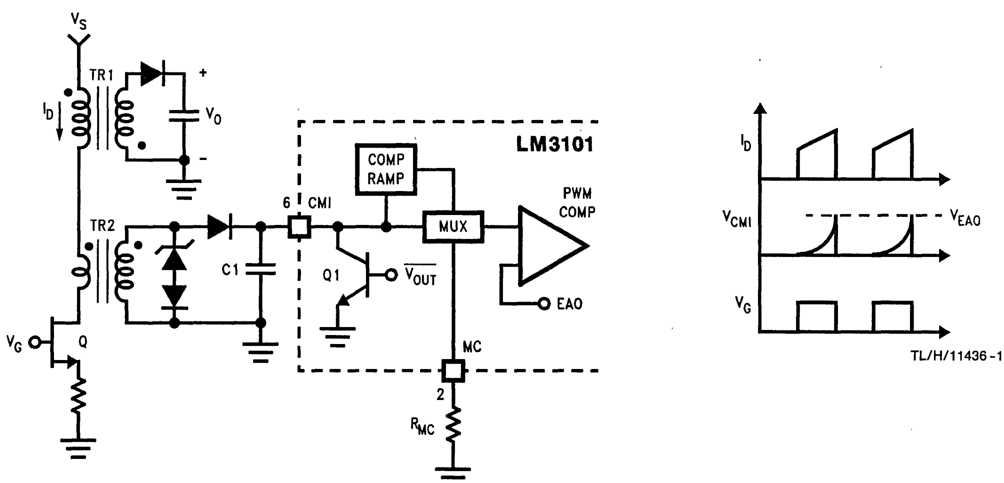

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FIGURE 5. Charge Mode Operation

Functional Description (Continued)

Soft-Start Section

Soft-Start is accomplished by gradually increasing the reference voltage during start-up. The gradual increase is implemented by charging the Soft-Start capacitor, C_{SFST}, on pin 3 (the SFST pin). The charging current is set according to the following equation:

$$I_{SFST} = 0.45/R_T \quad [A, \Omega].$$

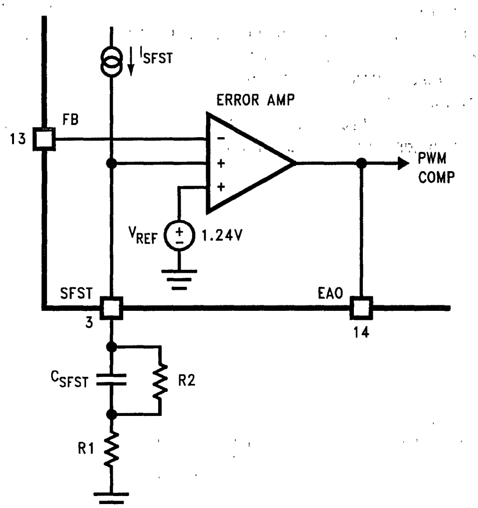


FIGURE 6. Soft-Start Block Diagram

Typically, I_{SFST} starts to flow when the supply voltage is raised above 3V.

As shown in *Figure 6*, at the beginning of start-up, C_{SFST} is not charged up, and the SFST pin pulls down the reference voltage from its nominal value to:

$$V_{SFSTO} = I_{SFST} \bullet R_1 \quad [V, A, \Omega].$$

V_{SFSTO} is designed to be 85% of the nominal reference voltage. The reference voltage rises smoothly from V_{SFSTO} to its nominal value as C_{SFST} charges up. When C_{SFST} charges up completely, the reference voltage is at its nominal value, start-up is over and steady-state operation begins.

The discharge time of C_{SFST} is set by the RC network as:

$$t_{DS} = 5 \bullet C_{SFST} \bullet R_2.$$

This is the time delay required to prepare the Soft-Start cycle after the LM3101 and the entire regulator has been turned off. R_2 must be large enough so that the final value of V_{SFST} is greater than the reference voltage:

$$V_{SFST} = I_{SFST} \bullet (R_1 + R_2) \geq 1.24V \quad [V, A, \Omega].$$

Power Supply Monitor Functions

The LM3101 provides two monitor functions, a power-on reset flag with programmable delay, and a crowbar driver output for overvoltage conditions.

POWER-ON RESET

The power-on reset (POR) flag monitors the output voltage via the feedback pin (FB - pin 13). The POR flag will go low after the output voltage reaches 95% of its nominal value, and the subsequent programmed delay has passed. The POR flag pin (pin 11) is an open-collector pin which needs an external resistor to pull it up. This pin is valid with supply voltages as low as 1V while sinking 1.6 mA.

To program the reset delay, connect an external capacitor to the C_{RD} pin (pin 12). The practical range of delay is from 10 μs to 5 ms, and follows the equation:

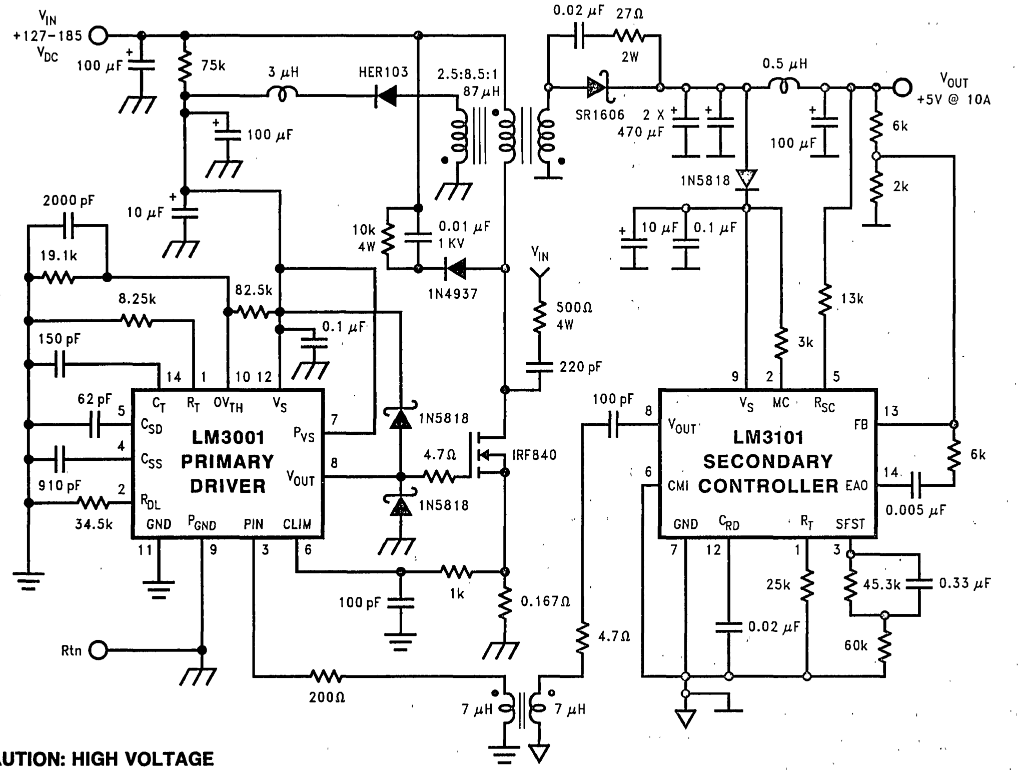
$$T_{RD} = C_{RD} \bullet 60 \bullet 10^3 \quad [s, F].$$

For a power-on reset delay of 120 μs, the reset delay capacitor must be 0.002 μF.

CROWBAR DRIVER OUTPUT

The second monitor function is a crowbar driver output (CD–pin 10). If the output voltage gets higher than 120% of its nominal value, the CD pin can supply more than 200 mA to an external SCR trigger input. The SCR will fire, shorting the regulator output and saving the load circuitry from excessive supply voltage.

Typical Applications



CAUTION: HIGH VOLTAGE
Handle with Extreme Care

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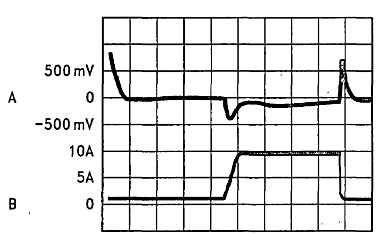
FIGURE 7. Offline Voltage Mode Flyback Regulator

This 500 kHz Offline Converter delivers 50W (5V @ 10A) from an input supply ranging from 90 VAC to 132 VAC (127 VDC to 185 VDC). The regulator achieves a line regulation of 0.06% and a load regulation of 0.05%. A 0.5 µH inductor and 100 µF capacitor form an LC filter that reduces the output ripple voltage to 50 mV. As shown in *Figure 8*, the regulator can respond to a "step" change in load current from 1A to 10A in about 12 µs. The efficiency of the converter is approximately 80% at full load.



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A: Output Voltage, 500 mV/div., AC Coupled
B: Load Current, 5A/div.
Horizontal Time Base: 20 µs/div.

FIGURE 8. Load Step Response

Typical Applications (Continued)

POWER STAGE OPERATION

The LM3001 Primary-Side PWM Driver sends a pulse-width-modulated signal (via pin 8) to a power switch, which in turn, drives a power transformer.

The power switch used in this case is an IRF840 Power MOSFET. It is an N-channel enhancement mode device that has a drain-to-source voltage (V_{DSS}) rating of 500V and a pulsed drain current (I_{DM}) rating of 32A. Even though the Power MOFSET has a high V_{DSS}, snubber circuits are needed to limit the drain voltage.

The power transformer has a primary inductance of 87 µH. The primary-to-secondary turns ratio is 8.5 to 1 and the secondary-to-tertiary turns ratio is 1 to 2.5. The tertiary winding delivers the LM3001 supply voltage (pins 7 and 12) to the primary-side driver.

There is an internal Overvoltage Threshold circuit (pin 10) monitoring the input voltage via a resistor divider. The overvoltage trip point is 3.3V typically. With the resistor values shown, the maximum supply voltage is approximately 17.5V.

The output rectifier, an SR1606, delivers the secondary current to the output. The SR1606 is specified for 16A forward current, 60V reverse breakdown voltage, and comes to a TO220-AB package. Since the SR1606 dissipates 7W to 8W at full load, it requires a heatsink. An RC snubber is placed in parallel to reduce the ringing voltage caused by the output rectifier turning off during the discontinous mode of operation.

Two Cornell Dubilier type 226 470 µF, 25V high frequency capacitors, with low ESRs of 0.25Ω, are used as the output capacitors.

OUTPUT VOLTAGE CONTROL

The output voltage is controlled by the LM3101 Secondary-Side PWM Controller. The LM3101 uses its error amplifier to compare the scaled-down output voltage against the internal precision 1.24V reference voltage. The error amplifier provides compensation for the regulator frequency response, by way of an RC feedback network.

The resulting error voltage is converted into a pulse-width-modulated waveform at the system oscillator frequency of approximately 500 kHz. This waveform is then differentiated (using an external high-pass RC filter) into a series of positive and negative pulses representing the desired switch duty cycle.

The pulses are transferred through a pulse transformer to the LM3001 Primary-Side Driver. The driver takes the feedback pulse signal and converts it into a PWM gate drive for the Power MOSFET.

FAULT RECOVERY OPERATION

A 0.167Ω resistor sets the peak primary current limits to 2.28A for the pulse-by-pulse limiting, and to 3.60A for the second-level limit. An RC network filters the current limit voltage to prevent the current limit (pin 6) from being activated by the reverse recovery spike of the output rectifier. When the second level current limit is triggered, the LM3001 shuts down and discharges the capacitor connected to pin 5 (the Shutdown Delay capacitor). After the capacitor is recharged to a voltage of approximately 2.1V, the device will try to restart. If the overcurrent condition persists, the device will shut down again.

The LM3101 provides the fault protection in case of an output short circuit. During normal operation, the operating frequency of this circuit is determined by a 25 kΩ resistor connected to pin 1 of the LM3101. However, during a short circuit condition on the output, the frequency of the LM3101 (and the entire circuit operating frequency) drops, yielding a very low duty cycle. This short-circuit frequency is set by the 13 kΩ resistor connected to pin 5.

The LM3101 Mode Control and Current Mode Input pins (pins 2 and 6 respectively) are for current mode control operation. The MC pin determines which control mode is being used—the resistor tied to the supply voltage means voltage mode control (the resistor tied to ground would indicate current mode control).

START-UP OPERATION

When power is initially applied to the regulator, the LM3001 Primary-Side PWM Driver receives its supply current through a 75 kΩ resistor connected to the input voltage (see *Figure 7*). Once the supply pin voltage reaches the threshold of 11.8V (typical), the LM3001 turns on, sending pulse signals (with an amplitude of approximately 10V) to the gate of the Power MOSFET. Because the output is driving Power MOSFETs, which need gate-to-source voltages greater than 10V for hard turn-on (low $R_{DS(ON)}$), the threshold voltage of 11.8V was selected to insure sufficient output voltage.

At the beginning of the start-up process, the secondary side of the regulator is still unbiased—hence the LM3001 does not receive a feedback signal from the secondary side (see the Start-up Sequence in *Figure 9*). Before the LM3101 Secondary-Side PWM Controller is controlling the circuit, the initial operating frequency of the gate drive is determined by the LM3001 internal oscillator. The oscillator uses an external capacitor and resistor, on pins 14 and 1 respectively. The initial operating frequency in this case is approximately 500 kHz. During this time, the regulator is operating in a "free-running" state.

Also during the start-up, the LM3001 executes Soft-Start by using the Soft-Start capacitor on pin 4. The voltage across this capacitor is compared to the oscillator ramp on pin 14 (see the LM3001 block diagram). In the offline regulator, the Soft-Start time is 15 µs approximately.

During this time, as the Soft-Start capacitor charges up, the duty cycle increases with each progressive cycle, until finally the duty cycle reaches its maximum value set by the Duty Cycle Limit circuit (R_{DL} - pin 2) or the Current Limit circuit (CLIM - pin 6). The Soft-Start phase ends when the duty cycle is limited by the R_{DL} circuit. A resistor at this pin connects to an internal current source which together will generate a voltage that will be compared to the oscillator ramp voltage. This comparison will determine the maximum duty cycle during this phase of the start-up cycle. For the circuit in *Figure 7*, the duty cycle is limited to 63% by the R_{DL} circuit.

Typical Applications (Continued)

The duty cycle will reach the R_{DL} limit for several cycles, letting energy build up in the transformer—see the drain current waveform in *Figure 9*. When the residual energy builds up enough, the duty cycle starts to decrease because it is now determined by the CLIM circuit. A voltage of 0.38V or greater at this pin will toggle a pulse-by-pulse comparator on every cycle (see the LM3001 block diagram). In the application circuit, a 0.167Ω resistor will generate the current limit threshold voltage when a 2.28A (peak) current flows through it. With the CLIM circuit in control of the duty cycle, the duty cycle will decrease with each successive cycle. The duty cycle will continue to shrink until the pulse feedback from the LM3101 takes control.

As the LM3001 switches the Power MOSFET on and off, the Power Transformer starts delivering power to the secondary side of the circuit. This action will cause the supply voltage of the LM3101 and the output voltage to gradually rise. When the supply voltage reaches the Undervoltage Lockout Threshold (of 3.9V), the LM3101 starts supplying a pulse train to the differentiator circuit on pin 8. The resulting PWM signals are fed back to the LM3001 via the pulse transformer. The first pulse signal to the LM3001 will cause it to disconnect its internal oscillator from its PWM and Output Driver circuits and trigger the Output Driver from the pulse feedback signals (of the LM3101). At this point, control of the frequency and the duty cycle changes from the LM3001 to the LM3101.

The LM3101 also exercises Soft-Start capability (pin 3). An RC network connected to this pin allows the LM3101 to gradually increase the duty cycle to its nominal value (in the example, the secondary Soft-Start time delay is 500 μs approximately).

The method of Soft-Start used by the LM3101 ensures that the error amplifier is in its linear region before the output voltage reaches its nominal value, thus yielding a smooth start-up of the output without any overshoot (see *Figure 10*).

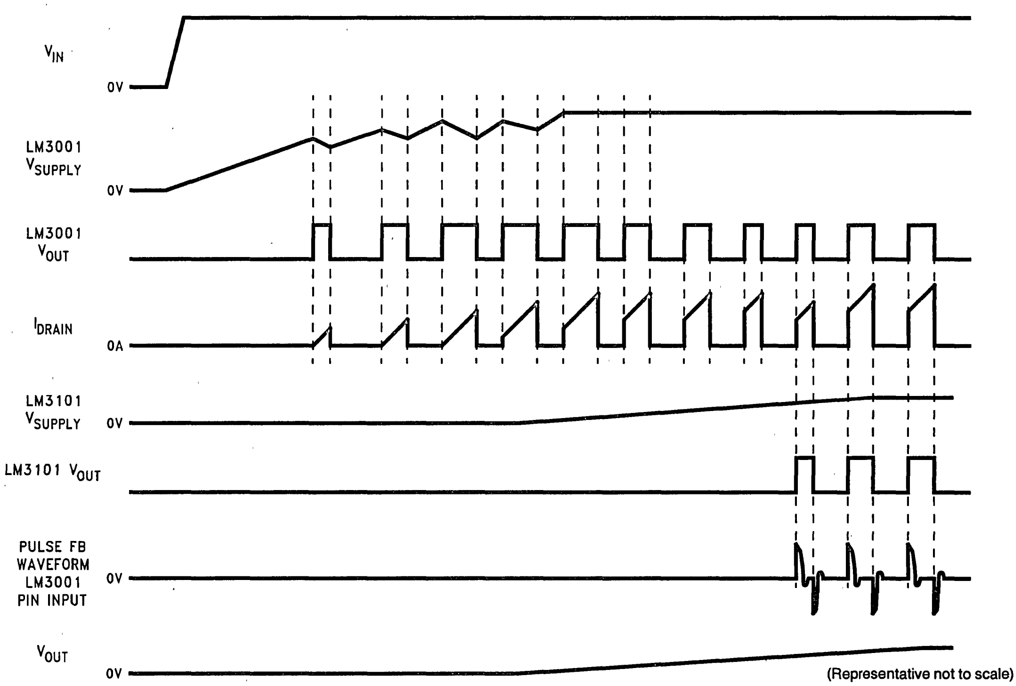

FIGURE 9. Start-Up Timing Sequence

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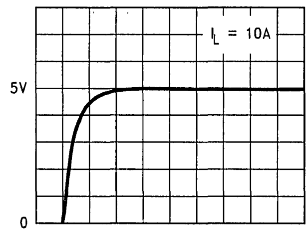
Typical Applications (Continued)



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Output Voltage, 1V/div.
Horizontal Time Base: 500 µs/div.

FIGURE 10. Output Voltage Start-up

At the end of the start-up sequence, the circuit is in steady-state or normal PWM operation.

Design Procedure

For the Offline Voltage Mode Flyback Regulator (*Figure 7*), the specifications for the power transformer, MOSFET switch, the switch snubber, and the output rectifier can be calculated based on the system specifications:

System specifications:

V_O = 5 VDC
V_I Range = 90 VAC–132 VAC
I_O Range = 0.5A–10A
Efficiency (η) ≈ 80%
F_O = 500 kHz.

TRANSFORMER SPECIFICATIONS

Manipulating the transfer function of a flyback regulator results in a calculation for the turns ratio of the power transformer, involving the minimum input voltage, the output voltage, and the maximum duty cycle (D):

$$V_O + V_F = (V_{IN(MIN)} - V_{SW(ON)}) \bullet (N_S/N_P) \bullet (D_{(MAX)}/(1 - D_{(MAX)}))$$

$$\downarrow$$

$$N_S/N_P = [(V_O + V_F)/(V_{IN(MIN)} - V_{SW(ON)})] \bullet ((1 - D_{(MAX)})/D_{(MAX)})$$

Assume that the diode forward voltage (V_F) is about 0.7V and the drain-to-source voltage when the switch is on ($V_{SW(ON)}$) is approximately 0.9V. Selecting a 28% maximum duty cycle results in a turns ratio of:

$$N_S/N_P = (5.7V/126.1V) \bullet (1 - 0.28)/0.28 = 0.12$$
$$(N_P/N_S = 8.5/1).$$

Assuming an efficiency (η) of 80%, the average input current (at the maximum load current and for the entire period) is:

$$I_{IN} = (V_O)(I_O)/(V_{IN(MIN)} \bullet \eta) = (50W)/(127V \bullet 0.80) = 0.49A.$$

The average current when the switch is on is the average current over the entire period divided by the duty cycle:

$$I_{IN(TON)} = I_{IN}/D = (0.49A)/(0.28) = 1.77A.$$

Selecting the primary inductance ripple current (ΔI_P) to be a certain percentage of $I_{IN(TON)}$, and combining that with the duty cycle, input voltage, and operating frequency, gives the primary inductance by the equation:

$$L_P = (V_{IN(MIN)} - V_{SW(ON)}) \bullet D_{(MAX)}/(\Delta I_P \bullet F_O)$$

Assuming the percentage to be 46% in the example, then:

$$L_P = 126.1V \bullet 0.28/(0.81A \bullet 500\ kHz) \cong 87\ \mu H.$$

MOSFET PARAMETERS

The peak current through the primary inductance and the Power MOSFET is the average current when the switch is on plus one-half the primary inductance ripple current:

$$I_{PRI(PK)} = I_{IN(TON)} + (\Delta I_P/2) = 1.77A + (0.81A/2) = 2.18A$$

Assuming ideal conditions, the maximum voltage at the drain of the Power MOSFET when the switch is off is:

$$V_{SW(OFF)} = (V_O + V_F)(N_P/N_S) + V_{IN(MAX)} = (5.7V)(8.5) + 185V = 233V \longrightarrow 250V.$$

However, leakage inductance exists in the transformer, causing a voltage spike immediately after the switch turns off. This voltage spike will add to the rest of the drain voltages, making $V_{SW(OFF)}$ even greater. With a leakage inductance that is 2% of the transformer primary inductance and selecting a switch which has a fall time of 2% the total off-time, the added voltage will be:

$$V_{LL} = 2\% \bullet L_P \bullet I_{PRI(PK)} \bullet F_O/[2\% \bullet (1 - D_{(MAX)})].$$

The maximum duty cycle of 28% is used for worst case purposes. Thus, the leakage inductance voltage spike is:

$$V_{LL} = 0.02 \bullet 87\ \mu H \bullet 2.18A \bullet 500\ kHz/[0.02 \bullet (1 - 0.28)] = 130V \longrightarrow 150V.$$

This means the actual peak drain voltage is approximately 400V. When choosing the Power MOSFET, add some margin to this number. A 500V MOSFET was used in this application.

SNUBBER DESIGN

A "snubber" circuit, consisting of a 1N4937 fast recovery diode and a parallel RC network, is inserted around the transformer primary to clamp the voltage spike. This is to reduce the switch voltage stress when it is off. The "snubber" components are calculated in the following manner:

$$C_{SN} \geq 0.02 \bullet L_P \bullet I_{P(PK)}^2/(V_{MAX}^2 - V_{SN}^2) = 0.02 \bullet 87\ \mu H \bullet (2.18A)^2/[(255V)^2 - (250V)^2] \approx 3.3\ nF$$

and

$$R_{SN} \leq [(V_{MAX} + V_{SN} - V_{IN})/2]^2 \bullet [100/(F_O \bullet L_P \bullet I_{P(PK)}^2)] = [(255V + 250V - 185V)/2]^2 \bullet [100/(500\ kHz \bullet 87\ \mu H \bullet (2.18A)^2)] \approx 12\ k\Omega.$$

In the Offline Flyback Regulator application, a 0.01 µF capacitor and a 10 kΩ resistor are used as the snubber components. V_{MAX} is the selected maximum voltage at the drain of the MOSFET. Usually the RC values are selected so that V_{MAX} is 5V to 10V higher than V_{SN}. The power dissipation of the resistor is:

$$P = [(V_{MAX} + V_{SN} - V_{IN})/2]^2/R = [(255V + 250V - 185V)/2]^2/10\ k\Omega = 2.56W.$$

To add some margin, a 4W resistor is chosen.

The fast recovery diode must have a reverse voltage rating greater than V_{MAX}. The 1N4937 has a 600V rating.

OUTPUT DIODE PARAMETERS

The peak secondary current can be calculated using the peak primary current and the turns ratio (this equation is for single output flyback regulators):

$$I_{SEC(PK)} = I_{PRI(PK)} \bullet (N_P/N_S) = 2.18A \bullet 8.5 = 18.43A \longrightarrow 20A.$$

Typical Applications (Continued)

The maximum average current through the secondary and the diode, when the switch is off, is the maximum load current divided by the inverse of the duty cycle:

$$I_{SEC(OFF)} = I_{LOAD}/(1-D_{(MAX)}) = 10A/0.72 = 13.90A \approx 15A.$$

The maximum average secondary current for the entire period is the maximum load current (10A).

The maximum reverse-bias voltage on the output rectifier is:

$$V_{RV} = V_{IN(MAX)} \bullet (N_S/N_P) + V_O + V_F = (185V)(1/8.5) + 5.7V = 27.47V \approx 30V.$$

A suitable diode for this circuit is the SR1606, which has a reverse voltage rating of 60V and an average current rating of 16A.

Telecom Converter

The schematic of a flyback regulator, used in Telecom applications, is shown in *Figure 11*. The circuit has many of the component values that are in the offline converter. Notable exceptions are the power transformer, in which the turns ratio and primary inductance has changed (due to the change in the input voltage range), and the Power MOSFET, which has a lower on-resistance and a lower breakdown voltage rating.

The most significant difference in the circuit design is the change in the mode of operation—from voltage mode to current mode. For current mode operation, the LM3101 Mode Control pin (MC–pin 2) is connected to ground by a 6 kΩ resistor, and the Control Mode pin (CMI– pin 6) is connected to the current sense transformer through a half-wave rectifier circuit and a low-pass filter. The filter is needed to remove the leading edge spike on the current waveform, caused by the rectifier recovery and interwinding capacitance of the power transformer.

Smaller component differences include reducing the current sensing resistor in the primary side ground path (to allow for the larger primary current), and removing a primary side snubber circuit (due to smaller peak voltages at the drain). Also, the output rectifier and Power MOSFET snubbers are modified.

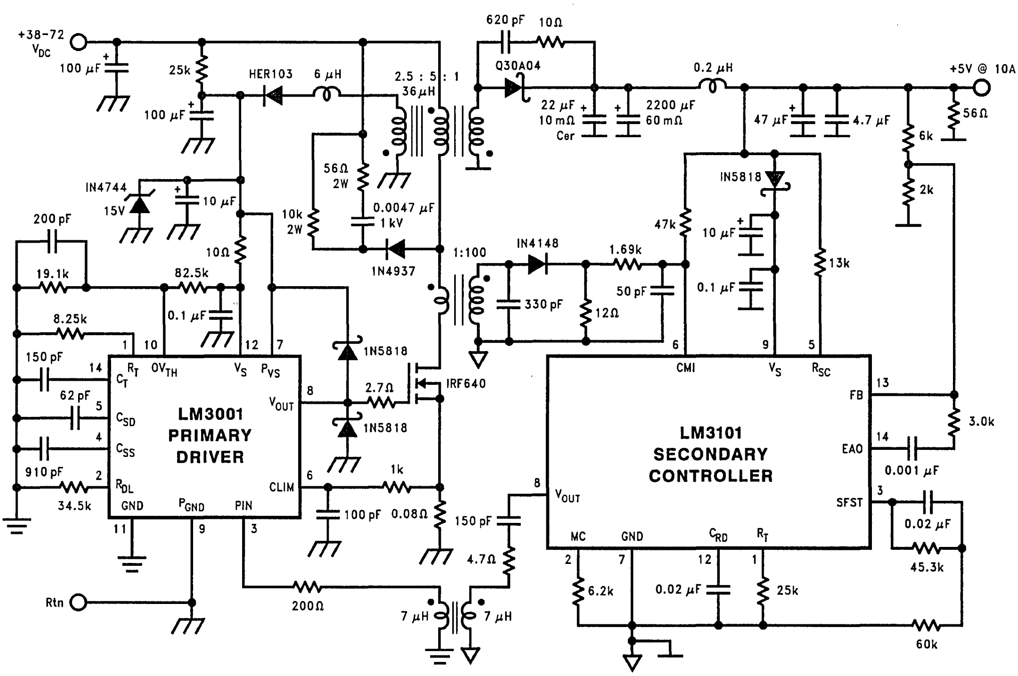

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FIGURE 11. Telecom Current Mode Flyback Regulator

Application Hints

Pulse Feedback Section

During steady-state operation, the LM3101 delivers pulse-width modulated signals to the feedback circuit. The feedback circuit will convert that signal into a series of AC-coupled pulse signals and apply them to the LM3001 via the pulse transformer (the first positive-edged pulse from the LM3101 will cause the LM3001 to disconnect its internal oscillator from its PWM and Output Driver circuits). The feedback pulses will trigger the LM3001 Output Driver to apply PWM drive signals to the Power MOSFET gate. The timing diagram in *Figure 12* demonstrates the feedback communication.

Pulse Interface Circuit

The pulse interface circuit provides isolation for the feedback circuit of the Offline Flyback Regulator. The differentiator circuit converts the PWM waveform into a pulse train. The differentiator delivers a train of 1V_{PK}, 15 ns wide pulses to the pulse transformer. The core should have high permeability (typically 10,000) at the switching frequency to allow the transfer of energy with a very small transformer (size). This one-to-one transformer transfers the pulse train to the LM3001 via a 200Ω resistor, which is used mainly to filter noise from the system.

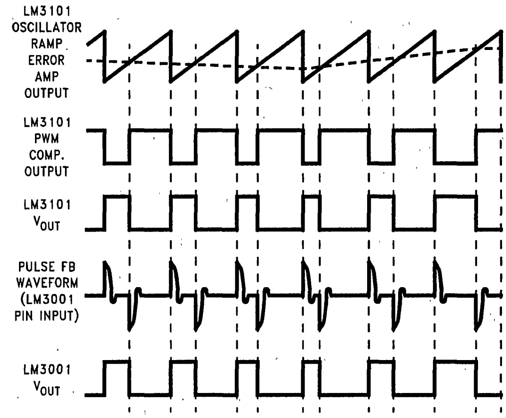

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FIGURE 12. Pulse Feedback Timing Diagram

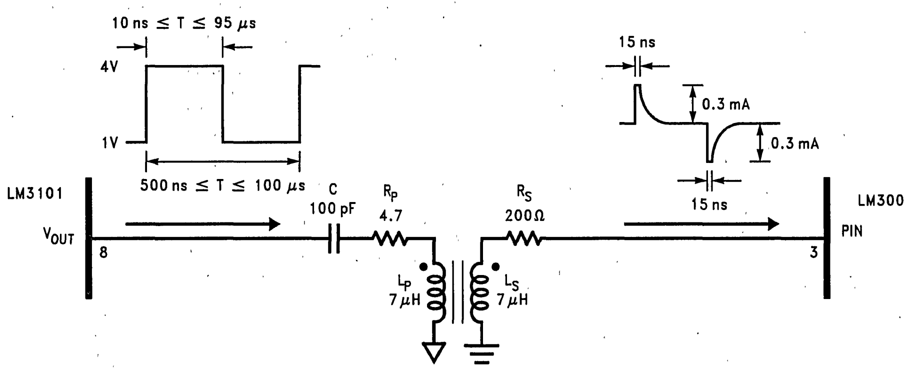

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FIGURE 13. Pulse Interface Circuit

National Semiconductor

LM3411 Precision Secondary Regulator/Driver

General Description

The LM3411 is a low power fixed-voltage (3.3V or 5.0V) precision shunt regulator designed specifically for driving an optoisolator to provide feedback isolation in a switching regulator.

The LM3411 circuitry includes an internally compensated op amp, a bandgap reference, NPN output transistor, and voltage setting resistors.

A trimmed precision bandgap reference with temperature drift curvature correction, provides a guaranteed 1% precision over the operating temperature range (A grade version). The amplifier's inverting input is externally accessible for loop frequency compensation when used as part of a larger servo system. The output is an open-emitter NPN transistor capable of driving up to 15 mA of load current.

Because of its small die size, one of the available packages is the sub-miniature 5-lead SOT23-5 surface mount package. This package is ideal for use in space critical applications.

Although its main application is to provide a precision output voltage (no trimming required) and maintain very good regulation in isolated DC/DC converters, it can also be used with other types of voltage regulators or power semiconductors to provide a precision output voltage without precision resistors or trimming.

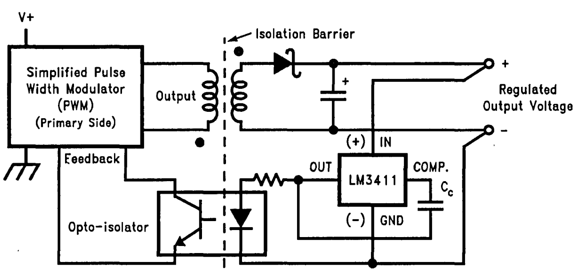
Features

- Fixed voltages of 3.3V and 5.0V with initial tolerance of ±1% for standard grade and ±0.5% for A grade
- Custom voltages available (3V–17V)
- Wide output current range, 20 μA–15 mA
- Low temperature coefficient
- Available in 8-pin DIP and 5-lead SOT23-5 surface mount package (tape and reel)

Applications

- Secondary controller for isolated DC/DC PWM switching regulators systems
- Use with LDO regulator for high-precision fixed output regulators
- Precision monitoring applications
- Use with many types of regulators to increase precision and improve performance

Typical Application and Functional Diagram



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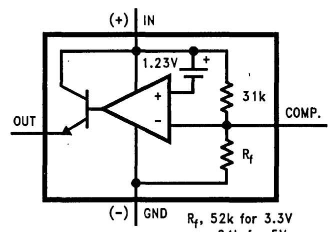
Basic Isolated DC/DC Converter



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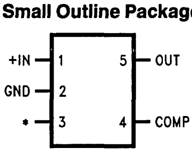
LM3411 Functional Diagram

Connection Diagrams and Order Information

5-Lead Small Outline Package (M5)



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Top View

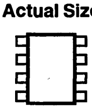
Actual Size

TL/H/11987-4

*No internal connection, but should be soldered to PC board for best heat transfer.

8-Lead Dual-In-Line Package (N)

Actual Size



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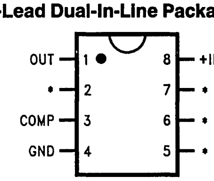

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Top View

For Ordering Information
See *Figure 1* in this Data Sheet
See NS Package Number MA05A

Order Number LM3411N-3.3, LM3411AN-3.3, L3411N-5.0 or LM3411AN-5.0
See NS Package Number N08E

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Input Voltage V(IN)	20V
Output Current	20 mA
Junction Temperature	150°C
Storage Temperature	−65°C to +150°C
Lead Temperature	
M5 Package	
Vapor Phase (60 sec.)	+215°C
Infrared (15 sec.)	+220°C
N Package Soldering (10 sec.)	+260°C
Power Dissipation (T_A = 25°C) (Note 2)	
M5 Package	300 mW
N Package	600 mW
ESD Susceptibility (Note 3)	
Human Body Model	1500V

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for methods on soldering surface-mount devices.

Operating Ratings (Notes 1 and 2)

Ambient Temperature Range	−40°C ≤ T_A ≤ +85°C
Junction Temperature Range	−40°C ≤ T_J ≤ +125°C
Output Current	15 mA

LM3411-3.3 Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, V(IN) = V_{REG}, V_{OUT} = 1.5V.

Symbol	Parameter	Conditions	Typical (Note 4)	LM3411A-3.3 Limit (Note 5)	LM3411-3.3 Limit (Note 5)	Units (Limits)
V_{REG}	Regulation Voltage	I_{OUT} = 5 mA	3.3	3.317/**3.333** 3.284/**3.267**	3.333/**3.366** 3.267/**3.234**	V V(max) V(min)
	Regulation Voltage Tolerance	I_{OUT} = 5 mA		±0.5/±**1**	±1/±**2**	%(max)
I_q	Quiescent Current	I_{OUT} = 5 mA	85	110/**115**	125/**150**	μA μA(max)
G_m	Transconductance $\Delta I_{OUT}/\Delta V_{REG}$	20 μA ≤ I_{OUT} ≤ 1 mA	3.3	1.5/**0.75**	1/**0.50**	mA/mV mA/mV(min)
		1 mA ≤ I_{OUT} ≤ 15 mA	6.0	3.3/**2.0**	2.5/**1.7**	mA/mV mA/mV(min)
A_V	Voltage Gain $\Delta V_{OUT}/\Delta V_{REG}$	1V ≤ V_{OUT} ≤ V_{REG} − 1.2V (**−1.3**) R_L = 140Ω (Note 6)	1000	550/**250**	450/**200**	V/V V/V(min)
		1V ≤ V_{OUT} ≤ V_{REG} − 1.2V (**−1.3**) R_L = 2 kΩ	3500	1500/**900**	1000/**700**	V/V V/V(min)
V_{SAT}	Output Saturation (Note 7)	V(IN) = V_{REG} + 100 mV I_{OUT} = 15 mA	1.0	1.2/**1.3**	1.2/**1.3**	V V(max)
I_L	Output Leakage Current	V(IN) = V_{REG} − 100 mV V_{OUT} = 0V	0.1	0.5/**1.0**	0.5/**1.0**	μA μA(max)
R_f	Internal Feedback Resistor (Note 8)		52	65 39	65 39	kΩ kΩ(max) kΩ(min)
E_n	Output Noise Voltage	I_{OUT} = 1 mA, 10 Hz ≤ f ≤ 10 kHz	50			μV_{RMS}

LM3411-5.0 Electrical Characteristics

Specifications with standard type face are for T_J = 25°C, and those with **boldface type** apply over **full Operating Temperature Range**. Unless otherwise specified, V(IN) = V_{REG}, V_{OUT} = 1.5V.

Symbol	Parameter	Conditions	Typical (Note 4)	LM3411A-5.0 Limit (Note 5)	LM3411-5.0 Limit (Note 5)	Units (Limits)
V_{REG}	Regulation Voltage	I_{OUT} = 5 mA	5			V
				5.025/**5.050**	5.050/**5.100**	V(max)
				4.975/**4.950**	4.950/**4.900**	V(min)
	Regulation Voltage Tolerance	I_{OUT} = 5 mA		±0.5/±**1**	±1/±**2**	%(max)
I_q	Quiescent Current	I_{OUT} = 5 mA	85			μA
				110/**115**	125/**150**	μA(max)
G_m	Transconductance $\Delta I_{OUT}/\Delta V_{REG}$	20 μA ≤ I_{OUT} ≤ 1 mA	3.3			mA/mV
				1.5/**0.75**	1.0/**0.5**	mA/mV(min)
		1 mA ≤ I_{OUT} ≤ 15 mA	6.0			mA/mV
				3.3/**2.0**	2.5/**1.7**	mA/mV(min)
A_V	Voltage Gain $\Delta V_{OUT}/\Delta V_{REG}$	1V ≤ V_{OUT} ≤ V_{REG} − 1.2V **(−1.3)** R_L = 250Ω (Note 6)	1000			V/V
				750/**350**	650/**300**	V/V(min)
		1V ≤ V_{OUT} ≤ V_{REG} − 1.2V **(−1.3)** R_L = 2 kΩ	3500			V/V
				1500/**900**	1000/**700**	V/V(min)
V_{SAT}	Output Saturation (Note 7)	V(IN) = V_{REG} +100 mV I_{OUT} = 15 mA	1.0			V
				1.2/**1.3**	1.2/**1.3**	V(max)
I_L	Output Leakage Current	V(IN) = V_{REG} −100 mV V_{OUT} = 0V	0.1			μA
				0.5/**1.0**	0.5/**1.0**	μA(max)
R_f	Internal Feedback Resistor (Note 8)		94			kΩ
				118	118	kΩ(max)
				70	70	kΩ(min)
E_n	Output Noise Voltage	I_{OUT} = 1 mA, 10 Hz ≤ f ≤ 10 kHz	80			μV_{RMS}

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

Note 2: The maximum power dissipation must be derated at elevated temperatures and is dictated by T_{Jmax} (maximum junction temperature), θ_{JA} (junction to ambient thermal resistance), and T_A (ambient temperature). The maximum allowable power dissipation at any temperature is ($P_{Dmax} = T_{Jmax} - T_A)/\theta_{JA}$ or the number given in the Absolute Maximum Ratings, whichever is lower. The typical thermal resistance (θ_{JA}) when soldered to a printed circuit board is approximately 306°C/W for the M5 package, and 100°C/W for the N package.

Note 3: The human body model is a 100 pF capacitor discharged through a 1.5 kΩ resistor into each pin.

Note 4: Typical numbers are at 25°C and represent the most likely parametric norm.

Note 5: Limits are 100% production tested at 25°C. Limits over the operating temperature range are guaranteed through correlation using Statistical Quality Control (SQC) methods. The limits are used to calculate National's Averaging Outgoing Level (AOQL).

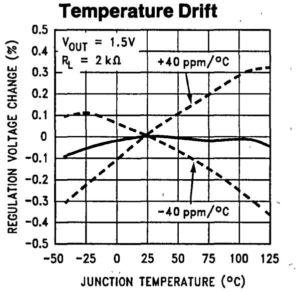
Note 6: Actual test is done using equivalent current sink instead of a resistor load.

Note 7: V_{SAT} = V(IN) − V_{OUT}, when the voltage at the IN pin is forced 100 mV above the nominal regulating voltage (V_{REG}).

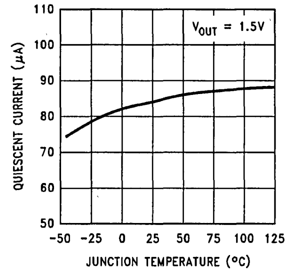
Note 8: See Applications and Curves sections for information on this resistor.

Typical Performance Characteristics

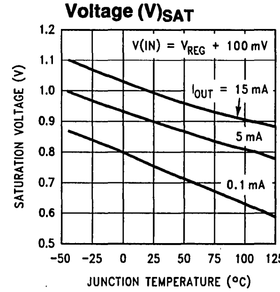
Normalized Temperature Drift



Quiescent Current



Output Saturation Voltage (V)SAT



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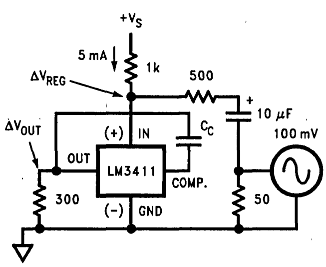
Circuit Used for Bode Plots



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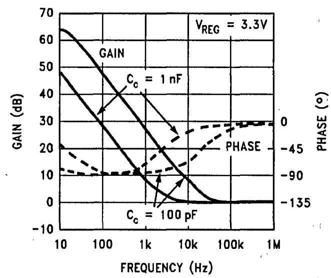
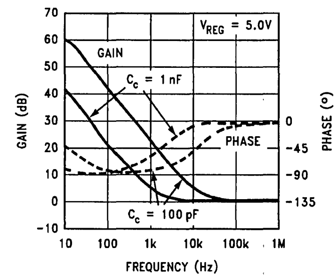
Bode Plot



Bode Plot



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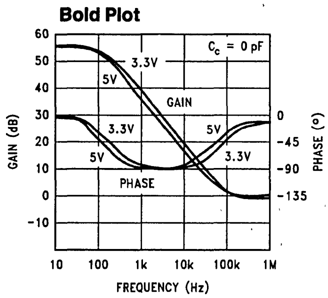
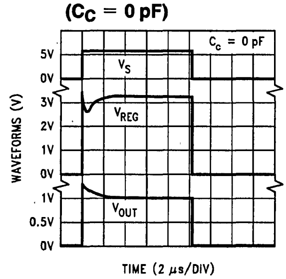
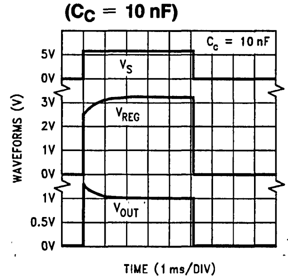
Bold Plot



Response Time for 3.3V Version (C_C = 0 pF)



Response Time for 3.3V Version (C_C = 10 nF)



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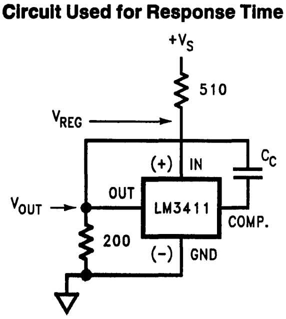
Circuit Used for Response Time



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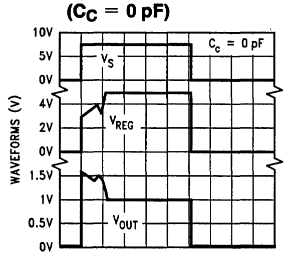
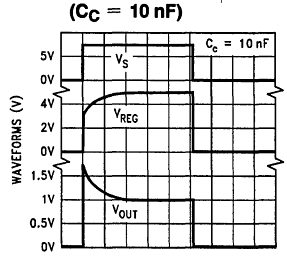
Response Time for 5V Version (C_C = 0 pF)



Response Time for 5V Version (C_C = 10 nF)



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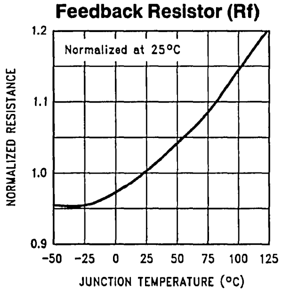
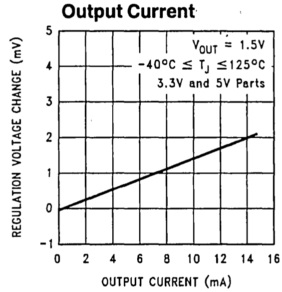
Typical Performance Characteristics (Continued)

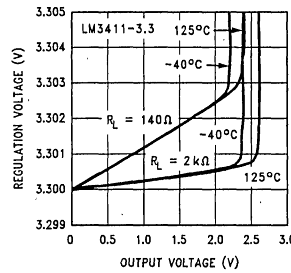
Tempco of Internal Feedback Resistor (Rf)



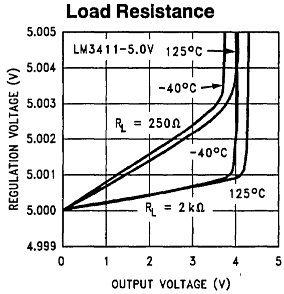
Regulation Voltage Change vs Output Current



Regulation Voltage vs Output Voltage and Load Resistance



Regulation Voltage vs Output Voltage and Load Resistance



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Five Lead Surface Mount Package Marking and Order Information (SOT23-5)

The small SOT23-5 package allows only 4 alphanumeric characters to identify the product. The table below contains the field information marked on the package.

	Grade	Order Information	Package Marking	Supplied as
3.3V	A (Prime)	LM3411AM5-3.3	D00A	250 unit increments on tape and reel
3.3V	A (Prime)	LM3411AM5X-3.3	D00A	3K unit increments on tape and reel
3.3V	B (Standard)	LM3411M5-3.3	D00B	250 unit increments on tape and reel
3.3V	B (Standard)	LM3411M5X-3.3	D00B	3K unit increments on tape and reel
5.0V	A (Prime)	LM3411AM5-5.0	D01A	250 unit increments on tape and reel
5.0V	A (Prime)	LM3411AM5X-5.0	D01A	3K unit increments on tape and reel
5.0V	B (Standard)	LM3411M5-5.0	D01B	250 unit increments on tape and reel
5.0V	B (Standard)	LM3411M5X-5.0	D01B	3K unit increments on tape and reel

FIGURE 1. SOT23-5 Marking and Order Information

The first letter "D" identifies the part as a Driver, the next two numbers indicate the voltage, "00" for 3.3V part and "01" for a 5V part. The fourth letter indicates the grade, "B" for standard grade, "A" for the prime grade.

The SOT23-5 surface mount package is only available on tape in quantities increments of 250 on tape and reel (indicated by the letters "M5" in the part number), or in quantities increments of 3000 on tape and reel (indicated by the letters "M5X" in the part number).

Product Description

The LM3411 is a shunt regulator specifically designed to be the reference and control section in an overall feedback loop of a regulated power supply. The regulated output voltage is sensed between the IN pin and GROUND pin of the LM3411. If the voltage at the IN pin is less than the LM3411 regulating voltage (V_{REG}), the OUT pin sources no current. As the voltage at the IN pin approaches the V_{REG} voltage, the OUT pin begins sourcing current. This current is then used to drive a feedback device, (opto-coupler) or a power device, (linear regulator, switching regulator, etc.) which servos the output voltage to be the same value as V_{REG}.

In some applications, (even under normal operating conditions) the voltage on the IN pin can be forced above the V_{REG} voltage. In these instances, the maximum voltage applied to the IN pin should not exceed 20V. In addition, an external resistor may be required on the OUT pin to limit the maximum current to 20 mA.

Compensation

The inverting input of the error amplifier is brought out to allow overall closed-loop compensation. In many of the applications circuits shown here, compensation is provided by a single capacitor connected from the compensation pin to the out pin of the LM3411. The capacitor values shown in the schematics are adequate under most conditions, but they can be increased or decreased depending on the desired loop response. Applying a load pulse to the output of a regulator circuit and observing the resultant output voltage response is a easy method of determining the stability of the control loop. Analyzing more complex feedback loops requires additional information.

The formula for AC gain at a frequency (f) is as follows;

$$\text{Gain (f)} = 1 + \frac{Z_f(f)}{R_f}$$

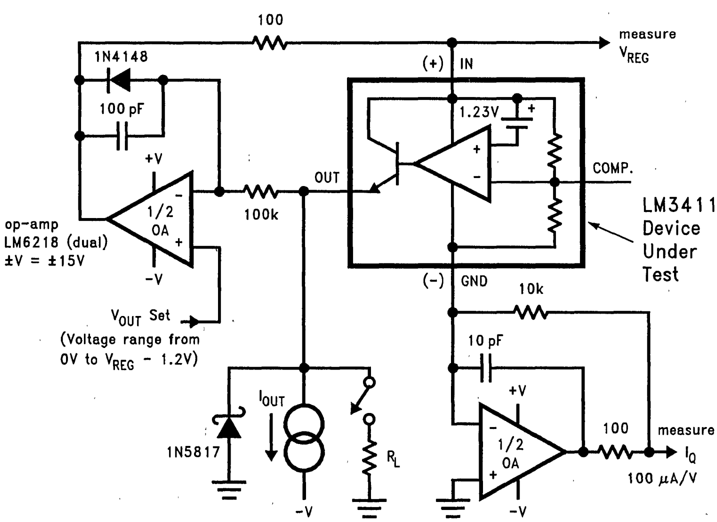
$$\text{where } Z_f\text{ (f)} = \frac{1}{j \bullet 2\pi \bullet f \bullet C}$$

where $R_f \approx 52\ k\Omega$ for the 3.3V part, and $R_f \approx 94\ k\Omega$ for the 5V part.

The resistor (R_f) in the formula is an internal resistor located on the die. Since this resistor value will affect the phase margin, the worst case maximum and minimum values are important when analyzing closed loop stability. The minimum and maximum room temperature values of this resistor are specified in the Electrical Characteristics section of this data sheet, and a curve showing the temperature coefficient is shown in the curves section. In the applications shown here, the worst case phase margin occurs with minimum values of R_f.

Test Circuit

The test circuit shown in *Figure 2* can be used to measure and verify various LM3411 parameters. Test conditions are set by forcing the appropriate voltage at the V_{OUT} Set test point and selecting the appropriate R_L or I_{OUT} as specified in the Electrical Characteristics section. Use a DVM at the "measure" test points to read the data.



TL/H/11987-14

FIGURE 2. LM3411 Test Circuit

Applications Information

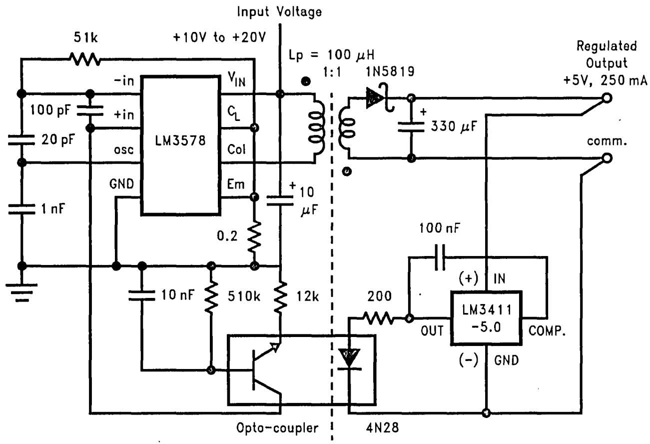


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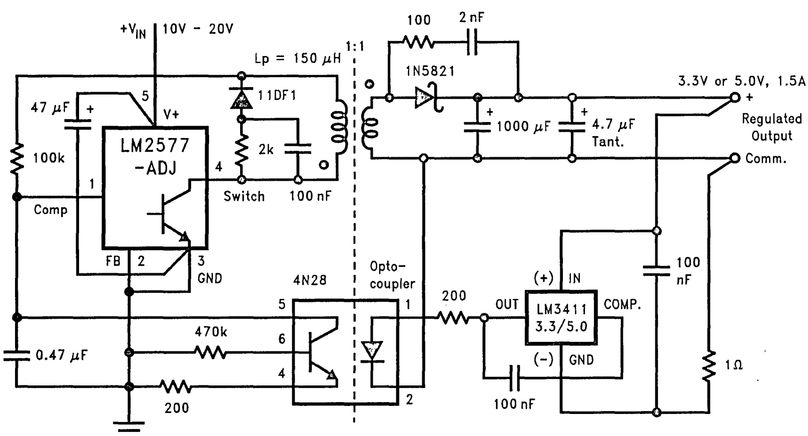
FIGURE 3. Isolated 250 mA Flyback Switching Regulator



TL/H/11987-16

FIGURE 4. Isolated 1.5A Flyback Switching Regulator Using a LM2577

The LM3411 regulator/driver provides the reference and feedback drive functions in a regulated power supply. It can also be used together with many different types of regulators, (both linear and switching) as well as other power semiconductor devices to add precision and improve regulation specifications. Output voltage tolerances better than 0.5% are possible without using trim pots or precision resistors.

One of the main applications of the LM3411 is to drive an opto-isolator to provide feedback signal isolation in a switching regulator circuit. For low current applications, (up to 250 mA) the circuit shown in *Figure 3* provides good regulation and complete input/output electrical isolation.

For an input voltage of 15V, this circuit can provide an output of either 3.3V or 5V with a load current up to 250 mA with excellent regulation characteristics. With the part values shown, this circuit operates at 80 kHz., and can be synchronized to a clock or an additional LM3578. (See LM1578 data sheet for additional information.)

An isolated DC/DC flyback converter capable of higher output current is shown in *Figure 4*. This circuit utilizes the LM2577 SIMPLE SWITCHER™ voltage regulator for the Pulse Width Modulation (PWM), power switch and protection functions, while the LM3411 provides the voltage reference, gain and opto coupler drive functions. In this circuit, the reference and error amplifier in the LM2577 are not used (note that the feedback pin is grounded). The gain is provided by the LM3411. Since the voltage reference is located on the secondary side of the transformer, this circuit provides very good regulation specifications.

The output of a switching regulator typically will contain a small ripple voltage at the switching frequency and may also contain voltage transients. These transient voltage spikes can be sensed by the LM3411 and could give an incorrect regulation voltage. An RC filter consisting of a 1Ω resistor and a 100 nF capacitor will filter these transients and minimize this problem. The 1Ω resistor should be located on the ground side of the LM3411, and the capacitor should be physically located near the package.

Applications Information (Continued)

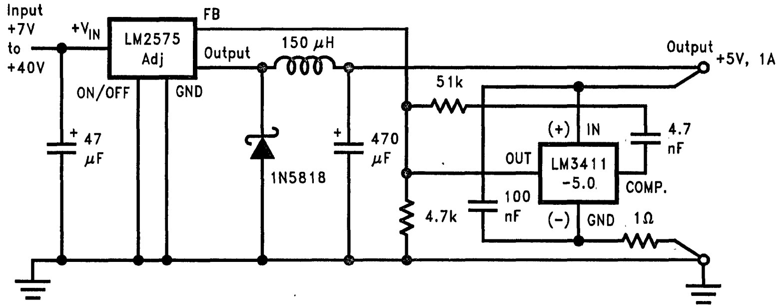


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FIGURE 5. Precision 1A Buck Regulator

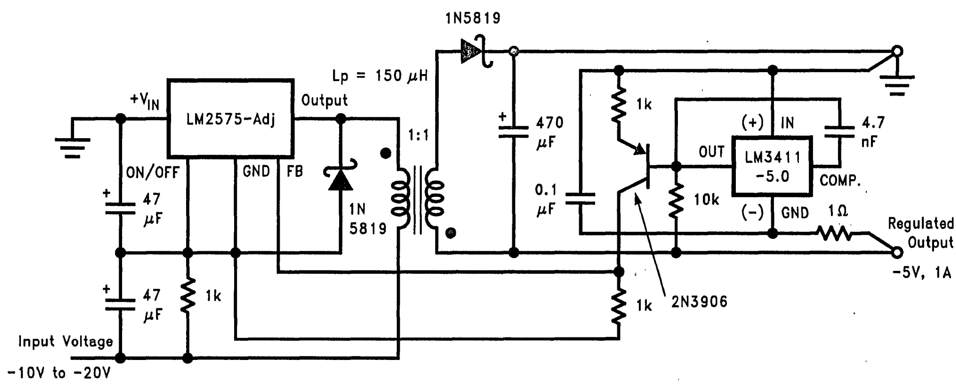

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FIGURE 6. Negative Input, Negative or Positive Output Flyback Regulator

Improved output voltage tolerance and regulation specifications are possible by combining the LM3411A with one of the SIMPLE SWITCHER buck regulator IC's, such as the LM2574, LM2575, or LM2576. The circuit shown in *Figure 5* can provide a 5V, ±0.5% Output (1% over the operating temperature range) without using any trim-pots or precision resistors. Typical line regulation numbers are a 1 mV change on the output for a 8V–18V change on the input, and load regulation of 1 mV with a load change from 100 mA–1A.

A DC-DC flyback converter that accepts a negative input voltage, and delivers either a positive or negative output is shown in *Figure 6*. The circuit utilizes a buck regulator (such as the LM2574, LM2575, or LM2576, depending on how much output current is needed) operating in a flyback configuration. The LM3411 provides the reference and the required level shifting circuitry needed to make the circuit work correctly.

A unique feature of this circuit is the ability to ground either the high or low side of the output, thus generating either a negative or a positive output voltage. Although no isolation is provided, with the addition of an opto-isolator and related components, this circuit could provide input/output isolation.

Combining a LM3411A-5.0 with a 1A low dropout linear regulator results in a 5V ±0.5% (1% over the operating temperature range) regulator with excellent regulation specifications, with no trimming or 1% resistors needed.

An added benefit of this circuit (and also true of many of the other circuits shown here) is the high-side and low-side remote output voltage sensing feature. Sensing the output voltage at the load eliminates the voltage drops associated with wire resistance, thus providing near perfect load regulation.

A 5V, 1A regulator circuit featuring low dropout, very good regulation specifications, self protection features and allows output voltage sensing is shown in *Figure 7*. The regulator used is a LM2941 adjustable low dropout positive regulator, which also features an ON/OFF pin to provide a shutdown feature.

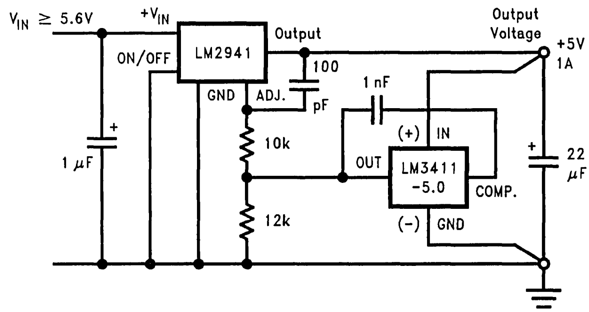

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FIGURE 7. Precision 5V 1A Low Dropout Regulator

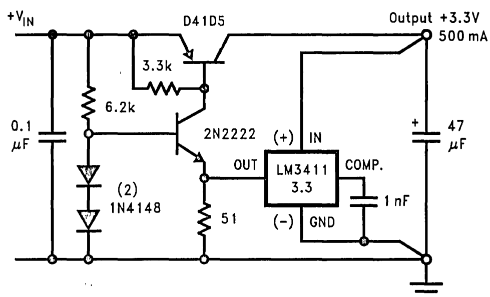

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FIGURE 8. 3.3V 0.5A Low Dropout Regulator

The circuit in *Figure 8* shows a 3.3V low dropout regulator using the LM3411-3.3 and several discrete components. This circuit is capable of excellent performance with both the dropout voltage and the ground pin current specifications improved over the LM2941/LM3411 circuit.

The standard LM317 three terminal adjustable regulator circuit can greatly benefit by adding a LM3411. Performance is increased and features are added. The circuit shown in *Figure 9* provides much improved line and load regulation, lower temperature drift, and full remote output voltage sensing on both the high and low side. In addition, a precise current limit or constant current feature is simple to add.

Current limit protection in most IC regulators is mainly to protect the IC from gross over-current conditions which could otherwise fuse bonding wires or blow IC metalization, therefore not much precision is needed for the actual current limit values. Current limit tolerances can sometimes vary from ±10% to as high as +300% over manufacturing and temperature variations. Often critical circuitry requires a much tighter control over the amount of current the power supply can deliver. For example, a power supply may be needed that can deliver 100% of its design current, but can still limit the maximum current to 110% to protect critical circuitry from high current fault conditions.

The circuit in *Figure 9* can provide a current limit accuracy that is better than ±4%, over all possible variations, in addition to having excellent line, load and temperature specifications.

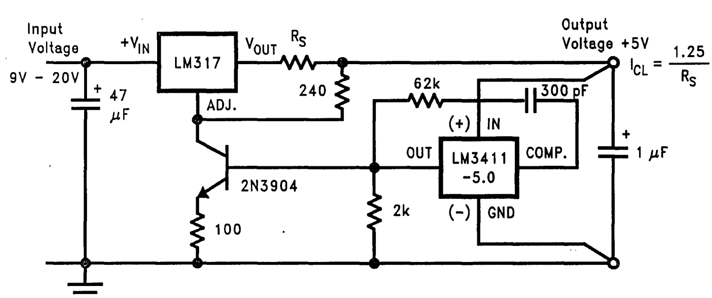

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FIGURE 9. Precision Positive Voltage Regulator with Accurate Current Limit

Applications Information (Continued)

Like the positive regulators, the performance of negative adjustable regulators can also be improved by adding the LM3411. Output voltages of either 3.3V or 5V at currents up to 1.5A (3A when using a LM333) are possible. Adding two resistors to the circuit in *Figure 10* adds the precision current limit feature as shown in *Figure 11*. Current limit tolerances of ±4% over manufacturing and temperature variations are possible with this circuit.

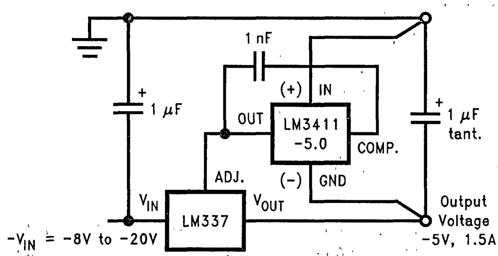

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FIGURE 10. Precision Negative Voltage Regulator

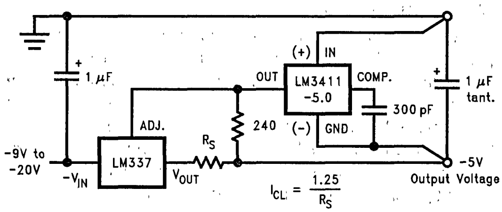

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FIGURE 11. Precision Negative Voltage Regulator with Accurate Current Limit

A simple 5V supply monitor circuit is shown in *Figure 12*. Using the LM3411's voltage reference, op-amp (as a comparator) and output driver, this circuit provides a LED indication of the presence of the 5V supply.

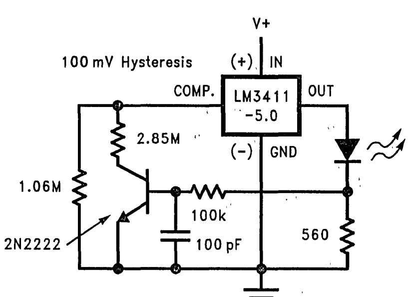

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FIGURE 12. 4.7V Power ON Detector with Hysteresis

The LM3411 initial room temperature tolerance is ±1% and ±0.5% for the "A" grade part. If a tighter tolerance is needed, a trim scheme is shown in *Figure 13* that provides approximately ±1% adjustment range of the regulation voltage (V_{REG}).

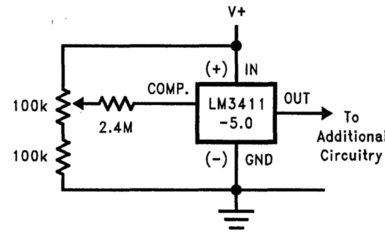

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FIGURE 13. ±50 mV External Trim

The LM3411 is guaranteed to drive a 15 mA load, but if more current is needed, a NPN boost transistor can be added. The circuit shown in *Figure 14* is a shunt regulator capable of providing excellent regulation over a very wide range of current.

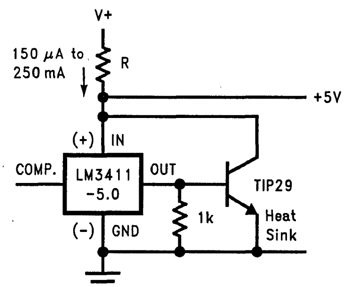

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FIGURE 14. 250 mA Shunt Regulator

Perhaps one of the simplest applications for the LM3411 is the voltage detector circuit shown in *Figure 15*. The OUT pin is low when the input voltage is less than V_{REG}. When the V(IN) pin rises above V_{REG}, the OUT pin is pulled high by the internal NPN output resistor.

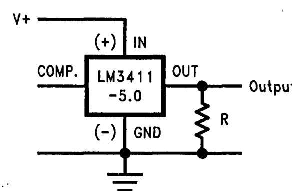

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FIGURE 15. Voltage Detector

Also an overvoltage detector, the crowbar circuit shown in *Figure 16* is normally located at the output of a power supply to protect the load from an overvoltage condition should the power supply fail with an input/output short.

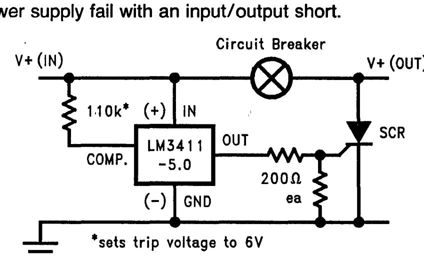

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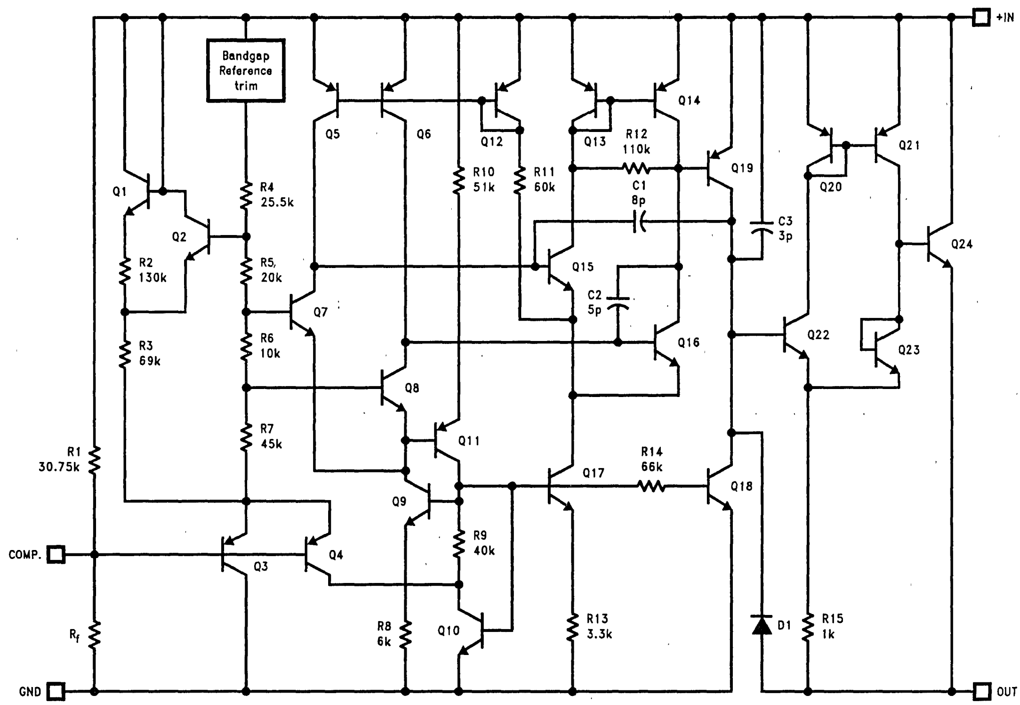
FIGURE 16. Overvoltage Crowbar

Schematic Diagram



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National Semiconductor

LM431A
Adjustable Precision Zener Shunt Regulator

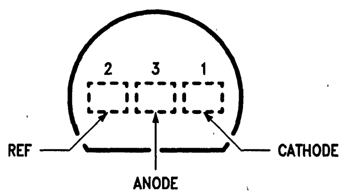
General Description

The LM431A is a 3-terminal adjustable shunt regulator with guaranteed temperature stability over the entire temperature range of operation. The output voltage may be set at any level greater than 2.5V (V_{REF}) up to 36V merely by selecting two external resistors that act as a voltage divided network. Due to the sharp turn-on characteristics this device is an excellent replacement for many zener diode applications.

Features

- Average temperature coefficient 50 ppm/°C
- Temperature compensated for operation over the full temperature range
- Programmable output voltage
- Fast turn-on response
- Low output noise

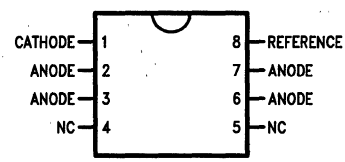
Connection Diagrams



TL/H/10055-1

Top View

Order Number LM431ACZ or LM431AIZ
See NS Package Number Z03A



TL/H/10055-2

Top View

Order Number LM431ACM or LM431AIM
See NS Package Number M08A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	−65°C to +150°C
Operating Temperature Range	
Industrial (LM431AI)	−40°C to +85°C
Commercial (LM431AC)	0°C to +70°C
Lead Temperature	
TO-92 Package/SO-8 Package (Soldering, 10 sec.)	265°C
Internal Power Dissipation (Notes 1, 2)	
TO-92 Package	0.78W
SO-8 Package	0.81W
Cathode Voltage	37V
Continuous Cathode Current	−10 mA to +150 mA
Reference Voltage	−0.5V
Reference Input Current	10 mA

Operating Conditions	Min	Max
Cathode Voltage	V_{REF}	37V
Cathode Current	1.0 mA	100 mA

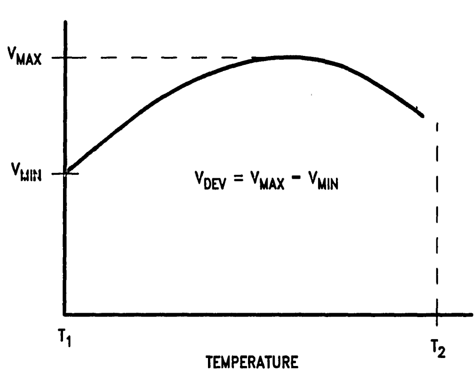
Note 1: $T_{J\,Max} = 150°C$.

Note 2: Ratings appy to ambient temperature at 25°C. Above this temperature, derate the TO-92 at 6.2 mW/°C, and the SO-8 at 6.5 mW/°C.

LM431A Electrical Characteristics $T_A = 25°C$ unless otherwise specified

Symbol	Parameter	Conditions	Min	Typ	Max	Units
V_{REF}	Reference Voltage	$V_Z = V_{REF}$, $I_I = 10$ mA *(Figure 1)*	2.440	2.495	2.550	V
V_{DEV}	Deviation of Reference Input Voltage Over Temperature (Note 3)	$V_Z = V_{REF}$, $I_I = 10$ mA, T_A = Full Range *(Figure 1)*		8.0	17	mV
$\frac{\Delta V_{REF}}{\Delta V_Z}$	Ratio of the Change in Reference Voltage to the Change in Cathode Voltage	$I_Z = 10$ mA *(Figure 2)*, V_Z from V_{REF} to 10V		−1.4	−2.7	mV/V
		$I_Z = 10$ mA *(Figure 2)*, V_Z from 10V to 36V		−1.0	−2.0	mV/V
I_{REF}	Reference Input Current	$R_1 = 10\,k\Omega$, $R_2 = \infty$, $I_I = 10$ mA *(Figure 2)*		2.0	4.0	μA
$\propto I_{REF}$	Deviation of Reference Input Current over Temperature	$R_1 = 10\,k\Omega$, $R_2 = \infty$, $I_I = 10$ mA, T_A = Full Range *(Figure 2)*		0.4	1.2	μA
$I_{Z(MIN)}$	Minimum Cathode Current for Regulation	$V_Z = V_{REF}$ *(Figure 1)*		0.4	1.0	mA
$I_{Z(OFF)}$	Off-State Current	$V_Z = 36V$, $V_{REF} = 0V$ *(Figure 3)*		0.3	1.0	μA
r_Z	Dynamic Output Impedance (Note 4)	$V_Z = V_{REF}$, Frequency = 0 Hz *(Figure 1)*			0.75	Ω

Note 3: Deviation of reference input voltage, V_{DEV}, is defined as the maximum variation of the reference input voltage over the full temperature range.



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The average temperature coefficient of the reference input voltage, $\propto V_{REF}$, is defined as:

$$\propto V_{REF}\,\frac{ppm}{°C} = \frac{\pm\left[\frac{V_{Max} - V_{Min}}{V_{REF}\,(at\ 25°C)}\right]10^6}{T_2 - T_1} = \frac{\pm\left[\frac{V_{DEV}}{V_{REF}\,(at\ 25°C)}\right]10^6}{T_2 - T_1}$$

Where:

$T_2 - T_1$ = full temperature change.

$\propto V_{REF}$ can be positive or negative depending on whether the slope is positive or negative.

Example: $V_{DEV} = 8.0$ mV, $V_{REF} = 2495$ mV, $T_2 - T_1 = 70°C$, slope is positive.

$$\propto V_{REF} = \frac{\left[\frac{8.0\ mV}{2495\ mV}\right]10^6}{70°C} = +46\ ppm/°C$$

Note 4: The dynamic output impedance, r_Z, is defined as:

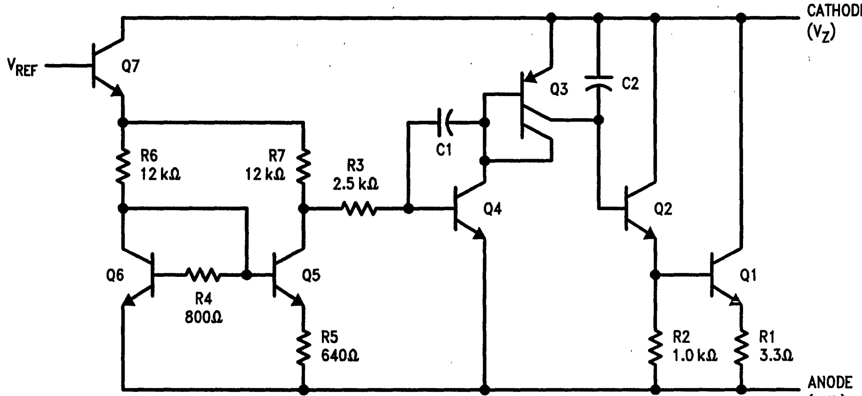
$$r_Z = \frac{\Delta V_Z}{\Delta I_Z}$$

When the device is programmed with two external resistors, R1 and R2, (see *Figure 2*), the dynamic output impedance of the overall circuit, r_Z, is defined as:

$$r_Z = \frac{\Delta V_Z}{\Delta I_Z} \approx \left[r_Z\ 1 + \frac{R1}{R2}\right]$$

3

Equivalent Circuit



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DC Test Circuits

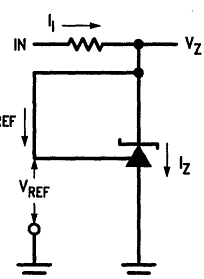

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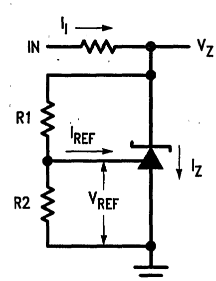
FIGURE 1. Test Circuit for $V_Z = V_{REF}$



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Note: $V_Z = V_{REF}(1 + R1/R2) + I_{REF} \bullet R1$

FIGURE 2. Test Circuit for $V_Z > V_{REF}$

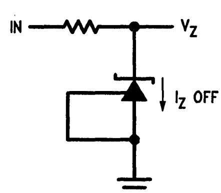

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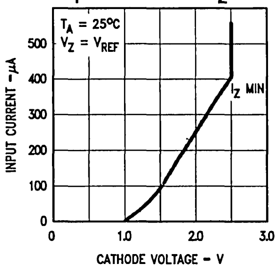
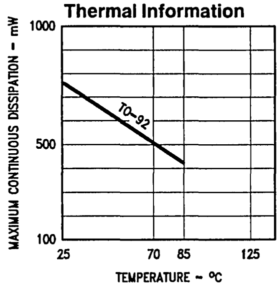
FIGURE 3. Test Circuit for Off-State Current

Typical Performance Characteristics

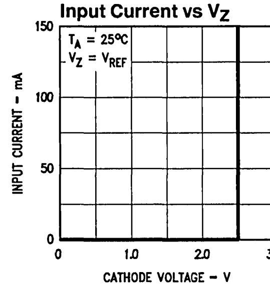
Input Current vs V_Z



Thermal Information



Input Current vs V_Z



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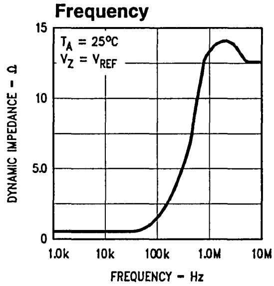
Dynamic Impedance vs Frequency



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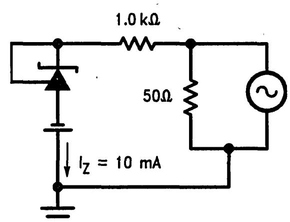

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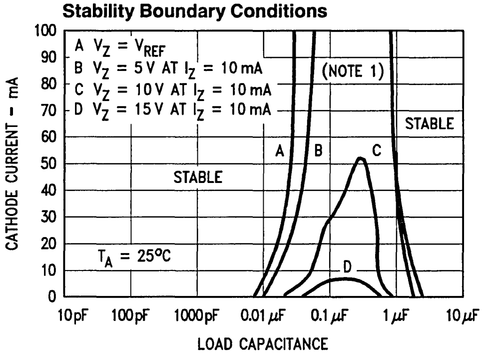
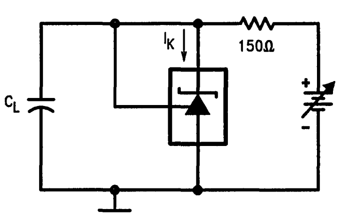
Stability Boundary Conditions



TL/H/10055-11

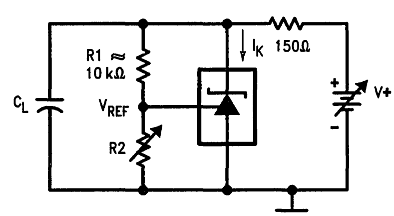
Note 1: The areas under the curves represent conditions that may cause the device to oscillate. For curves B, C, and D, R2 and V^+ were adjusted to establish the initial V_Z and I_Z conditions with C_L = 0. V^+ and C_L were then adjusted to determine the ranges of stability.

