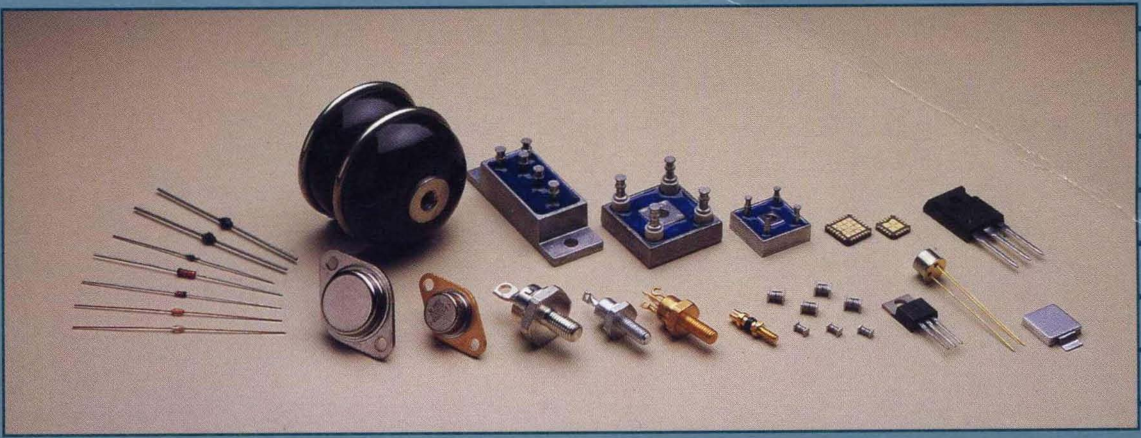
1989 - 1990 Databook and Application Notes

SEMICONDUCTOR
PRODUCTS
UNITRODE

Semiconductor Databook and Application Notes / 1989 - 1990

DB600



SEMICONDUCTOR
PRODUCTS

UNITRODE

PRINTED IN U.S.A.

UNITRODE CORPORATION

MISSION STATEMENT

Our Mission is to be a recognized leader in providing innovative solutions to the high performance needs of users of electronic components and subsystems.

We will excel at understanding and satisfying, in a timely manner, the high value-added needs of our customers. We will deliver quality products of superior performance that are fit for their intended use. They will be supplied on time and at a fair price. By matching our capabilities and customers' needs, we will best achieve our profit-growth objective.

We recognize that loyal, productive employees are our most important resource. Therefore, we will provide a safe, clean working environment and foster open communications, mutual respect and trust at all levels. We will encourage participation of all employees and recognize and reward their efforts in meeting our goals and our customers' expectations. We will provide equal opportunity in employment and promote employee development and advancement.

Successful innovation and the willingness to take risks are key to achieving individual and company growth.

Our relationships with customers, suppliers, stockholders, community and government will be characterized by mutual understanding and trust. We are committed to conducting our business in an ethical and responsible manner.

PRINTED IN U.S.A.

ABOUT THE DATABOOK...

This Databook contains complete data and applications information about Unitrode's broad line of discrete semiconductors for industrial and military applications. It includes the new ultra-fast HV Plus™ rectifier and the unique new electrically and mechanically superior UNIBOND™ diode.

For more information about these products or any other Unitrode components, please call or write.

TABLE OF CONTENTS

* Contact Unitrode
† For complete datasheet information contact Unitrode
Legend: J—JAN JTX—JANTX JTXV—JANTXV

PART NUMBER INDEX

* Contact Unitrode

† For complete datasheet information contact Unitrode

Legend: J—JAN JTX—JANTX JTXV—JANTXV

PAGE	PART NUMBER	DESCRIPTION
		POWER TRANSISTOR
8-15	2N3418, J, JTX, JTXV	NPN; 3.0A; 60V; TO-5
8-15	2N3419, J, JTX, JTXV	NPN; 3.0A; 80V; TO-5
8-15	2N3420, J, JTX, JTXV	NPN; 3.0A; 60V; TO-5
8-15	2N3421, J, JTX, JTXV	NPN; 3.0A; 80V; TO-5
8-11	2N3749, J, JTX, JTXV	NPN; 5.0A; 80V; TO-111
8-19	2N3996, J, JTX, JTXV	NPN; 5.0A; 80V; TO-111
8-19	2N3997, J, JTX, JTXV	NPN; 5.0A; 80V; TO-111
8-19	2N3998, J, JTX, JTXV	NPN; 5.0A; 80V; TO-59
8-19	2N3999, J, JTX, JTXV	NPN; 5.0A; 80V; TO-59
8-23	2N4150, J, JTX, JTXV	NPN; 10.0A; 70V; TO-5
8-27	2N5660, J, JTX, JTXV	NPN; 3A; 200V; TO-66
8-27	2N5661, J, JTX, JTXV	NPN; 3A; 300V; TO-66
8-27	2N5662, J, JTX, JTXV	NPN; 3A; 200V; TO-5
8-27	2N5663, J, JTX, JTXV	NPN; 3A; 300V; TO-5
8-32	2N5664, J, JTX, JTXV	NPN; 5A; 200V; TO-66
8-32	2N5665, J, JTX, JTXV	NPN; 5A; 300V; TO-66
8-32	2N5666, J, JTX, JTXV	NPN; 5A; 200V; TO-5
8-32	2N5667, J, JTX, JTXV	NPN; 5A; 300V; TO-5
		SCR
9-18	2N5724	1.6A@85°C 60V; TO-39
9-18	2N5725	1.6A@85°C 100V; TO-39
9-18	2N5726	1.6A@85°C 200V; TO-39
9-18	2N5727	1.6A@85°C 300V; TO-39
9-18	2N5728	1.6A@85°C 400V; TO-39
		PUT
9-22	2N6119	400mW@25°C 40V; TO-18
9-22	2N6120	400mW@25°C 40V; TO-18
9-26	2N6137	300mW@25°C 40V; TO-18
		POWER DARLINGTON
8-37	2N6350, J, JTX, JTXV	NPN; 10.0A; 80V; TO-33
8-37	2N6351, J, JTX, JTXV	NPN; 10.0A; 150V; TO-33
8-37	2N6352, J, JTX, JTXV	NPN; 10.0A; 80V; TO-66
8-37	2N6353, J, JTX, JTXV	NPN; 10.0A; 150V; TO-66
		FULL WAVE BRIDGE
3-12	469-1, J, JTX	1 ph; 10A; 200V
3-12	469-2, J, JTX	1 ph; 10A; 400V
3-12	469-3, J, JTX	1 ph; 10A; 600V
3-14	483-1, JTX	3 ph; 25.0A; 200V
3-14	483-2, JTX	3 ph; 25.0A; 400V
3-14	483-3, JTX	3 ph; 25.0A; 600V
3-16	673-1	1 ph; 1.5A; 100V
3-16	673-2	1 ph; 1.5A; 200V
3-16	673-3	1 ph; 1.5A; 300V
3-16	673-4	1 ph; 1.5A; 400V
3-16	673-5	1 ph; 1.5A; 500V
3-16	673-6	1 ph; 1.5A; 600V
3-18	673-7	1 ph; 0.6A; 1200V
3-18	673-7.5	1 ph; 0.5A; 1800V
3-18	673-8	1 ph; 0.4A; 2400V
3-18	673-8.5	1 ph; 0.3A; 3000V
3-18	673-9	1 ph; 0.2A; 3600V
3-18	673-10	1 ph; .18A; 4200V
3-18	673-11	1 ph; .16A; 4800V
3-18	673-12	1 ph; .16A; 5000V
3-16	676-1	1 ph; 1.0A; 100V
3-16	676-2	1 ph; 1.0A; 200V
3-16	676-3	1 ph; 1.0A; 300V
3-16	676-4	1 ph; 1.0A; 400V
3-16	676-5	1 ph; 1.0A; 500V
3-16	676-6	1 ph; 1.0A; 600V
3-18	676-12	1 ph; 0.4A; 1200V
3-18	676-18	1 ph; .35A; 1800V
3-18	676-24	1 ph; .325A; 2400V
3-18	676-30	1 ph; .25A; 3000V
3-18	676-36	1 ph; .175A; 3600V

PAGE	PART NUMBER	DESCRIPTION
		FULL WAVE BRIDGE
3-18	676-42	1 ph; .15A; 4200V
3-18	676-48	1 ph; .135A; 4800V
3-18	676-50	1 ph; .125A; 5000V
3-21	678-1	3 ph; 25A; 100V
3-21	678-2	3 ph; 25A; 200V
3-21	678-3	3 ph; 25A; 300V
3-21	678-4	3 ph; 25A; 400V
3-21	678-5	3 ph; 25A; 500V
3-21	678-6	3 ph; 25A; 600V
3-24	679-1	1 ph; 25A; 100V
3-24	679-2	1 ph; 25A; 200V
3-24	679-3	1 ph; 25A; 300V
3-24	679-4	1 ph; 25A; 400V
3-24	679-5	1 ph; 25A; 500V
3-24	679-6	1 ph; 25A; 600V
3-24	680-1	1 ph; 10A; 100V
3-24	680-2	1 ph; 10A; 200V
3-24	680-3	1 ph; 10A; 300V
3-24	680-4	1 ph; 10A; 400V
3-24	680-5	1 ph; 10A; 500V
3-24	680-6	1 ph; 10A; 600V
		DOUBLER OR CENTER-TAP
3-27	681-1	15A; 100V
3-27	681-2	15A; 200V
3-27	681-3	15A; 300V
3-27	681-4	15A; 400V
3-27	681-5	15A; 500V
3-27	681-6	15A; 600V
		FULL WAVE BRIDGE
3-21	682-1	3 ph; 20A;100V
3-21	682-2	3 ph; 20A; 200V
3-21	682-3	3 ph; 20A; 300V
3-21	682-4	3 ph; 20A; 400V
3-21	682-5	3 ph; 20A; 500V
3-21	682-6	3 ph; 20A; 600V
3-24	683-1	1 ph; 20A; 100V
3-24	683-2	1 ph; 20A; 200V
3-24	683-3	1 ph; 20A; 300V
3-24	683-4	1 ph; 20A; 400V
3-24	683-5	1 ph; 20A; 500V
3-24	683-6	1 ph; 20A; 600V
3-24	684-1	1 ph; 10A; 100V
3-24	684-2	1 ph; 10A; 200V
3-24	684-3	1 ph; 10A; 300V
3-24	684-4	1 ph; 10A; 400V
3-24	684-5	1 ph; 10A; 500V
3-24	684-6	1 ph; 10A; 600V
		RECTIFIER MODULE
3-29	688-10	10kV
3-29	688-12	12kV
3-29	688-15	15kV
3-29	688-18	18kV
3-29	688-20	20kV
3-29	688-25	25kV
		DOUBLER OR CENTER-TAP
3-27	689-1	15A; 100V
3-27	689-2	15A; 200V
3-27	689-3	15A; 300V
3-27	689-4	15A; 400V
3-27	689-5	15A; 500V
3-27	689-6	15A; 600V

* Contact Unitrode

† For complete datasheet information contact Unitrode

Legend: J—JAN JTX—JANTX JTXV—JANTXV

PART NUMBER INDEX

PAGE	PART NUMBER	DESCRIPTION
		FULL WAVE BRIDGE
3-21	695-1	3 ph; 15A; 100V
3-21	695-2	3 ph; 15A; 200V
3-21	695-3	3 ph; 15A; 300V
3-21	695-4	3 ph; 15A; 400V
3-21	695-5	3 ph; 15A; 500V
3-21	695-6	3 ph; 15A; 600V
3-21	696-1	3 ph; 15A; 100V
3-21	696-2	3 ph; 15A; 200V
3-21	696-3	3 ph; 15A; 300V
3-21	696-4	3 ph; 15A; 400V
3-21	696-5	3 ph; 15A; 500V
3-21	696-6	3 ph; 15A; 600V
3-31	697-1	1 ph; 2.5A; 100V
3-31	697-2	1 ph; 2.5A; 200V
3-31	697-3	1 ph; 2.5A; 300V
3-31	697-4	1 ph; 2.5A; 400V
3-31	697-5	1 ph; 2.5A; 500V
3-31	697-6	1 ph; 2.5A; 600V
3-31	698-1	1 ph; 2.25A; 100V
3-31	698-2	1 ph; 2.25A; 200V
3-31	698-3	1 ph; 2.25A; 300V
3-31	698-4	1 ph; 2.25A; 400V
3-31	698-5	1 ph; 2.25A; 500V
3-31	698-6	1 ph; 2.25A; 600V
3-33	700-1	3 ph; 2.5A; 100V
3-33	700-2	3 ph; 2.5A; 200V
3-33	700-3	3 ph; 2.5A; 300V
3-33	700-4	3 ph; 2.5A; 400V
3-33	700-5	3 ph; 2.5A; 500V
3-33	700-6	3 ph; 2.5A; 600V
3-33	701-1	3 ph; 2.25A; 100V
3-33	701-2	3 ph; 2.25A; 200V
3-33	701-3	3 ph; 2.25A; 300V
3-33	701-4	3 ph; 2.25A; 400V
3-33	701-5	3 ph; 2.25A; 500V
3-33	701-6	3 ph; 2.25A; 600V
3-35	800-1	3 ph; 40A; 50V
3-35	800-2	3 ph; 40A; 100V
3-35	800-3	3 ph; 40A; 125V
3-35	800-4	3 ph; 40A; 150V
3-35	801-1	3 ph; 20A; 50V
3-35	801-2	3 ph; 20A; 100V
3-35	801-3	3 ph; 20A; 125V
3-35	801-4	3 ph; 20A; 150V
3-38	802-1	1 ph; 35A; 50V
3-38	802-2	1 ph; 35A; 100V
3-38	802-3	1 ph; 35A; 125V
3-38	802-4	1 ph; 35A; 150V
3-38	803-1	1 ph; 20A; 50V
3-38	803-2	1 ph; 20A; 100V
3-38	803-3	1 ph; 20A; 125V
3-38	803-4	1 ph; 20A; 150V
		DOUBLER OR CENTER-TAP
3-41	804-1	20A; 50V
3-41	804-2	20A; 100V
3-41	804-3	20A; 125V
3-41	804-4	20A; 150V
		SCR
9-30	AA100	0.5A@100°C 60V; TO-18
9-30	AA101	0.5A@100°C 100V; TO-18
9-30	AA102	0.5A@100°C 200V; TO-18
9-30	AA103	0.5A@100°C 300V; TO-18
9-30	AA104	0.5A@100°C 400V; TO-18
9-30	AA107	0.5A@100°C 60V; TO-18
		SCR
9-30	AA108	0.5A@100°C 100V; TO-18
9-30	AA109	0.5A@100°C 200V; TO-18
9-30	AA110	0.5A@100°C 300V; TO-18
9-30	AA111	0.5A@100°C 400V; TO-18
9-30	AA114	0.5A@100°C 60V; TO-18
9-30	AA115	0.5A@100°C 100V; TO-18
9-30	AA116	0.5A@100°C 200V; TO-18
9-30	AA117	0.5A@100°C 300V; TO-18
9-30	AA118	0.5A@100°C 400V; TO-18
9-33	AD100	1.6A@85°C 60V; TO-39
9-33	AD101	1.6A@85°C 100V; TO-39
9-33	AD102	1.6A@85°C 200V; TO-39
9-33	AD103	1.6A@85°C 300V; TO-39
9-33	AD104	1.6A@85°C 400V; TO-39
9-33	AD107	1.6A@85°C 60V; TO-39
9-33	AD108	1.6A@85°C 100V; TO-39
9-33	AD109	1.6A@85°C 200V; TO-39
9-33	AD110	1.6A@85°C 300V; TO-39
9-33	AD111	1.6A@85°C 400V; TO-39
9-33	AD114	1.6A@85°C 60V; TO-39
9-33	AD115	1.6A@85°C 100V; TO-39
9-33	AD116	1.6A@85°C 200V; TO-39
9-33	AD117	1.6A@85°C 300V; TO-39
9-33	AD118	1.6A@85°C 400V; TO-39
		DIODE
*	BA127D	200mA; 100V; DO-35
*	BA129	225mA; 200V; DO-35
*	BA130	75mA; 35V; DO-35
*	BA155	100mA; 150V; DO-35
*	BA166	50mA; 20V; DO-35
*	BA167W	50mA; 25V; DO-35
*	BA180	50mA; 10V; DO-35
*	BA181	50mA; 20V; DO-35
*	BA209	225mA; 100V; DO-35
*	BA219	100mA; 100V; DO-35
*	BA220	200mA; 10V; DO-35
*	BA221	200mA; 30V; DO-35
*	BA317	100mA; 30V; DO-35
*	BAV10	300mA; 60V; DO-35
*	BAV18	250mA; 60V; DO-35
*	BAV19	250mA; 120V; DO-35
*	BAV20	250mA; 180V; DO-35
*	BAV21	250mA; 250V; DO-35
5-32	BAW24	600mA; 50V; DO-35
5-32	BAW25	600mA; 50V; DO-35
5-32	BAW26	600mA; 75V; DO-35
5-32	BAW27	600mA; 75V; DO-35
*	BAW62	100mA; 75V; DO-35
5-32	BAW75	300mA; 35V; DO-35
5-32	BAW76	300mA; 75V; DO-35
5-33	BAX12	400mA; 90V; DO-35
*	BAX13	75mA; 50V; DO-35
*	BAX16	200mA; 150V; DO-35
*	BAX17	200mA; 200V; DO-35
*	BAX81	350mA; 90V; DO-35
*	BAX84	75mA; 50V; DO-35
*	BAX92	75mA; 50V; DO-35
*	BAY18	250mA; 60V; DO-35
*	BAY19	250mA; 120V; DO-35
*	BAY20	250mA; 180V; DO-35
*	BAY21	250mA; 350V; DO-35
*	BAY31	15V; DO-35
*	BAY36	100mA; 30V; DO-35
5-33	BAY41	225mA; 40V; DO-35
5-33	BAY42	225mA; 60V; DO-35
5-33	BAY43	225mA; 80V; DO-35

* Contact Unitrode
† For complete datasheet information contact Unitrode
Legend: J—JAN JTX—JANTX JTXV—JANTXV

PAGE	PART NUMBER	DESCRIPTION
		DIODE
*	BAY44	250mA; 50V; DO-35
*	BAY45	250mA; 150V; DO-35
*	BAY46	250mA; 300V; DO-35
5-33	BAY60	115mA; 25V; DO-35
*	BAY71	75mA; 70V; DO-35
*	BAY72	225mA; 125V; DO-35
*	BAY73	225mA; 125V; DO-35
*	BAY80	250mA; 150V; DO-35
		DIODE
*	BY401	500mA; 50V; DO-7
*	BY402	500mA; 100V; DO-7
*	BY403	500mA; 200V; DO-7
*	BY404	500mA; 400V; DO-7
		SCHOTTKY RECTIFIER
*	BYS60-45	60A; 45V; DO-5
*	BYS75-20	75A; 20V; DO-5
*	BYS75-30	75A; 30V; DO-5
*	BYS75-45	75A; 45V; DO-5
*	BYV19-35	12A; 35V; TO-220AC
*	BYV19-40	12A; 40V; TO-220AC
*	BYV19-45	12A; 45V; TO-220AC
*	BYV23-35μ	75A; 35V; DO-5
*	BYV23-45μ	75A; 45V; DO-5
		RECTIFIER
2-87	BYV27-50 (UES1101)	2.5A; 50V
2-87	BYV27-100(UES1102)	2.5A; 100V
2-87	BYV27-150(UES1103)	2.5A; 150V
2-92	BYV28-50	3.5A; 50V
2-92	BYV28-100	3.5A; 100V
2-92	BYV28-150	3.5A; 150V
		SCHOTTKY RECTIFIER
*	BYV33-35	16A; 35V; TO-220AB
*	BYV33-40	16A; 40V; TO-220AB
*	BYV33-45	16A; 45V; TO-220AB
		RECTIFIER
2-97	BYW29-50	7.0A; 50V; TO-220AC
2-97	BYW29-100	7.0A; 100V; TO-220AC
2-97	BYW29-150	7.0A; 150V; TO-220AC
2-97	BYW29-200	7.0A; 200V; TO-220AC
2-74	BYW31-50	25A; 50V; DO-4
2-74	BYW31-100	25A; 100V; DO-4
2-74	BYW31-150	25A; 150V; DO-4
2-74	BYW77-50	30A; 50V; DO-4
2-74	BYW77-100	30A; 100V; DO-4
2-74	BYW77-150	30A; 150V; DO-4
2-80	BYW78-50	50A; 50V; DO-5
2-80	BYW78-100	50A; 100V; DO-5
2-80	BYW78-150	50A; 150V; DO-5
2-97	BYW80-50	7.0A; 50V; TO-220AC
2-97	BYW80-100	7.0A; 100V; TO-220AC
2-97	BYW80-150	7.0A; 150V; TO-220AC
2-97	BYW80-200	7.0A; 200V; TO-220AC
*	BYW81-50	25A; 50V; DO-4
*	BYW81-100	25A; 100V; DO-4
*	BYW81-150	25A; 150V; DO-4
*	BYW81-200	25A; 150V; DO-4
		BI-DIRECTIONAL TVS
4-18	EPS5 Series	1000W
		SCR
9-36	GA100	400mA@100°C 30V; TO-18
9-36	GA101	400mA@100°C 60V; TO-18
9-36	GA102	400mA@100°C 80V; TO-18
9-40	GA200-GA200A	60V; TO-18
9-40	GA201-GA201A	100V; TO-18
		SCR
9-43	GA300-GA300A	60V; TO-18
9-43	GA301-GA301A	100V; TO-18
9-40	GB200-GB200A	60V; TO-59
9-40	GB201-GB201A	100V; TO-59
9-43	GB300-GB300A	60V; TO-59
9-43	GB301-GB301A	100V; TO-59
9-46	ID100	0.5A@100°C 30V; TO-18
9-46	ID101	0.5A@100°C 60V; TO-18
9-46	ID102	0.5A@100°C 100V; TO-18
9-46	ID103	0.5A@100°C 150V; TO-18
9-46	ID104	0.5A@100°C 200V; TO-18
9-46	ID105	0.5A@100°C 300V; TO-18
9-46	ID106	0.5A@100°C 400V; TO-18
9-49	ID200	1.6A@70°C 50V; TO-39
9-49	ID201	1.6A@70°C 100V; TO-39
9-49	ID202	1.6A@70°C 150V; TO-39
9-49	ID203	1.6A@70°C 200V; TO-39
9-49	ID300	1.6A@70°C 300V; TO-39
9-49	ID301	1.6A@70°C 400V; TO-39
		POWER HYBRID
7-4	PIC600	5.0A; 60V (Pos.); TO-66
7-4	PIC601	5.0A; 80V (Pos.); TO-66
7-4	PIC602	5.0A; 100V (Pos.); TO-66
7-4	PIC610	5.0A; 60V (Neg.); TO-66
7-4	PIC611	5.0A; 80V (Neg.); TO-66
7-4	PIC612	5.0A; 100V (Neg.); TO-66
7-8	PIC625	15.0A; 60V (Pos.); TO-66
7-8	PIC626	15.0A; 80V (Pos.); TO-66
7-8	PIC627	15.0A; 100V (Pos.); TO-66
7-8	PIC635	15.0A; 60V (Neg.); TO-66
7-8	PIC636	15.0A; 80V (Neg.); TO-66
7-8	PIC637	15.0A; 100V (Neg.); TO-66
7-12	PIC645	15.0A; 60V (Pos.); TO-3
7-12	PIC646	15.0A; 80V (Pos.); TO-3
7-12	PIC647	15.0A; 100V (Pos.); TO-3
7-12	PIC655	15.0A; 60V (Neg.); TO-3
7-12	PIC656	15.0A; 80V (Neg.); TO-3
7-12	PIC657	15.0A; 100V (Neg.); TO-3
7-16	PIC660	10.0A; 60V (Pos.); TO-66
7-16	PIC661	10.0A; 80V (Pos.); TO-66
7-16	PIC662	10.0A; 100V (Pos.); TO-66
7-16	PIC670	10.0A; 60V (Neg.); TO-66
7-16	PIC671	10.0A; 80V (Neg.); TO-66
7-16	PIC672	10.0A; 100V (Neg.); TO-66
		SCREENED POWER HYBRIDS
7-20	PIC7501	5.0A; 60V (Pos.); TO-66
7-20	PIC7502	5.0A; 80V (Pos.); TO-66
7-20	PIC7503	5.0A; 100V (Pos.); TO-66
7-20	PIC7504	5.0A; 60V (Neg.); TO-66
7-20	PIC7505	5.0A; 80V (Neg.); TO-66
7-20	PIC7506	5.0A; 100V (Neg.); TO-66
7-20	PIC7507	15.0A; 60V (Pos.); TO-66
7-20	PIC7508	15.0A; 80V (Pos.); TO-66
7-20	PIC7509	15.0A; 100V (Pos.); TO-66
7-20	PIC7510	15.0A; 60V (Neg.); TO-66
7-20	PIC7511	15.0A; 80V (Neg.); TO-66
7-20	PIC7512	15.0A; 100V (Neg.); TO-66
7-29	PIC7513	15.0A; 60V (Pos.); TO-3
7-29	PIC7514	15.0A; 80V (Pos.); TO-3
7-29	PIC7515	15.0A; 100V (Pos.); TO-3
7-29	PIC7516	15.0A; 60V (Neg.); TO-3
7-29	PIC7517	15.0A; 80V (Neg.); TO-3
7-29	PIC7518	15.0A; 100V (Neg.); TO-3

* Contact Unitrode
† For complete datasheet information contact Unitrode
Legend: J—JAN JTX—JANTX JTXV—JANTXV

PART NUMBER INDEX

* Contact Unitrode

† For complete datasheet information contact Unitrode

Legend: J—JAN JTX—JANTX JTXV—JANTXV

---

* Contact Unitrode

† For complete datasheet information contact Unitrode
Legend: J—JAN JTX—JANTX JTXV—JANTXV

PART NUMBER INDEX

PAGE	PART NUMBER	DESCRIPTION
		RECTIFIER MODULE
3-57	US80A	8.0kV
3-57	US100A	10kV
3-57	US120A	12kV
3-57	US150A	15kV
3-57	US180A	18kV
3-57	US200A	20kV
3-51	USB2.5	2.5kV
3-51	USB5	5.0kV
3-51	USB7.5	7.5kV
3-51	USB10	10kV
		SCHOTTKY RECTIFIER
2-132	USD245C	4A; 45V; TO-39; Center-Tap
2-132	USD245CHR2	4A; 45V; TO-39; Center-Tap
2-132	USD245CR	4A; 45V; TO-39; Center-Tap
2-132	USD245CRHR2	4A; 45V; TO-39; Center-Tap
2-135	USD335C	30A; 35V; TO-3
2-135	USD335CHR2	30A; 35V; TO-3
2-135	USD345C	30A; 45V; TO-3
2-135	USD345CHR2	30A; 45V; TO-3
2-137	USD520	75A; 20V; DO-5
2-137	USD535	75A; 35V; DO-5
2-137	USD545	75A; 45V; DO-5
2-137	USD550	75A; 50V; DO-5
2-139	USD635	6A; 35V; TO-220AC
2-141	USD635C	12A; 35V; TO-220AB
2-139	USD640	6A; 40V; TO-220AC
2-141	USD640C	12A; 40V; TO-220AB
2-139	USD645	6A; 45V; TO-220AC
2-141	USD645C	12A; 45V; TO-220AB
2-139	USD650	6A; 50V; TO-220AC
2-141	USD650C	12A; 50V; TO-22AB
2-143	USD735	8A; 35V; TO-220AC
2-145	USD735C	16A; 35V; TO-220AB
2-143	USD740	8A; 40V; TO-220AC
2-145	USD740C	16A; 40V; TO-220AB
2-143	USD745	8A; 45V; TO-220AC
2-145	USD745C	16A; 45V; TO-220AB
2-143	USD750	8A; 50V; TO-220AC
2-145	USD750C	16A; 50V; TO-220AB
2-147	USD835	12A; 35V; TO-220AC
2-147	USD840	12A; 40V; TO-220AC
2-147	USD845	12A; 45V; TO-220AC
2-147	USD850	12A; 50V; TO-220AC
2-149	USD935	16A; 35V; TO-220AC
2-149	USD940	16A; 40V; TO-220AC
2-149	USD945	16A; 45V; TO-220AC
2-149	USD950	16A; 50V; TO-220AC
2-151	USD3030C	30A; 30V; TO-3P; Center-Tap
2-153	USD3030S	30A; 30V; TO-3P
2-151	USD3040C	30A; 40V; TO-3P; Center-Tap
2-153	USD3040S	30A; 40V; TO-3P
2-151	USD3045C	30A; 45V; TO-3P; Center-Tap
2-153	USD3045S	30A; 45V; TO-3P
2-155	USD4530C	45A; 30V; TO-3P; Center-Tap
2-157	USD4530S	45A; 30V; TO-3P
2-155	USD4540C	45A; 40V; TO-3P; Center-Tap
2-157	USD4540S	45A; 40V; TO-3P
2-155	USD4545C	45A; 45V; TO-3P; Center-Tap
2-157	USD4545S	45A; 45V; TO-3P
*	USD6035	60A; 35V; DO-5
*	USD6045	60A; 45V; DO-5
2-159	USD7520	75A; 20V; DO-5
2-159	USD7525	75A; 25V; DO-5
		RECTIFIER MODULE
3-57	USR12	1.2kV
3-57	USR15	1.5kV
3-57	USR20	2.0kV
3-57	USR25	2.5kV
3-57	USR30	3.0kV
3-57	USR35	3.5kV
3-57	USR40A	4.0kV
3-57	USR45A	4.5kV
3-57	USR50A	5.0kV
3-57	USR60A	6.0kV
3-57	USR70A	7.0kV
3-57	USR80A	8.0kV
3-57	USR100A	10kV
3-57	USR120A	12kV
3-57	USR150A	15kV
3-57	USR180A	18kV
3-51	USS5	5.0kV
3-51	USS7.5	7.5kV
3-51	USS10	10kV
3-51	USS15	15kV
		RECTIFIER
2-161	UT234	1.0A; 200V
2-161	UT235	1,0A; 400V
2-161	UT236	1.0A; 100V
2-161	UT237	1.0A; 500V
2-161	UT238	1.0A; 600V
2-161	UT242	1.25A; 200V
2-161	UT244	1.25A; 400V
2-161	UT245	1.25A; 500V
2-161	UT247	1.25A; 600V
2-161	UT249	1.25A; 100V
2-161	UT251	1.5A; 100V
2-161	UT252	1.5A; 200V
2-161	UT254	1.5A; 400V
2-161	UT255	1.5A; 500V
2-161	UT257	1.5A; 600V
2-161	UT258	1.5A; 800V
2-161	UT261	2.0A; 100V
2-161	UT262	2.0A; 200V
2-161	UT264	2.0A; 400V
2-161	UT265	2.0A; 500V
2-161	UT267	2.0A; 600V
2-161	UT268	2.0A; 800V
2-161	UT347	1.0A; 1000V
2-161	UT361	1.0A; 800V
2-161	UT362	1.2A; 800V
2-161	UT363	1.2A; 1000V
2-161	UT364	1.5A; 1000V
2-164	UT2005	2.0A; 50V
2-164	UT2010	2.0A; 100V
2-164	UT2020	2.0A; 200V
2-164	UT2040	2.0A; 400V
2-164	UT2060	2.0A; 600V
2-164	UT3005	3.0A; 50V
2-164	UT3010	3.0A; 100V
2-164	UT3020	3.0A; 200V
2-164	UT3040	3.0A; 400V
2-164	UT3060	3.0A; 600V
2-164	UT4005	4.0A; 50V
2-164	UT4010	4.0A; 100V
2-164	UT4020	4.0A; 200V
2-164	UT4040	4.0A; 400V
2-164	UT4060	4.0A; 600V
2-167	UT5105	7.5A; 50V
2-167	UT5105HR2	7.5A; 50V

* Contact Unitrode

† For complete datasheet information contact Unitrode

Legend: J—JAN JTX—JANTX JTXV—JANTXV

* Contact Unitrode

† For complete datasheet information contact Unitrode

Legend: J—JAN JTX—JANTX JTXV—JANTXV

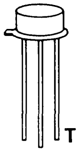
PART NUMBER INDEX

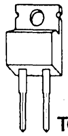
PAGE	PART NUMBER	DESCRIPTION	PAGE	PART NUMBER	DESCRIPTION
		ZENER			
4-27	UZ210HR2-UZ219HR2	3W; 10%			
4-27	UZ220HR2-UZ240HR2	3W; 10%			
4-27	UZ706HR2-UZ760HR2	3W; 5%			
4-27	UZ770HR2-UZ790HR2	3W; 5%			
4-27	UZ806HR2-UZ860HR2	3W; 10%			
4-27	UZ870HR2-UZ890HR2	3W; 10%			
4-29	UZ4110-UZ4120	5W; 5%			
4-29	UZ4210-UZ4220	5W; 10%			
4-29	UZ4706-UZ4791	5W; 5%			
4-29	UZ4806-UZ4891	5W; 10%			
4-31	UZ5110-UZ5119	5W; 5%			
4-31	UZ5120-UZ5140	5W; 5%			
4-31	UZ5210-UZ5240	5W; 10%			
4-31	UZ5706-UZ5760	5W; 5%			
4-31	UZ5770-UZ5790	5W; 5%			
4-31	UZ5806-UZ5860	5W; 10%			
4-31	UZ5870-UZ5890	5W; 10%			
4-33	UZ7110HR2	10W; 5%			
4-33	UZ7110LHR2	6W; 5%			
4-33	UZ7210HR2	10W; 10%			
4-33	UZ7210LHR2	6W; 10%			
4-33	UZ7706HR2-UZ7750HR2	10W; 5%			
4-33	UZ7706LHR2-UZ7750LHR2	6W; 5%			
4-33	UZ7756HR2-UZ7790HR2	10W; 5%			
4-33	UZ7756LHR2-UZ7790LHR2	6W; 5%			
4-33	UZ7806HR2-UZ7850HR2	10W; 10%			
4-33	UZ7806LHR2-UZ7850LHR2	6W; 10%			
4-33	UZ7856HR2-UZ7890HR2	10W; 10%			
4-33	UZ7856LHR2-UZ7890LHR2	6W; 10%			
4-36	UZ8110-UZ8120	1W; 5%			
4-36	UZ8210-UZ8220	1W; 10%			
4-36	UZ8706-UZ8790	1W; 5%			
4-36	UZ8806-UZ8890	1W; 10%			

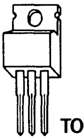
* Contact Unitrode
† For complete datasheet information contact Unitrode
Legend: J—JAN JTX—JANTX JTXV—JANTXV

SCHOTTKY RECTIFIERS

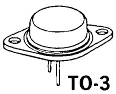
PRODUCT SELECTION GUIDE

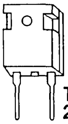

TO-39

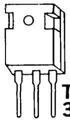

TO-220AC


TO-220AB


DO-4


TO-3


TO-3P 2 Lead


TO-3P 3 Lead

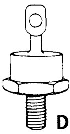
AVERAGE DC OUTPUT CURRENT	4A	6A	8A	12A[1]	12A
PKG PEAK REVERSE VOLTAGE	TO-39 HERMETIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)	TO-220 PLASTIC (2 LEAD)	TO-220 PLASTIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)
30V TYPE V_F I_{FSM}					
35V TYPE V_F I_{FSM}		USD635 .48 @ 6A 150A	USD735 .48 @ 8A 200A	USD635C .60 @ 12A 150A	USD835 .51 @ 12A 200A
40V TYPE V_F I_{FSM}		USD640 .48 @ 6A 150A	USD740 .48 @ 8A 200A	USD640C .60 @ 12A 150A	USD840 .45 @ 12A 200A
45V TYPE V_F I_{FSM}	1N6492[4] USD245C .45 @ 2A 80A	USD645 .48 @ 6A 150A	USD745 .48 @ 8A 200A	USD645C .60 @ 12A 150A	USD845 .45 @ 12A 200A
50V TYPE V_F I_{FSM}		USD650 .48 @ 6A 150A	USD750 .48 @ 8A 200A	USD650C .60 @ 12A 150A	USD850 .45 @ 12A 200A

AVERAGE DC OUTPUT CURRENT	16A[2]	16A	25A	30A	30A[3]	30A[3]
PKG PEAK REVERSE VOLTAGE	TO-220 PLASTIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)	DO-4 STUD	TO-3P (2 LEAD)	TO-3P (3 LEAD)	TO-3
30V TYPE V_F I_{FSM}				USD3030S .70 @ 30A 450A	USD3030C .71 @ 30A 400A	
35V TYPE V_F I_{FSM}	USD735C .60 @ 16A 200A	USD935 .53 @ 16A 250A				USD335C[5] .6 @ 20A 400A
40V TYPE V_F I_{FSM}	USD740C .60 @ 16A 200A	USD940 .53 @ 16A 250A		USD3040S .70 @ 30A 450A	USD3040C .71 @ 30A 400A	
45V TYPE V_F I_{FSM}	USD745C .60 @ 16A 200A	USD945 .53 @ 16A 250A	1N6391[4] .68 @ 50A 600A	USD3045S .70 @ 30A 450A	USD3045C .71 @ 30A 400A	USD345C[5] SD241[5] .6 @ 20A 400A
50V TYPE V_F I_{FSM}	USD750C .60 @ 16A 200A	USD950 .53 @ 16A 250A				

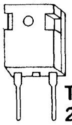
NOTES: 1. Center-tap 6A per leg.
2. Center-tap 8A per leg.
3. Center-tap 15A per leg.
4. Available as JAN, JANTX, JANTXV.
5. Available with High-Reliability (HR2) Screening.

SCHOTTKY RECTIFIERS

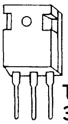
PRODUCT SELECTION GUIDE



DO-5



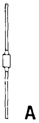
TO-3P
2 Lead



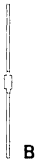
TO-3P
3 Lead

AVERAGE DC OUTPUT CURRENT	45A	45A[3]	50A	60A	75A	75A
PKG / PEAK REVERSE VOLTAGE	TO-3P (2 LEAD)	TO-3P (3 LEAD)	DO-5 STUD	DO-5 STUD	DO-5 STUD	DO-5 STUD
20V TYPE V_F I_{FSM}					USD520 .6 @ 60A 1000A	USD7520 .425 @ 60A 1000A
25V TYPE V_F I_{FSM}						USD7525 .425 @ 60A 1000A
30V TYPE V_F I_{FSM}	USD4530S .70 @ 45A 450A	USD4530C .70 @ 45A 450A	1N6097 .86 @ 157A 800A			
35V TYPE V_F I_{FSM}					USD535 .6 @ 60A 1000A	
40V TYPE V_F I_{FSM}	USD4540C .70 @ 45A 450A	USD4540C .70 @ 45A 450A	1N6098 .86 @ 157A 800A			
45V TYPE V_F I_{FSM}	USD4545S .70 @ 45A 450A	USD4545C .70 @ 45A 450A		1N6392[2] SD51[1] .6 @ 60A 800A	USD545 .6 @ 60A 1000A	
50V TYPE V_F I_{FSM}					USD550 .6 @ 60A 1000A	

NOTES: 1. V_{RRM} @ 25°C is 45V, V_{RRM} @ 150°C is 35V.
2. Available as JAN, JANTX, JANTXV.
3. Center-tap 23A per leg.



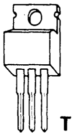
A



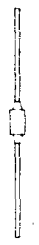
B

HV PLUS RECTIFIERS

Average DC Output Current			1.5A	2.0A	2.5A	3.0A	4.0A
Package Style			A	A	B	B	B
Peak Inverse Voltage	200V	V_F t_{rr}		1N6620 UHVP202 1.6V @ 2A 30 nSec			1N6626 UHVP402 1.5V @ 4A 30 nSec
	400V	V_F t_{rr}		1N6621 UHVP204 1.6V @ 2A 30 nSec			1N6627 UHVP404 1.5V @ 4A 30 nSec
	600V	V_F t_{rr}		1N6622 UHVP206 1.6V @ 2A 30 nSec			1N6628 UHVP406 1.5V @ 4A 30 nSec
	800V	V_F t_{rr}	1N6623 UHVP208 1.8V @ 1.5A 50 nSec			1N6629 UHVP408 1.7V @ 3A 50 nSec	
	900V	V_F t_{rr}	1N6624 UHVP209 1.8V @ 1.5A 50 nSec			1N6630 UHVP409 1.7V @ 3A 50 nSec	
	1000V	V_F t_{rr}	1N6625 UHVP210 1.95V @ 1.5A 65 nSec		1N6631 UHVP410 1.95V @ 2.5A 65 nSec		

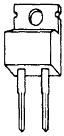


TO-220AB



A

B



TO-220AC

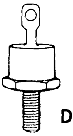
ULTRA-FAST RECOVERY (t_{rr} — 25 to 50ns)

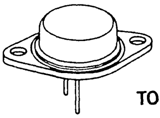
Average D.C. Output Current			1A	2A	2.5A	5A	6A	8A	16A	16A Center-Tap
Package Style			**A**	**A**	**A**	**B**	**B**	**TO-220AC**	**TO-220AC**	**TO-220AB**
Peak Inverse Voltage	50V	V_F t_{rr}	UES1001 .895 @ 1A 25ns		1N5802* UES1101 .895 @ 2A 25ns		1N5807* UES1301 .850 @ 6A 30ns	UES1401 .895 @ 8A 35ns	UES1501 .895 @ 16A 35ns	UES2401 .895 @ 8A 35ns
	75V	V_F t_{rr}			1N5803 .895 @ 1A 25ns		1N5808 .850 @ 6A 30ns			
	100V	V_F t_{rr}	UES1002 .895 @ 1A 25ns		1N5804* UES1102 .895 @ 2A 25ns		1N5809* UES1302 .850 @ 6A 30ns	UES1402 .895 @ 8A 35ns	UES1502 .895 @ 16A 35ns	UES2402 .895 @ 8A 35ns
	125V	V_F t_{rr}			1N5805 .895 @ 1A 25ns		1N5810 .850 @ 6A 30ns			
	150V	V_F t_{rr}	UES1003 .895 @ 1A 25ns		1N5806* UES1103 .895 @ 2A 25ns		1N5811* UES1303 .850 @ 6A 30ns	UES1403 .895 @ 8A 35ns	UES1503 .895 @ 16A 35ns	UES2403 .895 @ 8A 35ns
	200V	V_F t_{rr}		UES1104 1.15 @ 1A 50ns		UES1304 1.15 @ 3A 50ns		UES1404 .895 @ 8A 35ns	UES1504 .895 @ 16A 35ns	UES2404 .895 @ 8A 35ns
	300V	V_F t_{rr}		UES1105 1.15 @ 1A 50ns		UES1305 1.15 @ 3A 50ns				
	400V	V_F t_{rr}		UES1106 1.15 @ 1A 50ns		UES1306 1.15 @ 3A 50ns				

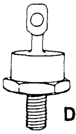
* Available as JAN, JANTX, JANTXV.

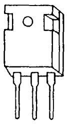
RECTIFIERS

PRODUCT SELECTION GUIDE


DO-4


TO-3


DO-5

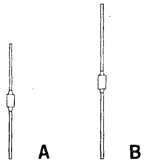

TO-3P

ULTRA-FAST RECOVERY (trr — 25 to 50ns)

Average D.C. Output Current		20A	25A	30A	30A Center-Tap	30A Center-Tap	45A	45A Center-Tap	50A	70A
Package Style		**DO-4**	**DO-4**	**TO-3P**	**TO-3P**	**TO-3**	**TO-3P**	**TO-3P**	**DO-5**	**DO-5**
Peak Inverse Voltage 50V			1N5812* UES701	UES3005S	UES3005C	UES2601[1]	UES4505S	UES4505C		1N6304* UES801
	V_F		.825 @ 25A	.93 @ 30A	.93 @ 30A	.825 @ 15A	.95 @ 45A	.95 @ 45A		.84 @ 70A
	t_{rr}		35ns	35ns	35ns	35ns	50ns	50ns		50ns
75V			1N5813							
	V_F		.825 @ 25A							
	t_{rr}		35ns							
100V			1N5814* UES702	UES3010S	UES3010C	UES2602[1]	UES4510S	UES4510C		1N6305* UES802
	V_F		.825 @ 25A	.93 @ 30A	.93 @ 30A	.825 @ 15A	.95 @ 45A	.95 @ 45A		.84 @ 70A
	t_{rr}		35ns	35ns	35ns	35ns	35ns	50ns		50ns
125V			1N5815							
	V_F		.825 @ 25A							
	t_{rr}		35ns							
150V			1N5816* UES703	UES3015S	UES3015C	UES2603[1]	UES4515S	UES4515C		1N6306* UES803
	V_F		.825 @ 25A	.93 @ 30A	.93 @ 30A	.825 @ 15A	.95 @ 45A	.95 @ 45A		.84 @ 70A
	t_{rr}		35ns	35ns	35ns	35ns	50ns	50ns		50ns
200V		UES704[1]				UES2604[1]			UES804[1]	
	V_F	1.15 @ 20A				1.15 @ 15A			1.15 @ 50A	
	t_{rr}	50ns				50ns			50ns	
300V		UES705[1]				UES2605[1]			UES805[1]	
	V_F	1.15 @ 20A				1.15 @ 15A			1.15 @ 50A	
	t_{rr}	50ns				50ns			50ns	
400V		UES706[1]				UES2606[1]			UES806[1]	
	V_F	1.15 @ 20A				1.15 @ 15A			1.15 @ 50A	
	t_{rr}	50ns				50ns			50ns	

* Available as JAN, JANTX, JANTXV.

[1] Available with High-Reliability (HR2) Screening.
See individual datasheets.



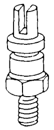
SUPER-FAST RECOVERY (trr — 75 to 100ns)

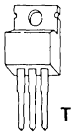
Average DC Output Current			1A	2A	3A	4A
Package Style			**A**	**A**	**B**	**B**
Peak Inverse Voltage	50V	V_F t_{rr}	UTX105 1.00 @ .5A 75ns	UTX205 1.0V @ 1A 75ns	UTX3105 1V @ 2A 100ns	UTX4105 1V @ 3A 100ns
	100V	V_F t_{rr}	UTX110 1.00 @ .5A 75ns	UTX210 1.0V @ 1A 75ns	UTX3110 1.0V @ 2A 100ns	UTX4110 1.0V @ 3A 100ns
	150V	V_F t_{rr}	UTX115 1.00 @ .5A 75ns	UTX215 1.0V @ 1A 75ns	UTX3115 1.0V @ 2A 100ns	UTX4115 1.0V @ 3A 100ns
	200V	V_F t_{rr}	UTX120 1.00 @ 1A 75ns	UTX220 1.0V @ 1A 75ns	UTX3120 1.0V @ 2A 100ns	UTX4120 1.0V @ 3A 100ns
	250V	V_F t_{rr}	UTX125 1.00 @ .5A 75ns	UTX225 1.0V @ 1A 75ns		

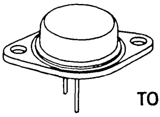
RECTIFIERS


A


B


C


TO-220AB


TO-3

FAST RECOVERY (t_{rr} — 150 to 500ns)

Average D.C. Output Current			1A	1A	2A	3A	3A	4A	6-9A
Package Style			**A**	**A**	**A**	**B**	**B**	**B**	**C**
Peak Inverse Voltage	50V		UTR01		UTR02	UTR3305	1N5415*	UTR4305	UTR4405[1] UTR5405[1] UTR6405[1]
		V_F	1.1V @ .5A		1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	1.1V @ 6A
		t_{rr}	250ns		250ns	250ns	150ns	250ns	300ns
	100V		UTR11		UTR12	UTR3310	1N5416* 1N5186**	UTR4310	UTR4410[1] UTR5410[1] UTR6410[1]
		V_F	1.1V @ .5A		1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	1.1V @ 6A
		t_{rr}	250ns		250ns	250ns	150ns	250ns	300ns
	200V		UTR21	1N4942* 1N5615*	UTR22	UTR3320	1N5417* 1N5187**	UTR4320	UTR4420[1] UTR5420[1] UTR6420[1]
		V_F	1.1V @ .5A	1.3V @ 1A	1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	1.1V @ 6A
		t_{rr}	250ns	150ns	250ns	250ns	150ns	250ns	400ns
	300V		UTR31		UTR32				
		V_F	1.1V @ .5A		1.1V @ 1A				
		t_{rr}	300ns		300ns				
	400V		UTR41	1N4944* 1N5617*	UTR42	UTR3340	1N5418* 1N5188**	UTR4340	UTR4440[1] UTR5440[1] UTR6440[1]
		V_F	1.1V @ .5A	1.3V @ 1A	1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	1.1V @ 6A
		t_{rr}	350ns	150ns	350ns	300ns	150ns	400ns	500ns
	500V		UTR51		UTR52	UTR3350	1N5419*	UTR4350	
		V_F	1.1V @ .5A		1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	
		t_{rr}	400ns		400ns	350ns	250ns	400ns	
	600V		UTR61	1N4946* 1N5619*	UTR62	UTR3360	1N5420* 1N5190**	UTR4360	
		V_F	1.1V @ .5A	1.3V @ 1A	1.1V @ 1A	1.1V @ 3A	1.5V @ 9A	1.1V @ 4A	
		t_{rr}	400ns	250ns	400ns	400ns	400ns	400ns	

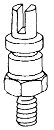
* Available as JAN, JANTX, JANTXV.

** Available as JAN, JANTX.

1. Available with High Reliability (HR2) Screening.
   See individual datasheets.

BI-SYNCHRONOUS RECTIFIER

Continuous Forward Current	20A		40A	
Package Style	**TO-220AB**		**TO-3**	
Forward Blocking Voltage, V_{CES}	50V	UBS421	50V	UBS430
h_{FE}	80		50	
$R_{CE(ON)}$	14mΩ Typical		7mΩ Typical	
$V_{CE(SAT)}$	.95V Typical		1.2V Typical	



STANDARD RECOVERY

Average DC Output Current		1A	2A	3A	4A	7.5A	9A	12A
Package Style		A	A	B	B	C	C	C
Peak Inverse Voltage	50V	UR105†	UR205	UT3005	UT4005	UT5105[1]	UT6105[1]	UT8105[1]
	100V	UT236 UT110†	UT261 UT210†	UT3010	UT4010	UT5110[1]	UT6110[1]	UT8110[1]
	150V	UR115†	UR215†					
	200V	UT234 UR120† 1N4245* 1N5614*	UT262 UR220† 1N3611**	UT3020	UT4020 1N5550*	UT5120[1]	UT6120[1]	UT8120[1]
	250V	UR125†	UR225†					
	400V	UT235 1N4246* 1N5616*	UT264 1N3612**	UT3040	UT4040 1N5551*	UT5140[1]	UT6140[1]	UT8140[1]
	600V	UT238 1N4247* 1N5618*	UT267 1N3613**	UT3060	UT4060 1N5552*	UT5160[1]	UT6160[1]	UT8160[1]
	800V	UT361 1N4248* 1N5620*	UT268 1N3614**		1N5553*			
	1000V	UT347 1N4249* 1N5622*	UT364					

* Available as JAN, JANTX, JANTXV.
** Available as JAN, JANTX.
† Radiation Tolerant
1. Available with High Reliability (HR) Screening.
See individual datasheets

RECTIFIERS

Military Approved, 1 Amp, General Purpose

JAN & JANTX 1N3611-1N3614

FEATURES

- Qualified to MIL-S-19500/228
- Continuous Rating: 1A
- Surge Rating: 30A
- PIV: to 800V

DESCRIPTION

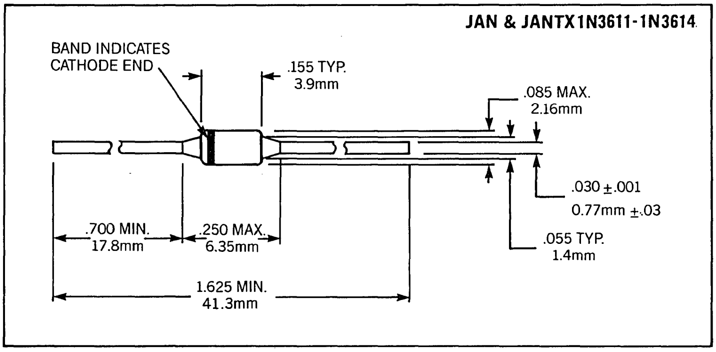
This series of MIL approved JAN and JANTX general purpose 1 amp rectifiers are useful in many high rel applications.

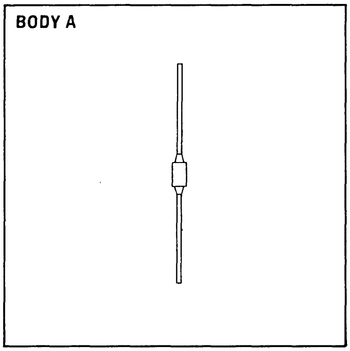
ABSOLUTE MAXIMUM RATINGS

Peak Reverse Voltage Min.	Reverse Working Voltage	Type
240V	200V	JAN & JANTX 1N3611
480V	400V	JAN & JANTX 1N3612
720V	600V	JAN & JANTX 1N3613
920V	800V	JAN & JANTX 1N3614

Maximum Average D.C. Output Current	
@ $T_A = 100°C$	1.0A
@ $T_A = 150°C$	0.3A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	30A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +200°C
Thermal Resistance	See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS

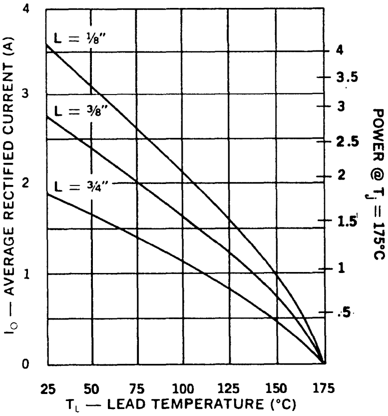


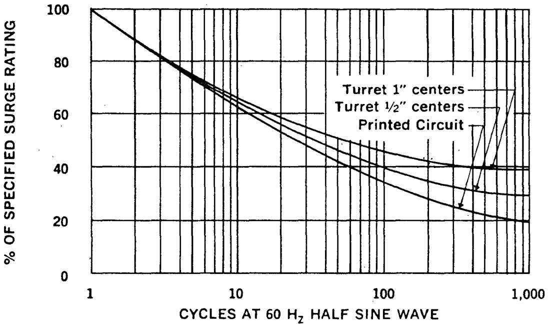


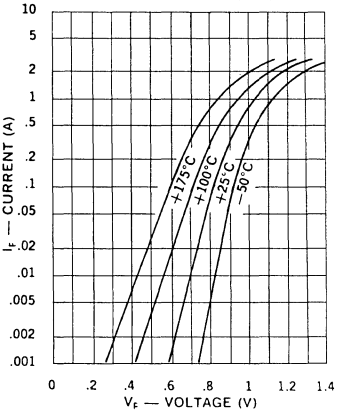
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

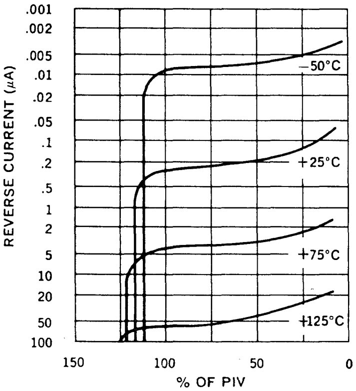
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Reverse D.C. Voltage	Minimum Reverse Breakdown Voltage @ 100µA	Peak Forward Voltage		Maximum D.C. Reverse Current at D.C. Voltage	
			Min.	Max.	25°C	150°C
JAN & JANTX 1N3611	200V	240V	0.6V	1.1V(pk) @ 1.0A	1µA	300µA
JAN & JANTX 1N3612	400V	480V				
JAN & JANTX 1N3613	600V	720V				
JAN & JANTX 1N3614	800V	920V				


Maximum Current vs Lead Temperature


Allowable Forward Surge vs Number of Cycles


Typical Forward Current vs Forward Voltage


Typical Reverse Current vs PIV

RECTIFIERS
Military Approved, 1 Amp, General Purpose

1N4245-1N4249
JAN, JANTX & JANTXV

FEATURES
- Qualified to MIL-S-19500/286.
- Surge Rating: 25A
- PIV: to 1000 V
- Controlled Avalanche
- No Plastic, Epoxy, Silicone, Oxides, Gases or Solder are used

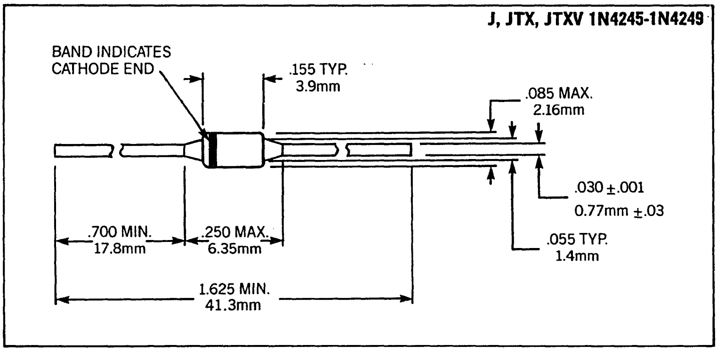
DESCRIPTION
This series of general purpose power rectifiers are available as JAN, JANTX or JANTXV for many power supply applicatons.

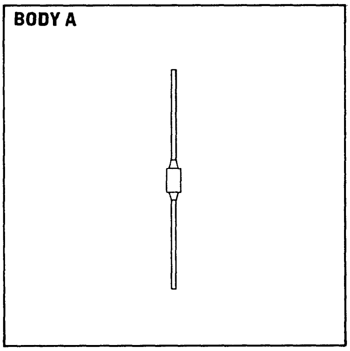
ABSOLUTE MAXIMUM RATINGS

Maximum Reverse Voltage	Type
200V	JAN, JANTX, JANTXV 1N4245
400V	JAN, JANTX, JANTXV 1N4246
600V	JAN, JANTX, JANTXV 1N4247
800V	JAN, JANTX, JANTXV 1N4248
1000V	JAN, JANTX, JANTXV 1N4249

Maximum Average D.C. Output Current @ T_A = 100°C	1.0A
@ T_A = 150°C	0.333A
Non-Repetitive Sinusoidal Surge Current	25A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +175°C
Thermal Resistance	See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS





THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

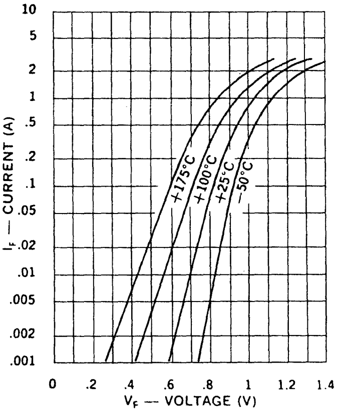
1/79

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

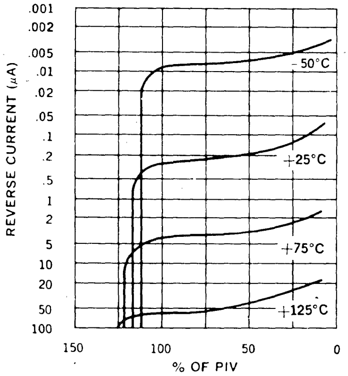
Type	PIV	Minimum Reverse Breakdown Voltage @ 100µA	Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
			Min.	Max.	25°C	150°C	
J, JTX, JTXV 1N4245	200V	240V	0.6V	1.3V(pk) @ 3.0A(pk)	1.0µA	150µA	5.0µs
J, JTX, JTXV 1N4246	400V	480V					
J, JTX, JTXV 1N4247	600V	720V					
J, JTX, JTXV 1N4248	800V	960V					
J, JTX, JTXV 1N4249	1000V	1150V					

*Measured in circuit $I_F = \frac{1}{2}A$, $I_R = 1.0A$, $I_{REC} = \frac{1}{4}A$

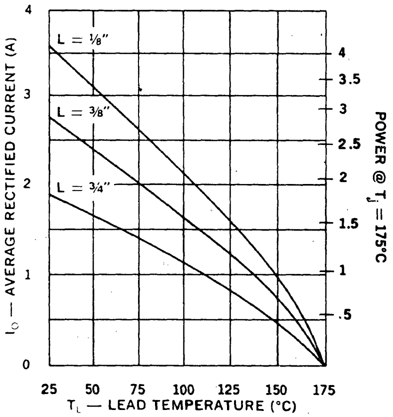
Typical Forward Current vs Forward Voltage



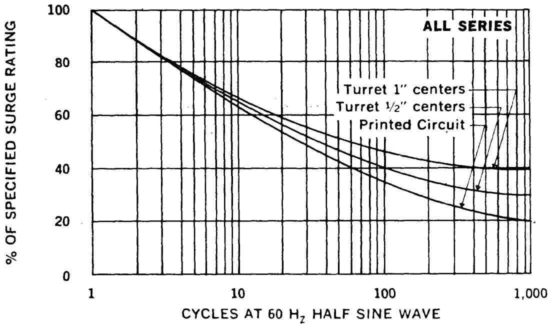
Typical Reverse Current vs PIV



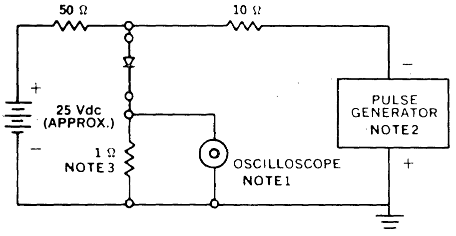
Maximum Current vs Lead Temperature



Allowable Forward Surge vs Number of Cycles



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
Military Approved, 1 Amp, Fast Recovery

JAN, JANTX, & JANTXV 1N4942
JAN, JANTX, & JANTXV 1N4944
JAN, JANTX, & JANTXV 1N4946

FEATURES
- Qualified to MIL-S-19500/359
- Surge Rating: 15A
- PIV: to 600V
- Controlled Avalanche

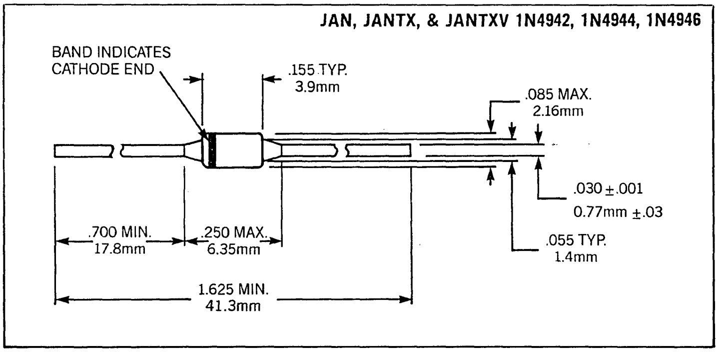
DESCRIPTION
These fast recovery rectifiers are suitable for use as power devices for many applications. Devices are available as JAN, JANTX or JANTXV.

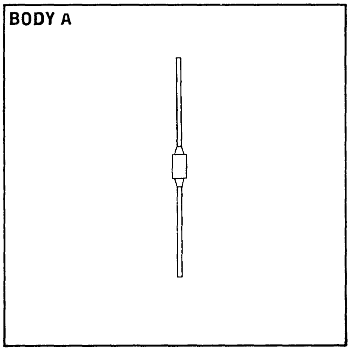
ABSOLUTE MAXIMUM RATINGS

Maximum Reverse Voltage	Type
200V	JAN, JANTX, & JANTXV 1N4942
400V	JAN, JANTX, & JANTXV 1N4944
600V	JAN, JANTX, & JANTXV 1N4946

Maximum Average D.C. Output Current	
@ $T_A = 55°C$	1.0A
@ $T_A = 100°C$	0.75A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	15A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +175°C
Thermal Resistance	See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS


JAN, JANTX, & JANTXV 1N4942, 1N4944, 1N4946


BODY A

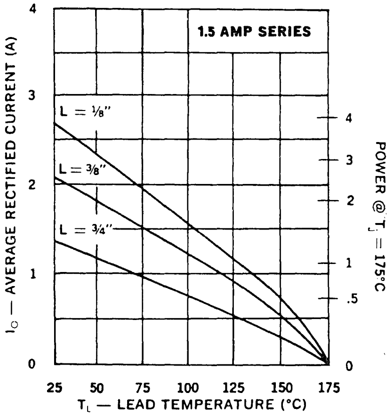
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

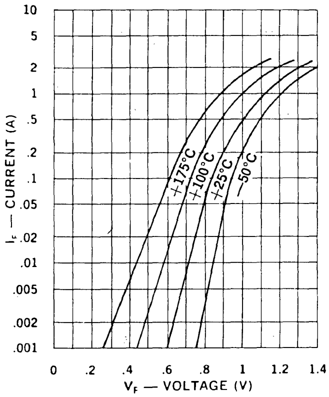
Type	Peak Inverse Voltage	Minimum Reverse Breakdown Voltage @ 50μA	Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*	Capacitance @ V_R = 12V f = 1MHz
			Min.	Max.	25°C	150°C		
J, JTX, JTXV 1N4942	200V	220V	0.6V	1.3Vdc @ 1 Adc	1.0μA	200μA	150ns	45pf
J, JTX, JTXV 1N4944	400V	440V					150ns	35pf
J, JTX, JTXV 1N4946	600V	660V					250ns	25pf

*Measured in circuit I_F = ½A, I_R = 1.0A, I_{REC} = ¼A

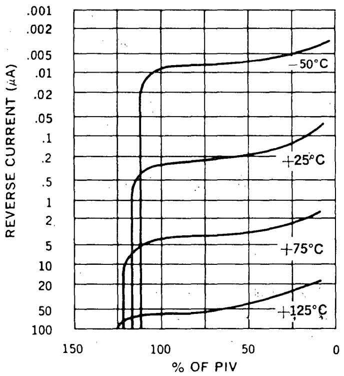
Maximum Current vs Lead Temperature



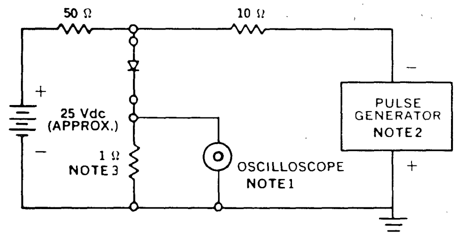
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs PIV



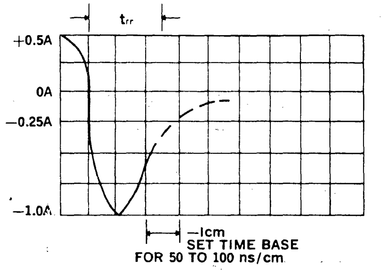
Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Characteristic Waveform.



RECTIFIERS

Military Approved, 3 Amp, Fast Recovery

1N5186-1N5190
JAN & JANTX

FEATURES

- Continuous Rating: 3A
- Qualified to MIL-S-19500/424
- PIV : to 600V
- Recovery Time: 150ns
- Miniature Size
- Controlled Avalanche

DESCRIPTION

These miniature fast recovery rectifiers permit operation at full power at frequencies as high as 100kHz sine wave.
They are qualified to military specification and available as JAN, JANTX

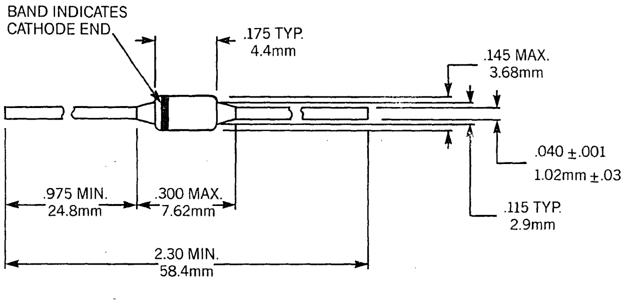
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
100V	JAN & JANTX 1N5186
200V	JAN & JANTX 1N5187
400V	JAN & JANTX 1N5188
600V	JAN & JANTX 1N5190

Maximum Average D.C. Output Current	
@ $T_A = 25°C$	3.0A
@ $T_A = 150°C$	0.7A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	80A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +200°C
Thermal Resistance	See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS

JAN & JANTX 1N5186-1N5190



BODY B

THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

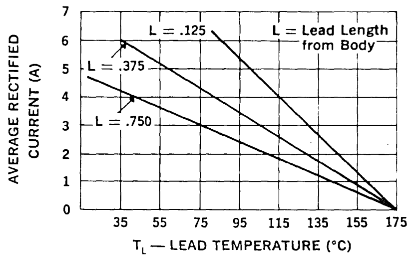
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage	Minimum Reverse Breakdown Voltage @ 100μA	Peak Forward Voltage		Maximum Reverse D.C. Current @ PIV	
			Min.	Max.	25°C	100°C
J, JTX 1N5186	100V	120V	0.9V @ 9A(pk) (8.3ms)	1.5V	2μA	100μA
J, JTX 1N5187	200V	240V				
J, JTX 1N5188	400V	480V				
J, JTX 1N5190	600V	660V				

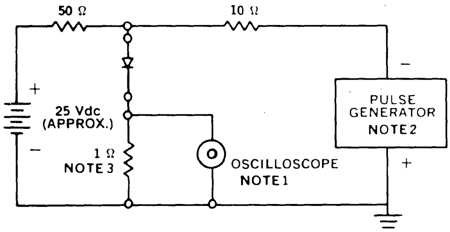
Type	Reverse Recovery Time*	Capacitance @ $V_R = 0V$ f = 1MHz	Capacitance @ $V_R = 4V$ f = 1MHz
J, JTX 1N5186	150ns	300pf	200pf
J, JTX 1N5187	200ns	300pf	170pf
J, JTX 1N5188	250ns	230pf	120pf
J, JTX 1N5190	400ns	180pf	90pf

*Recovery time measured from $I_F = 0.5A$ to $I_R = 1.0A$, $I_{REC} = 0.25A$

Maximum Current vs. Lead Temperature

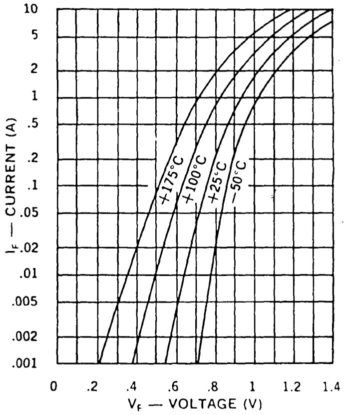


Reverse-Recovery Circuit

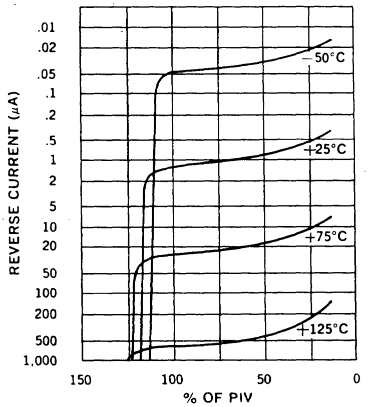


NOTES:
1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Typical Forward Current vs Forward Voltage



Typical Reverse Current vs PIV



RECTIFIERS

Military Approved, Fast Recovery, 3 Amp

1N5415-1N5420
JAN, JANTX & JANTXV

FEATURES

- Qualified to MIL-S-19500/411
- PIV: to 600V
- Controlled Avalanche

DESCRIPTION

This series of devices as designed to meet the need for high speed, power rectifiers in military high-rel power supplies.

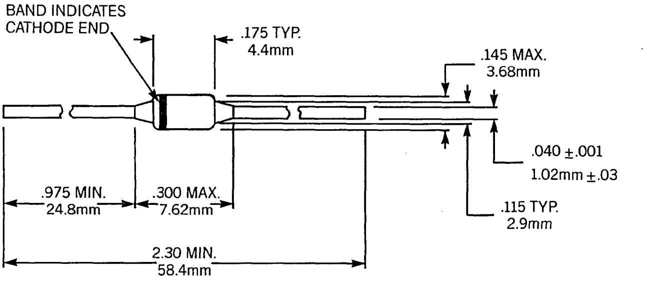
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
50V	JAN, JANTX, JANTXV 1N5415
100V	JAN, JANTX, JANTXV 1N5416
200V	JAN, JANTX, JANTXV 1N5417
400V	JAN, JANTX, JANTXV 1N5418
500V	JAN, JANTX, JANTXV 1N5419
600V	JAN, JANTX, JANTXV 1N5420

Maximum Average D.C. Output Current	
@ $T_A = 55°C$	3.0A
@ $T_A = 100°C$	2.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	80A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +200°C
Thermal Resistance θ_{JL} @ L = 3⁄8″	20°C/W See Lead Temperature Derating Curve

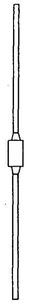
MECHANICAL SPECIFICATIONS

J, JTX, JTXV 1N5415-1N5420



Dimensions in inches.

BODY B



THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

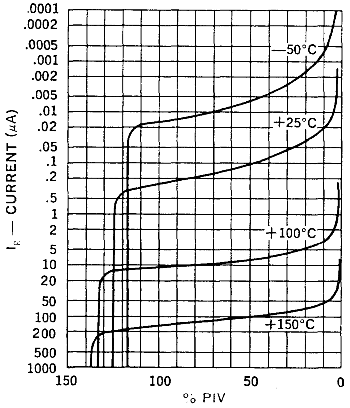
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

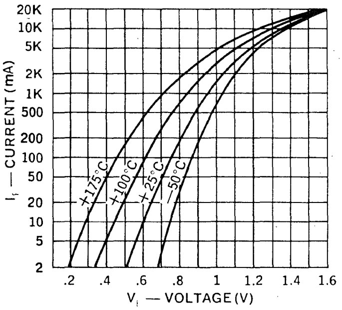
Type	PIV	Minimum Reverse Breakdown Voltage @ 50μA	Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
			Min.	Max.	25°C	100°C	
J, JTX, JTXV 1N5415	50V	55V	0.6V @ 9Adc tp = 300μs	1.5V(pk)	1.0μA	20μA	150
J, JTX, JTXV 1N5416	100V	110V					150
J, JTX, JTXV 1N5417	200V	220V					150
J, JTX, JTXV 1N5418	400V	440V					150
J, JTX, JTXV 1N5419	500V	550V					250
J, JTX, JTXV 1N5420	600V	660V					400

*Measured in circuit $I_F = 0.5$ A, $I_R = 1$A, $I_{REC} = 0.25$ A.

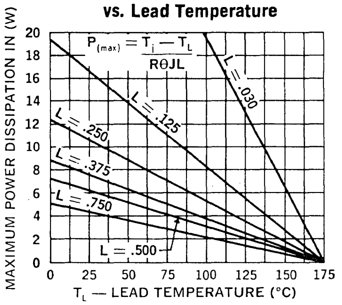
Typical Reverse Current vs. PIV



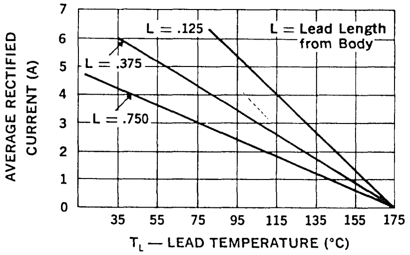
Typical Forward Current vs. Forward Voltage



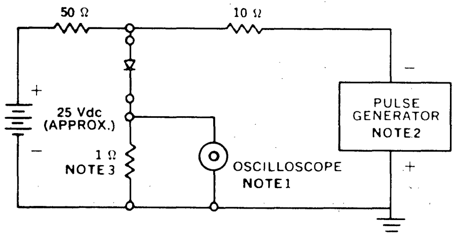
Maximum Power vs. Lead Temperature



Maximum Current vs. Lead Temperature



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
Military Approved, 5 Amp, General Purpose

1N5550-1N5553
JAN, JANTX & JANTXV

FEATURES
- Qualified to MIL-S-19500/420A
- Continuous Rating: 5A
- PIV: to 800V
- TX Parts 100% Screened
- Miniature Size
- Controlled Avalanche

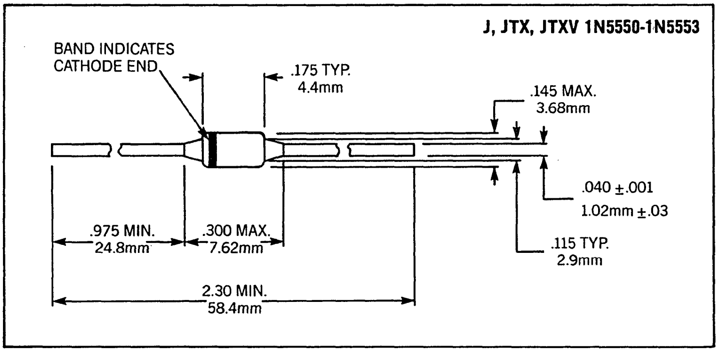
DESCRIPTION
This series of military approved rectifiers is useful in many military applications. The 100% screening requirements in the "TX" version combined with the unique Unitrode construction assures the highest degree of reliability.

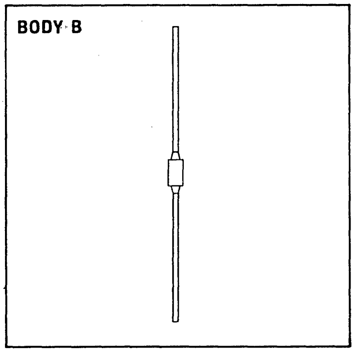
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
200V	JAN, JANTX & JANTXV 1N5550
400V	JAN, JANTX & JANTXV 1N5551
600V	JAN, JANTX & JANTXV 1N5552
800V	JAN, JANTX & JANTXV 1N5553

Maximum Average D.C. Output Current
@ $T_A = 55°C$ 3.0A
@ $T_L = 55°C$ 5.0A
Non-Repetitive Sinusoidal
Surge Current (8.3ms) 100A
Operating Temperature Range .... —65°C to +175°C
Storage Temperature Range .... —65°C to +200°C
Thermal Resistance .... See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS





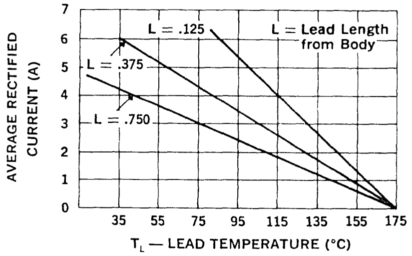
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

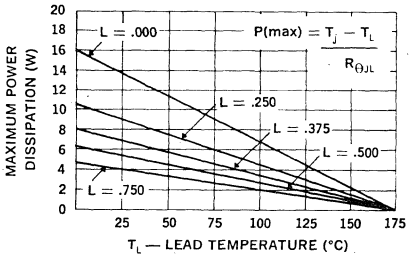
Type	Peak Inverse Voltage	Minimum Reverse Breakdown Voltage @ 50μA	Peak Forward Voltage		Maximum Leakage Current @ PIV		Maximum Reverse Recovery Time*
			Min.	Max.	25°C	100°C	
J, JTX, JTXV 1N5550	200V	240V	0.6V @ $I_F = 9A(pk)$ (8.3ms)	1.2V	1.0μA	75μA	2.0μs
J, JTX, JTXV 1N5551	400V	460V					
J, JTX, JTXV 1N5552	600V	660V					
J, JTX, JTXV 1N5553	800V	880V		1.3V			

*Measured in a test circuit $I_F = 0.5A$, $I_R = 1.0A$, $I_{REC} = 0.25A$

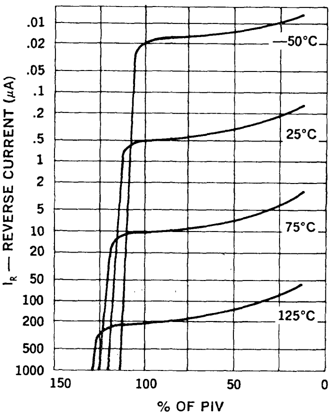
Maximum Current vs. Lead Temperature



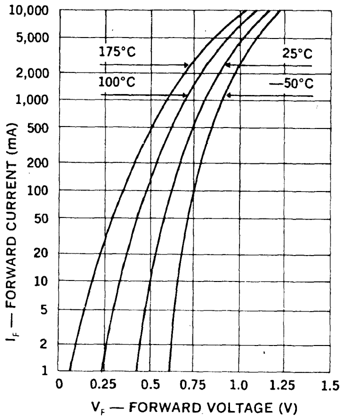
Maximum Power Dissipation vs. Lead Temperature



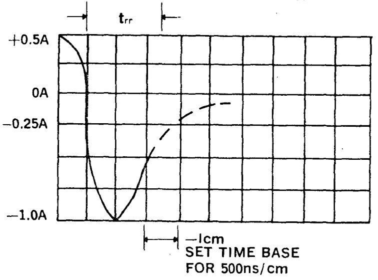
Typical Reverse Current vs. PIV



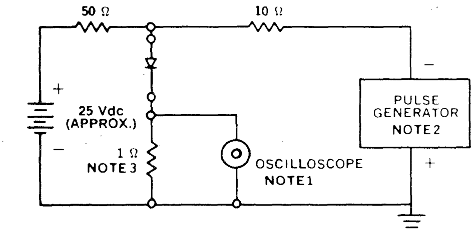
Typical Forward Current vs. Forward Voltage



Characteristic Wave Form



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
Standard Recovery, 1 Amp Military Approved

1N5614, 1N5616, 1N5618, 1N5620, 1N5622 JAN, JANTX & JANTXV

FEATURES
- Qualified to MIL-S-19500/427
- PIV: to 1000V
- Controlled Avalanche

DESCRIPTION
This series of medium power general purpose rectifiers can be used in the most demanding military supplies. Rugged mechanical integrity and tight electrical parameters make them particularly useful.

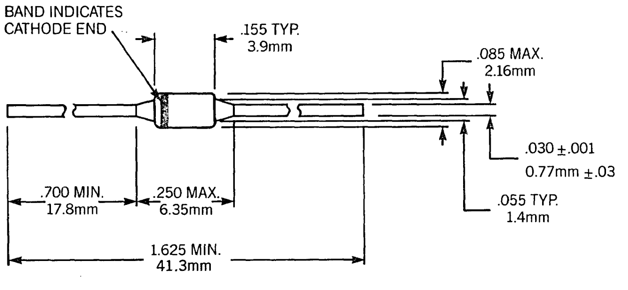
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
200V	JAN, JANTX & JANTXV 1N5614
400V	JAN, JANTX & JANTXV 1N5616
600V	JAN, JANTX & JANTXV 1N5618
800V	JAN, JANTX & JANTXV 1N5620
1000V	JAN, JANTX & JANTXV 1N5622

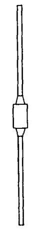
Maximum Average D.C. Output Current	
@ $T_A = 55°C$	1.0A
@ $T_A = 100°C$	0.75A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	30A
Operating Temperature Range	−65°C to +175°C
Storage Temperature Range	−65°C to +200°C
Thermal Resistance θ_{JL} @ $L = 3/8''$	38°C/W See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS

J, JTX, JTXV 1N5614, 1N5616, 1N5618, 1N5620, 1N5622



BODY A



THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

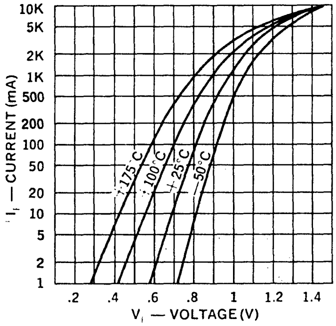
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

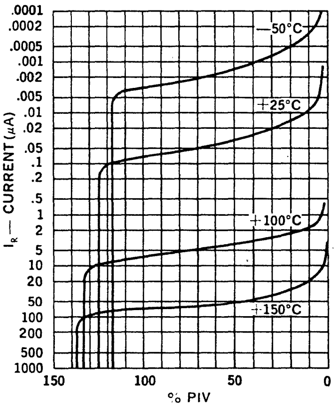
Type	PIV	Minimum Reverse Breakdown Voltage @ 50μA	Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
			Min.	Max.	25°C	100°C	
J, JTX, JTXV 1N5614	200V	220V	0.8	1.3V(pk) @3.0A tp = 300μS	0.5μA	25μA	2.0μS
J, JTX, JTXV 1N5616	400V	440V					
J, JTX, JTXV 1N5618	600V	660V					
J, JTX, JTXV 1N5620	800V	880V					
J, JTX, JTXV 1N5622	1000V	1100V					

*Measured in Circuit I_F = 1/2A, I_R =1.0A, I_{REC} = 1/4A

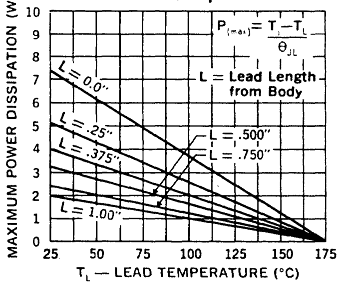
Typical Forward Voltage vs. Forward Current



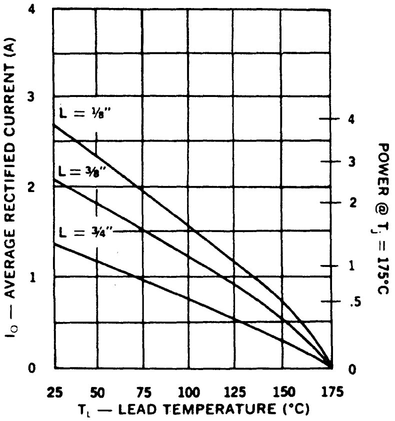
Typical Reverse Current vs. PIV



Maximum Power Dissipation vs. Lead Temperature



Maximum Current vs Lead Temperature



RECTIFIERS

Military Approved, Fast Recovery, 1 Amp

1N5615, 1N5617, 1N5619
JAN, JANTX & JANTXV

FEATURES

- Qualified to MIL-S-19500/429
- PIV: to 600V
- Controlled Avalanche

DESCRIPTION

This series of military approved rectifiers is useful in many military applications where fast recovery and medium power are required. The 100% screening requirements in the "TX" version combined with the unique Unitrode construction assures the highest degree of reliability.

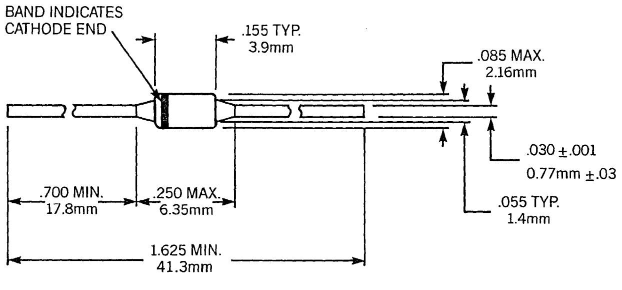
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
200V	JAN, JANTX, JANTXV 1N5615
400V	JAN, JANTX, JANTXV 1N5617
600V	JAN, JANTX, JANTXV 1N5619

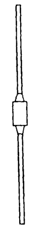
Maximum Average D.C. Output Current	
@ $T_A = 55°C$	1.0A
@ $T_A = 100°C$	0.75A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	25A
Operating Temperature Range	$-65°C$ to $+175°C$
Storage Temperature Range	$-65°C$ to $+200°C$
Thermal Resistance θ_{JL}	38°C/W
	See Lead Temperature Derating Curve

MECHANICAL SPECIFICATIONS

J, JTX, JTXV 1N5615, 1N5617, 1N5619



BODY A



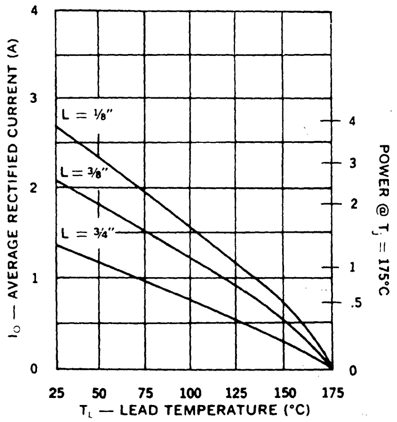
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

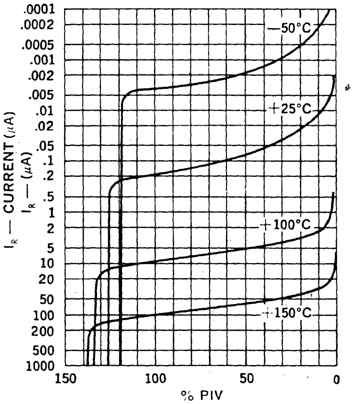
Type	PIV	Minimum Reverse Breakdown Voltage @ 50μA	Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*	Capacitance @ $V_R = 12V$ f = 1MHz
			Min.	Max.	25°C	100°C		
J, JTX, JTXV 1N5615	200V	220V	0.8V	1.6V(pk) @ 3.0 Adc tp = 300μs	0.5μA	25μA	150ns	45pf
J, JTX, JTXV 1N5617	400V	440V					150ns	35pf
J, JTX, JTXV 1N5619	600V	660V					250ns	25pf

*Measured in Circuit $I_F = ½A$, $I_R = 1A$, $I_{REC} = ¼A$

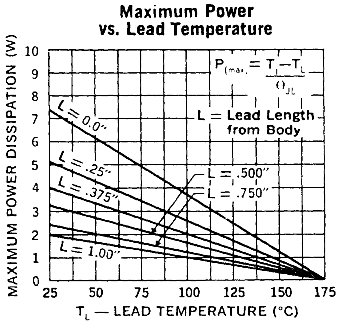
Maximum Current vs Lead Temperature



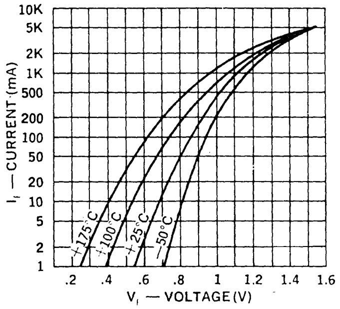
Typical Reverse Current vs. PIV



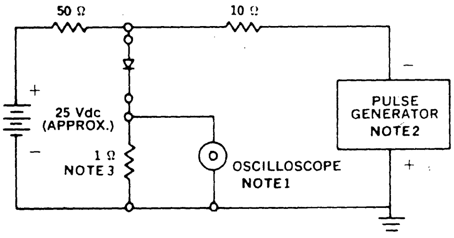
Maximum Power vs. Lead Temperature



Typical Forward Voltage vs. Forward Current



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, ESP, 2.5 Amp to 20 Amp

1N5802-1N5806
1N5807-1N5811
1N5812-1N5816

FEATURES
- Exceptional Efficiency
- Low Forward Voltage
- Extremely Fast Reverse Recovery Time
- Extremely Fast Forward Recovery Time
- High Surge
- Small Size
- Rugged, High Current Termination
- Radiation Tolerant

DESCRIPTION
This series of High Efficiency Power Rectifiers allows circuit designers to design high current, high frequency supplies to 500 kHz with very low diode losses. The high forward surge capability makes these devices useful in protective circuits.

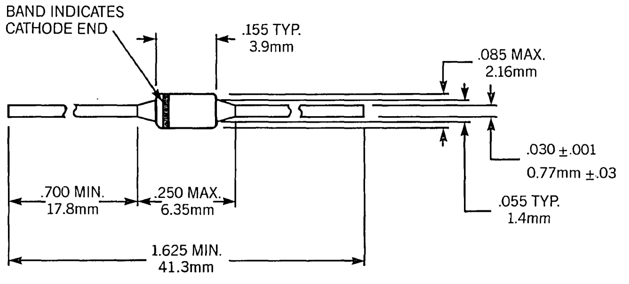
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	2.5 Amp Series	6 Amp Series	20 Amp Series
50V	1N5802	1N5807	1N5812
75V	1N5803	1N5808	1N5813
100V	1N5804	1N5809	1N5814
125V	1N5805	1N5810	1N5815
150V	1N5806	1N5811	1N5816

	2.5 AMP SERIES	6.0 AMP SERIES	20 AMP SERIES
Maximum Average D.C. Output Current			
@ $T_L = 75°C$, L = ⅜"	2.5A	6.0A	—
@ $T_C = 100°C$			20.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	35A	125A	250A
Operating and Storage Temperature Range	—65°C to +175°C		
Thermal Resistance 2.5A and 6A Series	See Lead Temperature Derating Curve		
20A Series			3.0°C/W

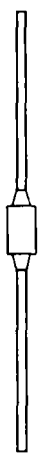
MECHANICAL SPECIFICATIONS

1N5802-1N5806

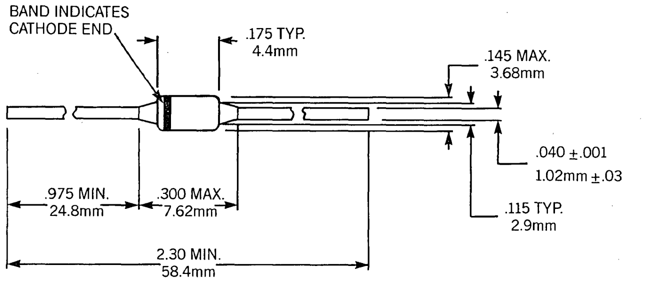


Typical Weight — 0.22 grams

BODY A

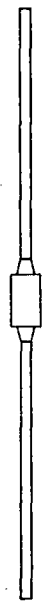


1N5807-1N5811



Typical Weight — 0.75 grams

BODY B

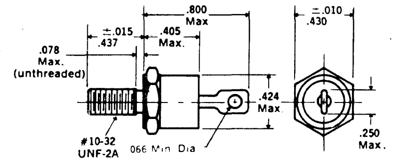


THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

MECHANICAL SPECIFICATIONS

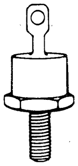
1N5812-1N5816



Part Identification: Type number printed on metal case.
Polarity: Cathode to stud end
Max. Weight: 7.0 Grams
Installation Precautions: Maximum unlubricated stud torque: 10 inch pounds
Thermal Resistance: 3.0°C/W

Dimensions in inches.

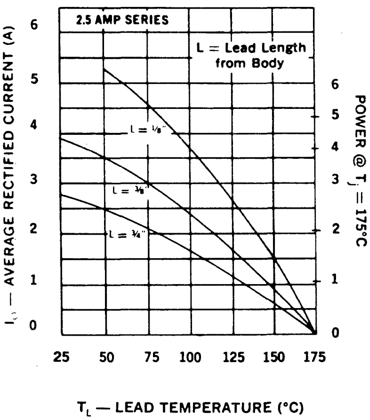
DO-4

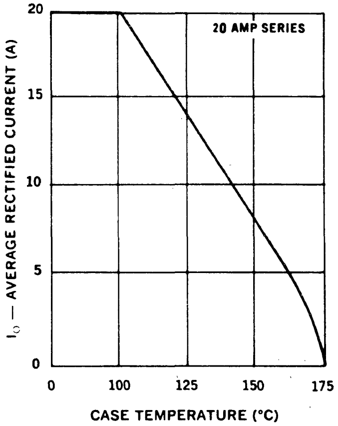


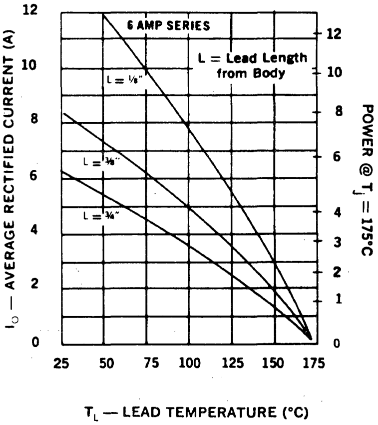
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	PIV	Maximum Forward Voltage Drop*	Leakage Current @ PIV		Maximum Reverse Recovery Time I_F, I_R, I_{REC}	Typical Forward Recovery Time @ 1A Recover to 1V	Typical Forward Recovery Voltage @ 1A tr = 8ns	Typical Junction Capacitance @ —10V
			25°C	100°C				
1N5802	50V	.875 @ 1A	1μA	50μA	25ns, 0.5A-0.5A-0.05A	15ns	1.5V	15pf
1N5803	75V							
1N5804	100V							
1N5805	125V							
1N5806	150V							
1N5807	50V	.875 @ 4A	5μA	150μA	30ns, 1.0-1.0-0.1A	15ns	1.5V	45pf
1N5808	75V							
1N5809	100V							
1N5810	125V							
1N5811	150V							
1N5812	50V	.900 @ 10A	10μA	750μA	35ns, 1.0-1.0-0.1A	15ns	1.5V	200pf
1N5813	75V							
1N5814	100V							
1N5815	125V							
1N5816	150V							

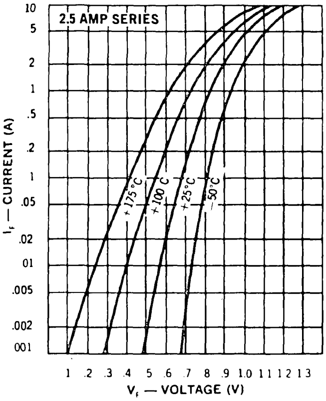
*Pulse width = 250ms


Output Current vs. Lead Temp.

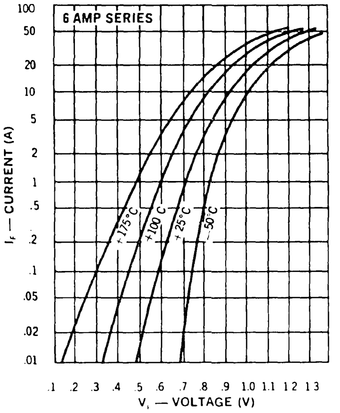

Output Current vs. Case Temp.


Output Current vs. Lead Temp.

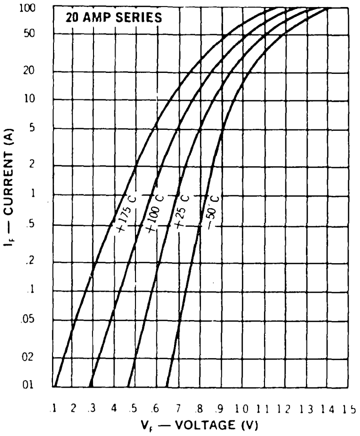
Typical Forward Current vs. Forward Voltage



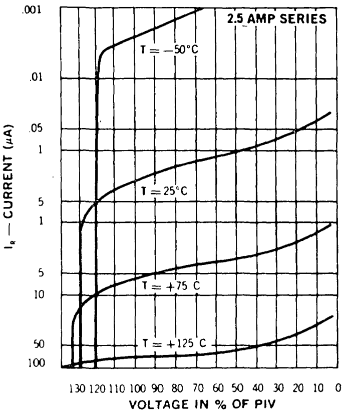
Typical Forward Current vs. Forward Voltage



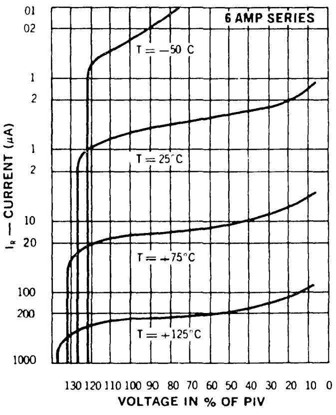
Typical Forward Current vs. Forward Voltage



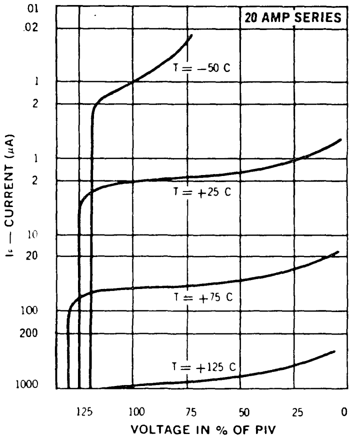
Typical Reverse Current vs. Voltage



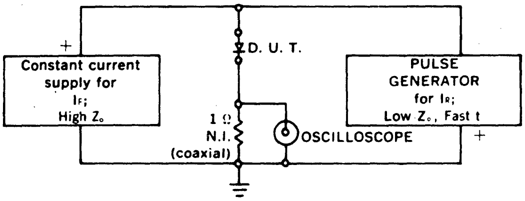
Typical Reverse Current vs. Voltage



Typical Reverse Current vs. Voltage



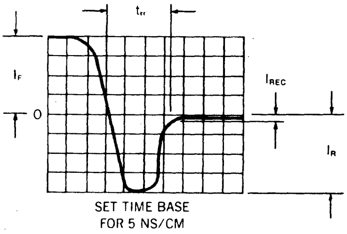
Reverse-Recovery Time Circuit



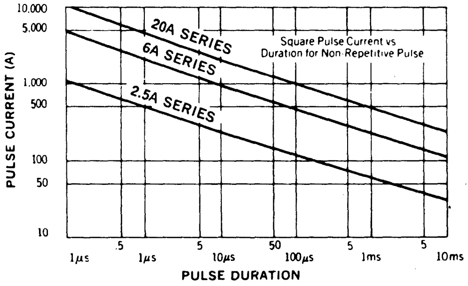
NOTES:

1. Oscilloscope: Rise time ≤ 3 ns; input impedance = 50 Ω.
2. Pulse Generator: Rise time ≤ 8 ns; source impedance 10 Ω.

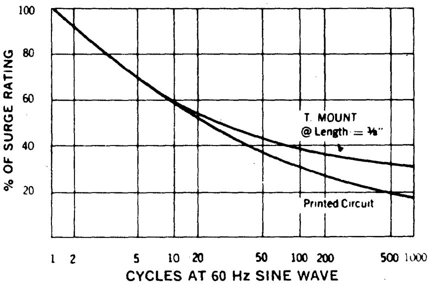
Characteristic Waveform



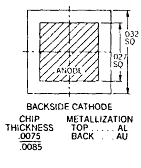
Forward Pulse Current vs. Duration



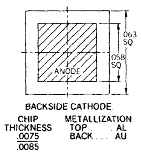
Multiple Surge Current vs. Duration



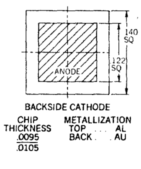
1N5804, 1N5806



1N5809, 1N5811



1N5814, 1N5816



RECTIFIERS
Military Approved, High Efficiency, 2.5 Amp and 6.0 Amp

1N5802, 1N5804, 1N5806, 1N5807, 1N5809, 1N5811 JAN, JANTX & JANTXV

FEATURES
- Qualified to MIL-S-19500/477
- PIV: to 150V
- Low Forward Voltage

DESCRIPTION
This series of high efficiency power rectifiers are particularly applicable to switching regulator power supplies where extremely fast switching and low forward losses are most important.

ABSOLUTE MAXIMUM RATINGS

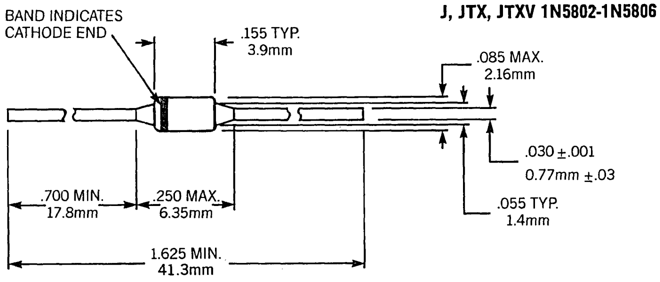
Peak Inverse Voltage	2.5A Series	6.A Series
50V	JAN, JANTX & JANTXV 1N5802	JAN, JANTX & JANTXV 1N5807
100V	JAN, JANTX & JANTXV 1N5804	JAN, JANTX & JANTXV 1N5809
150V	JAN, JANTX & JANTXV 1N5806	JAN, JANTX & JANTXV 1N5811

	2.5A SERIES	6A SERIES
Maximum Average D.C. Output Current		
@ $T_L = 75°C$, $L = 3/8''$	2.5A	6.0A
@ $T_A = 55°C$	1.0A	3.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	35A	125A
Operating Temperature Range	−65°C to +175°C	
Storage Temperature Range	−65°C to +200°C	
Thermal Resistance, θ_{JL} @ $L = 3/4''$	59°C/W	35.5°C/W

See lead temperature derating curve

MECHANICAL SPECIFICATIONS

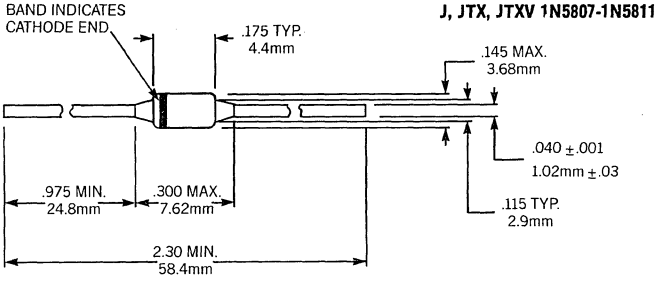
J, JTX, JTXV 1N5802-1N5806



Dimensions in inches.

BODY A

J, JTX, JTXV 1N5807-1N5811



Dimensions in inches.

BODY B

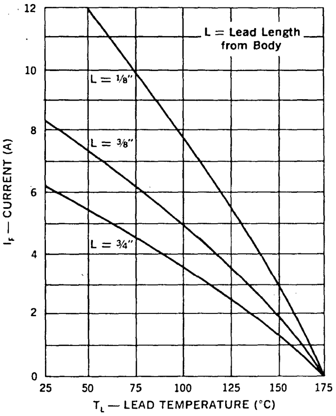
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

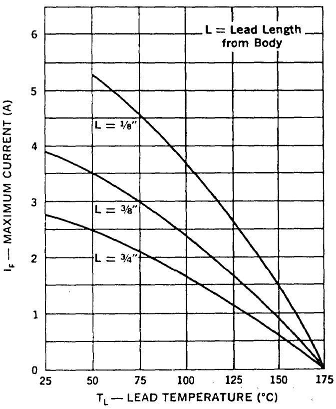
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

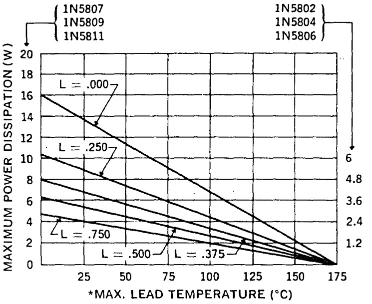
Type	PIV	Minimum Breakdown Voltage @ 100µA	Forward Voltage @ 25°C	Forward Voltage @ 100°C	Maximum Reverse Current @ PIV 25°C	Maximum Reverse Current @ PIV 100°C	Maximum Reverse Recovery Time
J, JTX, JTXV 1N5807	50V	60V	.875V Max. @ 4A (pk) .925V Max. @ 6A (pk)	.8V Max. @ 4A (pk)	5µA	150µA	30ns $I_F = I_R = 1.0A$ $I_{REC} = 0.1A$ di/dt = 100A/µs min.
J, JTX, JTXV 1N5809	100V	110V					
J, JTX, JTXV 1N5811	150V	160V					
J, JTX, JTXV 1N5802	50V	60V	.875V Max. @ 1A (pk) .975V Max. @ 2.5A (pk)	.8V Max. @ 1A (pk)	1µA	50µA	25ns $I_F = I_R = 0.5A$ $I_{REC} = 0.05A$ di/dt = 65A/µs min.
J, JTX, JTXV 1N5804	100V	110V					
J, JTX, JTXV 1N5806	150V	160V					

Output Current vs. Lead Temperature
1N5807-5811



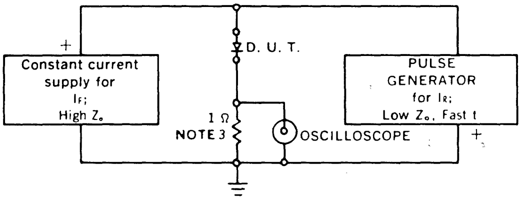
Output Current vs. Lead Temperature
1N5802-5806



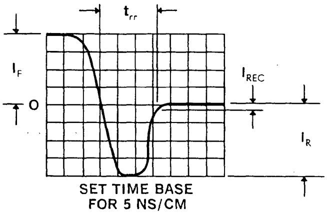


*Maximum lead temperature in °C (T_L) at point "L" from body. (For maximum operating junction temperature of 175°C with equal two-lead conditions.)