Test Circuit for Curve A Above



TL/H/10055-12

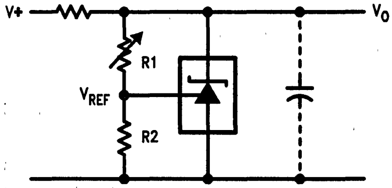
Test Circuit for Curves B, C and D Above



TL/H/10055-13

Typical Applications

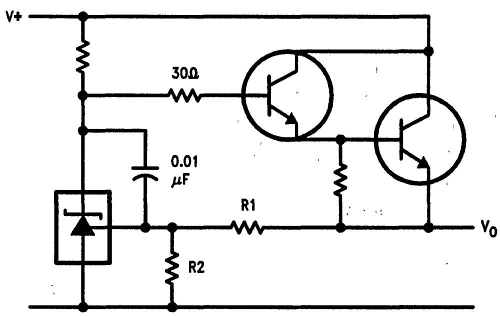
Shunt Regulator



TL/H/10055–14

$$V_O \approx \left(1 + \frac{R1}{R2}\right) V_{REF}$$

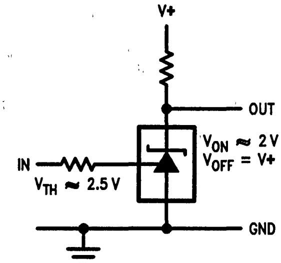
Series Regulator



TL/H/10055–16

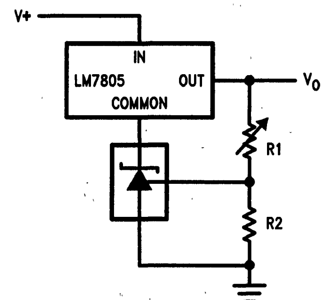
$$V_O \approx \left(1 + \frac{R1}{R2}\right) V_{REF}$$

Single Supply Comparator with Temperature Compensated Threshold



TL/H/10055–15

Output Control of a Three Terminal Fixed Regulator



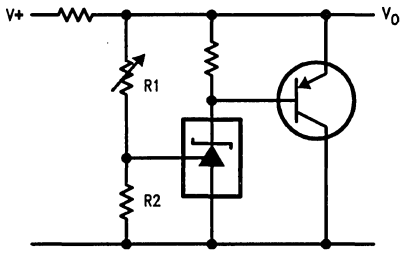
TL/H/10055–17

$$V_O = \left(1 + \frac{R1}{R2}\right) V_{REF}$$

$$V_{O\,MIN} = V_{REF} + 5V$$

Typical Applications (Continued)

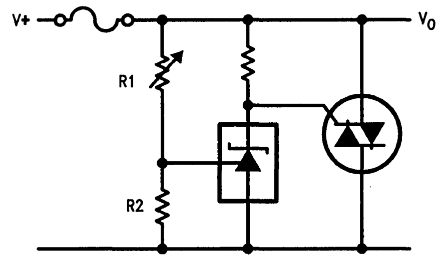
Higher Current Shunt Regulator



TL/H/10055-18

$V_O = \left(1 + \frac{R1}{R2}\right) V_{REF}$

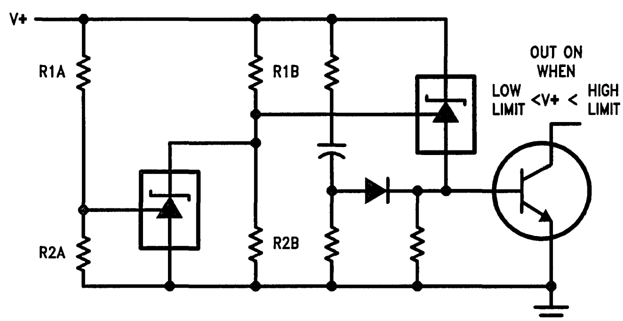
Crow Bar



TL/H/10055-19

$V_{LIMIT} \approx \left(1 + \frac{R1}{R2}\right) V_{REF}$

Over Voltage/Under Voltage Protection Circuit

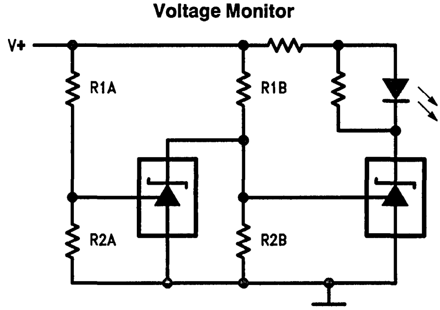


TL/H/10055-20

LOW LIMIT $\approx V_{REF} \left(1 + \frac{R1B}{R2B}\right) + V_{BE}$

HIGH LIMIT $\approx V_{REF} \left(1 + \frac{R1A}{R2A}\right)$

Voltage Monitor



TL/H/10055-21

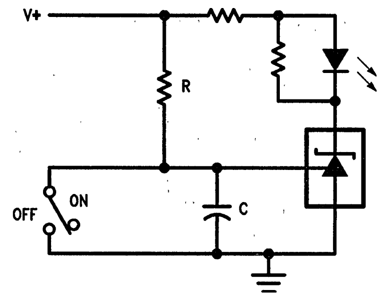
LOW LIMIT $\approx V_{REF} \left(1 + \frac{R1B}{R2B}\right)$

LED ON WHEN
LOW LIMIT $< V^+ <$ HIGH LIMIT

HIGH LIMIT $\approx V_{REF} \left(1 + \frac{R1A}{R2A}\right)$

Typical Applications (Continued)

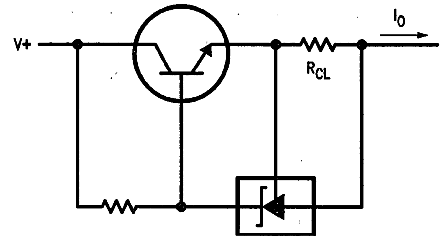
Delay Timer



TL/H/10055–22

$$\text{DELAY} = R \bullet C \bullet \ell n \frac{V+}{(V^{+}) - V_{REF}}$$

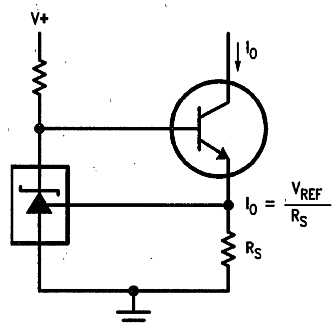
Current Limiter or Current Source



TL/H/10055–23

$$I_O = \frac{V_{REF}}{R_{CL}}$$

Constant Current Sink



TL/H/10055–24

National Semiconductor

LM78S40
Universal Switching Regulator Subsystem

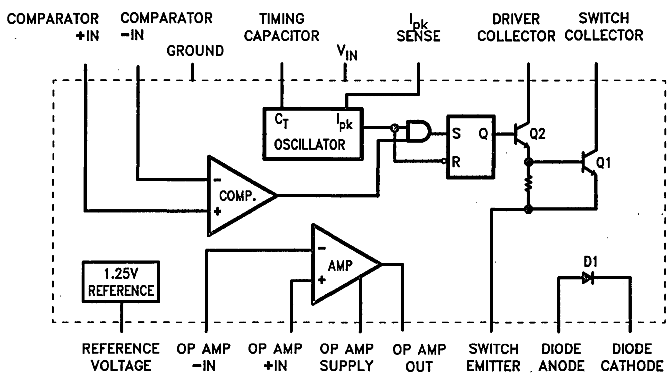
General Description

The LM78S40 is a monolithic regulator subsystem consisting of all the active building blocks necessary for switching regulator systems. The device consists of a temperature compensated voltage reference, a duty-cycle controllable oscillator with an active current limit circuit, an error amplifier, high current, high voltage output switch, a power diode and an uncommitted operational amplifier. The device can drive external NPN or PNP transistors when currents in excess of 1.5A or voltages in excess of 40V are required. The device can be used for step-down, step-up or inverting switching regulators as well as for series pass regulators. It features wide supply voltage range, low standby power dissipation, high efficiency and low drift. It is useful for any stand-alone, low part count switching system and works extremely well in battery operated systems.

Features

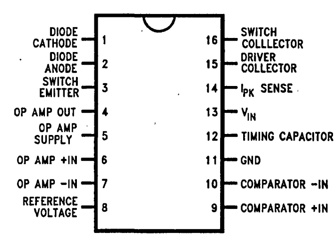
- Step-up, step-down or inverting switching regulators
- Output adjustable from 1.25V to 40V
- Peak currents to 1.5A without external transistors
- Operation from 2.5V to 40V input
- Low standby current drain
- 80 dB line and load regulation
- High gain, high current, independent op amp
- Pulse width modulation with no double pulsing

Block and Connection Diagrams



TL/H/10057–2

16-Lead DIP



TL/H/10057–1

Top View

Ordering Information

Part Number	NS Package	Temperature Range
LM78S40J/883	J16A Ceramic DIP	−55°C to +125°C
LM78S40N	N16E Molded DIP	−40°C to +125°C
LM78S40CN	N16E Molded DIP	0°C to +70°C

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Storage Temperature Range	
Ceramic DIP	−65°C to +175°C
Molded DIP	−65°C to +150°C
Operating Temperature Range	
Extended (LM78S40J)	−55°C to +125°C
Industrial (LM78S40N)	−40°C to +125°C
Commercial (LM78S40CN)	0°C to +70°C
Lead Temperature	
Ceramic DIP (Soldering, 60 sec.)	300°C
Molded DIP (Soldering, 10 sec.)	265°C
Internal Power Dissipation (Notes 1, 2)	
16L-Ceramic DIP	1.50W
16L-Molded DIP	1.04W
Input Voltage from V_{IN} to GND	40V
Input Voltage from V^+ (Op Amp) to GND	40V
Common Mode Input Range (Comparator and Op Amp)	−0.3 to V+
Differential Input Voltage (Note 3)	±30V
Output Short Circuit Duration (Op Amp)	Continuous
Current from V_{REF}	10 mA
Voltage from Switch Collectors to GND	40V
Voltage from Switch Emitters to GND	40V
Voltage from Switch Collectors to Emitter	40V
Voltage from Power Diode to GND	40V
Reverse Power Diode Voltage	40V
Current through Power Switch	1.5A
Current through Power Diode	1.5A
ESD Susceptibility	(to be determined)

LM78S40 Electrical Characteristics

T_A = Operating temperature range, V_{IN} = 5.0V, V^+(Op Amp) = 5.0V, unless otherwise specified. (Note 4)

Symbol	Parameter	Conditions		Min	Typ	Max	Units
GENERAL CHARACTERISTICS							
I_{CC}	Supply Current (Op Amp Disconnected)	V_{IN} = 5.0V			1.8	3.5	mA
		V_{IN} = 40V			2.3	5.0	mA
I_{CC}	Supply Current (Op Amp Connected)	V_{IN} = 5.0V				4.0	mA
		V_{IN} = 40V				5.5	mA
REFERENCE SECTION							
V_{REF}	Reference Voltage	I_{REF} = 1.0 mA	Extend $-55°C < T_A < +125°C$, Comm $0 < T_A < +70°C$, Indus $-40°C < T_A < +85°C$	1.180	1.245	1.310	V
$V_{R\ LINE}$	Reference Voltage Line Regulation	V_{IN} = 3.0V to V_{IN} = 40V, I_{REF} = 1.0 mA, T_A = 25°C			0.04	0.2	mV/V
$V_{R\ LOAD}$	Reference Voltage Load Regulation	I_{REF} = 1.0 mA to I_{REF} = 10 mA, T_A = 25°C			0.2	0.5	mV/mA
OSCILLATOR SECTION							
I_{CHG}	Charging Current	V_{IN} = 5.0V, T_A = 25°C		20		50	μA
I_{CHG}	Charging Current	V_{IN} = 40V, T_A = 25°C		20		70	μA
I_{DISCHG}	Discharge Current	V_{IN} = 5.0V, T_A = 25°C		150		250	μA
I_{DISCHG}	Discharge Current	V_{IN} = 40V, T_A = 25°C		150		350	μA
V_{OSC}	Oscillator Voltage Swing	V_{IN} = 5.0V, T_A = 25°C			0.5		V
t_{on}/t_{off}	Ratio of Charge/ Discharge Time				6.0		μs/μs

LM78S40

Electrical Characteristics (Continued)

T_A = Operating Temperature Range, V_{IN} = 5.0V, V^+(Op Amp) = 5.0V, unless otherwise specified. (Note 4)

Symbol	Parameter	Conditions	Min	Typ	Max	Units
CURRENT LIMIT SECTION						
V_{CLS}	Current Limit Sense Voltage	T_A = 25°C	250		350	mV
OUTPUT SWITCH SECTION						
$V_{SAT\,1}$	Output Saturation Voltage 1	I_{SW} = 1.0A *(Figure 1)*		1.1	1.3	V
$V_{SAT\,2}$	Output Saturation Voltage 2	I_{SW} = 1.0A *(Figure 2)*		0.45	0.7	V
h_{FE}	Output Transistor Current Gain	I_C = 1.0A, V_{CE} = 5.0V, T_A = 25°C		70		
I_L	Output Leakage Current	V_O = 40V, T_A = 25°C		10		nA
POWER DIODE						
V_{FD}	Forward Voltage Drop	I_D = 1.0A		1.25	1.5	V
I_{DR}	Diode Leakage Current	V_D = 40V, T_A = 25°C		10		nA
COMPARATOR						
V_{IO}	Input Offset Voltage	$V_{CM} = V_{REF}$		1.5	15	mV
I_{IB}	Input Bias Current	$V_{CM} = V_{REF}$		35	200	nA
I_{IO}	Input Offset Current	$V_{CM} = V_{REF}$		5.0	75	nA
V_{CM}	Common Mode Voltage Range	T_A = 25°C	0		$V_{IN}-2$	V
PSRR	Power Supply Rejection Ratio	V_{IN} = 3.0V to 40V, T_A = 25°C	70	96		dB
OPERATIONAL AMPLIFIER						
V_{IO}	Input Offset Voltage	V_{CM} = 2.5V		4.0	15	mV
I_{IB}	Input Bias Current	V_{CM} = 2.5V		30	200	nA
I_{IO}	Input Offset Current	V_{CM} = 2.5V		5.0	75	nA
A_{VS}^+	Voltage Gain+	R_L = 2.0 kΩ to GND; V_O = 1.0V to 2.5V, T_A = 25°C	25	250		V/mV
A_{VS}^-	Voltage Gain−	R_L = 2.0 kΩ to V^+ (Op Amp) V_O = 1.0V to 2.5V, T_A = 25°C	25	250		V/mV
V_{CM}	Common Mode Voltage Range	T_A = 25°C	0		$V_{CC} - 2$	V
CMR	Common Mode Rejection	V_{CM} = 0V to 3.0V, T_A = 25°C	76	100		dB
PSRR	Power Supply Rejection Ratio	V^+ (Op Amp) = 3.0V to 40V, T_A = 25°C	76	100		dB
I_O^+	Output Source Current	T_A = 25°C	75	150		mA
I_O^-	Output Sink Current	T_A = 25°C	10	35		mA
SR	Slew Rate	T_A = 25°C		0.6		V/μs
V_{OL}	Output Voltage LOW	I_L = −5.0 mA, T_A = 25°C			1.0	V
V_{OH}	Output Voltage High	I_L = 50 mA, T_A = 25°C	V + (Op Amp) − 3V			V

Note 1: $T_{J\,Max}$ = 150°C for the Molded DIP, and 175°C for the Ceramic DIP.

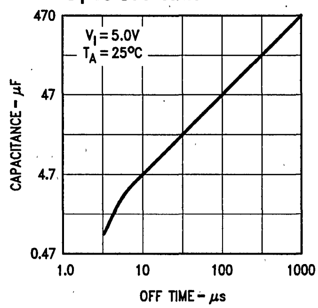
Note 2: Ratings apply to ambient temperature at 25°C. Above this temperature, derate the 16L-Ceramic DIP at 10 mW/°C, and the 16L-Molded DIP at 8.3 mW/°C.

Note 3: For supply voltages less than 30V, the absolute maximum voltage is equal to the supply voltage.

Note 4: A military RETS specification is available on request. At the time of printing, the LM78S40 RETS specification complied with the Min and Max limits in this table. The LM78S40J may also be procured as a Standard Military Drawing.

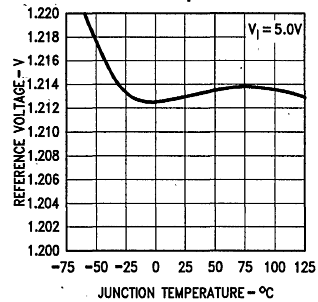
Typical Performance Characteristics

C_T vs OFF Time



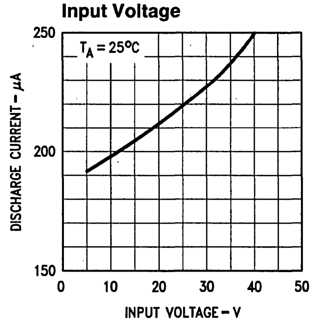
TL/H/10057–6

Reference Voltage vs Junction Temperature



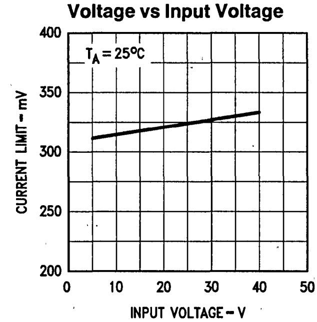
TL/H/10057–7

Discharge Current vs Input Voltage



TL/H/10057–8

Current Limit Sense Voltage vs Input Voltage



TL/H/10057–9

Design Formulas

Characteristic	Step-Down	Step-Up	Inverting	Units
$\frac{t_{on}}{t_{off}}$	$\frac{V_O + V_D}{V_I - V_{SAT} - V_O}$	$\frac{V_O + V_D - V_I}{V_I - V_{SAT}}$	$\frac{\lvert V_O \rvert + V_D}{V_I - V_{SAT}}$	
$(t_{on} + t_{off})$ Max	$\frac{1}{f_{Min}}$	$\frac{1}{f_{Min}}$	$\frac{1}{f_{MIN}}$	µs
C_T	$4 \times 10^{-5}\, t_{on}$	$4 \times 10^{-5}\, t_{on}$	$4 \times 10^{-5}\, t_{on}$	µF
I_{pk}	$2\, I_{O\,Max}$	$2\, I_{O\,Max} \bullet \frac{t_{on} + t_{off}}{t_{off}}$	$2\, I_{O\,Max} \bullet \frac{t_{on} + t_{off}}{t_{off}}$	A
L_{Min}	$\left(\frac{V_I - V_{SAT} - V_O}{I_{pk}}\right) t_{on\,Max}$	$\left(\frac{V_I - V_{SAT}}{I_{pk}}\right) t_{on\,Max}$	$\left(\frac{V_I - V_{SAT}}{I_{pk}}\right) t_{on\,Max}$	µH
R_{SC}	$0.33/I_{pk}$	$0.33/I_{pk}$	$0.33/I_{pk}$	Ω
C_O	$\frac{I_{pk}(t_{on} + t_{off})}{8\, V_{ripple}}$	$\approx \frac{I_O}{V_{ripple}} \bullet t_{on}$	$\approx \frac{I_O}{V_{ripple}} \bullet t_{on}$	µF

Note: V_{SAT} = Saturation voltage of the switching element.
V_D = Forward voltage of the flyback diode.

Functional Description

SWITCHING FREQUENCY CONTROL

The LM78S40 is a variable frequency, variable duty cycle device. The initial switching frequency is set by the timing capacitor. (Oscillator frequency is set by a single external capacitor and may be varied over a range of 100 Hz to 100 kHz). The initial duty cycle is 6:1. This switching frequency and duty cycle can be modified by two mechanisms—the current limit circuitry ($I_{pk\ sense}$) and the comparator.

The comparator modifies the OFF time. When the output voltage is correct, the comparator output is in the HIGH state and has no effect on the circuit operation. If the output voltage is too high then the comparator output goes LOW. In the LOW state the comparator inhibits the turn-on of the output stage switching transistors. As long as the comparator is LOW the system is in OFF time. As the output current rises the OFF time decreases. As the output current nears its maximum the OFF time approaches its minimum value. The comparator can inhibit several ON cycles, one ON cycle or any portion of an ON cycle. Once the ON cycle has begun the comparator cannot inhibit until the beginning of the next ON cycle.

The current limit modifies the ON time. The current limit is activated when a 300 mV potential appears between lead 13 (V_{CC}) and lead 14 (I_{pk}). This potential is intended to result when designed for peak current flows through R_{SC}. When the peak current is reached the current limit is turned on. The current limit circuitry provides for a quick end to ON time and the immediate start of OFF time.

Generally the oscillator is free running but the current limit action tends to reset the timing cycle.

Increasing load results in more current limited ON time and less OFF time. The switching frequency increases with load current.

USING THE INTERNAL REFERENCE, DIODE, AND SWITCH

The internal 1.245V reference (pin 8) must be bypassed, with 0.1 μF directly to the ground pin (pin 11) of the LM78S40, to assure its stability.

V_{FD} is the forward voltage drop across the internal power diode. It is listed on the data sheet as 1.25V typical, 1.5V maximum. If an external diode is used, then its own forward voltage drop must be used for V_{FD}.

V_{SAT} is the voltage across the switch element (output transistors Q1 and Q2) when the switch is closed or ON. This is listed on the data sheet as Output Saturation Voltage.

"Output saturation voltage 1" is defined as the switching element voltage for Q2 and Q1 in the Darlington configuration with collectors tied together. This applies to *Figure 1*, the step down mode.

"Output saturation voltage 2" is the switching element voltage for Q1 only when used as a transistor switch. This applies to *Figure 2*, the step up mode.

For the inverting mode, *Figure 3*, the saturation voltage of the external transistor should be used for V_{SAT}.

Typical Applications

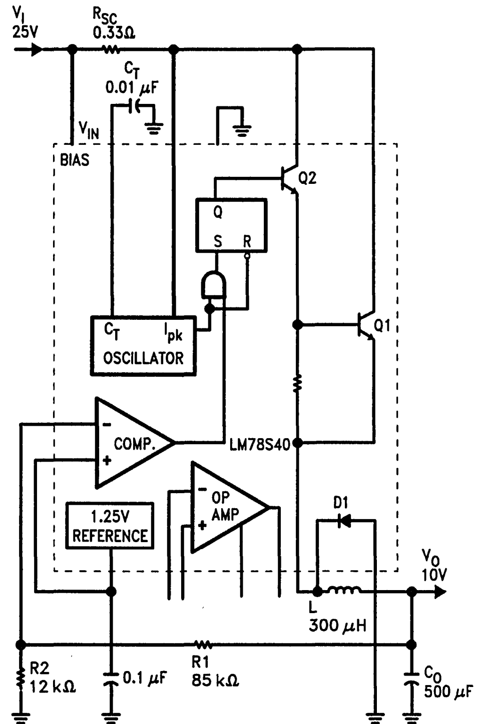
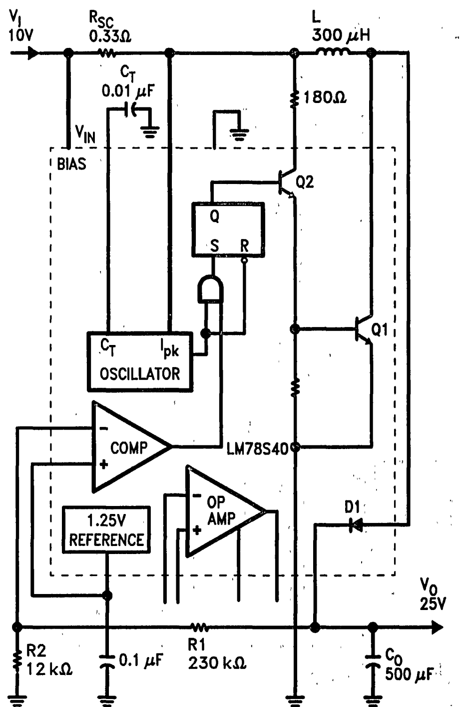


FIGURE 1. Typical Step-Down Regulator and Operational Performance (T_A = 25°C)

Characteristic	Condition	Typical Value
Output Voltage	I_O = 200 mA	10V
Line Regulation	20V ≤ V_I ≤ 30V	1.5 mV
Load Regulation	5.0 mA ≤ I_O I_O ≤ 300 mA	3.0 mV
Max Output Current	V_O = 9.5V	500 mA
Output Ripple	I_O = 200 mA	50 mV
Efficiency	I_O = 200 mA	74%
Standby Current	I_O = 200 mA	2.8 mA

Note A: For I_O ≥ 200 mA use external diode to limit on-chip power dissipation.

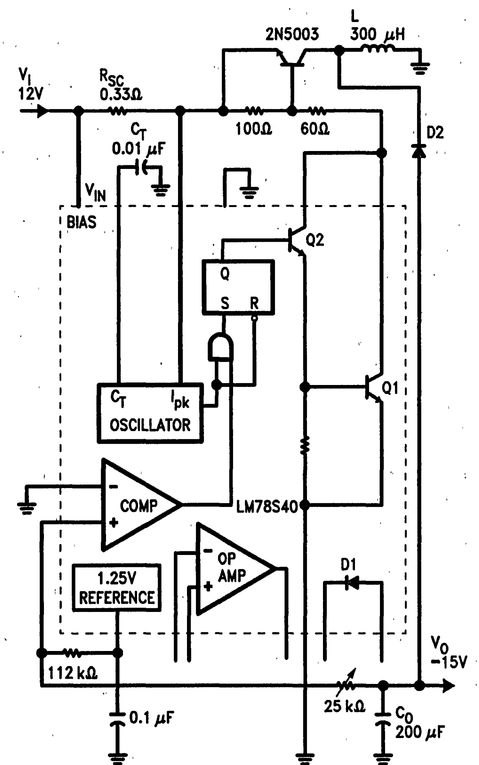
Typical Applications (Continued)



TL/H/10057-4

FIGURE 2. Typical Step-Up Regulator and Operational Performance (T_A = 25°C)

Characteristic	Condition	Typical Value
Output Voltage	I_O = 50 mA	25V
Line Regulation	5.0V ≤ V_I ≤ 15V	4.0 mV
Load Regulation	5.0 mA ≤ I_O I_O ≤ 100 mA	2.0 mV
Max Output Current	V_O = 23.75V	160 mA
Output Ripple	I_O = 50 mA	30 mV
Efficiency	I_O = 50 mA	79%
Standby Current	I_O = 50 mA	2.6 mA



TL/H/10057-5

FIGURE 3. Typical Inverting Regulator and Operational Performance (T_A = 25°C)

Characteristic	Condition	Typical Value
Output Voltage	I_O = 100 mA	−15V
Line Regulation	8.0V ≤ V_I ≤ 18V	5.0 mV
Load Regulation	5.0 mA ≤ I_O I_O ≤ 150 mA	3.0 mV
Max Output Current	V_O = 14.25V	160 mA
Output Ripple	I_O = 100 mA	20 mV
Efficiency	I_O = 100 mA	70%
Standby Current	I_O = 100 mA	2.3 mA

Typical Applications (Continued)

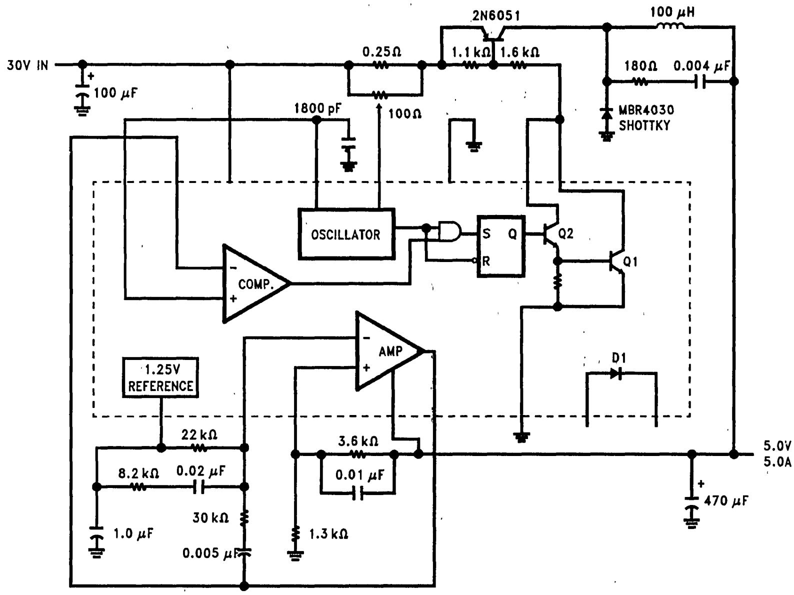


FIGURE 4. Pulse Width Modulated Step-Down Regulator (f_{OSC} = 20 kHz)

National Semiconductor

LMC7660 Switched Capacitor Voltage Converter

General Description

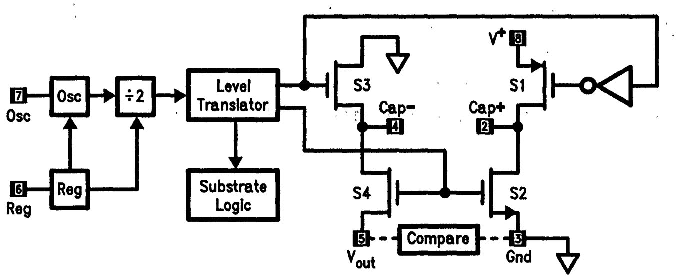
The LMC7660 is a CMOS voltage converter capable of converting a positive voltage in the range of +1.5V to +10V to the corresponding negative voltage of −1.5V to −10V. The LMC7660 is a pin-for-pin replacement for the industry-standard 7660. The converter features: operation over full temperature and voltage range without need for an external diode, low quiescent current, and high power efficiency.

The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two inexpensive electrolytic capacitors.

Features

- Operation over full temperature and voltage range without an external diode
- Low supply current, 200 μA max
- Pin-for-pin replacement for the 7660
- Wide operating range 1.5V to 10V
- 97% Voltage Conversion Efficiency
- 95% Power Conversion Efficiency
- Easy to use, only 2 external components
- Extended temperature range

Block Diagram



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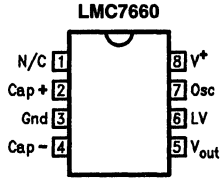
Pin Configuration

LMC7660



TL/H/9136-2

Ordering Information

LMC7660MJ −55°C ≤ T_A ≤ +125°C

LMC7660IN −40°C ≤ T_A ≤ +85°C

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	10.5V
Input Voltage on Pin 6, 7 (Note 2)	−0.3V to (V^+ + 0.3V) for V^+ < 5.5V; (V^+ − 5.5V) to (V^+ + 0.3V) for V^+ > 5.5V
Current into Pin 6 (Note 2)	20 μA
Output Short Circuit Duration (V^+ ≤ 5.5V)	Continuous

	Package J	Package N
Power Dissipation (Note 3)	0.9W	1.4W
T_j Max (Note 3)	150°C	150°C
θ_{ja} (Note 3)	140°C/W	90°C/W
Storage Temp. Range	−65°C ≤ T ≤ 150°C	
Lead Temp. (Soldering, 5 sec)	260°C	260°C
ESD Tolerance (Note 8)		±2000V

Electrical Characteristics (Note 4)

Symbol	Parameter	Conditions	Typ	LMC7660MJ Tested Limit (Note 5)	LMC7660IN Tested Limit (Note 5)	LMC7660IN Design Limit (Note 6)	Units Limits
I_S	Supply Current	$R_L = \infty$	120	200 **400**	200	**400**	μA max
V^+_H	Supply Voltage Range High (Note 7)	R_L = 10 kΩ, Pin 6 Open Voltage Efficiency ≥ 90%	3 to 10	**3 to 10**	3 to 10	**3 to 10**	V
V^+_L	Supply Voltage Range Low	R_L = 10 kΩ, Pin 6 to Gnd. Voltage Efficiency ≥ 90%	1.5 to 3.5	**1.5 to 3.5**	1.5 to 3.5	**1.5 to 3.5**	V
R_{out}	Output Source Resistance	I_L = 20 mA	55	100 **150**	100	**120**	Ω max
		V = 2V, I_L = 3 mA Pin 6 Short to Gnd.	110	200 **300**	200	**300**	Ω max
F_{osc}	Oscillator Frequency		10				kHz
P_{eff}	Power Efficiency	R_L = 5 kΩ	97	95 **90**	95	**90**	% min
$V_{o\ eff}$	Voltage Conversion Efficiency	$R_L = \infty$	99.9	97 **95**	97	**95**	% min
I_{osc}	Oscillator Sink or Source Current	Pin 7 = Gnd. or V^+	3				μA

Note 1: Absolute Maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 4 for conditions.

Note 2: Connecting any input terminal to voltages greater than V^+ or less than ground may cause destructive latchup. It is recommended that no inputs from sources operating from external supplies be applied prior to "power-up" of the LMC7660.

Note 3: For operation at elevated temperature, these devices must be derated based on a thermal resistance of θ_{ja} and T_j max, $T_j = T_A + \theta_{ja} P_D$.

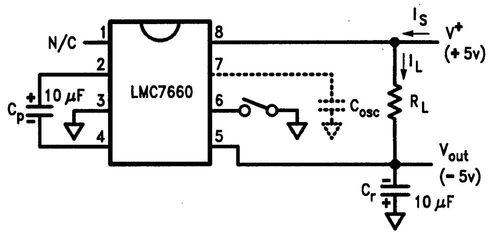
Note 4: Boldface numbers apply at temperature extremes. All other numbers apply at T_A = 25°C, V^+ = 5V, C_{osc} = 0, and apply for the LMC7660 unless otherwise specified. Test circuit is shown in *Figure 1*.

Note 5: Guaranteed and 100% production tested.

Note 6: Guaranteed over the operating temperature range (but not 100% tested). These limits are not used to calculate outgoing quality levels.

Note 7: The LMC7660 can operate without an external diode over the full temperature and voltage range. The LMC7660 can also be used with the external diode Dx, when replacing previous 7660 designs.

Note 8: The test circuit consists of the human body model of 100 pF in series with 1500Ω.

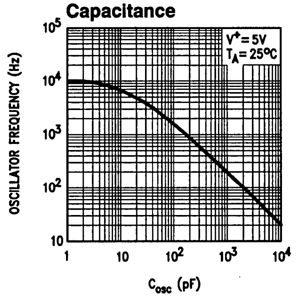


TL/H/9136-5

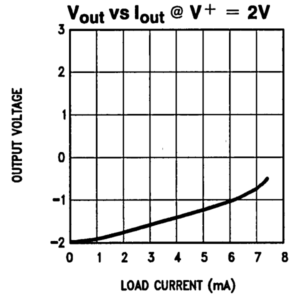
FIGURE 1. LMC7660 Test Circuit

Typical Performance Characteristics

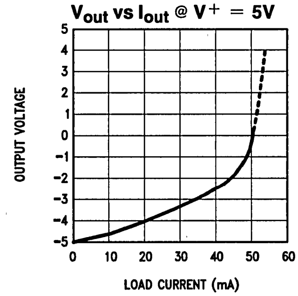
OSC Freq. vs OSC Capacitance



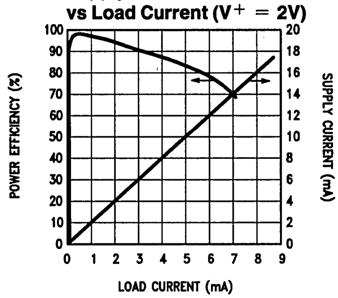
V_{out} vs I_{out} @ $V^+ = 2V$



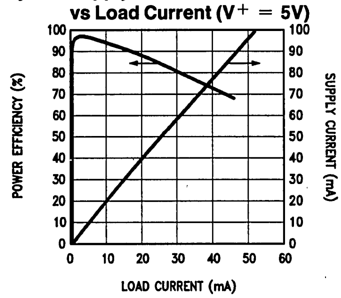
V_{out} vs I_{out} @ $V^+ = 5V$



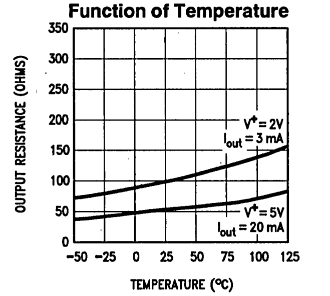
Supply Current & Power Efficiency vs Load Current ($V^+ = 2V$)



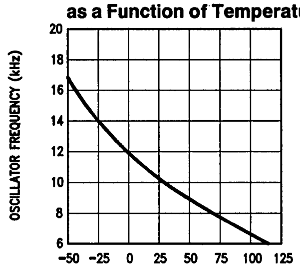
Supply Current & Power Efficiency vs Load Current ($V^+ = 5V$)



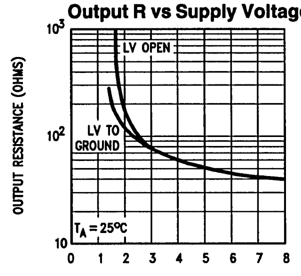
Output Source Resistance as a Function of Temperature



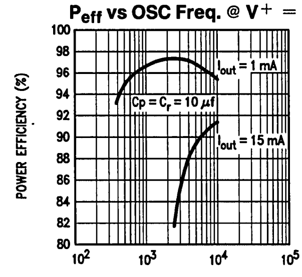
Unloaded Oscillator Frequency as a Function of Temperature



Output R vs Supply Voltage



P_{eff} vs OSC Freq. @ $V^+ = 5V$



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CIRCUIT DESCRIPTION

The LMC7660 contains four large CMOS switches which are switched in a sequence to provide supply inversion $V_{out} = -V_{in}$. Energy transfer and storage are provided by two inexpensive electrolytic capacitors. *Figure 2* shows how the LMC7660 can be used to generate $-V+$ from $V+$. When switches S1 and S3 are closed, C_p charges to the supply voltage $V+$. During this time interval, switches S2 and S4 are open. After C_p charges to $V+$, S1 and S3 are opened, S2 and S4 are then closed. By connecting S2 to ground, C_p develops a voltage $-V+/2$ on C_r. After a number of cycles C_r will be pumped to exactly $-V+$. This transfer will be exact assuming no load on C_r, and no loss in the switches.

In the circuit of *Figure 2*, S1 is a P-channel device and S2, S3, and S4 are N-channel devices. Because the output is biased below ground, it is important that the p^- wells of S3 and S4 never become forward biased with respect to either their sources or drains. A substrate logic circuit guarantees that these p^- wells are always held at the proper voltage. Under all conditions S4 p^- well must be at the lowest potential in the circuit. To switch off S4, a level translator generates $V_{GS4} = 0V$, and this is accomplished by biasing the level translator from the S4 p^- well.

An internal RC oscillator and $\div$ 2 circuit provide timing signals to the level translator. The built-in regulator biases the oscillator and divider to reduce power dissipation on high supply voltage. The regulator becomes active at about $V+ = 6.5V$. Low voltage operation can be improved if the LV pin is shorted to ground for $V+ \leq 3.5V$. For $V+ \geq 3.5V$, the LV pin must be left open to prevent damage to the part.

POWER EFFICIENCY AND RIPPLE

It is theoretically possible to approach 100% efficiency if the following conditions are met:

1) The drive circuitry consumes little power.
2) The power switches are matched and have low R_{on}.
3) The impedance of the reservoir and pump capacitors are negligibly small at the pumping frequency.

The LMC7660 closely approaches 1 and 2 above. By using a large pump capacitor C_p, the charge removed while supplying the reservoir capacitor is small compared to C_p's total charge. Small removed charge means small changes in the pump capacitor voltage, and thus small energy loss and high efficiency. The energy loss by C_p is:

$$E = \tfrac{1}{2}C_p\,(V1^2 - V2^2)$$

By using a large reservoir capacitor, the output ripple can be reduced to an acceptable level. For example, if the load current is 5 mA and the accepted ripple is 200 mV, then the reservoir capacitor can omit approximately be calculated from:

$$Is = C_r \frac{dv}{dt}$$

$$\sim C_r \times \frac{V_{ripple\ p\text{-}p}}{4/F_{osc}} \qquad C_r = \frac{0.5\ mA}{0.5V/ms} = 10\ \mu F$$

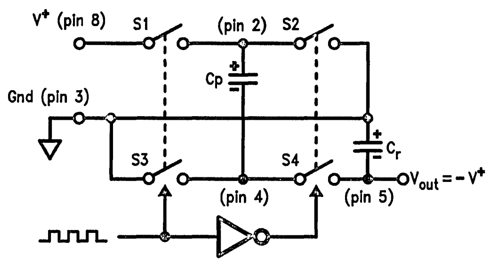
PRECAUTIONS

1) Do not exceed the maximum supply voltage or junction temperature.
2) Do not short pin 6 (LV terminal) to ground for supply voltages greater than 3.5V.
3) Do not short circuit the output to $V+$.
4) External electrolytic capacitors C_r and C_p should have their polarities connected as shown in *Figure 1.*

REPLACING PREVIOUS 7660 DESIGNS

To prevent destructive latchup, previous 7660 designs require a diode in series with the output when operated at elevated temperature or supply voltage. Although this prevented the latchup problem of these designs, it lowered the available output voltage and increased the output series resistance.

The National LMC7660 has been designed to solve the inherent latch problem. The LCM7660 can operate over the



TL/H/9136-6

FIGURE 2. Idealized Voltage Converter

entire supply voltage and temperature range without the need for an output diode. When replacing existing designs, the LMC7660 can be operated with diode Dx.

Typical Applications

Changing Oscillator Frequency

It is possible to dramatically reduce the quiescent operating current of the LMC7660 by lowering the oscillator frequency. The oscillator frequency can be lowered from a nominal 10 kHz to several hundred hertz, by adding a slow-down capacitor C_{OSC} *(Figure 3)*. As shown in the Typical Performance Curves the supply current can be lowered to the 10 μA range. This low current drain can be extremely useful when used in μPower and battery back-up equipment. It must be understood that the lower operating frequency and supply current cause an increased impedance of C_r and C_P. The increased impedance, due to a lower switching rate, can be offset by raising C_r and C_P until ripple and load current requirements are met.

Synchronizing to an External Clock

Figure 4 shows an LMC7660 synchronized to an external clock. The CMOS gate overrides the internal oscillator when it is necessary to switch faster or reduce power supply interference. The external clock still passes through the ÷2 circuit in the 7660, so the pumping frequency will be ½ the external clock frequency.

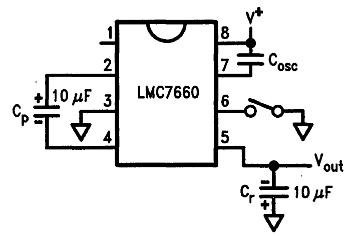


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FIGURE 3. Reduce Supply Current by Lowering Oscillator Frequency

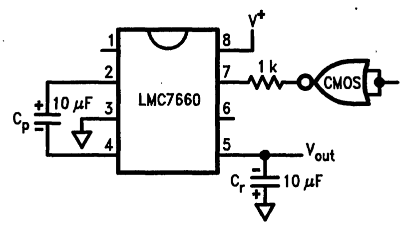

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FIGURE 4. Synchronizing to an External Clock

Typical Applications (Continued)

Lowering Output Impedance

Paralleling two or more LMC7660's lowers output impedance. Each device must have it's own pumping capacitor C_p, but the reservoir capacitor C_r is shared as depicted in *Figure 5*. The composite output resistance is:

$$R_{out} = \frac{R_{out} \text{ of one LMC7660}}{\text{Number of devices}}$$

Increasing Output Voltage

Stacking the LMC7660s is an easy way to produce a greater negative voltage. It should be noted that the input current required for each stage is twice the load current on that stage as shown in *Figure 6A*. The effective output resistance is approximately the sum of the individual R_{out} values, and so only a few levels of multiplication can be used.

It is possible to generate −15V from +5V by connecting the second 7660's pin 8 to +5V instead of ground as shown in *Figure 6B*. Note that the second 7660 sees a full 20V and the input supply should not be increased beyond +5V.

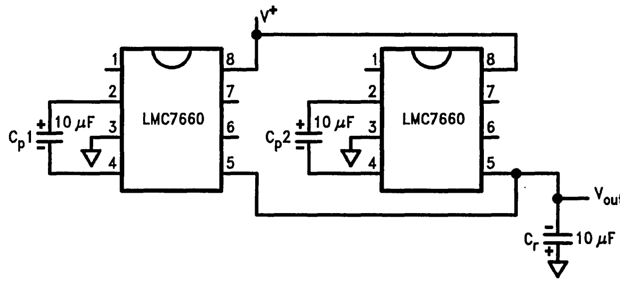

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FIGURE 5. Lowering Output Resistance by Paralleling Devices

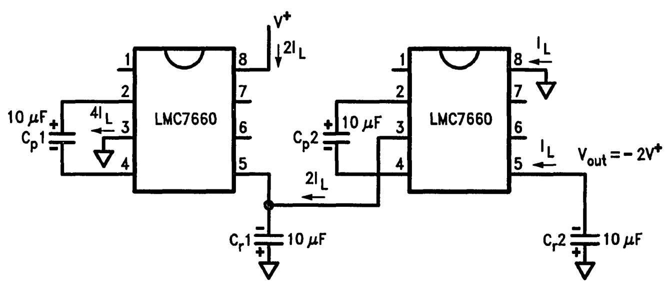

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FIGURE 6A. Higher Voltage by Cascade

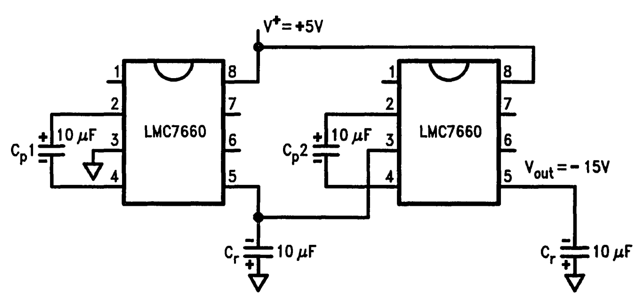

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FIGURE 6B. Getting −15V from +5V

Typical Applications (Continued)

Split V+ In Half

Figure 7 is one of the more interesting applications for the LMC7660. The circuit can be used as a precision voltage divider (for very light loads), alternately it is used to generate a ½ supply point in battery applications. In the ½ cycle when S1 and S3 are closed, the supply voltage divides across the capacitors in a conventional way proportional to their value. In the ½ cycle when S2 and S4 are closed, the capacitors switch from a series connection to a parallel connection. This forces the capacitors to have the same voltage; the charge redistributes to maintain precisely V+/2, across C_p and C_r. In this application all devices are only V+/2, and the supply voltage can be raised to 20V giving exactly 10V at V_{out}.

Getting Up . . . and Down

The LMC7660 can also be used as a positive voltage multiplier. This application, shown in *Figure 8*, requires 2 additional diodes. During the first ½ cycle S2 charges C_p1 through D1; D2 is reverse biased. In the next ½ cycle S2 is open and S1 is closed. Since C_p1 is charged to $V^+ - V_{D1}$ and is referenced to V^+ through S1, the junction of D1 and D2 is at $V^+ + (V^+ - V_{D1})$. D1 is reverse biased in this interval. This application uses only two of the four switches in the 7660. The other two switches can be put to use in performing a negative conversion at the same time as shown in *Figure 9*. In the ½ cycle that D1 is charging C_p1, C_p2 is connected from ground to $-V_{out}$ via S2 and S4, and C_r2 is storing C_p2's charge. In the interval that S1 and S3 are closed, C_p1 pumps the junction of D1 and D2 above V^+, while C_p2 is refreshed from V^+.

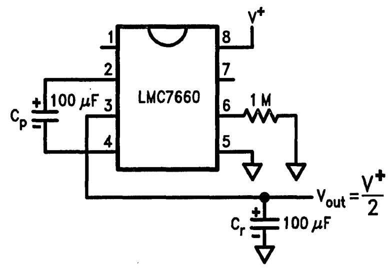

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FIGURE 7. Split V+ in Half

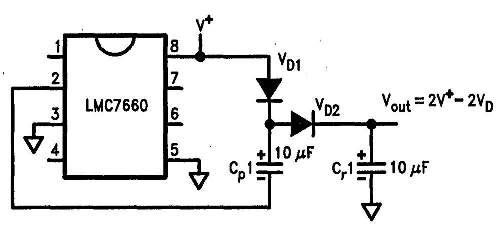

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FIGURE 8. Positive Voltage Multiplier

Typical Applications (Continued)

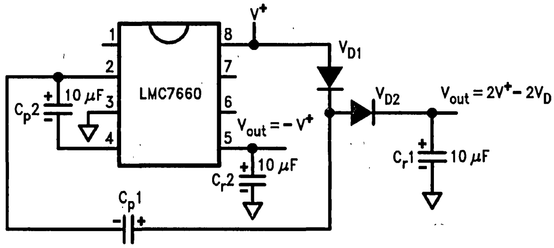

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FIGURE 9. Combined Negative Converter and Positive Multiplier

Thermometer Spans 180°C

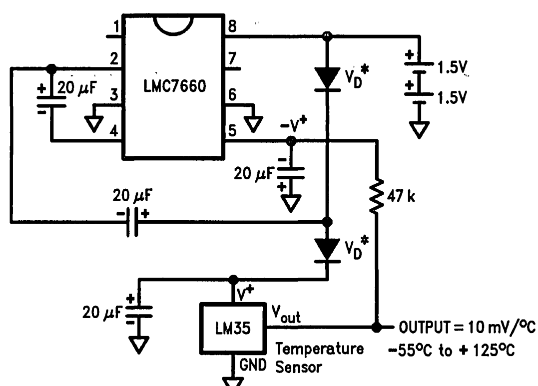
Using the combined negative and positive multiplier of *Figure 10* with an LM35 it is possible to make a μPower thermometer that spans a 180°C temperature range. The LM35 temperature sensor has an output sensitivity of 10 mV/°C, while drawing only 50 μA of quiescent current. In order for the LM35 to measure negative temperatures, a pull down to a negative voltage is required. *Figure 10* shows a thermometer circuit for measuring temperatures from −55°C to +125°C and requiring only two 1.5V cells. End of battery life can be extended by replacing the up converter diodes with Schottky's.

Regulating $-V_{out}$

It is possible to regulate the output of the LMC7660 and still maintain μPower performance. This is done by enclosing the LMC7660 in a loop with a LP2951. The circuit of *Figure 11* will regulate V_{out} to −5V for I_L = 10 mA, and V_{in} = 6V. For V_{in} > 7V, the output stays in regulation up to I_L = 25 mA. The error flag on pin 5 of the LP2951 sets low when the regulated output at pin 4 drops by about 5%. The LP2951 can be shutdown by taking pin 3 high; the LMC7660 can be shutdown by shorting pin 7 and pin 8.

The LP2951 can be reconfigured to an adjustable type regulator, which means the LMC7660 can give a regulated output from −2.0V to −10V dependent on the resistor ratios R1 and R2, as shown in *Figure 12*, V_{ref} = 1.235V:

$$V_{out} = V_{ref}\left(1 + \frac{R1}{R2}\right)$$



*For lower voltage operation, use Schottky rectifiers

TL/H/9136–15

FIGURE 10. μPower Thermometer Spans 180°C, and Pulls Only 150 μA

Typical Applications (Continued)

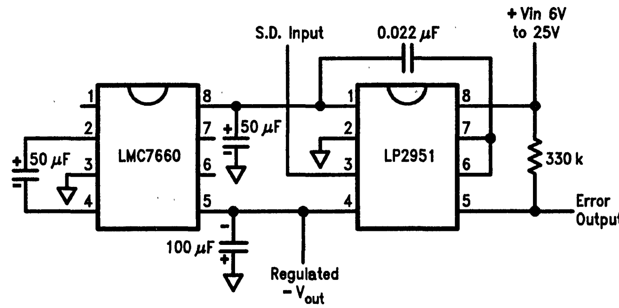


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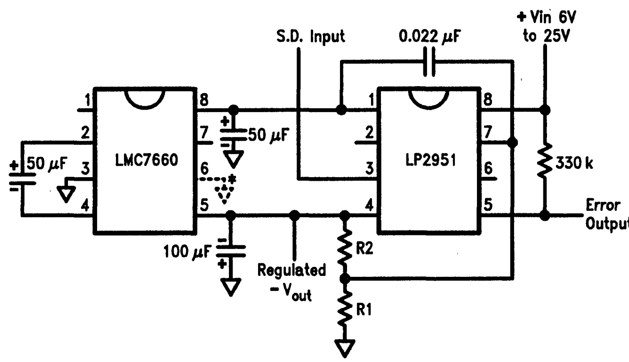
FIGURE 11. Regulated −5V with 200 μA Standby Current



$V_{out} = V_{ref}\left(1 + \frac{R1}{R2}\right)$

$V_{ref} = 1.235V$

*Low voltage operation

TL/H/9136–17

FIGURE 12. LMC7660 and LP2951 Make a Negative Adjustable Regulator

Section 4

Motion Control

Section 4 Contents

National Semiconductor

Motion Control and Motor Drive Selection Guide

Motor Drive Circuits—Bridges

Device	Description	Output Current (A)	Max Input Voltage (V)	Operating Temperature (T_J)	Package Availability	Page No.
LMD18200	DMOS H-Bridge with Internal Current Sense	3	55	−40°C to +125°C	11-Lead TO-220	4-44
LMD18201	DMOS H-Bridge	3	55	−40°C to +125°C	11-Lead TO-220	4-53
LMD18245	DMOS H-Bridge with Digital or Analog Control	3	55	−40°C to +125°C	15-Lead TO-220	4-59
LM18293	4-Channel Push-Pull Driver	1/Channel	36	−40°C to +125°C	16-Lead DIP	4-38

Motor Drive Circuits—Linear

Device	Description	Output Current (A)	Max Supply Voltage (V)	Operating Temperature (T_C)	Package Availability	Page No.
LM12	Monolithic Power Op-Amp	±10	±30	0°C to +70°C	4-Lead TO-3	4-4

Precision Motion Control Processor

Device	Features	Operating Temperature (T_A)	Max Clock Speed (MHz)	Package Availability	Page No.
LM628	32-Bit Position, Velocity, and Acceleration Registers; Position and Velocity Modes; 16-Bit PID Filter with Programmable Coefficients; 8 or 12-Bit DAC Output Data; Quadrature Incremental Encoder Interface; 8-Bit Asynchronous Host Interface	−40°C to +85°C	6 or 8	28-Lead DIP	4-17
LM629	Same Features as LM628, but with 8-Bit PWM Sign/Magnitude Output Data	−40°C to +85°C	6 or 8	28-Lead DIP	4-17

National Semiconductor

LM12 80W Operational Amplifier

General Description

The LM12 is a power op amp capable of driving ±25V at ±10A while operating from ±30V supplies. The monolithic IC can deliver 80W of sine wave power into a 4Ω load with 0.01% distortion. Power bandwidth is 60 kHz. Further, a peak dissipation capability of 800W allows it to handle reactive loads such as transducers, actuators or small motors without derating. Important features include:

- input protection
- controlled turn on
- thermal limiting
- overvoltage shutdown
- output-current limiting
- dynamic safe-area protection

The IC delivers ±10A output current at any output voltage yet is completely protected against overloads, including shorts to the supplies. The dynamic safe-area protection is provided by instantaneous peak-temperature limiting within the power transistor array.

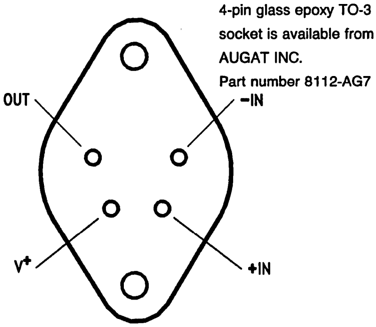
The turn-on characteristics are controlled by keeping the output open-circuited until the total supply voltage reaches 14V. The output is also opened as the case temperature exceeds 150°C or as the supply voltage approaches the BV_{CEO} of the output transistors. The IC withstands overvoltages to 80V.

This monolithic op amp is compensated for unity-gain feedback, with a small-signal bandwidth of 700 kHz. Slew rate is 9V/μs, even as a follower. Distortion and capacitive-load stability rival that of the best designs using complementary output transistors. Further, the IC withstands large differential input voltages and is well behaved should the common-mode range be exceeded.

The LM12 establishes that monolithic ICs can deliver considerable output power without resorting to complex switching schemes. Devices can be paralleled or bridged for even greater output capability. Applications include operational power supplies, high-voltage regulators, high-quality audio amplifiers, tape-head positioners, x-y plotters or other servo-control systems.

The LM12 is supplied in a four-lead, TO-3 package with V^- on the case. A gold-eutectic die-attach to a molybdenum interface is used to avoid thermal fatigue problems. The LM12 is specified for either military or commercial temperature range.

Connection Diagram

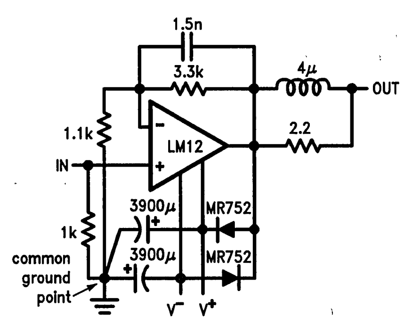


TL/H/8704–1

Bottom View

Order Number LM12CLK
See NS Package Number K04A

Typical Application*



TL/H/8704–2

*Low distortion (0.01%) audio amplifier

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (Note 1)	80V
Input Voltage	(Note 2)
Output Current	Internally Limited
Junction Temperature	(Note 3)
Storage Temperature Range	−65°C to 150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Operating Ratings

Total Supply Voltage	15V to 60V
Case Temperature (Note 4)	0°C to 70°C

Electrical Characteristics (Note 4)

Parameter	Conditions	Typ 25°C	LM12CL Limits	Units
Input Offset Voltage	$\pm 10V \le V_S \le \pm 0.5\ V_{MAX}$, $V_{CM} = 0$	2	15/**20**	mV (max)
Input Bias Current	$V^- + 4V \le V_{CM} \le V^+ - 2V$	0.15	0.7/**1.0**	μA (max)
Input Offset Current	$V^- + 4V \le V_{CM} \le V^+ - 2V$	0.03	0.2/**0.3**	μA (max)
Common Mode Rejection	$V^- + 4V \le V_{CM} \le V^+ - 2V$	86	70/**65**	dB (min)
Power Supply Rejection	$V^+ = 0.5\ V_{MAX}$, $-6V \ge V^- \ge -0.5\ V_{MAX}$	90	70/**65**	dB (min)
	$V^- = -0.5\ V_{MAX}$, $6V \le V^+ \le 0.5\ V_{MAX}$	110	75/**70**	dB (min)
Output Saturation Threshold	$t_{ON} = 1$ ms, $\Delta V_{IN} = 5$ (**10**) mV, $I_{OUT} = 1A$	1.8	2.2/**2.5**	V (max)
	8A	4	5/**7**	V (max)
	10A	5		V (max)
Large Signal Voltage Gain	$t_{ON} = 2$ ms, $V_{SAT} = 2V$, $I_{OUT} = 0$	100	30/**20**	V/mV (min)
	$V_{SAT} = 8V$, $R_L = 4\Omega$	50	15/**10**	V/mV (min)
Thermal Gradient Feedback	$P_{DISS} = 50W$, $t_{ON} = 65$ ms	30	100	μV/W (max)
Output-Current Limit	$t_{ON} = 10$ ms, $V_{DISS} = 10V$	13	16	A (max)
	$t_{ON} = 100$ ms, $V_{DISS} = 58V$	1.5	0.9/**0.6**	A (min)
		1.5	1.7	A (max)
Power Dissipation Rating	$t_{ON} = 100$ ms, $V_{DISS} = 20V$	100	80/**55**	W (min)
	$V_{DISS} = 58V$	80	52/**35**	W (min)
DC Thermal Resistance	(Note 5) $V_{DISS} = 20V$	2.3	2.9	°C/W (max)
	$V_{DISS} = 58V$	2.7	4.5	°C/W (max)
AC Thermal Resistance	(Note 5)	1.6	2.1	°C/W (max)
Supply Current	$V_{OUT} = 0$, $I_{OUT} = 0$	60	120/**140**	mA (max)

Note 1: Absolute maximum ratings indicate limits beyond which damage to the device may occur. The maximum voltage for which the LM12 is guaranteed to operate is given in the operating ratings and in Note 4. With inductive loads or output shorts, other restrictions described in applications section apply.

Note 2. Neither input should exceed the supply voltage by more than 50 volts nor should the voltage between one input and any other terminal exceed 60 volts.

Note 3. Operating junction temperature is internally limited near 225°C within the power transistor and 160°C for the control circuitry.

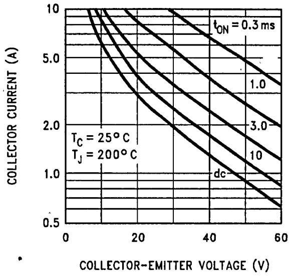
Note 4. The supply voltage is ±30V ($V_{MAX} = 60V$), unless otherwise specified. The voltage across the conducting output transistor (supply to output) is V_{DISS} and internal power dissipation is P_{DISS}. Temperature range is $0°C \le T_C \le 70°C$ where T_C is the case temperature. Standard typeface indicates limits at 25°C **while boldface type refers to limits or special conditions over full temperature range.** With no heat sink, the package will heat at a rate of 35°C/sec per 100W of internal dissipation.

Note 5. This thermal resistance is based upon a peak temperature of 200°C in the center of the power transistor and a case temperature of 25°C measured at the center of the package bottom. The maximum junction temperature of the control circuitry can be estimated based upon a dc thermal resistance of 0.9°C/W or an ac thermal resistance of 0.6°C/W for any operating voltage.

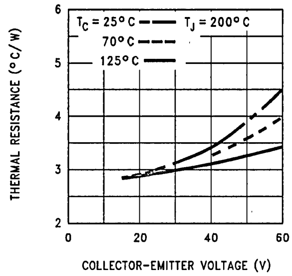
Although the output and supply leads are resistant to electrostatic discharges from handling, the input leads are not. The part should be treated accordingly.

Output-Transistor Ratings (guaranteed)

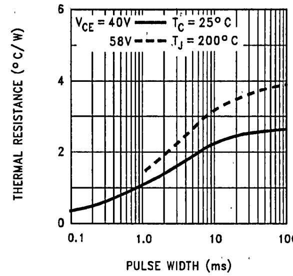
Safe Area



DC Thermal Resistance



Pulse Thermal Resistance



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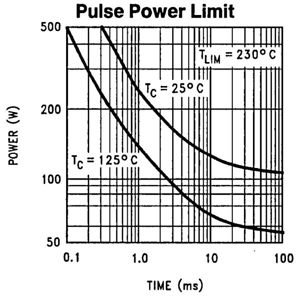
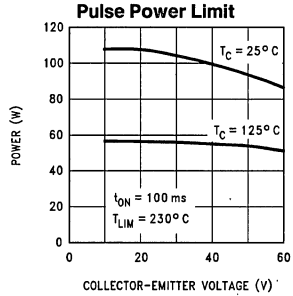
Typical Performance Characteristics

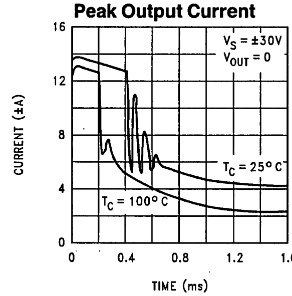
Pulse Power Limit



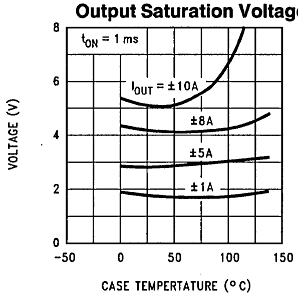
Pulse Power Limit



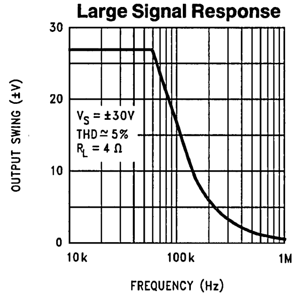
Peak Output Current



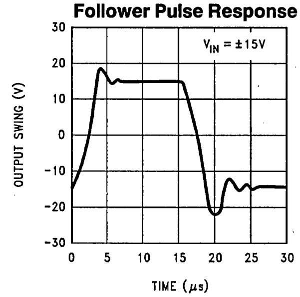
Output Saturation Voltage



Large Signal Response



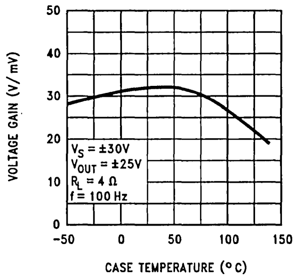
Follower Pulse Response



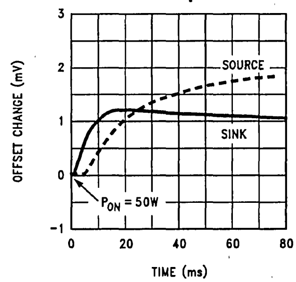
TL/H/8704-4

Typical Performance Characteristics (Continued)

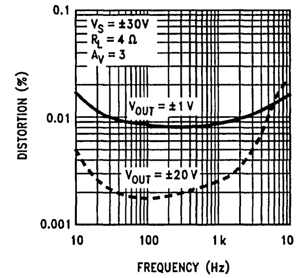
Large Signal Gain



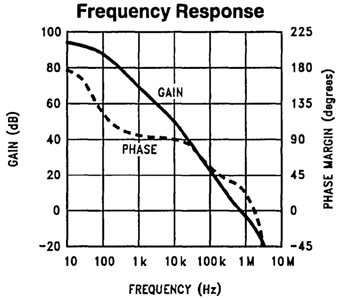
Thermal Response



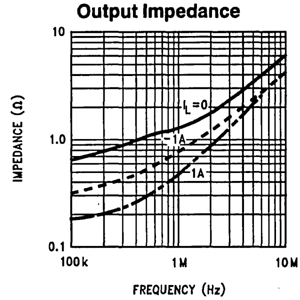
Total Harmonic Distortion



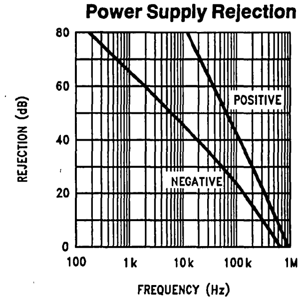
Frequency Response



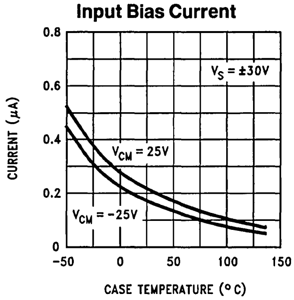
Output Impedance



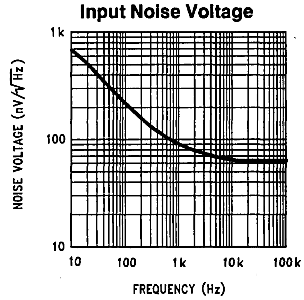
Power Supply Rejection



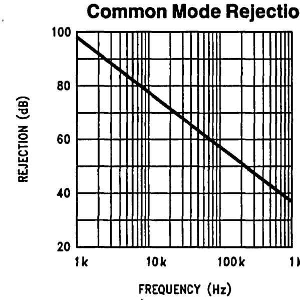
Input Bias Current



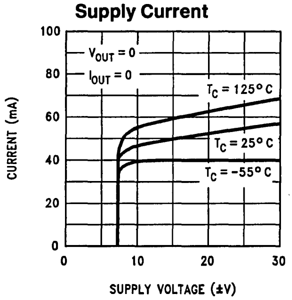
Input Noise Voltage



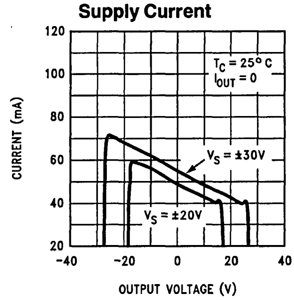
Common Mode Rejection



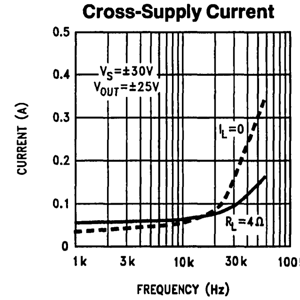
Supply Current



Supply Current



Cross-Supply Current



TL/H/8704-5

Application Information

GENERAL

Twenty five years ago the operational amplifier was a specialized design tool used primarily for analog computation. However, the availability of low cost IC op amps in the late 1960's prompted their use in rather mundane applications, replacing a few discrete components. Once a few basic principles are mastered, op amps can be used to give exceptionally good results in a wide range of applications while minimizing both cost and design effort.

The availability of a monolithic power op amp now promises to extend these advantages to high-power designs. Some conventional applications are given here to illustrate op amp design principles as they relate to power circuitry. The inevitable fall in prices, as the economies of volume production are realized, will prompt their use in applications that might now seem trivial. Replacing single power transistors with an op amp will become economical because of improved performance, simplification of attendant circuitry, vastly improved fault protection, greater reliability and the reduction of design time.

Power op amps introduce new factors into the design equation. With current transients above 10A, both the inductance and resistance of wire interconnects become important in a number of ways. Further, power ratings are a crucial factor in determining performance. But the power capability of the IC cannot be realized unless it is properly mounted to an adequate heat sink. Thus, thermal design is of major importance with power op amps.

This application summary starts off by identifying the origin of strange problems observed while using the LM12 in a wide variety of designs with all sorts of fault conditions. A few simple precautions will eliminate these problems. **One would do well to read the section on supply bypassing, lead inductance, output clamp diodes, ground loops and reactive loading before doing any experimentation. Should there be problems with erratic operation, blowouts, excessive distortion or oscillation, another look at these sections is in order.**

The management and protection circuitry can also affect operation. Should the total supply voltage exceed ratings or drop below 15–20V, the op amp shuts off completely. Case temperatures above 150°C also cause shut down until the temperature drops to 145°C. This may take several seconds, depending on the thermal system. Activation of the dynamic safe-area protection causes both the main feedback loop to lose control and a reduction in output power, with possible oscillations. In ac applications, the dynamic protection will cause waveform distortion. Since the LM12 is well protected against thermal overloads, the suggestions for determining power dissipation and heat sink requirements are presented last.

SUPPLY BYPASSING

All op amps should have their supply leads bypassed with low-inductance capacitors having short leads and located close to the package terminals to avoid spurious oscillation problems. Power op amps require larger bypass capacitors. The LM12 is stable with good-quality electrolytic bypass capacitors greater than 20 μF. Other considerations may require larger capacitors.

The current in the supply leads is a rectified component of the load current. If adequate bypassing is not provided, this distorted signal can be fed back into internal circuitry. Low distortion at high frequencies requires that the supplies be bypassed with 470 μF or more, at the package terminals.

LEAD INDUCTANCE

With ordinary op amps, lead-inductance problems are usually restricted to supply bypassing. Power op amps are also sensitive to inductance in the output lead, particularly with heavy capacitive loading. Feedback to the input should be taken directly from the output terminal, minimizing common inductance with the load. Sensing to a remote load must be accompanied by a high-frequency feedback path directly from the output terminal. Lead inductance can also cause voltage surges on the supplies. With long leads to the power source, energy stored in the lead inductance when the output is shorted can be dumped back into the supply bypass capacitors when the short is removed. The magnitude of this transient is reduced by increasing the size of the bypass capacitor near the IC. With 20 μF local bypass, these voltage surges are important only if the lead length exceeds a couple feet (> 1 μH lead inductance). Twisting together the supply and ground leads minimizes the effect.

GROUND LOOPS

With fast, high-current circuitry, all sorts of problems can arise from improper grounding. In general, difficulties can be avoided by returning all grounds separately to a common point. Sometimes this is impractical. When compromising, special attention should be paid to the ground returns for the supply bypasses, load and input signal. Ground planes also help to provide proper grounding.

Many problems unrelated to system performance can be traced to the grounding of line-operated test equipment used for system checkout. Hidden paths are particularly difficult to sort out when several pieces of test equipment are used but can be minimized by using current probes or the new isolated oscilloscope pre-amplifiers. Eliminating any direct ground connection between the signal generator and the oscilloscope synchronization input solves one common problem.

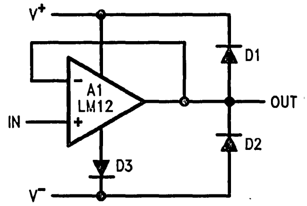
OUTPUT CLAMP DIODES

When a push-pull amplifier goes into power limit while driving an inductive load, the stored energy in the load inductance can drive the output outside the supplies. Although the LM12 has internal clamp diodes that can handle several amperes for a few milliseconds, extreme conditions can cause destruction of the IC. The internal clamp diodes are imperfect in that about half the clamp current flows into the supply to which the output is clamped while the other half flows across the supplies. Therefore, the use of external diodes to clamp the output to the power supplies is strongly recommended. This is particularly important with higher supply voltages.

Experience has demonstrated that hard-wire shorting the output to the supplies can induce random failures if these external clamp diodes are not used and the supply voltages are above ±20V. Therefore it is prudent to use output-

Application Information (Continued)

clamp diodes even when the load is not particularly inductive. This also applies to experimental setups in that blowouts have been observed when diodes were not used. In packaged equipment, it may be possible to eliminate these diodes, providing that fault conditions can be controlled.



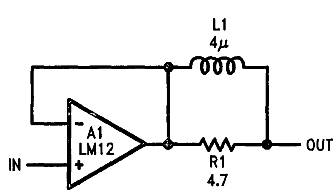
TL/H/8704-6

Heat sinking of the clamp diodes is usually unimportant in that they only clamp current transients. Forward drop with 15A fault transients is of greater concern. Usually, these transients die out rapidly. The clamp to the negative supply can have somewhat reduced effectiveness under worst case conditions should the forward drop exceed 1.0V. Mounting this diode to the power op amp heat sink improves the situation. Although the need has only been demonstrated with some motor loads, including a third diode (D3 above) will eliminate any concern about the clamp diodes. This diode, however, must be capable of dissipating continuous power as determined by the negative supply current of the op amp.

REACTIVE LOADING

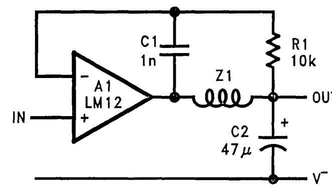
The LM12 is normally stable with resistive, inductive or smaller capacitive loads. Larger capacitive loads interact with the open-loop output resistance (about 1Ω) to reduce the phase margin of the feedback loop, ultimately causing oscillation. The critical capacitance depends upon the feedback applied around the amplifier; a unity-gain follower can handle about 0.01 μF, while more than 1 μF does not cause problems if the loop gain is ten. With loop gains greater than unity, a speedup capacitor across the feedback resistor will aid stability. In all cases, the op amp will behave predictably only if the supplies are properly bypassed, ground loops are controlled and high-frequency feedback is derived directly from the output terminal, as recommended earlier.

So-called capacitive loads are not always capacitive. A high-Q capacitor in combination with long leads can present a series-resonant load to the op amp. In practice, this is not usually a problem; but the situation should be kept in mind.



TL/H/8704-7

Large capacitive loads (including series-resonant) can be accommodated by isolating the feedback amplifier from the load as shown above. The inductor gives low output impedance at lower frequencies while providing an isolating impedance at high frequencies. The resistor kills the Q of series resonant circuits formed by capacitive loads. A low inductance, carbon-composition resistor is recommended. Optimum values of L and R depend upon the feedback gain and expected nature of the load, but are not critical. A 4 μH inductor is obtained with 14 turns of number 18 wire, close spaced, around a one-inch-diameter form.



TL/H/8704-8

The LM12 can be made stable for all loads with a large capacitor on the output, as shown above. This compensation gives the lowest possible closed-loop output impedance at high frequencies and the best load-transient response. It is appropriate for such applications as voltage regulators.

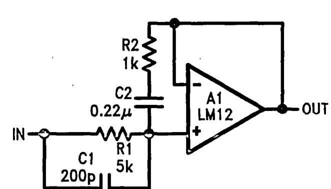
A feedback capacitor, C_1, is connected directly to the output pin of the IC. The output capacitor, C_2, is connected at the output terminal with short leads. Single-point grounding to avoid dc and ac ground loops is advised.

The impedance, Z_1, is the wire connecting the op amp output to the load capacitor. About 3-inches of number-18 wire (70 nH) gives good stability and 18-inches (400 nH) begins to degrade load-transient response. The minimum load capacitance is 47 μF, if a solid-tantalum capacitor with an equivalent series resistance (ESR) of 0.1Ω is used. Electrolytic capacitors work as well, although capacitance may have to be increased to 200 μF to bring ESR below 0.1Ω.

Loop stability is not the only concern when op amps are operated with reactive loads. With time-varying signals, power dissipation can also increase markedly. This is particularly true with the combination of capacitive loads and high-frequency excitation.

INPUT COMPENSATION

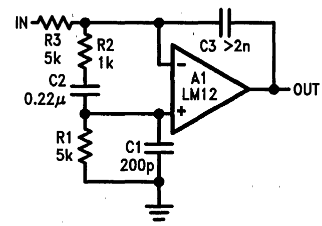
The LM12 is prone to low-amplitude oscillation bursts coming out of saturation if the high-frequency loop gain is near unity. The voltage follower connection is most susceptible. This glitching can be eliminated at the expense of small-signal bandwidth using input compensation. Input compensation can also be used in combination with LR load isolation to improve capacitive load stability.



TL/H/8704-9

An example of a voltage follower with input compensation is shown here. The R_2C_2 combination across the input works with R_1 to reduce feedback at high frequencies without greatly affecting response below 100 kHz. A lead capacitor, C_1, improves phase margin at the unity-gain crossover frequency. Proper operation requires that the output impedance of the circuitry driving the follower be well under 1 kΩ at frequencies up to a few hundred kilohertz.

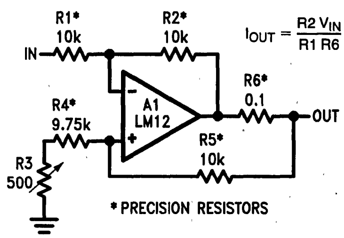
Application Information (Continued)



TL/H/8704-10

Extending input compensation to the integrator connection is shown here. Both the follower and this integrator will handle 1 μF capacitive loading without LR output isolation.

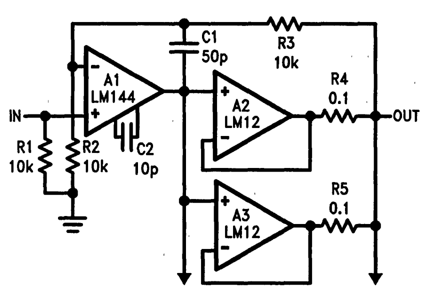
CURRENT DRIVE



TL/H/8704-11

This circuit provides an output current proportional to the input voltage. Current drive is sometimes preferred for servo motors because it aids in stabilizing the servo loop by reducing phase lag caused by motor inductance. In applications requiring high output resistance, such as operational power supplies running in the current mode, matching of the feedback resistors to 0.01% is required. Alternately, an adjustable resistor can be used for trimming.

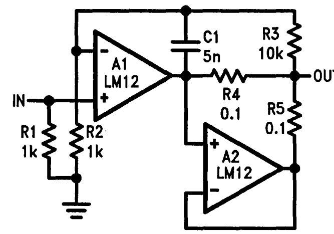
PARALLEL OPERATION



TL/H/8704-12

Output drive beyond the capability of one power amplifier can be provided as shown here. The power op amps are wired as followers and connected in parallel with the outputs coupled through equalization resistors. A standard, high-voltage op amp is used to provide voltage gain. Overall feedback compensates for the voltage dropped across the equalization resistors.

With parallel operation, there may be an increase in unloaded supply current related to the offset voltage across the equalization resistors. More output buffers, with individual equalization resistors, may be added to meet even higher drive requirements.

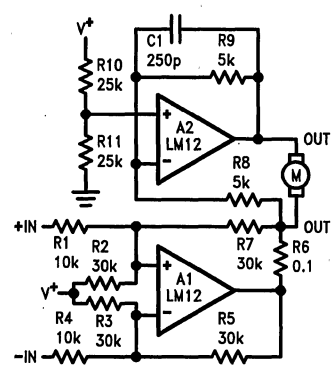


TL/H/8704-13

This connection allows increased output capability without requiring a separate control amplifier. The output buffer, A_2, provides load current through R_5 equal to that supplied by the main amplifier, A_1, through R_4. Again, more output buffers can be added.

Current sharing among paralleled amplifiers can be affected by gain error as the power-bandwidth limit is approached. In the first circuit, the operating current increase will depend upon the matching of high-frequency characteristics. In the second circuit, however, the entire input error of A_2 appears across R_4 and R_5. The supply current increase can cause power limiting to be activated as the slew limit is approached. This will not damage the LM12. It can be avoided in both cases by connecting A_1 as an inverting amplifier and restricting bandwidth with C_1.

SINGLE-SUPPLY OPERATION



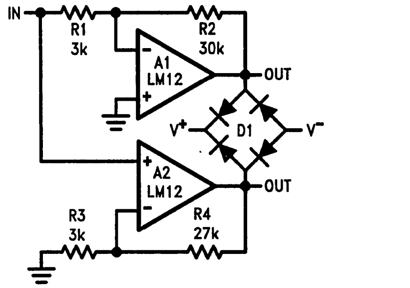
TL/H/8704-14

Although op amps are usually operated from dual supplies, single-supply operation is practical. This bridge amplifier supplies bi-directional current drive to a servo motor while operating from a single positive supply. The output is easily converted to voltage drive by shorting R_6 and connecting R_7 to the output of A_2, rather than A_1.

Either input may be grounded, with bi-directional drive provided to the other. It is also possible to connect one input to a positive reference, with the input signal varying about this voltage. If the reference voltage is above 5V, R_2 and R_3 are not required.

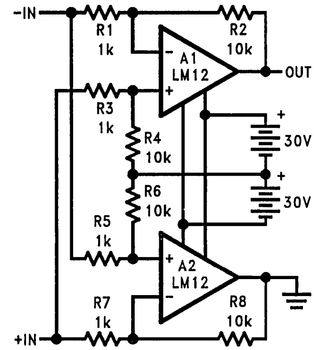
Application Information (Continued)

HIGH VOLTAGE AMPLIFIERS



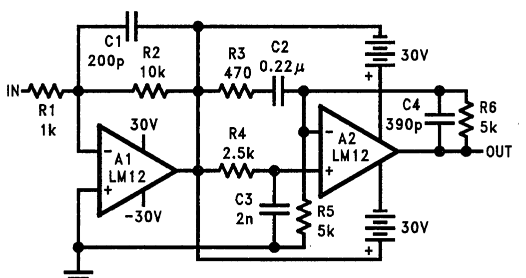
TL/H/8704-15

The voltage swing delivered to the load can be doubled by using the bridge connection shown here. Output clamping to the supplies can be provided by using a bridge-rectifier assembly.