Reverse-Recovery Circuit

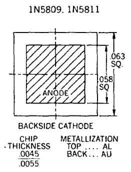


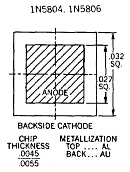
Characteristic Waveform

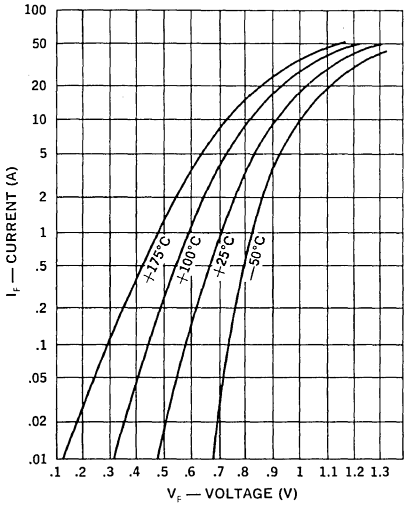


NOTES:

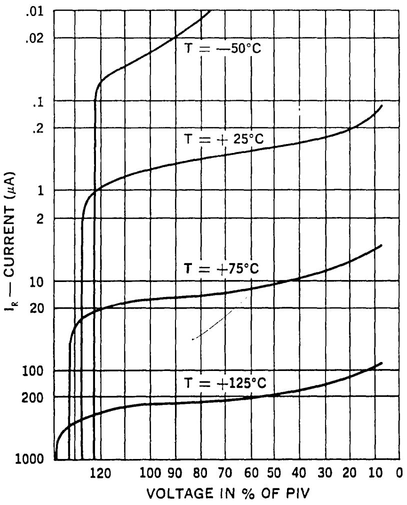
1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.



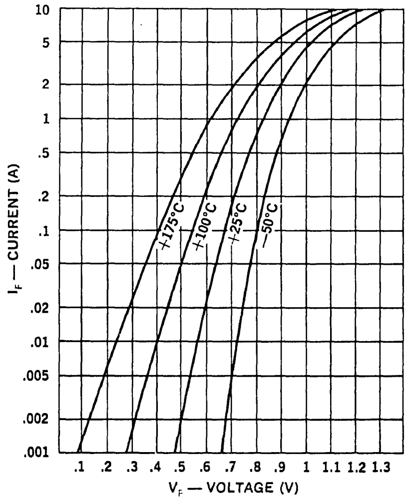




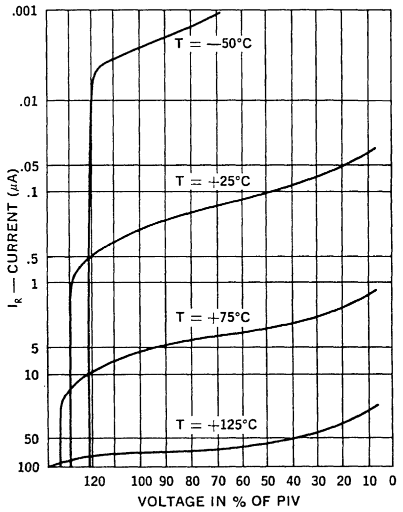
Typical Forward Current vs. Forward Voltage
JAN & JANTX 1N5807-5811



Typical Reverse Current vs. Voltage
JAN & JANTX 1N5807-5811



Typical Forward Current vs. Forward Voltage
JAN & JANTX 1N5802-5806

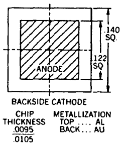


Typical Reverse Current vs. Voltage
JAN & JANTX 1N5802-5806

RECTIFIERS
Military Approved
High Efficiency, 20 Amp

1N5812, 1N5814, 1N5816
JAN, JANTX & JANTXV

FEATURES
- Qualified to MIL-S-19500/478
- Exceptional Efficiency
- Mechanically Rugged
- Low Thermal Resistance
- JAN, JANTX and JANTXV Available



DESCRIPTION
This series is suited for use as a power rectifier in switching regulator and high frequency inverter/converter and other appropriate equipment circuits where low voltage drop and fast recovery times are important.

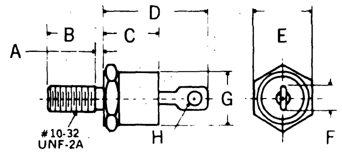
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	Type
50V	JAN, JANTX, JANTXV 1N5812
100V	JAN, JANTX, JANTXV, 1N5814
150V	JAN, JANTX, JANTXV 1N5816

Maximum Average D.C. Output Current	
@ $T_C = 100°C$	20A
@ $T_A = 55°C$	5A
Non-Repetitive Sinusoidal Surge Current @ 8.3mSec	400A
Thermal Resistance, Junction to Case	1.5°C/W
Operating Junction Temperature	−65°C to +175°C
Storage Ambient Temperature	−65°C to +200°C

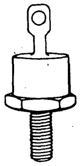
MECHANICAL SPECIFICATIONS

J, JTX, JTXV 1N5812, 1N5814, 1N5816



	ins.	mm
A	.078 MAX.	1.98 MAX.
B	.437 ± .015	11.10 ±0.38
C	.405 MAX.	10.29 MAX.
D	.800 MAX.	20.32 MAX.
E	.430 ± .010	10.92 ± 0.25
F	.250 MAX.	6.35 MAX.
G	.424 MAX.	10.77 MAX.
H	.066 MIN. DIA.	1.68 MIN. DIA.

DO-4



Notes:
1. Polarity is cathode-to-stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 15 inch pounds.
4. Angular orientation of terminal is undefined.

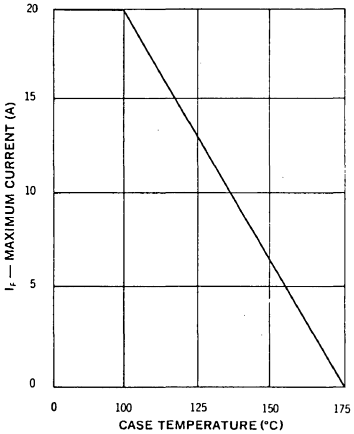
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

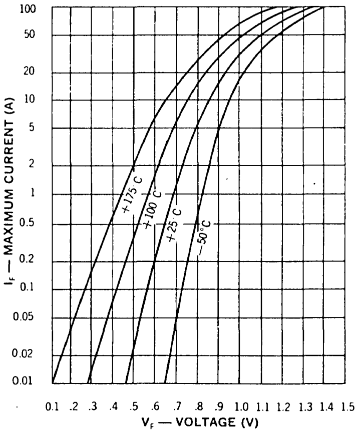
Type	Peak Inverse Voltage	Minimum Reverse Breakdown Voltage @ 100μA	Peak Forward Voltage		Maximum Leakage Current @ PIV	
			@ 10Apk	@ 20Apk	25°C	100°C
J, JTX, JTXV 1N5812	50V	60V	.86V MAX.	.95V MAX.	10μA	750μA
J, JTX, JTXV 1N5814	100V	110V				
J, JTX, JTXV 1N5816	150V	160V				

Maximum Reverse Recovery Time @ IF, IR, IREC	Maximum Forward Recovery Time @ 1A Recovery to 1V	Maximum Forward Recovery Voltage @ 1A tr = 8nsec	Maximum Junction Capacitance @ —10V
35nsec 1.0A —1.0A —0.1A	15nsec	2.2V	300pf

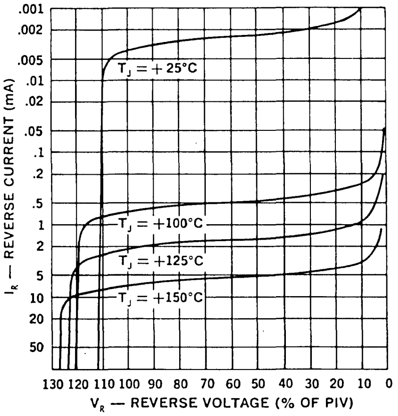
Output Current vs. Case Temperature



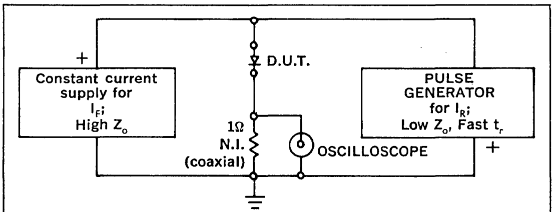
Typical Forward Current vs. Forward Voltage



Typical Reverse Current vs. Reverse Voltage



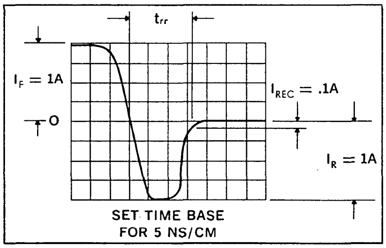
Reverse-Recovery Time Test Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3 ns; input impedance = 50 Ω.
2. Pulse Generator: Rise time ⩽ 8 ns; source impedance 10 Ω.

Characteristic Waveform



POWER SCHOTTKY RECTIFIERS

50 Amp, 30 and 40 Volts

1N6097
1N6098

FEATURES

- Very Low Forward Voltage
- Low Recovered Charge
- Rugged Package Design (DO-5)
- Low Thermal Resistance
- High Surge Current
- Reverse Energy Tested (2A pk)

DESCRIPTION

Unitrode's series of Schottky barrier power rectifiers is ideally suited for output rectifiers and catch diodes in low voltage power supplies. The Unitrode high conductivity design, using a heavy copper top post and 4 point crimp, ensures cool thermal operation and low dynamic impedance. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

ABSOLUTE MAXIMUM RATINGS

	1N6097	1N6098
Working Peak Reverse Voltage, V_{RWM}	30V	40V
DC Blocking Voltage, V_R	30V	40V
Repetitive Peak Reverse Voltage, V_{RRM}	30V	40V
Non-repetitive Peak Reverse Voltage, V_{RSM}	36V	48V
Average Rectified Forward Current, I_O	50A ($T_C = 70°C$) 20A ($T_C = 105°C$)	
Non-repetitive Peak Surge Current (8.3 mS), I_{FSM}	800A	
Storage Temperature Range, T_{stg}	−65 to + 125°C	
Peak Operating Junction Temperature, $T_{j(pk)}$	+150°C	
Thermal Resistance Junction to Case, $R_{\theta JC}$	1°C/WMax.	

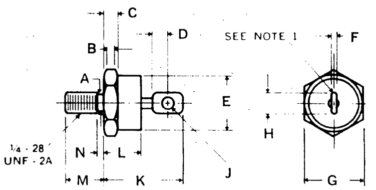
ELECTRICAL CHARACTERISTICS ($T_{CASE} = 25°C$)

Characteristic	Symbol	Both Types	Units	Conditions
Maximum Instantaneous Reverse Current	I_{RRM}	250	mA	V_{RWM} = Rated, $T_C = 125°C$ Pulse Width = 300μs, Duty Cycle ⩽ 2 percent
Maximum Reverse Current	I_R	250	mA	V_R = Rated, T_C = 115°C
Maximum Instantaneous Forward Voltage	V_{FM}	0.86	V	I_O = 50A* T_C = 70°C
	V_{FM}	0.60	V	$I_F = 10A$ Pulse Width 300μs Duty Cycle ⩽ 2 percent
Capacitance	C_t	7000	pF	$V_R = 1.0V$

*I_{FM} = 157A

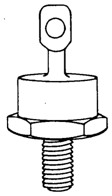
MECHANICAL SPECIFICATIONS

1N6097, 1N6098



	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA
K	1.000 MAX	25 40 MAX.
L	.450 MAX.	11 43 MAX.
M	.438 ± 015	11.13 ± 0.38
N	.078 MAX	1 98 MAX.

DO-5



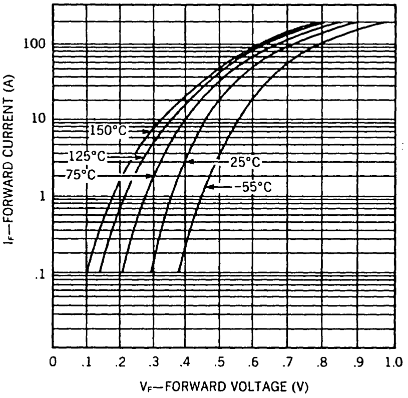
Notes:

1. Cathode is stud.
2. Maximum unlubricated stud torque: 30 inch pounds.
3. Angular orientation of terminal is undefined.
4. Maximum tension (90°) anode terminal 15 pounds for 30 seconds.

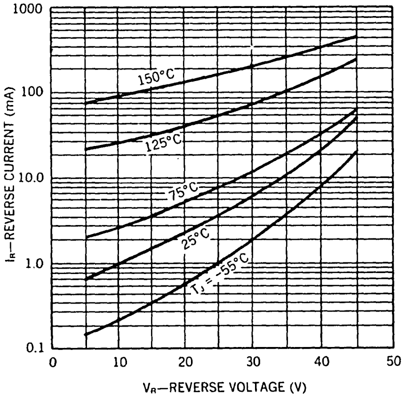
SEMICONDUCTOR PRODUCTS
UNITRODE

4/82

Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Reverse Voltage



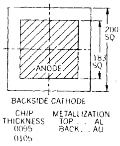
RECTIFIERS

High Efficiency, 70A

1N6304—1N6306
JAN, JANTX, JANTXV

FEATURES

- High Continuous Current Rating
- Very Low Forward Voltage
- Very Fast Switching Speeds
- High Surge Capability
- Low Thermal Resistance
- Mechanically Rugged
- Both Polarities Available
- Qualified to MIL-S-19500/550



DESCRIPTION

The 1N6304 Series is specifically designed for operation in power switching circuits operating at frequencies of at least 20KHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, 1N6304	50V
Peak Inverse Voltage, 1N6305	100V
Peak Inverse Voltage, 1N6306	150V
Maximum Average D.C. Output Current at T_C = 100°C	70A
Non-Repetitive Sinusodal Surge Current 8.3ms	800A
Thermal Resistance, Junction to Case	0.8°C/W
Operating and Storage Temperature Range	−65°C to +175°C
Operating and Storage Temperature Range (JEDEC types)	−55°C to +175°C

POWER CYCLING

These devices possess the unique ability to pass many thousands of cycles of a stress test designed to evaluate the integrity of the bonding systems used in the construction of power rectifiers.

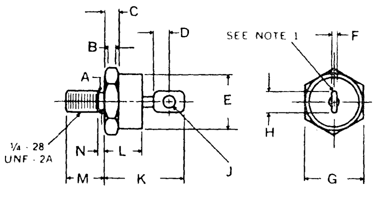
In this stress test, the case of the device is not heat sunk. Full rated forward current is supplied to force a case temperature increase at least 75°C, at which time, the current is removed and the case allowed to cool. The cycle is repeated a minimum of 5,000 times to simulate equipment being turned on and off. Extended power cycling tests demonstrate a product capability in excess of 25,000 cycles.

SWITCHING CHARACTERISTICS

The switching times of these ultra-fast rectifiers increase relatively little, with temperature or at different currents. Even in severe applications, such as catch diodes for switching regulators and output rectifiers for high frequency square wave inverters, these devices switch many times faster than the fastest associated transistors. Thus, the stresses on and powers dissipated in the switching transistors are substantially less than when using other rectifiers.

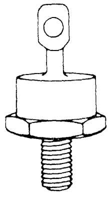
MECHANICAL SPECIFICATIONS

1N6304-1N6306



	ins.	mm
A	.225 ± 005	5.72 ± 0 13
B	060 MIN	1 52 MIN
C	156 ± 020	3.96 ± 0.51
D	156 MIN FLAT	3.96 MIN FLAT
E	667 DIA MAX.	16.94 DIA MAX
F	.090 MAX	2 29 MAX
G	677 ± 010	17 20 ± 0 25
H	375 MAX	9 53 MAX
J	140 MIN DIA	3 56 MIN DIA
K	1 000 MAX.	25 40 MAX
L	450 MAX	11 43 MAX
M	438 + 015	11 13 ± 0 38
N	078 MAX	1.98 MAX

DO-203AB (DO-5)



Notes:

1. Standard polarity is cathode-to-stud.
   For reverse polarity (anode-to-stud) add suffix "R", ie. 1N6304R.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 20 inch pounds (20 kg. cm).
4. Angular orientation of terminal is undefined.

SEMICONDUCTOR PRODUCTS
UNITRODE

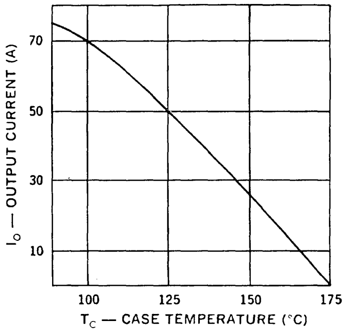
ELECTRICAL SPECIFICATIONS

Type	V_R	Maximum Forward Voltage V_F		Maximum Reverse Current I_R		Maximum Reverse Recovery Time t_{rr}
		$T_C = 25°C$	$T_C = 150°C$	$T_C = 25°C$	$T_C = 150°C$	
1N6304 1N6305 1N6306	50V 100V 150V	.975V @ 70A $t_P = 300\mu S$	.840V @ 70A $t_P = 300\mu S$	25μA	30mA	50ns 1A-1A-0.1A
J, JTX, JTXV 1N6304 J, JTX, JTXV 1N6305 J, JTX, JTXV 1N6306	50V 100V 150V	.975V @ 70A $t_P = 300\mu s$	.840V @ 70A $t_P = 300\mu s$	25μA	30mA	50ns(1)
		1.18V @ 150A $t_P = 300\mu s$				60ns(2)

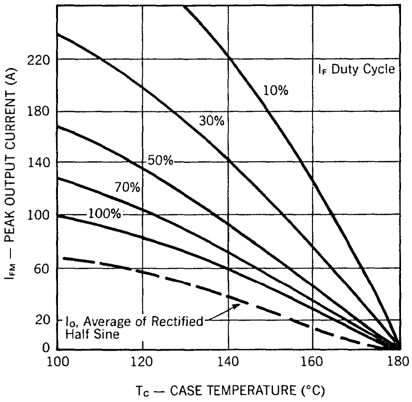
(1) $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$, $di/_{dt} = 85A/\mu s$ (min.).
(2) $I_{FM} = 70A$, $di/_{dt} = 130A/\mu s$.

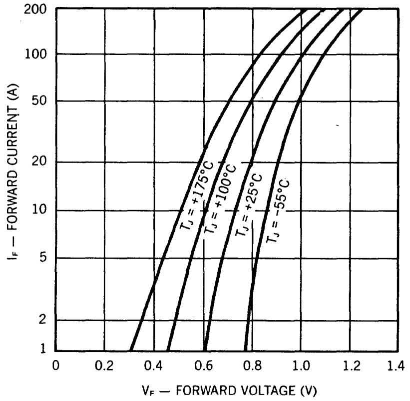
Type	V_R	Maximum Forward Recovery Time	Maximum Forward Voltage	Maximum Junction Capacitance
J, JTX, JTXV 1N6304 J, JTX, JTXV 1N6305 J, JTX, JTXV 1N6306	50V 100V 150V	15ns $I_{FM} = 1A$, $t_r = 8ns$	2.2V $I_{FM} = 1A$, $t_r = 8ns$	@ −10V 600pF

Output Current vs. Case Temperature

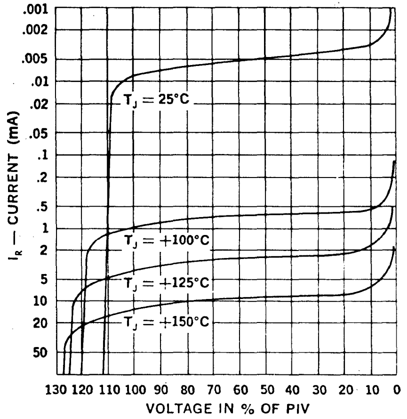


Peak Output Current vs. Case Temperature

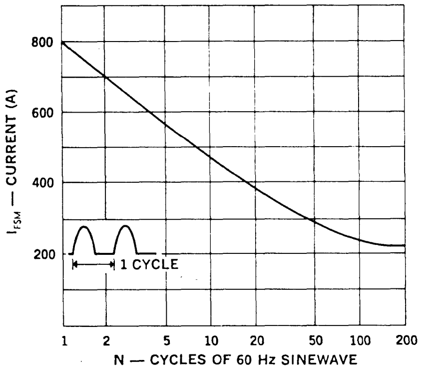




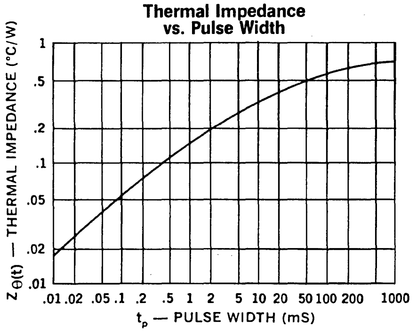
Forward Current vs. Forward Voltage



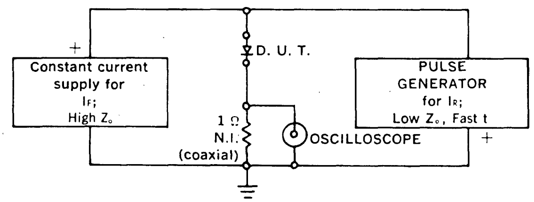
Typical Reverse Current vs. Reverse Voltage



Maximum Forward Surge vs. Number of Cycles



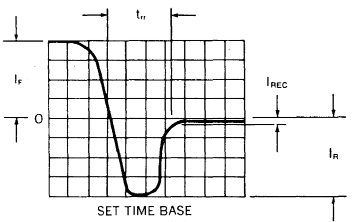
Thermal Impedance vs. Pulse Width



Reverse-Recovery Circuit

NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance = 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.



Characteristic Waveform

SET TIME BASE FOR 5 NS/CM

POWER SCHOTTKY RECTIFIERS 1N6391 JAN, JANTX, JANTXV
50A Pk, 45V

FEATURES

- Very Low Forward Voltage
- Low Recovered Charge
- Rugged Package Design (DO-4)
- High Efficiency for Low Voltage Supplies
- 45V Blocking @ Rated T_{jmax}
- 54V Repetitive Surge Voltage
- Qualified to MIL-S-19500/553

DESCRIPTION

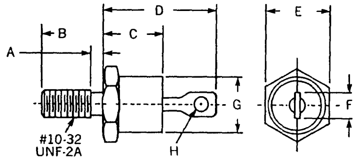
The 1N6391 has a Schottky barrier junction and is ideally suited for output rectifiers and catch diodes in low voltage power supplies. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

ABSOLUTE MAXIMUM RATINGS

Working Peak Reverse Voltage, V_{RWM}	45V
DC Blocking Voltage, V_R	45V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	54V
Average Rectified Forward Current, I_O @ T_C = 125°C	25A
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20kHz, 50% Duty Cycle), I_{FRM} @ T_C = 125°C	50A
Non-Repetitive Peak Surge Current (8.3ms), I_{FSM}	600A
Peak Reverse Transient Current, I_{RM}	2A
Operating and Storage Temperature Range	−55°C to +175°C
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.0°C/W

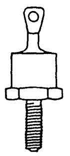
MECHANICAL SPECIFICATIONS

JAN, JANTX, JANTXV 1N6391



	INCHES	MILLIMETERS
A	.078 MAX.	1.98 MAX.
B	.437 ± .015	11.10 ± 0.38
C	.405 MAX.	10.29 MAX.
D	.800 MAX.	20.32 MAX.
E	.430 ± .010	10.92 ± 0.25
F	.250 MAX.	6.35 MAX.
G	.424 MAX.	10.77 MAX.
H	.066 MIN. DIA.	1.68 MIN. DIA.

DO-4



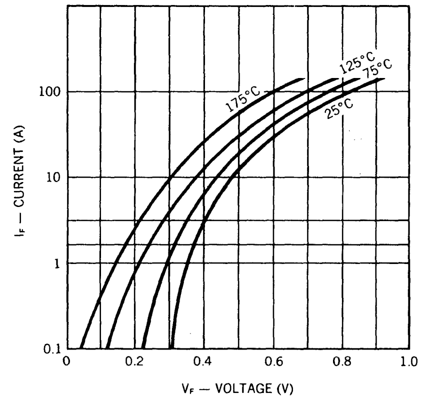
NOTES:

1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 10 inch pounds.
4. Angular orientation of terminal is undefined.

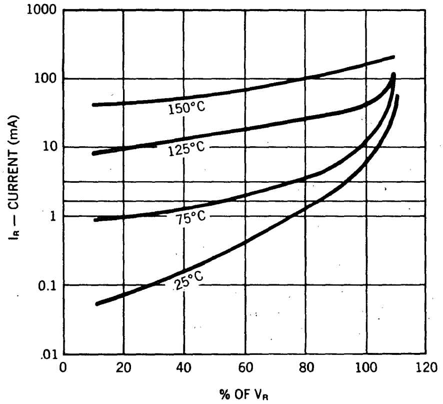
ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

Characteristic	Symbol	Limit	Units	Conditions
Maximum Instantaneous Reverse Current	i_R	15 40 400	mA mA mA	$T_C = 25°C, V_R = V_{RWM}$ $T_C = 125°C$ $T_C = 175°C$ Pulse Width = 400μs Duty Cycle = 1%
Maximum Instantaneous Forward Voltage	V_F	0.44 0.68	V V	$i_F = 5A, T_C = 25°C$ $i_F = 50A, T_C = 25°C$ Pulse Width = 300μs Duty Cycle = 1%
Capacitance	C_t	2000	pF	$V_R = 5.0V$

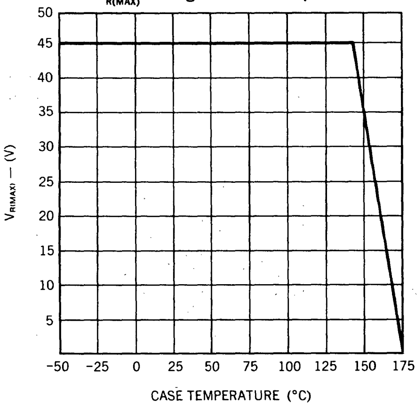
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Reverse Voltage



$V_{R(MAX)}$ Rating vs Case Temperature



POWER SCHOTTKY RECTIFIERS
120A Pk

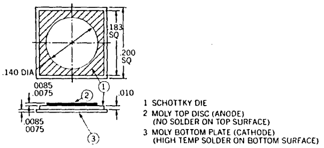
1N6392
JAN, JANTX, JANTXV

FEATURES
- Very Low Forward Voltage (0.6 at 60A, 125°C)
- Low Recovered Charge
- Rugged Package Design (DO-5)
- High Efficiency for Low Voltage Supplies
- Low Thermal Resistance (1.0°C/W)
- High Surge Current (800A)
- Low Reverse Current (60mA at rated V_R at 125°C)
- Qualified to MIL-S-19500/554

DESCRIPTION
The 1N6392 Schottky barrier power rectifier is ideally suited for output rectifiers and catch diodes in low voltage power supplies. The Unitrode high conductivity design, using a heavy copper top post and 4 point crimp, ensures cool thermal operation and low dynamic impedance. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

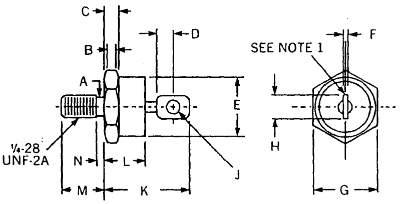
ABSOLUTE MAXIMUM RATINGS

Working Peak Reverse Voltage, V_{RWM}	45V
DC Blocking Voltage, V_R	45V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	54V
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20kHz, 50% Duty Cycle), I_{FRM}	120A (at T_C = 115°C)
Average Rectified Forward Current, $I_{F(AV)}$	60A (at T_C = 115°C)
Non-Repetitive Peak Surge Current (8.3ms), I_{FSM}	1,000A
Peak Reverse Transient Current, I_{RM}	2A
Operating and Storage Temperature Range	−55°C to +175°C
Thermal Resistance, Junction to Case, $R_{\theta JC}$	1.0°C/W



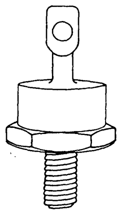
MECHANICAL SPECIFICATIONS

JAN, JANTX, JANTXV 1N6392



	INCHES	MILLIMETERS
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA. MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA.
K	1.000 MAX.	25.40 MAX.
L	.450 MAX.	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	.078 MAX.	1.98 MAX.

DO-5



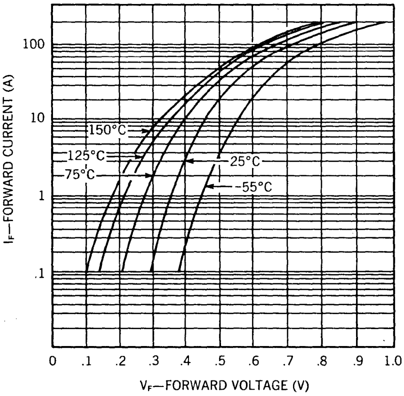
NOTES:
1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 30 inch pounds (35 kg. cm).
4. Angular orientation of terminal is undefined.

4/83

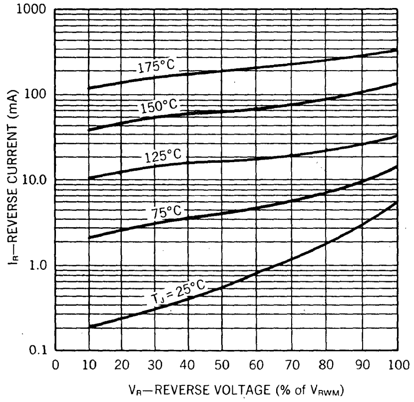
ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

Characteristic	Symbol	Limit	Units	Conditions
Maximum Instantaneous Reverse Current	i_R	20 60 600	mA mA mA	$V_R = V_{RWM}$ T_C = 125°C T_C = 175°C Pulse Width = 400μs Duty Cycle = 1%
Maximum Instantaneous Forward Voltage	V_F	0.47 0.68 0.82	V V V	i_F = 10A, T_C = 25°C i_F = 60A, T_C = 25°C i_F = 120A, T_C = 125°C Pulse Width = 300μs Duty Cycle = 1%
Maximum Capacitance	C_t	3000	pF	V_R = 5.0V

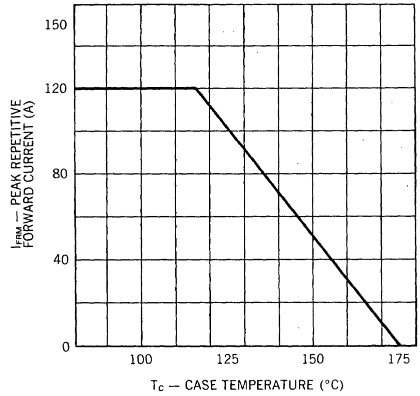
Typical Forward Current vs Forward Voltage



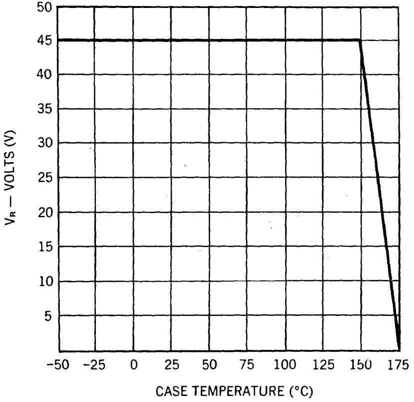
Typical Reverse Current vs Reverse Voltage



Maximum Current vs Case Temperature



$V_{R(MAX)}$ Rating vs Case Temperature



HERMETIC SCHOTTKY RECTIFIERS
4 Amp, 45 Volts

1N6492, JTX, JTXV

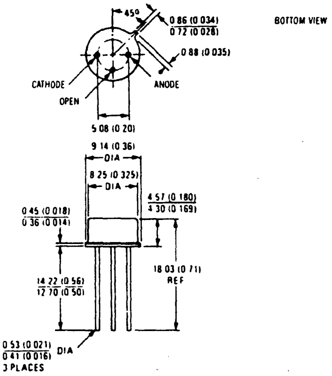
FEATURES
- Qualified to MIL-S-19500/567
- Extremely Low V_F and I_R
- High Surge Capability
- Low Recovered Charge
- Rugged Hermetic Package, No Pressure Contacts

DESCRIPTION
The 1N6492 hermetic Schottky rectifier is ideally suited for output rectifiers and catch diodes in high efficiency, low voltage, high reliability switching power supplies.

ABSOLUTE MAXIMUM RATINGS

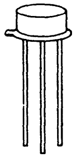
Peak Repetitive Reverse Voltage, V_{RRM}	45V
Working Peak Reverse Voltage, V_{RWM}	45V
DC Blocking Voltage, V_R	45V
Non-Repetitive Peak Reverse Voltage, V_{RSM}	54V
Average Forward Current (50% Duty Cycle), $I_{F(AV)}$, $T_A = 25°C$	1.2A
Average Forward Current (50% Duty Cycle), $I_{F(AV)}$ $T_{CASE} = 100°C$ $V_{RWM} = 45V$	4A
Non-Repetitive Peak Surge Current, I_{FSM} 8.3ms, Half Sine Wave	80A
Operating and Storage Junction Temperature Range	−65°C to +175°C
Thermal Resistance, Junction to Ambient, $R_{\theta J\text{-}A}$	175°C/W
Thermal Resistance, Junction to Case, $R_{\theta J\text{-}C}$	12°C/W

MECHANICAL SPECIFICATIONS



All Dimensions in Millimeters and Inches

TO-205AF (TO-39)



SEMICONDUCTOR PRODUCTS
UNITRODE

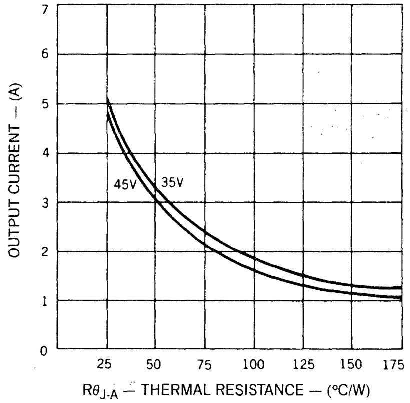
ELECTRICAL CHARACTERISTICS (at T_A = 25°C unless noted)

CHARACTERISTICS	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Reverse Leakage Current	I_{RM1}	2.0	mA	V_{RM} = 45V [1]
	I_{RM2}	20	mA	V_{RM} = 45V, T_A = 125°C
	I_{RM3}	200	mA	V_{RM} = 45V, T_A = 175°C
		20	mA	V_{RM} = 45V, T_A = −55°C
	I_{RM4}	2.0	A	V_{RSM} = 54V
Maximum Forward Voltage	V_{FM1}	0.92	V	I_{FM} = 8A (pk) [1, 2]
	V_{FM2}	0.68	V	I_{FM} = 4A (pk)
	V_{FM3}	0.56	V	I_{FM} = 2A (pk)
		0.63	V	I_{FM} = 2A (pk), T_A = −55°C
	V_{FM4}	0.48	V	I_{FM} = 1A (pk)
Capacitance	C_T	450	pf	V_R = 5V
Surge Current	I_{SURGE}			I_{FSM} = 80A (pk) V_{RM} = 45V (pk) I_O = 0.75A 10 surges of 8.3mSec at 1 minute intervals

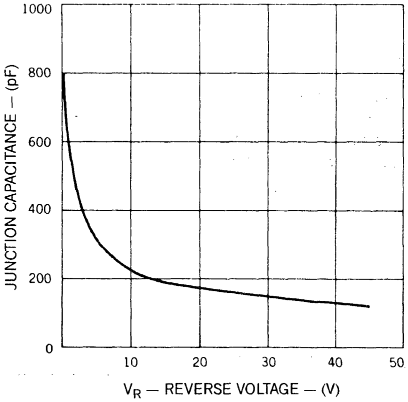
[1] Pulse width = 400μSec, duty cycle = 1%

[2] Measured with anode and cathode lead length of 0.2″ from case

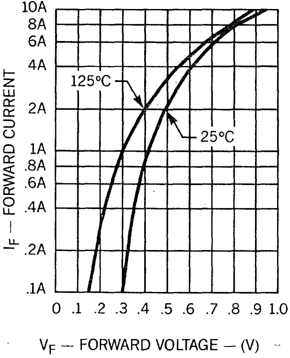
Output Current vs $R_{\theta J\text{-}A}$
$T_{ambient}$ = 25°C, 50% Duty Cycle



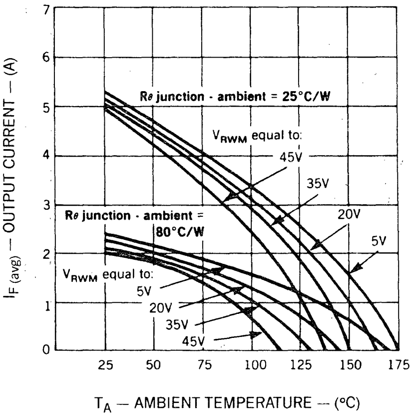
Typical Junction Capacitance vs Reverse Voltage



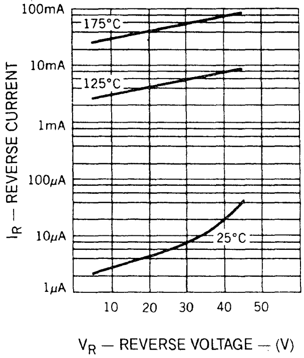
Typical Forward Current vs Forward Voltage



Output Current vs Ambient Temperature
50% Duty Cycle Application ($I_{F(avg)}$ and V_{RRM})



Typical Reverse Current vs Reverse Voltage



RECTIFIERS
HIGH RELIABILITY, HVPlus™ SERIES 2.0 AMPS

1N6620-1N6625

FEATURES

- Ultra Fast Recovery Time
- Controlled Avalanche
- High Temperature Operation with Low Loss
- Minimal Recovery Transients
- Low Capacitance
- Low Turn-On Voltage
- Non-Cavity Metallurgically Bonded Package

DESCRIPTION

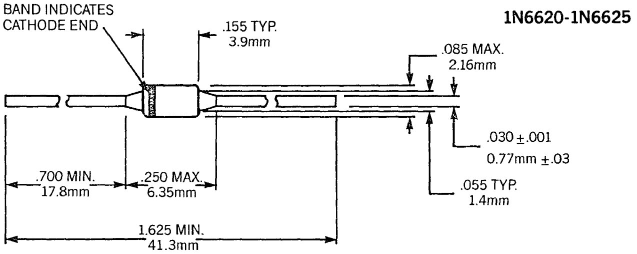
This state-of-the-art high efficiency rectifier is ideally suited for applications requiring high blocking voltage. It has the ability to switch significant current with minimal switching transients and losses. Leakage current at high junction temperatures has been minimized achieving exceptionally low reverse losses. An ultra stable process ensures high reliability and long life. This device is designed for a wide variety of applications including high frequency switching power supplies.

ABSOLUTE MAXIMUM RATINGS

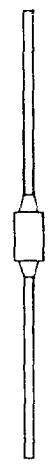
TYPE NUMBER	REVERSE VOLTAGE	AVERAGE DC OUTPUT CURRENT $T_L = 55°C$, $L = 3/8''$	AVERAGE DC OUTPUT CURRENT $T_A = 25°C$	PEAK FWD. SURGE CURRENT $t_p = 8.3ms$
1N6620	200V	2.0A	1.2A	20A
1N6621	400V	2.0A	1.2A	20A
1N6622	600V	2.0A	1.2A	20A
1N6623	800V	1.5A	1.0A	20A
1N6624	900V	1.5A	1.0A	20A
1N6625	1000V	1.5A	1.0A	15A

Operating and Storage Temperature Range −65°C +175°C.
Thermal Resistance, θ_{JL}. See Lead Temperature Derating Curve. (Figures 13, 14)

MECHANICAL SPECIFICATIONS



BODY A



Available in surface mount package; consult factory for information.

ELECTRICAL SPECIFICATIONS (AT 25°C UNLESS NOTED)

TYPE NUMBER	REVERSE BREAKDOWN VOLTAGE @50μA	FORWARD VOLTAGE	FORWARD VOLTAGE	REVERSE LEAKAGE T_A=25°C	REVERSE LEAKAGE T_A=150°C	REVERSE RECOVERY TIME 0.5A-1.0A-.25A*	JUNCTION CAPACITANCE @ −10V	I_{RM} (rec) 2A-100A/μs V_R=50V	V_{FRM} I_F=1A t_r=10ns
1N6620	220V	1.6V@2A	1.4V@1.2A	0.5μA	200μA	30ns	8pf	4A	6V
1N6621	440V	1.6V@2A	1.4V@1.2A	0.5μA	200μA	30ns	8pf	4A	6V
1N6622	660V	1.6V@2A	1.4V@1.2A	0.5μA	200μA	30ns	8pf	4A	6V
1N6623	880V	1.8V@1.5A	1.55V@1.0A	0.5μA	200μA	50ns	8pf	6A	15V
1N6624	990V	1.8V@1.5A	1.55V@1.0A	0.5μA	200μA	50ns	8pf	6A	15V
1N6625	1100V	1.95V@1.5A	1.75V@1.0A	1.0μA	300μA	60ns	8pf	6A	20V

* See Figure 20 for characteristic waveform.

OPTIONAL HIGH RELIABILITY SCREENING

The following tests are performed on 100% of the devices, per table II of MIL-S-19500

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature Life (Stabilization Bake)	1032	24 Hours @ T_A = 175°C
2. Thermal Shock (Temperature Cycling)	1051	C, 20 Cycles @ T_A = (−65 to +175°C)
3. Hermetic Seal a. Gross	1071	E - Dye Penetrant
4. High Temperature Reverse Bias	1038	A, 48 Hours @ T_A = 150°C, V_R = 80%
5. Interim Electrical Parameters	—	V_F and I_R @ 25°C
6. Power Burn-In	1038	B, 96 Hours @ T_A = 25°C I_O = Maximum T_A Rated, V_R @ Rated
7. Final Electrical and Delta Parameters	GO/NO GO	ΔI_R ±100% or 250NA (whichever is greater) ΔV_F ± 2%, using approved JTX celling method

When ordering screening, specify T2 as suffix (i.e., 6620T2).

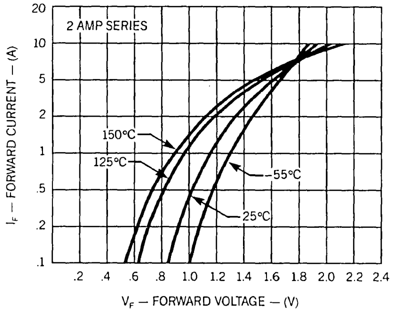

Typical Forward Current vs Forward Voltage

Figure 1

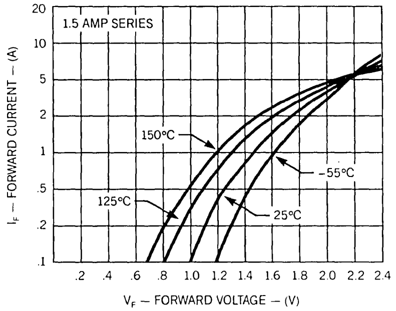

Typical Forward Current vs Forward Voltage

Figure 2

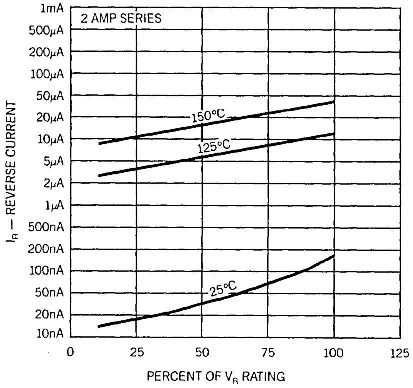

Typical Reverse Current vs Applied Reverse Voltage

Figure 3

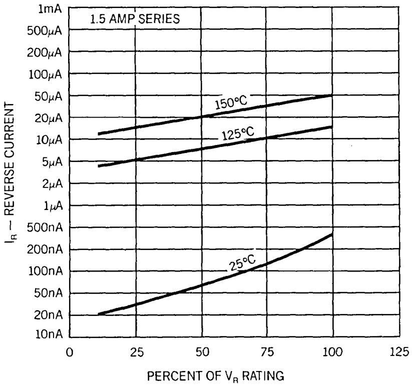

Typical Reverse Current vs Applied Reverse Voltage

Figure 4

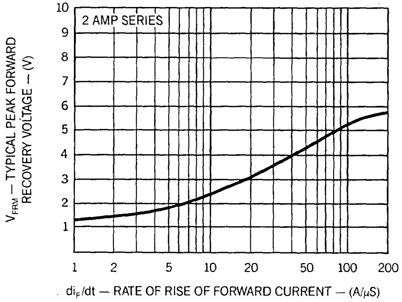

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

Figure 5

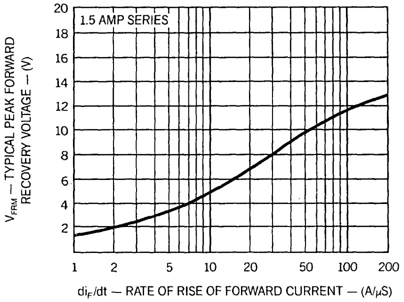
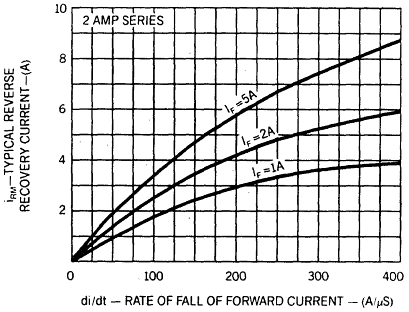

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

Figure 6

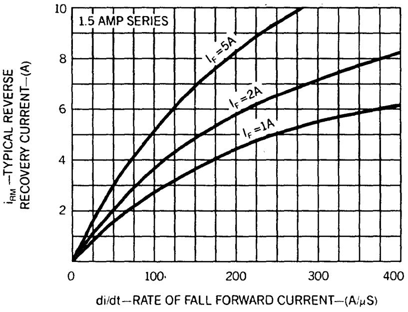
Reverse Recovery Current vs di/dt



NOTE: See Figures 11 and 12.

Figure 7

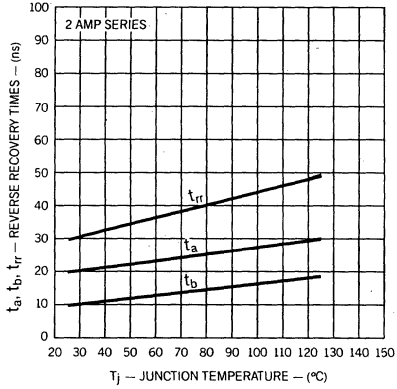
Reverse Recovery Current vs di/dt



NOTE: See Figures 11 and 12.

Figure 8

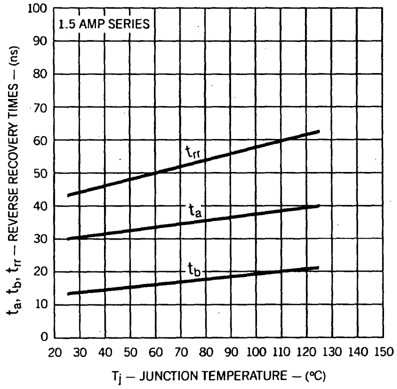
Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/μs, V_R = 50V)



NOTE: See Figures 11 and 12.

Figure 9

Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/μs, V_R = 50V)



NOTE: See Figures 11 and 12.

Figure 10

Rectifier Current During Reverse Recovery

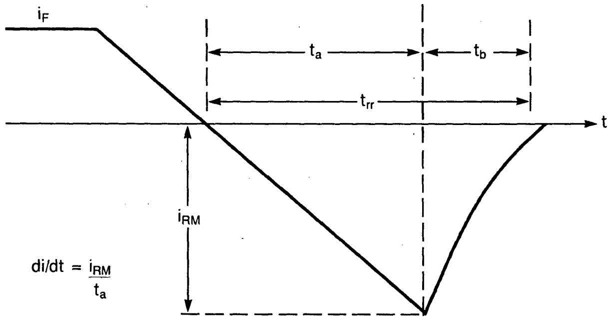
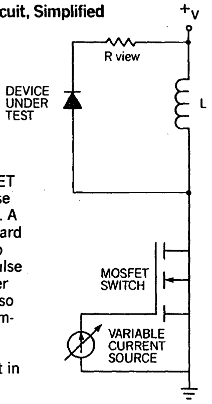


Figure 11

t_{rr}/I_{RM} Measurement Circuit, Simplified



NOTE: The gate of the MOSFET is double pulsed. The first pulse ramps up the inductor current. A short interpulse period forward biases the device under test to the desired I_F. The second pulse reverse biases the device under test creating the desired di/dt so that the reverse recovery parameters can be measured. The pulse pair is repeated at a low duty factor and does not result in device heating.

Figure 12

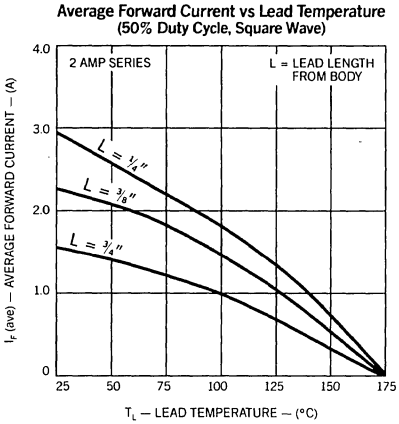

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

Figure 13

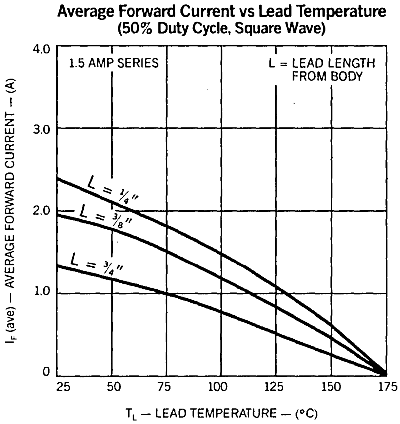

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

Figure 14

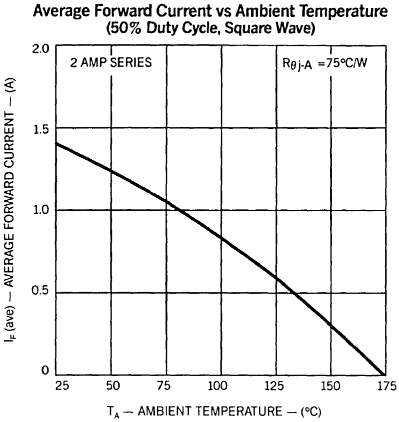

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

Figure 15

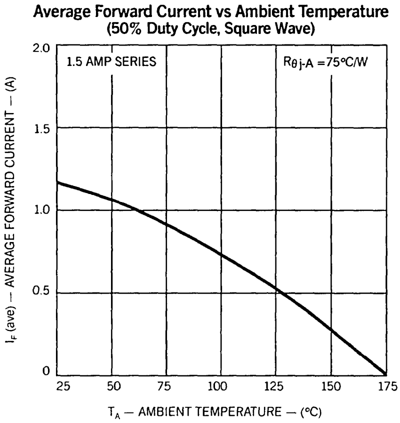

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

Figure 16

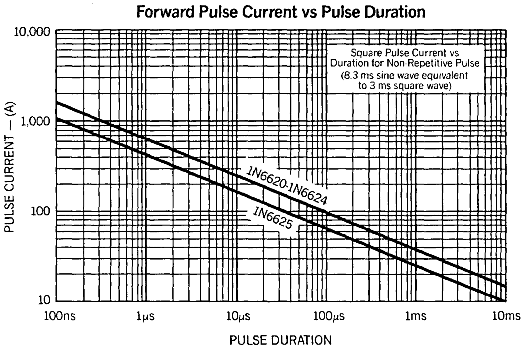

Forward Pulse Current vs Pulse Duration

Figure 17

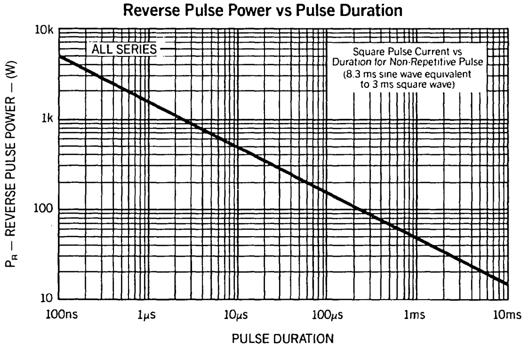

Reverse Pulse Power vs Pulse Duration

Figure 18

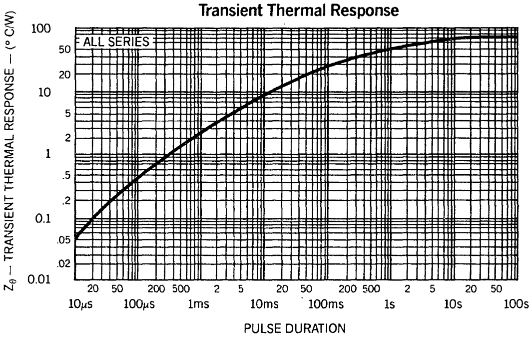


Figure 19

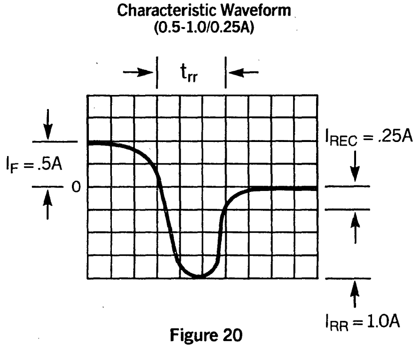


Figure 20

RECTIFIERS
HIGH RELIABILITY, HVPlus™ SERIES
4.0 AMPS

FEATURES
- Ultra Fast Recovery Time
- Controlled Avalanche
- High Temperature Operation with Low Loss
- Minimal Recovery Transients
- Low Capacitance
- Low Turn-On Voltage
- Non-Cavity Metallurgically Bonded Package

DESCRIPTION
This state-of-the-art high efficiency rectifier is ideally suited for applications requiring high blocking voltage. It has the ability to switch significant current with minimal switching transients and losses. Leakage current at high junction temperatures has been minimized achieving exceptionally low reverse losses. An ultra stable process ensures high reliability and long life. This device is designed for a wide variety of applications including high frequency switching power supplies.

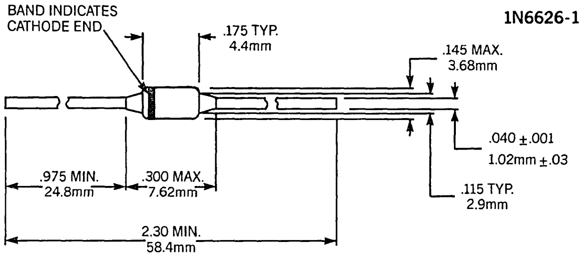
ABSOLUTE MAXIMUM RATINGS

TYPE NUMBER	REVERSE VOLTAGE	AVERAGE DC OUTPUT CURRENT $T_L=75°C$, L=3/8″	AVERAGE DC OUTPUT CURRENT $T_A=25°C$	PEAK FWD. SURGE CURRENT $t_p=8.3ms$
1N6626	200V	4.0A	2.0A	75A
1N6627	400V	4.0A	2.0A	75A
1N6628	600V	4.0A	2.0A	75A
1N6629	800V	3.0A	1.4A	75A
1N6630	900V	3.0A	1.4A	75A
1N6631	1000V	2.5A	1.4A	60A

Operating and Storage Temperature Range −65°C +175°C.
Thermal Resistance, θ_{JL}. See Lead Temperature Derating Curve. (Figures 13, 14)

MECHANICAL SPECIFICATIONS

1N6626-1N6631



BODY B

Available in surface mount package; consult factory for information.

SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (AT 25°C UNLESS NOTED)

TYPE NUMBER	REVERSE BREAKDOWN VOLTAGE @50μA	FORWARD VOLTAGE	FORWARD VOLTAGE	REVERSE LEAKAGE T_A=25°C	REVERSE LEAKAGE T_A=150°C	REVERSE RECOVERY TIME 0.5A-1.0A-.25A*	JUNCTION CAPACITANCE @ −10V	$I_{RM\,(rec)}$ 2A-100A/μs V_R=50V	V_{FRM} I_F=1A t_r=10ns
1N6626	220V	1.5V@4.0A	1.35V@2.0A	2.0μA	500μA	30ns	30pf	5A	4V
1N6627	440V	1.5V@4.0A	1.35V@2.0A	2.0μA	500μA	30ns	30pf	5A	4V
1N6628	660V	1.5V@4.0A	1.35V@2.0A	2.0μA	500μA	30ns	30pf	5A	4V
1N6629	880V	1.7V@3.0A	1.4V@1.4A	2.0μA	500μA	50ns	30pf	6A	8V
1N6630	990V	1.7V@3.0A	1.4V@1.4A	2.0μA	500μA	50ns	30pf	6A	8V
1N6631	1100V	1.95V@2.5A	1.60V@1.4A	4.0μA	1000μA	60ns	30pf	6A	10V

* See Figure 20 for characteristic waveform.

OPTIONAL HIGH RELIABILITY SCREENING

The following tests are performed on 100% of the devices, per table II of MIL-S-19500

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature Life (Stabilization Bake)	1032	24 Hours @ T_A = 175°C
2. Thermal Shock (Temperature Cycling)	1051	C, 20 Cycles @ T_A = (−65 to +175°C)
3. Hermetic Seal a. Gross	1071	E - Dye Penetrant
4. High Temperature Reverse Bias	1038	A, 48 Hours @ T_A = 150°C, V_R = 80%
5. Interim Electrical Parameters	—	V_F and I_R @ 25°C
6. Power Burn-In	1038	B, 96 Hours @ T_A = 25°C I_O = Maximum T_A Rated, V_R @ Rated
7. Final Electrical and Delta Parameters	GO/NO GO	ΔI_R ±100% or 250NA (whichever is greater) ΔV_F ± 2%, using approved JTX celling method

When ordering screening, specify T2 as suffix (i.e., 6620T2).

Typical Forward Current vs Forward Voltage

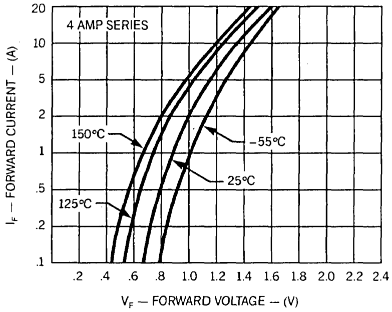


Figure 1

Typical Forward Current vs Forward Voltage

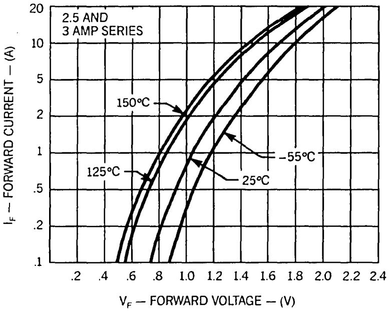


Figure 2

Typical Reverse Current vs Applied Reverse Voltage

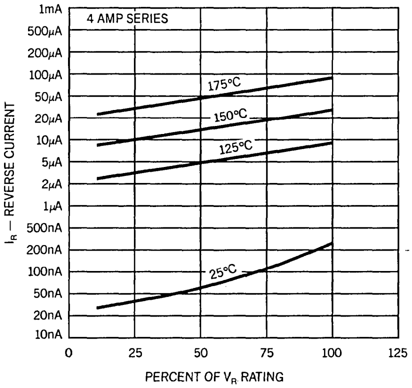


Figure 3

Typical Reverse Current vs Applied Reverse Voltage

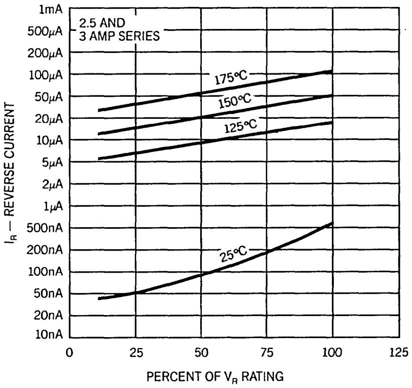


Figure 4

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

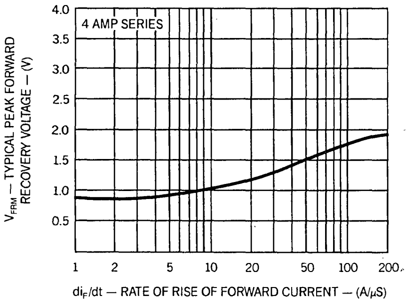


Figure 5

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

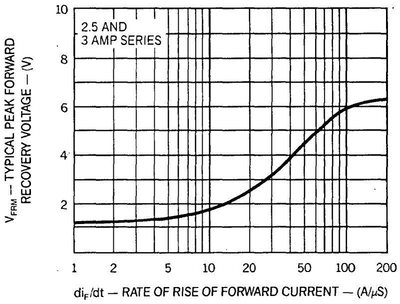
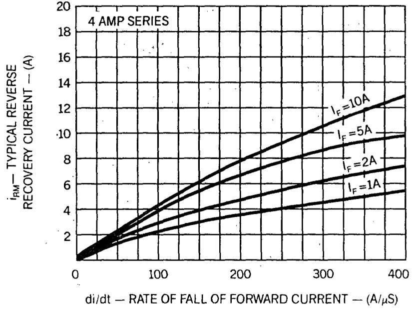


Figure 6

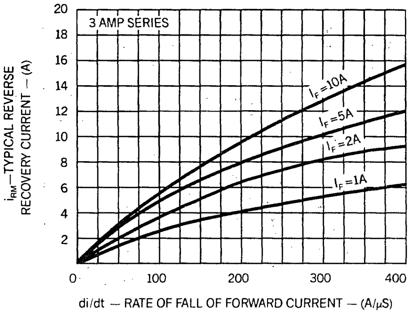
Reverse Recovery Current vs di/dt



NOTE: See Figures 11 and 12.

Figure 7

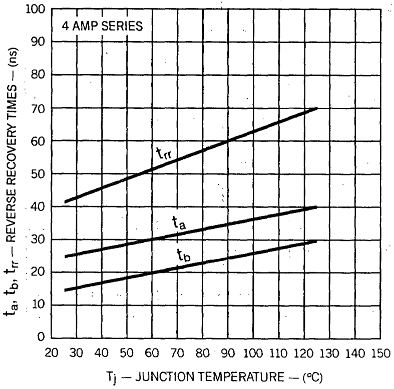
Reverse Recovery Current vs di/dt



NOTE: See Figures 11 and 12.

Figure 8

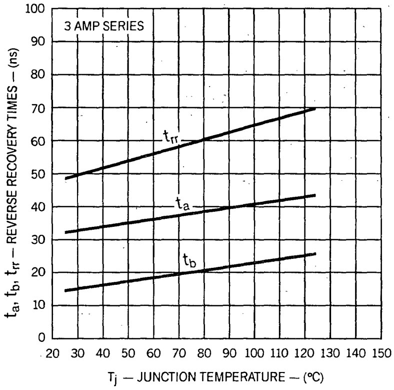
Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/µs, V_R = 50V)



NOTE: See Figures 11 and 12.

Figure 9

Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/µs, V_R = 50V)



NOTE: See Figures 11 and 12.

Figure 10

Rectifier Current During Reverse Recovery

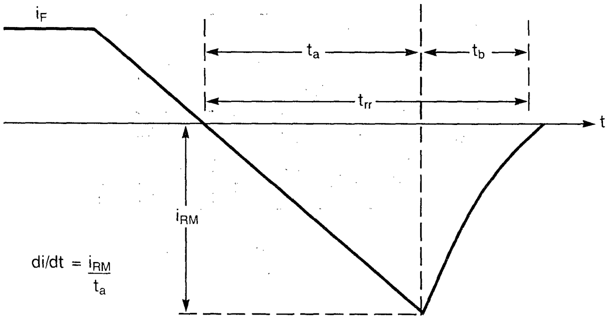
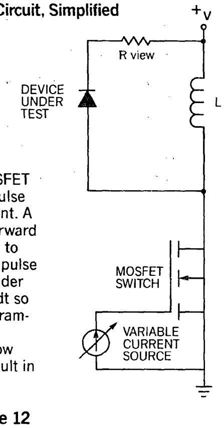


Figure 11

t_{rr}/I_{RM} Measurement Circuit, Simplified



NOTE: The gate of the MOSFET is double pulsed. The first pulse ramps up the inductor current. A short interpulse period forward biases the device under test to the desired I_F. The second pulse reverse biases the device under test creating the desired di/dt so that the reverse recovery parameters can be measured. The pulse pair is repeated at a low duty factor and does not result in device heating.

Figure 12

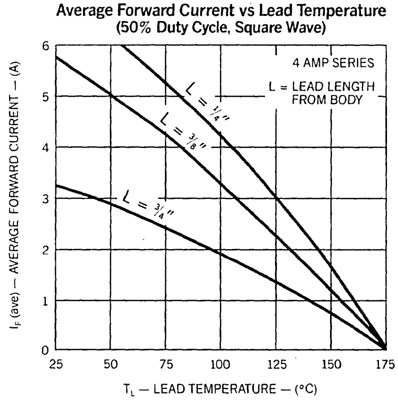

Average Forward Current vs Lead Temperature (50% Duty Cycle, Square Wave)

Figure 13

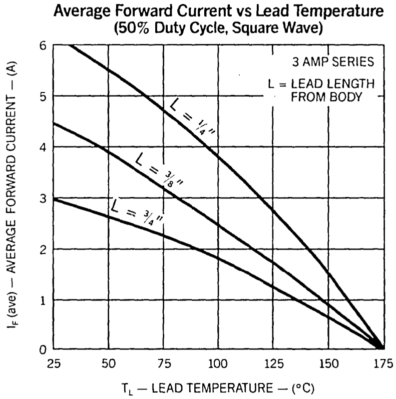

Average Forward Current vs Lead Temperature (50% Duty Cycle, Square Wave)

Figure 14

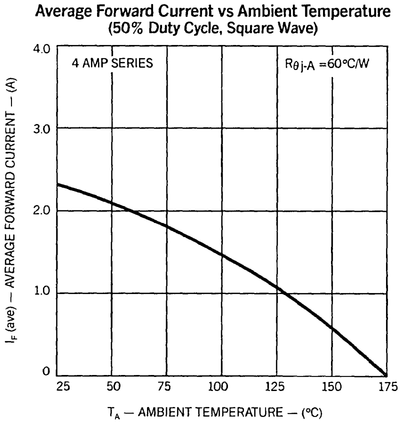

Average Forward Current vs Ambient Temperature (50% Duty Cycle, Square Wave)

Figure 15

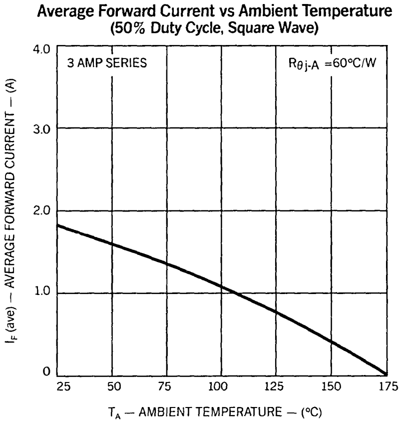

Average Forward Current vs Ambient Temperature (50% Duty Cycle, Square Wave)

Figure 16

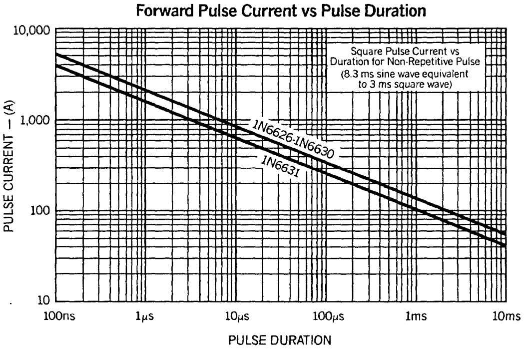

Forward Pulse Current vs Pulse Duration

Figure 17

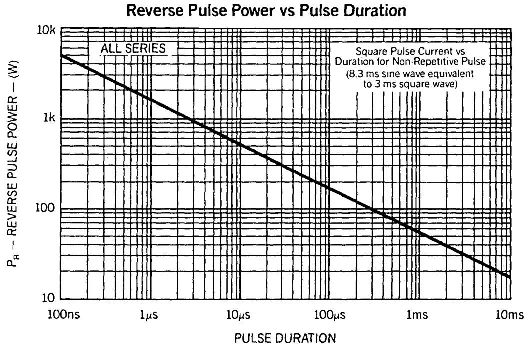

Reverse Pulse Power vs Pulse Duration

Figure 18

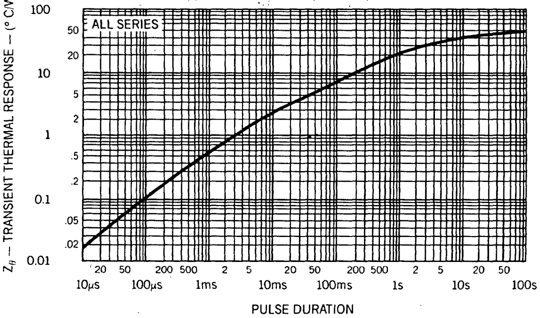

Transient Thermal Response

Figure 19

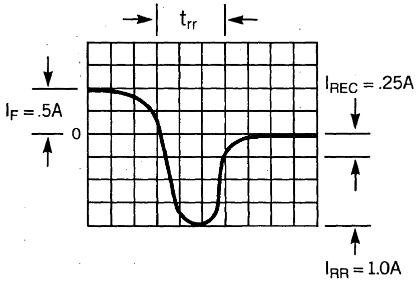

Characteristic Waveform
(0.5-1.0/0.25A)

Figure 20

POWER SCHOTTKY RECTIFIERS

SD51

120 Amp Pk, 45V

FEATURES

- Very Low Forward Voltage
- Low Recovered Charge
- Rugged Package Design (DO-5)
- High Efficiency for Low Voltage Supplies
- Available with Flexible Top Lead

DESCRIPTION

The SD51 has a Schottky barrier junction and is ideally suited for output rectifiers and catch diodes in low voltage power supplies. The Unitrode high conductivity design, using a heavy copper top post and a 4 point crimp, ensures cool terminal operation and low dynamic impedance. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

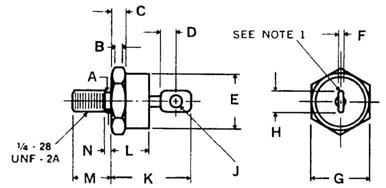
ABSOLUTE MAXIMUM RATINGS ($T_{CASE} = 25°C$)

Peak Repetitive Reverse Voltage, V_{RRM}	45V*
Working Peak Reverse Voltage, V_{RWM}	35V*
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 KHz, 50 percent Duty Cycle), I_{FRM}	120A
Non-repetitive Peak Surge Current (8.3 mS), I_{FSM}	800A
Peak Reverse Transient Current, I_{RM}	2A
Storage Temperature Range, T_{stg}	−55°C to +165°C
Junction Operating Temperature Range, T_j	−55°C to +150°C
Thermal Resistance, Junction-to-Case, $R_{\Theta JC}$	1.0°C/W

*See curve of V_{RRM} Rating vs Case Temperature

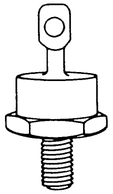
MECHANICAL SPECIFICATIONS

SD51



	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA. MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA.
K	1.000 MAX.	25.40 MAX.
L	.450 MAX.	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	.078 MAX.	1.98 MAX.

DO-5



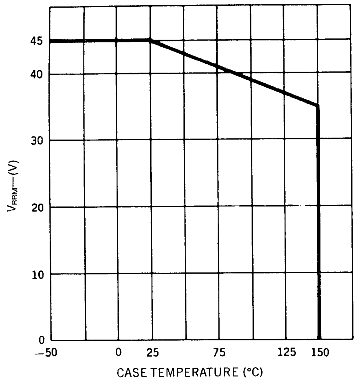
Notes:

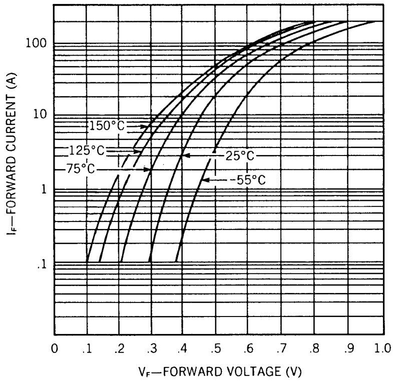
1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 30 inch pounds (35 kg. cm).
4. Angular orientation of terminal is undefined.

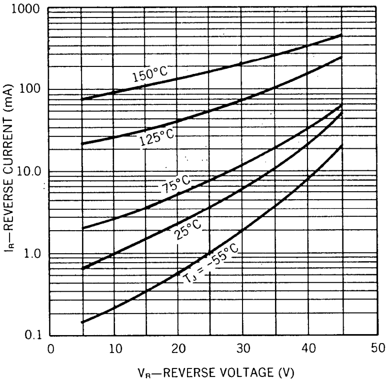
SEMICONDUCTOR
PRODUCTS
UNITRODE

ELECTRICAL CHARACTERISTICS ($T_{CASE} = 25°C$)

Characteristic	Symbol	Limit	Units	Conditions
Maximum Instantaneous Reverse Current	i_R	50 200	mA mA	$T_C = 25°C$, $V_R = 35V$ $T_C = 125°C$ Pulse Width = 400μS Duty Cycle = 1 percent
Maximum Instantaneous Forward Voltage	v_F	0.60	V	$i_F = 60A$ $T_c = 125°C$ Pulse Width = 300μS Duty Cycle = 1 percent
Flexible Top Lead Option	v_F	0.65	V	
Maximum Capacitance	C_t	4000	pF	$V_R = 5.0V$
Maximum Voltage Rate of Change	dv/dt	700	V/μS	$v_R = 35V$


V_{RRM} Rating vs Case Temperature


Typical Forward Current vs Forward Voltage


Typical Reverse Current vs Reverse Voltage

DUAL POWER SCHOTTKY RECTIFIERS

SD241
SD241HR2

30 Amp Pk per diode, 45V

FEATURES

- Very Low Forward Voltage
- Low Recovered Charge
- Rugged Packaged Design (TO-3)
- High Efficiency for Low Voltage Supplies
- Dual Schottky Rectifiers in a Single Package

DESCRIPTION

The SD241 has two Schottky barrier junctions arranged in a common cathode configuration and is ideally suited for output rectifiers and catch diodes in low voltage supplies.

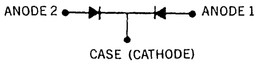
ABSOLUTE MAXIMUM RATINGS (T_{CASE} = 25°C) Per Diode

Peak Repetitive Reverse Voltage, V_{RRM} 45V*
Working Peak Reverse Voltage, V_{RWM} 35V
Average Rectified Forward Current, I_O 30A
Non-repetitive Peak
Surge current (8.3 mS), I_{FSM} 400A
Peak Reverse Transient Current, I_{RM} 2A
Storage Temperature Range, T_{stg} .... −55°C to +175°C
Junction Operating Temperature Range, T_j .... −55°C to +150°C
Package Thermal Resistance, Junction to Case, $R_{\theta JC}$ .... 1.4°C/W

* See curve of V_{RRM} Rating vs Case Temperature.

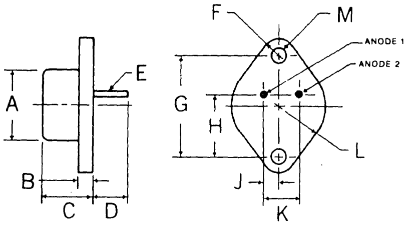
MECHANICAL SPECIFICATIONS

NOTE:
Leads may be soldered to within 1/16" of base provided temperature-time exposure is less than 260°C for 10 seconds.

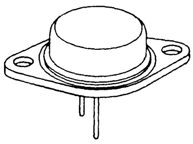


SD241
SD241HR2

	ins.	mm.
A	.875 MAX.	22.23 MAX.
B	.135 MAX.	3.43 MAX.
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.038-.043 DIA.	0.97-1.09 DIA.
F	.188 MAX. RAD.	4.78 MAX. RAD.
G	1.177-1.197	29.90-30.40
H	.655-.675	16.64-17.15
J	.205-.225	5.21-5.72
K	.420-.440	10.67-11.18
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.151-.161 DIA.	3.84-4.09 DIA.



TO-204AA (TO-3)



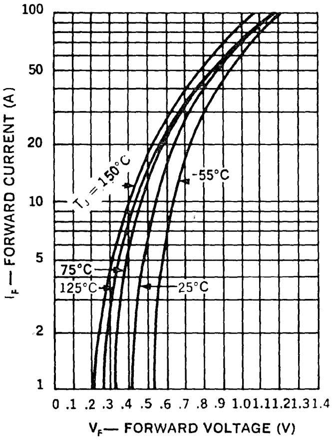
Notes: All metal surfaces tin plated.

SEMICONDUCTOR PRODUCTS
UNITRODE

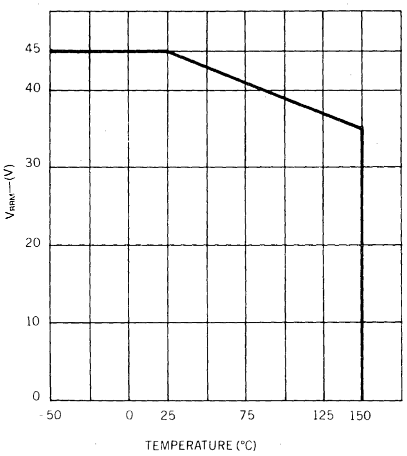
ELECTRICAL CHARACTERISTICS ($T_{CASE} = 25°C$) Per Diode

Characteristic	Symbol	Limit	Units	Conditions
Maximum Instantaneous Reverse Current	i_R [1]	25 100	mA mA	$T_C = 25°C$, $V_R = 35V$ $T_C = 125°C$ Pulse Width = 400μS Duty Cycle = 1 percent
Maximum Instantaneous Forward Voltage	v_F	.47	V	$i_F = 10A$ Pulse Width = 300μS Duty Cycle = 1 percent $T_c = 125°C$
		.60	V	$i_F = 20A$ Pulse Width = 300μS Duty Cycle = 1 percent $T_c = 125°C$
Maximum Capacitance	C_t	2000	pF	$V_R = 5.0V$
Maximum Voltage Rate of Change	dv/dt	1000	v/μS	$V_R = 35V$

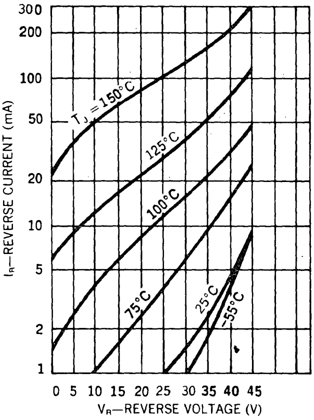
Typical Forward Current vs Forward Voltage



V_{RRM} Rating vs Case Temperature



Typical Reverse Current vs Reverse Voltage



OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified SD241HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ $T_A = 150°C$
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ≥ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, $T_C = 125°C$, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	$V_F + I_R$ @ 25°C PDA = 10% (Final Electricals)

BISYN SYNCHRONOUS RECTIFIER

UBS421

For Low-Voltage (< 5.0V) Loads

FEATURES

- Very Low On Resistance, Typically 14mΩ
- High Reverse Blocking V_{ECS} = 40V
- Can be PWM Controlled to Provide Regulated Voltage to Load
- Low Temperature Coefficient of On Resistance
- Fast Switching Times Permit Ease of Operation at High Frequency
- High Gain Reduces Base Losses
- Load Regulation is Programmable

DESCRIPTION

The BISYN is a bipolar junction transistor specifically designed to perform the rectifying function in the secondary of a switching power supply. Unlike a conventional bipolar, the BISYN has a much higher emitter-base breakdown voltage (typically 50V) which is needed for full-wave rectifier circuits. Base drive losses are kept at a minimum by the relatively high current gain of the BISYN.

The BISYN's most significant specification feature is its very low forward voltage, 0.3V @ 20A compared with 0.6V for a typical Schottky.

With a 3V load the power loss associated with the Schottky contributes to a 20% reduction in efficiency, while with a synchronous rectifier this loss is reduced to 10% or less.

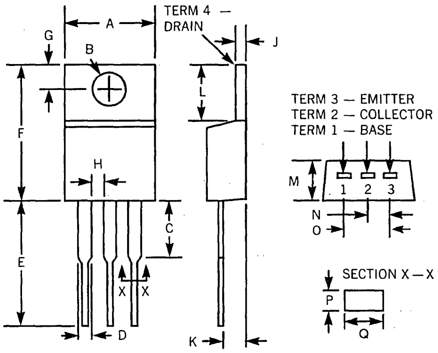
ABSOLUTE MAXIMUM RATINGS

Continuous Forward Current, I_F	20A
Peak Forward Emitter Current*, I_{ERM}	60A
Inductive Forward Current Clamped, I_{FLM}	35A**
Continuous Base Current*, I_B	6A
Peak Base Current, I_{BRM}	30A
Forward Blocking Voltage, V_{CES}	50V
Reverse Blocking Voltage, V_{ECS}	40V
Thermal Resistance, $R_{\theta JC}$	1.75°C/W
Power Dissipation, P_{Diss}	70W @ 25°C
Derating Factor	0.57W/°C
Operating Temperature Range, T_J	−55°C to +150°C

Notes: *1mS pulse.
**See Figure 1.

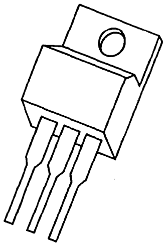
MECHANICAL SPECIFICATIONS

UBS421



	INCHES	MILLIMETERS
A	0.420-0.380	10.66-9.66
B	0.161-0.139 DIA.	4.08-3.54 DIA.
C	0.250 MAX.	6.35 MAX.
D	0.070-0.045	1.77-1.15
E	0.580-0.500	14.73-12.70
F	0.650-0.560	16.51-14.23
G	0.135-0.100	3.42-2.54
H	0.045 MIN.	1.15 MIN.
J	0.055-0.020	1.39-0.51
K	0.115-0.080	2.92-2.04
L	0.270-0.230	6.85-5.85
M	0.190-0.140	4.82-3.56
N	0.110-0.090	2.79-2.29
O	0.210-0.190	5.33-4.83
P	0.045-0.012	1.14-0.31
Q	0.045-0.020	1.14-0.51

TO-220AB

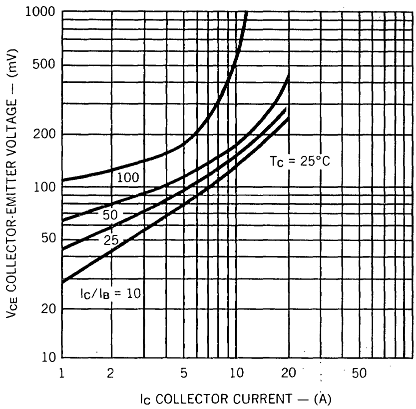


SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL CHARACTERISTICS (at 25°C unless noted)

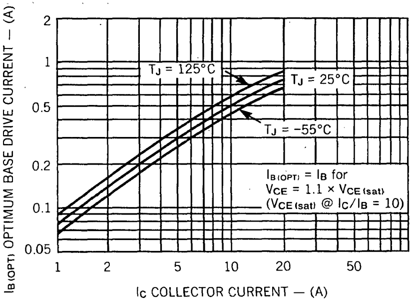
TEST	SYMBOL	MIN.	TYP.	MAX.	UNITS	CONDITIONS
On Resistance	$R_{CE(ON)}$		14 20	17 24	mΩ mΩ	$I_C = 15A, I_B = 0.6A,$ $I_C = 15A, I_B = 0.6A, T = 125°C$
Current Gain	h_{FE}	80	100			$I_C = 10A, V_{CE} = 0.5V$
Base Saturation Voltage	$V_{BE(sat)}$		0.95	1.1	V	$I_C = 15A, I_{B1} = 0.6A,$ $I_{B2} = 0.6A$
Rise Time	t_r		95	150	nS	$I_C = 15A, I_{B1} = 1.5A,$ $V_{CC} = 10V, I_{B2} = 1.5A$
Storage Time	t_s		200	250	nS	$I_C = 15A, I_{B1} = 1.5A,$ $V_{CC} = 10V, I_{B2} = 1.5A$
Fall Time	t_f		50	100	nS	$I_C = 15A, I_B = 1.5A,$ $V_{CC} = 10V, I_{B2} = 1.5A$
Forward Leakage Current	I_{CES}			100 1	μA mA	$V_{CE} = 50V$ $V_{CE} = 50V, T = 125°C$
Reverse Leakage Current	I_{ECS}			200 1	μA mA	$V_{EC} = 40V$ $V_{CE} = 40V, T = 125°C$
Collector Capacitance	C_{OBO}		650	1000	pF	$V_{CE} = 10V, f = 1MHz$

Collector-Emitter Voltage vs Collector Current at Various Forced Gains



CURVE # 1

Optimum Base Drive Current vs Collector Current



CURVE # 2

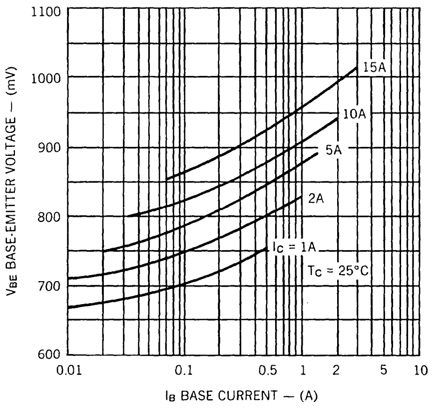
DESIGNING FOR MINIMUM POWER DISSIPATION

Although used as a rectifier the BISYN is a three terminal device. Therefore, the power dissipation due to the On Resistance and also the dissipation due to the base current must be taken into consideration. You will notice on Curve 1 that the change in On Voltage (V_{CE}) at a particular collector current is small even with large changes in base current. As a result, achieving the lowest On Voltage for a particular load current does not result in the lowest overall power loss.

It has been determined that operating at a base current that achieves an On Voltage that is 110% of the On Voltage at a circuit gain of ten gives a result that is very close to optimum power dissipation. Curve 2 gives you the appropriate base current to achieve 110% of this On Voltage. This same curve shows that the appropriate base drive for optimum power dissipation at any particular load current is virtually the same throughout the operating temperature range.

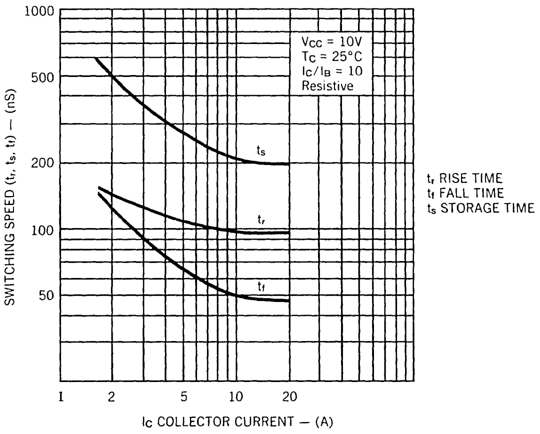
To calculate the power dissipation first estimate the operating temperature of the BISYN. Then using the appropriate temperature curve determine the On Voltage at a circuit gain of 10 for your load. Multiply this voltage by 1.1 and then by the load current to determine On Resistance power dissipation. Base current power dissipation is calculated by finding the base drive current on Curve 2 and then going to the applicable temperature curve for Base Emitter Voltage vs Base Current, Curve 3. Multiplying the Base Emitter Voltage by Base Current will give you the power dissipation due to base current.

Base Emitter Voltage vs Base Current at Various Collector Currents



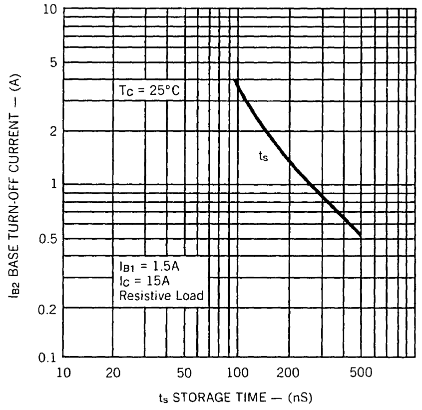
CURVE # 3

Switching Speed (t_r, t_s, t_f) vs Collector Current



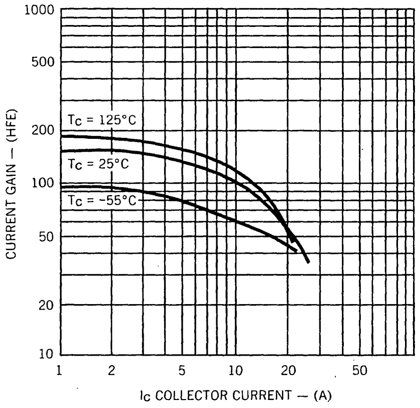
CURVE # 4

Storage Time vs Base Turn-Off Current

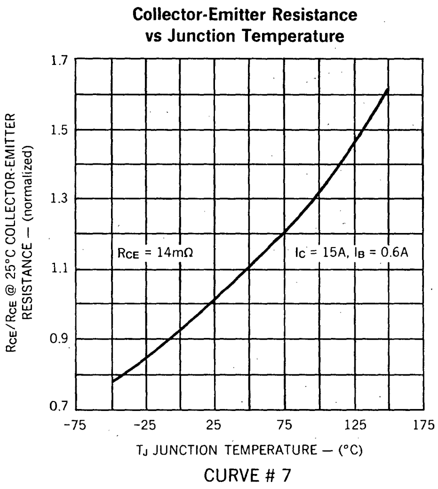


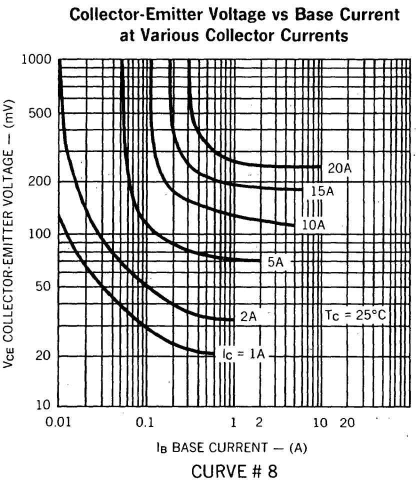
CURVE # 5

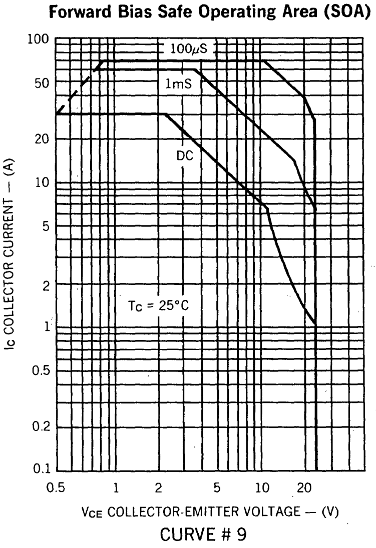
Gain vs Collector Current @ V_{CE} = 0.5V

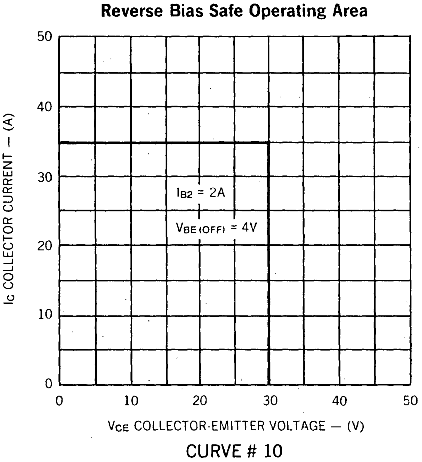


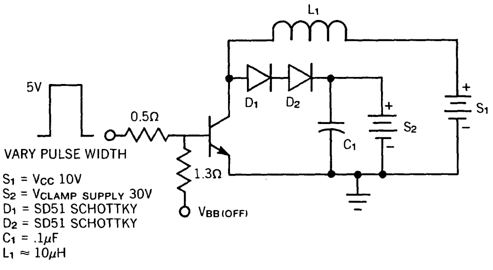
CURVE # 6







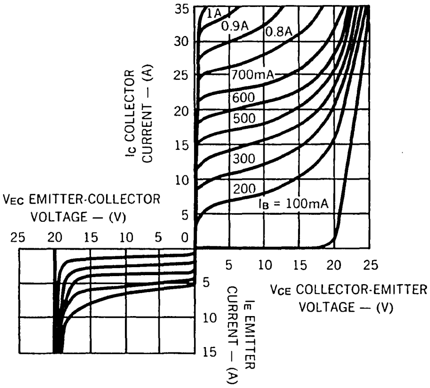




S_1 = V_{CC} 10V
S_2 = $V_{CLAMP\ SUPPLY}$ 30V
D_1 = SD51 SCHOTTKY
D_2 = SD51 SCHOTTKY
C_1 = .1μF
L_1 ≈ 10μH

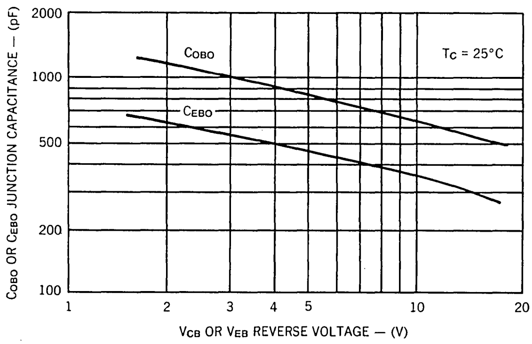
Figure 1. — Test Circuit for I_{LPK}.

Common-Emitter Collector Characteristics



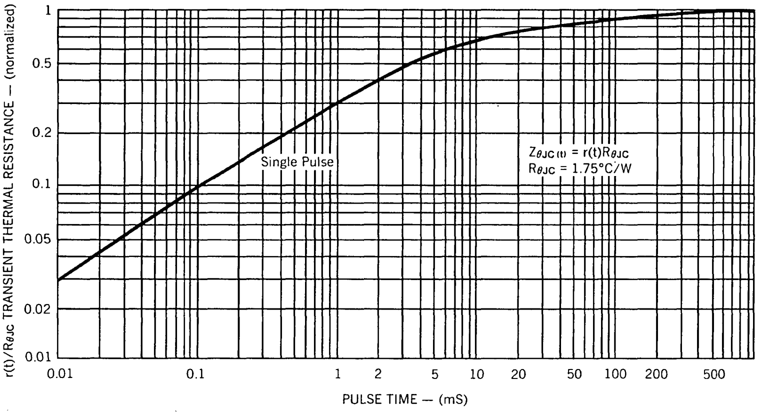
CURVE # 11

Junction Capacitance vs Reverse Bias Voltage



CURVE # 12

Transient Thermal Resistance (normalized) vs Time



CURVE # 13

BISYN™ SYNCHRONOUS RECTIFIER

UBS430

For Low-Voltage (<5.0V) Loads

FEATURES

- Very Low On Resistance — Typically 7 milliohms
- High Reverse Blocking Voltage — V_{ECS} = 40V
- Can be PWM Controlled to Provide Regulated Voltage to Load
- Low Temperature Coefficient of On Resistance
- Fast Switching Times Make Operation at High Frequency Easy
- High Gain Reduces Base Losses

DESCRIPTION

The BISYN is a bipolar junction transistor that is specifically designed to perform the rectifying function in the secondary of a switching power supply. Unlike a conventional bipolar, the BISYN has a much higher emitter-base breakdown voltage (typically 50V) which is needed for full-wave rectifier circuits. Base drive losses are kept at a minimum by the relatively high current gain of the BISYN.

The BISYN's most significant specification feature is its very low V_F, 0.3V at 30A, compared with 0.6V for a Schottky and only 0.1V at 10A. Its most significant functional feature is its programmability.

The very low V_F of this product reduces the rectifier power loss in a power supply secondary, improving its efficiency. This becomes particularly significant as load voltages drop below 5V. For example, with a 3V load the power loss associated with the Schottky contributes to a 20% reduction in efficiency, while with a synchronous rectifier this loss is reduced to 10% or less.

The programmability feature gives the designer a new way to provide regulation to a load. Its main advantage is the reduced power component count as compared with a buck regulator and the resulting improvement in efficiency.

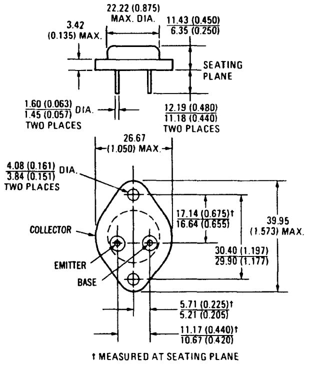
ABSOLUTE MAXIMUM RATINGS

Continuous Forward Current	I_F	40A
Peak Forward Emitter Current*	I_{ERM}	150A
Inductive Forward Current Clamped	I_{FLM}	80A**
Continuous Base Current*	I_B	8A
Peak Base Current*	I_{BRM}	50A
Forward Blocking Voltage	V_{CES}	50V
Reverse Blocking Voltage	V_{ECS}	40V
Thermal Resistance	R_θ	1.0°C/W
Power Dissipation		150W @ 25°C
Derating Factor		1.0W/°C
Operating Temperature Range		−65°C to +175°C

Notes: *1msec pulse.
**See Figure 1.

MECHANICAL SPECIFICATIONS

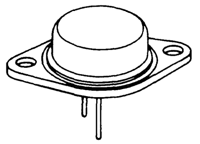
UBS430



† MEASURED AT SEATING PLANE

Dimensions in Millimeters and (Inches)

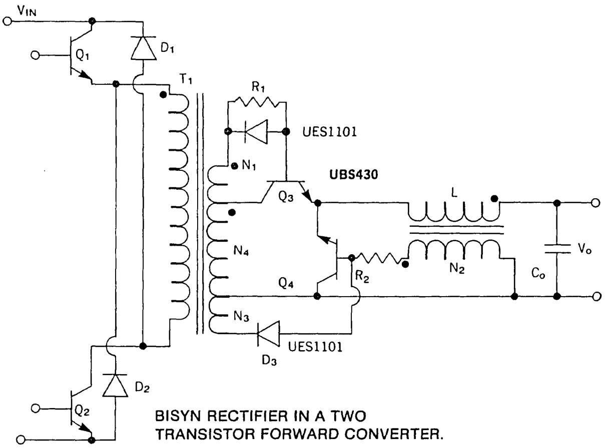
TO-204AE (TO-3 modified, 60 mil. pin)



ELECTRICAL CHARACTERISTICS (at 25°C unless noted)

TEST	SYMBOL	MIN.	TYP.	MAX.	UNIT	CONDITIONS
On Resistance	$R_{CE(ON)}$		7	10	mΩ	$I_C = 30A$, $I_B = 1.2A$
			10	13	mΩ	$I_C = 30A$, $I_B = 1.2A$, $T = 125°C$
Current Gain	h_{FE}	50	100			$I_C = 20A$, $V_{CE} = 0.5V$
Base Saturation Voltage	$V_{BE(sat)}$		1.2	1.5	V	$I_C = 30A$, $I_B = 1.2A$
Rise Time	t_r		85	120	nS	$I_C = 20A$, $I_B = 2A$, $V_{CC} = 10V$
Storage Time	t_s		300	500	nS	$I_C = 20A$, $I_B = 2A$, $V_{CC} = 10V$
Fall Time	t_f		75	120	nS	$I_C = 20A$, $I_B = 2A$, $V_{CC} = 10V$
Forward Leakage Current	I_{CES}			100	μA	$V_{CE} = 50V$
				1	mA	$V_{CE} = 50V$, $T = 125°C$
Reverse Leakage Current	I_{ECS}			200	μA	$V_{EC} = 40V$
				1	mA	$V_{CE} = 40V$, $T = 125°C$
Collector Capacitance	C_{OBO}		1000	1500	pf	$V_{EC} = 10V$, $f = 1MHz$

A RECOMMENDED DRIVE CIRCUIT



BISYN RECTIFIER IN A TWO TRANSISTOR FORWARD CONVERTER.

THE OPERATION OF THE CIRCUIT IS AS FOLLOWS:

During the on-time of transistors Q_1 and Q_2, BISYN Q_3 is biased on and delivers output load current through filter inductor L. The polarity of voltage developed across winding N_2 is such that BISYN Q_4 remains in a blocking state. Diode D_3 is also biased off. When transistors Q_1 and Q_2 turn-off; some of the energy stored in the magnetizing and leakage inductance enhances the recovery process of BISYN Q_3. The recovery time (300-400nS) of BISYN Q_3 extends the reset time of the core. However, in a typical design, half of the switching period is allocated for core reset time. Thus, the storage time has no significant effect on operation. The BISYN Q_4 starts conducting filter inductor current as soon as the voltage across the secondary collapses. BISYN Q_4 receives base drive energy from the filter inductor L, through winding N_2. The diode D_3 still remains reverse biased.

When transistors Q_1 and Q_2 turn-on again, the voltage across winding N_3 is clamped to approximately zero by diode D_3 and the forward biased collector to base junction of BISYN Q_4. This junction acts as a voltage source (≈0.7V) as long as BISYN Q_4 is conducting during the storage time. The turn-on of BISYN Q_3 is held off due to lack of base drive because winding N_3 is shorted, through diode D_3 and the collector-base junction of BISYN Q_4. Meanwhile, the current through the shorted turns (the rate of rise of which is limited by leakage inductance) is utilized to rapidly commutate BISYN Q_4 off. Diode D_3 is then reverse biased and BISYN Q_3 turns on through winding N_1.

The effect of the turn-off circuit, consisting of winding N_3 and D_3 is to eliminate high peak currents in the secondary. You will also find that with this circuit there are practically no switching losses.

Application Note U-103 contains additional design information and circuits for the BISYN.

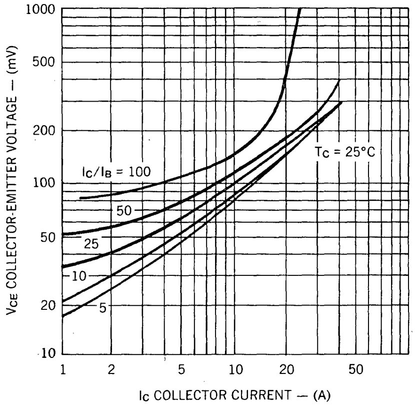
DESIGNING FOR MINIMUM POWER DISSIPATION

Although used as a rectifier the BISYN is a three terminal device. Therefore, the power dissipation due to the On Resistance and also the dissipation due to the base current must be taken into consideration. You will notice on curves 1 and 2 that the change in On Voltage (V_{CE}) at a particular collector current is small even with large changes in base current. As a result, achieving the lowest On Voltage for a particular load current does not result in the lowest overall power loss.

It has been determined that operating at a base current that achieves an On Voltage that is 110% of the On Voltage at a circuit gain of ten gives a result that is very close to optimum power dissipation. Curve 3 gives you the appropriate base current to achieve 110% of this On Voltage. This same curve shows that the appropriate base drive for optimum power dissipation at any particular load current is virtually the same throughout the operating temperature range.

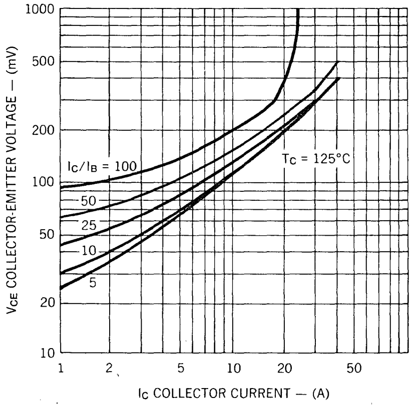
To calculate the power dissipation first estimate the operating temperature of the BISYN. Then using the appropriate temperature curve determine the On Voltage at a circuit gain of 10 for your load. Multiply this voltage by 1.1 and then by the load current to determine On Resistance power dissipation. Base current power dissipation is calculated by finding the base drive current on curve 3 and then going to the applicable temperature curve for Base Emitter Voltage vs Base Current (curves 4 and 5). Multiplying the Base Emitter Voltage by Base Current will give you the power dissipation due to base current.

Collector-Emitter Voltage vs Collector Current at Various Forced Gains



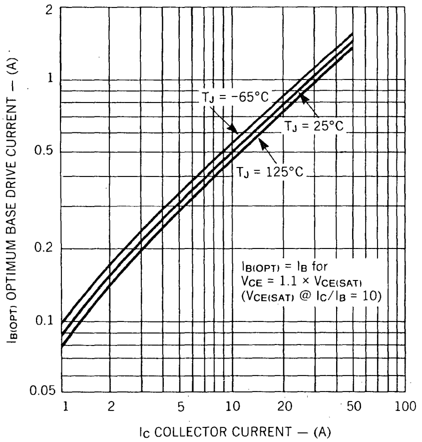
CURVE # 1

Collector-Emitter Voltage vs Collector Current at Various Forced Gains



CURVE # 2

Optimum Base Drive Current vs Collector Current



CURVE # 3

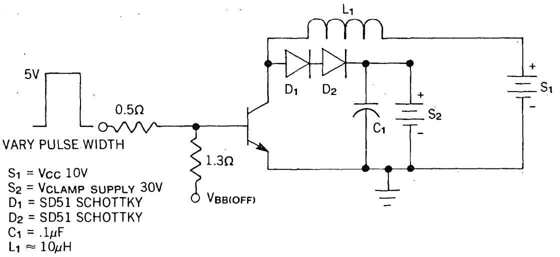
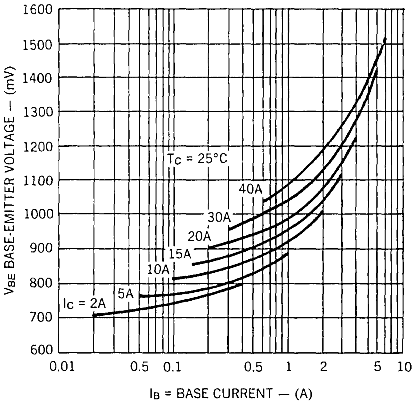


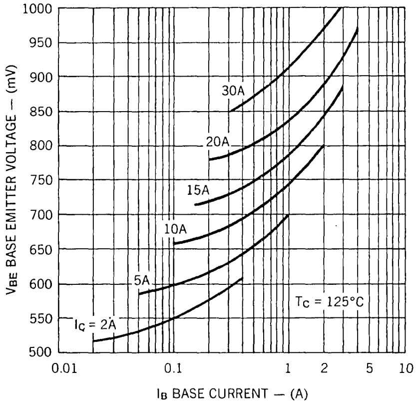
FIGURE 1. TEST CIRCUIT FOR I_{LPK}.