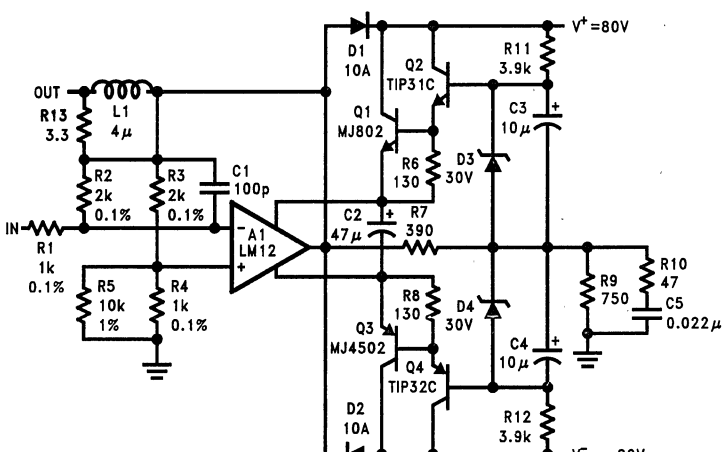
TL/H/8704-16

One limitation of the standard bridge connection is that the load cannot be returned to ground. This can be circumvented by operating the bridge with floating supplies, as shown above. For single-ended drive, either input can be grounded.



TL/H/8704-17

This circuit shows how two amplifiers can be cascaded to double output swing. The advantage over the bridge is that the output can be increased with any number of stages, although separate supplies are required for each.

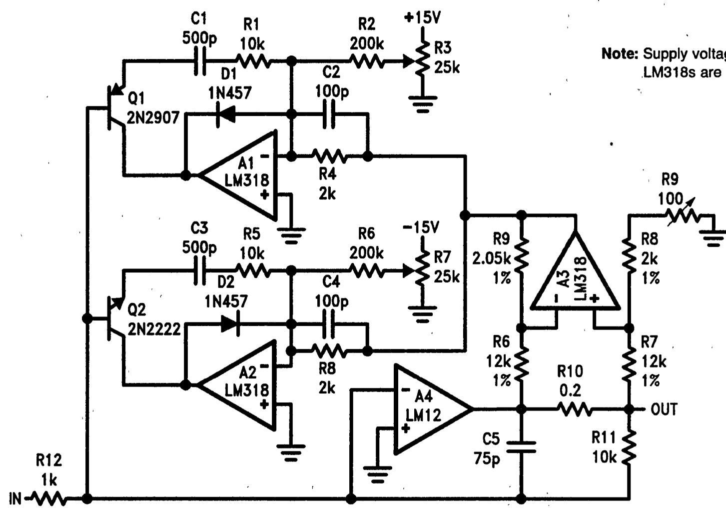


TL/H/8704-18

Discrete transistors can be used to increase output drive to ±70V at ±10A as shown above. With proper thermal design, the IC will provide safe-area protection for the external transistors. Voltage gain is about thirty.

Application Information (Continued)

OPERATIONAL POWER SUPPLY



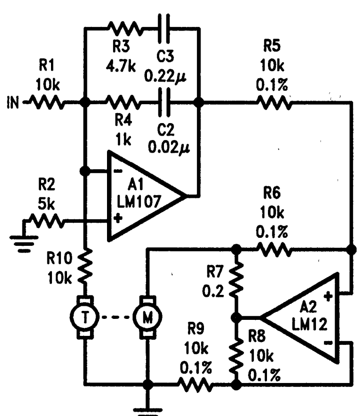
Note: Supply voltages for the LM318s are ±15V

TL/H/8704–19

External current limit can be provided for a power op amp as shown above. The positive and negative current limits can be set precisely and independently. Fast response is assured by D_1 and D_2. Adjustment range can be set down to zero with potentiometers R_3 and R_7. Alternately, the limit can be programmed from a voltage supplied to R_2 and R_6. This is the set up required for an operational power supply or voltage-programmable power source.

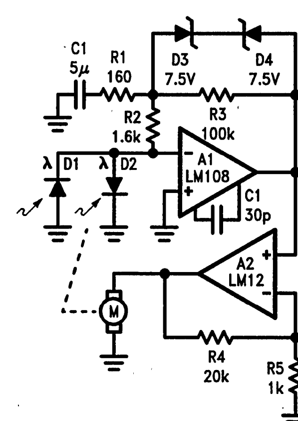
SERVO AMPLIFIERS

When making servo systems with a power op amp, there is a temptation to use it for frequency shaping to stabilize the servo loop. Sometimes this works; other times there are better ways; and occasionally it just doesn't fly. Usually it's a matter of how quickly and to what accuracy the servo must stabilize.



TL/H/8704–20

This motor/tachometer servo gives an output speed proportional to input voltage. A low-level op amp is used for frequency shaping while the power op amp provides current drive to the motor. Current drive eliminates loop phase shift due to motor inductance and makes high-performance servos easier to stabilize.

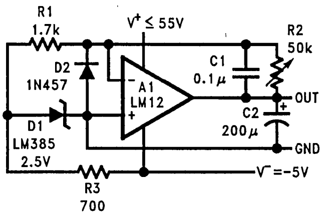


TL/H/8704–21

This position servo uses an op amp to develop the rate signal electrically instead of using a tachometer. In high-performance servos, rate signals must be developed with large error signals well beyond saturation of the motor drive. Using a separate op amp with a feedback clamp allows the rate signal to be developed properly with position errors more than an order of magnitude beyond the loop-saturation level as long as the photodiode sensors are positioned with this in mind.

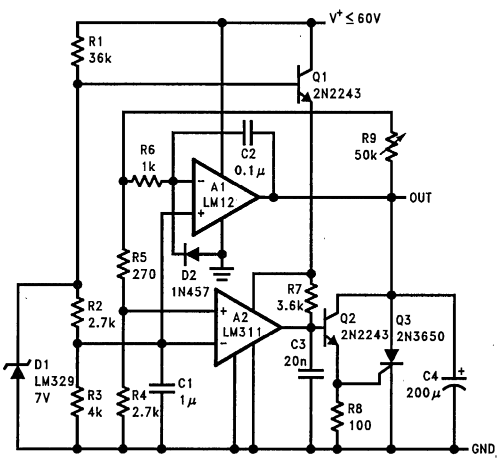
Application Information (Continued)

VOLTAGE REGULATORS



TL/H/8704–22

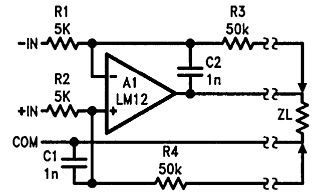
An op amp can be used as a positive or negative regulator. Unlike most regulators, it can sink current to absorb energy dumped back into the output. This positive regulator has a 0–50V output range.



TL/H/8704–23

Dual supplies are not required to use an op amp as a voltage regulator if zero output is not required. This 4V to 50V regulator operates from a single supply. Should the op amp not be able to absorb enough energy to control an overvoltage condition, a SCR will crowbar the output.

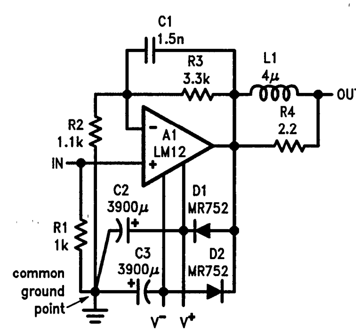
REMOTE SENSING



TL/H/8704–24

Remote sensing as shown above allows the op amp to correct for dc drops in cables connecting the load. Even so, cable drop will affect transient response. Degradation can be minimized by using twisted, heavy-gauge wires on the output line. Normally, common and one input are connected together at the sending end.

AUDIO AMPLIFIERS



TL/H/8704–25

A power amplifier suitable for use in high-quality audio equipment is shown above. Harmonic distortion is about 0.01-percent. Intermodulation distortion (60 Hz/7 kHz, 4:1) measured 0.015-percent. Transient response and saturation recovery are clean, and the 9 V/µs slew rate of the LM12 virtually eliminates transient intermodulation distortion. Using separate amplifiers to drive low- and high-frequency speakers gets rid of high-level crossover networks and attenuators. Further, it prevents clipping on the low-frequency channel from distorting the high frequencies.

Application Information (Continued)

DETERMINING MAXIMUM DISSIPATION

It is a simple matter to establish power requirements for an op amp driving a resistive load at frequencies well below 10 Hz. Maximum dissipation occurs when the output is at one-half the supply voltage with high-line conditions. The individual output transistors must be rated to handle this power continuously at the maximum expected case temperature. The power rating is limited by the maximum junction temperature as determined by

$$T_J = T_C + P_{DISS}\,\theta_{JC},$$

where T_C is the case temperature as measured at the center of the package bottom, P_{DISS} is the maximum power dissipation and θ_{JC} is the thermal resistance at the operating voltage of the output transistor. Recommended maximum junction temperatures are 200°C within the power transistor and 150°C for the control circuitry.

If there is ripple on the supply bus, it is valid to use the average value in worst-case calculations as long as the peak rating of the power transistor is not exceeded at the ripple peak. With 120 Hz ripple, this is 1.5 times the continuous power rating.

Dissipation requirements are not so easily established with time varying output signals, especially with reactive loads. Both peak and continuous dissipation ratings must be taken into account, and these depend on the signal waveform as well as load characteristics.

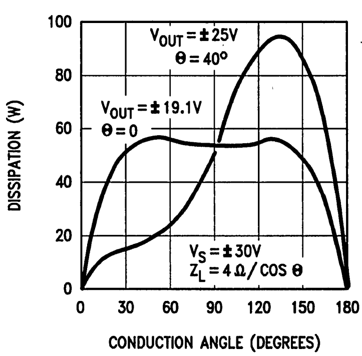
With a sine wave output, analysis is fairly straightforward. With supply voltages of $\pm V_S$, the maximum average power dissipation of both output transistors is

$$P_{MAX} = \frac{2V_S^2}{\pi^2 Z_L \cos\theta}, \quad \theta < 40°;$$

and

$$P_{MAX} = \frac{V_S^2}{2Z_L}\left[\frac{4}{\pi} - \cos\theta\right], \quad \theta \geq 40°,$$

where Z_L is the magnitude of the load impedance and θ its phase angle. Maximum average dissipation occurs below maximum output swing for $\theta < 40°$.



TL/H/8704–26

The instantaneous power dissipation over the conducting half cycle of one output transistor is shown here. Power dissipation is near zero on the other half cycle. The output level is that resulting in maximum peak and average dissipation. Plots are given for a resistive and a series RL load. The latter is representative of a 4Ω loudspeaker operating below resonance and would be the worst case condition in most audio applications. The peak dissipation of each transistor is about four times average. In ac applications, power capability is often limited by the peak ratings of the power transistor.

The pulse thermal resistance of the LM12 is specified for constant power pulse duration. Establishing an exact equivalency between constant-power pulses and those encountered in practice is not easy. However, for sine waves, reasonable estimates can be made at any frequency by assuming a constant power pulse amplitude given by:

$$P_{PK} \cong \frac{V_S^2}{2Z_L}\left[1 - \cos(\phi - \theta)\right],$$

where $\phi = 60°$ and θ is the absolute value of the phase angle of Z_L. Equivalent pulse width is $t_{ON} \cong 0.4\tau$ for $\theta = 0$ and $t_{ON} \cong 0.2\tau$ for $\theta \geq 20°$, where τ is the period of the output waveform.

DISSIPATION DRIVING MOTORS

A motor with a locked rotor looks like an inductance in series with a resistance, for purposes of determining driver dissipation. With slow-response servos, the maximum signal amplitude at frequencies where motor inductance is significant can be so small that motor inductance does not have to be taken into account. If this is the case, the motor can be treated as a simple, resistive load as long as the rotor speed is low enough that the back emf is small by comparison to the supply voltage of the driver transistor.

A permanent-magnet motor can build up a back emf that is equal to the output swing of the op amp driving it. Reversing this motor from full speed requires the output drive transistor to operate, initially, along a loadline based upon the motor resistance and total supply voltage. Worst case, this loadline will have to be within the continuous dissipation rating of the drive transistor; but system dynamics may permit taking advantage of the higher pulse ratings. Motor inductance can cause added stress if system response is fast.

Shunt- and series-wound motors can generate back emf's that are considerably more than the total supply voltage, resulting in even higher peak dissipation than a permanent-magnet motor having the same locked-rotor resistance.

VOLTAGE REGULATOR DISSIPATION

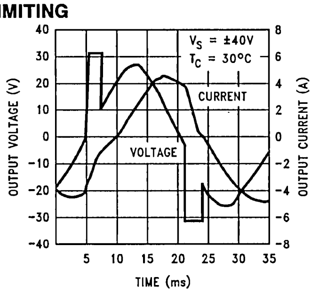
The pass transistor dissipation of a voltage regulator is easily determined in the operating mode. Maximum continuous dissipation occurs with high line voltage and maximum load current. As discussed earlier, ripple voltage can be averaged if peak ratings are not exceeded; however, a higher average voltage will be required to insure that the pass transistor does not saturate at the ripple minimum.

Conditions during start-up can be more complex. If the input voltage increases slowly such that the regulator does not go into current limit charging output capacitance, there are no problems. If not, load capacitance and load characteristics must be taken into account. This is also the case if automatic restart is required in recovering from overloads.

Automatic restart or start-up with fast-rising input voltages cannot be guaranteed unless the continuous dissipation rating of the pass transistor is adequate to supply the load current continuously at all voltages below the regulated output voltage. In this regard, the LM12 performs much better than IC regulators using foldback current limit, especially with high-line input voltage above 20V.

Application Information (Continued)

POWER LIMITING



TL/H/8704-27

Should the power ratings of the LM12 be exceeded, dynamic safe-area protection is activated. Waveforms with this power limiting are shown for the LM12 driving ±26V at 30 Hz into 3Ω in series with 24 mH (θ = 45°). With an inductive load, the output clamps to the supplies in power limit, as above. With resistive loads, the output voltage drops in limit. Behavior with more complex RCL loads is between these extremes.

Secondary thermal limit is activated should the case temperature exceed 150°C. This thermal limit shuts down the IC completely (open output) until the case temperature drops to about 145°C. Recovery may take several seconds.

POWER SUPPLIES

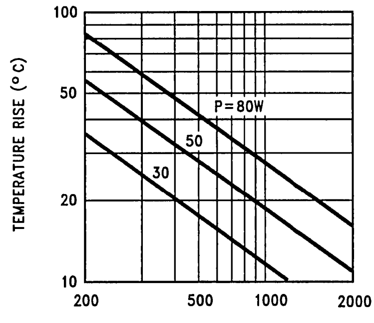
Power op amps do not require regulated supplies. However, the worst-case output power is determined by the low-line supply voltage in the ripple trough. The worst-case power dissipation is established by the average supply voltage with high-line conditions. The loss in power output that can be guaranteed is the square of the ratio of these two voltages.

Relatively simple off-line switching power supplies can provide voltage conversion, line isolation and 5-percent regulation while reducing size and weight.

The regulation against ripple and line variations can provide a substantial increase in the power output that can be guaranteed under worst-case conditions. In addition, switching power supplies can convert low-voltage power sources such as automotive batteries up to regulated, dual, high-voltage supplies optimized for powering power op amps.

HEAT SINKING

A semiconductor manufacturer has no control over heat sink design. Temperature rating can only be based upon case temperature as measured at the center of the package bottom. With power pulses of longer duration than 100 ms, case temperature is almost entirely dependent on heat sink design and the mounting of the IC to the heat sink.



TL/H/8704-28

The design of heat sink is beyond the scope of this work. Convection-cooled heat sinks are available commercially, and their manufacturers should be consulted for ratings. The preceding figure is a rough guide for temperature rise as a function of fin area (both sides) available for convection cooling.

Proper mounting of the IC is required to minimize the thermal drop between the package and the heat sink. The heat sink must also have enough metal under the package to conduct heat from the center of the package bottom to the fins without excessive temperature drop.

A thermal grease such as Wakefield type 120 or Thermalloy Thermacote should be used when mounting the package to the heat sink. Without this compound, thermal resistance will be no better than 0.5°C/W, and probably much worse. With the compound, thermal resistance will be 0.2°C/W or less, assuming under 0.005 inch combined flatness runout for the package and heat sink. Proper torquing of the mounting bolts is important. Four to six inch-pounds is recommended.

Should it be necessary to isolate V^- from the heat sink, an insulating washer is required. Hard washers like berylium oxide, anodized aluminum and mica require the use of thermal compound on both faces. Two-mil mica washers are most common, giving about 0.4°C/W interface resistance with the compound. Silicone-rubber washers are also available. A 0.5°C/W thermal resistance is claimed without thermal compound. Experience has shown that these rubber washers deteriorate and must be replaced should the IC be dismounted.

"Isostrate" insulating pads for four-lead TO-3 packages are available from Power Devices, Inc. Thermal grease is not required, and the insulators should not be reused.

Definition of Terms

Input offset voltage: The absolute value of the voltage between the input terminals with the output voltage and current at zero.

Input bias current: The absolute value of the average of the two input currents with the output voltage and current at zero.

Input offset current: The absolute value of the difference in the two input currents with the output voltage and current at zero.

Common-mode rejection: The ratio of the input voltage range to the change in offset voltage between the extremes.

Supply-voltage rejection: The ratio of the specified supply-voltage change to the change in offset voltage between the extremes.

Output saturation threshold: The output swing limit for a specified input drive beyond that required for zero output. It is measured with respect to the supply to which the output is swinging.

Large signal voltage gain: The ratio of the output voltage swing to the differential input voltage required to drive the output from zero to either swing limit. The output swing limit is the supply voltage less a specified quasi-saturation voltage. A pulse of short enough duration to minimize thermal effects is used as a measurement signal.

Thermal gradient feedback: The input offset voltage change caused by thermal gradients generated by heating of the output transistors, but not the package. This effect is delayed by several milliseconds and results in increased gain error below 100 Hz.

Output-current limit: The output current with a fixed output voltage and a large input overdrive. The limiting current drops with time once the protection circuitry is activated.

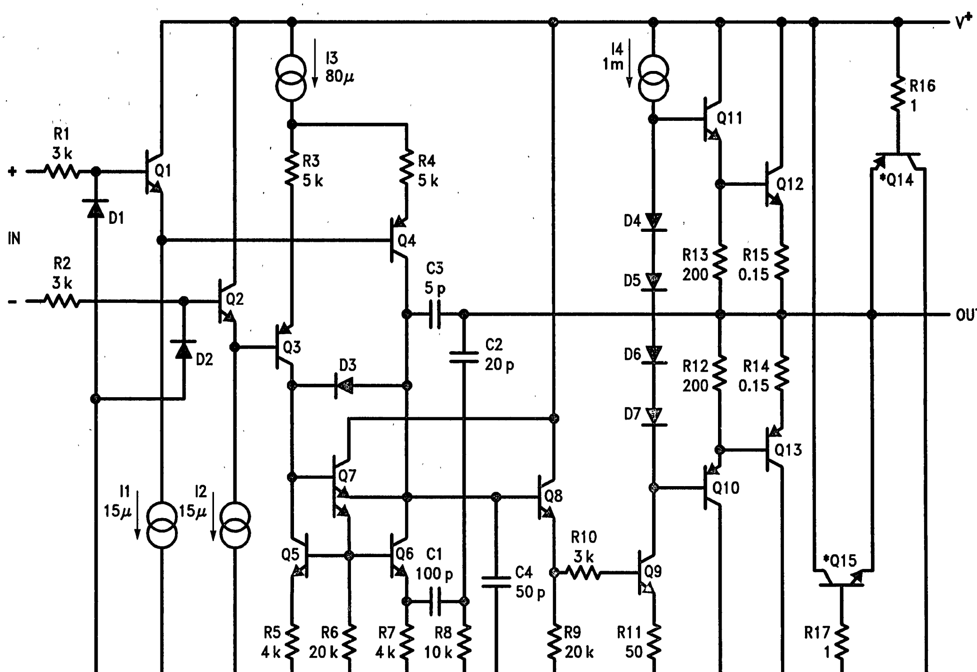
Power dissipation rating: The power that can be dissipated for a specified time interval without activating the protection circuitry. For time intervals in excess of 100 ms, dissipation capability is determined by heat sinking of the IC package rather than by the IC itself.

Thermal resistance: The peak, junction-temperature rise, per unit of internal power dissipation, above the case temperature as measured at the center of the package bottom.

The dc thermal resistance applies when one output transistor is operating continuously. The ac thermal resistance applies with the output transistors conducting alternately at a high enough frequency that the peak capability of neither transistor is exceeded.

Supply current: The current required from the power source to operate the amplifier with the output voltage and current at zero.

Equivalent Schematic (excluding active protection circuitry)



TL/H/8704–29

National Semiconductor

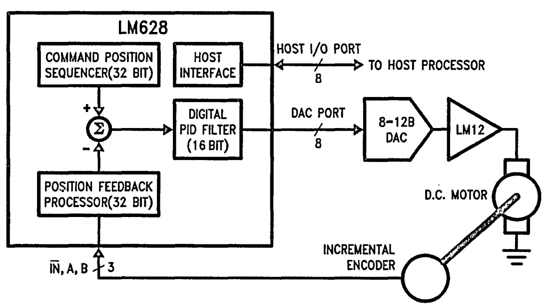
LM628/LM629 Precision Motion Controller

General Description

The LM628/LM629 are dedicated motion-control processors designed for use with a variety of DC and brushless DC servo motors, and other servomechanisms which provide a quadrature incremental position feedback signal. The parts perform the intensive, real-time computational tasks required for high performance digital motion control. The host control software interface is facilitated by a high-level command set. The LM628 has an 8-bit output which can drive either an 8-bit or a 12-bit DAC. The components required to build a servo system are reduced to the DC motor/actuator, an incremental encoder, a DAC, a power amplifier, and the LM628. An LM629-based system is similar, except that it provides an 8-bit PWM output for directly driving H-switches. The parts are fabricated in NMOS and packaged in a 28-pin dual in-line package or a 24-pin surface mount package (LM629 only). Both 6 MHz and 8 MHz maximum frequency versions are available with the suffixes -6 and -8, respectively, used to designate the versions. They incorporate an SDA core processor and cells designed by SDA.

Features

- 32-bit position, velocity, and acceleration registers
- Programmable digital PID filter with 16-bit coefficients
- Programmable derivative sampling interval
- 8- or 12-bit DAC output data (LM628)
- 8-bit sign-magnitude PWM output data (LM629)
- Internal trapezoidal velocity profile generator
- Velocity, target position, and filter parameters may be changed during motion
- Position and velocity modes of operation
- Real-time programmable host interrupts
- 8-bit parallel asynchronous host interface
- Quadrature incremental encoder interface with index pulse input
- Available in a 28-pin dual in-line package or a 24-pin surface mount package (LM629 only)

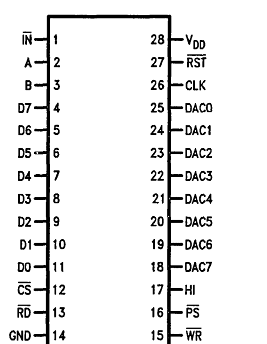


TL/H/9219–1

FIGURE 1. Typical System Block Diagram

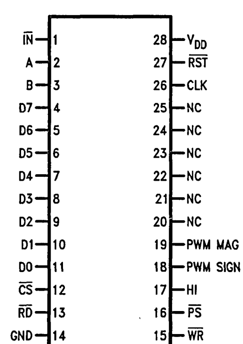
Connection Diagrams

LM628N



TL/H/9219–2

LM629N



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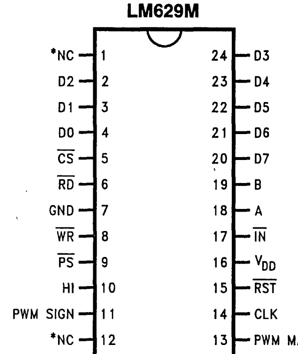
LM629M



*Do not connect.

TL/H/9219–21

Order Number LM629M-6, LM629M-8, LM628N-6, LM628N-8, LM629N-6 or LM629N-8
See NS Package Number M24B or N28B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Voltage at Any Pin with Respect to GND	−0.3V to +7.0V
Ambient Storage Temperature	−65°C to +150°C
Lead Temperature	
28-pin Dual In-Line Package (Soldering, 4 sec.)	260°C
24-pin Surface Mount Package (Soldering, 10 sec.)	300°C
Maximum Power Dissipation ($T_A \leq 85°C$, Note 2)	605 mW
ESD Tolerance (C_{ZAP} = 120 pF, R_{ZAP} = 1.5k)	2000V

Operating Ratings

Temperature Range	$-40°C < T_A < +85°C$
Clock Frequency:	
LM628N-6, LM629N-6, LM629M-6	$1.0\ MHz < f_{CLK} < 6.0\ MHz$
LM628N-8, LM629N-8, LM629M-8	$1.0\ MHz < f_{CLK} < 8.0\ MHz$
V_{DD} Range	$4.5V < V_{DD} < 5.5V$

DC Electrical Characteristics (V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz)

Symbol	Parameter	Conditions	Tested Limits		Units
			Min	Max	
I_{DD}	Supply Current	Outputs Open		110	mA
INPUT VOLTAGES					
V_{IH}	Logic 1 Input Voltage		2.0		V
V_{IL}	Logic 0 Input Voltage			0.8	V
I_{IN}	Input Currents	$0 \leq V_{IN} \leq V_{DD}$	−10	10	μA
OUTPUT VOLTAGES					
V_{OH}	Logic 1	I_{OH} = −1.6 mA	2.4		V
V_{OL}	Logic 0	I_{OL} = 1.6 mA		0.4	V
I_{OUT}	TRI-STATE® Output Leakage Current	$0 \leq V_{OUT} \leq V_{DD}$	−10	10	μA

AC Electrical Characteristics

(V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz; C_{LOAD} = 50 pF; Input Test Signal $t_r = t_f$ = 10 ns)

Timing Interval	T#	Tested Limits		Units
		Min	Max	
ENCODER AND INDEX TIMING (See *Figure 2*)				
Motor-Phase Pulse Width	T1	$\frac{16}{f_{CLK}}$		μs
Dwell-Time per State	T2	$\frac{8}{f_{CLK}}$		μs
Index Pulse Setup and Hold (Relative to A and B Low)	T3	0		μs
CLOCK AND RESET TIMING (See *Figure 3*)				
Clock Pulse Width				
LM628N-6, LM629N-6, LM629M-6	T4	78		ns
LM628N-8, LM629N-8, LM629M-8	T4	57		ns
Clock Period				
LM628N-6, LM629N-6, LM629M-6	T5	166		ns
LM628N-8, LM629N-8, LM629M-8	T5	125		ns
Reset Pulse Width	T6	$\frac{8}{f_{CLK}}$		μs

AC Electrical Characteristics (Continued)

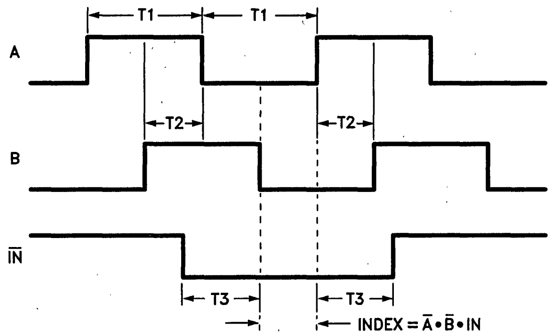
(V_{DD} and T_A per Operating Ratings; f_{CLK} = 6 MHz; C_{LOAD} = 50 pF; Input Test Signal t_r = t_f = 10 ns)

Timing Interval	T#	Tested Limits Min	Tested Limits Max	Units
STATUS BYTE READ TIMING (See *Figure 4*)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Read Data Access Time	T10		180	ns
Read Data Hold Time	T11	0		ns
$\overline{RD}$ High to Hi-Z Time	T12		180	ns
COMMAND BYTE WRITE TIMING (See *Figure 5*)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Busy Bit Delay	T13		(Note 3)	ns
$\overline{WR}$ Pulse Width	T14	100		ns
Write Data Setup Time	T15	50		ns
Write Data Hold Time	T16	120		ns
DATA WORD READ TIMING (See *Figure 6*)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Read Data Access Time	T10		180	ns
Read Data Hold Time	T11	0		ns
$\overline{RD}$ High to Hi-Z Time	T12		180	ns
Busy Bit Delay	T13		(Note 3)	ns
Read Recovery Time	T17	120		ns
DATA WORD WRITE TIMING (See *Figure 7*)				
Chip-Select Setup/Hold Time	T7	0		ns
Port-Select Setup Time	T8	30		ns
Port-Select Hold Time	T9	30		ns
Busy Bit Delay	T13		(Note 3)	ns
$\overline{WR}$ Pulse Width	T14	100		ns
Write Data Setup Time	T15	50		ns
Write Data Hold Time	T16	120		ns
Write Recovery Time	T18	120		ns

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond the above Operating Ratings.

Note 2: When operating at ambient temperatures above 70°C, the device must be protected against excessive junction temperatures. Mounting the package on a printed circuit board having an area greater than three square inches and surrounding the leads and body with wide copper traces and large, uninterrupted areas of copper, such as a ground plane, suffices. The 28-pin DIP (N) and the 24-pin surface mount package (M) are molded plastic packages with solid copper lead frames. Most of the heat generated at the die flows from the die, through the copper lead frame, and into copper traces on the printed circuit board. The copper traces act as a heat sink. Double-sided or multi-layer boards provide heat transfer characteristics superior to those of single-sided boards.

Note 3: In order to read the busy bit, the status byte must first be read. The time required to read the busy bit far exceeds the time the chip requires to set the busy bit. It is, therefore, impossible to test actual busy bit delay. The busy bit is guaranteed to be valid as soon as the user is able to read it.



TL/H/9219–4

FIGURE 2. Quadrature Encoder Input Timing

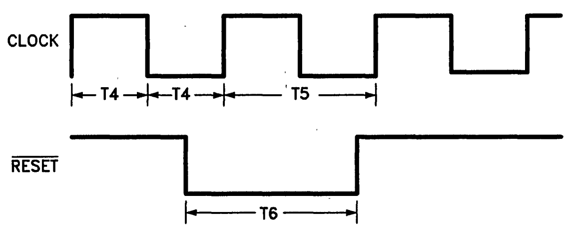


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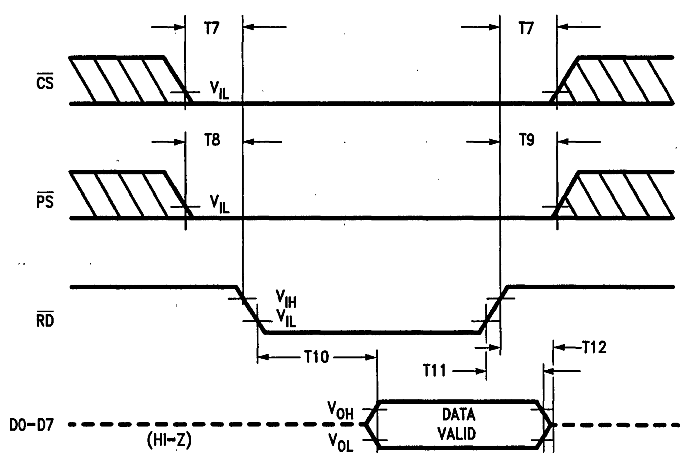
FIGURE 3. Clock and Reset Timing



TL/H/9219–6

FIGURE 4. Status Byte Read Timing

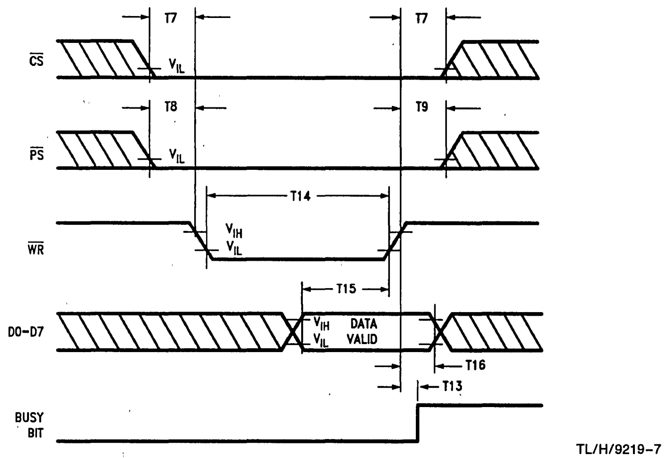


FIGURE 5. Command Byte Write Timing

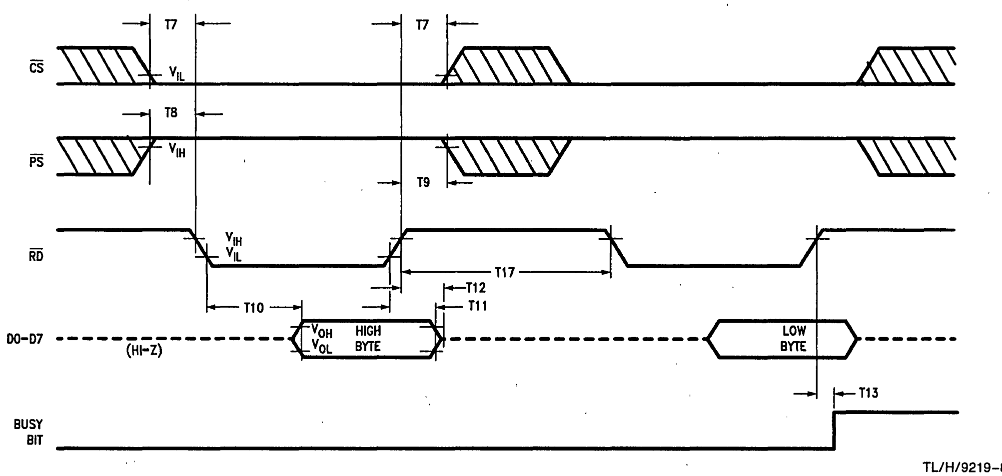


FIGURE 6. Data Word Read Timing

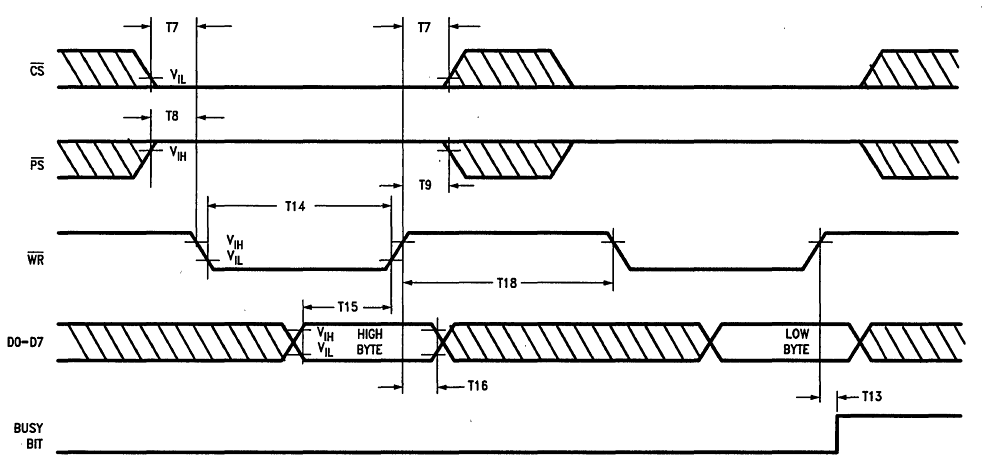


FIGURE 7. Data Word Write Timing

Pinout Description

(See Connection Diagrams) Pin numbers for the 24-pin surface mount package are indicated in parentheses.

Pin 1 (17), Index ($\overline{\text{IN}}$) Input: Receives optional index pulse from the encoder. Must be tied high if not used. The index position is read when Pins 1, 2, and 3 are low.

Pins 2 and 3 (18 and 19), Encoder Signal (A, B) Inputs: Receive the two-phase quadrature signals provided by the incremental encoder. When the motor is rotating in the positive ("forward") direction, the signal at Pin 2 leads the signal at Pin 3 by 90 degrees. Note that the signals at Pins 2 and 3 must remain at each encoder state (See *Figure 9*) for a minimum of 8 clock periods in order to be recognized. Because of a four-to-one resolution advantage gained by the method of decoding the quadrature encoder signals, this corresponds to a maximum encoder-state capture rate of 1.0 MHz (f_{CLK} = 8.0 MHz) or 750 kHz (f_{CLK} = 6.0 MHz). For other clock frequencies the encoder signals must also remain at each state a minimum of 8 clock periods.

Pins 4 to 11 (20 to 24 and 2 to 4), Host I/O Port (D0 to D7): Bi-directional data port which connects to host computer/processor. Used for writing commands and data to the LM628, and for reading the status byte and data from the LM628, as controlled by $\overline{\text{CS}}$ (Pin 12), $\overline{\text{PS}}$ (Pin 16), $\overline{\text{RD}}$ (Pin 13), and $\overline{\text{WR}}$ (Pin 15).

Pin 12 (5), Chip Select ($\overline{\text{CS}}$) Input: Used to select the LM628 for writing and reading operations.

Pin 13 (6), Read ($\overline{\text{RD}}$) Input: Used to read status and data.

Pin 14 (7), Ground (GND): Power-supply return pin.

Pin 15 (8), Write ($\overline{\text{WR}}$) Input: Used to write commands and data.

Pin 16 (9), Port Select ($\overline{\text{PS}}$) Input: Used to select command or data port. Selects command port when low, data port when high. The following modes are controlled by Pin 16:

1. Commands are written to the command port (Pin 16 low),
2. Status byte is read from command port (Pin 16 low), and
3. Data is written and read via the data port (Pin 16 high).

Pin 17 (10), Host Interrupt (HI) Output: This active-high signal alerts the host (via a host interrupt service routine) that an interrupt condition has occurred.

Pins 18 to 25, DAC Port (DAC0 to DAC7): Output port which is used in three different modes:

1. LM628 (8-bit output mode): Outputs latched data to the DAC. The MSB is Pin 18 and the LSB is Pin 25.
2. LM628 (12-bit output mode): Outputs two, multiplexed 6-bit words. The less-significant word is output first. The MSB is on Pin 18 and the LSB is on Pin 23. Pin 24 is used to demultiplex the words; Pin 24 is low for the less-significant word. The positive-going edge of the signal on Pin 25 is used to strobe the output data. *Figure 8* shows the timing of the multiplexed signals.
3. LM629 (sign/magnitude outputs): Outputs a PWM sign signal on Pin 18 (11 for surface mount), and a PWM magnitude signal on Pin 19 (13 for surface mount). Pins 20 to 25 are not used in the LM629. *Figure 11* shows the PWM output signal format.

Pin 26 (14), Clock (CLK) Input: Receives system clock.

Pin 27 (15), Reset ($\overline{\text{RST}}$) Input: Active-low, positive-edge triggered, resets the LM628 to the internal conditions shown below. Note that the reset pulse must be logic low for a minimum of 8 clock periods. Reset does the following:

1. Filter coefficient and trajectory parameters are zeroed.
2. Sets position error threshold to maximum value (7FFF hex), and effectively executes command LPEI.
3. The SBPA/SBPR interrupt is masked (disabled).
4. The five other interrupts are unmasked (enabled).
5. Initializes current position to zero, or "home" position.
6. Sets derivative sampling interval to 2048/f_{CLK} or 256 μs for an 8.0 MHz clock.
7. DAC port outputs 800 hex to "zero" a 12-bit DAC and then reverts to 80 hex to "zero" an 8-bit DAC.

Immediately after releasing the reset pin from the LM628, the status port should read '00'. If the reset is successfully completed, the status word will change to hex '84' or 'C4' within 1.5 ms. If the status word has not changed from hex '00' to '84' or 'C4' within 1.5 ms, perform another reset and repeat the above steps. To be certain that the reset was properly performed, execute a **RSTI** command. If the chip has reset properly, the status byte will change from hex '84' or 'C4' to hex '80' or 'C0'. If this does not occur, perform another reset and repeat the above steps.

Pin 28 (16), Supply Voltage (V_{DD}): Power supply voltage (+5V).

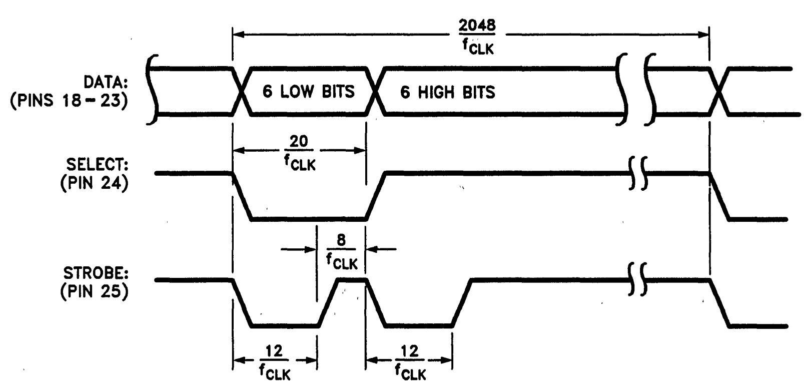


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FIGURE 8. 12-Bit Multiplexed Output Timing

Theory of Operation

INTRODUCTION

The typical system block diagram (See *Figure 1*) illustrates a servo system built using the LM628. The host processor communicates with the LM628 through an I/O port to facilitate programming a trapezoidal velocity profile and a digital compensation filter. The DAC output interfaces to an external digital-to-analog converter to produce the signal that is power amplified and applied to the motor. An incremental encoder provides feedback for closing the position servo loop. The trapezoidal velocity profile generator calculates the required trajectory for either position or velocity mode of operation. In operation, the LM628 subtracts the actual position (feedback position) from the desired position (profile generator position), and the resulting position error is processed by the digital filter to drive the motor to the desired position. Table I provides a brief summary of specifications offered by the LM628/LM629:

POSITION FEEDBACK INTERFACE

The LM628 interfaces to a motor via an incremental encoder. Three inputs are provided: two quadrature signal inputs, and an index pulse input. The quadrature signals are used to keep track of the absolute position of the motor. Each time a logic transition occurs at one of the quadrature inputs, the LM628 internal position register is incremented or decremented accordingly. This provides four times the resolution over the number of lines provided by the encoder. See *Figure 9*. Each of the encoder signal inputs is synchronized with the LM628 clock.

The optional index pulse output provided by some encoders assumes the logic-low state once per revolution. If the LM628 is so programmed by the user, it will record the absolute motor position in a dedicated register (the index register) at the time when all three encoder inputs are logic low.

If the encoder does not provide an index output, the LM628 index input can also be used to record the home position of the motor. In this case, typically, the motor will close a switch which is arranged to cause a logic-low level at the index input, and the LM628 will record motor position in the index register and alert (interrupt) the host processor. Permanently grounding the index input will cause the LM628 to malfunction.

TABLE I. System Specifications Summary

Position Range	−1,073,741,824 to 1,073,741,823 counts
Velocity Range	0 to 1,073,741,823/2^{16} counts/sample; ie, 0 to 16,383 counts/sample, with a resolution of 1/2^{16} counts/sample
Acceleration Range	0 to 1,073,741,823/2^{16} counts/sample/sample; ie, 0 to 16,383 counts/sample/sample, with a resolution of 1/2^{16} counts/sample/sample
Motor Drive Output	LM628: 8-bit parallel output to DAC, or 12-bit multiplexed output to DAC LM629: 8-bit PWM sign/magnitude signals
Operating Modes	Position and Velocity
Feedback Device	Incremental Encoder (quadrature signals; support for index pulse)
Control Algorithm	Proportional Integral Derivative (PID) (plus programmable integration limit)
Sample Intervals	Derivative Term: Programmable from 2048/f_{CLK} to (2048 * 256)/f_{CLK} in steps of 2048/f_{CLK} (256 to 65,536 μs for an 8.0 MHz clock). Proportional and Integral: 2048/f_{CLK}

Theory of Operation (Continued)

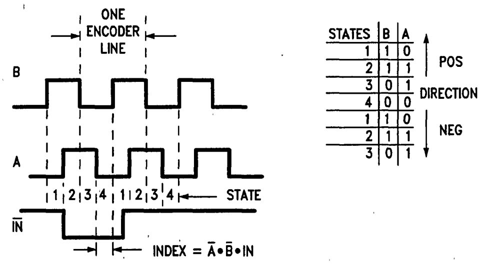

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FIGURE 9. Quadrature Encoder Signals

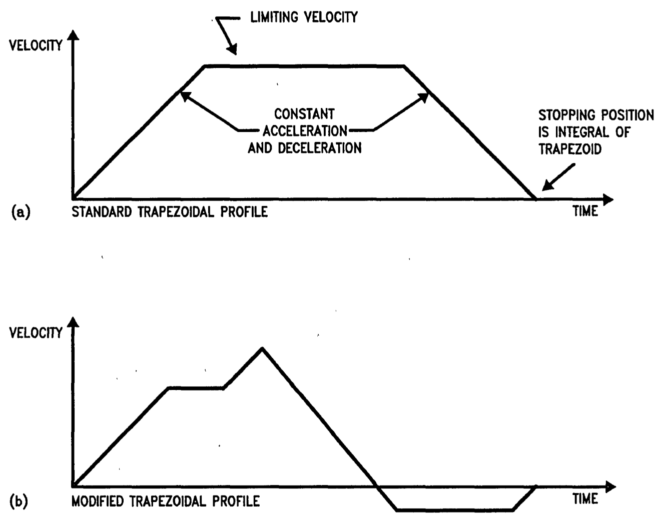

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FIGURE 10. Typical Velocity Profiles

VELOCITY PROFILE (TRAJECTORY) GENERATION

The trapezoidal velocity profile generator computes the desired position of the motor versus time. In the position mode of operation, the host processor specifies acceleration, maximum velocity, and final position. The LM628 uses this information to affect the move by accelerating as specified until the maximum velocity is reached or until deceleration must begin to stop at the specified final position. The deceleration rate is equal to the acceleration rate. At any time during the move the maximum velocity and/or the target position may be changed, and the motor will accelerate or decelerate accordingly. *Figure 10* illustrates two typical trapezoidal velocity profiles. *Figure 10 (a)* shows a simple trapezoid, while *Figure 10 (b)* is an example of what the trajectory looks like when velocity and position are changed at different times during the move.

When operating in the velocity mode, the motor accelerates to the specified velocity at the specified acceleration rate and maintains the specified velocity until commanded to stop. The velocity is maintained by advancing the desired position at a constant rate. If there are disturbances to the motion during velocity mode operation, the long-time average velocity remains constant. If the motor is unable to maintain the specified velocity (which could be caused by a locked rotor, for example), the desired position will continue to be increased, resulting in a very large position error. If this condition goes undetected, and the impeding force on the motor is subsequently released, the motor could reach a very high velocity in order to catch up to the desired position (which is still advancing as specified). This condition is easily detected; see commands LPEI and LPES.

All trajectory parameters are 32-bit values. Position is a signed quantity. Acceleration and velocity are specified as 16-bit, positive-only integers having 16-bit fractions. The integer portion of velocity specifies how many counts per sampling interval the motor will traverse. The fractional portion designates an additional fractional count per sampling interval. Although the position resolution of the LM628 is limited to integer counts, the fractional counts provide increased average velocity resolution. Acceleration is treated in the same manner. Each sampling interval the commanded acceleration value is added to the current desired velocity to generate a new desired velocity (unless the command velocity has been reached).

One determines the trajectory parameters for a desired move as follows. If, for example, one has a 500-line shaft encoder, desires that the motor accelerate at one revolution per second per second until it is moving at 600 rpm, and then decelerate to a stop at a position exactly 100 revolutions from the start, one would calculate the trajectory parameters as follows:

Theory of Operation (Continued)

let P = target position (units = encoder counts)
let R = encoder lines * 4 (system resolution)
then R = 500 * 4 = 2000
and P = 2000 * desired number of revolutions
P = 2000 * 100 revs = 200,000 counts (value to load)
P (coding) = 00030D40 (hex code written to LM628)

let V = velocity (units = counts/sample)
let T = sample time (seconds) = 341 μs (with 6 MHz clock)
let C = conversion factor = 1 minute/60 seconds
then V = R * T * C * desired rpm
and V = 2000 * 341E−6 * 1/60 * 600 rpm
V = 6.82 counts/sample
V (scaled) = 6.82 * 65,536 = 446,955.52
V (rounded) = 446,956 (value to load)
V (coding) = 0006D1EC (hex code written to LM628)

let A = acceleration (units = counts/sample/sample)
A = R * T * T * desired acceleration (rev/sec/sec)
then A = 2000 * 341E−6 * 341E-6 * 1 rev/sec/sec
and A = 2.33E−4 counts/sample/sample
A (scaled) = 2.33E−4 * 65,536 = 15.24
A (rounded) = 15 (value to load)
A (coding) = 0000000F (hex code written to LM628)

The above position, velocity, and acceleration values must be converted to binary codes to be loaded into the LM628. The values shown for velocity and acceleration must be multiplied by 65,536 (as shown) to adjust for the required integer/fraction format of the input data. Note that after scaling the velocity and acceleration values, literal fractional data cannot be loaded; the data must be rounded and converted to binary. The factor of four increase in system resolution is due to the method used to decode the quadrature encoder signals, see *Figure 9*.

PID COMPENSATION FILTER

The LM628 uses a digital Proportional Integral Derivative (PID) filter to compensate the control loop. The motor is held at the desired position by applying a restoring force to the motor that is proportional to the position error, plus the integral of the error, plus the derivative of the error. The following discrete-time equation illustrates the control performed by the LM628:

$$u(n) = kp^*e(n) + ki\sum_{N=0}^{n} e(n) + kd[e(n') - e(n' - 1)] \qquad \text{(Eq.1)}$$

where u(n) is the motor control signal output at sample time n, e(n) is the position error at sample time n, n′ indicates sampling at the derivative sampling rate, and kp, ki, and kd are the discrete-time filter parameters loaded by the users.

The first term, the proportional term, provides a restoring force porportional to the position error, just as does a spring obeying Hooke's law. The second term, the integration term, provides a restoring force that grows with time, and thus ensures that the static position error is zero. If there is a constant torque loading, the motor will still be able to achieve zero position error.

The third term, the derivative term, provides a force proportional to the rate of change of position error. It acts just like viscous damping in a damped spring and mass system (like a shock absorber in an automobile). The sampling interval associated with the derivative term is user-selectable; this capability enables the LM628 to control a wider range of inertial loads (system mechanical time constants) by providing a better approximation of the continuous derivative. In general, longer sampling intervals are useful for low-velocity operations.

In operation, the filter algorithm receives a 16-bit error signal from the loop summing-junction. The error signal is saturated at 16 bits to ensure predictable behavior. In addition to being multiplied by filter coefficient kp, the error signal is added to an accumulation of previous errors (to form the integral signal) and, at a rate determined by the chosen *derivative* sampling interval, the previous error is subtracted from it (to form the derivative signal). All filter multiplications are 16-bit operations; only the bottom 16 bits of the product are used.

The integral signal is maintained to 24 bits, but only the top 16 bits are used. This scaling technique results in a more usable (less sensitive) range of coefficient ki values. The 16 bits are right-shifted eight positions and multiplied by filter coefficient ki to form the term which contributes to the motor control output. The absolute magnitude of this product is compared to coefficient il, and the lesser, appropriately signed magnitude then contributes to the motor control signal.

The derivative signal is multiplied by coefficient kd each *derivative* sampling interval. This product contributes to the motor control output *every* sample interval, independent of the user-chosen *derivative* sampling interval.

The kp, limited ki, and kd product terms are summed to form a 16-bit quantity. Depending on the output mode (wordsize), either the top 8 or top 12 bits become the motor control output signal.

LM628 READING AND WRITING OPERATIONS

The host processor writes commands to the LM628 via the host I/O port when Port Select ($\overline{PS}$) input (Pin 16) is logic low. The desired command code is applied to the parallel port line and the Write ($\overline{WR}$) input (Pin 15) is strobed. The command byte is latched into the LM628 on the rising edge of the $\overline{WR}$ input. When writing command bytes it is necessary to first read the status byte and check the state of a flag called the "busy bit" (Bit 0). If the busy bit is logic high, no command write may take place. The busy bit is never high longer than 100 μs, and typically falls within 15 μs to 25 μs.

The host processor reads the LM628 status byte in a similar manner: by strobing the Read ($\overline{RD}$) input (Pin 13) when $\overline{PS}$ (Pin 16) is low; status information remains valid as long as $\overline{RD}$ is low.

Writing and reading data to/from the LM628 (as opposed to writing commands and reading status) are done with $\overline{PS}$ (Pin 16) logic high. These writes and reads are always an integral number (from one to seven) of two-byte words, with the first byte of each word being the more significant. Each byte requires a write ($\overline{WR}$) or read ($\overline{RD}$) strobe. When transferring data words (byte-pairs), it is necessary to first read the status byte and check the state of the busy bit. When the

Theory of Operation (Continued)

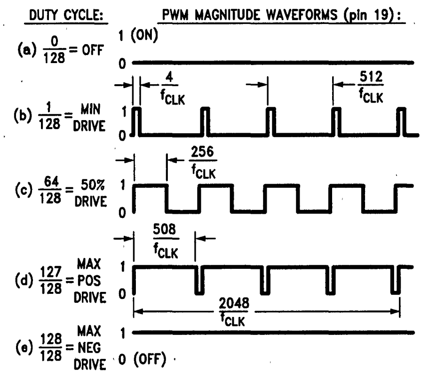
busy bit is logic low, the user may then sequentially transfer both bytes comprising a data word, but the busy bit must again be checked and found to be low before attempting to transfer the next byte pair (when transferring multiple words). Data transfers are accomplished via LM628-internal interrupts (which are not nested); the busy bit informs the host processor when the LM628 may not be interrupted for data transfer (or a command byte). If a command is written when the busy bit is high, the command will be ignored.

The busy bit goes high immediately after writing a command byte, or reading or writing a second byte of data (See *Figures 5* thru *7*).

MOTOR OUTPUTS

The LM628 DAC output port can be configured to provide either a latched eight-bit parallel output or a multiplexed 12-bit output. The 8-bit output can be directly connected to a flow-through (non-input-latching) D/A converter; the 12-bit output can be easily demultiplexed using an external 6-bit latch and an input-latching 12-bit D/A converter. The DAC output data is offset-binary coded; the 8-bit code for zero is 80 hex and the 12-bit code for zero is 800 hex. Values less than these cause a negative torque to be applied to the motor and, conversely, larger values cause positive motor torque. The LM628, when configured for 12-bit output, provides signals which control the demultiplexing process. See *Figure 8* for details.

The LM629 provides 8-bit, sign and magnitude PWM output signals for directly driving switch-mode motor-drive amplifiers. *Figure 11* shows the format of the PWM magnitude output signal.



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Note: Sign output (pin 18) not shown

FIGURE 11. PWM Output Signal Format

TABLE II. LM628 User Command Set

Command	Type	Description	Hex	Data Bytes	Note
RESET	Initialize	Reset LM628	00	0	1
PORT8	Initialize	Select 8-Bit Output	05	0	2
PORT12	Initialize	Select 12-Bit Output	06	0	2
DFH	Initialize	Define Home	02	0	1
SIP	Interrupt	Set Index Position	03	0	1
LPEI	Interrupt	Interrupt on Error	1B	2	1
LPES	Interrupt	Stop on Error	1A	2	1
SBPA	Interrupt	Set Breakpoint, Absolute	20	4	1
SBPR	Interrupt	Set Breakpoint, Relative	21	4	1
MSKI	Interrupt	Mask Interrupts	1C	2	1
RSTI	Interrupt	Reset Interrupts	1D	2	1
LFIL	Filter	Load Filter Parameters	1E	2 to 10	1
UDF	Filter	Update Filter	04	0	1
LTRJ	Trajectory	Load Trajectory	1F	2 to 14	1
STT	Trajectory	Start Motion	01	0	3
RDSTAT	Report	Read Status Byte	None	1	1, 4
RDSIGS	Report	Read Signals Register	0C	2	1
RDIP	Report	Read Index Position	09	4	1
RDDP	Report	Read Desired Position	08	4	1
RDRP	Report	Read Real Position	0A	4	1
RDDV	Report	Read Desired Velocity	07	4	1
RDRV	Report	Read Real Velocity	0B	2	1
RDSUM	Report	Read Integration Sum	0D	2	1

Note 1: Commands may be executed "On the Fly" during motion.

Note 2: Commands not applicable to execution during motion.

Note 3: Command may be executed during motion if acceleration parameter was not changed.

Note 4: Command needs no code because the command port status-byte read is totally supported by hardware.

User Command Set

GENERAL

The following paragraphs describe the user command set of the LM628. Some of the commands can be issued alone and some require a supporting data structure. As examples, the command STT (STarT motion) does not require additional data; command LFIL (Load FILter parameters) requires additional data (derivative-term sampling interval and/or filter parameters).

Commands are categorized by function: initialization, interrupt control, filter control, trajectory control, and data reporting. The commands are listed in Table II and described in the following paragraphs. Along with each command name is its command-byte code, the number of accompanying data bytes that are to be written (or read), and a comment as to whether the command is executable during motion.

Initialization Commands

The following four LM628 user commands are used primarily to initialize the system for use.

RESET COMMAND: RESET the LM628

Command Code:	00 Hex
Data Bytes:	None
Executable During Motion:	Yes

This command (and the hardware reset input, Pin 27) results in setting the following data items to zero: filter coefficients and their input buffers, trajectory parameters and their input buffers, and the motor control output. A zero motor control output is a half-scale, offset-binary code: (80 hex for the 8-bit output mode; 800 hex for 12-bit mode). During reset, the DAC port outputs 800 hex to "zero" a 12-bit DAC and reverts to 80 hex to "zero" an 8-bit DAC. The command also clears five of the six interrupt masks (only the SBPA/SBPR interrupt is masked), sets the output port size to 8 bits, and defines the current absolute position as home. Reset, which may be executed at any time, will be completed in less than 1.5 ms. Also see commands PORT8 and PORT12.

PORT8 COMMAND: Set Output PORT Size to 8 Bits

Command Code:	05 Hex
Data Bytes:	None
Executable During Motion:	Not Applicable

The default output port size of the LM628 is 8 bits; so the PORT8 command need not be executed when using an 8-bit DAC. This command must not be executed when using a 12-bit converter; it will result in erratic, unpredictable motor behavior. The 8-bit output port size is the required selection when using the LM629, the PWM-output version of the LM628.

PORT12 COMMAND: Set Output PORT Size to 12 Bits

Command Code:	06 Hex
Data Bytes:	None
Executable During Motion:	Not Applicable

When a 12-bit DAC is used, command PORT12 should be issued very early in the initialization process. Because use of this command is determined by system hardware, there is only one foreseen reason to execute it later: if the RESET command is issued (because an 8-bit output would then be selected as the default) command PORT12 should be immediately executed. This command must not be issued when using an 8-bit converter or the LM629, the PWM-output version of the LM628.

DFH COMMAND: DeFine Home

Command Code:	02 Hex
Data Bytes:	None
Executable During Motion:	Yes

This command declares the current position as "home", or absolute position 0 (Zero). If DFH is executed during motion it will not affect the stopping position of the on-going move unless command STT is also executed.

Interrupt Control Commands

The following seven LM628 user commands are associated with conditions which can be used to interrupt the host computer. In order for any of the potential interrupt conditions to actually interrupt the host via Pin 17, the corresponding bit in the interrupt mask data associated with command MSKI must have been set to logic high (the non-masked state).

The identity of all interrupts is made known to the host via reading and parsing the status byte. Even if all interrupts are masked off via command MSKI, the state of each condition is still reflected in the status byte. This feature facilitates polling the LM628 for status information, as opposed to interrupt driven operation.

SIP COMMAND: Set Index Position

Command Code:	03 Hex
Data Bytes:	None
Executable During Motion:	Yes

After this command is executed, the absolute position which corresponds to the occurrence of the next index pulse input will be recorded in the index register, and bit 3 of the status byte will be set to logic high. The position is recorded when both encoder-phase inputs and the index pulse input are logic low. This register can then be read by the user (see description for command RDIP) to facilitate aligning the definition of home position (see description of command DFH) with an index pulse. The user can also arrange to have the LM628 interrupt the host to signify that an index pulse has occurred. See the descriptions for commands MSKI and RSTI.

LPEI COMMAND: Load Position Error for Interrupt

Command Code:	1B Hex
Data Bytes:	Two
Data Range:	0000 to 7FFF Hex
Executable During Motion:	Yes

An excessive position error (the output of the loop summing junction) can indicate a serious system problem; e.g., a stalled rotor. Instruction LPEI allows the user to input a threshold for position error detection. Error detection occurs when the absolute magnitude of the position error exceeds the threshold, which results in bit 5 of the status byte being set to logic high. If it is desired to also stop (turn off) the motor upon detecting excessive position error, see command LPES, below. The first byte of threshold data written with command LPEI is the more significant. The user can have the LM628 interrupt the host to signify that an excessive position error has occurred. See the descriptions for commands MSKI and RSTI.

Interrupt Control Commands (Continued)

LPES COMMAND: Load Position Error for Stopping

Command Code:	1A Hex
Data Bytes:	Two
Data Range:	0000 to 7FFF Hex
Executable During Motion:	Yes

Instruction LPES is essentially the same as command LPEI above, but adds the feature of turning off the motor upon detecting excessive position error. The motor drive is not actually switched off, it is set to half-scale, the offset-binary code for zero. As with command LPEI, bit 5 of the status byte is also set to logic high. The first byte of threshold data written with command LPES is the more significant. The user can have the LM628 interrupt the host to signify that an excessive position error has occurred. See the descriptions for commands MSKI and RSTI.

SBPA COMMAND:

Command Code:	20 Hex
Data Bytes:	Four
Data Range:	C0000000 to 3FFFFFFF Hex
Executable During Motion:	Yes

This command enables the user to set a breakpoint in terms of absolute position. Bit 6 of the status byte is set to logic high when the breakpoint position is reached. This condition is useful for signaling trajectory and/or filter parameter updates. The user can also arrange to have the LM628 interrupt the host to signify that a breakpoint position has been reached. See the descriptions for commands MSKI and RSTI.

SBPR COMMAND:

Command Code:	21 Hex
Data Bytes:	Four
Data Range:	See Text
Executable During Motion:	Yes

This command enables the user to set a breakpoint in terms of relative position. As with command SBPA, bit 6 of the status byte is set to logic high when the breakpoint position (relative to the current commanded target position) is reached. The relative breakpoint input value must be such that when this value is added to the target position the result remains within the absolute position range of the system (C0000000 to 3FFFFFFF hex). This condition is useful for signaling trajectory and/or filter parameter updates. The user can also arrange to have the LM628 interrupt the host to signify that a breakpoint position has been reached. See the descriptions for commands MSKI and RSTI.

MSKI COMMAND: MaSK Interrupts

Command Code:	1C Hex
Data Bytes:	Two
Data Range:	See Text
Executable During Motion:	Yes

The MSKI command lets the user determine which potential interrupt condition(s) will interrupt the host. Bits 1 through 6 of the status byte are indicators of the six conditions which are candidates for host interrupt(s). When interrupted, the host then reads the status byte to learn which condition(s) occurred. Note that the MSKI command is immediately followed by two data bytes. Bits 1 through 6 of the second (less significant) byte written determine the masked/unmasked status of each potential interrupt. Any zero(s) in this 6-bit field will mask the corresponding interrupt(s); any one(s) enable the interrupt(s). Other bits comprising the two bytes have no effect. The mask controls only the host interrupt process; reading the status byte will still reflect the actual conditions independent of the mask byte. See Table III.

TABLE III. Mask and Reset Bit Allocations for Interrupts

Bit Position	Function
Bits 15 thru 7	Not Used
Bit 6	Breakpoint Interrupt
Bit 5	Position-Error Interrupt
Bit 4	Wrap-Around Interrupt
Bit 3	Index-Pulse Interrupt
Bit 2	Trajectory-Complete Interrupt
Bit 1	Command-Error Interrupt
Bit 0	Not Used

RSTI COMMAND: ReSeT Interrupts

Command Code:	1D Hex
Data Bytes:	Two
Data Range:	See Text
Executable During Motion:	Yes

When one of the potential interrupt conditions of Table III occurs, command RSTI is used to reset the corresponding interrupt flag bit in the status byte. The host may reset one or all flag bits. Resetting them one at a time allows the host to service them one at a time according to a priority programmed by the user. As in the MSKI command, bits 1 through 6 of the second (less significant) byte correspond to the potential interrupt conditions shown in Table III. Also see description of RDSTAT command. Any zero(s) in this 6-bit field reset the corresponding interrupt(s). The remaining bits have no effect.

Filter Control Commands

The following two LM628 user commands are used for setting the derivative-term sampling interval, for adjusting the filter parameters as required to tune the system, and to control the timing of these system changes.

LFIL COMMAND: Load FILter Parameters

Command Code:	1E Hex
Data Bytes:	Two to Ten
Data Ranges . . .	
Filter Control Word:	See Text
Filter Coefficients:	0000 to 7FFF Hex (Pos Only)
Integration Limit:	0000 to 7FFF Hex (Pos Only)
Executable During Motion:	Yes

The filter parameters (coefficients) which are written to the LM628 to control loop compensation are: kp, ki, kd, and il (integration limit). The integration limit (il) constrains the contribution of the integration term

$$\left[ki * \sum_{N=0}^{n} e(n) \right]$$

(see Eq. 1) to values equal to or less than a user-defined maximum value; this capability minimizes integral or reset "wind-up" (an overshooting effect of the integral action). The positive-only input value is compared to the absolute

Filter Control Commands (Continued)

magnitude of the integration term; when the magnitude of integration term value exceeds il, the il value (with appropriate sign) is substituted for the integration term value.

The derivative-term sampling interval is also programmable via this command. After writing the command code, the first two data bytes that are written specify the derivative-term sampling interval and which of the four filter parameters is/are to be written via any forthcoming data bytes. The first byte written is the more significant. Thus the two data bytes constitute a filter control word that informs the LM628 as to the nature and number of any following data bytes. See Table IV.

TABLE IV. Filter Control word Bit Allocation

Bit Position	Function
Bit 15	Derivative Sampling Interval Bit 7
Bit 14	Derivative Sampling Interval Bit 6
Bit 13	Derivative Sampling Interval Bit 5
Bit 12	Derivative Sampling Interval Bit 4
Bit 11	Derivative Sampling Interval Bit 3
Bit 10	Derivative Sampling Interval Bit 2
Bit 9	Derivative Sampling Interval Bit 1
Bit 8	Derivative Sampling Interval Bit 0
Bit 7	Not Used
Bit 6	Not Used
Bit 5	Not Used
Bit 4	Not Used
Bit 3	Loading kp Data
Bit 2	Loading ki Data
Bit 1	Loading kd Data
Bit 0	Loading il Data

Bits 8 through 15 select the derivative-term sampling interval. See Table V. The user must locally save and restore these bits during successive writes of the filter control word.

Bits 4 through 7 of the filter control word are not used.

Bits 0 to 3 inform the LM628 as to whether any or all of the filter parameters are about to be written. The user may choose to update any or all (or none) of the filter parameters. Those chosen for updating are so indicated by logic one(s) in the corresponding bit position(s) of the filter control word.

The data bytes specified by and immediately following the filter control word are written in pairs to comprise 16-bit words. The order of sending the data words to the LM628 corresponds to the descending order shown in the above description of the filter control word; i.e., beginning with kp, then ki, kd and il. The first byte of each word is the more-significant byte. Prior to writing a word (byte pair) it is necessary to check the busy bit in the status byte for readiness. The required data is written to the primary buffers of a double-buffered scheme by the above described operations; it is not transferred to the secondary (working) registers until the UDF command is executed. This fact can be used advantageously; the user can input numerous data ahead of their actual use. This simple pipeline effect can relieve potential host computer data communications bottlenecks, and facilitates easier synchronization of multiple-axis controls.

UDF COMMAND: UpDate Filter

Command Code: 04 Hex
Data Bytes: None
Executable During Motion: Yes

The UDF command is used to update the filter parameters, the specifics of which have been programmed via the LFIL command. Any or all parameters (derivative-term sampling interval, kp, ki, kd, and/or il) may be changed by the appropriate command(s), but command UDF must be executed to affect the change in filter tuning. Filter updating is synchronized with the calculations to eliminate erratic or spurious behavior.

Trajectory Control Commands

The following two LM628 user commands are used for setting the trajectory control parameters (position, velocity, acceleration), mode of operation (position or velocity), and direction (velocity mode only) as required to describe a desired motion or to select the mode of a manually directed stop, and to control the timing of these system changes.

LTRJ COMMAND: Load TRaJectory Parameters

Command Code: 1F Hex
Data Bytes: Two to Fourteen
Data Ranges . . .
Trajectory Control Word: See Text
Position: C0000000 to 3FFFFFFF Hex
Velocity: 00000000 to 3FFFFFFF Hex (Pos Only)
Acceleration: 00000000 to 3FFFFFFF Hex (Pos Only)
Executable During Motion: Conditionally, See Text

TABLE V. Derivative-Term Sampling Interval Selection Codes

	Bit Position								Selected Derivative Sampling Interval
	15	14	13	12	11	10	9	8	
	0	0	0	0	0	0	0	0	256 μs
	0	0	0	0	0	0	0	1	512 μs
	0	0	0	0	0	0	1	0	768 μs
	0	0	0	0	0	0	1	1	1024 μs, etc . . .
thru	1	1	1	1	1	1	1	1	65,536 μs

Note: Sampling intervals shown are when using an 8.0 MHz clock. The 256 corresponds to 2048/8 MHz; sample intervals must be scaled for other clock frequencies.

Trajectory Control Commands (Continued)

The trajectory control parameters which are written to the LM628 to control motion are: acceleration, velocity, and position. In addition, indications as to whether these three parameters are to be considered as absolute or relative inputs, selection of velocity mode and direction, and manual stopping mode selection and execution are programmable via this command. After writing the command code, the first two data bytes that are written specify which parameter(s) is/are being changed. The first byte written is the more significant. Thus the two data bytes constitute a trajectory control word that informs the LM628 as to the nature and number of any following data bytes. See Table VI.

TABLE VI. Trajectory Control Word Bit Allocation

Bit Position	Function
Bit 15	Not Used
Bit 14	Not Used
Bit 13	Not Used
Bit 12	Forward Direction (Velocity Mode Only)
Bit 11	Velocity Mode
Bit 10	Stop Smoothly (Decelerate as Programmed)
Bit 9	Stop Abruptly (Maximum Deceleration)
Bit 8	Turn Off Motor (Output Zero Drive)
Bit 7	Not Used
Bit 6	Not Used
Bit 5	Acceleration Will Be Loaded
Bit 4	Acceleration Data Is Relative
Bit 3	Velocity Will Be Loaded
Bit 2	Velocity Data Is Relative
Bit 1	Position Will Be Loaded
Bit 0	Position Data Is Relative

Bit 12 determines the motor direction when in the velocity mode. A logic one indicates forward direction. This bit has no effect when in position mode.

Bit 11 determines whether the LM628 operates in velocity mode (Bit 11 logic one) or position mode (Bit 11 logic zero).

Bits 8 through 10 are used to select the method of *manually stopping* the motor. These bits are *not* provided for one to merely specify the desired *mode* of stopping, in position mode operations, normal stopping is always smooth and occurs automatically at the end of the specified trajectory. Under exceptional circumstances it may be desired to manually intervene with the trajectory generation process to affect a premature stop. In velocity mode operations, however, the normal means of stopping *is* via bits 8 through 10 (usually bit 10). Bit 8 is set to logic one to stop the motor by turning off motor drive output (outputting the appropriate offset-binary code to apply zero drive to the motor); bit 9 is set to one to stop the motor abruptly (at maximum available acceleration, by setting the target position equal to the current position); and bit 10 is set to one to stop the motor smoothly by using the current user-programmed acceleration value. Bits 8 through 10 are to be used *exclusively;* only one bit should be a logic one at any time.

Bits 0 through 5 inform the LM628 as to whether any or all of the trajectory controlling parameters are about to be written, and whether the data should be interpreted as absolute or relative. The user may choose to update any or all (or none) of the trajectory parameters. Those chosen for updating are so indicated by logic one(s) in the corresponding bit position(s). Any parameter may be changed while the motor is in motion; however, if acceleration is changed then the next STT command must not be issued until the LM628 has completed the current move or has been manually stopped.

The data bytes specified by and immediately following the trajectory control word are written in pairs which comprise 16-bit words. Each data item (parameter) requires two 16-bit words; the word and byte order is most-to-least significant. The order of sending the parameters to the LM628 corresponds to the descending order shown in the above description of the trajectory control word; i.e., beginning with acceleration, then velocity, and finally position.

Acceleration and velocity are 32 bits, positive only, but range only from 0 (00000000 hex) to $[2^{30}]-1$ (3FFFFFFF hex). The bottom 16 bits of both acceleration and velocity are scaled as fractional data; therefore, the least-significant integer data bit for these parameters is bit 16 (where the bits are numbered 0 through 31). To determine the coding for a given velocity, for example, one multiplies the desired velocity (in counts per sample interval) times 65,536 and converts the result to binary. The units of acceleration are counts per sample per sample. The value loaded for acceleration must not exceed the value loaded for velocity. Position is a signed, 32-bit integer, but ranges only from $-[2^{30}]$ (C0000000 hex) to $[2^{30}]-1$ (3FFFFFFF Hex).

The required data is written to the primary buffers of a double-buffered scheme by the above described operations; it is not transferred to the secondary (working) registers until the STT command is executed. This fact can be used advantageously; the user can input numerous data ahead of their actual use. This simple pipeline effect can relieve potential host computer data communications bottlenecks, and facilitates easier synchronization of multiple-axis controls.

STT COMMAND: STarT Motion Control

Command Code:	01 Hex
Data Bytes:	None
Executable During Motion:	Yes, if acceleration has not been changed

The STT command is used to execute the desired trajectory, the specifics of which have been programmed via the LTRJ command. Synchronization of multi-axis control (to within one sample interval) can be arranged by loading the required trajectory parameters for each (and every) axis and then simultaneously issuing a single STT command to all axes. This command may be executed at any time, unless the acceleration value has been changed and a trajectory has not been completed or the motor has not been manually stopped. If STT is issued during motion and acceleration has been changed, a command error interrupt will be generated and the command will be ignored.

Data Reporting Commands

The following seven LM628 user commands are used to obtain data from various registers in the LM628. Status, position, and velocity information are reported. With the exception of RDSTAT, the data is read from the LM628 data port after first writing the corresponding command to the command port.

Data Reporting Commands (Continued)

RDSTAT COMMAND: ReaD STATus Byte

Command Code: None
Byte Read: One
Data Range: See Text
Executable During Motion: Yes

The RDSTAT command is really not a command, but is listed with the other commands because it is used very frequently to control communications with the host computer. There is no identification code; it is directly supported by the hardware and may be executed at any time. The single-byte status read is selected by placing $\overline{CS}$, $\overline{PS}$ and $\overline{RD}$ at logic zero. See Table VII.

TABLE VII. Status Byte Bit Allocation

Bit Position	Function
Bit 7	Motor Off
Bit 6	Breakpoint Reached [Interrupt]
Bit 5	Excessive Position Error [Interrupt]
Bit 4	Wraparound Occurred [Interrupt]
Bit 3	Index Pulse Observed [Interrupt]
Bit 2	Trajectory Complete [Interrupt]
Bit 1	Command Error [Interrupt]
Bit 0	Busy Bit

Bit 7, the motor-off flag, is set to logic one when the motor drive output is off (at the half-scale, offset-binary code for zero). The motor is turned off by any of the following conditions: power-up reset, command RESET, excessive position error (if command LPES had been executed), or when command LTRJ is used to manually stop the motor via turning the motor off. Note that when bit 7 is set in conjunction with command LTRJ for producing a manual, motor-off stop, the actual setting of bit 7 does not occur until command STT is issued to affect the stop. Bit 7 is cleared by command STT, except as described in the previous sentence.

Bit 6, the breakpoint-reached interrupt flag, is set to logic one when the position breakpoint loaded via command SBPA or SBPR has been exceeded. The flag is functional independent of the host interrupt mask status. Bit 6 is cleared via command RSTI.

Bit 5, the excessive-position-error interrupt flag, is set to logic one when a position-error interrupt condition exists. This occurs when the error threshold loaded via command LPEI or LPES has been exceeded. The flag is functional independent of the host interrupt mask status. Bit 5 is cleared via command RSTI.

Bit 4, the wraparound interrupt flag, is set to logic one when a numerical "wraparound" has occurred. To "wraparound" means to exceed the position address space of the LM628, which could occur during velocity mode operation. If a wraparound has occurred, then position information will be in error and this interrupt helps the user to ensure position data integrity. The flag is functional independent of the host interrupt mask status. Bit 4 is cleared via command RSTI.

Bit 3, the index-pulse acquired interrupt flag, is set to logic one when an index pulse has occurred (if command SIP had been executed) and indicates that the index position register has been updated. The flag is functional independent of the host interrupt mask status. Bit 3 is cleared by command RSTI.

Bit 2, the trajectory complete interrupt flag, is set to logic one when the trajectory programmed by the LTRJ command and initiated by the STT command has been completed. Because of overshoot or a limiting condition (such as commanding the velocity to be higher than the motor can achieve), the motor may not yet be at the final commanded position. This bit is the logical OR of bits 7 and 10 of the Signals Register, see command RDSIGS below. The flag functions independently of the host interrupt mask status. Bit 2 is cleared via command RSTI.

Bit 1, the command-error interrupt flag, is set to logic one when the user attempts to read data when a write was appropriate (or vice versa). The flag is functional independent of the host interrupt mask status. Bit 1 is cleared via command RSTI.

Bit 0, the busy flag, is frequently tested by the user (via the host computer program) to determine the busy/ready status prior to writing and reading any data. Such writes and reads may be executed only when bit 0 is logic zero (not busy). Any command or data writes when the busy bit is high will be ignored. Any data reads when the busy bit is high will read the current contents of the I/O port buffers, not the data expected by the host. Such reads or writes (with the busy bit high) will not generate a command-error interrupt.

RDSIGS COMMAND: ReaD SIGnalS Register

Command Code: 0C Hex
Bytes Read: Two
Data Range: See Text
Executable During Motion: Yes

The LM628 internal "signals" register may be read using this command. The first byte read is the more significant. The less significant byte of this register (with the exception of bit 0) duplicates the status byte. See Table VIII.

TABLE VIII. Signals Register Bit Allocation

Bit Position	Function
Bit 15	Host Interrupt
Bit 14	Acceleration Loaded (But Not Updated)
Bit 13	UDF Executed (But Filter Not yet Updated)
Bit 12	Forward Direction
Bit 11	Velocity Mode
Bit 10	On Target
Bit 9	Turn Off upon Excessive Position Error
Bit 8	Eight-Bit Output Mode
Bit 7	Motor Off
Bit 6	Breakpoint Reached [Interrupt]
Bit 5	Excessive Position Error [Interrupt]
Bit 4	Wraparound Occurred [Interrupt]
Bit 3	Index Pulse Acquired [Interrupt]
Bit 2	Trajectory Complete [Interrupt]
Bit 1	Command Error [Interrupt]
Bit 0	Acquire Next Index (SIP Executed)

Bit 15, the host interrupt flag, is set to logic one when the host interrupt output (Pin 17) is logic one. Pin 17 is set to logic one when any of the six host interrupt conditions occur (if the corresponding interrupt has not been masked). Bit 15 (and Pin 17) are cleared via command RSTI.

Bit 14, the acceleration-loaded flag, is set to logic one when acceleration data is written to the LM628. Bit 14 is cleared by the STT command.

Data Reporting Commands (Continued)

Bit 13, the UDF-executed flag, is set to logic one when the UDF command is executed. Because bit 13 is cleared at the end of the sampling interval in which it has been set, this signal is very short-lived and probably not very profitable for monitoring.

Bit 12, the forward direction flag, is meaningful only when the LM628 is in velocity mode. The bit is set to logic one to indicate that the desired direction of motion is "forward"; zero indicates "reverse" direction. Bit 12 is set and cleared via command LTRJ. The actual setting and clearing of bit 12 does not occur until command STT is executed.

Bit 11, the velocity mode flag, is set to logic one to indicate that the user has selected (via command LTRJ) velocity mode. Bit 11 is cleared when position mode is selected (via command LTRJ). The actual setting and clearing of bit 11 does not occur until command STT is executed.

Bit 10, the on-target flag, is set to logic one when the trajectory generator has completed its functions for the last-issued STT command. Bit 10 is cleared by the next STT command.

Bit 9, the turn-off on-error flag, is set to logic one when command LPES is executed. Bit 9 is cleared by command LPEI.

Bit 8, the 8-bit output flag, is set to logic one when the LM628 is reset, or when command PORT8 is executed. Bit 8 is cleared by command PORT12.

Bits 0 through 7 replicate the status byte (see Table VII), with the exception of bit 0. Bit 0, the acquire next index flag, is set to logic one when command SIP is executed; it then remains set until the next index pulse occurs.