Base Emitter Voltage vs Base Current at Various Collector Currents



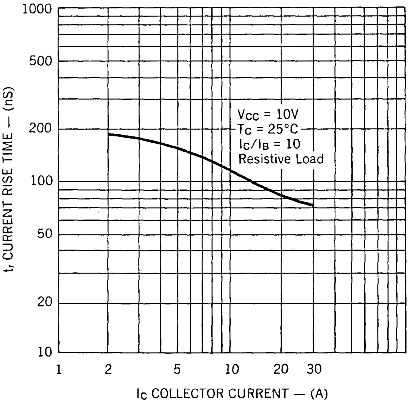
CURVE # 4

Base Emitter Voltage vs Base Current at Various Collector Currents



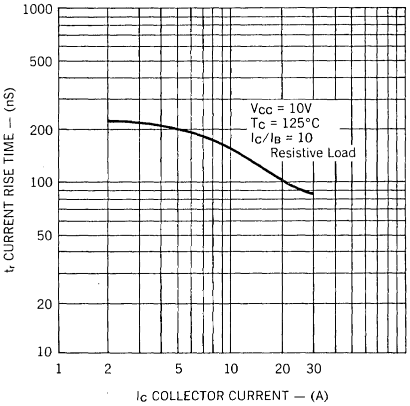
CURVE # 5

Current Rise Time vs Collector Current



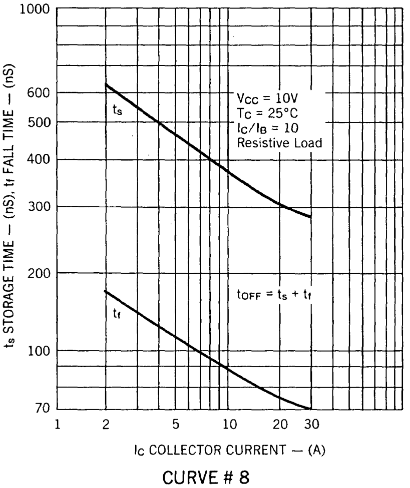
CURVE # 6

Current Rise Time vs Collector Current



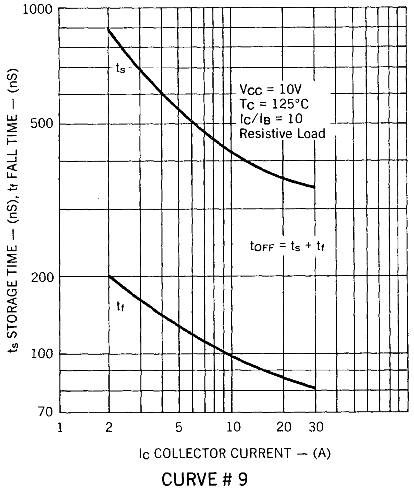
CURVE # 7

Turn Off Time vs Collector Current



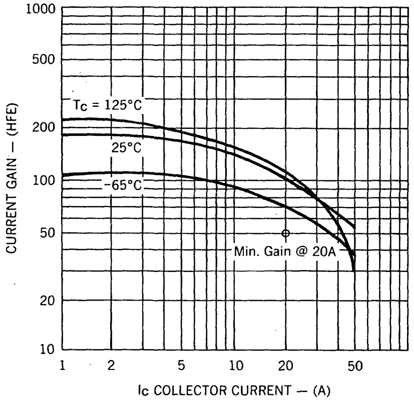
CURVE # 8

Turn Off Time vs Collector Current



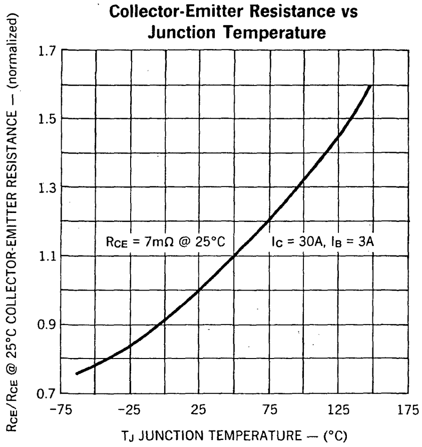
CURVE # 9

Gain vs Collector Current @ V_{CE} = 0.5V at Various Temperatures



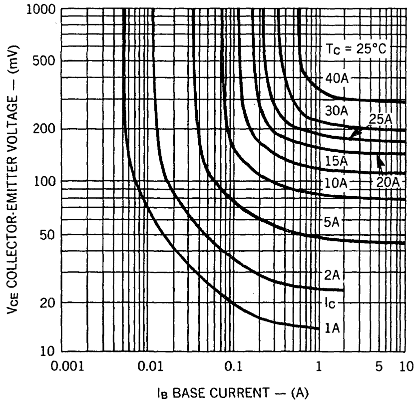
CURVE # 10

Collector-Emitter Resistance vs Junction Temperature



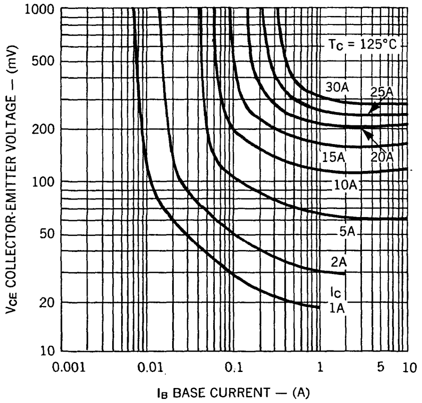
CURVE # 11

Collector-Emitter Voltage vs Base Current



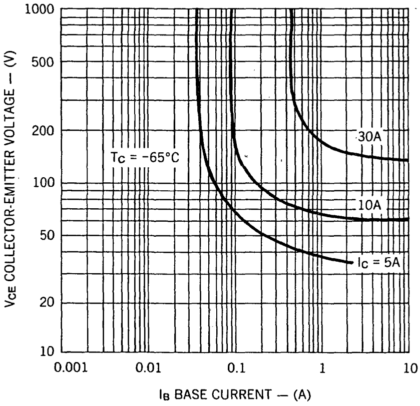
CURVE # 12

Collector-Emitter Voltage vs Base Current



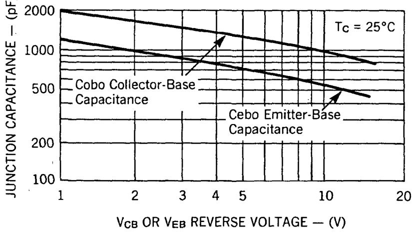
CURVE # 13

Collector-Emitter Voltage vs Base Current at Various Collector Currents



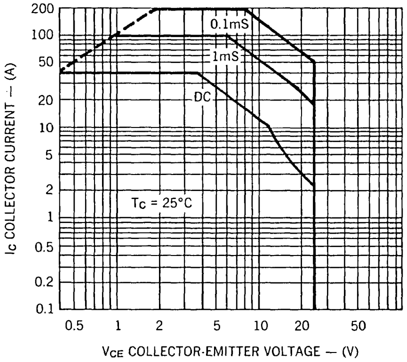
CURVE # 14

Junction Capacitance



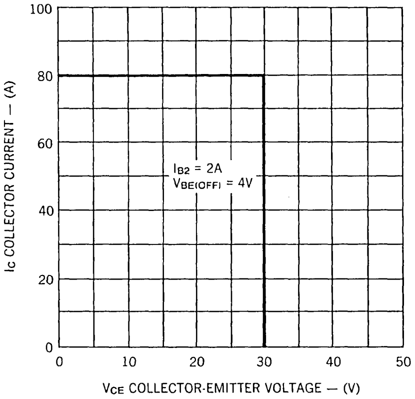
CURVE # 15

Forward Bias Safe Operating Area (SOA)



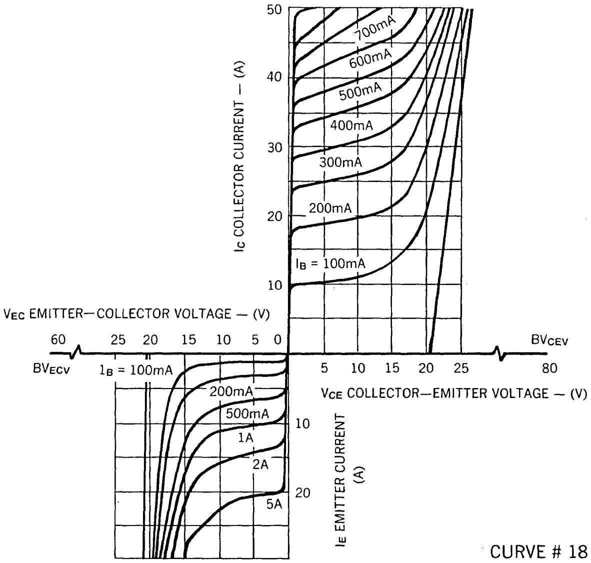
CURVE # 16

Reverse Bias Safe Operating Area



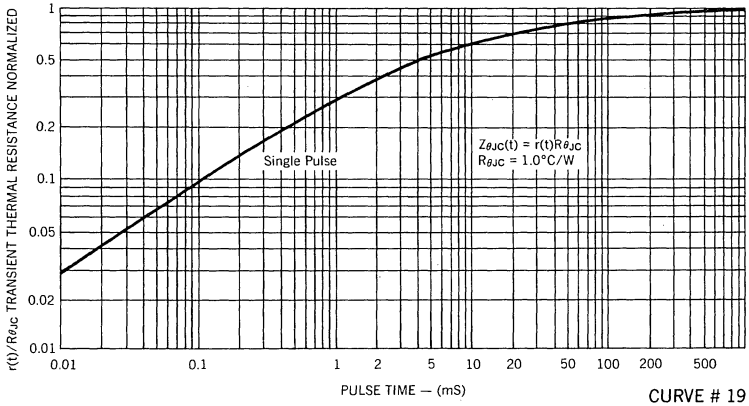
CURVE # 17

Common-Emitter Collector Characteristics



CURVE # 18

Transient Thermal Resistance vs Time



CURVE # 19

RECTIFIERS
High Efficiency, 25 A

UES701 BYW31-50 BYW77-50
UES702 BYW31-100 BYW77-100
UES703 BYW31-150 BYW77-150

FEATURES

- Low Forward Voltage
- Very Fast Switching
- Low Thermal Resistance
- High Surge Capability
- Mechanically Rugged
- Both Polarities Available

DESCRIPTION

Designed to meet the efficiency demand of switching type power supplies, these devices are useful in many switching applications.

The low thermal resistance and forward voltage drop of this series allows the user to replace DO-5 size devices in many applications.

ABSOLUTE MAXIMUM RATINGS

	UES701	UES702	UES703
Peak Inverse Voltage, V_R	50V	100V	150V
Repetitive Peak Inverse Voltag, V_{RRM}	50V	100V	150V
Non-Repetitive Peak Inverse Voltage, V_{RSM}	50V	100V	150V
Maximum Average D.C. Output Current I_O @ T_C	25A @ 100°C		
RMS Forward Current, $I_{F\ (RMS)}$	40A		
Non-Repetitive Sinusoidal Surge Current (8.3mS), I_{FSM}	400A		
Thermal Resistance, Junction to Case, $R_{\theta JC}$	1.5°C/W		
Storage Temperature Range, T_{STG}	−55°C to +175°C		
Maximum Operating Junction Temperature, $T_{J\ MAX}$	+175°C		

ABSOLUTE MAXIMUM RATINGS

	BYW31-50	BYW31-100	BYW31-150	BYW77-50	BYW77-100	BYW77-150
Peak Inverse Voltage, V_R	50V	100V	150V	50V	100V	150V
Repetitive Peak Inverse Voltage, V_{RRM}	50V	100V	150V	50V	100V	150V
Non-Repetitive Peak Inverse Voltage, V_{RSM}	50V	100V	150V	50V	100V	150V
Maximum Average D.C. Output Current, I_o @ T_C = 100°C	25A @ 100°C			30A @ 107°C		
RMS Forward Current, $I_{F\ (RMS)}$	40A			50A		
Non-Repetitive Sinusoidal Surge Current (8.3mS), I_{FSM}	320A			500A		
Thermal Resistance, Junction to Case, $R_{\theta JC}$	1.5°C/W			1.5°C/W		
Storage Temperature Range, T_{STG}	−55°C to +150°C			−55°C to +150°C		
Maximum Operating Junction Temperature, $T_{J\ MAX}$	+150°C			+150°C		

ELECTRICAL SPECIFICATIONS

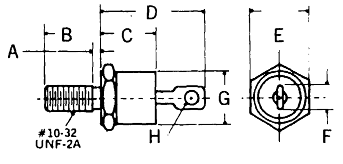
Type	Maximum Reverse Voltage V_R	Maximum Forward Voltage V_F		Maximum Reverse Current I_R		Maximum Reverse Recovery Time t_{RR}
		T_C = 25°C	T_C = 125°C	T_C = 25°C	T_C = 125°C	
UES701 UES702 UES703	50V 100V 150V	0.95V @ I_F = 25A	0.825V @ I_F = 25A	20μA @ Rated V_R	4mA @ Rated V_R	35ns(1)
		T_C = 25°C	T_C = 100°C	T_C = 25°C	T_C = 100°C	
BYW31-50 BYW31-100 BYW31-150	50V 100V 150V	1.3V @ I_F = 100A	0.85V @ I_F = 20A	20μA @ Rated V_R	2.5mA @ Rated V_R	50ns(2)
		T_C = 25°C	T_C = 100°C	T_C = 25°C	T_C = 100°C	
BYW77-50 BYW77-100 BYW77-150	50V 100V 150V	1.1V @ I_F = 63A	V_F I_F 0.75V 10A 0.85V 20A 1.2V 100A	25μA @ Rated V_R	2.5mA @ Rated V_R	50ns(2)

(1) Measured in circuit I_F = 0.5A, I_R = 1A, I_{REC} = 0.25A

(2) Measured in circuit I_F = 1A to V_R > 30V $dI_F/_{dt}$ = 20A/μs

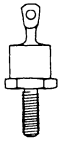
MECHANICAL SPECIFICATIONS

UES701 SERIES
BYW31 SERIES
BYW77 SERIES



	ins.	mm
A	.078 MAX.	1.98 MAX.
B	.437 ± .015	11.10 ±0.38
C	.405 MAX.	10.29 MAX.
D	.800 MAX.	20.32 MAX.
E	.430 ± .010	10.92 ± 0.25
F	.250 MAX.	6.35 MAX.
G	.424 MAX.	10.77 MAX.
H	.066 MIN. DIA.	1.68 MIN. DIA.

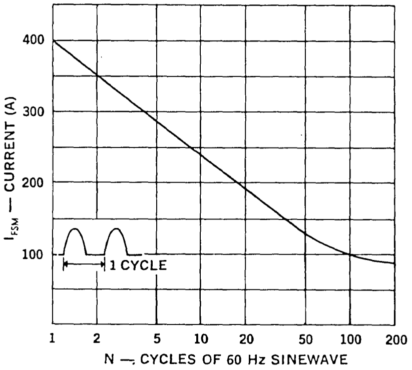
DO-4



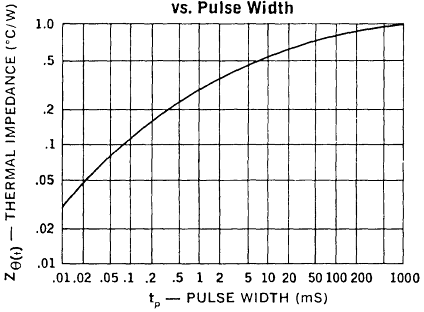
Notes:

1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 10 inch pounds.
4. Angular Orientation of terminal is undefined.

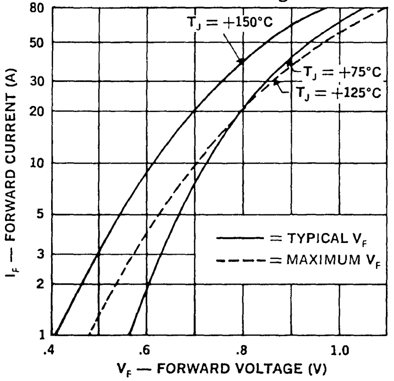
Maximum Forward Surge vs. Number of Cycles



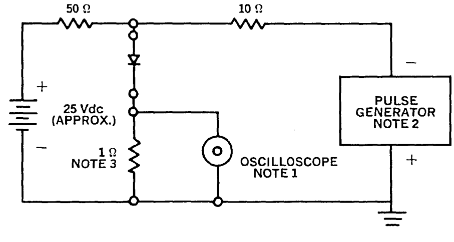
Thermal Impedance vs. Pulse Width



Forward Current vs. Forward Voltage



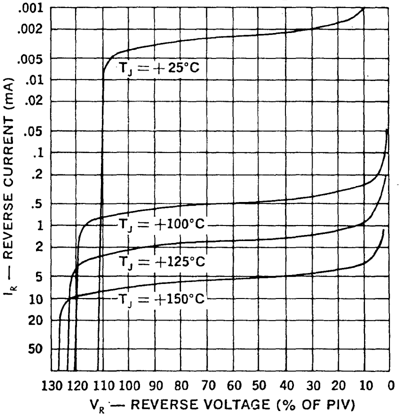
Reverse-Recovery Circuit



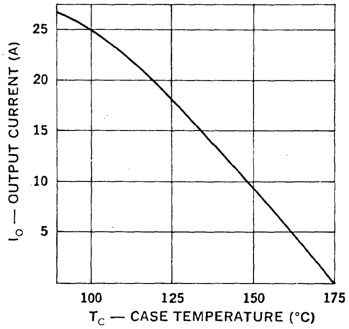
NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Typical Reverse Current vs. Reverse Voltage

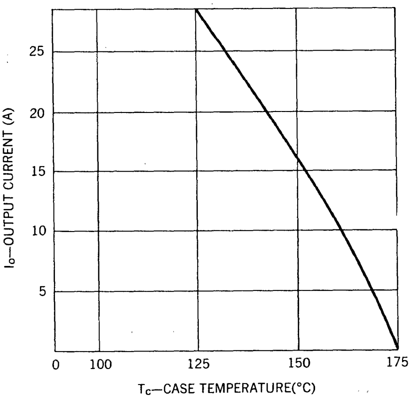


Output Current vs. Case Temperature



UES701 SERIES
BYW31 SERIES

Output Current vs Case Temperature

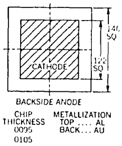


BYW77 SERIES

RECTIFIERS
High Efficiency, 20A

UES704
UES705
UES706
UES704HR2
UES705HR2
UES706HR2

FEATURES
- Very Low Forward Voltage (1.15V)
- Very Fast Recovery Times (50nSec)
- Low Thermal Resistance
- High Surge Capability
- Mechanically Rugged
- Both Polarities Available



DESCRIPTION
The UES704 series is specifically designed for operation in power switching circuits operating at frequencies of at least 20 KHz.

The low thermal resistance and forward voltage drop of this series allows the user to replace DO-5 size devices in many applications.

ABSOLUTE MAXIMUM RATINGS
Peak Inverse Voltage, UES704, UES704HR2	200V
Peak Inverse Voltage, UES705, UES705HR2	300V
Peak Inverse Voltage, UES706, UES706HR2	400V
Average D.C. Output Current, I_O @ T_C = 100°C	20A
Surge Current, 8.3mS	300A
Thermal Resistance, Junction to Case	1.5°C/W
Operating and Storage Temperature Range	−55°C to +150°C

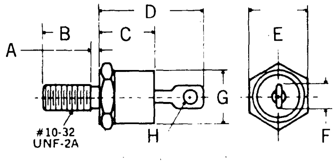
POWER CYCLING
These devices possess the unique ability to pass many thousands of cycles of a stress test designed to evaluate the integrity of the bonding systems used in the construction of power rectifiers.

In this stress test, the case of the device is not heat sunk. Full rated forward current is supplied to force a case temperature increase at least 75°C, at which time, the current is removed and the case allowed to cool. The cycle is repeated a minimum of 5,000 times to simulate equipment being turned on and off. Extended power cycling tests demonstrate a product capability in excess of 25,000 cycles.

SWITCHING CHARACTERISTICS
The switching times of these ultra-fast rectifiers increase relatively little, with temperature or at different currents. Even in severe applications, such as catch diodes for switching regulators and output rectifiers for high frequency square wave inverters, these devices switch many times faster than the fastest associated transistors. Thus, the stresses on and powers dissipated in the switching transistors are substantially less than when using other rectifiers.

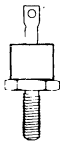
MECHANICAL SPECIFICATIONS

UES704 UES704HR2 **UES705 UES705HR2** **UES706 UES706HR2**



	ins.	mm
A	.078 MAX.	1.98 MAX.
B	.437 ± .015	11.10 ±0.38
C	.405 MAX.	10.29 MAX.
D	.800 MAX.	20.32 MAX.
E	.430 ± .010	10.92 ± 0.25
F	.250 MAX.	6.35 MAX.
G	.424 MAX.	10.77 MAX.
H	.066 MIN. DIA.	1.68 MIN. DIA.

DO-4



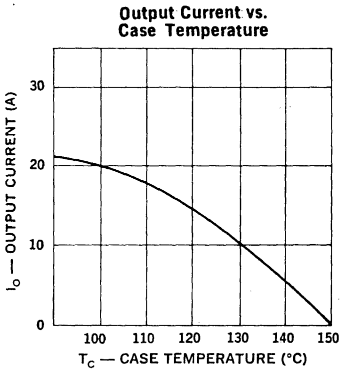
Notes:
1. Standard polarity is cathode-to-stud.
   For reverse Polarity (anode-to-stud) add suffix "R", ie. UES704R.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 15 inch pounds.
4. Angular orientation of terminal is undefined.

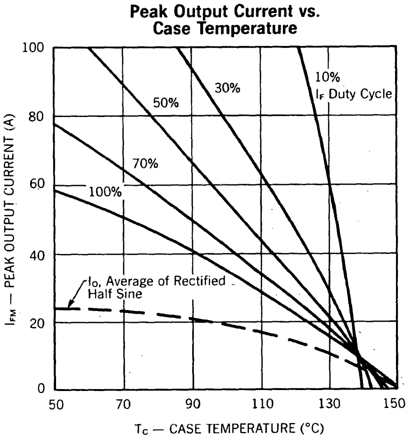
SEMICONDUCTOR PRODUCTS
UNITRODE

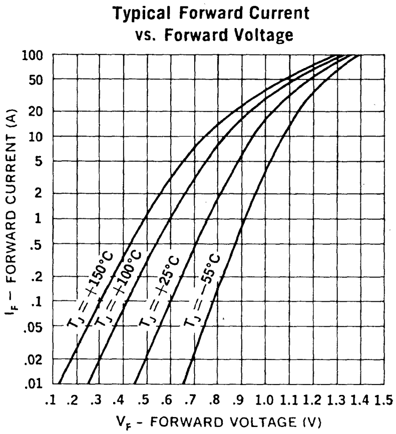
ELECTRICAL SPECIFICATIONS

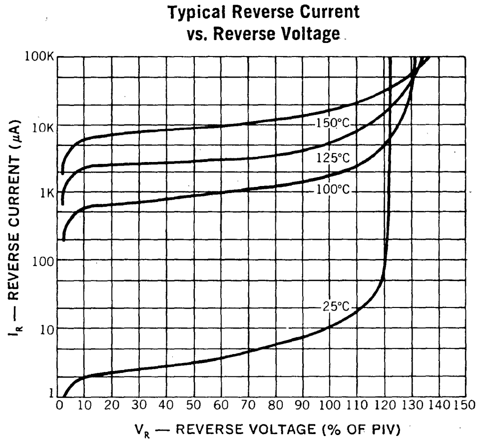
Type	PIV	Maximum Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
		$T_C = 25°C$	$T_C = 125°C$	$T_C = 25°C$	$T_C = 125°C$	
UES704/704HR2 UES705/705HR2 UES706/706HR2	200V 300V 400V	1.25V @ 20A $t_p = 300\mu S$	1.15V @ 20A $t_p = 300\mu S$	50μA	10mA	50nS

* Measured in circuit $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$

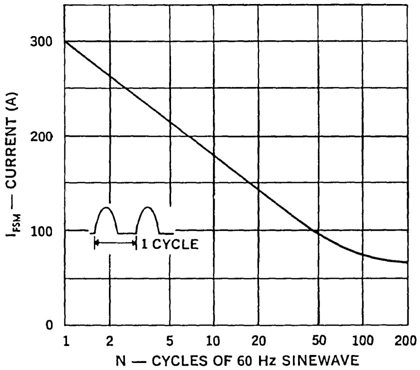




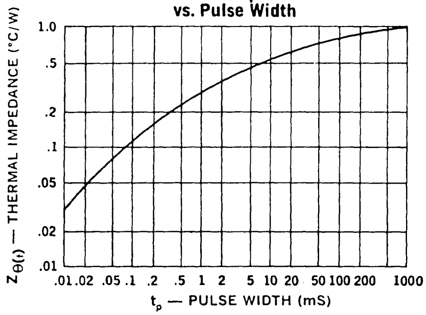




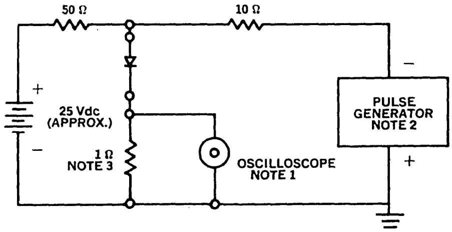
Maximum Forward Surge vs. Number of Cycles



Thermal Impedance vs. Pulse Width



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UES704HR2, 5HR2, 6HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, T_C = 125°C, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

RECTIFIERS
High Efficiency, 50A and 70A

UES801 BYW78-50
UES802 BYW78-100
UES803 BYW78-150

FEATURES
- High Continuous Current Rating
- Very Low Forward Voltage
- Very Fast Switching Speeds
- High Surge Capability
- Low Thermal Resistance
- Mechanically Rugged DO-5 Package

DESCRIPTION
This Series is specifically designed for operation in power switching circuits operating at frequencies of at least 20KHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS

	UES801	UES802	UES803	BYW78-50	BYW78-100	BYW78-150
Peak Inverse Voltage, V_R	50V	100V	150V	50V	100V	150V
Repetitive Peak Inverse Voltage, V_{RRM}	50V	100V	150V	50V	100V	150V
Non-Repetitive Peak Inverse Voltage, V_{RSM}	50V	100V	150V	50V	100V	150V
Maximum Average D.C. Output Current, I_o @ T_C = 100°C	70A			50A		
Non-Repetitive Sinusoidal Surge Current (8.3mS), I_{FSM}	800A			1500A		
Thermal Resistance, Junction to Case, $R_{\theta JC}$	0.8°C/W					
Storage Temperature Range, T_{STG}	-55°C to +175°C					
Maximum Operating Junction Temperature, $T_{J\ MAX}$	+175°C					

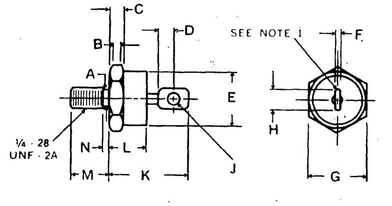
ELECTRICAL SPECIFICATIONS

Type	Maximum Reverse Voltage V_R	Maximum Forward Voltage V_F		Maximum Reverse Current I_R		Maximum Reverse Recovery Time t_{RR}
		T_C = 25°C	T_C = 150°C	T_C = 25°C	T_C = 150°C	
UES801 UES802 UES803	50V 100V 150V	0.975V @ I_F = 70A	0.84V @ I_F = 70A	25μA @ Rated V_R	30mA @ Rated V_R	50ns(1)
		T_C = 25°C	T_C = 100°C	T_C = 25°C	T_C = 100°C	
BYW78-50 BYW78-100 BYW78-150	50V 100V 150V	1.1V @ I_F = 160A	0.85V @ I_F = 50A	50μA @ Rated V_R	5mA @ Rated V_R	60ns(2)

(1) Measured in circuit I_F = 0.5A, I_R = lA, I_{REC} = 0.25A
(2) Measured in circuit I_F = 1A, V_R = 30V, $dI_F/_{dt}$ = 50A/μs

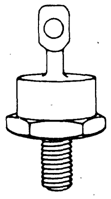
MECHANICAL SPECIFICATIONS

UES800 SERIES
BYW78 SERIES



	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	677 ± .010	17 20 ± 0.25
H	375 MAX.	9.53 MAX.
J	.140 MIN. DIA	3.56 MIN DIA
K	1 000 MAX.	25.40 MAX.
L	.450 MAX	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	078 MAX.	1.98 MAX

DO-5

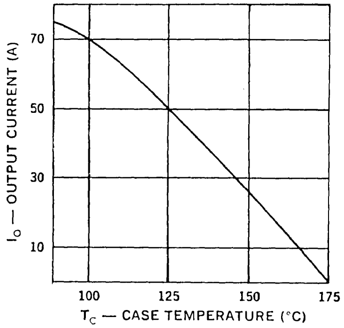


Notes:
1. **Standard polarity is cathode-to-stud.**
2. **All metal surfaces tin plated.**
3. **Maximum unlubricated stud torque: 20 inch pounds (20 kg. cm).**
4. **Angular orientation of terminal is undefined.**

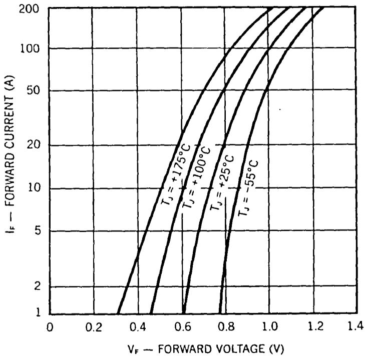
SEMICONDUCTOR PRODUCTS
UNITRODE

4/82

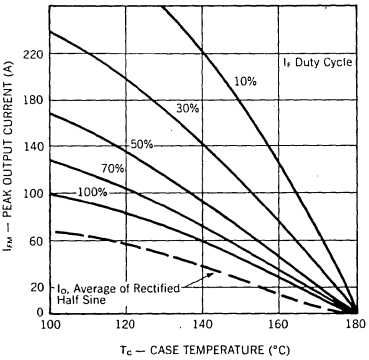
Output Current vs. Case Temperature



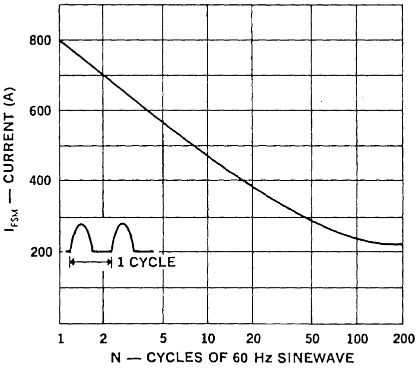
Forward Current vs. Forward Voltage



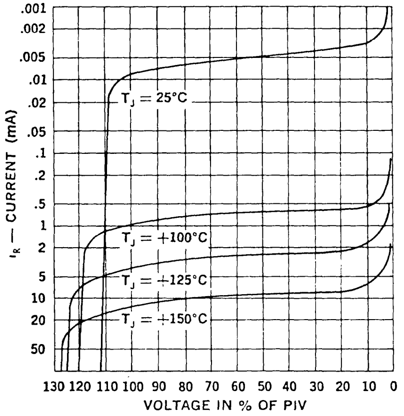
Peak Output Current vs. Case Temperature



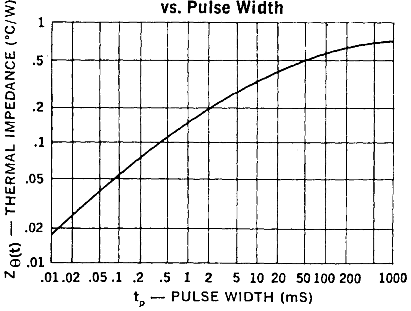
Maximum Forward Surge vs. Number of Cycles



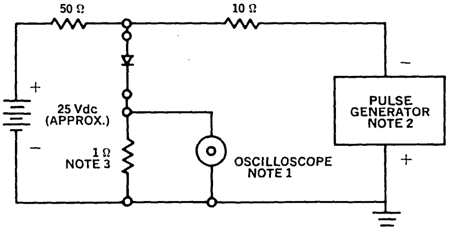
Typical Reverse Current vs. Reverse Voltage



Thermal Impedance vs. Pulse Width



Reverse-Recovery Circuit



NOTES:

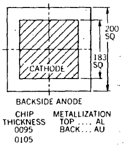
1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 50A

UES804
UES805
UES806
UES804HR2
UES805HR2
UES806HR2

FEATURES

- Very Low Forward Voltage (1.15V)
- Very Fast Recovery Times (50nSec)
- High Surge Capability
- Low Thermal Resistance
- Mechanically Rugged
- Both Polarities Available



DESCRIPTION

The UES804 is specifically designed for operation in power switching circuits operating at frequencies of at least 20 KHz.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, UES804, UES804HR2	200V
Peak Inverse Voltage, UES805, UES805HR2	300V
Peak Inverse Voltage, UES806, UES806HR2	400V
Maximum Average D.C. Output Current @ T_C = 100°C	50A
Surge Current, 8.3mS	600A
Thermal Resistance, Junction to Case	.8°C/W
Operating and Storage Temperature Range	−55°C to +150°C

POWER CYCLING

These devices possess the unique ability to pass many thousands of cycles of a stress test designed to evaluate the integrity of the bonding systems used in the construction of power rectifiers.

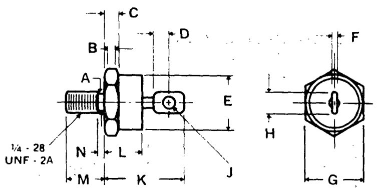
In this stress test, the case of the device is not heat sunk. Full rated forward current is supplied to force a case temperature increase at least 75°C, at which time, the current is removed and the case allowed to cool. The cycle is repeated a minimum of 5,000 times to simulate equipment being turned on and off. Extended power cycling tests demonstrate a product capability in excess of 25,000 cycles.

SWITCHING CHARACTERISTICS

The switching times of these ultra-fast rectifiers increase relatively little, with temperature or at different currents. Even in severe applications, such as catch diodes for switching regulators and output rectifiers for high frequency square wave inverters, these devices switch many times faster than the fastest associated transistors. Thus, the stresses on and powers dissipated in the switching transistors are substantially less than when using other rectifiers.

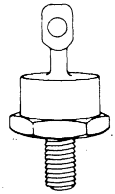
MECHANICAL SPECIFICATIONS

UES804 UES804HR2 UES805 UES805HR2 UES806 UES806HR2



	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA. MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA.
K	1:000 MAX.	25.40 MAX.
L	.450 MAX.	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	.078 MAX.	1.98 MAX.

DO-5



Notes:
1. Standard polarity is cathode-to-stud.
   For reverse polarity (anode-to-stud) add suffix "R", ie. UES804R.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 30 inch pounds.
4. Angular orientation of terminal is undefined.

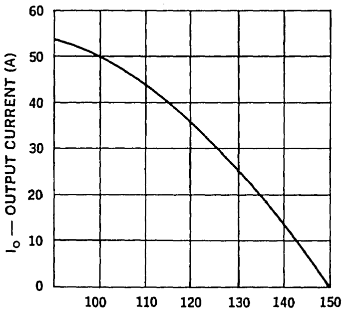
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS

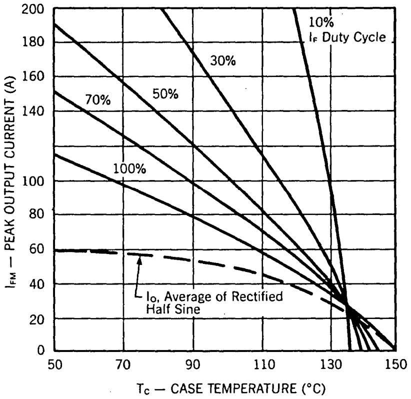
Type	PIV	Maximum Forward Voltage		Maximum Reverse Curent		Maximum Reverse Recovery Time*
		$T_C = 25°C$	$T_C = 125°C$	$T_C = 25°C$	$T_C = 125°C$	
UES804/804HR2 UES805/805HR2 UES806/806HR2	200V 300V 400V	1.25V @ $I_F = 50A$ $t_p = 300\mu S$	1.15V @ $I_F = 50A$ $t_p = 300\mu S$	70μA	30mA	50nS

* Measured in circuit $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$

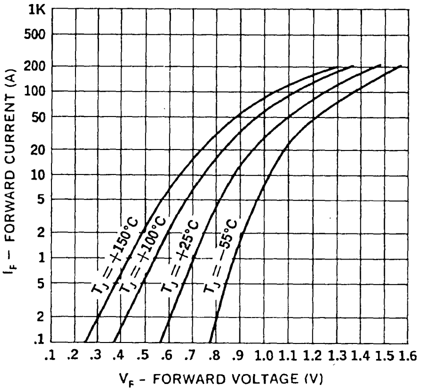
Output Current vs. Case Temperature



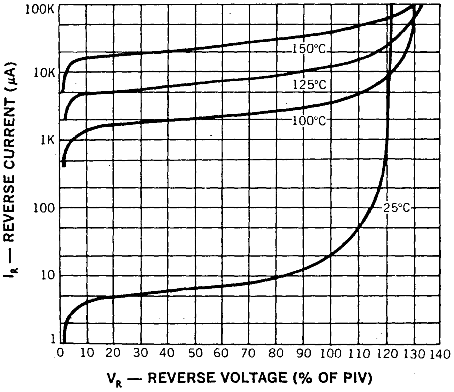
Peak Output Current vs. Case Temperature



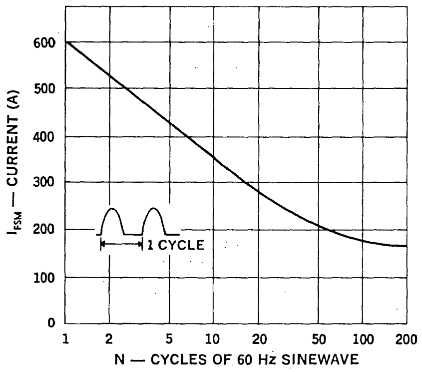
Typical Forward Current vs. Forward Voltage



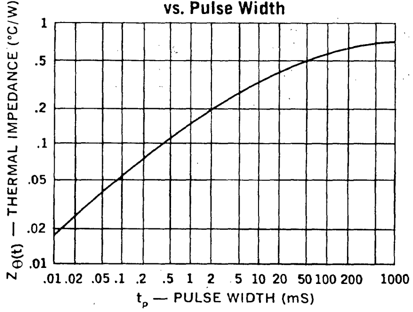
Typical Reverse Current vs. Reverse Voltage



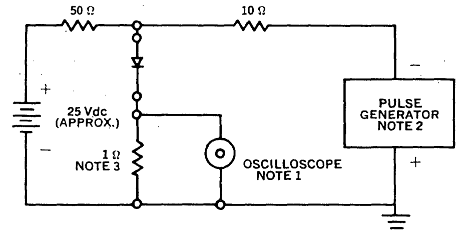
Maximum Forward Surge vs. Number of Cycles



Thermal Impedance vs. Pulse Width



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UES804HR2, 5HR2, 6HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, T_C = 125°C, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

RECTIFIERS
High Efficiency, 1A

UES1001-UES1003

FEATURES
- Very Fast Recovery Times
- Very Low Forward Voltage
- Small Size
- Convenient Package

DESCRIPTION

An axial leaded power rectifier useful in many switching applications. Particularly suited where very fast recovery and low forward voltage are required.

ABSOLUTE MAXIMUM RATINGS

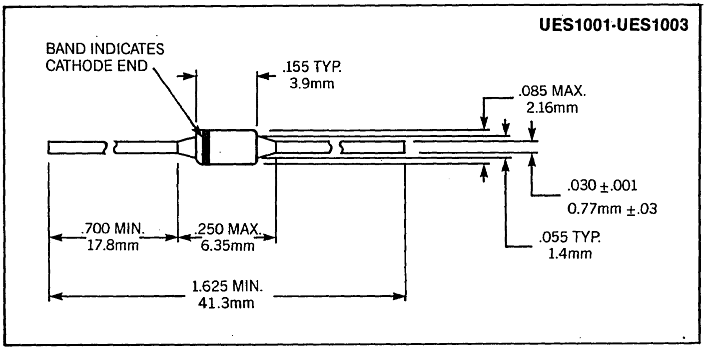
Peak Inverse Voltage, UES1001 .... 50V
Peak Inverse Voltage, UES1002 .... 100V
Peak Inverse Voltage, UES1003 .... 150V
Maximum Average D.C. Output Current at T_L = 75°C, L = 3/8″ 1A
Non-Repetitive Surge Current at 8.3mS 30A
Thermal Resistance at L = 3/8″ .... 75°C/W
Operating and Storage Temperature Range .... −55°C +175°C

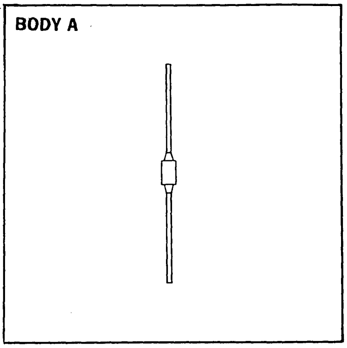
ELECTRICAL SPECIFICATIONS

Type	PIV	Maximum Forward Voltage (V_F) @		Maximum Reverse Current (I_R) @PIV		Maximum Reverse Recovery Time*
		T_J = 25°C	T_J = 100°C	@ T_J = 25°C	@ T_J = 100°C	
UES1001	50V	.975V	.895V			
UES1002	100V	@	@	2μA	50μA	25nS
UES1003	150V	1A	1A			

*Measured in circuit I_F = .5A, I_R = 1.0A, I_{REC} = .25A

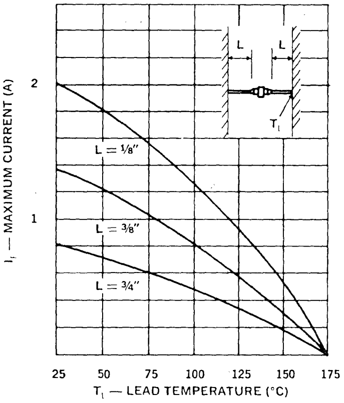
MECHANICAL SPECIFICATIONS



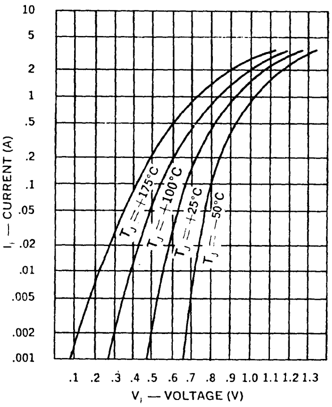


THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

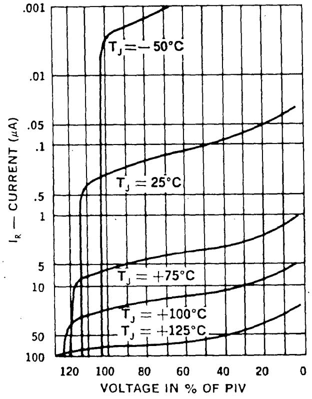
Output Current vs. Lead Temperature



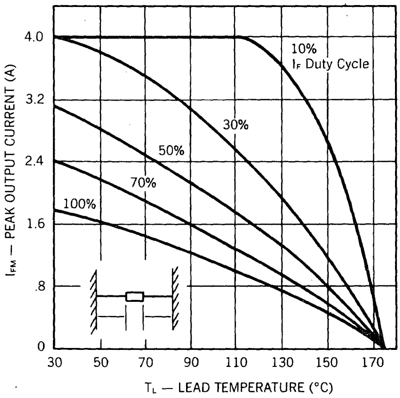
Typical Forward Current vs. Forward Voltage



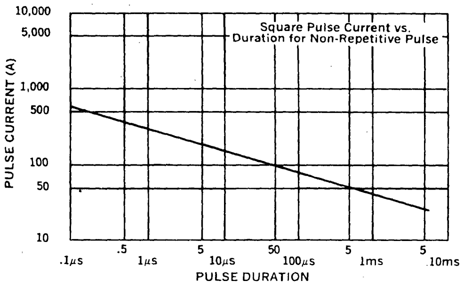
Typical Reverse Current vs. Voltage



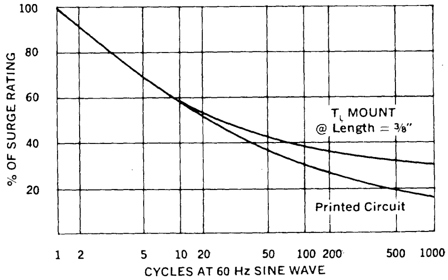
Peak Output Current vs. Lead Temperature



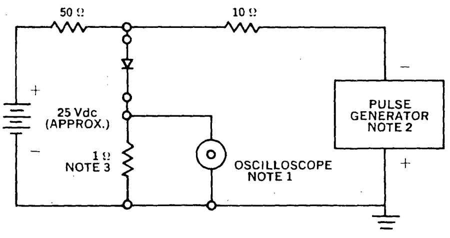
Forward Pulse Current vs. Duration



Multiple Surge Current vs. Duration



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time<3nS; input impedance = 50Ω.
2. Pulse Generator: Rise time<8nS; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS

High Efficiency, 2.5A

UES1101 BYV27-50
UES1102 BYV27-100
UES1103 BYV27-150

FEATURES

- Very Fast Recovery Times
- Very Low Forward Voltage
- Small Size
- Convenient Package

DESCRIPTION

An axial leaded power rectifier useful in many switching applications. Particularly suited where very fast recovery and low forward voltage are required.

ABSOLUTE MAXIMUM RATINGS

	UES1101	UES1102	UES1103	BYV27-50	BYV27-100	BYV27-150
Peak Inverse Voltage, V_R	50V	100V	150V	50V	100V	150V
Maximum Average D.C. Output at $T_L = 75°C$, L = ⅜", I_O	2.5A			2.0A		
Non-Repetitive Surge Current at 8.3ms, I_{FSM}	35A			50A		
Thermal Resistance at L = ⅜", $R_{\theta JC}$	38°C/W			46°C/W		
Junction Operating Temperature, T_j	175°C			165°C		
Operating and Storage Temperature Range	−55°C to +175°C					

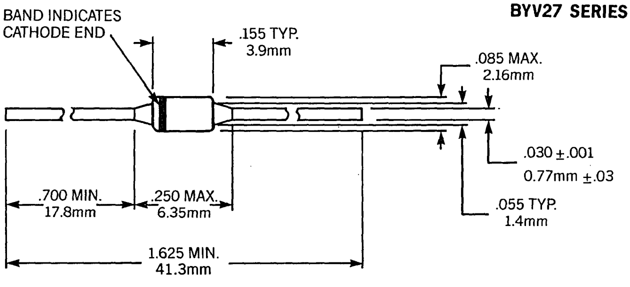
ELECTRICAL SPECIFICATIONS

Type	Maximum Reverse Voltage V_R	Maximum Forward Voltage @		Maximum Reverse Current @ Rated V_R		Maximum Reverse Recovery Time*
		$T_J = 25°C$	$T_J = 100°C$	$T_J = 25°C$	$T_J = 100°C$	
UES1101 UES1102 UES1103	50V 100V 150V	.975V @ 2A	.895V @ 2A	2µA	50µA	25nS
		$T_J = 25°C$	$T_J = 165°C$	$T_J = 25°C$	$T_J = 165°C$	
BYV27-50 BYV27-100 BYV27-150	50V 100V 150V	1.25V @ 5A	.85V @ 2.5A	1µA	150µA	25nS

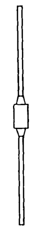
*Measured in circuit $I_F = ½A$, I_R 1.0A, $I_{REC} = ¼A$

MECHANICAL SPECIFICATIONS

UES1100 SERIES
BYV27 SERIES



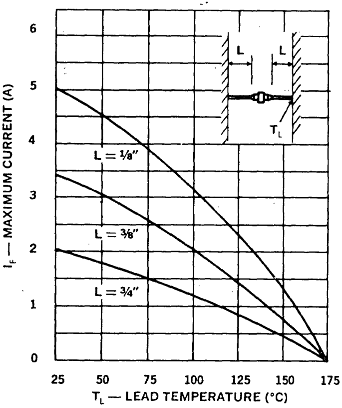
BODY A



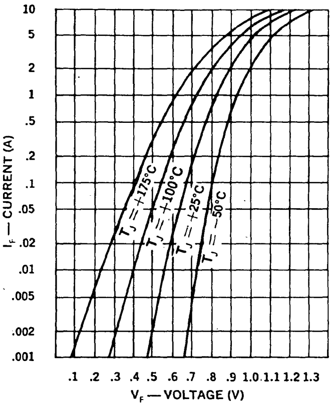
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

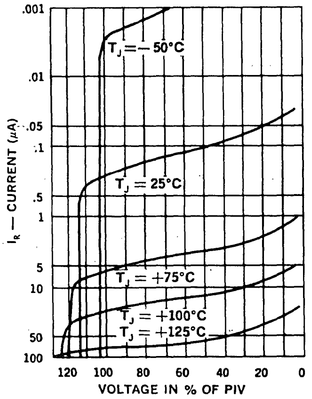
Output Current vs. Lead Temperature



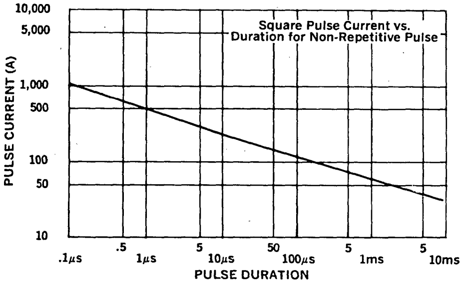
Typical Forward Current vs. Forward Voltage



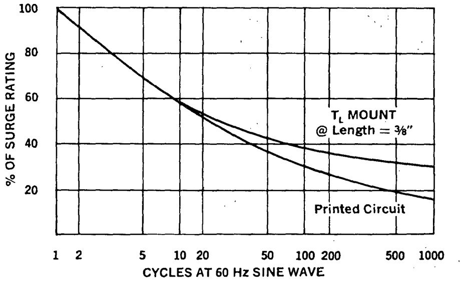
Typical Reverse Current vs. Voltage



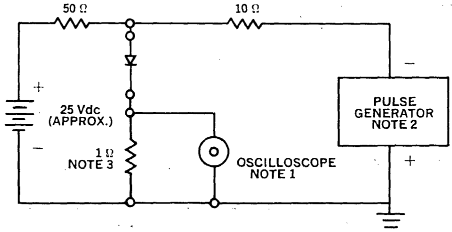
Forward Pulse Current vs. Duration



Multiple Surge Current vs. Duration



Reverse-Recovery Circuit



Notes:
1. Oscilloscope: Rise time ≤ 3nS; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8nS; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

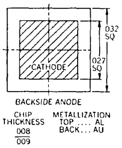
RECTIFIERS

High Efficiency, 2A

UES1104
UES1105
UES1106

FEATURES

- Very Low Forward Voltage (1.15V)
- Very Fast Recovery Times (50nSec)
- Small Size
- Convenient Package



DESCRIPTION

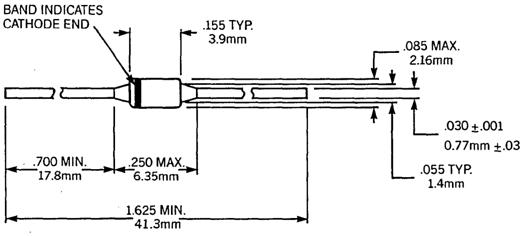
The UES1104 series is specifically designed for operation in power switching circuits operating at frequencies of at least 20 KHz.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, UES1104	200V
Peak Inverse Voltage, UES1105	300V
Peak Inverse Voltage, UES1106	400V
Maximum Average DC Output Current, I_O	
@ T_A = 25°C (Free Air)	1A
@ T_L = 50°C, L = ⅜″	2A
Surge Current, 8.3mSec	20A
Thermal Resistance @ L = ⅜″	38°C/W
Operating and Storage Temperature Range	−55°C to +150°C

MECHANICAL SPECIFICATIONS

UES1104 UES1105 UES1106



BODY A

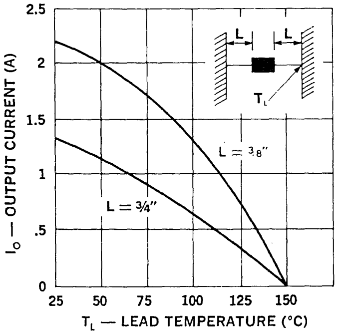
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS

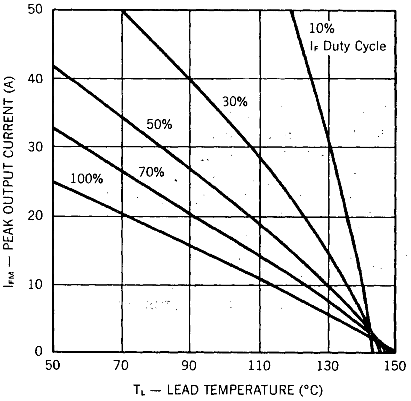
Type	PIV	Maximum Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
		$T_J = 25°C$	$T_J = 100°C$	@ PIV, $T_J = 25°C$	$T_J = 100°C$	
UES1104/1104HR	200V	1.25V	1.15V	10µA	200µA	50nS
UES1105/1105HR	300V	@ 1A	@ 1A			
UES1106/1106HR	400V	tp = 300µS	tp = 300µS			

* Measured in circuit $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$

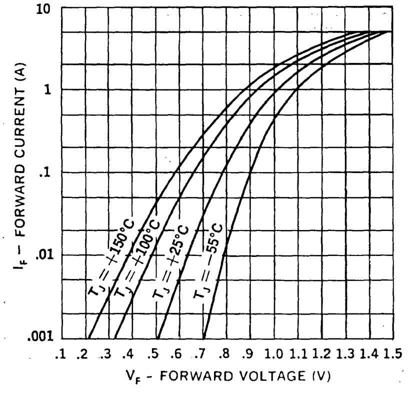
Output Current vs. Lead Temperature



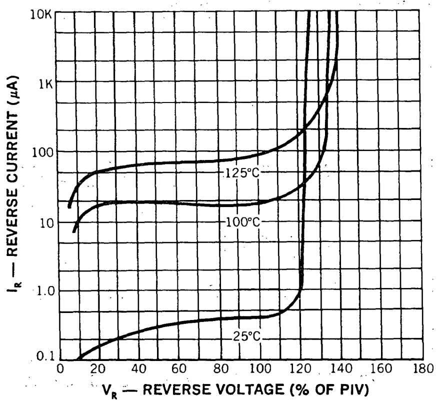
Peak Output Current vs. Lead Temperature



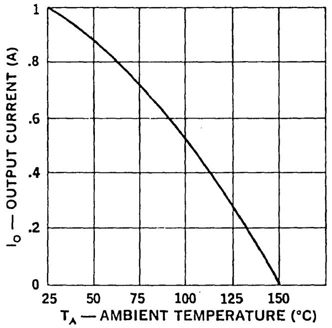
Typical Forward Current vs. Forward Voltage



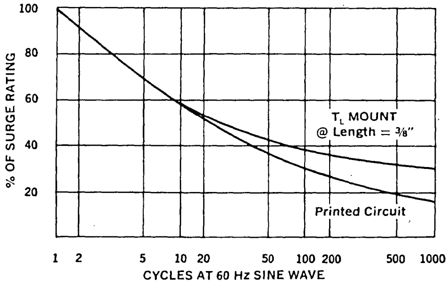
Typical Reverse Current vs. Reverse Voltage



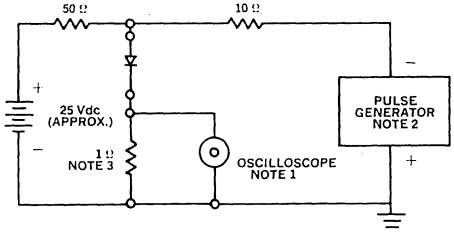
Output Current vs. Ambient Temperature



Multiple Surge Current vs. Duration



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

- **OPTIONAL HIGH RELIABILITY (HR2) SCREENING (See 1N6620-1N6625)**

RECTIFIERS
High Efficiency, 3.5A

UES1301 BYV28-50
UES1302 BYV28-100
UES1303 BYV28-150

FEATURES
- Very Fast Recovery Times
- Very Low Forward Voltage
- Small Size
- Convenient Package

DESCRIPTION
An axial leaded power rectifier useful in many switching applications. Particularly suited where very fast recovery and low forward voltage are required.

ABSOLUTE MAXIMUM RATINGS

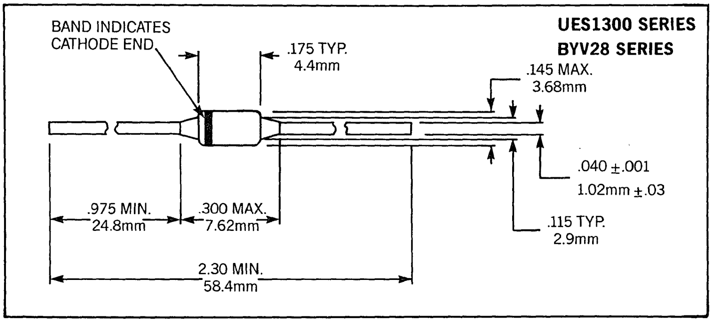
	UES1301	UES1302	UES1303	BYV28-50	BYV28-100	BYV28-150
Peak Inverse Voltage, V_R	50V	100V	150V	50V	100V	150V
Maximum Average D.C. Output at T_L = 75°C, L = 3/8" I_O		6.0A			3.5A	
Non-Repetitive Surge Current at 8.3ms, I_{FSM}		125A			80A	
Thermal Resistance at L = 3/8", $R_{\theta JC}$		20°C/W			25°C/W	
Junction Operating Temperature, T_j		175°C			165°C	
Operating and Storage Temperature Range			−55°C to +175°C			

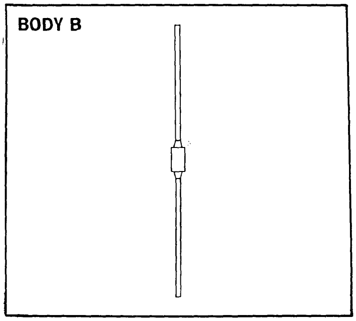
ELECTRICAL SPECIFICATIONS

<table>
<tr><th rowspan="2">Type</th><th rowspan="2">Maximum Reverse Voltage V_R</th><th colspan="3">Maximum Forward Voltage @</th><th colspan="2">Maximum Reverse Current @ Rated V_R</th><th rowspan="2">Maximum Reverse Recovery Time*</th></tr>
<tr><th>T_J = 25°C</th><th colspan="2">T_J = 100°C</th><th>T_J = 25°C</th><th>T_J = 100°C</th></tr>
<tr><td>UES1301
UES1302
UES1303</td><td>50V
100V
150V</td><td>.925V
@
6A</td><td colspan="2">.850V
@
6A</td><td>5μA</td><td>150μA</td><td>30ns</td></tr>
<tr><td rowspan="2">BYV28-50
BYV28-100
BYV28-150</td><td rowspan="2">50V
100V
150V</td><td>T_J = 25°C</td><td colspan="2">T_J = 165°C</td><td>T_J = 25°C</td><td>T_J = 100°C</td><td rowspan="2">30ns</td></tr>
<tr><td>1.10V
@
5A</td><td>.75V
@
3A</td><td>.90V
@
5A</td><td>1μA</td><td>150μA</td></tr>
</table>

*Measured in circuit I_F = 0.5A, I_R = 1.0A, I_{REC} = .25A

MECHANICAL SPECIFICATIONS

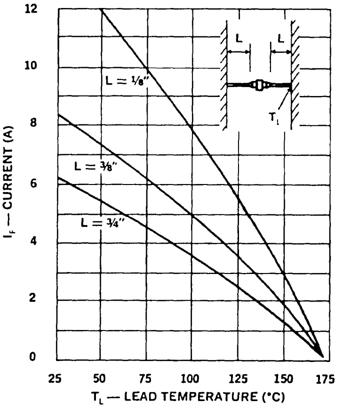

UES1300 SERIES
BYV28 SERIES


BODY B

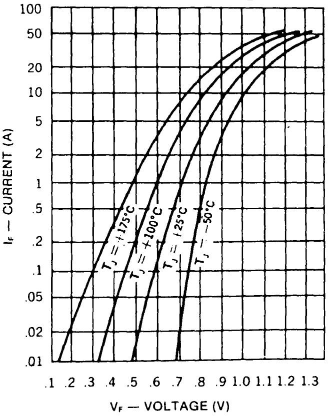
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

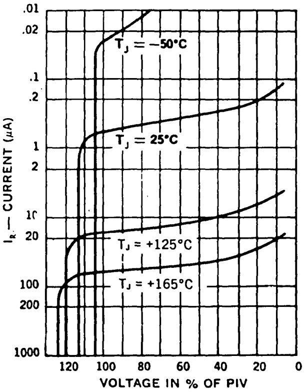
Output Current vs. Lead Temperature



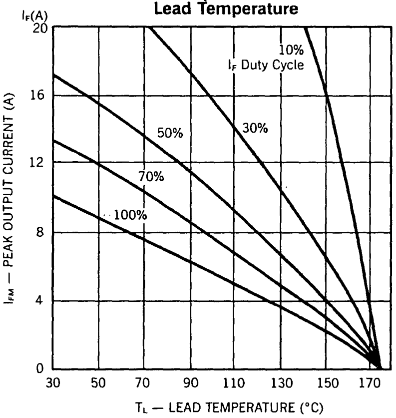
Typical Forward Current vs. Forward Voltage



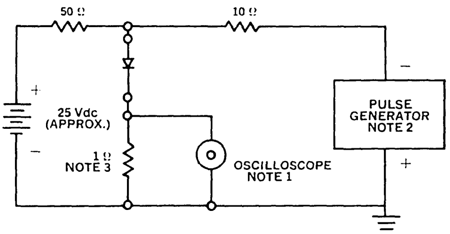
Typical Reverse Current vs. Voltage



Peak Output Current vs. Lead Temperature

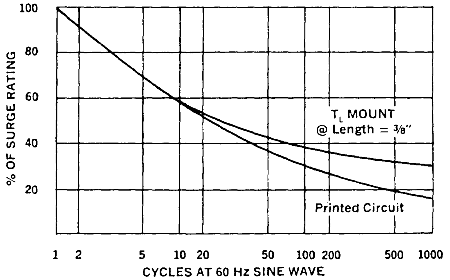


Reverse-Recovery Circuit

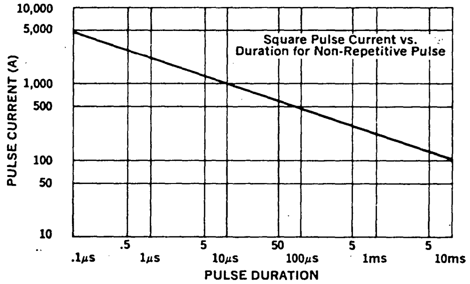


NOTES:
1. Oscilloscope: Rise time<3nS; input impedance = 50Ω.
2. Pulse Generator: Rise time<8nS; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Multiple Surge Current vs. Duration



Forward Pulse Current vs. Duration

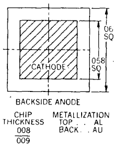


RECTIFIERS
High Efficiency, 5A

UES1304
UES1305
UES1306

FEATURES

- Very Low Forward Voltage (1.15V)
- Very Fast Recovery Times (50nSec)
- Small Size
- High Surge



DESCRIPTION

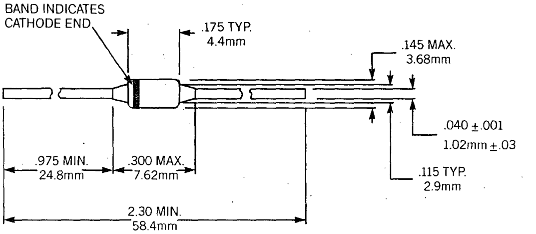
The UES1304 series is specifically designed for operation in power switching circuits operating at frequencies of at least 20 KHz.

ABSOLUTE MAXIMUM RATINGS

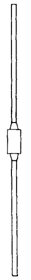
Peak Inverse Voltage, UES1304	200V
Peak Inverse Voltage, UES1305	300V
Peak Inverse Voltage, UES1306	400V
Maximum Average DC Output Current, I_O	
@ T_A = 25°C (Free Air)	3A
@ T_L = 50°C, L = ⅜″	5A
Surge Current, 8.3mSec	70A
Thermal Resistance @ L = ⅜″	20°C/W
Operating and Storage Temperature Range	−55°C to +150°C

MECHANICAL SPECIFICATIONS

UES1304 UES1305 UES1306



BODY B



THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

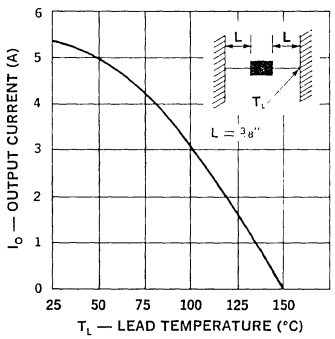
SEMICONDUCTOR
PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS

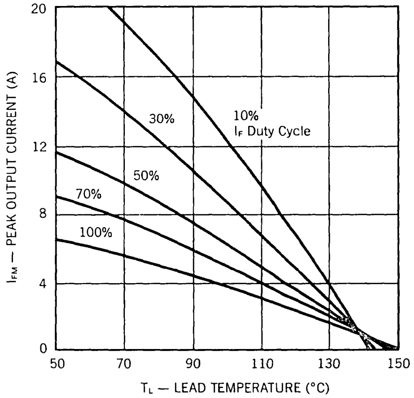
Type	PIV	Maximum Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
		$T_J = 25°C$	$T_J = 100°C$	@ PIV, $T_J = 25°C$	$T_J = 100°C$	
UES1304 UES1305 UES1306	200V 300V 400V	1.25V @3A tp = 300μS	1.15V @3A tp = 300μS	20μA	500μA	50nS

* Measured in circuit $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$

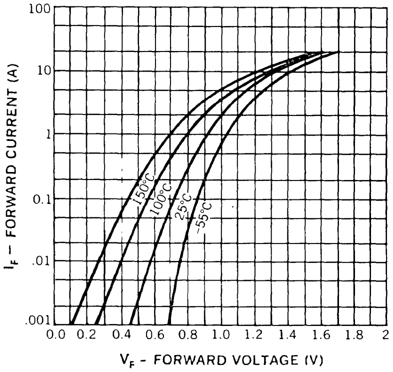
Output Current vs. Lead Temperature



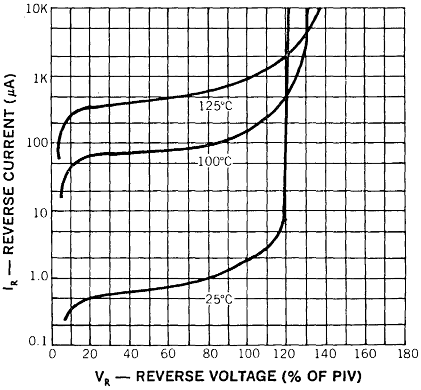
Peak Output Current vs. Lead Temperature



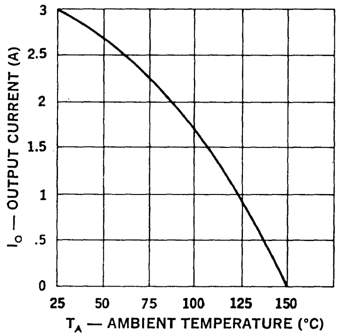
Typical Forward Current vs. Forward Voltage



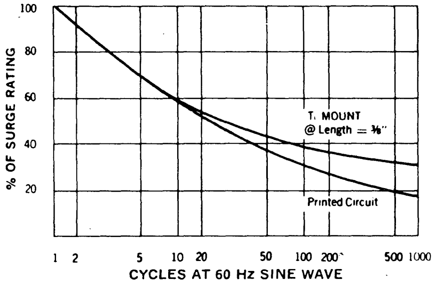
Typical Reverse Current vs. Reverse Voltage



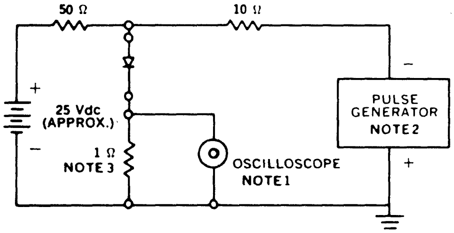
Output Current vs Ambient Temperature



Multiple Surge Current vs. Duration



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 7A and 8A

UES1401 BYW29-50 BYW80-50
UES1402 BYW29-100 BYW80-100
UES1403 BYW29-150 BYW80-150
UES1404 BYW29-200 BYW80-200

FEATURES
- Very Low Forward Voltage
- Very Fast Recovery Times
- Economical, Convenient Plastic Package
- Low Thermal Resistance
- Mechanically Rugged

DESCRIPTION
The UES1400/BYW29/BYW80 Series, in a plastic package similar to the TO-220, is specifically designed for operation in power switching circuits to frequencies in excess of 100KHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS

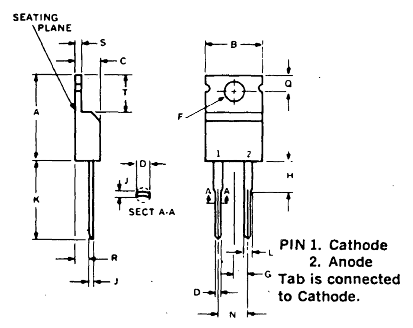
	UES1401	UES1402	UES1403	UES1404
Peak Inverse Voltage, V_R	50V	100V	150V	200V
Repetitive Peak Inverse Voltage, V_{RWM}	50V	100V	150V	200V
Non-Repetitive Peak Inverse Voltage, V_{RSM}	50V	100V	150V	200V
Maximum Average D.C. Output Current, I_O				
@ T_C = 125°C, (Note 1)	8.0A			
@ T_A = 25°C	3.0A			
@ T_A = 25°C, (Note 2)	8.0A			
Non-Repetitive Sinusoidal Surge Current at 8.3 ms, I_{FSM}	80A			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.5°C/W			
Thermal Resistance, Junction to Ambient, $R_{\theta JA}$	60°C/W			
Storage Temperature Range, T_{STG}	−55°C to +150°C			
Maximum Operating Junction Temperature, T_{jmax}	+150°C			

Note 1. Above 100°C use the tab for electrical connection.
Note 2. Using Wakefield Type 295 heatsink with convection cooling. For more definitive data refer to the Output Current vs. Temperature Curves on this datasheet.

	BYW29-50	BYW29-100	BYW29-150	BYW29-200	BYW80-50	BYW80-100	BYW80-150	BYW80-200
Peak Inverse Voltage, V_R	50V	100V	150V	200V	50V	100V	150V	200V
Repetitive Peak Inverse Voltage, V_{RWM}	50V	100V	150V	200V	50V	100V	150V	200V
Non-Repetitive Peak Inverse Voltage, V_{RSM}	50V	100V	150V	200V	50V	100V	150V	200V
Maximum Average D.C. Output Current								
@ T_C = 125°C, (Note 1)	7.0A				7.0A			
Non-Repetitive Sinusoidal Surge Current at 8.3ms,	80A				100A			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.5°C/W							
Thermal Resistance, Junction to Ambient, $R_{\theta JA}$	60°C/W							
Operating and Storage Temperature Range	−55°C to +150°C							
Maximum Operating Junction Temperature, T_{jmax}	+150°C							

Note 1. Above 100°C use the tab for electrical connection.

MECHANICAL SPECIFICATIONS

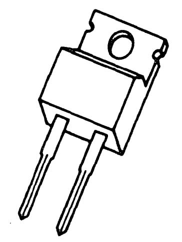


PIN 1. Cathode
2. Anode
Tab is connected to Cathode.

UES1401 SERIES
BYW29 SERIES
BYW80 SERIES

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AC

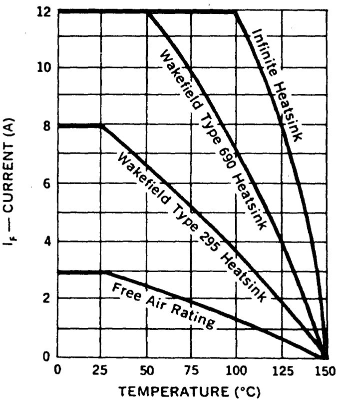


ELECTRICAL SPECIFICATIONS

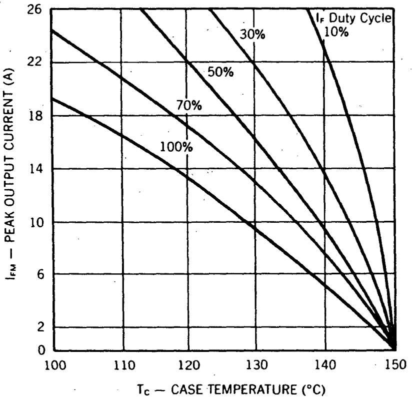
Type	Maximum Reverse Voltage V_R	Maximum Forward Voltage, V_F		Maximum Reverse Current, I_R @ rated V_R		Maximum Reverse Recovery Time	Typical Forward Recovery Voltage @ 1A	Typical Forward Recovery Charge
		T_J = 25°C	T_J = 100°C	T_J = 25°C	T_J = 100°C	T_{rr}	T_R = 8nS	Q_{RR} @ 25°
UES1401 UES1402 UES1403 UES1404	50V 100V 150V 200V	0.9V @ 4A 0.975V @ 8A tp = 300µS	0.8V @ 4A 0.895V @ 8A	5µA	150µA 150µA 150µA 500µA	35nS[1]	1.4V	—
BYW29-50 BYW29-100 BYW29-150 BYW29-200	50V 100V 150V 200V	1.300V @ 20A	0.850V @ 5A	—	600µA	35nS[2]	1.4V	—
BYW80-50 BYW80-100 BYW80-150 BYW80-200	50V 100V 150V 200V	1.25V @ 22A	0.850V @ 7A	10µA	1mA	35nS[2]	—	15nc[3]

NOTES: 1. Measured in circuit I_F = 0.5A, I_R = 1.0A, I_{REC} = 0.25A
2. Measured in circuit I_F = 1A to $V_R \geq$ 30V, di_F/dt = 50A/µS
3. Measured in circuit I_F = 2A, $V_R \leq$ 30V, di_F/dt = −20A/µS

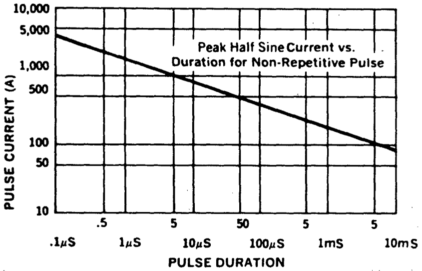
Output Current vs Temperature



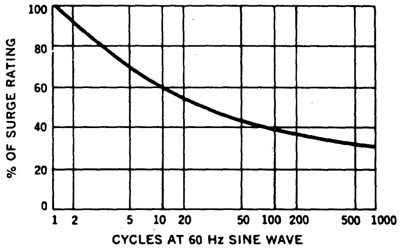
Peak Output Current vs Case Temperature

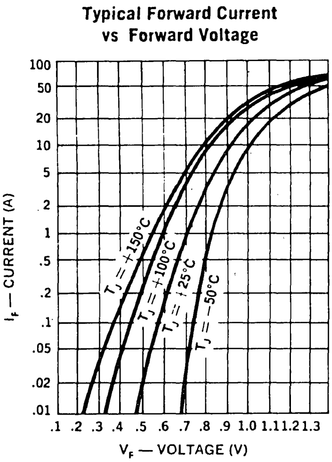


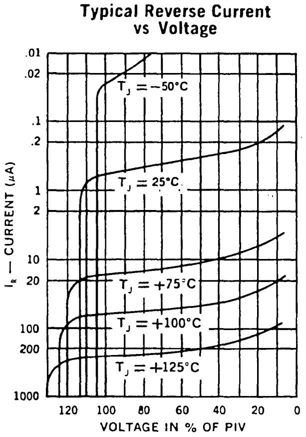
Forward Pulse Current vs. Duration

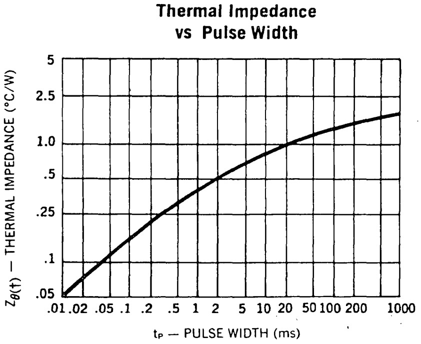


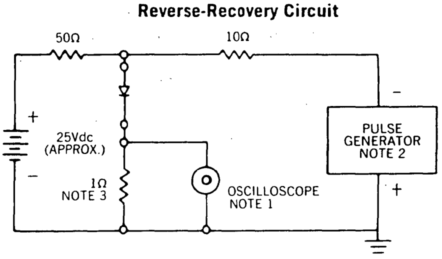
Multiple Surge Current vs. Duration











NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 16A

UES1501
UES1502
UES1503
UES1504

FEATURES

- Very Low Forward Voltage
- Very Fast Recovery Times
- Economical, Convenient TO-220 Package
- Low Thermal Resistance
- Mechanically Rugged

DESCRIPTION

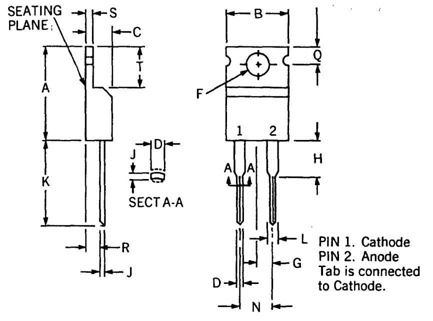
The UES1500 Series, in the economical, convenient TO-220 package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, UES1501	50V
Peak Inverse Voltage, UES1502	100V
Peak Inverse Voltage, UES1503	150V
Peak Inverse Voltage, UES1504	200V
Maximum Average D.C. Output Current	
@ $T_C = 100°C$	16A
@ $T_A = 25°C$	3.3A
@ $T_A = 25°C$ (Note 1)	10.0A
Non-Repetitive Sinusoidal Surge Current, 8.3ms	300A
Thermal Resistance, Junction to Case, θ_{J-C}	1.5°C/W
Thermal Resistance, Junction to Ambient, θ_{J-A}	60°C/W
Operating and Storage Temperature	−55°C to +150°C

Note: 1. Using Wakefield Type 295 heatsink with convection cooling. For more definitive data refer to the Output Current vs Temperature Curve on this data sheet.

MECHANICAL SPECIFICATIONS

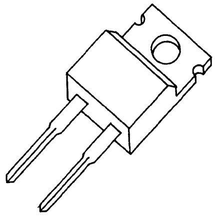


PIN 1. Cathode
PIN 2. Anode
Tab is connected to Cathode.

UES1501-UES1504

	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.560	0.625	14.23	15.87
B	0.380	0.420	9.66	10.66
C	0.140	0.190	3.56	4.82
D	0.020	0.045	0.51	1.14
F	0.139	0.147	3.531	3.733
G	0.090	0.110	2.29	2.79
H	—	0.250	—	6.35
J	0.015	0.025	0.38	0.64
K	0.500	0.562	12.70	14.27
L	0.045	0.070	1.14	1.77
N	0.190	0.210	4.83	5.33
Q	0.100	0.120	2.54	3.04
R	0.080	0.115	2.04	2.92
S	0.045	0.055	1.14	1.39
T	0.230	0.270	5.85	6.85

TO-220AC



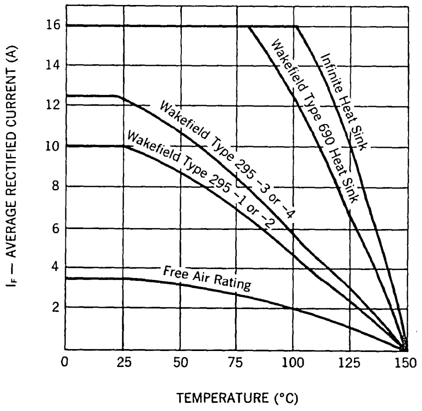
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS

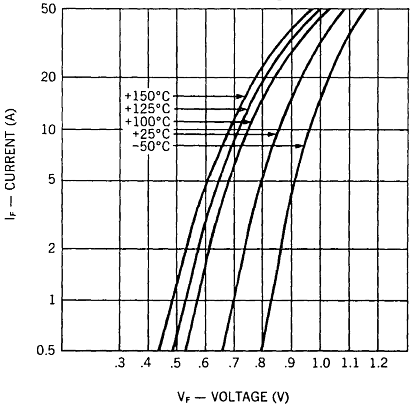
Type	PIV	Maximum Forward Voltage		Maximum Reverse Current @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A t_r = 8ns
		T_J = 25°C	T_J = 100°C	T_J = 25°C	T_J = 100°C		
UES1501	50V	.975V @ 16A	.895V @ 16A	10μA	800μA	35ns	2.0V
UES1502	100V						
UES1503	150V	1.10V @ 32A	1.0V @ 32A				
UES1504	200V						

* Measured in circuit $I_F = {}^1/_2$A, I_R = 1.0A, $I_{REC} = {}^1/_4$A

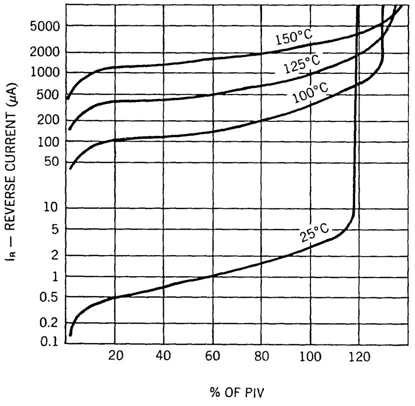
Output Current vs Temperature



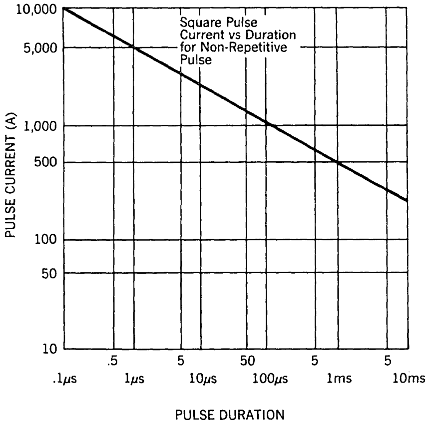
Typical Forward Current vs Forward Voltage

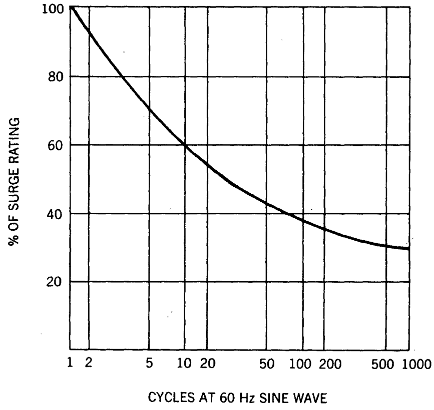


Typical Reverse Current vs Voltage

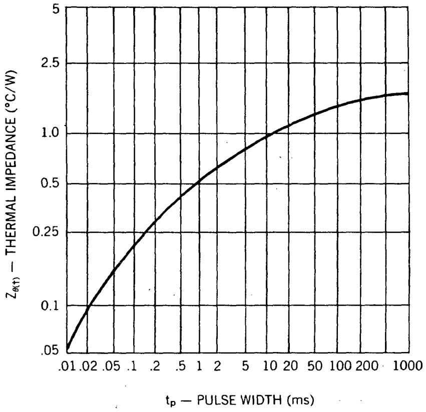


Forward Pulse Current vs Duration

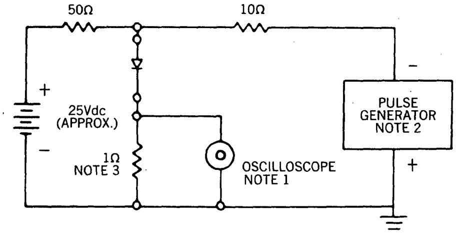




Multiple Surge Current vs Duration



Thermal Impedance vs Pulse Width



Reverse-Recovery Circuit

NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 16A Center-Tap

UES2401-UES2404

FEATURES

- Very Low Forward Voltage
- Very Fast Recovery Times
- Economical, Convenient TO-220AB Package
- Low Thermal Resistance
- Mechanically Rugged
- PIV up to 200V

DESCRIPTION

The UES2401 Series in the economical, convenient TO-220AB package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The series combines two high efficiency devices into one package, simplifying installation, reducing heatsink requirements and the need to purchase matched components.

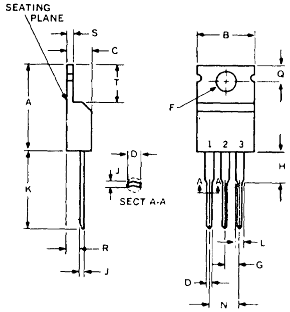
ABSOLUTE MAXIMUM RATINGS

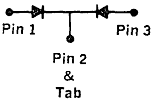
Peak Inverse Voltage, UES2401	50V
Peak Inverse Voltage, UES2402	100V
Peak Inverse Voltage, UES2403	150V
Peak Inverse Voltage, UES2404	200V
Maximum Average D.C. Output Current	
@ T_C = 125°C (Note 1)	16A
@ T_A = 25°C	3A
@ T_A = 25°C (Note 2)	10A
Non-Repetitive Sinusoidal Surge Current, 8.3ms	80A
Thermal Resistance, Junction to Case, $\theta_{J\text{-}C}$	1.75°C/W
Thermal Resistance, Junction to Ambient, $\theta_{J\text{-}A}$	60°C/W
Operating and Storage Temperature Range	−55°C to +150°C

Note 1. Above 8A use the tab for electrical connection.
Note 2. Using Wakefield Type 295 heatsink with convection cooling. For more definitive data refer to the Output Current vs. Temperature Curves on this datasheet.

MECHANICAL SPECIFICATIONS

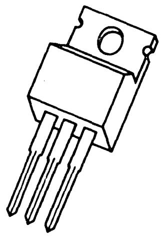
UES2401-2404





	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.560	0.625	14.23	15.87
B	0.380	0.420	9.66	10.66
C	0.140	0.190	3.56	4.82
D	0.020	0.045	0.51	1.14
F	0.139	0.147	3.531	3.733
G	0.090	0.110	2.29	2.79
H	—	0.250	—	6.35
J	0.015	0.025	0.38	0.64
K	0.500	0.562	12.70	14.27
L	0.045	0.070	1.14	1.77
N	0.190	0.210	4.83	5.33
Q	0.100	0.120	2.54	3.04
R	0.080	0.115	2.04	2.92
S	0.045	0.055	1.14	1.39
T	0.230	0.270	5.85	6.85

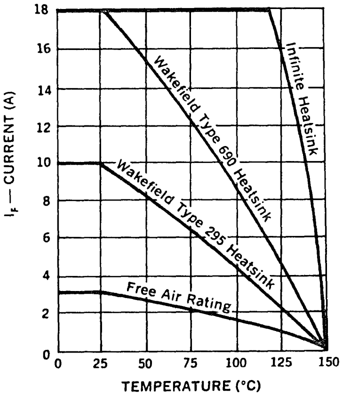
TO-220AB

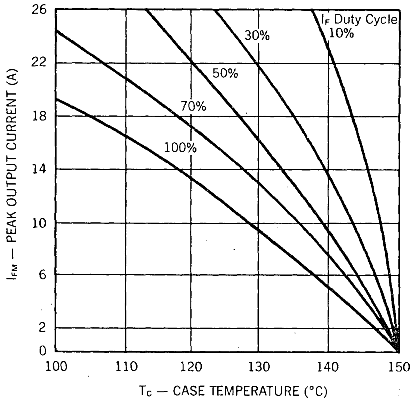


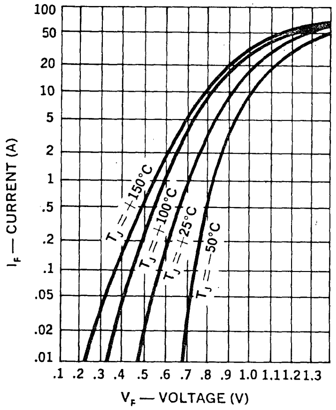
ELECTRICAL SPECIFICATIONS

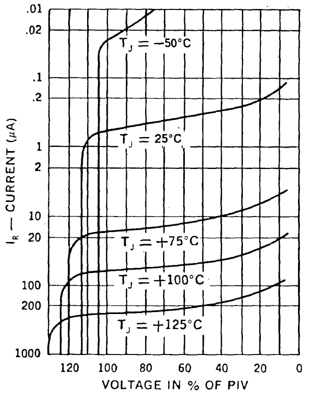
Type	PIV	Maximum Forward Voltage @		Maximum Reverse Current @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A $t_r = 8ns$
		$T_J = 25°C$	$T_J = 100°C$	$T_J = 25°C$	$T_J = 100°C$		
UES2401	50V	0.9V@ 4A 0.975 @ 8A tp = 300µs	0.8V @ 4A 0.895 @ 8A	5µA	150µA	35ns	1.4V
UES2402	100V				150µA		
UES2403	150V				150µA		
UES2404	200V				500µA		

*Measured in circuit $I_F = 0.5A$, $I_R = 1.0A$, $I_{REC} = 0.25A$

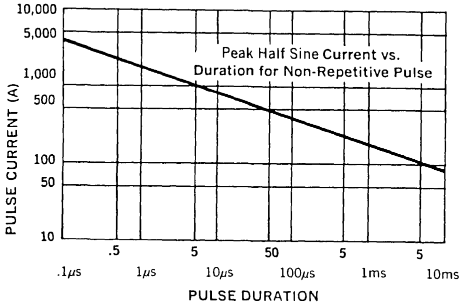

Output Current vs Temperature


Peak Output Current vs Case Temperature

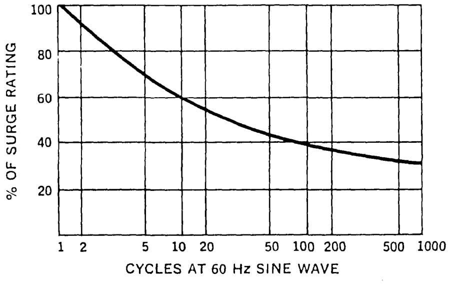

Typical Forward Current vs Forward Voltage


Typical Reverse Current vs Voltage

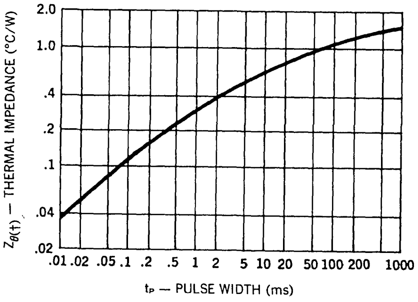
Forward Pulse Current vs Duration



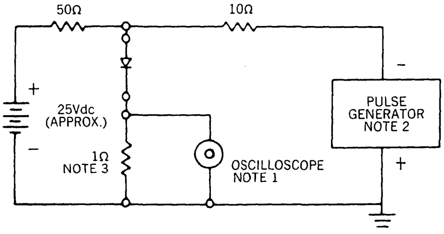
Multiple Surge Current vs Duration



Thermal Impedance vs Pulse Width



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 30A Center-Tap

UES2601
UES2602
UES2603
UES2601HR2
UES2602HR2
UES2603HR2

FEATURES
- Very Low Forward Voltage
- Very Fast Switching Speed
- Convenient Package
- High Surge
- Low Thermal Resistance
- Mechanically Rugged
- Both Polarities Available

DESCRIPTION
This series combines two high efficiency devices into one package, simplifying installation, reducing heat sink requirements and the need to purchase matched components.

ABSOLUTE MAXIMUM RATINGS

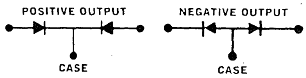
Peak Inverse Voltage, UES2601, UES2601HR2	50V
Peak Inverse Voltage, UES2602, UES2602HR2	100V
Peak Inverse Voltage, UES2603, UES2603HR2	150V
Maximum Average D.C. Output Current at T_C = 100°C	30A
Non-Repetitive Sinusoidal Surge Current 8.3 ms	400A
Thermal Resistance, Junction to Case	1°C/W
Operating and Storage Temperature Range	−55°C to +175°C

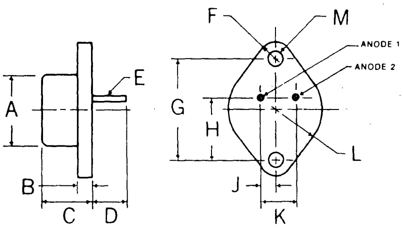
POWER CYCLING
These devices possess the unique ability to pass many thousands of cycles of a stress test designed to evaluate the integrity of the bonding systems used in the construction of power rectifiers.

In this stress test, the case of the device is not heat sunk. Full rated forward current is supplied to force a case temperature increase at least 75°C, at which time, the current is removed and the case allowed to cool. The cycle is repeated a minimum of 5,000 times to simulate equipment being turned on and off. Extended power cycling tests demonstrate a product capability in excess of 25,000 cycles.

SWITCHING CHARACTERISTICS
The switching times of these ultra-fast rectifiers increase relatively little, with temperature or at different currents. Even in severe applications, such as catch diodes for switching regulators and output rectifiers for high frequency square wave inverters, these devices switch many times faster than the fastest associated transistors. Thus, the stresses on and powers dissipated in the switching transistors are substantially less than when using other rectifiers.

MECHANICAL SPECIFICATIONS

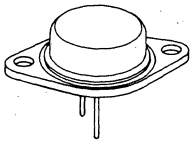




UES2601 UES2601HR2 **UES2602 UES2602HR2** **UES2603 UES2603HR2**

	ins.	mm.
A	.875 MAX.	22.23 MAX.
B	.135 MAX.	3.43 MAX.
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.038-.043 DIA.	0.97-1.09 DIA.
F	.188 MAX. RAD.	4.78 MAX. RAD.
G	1.177-1.197	29.90-30.40
H	.655-.675	16.64-17.15
J	.205-.225	5.21-5.72
K	.420-.440	10.67-11.18
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.151-.161 DIA.	3.84-4.09 DIA.

TO-204AA (TO-3)



Note:
Standard polarity is positive output.
For reverse polarity (negative output) add suffix "R", ie. UES2601R.

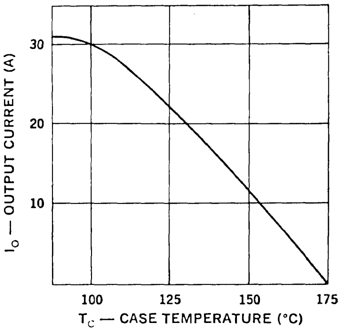
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS

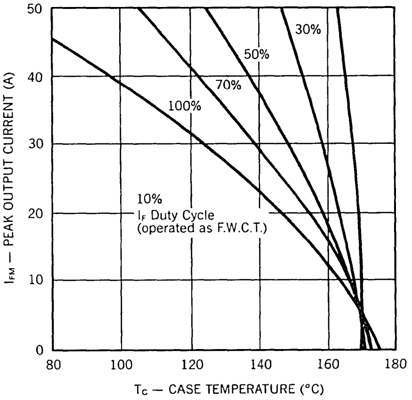
Type	PIV	Maximum Forward Voltage @		Maximum Reverse Current @		Maximum Reverse Recovery Time*
		$T_C = 25°C$	$T_C = 125°C$	$T_C = 25°C$	$T_C = 125°C$	
UES2601/2601HR2 UES2602/2602HR2 UES2603/2603HR2	50V 100V 150V	.930V @ 15A $t_p = 300\mu S$	.825V @ 15A $t_p = 300\mu S$	$20\mu A$	4mA	35nS

* Measured in circuit $I_F = 0.5A$, $I_R = 1A$, $I_{REC} = 0.25A$

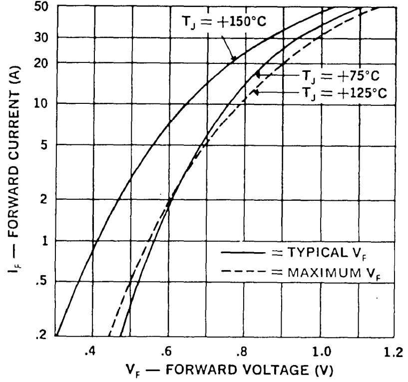
Output Current vs. Case Temperature



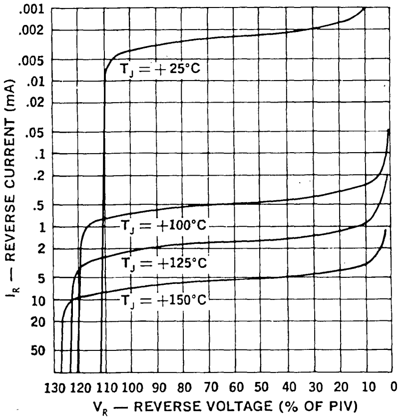
Peak Output Current vs. Case Temperature

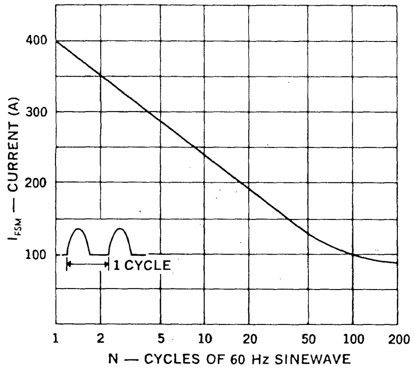


Forward Current vs. Forward Voltage

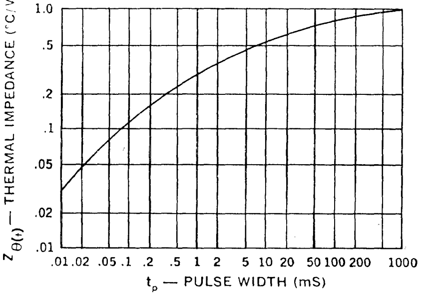


Typical Reverse Current vs. Reverse Voltage



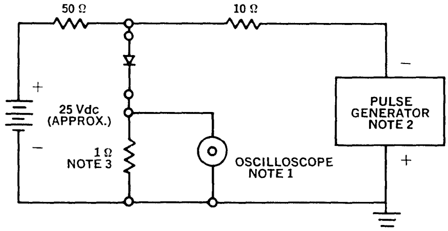


Maximum Forward Surge vs. Number of Cycles



Thermal Impedance vs. Pulse Width

Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UES2601HR2, 2HR2, 3HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Thermal Shock (Temperature Cycling)	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. at extremes.
3. Hermetic Seal a. Fine b. Gross	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Bias (HTRB)	1038	A, 48 Hours, T_C = 125°C, V_R = 80% of rating
7. Final Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C

RECTIFIERS

High Efficiency, 30A Center-Tap

UES2604
UES2605
UES2606
UES2604HR2
UES2605HR2
UES2606HR2

FEATURES

- Very Low Forward Voltage (1.15V)
- Very Fast Recovery Times (50nSec)
- Low Profile Package
- High Surge Capability
- Low Thermal Resistance
- Mechanically Rugged
- Both Polarities Available

DESCRIPTION

The UES2604 series is specifically designed for operation in power switching circuits operating at frequencies of at least 20 KHz.

This series combines two high efficiency devices into one package, simplifying installation, reducing heat sink requirements and the need to purchase matched components.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, UES2604, UES2604HR2	200V
Peak Inverse Voltage, UES2605, UES2605HR2	300V
Peak Inverse Voltage, UES2606, UES2606HR2	400V
Maximum Average D.C. Output Current @ T_C = 100°C	30A
Surge Current, 8.3mS	300A
Thermal Resistance, Junction to Case	1°C/W
Operating and Storage Temperature Range	−55°C to +150°C

POWER CYCLING

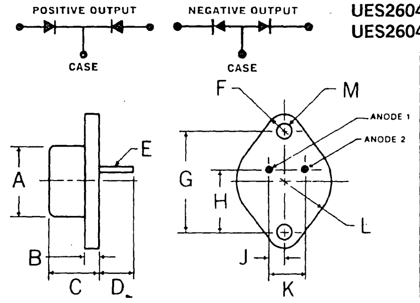
These devices possess the unique ability to pass many thousands of cycles of a stress test designed to evaluate the integrity of the bonding systems used in the construction of power rectifiers.

In this stress test, the case of the device is not heat sunk. Full rated forward current is supplied to force a case temperature increase at least 75°C, at which time, the current is removed and the case allowed to cool. The cycle is repeated a minimum of 5,000 times to simulate equipment being turned on and off. Extended power cycling tests demonstrate a product capability in excess of 25,000 cycles.

SWITCHING CHARACTERISTICS

The switching times of these ultra-fast rectifiers increase relatively little, with temperature or at different currents. Even in severe applications, such as catch diodes for switching regulators and output rectifiers for high frequency square wave inverters, these devices switch many times faster than the fastest associated transistors. Thus, the stresses on and powers dissipated in the switching transistors are substantially less than when using other rectifiers.

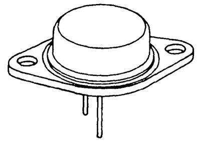
MECHANICAL SPECIFICATIONS



UES2604 UES2605 UES2606
UES2604HR2 UES2605HR2 UES2606HR2

	ins.	mm.
A	.875 MAX.	22.23 MAX.
B	.135 MAX.	3.43 MAX.
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.038-.043 DIA.	0.97-1.09 DIA.
F	.188 MAX. RAD.	4.78 MAX. RAD.
G	1.177-1.197	29.90-30.40
H	.655-.675	16.64-17.15
J	.205-.225	5.21-5.72
K	.420-.440	10.67-11.18
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.151-.161 DIA.	3.84-4.09 DIA.

TO-204AA (TO-3)



Note:
Standard polarity is positive output.
For reverse polarity (negative output) add suffix "R", ie. UES2604R.

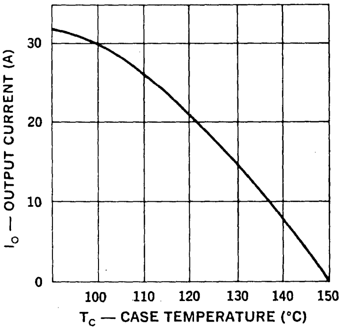
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS, PER LEG

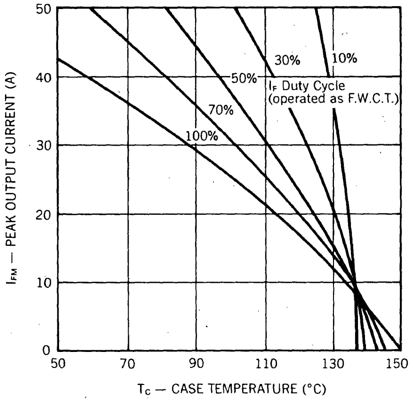
Type	PIV	Maximum Forward Voltage		Maximum Reverse Current		Maximum Reverse Recovery Time*
		$T_C = 25°C$	$T_C = 125°C$	$T_C = 25°C$	$T_C = 125°C$	
UES2604/2604HR2	200V	1.25V @ 15A $t_p = 300\mu S$	1.15V @ 15A $t_p = 300\mu S$	50μA	10mA	50nS
UES2605/2605HR2	300V					
UES2606/2606HR2	400V					

*Measured in circuit I_F = .5A, I_R =1A, I_{REC} = .25A

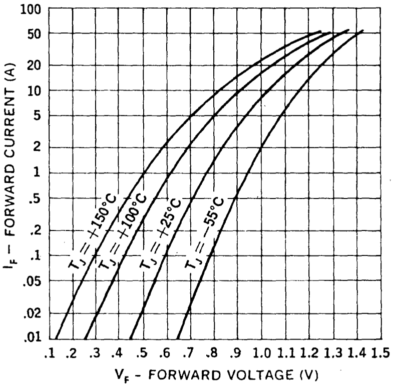
Output Current vs. Case Temperature



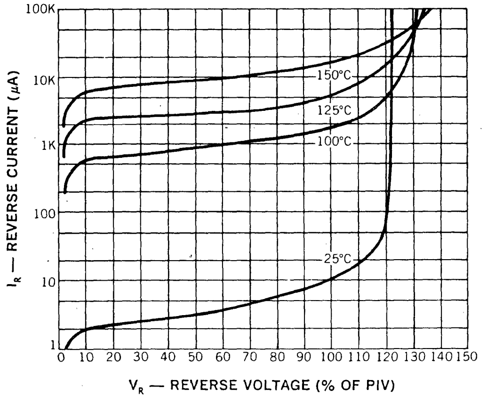
Peak Output Current vs. Case Temperature



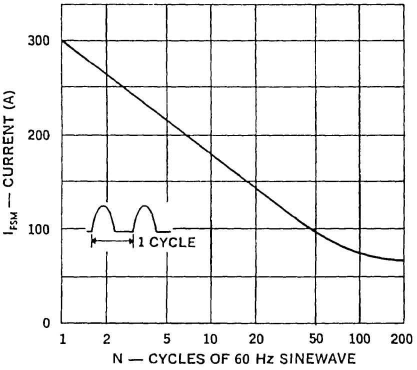
Forward Current vs. Forward Voltage



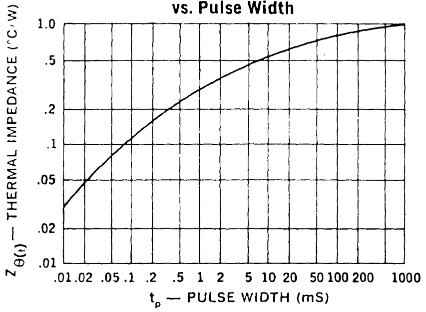
Typical Reverse Current vs. Reverse Voltage



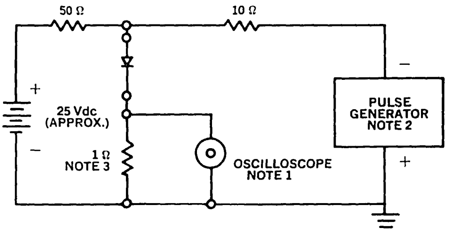
Maximum Forward Surge vs. Number of Cycles



Thermal Impedance vs. Pulse Width



Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UES2604HR2, 5HR2, 6HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, T_C = 125°C, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

RECTIFIERS
High Efficiency, 30A Centertap, 50-150V

UES3005C
UES3010C
UES3015C

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Ultra-Fast Recovery Time
- Extremely Low V_F

DESCRIPTION

The UES3005C Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

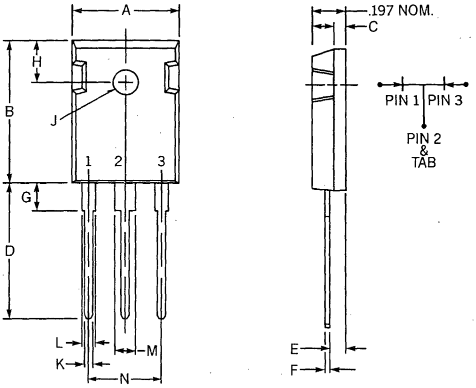
ABSOLUTE MAXIMUM RATINGS, either leg unless noted		**UES3005C**	**UES3010C**	**UES3015C**
Peak Inverse Voltage	V_R, V_{RWM}, V_{RRM}	50V	100V	150V
Maximum Average D.C. Output Current @ T_C = 125°C, full wave operation (see curves)	$I_{F(AV)}$		30A	
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}		300A	
Thermal Resistance Junction to Case	$R_{\theta J-C}$		1.5°C/W	
Thermal Resistance Junction to Case both legs together, full wave	$R_{\theta J-C}$		0.9°C/W	
Thermal Resistance Junction to Ambient either leg, or both legs together	$R_{\theta J-A}$		40°C/W	
Operating and Storage Temperature Range	T_{OP}, T_{STG}		−55°C to +150°C	

ELECTRICAL SPECIFICATIONS

Type	PIV	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A T_R = 14ns
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
UES3005C UES3010C UES3015C	50V 100V 150V	1.0 @ 15A 1.1 @ 30A	0.9 @ 15A 1.0 @ 30A	15μA	5mA	35ns	2.0V

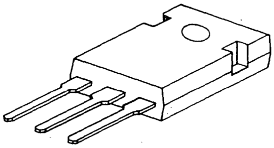
* Measured in circuit I_F = 0.50A, I_{RM} = 1.0A, I_{REC} = 0.25A.