RDIP COMMAND: ReaD Index Position

Command Code:	09 Hex
Bytes Read:	Four
Data Range:	C0000000 to 3FFFFFFF Hex
Executable During Motion:	Yes

This command reads the position recorded in the index register. Reading the index register can be part of a system error checking scheme. Whenever the SIP command is executed, the new index position minus the old index position, divided by the incremental encoder resolution (encoder lines times four), should always be an integral number. The RDIP command facilitates acquiring these data for host-based calculations. The command can also be used to identify/verify home or some other special position. The bytes are read in most-to-least significant order.

RDDP COMMAND: ReaD Desired Position

Command Code:	08 Hex
Bytes Read:	Four
Data Range:	C0000000 to 3FFFFFFF Hex
Executable During Motion:	Yes

This command reads the instantaneous desired (current *temporal*) position output of the profile generator. This is the "setpoint" input to the position-loop summing junction. The bytes are read in most-to-least significant order.

RDRP COMMAND: ReaD Real Position

Command Code:	0A Hex
Bytes Read:	Four
Data Range:	C0000000 to 3FFFFFFF Hex
Executable During Motion:	Yes

This command reads the current actual position of the motor. This is the feedback input to the loop summing junction. The bytes are read in most-to-least significant order.

RDDV COMMAND: ReaD Desired Velocity

Command Code:	07 Hex
Bytes Read:	Four
Data Range:	C0000001 to 3FFFFFFF
Executable During Motion:	Yes

This command reads the integer and fractional portions of the instantaneous desired (current *temporal*) velocity, as used to generate the desired position profile. The bytes are read in most-to-least significant order. The value read is properly scaled for numerical comparison with the user-supplied (commanded) velocity; however, because the two least-significant bytes represent *fractional* velocity, only the two most-significant bytes are appropriate for comparison with the data obtained via command RDRV (see below). Also note that, although the velocity *input* data is constrained to positive numbers (see command LTRJ), the data returned by command RDDV represents a *signed* quantity where negative numbers represent operation in the reverse direction.

RDRV COMMAND: ReaD Real Velocity

Command Code:	0B Hex
Bytes Read:	Two
Data Range:	C000 to 3FFF Hex, See Text
Executable During Motion:	Yes

This command reads the *integer* portion of the instantaneous actual velocity of the motor. The internally maintained fractional portion of velocity is not reported because the reported data is derived by reading the incremental encoder, which produces only integer data. For comparison with the result obtained by executing command RDDV (or the user-supplied input value), the value returned by command RDRV must be multiplied by 2^{16} (shifted left 16 bit positions). Also, as with command RDDV above, data returned by command RDRV is a *signed* quantity, with negative values representing reverse-direction motion.

RDSUM COMMAND: ReaD Integration-Term SUMmation Value

Command Code:	0D Hex
Bytes Read:	Two
Data Range:	00000 Hex to ± the Current Value of the Integration Limit
Executable During Motion:	Yes

This command reads the value to which the integration term has accumulated. The ability to read this value may be helpful in initially or adaptively tuning the system.

Typical Applications

Programming LM628 Host Handshaking (Interrupts)

A few words regarding the LM628 host handshaking will be helpful to the system programmer. As indicated in various portions of the above text, the LM628 handshakes with the host computer in two ways: via the host interrupt output (Pin 17), or via polling the status byte for "interrupt" conditions. When the hardwired interrupt is used, the status byte is also read and parsed to determine which of six possible conditions caused the interrupt.

Typical Applications (Continued)

When using the hardwired interrupt it is very important that the host interrupt service routine does not interfere with a command sequence which might have been in progress when the interrupt occurred. If the host interrupt service routine were to issue a command to the LM628 while it is in the middle of an ongoing command sequence, the ongoing command will be aborted (which could be detrimental to the application).

Two approaches exist for avoiding this problem. If one is using hardwired interrupts, they should be disabled at the host prior to issuing any LM628 command sequence, and re-enabled after each command sequence. The second approach is to avoid hardwired interrupts and poll the LM628 status byte for "interrupt" status. The status byte always reflects the interrupt-condition status, independent of whether or not the interrupts have been masked.

Typical Host Computer/Processor Interface

The LM628 is interfaced with the host computer/processor via an 8-bit parallel bus. *Figure 12* shows such an interface and a minimum system configuration.

As shown in *Figure 12*, the LM628 interfaces with the host data, address and control lines. The address lines are decoded to generate the LM628 $\overline{\text{CS}}$ input; the host address LSB directly drives the LM628 $\overline{\text{PS}}$ input. *Figure 12* also shows an 8-bit DAC and an LM12 Power Op Amp interfaced to the LM628.

LM628 and High Performance Controller (HPC) Interface

Figure 13 shows the LM628 interfaced to a National HPC High Performance Controller. The delay and logic associated with the $\overline{\text{WR}}$ line is used to effectively increase the write-data hold time of the HPC (as seen at the LM628) by causing the $\overline{\text{WR}}$ pulse to rise early. Note that the HPC CK2 output provides the clock for the LM628. The 74LS245 is used to decrease the read-data hold time, which is necessary when interfacing to fast host busses.

Interfacing a 12-Bit DAC

Figure 14 illustrates use of a 12-bit DAC with the LM628. The 74LS378 hex gated-D flip-flop and an inverter demultiplex the 12-bit output. DAC offset must be adjusted to minimize DAC linearity and monotonicity errors. Two methods exist for making this adjustment. If the DAC1210 has been socketed, remove it and temporarily connect a 15 kΩ resistor between Pins 11 and 13 of the DAC socket (Pins 2 and 6 of the LF356) and adjust the 25 kΩ potentiometer for 0V at Pin 6 of the LF356.

If the DAC is not removable, the second method of adjustment requires that the DAC1210 inputs be presented an all-zeros code. This can be arranged by commanding the appropriate move via the LM628, but with no feedback from the system encoder. When the all-zeros code is present, adjust the pot for 0V at Pin 6 of the LF356.

A Monolithic Linear Drive Using LM12 Power Op Amp

Figure 15 shows a motor-drive amplifier built using the LM12 Power Operational Amplifier. This circuit is very simple and can deliver up to 8A at 30V (using the LM12L/LM12CL). Resistors R1 and R2 should be chosen to set the gain to provide maximum output voltage consistent with maximum input voltage. This example provides a gain of 2.2, which allows for amplifier output saturation at ±22V with a ±10V input, assuming power supply voltages of ±30V. The amplifier gain should not be higher than necessary because the system is non-linear when saturated, and because gain should be controlled by the LM628. The LM12 can also be configured as a current driver, see 1987 Linear Databook, Vol. 1, p. 2-280.

Typical PWM Motor Drive Interfaces

Figure 16 shows an LM18298 dual full-bridge driver interfaced to the LM629 PWM outputs to provide a switch-mode power amplifier for driving small brush/commutator motors. *Figure 17* shows an LM621 brushless motor commutator interfaced to the LM629 PWM outputs and a discrete device switch-mode power amplifier for driving brushless DC motors.

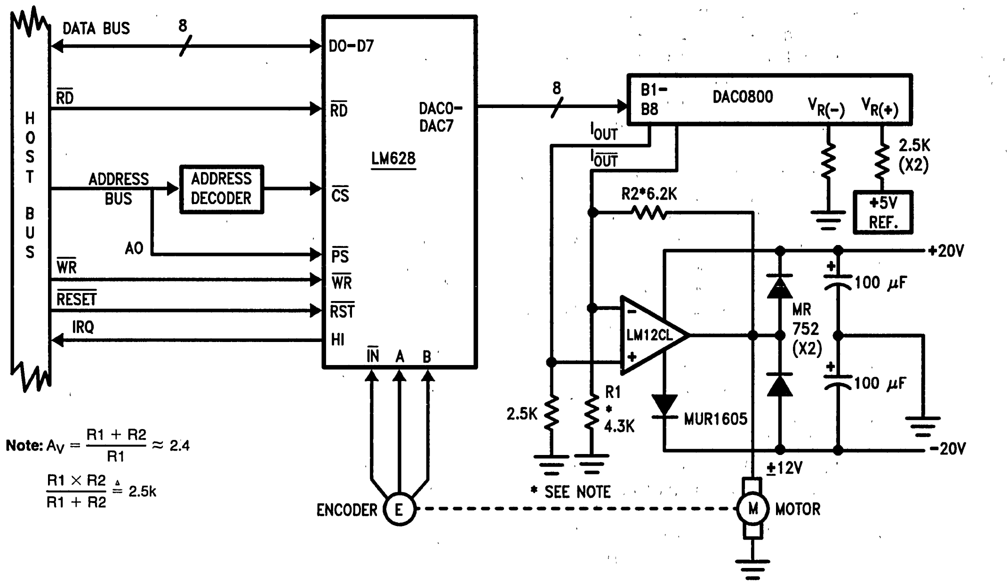
Incremental Encoder Interface

The incremental (position feedback) encoder interface consists of three lines: Phase A (Pin 2), Phase B (Pin 3), and Index (Pin 1). The index pulse output is not available on some encoders. The LM628 will work with both encoder types, but commands SIP and RDIP will not be meaningful without an index pulse (or alternative input for this input . . . be sure to tie Pin 1 high if not used).

Some consideration is merited relative to use in high Gaussian-noise environments. If noise is added to the encoder inputs (either or both inputs) and is such that it is not sustained until the next encoder transition, the LM628 decoder logic will reject it. Noise that mimics quadrature counts or persists through encoder transitions must be eliminated by appropriate EMI design.

Simple digital "filtering" schemes merely reduce susceptibility to noise (there will always be noise pulses longer than the filter can eliminate). Further, any noise filtering scheme reduces decoder bandwidth. In the LM628 it was decided (since simple filtering does not eliminate the noise problem) to not include a noise filter in favor of offering maximum possible decoder bandwidth. Attempting to drive encoder signals too long a distance with simple TTL lines can also be a source of "noise" in the form of signal degradation (poor risetime and/or ringing). This can also cause a system to lose positional integrity. Probably the most effective countermeasure to noise induction can be had by using balanced-line drivers and receivers on the encoder inputs. *Figure 18* shows circuitry using the DS26LS31 and DS26LS32.

Typical Applications (Continued)



TL/H/9219–14

FIGURE 12. Host Interface and Minimum System Configuration

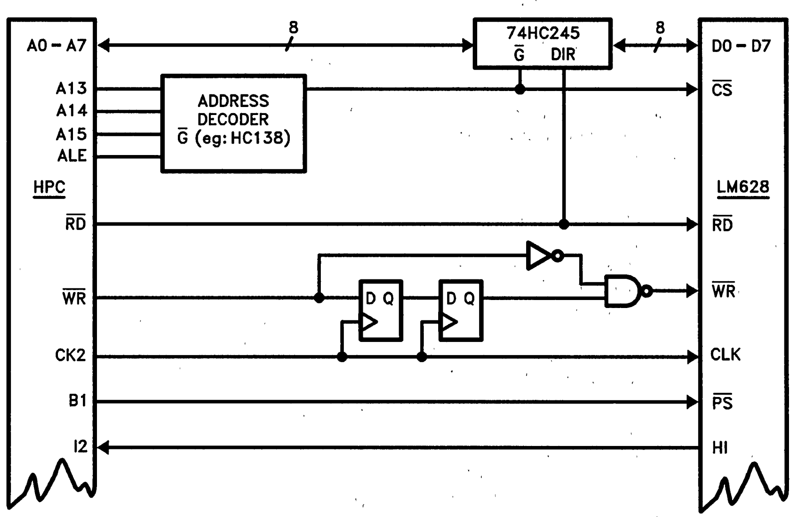


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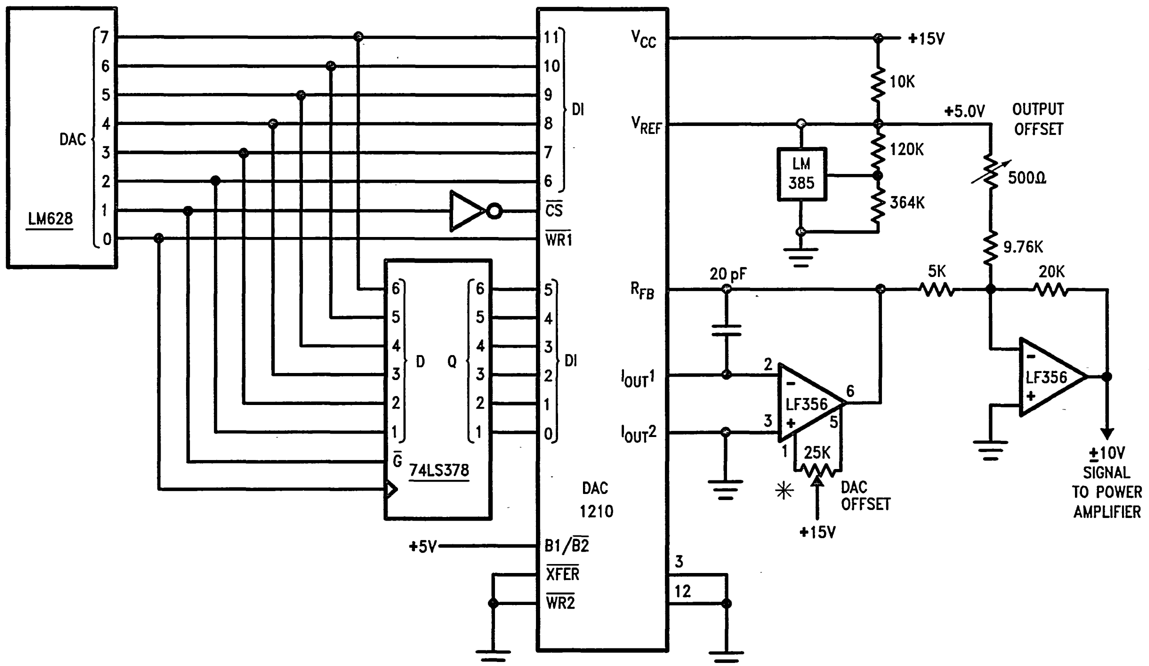
FIGURE 13. LM628 and HPC Interface

Typical Applications (Continued)



*DAC offset must be adjusted to minimize DAC linearity and monotonicity errors. See text.

FIGURE 14. Interfacing a 12-Bit DAC and LM628

Typical Applications (Continued)

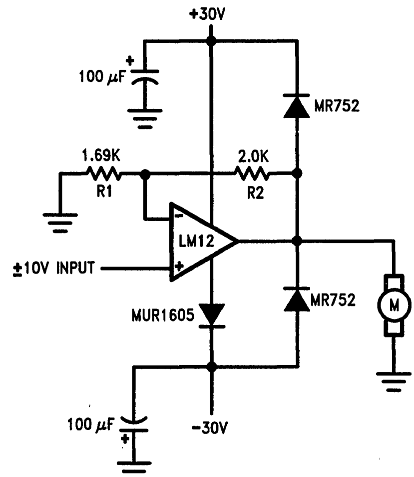


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FIGURE 15. Driving a Motor with the LM12 Power Op Amp

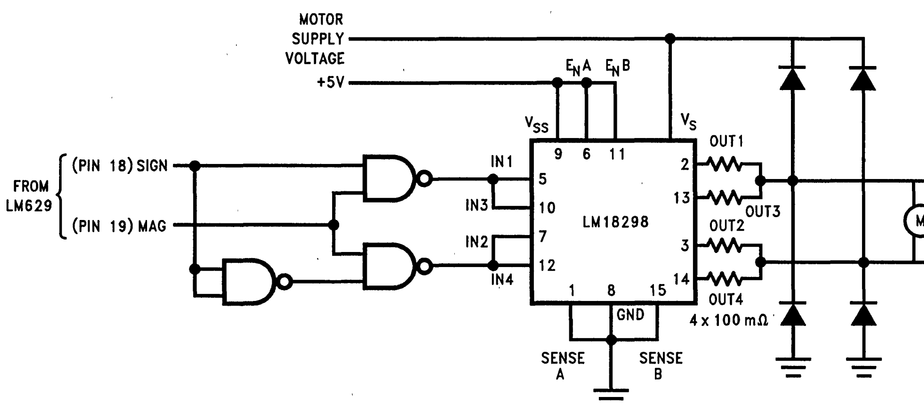

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FIGURE 16. PWM Drive for Brush/Commutator Motors

Typical Applications (Continued)

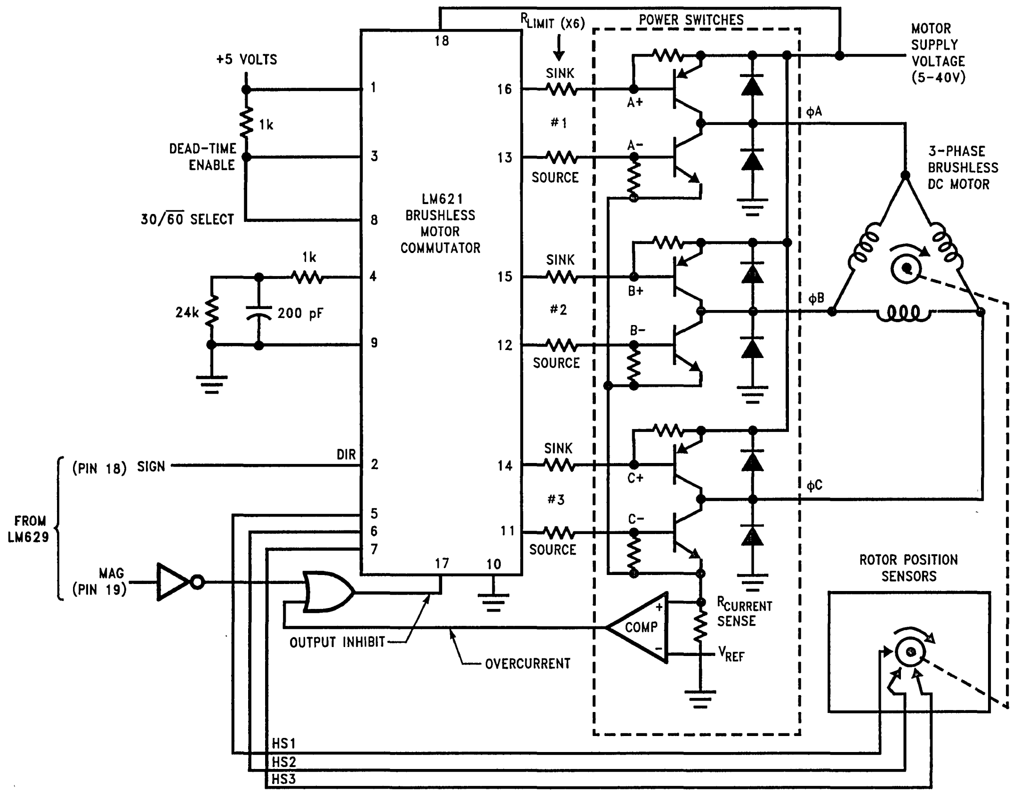


FIGURE 17. PWM Drive for Brushless Motors

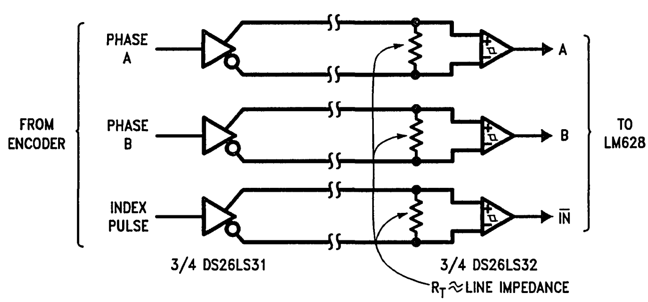


FIGURE 18. Typical Balanced-Line Encoder Input Circuit

National Semiconductor

LM18293 Four Channel Push-Pull Driver

General Description

The LM18293 is designed to drive DC loads up to one amp. Typical applications include driving such inductive loads as solenoids, relays and stepper motors along with driving switching power transistors and use as a buffer for low level logic signals. The four inputs accept standard TTL and DTL levels for ease of interfacing. Two enable pins are provided that also accept the standard TTL and DTL levels. Each enable controls 2 channels and when an enable pin is disabled (tied low), the corresponding outputs are forced to the TRI-STATE® condition. If the enable pins are not connected (i.e., floating), the circuit will function as if it has been enabled. Separate pins are provided for the main power supply (pin 8), and the logic supply (pin 16). This allows a lower voltage to be used to bias up the logic resulting in reduced power dissipation. The chip is packaged in a specially designed 16 pin power DIP. The 4 center pins of this package are tied together and form the die paddle inside the package. This provides much better heat sinking capability than most other DIP packages available. The device is capable of operating at voltages up to 36 volts.

Features

- 1A output current capability per channel
- Pin for pin replacement for L293B
- Special 16 pin power DIP package
- 36 volt operation
- Internal thermal overload protection
- Logical "0" input voltage up to 1.5 volts results in high noise immunity

Typical Connection

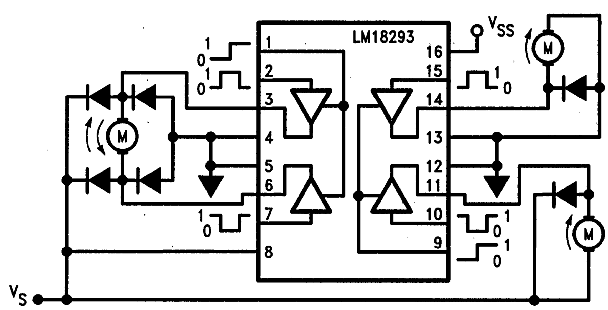


FIGURE 1. Application circuit showing bidirectional and on/off control of a single DC motor using two outputs and unidirectional on/off function of two DC motors using a single output each.

Order Number LM18293N
NS Package Number N16A

Absolute Maximum Ratings

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Output Drive Supply Voltage (V_S)	36V
Logic Supply Voltage (V_{SS})	36V
Input Voltage (V_I)	7V
Enable Voltage (V_E)	7V
Peak Output Current (Non-Repetitive t = 5 ms)	2A
Junction Temperature (T_J)	+150°C
Thermal Resistance Junction to Case (θ_{JC})	14°C/W
Thermal Resistance Junction to Ambient (θ_{JA})	80°C/W
Internal Power Dissipation	Internally Limited
Operating Temperature Range	−40°C to +125°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Solder 10 seconds)	260°C

Electrical Characteristics

V_S = 24V, V_{SS} = 5V, T = 25°C, L = 0.4V, H = 3.5V, each channel, unless otherwise noted

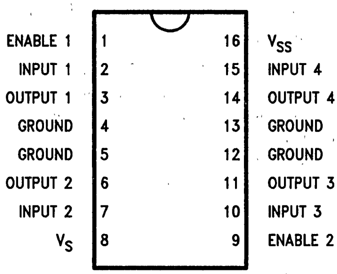
Symbol	Parameter	Conditions	Typical	Tested Limit (Note 1)	Design Limit (Note 2)	Units
V_S	Main Supply (Pin 8)	Maximum Supply Voltage		36		Vmax
V_{SS}	Logic Supply (Pin 16)	Minimum Logic Supply Voltage Maximum Logic Supply Voltage		4.5 36		Vmin Vmax
I_S	Total Quiescent Supply Current	V_I = L I_O = 0 V_E = H V_I = H I_O = 0 V_E = H V_E = L	2 16	6 24 4		mAmax mAmax mAmax
I_{SS}	Total Quiescent Logic Supply Current (pin 16)	V_I = L I_O = 0 V_E = H V_I = H I_O = 0 V_E = H V_E = L	44 16 16	60 22 24		mAmax mAmax mAmax
V_I	Input Voltage	Min Value of Low Max Value of Low Min Value of High Max Value of High (V_{SS} ≤ 7) Max Value of High (V_{SS} > 7)		−0.3 1.5 2.3 V_{SS} 7		Vmin Vmax Vmin Vmax Vmax
I_I	Input Current	V_I = L V_I = H	 30	−10 100		μAmax μAmax
V_E	Enable Voltage (Pins 1, 9)	Min Value of Low Max Value of Low Min Value of High Max Value of High (V_{SS} ≤7) Max Value of High (V_{SS} >7)		−0.3 1.5 2.3 V_{SS} 7		Vmin Vmax Vmin Vmax Vmax
I_E	Enable Current	V_E = L V_E = H	−30	−100 ±10		μAmax μAmax
V_{CE} sat Top	Source Saturation Voltage	I_o = −1 amp	1.4	1.8		Vmax
V_{CE} sat Bottom	Sink Saturation Voltage	I_o = 1 amp	1.2	1.8		Vmax
t_r	Rise Time	10%–90% V_o	250			ns
t_f	Fall Time	90%–10% V_o	250			ns
t_{on}	Turn-On Delay	50% V_I to 50% V_o	450			ns
t_{off}	Turn-Off Delay	50% V_I to 50% V_o	200			ns

Note 1: Tested limits are guaranteed and 100% production tested.

Note 2: Design limits are guaranteed (but not 100% production tested) over the full supply and temperature range. These limits are not used to calculate outgoing quality levels.

4

Connection Diagram



Enable 1 activates outputs 1 & 2

Enable 2 activates outputs 3 & 4

TL/H/8706-2

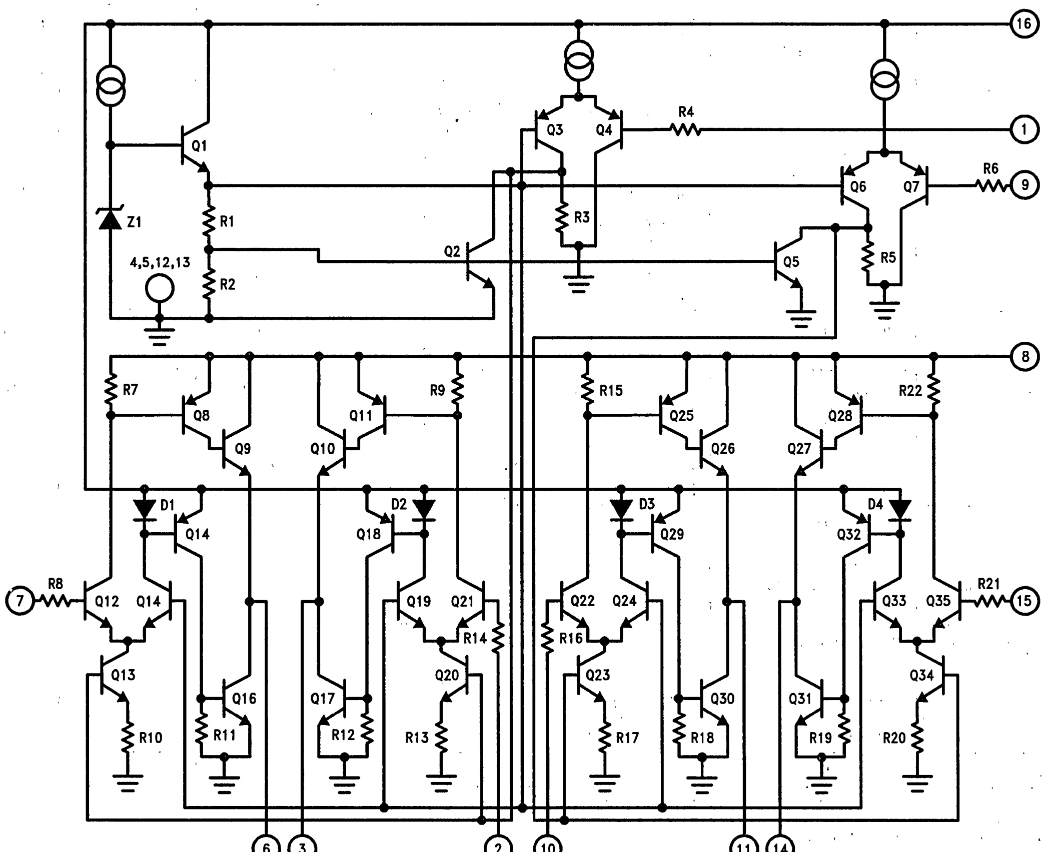
Input/Output Truth Table

V_E (**)	V_I (Each Channel)	V_O
H	H	H
H	L	L
L	H	X (*)
L	L	X (*)

(*) High output impedance.

(**) Relative to the pertinent channel.

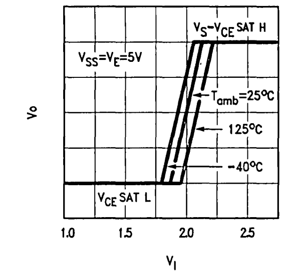
Simplified Schematic



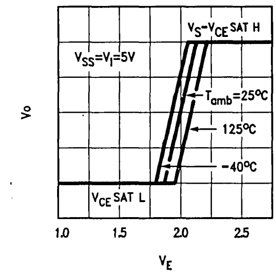
TL/H/8706-3

Typical Performance Characteristics V_S In all cases = 24V

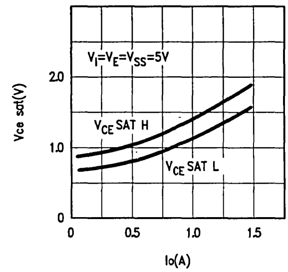
Output Voltage vs. Input Voltage



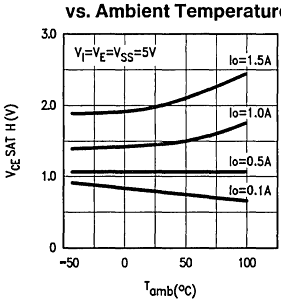
Output Voltage vs. Enable Voltage



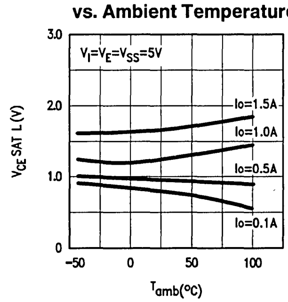
Saturation Voltage vs. Output Current



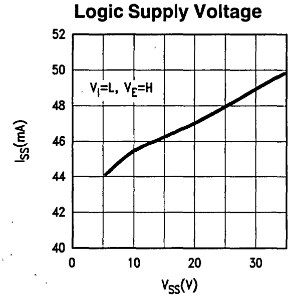
Source Saturation Voltage vs. Ambient Temperature



Sink Saturation Voltage vs. Ambient Temperature



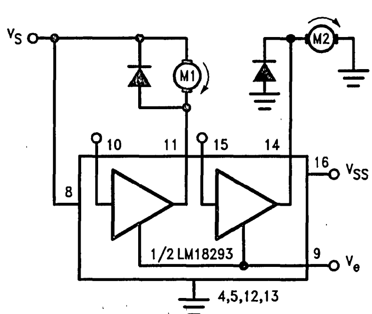
Quiescent Logic Supply Current vs. Logic Supply Voltage



TL/H/8706-4

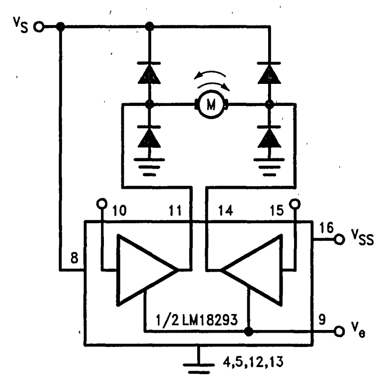
Typical Applications

DC motor controls (with connections to ground and to the supply voltages)



TL/H/8706-5

Bidirectional DC motor control



TL/H/8706-6

V_E	Pin 10	Pin 15	M1	M2
H	H	H	Fast Motor Stop	Run
H	H	L	Fast Motor Stop	Fast Motor Stop
H	L	H	Run	Run
H	L	L	Run	Fast Motor Stop
L	X	X	Free Running Motor Stop	Free Running Motor Stop

L = Low H = High X = Don't care

Inputs		Function
V_E = H	Pin 10 = H Pin 15 = L	Turn CW
	Pin 10 = L Pin 15 = H	Turn CCW
	Pin 10 = Pin 15	Fast Motor Stop
V_E = L	Pin 10 = X Pin 15 = X	Free Running Motor Stop

L = Low H = High X = Don't care

Bipolar Stepping Motor Control

Step Sequencing Tables

Full Step *

V_{IN} 1	V_{IN} 2	Step
L	L	1
L	H	2
H	H	3
H	L	4
L	L	1

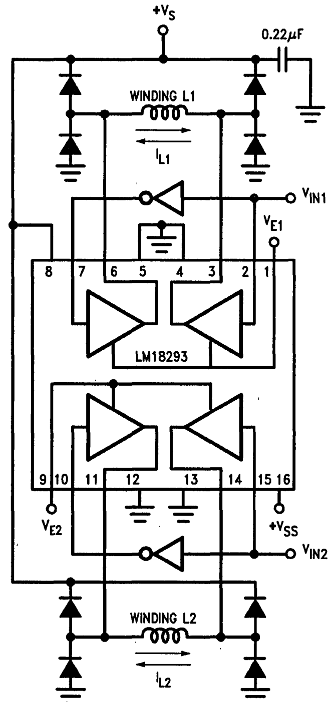
***V_E 1 and V_E 2 = H**

Half Step

V_E 1	V_E 2	V_{IN} 1	V_{IN} 2	Step
H	L	L	X	1
H	H	L	L	2
L	H	X	L	3
H	H	H	L	4
H	L	H	X	5
H	H	H	H	6
L	H	X	H	7
H	H	L	H	8
H	L	L	X	1

H = High L = Low X = Don't care

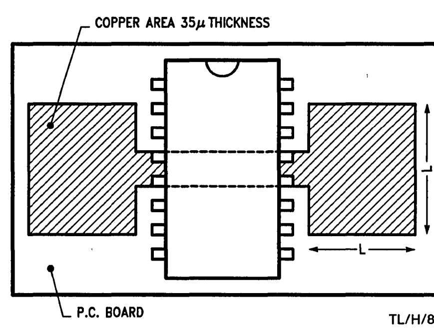
Motor Control Block Diagram



TL/H/8706-7

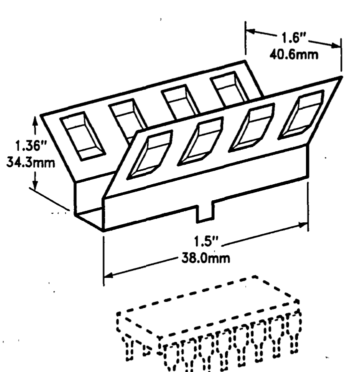
Mounting Instructions

The junction to ambient thermal resistance of the LM18293 can be reduced by soldering the ground pins to a suitable copper area of the printed circuit board or to an external heatsink. The graph below, which shows the maximum power dissipated and junction to ambient thermal resistance as a function of the side "l" of two equal square copper areas having a thickness of 35µ, illustrates this. In addition, it is possible to use an external heatsink (see illustration below). During soldering the pins temperature must not exceed 230°C and the soldering time must not be longer than 12 seconds. The external heatsink or printed circuit copper area must be connected to electrical ground.



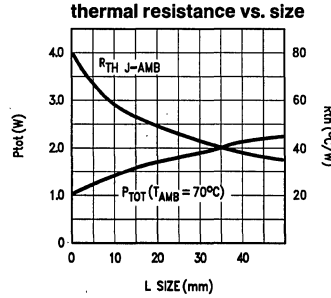
TL/H/8706-8

Staver External Heat-sink



TL/H/8706-10

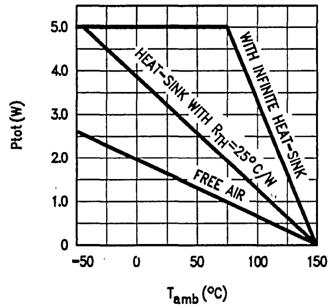
Maximum power dissipated and junction to ambient thermal resistance vs. size



TL/H/8706-9

Mounting Instructions (Continued)

Maximum Allowable Power Dissipation vs Ambient Temperature



TL/H/8706-11

National Semiconductor

LMD18200 3A, 55V H-Bridge

General Description

The LMD18200 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. Ideal for driving DC and stepper motors; the LMD18200 accommodates peak output currents up to 6A. An innovative circuit which facilitates low-loss sensing of the output current has been implemented.

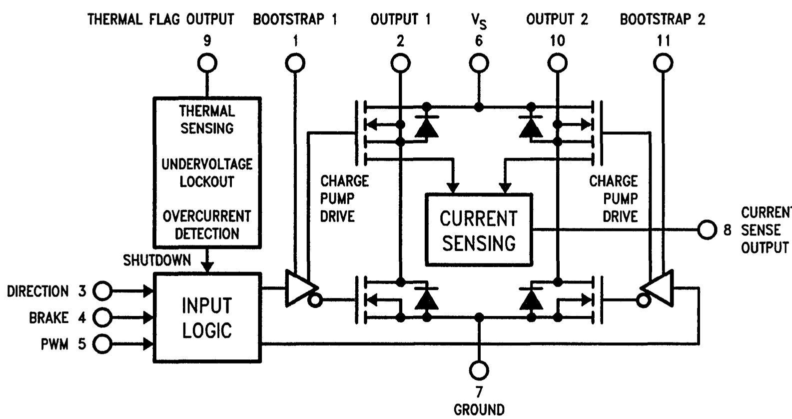
Features

- Delivers up to 3A continuous output
- Operates at supply voltages up to 55V
- Low R_{DS}(ON) typically 0.3Ω per switch
- TTL and CMOS compatible inputs
- No "shoot-through" current
- Thermal warning flag output at 145°C
- Thermal shutdown (outputs off) at 170°C
- Internal clamp diodes
- Shorted load protection
- Internal charge pump with external bootstrap capability

Applications

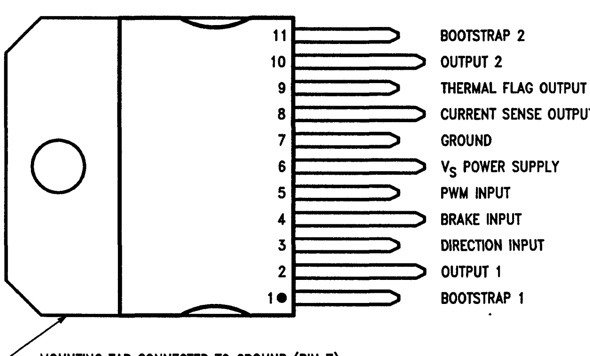
- DC and stepper motor drives
- Position and velocity servomechanisms
- Factory automation robots
- Numerically controlled machinery
- Computer printers and plotters

Functional Diagram



TL/H/10568–1

Connection Diagram and Ordering Information



TL/H/10568–2

Top View

Order Number LMD18200T
See NS Package TA11B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (V_S, Pin 6)	60V
Voltage at Pins 3, 4, 5, 8 and 9	12V
Voltage at Bootstrap Pins (Pins 1 and 11)	V_{OUT} +16V
Peak Output Current (200 ms)	6A
Continuous Output Current (Note 2)	3A
Power Dissipation (Note 3)	25W
Power Dissipation (T_A = 25°C, Free Air)	3W
Junction Temperature, $T_{J(max)}$	150°C
ESD Susceptibility (Note 4)	1500V
Storage Temperature, T_{STG}	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Operating Ratings (Note 1)

Junction Temperature, T_J	−40°C to +125°C
V_S Supply Voltage	+12V to +55V

Electrical Characteristics

The following specifications apply for V_S = 42V, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, −40°C ≤ T_J ≤ +125°C, all other limits are for T_A = T_J = 25°C. (Note 5)

Symbol	Parameter	Conditions	Typ	Limit	Units
R_{DS}(ON)	Switch ON Resistance	Output Current = 3A (Note 6)	0.33	0.4/**0.6**	Ω (max)
R_{DS}(ON)	Switch ON Resistance	Output Current = 6A (Note 6)	0.33	0.4/**0.6**	Ω (max)
V_{CLAMP}	Clamp Diode Forward Drop	Clamp Current = 3A (Note 6)	1.2	1.5	V (max)
V_{IL}	Logic Low Input Voltage	Pins 3, 4, 5		**−0.1** **0.8**	V (min) V (max)
I_{IL}	Logic Low Input Current	V_{IN} = −0.1V, Pins = 3, 4, 5		**−10**	μA (max)
V_{IH}	Logic High Input Voltage	Pins 3, 4, 5		**2** **12**	V (min) V (max)
I_{IH}	Logic High Input Current	V_{IN} = 12V, Pins = 3, 4, 5		**10**	μA (max)
	Current Sense Output	I_{OUT} = 1A (Note 8)	377	325/**300** 425/**450**	μA (min) μA (max)
	Current Sense Linearity	1A ≤ I_{OUT} ≤ 3A (Note 7)	±6	±9	%
	Undervoltage Lockout	Outputs turn OFF		9 11	V (min) V (max)
T_{JW}	Warning Flag Temperature	Pin 9 ≤ 0.8V, I_L = 2 mA	145		°C
V_F(ON)	Flag Output Saturation Voltage	T_J = T_{JW}, I_L = 2 mA	0.15		V
I_F(OFF)	Flag Output Leakage	V_F = 12V	0.2	10	μA (max)
T_{JSD}	Shutdown Temperature	Outputs Turn OFF	170		°C
I_S	Quiescent Supply Current	All Logic Inputs Low	13	25	mA (max)
t_{Don}	Output Turn-On Delay Time	Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	300 300		ns ns
t_{on}	Output Turn-On Switching Time	Bootstrap Capacitor = 10 nF Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	 100 80		 ns ns
t_{Doff}	Output Turn-Off Delay Times	Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	200 200		ns ns
t_{off}	Output Turn-Off Switching Times	Bootstrap Capacitor = 10 nF Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	 75 70		 ns ns
t_{pw}	Minimum Input Pulse Width	Pins 3, 4 and 5	1		μs
t_{cpr}	Charge Pump Rise Time	No Bootstrap Capacitor	20		μs

Electrical Characteristics Notes

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: See Application Information for details regarding current limiting.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is a function of $T_{J(max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any temperature is $P_{D(max)} = (T_{J(max)} - T_A)/\theta_{JA}$, or the number given in the Absolute Ratings, whichever is lower. The typical thermal resistance from junction to case (θ_{JC}) is 1.0°C/W and from junction to ambient (θ_{JA}) is 30°C/W. For guaranteed operation $T_{J(max)} = 125°C$.

Note 4: Human-body model, 100 pF discharged through a 1.5 kΩ resistor. Except Bootstrap pins (pins 1 and 11) which are protected to 1000V of ESD.

Note 5: All limits are 100% production tested at 25°C. Temperature extreme limits are guaranteed via correlation using accepted SQC (Statistical Quality Control) methods. All limits are used to calculate AOQL, (Average Outgoing Quality Level).

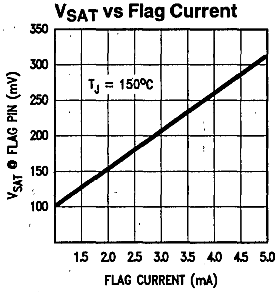
Note 6: Output currents are pulsed (t_W < 2 ms, Duty Cycle < 5%).

Note 7: Regulation is calculated relative to the current sense output value with a 1A load.

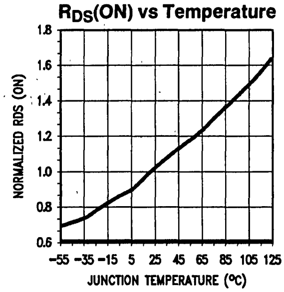
Note 8: Selections for tighter tolerance are available. Contact factory.

Typical Performance Characteristics

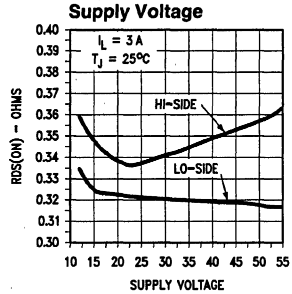
V_{SAT} vs Flag Current



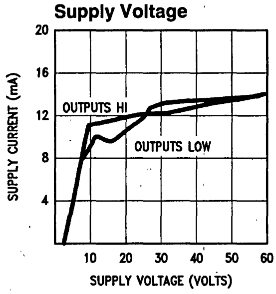
R_{DS}(ON) vs Temperature



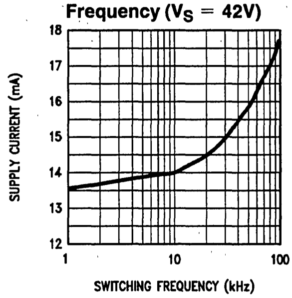
R_{DS}(ON) vs Supply Voltage



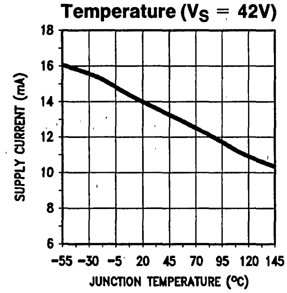
Supply Current vs Supply Voltage



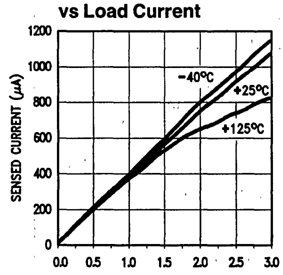
Supply Current vs Frequency (V_S = 42V)



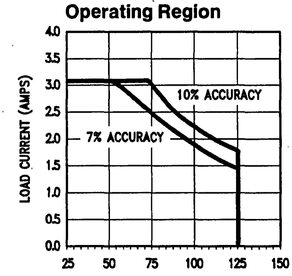
Supply Current vs Temperature (V_S = 42V)



Current Sense Output vs Load Current



Current Sense Operating Region



TL/H/10568-3

Pinout Description (See Connection Diagram)

Pin 1, BOOTSTRAP 1 Input: Bootstrap capacitor pin for half H-bridge number 1. The recommended capacitor (10 nF) is connected between pins 1 and 2.

Pin 2, OUTPUT 1: Half H-bridge number 1 output.

Pin 3, DIRECTION Input: See Table I. This input controls the direction of current flow between OUTPUT 1 and OUTPUT 2 (pins 2 and 10) and, therefore, the direction of rotation of a motor load.

Pin 4, BRAKE Input: See Table I. This input is used to brake a motor by effectively shorting its terminals. When braking is desired, this input is taken to a logic high level and it is also necessary to apply logic high to PWM input, pin 5. The drivers that short the motor are determined by the logic level at the DIRECTION input (Pin 3): with Pin 3 logic high, both current sourcing output transistors are ON; with Pin 3 logic low, both current sinking output transistors are ON. All output transistors can be turned OFF by applying a logic high to Pin 4 and a logic low to PWM input Pin 5; in this case only a small bias current (approximately −1.5 mA) exists at each output pin.

Pin 5, PWM Input: See Table I. How this input (and DIRECTION input, Pin 3) is used is determined by the format of the PWM Signal.

Pin 6, V_S Power Supply

Pin 7, GROUND Connection: This pin is the ground return, and is internally connected to the mounting tab.

Pin 8, CURRENT SENSE Output: This pin provides the sourcing current sensing output signal, which is typically 377 μA/A.

Pin 9, THERMAL FLAG Output: This pin provides the thermal warning flag output signal. Pin 9 becomes active-low at 145°C (junction temperature). However the chip will not shut itself down until 170°C is reached at the junction.

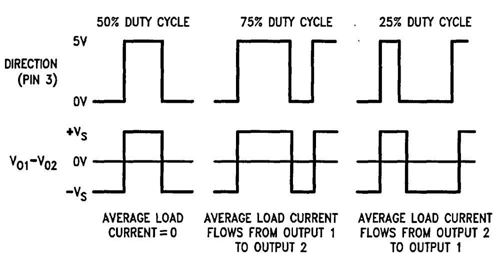
Pin 10, OUTPUT 2: Half H-bridge number 2 output.

Pin 11, BOOTSTRAP 2 Input: Bootstrap capacitor pin for Half H-bridge number 2. The recommended capacitor (10 nF) is connected between pins 10 and 11.

TABLE I. Logic Truth Table

PWM	Dir	Brake	Active Output Drivers
H	H	L	Source 1, Sink 2
H	L	L	Sink 1, Source 2
L	X	L	Source 1, Source 2
H	H	H	Source 1, Source 2
H	L	H	Sink 1, Sink 2
L	X	H	NONE

Locked Anti-Phase PWM Control



TL/H/10568–4

Application Information

TYPES OF PWM SIGNALS

The LMD18200 readily interfaces with different forms of PWM signals. Use of the part with two of the more popular forms of PWM is described in the following paragraphs.

Simple, locked anti-phase PWM consists of a single, variable duty-cycle signal in which is encoded both direction and amplitude information. A 50% duty-cycle PWM signal represents zero drive, since the net value of voltage (integrated over one period) delivered to the load is zero. For the LMD18200, the PWM signal drives the direction input (pin 3) and the PWM input (pin 5) is tied to logic high.

Sign/magnitude PWM consists of separate direction (sign) and amplitude (magnitude) signals. The (absolute) magnitude signal is duty-cycle modulated, and the absence of a pulse signal (a continuous logic low level) represents zero drive. Current delivered to the load is proportional to pulse width. For the LMD18200, the DIRECTION input (pin 3) is driven by the sign signal and the PWM input (pin 5) is driven by the magnitude signal.

USING THE CURRENT SENSE OUTPUT

The CURRENT SENSE output (pin 8) has a sensitivity of 377 μA per ampere of output current. For optimal accuracy and linearity of this signal, the value of voltage generating resistor between pin 8 and ground should be chosen to limit the maximum voltage developed at pin 8 to 5V, or less. The maximum voltage compliance is 12V.

It should be noted that the recirculating currents (free wheeling currents) are ignored by the current sense circuitry. Therefore, only the currents in the upper sourcing outputs are sensed.

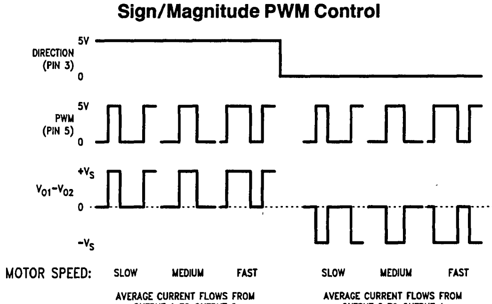
USING THE THERMAL WARNING FLAG

The THERMAL FLAG output (pin 9) is an open collector transistor. This permits a wired OR connection of thermal warning flag outputs from multiple LMD18200's, and allows the user to set the logic high level of the output signal swing to match system requirements. This output typically drives the interrupt input of a system controller. The interrupt service routine would then be designed to take appropriate steps, such as reducing load currents or initiating an orderly system shutdown. The maximum voltage compliance on the flag pin is 12V.

SUPPLY BYPASSING

During switching transitions the levels of fast current changes experienced may cause troublesome voltage transients across system stray inductance.

Sign/Magnitude PWM Control



TL/H/10568–5

Application Information (Continued)

It is normally necessary to bypass the supply rail with a high quality capacitor(s) connected as close as possible to the V_S Power Supply (Pin 6) and GROUND (Pin 7). A 1 μF high-frequency ceramic capacitor is recommended. Care should be taken to limit the transients on the supply pin below the Absolute Maximum Rating of the device. When operating the chip at supply voltages above 40V a voltage suppressor (transorb) such as P6KE62A is recommended from supply to ground. Typically the ceramic capacitor can be eliminated in the presence of the voltage suppressor. Note that when driving high load currents a greater amount of supply bypass capacitance (in general at least 100 μF per Amp of load current) is required to absorb the recirculating currents of the inductive loads.

CURRENT LIMITING

Current limiting protection circuitry has been incorporated into the design of the LMD18200. With any power device it is important to consider the effects of the substantial surge currents through the device that may occur as a result of shorted loads. The protection circuitry monitors this increase in current (the threshold is set to approximately 10 Amps) and shuts off the power device as quickly as possible in the event of an overload condition. In a typical motor driving application the most common overload faults are caused by shorted motor windings and locked rotors. Under these conditions the inductance of the motor (as well as any series inductance in the V_{CC} supply line) serves to reduce the magnitude of a current surge to a safe level for the LMD18200. Once the device is shut down, the control circuitry will periodically try to turn the power device back on. This feature allows the immediate return to normal operation in the event that the fault condition has been removed. While the fault remains however, the device will cycle in and out of thermal shutdown. This can create voltage transients on the V_{CC} supply line and therefore proper supply bypassing techniques are required.

The most severe condition for any power device is a direct, hard-wired ("screwdriver") long term short from an output to ground. This condition can generate a surge of current through the power device on the order of 15 Amps and require the die and package to dissipate up to 500 Watts of power for the short time required for the protection circuitry to shut off the power device. This energy can be destructive, particularly at higher operating voltages (>30V) so some precautions are in order. Proper heat sink design is essential and it is normally necessary to heat sink the V_{CC} supply pin (pin 6) with 1 square inch of copper on the PCB.

INTERNAL CHARGE PUMP AND USE OF BOOTSTRAP CAPACITORS

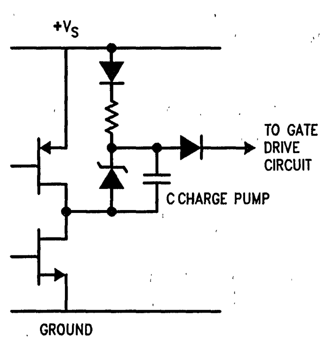
To turn on the high-side (sourcing) DMOS power devices, the gate of each device must be driven approximately 8V more positive than the supply voltage. To achieve this an internal charge pump is used to provide the gate drive voltage. As shown in *Figure 1*, an internal capacitor is alternately switched to ground and charged to about 14V, then switched to V supply thereby providing a gate drive voltage greater than V supply. This switching action is controlled by a continuously running internal 300 kHz oscillator. The rise time of this drive voltage is typically 20 μs which is suitable for operating frequencies up to 1 kHz.

For higher switching frequencies, the LMD18200 provides for the use of external bootstrap capacitors. The bootstrap principle is in essence a second charge pump whereby a large value capacitor is used which has enough energy to quickly charge the parasitic gate input capacitance of the power device resulting in much faster rise times. The switching action is accomplished by the power switches themselves *(Figure 2)*. External 10 nF capacitors, connected from the outputs to the bootstrap pins of each high-side switch provide typically less than 100 ns rise times allowing switching frequencies up to 500 kHz.

INTERNAL PROTECTION DIODES

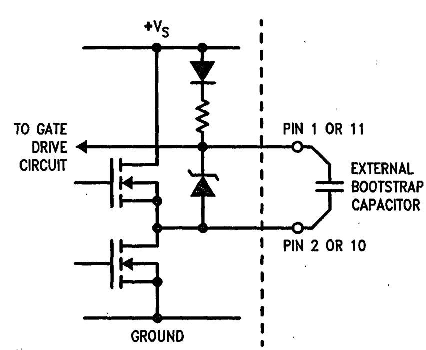
A major consideration when switching current through inductive loads is protection of the switching power devices from the large voltage transients that occur. Each of the four switches in the LMD18200 have a built-in protection diode to clamp transient voltages exceeding the positive supply or ground to a safe diode voltage drop across the switch.

The reverse recovery characteristics of these diodes, once the transient has subsided, is important. These diodes must come out of conduction quickly and the power switches must be able to conduct the additional reverse recovery current of the diodes. The reverse recovery time of the diodes protecting the sourcing power devices is typically only 70 ns with a reverse recovery current of 1A when tested with a full 6A of forward current through the diode. For the sinking devices the recovery time is typically 100 ns with 4A of reverse current under the same conditions.



TL/H/10568-6

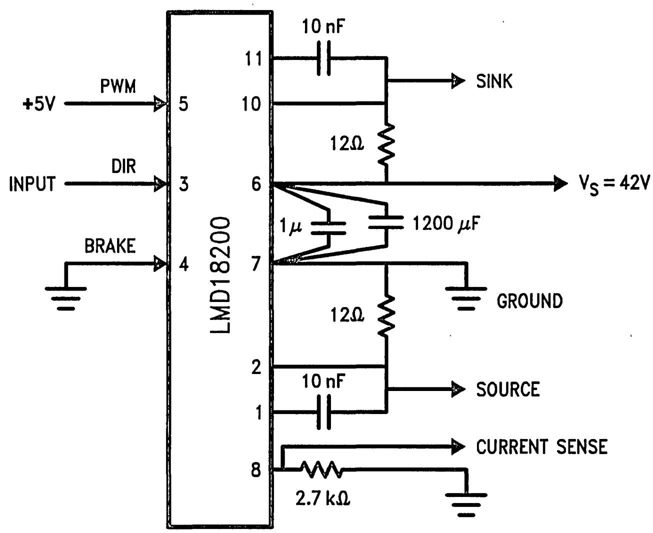
FIGURE 1. Internal Charge Pump Circuitry



TL/H/10568-7

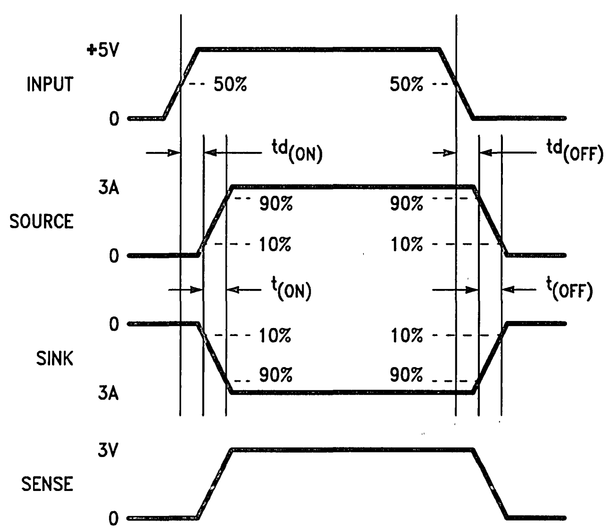
FIGURE 2. Bootstrap Circuitry

Test Circuit



TL/H/10568–8

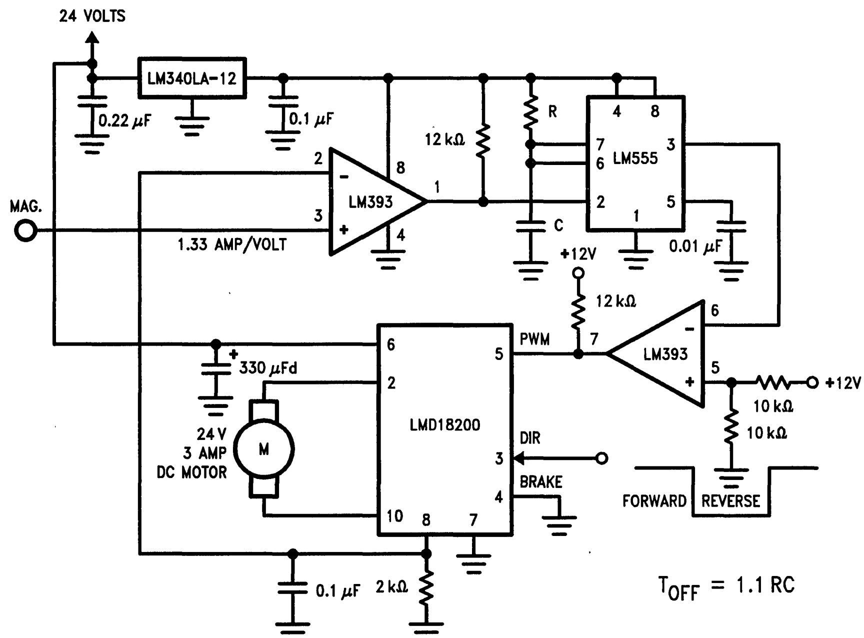
Switching Time Definitions



TL/H/10568–9

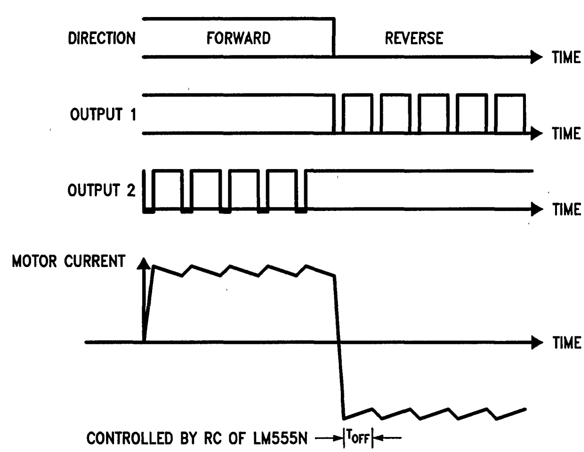
Typical Applications

Fixed Off-Time Control: This circuit controls the current through the motor by applying an average voltage equal to zero to the motor terminals for a fixed period of time, whenever the current through the motor exceeds the commanded current. This action causes the motor current to vary slightly about an externally controlled average level. The duration of the Off-period is adjusted by the resistor and capacitor combination of the LM555. In this circuit the Sign/Magnitude mode of operation is implemented (see Types of PWM Signals).



TL/H/10568–10

Switching Waveforms

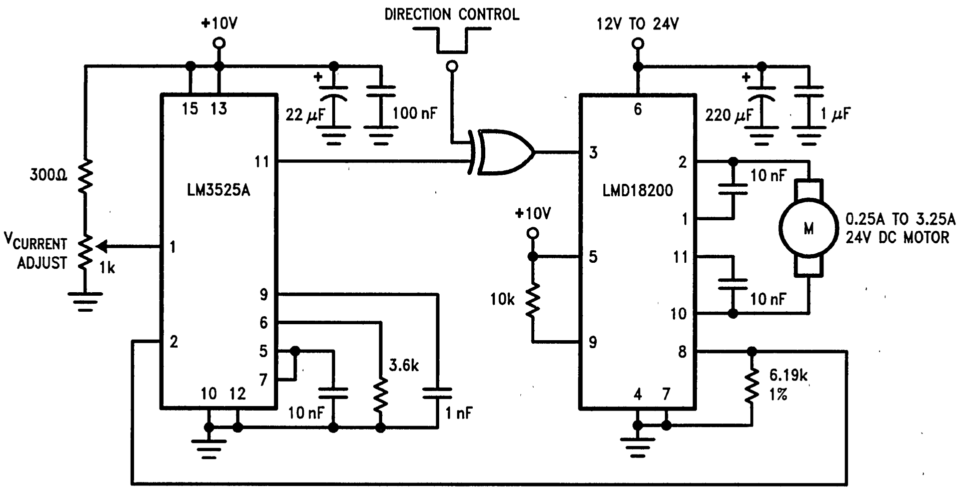


TL/H/10568–11

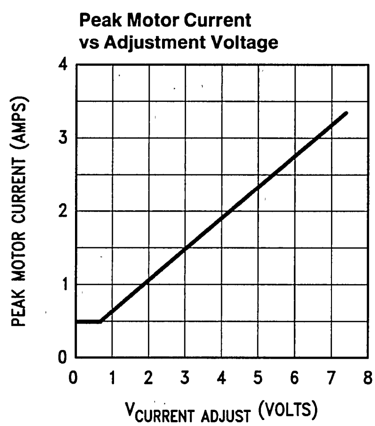
Typical Applications (Continued)

TORQUE REGULATION

Locked Anti-Phase Control of a brushed DC motor. Current sense output of the LMD18200 provides load sensing. The LM3525A is a general purpose PWM controller.



TL/H/10568-12

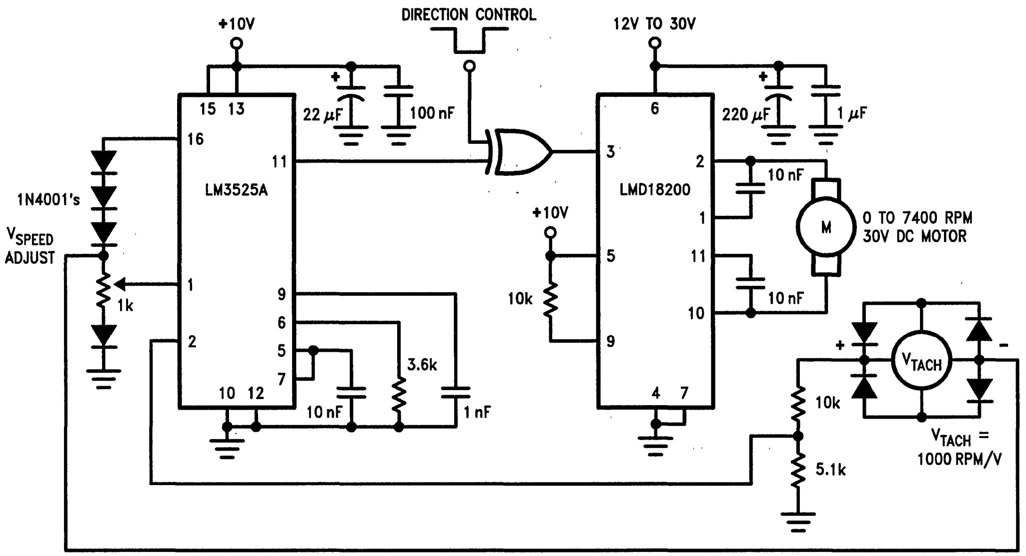


TL/H/10568-13

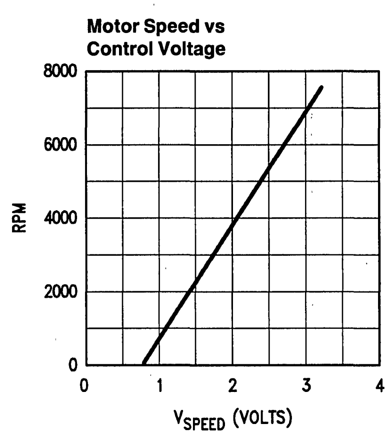
Typical Applications (Continued)

VELOCITY REGULATION

Utilizes tachometer output from the motor to sense motor speed for a locked anti-phase control loop.



TL/H/10568–14



TL/H/10568–15

National Semiconductor

LMD18201 3A, 55V H-Bridge

General Description

The LMD18201 is a 3A H-Bridge designed for motion control applications. The device is built using a multi-technology process which combines bipolar and CMOS control circuitry with DMOS power devices on the same monolithic structure. The H-Bridge configuration is ideal for driving DC and stepper motors. The LMD18201 accommodates peak output currents up to 6A. Current sensing can be achieved via a small sense resistor connected in series with the power ground lead. For current sensing without disturbing the path of current to the load, the LMD18200 is recommended.

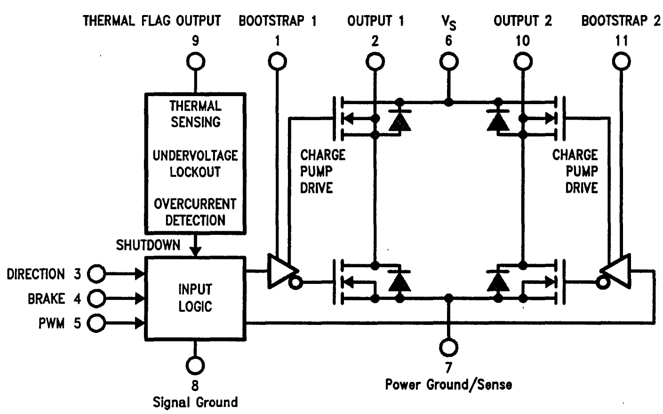
Features

- Delivers up to 3A continuous output
- Operates at supply voltages up to 55V
- Low $R_{DS(ON)}$ typically 0.33Ω per switch
- TTL and CMOS compatible inputs
- No "shoot-through" current
- Thermal warning flag output at 145°C
- Thermal shutdown (outputs off) at 170°C
- Internal clamp diodes
- Shorted load protection
- Internal charge pump with external bootstrap capability

Applications

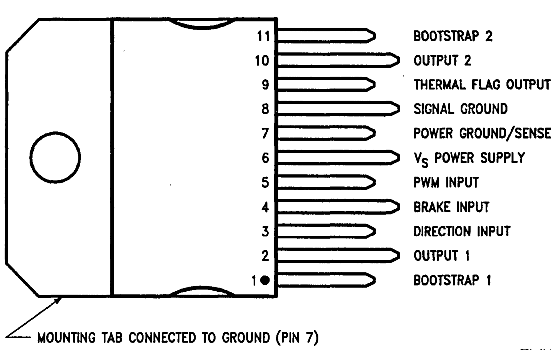
- DC and stepper motor drives
- Position and velocity servomechanisms
- Factory automation robots
- Numerically controlled machinery
- Computer printers and plotters

Functional Diagram



TL/H/10793-1

Connection Diagram and Ordering Information



Top View

TL/H/10793-2

Order Number LMD18201T
See NS Package Number TA11B

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Total Supply Voltage (V_S, Pin 6)	60V
Voltage at Pins 3, 4, 5 and 9	12V
Voltage at Bootstrap Pins (Pins 1 and 11)	V_{OUT} + 16V
Peak Output Current (200 ms)	6A
Continuous Output Current (Note 2)	3A
Power Dissipation (Note 3)	25W
Sense Voltage (Pin 7 to Pin 8)	+0.5V to −1.0V
Power Dissipation (T_A = 25°C, Free Air)	3W
Junction Temperature, $T_{J(max)}$	150°C
ESD Susceptibility (Note 4)	1500V
Storage Temperature, T_{STG}	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	300°C

Operating Ratings (Note 1)

Junction Temperature, T_J	−40°C to +125°C
V_S Supply Voltage	+12V to +55V

Electrical Characteristics

The following specifications apply for V_S = 42V, unless otherwise specified. **Boldface** limits apply over the entire operating temperature range, $-40°C \le T_J \le +125°C$, all other limits are for $T_A = T_J = 25°C$. (Note 5)

Symbol	Parameter	Conditions	Typ	Limit	Units
$R_{DS(ON)}$	Switch ON Resistance	Output Current = 3A (Note 6)	0.33	0.4/**0.6**	Ω (max)
$R_{DS(ON)}$	Switch ON Resistance	Output Current = 6A (Note 6)	0.33	0.4/**0.6**	Ω (max)
V_{CLAMP}	Clamp Diode Forward Drop	Clamp Current = 3A (Note 6)	1.2	1.5	V (max)
V_{IL}	Logic Low Input Voltage	Pins 3, 4, 5		**−0.1** **0.8**	V (min) V (max)
I_{IL}	Logic Low Input Current	V_{IN} = −0.1V, Pins = 3, 4, 5		**−10**	μA (max)
V_{IH}	Logic High Input Voltage	Pins 3, 4, 5		**2** **12**	V (min) V (max)
I_{IL}	Logic High Input Current	V_{IN} = 12V, Pins = 3, 4, 5		**10**	μA (max)
	Undervoltage Lockout	Outputs Turn OFF		9 11	V (min) V (max)
T_{JW}	Warning Flag Temperature	Pin 9 ≤ 0.8V, I_L = 2 mA	145		°C
$V_{F(ON)}$	Flag Output Saturation Voltage	$T_J = T_{JW}$, I_L = 2 mA	0.15		V
$I_{F(OFF)}$	Flag Output Leakage	V_F = 12V	0.2	10	μA (max)
T_{JSD}	Shutdown Temperature	Outputs Turn OFF	170		°C
I_S	Quiescent Supply Current	All Logic Inputs Low	13	25	mA (max)
$t_{D(ON)}$	Output Turn-On Delay Time	Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	300 300		ns ns
t_{ON}	Output Turn-On Switching Time	Bootstrap Capacitor = 10 nF Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	 100 80		 ns ns
$t_{D(OFF)}$	Output Turn-Off Delay Times	Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	200 200		ns ns
t_{OFF}	Output Turn-Off Switching Times	Bootstrap Capacitor = 10 nF Sourcing Outputs, I_{OUT} = 3A Sinking Outputs, I_{OUT} = 3A	 75 70		 ns ns
t_{PW}	Minimum Input Pulse Width	Pins 3, 4 and 5	1		μs
t_{CPR}	Charge Pump Rise Time	No Bootstrap Capacitor	20		μs

Electrical Characteristics (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions.

Note 2: See Application Information for details regarding current limiting.

Note 3: The maximum power dissipation must be derated at elevated temperatures and is a function of $T_{J(max)}$, θ_{JA}, and T_A. The maximum allowable power dissipation at any temperature is $P_{D(max)} = (T_{J(max)} - T_A)/\theta_{JA}$, or the number given in the Absolute Ratings, whichever is lower. The typical thermal resistance from junction to case (θ_{JC}) is 1.0°C/W and from junction to ambient (θ_{JA}) is 30°C/W. For guaranteed operation $T_{J(max)} = 125°C$.

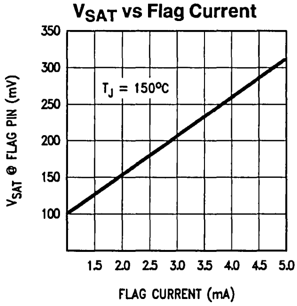
Note 4: Human-body model, 100 pF discharged through a 1.5 kΩ resistor. Except Bootstrap pins (pins 1 and 11) which are protected to 1000V of ESD.

Note 5: All limits are 100% production tested at 25°C. Temperature extreme limits are guaranteed via correlation using accepted SQC (Statistical Quality Control) methods. All limits are used to calculate AOQL, (Average Outgoing Quality Level).

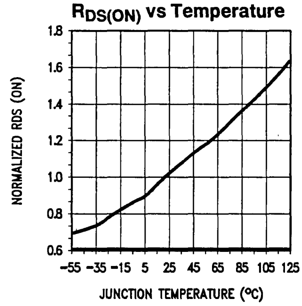
Note 6: Output currents are pulsed (t_W < 2 ms, Duty Cycle < 5%).

Typical Performance Characteristics

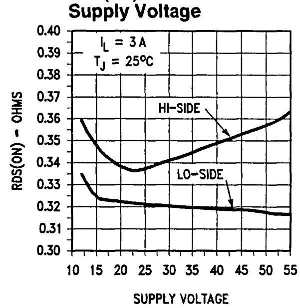
V_{SAT} vs Flag Current



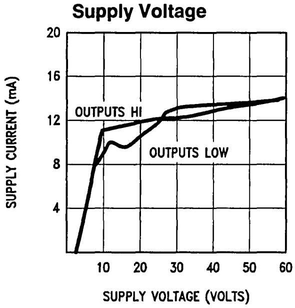
$R_{DS(ON)}$ vs Temperature



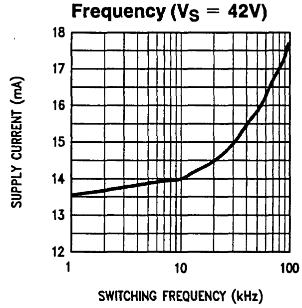
$R_{DS(ON)}$ vs Supply Voltage



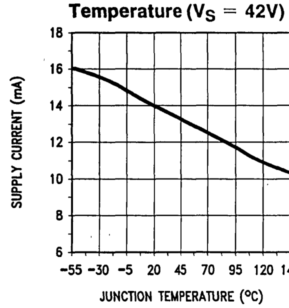
Supply Current vs Supply Voltage



Supply Current vs Frequency (V_S = 42V)

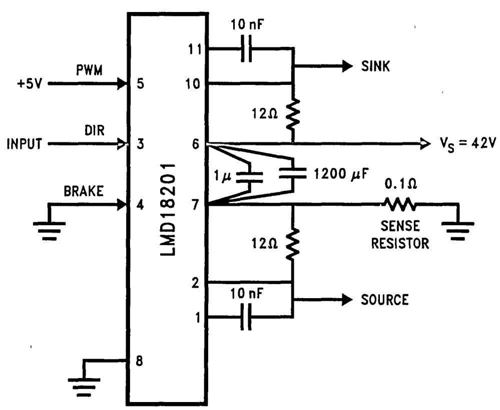


Supply Current vs Temperature (V_S = 42V)



TL/H/10793-3

Test Circuit



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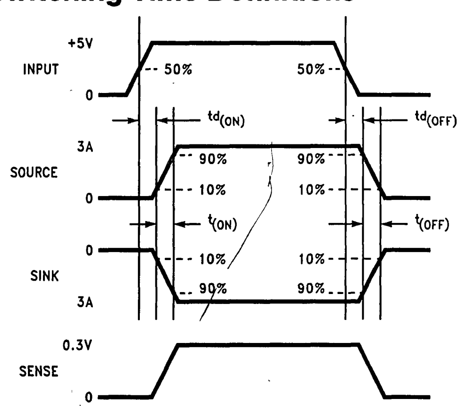
Switching Time Definitions



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4

Pinout Description (See Connection Diagram)

Pin 1, BOOTSTRAP 1 Input: Bootstrap capacitor pin for half H-Bridge number 1. The recommended capacitor (10 nF) is connected between pins 1 and 2.

Pin 2, OUTPUT 1: Half H-Bridge number 1 output.

Pin 3, DIRECTION Input: See Table I. This input controls the direction of current flow between OUTPUT 1 and OUTPUT 2 (pins 2 and 10) and, therefore, the direction of rotation of a motor load.

Pin 4, BRAKE Input: See Table I. This input is used to brake a motor by effectively shorting its terminals. When braking is desired, this input is taken to a logic high level and it is also necessary to apply logic high to PWM input, pin 5. The drivers that short the motor are determined by the logic level at the DIRECTION input (Pin 3): with Pin 3 logic high, both current sourcing output transistors are ON; with Pin 3 logic low, both current sinking output transistors are ON. All output transistors can be turned OFF by applying a logic high to Pin 4 and a logic low to PWM input Pin 5; in this case only a small bias current (approximately −1.5 mA) exists at each output pin.

Pin 5, PWM Input: See Table I. How this input (and DIRECTION input, Pin 3) is used is determined by the format of the PWM Signal.

Pin 6, V_S Power Supply

Pin 7, POWER GROUND/SENSE Connection: This pin is the ground return for the power DMOS transistors of the H-Bridge. The current through the H-Bridge can be sensed by adding a small, 0.1Ω, sense resistor from this pin to the power supply ground.

Pin 8, SIGNAL GROUND: This is the ground return for the internal logic circuitry used to control the PWM switching of the H-Bridge.

Pin 9, THERMAL FLAG Output: This pin provides the thermal warning flag output signal. Pin 9 becomes active-low at 145°C (junction temperature). However the chip will not shut itself down until 170°C is reached at the junction.

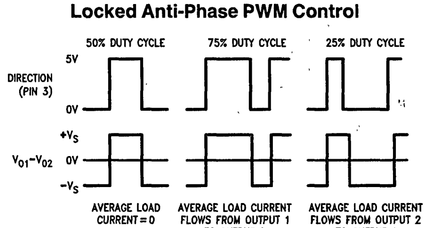
Pin 10, OUTPUT 2: Half H-Bridge number 2 output.

Pin 11, BOOTSTRAP 2 Input: Bootstrap capacitor pin for half H-Bridge number 2. The recommended capacitor (10 nF) is connected between pins 10 and 11.

TABLE I. Logic Truth Table

PWM	Dir	Brake	Active Output Drivers
H	H	L	Source 1, Sink 2
H	L	L	Sink 1, Source 2
L	X	L	Source 1, Source 2
H	H	H	Source 1, Source 2
H	L	H	Sink 1, Sink 2
L	X	H	NONE

Locked Anti-Phase PWM Control



TL/H/10793-4

Application Information

TYPES OF PWM SIGNALS

The LMD18201 readily interfaces with different forms of PWM signals. Use of the part with two of the more popular forms of PWM is described in the following paragraphs.

Simple, locked anti-phase PWM consists of a single, variable duty-cycle signal in which is encoded both direction and amplitude information. A 50% duty-cycle PWM signal represents zero drive, since the net value of voltage (integrated over one period) delivered to the load is zero. For the LMD18201, the PWM signal drives the direction input (pin 3) and the PWM input (pin 5) is tied to logic high.

Sign/magnitude PWM consists of separate direction (sign) and amplitude (magnitude) signals. The (absolute) magnitude signal is duty-cycle modulated, and the absence of a pulse signal (a continuous logic low level) represents zero drive. Current delivered to the load is proportional to pulse width. For the LMD18201, the DIRECTION input (pin 3) is driven by the sign signal and the PWM input (pin 5) is driven by the magnitude signal.

USING THE THERMAL WARNING FLAG

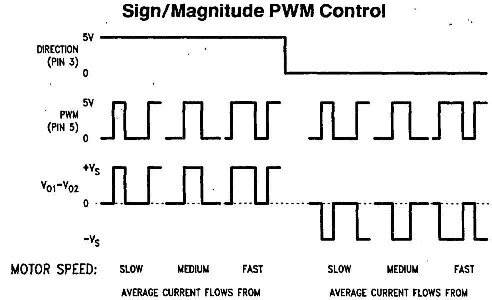
The THERMAL FLAG output (pin 9) is an open collector transistor. This permits a wired OR connection of thermal warning flag outputs from multiple LMD18201's, and allows the user to set the logic high level of the output signal swing to match system requirements. This output typically drives the interrupt input of a system controller. The interrupt service routine would then be designed to take appropriate steps, such as reducing load currents or initiating an orderly system shutdown. The maximum voltage compliance on the flag pin is 12V.

SUPPLY BYPASSING

During switching transitions the levels of fast current changes experienced may cause troublesome voltage transients across system stray inductances.

It is normally necessary to bypass the supply rail with a high quality capacitor(s) connected as close as possible to the V_S Power Supply (Pin 6) and POWER GROUND (Pin 7). A 1 μF high-frequency ceramic capacitor is recommended. Care should be taken to limit the transients on the supply pin below the Absolute Maximum Rating of the device. When operating the chip at supply voltages above 40V a voltage suppressor (transorb) such as P6KE62A is recommended from supply to ground. Typically the ceramic capacitor can be eliminated in the presence of the voltage suppressor. Note that when driving high load currents a greater amount of supply bypass capacitance (in general at least 100 μF per Amp of load current) is required to absorb the recirculating currents of the inductive loads.

Sign/Magnitude PWM Control



TL/H/10793-5

Application Information (Continued)

CURRENT LIMITING

Current limiting protection circuitry has been incorporated into the design of the LMD18201. With any power device it is important to consider the effects of the substantial surge currents through the device that may occur as a result of shorted loads. The protection circuitry monitors the current through the upper transistors and shuts off the power device as quickly as possible in the event of an overload condition (the threshold is set to approximately 10A). In a typical motor driving application the most common overload faults are caused by shorted motor windings and locked rotors. Under these conditions the inductance of the motor (as well as any series inductance in the V_{CC} supply line) serves to reduce the magnitude of a current surge to a safe level for the LMD18201. Once the device is shut down, the control circuitry will periodically try to turn the power device back on. This feature allows the immediate return to normal operation once the fault condition has been removed. While the fault remains however, the device will cycle in and out of thermal shutdown. This can create voltage transients on the V_{CC} supply line and therefore proper supply bypassing techniques are required.

The most severe condition for any power device is a direct, hard-wired ("screwdriver") long term short from an output to ground. This condition can generate a surge of current through the power device on the order of 15 Amps and require the die and package to dissipate up to 500W of power for the short time required for the protection circuitry to shut off the power device. This energy can be destructive, particularly at higher operating voltages (>30V) so some precautions are in order. Proper heat sink design is essential and it is normally necessary to heat sink the V_{CC} supply pin (pin 6) with 1 square inch of copper on the PC board.

INTERNAL CHARGE PUMP AND USE OF BOOTSTRAP CAPACITORS

To turn on the high-side (sourcing) DMOS power devices, the gate of each device must be driven approximately 8V more positive than the supply voltage. To achieve this an internal charge pump is used to provide the gate drive voltage. As shown in *Figure 1*, an internal capacitor is alternately switched to ground and charged to about 14V, then switched to V_S thereby providing a gate drive voltage greater than V_S. This switching action is controlled by a continuously running internal 300 kHz oscillator. The rise time of this drive voltage is typically 20 μs which is suitable for operating frequencies up to 1 kHz.

For higher switching frequencies, the LMD18201 provides for the use of external bootstrap capacitors. The bootstrap principle is in essence a second charge pump whereby a large value capacitor is used which has enough energy to quickly charge the parasitic gate input capacitance of the power device resulting in much faster rise times. The switching action is accomplished by the power switches themselves *(Figure 2)*. External 10 nF capacitors, connected from the outputs to the bootstrap pins of each high-side switch provide typically less than 100 ns rise times allowing switching frequencies up to 500 kHz.

INTERNAL PROTECTION DIODES

A major consideration when switching current through inductive loads is protection of the switching power devices from the large voltage transients that occur. Each of the four switches in the LMD18201 have a built-in protection diode to clamp transient voltages exceeding the positive supply or ground to a safe diode voltage drop across the switch.

The reverse recovery characteristics of these diodes, once the transient has subsided, is important. These diodes must come out of conduction quickly and the power switches must be able to conduct the additional reverse recovery current of the diodes. The reverse recovery time of the diodes protecting the sourcing power devices is typically only 70 ns with a reverse recovery current of 1A when tested with a full 3A of forward current through the diode. For the sinking devices the recovery time is typically 100 ns with 4A of reverse current under the same conditions.

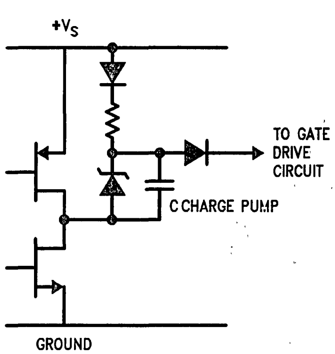


FIGURE 1. Internal Charge Pump Circuitry

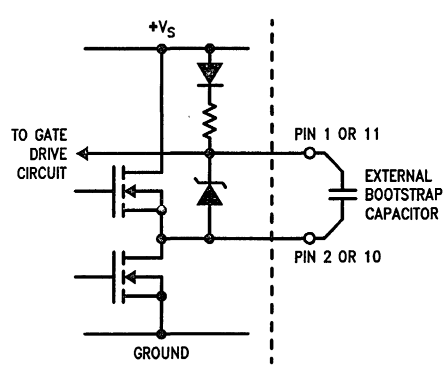


FIGURE 2. Bootstrap Circuitry

Typical Applications

BASIC MOTOR DRIVER

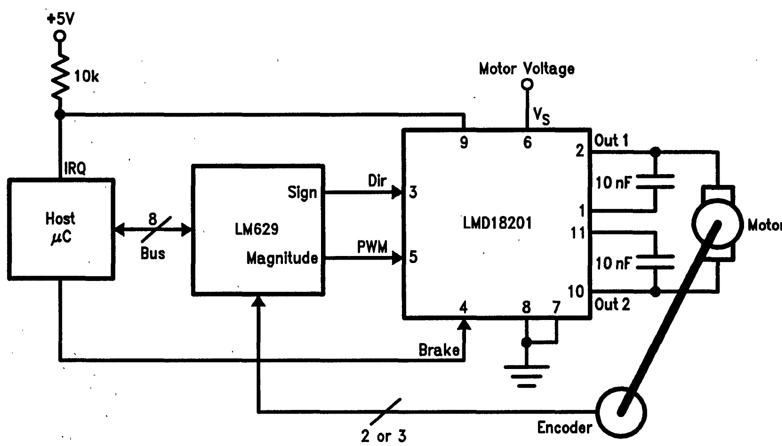
The LMD18201 can directly interface to any Sign/Magnitude PWM controller. The LM629 is a motion control processor that outputs a Sign/Magnitude PWM signal to coordinate either positional or velocity control of DC motors. The LMD18201 provides fully protected motor driver stage.

CURRENT SENSING

In many motor control applications it is desirable to sense and control the current through the motor. For these types of applications a companion product, the LMD18200, is also available. The LMD18200 is identical to the LMD18201 but has current sensing transistors that output a current directly proportional to the current conducted by the two upper DMOS power devices to a separate current sense pin. This technique does not require a low valued, power sense resistor and does not subtract from the available voltage drive to the motor.

To sense the bridge current through the LMD18201 requires the addition of a small sense resistor between the power ground/sense pin (Pin 7) and the actual circuit ground. This resistor should have a value of 0.1Ω or less to stay within the allowable voltage compliance of the sense pin, particularly at higher operating current levels. The voltage between power ground/sense (Pin 7) and the signal ground (Pin 8) must stay within the range of −1V to +0.5V. Internally there is approximately 25Ω between pins 7 and 8 and this resistance will slightly reduce the value of the external sense resistor. Approximately 70% of the quiescent supply current (10 mA) flows out of pin 7. This will cause a slight offset to the voltage across the sense resistor when the bridge is not conducting. During reverse recovery of the internal protection diodes the voltage compliance between pins 7 and 8 may be exceeded. The duration of these spikes however are only approximately 100 ns and do not have enough time or energy to disrupt the operation of the LMD18201.

Basic Motor Driver



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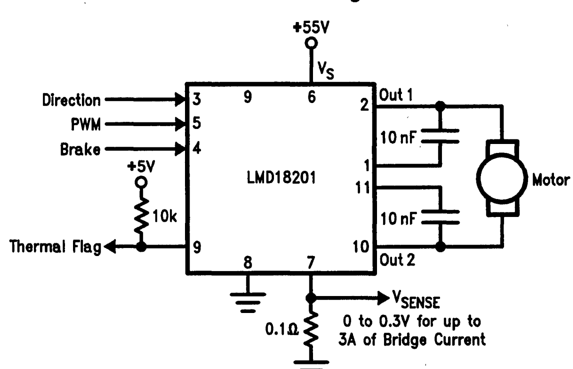
Current Sensing



TL/H/10793–11

National Semiconductor

LMD18245
3A, 55V DMOS Full-Bridge Motor Driver

General Description

The LMD18245 full-bridge power amplifier incorporates all the circuit blocks required to drive and control current in a brushed type DC motor or one phase of a bipolar stepper motor. The multi-technology process used to build the device combines bipolar and CMOS control and protection circuitry with DMOS power switches on the same monolithic structure. The LMD18245 controls the motor current via a fixed off-time chopper technique.

An all DMOS H-bridge power stage delivers continuous output currents up to 3A (6A peak) at supply voltages up to 55V. The DMOS power switches feature low $R_{DS(ON)}$ for high efficiency, and a diode intrinsic to the DMOS body structure eliminates the discrete diodes typically required to clamp bipolar power stages.

An innovative current sensing method eliminates the power loss associated with a sense resistor in series with the motor. A four-bit digital-to-analog converter (DAC) provides a digital path for controlling the motor current, and, by extension, simplifies implementation of full, half and microstep stepper motor drives. For higher resolution applications, an external DAC can be used.

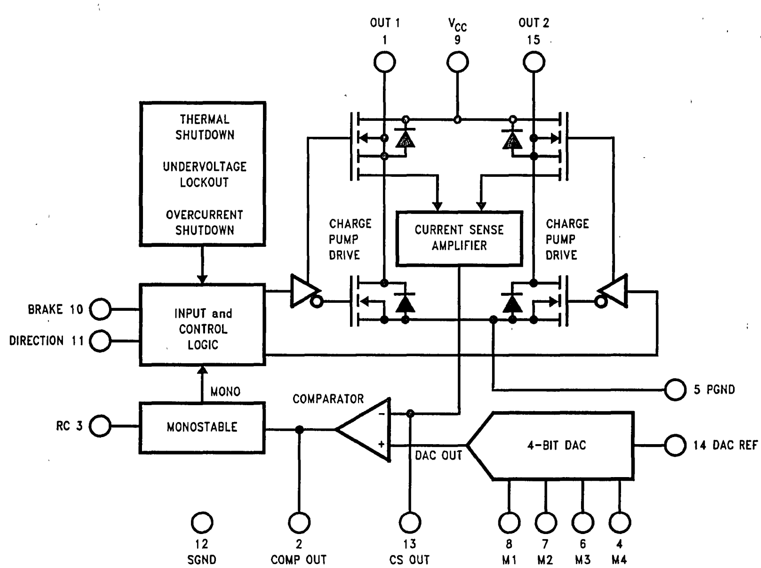
Features

- DMOS power stage rated at 55V and 3A continuous
- Low $R_{DS(ON)}$ of typically 0.3Ω per power switch
- Internal clamp diodes
- Low-loss current sensing method
- Digital or analog control of motor current
- TTL and CMOS compatible inputs
- Thermal shutdown (outputs off) at T_J = 155°C
- Overcurrent protection
- No shoot-through currents
- 15-lead TO-220 molded power package

Applications

- Full, half and microstep stepper motor drives
- Stepper motor and brushed DC motor servo drives
- Automated factory, medical and office equipment

Functional Block and Connection Diagram (15-Lead TO-220 Molded Power Package (T))



TL/H/11878–1

Order Number LMD18245T
See NS Package Number TA15A

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

DC Voltage at:	
OUT 1, V_{CC}, and OUT 2	+60V
COMP OUT, RC, M4, M3, M2, M1, BRAKE, DIRECTION, CS OUT, and DAC REF	+12V
DC Voltage PGND to SGND	±400mV
Continuous Load Current	3A
Peak Load Current (Note 2)	6A
Junction Temperature ($T_{J(max)}$)	+150°C
Power Dissipation (Note 3):	
TO-220 (T_A = 25°C, Infinite Heatsink)	25W
TO-220 (T_A = 25°C, Free Air)	3.5W
ESD Susceptibility (Note 4)	1500V
Storage Temperature Range (T_S)	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

Operating Conditions (Note 1)

Temperature Range (T_J) (Note 3)	−40°C to +125°C
Supply Voltage Range (V_{CC})	+12V to +55V
CS OUT Voltage Range	0V to +5V
DAC REF Voltage Range	0V to +5V
MONOSTABLE Pulse Range	10 μs to 100 ms

Electrical Characteristics

The following specifications apply for V_{CC} = +42V, unless otherwise stated. **Boldface limits apply over the operating temperature range, −40°C ≤ T_J ≤ +125°C.** All other limits apply for T_A = T_J = 25°C. (Note 2)

Symbol	Parameter	Conditions	Typical (Note 5)	Limit (Note 5)	Units (Limits)
I_{CC}	Quiescent Supply Current	DAC REF = 0V, V_{CC} = +20V	8		mA
				15	mA (max)
POWER OUTPUT STAGE					
$R_{DS(ON)}$	Switch ON Resistance	I_{LOAD} = 3A	0.3	0.4	Ω (max)
				0.6	Ω (max)
		I_{LOAD} = 6A	0.3	0.4	Ω (max)
				0.6	Ω (max)
V_{DIODE}	Body Diode Forward Voltage	I_{DIODE} = 3A	1.0		V
				1.5	V(max)
T_{rr}	Diode Reverse Recovery Time	I_{DIODE} = 1A	80		ns
Q_{rr}	Diode Reverse Recovery Charge	I_{DIODE} = 1A	40		nC
$t_{D(ON)}$	Output Turn ON Delay Time				
	Sourcing Outputs	I_{LOAD} = 3A	5		μs
	Sinking Outputs	I_{LOAD} = 3A	900		ns
$t_{D(OFF)}$	Output Turn OFF Delay Time				
	Sourcing Outputs	I_{LOAD} = 3A	600		ns
	Sinking Outputs	I_{LOAD} = 3A	400		ns
t_{ON}	Output Turn ON Switching Time				
	Sourcing Outputs	I_{LOAD} = 3A	40		μs
	Sinking Outputs	I_{LOAD} = 3A	1		μs
t_{OFF}	Output Turn OFF Switching Time				
	Sourcing Outputs	I_{LOAD} = 3A	200		ns
	Sinking Outputs	I_{LOAD} = 3A	80		ns
t_{pw}	Minimum Input Pulse Width	Pins 10 and 11	2		μs
t_{DB}	Minimum Dead Band	(Note 6)	40		ns

Electrical Characteristics The following specifications apply for V_{CC} = +42V, unless otherwise stated. **Boldface limits apply over the operating temperature range, −40°C ≤ T_J ≤ +125°C.** All other limits apply for T_A = T_J = 25°C. (Note 2) (Continued)

Symbol	Parameter	Conditions	Typical (Note 5)	Limit (Note 5)	Units (Limits)
CURRENT SENSE AMPLIFIER					
	Current Sense Output	I_{LOAD} = 1A (Note 7)	250	200 **175** 300 **325**	μA (min) μA (min) μA (max) μA (max)
	Current Sense Linearity Error	0.5A ≤ I_{LOAD} ≤ 3A (Note 7)	±6	 ±9	% %(max)
	Current Sense Offset	I_{LOAD} = 0A	5	 20	μA μA (max)
DIGITAL-TO-ANALOG CONVERTER (DAC)					
	Resolution			**4**	Bits (min)
	Monotonicity			**4**	Bits (min)
	Total Unadjusted Error		0.125	0.25 **0.5**	LSB (max) LSB (max)
	Propagation Delay		50		ns
I_{REF}	DAC REF Input Current	DAC REF = +5V	−0.5	 **±10**	μA μA (max)
COMPARATOR AND MONOSTABLE					
	Comparator High Output Level		6.27		V
	Comparator Low Output Level		88		mV
	Comparator Output Current Source Sink		 0.2 3.2		 mA mA
t_{DELAY}	Monostable Turn OFF Delay	(Note 8)	1.2	 2.0	μs μs (max)
PROTECTION AND PACKAGE THERMAL RESISTANCES					
	Undervoltage Lockout, V_{CC}			5 8	V (min) V (max)
T_{JSD}	Shutdown Temperature, T_J		155		°C
 θ_{JC} θ_{JA}	Package Thermal Resistances Junction-to-Case, TO-220 Junction-to-Ambient, TO-220		 1.5 35		 °C/W °C/W
LOGIC INPUTS					
V_{IL}	Low Level Input Voltage			**−0.1** **0.8**	V (min) V (max)
V_{IH}	High Level Input Voltage			**2** **12**	V (min) V (max)
I_{IN}	Input Current	V_{IN} = 0V or 12V		**±10**	μA (max)

4

Electrical Characteristics

The following specifications apply for $V_{CC} = +42V$, unless otherwise stated. **Boldface limits apply over the operating temperature range, $-40°C \leq T_J \leq +125°C$.** All other limits apply for $T_A = T_J = 25°C$. (Note 2) (Continued)

Note 1: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device outside the rated Operating Conditions.

Note 2: Unless otherwise stated, load currents are pulses with widths less than 2 ms and duty cycles less than 5%.

Note 3: The maximum allowable power dissipation at any ambient temperature is $P_{Max} = (125 - T_A)/\theta_{JA}$, where 125°C is the maximum junction temperature for operation, T_A is the ambient temperature in °C, and θ_{JA} is the junction-to-ambient thermal resistance in °C/W. Exceeding P_{max} voids the Electrical Specifications by forcing T_J above 125°C. If the junction temperature exceeds 155°C, internal circuitry disables the power bridge. When a heatsink is used, θ_{JA} is the sum of the junction-to-case thermal resistance of the package, θ_{JC}, and the case-to-ambient thermal resistance of the heatsink.

Note 4: ESD rating is based on the human body model of 100 pF discharged through a 1.5 kΩ resistor. M1, M2, M3 and M4, pins 8, 7, 6 and 4 are protected to 800V.

Note 5: All limits are 100% production tested at 25°C. Temperature extreme limits are guaranteed via correlation using accepted SQC (Statistical Quality Control) methods. All limits are used to calculate AOQL (Average Outgoing Quality Level). Typicals are at $T_J = 25°C$ and represent the most likely parametric norm.

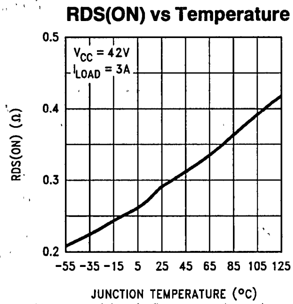
Note 6: Asymmetric turn OFF and ON delay times and switching times ensure a switch turns OFF before the other switch in the same half H-bridge begins to turn ON (preventing momentary short circuits between the power supply and ground). The transitional period during which both switches are OFF is commonly referred to as the dead band.

Note 7: (I_{LOAD}, I_{SENSE}) data points are taken for load currents of 0.5A, 1A, 2A and 3A. The current sense gain is specified as I_{SENSE}/I_{LOAD} for the 1A data point. The current sense linearity is specified as the slope of the line between the 0.5A and 1A data points minus the slope of the line between the 2A and 3A data points all divided by the slope of the line between the 0.5A and 1A data points.

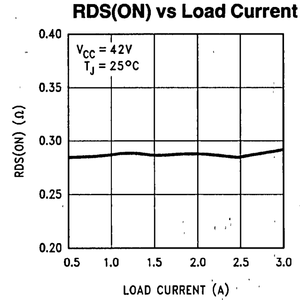
Note 8: Turn OFF delay, t_{DELAY}, is defined as the time from the voltage at the output of the current sense amplifier reaching the DAC output voltage to the lower DMOS switch beginning to turn OFF. With $V_{CC} = 32V$, DIRECTION high, and 200Ω connected between OUT1 and V_{CC}, the voltage at RC is increased from 0V to 5V at 1.2V/µs, and t_{DELAY} is measured as the time from the voltage at RC reaching 2V to the time the voltage at OUT 1 reaches 3V.

Typical Performance Characteristics

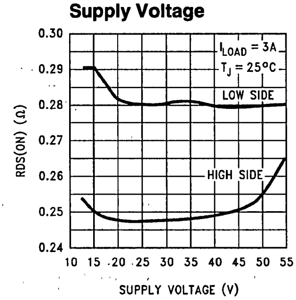
RDS(ON) vs Temperature



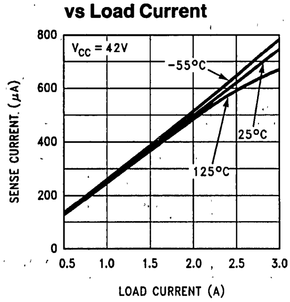
RDS(ON) vs Load Current



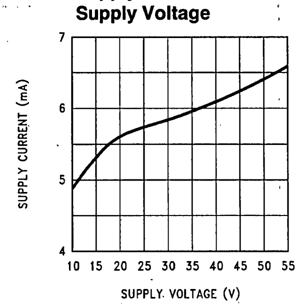
RDS(ON) vs Supply Voltage



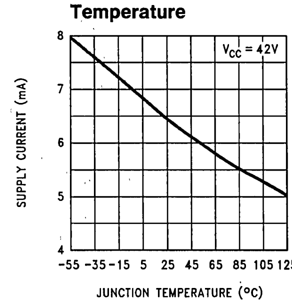
Current Sense Output vs Load Current



Supply Current vs Supply Voltage



Supply Current vs Temperature



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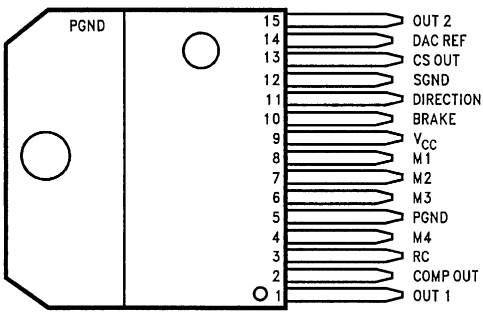
Connection Diagram



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Top View

15-Lead TO-220 Molded Power Package
Order Number LMD18245T
See NS Package Number TA15A

Pinout Descriptions (See Functional Block and Connection Diagrams)

Pin 1, OUT 1: Output node of the first half H-bridge.

Pin 2, COMP OUT: Output of the comparator. If the voltage at CS OUT exceeds that provided by the DAC, the comparator triggers the monostable.

Pin 3, RC: Monostable timing node. A parallel resistor-capacitor network connected between this node and ground sets the monostable timing pulse at about 1.1 RC seconds.

Pin 5, PGND: Ground return node of the power bridge. Bond wires (internal) connect PGND to the tab of the TO-220 package.

Pins 4 and 6 through 8, M4 through M1: Digital inputs of the DAC. These inputs make up a four-bit binary number with M4 as the most significant bit or MSB. The DAC provides an analog voltage directly proportional to the binary number applied at M4 through M1.

Pin 9, V_{CC}: Power supply node.

Pin 10, BRAKE: Brake logic input. Pulling the BRAKE input logic-high activates both sourcing switches of the power bridge—effectively shorting the load. See Table I. Shorting the load in this manner forces the load current to recirculate and decay to zero.

Pin 11, DIRECTION: Direction logic input. The logic level at this input dictates the direction of current flow in the load. See Table I.

Pin 12, SGND: Ground return node of all signal level circuits.

Pin 13, CS OUT: Output of the current sense amplifier. The current sense amplifier sources 250 μA (typical) per ampere of total forward current conducted by the upper two switches of the power bridge.

Pin 14, DAC REF: Voltage reference input of the DAC. The DAC provides an analog voltage equal to $V_{DAC\ REF} \times D/16$, where D is the decimal equivalent (0–15) of the binary number applied at M4 through M1.

Pin 15, OUT 2: Output node of the second half H-bridge.

TABLE I. Switch Control Logic Truth Table

BRAKE	DIRECTION	MONO	Active Switches
H	X	X	Source 1, Source 2
L	H	L	Source 2
L	H	H	Source 2, Sink 1
L	L	L	Source 1
L	L	H	Source 1, Sink 2

X = don't care

MONO is the output of the monostable.

Functional Descriptions

TYPICAL OPERATION OF A CHOPPER AMPLIFIER

Chopper amplifiers employ feedback driven switching of a power bridge to control and limit current in the winding of a motor *(Figure 1).* The bridge consists of four solid state power switches and four diodes connected in an H configuration. Control circuitry (not shown) monitors the winding current and compares it to a threshold. While the winding current remains less than the threshold, a source switch and a sink switch in opposite halves of the bridge force the supply voltage across the winding, and the winding current increases rapidly towards V_{CC}/R (*Figures 1a* and *1d*). As the winding current surpasses the threshold, the control circuitry turns OFF the sink switch for a fixed period or *off-time.* During the off-time, the source switch and the opposite upper diode short the winding, and the winding current recirculates and decays slowly towards zero (*Figures 1b* and *1e*). At the end of the off-time, the control circuitry turns back ON the sink switch, and the winding current again increases rapidly towards V_{CC}/R (*Figures 1a* and *1d* again). The above sequence repeats to provide a current chopping action that limits the winding current to the threshold *(Figure 1g).* Chopping only occurs if the winding current reaches the threshold. During a change in the direction of the winding current, the diodes provide a decay path for the initial winding current (*Figures 1c* and *1f*). Since the bridge shorts the winding for a fixed period, this type of chopper amplifier is commonly referred to as a *fixed off-time chopper.*

Functional Descriptions (Continued)

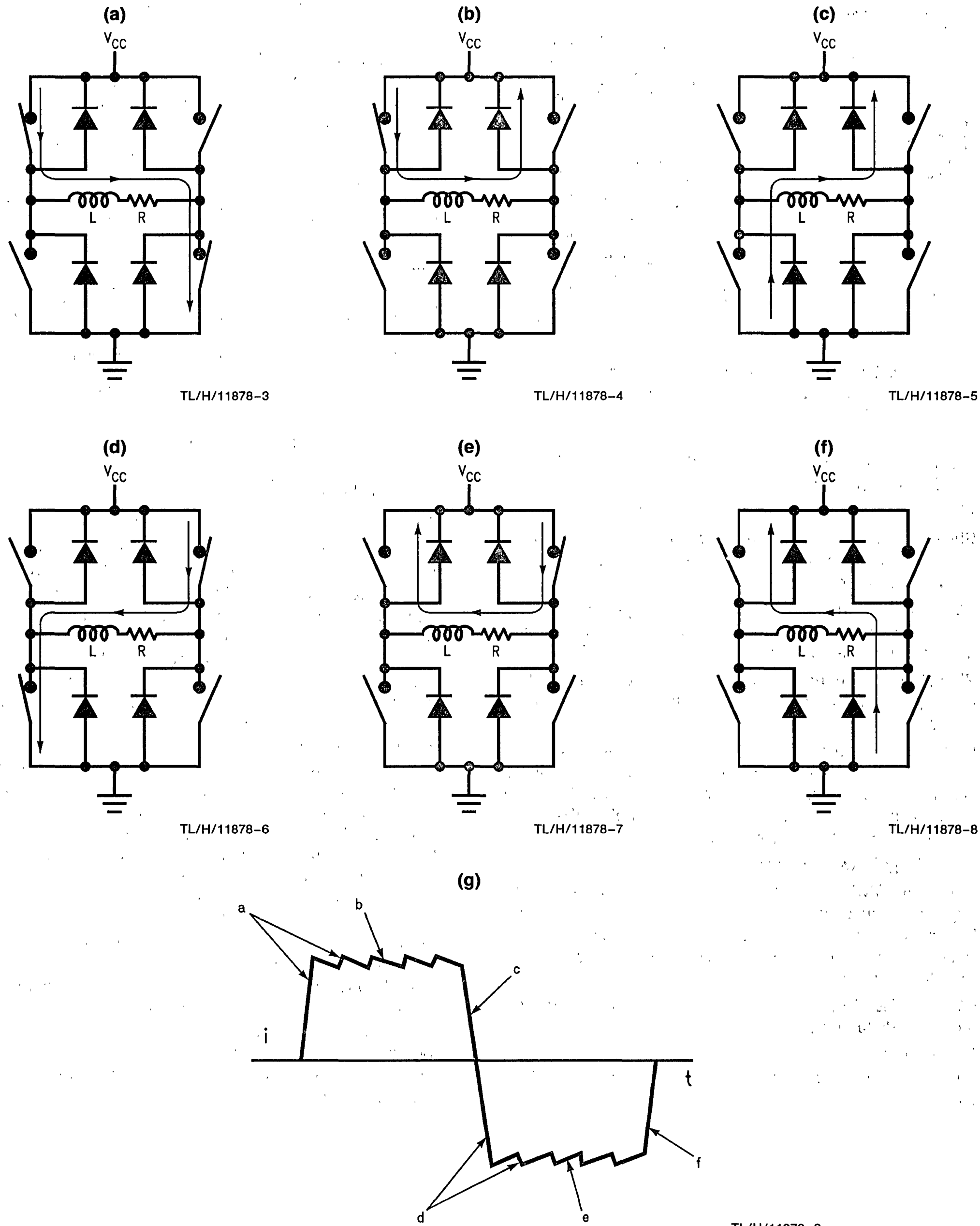

FIGURE 1. Chopper Amplifier Chopping States: Full V_{CC} Applied Across the Winding (a) and (d), Shorted Winding (b) and (e), Winding Current Decays During a Change in the Direction of the Winding Current (c) and (f), and the Chopped Winding Current (g)

Functional Descriptions (Continued)

THE LMD18245 CHOPPER AMPLIFIER

The LMD18245 incorporates all the circuit blocks needed to implement a fixed off-time chopper amplifier. These blocks include: an all DMOS, full H-bridge with clamp diodes, an amplifier for sensing the load current, a comparator, a monostable, and a DAC for digital control of the chopping threshold. Also incorporated are logic, level shifting and drive blocks for digital control of the direction of the load current and braking.

THE H-BRIDGE

The power stage consists of four DMOS power switches and associated body diodes connected in an H-bridge configuration *(Figure 2).* Turning ON a source switch and a sink switch in opposite halves of the bridge forces the full supply voltage less the switch drops across the motor winding. While the bridge remains in this state, the winding current increases exponentially towards a limit dictated by the supply voltage, the switch drops, and the winding resistance. Subsequently turning OFF the sink switch causes a voltage transient that forward biases the body diode of the other source switch. The diode clamps the transient at one diode drop above the supply voltage and provides an alternative current path. While the bridge remains in this state, it essentially shorts the winding and the winding current recirculates and decays exponentially towards zero. During a change in the direction of the winding current, both the switches and the body diodes provide a decay path for the initial winding current *(Figure 3).*

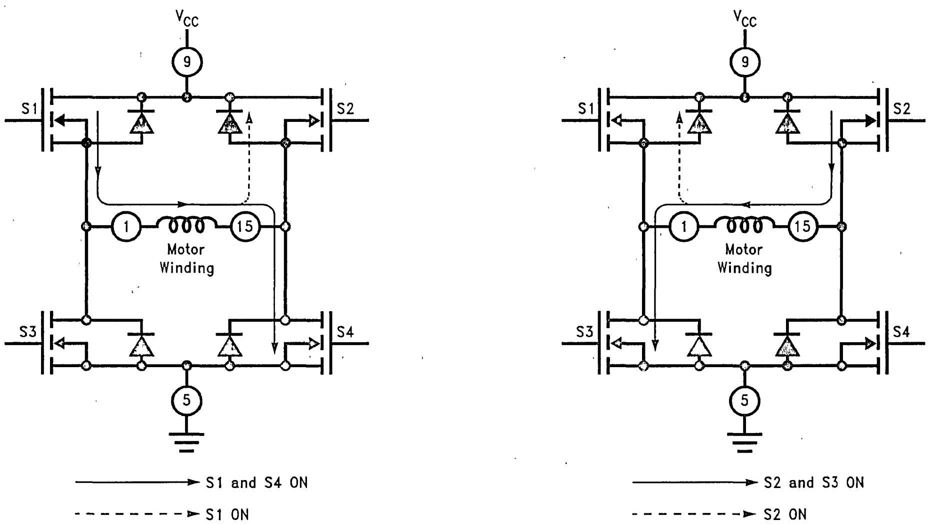

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FIGURE 2. The DMOS H-Bridge

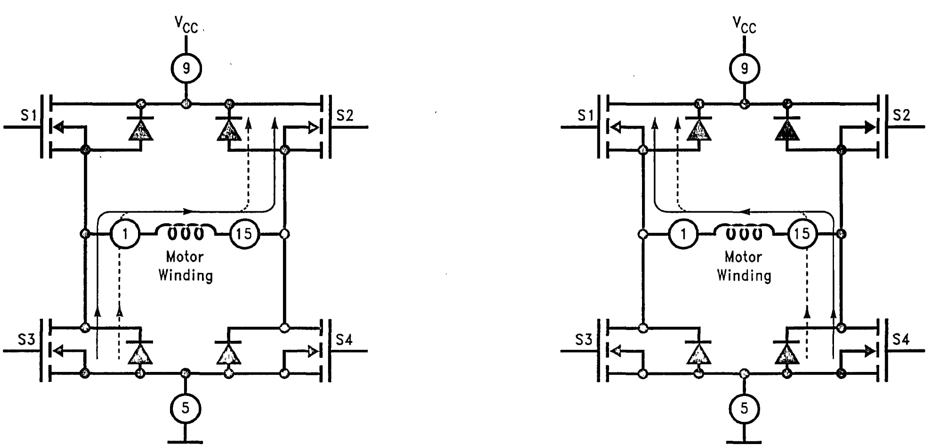

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FIGURE 3. Decay Paths for Initial Winding Current During a Change in the Direction of the Winding Current

Functional Descriptions (Continued)

THE CURRENT SENSE AMPLIFIER

Many transistor cells in parallel make up the DMOS power switches. The current sense amplifier *(Figure 4)* uses a small fraction of the cells of both upper switches to provide a unique, low-loss means for sensing the load current. In practice, each upper switch functions as a 1x sense device in parallel with a 4000x power device. The current sense amplifier forces the voltage at the source of the sense device to equal that at the source of the power device; thus, the devices share the total drain current in proportion to the 1:4000 cell ratio. Only the current flowing from drain to source, the forward current, registers at the output of the current sense amplifier. The current sense amplifier, therefore, sources 250 μA per ampere of total forward current conducted by the upper two switches of the power bridge.

The sense current develops a potential across R_S that is proportional to the load current; for example, per ampere of load current, the sense current develops one volt across a 4 kΩ resistor (the product of 250 μA per ampere and 4 kΩ). Since chopping of the load current occurs as the voltage at CS OUT surpasses the threshold (the DAC output voltage), R_S sets the gain of the chopper amplifier; for example, a 2 kΩ resistor sets the gain at two amperes of load current per volt of the threshold (the reciprocal of the product of 250 μA per ampere and 2 kΩ). A quarter watt resistor suffices. A low value capacitor connected in parallel with R_S filters the effects of switching noise from the current sense signal.

While the specified maximum DC voltage compliance at CS OUT is 12V, the specified operating voltage range at CS OUT is 0V to 5V.

THE DIGITAL-TO-ANALOG CONVERTER (DAC)

The DAC sets the threshold voltage for chopping at $V_{DAC\ REF} \times D/16$, where D is the decimal equivalent (0–15) of the binary number applied at M4 through M1, the digital inputs of the DAC. M4 is the MSB or most significant bit. For applications that require higher resolution, an external DAC can drive the DAC REF input. While the specified maximum DC voltage compliance at DAC REF is 12V, the specified operating voltage range at DAC REF is 0V to 5V.

THE COMPARATOR, MONOSTABLE AND WINDING CURRENT THRESHOLD FOR CHOPPING

As the voltage at CS OUT surpasses that at the output of the DAC, the comparator triggers the monostable, and the monostable, once triggered, provides a timing pulse to the control logic. During the timing pulse, the power bridge shorts the motor winding, causing current in the winding to recirculate and decay slowly towards zero (*Figures 1b* and *1e* again). A parallel resistor-capacitor network connected between RC (pin #3) and ground sets the timing pulse or off-time at about 1.1 RC seconds.

Chopping of the winding current occurs as the voltage at CS OUT exceeds that at the output of the DAC; so chopping occurs at a winding current threshold of about

$$(V_{DAC\ REF} \times D/16) \div ((250 \times 10^{-6}) \times R_S)) \text{ amperes.}$$

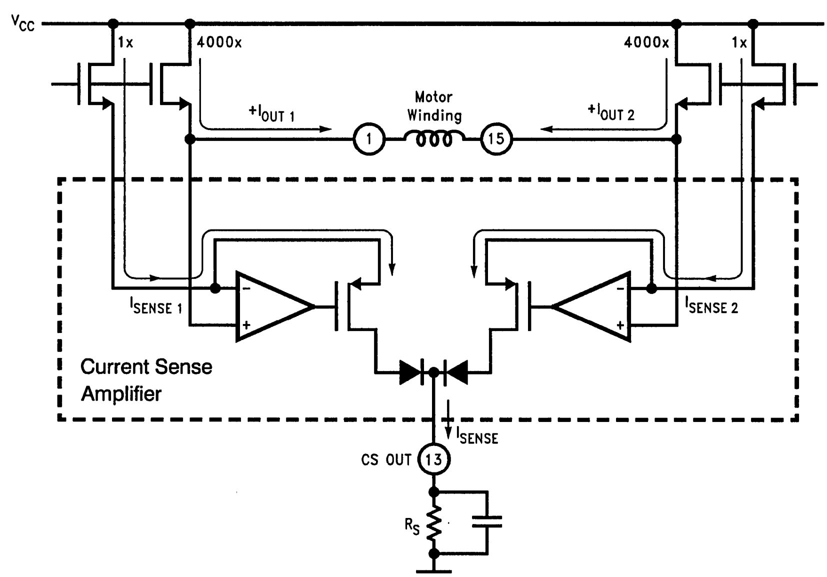

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FIGURE 4. The Source Switches of the Power Bridge and the Current Sense Amplifier

Applications Information

POWER SUPPLY BYPASSING

Step changes in current drawn from the power supply occur repeatedly during normal operation and may cause large voltage spikes across inductance in the power supply line. Care must be taken to limit voltage spikes at V_{CC} to less than the 60V Absolute Maximum Rating. At a change in the direction of the load current, the initial load current tends to raise the voltage at the power supply rail (*Figure 3* again). Current transients caused by the reverse recovery of the clamp diodes tend to pull down the voltage at the power supply rail.

Bypassing the power supply line at V_{CC} is required to protect the device and minimize the adverse effects of normal operation on the power supply rail. Using both a 1 μF high frequency ceramic capacitor and a large-value aluminum electrolytic capacitor is highly recommended. A value of 100 μF per ampere of load current usually suffices for the aluminum electrolytic capacitor. Both capacitors should have short leads and be located within one half inch of V_{CC}.

OVERCURRENT PROTECTION

If the forward current in either source switch exceeds a 12A threshold, internal circuitry disables both source switches, forcing a rapid decay of the fault current *(Figure 5)*. Approximately 3 μs after the fault current reaches zero, the device restarts. Automatic restart allows an immediate return to normal operation once the fault condition has been removed. If the fault persists, the device will begin cycling into and out of thermal shutdown. Switching large fault currents may cause potentially destructive voltage spikes across inductance in the power supply line; therefore, the power supply line must be properly bypassed at V_{CC} for the motor driver to survive an extended overcurrent fault.

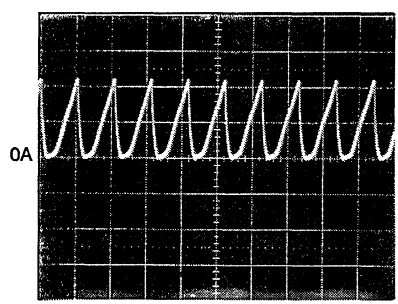
In the case of a locked rotor, the inductance of the winding tends to limit the rate of change of the fault current to a value easily handled by the protection circuitry. In the case of a low inductance short from either output to ground or between outputs, the fault current could surge past the 12A shutdown threshold, forcing the device to dissipate a substantial amount of power for the brief period required to disable the source switches. Because the fault power must be dissipated by only one source switch, a short from output to ground represents the worst case fault. Any overcurrent fault is potentially destructive, especially while operating with high supply voltages ($\geq$30V), so precautions are in order. Sinking V_{CC} for heat with 1 square inch of 1 ounce copper on the printed circuit board is highly recommended. The sink switches are not internally protected against shorts to V_{CC}.

THERMAL SHUTDOWN

Internal circuitry senses the junction temperature near the power bridge and disables the bridge if the junction temperature exceeds about 155°C. When the junction temperature cools past the shutdown threshold (lowered by a slight hysteresis), the device automatically restarts.

UNDERVOLTAGE LOCKOUT

Internal circuitry disables the power bridge if the power supply voltage drops below a rough threshold between 8V and 5V. Should the power supply voltage then exceed the threshold, the device automatically restarts.



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Trace: Fault Current at 5A/div
Horizontal: 20 μs/div

FIGURE 5. Fault Current with V_{CC} = 30V, OUT 1 Shorted to OUT 2, and CS OUT Grounded

The Typical Application

Figure 6 shows the typical application, the power stage of a chopper drive for bipolar stepper motors. The 20 kΩ resistor and 2.2 nF capacitor connected between RC and ground set the off-time at about 48 μs, and the 20 kΩ resistor connected between CS OUT and ground sets the gain at about 200 mA per volt of the threshold for chopping. Digital signals control the thresholds for chopping, the directions of the winding currents, and, by extension, the drive type (full step, half step, etc.). A μprocessor or μcontroller usually provides the digital control signals.

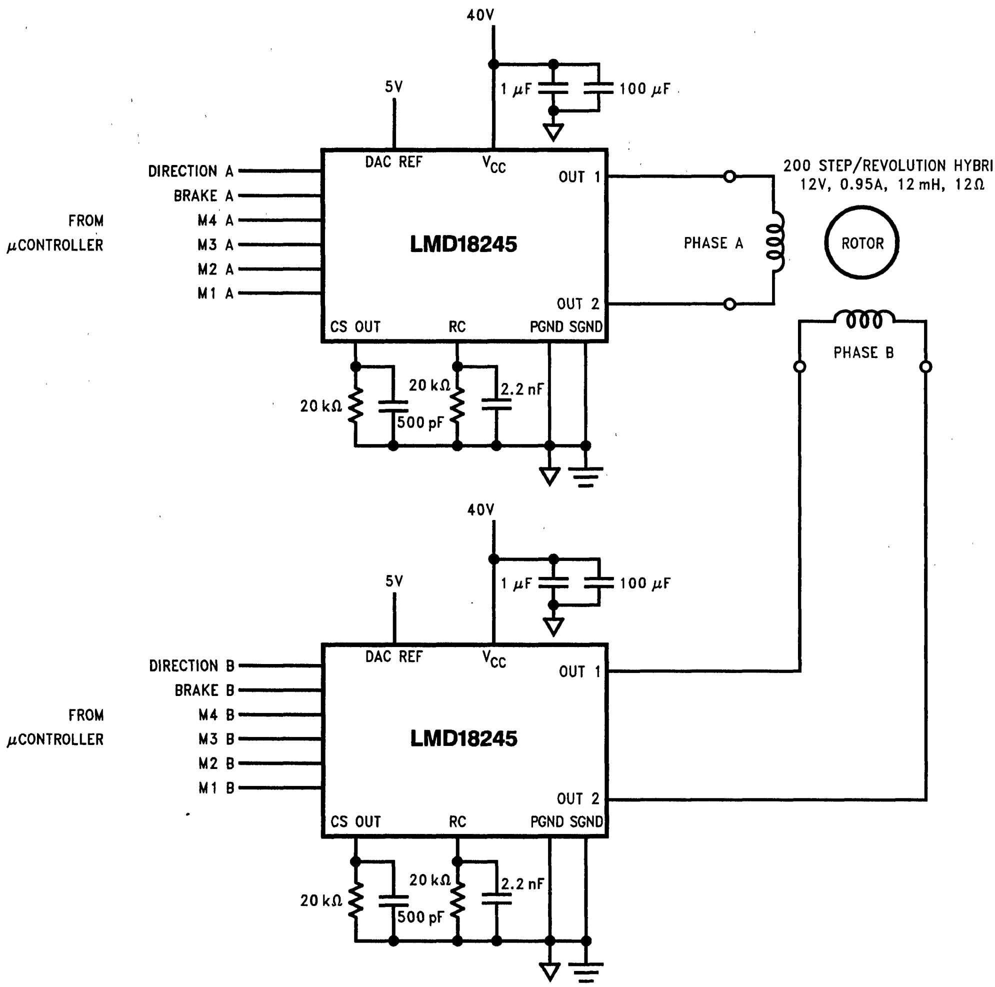

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FIGURE 6. Typical Application Circuit for Driving Bipolar Stepper Motors

The Typical Application (Continued)

ONE-PHASE-ON FULL STEP DRIVE (WAVE DRIVE)

To make the motor take full steps, windings A and B can be energized in the sequence

$$A \rightarrow B \rightarrow A^* \rightarrow B^* \rightarrow A \rightarrow \ldots,$$

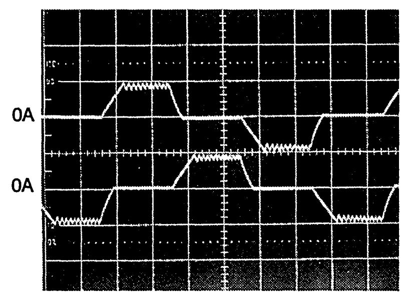
where A represents winding A energized with current in one direction and A* represents winding A energized with current in the opposite direction. The motor takes one full step each time one winding is de-energized and the other is energized. To make the motor step in the opposite direction, the order of the above sequence must be reversed. *Figure 7* shows the winding currents and digital control signals for a wave drive application of the typical application circuit.

TWO-PHASE-ON FULL STEP DRIVE

To make the motor take full steps, windings A and B can also be energized in the sequence

$$AB \rightarrow A^*B \rightarrow A^*B^* \rightarrow AB^* \rightarrow AB \rightarrow \ldots,$$

and because both windings are energized at all times, this sequence produces more torque than that produced with wave drive. The motor takes one full step at each change of direction of either winding current. *Figure 8* shows the winding currents and digital control signals for this application of the typical application circuit, and *Figure 9* shows, for a single phase, the winding current and voltage at the output of the associated current sense amplifier.



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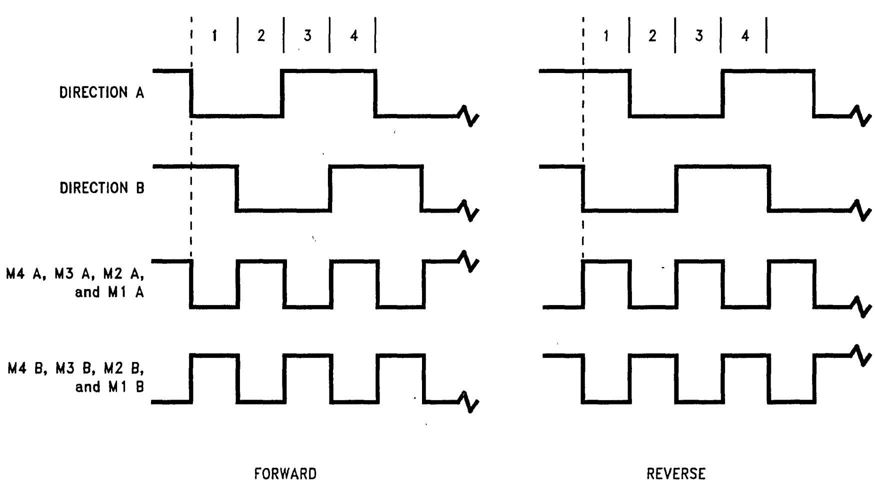
Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase B Winding Current at 1A/div
Horizontal: 1 ms/div
*500 steps/second



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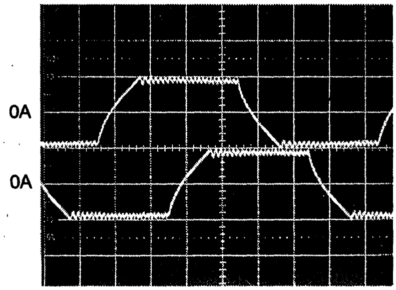
BRAKE A = BRAKE B = 0

FIGURE 7. Winding Currents and Digital Control Signals for One-Phase-On Drive (Wave Drive)

The Typical Application (Continued)



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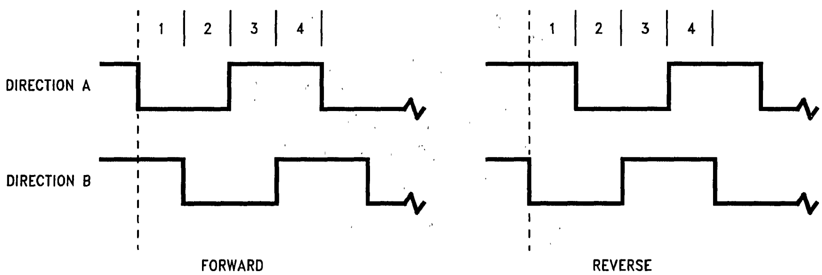
Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase B Winding Current at 1A/div
Horizontal: 1 ms/div
*500 steps/second



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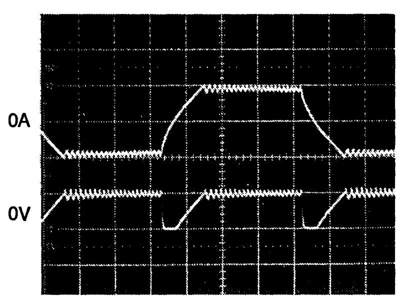
M4 A through M1 A = M4 B through M1 B = 1
BRAKE A = BRAKE B = 0

FIGURE 8. Winding Currents and Digital Control Signals for Two-Phase-On Drive



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Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase A Sense Voltage at 5V/div
Horizontal: 1 ms/div
*500 steps/second

FIGURE 9. Winding Current and Voltage at the Output of the Associated Current Sense Amplifier

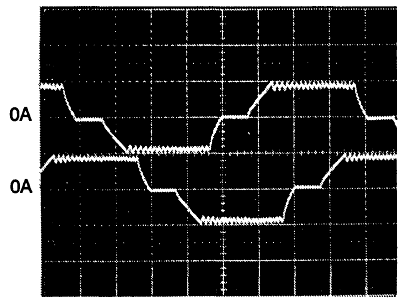
The Typical Application (Continued)

HALF STEP DRIVE WITHOUT TORQUE COMPENSATION

To make the motor take half steps, windings A and B can be energized in the sequence

A ⟶ AB ⟶ B ⟶ A*B ⟶ A* ⟶
A*B* ⟶ B* ⟶ AB* ⟶ A ⟶ . . .

The motor takes one half step each time the number of energized windings changes. It is important to note that although half stepping doubles the step resolution, changing the number of energized windings from two to one decreases (one to two increases) torque by about 40%, resulting in significant torque ripple and possibly noisy operation. *Figure 10* shows the winding currents and digital control signals for this half step application of the typical application circuit.



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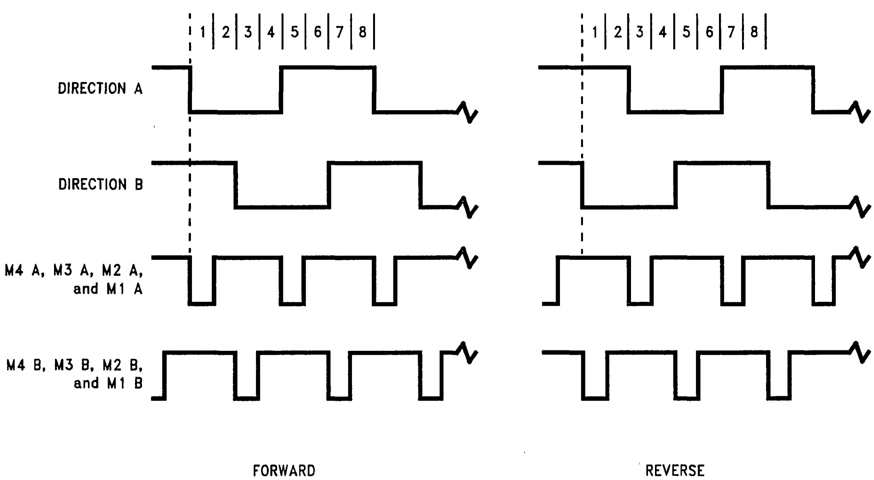
Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase B Winding Current at 1A/div
Horizontal: 1 ms/div
*500 steps/second



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BRAKE A = BRAKE B = 0

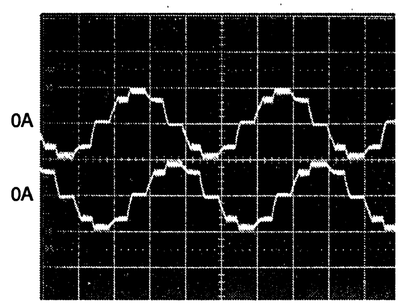
FIGURE 10. Winding Currents and Digital Control Signals for Half Step Drive without Torque Compensation

The Typical Application (Continued)

HALF STEP DRIVE WITH TORQUE COMPENSATION

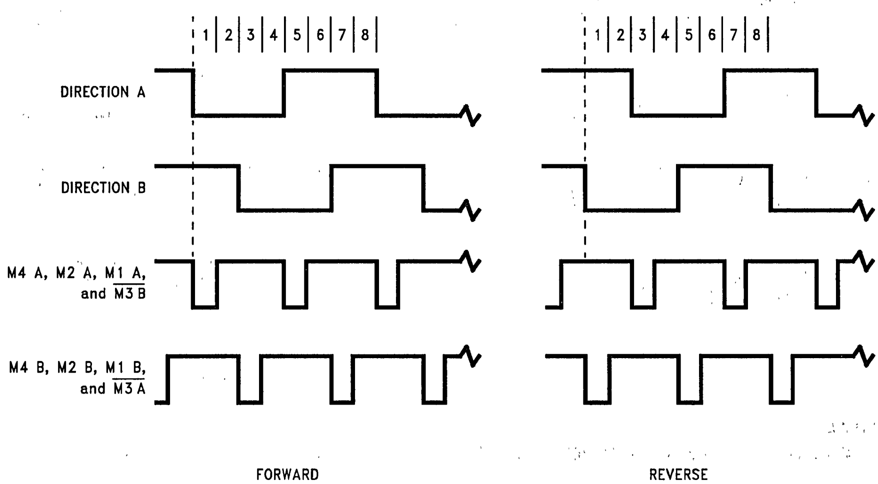
To make the motor take half steps, the windings can also be energized with sinusoidal currents *(Figure 11)*. Controlling the winding currents in the fashion shown doubles the step resolution without the significant torque ripple of the prior drive technique. The motor takes one half step each time the level of either winding current changes. Half step drive with torque compensation is microstepping drive. Along with the obvious advantage of increased step resolution, microstepping reduces both full step oscillations and resonances that occur as the motor and load combination is driven at its natural resonant frequency or subharmonics thereof. Both of these advantages are obtained by replacing full steps with bursts of microsteps. When compared to full step drive, the motor runs smoother and quieter.

Figure 12 shows the lookup table for this application of the typical application circuit. Dividing 90°electrical per full step by two microsteps per full step yields 45° electrical per microstep. α, therefore, increases from 0 to 315° in increments of 45°. Each full 360° cycle comprises eight half steps. Rounding $|\cos\alpha|$ to four bits gives D A, the decimal equivalent of the binary number applied at M4 A through M1 A. DIRECTION A controls the polarity of the current in winding A. *Figure 11* shows the sinusoidal winding currents.



TL/H/11878-24

Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase B Winding Current at 1A/div
Horizontal: 2 ms/div
*500 steps/second



BRAKE A = BRAKE B = 0

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FIGURE 11. Winding Currents and Digital Control Signals for Half Step Drive with Torque Compensation

The Typical Application (Continued)

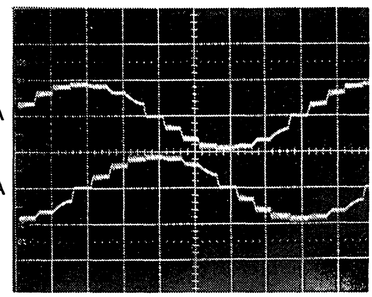
90° ELECTRICAL/FULL STEP ÷ 2 MICROSTEPS/FULL STEP = 45° ELECTRICAL/MICROSTEP

	α	|cos(α)|	D A	DIRECTION A	|sin(α)|	D B	DIRECTION B
|	0	1	15	1	0	0	1
FORWARD	45	0.707	11	1	0.707	11	1
↓	90	0	0	0	1	15	1
	135	0.707	11	0	0.707	11	1
↑	180	1	15	0	0	0	0
REVERSE	225	0.707	11	0	0.707	11	0
|	270	0	0	1	1	15	0
	315	0.707	11	1	0.707	11	0
	REPEAT						

FIGURE 12. Lookup Table for Half Step Drive with Torque Compensation

QUARTER STEP DRIVE WITH TORQUE COMPENSATION

Figure 13 shows the winding currents and lookup table for a quarter step drive (four microsteps per full step) with torque compensation.



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Top Trace: Phase A Winding Current at 1A/div
Bottom Trace: Phase B Winding Current at 1A/div
Horizontal: 2ms/div
*250 steps/second

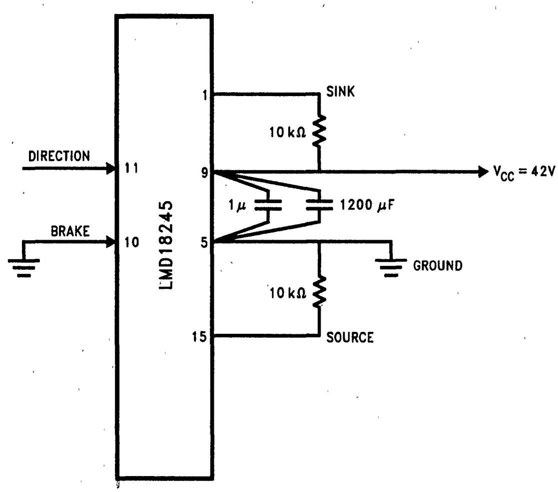
90° ELECTRICAL/FULL STEP ÷ 4 MICROSTEPS/FULL STEP = 22.5° ELECTRICAL/MICROSTEP

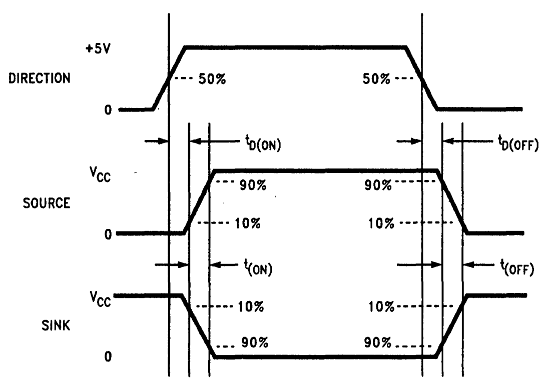
	α	|cos(α)|	D A	DIRECTION A	|sin(α)|	D B	DIRECTION B
	0	1	15	1	0	0	1
	22.5	0.924	14	1	0.383	6	1
|	45	0.707	11	1	0.707	11	1
FORWARD	67.5	0.383	6	1	0.924	14	1
↓	90	0	0	0	1	15	1
	112.5	0.383	6	0	0.924	14	1
↑	135	0.707	11	0	0.707	11	1
REVERSE	157.5	0.924	14	0	0.383	6	1
|	180	1	15	0	0	0	0
	202.5	0.924	14	0	0.383	6	0
	225	0.707	11	0	0.707	11	0
	247.5	0.383	6	0	0.924	14	0
	270	0	0	1	1	15	0
	292.5	0.383	6	1	0.924	14	0
	315	0.707	11	1	0.707	11	0
	337.5	0.924	14	1	0.383	6	0
	REPEAT						

BRAKE A = BRAKE B = 0

FIGURE 13. Winding Currents and Lookup Table for Quarter Step Drive with Torque Compensation

Test Circuit and Switching Time Definitions





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Section 5

Surface Mount

Section 5 Contents

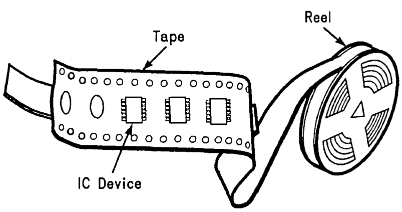
National Semiconductor

Packing Considerations (Methods, Materials and Recycling)

Transport Media

All NSC devices are prepared, inspected and packed to insure proper physical support and to protect during transport and shipment. All assembled devices are packed in one or more of the following container forms—immediate containers, intermediate containers and outer/shipping containers. An example of each container form is illustrated below.

IMMEDIATE CONTAINER



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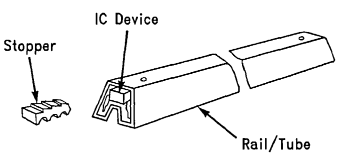
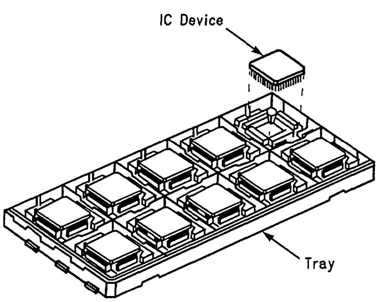


TL/P/11809–2



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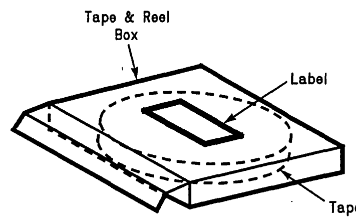
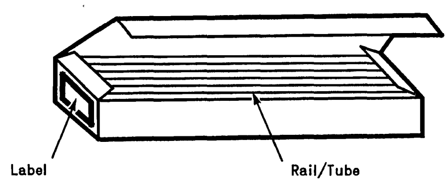
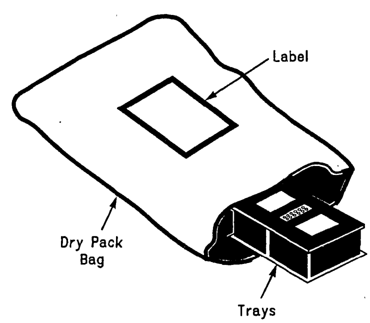
INTERMEDIATE CONTAINER



TL/P/11809–4



TL/P/11809–5



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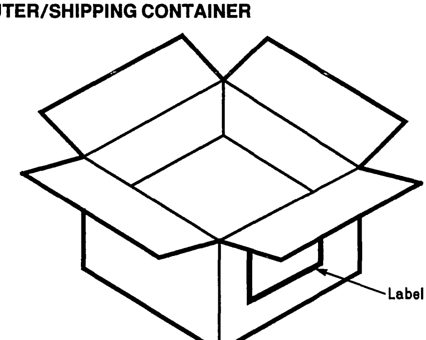
OUTER/SHIPPING CONTAINER



TL/P/11809–7

Methods of immediate carrier packing include insertion of components into molded trays and rails/tubes, mounting of components onto tape and reel or placement in corrugated cartons. The immediate containers are then packed into intermediate containers (bags or boxes) which specify quantities of trays, rails/tubes or tape and reels. Outer/shipping containers are then filled or partially filled with intermediate containers to meet order quantity requirements and to further insure protection from transportation hazards. Additional dunnage filler material is required to fill voids within the intermediate and outer/shipping containers.

General Packing Requirements

NSC packing methods and materials are designed based on the following considerations:

- Optimum protection to the products—it must provide adequate protection from handling (electrostatic discharge) and transportation hazards;
- Ease of handling—it should be easy to assemble, load and unload products in and from it; and
- Impacts to the environment—it shall be reusable and recyclable.

Levels of Product Packing

IMMEDIATE CONTAINER

The first level of product packing is the immediate container. The immediate container type varies with the product or package being packed. In addition, the materials used in the immediate container depend on the fragility, size and profile of the product. The four types of immediate containers used by NSC are rails/tubes, trays, tape and reel, and corrugated and chipboard containers.

Rails/tubes are generally made of acrylic or polyvinyl chloride (PVC) plastics. The electrical characteristics of the material are altered by either intrinsically adding carbon fillers, and/or topically coating it with antistatic solution. Refer to Table I for rail/tube material and recyclabillty information.

TABLE I. Plastic Rail/Tube and Stopper Requirements

Package Type	Rail		Type	Stopper Material	Code/Symbol (Note 1)	Recyclability
	Material	Code/Symbol (Note 1)				
DIP's						
Plastic	Polyvinylchloride	03/PVC	Pin	Polyamide	07/PA	Yes
Ceramic	Polyvinylchloride	03/PVC	Pin	Polyamide	07/PA	Yes
Sidebraze	Polyvinylchloride	03/PVC	Pin	Polyamide	07/PA	Yes
PLCC	Polyvinylchloride	03/PVC	Plug	Rubber	07/SBR	Yes
TapePak	Polyvinylchloride	03/PVC	Plug	Rubber	07/SBR	Yes
Flatpack	Polyvinylchloride	03/PVC	Pin	Polymide	07/PA	Yes
Cerpack	Polyvinylchloride	03/PVC	Pin	Polymide	07/PA	Yes
TO-220/202	Polyvinylchloride	03/PVC	Pin	Polymide	07/PA	Yes
TO-5/8 (in Carrier)	Polyvinylchloride	03/PVC	Pin	Polymide	07/PA	Yes
SOP	Polyvinylchloride	03/PVC	Plug	Rubber	07/SBR	Yes
LCC 18L–44L	Polyvinylchloride	03/PVC	Plug	Rubber	07/SBR	Yes

Note 1: ISO 1043-1 International Standards—Plastic Symbols.
SAE J1344 Marking of Plastic Parts.
ASTM D 1972–91 Standard Practice for Generic Marking of Plastic Products.
DIN 6120, German Recycling Systems, RESY for paperbased and VGK for plastic packing materials.

Molded injection and vacuum formed trays can be either conductive or static dissipative. Molded injection trays are classified as either low-temperature or high-temperature depending on the material type. Vacuum formed trays are only used in ambient room temperature conditions. Refer to Table II for tray material and recyclability information.

TABLE II. Tray Requirements

Package Type	Class	Material	Tray		Binding Type
			Recyclability (Note 1)	Code/Symbol (Note 1)	
PQFP (All)	High Temperature	Polyethersulfone	Yes	07/PES	Wire Tie or Nylon Strap
	Low Temperature	Acrylonitrilebutadiene Styrene	Yes	07/ABS	Wire Tie or Nylon Strap
PGA, LDCC CERQUADs and LCC (48 leads–125 leads)	Low Temperature Only	ABS/PVC	Yes	07/ABS-PVC	Wire Tie
PPGA	Low Temperature Only	Polyarylsulfone	Yes	07/PAS	Wire Tie

Tape and reel is a multi-part immediate container system. The reel is made of either polystyrene (PS) material coated with antistatic solution or chipboard. The embossed or cavity tape is made of either PVC or PS material. The cover tape is made of polyester (PET) and polyethylene (PE) materials. Refer to Table III for tape and reel material and recyclability Information.

TABLE III. Tape and Reel Requirements

Package Type	Reel		Cover Type		Carrier Tape		Recyclability (Note 1)
	Material	Code/ Symbol (Note 1)	Material	Code/ Symbol (Note 1)	Material	Code/ Symbol (Note 1)	
TO-92	Chipboard	Resy	N/A		Paper Tape		Yes
SOP-23	Polystyrene Chipboard	06/PS Resy	Polystyrene	06/PS	PVC	03/PVC	Yes
SOP, SSOP and PLCC	Polystyrene Polyethylene	06/PS	Polyester	07/PET-PE	PVC	03/PVC	Yes

Note 1: 150 1043-1 International Standards—Plastic Symbols.
SAE J1344 Marking of Plastic Parts.
ASTM D 1972–91 Standard Practice for Generic Marking of Plastic Products.
DIN 6120, German Recycling Systems, RESY for paperbased and VGK for plastic packing materials.

Corrugated containers are generally constructed with fibreboard facings and a fluted corrugated medium in between the facings. Chipboard containers are comprised of just one fibreboard facing. Facings and corrugated medium are kraft (brown) fibreboard, and generally single wall construction. Refer to Table IV for material and recyclability information.

TABLE IV. Fibreboard Container Requirements

Package Type	Pack Method: Material	Pack Method: Code/ Symbol (Note 1)	Container Type: Immediate (IMM) Intermediate (INT) Outer or Shipping (SHP)		Recyclability
TO-92/18, TO-46/5, TO-39, 220, TO-202/126, TO-237	Corrugated (E070 BOX)	Resy	IMM		Yes
All Products	Corrguated	Resy	INT and SHIP		Yes
All Products	3-Ply Paper (Padpak)	Resy	Dunnage		Yes
All Products PLCC	Plastic Bubble Sheet	04/PE	Dunnage		Yes

Note 1: ISO 1043-1 International Standards—Plastic Symbols.
SAE J1344 Marking of Plastic Parts.
ASTM D1972–91 Standard Practice for Generic Marking of Plastic Products.
DIN 6120, German Recycling Systems, RESY for paperbased and VGK for plastic packing materials.

INTERMEDIATE CONTAINERS

The second level of product packing is the intermediate container. Three types on intermediate containers are used by NSC. They are plastic bags, moisture barrier bags and corrugated cartons/boxes.

Two types of plastic bags are used and usage of each type depends on the product or package being packed. Conductive bags are made of polyvinylchloride plastic material. The electrical characteristics of the bag are altered by adding carbon fillers which make the bag black (opaque) in color. Conductive bags are used on products or packages that are packed in static dissipative (SD) rails/tubes. Static shielding bags are made of two layers of SD polyethylene sheets with a metallized film separating the sheets. Refer to Table V for material and recyclability information.

Moisture barrier bags are used on rail/tube, tape and reel, and tray packs for moisture sensitive products. NSC uses National Metallizing's Stratoguard™ 4.6.

TABLE V. Conductive and Static Shielding Bag Requirements

Package Type	Container Type	Material Type	Mat'l and Symbol (Note 1)	Mat'l Recyclability
All Prod. in Rails	Conductive Bag	Polyethlene	04/PE	Yes
TO-92/81, TO-46/5, TO-39/220, TO-202/126, TO-3/237	Static Shielding Bag	Polyethlene Alum. Laminant	N/A	No

TABLE VI. Drypack Bag Requirements

Package Type	Container Type	Material Type	Mat'l and Symbol (Note 1)	Mat'l Recyclability
TapePak PLCC (52-84L) PQFP	Drypack Bag	Stratoguard™ 4.6	N/A	No

Note 1: ISO 1043-1 International Standards—Plastic Symbols.
SAE J1344 Marking of Plastic Parts.
ASTM D1972-91 Standard Practice for Generic Marking of Plastic Products.
DIN 6120, German Recycling Systems, RESY for paperbased and VGK for plastic packing materials

Corrugated cartons/boxes are generally constructed with fibreboard facings and a fluted corrugated medium in between the facings. Facings and corrugated medium are kraft (brown) fibreboards, and are generally of single wall construction. Carton style varies with the product that it will contain. For example, packing of a rail/tube will require the use of a carton with a roll end from lock (REFL) design. Other products generally use the regular slotted container (RSC) box. Refer to Table IV for material and recyclability information.

OUTER/SHIPPING CONTAINERS

The third level of product packing is the outer/shipping container. The outer/shipping containers use by NSC are similar to the corrugated containers used for immediate and intermediate packaging, but are heavier in facing thickness. The style generally used is the regular slotted container (RSC) box and can be single, double or triple wall, depending on the total weight of products being transported or shipped. Refer to Table IV for material and recyclability information.

OTHER PACKING MATERIALS

Additional dunnage and void filler materials are required to fill voids within the intermediate and outer/shipping containers. Two types of dunnage/filler material are Padpack and bubble pack. Padpak is a machine processed, 3-ply kraft paper sheet dunnage system. Refer to Table IV for material and recyclability information.

Bubble pack is made of polyethylene plastic sheets with air pockets trapped in between the plastic layers and can be either static dissipative or conductive. Refer to Table IV for material and recyclability information.

Immediate Container Pack Methods

The following table identifies the primary immediate container pack method for all hermetic and plastic packages offered by National Semiconductor. A secondary immediate container pack method is identified where applicable.

Immediate Packing Method for Ceramic Packages

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Ceramic Sidebrazed Dual-In-Line Package (SB)	D08C	Rail/Tube	35		
	D14D	Rail/Tube	25		
	D16C	Rail/Tube	20		
	D18A	Rail/Tube	20		
	D20A	Rail/Tube	18		
	D20B	Rail/Tube	18		
	D24C	Rail/Tube	15		
	D24H	Rail/Tube	15		
	D24K	Rail/Tube	15		
	D28D	Rail/Tube	13		
	D28G	Rail/Tube	13		
	D28H	Rail/Tube	13		
	D40C	Rail/Tube	9		
	D40J	Rail/Tube	9		
	D48A	Rail/Tube	7		
	D52A	Rail/Tube	7		
Ceramic Leadless Chip Carrier (LCC)	E20A	Rail/Tube	50		
	EA20B	Rail/Tube	50		
	E24B	Tray	25		
	E28A	Tray	28		
	EA028C	Tray	100		
	E32A	Rail/Tube	35		
	E32B	Rail/Tube	35		
	E32C	Rail/Tube	35		
	E40A	Rail/Tube	35		
	E44A	Rail/Tube	25		
	E48A	Tray	25		
	E68B	Tray	48		
	E68C	Tray	48		
	E84A	Tray	42		
	E84B	Tray	42		

Immediate Packing Method for Ceramic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Ceramic Quad J-Bend (CQJB)	EL28A	Tray	96		
	EL44A	Tray	80		
	EL44B	Tray	80		
	EL44C	Tray	80		
	EL52A	Tray	50		
	EL68A	Tray	44		
	EL68B	Tray	44		
	EL68C	Tray	44		
	EL84A	Tray	42		
Ceramic Quad Flatpack (CQFP)	EL28B	Rail	15		
	EL64A	Box	36		
	EL100A	Tray	12		
	EL116A	Tray	12		
	EL132B	Tray	20		
	EL132C	Tray	20		
	EL132D	Tray	20		
	EL164A	Tray	12		
	EL172B	Tray	12		
	EL172C	Tray	12		
Ceramic Flatpack	F10B	Carrier/Rail	19	Carrier/Box	200
	F14C	Carrier/Rail	19	Carrier/Box	200
	F16B	Carrier/Rail	19	Carrier/Box	200

Immediate Packing Method for Ceramic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Ceramic Dual-In-Line Package (Cerdip)	J08A	Rail/Tube	40		
	J14A	Rail/Tube	25		
	J16A	Rail/Tube	25		
	J18A	Rail/Tube	20		
	J20A	Rail/Tube	20		
	J22A	Rail/Tube	17		
	J24A	Rail/Tube	15		
	J24AQ	Rail/Tube	15		
	J24B-Q	Rail/Tube	15		
	J24CQ	Rail/Tube	15		
	J24E	Rail/Tube	16		
	J24F	Rail/Tube	15		
	J28A	Rail/Tube	12		
	J28AQ	Rail/Tube	12		
	J28B	Rail/Tube	12		
	J28BQ	Rail/Tube	12		
	J28CQ	Rail/Tube	13		
	J32B	Rail/Tube	11		
	J32AQ	Rail/Tube	11		
	J40A	Rail/Tube	9		
	J40AQ	Rail/Tube	9		
	J40BQ	Rail/Tube	9		
Ceramic Small Outline Package, Wide	MC16A	Rail/Tube	45		
	MC20A	Rail/Tube	36		
	MC20B	Rail/Tube	36		
	MC24A	Rail/Tube	30		
	MC28A	Rail/Tube	26		
	MC28B	Rail/Tube	26		

Immediate Packing Method for Ceramic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Ceramic Pin Grid Array (CPGA)	U44A	Tray	80		
	U68B	Tray	42		
	U68C	Tray	42		
	U68D	Tray	42		
	U68E	Tray	42		
	U75A	Tray	35		
	U84A	Tray	42		
	U84B	Tray	42		
	U84C	Tray	42		
	U99A	Tray	25		
	U100A	Tray	30		
	U109A	Tray	25		
	U120A	Tray	30		
	U120C	Tray	30		
	U124A	Tray	30		
	U132A	Tray	30		
	U132B	Tray	30		
	U144A	Tray	20		
	U156A	Tray	20		
	U156B	Tray	20		
	U169A	Tray	20		
	U173A	Tray	20		
	U175A	Tray	20		
	U180A	Tray	20		
	U223A	Tray	20		
	U224A	Tray	20		
	U257A	Tray	12		
	U259A	Tray	12		
	U299A	Tray	12		
	U301A	Tray	12		
	U303A	Tray	12		
	U323A	Tray	12		

Immediate Packing Method for Ceramic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Cerpack	W10A	Carrier/Rail	19	Carrier/Box	200
	W14B	Carrier/Rail	19	Carrier/Box	200
	W14C	Carrier/Rail	19	Carrier/Box	200
	W16A	Carrier/Rail	19	Carrier/Box	200
	W20A	Carrier/Rail	19	Carrier/Box	200
	W24C	Carrier/Rail	15	Carrier/Box	80
	W28A	Carrier/Rail	15	Carrier/Box	80
	WA28D	Carrier/Rail	15	Carrier/Box	80
Cerquad	W24B	Rail/Tube	15		
	W56B	Tray	20		
	W64A	Tray	20		
	W68A	Tray	12		
	W84A	Tray	12		
Cerquad, EIAJ	WA80A	Tray	84		
	WA80AQ	Tray	84		
	W120A	Tray	12		
	W144A	Tray	12		
	W144B	Tray	12		
	W160A	Tray	12		
	W208A	Tray	12		

Immediate Packing Method for Metal Cans

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
TO-5	H06C	Tray	100	Carrier/Rail	18
	H08A	Tray	100	Carrier/Rail	18
	H08C	Tray	100	Carrier/Rail	18
	H10C	Tray	100	Cerrier/Rail	18
TO-18	H03C	Box	1800	Tray	100
TO-39	H03A	Tray	100	Carrier/Rail	18
	H03B	Tray	100	Carrier/Rail	18
	HA04E	Tray	100	Carrier/Rail	18
TO-46	H02A	Box	1800	Tray	100
	H03H	Box	1800	Tray	100
	H04A	Box	1800	Tray	100
	H04D	Box	1800	Tray	100
TO-52	H03J	Box	1800	Tray	100
TO-72	H04C	Box	1800	Tray	100

Immediate Packing Method for Plastic Packages

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Small Outline Transistor (SOT-23)	M03A	Tape and Reel	3000/ 10000	Bulk/Bag	500
	M03B	Tape and Reel	3000/ 10000	Bulk/Bag	500
Small Outline Package, JEDEC (SOP)	M08A	Rail/Tube	95	Tape and Reel	2500
	M14A	Rail/Tube	55	Tape and Reel	2500
	M14B	Rail/Tube	50	Tape and Reel	1000
	M16A	Rail/Tube	48	Tape and Reel	2500
	M16B	Rail/Tube	45	Tape and Reel	1000
	M20B	Rail/Tube	36	Tape and Reel	1000
	M24B	Rail/Tube	30	Tape and Reel	1000
	M28B	Rail/Tube	26	Tape and Reel	1000
Small Outline Package, EIAJ (SOP)	M14D	Rail/Tube	47	Tape and Reel	1000
	M16D	Rail/Tube	47	Tape and Reel	1000
	M20D	Rail/Tube	37	Tape and Reel	1000
Shrink Small Outline Package, JEDEC (SSOP)	MQA20	Rail/Tube	54	Tape and Reel	2500
	MQA24	Rail/Tube	54	Tape and Reel	2500
	MS48A	Rail/Tube	29	Tape and Reel	1000
	MS56A	Rail/Tube	25	Tape and Reel	1000
Shrink Small Outline Package, EIAJ (SSOP)	MSA20	Rail/Tube	65	Tape and Reel	1000
	MSA24	Rail/Tube	58	Tape and Reel	1000
	MS40A	Rail/Tube	34	Tape and Reel	1000
Very Small Outline Package (VSOP)	M40A	Rail/Tube	34	Tape and Reel	1000
Thin Small Outline Package, EIAJ (TSOP)	MBH32A	Tray	156		
Thin Shrink Small Outline Package, EIAJ (TSSOP)	MTA20	Tape and Reel	2500		

Immediate Packing Method for Plastic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Molded Dual-In-Line Package (MDIP)	N08E	Rail/Tube	40		
	N14A	Rail/Tube	25		
	N16A	Rail/Tube	20		
	N16E	Rail/Tube	25		
	N16G	Rail/Tube	20		
	N18A	Rail/Tube	20		
	N20A	Rail/Tube	18		
	N22A	Rail/Tube	15		
	N22B	Rail/Tube	15		
	N24A	Rail/Tube	15		
	N24C	Rail/Tube	15		
	N24D	Rail/Tube	15		
	N24E	Rail/Tube	15		
	N28B	Rail/Tube	13		
	N40A	Rail/Tube	9		
	N48A	Rail/Tube	7		
TO-202	P03A	Rail/Tube	45	Box	300
	P03B	Rail/Tube	45	Box	300
	P03C	Rail/Tube	45	Box	300
	P03D	Rail/Tube	45	Box	300
	P03E	Rail/Tube	45	Box	300
	P03F	Rail/Tube	45	Box	300
	P03G	Rail/Tube	45	Box	300
	P03H	Rail/Tube	45	Box	300
	P03J	Rail/Tube	45	Box	300
	P04A	Rail/Tube	45	Box	300
	P11A	Rail/Tube	15		
TO-237	R03A	Box	1500	Tape and Reel	2000
	R03B	Box	1500	Tape and Reel	2000
	R03C	Box	1500	Tape and Reel	2000
	R03D	Box	1500	Tape and Reel	2000
TO-226	RC03A	Box	1500	Tape and Reel	2000
	RC03B	Box	1500	Tape and Reel	2000
	RC03C	Box	1500	Tape and Reel	2000
	RC03D	Box	1500	Tape and Reel	2000

Immediate Packing Method for Plastic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
TO-220	TA02A	Rail/Tube	45	Box	300
	T02D	Rail/Tube	45	Box	300
	TA03A	Rail/Tube	45	Box	300
	TA03B	Rail/Tube	45	Box	300
	TA03D	Rail/Tube	45	Box	300
	T03A	Rail/Tube	45	Box	300
	T03B	Rail/Tube	45	Box	300
	T03D	Rail/Tube	45	Box	300
	T03F	Rail/Tube	45	Box	300
	T05A	Rail/Tube	45	Box	300
	T05B	Rail/Tube	45	Box	300
	T05C	Rail/Tube	45	Box	300
	T05D	Rail/Tube	45	Box	300
	T05E	Rail/Tube	45	Box	300
	T05F	Rail/Tube	45	Box	300
	TA05A	Rail/Tube	45	Box	300
	TA05B	Rail/Tube	45	Box	300
	TA11A	Rail/Tube	20	Box	300
	TA11B	Rail/Tube	20	Box	300
	TA11C	Rail/Tube	20	Box	300
	TA11D	Rail/Tube	20	Box	300
	TA11E	Rail/Tube	20	Box	300
	TA12A	Rail/Tube	20	Box	300
	TA15A	Rail/Tube	20	Box	300
	TA23A	Rail/Tube	15	Box	300
TapePak®	TP40A	Coinstack Tube	100	Flat Rail	25
Plastic Pin Grid Array (PPGA)	UP124A	Tray	30		
	UP159A	Tray	20		
	UP175A	Tray	20		
Plastic Leaded Chip Carrier (PLCC)	V20A	Rail/Tube	40	Tape and Reel	1000
	V28A	Rail/Tube	35	Tape and Reel	750
	V32A	Rail/Tube	30		
	V44A	Rail/Tube	25	Tape and Reel	500
	V52A	Rail/Tube	22	Tape and Reel	500
	V68A	Rail/Tube	18	Tape and Reel	250
	V84A	Rail/Tube	15	Tape and Reel	250

Immediate Packing Method for Plastic Packages (Continued)

Package Type (Code)	Package Marketing Drawing	Primary Immediate Container		Secondary Immediate Container	
		Method	Quantity	Method	Quantity
Plastic Quad Flatpack (PQFP)	VEF44A	Tray	96		
	VBG48A	Tray	60		
	VHG80A	Tray	60		
	VJE80A	Tray	84		
	VCC80A	Tray	50/66		
	VCE100A	Tray	84		
	VLJ100A	Tray	50		
	VJG100A	Tray	60		
	VNG144A	Tray	60		
	VUL160A	Tray	24		
	VQL160A	Tray	24		
	VUW208A	Tray	24		
	VF132A	Tray	36		
	VF196A	Tray	21		
TO-92	Z03A	Box	1800	Tape and Reel	2000
	Z03B	Box	1800	Tape and Reel	2000
	Z03C	Box	1800	Tape and Reel	2000
	Z03D	Box	1800	Tape and Reel	2000
	Z03E	Box	1800	Tape and Reel	2000
	Z03G	Box	1800	Tape and Reel	2000
	Z03H	Box	1800	Tape and Reel	2000
	Z03J	Box	1800	Tape and Reel	2000

Labeling

National Semiconductor offers 3 standard bar code labels; reel and intermediate container labels for Tape and Reel; intermediate container label other than for Tape and Reel; and outer/shipping container labels. The tape and reel, and intermediate container labels are National's own format while the outer/shipping container label is based on the EIA-556-A label standard.