MECHANICAL SPECIFICATIONS



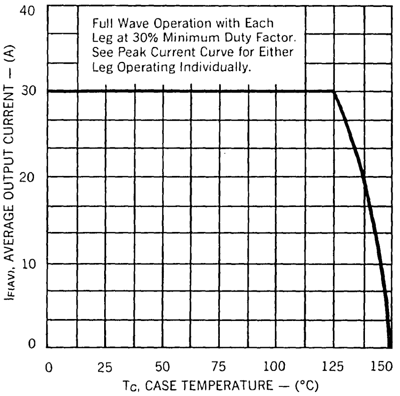
DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
M	.113	.123
N	.430 Nom.	

TO-3P

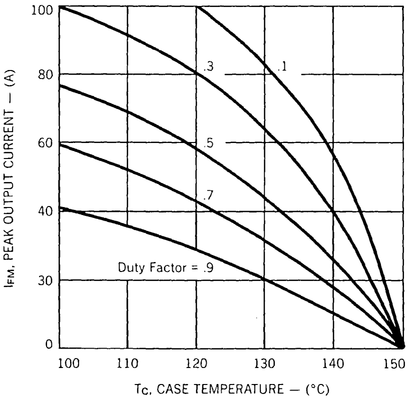


SEMICONDUCTOR PRODUCTS
UNITRODE

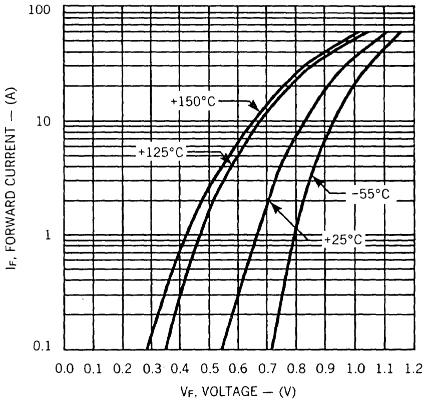
Average Output Current vs Case Temperature



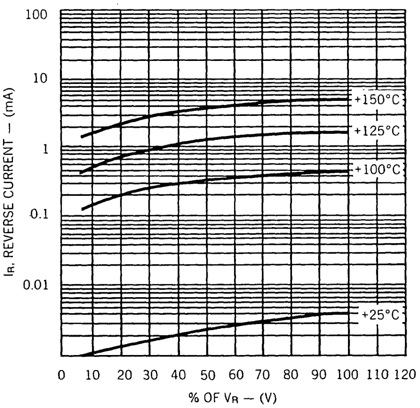
Peak Output Current vs Case Temperature (Either Leg)



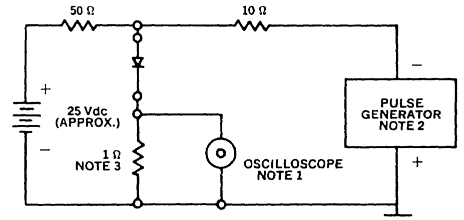
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Voltage



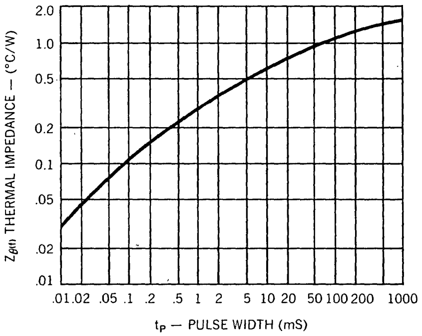
Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Thermal Impedance vs Pulse Width (Each Leg)



RECTIFIERS
High Efficiency, 30A, 50-150V

UES3005S
UES3010S
UES3015S

FEATURES
- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Ultra-Fast Recovery Time

DESCRIPTION
The UES3005S Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

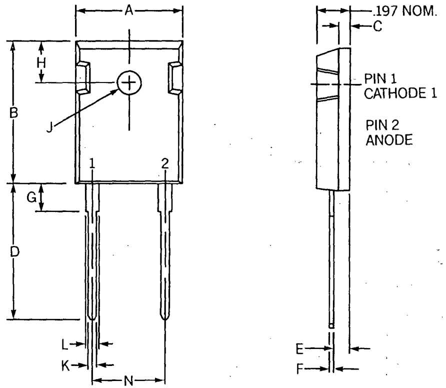
ABSOLUTE MAXIMUM RATINGS		UES3005S	UES3010S	UES3015S
Peak Inverse Voltage	V_R, V_{RWM}, V_{RRM}	50V	100V	150V
Maximum Average D.C. Output Current @ T_C = 115°C	$I_{F(AV)}$	30A		
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}	400A		
Thermal Resistance Junction to Case	$R_{\theta J\text{-}C}$	1.2°C/W		
Thermal Resistance Junction to Ambient	$R_{\theta J\text{-}A}$	40°C/W		
Operating and Storage Temperature Range	T_{OP}, T_{STG}	−55°C to +150°C		

ELECTRICAL SPECIFICATIONS

Type	PIV	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A T_R = 14ns
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
UES3005S UES3010S UES3015S	50V 100V 150V	1.1 @ 30A 1.3 @ 60A	1.0 @ 30A 1.25 @ 60A	15μA	5mA	35ns	2.0V

* Measured in circuit I_F = 0.50A, I_{RM} = 1.0A, I_{REC} = 0.25A.

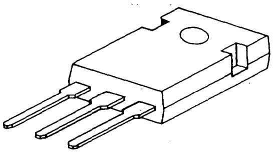
MECHANICAL SPECIFICATIONS



DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
N	.430 Nom.	

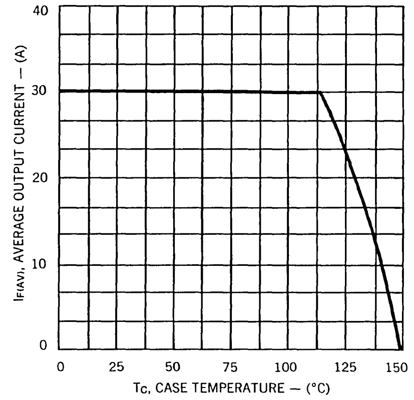
1. Mounting surface common to cathode

TO-3P

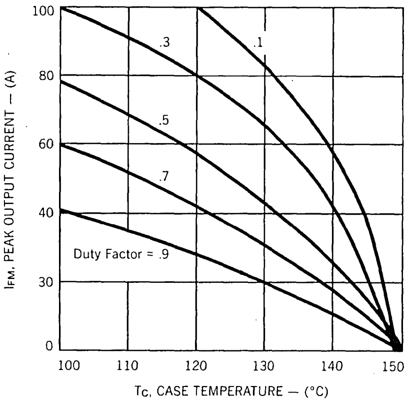


SEMICONDUCTOR PRODUCTS
UNITRODE

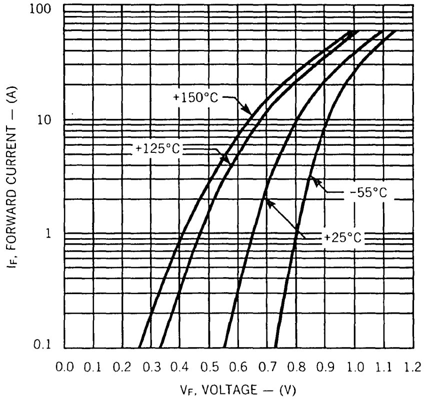
Average Output Current vs Case Temperature



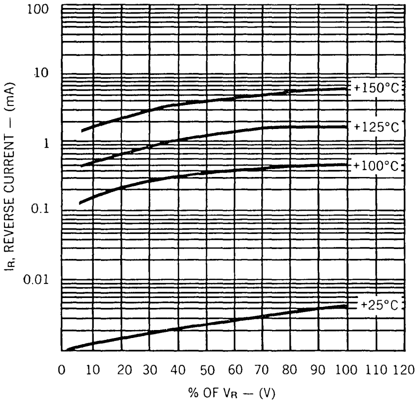
Peak Output Current vs Case Temperature



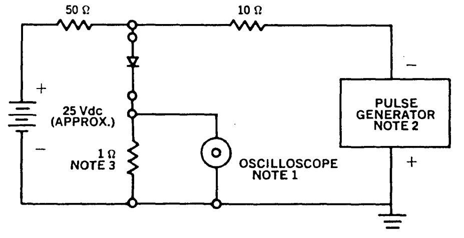
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Voltage



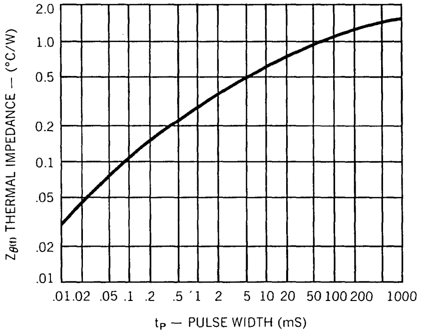
Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Thermal Impedance vs Pulse Width



RECTIFIERS
High Efficiency, 45A Centertap, 50 - 150V

UES4505C
UES4510C
UES4515C

FEATURES

- Low Forward Voltage
- Fast Recovery Times
- Economical Convenient TO-3P Package
- Low Thermal Resistance
- Mechanically Rugged
- PIV up to 150V

DESCRIPTION

The UES4505C Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS, either leg unless noted

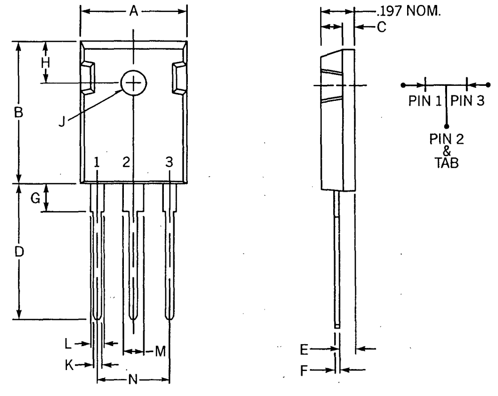
		UES4505C	**UES4510C**	**UES4515C**
Peak Inverse Voltage	V_R, V_{RWM}, V_{RRM}	50V	100V	150V
Maximum Average D.C. Output Current @ T_C = 125°C, full wave operation (see curves)	$I_{F(AV)}$		45A	
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}		450A	
Thermal Resistance Junction to Case	$R_{\theta J\text{-}C}$		0.8°C/W	
Thermal Resistance Junction to Case both legs together, full wave	$R_{\theta J\text{-}C}$		0.6°C/W	
Thermal Resistance Junction to Ambient either leg, or both legs together	$R_{\theta J\text{-}A}$		40°C/W	
Operating and Storage Temperature Range	T_{OP}, T_{STG}		−55°C to +150°C	

ELECTRICAL SPECIFICATIONS

Type	PIV	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A t_r = 14ns
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
UES4505C UES4510C UES4515C	50V 100V 150V	1.1 @ 45A 1.0 @ 22.5A	1.0 @ 45A .88 @ 22.5A	20μA	10mA	50ns	2.0V

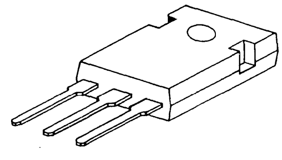
* Measured in circuit I_F = 0.50A, I_{RM} = 1.0A, I_{REC} = 0.25A.

MECHANICAL SPECIFICATIONS



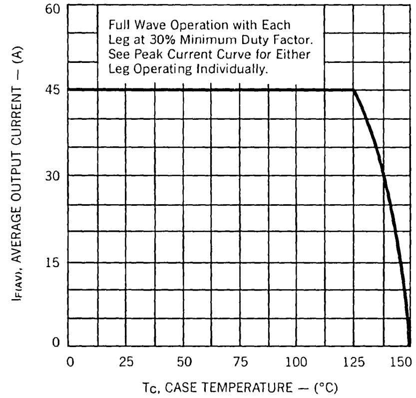
DIM.	INCHES MIN.	MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
M	.113	.123
N	.430 Nom.	

TO-3P

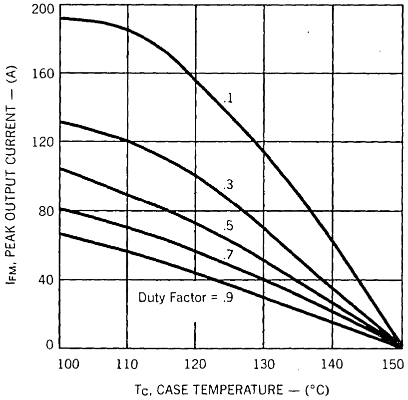


SEMICONDUCTOR PRODUCTS
UNITRODE

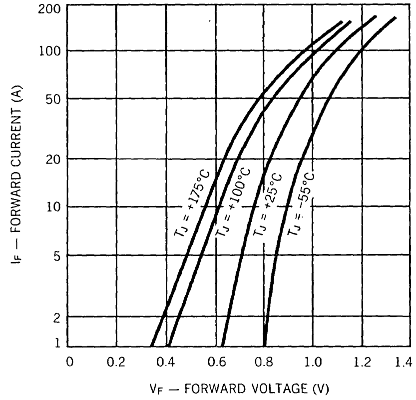
Average Output Current vs Case Temperature



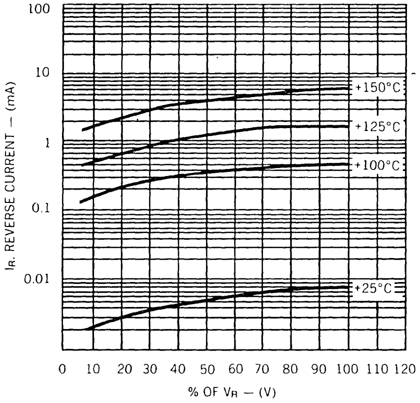
Peak Output Current vs Case Temperature (Either Leg)



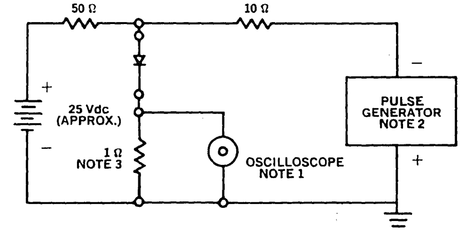
Forward Current vs Forward Voltage



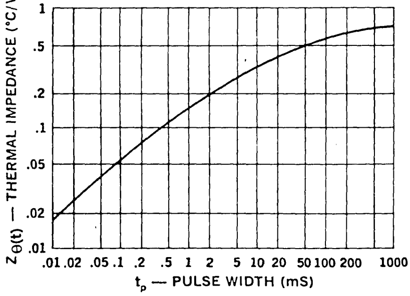
Typical Reverse Current vs Voltage



Reverse-Recovery Circuit



Thermal Impedance vs Pulse Width (Each Leg)



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
High Efficiency, 45A, 50-150V

UES4505S
UES4510S
UES4515S

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Ultra-Fast Recovery Time

DESCRIPTION

The UES4505S Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and very fast recovery time make them particularly suited for switching type power supplies.

ABSOLUTE MAXIMUM RATINGS

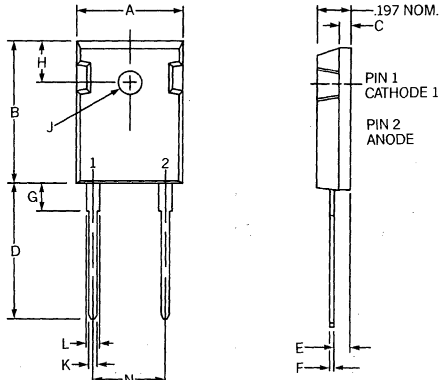
		UES4505S	UES4510S	UES4515S
Peak Inverse Voltage	V_R, V_{RWM}, V_{RRM}	50V	100V	150V
Maximum Average D.C. Output Current @ T_C = 110°C	$I_{F(AV)}$		45A	
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}		450A	
Thermal Resistance Junction to Case	$R_{\theta J-C}$		0.8°C/W	
Thermal Resistance Junction to Ambient	$R_{\theta J-A}$		40°C/W	
Operating and Storage Temperature Range	T_{OP}, T_{STG}		−55°C to +150°C	

ELECTRICAL SPECIFICATIONS

Type	PIV	Maximum Forward Volatge (V_F)		Maximum Reverse Current (I_R) @ PIV		Maximum Reverse Recovery Time*	Typical Forward Recovery Voltage @ 1A T_R = 14ns
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
UES4505S UES4510S UES4515S	50V 100V 150V	1.1 @ 45A 1.3 @ 90A	1.0 @ 45A 1.20 @ 90A	20μA	10mA	50ns	2.0V

* Measured in circuit I_F = 0.50A, I_{RM} = 1.0A, I_{REC} = 0.25A.

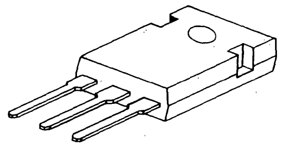
MECHANICAL SPECIFICATIONS



DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
N	.430 Nom.	

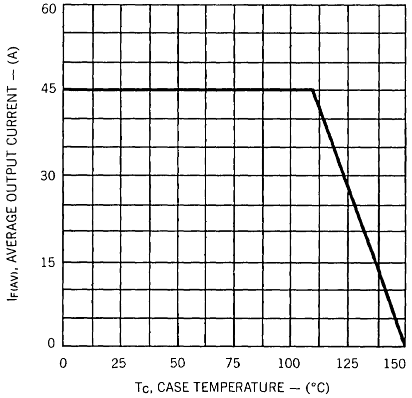
1. Mounting surface common to cathode

TO-3P

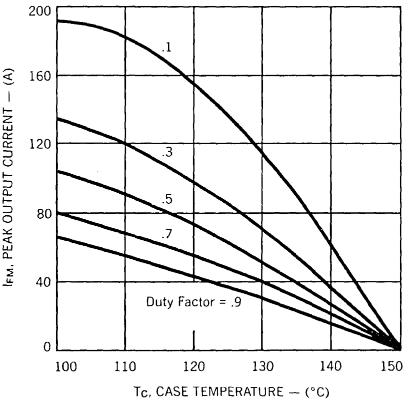


SEMICONDUCTOR PRODUCTS
UNITRODE

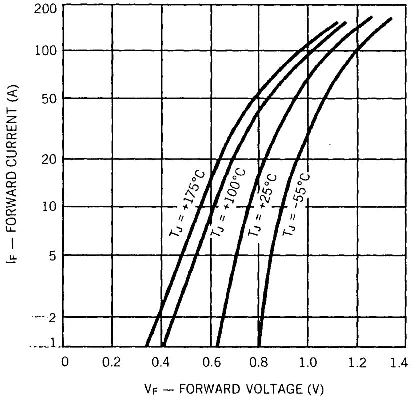
Average Output Current vs Case Temperature



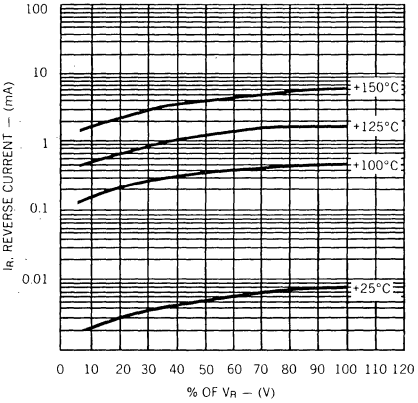
Peak Output Current vs Case Temperature



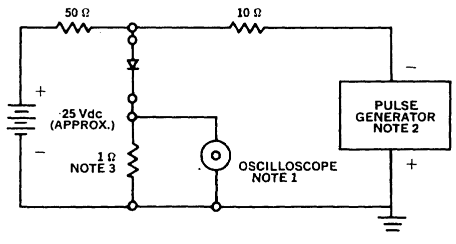
Forward Current vs Forward Voltage



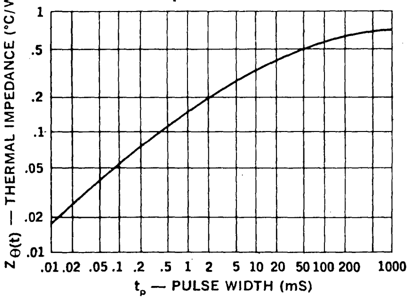
Typical Reverse Current vs Voltage



Reverse-Recovery Circuit



Thermal Impedance vs Pulse Width



NOTES:

1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIERS
HIGH RELIABILITY, HVPlus™ SERIES
2.0 AMPS

FEATURES

- Ultra Fast Recovery Time
- Controlled Avalanche
- High Temperature Operation with Low Loss
- Minimal Recovery Transients
- Low Capacitance
- Low Turn-On Voltage
- Non-Cavity Metallurgically Bonded Package

DESCRIPTION

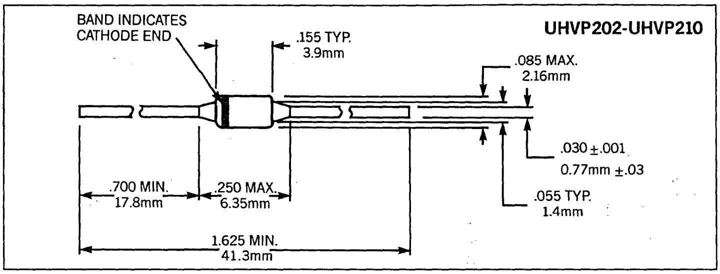
This state-of-the-art high efficiency rectifier is ideally suited for applications requiring high blocking voltage. It has the ability to switch significant current with minimal switching transients and losses. Leakage current at high junction temperatures has been minimized achieving exceptionally low reverse losses. An ultra stable process ensures high reliability and long life. This device is designed for a wide variety of applications including high frequency switching power supplies.

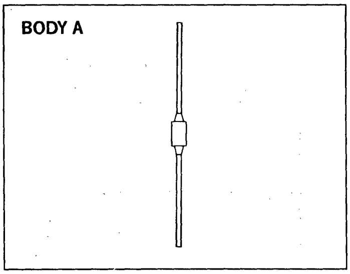
ABSOLUTE MAXIMUM RATINGS

TYPE NUMBER	REVERSE VOLTAGE	AVERAGE DC OUTPUT CURRENT $T_L = 55°C$, L=3/8″	AVERAGE DC OUTPUT CURRENT $T_A = 25°C$	PEAK FWD. SURGE CURRENT $t_p = 8.3ms$
UHVP202	200V	2.0A	1.2A	20A
UHVP204	400V	2.0A	1.2A	20A
UHVP206	600V	2.0A	1.2A	20A
UHVP208	800V	1.5A	1.0A	20A
UHVP209	900V	1.5A	1.0A	20A
UHVP210	1000V	1.5A	1.0A	15A

Operating and Storage Temperature Range −55°C to +150°C.
Thermal Resistance, θ_{JL}. See Lead Temperature Derating Curve.

MECHANICAL SPECIFICATIONS





Available in surface mount package; consult factory for information.

ELECTRICAL SPECIFICATIONS (AT 25°C UNLESS NOTED)

TYPE NUMBER	REVERSE BREAKDOWN VOLTAGE @50μA	FORWARD VOLTAGE	FORWARD VOLTAGE	REVERSE LEAKAGE $T_A=25°C$	REVERSE LEAKAGE $T_A=125°C$	REVERSE RECOVERY TIME 0.5A-1.0A-.25A*
UHVP202	220V	1.6V@2A	1.4V@1.2A	1.0μA	100μA	30ns
UHVP204	440V	1.6V@2A	1.4V@1.2A	1.0μA	100μA	30ns
UHVP206	660V	1.6V@2A	1.4V@1.2A	1.0μA	100μA	30ns
UHVP208	880V	1.8V@1.5A	1.55V@1.0A	1.0μA	100μA	50ns
UHVP209	990V	1.8V@1.5A	1.55V@1.0A	1.0μA	100μA	50ns
UHVP210	1100V	1.95V@1.5A	1.75V@1.0A	2.0μA	150μA	65ns

* See Figure 20 for characteristic waveform.

Typical Forward Current vs Forward Voltage

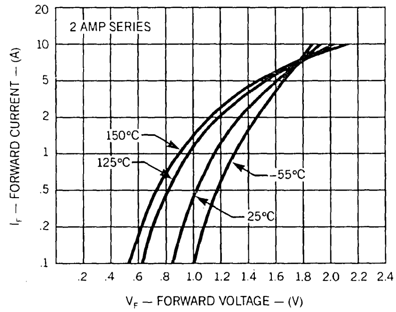


Figure 1

Typical Forward Current vs Forward Voltage

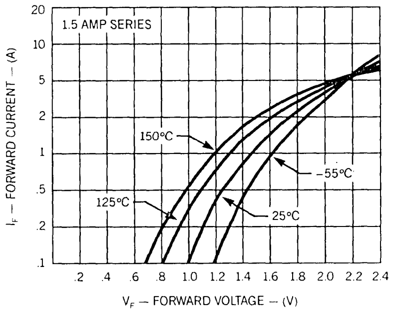


Figure 2

Typical Reverse Current vs Applied Reverse Voltage

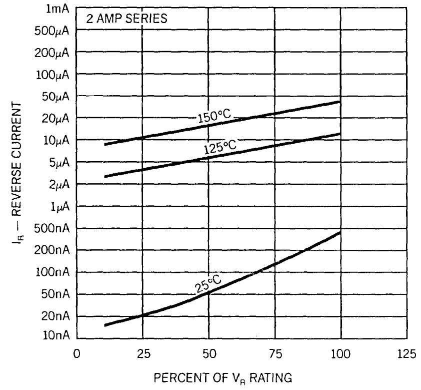


Figure 3

Typical Reverse Current vs Applied Reverse Voltage

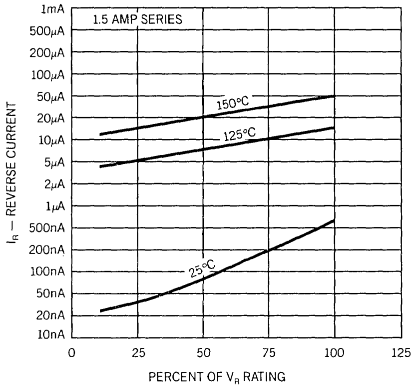
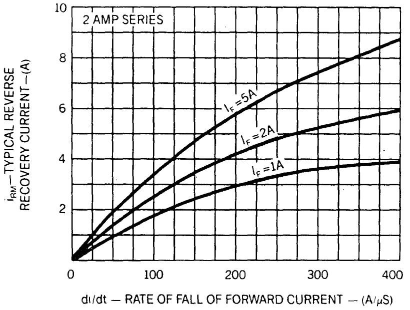


Figure 4

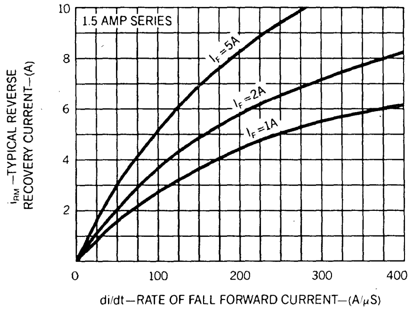
Reverse Recovery Current vs di/dt



NOTE: See Figures 9 and 10.

Figure 5

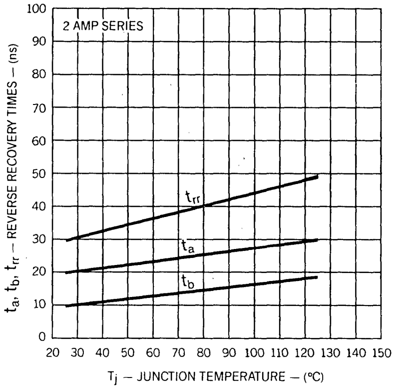
Reverse Recovery Current vs di/dt



NOTE: See Figures 9 and 10.

Figure 6

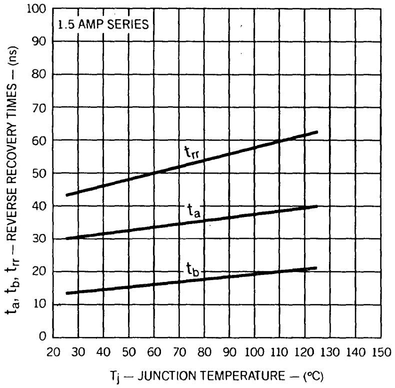
Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/μs, V_R = 50V)



NOTE: See Figures 9 and 10.

Figure 7

Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/μs, V_R = 50V)



NOTE: See Figures 9 and 10.

Figure 8

Rectifier Current During Reverse Recovery

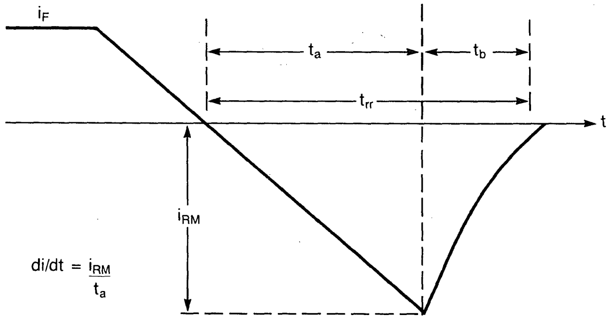
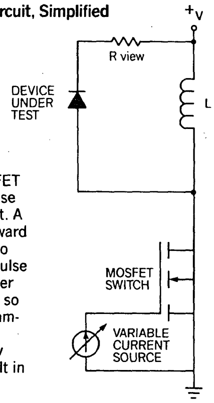


Figure 9

t_{rr}/I_{RM} Measurement Circuit, Simplified



NOTE: The gate of the MOSFET is double pulsed. The first pulse ramps up the inductor current. A short interpulse period forward biases the device under test to the desired I_F. The second pulse reverse biases the device under test creating the desired di/dt so that the reverse recovery parameters can be measured. The pulse pair is repeated at a low duty factor and does not result in device heating.

Figure 10

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

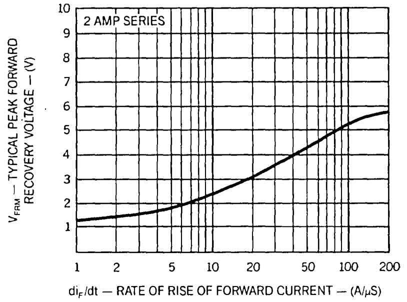


Figure 11

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

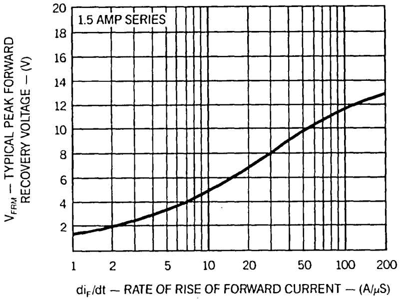


Figure 12

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

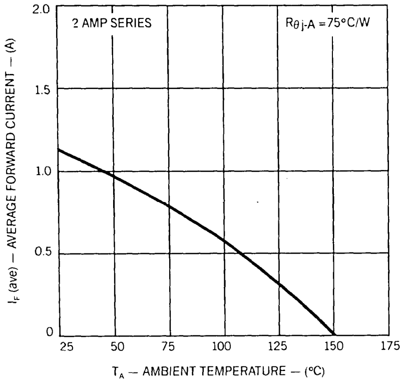


Figure 13

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

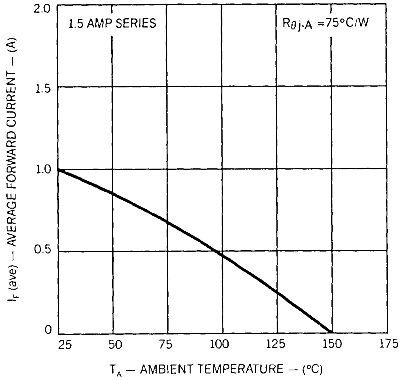


Figure 14

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

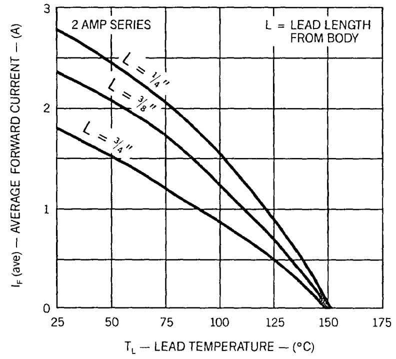


Figure 15

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

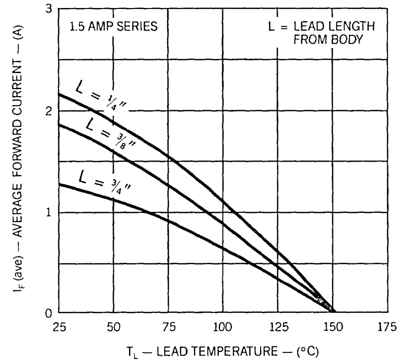


Figure 16

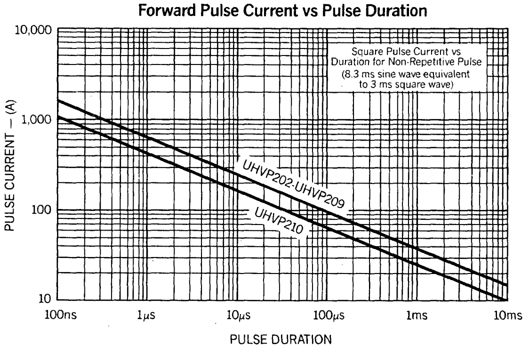


Figure 17

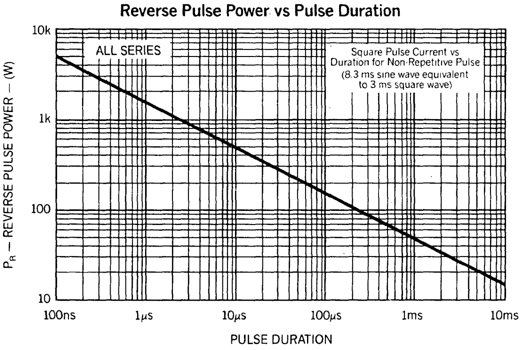


Figure 18

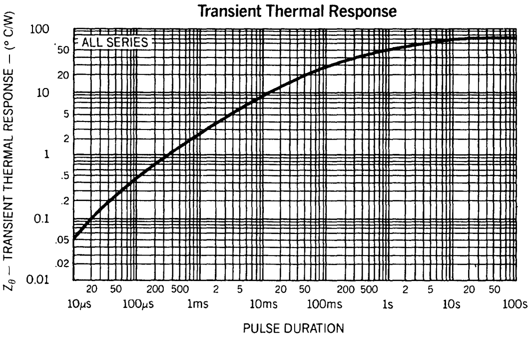


Figure 19

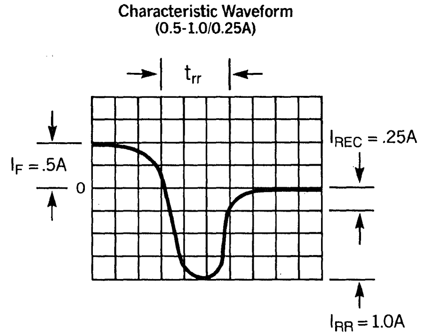


Figure 20

RECTIFIERS
HIGH RELIABILITY, HVPlus™ SERIES
4.0 AMPS

FEATURES

- Ultra Fast Recovery Time
- Controlled Avalanche
- High Temperature Operation with Low Loss
- Minimal Recovery Transients
- Low Capacitance
- Low Turn-On Voltage
- Non-Cavity Metallurgically Bonded Package

DESCRIPTION

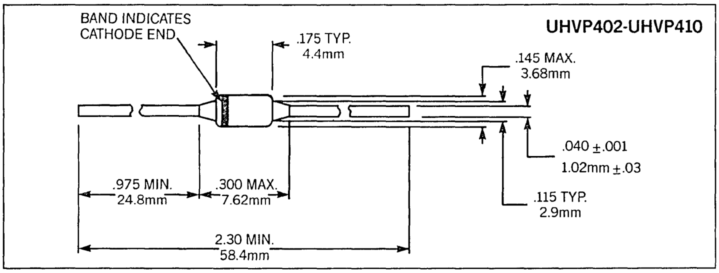
This state-of-the-art high efficiency rectifier is ideally suited for applications requiring high blocking voltage. It has the ability to switch significant current with minimal switching transients and losses. Leakage current at high junction temperatures has been minimized achieving exceptionally low reverse losses. An ultra stable process ensures high reliability and long life. This device is designed for a wide variety of applications including high frequency switching power supplies.

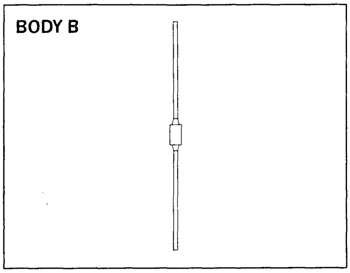
ABSOLUTE MAXIMUM RATINGS

TYPE NUMBER	REVERSE VOLTAGE	AVERAGE DC OUTPUT CURRENT T_L=55°C, L=3/8″	AVERAGE DC OUTPUT CURRENT T_A=25°C	PEAK FWD. SURGE CURRENT t_p=8.3ms
UHVP402	200V	4.0A	2.0A	75A
UHVP404	400V	4.0A	2.0A	75A
UHVP406	600V	4.0A	2.0A	75A
UHVP408	800V	3.0A	1.4A	75A
UHVP409	900V	3.0A	1.4A	75A
UHVP410	1000V	2.5A	1.4A	60A

Operating and Storage Temperature Range −55°C to +150°C.
Thermal Resistance, θ_{JL}. See Lead Temperature Derating Curve.

MECHANICAL SPECIFICATIONS





Available in surface mount package; consult factory for information.

ELECTRICAL SPECIFICATIONS (AT 25°C UNLESS NOTED)

TYPE NUMBER	REVERSE BREAKDOWN VOLTAGE @50μA	FORWARD VOLTAGE	FORWARD VOLTAGE	REVERSE LEAKAGE T_A=25°C	REVERSE LEAKAGE T_A=125°C	REVERSE RECOVERY TIME 0.5A-1.0A-.25A*
UHVP402	220V	1.5V@4.0A	1.35V@2.0A	4.0μA	250μA	30ns
UHVP404	440V	1.5V@4.0A	1.35V@2.0A	4.0μA	250μA	30ns
UHVP406	660V	1.5V@4.0A	1.35V@2.0A	4.0μA	250μA	30ns
UHVP408	880V	1.7V@3.0A	1.4V@1.4A	4.0μA	250μA	50ns
UHVP409	990V	1.7V@3.0A	1.4V@1.4A	4.0μA	250μA	50ns
UHVP410	1100V	1.95V@2.5A	1.6V@1.4A	5.0μA	500μA	65ns

* See Figure 20 for characteristic waveform.

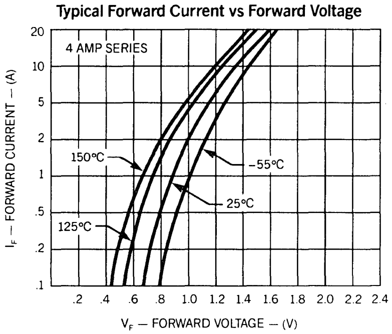

Typical Forward Current vs Forward Voltage

Figure 1

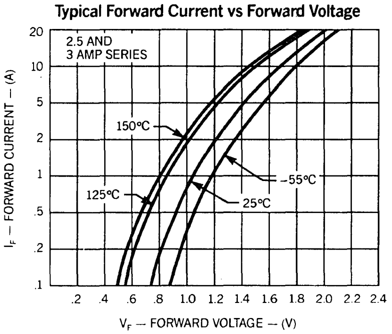

Typical Forward Current vs Forward Voltage

Figure 2

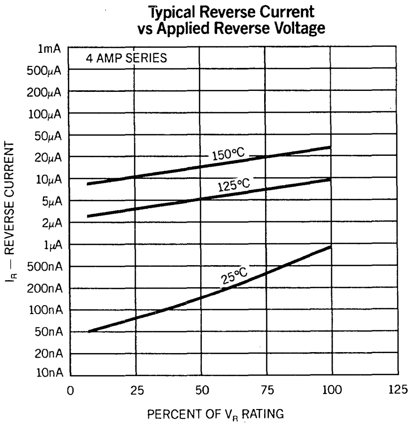

Typical Reverse Current vs Applied Reverse Voltage

Figure 3

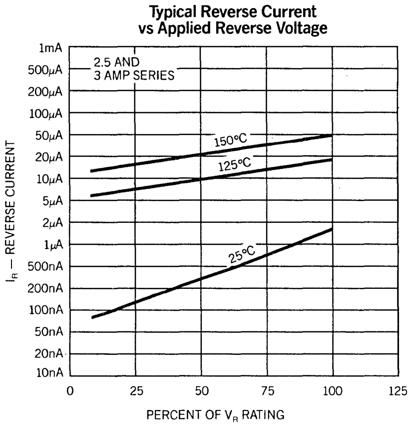
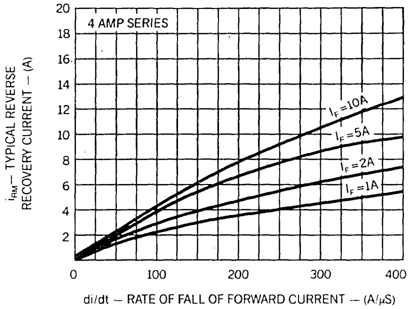

Typical Reverse Current vs Applied Reverse Voltage

Figure 4

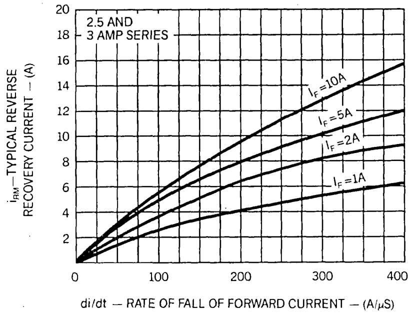
Reverse Recovery Current vs di/dt



NOTE: See Figures 9 and 10.

Figure 5

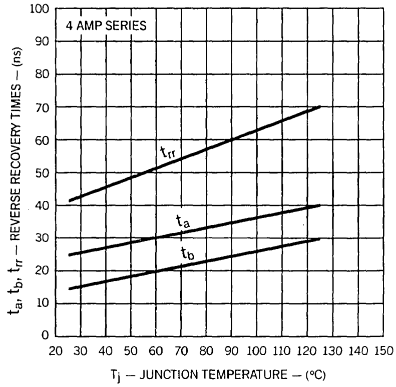
Reverse Recovery Current vs di/dt



NOTE: See Figures 9 and 10.

Figure 6

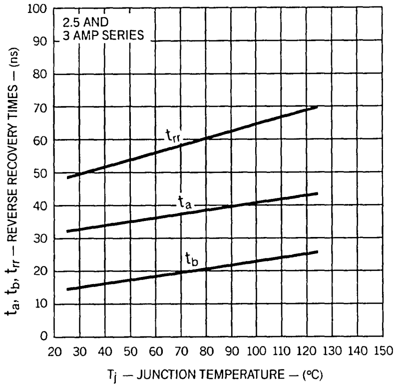
Reverse Recovery Time vs Junction Temperature
(i_F = 2A, di/dt = 200A/μs, V_R = 50V)



NOTE: See Figures 9 and 10.

Figure 7

Reverse Recovery Time vs Junction Temperature
I_F = 2A, di/dt = 200A/μs, V_R = 50V



NOTE: See Figures 9 and 10.

Figure 8

Rectifier Current During Reverse Recovery

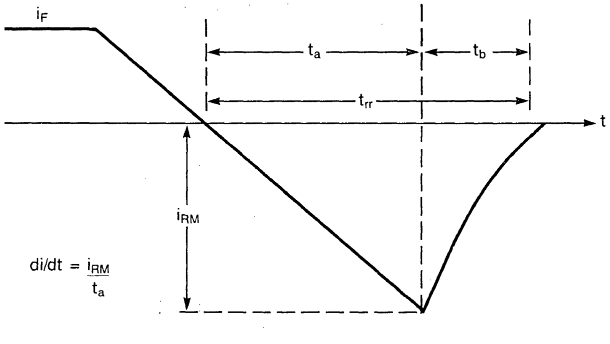
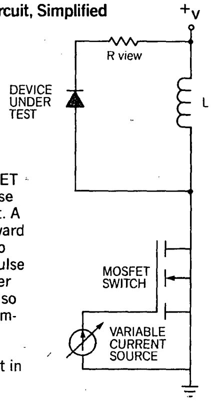


Figure 9

t_{rr}/I_{RM} Measurement Circuit, Simplified



NOTE: The gate of the MOSFET is double pulsed. The first pulse ramps up the inductor current. A short interpulse period forward biases the device under test to the desired I_F. The second pulse reverse biases the device under test creating the desired di/dt so that the reverse recovery parameters can be measured. The pulse pair is repeated at a low duty factor and does not result in device heating.

Figure 10

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

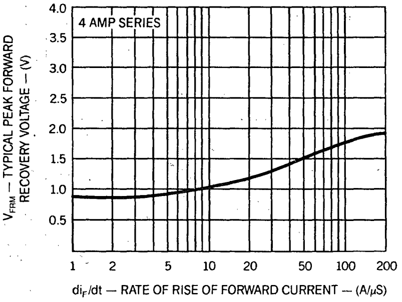


Figure 11

Typical Peak Forward Recovery Voltage vs di_F/dt
(i_F = 1A, di/dt measured from 10% to 90% of i_F)

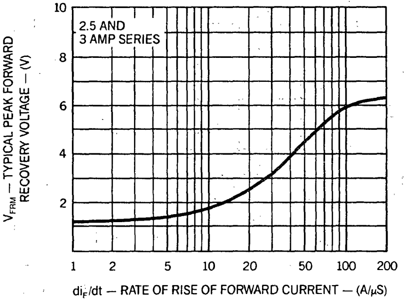


Figure 12

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

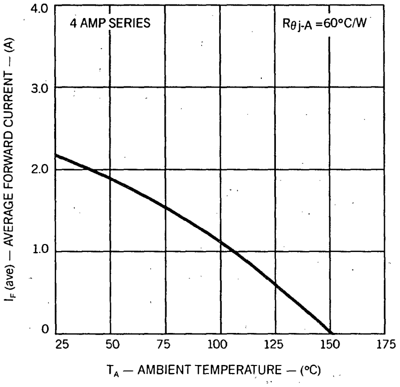


Figure 13

Average Forward Current vs Ambient Temperature
(50% Duty Cycle, Square Wave)

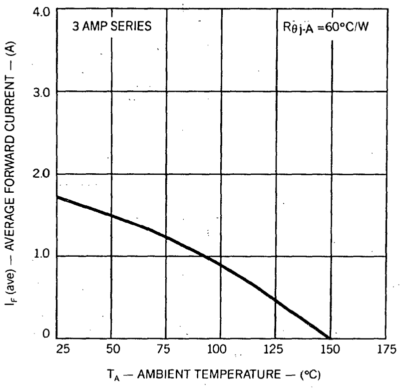


Figure 14

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

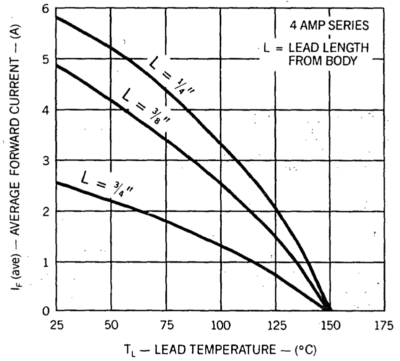


Figure 15

Average Forward Current vs Lead Temperature
(50% Duty Cycle, Square Wave)

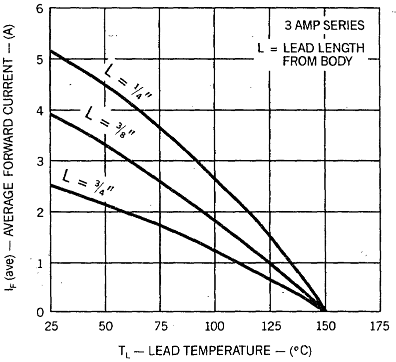


Figure 16

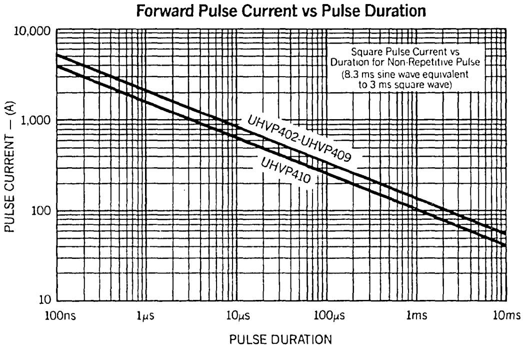


Figure 17

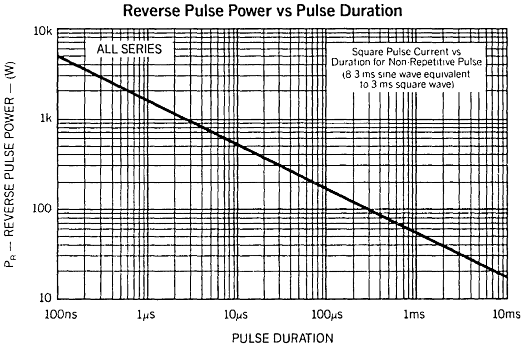


Figure 18

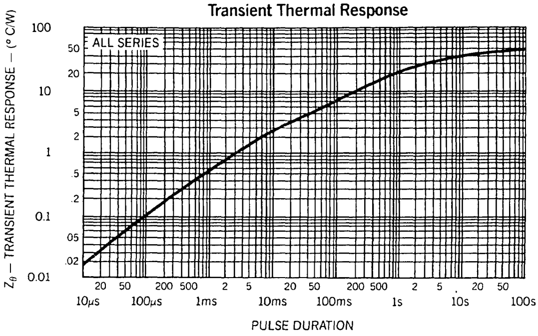


Figure 19

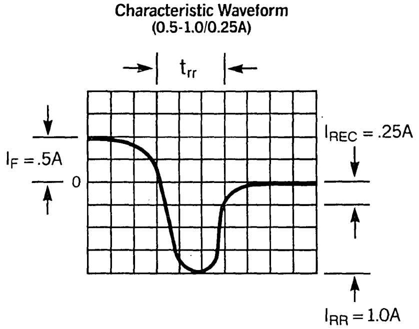


Figure 20

RECTIFIERS
Radiation Tolerant, 1 Amp-2 Amp

UR105-UR125
UR205-UR225

FEATURES
- Radiation Tolerant: to 10^{16} NVT
- Continuous Rating: to 2A
- Controlled Avalanche
- Surge Rating: to 25A
- Miniature Package

DESCRIPTION
These devices are particularly suited to applications where radiation is present. These units have unique ability to withstand high levels of neutron, gamma and electron radiation.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	1 Amp Series	2 Amp Series
50V	UR105	UR205
100V	UR110	UR210
150V	UR115	UR215
200V	UR120	UR220
250V	UR125	UR225

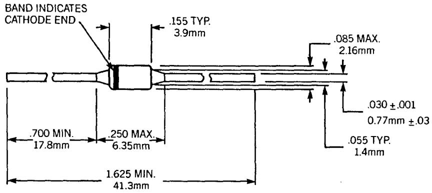
	1 AMP SERIES	2 AMP SERIES
Maximum Average D.C. Output Current		
@ $T_A = 25°C$	1A	2A
@ $T_A = 100°C$	0.5A	1A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	20A	25A
Operating Temperature Range	−195°C to +175°C	
Storage Temperature Range	−195°C to +200°C	
Thermal Resistance	See Lead Temperature Derating Curve	

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV		Maximum Radiation Tolerance
			25°C	100°C	
UR205	50V	1.0V @ 1A	3μA	50μA	10^{16} NVT
UR210	100V				10^{16}
UR215	150V				10^{15}
UR220	200V				10^{14}
UR225	250V				10^{14}
UR105	50V	1.0V @ 0.5A	3μA	50μA	10^{16}
UR110	100V				10^{16}
UR115	150V				10^{15}
UR120	200V				10^{14}
UR125	250V				10^{14}

MECHANICAL SPECIFICATIONS

UR105-UR125 UR205-UR225

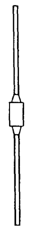


Part Identification: White band indicates "UR." Part number printed on body.