NSC Standard Tape and Reel Label

(P) CPN: CPN 123456789012 XYZ COMPANY

PO #: PO 123456789012

(Q) QTY: 1000 (D) D/C: P9236 NSID: DM74ALS253WM

SPEC: SPEC1234

LOT : LOT 12345678912

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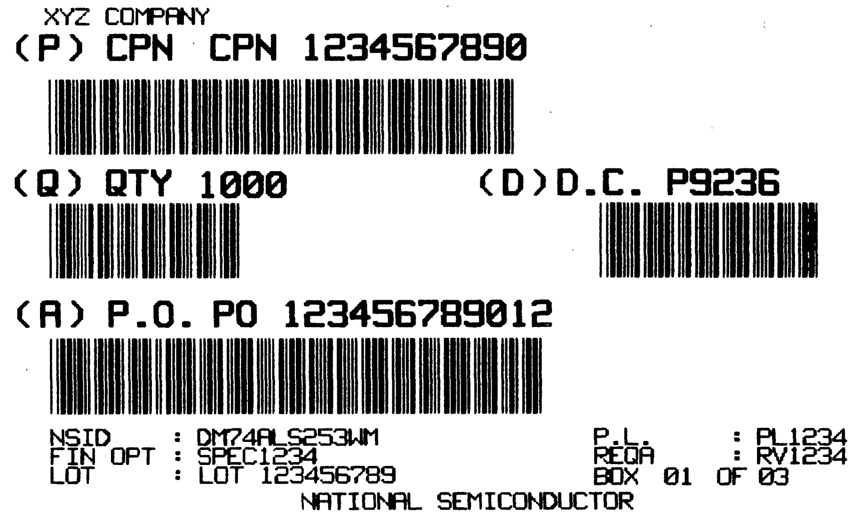
This label is placed on the reel (immediate container) as well as on the intermediate box.

NSC Standard Intermediate Container Label



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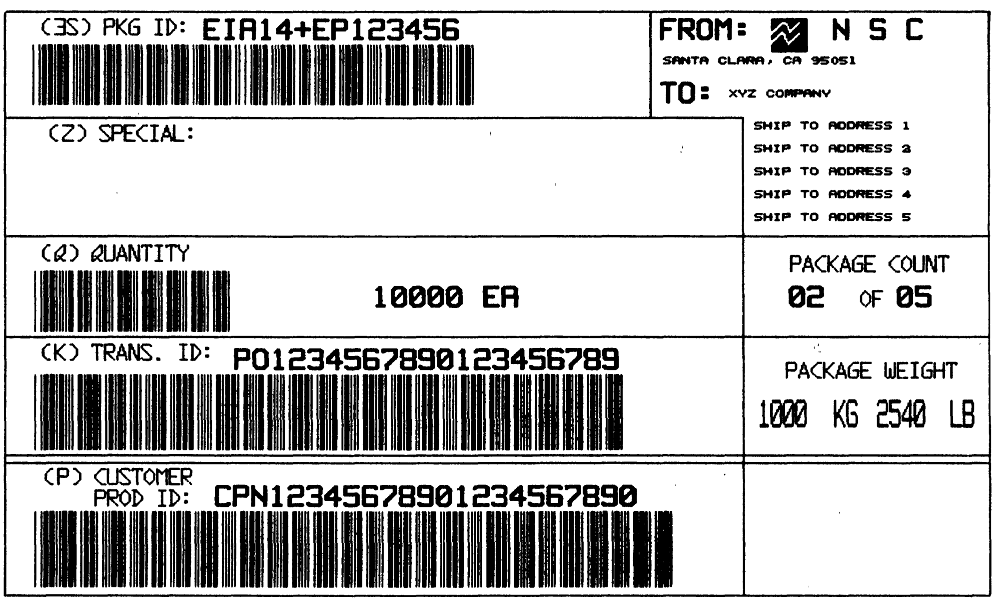
NSC Standard Outer/Shipping Container Label



TL/P/11809-10

National Semiconductor

Board Mount of Surface Mount Components

Abstract

In facing the challenges of "Surface Mount Technology", many manufacturers of printed circuit boards have taken steps to convert some portions of their boards to this process. However, as the availability of all products as surface mount components is still limited, many have had to mix lead-inserted components with surface mount devices (SMD's). Furthermore, to take advantage of using both sides of the board, some surface mounted components are adhered to the bottom side of the board while the top side is reserved for the conventional lead-insert packages and fine pitch surface mount packages.

There are three surface mount processes in hi-volume use today:

1. **WAVE SOLDER;** the surface mounted components are adhered to the bottom side of the board while the top side is reserved for the lead-inserted packages. The surface mount components are subjected to severe thermal stress when they are immersed into the molten solder.
2. **INFRA-RED** mass reflow; the surface mount components are placed on the solder paste which has been applied to the board, the solder joints are formed when the board is passed thru the reflow media. The surface mount devices are subjected to a controlled thermal environment.
3. **VAPOR PHASE** mass reflow; the surface mount components are placed on the solder paste which has been applied to the board, tbe solder joints are formed when the board is passed thru the reflow media. The surface mount devices are subjected to a controlled thermal environment, more severe than Infra-red but much less than wavesolder.

A discussion of the effect of these processes on the reliability of plastic semiconductor packages follows.

Role of Wave Soldering in Application of SMDs

The generally acceptable methods of soldering SMDs are vapor phase reflow soldering and IR reflow soldering, both requiring application of solder paste on PW boards prior to placement of the components. However, sentiment still exists for retaining the use of the old wave soldering machine. The reasons being:

Most PC Board Assembly houses already possess wave soldering equipment. Switching to another technology such as vapor phase soldering requires substantial investment in equipment and people.

Due to the limited number of devices that are surface mount components, it is necessary to mix both lead inserted components and surface mount components on the same board.

Some components such as relays and switches are made of materials which would not be able to survive the temperature exposure in a vapor phase or IR furnace.

PW Board Assembly Procedures

There are two considerations in which through-hole ICs may be combined with surface mount components on the PW Board:

a) Whether to mount ICs on one or both sides of the board.

b) The sequence of soldering using Vapor Phase, IR or Wave Soldering singly or a combination of two or more methods.

The various processes that may be employed are:

A) WAVE SOLDER BEFORE VAPOR/IR REFLOW SOLDER

1. Components on the same side of PW Board. Lead insert standard DIPS onto PW Board Wave solder (conventional). Wash and lead trim. Dispense solder paste on SEM pads. Pick and place SMDs onto PW Board. Bake Vapor phase/IR reflow. Clean.
2. Components on opposite side of PW Board. Lead insert standard DIPs onto PW Board Wave Solder (conventional). Clean and lead trim. Invert PW Board. Dispense drop of adhesive on SMD sites (optional for smaller components). Pick and place SMDs onto board. Bake/Cure. Invert board to rest on raised fixture. Vapor/IR reflow soldering. Clean.

B) VAPOR/IR REFLOW SOLDER THEN WAVE SOLDER

1. Components on the same side of PW Board. Solder paste screened on SMD side of Printed Wire Board. Pick and place SMDs. Bake Vapor/IR reflow. Lead insert on same side as SMD's. Wave solder. Clean and trim underside of PCB.

C) VAPOR/IR REFLOW ONLY

1. Components on the same side of PW Board Trim and form standard DIPs in "gull wing" configuration. Solder paste screened on PW Board. Pick and place SMDs and DIPs. Bake Vapor/IR reflow. Clean.
2. Components on opposite sides of PW Board. Solder paste screened on SMD-side of Printed Wire Board. Adhesive dispensed at central location of each component. Pick and place SMDs. Bake. Solder paste screened on all pads on DIP-side or alternatively apply solder rings (performs) on leads. Lead insert DIPs. Vapor/IR reflow. Clean and lead trim.

PW Board Assembly Procedures

(Continued)

D) WAVE SOLDERING ONLY

1. Components on opposite sides of PW board. Adhesive dispense on SMD side of PW Board. Pick and place SMDs. Cure adhesive. Lead insert top side with DIPs. Wave solder with SMDs down and into solder bath. Clean and lead trim.

All of the above assembly procedures can be divided into three categories for IC. Reliability considerations:

1) Components are subjected to both a vapor phase/IR heat cycle then followed by a wave-solder heat cycle or vice versa.
2) Components are subjected to only a vapor phase/IR heat cycle.
3) Components are subjected to wave-soldering only and SMDs are subjected to heat by immersion into a solder pot.

Of these three categories, the last is the most severe regarding heat treatment to a semiconductor device. However, note that semiconductor molded packages generally possess a coating of solder on their leads as a final finish for solderability and protection of base leadframe material. Most semiconductor manufacturers solder-plate the component leads, while others perform hot solder dip. In the latter case the packages may be subjected to total immersion into a hot solder bath under controlled conditions (manual operation) or be partially immersed while in a "pallet" where automatic wave or DIP soldering processes are used. It is, therefore, possible to subject SMDs to solder heat under certain conditions and not cause catastrophic failures.

Thermal Characteristics of Molded Integrated Circuits

Since Plastic DIPs and SMDs are encapsulated with a thermoset epoxy, the thermal characteristics of the material generally correspond to a TMA (Thermo-Mechanical Analysis) graph. The critical parameters are (a) its Linear thermal expansion characteristics and (b) its glass transition temperature after the epoxy has been fully cured. A typical TMA graph is illustrated in *Figure 1.* Note that the epoxy changes to a higher thermal expansion once it is subjected to temperatures exceeding its glass transition temperature. Metals (as used on leadframes, for example) do not have this characteristic and generally will have a consistent Linear thermal expansion over the same temperature range.

In any good reliable plastic package, the choice of leadframe material should be such to match its thermal expansion properties to that of the encapsulating epoxy. In the event that there is a mismatch between the two, stresses can build up at the interface of the epoxy and metal. There now exists a tendency for the epoxy to separate from the metal leadframe in a manner similar to that observed on bimetallic thermal range.

In most cases when the packages are kept at temperatures below their glass transition, there is a small possibility of separation at the epoxy-metal interface. However, If the package is subjected to temperature above its glass-transition temperature, the epoxy will expand much faster than the metal and the probability of separation is greatly increased.

Transition Temperature

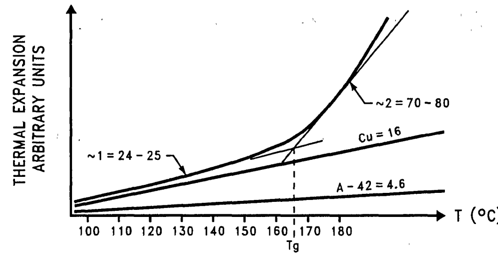


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FIGURE 1. Thermal Expansion and Glass

Conventional Wave Soldering

Most wave soldering operations occur at temperatures between 240°C–260°C. Conventional epoxies for encapsulation have glass-transition temperatures between 140°C–170°C. An I.C. directly exposed to these temperatures risks its long term functionality due to epoxy/metal separation.

Fortunately, there are factors that can reduce that element of risk:

1. The PW board has a certain amount of heat-sink effort and tends to shield the components from the temperature of the solder (if they were placed on the top side of the board). In actual measurements, DIPs achieve a temperature between 120°C–150°C in a 5-second pass over the solder. This accounts for the fact that DIPs mounted in the conventional manner are reliable.
2) In conventional soldering, only the tip of each lead in DIP would experience the solder temperature because the epoxy and die are standing above the PW board and out of the solder bath.

Effect on Package Performance by Epoxy-Metal Separation

In wave soldering, it is necessary to use fluxes to assist the solderability of the components and PW boards. Some facilities may even process the boards and components through some form of acid cleaning prior to the soldering temperature. If separation occurs, the flux residues and acid residues (which may be present owing to inadequate cleaning) will be forced into the package mainly by capillary action as the residues move away from the solder heat source. Once the package is cooled, these contaminants are now trapped within the package and are available to diffuse with moisture from the epoxy over time. It should be noted that electrical tests performed immediately after soldering generally will give no indication of this potential problem. In any case, the end result will be corrosion of the chip metalization over time and premature failure of the device in the field.

Vapor Phase/IR Reflow Soldering

In both vapor phase and IR reflow soldering, the risk of separation between epoxy/metal can also be high. Maximum operating temperatures are 219°C (vapor phase) or 240°C (IR) and duration may also be longer (30 sec–60 sec). On the same theoretical basis, there should also be separation. However, in both these methods, solder paste is applied to the pads of the boards; no fluxes are used. Also, the devices are not immersed into the hot solder. This reduces the possibility of solder forcing itself into the epoxy-leadframe interface. Furthermore, in the vapor phase system, the soldering environment is "oxygen-free" and considered "contaminant free". Being so, it could be visualized that as far as reliability with respect to corrosion, both of these methods are advantageous over wave soldering,

Bias Moisture Test

A bias moisture test was designed to determine the effect on package performance. In this test, the packages are pressured in a steam chamber to accelerate penetration of moisture into the package. An electrical bias is applied on the device. Should there be any contaminants trapped within the package, the moisture will quickly form an electrolyte and cause the electrodes (which are the lead fingers), the gold wire and the aluminum bond-pads of the silicon device to corrode. The aluminum bond-pads, being the weakest link of the system, will generally be the first to faiL

This proprietary accelerated bias/moisture pressure-test is significant in relation to the life test condition at 85°C and 85% relative humidity. One cycle of approximately 100 hours has been shown to be equivalent to 2,000 hours in the 85/85 condition. Should the packages start to fail within the first cycle in the test, it is anticipated that the boards with these components in the harsh operating environment (85°C/85% RH) will experience corrosion and eventual electrical failures within its first 2,000 hours of operation.

Whether this is significant to a circuit board manufacturer will obviously be dependent on the products being manufactured and the workmanship or reliability standards. Generally in systems with a long warranty and containing many components, it is advisable both on a reputation and cost basis to have the most reliable parts available.

Test Results

The comparison of vapor phase and wave-soldering upon the reliability of molded Small-Outline packages was performed using the bias moisture test (see Table IV). It is clearly seen that vapor phase reflow soldering gave more consistent results. Wave soldering results were based on manual operation giving variations in soldering parameters such as temperature and duration.

TABLE IV. Vapor Phase vs. Wave Solder

1. Vapor phase (60 sec. exposure @ 217°C)	
= 9 failures/1723 samples	
= 0.5% (average over 32 sample lots)	
2. Wave solder (2 sec total immersion @ 260°C)	
= 16 failures/1201 samples	
= 1.3% (average over 27 sample lots)	
Package:	SO-14 lead
Test:	Bias moisture test 85% R.H.
	85°C for 2,000 hours
Device:	LM324M

In Table V we examine the tolerance of the Small-Outlined (SOIC) package to varying immersion time in a hot solder pot. SO-14 lead molded packages were subjected to the bias moisture test after being treated to the various soldering conditions and repeated four (4) times. End point was an electrical test after an equivalent of 4,000 hours 85/85 test. Results were compared for packages by themselves against packages which were surface-mounted onto a FR-4 printed wire board.

TABLE V. Summary of Wave Solder Results

	Unmounted	Mounted
Control/Vapor Phase 15 sec @ 215°C	0/114	0/84
Solder Dip 4 Sec @ 260°C	2/144 (1.4%)	0/85
Solder Dip 4 Sec @ 260°C	—	0/83
Solder Dip 6 Sec @ 260°C	13/248 (5.2%)	1/76 (1.3%)
Solder Dip 10 Sec @ 260°C	14/127 (11.0%)	3/79 (3.8%)
Package: SO-14 lead Device: LM324M		

Since the package is of very small mass and experiences a rather sharp thermal shock followed by stresses created by the mismatch in expansion, the results show the packages being susceptible to failures after being immersed in excess of 6 seconds in a solder pot. In the second case where the packages were mounted, the effect of severe temperature excursion was reduced. In any case, because of the repeated treatment, the package had failures when subjected in excess of 6 seconds immersion in hot solder. The safety margin is therefore recommended as maximum 4 seconds immersion. If packages were immersed longer than 4 seconds, there is a probable chance of finding some long term reliability failures even though the immediate electrical test data could be acceptable.

Finally, Table VI examines the bias moisture test performed on surface mount (SOIC) components manufactured by various semiconductor houses. End point was an electrical test after an equivalent of 6,000 hours in an 85/85 test. Failures were analyzed and corrosion was checked for in each case to detect flaws in package integrity.

TABLE VI. U.S. Manufacturing Integrated Circuits Reliability in Various Solder Environments (# Failure/Total Environment)

Package SO-8	Vapor Phase 30 sec	Wave Solder 2 sec	Wave Solder 4 sec	Wave Solder 6 sec	Wave Solder 10 sec
Manuf A	8/30*	1/30*	0/30	12/30*	16/30*
Manuf B	2/30*	8/30*	2/30*	22/30*	20/30*
Manuf C	0/30	0/29	0/29	0/30	0/30
Manuf D	1/30*	12/30*	14/30*	2/30*	
Manuf E	1/30**	0/30	0/30	0/30	
Manuf F	0/30	0/30	0/30	0/30	
NSC	0/30	0/30	0/30	0/30	

*Corrosion failures

**No Visual Defects-Non-corrosion failues

Test Accelerated Bias Moisture Test: 85% R.H./85°C. 6,000 equivalent hours

Summary

Based on the results presented, it is noted that surface-mounted components are as reliable as standard molded DIP packages. Whereas DIPs were never processed by being totally immersed in hot solder wave during printed circuit board soldering, surface mounted components such as SOICs (Small Outline) are expected to survive a total immersion in the hot solder in order to capitalize on maximum population on boards. Being constructed from a thermoset plastic of relatively low T_g compared to the soldering temperature, the ability of the package to survive is dependent on the time of immersion and also the cleanliness of material. The results indicate that one should limit the immersion time of the package in the solder wave to a maximum of 4 seconds in order to truly duplicate the reliability of a DIP. As the package size is reduced, as in a SO-8 lead, the requirement becomes even more critical. This is shown by the various manufacturers' performance. Results indicate there is room for improvement since not all survived the hot solder immersion without compromise to lower reliability.

National Semiconductor

Recommended Soldering Profiles—Surface Mount

		Wave Solder	IR Profile	Vapor Phase
Ramp Up °C/sec	Maximum	6°C/sec	4°C/sec	24°C/sec
	Recommended	**4°C/sec***	**2°C/sec***	**2°C/sec**
	Minimum	**	**	**
ΔT	Maximum	135°C	N/A	N/A
	Recommended	**120°C**	**N/A**	**N/A**
	Minimum	110°C	N/A	N/A
Dwell Time ≥ 183°C	Maximum	N/A	85 seconds	85 seconds
	Recommended	**N/A**	**75 seconds***	**75 seconds***
	Minimum	N/A	30 seconds**	**
Solder Temperature	Maximum	260°C	240°C***	219°C
	Recommended	**240°C**	**215°C***	**215°C***
	Minimum	**	**	**
Dwell Time @ Max.	Maximum	4 seconds	10 seconds	75
	Recommended	**3 seconds**	**5 seconds**	**70 seconds**
	Minimum	**	1 second	**
Ramp Down °C/sec	Maximum	No Information	4°C/sec	4°C/sec
	Recommended	**4°C/sec**	**2°C/sec**	**2°C/sec**
	Minimum	No Information	**	**

Note: Temperature in degrees celcius. N/A = Not Applicable.

ΔT = The temperature differential between the final preheat stage and the soldering stage. Temperature measured at the component lead area.

*Will vary depending on board density, geometry, and package type.

**Will vary depending on package types, and board density.

***For plastic packages; ceramic packages maximum may be 250°C.

5

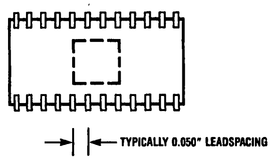
Small Outline (SO) Package Surface Mounting Methods-Parameters and Their Effect on Product Reliability

National Semiconductor
Application Note 450
Josip Huljev
W. K. Boey

The SO (small outline) package has been developed to meet customer demand for ever-increasing miniaturization and component density.

COMPONENT SIZE COMPARISON

S.O. Package



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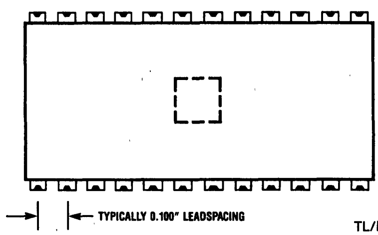
Standard DIP Package



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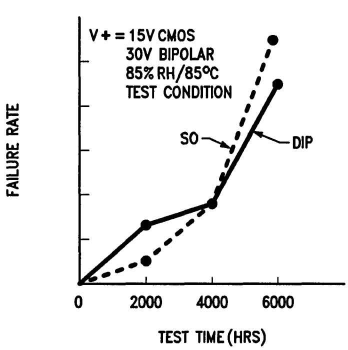
Because of its small size, reliability of the product assembled in SO packages needs to be carefully evaluated.

SO packages at National were internally qualified for production under the condition that they be of comparable reliability performance to a standard dual in line package under all accelerated environmental tests. *Figure A* is a summary of accelarated bias moisture test performance on 30V bipolar and 15V CMOS product assembled in SO and DIP (control) packages.



TL/F/8766–3

FIGURE A

In order to achieve reliability performance comparable to DIPs—SO packages are designed and built with materials and processes that effectively compensate for their small size.

All SO packages tested on 85%RA, 85°C were assembled on PC conversion boards using vapor-phase reflow soldering. With this approach we are able to measure the effect of surface mounting methods on reliability of the process. As illustrated in *Figure A* no significant difference was detected between the long term reliability performance of surface mounted S.O. packages and the DIP control product for up to 6000 hours of accelerated 85%/85°C testing.

SURFACE-MOUNT PROCESS FLOW

The standard process flowcharts for basic surface-mount operation and mixed-lead insertion/surface-mount operations, are illustrated on the following pages.

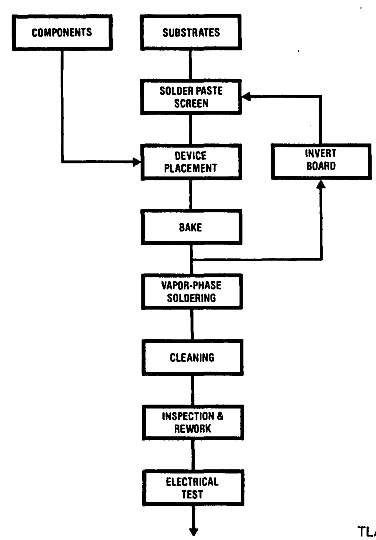
Usual variations encountered by users of SO packages are:

- Single-sided boards, surface-mounted components only.
- Single-sided boards, mixed-lead inserted and surface-mounted components.
- Double-sided boards, surface-mounted components only.
- Double-sided boards, mixed-lead inserted and surface-mounted components.

In consideration of these variations, it became necessary for users to utilize techniques involving wave soldering and adhesive applications, along with the commonly-used vapor-phase solder reflow soldering technique.

PRODUCTION FLOW

Basic Surface-Mount Production Flow



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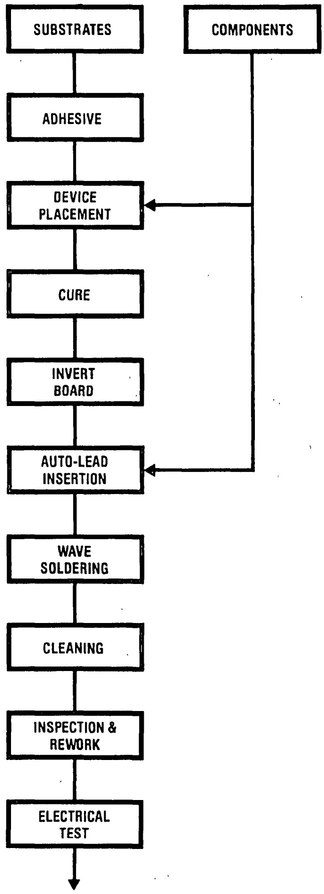
Mixed Surface-Mount and Axial-Leaded Insertion Components Production Flow



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Thermal stress of the packages during surface-mounting processing is more severe than during standard DIP PC board mounting processes. *Figure B* illustrates package temperature versus wave soldering dwell time for surface mounted packages (components are immersed into the molten solder) and the standard DIP wave soldering process. (Only leads of the package are immersed into the molten solder).

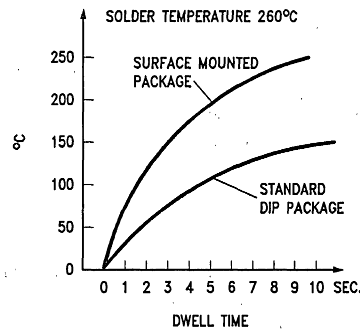

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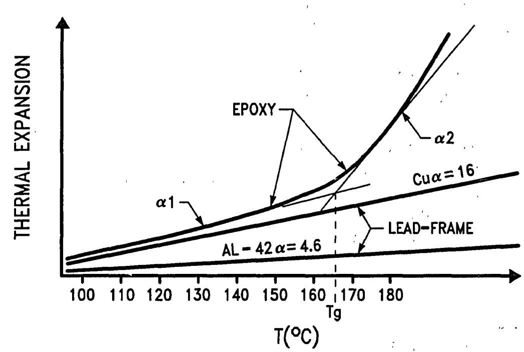
FIGURE B

For an ideal package, the thermal expansion rate of the encapsulant should match that of the leadframe material in order for the package to maintain mechanical integrity during the soldering process. Unfortunately, a perfect matchup of thermal expansion rates with most presently used packaging materials is scarce. The problem lies primarily with the epoxy compound.

Normally, thermal expansion rates for epoxy encapsulant and metal lead frame materials are linear and remain fairly close at temperatures approaching 160°C, *Figure C.* At lower temperatures the difference in expansion rate of the two materials is not great enough to cause interface separation. However, when the package reaches the glass-transition temperature (T_g) of epoxy (typically 160–165°C), the thermal expansion rate of the encapsulant increases sharply, and the material undergoes a transition into a plastic state. The epoxy begins to expand at a rate three times or more greater than the metal leadframe, causing a separation at the interface.



TL/F/8766–26

FIGURE C

When this happens during a conventional wave soldering process using flux and acid cleaners, process residues and even solder can enter the cavity created by the separation and become entrapped when the material cools. These contaminants can eventually diffuse into the interior of the package, especially in the presence of moisture. The result is die contamination, excessive leakage, and even catastrophic failure. Unfortunately, electrical tests performed immediately following soldering may not detect potential flaws.

Most soldering processes involve temperatures ranging up to 260°C, which far exceeds the glass-transition temperature of epoxy. Clearly, circuit boards containing SMD packages require tighter process controls than those used for boards populated solely by DIPs.

Figure D is a summary of accelerated bias moisture test performance on the 30V bipolar process.

Group 1 — Standard DIP package

Group 2 — SO packages vapor-phase reflow soldered on PC boards

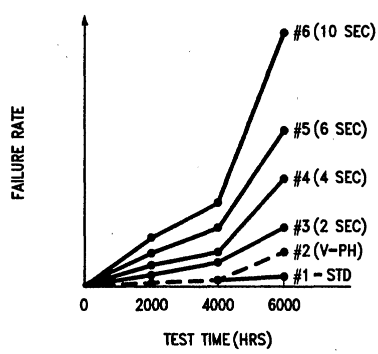
Group 3–6 SO packages wave soldered on PC boards

Group 3 — dwell time 2 seconds

4 — dwell time 4 seconds

5 — dwell time 6 seconds

6 — dwell time 10 seconds



TL/F/8766-7

FIGURE D

It is clear based on the data presented that SO packages soldered onto PC boards with the vapor phase reflow process have the best long term bias moisture performance and this is comparable to the performance of standard DIP packages. The key advantage of reflow soldering methods is the clean environment that minimized the potential for contamination of surface mounted packages, and is preferred for the surface-mount process.

When wave soldering is used to surface mount components on the board, the dwell time of the component under molten solder should be no more than 4 seconds, preferrably under 2 seconds in order to prevent damage to the component. Non-Halide, or (organic acid) fluxes are highly recommended.

PICK AND PLACE

The choice of automatic (all generally programmable) pick-and-place machines to handle surface mounting has grown considerably, and their selection is based on individual needs and degree of sophistication.

The basic component-placement systems available are classified as:

(a) In-line placement
- — Fixed placement stations
- — Boards indexed under head and respective components placed

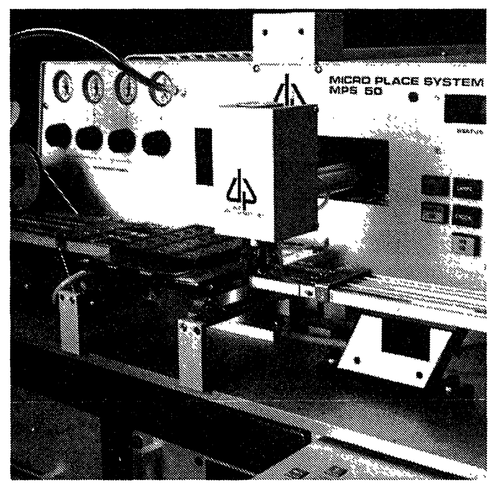
(b) Sequential placement
- — Either a X-Y moving table system or a θ, X-Y moving pickup system used
- —Individual components picked and placed onto boards

(c) Simultaneous placement
- — Multiple pickup heads
- — Whole array of components placed onto the PCB at the same time

(d) Sequential/simultaneous placement
- — X–Y moving table, multiple pickup heads system
- — Components placed on PCB by successive or simultaneous actuation of pickup heads

The SO package is treated almost the same as surface-mount, passive components requiring correct orientation in placement on the board.

Pick and Place Action



TL/F/8766-8

BAKE

This is recommended, despite claims made by some solder paste suppliers that this step be omitted.

The functions of this step are:

- Holds down the solder globules during subsequent reflow soldering process and prevents expulsion of small solder balls.
- Acts as an adhesive to hold the components in place during handling between placement to reflow soldering.
- Holds components in position when a double-sided surface-mounted board is held upside down going into a vapor-phase reflow soldering operation.
- Removes solvents which might otherwise contaminate other equipment.
- Initiates activator cleaning of surfaces to be soldered.
- Prevents moisture absorption.

The process is moreover very simple. The usual schedule is about 20 minutes in a 65°C–95°C (dependent on solvent system of solder paste) oven with adequate venting. Longer bake time is not recommended due to the following reasons:

- The flux will degrade and affect the characteristics of the paste.
- Solder globules will begin to oxidize and cause solderability problems.
- The paste will creep and after reflow, may leave behind residues between traces which are difficult to remove and vulnerable to electro-migration problems.

REFLOW SOLDERING

There are various methods for reflowing the solder paste, namely:

- Hot air reflow
- Infrared heating (furnaces)
- Convectional oven heating
- Vapor-phase reflow soldering
- Laser soldering

For SO applications, hot air reflow/infrared furnace may be used for low-volume production or prototype work, but vapor-phase soldering reflow is more efficient for consistency and speed. Oven heating is not recommended because of "hot spots" in the oven and uneven melting may result. Laser soldering is more for specialized applications and requires a great amount of investment.

HOT GAS REFLOW/INFRARED HEATING

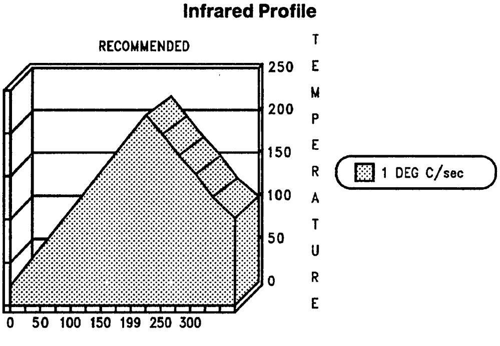
A hand-held or table-mount air blower (with appropriate orifice mask) can be used.

The boards are preheated to about 100°C and then subjected to an air jet at about 260°C. This is a slow process and results may be inconsistent due to various heat-sink properties of passive components.

INFRARED REFLOW SOLDERING

Use of an infrared furnace is currently the most popular method to automate mass reflow, the heating is promoted by use of IR lamps or panels. Early objections to this method were that certain materials may heat up at different rates under IR radiation and could result in damage to those components (usually sockets and connectors). This has been minimized by using far-infrared (non-focused) systems and convected air.

Infrared Profile



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VAPOR-PHASE REFLOW SOLDERING

Currently the most popular and consistent method, vapor-phase soldering utilizes a fluoroinert fluid with excellent heat-transfer properties to heat up components until the solder paste reflows. The maximum temperature is limited by the vapor temperature of the fluid.

The commonly used fluids (supplied by 3M Corp) are:

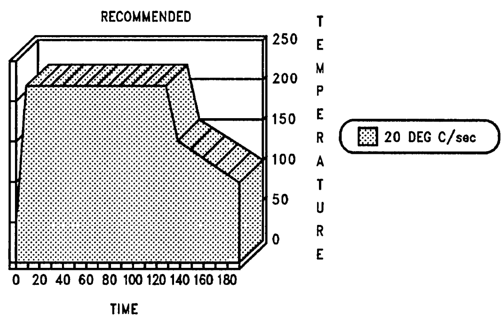
- FC-70, 215°C vapor (most applications) or FX-38
- FC-71, 253°C vapor (low-lead or tin-plate)

HTC, Concord, CA, manufactures equipment that utilizes this technique, with two options:

- Batch systems, where boards are lowered in a basket and subjected to the vapor from a tank of boiling fluid.
- In-line conveyorized systems, where boards are placed onto a continuous belt which transports them into a concealed tank where they are subjected to an environment of hot vapor.

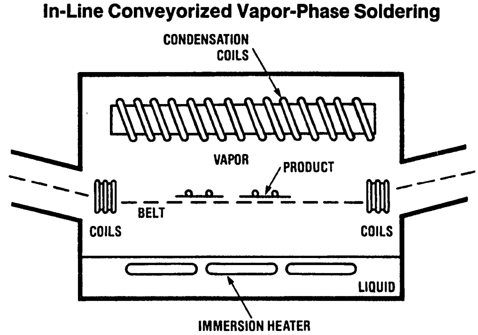
Dwell time in the vapor is generally on the order of 15–30 seconds (depending on the mass of the boards and the loading density of boards on the belt).

Vapor-Phase Profile



TL/F/8766-28

In-Line Conveyorized Vapor-Phase Soldering



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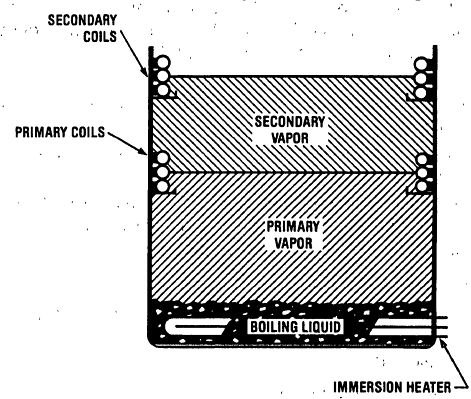
The question of thermal shock is asked frequently because of the relatively sharp increase in component temperature from room temperature to 215°C. SO packages mounted on representative boards have been tested and have shown little effect on the integrity of the packages. Various packages, such as cerdips, metal cans and TO-5 cans with glass seals, have also been tested.

Vapor-Phase Furnace

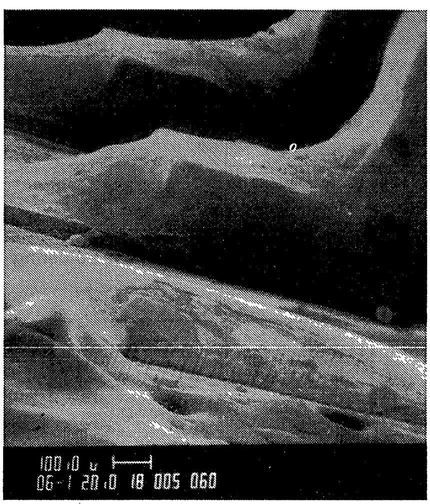
TL/F/8766-10

Batch-Fed Production Vapor-Phase Soldering Unit



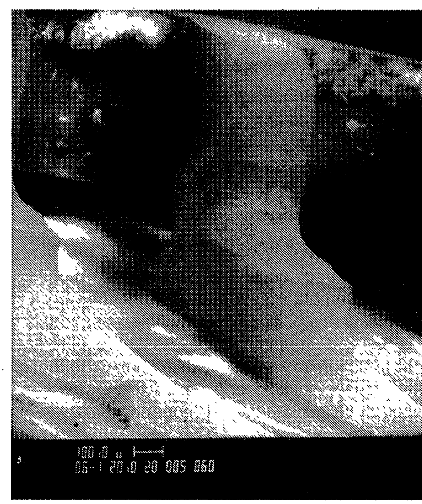
TL/F/8766-11

Solder Joints on a SO-14 Package on PCB



TL/F/8766-12

Solder Joints on a SO-14 Package on PCB



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PRINTED CIRCUIT BOARD

The SO package is molded out of clean, thermoset plastic compound and has no particular compatibility problems with most printed circuit board substrates.

The package can be reliably mounted onto substrates such as:

- G10 or FR4 glass/resin
- FR5 glass/resin systems for high-temperature applications
- Polymide boards, also high-temperature applications
- Ceramic substrates

General requirements for printed circuit boards are:

- Mounting pads should be solder-plated whenever applicable.
- Solder masks are commonly used to prevent solder bridging of fine lines during soldering.

  The mask also protects circuits from processing chemical contamination and corrosion.

  If coated over pre-tinned traces, residues may accumulate at the mask/trace interface during subsequent reflow, leading to possible reliability failures.

  Recommended application of solder resist on bare, clean traces prior to coating exposed areas with solder.

  General requirements for solder mask:

  — Good pattern resolution.

  — Complete coverage of circuit lines and resistance to flaking during soldering.

  — Adhesion should be excellent on substrate material to keep off moisture and chemicals.

  — Compatible with soldering and cleaning requirements.

SOLDER PASTE SCREEN PRINTING

With the initial choice of printed circuit lithographic design and substrate material, the first step in surface mounting is the application of solder paste.

The typical lithographic "footprints" for SO packages are illustrated below. Note that the 0.050" lead center-center spacing is not easily managed by commercially-available air pressure, hand-held dispensers.

Using a stainless-steel, wire-mesh screen stencilled with an emulsion image of the substrate pads is by far the most common and well-tried method. The paste is forced through the screen by a V-shaped plastic squeegee in a sweeping manner onto the board placed beneath the screen.

The setup for SO packages has no special requirement from that required by other surface-mounted, passive components. Recommended working specifications are:

- Use stainless-steel, wire-mesh screens, #80 or #120, wire diameter 2.6 mils. Rule of thumb: mesh opening should be approximately 2.5–5 times larger than the average particle size of paste material.
- Use squeegee of Durometer 70.
- Experimentation with squeegee travel speed is recommended, if available on machine used.
- Use solder paste of mesh 200–325.
- Emulsion thickness of 0.005" usually used to achieve a solder paste thickness (wet) of about 0.008" typical.
- Mesh pattern should be 90 degrees, square grid.
- Snap-off height of screen should not exceed ⅛", to avoid damage to screens and minimize distortion.

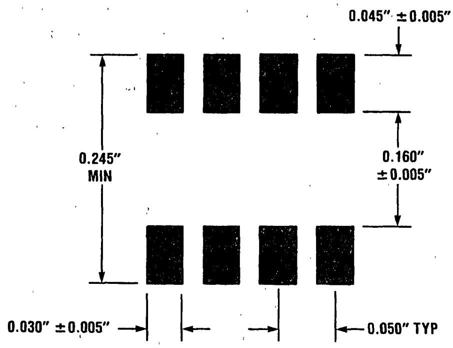
SOLDER PASTE

Selection of solder paste tends to be confusing, due to numerous formulations available from various manufacturers. In general, the following guidelines are sufficient to qualify a particular paste for production:

- Particle sizes (see following photographs). Mesh 325 (approximately 45 microns) should be used for general purposes, while larger (solder globules) particles are preferred for leadless components (LCC). The larger particles can easily be used for SO packages.
- Uniform particle distribution. Solder globules should be spherical in shape with uniform diameters and minimum amount of elongation (visual under 100/200 × magnification). Uneven distribution causes uneven melting and subsequent expulsion of smaller solder balls away from their proper sites.
- Composition, generally 60/40 or 63/37 Sn/Pb. Use 62/36 Sn/Pb with 2% Ag in the presence of Au on the soldering area. This formulation reduces problems of metal leaching from soldering pads.
- RMA flux system usually used.
- Use paste with aproximately 88–90% solids.

RECOMMENDED SOLDER PADS FOR SO PACKAGES

SO-8, SO-14, SO-16



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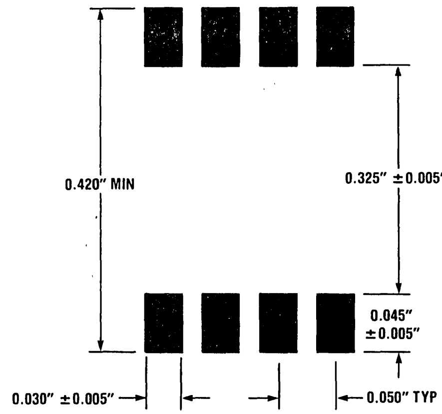
SO-16L, SO-20



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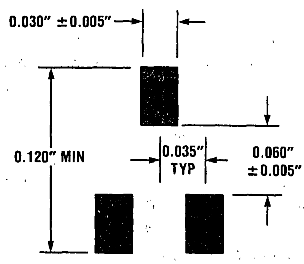
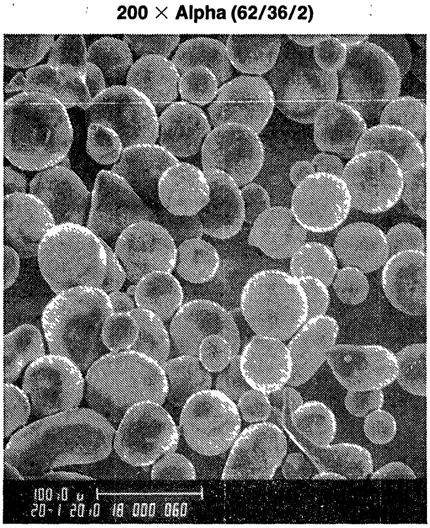
SOT-23



TL/F/8766–16

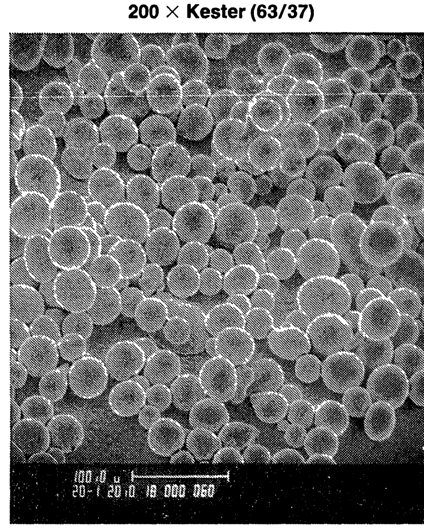
Comparison of Particle Size/Shape of Various Solder Pastes

200 × Alpha (62/36/2)



TL/F/8766–17

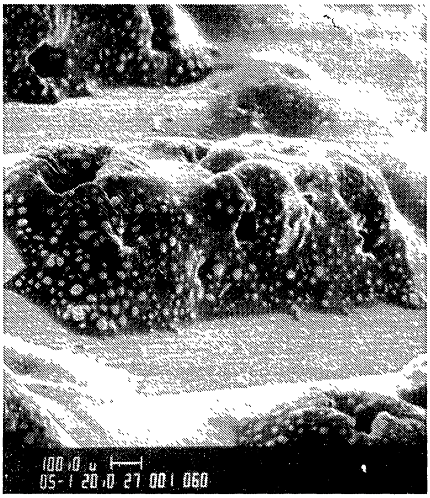
200 × Kester (63/37)



TL/F/8766–18

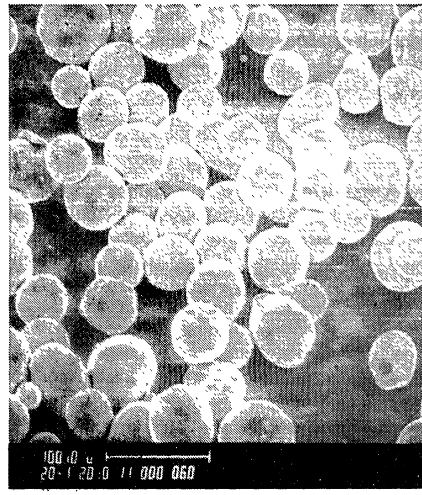
Comparison of Particle Size/Shape of Various Solder Pastes (Continued)

Solder Paste Screen on Pads



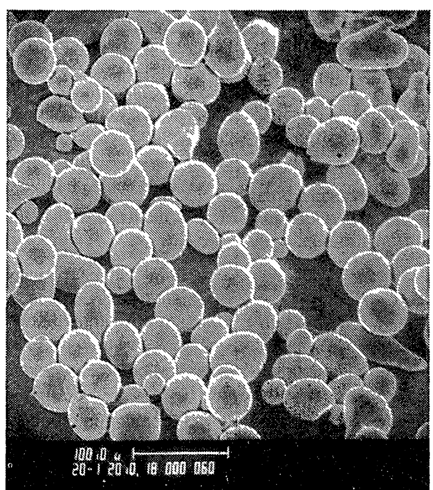
TL/F/8766–19

200 × Fry Metal (63/37)



TL/F/8766–20

200 ESL (63/37)



TL/F/8766–21

CLEANING

The most critical process in surface mounting SO packages is in the cleaning cycle. The package is mounted very close to the surface of the substrate and has a tendency to collect residue left behind after reflow soldering.

Important considerations in cleaning are:

- Time between soldering and cleaning to be as short as possible. Residue should not be allowed to solidify on the substrate for long periods of time, making it difficult to dislodge.
- A low surface tension solvent (high penetration) should be employed. CFC solvents are being phased out as they are hazardous to the environment. Other approaches to cleaning are commercially available and should be investigated on an individual basis considering local and government environmental rules.

    Prelete or 1,1,1-Trichloroethane
    Kester 5120/5121
- A defluxer system which allows the workpiece to be subjected to a solvent vapor, followed by a rinse in pure solvent and a high-pressure spray lance are the basic requirments for low-volume production.
- For volume production, a conveyorized, multiple hot solvent spray/jet system is recommended.
- Rosin, being a natural occurring material, is not readily soluble in solvents, and has long been a stumbling block to the cleaning process. In recent developments, synthetic flux (SA flux), which is readily soluble in Freon TMS solvent, has been developed. This should be explored where permissible.

The dangers of an inadequate cleaning cycle are:

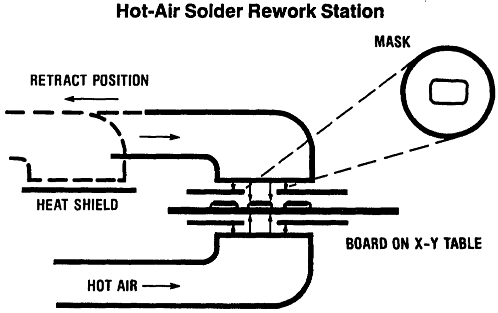
- Ion contamination, where ionic residue left on boards would cause corrosion to metallic components, affecting the performance of the board.
- Electro-migration, where ionic residue and moisture present on electrically-biased boards would cause dentritic growth between close spacing traces on the substrate, resulting in failures (shorts).

REWORK

Should there be a need to replace a component or re-align a previously disturbed component, a hot air system with appropriate orifice masking to protect surrounding components may be used.

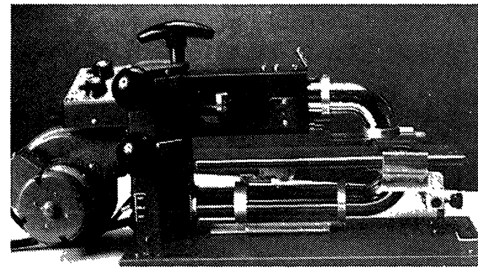
When rework is necessary in the field, specially-designed tweezers that thermally heat the component may be used to remove it from its site. The replacement can be fluxed at the

Hot-Air Solder Rework Station



TL/F/8766-22

Hot-Air Rework Machine



TL/F/8766-23

lead tips or, if necessary, solder paste can be dispensed onto the pads using a varimeter. After being placed into position, the solder is reflowed by a hot-air jet or even a standard soldering iron.

WAVE SOLDERING

In a case where lead insertions are made on the same board as surface-mounted components, there is a need to include a wave-soldering operation in the process flow.

Two options are used:

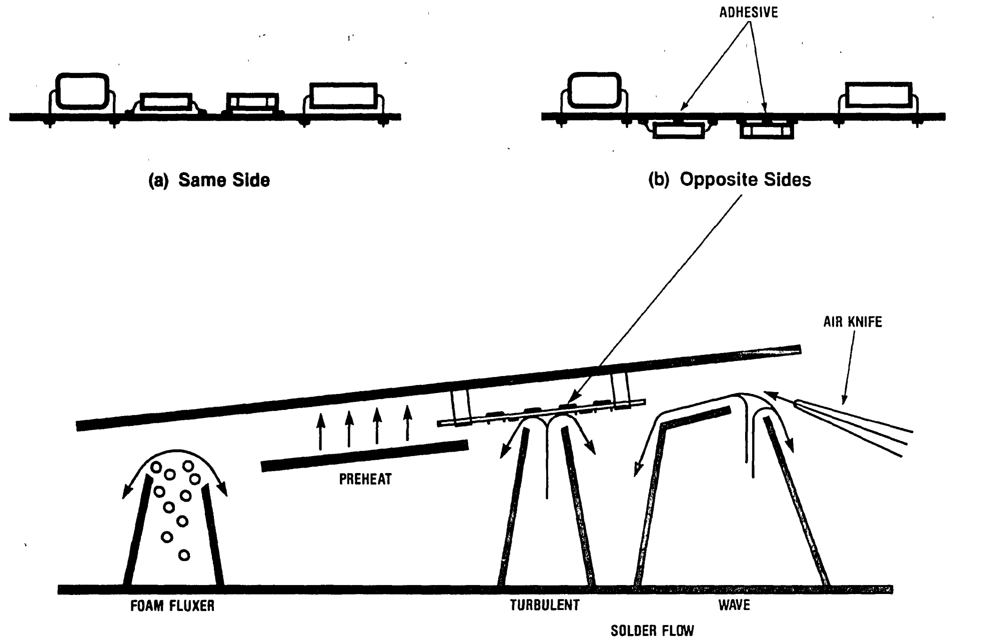
- Surface mounted components are placed and vapor phase reflowed before auto-insertion of remaining components. The board is carried over a standard wave-solder system and the underside of the board (only lead-inserted leads) soldered.
- Surface-mounted components are placed in position, but no solder paste is used. Instead, a drop of adhesive about 5 mils maximum in height with diameter not exceeding 25% width of the package is used to hold down the package. The adhesive is cured and then proceeded to auto-insertion on the reverse side of the board (surface-mounted side facing down). The assembly is then passed over a "dual wave" soldering system. Note that the surface-mounted components are immersed into the molten solder.

Lead trimming will pose a problem after soldering in the latter case, unless the leads of the insertion components are pre-trimmed or the board specially designed to localize certain areas for easy access to the trim blade.

The controls required for wave soldering are:

- Solder temperature to be 240–260°C. The dwell time of components under molten solder to be short (preferably kept under 2 seconds), to prevent damage to most components and semiconductor devices.
- RMA (Rosin Mildly Activated) flux or more aggressive OA (Organic Acid) flux are applied by either dipping or foam fluxing on boards prior to preheat and soldering. Cleaning procedures are also more difficult (aqueous, when OA flux is used), as the entire board has been treated by flux (unlike solder paste, which is more or less localized). Non-halide OA fluxes are highly recommended.
- Preheating of boards is essential to reduce thermal shock on components. Board should reach a temperature of about 100°C just before entering the solder wave.
- Due to the closer lead spacings (0.050″ vs 0.100″ for dual-in-line packages), bridging of traces by solder could occur. The reduced clearance between packages also causes "shadowing" of some areas, resulting in poor solder coverage. This is minimized by dual-wave solder systems.

Mixed Surface Mount and Lead Insertion



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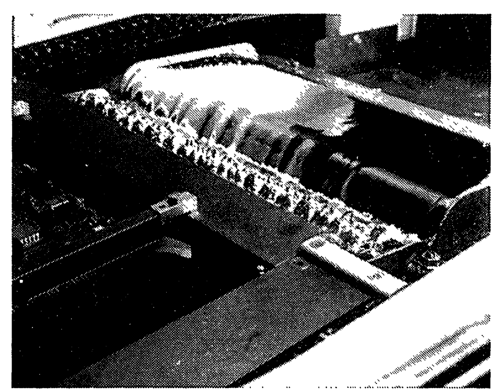
A typical dual-wave system is illustrated below, showing the various stages employed. The first wave typically is in turbulence and given a transverse motion (across the motion of the board). This covers areas where "shadowing" occurs. A second wave (usually a broad wave) then proceeds to perform the standard soldering. The departing edge from the solder is such to reduce "icicles," and is still further reduced by an air knife placed close to the final soldering step. This air knife will blow off excess solder (still in the fluid stage) which would otherwise cause shorts (bridging) and solder bumps.

AQUEOUS CLEANING

- For volume production, a conveyorized system is often used with a heated recirculating spray wash (water temperature 130°C), a final spray rinse (water temperature 45–55°C), and a hot (120°C) air/air-knife drying section.
- For low-volume production, the above cleaning can be done manually, using several water rinses/tanks. Fast-drying solvents, like alcohols that are miscible with water, are sometimes used to help the drying process.
- Neutralizing agents which will react with the corrosive materials in the flux and produce material readily soluble in water may be used; the choice depends on the type of flux used.
- Final rinse water should be free from chemicals which are introduced to maintain the biological purity of the water. These materials, mostly chlorides, are detrimental to the assemblies cleaned because they introduce a fresh amount of ionizable material.

Dual Wave



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CONFORMAL COATING

Conformal coating is recommended for high-reliability PCBs to provide insulation resistance, as well as protection against contamination and degradation by moisture.

Requirements:

- Complete coating over components and solder joints.
- Thixotropic material which will not flow under the packages or fill voids, otherwise will introduce stress on solder joints on expansion.
- Compatibility and possess excellent adhesion with PCB material/components.
- Silicones are recommended where permissible in application.

SMD Lab Support

FUNCTIONS

Demonstration—Introduce first-time users to surface-mounting processes.

Service—Investigate problems experienced by users on surface mounting.

Reliability Builds—Assemble surface-mounted units for reliability data acquisition.

Techniques—Develop techniques for handling different materials and processes in surface mounting.

Equipment—In conjunction with equipment manufacturers, develop customized equipments to handle high density, new technology packages developed by National.

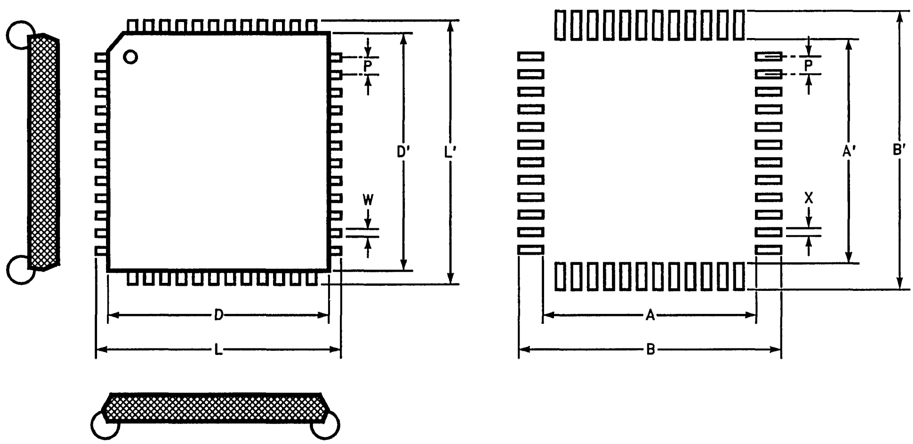
In-House Expertise—Availability of in-house expertise on semiconductor research/development to assist users on packaging queries.

National Semiconductor

Land Pattern Recommendations

The following land pattern recommendations are provided as guidelines for board layout and assembly purposes.
These recommendations cover the following National Semiconductor packages: PLCC, PQFP, SOP, SSOP and TSOP.
For SOT-23 (5-Lead) and TO-263 (3- or 5-Lead) packages, refer to land patterns shown in the Physical Dimensions for MA05A and TS3B or TS5B packages, respectively.

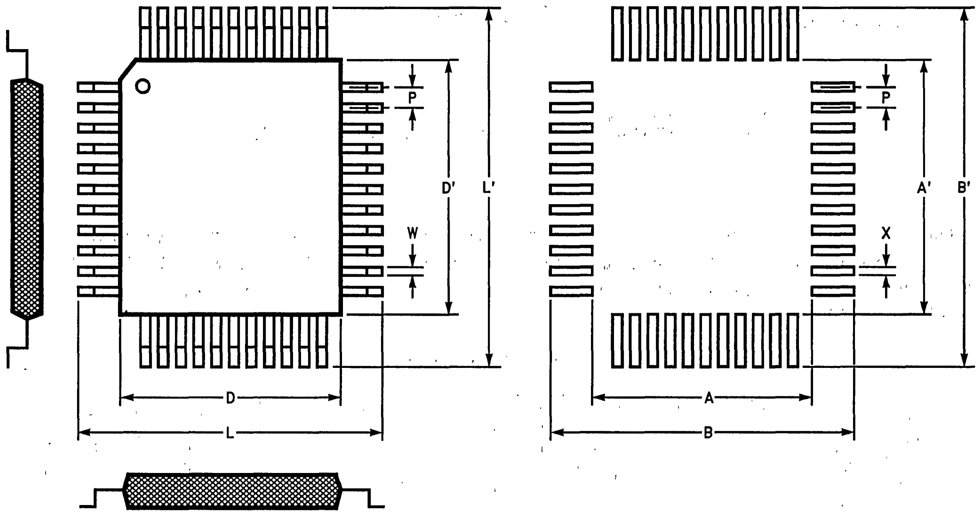
Plastic Leaded Chip Carriers (PLCC)



TL/P/11811-1

D Body Size (mm)	D' Body Size (mm)	Lead Count No.	L Lead Tip to Tip (mm)	L' Lead Tip to Tip (mm)	W Lead Width (mm)	P Lead/Pad Pitch (mm)	A Inner Pad to Pad Edge (mm)	A' Inner Pad to Pad Edge (mm)	B Outer Pad to Pad Edge (mm)	B' Outer Pad to Pad Edge (mm)	X Land Width (mm)
8.89	8.89	20	10.03	10.03	0.53	1.27	6.73	6.73	10.80	10.80	0.63
11.43	11.43	28	12.57	12.57	0.53	1.27	9.27	9.27	13.34	13.34	0.63
11.43	14.05	32	12.57	15.11	0.53	1.27	9.27	12.00	13.34	16.00	0.63
16.51	16.51	44	17.65	17.65	0.53	1.27	14.35	14.35	18.42	18.42	0.63
19.05	19.05	52	20.19	20.19	0.53	1.27	16.89	16.89	20.96	20.96	0.63
24.13	24.13	68	25.27	25.27	0.53	1.27	21.97	21.97	26.04	26.04	0.63
29.21	29.21	84	30.35	30.35	0.53	1.27	27.05	27.05	31.12	31.12	0.63

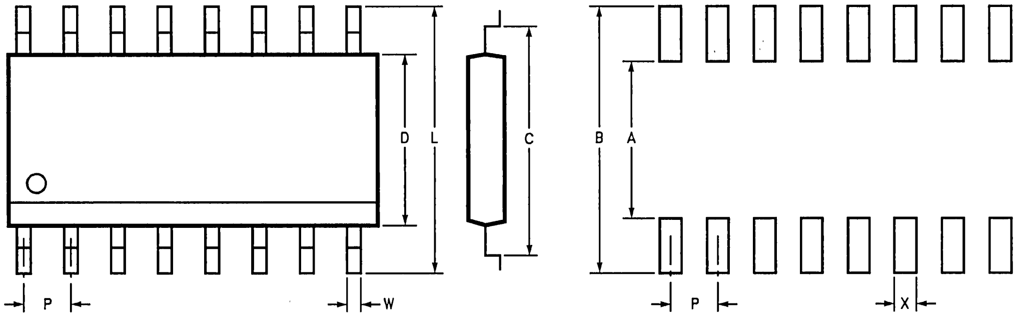
Plastic Quad Flat Packages (PQFP)



TL/P/11811-2

D Body Size (mm)	D' Body Size (mm)	Lead Count No.	L Lead Tip to Tip (mm)	L' Lead Tip to Tip (mm)	W Lead Width (mm)	P Lead/Pad Pitch (mm)	A Inner Pad to Pad Edge (mm)	A' Inner Pad to Pad Edge (mm)	B Outer Pad to Pad Edge (mm)	B' Outer Pad to Pad Edge (mm)	X Land Width (mm)
7	7	40	9.29	9.29	0.26	0.50	7.50	7.50	9.78	9.78	0.30
7	7	48	9.40	9.40	0.27	0.50	6.88	6.90	10.42	10.40	0.32
10	10	44	13.35	13.35	0.45	0.80	10.53	10.53	14.47	14.47	0.55
10	10	52	14.15	14.15	0.38	0.65	9.08	9.08	15.17	15.17	0.43
12	12	64	14.00	14.00	0.38	0.65	11.48	11.48	15.02	15.02	0.43
14	14	80	18.15	18.15	0.38	0.65	13.08	13.08	19.17	19.17	0.43
14	20	80	17.80	23.80	0.35	0.80	13.50	19.50	18.50	24.50	0.40
14	14	100	17.45	17.45	0.30	0.50	13.08	13.08	18.47	18.47	0.35
14	20	100	17.80	23.80	0.30	0.65	13.50	19.50	18.50	24.50	0.35
20	20	100	24.30	18.30	0.40	0.65	21.28	15.28	25.32	19.32	0.45
24	24	132	24.21	24.21	0.30	0.64	21.67	21.67	25.23	25.23	0.40
28	28	120	32.15	32.15	0.45	0.80	27.88	27.88	33.17	33.17	0.55
28	28	128	31.45	31.45	0.45	0.80	28.03	28.03	32.47	32.47	0.55
28	28	144	32.15	32.15	0.38	0.65	28.03	28.03	33.17	33.17	0.43
28	28	160	32.40	32.40	0.38	0.65	29.48	29.48	33.42	33.42	0.43
28	28	208	30.60	30.60	0.30	0.50	28.08	28.08	31.62	31.62	0.35

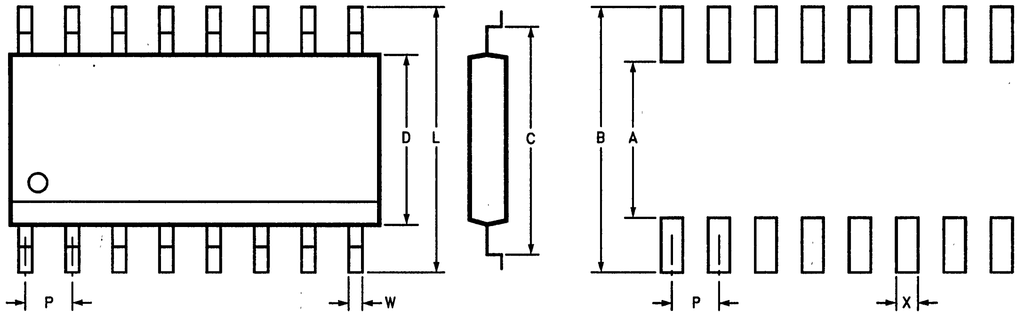
JEDEC Small Outline and Shrink Small Outline Packages (SOP and SSOP)



TL/P/11811-3

D Body Size (in)	Lead Count No.	C Shoulder to Shoulder (in)	L Lead Tip to Tip (in)	W Lead Width (in)	P Lead/Pad Pitch (in)	A Inner Pad to Pad Edge (in)	B Outer Pad to Pad Edge (in)	X Pad Width (in)
SOP								
0.150	8	0.144	0.244	0.020	0.050	0.094	0.294	0.028
0.150	14	0.144	0.244	0.020	0.050	0.094	0.294	0.028
0.150	16	0.144	0.244	0.020	0.050	0.094	0.294	0.028
0.300	14	0.3300	0.4100	0.0190	0.0500	0.2800	0.4600	0.0270
0.300	16	0.3300	0.4100	0.0190	0.0500	0.2800	0.4600	0.0270
0.300	20	0.3300	0.4100	0.0190	0.0500	0.2800	0.4600	0.0270
0.300	24	0.3300	0.4100	0.0190	0.0500	0.2800	0.4600	0.0270
0.300	28	0.3300	0.4100	0.0190	0.0500	0.2800	0.4600	0.0270
SSOP								
0.150	20	0.185	0.241	0.010	0.025	0.145	0.281	0.014
0.150	24	0.185	0.241	0.010	0.025	0.145	0.281	0.014
0.300	48	0.340	0.420	0.012	0.025	0.300	0.460	0.016
0.300	56	0.340	0.420	0.012	0.025	0.300	0.460	0.016

EIAJ Small Outline, Shrink Small Outline, and Thin Small Outline Packages (SOP, SSOP and TSOP)



TL/P/11811-4

D Body Size (mm)	Lead Count No.	C Shoulder to Shoulder (mm)	L Lead Tip to Tip (mm)	W Lead Width (mm)	P Lead/Pad Pitch (mm)	A Inner Pad to Pad Edge (mm)	B Outer Pad to Pad Edge (mm)	X Pad Width (mm)
SOP TYPE II								
5.300	14	6.280	8.000	0.400	1.270	5.010	9.270	0.600
5.300	16	6.280	8.000	0.400	1.270	5.010	9.270	0.600
5.300	20	6.280	8.000	0.400	1.270	5.010	9.270	0.600
SSOP TYPE II								
5.300	20	6.600	8.100	0.400	0.650	5.584	9.116	0.451
5.300	24	6.600	8.100	0.400	0.650	5.584	9.116	0.451
SSOP TYPE III								
7.500	40	8.900	10.500	0.350	0.650	7.884	11.516	0.452
TSOP TYPE I								
18.500	32	19.000	20.200	0.250	0.500	17.984	21.216	0.301

Section 6
Appendices/
Physical Dimensions

Section 6 Contents

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Appendix A
General Product Marking & Code Explanation

LF 356 N /A+

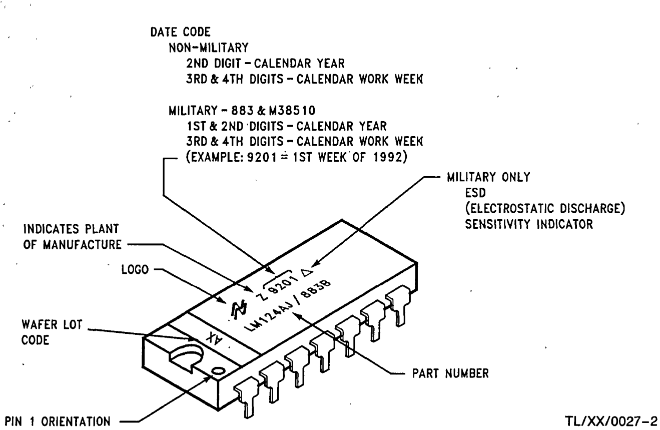
- /A+ — Reliability Program (Optional) (Refer to Appendix C)
- N — Package Type (See Right)
- 356 — Device Number (Generic Type) and Suffix Letter (Optional)
  - A or B: Improved Electrical Specification
  - C, I, E or M: Temperature Range
- LF — Device Family (See Below)

Device Family

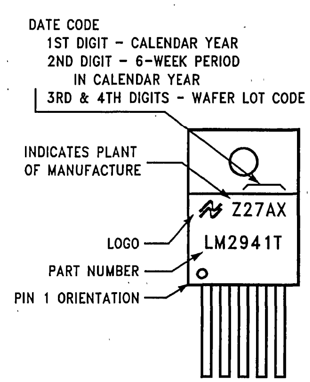
ADC	Data Conversion
AF	Active Filter
AH	Analog Switch (Hybrid)
DAC	Data Conversion
DM	Digital (Monolithic)
HS	Hybrid
LF	Linear (BI-FET™)
LH	Linear (Hybrid)
LM	Linear (Monolithic)
LMC	Linear CMOS
LMD	Linear DMOS
LP	Linear (Low Power)
LPC	Linear CMOS (Low Power)
MF	Linear (Monolithic Filter)
LMF	Linear Monolithic Filter

Package Type

D	Glass/Metal DIP
E	Ceramic Leadless Chip Carrier (LCC)
F	Glass/Metal Flat Pak (¼″ x ¼″)
G	12 Lead TO-8 Metal Can (M/C)
H	Multi-Lead Metal Can (M/C)
H-05	4 Lead M/C (TO-5) } Shipped with Thermal Shield
H-46	4 Lead M/C (TO-46) } Shipped with Thermal Shield
J	Lo-Temp Ceramic DIP
J-8	8 Lead Ceramic DIP ("MiniDIP")
J-14	14 Lead Ceramic DIP (-14 used only when product is also available in -8 pkg).
K	TO-3 M/C in Steel, except LM309K which is shipped in Aluminum
KC	TO-3 M/C (Aluminum)
K Steel	TO-3 M/C (Steel)
M	Small Outline Package
M3	3-Lead Small Outline Package
M5	5-Lead Small Outline Package
N	Molded DIP (EPOXY B)
N-01	Molded DIP (Epoxy B) with Staggered Leads
N-8	8 Lead Molded DIP (Epoxy B) ("Mini-DIP")
N-14	14 Lead Molded DIP (Epoxy B) (-14 used only when product is also available in -8 pkg).
P	3 Lead TO-202 Power Pkg
Q	Cerdip with UV Window
S	3,5,11, & 15 Lead TO-263 Surf. Mt. Power Pkg
T	3,5,11,15 & 23 Lead TO-220 PWR Pkg (Epoxy B)
V	Multi-lead Plastic Chip Carrier (PCC)
W	Lo-Temp Ceramic Flat Pak
WM	Wide Body Small Outline Package



TL/XX/0027-2



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National Semiconductor

Appendix B
Device/Application Literature Cross-Reference

Device Number	Application Literature
ADCXXXX	AN-156
ADC80	AN-360
ADC0801	AN-233, AN-271, AN-274, AN-280, AN-281, AN-294, LB-53
ADC0802	AN-233, AN-274, AN-280, AN-281, LB-53
ADC0803	AN-233, AN-274, AN-280, AN-281, LB-53
ADC08031	AN-460
ADC0804	AN-233, AN-274, AN-276, AN-280, AN-281, AN-301, AN-460, LB-53
ADC0805	AN-233, AN-274, AN-280, AN-281, LB-53
ADC0808	AN-247, AN-280, AN-281
ADC0809	AN-247, AN-280
ADC0816	AN-193, AN-247, AN-258, AN-280
ADC0817	AN-247, AN-258, AN-280
ADC0820	AN-237
ADC0831	AN-280, AN-281
ADC0832	AN-280, AN-281
ADC0833	AN-280, AN-281
ADC0834	AN-280, AN-281
ADC0838	AN-280, AN-281
ADC1001	AN-276, AN-280, AN-281
ADC1005	AN-280
ADC10461	AN-769
ADC10462	AN-769
ADC10464	AN-769
ADC10662	AN-769
ADC10664	AN-769
ADC12030	AN-929
ADC12032	AN-929
ADC12034	AN-929
ADC12038	AN-929
ADC12H030	AN-929
ADC12H032	AN-929
ADC12H034	AN-929
ADC12H038	AN-929
ADC12L030	AN-929
ADC12L032	AN-929
ADC12L034	AN-929
ADC12L038	AN-929
ADC1210	AN-245
ADC12441	AN-769
ADC12451	AN-769
DACXXXX	AN-156
DAC0800	AN-693
DAC0830	AN-284

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
DAC0831	AN-271, AN-284
DAC0832	AN-271, AN-284
DAC1006	AN-271, AN-275, AN-277, AN-284
DAC1007	AN-271, AN-275, AN-277, AN-284
DAC1008	AN-271, AN-275, AN-277, AN-284
DAC1020	AN-263, AN-269, AN-2293, AN-294, AN-299
DAC1021	AN-269
DAC1022	AN-269
DAC1208	AN-271, AN-284
DAC1209	AN-271, AN-284
DAC1210	AN-271, AN-284
DAC1218	AN-293
DAC1219	AN-693
DAC1220	AN-253, AN-269
DAC1221	AN-269
DAC1222	AN-269
DAC1230	AN-284
DAC1231	AN-271, AN-284
DAC1232	AN-271, AN-284
DAC1280	AN-261, AN-263
DH0034	AN-253
DH0035	AN-49
INS8070	AN-260
LF111	LB-39
LF155	AN-263, AN-447
LF198	AN-245, AN-294
LF311	AN-301
LF347	AN-256, AN-262, AN-263, AN-265, AN-266, AN-301, AN-344, AN-447, LB-44
LF351	AN-242, AN-263, AN-266, AN-271, AN-275, AN-293, AN-447, Appendix C
LF351A	AN-240
LF351B	Appendix D
LF353	AN-256, AN-258, AN-262, AN-263, AN-266, AN-271, AN-285, AN-293, AN-447, LB-44, Appendix D
LF356	AN-253, AN-258, AN-260, AN-263, AN-266, AN-271, AN-272, AN-275, AN-293, AN-294, AN-295, AN-301, AN-447, AN-693
LF357	AN-263, AN-447, LB-42
LF398	AN-247, AN-258, AN-266, AN-294, AN-298, LB-45
LF411	AN-294, AN-301, AN-344, AN-447
LF412	AN-272, AN-299, AN-301, AN-344, AN-447
LF441	AN-301, AN-447
LF13006	AN-344
LF13007	AN-344
LF13331	AN-294, AN-447
LH0002	AN-13, AN-227, AN-263, AN-272, AN-301
LH0024	AN-253
LH0032	AN-242, AN-253
LH0033	AN-48, AN-227, AN-253
LH0063	AN-227
LH0070	AN-301
LH0071	AN-245
LH0094	AN-301
LH0101	AN-261

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LH1605	AN-343
LH2424	AN-867
LM10	AN-211, AN-247, AN-258, AN-271, AN-288, AN-299, AN-300, AN-460, AN-693
LM11	AN-241, AN-242, AN-260, AN-266, AN-271
LM12	AN-446, AN-693, AN-706
LM101	AN-4, AN-13, AN-20, AN-24, LB-42, Appendix A
LM101A	AN-29, AN-30, AN-31, AN-79, AN-241 AN-711, LB-1, LB-2, LB-4, LB-8, LB-14, LB-16, LB-19, LB-28
LM102	AN-4, AN-13, AN-30, LB-1, LB-5, LB-6, LB-11
LM103	AN-110, LB-41
LM105	AN-23, AN-110, LB-3
LM106	AN-41, LB-6, LB-12
LM107	AN-20, AN-31, LB-1, LB-12, LB-19, Appendix A
LM108	AN-29, AN-30, AN-31, AN-79, AN-211, AN-241, LB-14, LB-15, LB-21
LM108A	AN-260, LB-15, LB-19
LM109	AN-42, LB-15
LM109A	LB-15
LM110	LB-11, LB-42
LM111	AN-41, AN-103, LB-12, LB-16, LB-32, LB-39
LM112	LB-19
LM113	AN-56, AN-110, LB-21, LB-24, LB-28, LB-37
LM117	AN-178, AN-181, AN-182, LB-46, LB-47
LM117HV	LB-46, LB-47
LM118	LB-17, LB-19, LB-21, LB-23, Appendix A
LM119	LB-23
LM120	AN-182
LM121	AN-79, AN-104, AN-184, AN-260, LB-22
LM121A	LB-32
LM122	AN-97, LB-38
LM125	AN-82
LM126	AN-82
LM129	AN-173, AN-178, AN-262, AN-266
LM131	AN-210, AN-460, Appendix D
LM131A	AN-210
LM134	LB-41, AN-460
LM135	AN-225, AN-262, AN-292, AN-298, AN-460
LM137	LB-46
LM137HV	LB-46
LM138	LB-46
LM139	AN-74
LM143	AN-127, AN-271
LM148	AN-260
LM150	LB-46
LM158	AN-116
LM160	AN-87
LM161	AN-87, AN-266
LM163	AN-295
LM194	AN-222, LB-21
LM195	AN-110
LM199	AN-161, AN-260
LM199A	AN-161
LM211	LB-39

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM231	AN-210
LM231A	AN-210
LM235	AN-225
LM239	AN-74
LM258	AN-116
LM260	AN-87
LM261	AN-87
LM34	AN-460
LM35	AN-460
LM301A	AN-178, AN-181, AN-222
LM308	AN-88, AN-184, AN-272, LB-22, LB-28, Appendix D
LM308A	AN-225, LB-24
LM309	AN-178, AN-182
LM311	AN-41, AN-103, AN-260, AN-263, AN-288, AN-294, AN-295, AN-307, LB-12, LB-16, LB-18, LB-39
LM313	AN-263
LM316	AN-258
LM317	AN-178, LB-35, LB-46
LM317H	LB-47
LM318	AN-299, LB-21
LM319	AN-828, AN-271, AN-293
LM320	AN-288
LM321	LB-24
LM324	AN-88, AN-258, AN-274, AN-284, AN-301, LB-44, AB-25, Appendix C
LM329	AN-256, AN-263, AN-284, AN-295, AN-301
LM329B	AN-225
LM330	AN-301
LM331	AN-210, AN-240, AN-265, AN-278, AN-285, AN-311, LB-45, Appendix C, Appendix D
LM331A	AN-210, Appendix C
LM334	AN-242, AN-256, AN-284
LM335	AN-225, AN-263, AN-295
LM336	AN-202, AN-247, AN-258
LM337	LB-46
LM338	LB-49, LB-51
LM339	AN-74, AN-245, AN-274
LM340	AN-103, AN-182
LM340L	AN-256
LM342	AN-288
LM346	AN-202, LB-54
LM348	AN-202, LB-42
LM349	LB-42
LM358	AN-116, AN-247, AN-271, AN-274, AN-284, AN-298, Appendix C
LM358A	Appendix D
LM359	AN-278, AB-24
LM360	AN-87
LM361	AN-87, AN-294
LM363	AN-271
LM380	AN-69, AN-146
LM385	AN-242, AN-256, AN-301, AN-344, AN-460, AN-693, AN-777
LM386	LB-54
LM391	AN-272
LM392	AN-274, AN-286

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM393	AN-271, AN-274, AN-293, AN-694
LM394	AN-262, AN-263, AN-271, AN-293, AN-299, AN-311, LB-52
LM395	AN-178, AN-181, AN-262, AN-263, AN-266, AN-301, AN-460, LB-28
LM399	AN-184
LM555	AN-694, AB-7
LM556	AB-7
LM565	AN-46, AN-146
LM566	AN-146
LM604	AN-460
LM628	AN-693, AN-706
LM629	AN-693, AN-694, AN-706
LM709	AN-24, AN-30
LM710	AN-41, LB-12
LM725	LB-22
LM741	AN-79, LB-19, LB-22
LM833	AN-346
LM1036	AN-390
LM1202	AN-867
LM1203	AN-861
LM1204	AN-934
LM1458	AN-116
LM1524	AN-272, AN-288, AN-292, AN-293
LM1558	AN-116
LM1578A	AB-30
LM1823	AN-391
LM1830	AB-10
LM1865	AN-390
LM1886	AN-402
LM1889	AN-402
LM1894	AN-384, AN-386, AN-390
LM2419	AN-861
LM2577	AN-776, AN-777
LM2876	AN-898
LM2889	AN-391, AN-402
LM2907	AN-162
LM2917	AN-162
LM2931	AB-12
LM2931CT	AB-11
LM3045	AN-286
LM3046	AN-146, AN-299
LM3089	AN-147
LM3524	AN-272, AN-288, AN-292, AN-293
LM3525A	AN-694
LM3578A	AB-30
LM3875	AN-898
LM3876	AN-898
LM3886	AN-898
LM3900	AN-72, AN-263, AN-274, AN-278, LB-20, AB-24
LM3909	AN-154
LM3914	AN-460, LB-48, AB-25
LM3915	AN-386
LM3999	AN-161

Device/Application Literature Cross-Reference (Continued)

Device Number	Application Literature
LM4250	AN-88, LB-34
LM6181	AN-813, AN-840
LM7800	AN-178
LM12454	AN-906, AN-947, AN-949
LM12458	AN-906, AN-947, AN-949
LM12H454	AN-906, AN-947, AN-949
LM12H458	AN-906, AN-947, AN-949
LM12L458	AN-906, AN-947, AN-949
LM18293	AN-706
LM78L12	AN-146
LM78S40	AN-711
LMC555	AN-460, AN-828
LMC660	AN-856
LMC835	AN-435
LMC6044	AN-856
LMC6062	AN-856
LMC6082	AN-856
LMC6484	AN-856
LMD18200	AN-694, AN-828
LMF40	AN-779
LMF60	AN-779
LMF90	AN-779
LMF100	AN-779
LMF380	AN-779
LMF390	AN-779
LP324	AN-284
LP395	AN-460
LPC660	AN-856
MF4	AN-779
MF5	AN-779
MF6	AN-779
MF8	AN-779
MF10	AN-307, AN-779
MM2716	LB-54
MM54104	AN-252, AN-287, LB-54
MM57110	AN-382
MM74C00	AN-88
MM74C02	AN-88
MM74C04	AN-88
MM74C948	AN-193
MM74HC86	AN-861, AN-867
MM74LS138	LB-54
MM53200	AN-290
2N4339	AN-32

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Appendix C
Summary of Commercial Reliability Programs

P+ Product Enhancement

The P+ product enhancement program involves dynamic tests that screen out assembly related and silicon defects that can lead to infant mortality and/or reduce the survivability of the device under high stress conditions. This program includes but is not limited to the following power devices:

Device	Package Types					
	TO-3 K STEEL	TO-39 (H)	TO-220 (T)	DIP (N)	SO (M)	TO-263 (S)
LM12	X					
LM109/309	X	X				
LM117/317	X	X	X			X
LM117HV/317HV	X	X				
LM120/320	X	X	X			
LM123/323	X					
LM133/333	X		X			
LM137/337	X	X	X			
LM137HV/337HV	X	X				
LM138/338	X		X			
LM140/340	X		X			
LM145/345	X					
LM150/350	X		X			
LM195/395	X	X	X			
LM2930/2935/2984			X			X
LM2937			X			X
LM2940/2941			X			X
LM2990/2991			X			X
LM2575/2575HV			X	X	X	X
LM2576			X			X
LM2577			X	X	X	X
LMD18200/18201			X			

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Appendix D
Military Aerospace Programs from National Semiconductor

This appendix is intended to provide a brief overview of military products available from National Semiconductor. The process flows and catagories shown below are for general reference only. For further information and availability, please contact the Customer Response Center at 1-800-272-9959, Military/Aerospace Marketing group or your local sales office.

National Semiconductor's Military/Aerospace Program is founded on dedication to excellence. National offers complete support across the broadest range of products with the widest selection of qualification levels and screening flows. These flows include:

Process Flows (Integrated Circuits)	Description
JAN S	QML products processed to MIL-I-38535 Level S or V for Space level applications.
JAN B	QML products processed to MIL-I-38535 Level B or Q for Military applications.
SMD	QML products processed to a Standard Microcircuit Drawing with Table I Electricals controlled by DESC.
883	QML products processed to MIL-STD-883 Level B for Military applications.
MLP	Products processed on the Monitored Line (Program) developed by the Air Force for Space level applications.
-MIL	Similar to MIL-STD-883 with exceptions noted on the Certificate of Conformance.
MSP	Military Screening Products for initial release of advanced products.
MCP	Commercial products processed in a military assembly. Electrical testing performed at 25°C, plus minimum and maximum operating temperature to commercial limits.
MCR	Commercial products processed in a military assembly. Electrical testing performed at 25°C to commercial limits
MRP	Military Ruggedized Plastic products processed to avionics requirements.
MRR	Commercial Ruggedized plastic product processed in a commercial assembly with electrical testing at 25°C.
MPC	Commercial plastic products processed in a commercial assembly with electrical testing at 25°C.

- **QML:** The purpose of the QML program, which is administered by the Defense Electronics Supply Center (DESC), is to provide the military community with standardized products that have been manufactured and screened to the highest quality and reliability standards in facilities that have been certified by the government. To achieve QML status, manufacturers must submit their facilities, quality procedures and design philosophies to a thorough audit aimed at confirming their ability to produce product to the highest design and quality standards. They must be listed on DESC's Qualified Manufacturer List (QML) before devices can be marked and shipped as QML product.
  Two processing levels are specified within MIL-I-38535, the QML standard: Class S (typically specified for space and strategic applications) and Class B (used for tactical missile, airborne, naval and ground systems). The requirements for both classes are defined within MIL-STD-883. National is one of the industry's leading suppliers of both classes.
- **Standard Microcircuit Drawings (SMD).** SMDs are issued to provide standardized versions of devices offered under QML. MIL-STD-883 screening is coupled with tightly controlled electrical test specifications that allow a manufacturer to use his standard electrical tests. Table I explains the marking of JAN devices, and Table II outlines current marking requirements for QML/SMD devices. Copies of MIL-I-38535 and the QML can be obtained from the Naval Publications and Forms Center (5801 Tabor Avenue, Philadelphia, PA 19120, 212/697-2179. A current listing of National's SMD offerings can be obtained from our authorized distributors, our sales offices, our Customer Response Center (Arlington, Texas, 817/468-6300), or from DESC.
- **MIL-STD-883.** Originally intended to establish uniform test methods and procedures, MIL-STD-883 has also become the general specification for non-SMD military product. MIL-STD-883 defines the minimum requirements for a device to be marked and advertised as 883-compliant. Design and construction criteria, documentation controls, electrical and mechanical screening requirements, and quality control procedures are outlined in paragraph 1.1.2 of MIL-STD-883.
  National offers both 883 Class B and 883 Class S product. The screening requirements for both classes of product are outlined in Table III.
  As with SMDs a manufacturer is allowed to use his standard electrical tests provided that all critical parameters are tested. Also, the electrical test parameters, test conditions, test limits and test temperatures must be clearly documented. At National Semiconductor, this information is available via our Table I (formerly RETS, Reliability Electrical Test Specification Program). The Table I document is a complete description of the electrical tests performed and is controlled by our QA department. Individual copies are available upon request.
  Some of National's products are produced on a flow similar to MIL-STD-883. These devices are screened to the same stringent requirements as 883 product, but are marked as **-MIL**; specific reasons for prevention of compliancy are clearly defined in the Certificate of Conformance (C of C) shipped with the product.
- **Monitored Line Program (MLP):** is a non JAN Level S program developed by the Air Force. Monitored Line product usually provides the shortest cycle time, and is acceptable for application in several space level programs. Lockheed Missiles and Space Company in Sunnyvale, California, under an Air Force contract, provides "on-site" monitoring of product processing, and as appropriate, program management. Monitored Line orders generally do not allow "customizing", and most flows do not include quality conformance inspection. Drawing control is maintained by the Lockheed Company.
- **Military Screening Program (MSP):** National's Military Screening Program was developed to make screened versions of advanced products such as gate arrays and microprocessors available more quickly. Through this program, screened product is made available for prototypes and breadboards prior to or during the QML activities. MSP products receive the 100% screening of Table III, but are not subjected to Group C and D quality conformance testing. Other criteria such as electrical testing and temperature range will vary depending upon individual device status and capability.

TABLE I. JAN S or B Part Marking

JM38510/XXXXXYYY

- Lead Finish
  - A = Solder Dipped
  - B = Tin Plate
  - C = Gold Plate
  - X = Any lead finish above is acceptable
- Device Package (see Table II)
- Screening Level S or B
- Device Number on Slash Sheet
- Slash Sheet Number
- For radiation hard devices this slash is replaced by the Radiation Hardness Assurance Designator (M, D, R, or H of MIL-I-38535)
- MIL-M-38510
- JAN Prefix

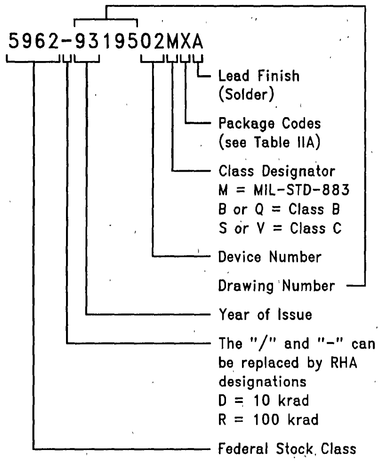
TL/XX/0030-1

TABLE I-A. JAN Package Codes

JAN Package Designation	Microcircuit Industry Description
A	14-pin $\frac{1}{4}$″ x $\frac{1}{4}$″ (Metal) Flatpak
B	14-pin $\frac{3}{16}$″ x $\frac{1}{4}$″ (Metal) Flatpak
C	14-pin $\frac{1}{4}$″ x $\frac{3}{4}$″ Dual-In-Line
D	14-pin $\frac{1}{4}$″ x $\frac{3}{8}$″ (Ceramic) Flatpak
E	16-pin $\frac{1}{4}$″ x $\frac{7}{8}$″ Dual-In-Line
F	16-pin $\frac{1}{4}$″ x $\frac{3}{8}$″ (Metal or Ceramic) Flatpak
G	8-pin TO-99 Can or Header
H	10-pin $\frac{1}{4}$″ x $\frac{1}{4}$″ (Metal) Flatpak
I	10-pin TO-100 Can or Header
J	24-pin $\frac{1}{2}$″ x 1$\frac{1}{4}$″ Dual-In-Line
K	24-pin $\frac{3}{8}$″ x $\frac{5}{8}$″ Flatpak
L	24-pin $\frac{1}{4}$″ x 1$\frac{1}{4}$″ Dual-In-Line
M	12-pin TO-101 Can or Header
N	(Note 1)
P	8-pin $\frac{1}{4}$″ x $\frac{3}{8}$″ Dual-In-Line
Q	40-pin $\frac{3}{16}$″ x 2$\frac{1}{16}$″ Dual-In-Line
R	20-pin $\frac{1}{4}$″ x 1$\frac{1}{16}$″ Dual-In-Line
S	20-pin $\frac{1}{4}$″ x $\frac{1}{2}$″ Flatpak
T	(Note 1)
U	(Note 1)
V	18-pin $\frac{3}{8}$″ x $\frac{15}{16}$″ Dual-In-Line
W	22-pin $\frac{3}{8}$″ x 1$\frac{1}{8}$″ Dual-In-Line
X	(Note 1)
Y	(Note 1)
Z	(Note 1)
2	20-terminal 0.350″ x 0.350″ Chip Carrier
3	28-terminal 0.450″ x 0.450″ Chip Carrier

Note 1: These letters are assigned to packages by individual detail specifications and may be assigned to different packages in different specifications.

TABLE II. Standard Military Drawing (SMD) Marking



TL/XX/0030-2

TABLE II-A. SMD Package Codes

SMD Package Designation	Microcircuit Industry Description
C	14-pin Flatpak
D	14-pin C DIP
E	16-pin C DIP
F	16-pin Flatpak
G	8-pin TO-99 Can
H	10-pin (Metal) Flatpak
I	10-pin TO-100 Can
X	(Note 2)
Y	(Note 2)
P	8-pin C DIP
2	20-pin LCC
R	20-Pin DIP

Note 2: These letters are assigned to packages by individual detail specifications and may be assigned to different packages in different specifications.

TABLE III. 100% Screening Requirements

	Screen	Class S		Class B	
		Method	Reqmt	Method	Reqmt
1.	Wafer Lot Acceptance	5007	All Lots		
2.	Nondestructive Bond Pull (Note 14)	2023	100%		
3.	Internal Visual (Note 1)	2020, Condition A	100%	2010, Condition B	100%
4.	Stabilization Bake (Note 16)	1008, Condition C, Min 24 Hrs. Min	100%	1008, Condition C, Min 24 Hrs. Min	100%
5.	Temperature Cycling (Note 2)	1010, Condition C	100%	1010, Condition C	100%
6.	Constant Acceleration	2001, Condition E Min Y_1 Orientation Only	100%	2001, Condition E Min Y_1 Orientation Only	100%
7.	Visual Inspection (Note 3)		100%		100%
8.	Particle Impact Noise Detection (PIND)	2010, Condition A (Note 4)	100%		
9.	Serialization	(Note 5)	100%		
10.	Interim (Pre-Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 13)	100%	Per Applicable Device Specification (Note 6)	
11.	Burn-In Test	1015 240 Hrs. @ 125°C Min (Cond. F Not Allowed)	100%	1015 160 Hrs. @ 125°C Min	100%
12.	Interim (Post Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 3)	100%		

TABLE III. 100% Screening Requirements (Continued)

	Screen	Class S		Class B	
		Method	Reqmt	Method	Reqmt
13.	Reverse Bias Burn-In (Note 7)	1015; Test Condition A, C, 72 Hrs. @ 150°C Min (Cond. F Not Allowed)	100%		
14.	Interim (Post-Burn-In) Electrical Parameters	Per Applicable Device Specification (Note 13)	100%	Per Applicable Device Specification	100%
15.	PDA Calculation	5% Parametric (Note 14), 3% Functional	All Lots	5% Parametric (Note 14)	All Lots
16.	Final Electrical Test (Note 15)	Per Applicable Device Specification		Per Applicable Device Specification	
	a) Static Tests				
	1) 25°C (Subgroup 1, Table I, 5005)		100%		100%
	2) Max & Min Rated Operating Temp. (Subgroups 2, 3, Table I, 5005)		100%		100%
	b) Dynamic Tests or Functional Tests				
	1) 25°C (Subgroup 4 or 7)		100%		100%
	2) Max and Min Rated Operating Temp. (Subgroups 5 and 6 or 8, Table I, 5005)		100%		100%
	c) Switching Tests 25°C (Subgroup 9, Table I, 5005)		100%		100%
17.	Seal Fine, Gross	1014	100% (Note 8)	1014	100% (Note 9)
18.	Radiographic (Note 10)	2012 Two Views	100%		
19.	Qualification or Quality Conformance Inspection Test Sample Selection	(Note 11)	Samp.	(Note 11)	Samp.
20.	External Visual (Note 12)	2009	100%		100%

Note 1: Unless otherwise specified, at the manufacturer's option, test samples for Group B, bond strength (Method 5005) may be randomly selected prior to or following internal visual (Method 5004), prior to sealing provided all other specification requirements are satisfied (e.g., bond strength requirements shall apply to each inspection lot, bond failures shall be counted even if the bond would have failed internal visual).

Note 2: For Class B devices, this test may be replaced with thermal shock Method 1011, Test Condition A, minimum.

Note 3: At the manufacturer's option, visual inspection for catastrophic failures may be conducted after each of the thermal/mechanical screens, after the sequence or after seal test. Catastrophic failures are defined as missing leads, broken packages, or lids off.

Note 4: The PIND test may be performed in any sequence after step 6 and prior to step 16. See MIL-I-38585 paragraph 40.6.3.

Note 5: Class S devices shall be serialized prior to interim electrical parameter measurements.

Note 6: When specified, all devices shall be tested for those parameters requiring delta calculations.

Note 7: Reverse bias burn-in is a requirement only when specified in the applicable device specification. The order of performing burn-in and reverse bias burn-in may be inverted.

Note 8: For Class S devices, the seal test may be performed in any sequence between step 16 and step 19, but it shall be performed after all shearing and forming operations on the terminals.

Note 9: For Class B devices, the fine and gross seal tests shall be performed separately or together in any sequence and order between step 6 and step 20 except that they shall be performed after all shearing and forming operations on the terminals. When 100% seal screen cannot be performed after shearing and forming (e.g., flatpaks and chip carriers) the seal screen shall be done 100% prior to these operations and a sample test (LTPD = 5) shall be performed on each inspection lot following these operations. If the sample fails, 100% rescreening shall be required.

Note 10: The radiographic screen may be performed in any sequence after step 9.

Note 11: Samples shall be selected for testing in accordance with the specific device class and lot requirements of Method 5005.

Note 12: External Visual shall be performed on the lot any time after step 19 and prior to shipment.

Note 13: Read and record is required at steps 10 and 12 only for those parameters for which post-burn-in delta measurements are specified. All parameters shall be read and recorded at step 14.

Note 14: The PDA shall apply to all subgroup 1 parameters at 25°C and all delta parameters.

Note 15: Only one view is required for flat packages and leadless chip carriers with leads on all four sides.

Note 16: May be performed at any time prior to step 10.

Military Analog Products Available from National Semiconductor

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
HIGH PERFORMANCE AMPLIFIERS AND BUFFERS				
LF147	D, J	Wide BW Quad JFET Op Amp	SMD/JAN	/11906
LF155A	H	JFET Input Op Amp	883	—
LF156	H	JFET Input Op Amp	883	—
LF156A	H	JFET Input Op Amp	883	—
LF157	H	JFET Input Op Amp	883	—
LF157A	H	JFET Input Op Amp	883	—
LF411M	H	Low Offset, Low Drift JFET Input	883/JAN	/11904
LF412M	H, J	Low Offset, Low Drift JFET Input-Dual	883/JAN	/11905
LF441M	H	Low Power JFET Input	883	—
LF442M	H	Low Power JFET Input-Dual	883	—
LF444M	D	Low Power JFET Input-Quad	883	—
LH0002	H	Buffer Amp	"-MIL"	—
LH0021	K	1.0 Amp Power Op Amp	"-MIL"	—
LH0024	H	High Slew Rate Op Amp	"-MIL"	—
LH0032	G	Ultra Fast FET-Input Op Amp	"-MIL"	—
LH0041	G	0.2 Amp Power Op Amp	"-MIL"	—
LH0101	K	Power Op Amp	"-MIL"	—
LM10	H	Super-Block™ Micropower Op Amp/Ref	883/SMD	5962-87604
LM101A	J, H, W	General Purpose Op Amp	883/JAN	/10103
LM108A	J, H, W	Precision Op Amp	883/JAN	/10104
LM118	J, H	Fast Op Amp	883/JAN	/10107
LM124	J, E, W	Low Power Quad Op Amp	883/JAN	/11005
LM124A	J, E, W	Low Power Quad	883/JAN	/11006
LM146	J	Quad Programmable Op Amp	883	—
LM148	J, E	Quad 741 Op amp	883/JAN	/11001
LM158A	J, H	Low Power Dual Op Amp	883/SMD	5962-8771002
LM158	J, H	Low Power Dual Op Amp	883/SMD	5962-8771001
LM611AM	J	Super-Block Op Amp/Reference	883/SMD	—
LM613AM	J, E	Super-Block Dual Op Amp/Dual Comp/Ref	883/SMD	—
LM614AM	J	Super-Block Quad Op Amp/Ref	883/SMD	—
LM709A	H, J, W	General Purpose Op Amp	883/SMD	7800701
LM741	J, H, W	General Purpose Op Amp	883/JAN	/10101
LM747	J, H	General Purpose Dual Op Amp	883/JAN	/10102
LM6118	J, E	VIP Dual Op Amp	883/SMD	5962-91565
LM6121	H, J	VIP Buffer	883/SMD	5962-90812
LM6125	H	VIP Buffer with Error Flag	883/SMD	5962-90815
LM6161	J, E, W	VIP Op Amp (Unity Gain)	883/SMD	5962-89621
LM6162	J, E, W	VIP Op Amp ($A_V > 2, -1$)	883/SMD	5962-92165
LM6164	J, E, W	VIP Op Amp ($A_V > 5$)	883/SMD	5962-89624
LM6165	J, E, W	VIP Op Amp ($A_V > 25$)	883/SMD	5962-89625
LM6181AM	J	VIP Current Feedback Op Amp	883/SMD	5962-9081802
LM6182AM	J	VIP Current Feedback Dual Op Amp	883/SMD	5962-9460301
LMC660AM	J	Low Power CMOS Quad Op Amp	883/SMD	5962-9209301
LMC662AM	J	Low Power CMOS Dual Op Amp	883/SMD	5962-9209401
LPC660AM	J	Micropower CMOS Quad Op Amp	883/SMD	5962-9209302
LPC662AM	J	Micropower CMOS Dual Op Amp	883/SMD	5962-9209402
LMC6482AM	J	Rail to Rail CMOS Dual Op Amp	883/SMD	5962-9453401
LMC6484AM	J	Rail to Rail CMOS Quad Op Amp	883/SMD	5962-9453402
OP07	H	Precision Op Amp	883	—

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
COMPARATORS				
LF111	H	Voltage Comparator	"-MIL"	—
LH2111	J, W	Dual Voltage Comparator	883/JAN	/10305
LM106	H, W	Voltage Comparator	883/SMD	8003701
LM111	J, H, E, W	Voltage Comparator	883/JAN	/10304
LM119	J, H, E, W	High Speed Dual Comparator	883/JAN	/10306
LM139	J, E, W	Quad Comparator	883/JAN	/11201
LM139A	J, E, W	Precision Quad Comparator	883/SMD	5962-87739
LM160	J, H	High Speed Differential Comparator	883/SMD	8767401
LM161	J, H, W	High Speed Differential Comparator	883/SMD	5962-87572
LM193	J, H	Dual Comparator	883	—
LM193A	J, H	Dual Comparator	883/JAN	/11202
LM612AM	J	Dual-Channel Comparator/Reference	883/SMD	5962-93002
LM613AM	J, E	Super-Block Dual Comparator/ Dual Op Amp/Adj Reference	883/SMD	5962-93003
LM615AM	J	Quad Comparator/Adjustable Reference	883	—
LM710A*	J, H, W	Voltage Comparator	883/JAN	/10301
LM711A*	J, H, W	Dual LM710	883/JAN	/10302
LM760	J, H	High Speed Differential Comparator	883/SMD	5962-87545

*Formerly manufactured by Fairchild Semiconductor as part numbers μA710 and μA711.

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
LINEAR REGULATORS				
Positive Voltage Regulators				
LM105	H	Adjustable Voltage Regulator	883/SMD	5962-89588
LM109	H	5V Regulator, $I_O = 20$ mA	883/JAN	/10701BXA
LM109	K	5V Regulator, $I_O = 1$A	883/JAN	/10701BYA
LM117	H, E, K	Adjustable Regulator	883/JAN	/11703, /11704
LM117HV	H	Adjustable Regulator, $I_O = 0.5$A	883/SMD	7703402XA
LM117HV	K	Adjustable Regulator, $I_O = 1.5$A	883/SMD	7703402YA
LM123	K	3A Voltage Regulator	883	—
LM138	K	5A Adjustable Regulator	"-MIL"	—
LM140-5.0	H	0.5A Fixed 5V Regulator	883/JAN	/10702
LM140-6.0	H	0.5A Fixed 6V Regulator	883	—
LM140-8.0	H	0.5A Fixed 8V Regulator	883	—
LM140-12	H	0.5A Fixed 12V Regulator	883/JAN	/10703
LM140-15	H	0.5A Fixed 15V Regulator	883/JAN	/10704
LM140-24	H	0.5A Fixed 24V Regulator	883	—
LM140A-5.0	K	1.0A Fixed 5V Regulator	883	—
LM140A-12	K	1.0A Fixed 12V Regulator	883	—
LM140A-15	K	1.0A Fixed 15V Regulator	883	—
LM140K-5.0	K	1.0A Fixed 5V Regulator	883/JAN	/10706
LM140K-12	K	1.0A Fixed 12V Regulator	883/JAN	/10707
LM140K-15	K	1.0A Fixed 15V Regulator	883/JAN	/10708
LM140LAH-5.0	H	100 mA Fixed 5V Regulator	883	—
LM140LAH-12	H	100 mA Fixed 12V Regulator	883	—
LM140LAH-15	H	100 mA Fixed 15V Regulator	883	—
LM150	K	3A Adjustable Power Regulator	883	—
LM2940-5.0	K	5V Low Dropout Regulator	883/SMD	5962-89587
LM2940-8.0	K	8V Low Dropout Regulator	883/SMD	5962-90883
LM2940-12	K	12V Low Dropout Regulator	883/SMD	5962-90884
LM2940-15	K	15V Low Dropout Regulator	883/SMD	5962-90885
LM2941	K	Adjustable Low Dropout Regulator	883/SMD	TBD
LM431	H, K	Adjustable Shunt Regulator	883	—
LM723	H, J, E	Precision Adjustable Regulator	883/JAN	/10201
LP2951	H, E, J	Adjustable Micropower LDO	883/SMD	5962-38705
LP2953AM	J	250 mA Adj. Micropower LDO	883/SMD	5962-9233601

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
LINEAR REGULATORS (Continued)				
Negative Voltage Regulators				
LM120-5.0	H	Fixed 0.5A Regulator, $V_{OUT} = -5V$	883/JAN	/11501
LM120-8.0	H	Fixed 0.5A Regulator, $V_{OUT} = -8V$	883	—
LM120-12	H	Fixed 0.5A Regulator, $V_{OUT} = -12V$	883/JAN	/11502
LM120-15	H	Fixed 0.5A Regulator, $V_{OUT} = -15V$	883/JAN	/11503
LM120-5.0	K	Fixed 1.0A Regulator, $V_{OUT} = -5V$	883/JAN	/11505
LM120-12	K	Fixed 1.0A Regulator, $V_{OUT} = -12V$	883/JAN	/11506
LM120-15	K	Fixed 1.0A Regulator, $V_{OUT} = -15V$	883/JAN	/11507
LM137A	H	Precision Adjustable Regulator	883/SMD	7703406XA
LM137A	K	Precision Adjustable Regulator	883/SMD	7703406YA
LM137	H, K	Adjustable Regulator	883/JAN	/11803, /11804
LM137HV	H	Adjustable (High Voltage) Regulator	883/SMD	7703404XA
LM137HV	K	Adjustable (High Voltage) Regulator	883/SMD	7703404YA
LM145-5.0	K	Negative 3 Amp Regulator	883/SMD	5962-90645
LM145-5.2	K	Negative 3 Amp Regulator	883	—
SWITCHING REGULATORS				
LM1575-5	J, K	Simple Switcher™ Step-Down, $V_{OUT} = 5V$	883/SMD	5962-9167201
LM1575-12	J, K	Simple Switcher Step-Down, $V_{OUT} = 12V$	883/SMD	5962-9167301
LM1575-15	J, K	Simple Switcher Step-Down, $V_{OUT} = 15V$	883/SMD	5962-9167401
LM1575-ADJ	J, K	Simple Switcher Step-Down, Adj V_{OUT}	883/SMD	5962-9167101
LM1575HV-5	K	Simple Switcher Step-Down, $V_{OUT} = 5V$	883	—
LM1575HV-12	K	Simple Switcher Step-Down, $V_{OUT} = 12V$	883	—
LM1575HV-15	K	Simple Switcher Step-Down, $V_{OUT} = 15V$	883	—
LM1575HV-ADJ	K	Simple Switcher Step-Down, Adj V_{OUT}	883	—
LM1577-12	K	Simple Switcher Step-Up, $V_{OUT} = 12V$	883/SMD	5962-9216701
LM1577-15	K	Simple Switcher Step-Up, $V_{OUT} = 15V$	883/SMD	5962-9216801
LM1577-ADJ	K	Simple Switcher Step-Up, Adj V_{OUT}	883/SMD	5962-9216601
LM1578	H	750 mA Switching Regulator	883/SMD	5962-89586
LM78S40*	J	Universal Switching Regulator Subsystem	883/SMD	5962-88761

*Formerly manufactured by Fairchild Semiconductor as the μA78S40DMQB.

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
VOLTAGE REFERENCES				
LM103-3.0	H	Reference Diode, BV = 3.0V	883/SMD	7702806
LM103-3.3	H	Reference Diode, BV = 3.3V	883/SMD	7702807
LM103-3.6	H	Reference Diode, BV = 3.6V	883/SMD	7702808
LM103-3.9	H	Reference Diode, BV = 3.9V	883/SMD	7702809
LM113	H	Reference Diode with 5% Tolerance	883/SMD	5962-8671101
LM113-1	H	Reference Diode with 1% Tolerance	883/SMD	5962-8671102
LM113-2	H	Reference Diode with 2% Tolerance	883/SMD	5962-8671103
LM129A	H	Precision Reference, 10 ppm/°C Drift	883/SMD	5962-8992101XA
LM129B	H	Precision Reference, 20 ppm/°C Drift	883/SMD	5962-8992102XA
LM136A-2.5	H	2.5V Reference Diode, 1% V_{OUT} Tolerance	883	—
LM136A-5.0	H	5V Reference Diode, 1% V_{OUT} Tolerance	883/SMD	8418001
LM136-2.5	H	2.5V Reference Diode, 2% V_{OUT} Tolerance	883	—
LM136-5.0	H	5V Reference Diode, 2% V_{OUT} Tolerance	883	—

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
VOLTAGE REFERENCES (Continued)				
LM169	H	10V Precision Reference, Low Tempco 0.05% Tolerance	883	—
LM185B	H, E	Adjustable Micropower Voltage Reference	883/SMD	5962-9041401
LM185BX2.5	H	2.5V Micropower Reference Diode, Ultralow Drift	883/SMD	5962-8759404
LM185BY	H	Adjustable Micropower Voltage Reference	883	—
LM185BY1.2	H	1.2V Micropower Reference Diode, Low Drift	883/SMD	5962-8759405
LM185BY2.5	H	2.5V Micropower Reference Diode, Low Drift	883/SMD	5962-8759406
LM185-1.2	H, E	1.2V Micropower Reference Diode, Low Drift	883/SMD	5962-8759401
LM185-2.5	H, E	2.5V Micropower Reference Diode, Low Drift	883/SMD	5962-8759402
LM199	H	Precision Reference, Low Tempco	883/SMD	5962-8856102
LM199A	H	Precision Reference, Ultralow Tempco	883/SMD	5962-8856101
LM199A-20	H	Precision Reference, Ultralow Tempco	883	—
LM611AM	J	Super-Block Op Amp/Reference	883	—
LM612AM	J	Super-Block Dual-Channel Comparator/Reference	883/SMD	5962-9300201
LM613AM	J, E	Super-Block Dual Op Amp/DualComp/Dual Ref	883/SMD	5962-9300301
LM614AM	J	Super-Block Quad Op Amp/Reference	883/SMD	5962-9300401
LM615AM	J	Super-Block Quad Comparator/Reference	883/SMD	TBD
LH0070-0	H	Precision BCD Buffered Reference	"-MIL"	—
LH0070-1	H	Precision BCD Buffered Reference	"-MIL"	—
LH0070-2	H	Precision BCD Buffered Reference	"-MIL"	—
DATA ACQUISITION				
ADC08020L	J	8-Bit μP-Compatible	883/SMD	5962-90966
ADC0851	J	8-Bit Analog Data Acquisition & Monitoring System	883/SMD	TBD
ADC0858	J	8-Bit Analog Data Acquisition & Monitoring System	883/SMD	TBD
ADC08061CM	J	8-Bit Multistep ADC	883/SMD	TBD
ADC10061CM	J	10-Bit Multistep ADC	883/SMD	TBD
ADC10062CM	J	10-Bit Multistep ADC w/Dual Input Mutiplexer	883/SMD	TBD
ADC10064CM	J	10-Bit Multistep ADC w/Quad Input Multiplexer	883/SMD	TBD
ADC1241CM	J	12-Bit Plus Sign Self-Calibrating with Sample/Hold Function	883/SMD	5962-9157801
ADC12441CM	J	Dynamically-Tested ADC1241	883/SMD	5962-9157802
ADC1251CM	J	12-Bit Plus Sign Self-Calibrating with Sample/Hold Function	883/SMD	5962-9157801
ADC12451CM	J	Dynamically-Tested ADC1251	883/SMD	TBD
DAC0854CM	J	Quad 8-Bit D/A Converter with Read Back	883/SMD	TBD
DAC1054CM	J	Quad 10-Bit D/A Converter with Read Back	883/SMD	TBD
LM12458M	EL, W	12-Bit Data Acquisition System	883/SMD	5962-9319501
LM12H458M	EL, W	12-Bit Data Acquisition System	883/SMD	5962-9319502

Military Analog Products Available from National Semiconductor (Continued)

Device	Package Styles (Note 1)	Description	Process Flows (Note 2)	SMD/JAN (Note 3)
DATA ACQUISITION SUPPORT				
Switched Capacitor Filters				
LMF60CMJ50	J	6th Order Butterworth Lowpass	883/SMD	5962-90967
LMF60CMJ100	J	6th Order Butterworth Lowpass	883/SMD	5962-90967
LMF90CM	J	4th Order Elliptic Notch	883/SMD	5962-90968
LMF100A	J, E	Dual 2nd Order General Purpose	883/SMD	5962-9153301
Sample and Hold				
LF198	H	Monolithic Sample and Hold	SMD/JA	5962-87608 /12501
Motion Control				
LMD18200-2	D	Dual 3A, 55V H-Bridge	883/JAN	5962-9232501

Note 1: D: Side-Brazed DIP
E: Leadless Ceramic Chip Carrier
G: Metal Can (TO-8)
H: Metal Can (TO-39, TO-5, TO-99, TO-100)
J: Ceramic DIP
K: Metal Can (TO-3)
W: Flatpak

Note 2: Process Flows
JAN = JM38510, Level B
SMD = Standard Military Drawing
883 = MIL-STD-883 Rev C
-MIL = Exceptions to 883C noted on Certificate of Conformance

Note 3: Please call your local sales office to determine price and availability of space-level products. All "LM" prefix products in this guide are availble with space-level processing.

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Appendix E
Understanding Integrated Circuit Package Power Capabilities

INTRODUCTION

The short and long term reliability of National Semiconductor's interface circuits, like any integrated circuit, is very dependent on its environmental condition. Beyond the mechanical/environmental factors, nothing has a greater influence on this reliability than the electrical and thermal stress seen by the integrated circuit. Both of these stress issues are specifically addressed on every interface circuit data sheet, under the headings of Absolute Maximum Ratings and Recommended Operating Conditions.

However, through application calls, it has become clear that electrical stress conditions are generally more understood than the thermal stress conditions. Understanding the importance of electrical stress should never be reduced, but clearly, a higher focus and understanding must be placed on thermal stress. Thermal stress and its application to interface circuits from National Semiconductor is the subject of this application note.

FACTORS AFFECTING DEVICE RELIABILITY

Figure 1 shows the well known "bathtub" curve plotting failure rate versus time. Similar to all system hardware (mechanical or electrical) the reliability of interface integrated circuits conform to this curve. The key issues associated with this curve are infant mortality, failure rate, and useful life.

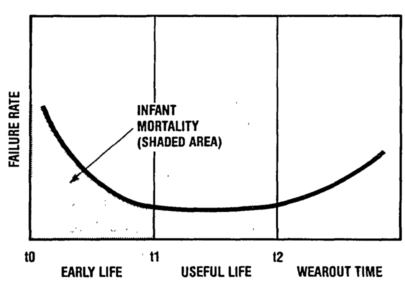

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FIGURE 1. Failure Rate vs Time

Infant mortality, the high failure rate from time t0 to t1 (early life), is greatly influenced by system stress conditions other than temperature, and can vary widely from one application to another. The main stress factors that contribute to infant mortality are electrical transients and noise, mechanical maltreatment and excessive temperatures. Most of these failures are discovered in device test, burn-in, card assembly and handling, and initial system test and operation. Although important, much literature is available on the subject of infant mortality in integrated circuits and is beyond the scope of this application note.

Failure rate is the number of devices that will be expected to fail in a given period of time (such as, per million hours). The mean time between failure (MTBF) is the average time (in hours) that will be expected to elapse after a unit has failed before the next unit failure will occur. These two primary "units of measure" for device reliability are inversely related:

$$\text{MTBF} = \frac{1}{\text{Failure Rate}}$$

Although the "bathtub" curve plots the overall failure rate versus time, the useful failure rate can be defined as the percentage of devices that fail per-unit-time during the flat portion of the curve. This area, called the useful life, extends between t1 and t2 or from the end of infant mortality to the onset of wearout. The useful life may be as short as several years but usually extends for decades if adequate design margins are used in the development of a system.

Many factors influence useful life including: pressure, mechanical stress, thermal cycling, and electrical stress. However, die temperature during the device's useful life plays an equally important role in triggering the onset of wearout.

FAILURE RATES vs TIME AND TEMPERATURE

The relationship between integrated circuit failure rates and time and temperature is a well established fact. The occurrence of these failures is a function which can be represented by the Arrhenius Model. Well validated and predominantly used for accelerated life testing of integrated circuits, the Arrhenius Model assumes the degradation of a performance parameter is linear with time and that MTBF is a function of temperature stress. The temperature dependence is an exponential function that defines the probability of occurrence. This results in a formula for expressing the lifetime or MTBF at a given temperature stress in relation to another MTBF at a different temperature. The ratio of these two MTBFs is called the acceleration factor F and is defined by the following equation:

$$F = \frac{X1}{X2} = \exp\left[\frac{E}{K}\left(\frac{1}{T2} - \frac{1}{T1}\right)\right]$$

Where: X1 = Failure rate at junction temperature T1

X2 = Failure rate at junction temperature T2

T = Junction temperature in degrees Kelvin

E = Thermal activation energy in electron volts (ev)

K = Boltzman's constant

However, the dramatic acceleration effect of junction temperature (chip temperature) on failure rate is illustrated in a plot of the above equation for three different activation energies in *Figure 2*. This graph clearly demonstrates the importance of the relationship of junction temperature to device failure rate. For example, using the 0.99 ev line, a 30° rise in junction temperature, say from 130°C to 160°C, results in a 10 to 1 increase in failure rate.

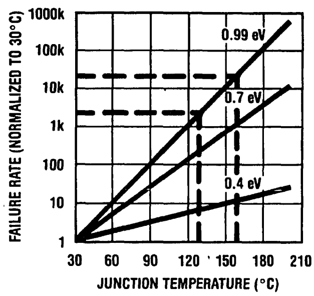

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FIGURE 2. Failure Rate as a Function of Junction Temperature

DEVICE THERMAL CAPABILITIES

There are many factors which affect the thermal capability of an integrated circuit. To understand these we need to understand the predominant paths for heat to transfer out of the integrated circuit package. This is illustrated by *Figures 3* and *4*.

Figure 3 shows a cross-sectional view of an assembled integrated circuit mounted into a printed circuit board.

Figure 4 is a flow chart showing how the heat generated at the power source, the junctions of the integrated circuit flows from the chip to the ultimate heat sink, the ambient environment. There are two predominant paths. The first is from the die to the die attach pad to the surrounding package material to the package lead frame to the printed circuit board and then to the ambient. The second path is from the package directly to the ambient air.

Improving the thermal characteristics of any stage in the flow chart of *Figure 4* will result in an improvement in device thermal characteristics. However, grouping all these characteristics into one equation determining the overall thermal capability of an integrated circuit/package/environmental condition is possible. The equation that expresses this relationship is:

$$T_J = T_A + P_D (\theta_{JA})$$

Where: T_J = Die junction temperature

T_A = Ambient temperature in the vicinity device

P_D = Total power dissipation (in watts)

θ_{JA} = Thermal resistance junction-to-ambient

θ_{JA}, the thermal resistance from device junction-to-ambient temperature, is measured and specified by the manufacturers of integrated circuits. National Semiconductor utilizes special vehicles and methods to measure and monitor this parameter. All circuit data sheets specify the thermal characteristics and capabilities of the packages available for a given device under specific conditions—these package power ratings directly relate to thermal resistance junction-to-ambient or θ_{JA}.

Although National provides these thermal ratings, it is critical that the end user understand how to use these numbers to improve thermal characteristics in the development of his system using IC components.

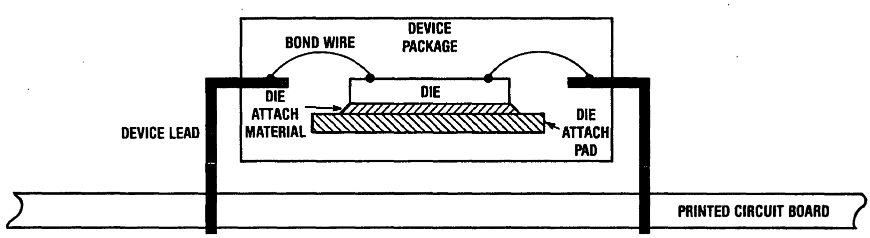

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FIGURE 3. Integrated Circuit Soldered into a Printed Circuit Board (Cross-Sectional View)

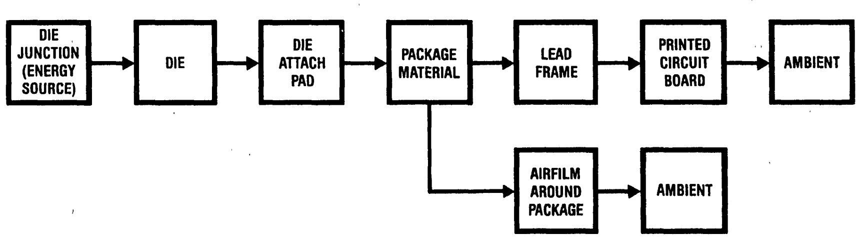

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FIGURE 4. Thermal Flow (Predominant Paths)

DETERMINING DEVICE OPERATING JUNCTION TEMPERATURE

From the above equation the method of determining actual worst-case device operating junction temperature becomes straightforward. Given a package thermal characteristic, θ_{JA}, worst-case ambient operating temperature, $T_A(max)$, the only unknown parameter is device power dissipation, P_D. In calculating this parameter, the dissipation of the integrated circuit due to its own supply has to be considered, the dissipation within the package due to the external load must also be added. The power associated with the load in a dynamic (switching) situation must also be considered. For example, the power associated with an inductor or a capacitor in a static versus dynamic (say, 1 MHz) condition is significantly different.

The junction temperature of a device with a total package power of 600 mW at 70°C in a package with a thermal resistance of 63°C/W is 108°C.

$$T_J = 70°C + (63°C/W) \times (0.6W) = 108°C$$

The next obvious question is, "how safe is 108°C?"

MAXIMUM ALLOWABLE JUNCTION TEMPERATURES

What is an acceptable maximum operating junction temperature is in itself somewhat of a difficult question to answer. Many companies have established their own standards based on corporate policy. However, the semiconductor industry has developed some defacto standards based on the device package type. These have been well accepted as numbers that relate to reasonable (acceptable) device lifetimes, thus failure rates.

National Semiconductor has adopted these industry-wide standards. For devices fabricated in a molded package, the maximum allowable junction temperature is 150°C. For these devices assembled in ceramic or cavity DIP packages, the maximum allowable junction temperature is 175°C. The numbers are different because of the differences in package types. The thermal strain associated with the die package interface in a cavity package is much less than that exhibited in a molded package where the integrated circuit chip is in direct contact with the package material.

Let us use this new information and our thermal equation to construct a graph which displays the safe thermal (power) operating area for a given package type. *Figure 5* is an example of such a graph. The end points of this graph are easily determined. For a 16-pin molded package, the maximum allowable temperature is 150°C; at this point no power dissipation is allowable. The power capability at 25°C is 1.98W as given by the following calculation:

$$P_D @ 25°C = \frac{T_J(max) - T_A}{\theta_{JA}} = \frac{150°C - 25°C}{63°C/W} = 1.98W$$

The slope of the straight line between these two points is minus the inversion of the thermal resistance. This is referred to as the derating factor.

$$\text{Derating Factor} = -\frac{1}{\theta_{JA}}$$

As mentioned, *Figure 5* is a plot of the safe thermal operating area for a device in a 16-pin molded DIP. As long as the intersection of a vertical line defining the maximum ambient temperature (70°C in our previous example) and maximum device package power (600 mW) remains below the maximum package thermal capability line the junction temperature will remain below 150°C—the limit for a molded package. If the intersection of ambient temperature and package power fails on this line, the maximum junction temperature will be 150°C. Any intersection that occurs above this line will result in a junction temperature in excess of 150°C and is not an appropriate operating condition.

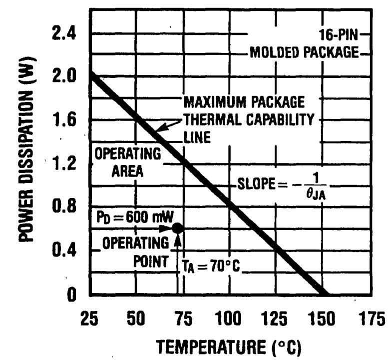

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FIGURE 5. Package Power Capability vs Temperature

The thermal capabilities of all integrated circuits are expressed as a power capability at 25°C still air environment with a given derating factor. This simply states, for every degree of ambient temperature rise above 25°C, reduce the package power capability stated by the derating factor which is expressed in mW/°C. For our example—a θ_{JA} of 63°C/W relates to a derating factor of 15.9 mW/°C.

FACTORS INFLUENCING PACKAGE THERMAL RESISTANCE

As discussed earlier, improving any portion of the two primary thermal flow paths will result in an improvement in overall thermal resistance junction-to-ambient. This section discusses those components of thermal resistance that can be influenced by the manufacturer of the integrated circuit. It also discusses those factors in the overall thermal resistance that can be impacted by the end user of the integrated circuit. Understanding these issues will go a long way in understanding chip power capabilities and what can be done to insure the best possible operating conditions and, thus, best overall reliability.

Die Size

Figure 6 shows a graph of our 16-pin DIP thermal resistance as a function of integrated circuit die size. Clearly, as the chip size increases the thermal resistance decreases—this relates directly to having a larger area with which to dissipate a given power.

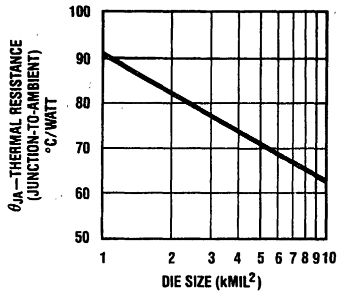

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FIGURE 6. Thermal Resistance vs Die Size

Lead Frame Material

Figure 7 shows the influence of lead frame material (both die attach and device pins) on thermal resistance. This graph compares our same 16-pin DIP with a copper lead frame, a Kovar lead frame, and finally an Alloy 42 type lead frame—these are lead frame materials commonly used in the industry. Obviously the thermal conductivity of the lead frame material has a significant impact in package power capability. Molded interface circuits from National Semiconductor use the copper lead frame exclusively.

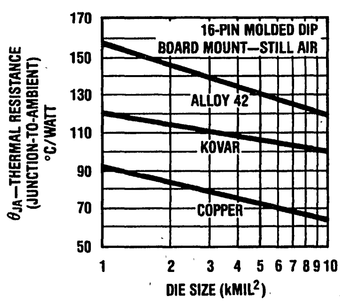

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FIGURE 7. Thermal Resistance vs Lead Frame Material

Board vs Socket Mount

One of the major paths of dissipating energy generated by the integrated circuit is through the device leads. As a result of this, the graph of *Figure 8* comes as no surprise. This compares the thermal resistance of our 16-pin package soldered into a printed circuit board (board mount) compared to the same package placed in a socket (socket mount). Adding a socket in the path between the PC board and the device adds another stage in the thermal flow path, thus increasing the overall thermal resistance. The thermal capabilities of National Semiconductor's interface circuits are specified assuming board mount conditions. If the devices are placed in a socket the thermal capabilities should be reduced by approximately 5% to 10%.

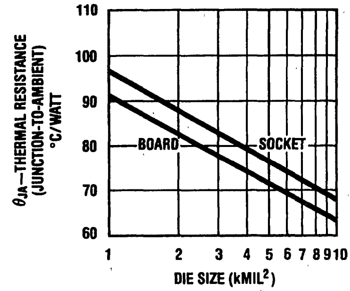

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FIGURE 8. Thermal Resistance vs Board or Socket Mount

Air Flow

When a high power situation exists and the ambient temperature cannot be reduced, the next best thing is to provide air flow in the vicinity of the package. The graph of *Figure 9* illustrates the impact this has on thermal resistance. This graph plots the relative reduction in thermal resistance normalized to the still air condition for our 16-pin molded DIP. The thermal ratings on National Semiconductor's interface circuits data sheets relate to the still air environment.

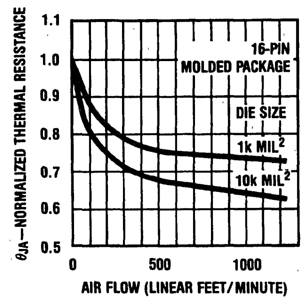

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FIGURE 9. Thermal Resistance vs Air Flow

Other Factors

A number of other factors influence thermal resistance. The most important of these is using thermal epoxy in mounting ICs to the PC board and heat sinks. Generally these techniques are required only in the very highest of power applications.

Some confusion exists between the difference in thermal resistance junction-to-ambient (θ_{JA}) and thermal resistance junction-to-case (θ_{JC}). The best measure of actual junction temperature is the junction-to-ambient number since nearly all systems operate in an open air environment. The only situation where thermal resistance junction-to-case is important is when the entire system is immersed in a thermal bath and the environmental temperature is indeed the case temperature. This is only used in extreme cases and is the exception to the rule and, for this reason, is not addressed in this application note.

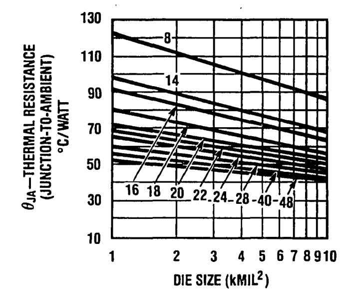
NATIONAL SEMICONDUCTOR PACKAGE CAPABILITIES

Figures 10 and *11* show composite plots of the thermal characteristics of the most common package types in the National Semiconductor Linear Circuits product family. *Figure 10* is a composite of the copper lead frame molded package. *Figure 11* is a composite of the ceramic (cavity) DIP using poly die attach. These graphs represent board mount still air thermal capabilities. Another, and final, thermal resistance trend will be noticed in these graphs. As the number of device pins increase in a DIP the thermal resistance decreases. Referring back to the thermal flow chart, this trend should, by now, be obvious.

RATINGS ON INTEGRATED CIRCUITS DATA SHEETS

In conclusion, all National Semiconductor Linear Products define power dissipation (thermal) capability. This information can be found in the Absolute Maximum Ratings section of the data sheet. The thermal information shown in this application note represents average data for characterization of the indicated package. Actual thermal resistance can vary from ±10% to ±15% due to fluctuations in assembly quality, die shape, die thickness, distribution of heat sources on the die, etc. The numbers quoted in the linear data sheets reflect a 15% safety margin from the average numbers found in this application note. Insuring that total package power remains under a specified level will guarantee that the maximum junction temperature will not exceed the package maximum.

Molded (N Package) DIP*
Copper Leadframe—HTP
Die Attach Board Mount—
Still Air



*Packages from 8- to 20-pin 0.3 mil width
22-pin 0.4 mil width
24- to 40-pin 0.6 mil width

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FIGURE 10. Thermal Resistance vs Die Size vs Package Type (Molded Package)

Surface Mount (M, MW Packages), Board Mount, Still Air

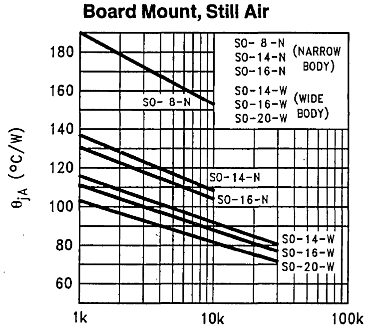

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FIGURE 12. Thermal Resistance for "SO" Packages (Board Mount)

The package power ratings are specified as a maximum power at 25°C ambient with an associated derating factor for ambient temperatures above 25°C. It is easy to determine the power capability at an elevated temperature. The power specified at 25°C should be reduced by the derating factor for every degree of ambient temperature above 25°C. For example, in a given product data sheet the following will be found:

Maximum Power Dissipation* at 25°C

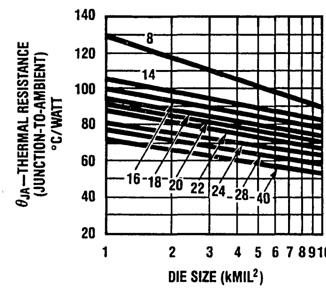
Cavity Package	1509 mW
Molded Package	1476 mW

* Derate cavity package at 10 mW/°C above 25°C; derate molded package at 11.8 mW/°C above 25°C.

If the molded package is used at a maximum ambient temperature of 70°C, the package power capability is 945 mW.

$$P_D \text{ @ } 70°C = 1476\text{ mW} - (11.8\text{ mW/°C}) \times (70°C - 25°C)$$
$$= 945\text{ mW}$$

Cavity (J Package) DIP*
Poly Die Attach Board
Mount—Still Air



*Packages from 8- to 20-pin 0.3 mil width
22-pin 0.4 mil width
24- to 48-pin 0.6 mil width

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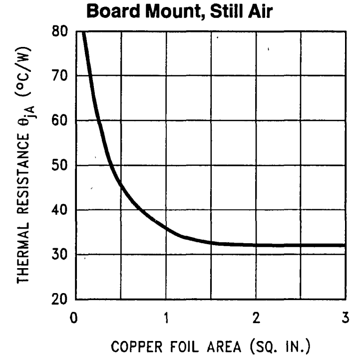
FIGURE 11. Thermal Resistance vs Die Size vs Package Type (Cavity Package)

TO-263 (S Package)
Board Mount, Still Air



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*For products with high current ratings (>3A), thermal resistance may be lower. Consult product datasheet for more information.

FIGURE 13. Thermal Resistance (typ.*) for 3-, 5-, and 7-L TO-263 packages mounted on 1 oz. (0.036mm) PC board foil

National Semiconductor

APPENDIX F
How to Get the Right Information From a Data Sheet

Not All Data Sheets Are Created Alike, and False Assumptions Could Cost an Engineer Time and Money

By Robert A. Pease

When a new product arrives in the marketplace, it hopefully will have a good, clear data sheet with it.

The data sheet can show the prospective user how to apply the device, what performance specifications are guaranteed and various typical applications and characteristics. If the data-sheet writer has done a good job, the user can decide if the product will be valuable to him, exactly how well it will be of use to him and what precautions to take to avoid problems.

SPECIFICATIONS

The most important area of a data sheet specifies the characteristics that are guaranteed—and the test conditions that apply when the tests are done. Ideally, all specifications that the users will need will be spelled out clearly. If the product is similar to existing products, one can expect the data sheet to have a format similar to other devices.

But, if there are significant changes and improvements that nobody has seen before, then the writer must clarify what is meant by each specification. Definitions of new phrases or characteristics may even have to be added as an appendix.

For example, when fast-settling operational amplifiers were first introduced, some manufacturers defined settling time as the time after slewing before the output finally enters and stays within the error-band; but other manufacturers included the slewing time in their definition. Because both groups made their definitions clear, the user was unlikely to be confused or misled.

However, the reader ought to be on the alert. In a few cases, the data-sheet writer is playing a specsmanship game, and is trying to show an inferior (to some users) aspect of a product in a light that makes it look superior (which it may be, to a couple of users).

GUARANTEES

When a data sheet specifies a guaranteed minimum value, what does it mean? An assumption might be made that the manufacturer has actually tested that specification and has great confidence that no part could fail that test and still be shipped. Yet that is not always the case.

For instance, in the early days of op amps (20 years ago), the differential-input impedance might have been guaranteed at 1 MΩ—but the manufacturer obviously did not measure the impedance. When a customer insisted, "I have to know how you measure this impedance," it had to be explained that the impedance was not measured, but that the base current was. The correlation between I_b and Z_{in} permitted the substitution of this simple dc test for a rather messy, noisy, hard-to-interpret test.

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Every year, for the last 20 years, manufacturers have been trying to explain, with varying success, why they do not measure the Z_{in} *per se,* even though they do guarantee it.

In other cases, the manufacturer may specify a test that can be made only on the die as it is probed on the wafer, but cannot be tested after the die is packaged because that signal is not accessible any longer. To avoid frustrating and confusing the customer, some manufacturers are establishing two classes of guaranteed specifications:

- The tested limit represents a test that cannot be doubted, one that is actually performed directly on 100 percent of the devices, 100 percent of the time.
- The design limit covers other tests that may be indirect, implicit or simply guaranteed by the inherent design of the device, and is unlikely to cause a failure rate (on that test), even as high as one part per thousand.

Why was this distinction made? Not just because customers wanted to know which specifications were guaranteed by testing, but because the quality-assurance group insisted that it was essential to separate the tested guarantees from the design limits so that the AQL (assurance-quality level) could be improved from 0.1 percent to down below 100 ppm.

Some data sheets guarantee characteristics that are quite expensive and difficult to test (even harder than noise) such as long-term drift (20 ppm or 50 ppm over 1,000 hours).

The data sheet may not tell the reader if it is measured, tested or estimated. One manufacturer may perform a 100-percent test, while another states, "Guaranteed by sample testing." This is not a very comforting assurance that a part is good, especially in a critical case where only a long-term test can prove if the device did meet the manufacturer's specification. If in doubt, question the manufacturer.

TYPICALS

Next to a guaranteed specification, there is likely to be another in a column labeled "typical".

It might mean that the manufacturer once actually saw one part as good as that. It could indicate that half the parts are better than that specification, and half will be worse. But it is equally likely to mean that, five years ago, half the parts were better and half worse. It could easily signify that a few parts might be slightly better, and a few parts a lot worse; after all, if the noise of an amplifier is extremely close to the theoretical limit, one cannot expect to find anything much better than that, but there will always be a few noisy ones.

If the specification of interest happens to be the bias current (I_b) of an op amp, a user can expect broad variations. For example, if the specification is 200 nA maximum, there might be many parts where I_b is 40 nA on one batch (where the beta is high), and a month later, many parts where the I_b is 140 nA when the beta is low.

Absolute Maximum Ratings (Note 11)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+35V to −0.2V
Output Voltage	+6V to −1.0V
Output Current	10 mA
Storage Temperature,	
TO-46 Package	−76°F to +356°F
TO-92 Package	−76°F to +300°F
Lead Temp. (Soldering, 4 seconds) *	
TO-46 Package	+300°C
TO-92 Package	+260°C
Specified Operating Temp. Range (Note 2)	
	T_{MIN} to T_{MAX}
LM34, LM34A	−50°F to +300°F
LM34C, LM34CA	−40°F to +230°F
LM34D	+32°F to +212°F

DC Electrical Characteristics (Note 1, Note 6)

Parameter	Conditions	LM34A			LM34CA			Units (Max)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	$T_A = +77°F$	±0.4	±1.0		±0.4	±1.0		°F
	$T_A = 0°F$	±0.6			±0.6		±2.0	°F
	$T_A = T_{MAX}$	±0.8	±2.0		±0.8	±2.0		°F
	$T_A = T_{MIN}$	±0.8	±2.0		±0.8		±3.0	°F
Nonlinearity (Note 8)	$T_{MIN} \le T_A \le T_{MAX}$	**±0.35**		**±0.7**	**±0.30**		**±0.6**	°F
Sensor Gain (Average Slope)	$T_{MIN} \le T_A \le T_{MAX}$	**+10.0**	**+9.9,**		**+10.0**		**+9.9,**	mV/°F, min
			+10.1				**+10.1**	mV/°F, max
Load Regulation (Note 3)	$T_A = +77°F$	±0.4	±1.0		±0.4	±1.0		mV/mA
	$T_{MIN} \le T_A \le T_{MAX}$ $0 \le I_L \le 1$ mA	**±0.5**		**±3.0**	**±0.5**		**±3.0**	mV/mA
Line Regulation (Note 3)	$T_A = +77°F$	±0.01	±0.05		±0.01	±0.05		mV/V
	$5V \le V_S \le 30V$	**±0.02**		**±0.1**	**±0.02**		**±0.1**	mV/V
Quiescent Current (Note 9)	$V_S = +5V, +77°F$	75	90		75	90		μA
	$V_S = +5V$	**131**		**160**	**116**		**139**	μA
	$V_S = +30V, +77°F$	76	92		76	92		μA
	$V_S = +30V$	**132**		**163**	**117**		**142**	μA
Change of Quiescent Current (Note 3)	$4V \le V_S \le 30V, +77°F$	+0.5	2.0		0.5	2.0		μA
	$5V \le V_S \le 30V$	**+1.0**		**3.0**	**1.0**		**3.0**	μA
Temperature Coefficient of Quiescent Current		**+0.30**		**+0.5**	**+0.30**		**+0.5**	μA/°F
Minimum Temperature for Rated Accuracy	In circuit of *Figure 1,* $I_L = 0$	+3.0		+5.0	+3.0		+5.0	°F
Long-Term Stability	$T_j = T_{MAX}$ for 1000 hours	±0.16			±0.16			°F

Note 1: Unless otherwise noted, these specifications apply: $-50°F \le T_j \le +300°F$ for the LM34 and LM34A; $-40°F \le T_j \le +230°F$ for the LM34C and LM34CA; and $+32°F \le T_j \le +212°F$ for the LM34D. $V_S = +5$ Vdc and $I_{LOAD} = 50$ μA in the circuit of *Figure 2;* +6 Vdc for LM34 and LM34A for $230°F \le T_j \le 300°F$. These specifications also apply from +5°F to T_{MAX} in the circuit of *Figure 1.*

Note 2: Thermal resistance of the TO-46 package is 292°F/W junction to ambient and 43°F/W junction to case. Thermal resistance of the TO-92 package is 324°F/W junction to ambient.

Note 3: Regulation is measured at constant junction temperature using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested limits are guaranteed and 100% tested in production.

Note 5: Design limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specification in **BOLDFACE TYPE** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and 10 mV/°F times the device's case temperature at specified conditions of voltage, current, and temperature (expressed in °F).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of *Figure 1.*

Note 10: Contact factory for availability of LM34CAZ.

* * **Note 11:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions (see Note 1).

A Point-By-Point Look

Let's look a little more closely at the data sheet of the National Semiconductor LM34, which happens to be a temperature sensor.

Note 1 lists the nominal test conditions and test circuits in which all the characteristics are defined. Some additional test conditions are listed in the column "Conditions", but Note 1 helps minimize the clutter.

Note 2 gives the thermal impedance, (which may also be shown in a chart or table).

Note 3 warns that an output impedance test, if done with a long pulse, could cause significant self-heating and thus, error.

Note 6 is intended to show which specs apply at all rated temperatures.

Note 7 is the definition of the "Accuracy" spec, and Note 8 the definition for non-linearity. Note 9 states in what test circuit the quiescent current is defined. Note 10 indicates that one model of the family may not be available at the time of printing (but happens to be available now), and Note 11 is the definition of Absolute Max Ratings.

* Note—the "4 seconds" soldering time is a new standard for plastic packages.

** Note—the wording of Note 11 has been revised—this is the best wording we can devise, and we will use it on all future datasheets.

APPLICATIONS

Another important part of the data sheet is the applications section. It indicates the novel and conventional ways to use a device. Sometimes these applications are just little ideas to tweak a reader's mind. After looking at a couple of applications, one can invent other ideas that are useful. Some applications may be of no real interest or use.

In other cases, an application circuit may be the complete definition of the system's performance; it can be the test circuit in which the specification limits are defined, tested and guaranteed. But, in all other instances, the performance of a typical application circuit is not guaranteed, it is only typical. In many circumstances, the performance may depend on external components and their precision and matching. Some manufacturers have added a phrase to their data sheets:

"Applications for any circuits contained in this document are for illustration purposes only and the manufacturer makes no representation or warranty that such applications will be suitable for the use indicated without further testing or modification."

In the future, manufacturers may find it necessary to add disclaimers of this kind to avoid disappointing users with circuits that work well, much of the time, but cannot be easily guaranteed.

The applications section is also a good place to look for advice on quirks—potential drawbacks or little details that may not be so little when a user wants to know if a device will actually deliver the expected performance.

For example, if a buffer can drive heavy loads and can handle fast signals cleanly (at no load), the maker isn't doing anybody any favors if there is no mention that the distortion goes sky-high if the rated load is applied.

Another example is the application hint for the LF156 family: "Exceeding the negative common-mode limit on either input will cause a reversal of the phase to output and force the amplifier output to the corresponding high or low state. Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur, since raising the input back within the common-mode range again puts the input stage and, thus the amplifier, in a normal operating mode."

That's the kind of information a manufacturer should really give to a data-sheet reader because no one could ever guess it.

Sometimes, a writer slips a quirk into a characteristic curve, but it's wiser to draw attention to it with a line of text. This is because it's better to make the user sad before one gets started, rather than when one goes into production. Conversely, if a user is going to spend more than 10 minutes using a new product, one ought to spend a full five minutes reading the entire data sheet.

FINE PRINT

What other fine print can be found on a data sheet? Sometimes the front page may be marked "advance" or "preliminary." Then on the back page, the fine print may say something such as:

"This data sheet contains preliminary limits and design specifications. Supplemental information will be published at a later date. The manufacturer reserves the right to make changes in the products contained in this document in order to improve design or performance and to supply the best possible products. We also assume no responsibility for the use of any circuits described herein, convey no license under any patent or other right and make no representation that the circuits are free from patent infringement."

In fact, after a device is released to the marketplace in a preliminary status, the engineers love to make small improvements and upgrades in specifications and characteristics, and hate to degrade a specification from its first published value—but occasionally that is necessary.

Another item in the fine print is the manufacturer's telephone number. Usually it is best to refer questions to the local sales representative or field-applications engineer, because they may know the answer or they may be best able to put a questioner in touch with the right person at the factory.

Occasionally, the factory's applications engineers have all the information. Other times, they have to bring in product engineers, test engineers or marketing people. And sometimes the answer can't be generated quickly—data have to be gathered, opinions solidified or policies formulated before the manufacturer can answer the question. Still, the telephone number is the key to getting the factory to help.

ORIGINS OF DATA SHEETS

Of course, historically, most data sheets for a class of products have been closely modeled on the data sheet of the forerunner of that class. The first data sheet was copied to make new versions.

That's the way it happened with the UA709 (the first monolithic op amp) and all its copies, as well as many other similar families of circuits.

Even today, an attempt is made to build on the good things learned from the past and add a few improvements when necessary. But, it's important to have real improvements, not just change for the sake of change.

So, while it's not easy to get the format and everything in it exactly right to please everybody, new data sheets are continually surfacing with new features, applications ideas, specifications and aids for the user. And, if the users complain loudly enough about misleading or inadequate data sheets, they can help lead the way to change data sheets. That's how many of today's improvements came about—through customer demand.

Who writes data sheets? In some cases, a marketing person does the actual writing and engineers do the checking. In other companies, the engineer writes, while marketing people and other engineers check. Sometimes, a committee seems to be doing the writing. None of these ways is necessarily wrong.

For example, one approach might be: The original designer of the product writes the data sheet (inside his head) at the same time the product is designed. The concept here is, if one can't find the proper ingredients for a data sheet—good applications, convenient features for the user and nicely tested specifications as the part is being designed—then maybe it's not a very good product until all those ingredients are completed. Thus, the collection of raw materials for a good data sheet is an integral part of the design of a product. The actual assembly of these materials is an art which can take place later.

WHEN TO WRITE DATA SHEETS

A new product becomes available. The applications engineers start evaluating their application circuits and the test engineers examine their production test equipment.

But how can the users evaluate the new device? They have to have a data sheet—which is still in the process of being written. Every week, as the data sheet writer tries to polish and refine the incipient data sheet, other engineers are reporting, "These spec limits and conditions have to be revised," and, "Those application circuits don't work like we thought they would; we'll have one running in a couple of days." The marketing people insist that the data sheet must be finalized and frozen right away so that they can start printing copies to go out with evaluation samples.

These trying conditions may explain why data sheets always seem to have been thrown together under panic conditions and why they have so many rough spots. Users should be aware of the conflicting requirements: Getting a data sheet "as completely as possible" and "as accurately as possible" is compromised if one wants to get the data sheet "as quickly as possible."

The reader should always question the manufacturer. What are the alternatives? By not asking the right question, a misunderstanding could arise; getting angry with the manufacturer is not to anyone's advantage.

Robert Pease has been staff scientist at National Semiconductor Corp., Santa Clara, Calif., for eleven years. He has designed numerous op amps, data converters, voltage regulators and analog-circuit functions.

Appendix H
Safe Operating Areas for Peripheral Drivers

National Semiconductor
Application Note 213
Bill Fowler

Peripheral Drivers is a broad definition given to Interface Power devices. The devices generally have open-collector output transistors that can switch hundreds of milliamps at high voltage, and are driven by standard Digital Logic gates. They serve many applications such as: Relay Drivers, Printer Hammer Drivers, Lamp Drivers, Bus Drivers, Core Memory Drivers, Voltage Level Transistors, and etc. Most IC devices have a specified maximum load such as one TTL gate can drive ten other TTL gates. Peripheral drivers have many varied load situations depending on the application, and requires the design engineer to interpret the limitations of the device vs its application. The major considerations are *Peak Current, Breakdown Voltage,* and *Power Dissipation.*

OUTPUT CURRENT AND VOLTAGE CHARACTERISTICS

Figure 1 shows the circuit of a typical peripheral driver, the DS75451. The circuit is equivalent to a TTL gate driving a 300 mA output transistor. *Figure 2* shows the characteristics of the output transistor when it is ON and when it is OFF. The output transistor is capable of sinking more than one amp of current when it is ON, and is specified at a V_{OL} = 0.7V at 300 mA. The output transistor is also specified to operate with voltages up to 30V without breaking down, but there is more to that as shown by the breakdown voltages labeled BVCES, BVCER, and LVCEO.

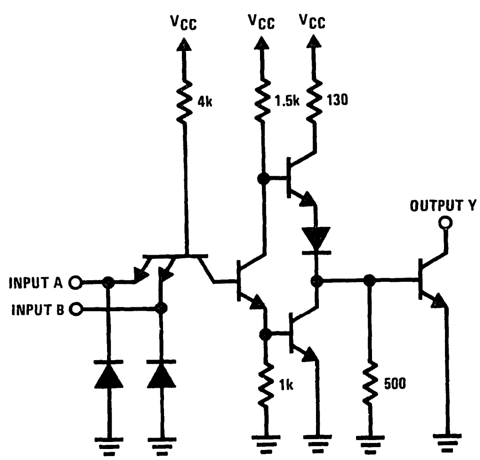

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FIGURE 1. Typical Peripheral Driver DS75451

BVCES corresponds to the breakdown voltage when the output transistor is held off by the lower output transistor of the TTL gate, as would happen if the power supply (V_{CC}) was 5V. BVCER corresponds to the breakdown voltage when the output transistor is held off by the 500 resistor, as would happen if the power supply (V_{CC}) was off (0V). LVCEO corresponds to the breakdown voltage of the output transistor if it could be measured with the base open. LVCEO can be measured by exceeding the breakdown voltage BVCES and measuring the voltage at output currents of 1 to 10 mA on a transistor curve tracer (LVCEO is sometimes measured in an Inductive Latch-Up Test). Observe that all breakdown voltages converge on LVCEO at high currents, and that destructive secondary breakdown voltage occurred (shown as dotted line) at high currents and high voltage corresponding to exceeding the power dissipation of the device. The characteristics of secondary breakdown voltage vary with the length of time the condition exists, device temperature, voltage, and current.

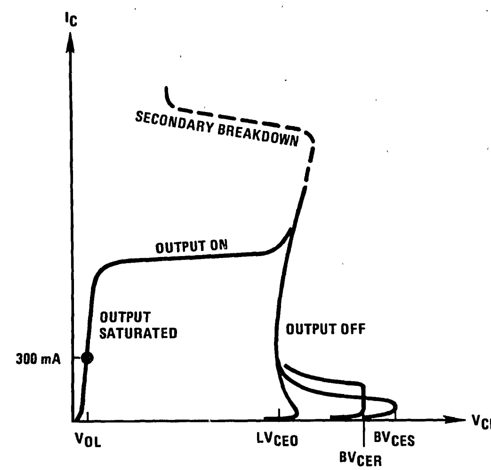

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FIGURE 2. Output Characteristics ON and OFF

OUTPUT TRANSFER CHARACTERISTICS VS INDUCTIVE AND CAPACITIVE LOADS

Figure 3 shows the switching transfer characteristics superimposed on the DC characteristics of the output transistor for an inductive load. *Figure 4* shows the switching transfer characteristics for a capacitor load. In both cases in these examples, the load voltage (V_B) exceeds LVCEO. When the output transistor turns on with an inductive load the initial current through the load is 0 mA, and the transfer curve switches across to the left (V_{OL}) and slowly charges the inductor. When the output transistor turns off with an inductive load, the initial current is I_{OL}, which is sustained by the inductor and the transistor curve switches across to the right (V_B) through a high current and high voltage area which exceeds LVCEO and instead of turning off (shown as dotted line) the device goes into secondary breakdown. It is generally not a good practice to let the output transistor's voltage exceed LVCEO with an inductive load.

In a similar case with a capacitive load shown in *Figure 4*, the switching transfer characteristics rotate counter-clockwise through the DC characteristics, unlike the inductive load which rotated clockwise. Even though the switching transfer curve exceeds LVCEO, it didn't go into secondary breakdown. Therefore, it is an acceptable practice to let the output transistor voltage exceed LVCEO, but not exceed BVCER with a capacitive load.

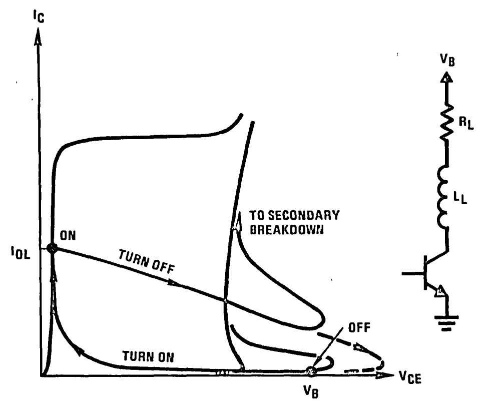

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FIGURE 3. Inductive Load Transfer Characteristics

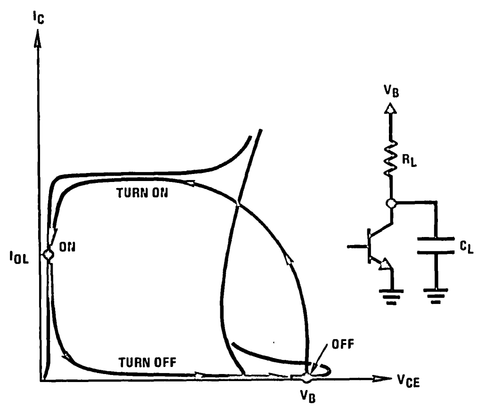

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FIGURE 4. Capacitive Load Transfer Characteristics

Figure 5 shows an acceptable application with an inductive load. The load voltage (V_B) is less than LVCEO, and the inductive voltage spike caused by the initial inductive current is quenched by a diode connected to V_B.

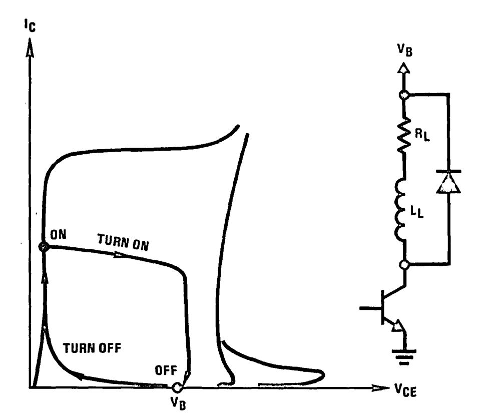

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FIGURE 5. Inductive Load Transfer Characteristics Clamped by Diode

Figure 6 shows the switching transfer characteristics of a capacitive load which leads to secondary breakdown. This condition occurs due to high sustained currents, not breakdown voltage. In this example, the large capacitor prevented the output transistor from switching fast enough through the high current and high voltage region; in turn the power dissipation of the device was exceeded and the output transistor went into secondary breakdown.

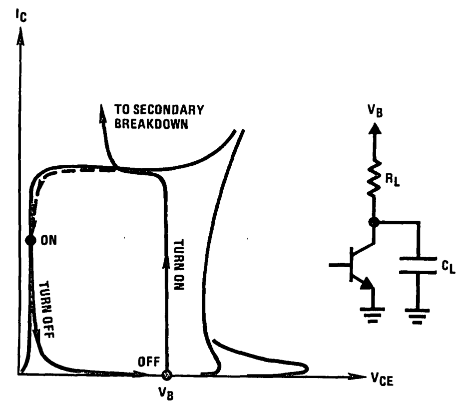

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FIGURE 6. Capacitive Load Transfer Characteristics

Figure 7 shows another method of quenching the inductive voltage spike caused by the initial inductive current. This method dampens the switching response by the addition of R_D and C_D. The values of R_D and C_D are chosen to critically dampen the values of R_L and L_L; this will limit the output voltage to $2 \times V_B$.

$$\frac{L_L}{(R_L + R_D)} \times \sqrt{\frac{1}{L_L C_D}} \leq 0.5$$

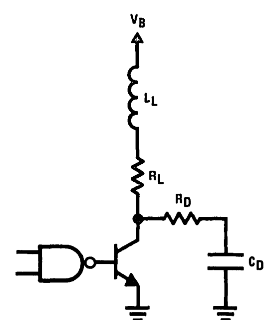

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FIGURE 7. Inductive Load Dampened by Capacitor

Figure 8 shows a method of reducing high sustaining currents in a capacitive load. R_D in series with the capacitor (C_L) will limit the switching transistor without affecting final amplitude of the output voltage, since the IR drop across R_D will be zero after the capacitor is charged.

As an additional warning, beware of parasitic reactance. If the driver's load is located some distance from the driver (as an example: on the inclosure panel or through a connecting cable) there will be additional inductance and capacitance which may cause ringing on the driver output which will exceed LVCEO or transient current that exceeds the sustaining current of the driver. A 300 mA current through a small inductor can cause a good size transient voltage, as compared with 20 mA transient current observed with TTL gates. For no other reason than to reduce the noise associated with these transients, it is good practice to dampen the driver's output.

In conclusion, transient voltage associated with inductive loads can damage the peripheral driver, and transient currents associated with capacitive loads can also damage the driver. In some instances the device may not exhibit failure with the first switching cycle, but its conditions from ON to OFF will worsen after many cycles. In some cases the device will recover after the power has been turned off, but its long term reliability may have been degraded.

POWER DISSIPATION

Power Dissipation is limited by the IC Package Thermal Reactance and the external thermal reactance of the environment (PC board, heat sink, circulating air, etc.). Also, the power dissipation is limited by the maximum allowable junction temperature of the device. There are two contributions to the power: the internal bias currents and voltage of the device, and the power on the output of the device due to the Driver Load.

POWER LIMITATIONS OF PACKAGE

Figure 9 shows the equivalent circuit of a typical power device in its application. Power is shown equivalent to electrical current, thermal resistance is shown equivalent to electrical resistance, the electrical reactance C and L are equivalent to the capacity to store heat, and the propagation delay through the medium. There are two mediums of heat transfer: conduction through mass and radiant convection. Convection is insignificant compared with conduction and isn't shown in the thermal resistance circuits. From the point power is generated (device junction) there are three possible paths to the ultimate heat sink: 1) through the device leads; 2) through the device surface by mechanical connection; and 3) through the device surface to ambient air. In all cases, the thermal paths are like delay lines and have a corresponding propagation delay. The thermal resistance is proportional to the length divided by the cross sectional area of the material. The Thermal Inductance is proportional to the length of the material (copper, molding compound, etc.) and inversely proportional to the cross sectional area. The thermal capacity is proportional to the volume of the material.

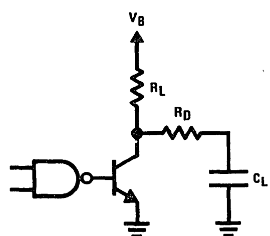

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FIGURE 8. Capacitive Load with Current Limiting Resistor

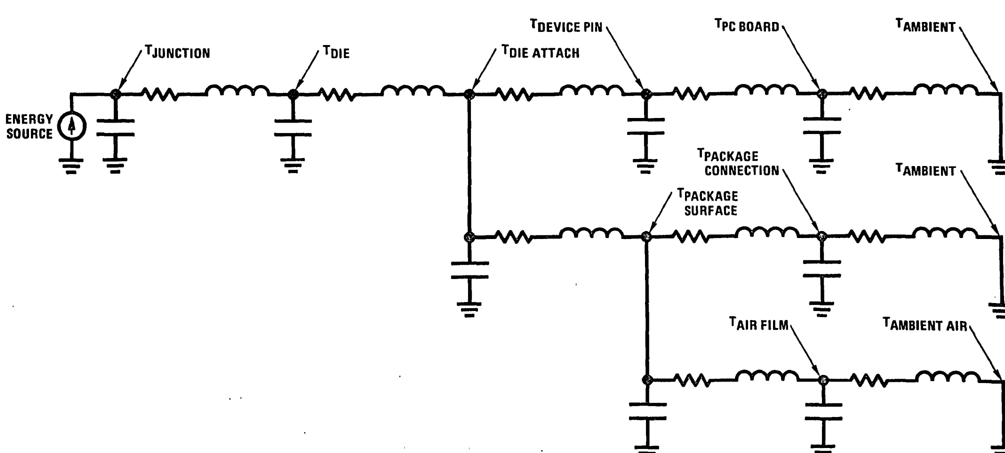

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FIGURE 9. Thermal Reactance from Junction to Ambient

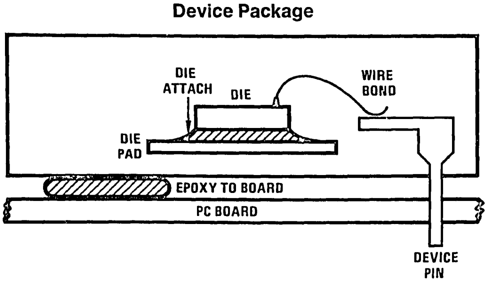

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FIGURE 10. Components of Thermal Reactance for a Typical IC Package

National Semiconductor specifies the thermal resistance from device junction through the device leads soldered in a small PC board, measured in one cubic foot of still air. *Figure 11* shows the maximum package power rating for an 8 pin Molded, an 8 pin Ceramic, 14 pin Molded and a 14 pin Ceramic package. The slope of the line corresponds to thermal resistance ($\phi_{JA} = \Delta P/\Delta T$).

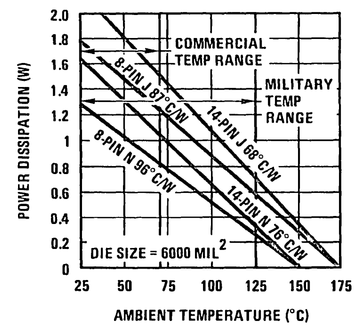

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FIGURE 11. Maximum Package Power Rating

The maximum allowable junction temperature for ceramic packages is 175°C; operation above this temperature will reduce the reliability and life of the device below an acceptable level. At a temperature of 500°C the aluminum metallization paths on the die start to melt. The maximum allowable junction temperature for a molded device is 150°C, operations above this may cause the difference in thermal expansion between the molding compound and package lead frame to sheer off the wire bonds from the die to the package lead. The industry standard for a molded device is 150°C, but National further recommends operation below 135°C if the device in its application will encounter a lot of thermal cycling (such as powered on and off over its life).

The way to determine the maximum allowable power dissipation from *Figure 11*, is to project a line from the maximum ambient temperature (T_A) of the application vertically (shown dotted in *Figure 12*), until the line intercepts the diagonal line of the package type, and then project a line (shown dotted) horizontally until the line intercepts the Power Dissipation Axis (P_{MAX}).

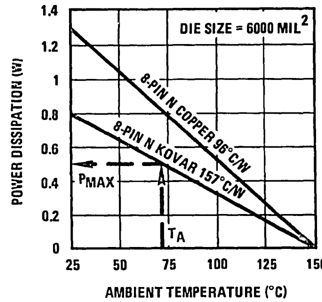

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FIGURE 12. Maximum Package Rating Copper vs Kovar Lead Frame Packages

Figure 11 shows that 14 pin packages have less thermal resistance than 8 pin packages; which should be expected since it has more pins to conduct heat and has more surface area. Something that may not be expected is that the Thermal Resistance of the molded devices is comparable to the ceramic devices. The reason for the lower thermal resistance of the molded devices is the Copper lead frame, which is a better thermal conductor than the Kovar lead frame of the ceramic package. Almost all the peripheral drivers made by National Semiconductor are constructed with Copper lead frames (refer to ϕ_{JA} on the specific devices data sheet). The difference between the thermal resistance of Copper and Kovar in a molded package is shown in *Figure 12*.

Another variance in thermal resistance is the size of the IC die. If the contact area to the lead frame is greater, then the thermal resistance from the Die to the Lead Frame is reduced. This is shown in *Figure 13*. The thermal resistance shown in *Figure 11* corresponds to die that are 6000 mil^2 in area.

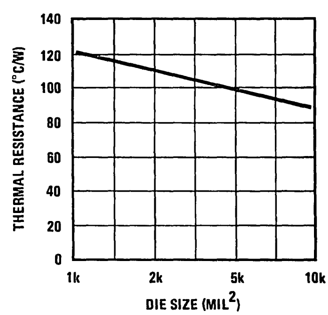

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FIGURE 13. Thermal Resistance vs Die Size

In most applications the prime medium for heat conduction is through the device leads to the PC board, but the thermal resistance can be significantly improved by cooling air driven across the surface of the package. The conduction to air is limited by a stagnant film of air at the surface of the package. The film acts as an additional thermal resistance. The thickness of the film is proportional to its resistance. The thickness of the film is reduced by the velocity of the air across the package as shown in *Figure 14*. In most cases, the thermal resistance is reduced 25% to 250 linear feet/min, and 30% at 500 linear feet/min, above 500 linear feet/min the improvement flattens out.

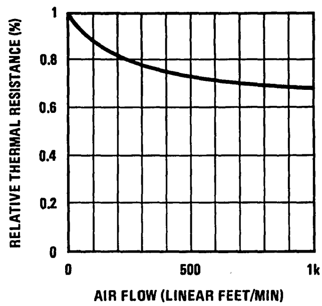

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FIGURE 14. Thermal Resistance vs Air Velocity

The thermal resistance can also be improved by connecting the package to the PC board copper or by attaching metal wings to the package. The improvement by these means is outside the control of the IC manufacturer, but is available from the manufacturer of the heat sink device. If the IC is mounted in a socket rather than soldered to a PC board, the thermal resistance through the device leads will worsen. In most cases, the thermal resistance is increased by 20%; again this is a variable subject to the specific socket type.

The maximum package rating shown in this note corresponds to a 90% confidence level that the package will have thermal resistance equal to or less than the value shown. The thermal resistance varies ±5% about the mean due to variables in assembly and package material.

CALCULATIONS OF POWER DISSIPATION

Most IC devices (such as T^2L) operate at power levels well below the device package rating, but peripheral drivers can easily be used at power levels that exceed the package rating unknowingly, if the power dissipation isn't calculated. As an example, the DS3654 Ten Bit Printer Driver could dissipate 3 watts (DC and, even more AC), and it is only in a 0.8 watt package. In this example, the device would be destroyed in moments, and may even burn a hole in the PC board it is mounted on. The DS3654 data sheet indicated that the 10 outputs could sink 300 mA with a V_{OL} of 1 volt, but it wasn't intended that all the outputs would be sinking this current at the same time, and if so, not for a long period. The use of the DS3654 requires that the power be calculated vs the duty cycle of the outputs.

The DC power dissipation is pretty obvious, but in another example, a customer used the DS3686 relay driver to drive 6.5h inductive load. The DS3687 has an internal clamp network to quench the inductive back swing at 60V. At 5 Hz the device dissipates 2 watts, with transient peaks up to 11 watts. After 15 minutes of operation, the driver succumbs to thermal overload and becomes non-functional. The DS3687 was intended for telephone relay, which in most applications switches 20 times a day.

Peripheral driver will dissipate peak power levels that greatly exceed the average DC power. This is due to the capacity of the die and package to consume the transient energy while still maintaining the junction temperature at a safe level. This capacity is shown as a capacitor in *Figure 9*. In the lab (under a microscope) a device may be observed to glow orange around the parameter of the junction under excessive peak power without damage to the device. *Figure 15* shows a plot of maximum peak power vs applied time for the DS3654, and the same information plotted as energy vs applied time. To obtain these curves, the device leakage current when it switches off was used to monitor device limitation. Note in *Figure 15* there is a transition in the curve about 10 μs. At this point, the thermal capacity of the die has been exceeded. The thermal delay to the next thermal capacity (the package) was too long, and limited the peak power. These levels are not suggested operating levels, but an example of a Peripheral Driver to handle peak transient power.

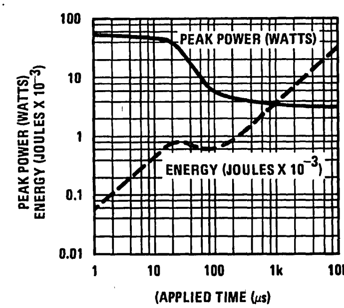

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FIGURE 15. Peak Power and Energy vs the Period of Time the Power was Applied

To calculate power dissipation, the only information available to the design engineer is the parametric limits in the device data sheet, and the same information about the load reactance. If the calculations indicate the device is within its limits of power dissipation, then using those parametric limits is satisfactory. If the calculation of power dissipation is marginal, the parametric limits used in the calculations might be worst case at low temperature instead of high temperature due to a positive temperature coefficient (T_C) of resistance. IC resistors and resistors associated with the load generally have a positive T_C. On the other hand, diodes and transistor emitter base voltages have a negative T_C; which may in some circuits negate the effect of the resistors T_C. Peripheral output transistors have a positive T_C associated with V_{OL}; while output Darlington transistors have a negative T_C at low currents and may be flat at high currents. *Figure 16* shows an example of power dissipation vs temperature; note that the power dissipation at the application's maximum temperature (T_A) was less than the power dissipation at lower temperatures. Since maximum junction temperature is the concern of the calculation, then maximum ambient temperature power should be used. The junction temperature may be determined by projecting a line (shown dotted in *Figure 16*), with a slope proportional to ϕ_{JA} back to the horizontal axis (shown as T_J). If the point is below the curve then T_J will be less than 150°C. T_J must not exceed the maximum junction temperature for that package type. In this example, T_J is less than 150°C as required by a molded package. To calculate the power vs temperature, it is necessary to characterize the device parameters vs temperature. Unfortunately, this information is not always provided by IC manufacturers in the device data sheets. A method to calculate I_{CC} vs temperature is to measure a device, then normalize the measurements vs the typical value for I_{CC} in the data sheet, then worst case the measurements by adding 30%. Thirty percent is normally the worst-case resistor tolerance that IC devices are manufactured to.

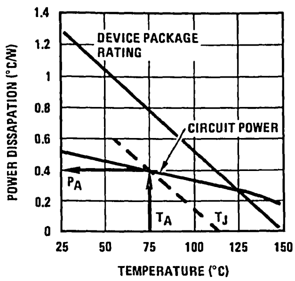

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FIGURE 16. IC Power Dissipation vs Temperature

CALCULATION OF OUTPUT POWER WITH AN INDUCTIVE LOAD

For this example, the device output circuit is similar to the DS3654 (10-Bit Printer Solenoid Driver) and the DS3686 and DS3687 (Telephone Relay Driver) as shown in *Figure 17.* Special features of the circuit type are the Darlington output transistors Q1 and Q2 and the zener diode from the collector of Q1 to the base of Q2. The Darlington output requires very little drive from the logic gate driving it and in turn dissipates less power when the output is turned ON and OFF, than a single saturating transistor output would. The zener diode (D_Z) quenches the inductive backswing when the output is turned OFF.

Device and Load Characteristics Used for Power Calculation

V_{OL}	Output Voltage ON	1.5V
V_C	Output Clamp Voltage	65V
V_B	Load Voltage	30V
R_L	Load Resistance	120Ω
L_L	Load Inductance	5h
T_{ON}	Period ON	100 ms
T_{OFF}	Period OFF	100 ms
T	Total Period	200 ms

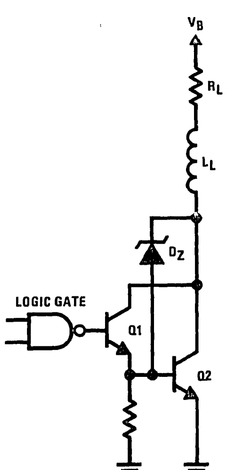

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FIGURE 17. Peripheral Driver with Inductive Load

Refer to *Figure 18* voltage and current waveforms corresponding to the power dissipation calculated for this example of an inductive load.

P_{ON} = Average power dissipation in device output when device is ON during total period (T)

$$\tau = \frac{L_L}{R_L} = \frac{5h}{120\Omega} = 41.7\text{ ms}$$

$$I_L = \frac{V_B - V_{OL}}{R_L} = \frac{30 - 1.5}{120} = 237.5\text{ mA}$$

$$I_P = I_L\left(1 - e^{-T_{ON}/\tau}\right)$$

$$I_P = 237.5\text{ mA}\left(1 - e^{-100\text{ ms}/41.7\text{ ms}}\right)$$

$$I_P = 215.9\text{ mA}$$

$$P_{ON} = V_{OL} \times I_L \times \frac{T_{ON}}{T}\left[1 - \int_{\circ}^{T_{ON}} \frac{e^{-t/\tau}\,dt}{T_{ON}}\right]$$

$$P_{ON} = V_{OL} \times I_L \times \frac{T_{ON}}{T}\left[1 - \frac{\tau}{T_{ON}}\left(1 - e^{-T_{ON}/\tau}\right)\right]$$

$$P_{ON} = 1.5 \times 237.5\text{ mA} \times \frac{100}{200}\left[1 - \frac{41.7}{100}\left(1 - e^{-100/41.7}\right)\right]$$

$$P_{ON} = 110.6\text{ mW}$$

P_{OFF} = Average power dissipation in device output when device is OFF during total period (T)

$$I_R = \frac{V_C - V_B}{R_L} = \frac{65 - 30}{120\Omega} = 291.7\text{ mA}$$

$$t_x = \tau\,\ell n\left(\frac{I_P + I_R}{I_R}\right)$$

$$t_x = 41.7\text{ ms}\,\ell n\left(\frac{215.9 + 291.7}{291.7}\right) = 23.1\text{ ms}$$

$$P_{OFF} = V_C \times \frac{t_x}{T}\left[(I_P + I_R)\int_{\circ}^{t_x} \frac{e^{-t/\tau}\,dt}{t_x} - I_R\right]$$

$$P_{OFF} = V_C \times \frac{t_x}{T}\left[(I_P + I_R) \times s\frac{\tau}{t_x}\left(1 - e^{-t_x/\tau}\right) - I_R\right]$$

$$P_{OFF} = 65 \times \frac{23.1}{200}\left[(215.9\text{ mA} + 291.7\text{ mA})\frac{41.7}{23.1}\left(1 - e^{-23.1/41.7}\right) - 291.7\text{ mA}\right]$$

$$P_{OFF} = 736\text{ mW}$$

P_O = Average power dissipation in device output

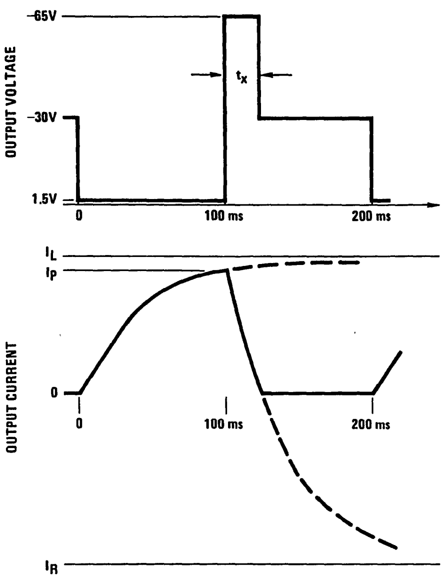
$$P_O = P_{ON} + P_{OFF} = 110.6 + 736 = 846.6\text{ mW}$$

In the above example, driving a 120Ω inductive load at 5 Hz, the power dissipation exceeded a more simple calculation of power dissipation, which would have been:

$$P_O = \frac{V_{OL}\,(V_B - V_{OL})}{R_L} \times \frac{T_{ON}}{T}$$

$$P_O = \frac{1.5\,(30 - 1.5)}{120} \times \frac{100\text{ ms}}{200\text{ ms}} = 182.5\text{ mW}$$

An error 460% would have occurred by not including the reactive load. The total power dissipation must also include other outputs (if the device has more than one output), and the power dissipation due to the device power supply currents. This is an example where the load will most likely exceed the device package rating. If the load is fixed, the power can be reduced by changing the period (T) and duty rate (T_{ON}/T_{OFF}).

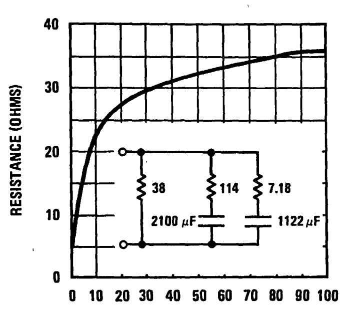


TL/F/5860-18

FIGURE 18. Voltage and Current Waveforms Corresponding to Inductive Load

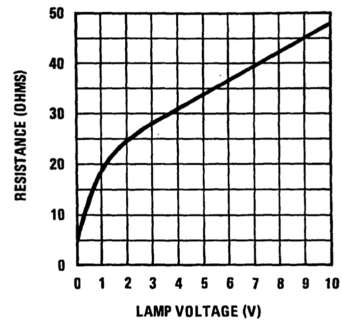
CALCULATION OF OUTPUT POWER WITH AN INCANDESCENT LAMP

An incandescent lamp is equivalent to a reactive load. The reactance is related to the period of time required to heat the lamp and the filaments positive temperature coefficient of resistance. *Figure 19* shows the transient response for a typical lamp used on instrument panels, and the equivalent electrical model for the lamp. Much like IC packages the lamp has a thermal circuit and its associated propagation delay. This lamp filament has an 8 ms time constant, and a longer 250 ms time constant from the lamp body to ambient. The DC characteristics are shown in *Figure 20.* Note the knee in the characteristics at 2 volts; this is where power starts to be dissipated in the form of light. This subject is important, since more peripheral drivers are damaged by lamps than any other load.



TL/F/5860-19

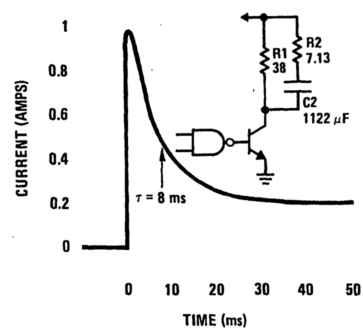
FIGURE 19. Transient Response of an Incandescent Lamp



TL/F/5860-20

FIGURE 20. DC Characteristics of an Incandescent Lamp

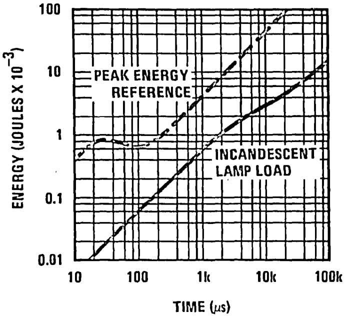
Figure 21 shows the transient response of a driver similar to a DS75451 driving the lamp characterized in *Figures 19* and *20.* The equivalent load doesn't include the reactance of the lamp base to ambient, which has a 250 ms time constant, since 10 ms to an IC is equivalent to DC. The peak transient current was 1 amp, settling to 200 ms, with an 8 ms time constant. Observe the peak current is clamped at 1 amp, by the sinking ability of the driver; otherwise the peak current may have been 1.2 amps. The DS75451 is only rated at 300 mA, but it is reasonable to assume it could sink 1 amp because of the designed force β required for switching response and worst case operating temperature.



TL/F/5860-21

FIGURE 21. Transient Incandescent Lamp Current

Calculation of the energy dissipated by a peripheral driver for the transient lamp current shown in *Figure 21* is shown above, and the plot of energy vs time is shown in *Figure 22. Figure 22* also includes as a reference the maximum peak energy from *Figure 15.* It can be seen from *Figure 22* that in this example there is a good safety margin between the lamp load and the reference max peak energy. If there were more drivers than one per package under the same load, the margin would have been reduced. Also, if the peripheral driver couldn't saturate because it couldn't sink the peak transient lamp current, then the energy would also reduce the margin of safe operation.



TL/F/5860-22

FIGURE 22. Energy vs Time for a Peripheral Driver with an Incandescent Lamp Load

CALCULATION OF ENERGY IN AN INCANDESCENT LAMP

$$\text{Energy} = \int_{0}^{t} V_{OL}\,(I_{R1} + I_{R2})\,dt$$

$$i_{R1} = \frac{V_B - V_{OL}}{R1} = I_{R1}$$

$$i_{R2} = \left(\frac{V_B - V_{OL}}{R2}\right) e^{-t/\tau}$$

$$= I_{R2}\,e^{-t/\tau} \quad \tau = R2C2$$

$$\text{Energy} = \int_{0}^{t} V_{OL}\,(I_{R1} + I_{R2}\,e^{-t/\tau})\,dt$$

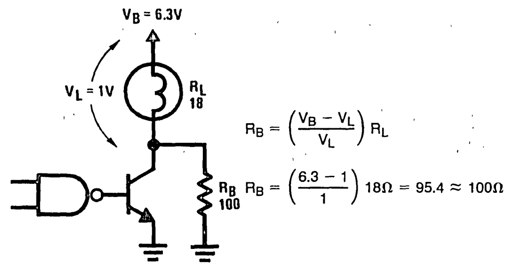
$$= V_{OL}\,[I_{R1}t + I_{R2}\tau\,(i - e^{-t/\tau})]$$

Given: $V_{OL} = 0.6V$

$I_{R1} = 0.2$ Amps

$I_{R1} + I_{R2} = 1$ Amp

A common technique used to reduce the 10 to 1 peak to DC transient lamp current is to bias the lamp partially ON, so the lamp filament is warm. This can be accomplished as shown in *Figure 23*. From *Figure 20* it can be seen that the lamp resistance at 0V is 5.7Ω, but at 1V the resistance is 18Ω. At 1V the lamp dosen't start to emit light. Using a lamp resistance of 100Ω and lamp voltage of 1V, R_B was calculated to be approximately 100Ω. This circuit will reduce the peak lamp current from 1 amp to 316 mA.



TL/F/5860-23

FIGURE 23. Circuit Used to Reduce Peak Transient Lamp Current

PERIPHERAL DRIVER SECTION

National Semiconductor has a wide selection of peripheral drivers as shown in this section's guide. The DS75451, DS75461, DS3631 and the DS3611 series have the same selection of logic function in an 8-pin package. The DS75461 is a high voltage selection of the DS75451 and may switch slower. The DS3611 and DS3631 are very high voltage circuits and were intended for slow relay applications. The DS3680, DS3686, and DS3687 were intended for 56V telephone relay applications. The DS3654 contains a 10-bit shift register followed by ten 250 mA clamped drivers. The DS3654 was intended for printer solenoid applications.

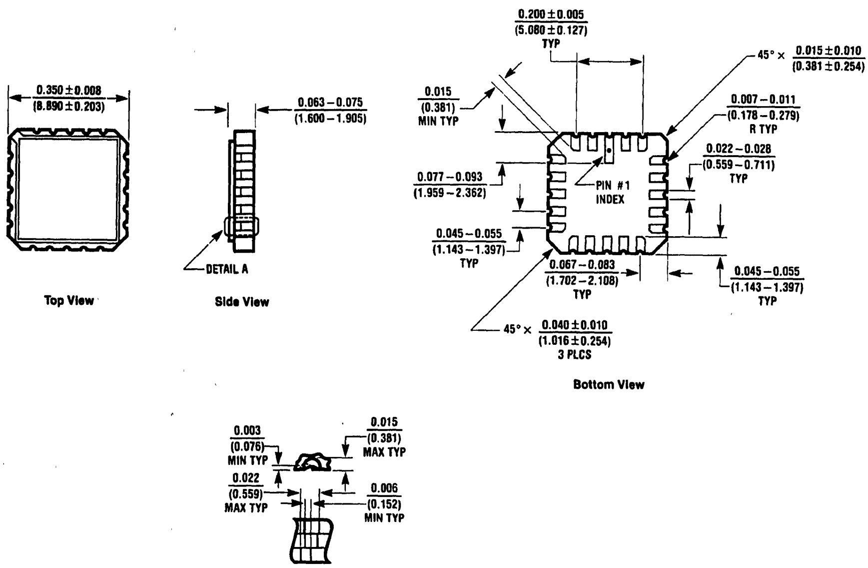
High current and high voltage peripheral drivers find many applications associated with digital systems, and it is the intention of the application note to insure that reliability and service life of peripheral drivers equal or exceed the performance of the other logic gates made by National.

For additional information, please contact the Interface Marketing Department at National or one of the many field application engineers world-wide.

National Semiconductor

20 Lead Ceramic Leadless Chip Carrier, Type C
NS Package Number E20A

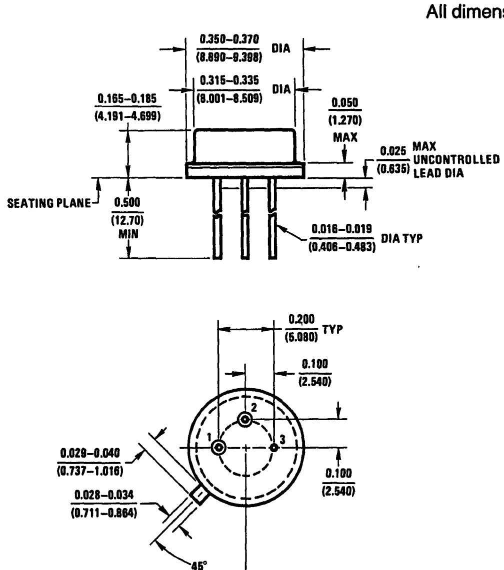
All dimensions are in inches (millimeters)



E20A (REV D)

3 Lead (0.200″ Diameter P.C.) TO-39 Metal Can Package, Low Profile
NS Package Number H03A

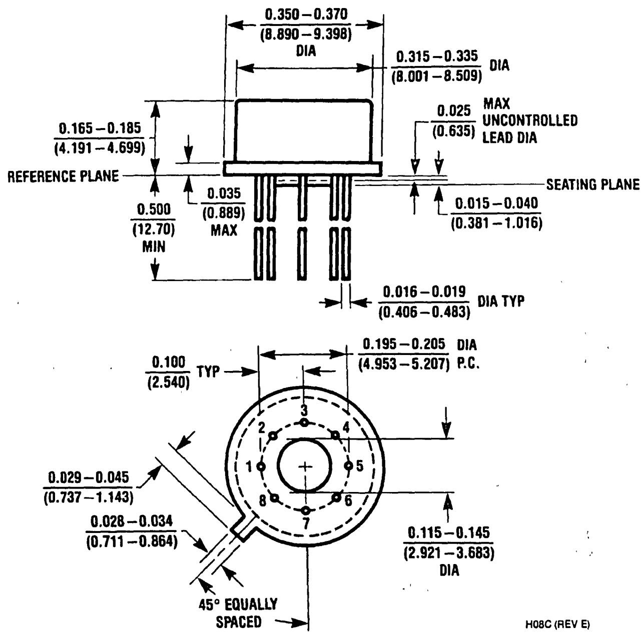
All dimensions are in inches (millimeters)



H03A (REV B)

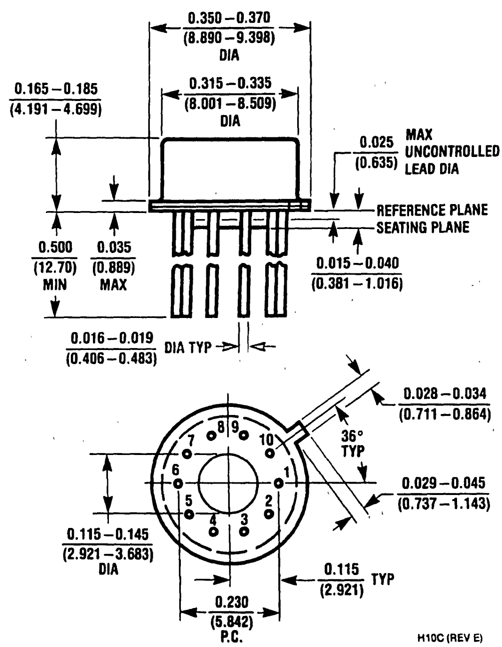
8 Lead (0.200″ Diameter P.C.) TO-5 Metal Can Package
NS Package Number H08C

All dimensions are in inches (millimeters)



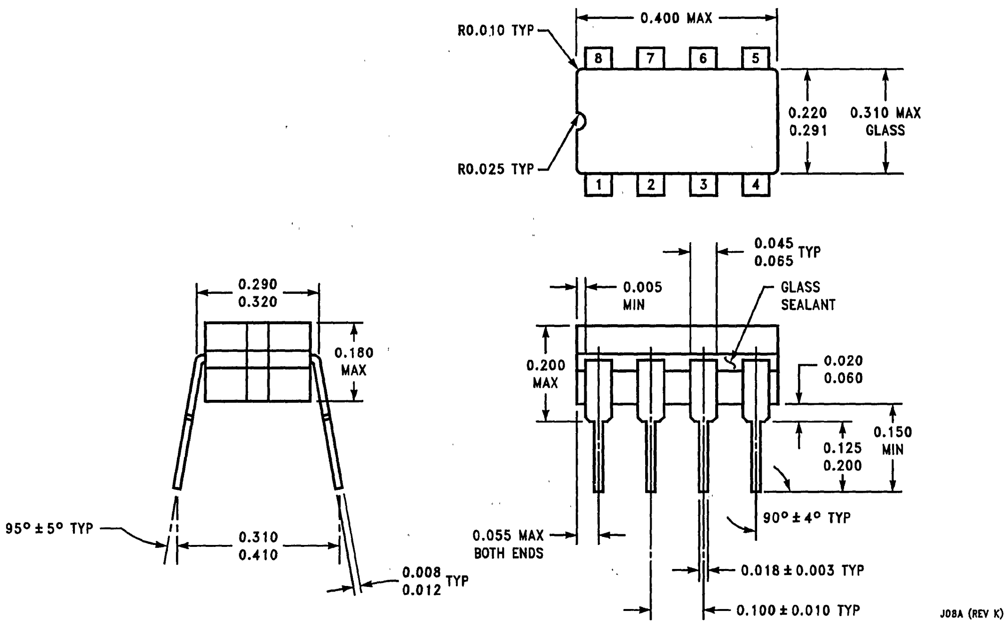
10 Lead (0.230″ Diameter P.C.) TO-5 Metal Can Package
NS Package Number H10C

All dimensions are in inches (millimeters)



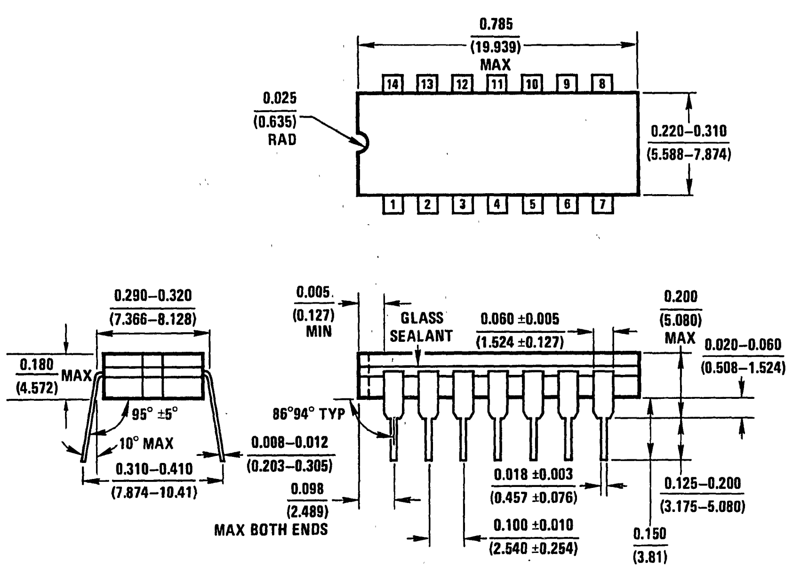
8 Lead Ceramic Dual-in-Line Package
NS Package Number J08A

All dimensions are in inches



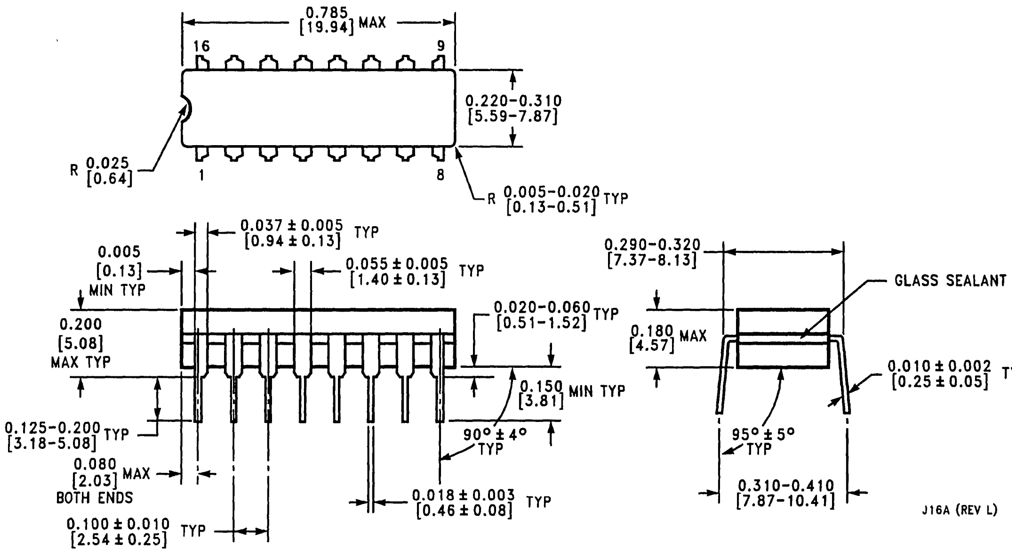
14 Lead Ceramic Dual-in-Line Package
NS Package Number J14A

All dimensions are in inches (millimeters)



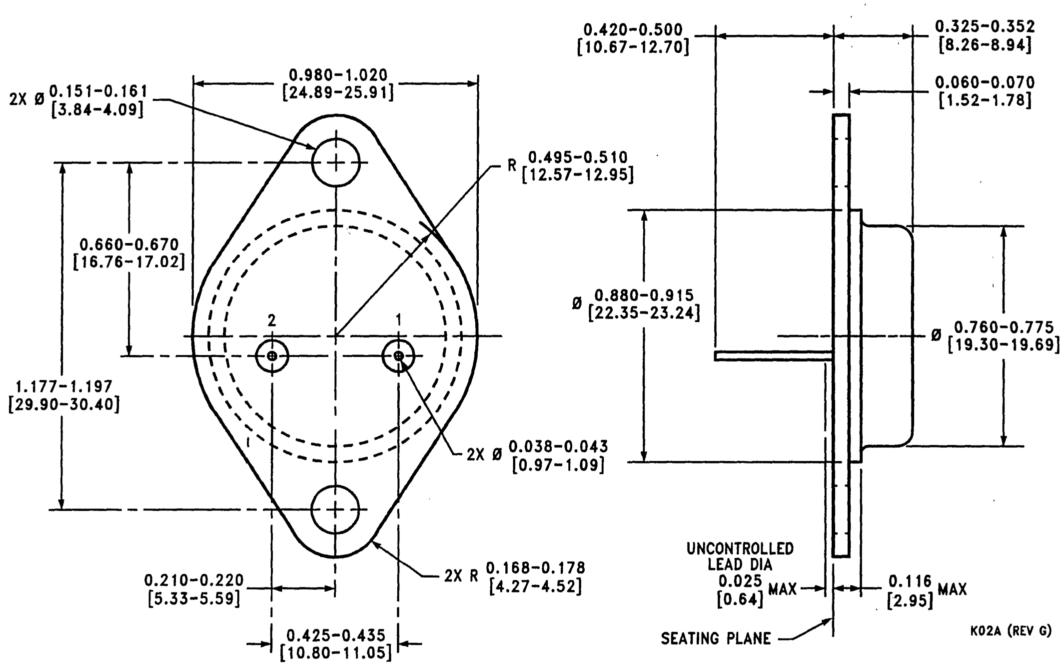
16 Lead Ceramic Dual-in-Line Package
NS Package Number J16A

All dimensions are in inches [millimeters]



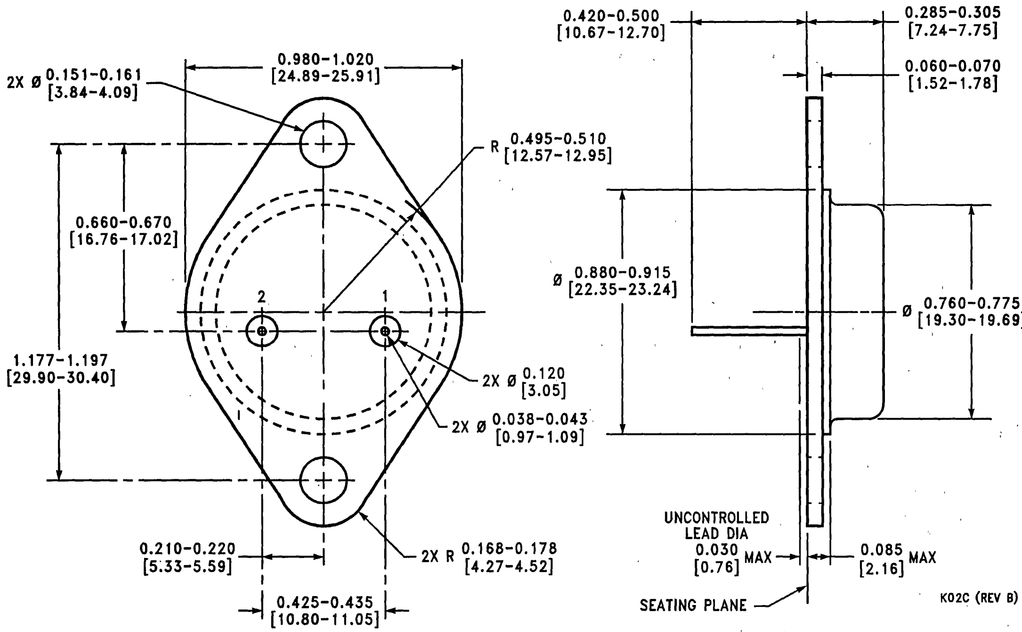
2 Lead TO-3 Metal Can Package
NS Package Number K02A

All dimensions are in inches [millimeters]



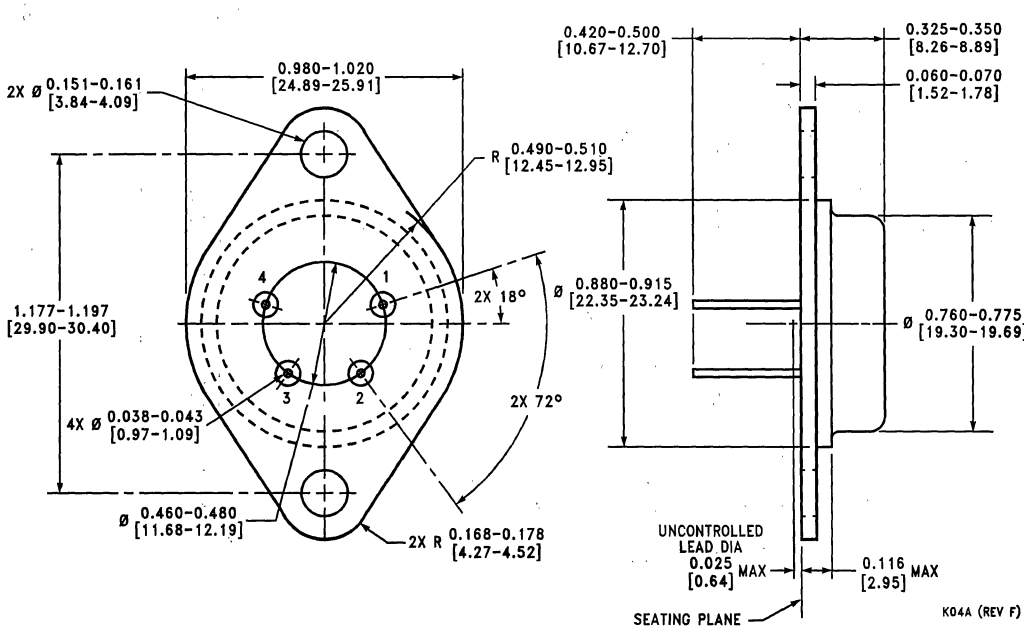
2 Lead TO-3 Metal Can Package, Low Profile
NS Package Number K02C

All dimensions are in inches [millimeters]



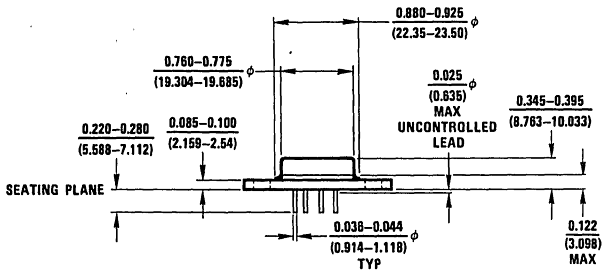
4 Lead TO-3 Metal Can Package
NS Package Number K04A

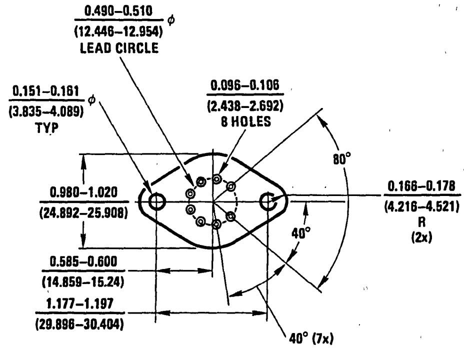
All dimensions are in inches [millimeters]



8 Lead TO-3 Metal Can Package
NS Package Number K08A

All dimensions are in inches (millimeters)

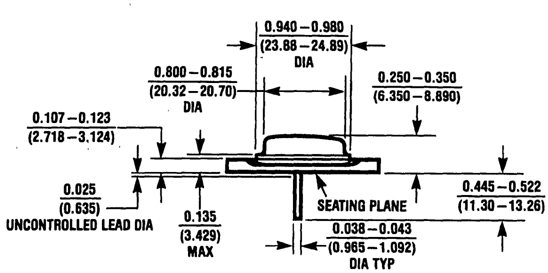


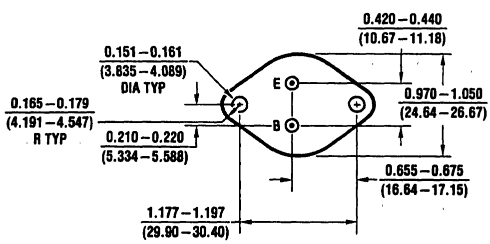


K08A (REV C)

2 Lead TO-3 Metal Can Package, Aluminum
NS Package Number KC02A

All dimensions are in inches (millimeters)

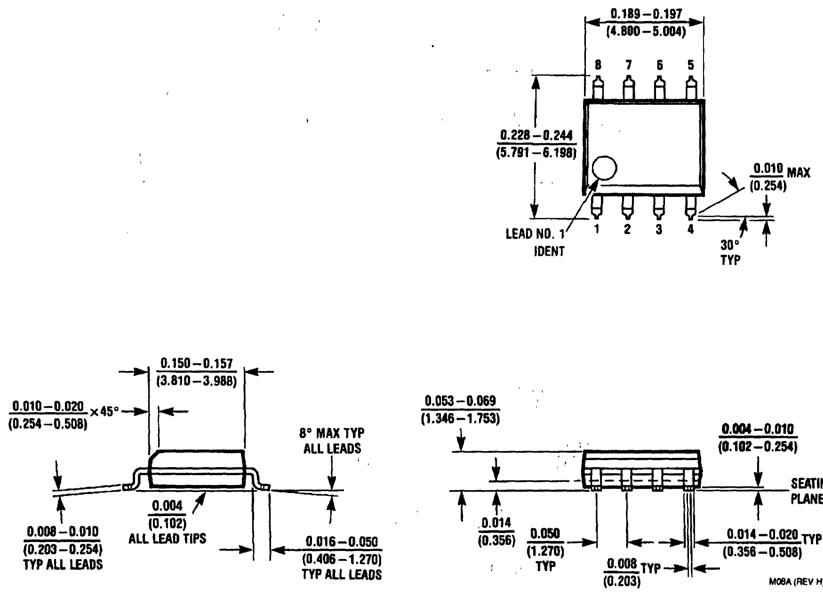




KC02A (REV C)

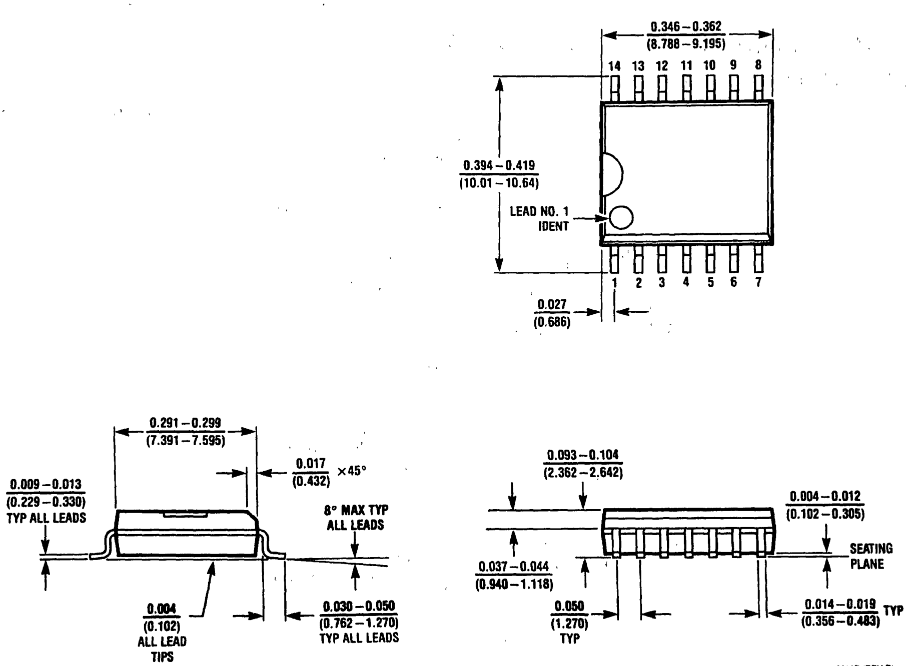
8 Lead (0.150″ Wide) Molded Small Outline Package, JEDEC
NS Package Number M08A

All dimensions are in inches (millimeters)



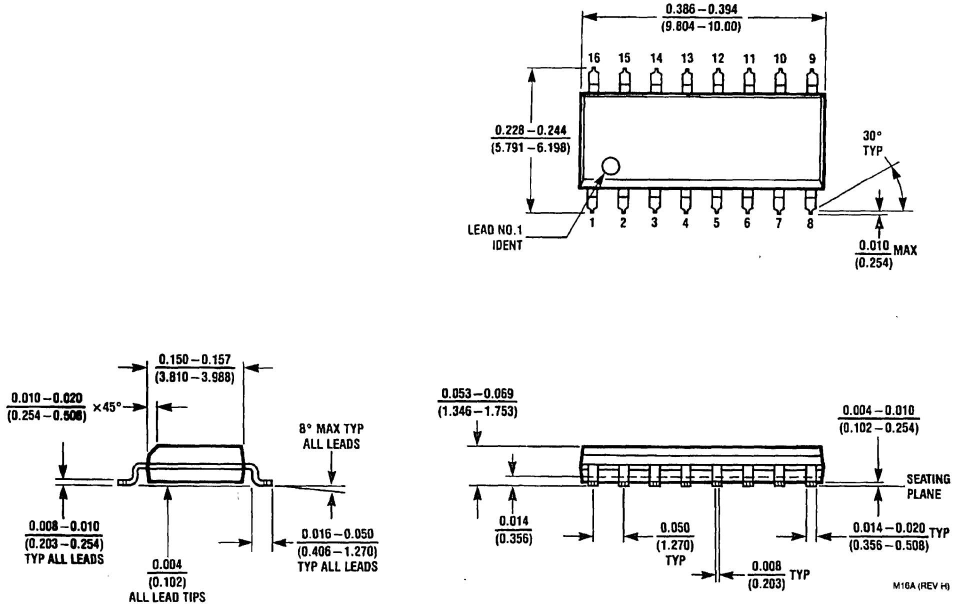
14 Lead (0.300″ Wide) Molded Small Outline Package, JEDEC
NS Package Number M14B

All dimensions are in inches (millimeters)



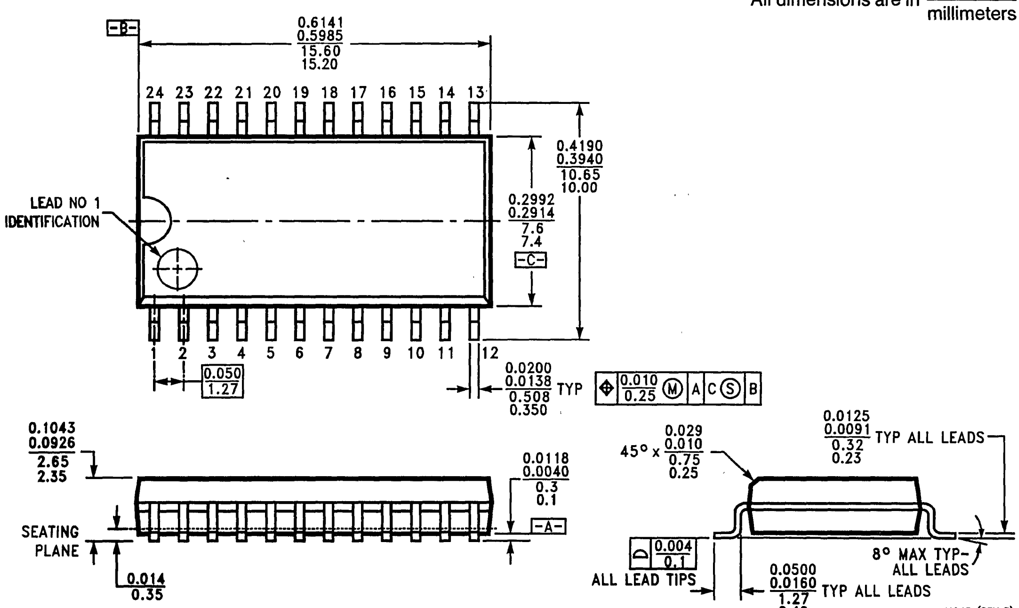
16 Lead (0.150" Wide) Molded Small Outline Package, JEDEC
NS Package Number M16A

All dimensions are in inches (millimeters)



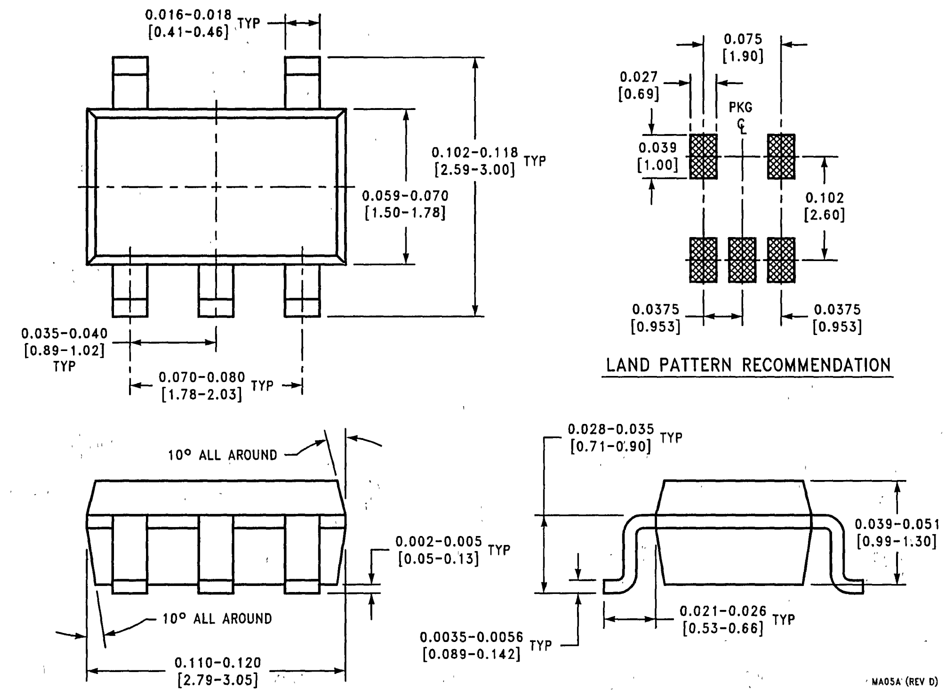
24 Lead (0.300" Wide) Molded Small Outline Package, JEDEC
NS Package Number M24B

All dimensions are in $\frac{\text{inches}}{\text{millimeters}}$



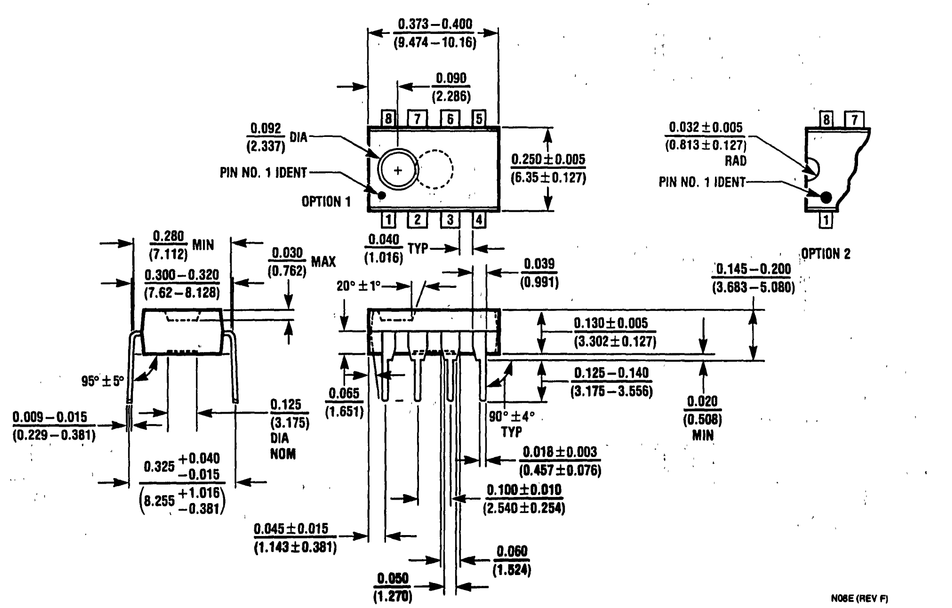
5 Lead Molded SOT-23-5
NS Package Number MA05A

All dimensions are in inches [millimeters]



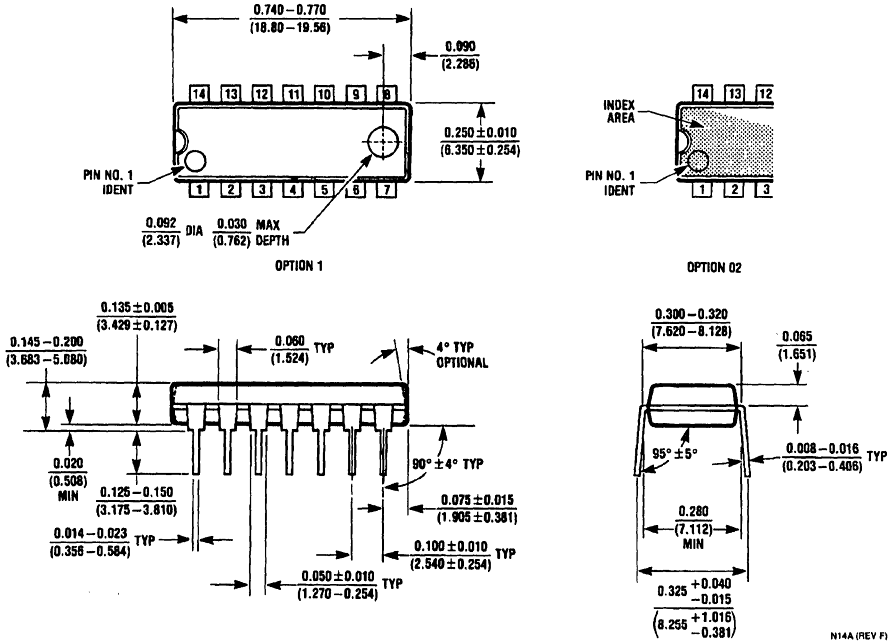
8 Lead (0.300″ Wide) Molded Dual-in-Line Package
NS Package Number N08E

All dimensions are in inches (millimeters)



14 Lead (0.300" Wide) Molded Dual-In-Line Package
NS Package Number N14A

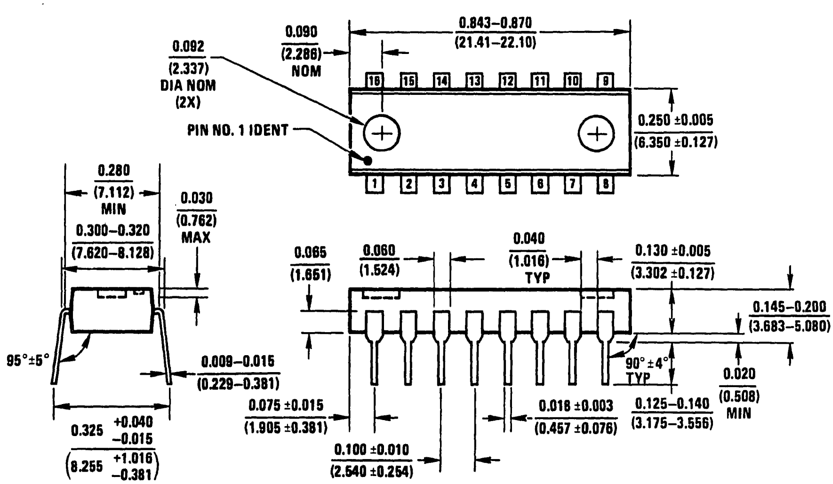
All dimensions are in inches (millimeters)



N14A (REV F)

16 Lead (0.300" Wide) Molded Dual-In-Line Package
NS Package Number N16A

All dimensions are in inches (millimeters)

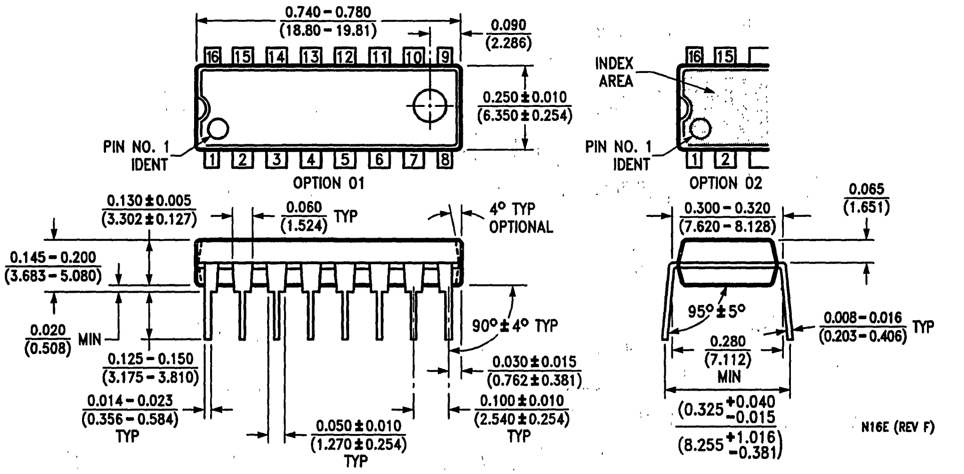


N16A (REV E)

6

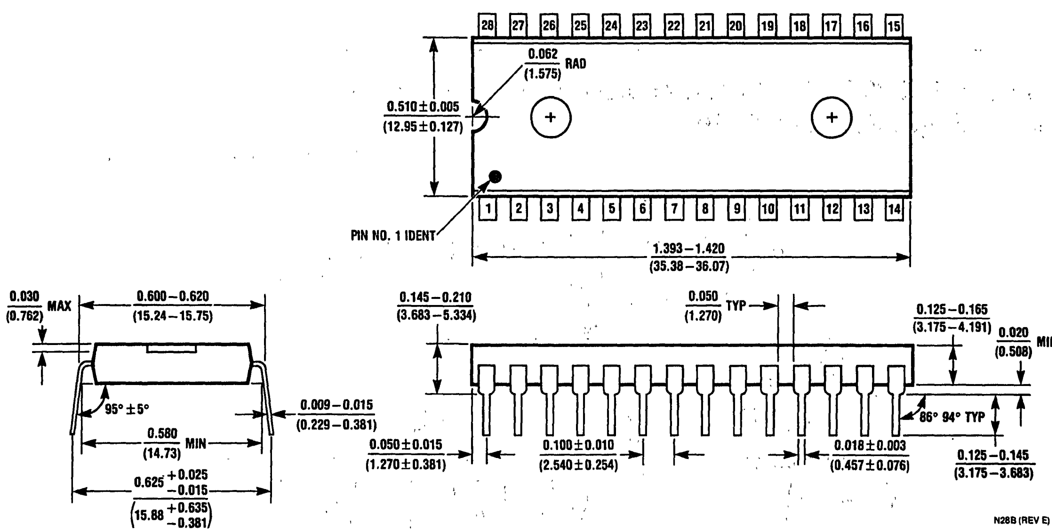
16 Lead (0.300" Wide) Molded Dual-in-Line Package
NS Package Number N16E

All dimensions are in inches (millimeters)



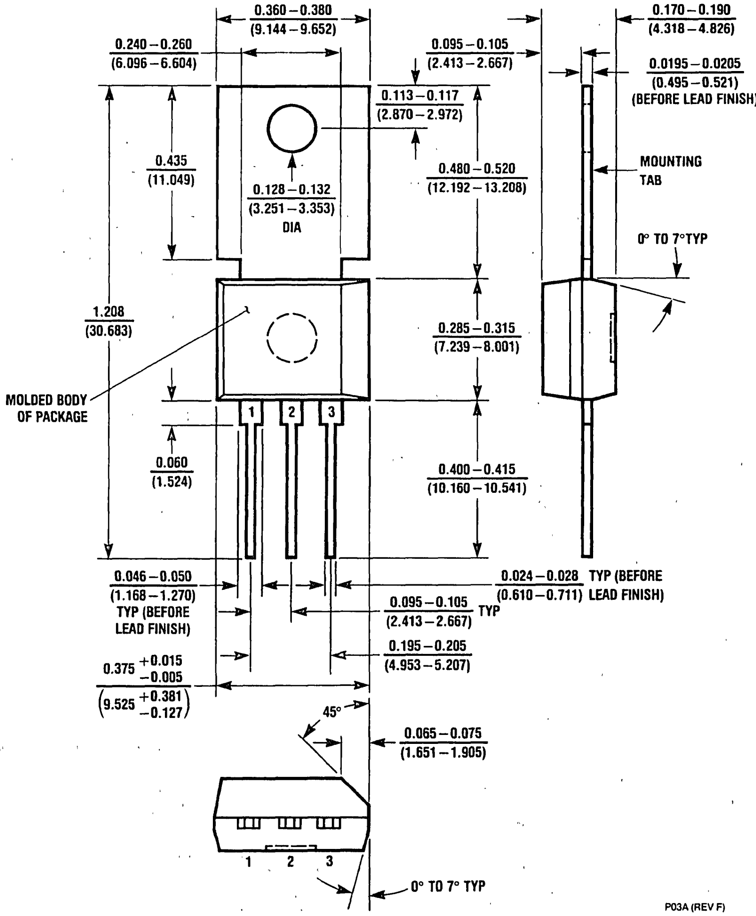
28 Lead (0.600" Wide) Molded Dual-in-Line Package
NS Package Number N28B

All dimensions are in inches (millimeters)



3 Lead Molded TO-202
NS Package Number P03A

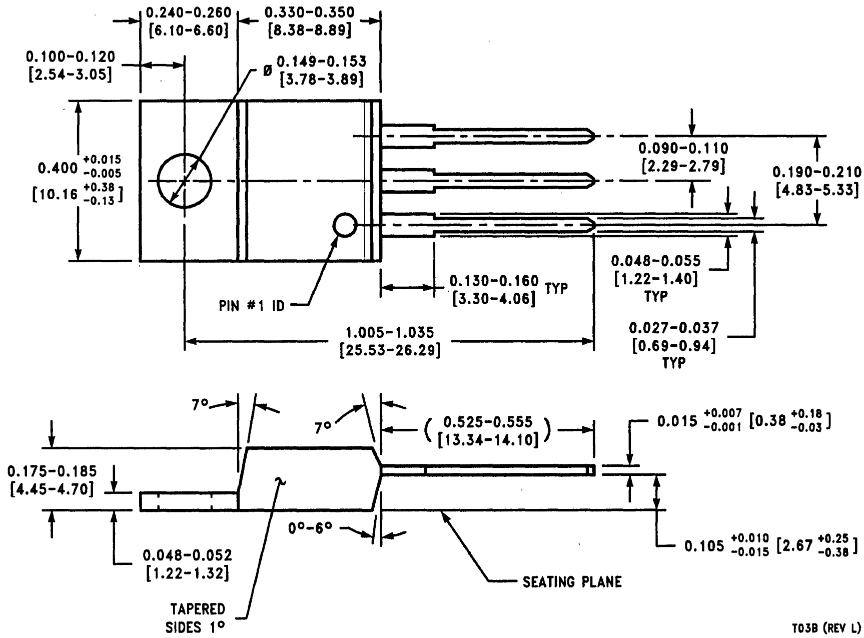
All dimensions are in inches (millimeters)



P03A (REV F)

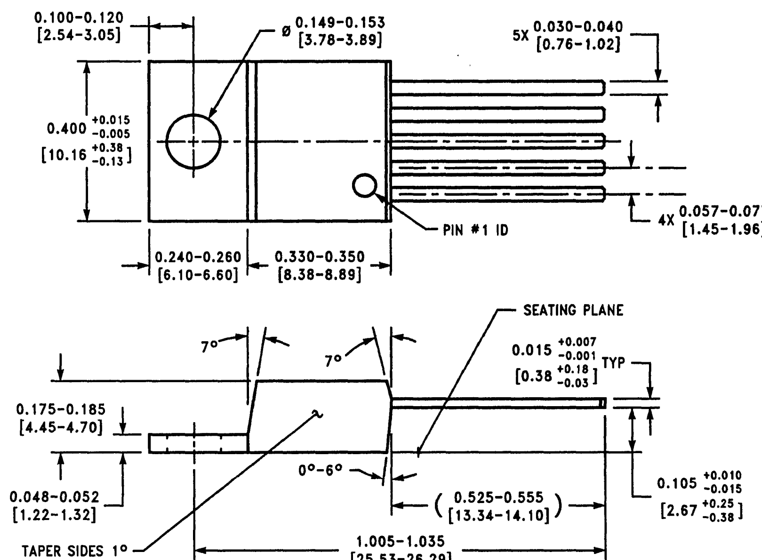
3 Lead Molded TO-220
NS Package Number T03B

All dimensions are in inches [millimeters]



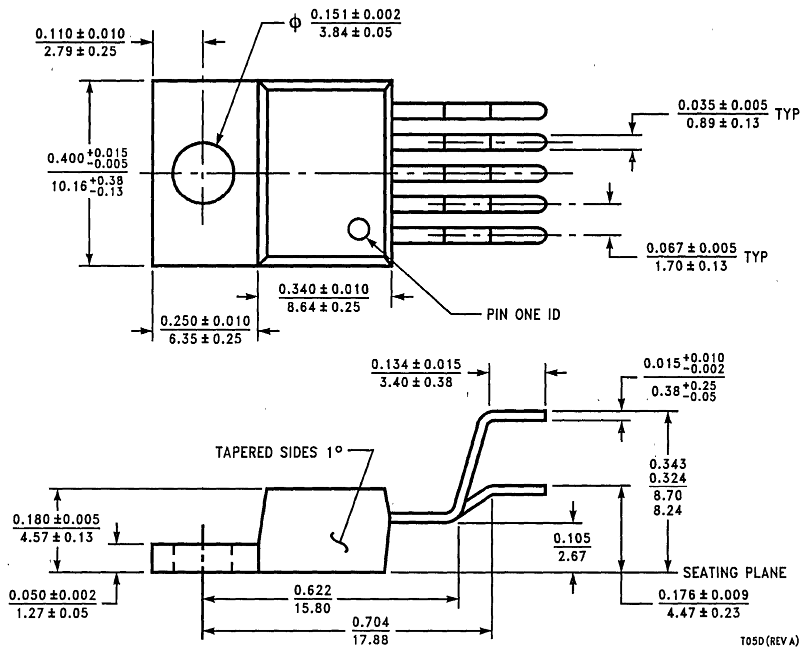
5 Lead Molded TO-220
NS Package Number T05A

All dimensions are in inches [millimeters]



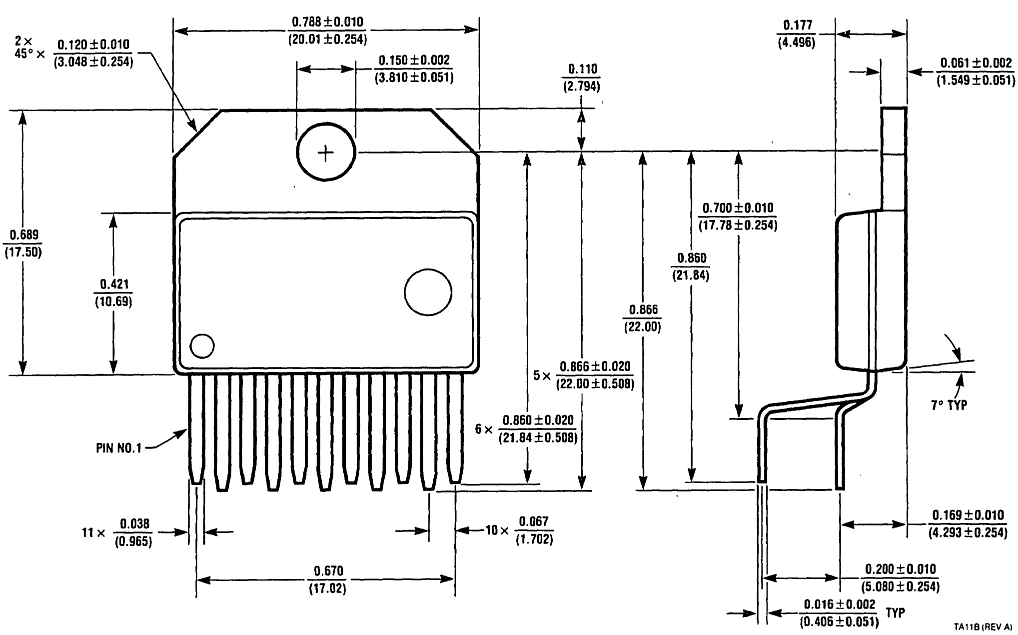
5 Lead Molded TO-220
NS Package Number T05D

All dimensions are in inches / millimeters



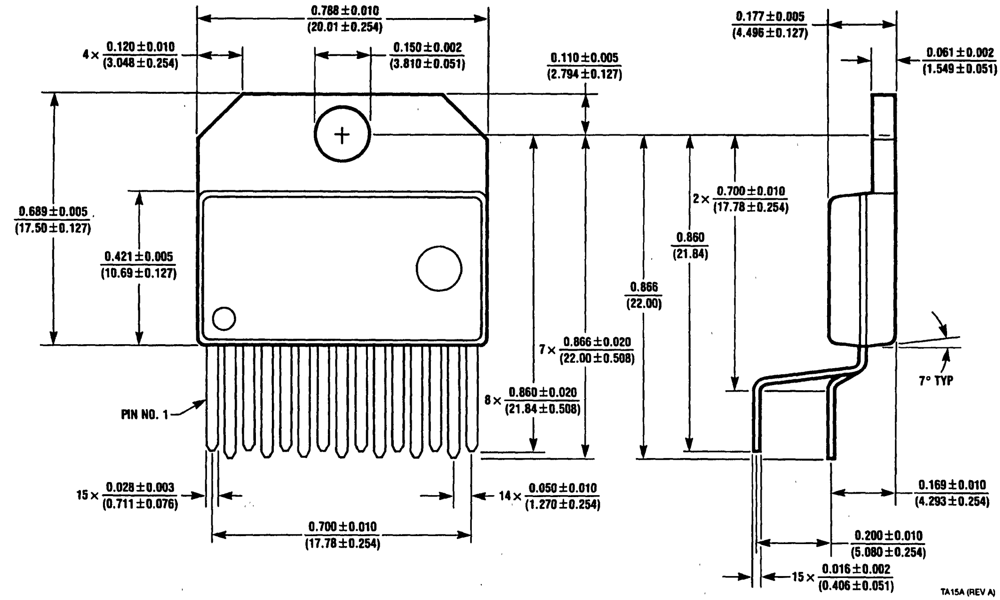
11 Lead Molded TO-220
NS Package Number TA11B

All dimensions are in inches (millimeters)



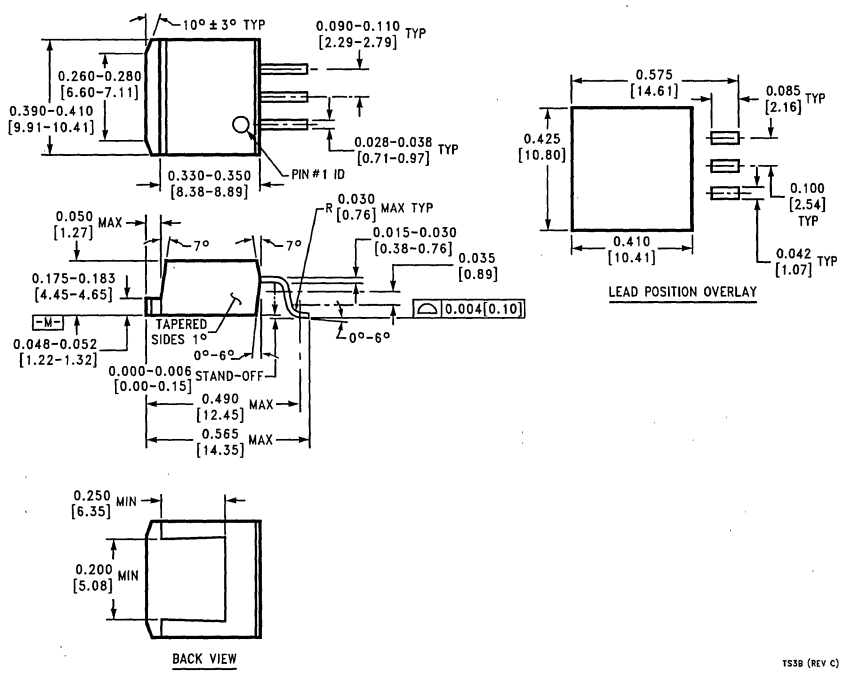
15 Lead Molded TO-220
NS Package Number TA15A

All dimensions are in inches (millimeters)



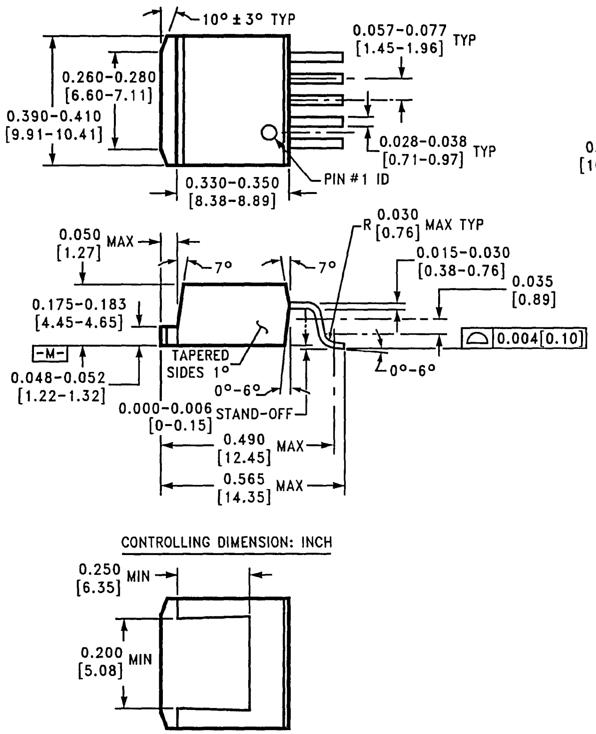
3 Lead Molded TO-263
NS Package Number TS3B

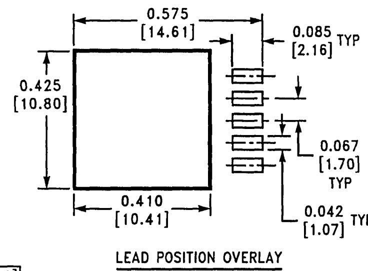
All dimensions are in inches [millimeters]



5 Lead Molded TO-263
NS Package Number TS5B

All dimensions are in inches [millimeters]

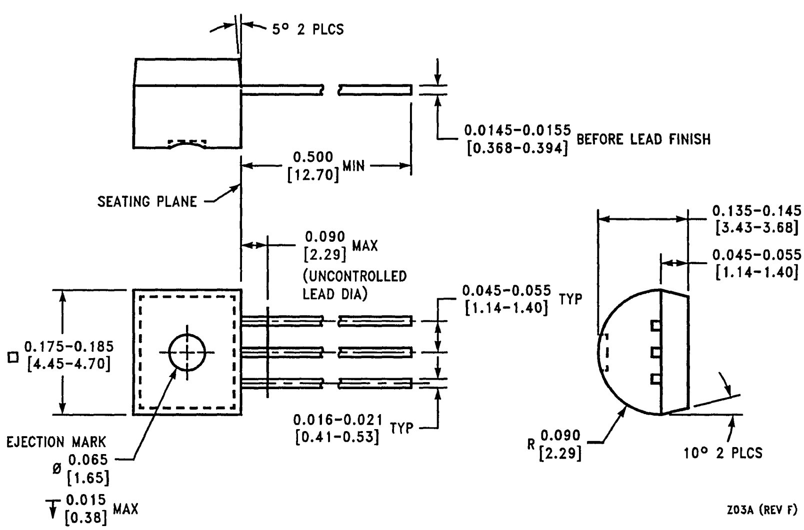




TS5B (REV B)

3 Lead Molded TO-92
NS Package Number Z03A

All dimensions are in inches [millimeters]



Z03A (REV F)

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ADVANCED BiCMOS LOGIC (ABTC, IBF, BiCMOS SCAN, LOW VOLTAGE BiCMOS, EXTENDED TTL TECHNOLOGY) DATABOOK—1994

ABTC/BCT Description and Family Characteristics • ABTC/BCT Ratings, Specifications and Waveforms
ABTC Applications and Design Considerations • Quality and Reliability • Integrated Bus Function (IBF) Introduction
54/74ABT3283 Synchronous Datapath Multiplexer • 74FR900/25900 9-Bit 3-Port Latchable Datapath Multiplexer
54/74ACTQ3283 32-Bit Latchable Transceiver with Parity Generator/Checker and Byte Multiplexing
SCAN18xxxA BiCMOS 5V Logic with Boundary Scan • 74LVT Low Voltage BiCMOS Logic
VME Extended TTL Technology for Backplanes

ALS/AS LOGIC DATABOOK—1990

Introduction to Advanced Bipolar Logic • Advanced Low Power Schottky • Advanced Schottky

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ASIC DESIGN MANUAL/GATE ARRAYS & STANDARD CELLS—1987

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Bibliography • MIL-M-38510 and DESC Drawing Cross Listing

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VHC/VHCT ADVANCED CMOS LOGIC DATABOOK—1993

This databook introduces National's Very High Speed CMOS (VHC) and Very High Speed TTL Compatible CMOS (VHCT) designs. The databook includes Description and Family Characteristics • Ratings, Specifications and Waveforms
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