Polarity: Denoted by white band.

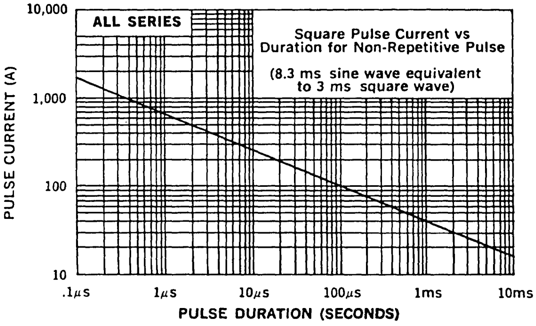
Weight: 0.26 grams, typical.

BODY A

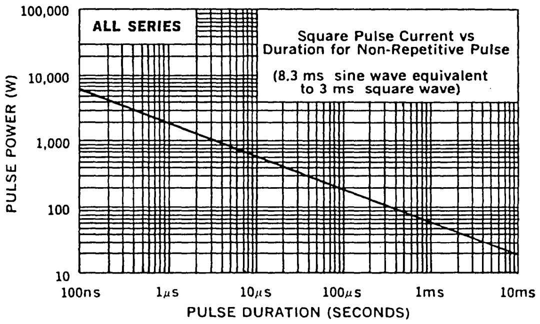


SEMICONDUCTOR PRODUCTS
UNITRODE

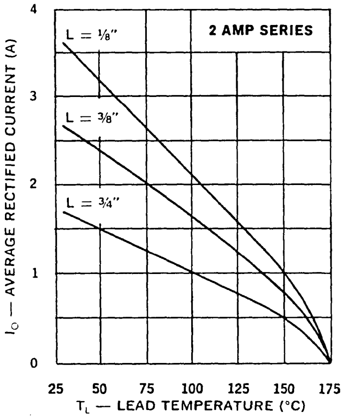
Forward Pulse Current vs Pulse Duration



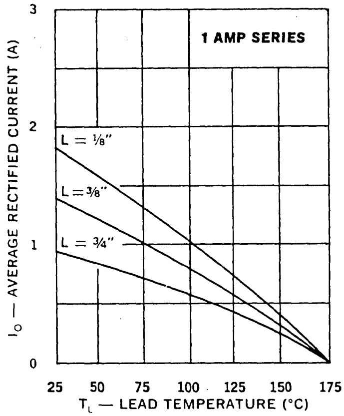
Reverse Pulse Power vs Pulse Duration



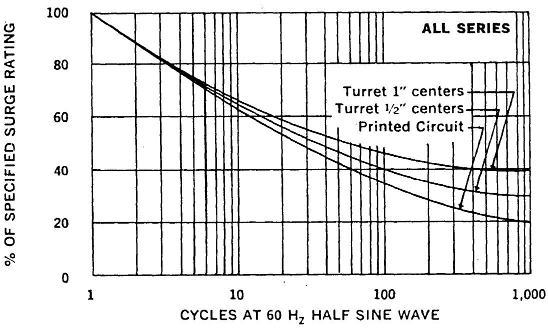
Maximum Current vs Lead Temperature



Maximum Current vs Lead Temperature



Allowable Forward Surge vs Number of Cycles



HERMETIC SCHOTTKY RECTIFIERS
6 Amp, 45 Volts

USD245C
USD245CHR2
USD245CR
USD245CRHR2

FEATURES

- MIL-S-19500 Type Screening Available
- Extremely Low V_F and I_R
- High Surge Capability
- Low Recovered Charge
- Rugged Hermetic Package, No Pressure Contacts
- Dual Rectifier in One Package
- Available in Reverse Polarity (CR)

DESCRIPTION

The USD245C series hermetic Schottky rectifier is ideally suited for output rectifiers and PWM protection in high efficiency, low voltage, high reliability switching power supplies. The series combines Schottky rectifiers in one convenient package; thus simplifying installation and reducing component parts count.

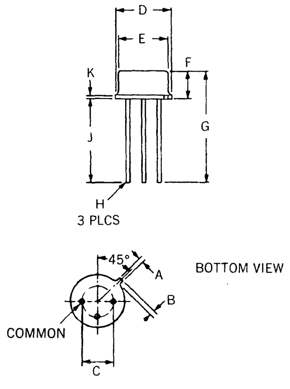
ABSOLUTE MAXIMUM RATINGS (Either leg, unless noted.)

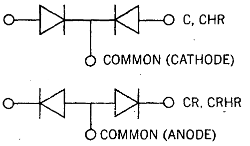
Peak Repetitive Reverse Voltage, V_{RRM} 45V
Working Peak Reverse Voltage, V_{RWM} 45V
DC Blocking Voltage, V_R 45V
Non-Repetitive Peak Reverse Voltage, V_{RSM} 54V
Average Forward Current (50% Duty Cycle), $I_{F(AV)}$, Full Wave Configuration 6A
Either Leg Alone 4A
$T_{CASE} = 100°C$
$V_{RWM} = 45V$
Average Forward Current (50% Duty Cycle), $I_{F(AV)}$ (Note 1), Either Leg Alone 2A
$R_{\theta C-A} = 68°C/W$, $T_A = 25°C$
$V_{RWM} = 45V$
Non-Repetitive Peak Surge Current, I_{FSM} 80A
8.3ms, Half Sine Wave
Operating and Storage Junction Temperature Range, T_{OP}, T_{STA} .... −65°C to +175°C
Thermal Resistance, Junction to Ambient, $R_{\theta J-A}$ .... 175°C/W
Thermal Resistance, Junction to Case, $R_{\theta J-C}$ .... 15°C/W

Note: 1. Using Wakefield Type 205 heatsink with convection cooling.
For more definitive data refer to the Output vs Temperature curves on this data sheet.

MECHANICAL SPECIFICATIONS

USD245C SERIES

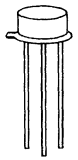




	MILLIMETERS	INCHES
A	0.72-0.86	0.028-0.034
B	0.88	0.035
C	5.08	0.20
D	9.14 DIA.	0.36 DIA.
E	8.25 DIA.	0.325 DIA.
F	4.30-4.57	0.169-0.180
G	18.03 REF.	0.71 REF.
H	0.41-0.53 DIA.	0.016-0.021 DIA.
J	12.70-14.22	0.50-0.56
K	0.36-0.45	0.014-0.018

All Dimensions in Inches and Millimeters

TO-205AF (TO-39)



ELECTRICAL CHARACTERISTICS PER LEG (T_j = 25°C)

CHARACTERISTICS	SYMBOL	LIMIT	UNITS	CONDITIONS	
Maximum Instantaneous Reverse Current	i_R	2	mA	V_R = 45V Pulse Width = 400μs Duty Cycle = 1%	
Maximum Instantaneous Reverse Current	i_R	20	mA	V_R = 45V Pulse Width = 400μs Duty Cycle = 1% T_C = 125°C	
Maximum Instantaneous Forward Voltage (Note 1)	V_F	0.48 0.56 0.68	V	i_F = 1A i_F = 2A i_F = 4A	Pulse Width = 400μs Duty Cycle = 1%
		0.45		i_F = 2A T_j = 125°C	
Capacitance	C_T	450	pF	V_R = 5V	
Voltage Rate of Change	dv/dt	1000	V/μs	V_R = 45V	

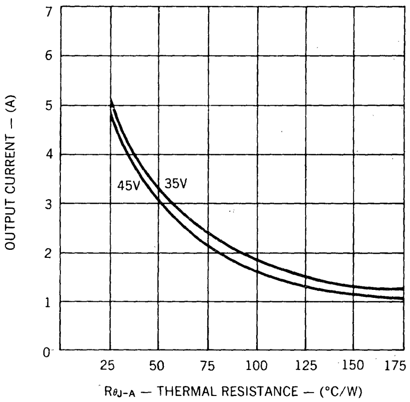
Note: 1. Measured with anode and cathode lead length of 0.2" from case.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

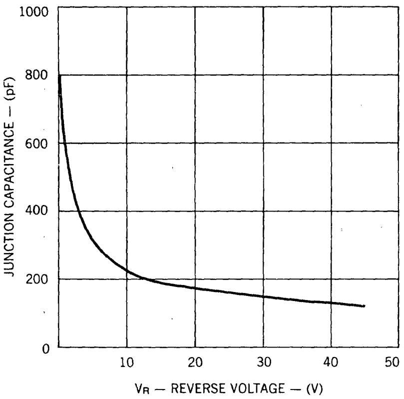
The following tests are performed on 100% of the devices specified USD245CHR2 and USD245CRHR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, T_C = 125°C, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

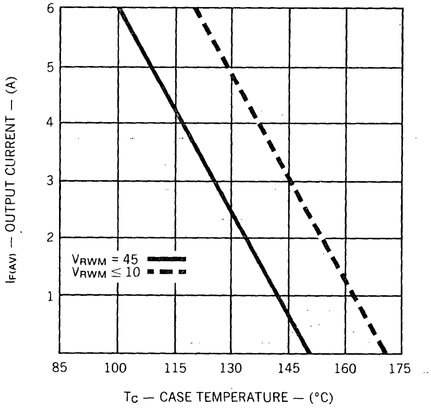
Output Current vs $R_{\theta J\text{-}A}$
$T_{ambient}$ = 25°C, 50% Duty Cycle



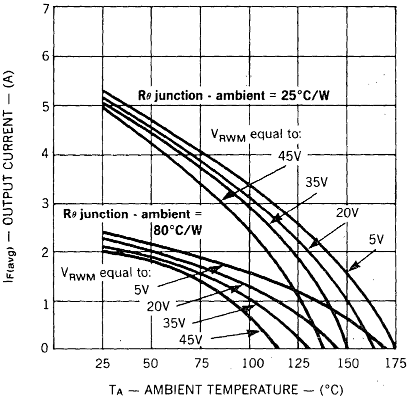
Typical Junction Capacitance
vs Reverse Voltage



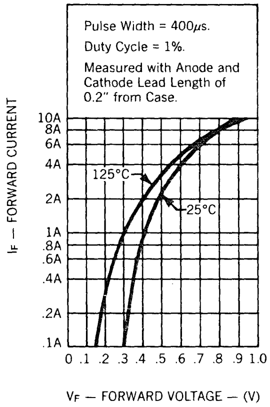
Full-Wave Output Current
vs Case Temperature



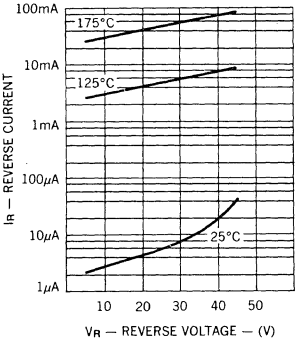
Output Current vs Ambient Temperature
50% Duty Cycle Application ($I_{F(avg)}$ and V_{RRM})



Typical Forward Current
vs Forward Voltage



Typical Reverse Current
vs Reverse Voltage



NOTE: All curves, except Full-Wave Output Current, apply to either leg.

DUAL POWER SCHOTTKY RECTIFIERS
60A Pk, 45V

USD335C
USD345C
USD335CHR2
USD345CHR2

FEATURES
- Very Low Forward Voltage
- Low Recovered Charge
- Rugged Package Design (TO-3)
- High Efficiency for Low Voltage Supplies
- 45V Blocking @ Rated T_{jmax}
- 50V Repetitive Surge Voltage
- Dual Schottky Rectifier in a Single Package

DESCRIPTION
The USD320C series has two Schottky barriers arranged in a common cathode configuration and is ideally suited for a full wave output rectifier in low voltage switching power supplies.

ABSOLUTE MAXIMUM RATINGS (Total for USD300C Series)

	USD335C USD335CHR2	USD345C USD345CHR2
Average Rectified Forward Current, I_O @ T_C = 100°C	30A	

ABSOLUTE MAXIMUM RATINGS (Per Diode)

	USD335C USD335CHR2	USD345C USD345CHR2
Working Peak Reverse Voltage V_{RWM}	35V	45V
DC Blocking Voltage, V_R	35V	45V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	54V
Average Rectified Forward Current, I_O	30A in full wave configuration*	
Non-repetitive Peak Surge current (8.3 mS), I_{FSM}	500A	
Peak Reverse Transient Current, I_{RM}	2A	
Storage Temperature Range, T_{stg}	−55°C to +200°C	
Peak Operating Junction Temperature, $T_{j\ max}$	175°C	
Thermal Resistance, Junction to Case, $R_{\theta JC}$	1.4°C/W	

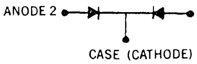
* Each Anode Pin Limited to 18A Average.
Package Capability 30A Average.

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

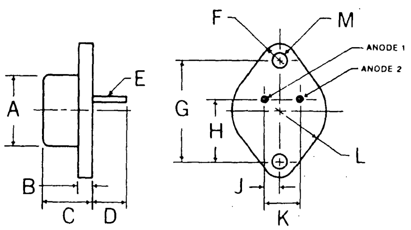
Characteristic	Symbol	Limit	Units	Conditions
Maximum Instantaneous Reverse Current	i_R	10 50	mA mA	T_C = 25°C, V_R = V_{RWM} T_C = 125°C Pulse Width = 400µS Duty Cycle = 1 percent
Maximum Instantaneous Forward Voltage	V_F	0.57 0.66 0.60	V V V	i_F = 10A, T_C = 25°C i_F = 20A, T_C = 25°C i_F = 20A, T_C = 125°C Pulse Width = 300µS Duty Cycle = 1 percent
Capacitance	C_t	2000	pF	V_R = 5.0V
Voltage Rate of Change	dv/dt	1000	v/µS	V_R = V_{RWM}

MECHANICAL SPECIFICATIONS

NOTE:
Leads may be soldered to within 1/16" of base provided temperature-time exposure is less than 260°C for 10 seconds.

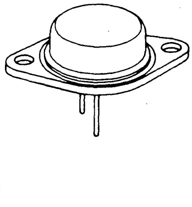


USD300C SERIES
USD300CHR2 SERIES



	ins.	mm.
A	.875 MAX.	22.23 MAX.
B	.135 MAX.	3.43 MAX.
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.038-.043 DIA.	0.97-1.09 DIA.
F	.188 MAX. RAD.	4.78 MAX. RAD.
G	1.177-1.197	29.90-30.40
H	.655-.675	16.64-17.15
J	.205-.225	5.21-5.72
K	.420-.440	10.67-11.18
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.151-.161 DIA.	3.84-4.09 DIA.

TO-204AA (TO-3)

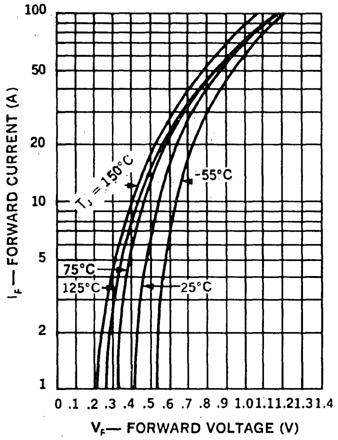


Notes: All metal surfaces tin plated.

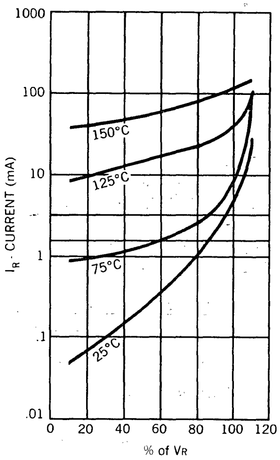
4/82

SEMICONDUCTOR PRODUCTS
UNITRODE

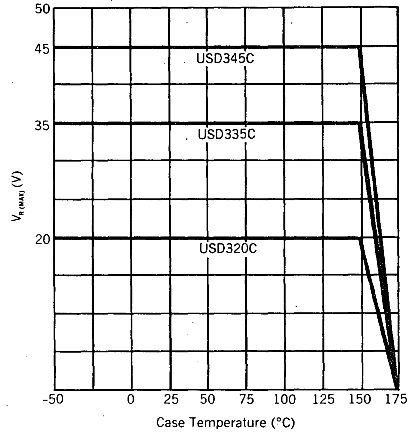
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs. Reverse Voltage



$V_{R(MAX)}$ Rating vs. Case Temperature



OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified USD335CHR2, 345CHR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 150°C
2. Temperature Cycle	1051	F, 20 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes
3. Hermetic Seal a. Fine Leak b. Gross Leak	1071	 H, Helium C, Liquid
4. Thermal Impedance		Sage Test
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. High Temperature Reverse Blocking	Similar to Method 1040	½ Sine Reverse, t = 48 Hours, T_C = 125°C, VRW_M = rating, F = 50-60 Hz, I_O = OA
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

POWER SCHOTTKY RECTIFIERS

150 Amp Pk, Up to 50V

USD520
USD535
USD545
USD550

FEATURES

- Very Low Forward Voltage (0.6V at 60A, 125°C)
- Low Recovered Charge
- Rugged Package Design (DO-5)
- High Efficiency for Low Voltage Supplies
- Low Thermal Resistance (0.8°C/W)
- High Surge Current (1000A)
- Low Reverse Current (<50mA at rated v_R at 125°C)
- Available with Flexible Top Lead

DESCRIPTION

This series of Schottky barrier power rectifiers is ideally suited for output rectifiers and catch diodes in low voltage power supplies. The Unitrode high conductivity design, using a heavy copper top post and 4 point crimp, ensures cool thermal operation and low dynamic impedance. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

ABSOLUTE MAXIMUM RATINGS

	USD520	USD535	USD545	USD550
Working Peak Reverse Voltage, V_{RWM}	20V	35V	45V	50V
DC Blocking Voltage, V_R	20V	35V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	24V	42V	54V	60V

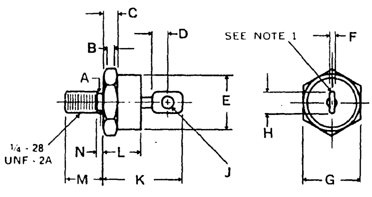
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20KHz, 50 percent Duty Cycle), I_{FRM} .... 150A (at T_c = 115°C)
Average Rectified Forward Current, $I_{F(AV)}$ .... 75A (at T_c = 115°C)
Non-repetitive Peak Surge Current (8.3mS), I_{FSM} 1000A
Peak Reverse Transient Current, I_{RM} 2A
Storage Temperature Range, T_{Stg} .... −55° to +200°C
Operating Junction Temperature, T_j .... +175°C
Thermal Resistance Junction-to-Case, $R_{\theta JC}$ .... 0.8°C/W

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

Characteristic	Symbol	Limit		Units	Conditions
		USD520-545	USD550		
Maximum Instantaneous Reverse Current	i_R	20 (50)	20 (75)	mA	$V_R = V_{RWM}$ (T_C = 125°C) Pulse Width = 300μs, Duty Cycle = 1 percent
Maximum Instantaneous Forward Voltage	V_F	0.50 0.68 0.60		V V V	i_F = 10A, T_C = 25°C i_F = 60A, T_C = 25°C i_F = 60A, T_C = 125°C
Flexible Top Lead Option	V_F	(0.63)		V	i_F = 60A, (T_C = 125°C)
Maximum Capacitance	C_t	4000		pF	V_R = 5.0V
Maximum Voltage Rate of Change	dv/dt	1000		V/μS	V_R = rated

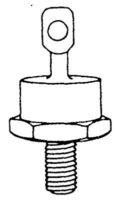
MECHANICAL SPECIFICATIONS

USD520
USD535
USD545
USD550



	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA. MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA.
K	1.000 MAX.	25.40 MAX.
L	.450 MAX.	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	.078 MAX.	1.98 MAX.

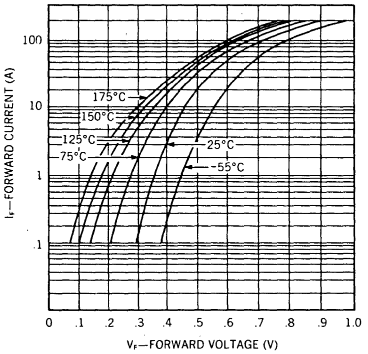
DO-5



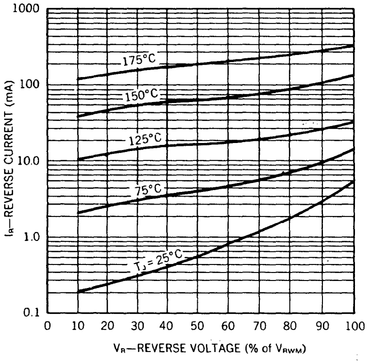
Notes:
1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 30 inch pounds (35 kg. cm).
4. Angular orientation of terminal is undefined.

SEMICONDUCTOR PRODUCTS
UNITRODE

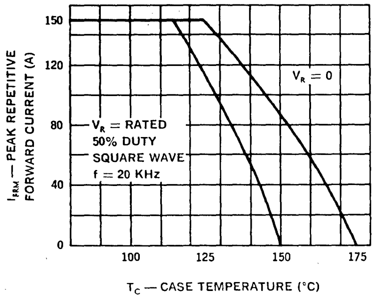
Typical Forward Current vs Forward Voltage



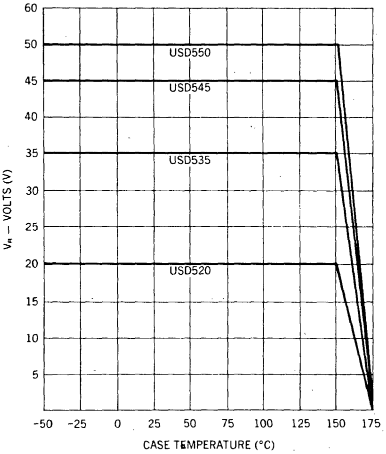
Typical Reverse Current vs Reverse Voltage



Maximum Current vs Case Temperature



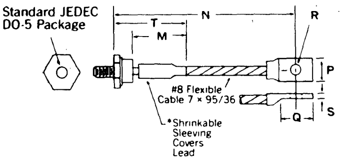
$V_{R(MAX)}$ Rating vs Case Temperature



MECHANICAL SPECIFICATIONS

FLEXIBLE TOP LEAD (OPTIONAL)
Add an "F" Suffix to Part Number.

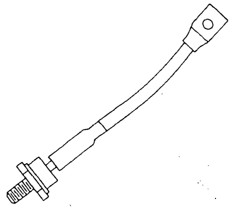
USD520F
USD535F
USD545F
USD550F



	INCHES	MILLIMETERS
M	.718 MAX.	18 24 MAX.
N	4 50 ± .250	114.3 ± 6.35
P	.525 MAX.	13.23 MAX.
Q	.675 ± .035	17.15 ± 0.89
R	.205 ± .005	5.21 ± 0.13
S	.075 ± .010	1.91 ± 0.25
T	1 125 MAX.	28.58 MAX.

*To 125°C (Ambient)

DO-5 with Flexible Lead



Note: Consult Factory for Non-standard Lead Lengths.

POWER SCHOTTKY RECTIFIERS
12A Pk, up to 50V

USD635
USD640
USD645
USD650

FEATURES
- Very Low Forward Voltage
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Working Voltage @ Rated $T_{j(max)}$

DESCRIPTION
The USD600 series of Schottky power rectifiers is ideally suited for output rectifiers and catch diodes in high frequency low voltage power supplies.

ABSOLUTE MAXIMUM RATINGS

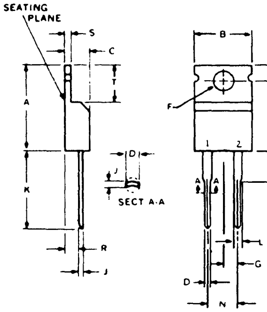
	USD635	USD640	USD645	USD650
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, $I_{F(AV)}$	6A			
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 KHz, 50% Duty Cycle, @ T_C = 115°C), I_{FRM}	12A			
Non-repetitive Peak Surge Current (8.3ms), I_{FSM}	150A			
Peak Reverse Transient Current, I_{RM}	1A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	3.0°C/W			

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	5	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent
Maximum Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent T_C = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.55 0.65	V	i_F = 6A i_F = 12A
		0.48 0.60	V	i_F = 6A } T_C = 125°C i_F = 12A }
Capacitance	C_t	1000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μs	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS

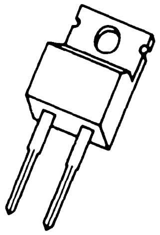
USD600 SERIES



PIN 1. Cathode
2. Anode
Tab is connected
to Cathode.

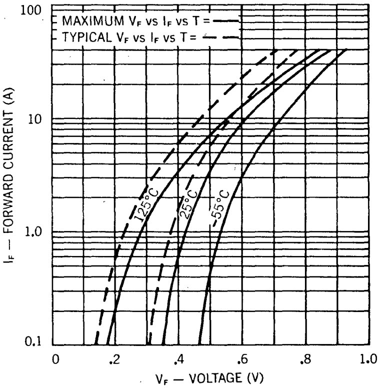
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14 23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0 147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AC

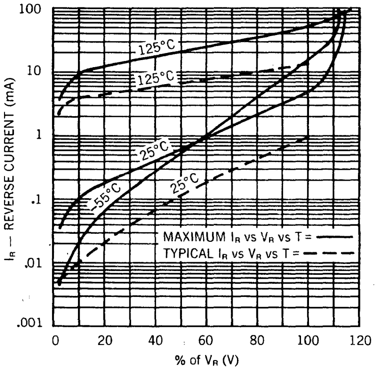


SEMICONDUCTOR
PRODUCTS
UNITRODE

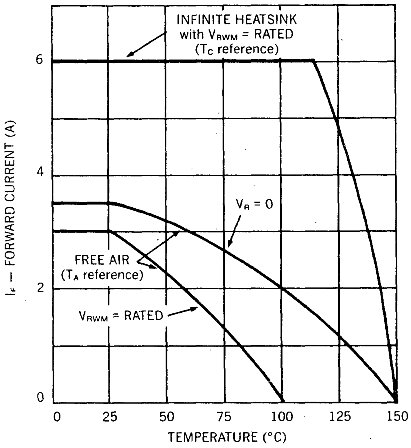
Forward Current vs. Forward Voltage



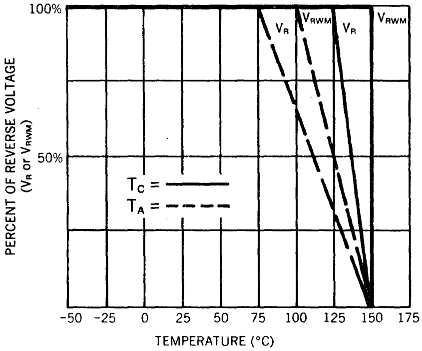
Reverse Current vs. Voltage



Average Forward Current vs. Temperature



V_R Rating vs. Temperature



DUAL POWER SCHOTTKY RECTIFIERS

12A Av, up to 50V

USD635C
USD640C
USD645C
USD650C

FEATURES

- Very Low Forward Voltage
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Working Voltage @ Rated $T_{j(max)}$

DESCRIPTION

The USD600C series of power Schottky rectifiers, in the industry standard TO-220 package, is specifically designed for operation in power switching circuits to frequencies in excess of 100 KHz. The series combines Schottky rectifiers in one convenient package; thus, simplifying installation, reducing heatsink requirements and component parts count.

ABSOLUTE MAXIMUM RATINGS (Per Diode Unless Otherwise Noted)

	USD635C	USD640C	USD645C	USD650C
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, I_O*	12A			
Non-repetitive Peak Surge Current (8.3ms), I_{FSM}	150A			
Peak Reverse Transient Current, I_{RM}	1A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{Stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	3.0°C/W			

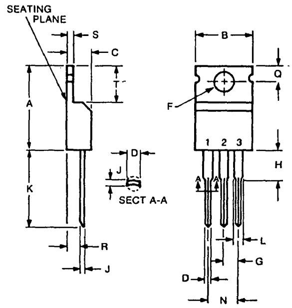
*Full Wave Center-Tap; $I_{O\ (AV)}$ 20 KHz Square Wave

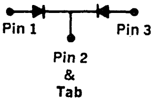
ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C) (Per Diode)

CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	5	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent
Maximum Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent T_C = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.55 0.65	V	i_F = 6A i_F = 12A
		0.48 0.60	V	i_F = 6A } T_C = 125°C i_F = 12A }
Capacitance	C_t	1000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μs	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS

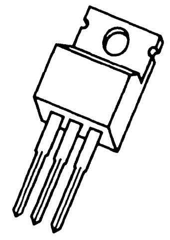
USD600C SERIES





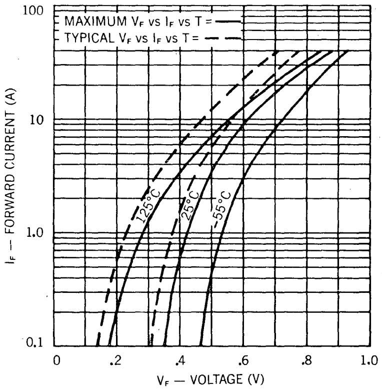
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AB

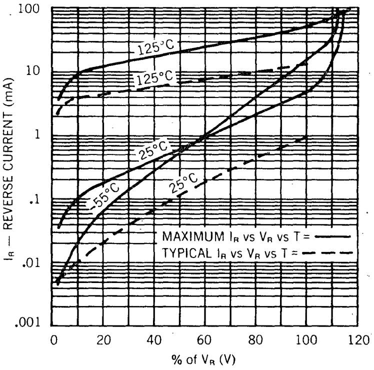


SEMICONDUCTOR PRODUCTS
UNITRODE

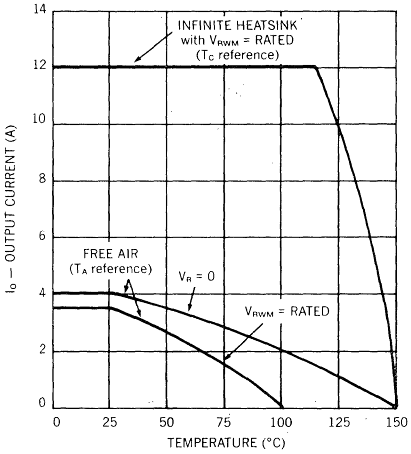
Forward Current vs. Forward Voltage



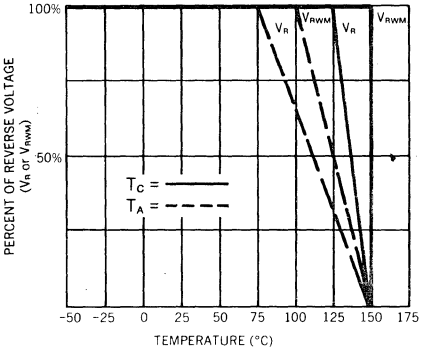
Reverse Current vs. Voltage



Average Output Current vs. Temperature



V_R Rating vs. Temperature



POWER SCHOTTKY RECTIFIERS

16A Pk, up to 50V

USD735
USD740
USD745
USD750

FEATURES

- Very Low Forward Voltage
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Working Voltage @ Rated $T_{j(max)}$

DESCRIPTION

The USD700 series of Schottky power rectifiers is ideally suited for output rectifiers and catch diodes in high frequency low voltage power supplies.

ABSOLUTE MAXIMUM RATINGS

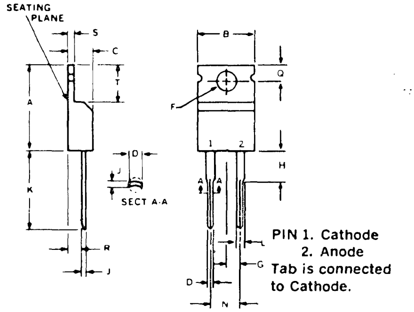
	USD735	USD740	USD745	USD750
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, $I_{F\,(AV)}$	8A			
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 KHz, 50% Duty Cycle, @ T_C = 115°C), I_{FRM}	16A			
Non-repetitive Peak Surge Current (8.3ms), I_{FSM}	200A			
Peak Reverse Transient Current, I_{RM}	1A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{Stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.8°C/W			

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	5	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent
Maximum Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent T_C = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.55 0.65	V	i_F = 8A i_F = 16A
		0.48 0.60	V	i_F = 8A i_F = 16A } T_C = 125°C
Capacitance	C_t	1000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μs	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS

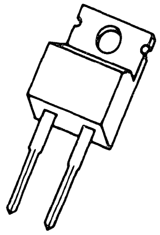
USD700 SERIES



PIN 1. Cathode
2. Anode
Tab is connected to Cathode.

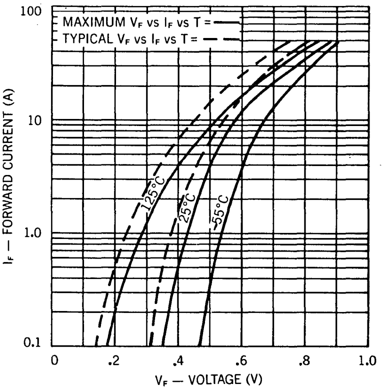
DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AC

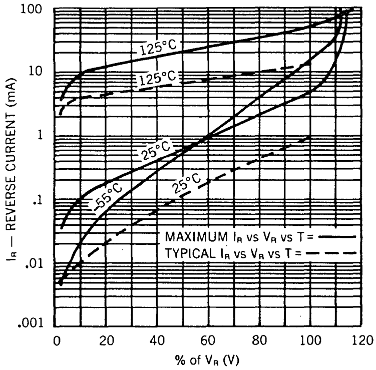


SEMICONDUCTOR PRODUCTS
UNITRODE

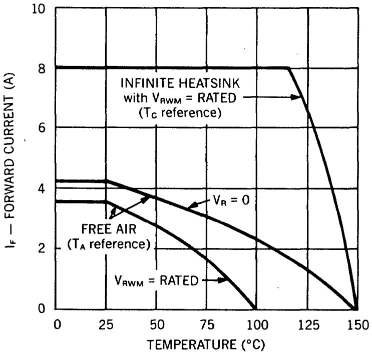
Forward Current vs. Forward Voltage



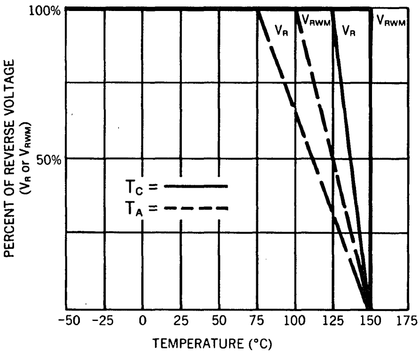
Reverse Current vs. Voltage



Average Forward Current vs. Temperature



V_R Rating vs. Temperature



DUAL POWER SCHOTTKY RECTIFIERS

16A Av, up to 50V

USD735C
USD740C
USD745C
USD750C

FEATURES

- Very Low Forward Voltage
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Working Voltage @ Rated $T_{j(max)}$

DESCRIPTION

The USD700C series of power Schottky rectifiers, in the industry standard TO-220 package, is specifically designed for operation in power switching circuits to frequencies in excess of 100 KHz. The series combines Schottky rectifiers in one convenient package; thus, simplifying installation, reducing heatsink requirements and component parts count.

ABSOLUTE MAXIMUM RATINGS (Per Diode Unless Otherwise Noted)

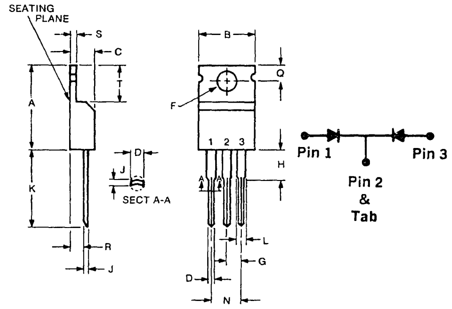
	USD735C	USD740C	USD745C	USD750C
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, I_o*	16A			
Non-repetitive Peak Surge Current (8.3ms), I_{FSM}	200A			
Peak Reverse Transient Current, I_{RM}	1A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.8°C/W			

*Full Wave Center-Tap; $I_{O\ (AV)}$ 20KHz Square Wave

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C) (Per Diode)

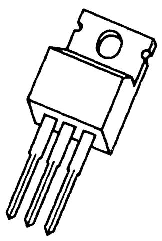
CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	5	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent
Maximum Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μs Duty Cycle = 1 percent T_c = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.55 0.65	V	i_F = 8A i_F = 16A
		0.48 0.60	V	i_F = 8A i_F = 16A } T_c = 125°C
Capacitance	C_t	1000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μs	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS



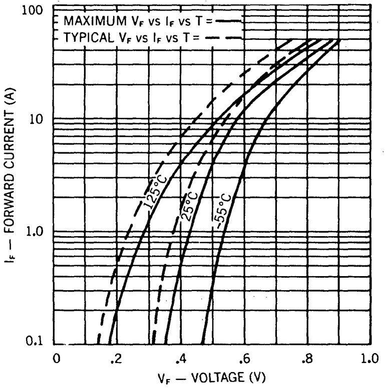
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AB

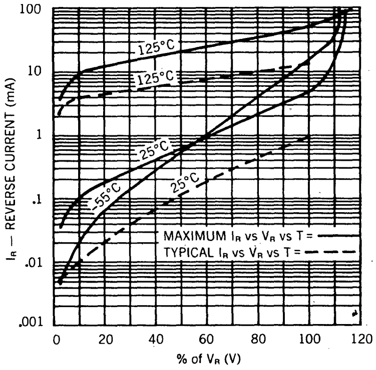


SEMICONDUCTOR
PRODUCTS
UNITRODE

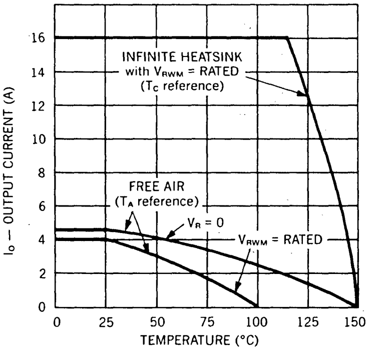
Forward Current vs. Forward Voltage



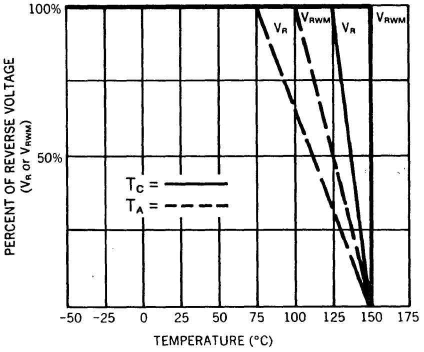
Reverse Current vs. Voltage



Average Output Current vs. Temperature



V_R Rating vs. Temperature



POWER SCHOTTKY RECTIFIERS

24A Pk, up to 50V

USD835
USD840
USD845
USD850

FEATURES

- Very Low Forward Voltage (0.45V max @ 12A)
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Blocking Voltage @ Rated T_{jmax}

DESCRIPTION

The USD800 series of Schottky barrier power rectifiers is ideally suited for output rectifiers and catch diodes in low voltage power supplies.

ABSOLUTE MAXIMUM RATINGS

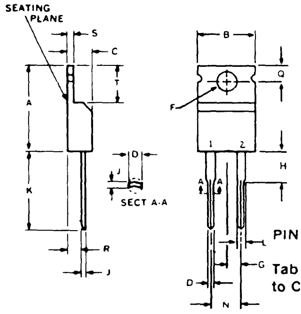
	USD835	USD840	USD845	USD850
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, I_O	12A			
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20KHz, 50% Duty Cycle, @ T_C = 115°C), I_{FRM}	24A			
Non-repetitive Peak Surge Current (8.3mS), I_{FSM}	200A			
Peak Reverse Transient Current, I_{RM}	1A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, $R_{\theta JC}$	2.4°C/W			

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	20	mA	$V_R = V_{RWM}$ Pulse Width = 400μS Duty Cycle = 1 percent
Typical Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μS Duty Cycle = 1 percent T_C = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.59	V	i_F = 12A
		0.51	V	i_F =12A T_C = 125°C
Capacitance	C_t	2000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μS	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS

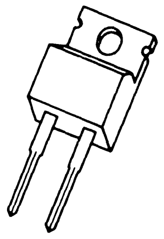
USD800 SERIES



PIN 1. Cathode
2. Anode
Tab is connected to Cathode.

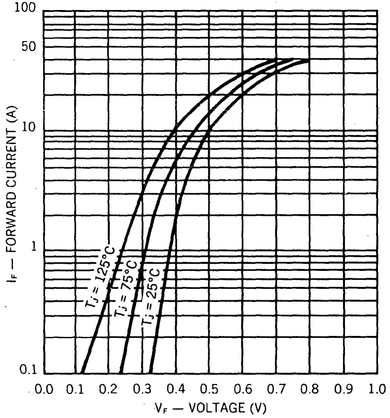
DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AC

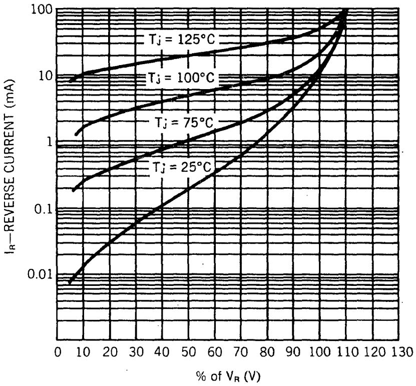


SEMICONDUCTOR PRODUCTS
UNITRODE

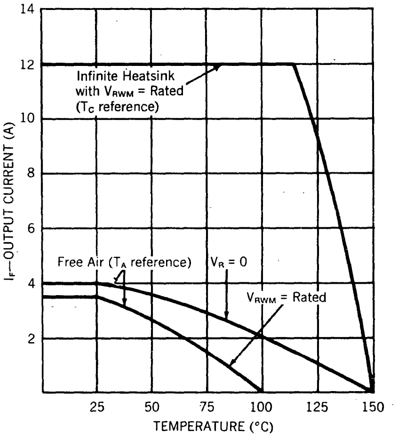
Typical Forward Current vs. Forward Voltage



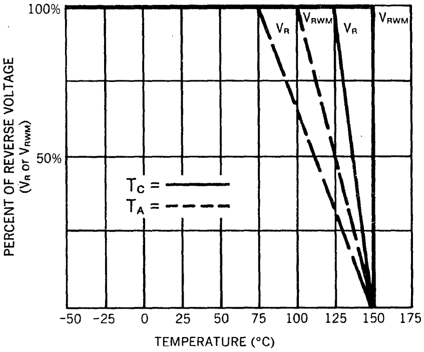
Typical Reverse Current vs. Voltage



Output Current vs. Temperature



VR Rating vs. Temperature



POWER SCHOTTKY RECTIFIERS

32A Pk, up to 50V

USD935
USD940
USD945
USD950

FEATURES

- Very Low Forward Voltage (0.5V max @ 16A)
- Reverse Transient Capability
- Economical Convenient Plastic Package
- Mechanically Rugged
- 50V Blocking Voltage @ Rated T_{jmax}

DESCRIPTION

The USD900 series of Schottky barrier power rectifiers is ideally suited for output rectifiers and catch diodes in low voltage power supplies.

ABSOLUTE MAXIMUM RATINGS

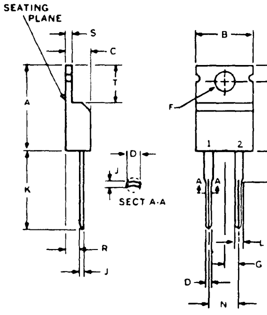
	USD935	USD940	USD945	USD950
Working Peak Reverse Voltage, V_{RWM}	35V	40V	45V	50V
DC Blocking Voltage, V_R	35V	40V	45V	50V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	42V	48V	54V	60V
Average Rectified Forward Current @ T_C = 115°C, I_O	16A			
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20KHz, 50% Duty Cycle, @ T_C = 115°C), I_{FRM}	32A			
Non-repetitive Peak Surge Current (8.3mS), I_{FSM}	250A			
Peak Reverse Transient Current, I_{RM}	2A			
Operating Junction Temperature, T_j	150°C			
Storage Temperature Range, T_{stg}	−55°C to +150°C			
Thermal Resistance, Junction to Case, R_{JC}	2°C/W			

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C)

CHARACTERISTIC	SYMBOL	LIMIT	UNITS	CONDITIONS
Maximum Instantaneous Reverse Current	i_R	20	mA	$V_R = V_{RWM}$ Pulse Width = 400μS Duty Cycle = 1 percent
Typical Instantaneous Reverse Current	i_R	50	mA	$V_R = V_{RWM}$ Pulse Width = 400μS Duty Cycle = 1 percent T_C = 125°C
Maximum Instantaneous Forward Voltage	V_F	0.6	V	i_F = 16A
		0.53	V	i_F =16A T_C = 125°C
Capacitance	C_t	2000	pF	V_R = 5V
Voltage Rate of Change	dv/dt	1000	V/μS	$V_R = V_{RWM}$

MECHANICAL SPECIFICATIONS

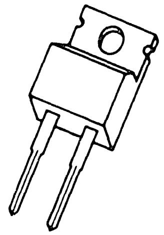
USD900 SERIES



PIN 1. Cathode
2. Anode
Tab is connected
to Cathode.

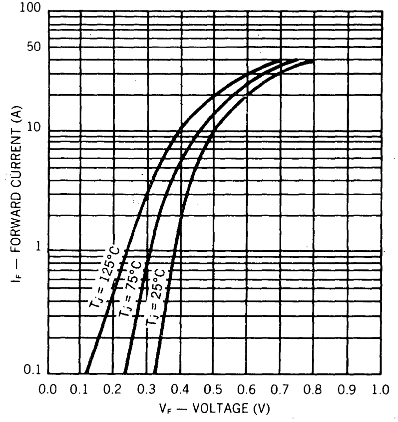
DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.23	15.87	0.560	0.625
B	9.66	10.66	0.380	0.420
C	3.56	4.82	0.140	0.190
D	0.51	1.14	0.020	0.045
F	3.531	3.733	0.139	0.147
G	2.29	2.79	0.090	0.110
H	—	6.35	—	0.250
J	0.38	0.64	0.015	0.025
K	12.70	14.27	0.500	0.562
L	1.14	1.77	0.045	0.070
N	4.83	5.33	0.190	0.210
Q	2.54	3.04	0.100	0.120
R	2.04	2.92	0.080	0.115
S	1.14	1.39	0.045	0.055
T	5.85	6.85	0.230	0.270

TO-220AC

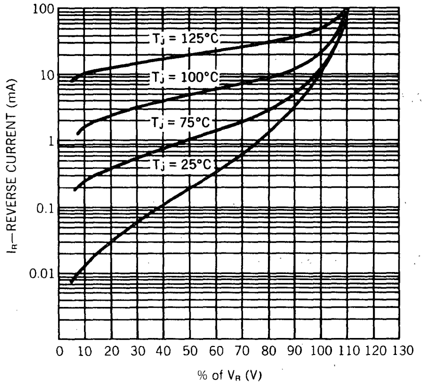


SEMICONDUCTOR
PRODUCTS
UNITRODE

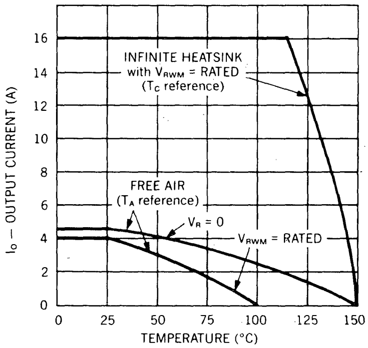
Typical Forward Current vs. Forward Voltage



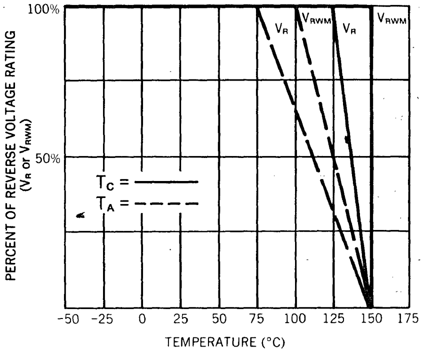
Typical Reverse Current vs. Voltage



Output Current vs. Temperature



V_R Rating vs. Temperature



POWER SCHOTTKY RECTIFIERS

30A Av, Up to 45V

USD3030C
USD3040C
USD3045C

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Extremely Low V_F

DESCRIPTION

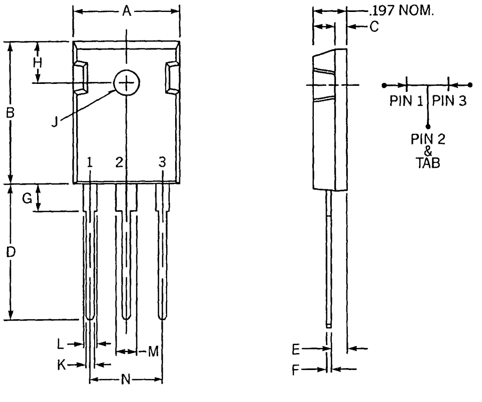
The USD3030C Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and low recovered charge translates to extremely high efficiency making them particularly suited for low voltage switching type power supplies.

ABSOLUTE MAXIMUM RATINGS, either leg unless noted		**USD3030C**	**USD3040C**	**USD3045C**
Working Peak Inverse Voltage	V_{RWM}, V_{RRM}	30V	40V	45V
D.C. Blocking Voltage	V_R	30V	40V	45V
Peak Repetitive Surge Voltage	V_{RSM} @ I_{RM}	36V	48V	54V
Maximum Average D.C. Output Current @ T_C = 125°C, full wave operation (see curves)	$I_{F(AV)}$	30A		
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}	400A		
Peak Reverse Transient Current	I_{RM}	2A		
Thermal Resistance Junction to Case	$R_{\theta J-C}$	1.4°C/W		
Thermal Resistance Junction to Case both legs together, full wave	$R_{\theta J-C}$	0.85°C/W		
Thermal Resistance Junction to Ambient either leg, or both legs together	$R_{\theta J-A}$	40°C/W		
Operating and Storage Temperature Range	T_{OP}, T_{STG}	−55°C to +150°C		

ELECTRICAL SPECIFICATIONS

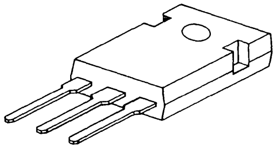
Type	V_{RWM}	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ V_{RWM}		Maximum Capacitance C_T at V_R = 5.0V	Voltage Rate of Change (dv/dt)
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
USD3030C USD3040C USD3045C	30V 40V 45V	.61 @ 15A .75 @ 30A	.55 @ 15A .71 @ 30A	20mA	50mA	2000pF	1000V/μs

MECHANICAL SPECIFICATIONS



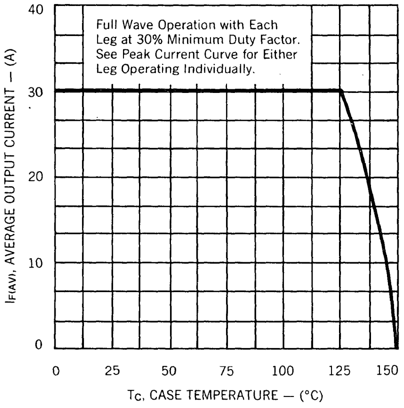
DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
M	.113	.123
N	.430 Nom.	

TO-3P

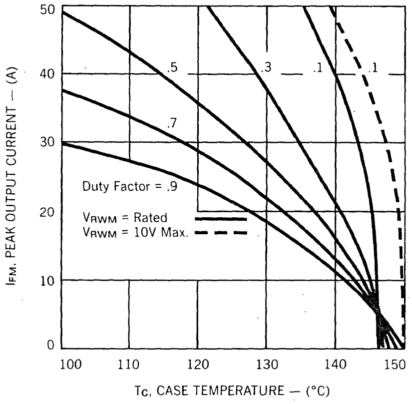


SEMICONDUCTOR PRODUCTS
UNITRODE

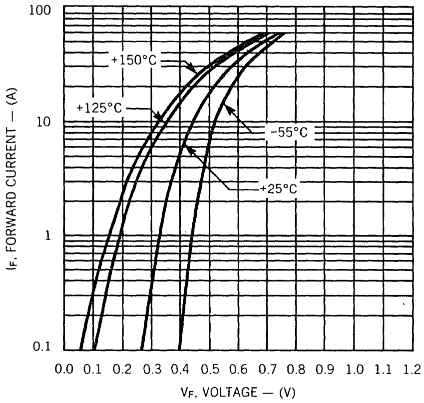
Average Output Current vs Case Temperature



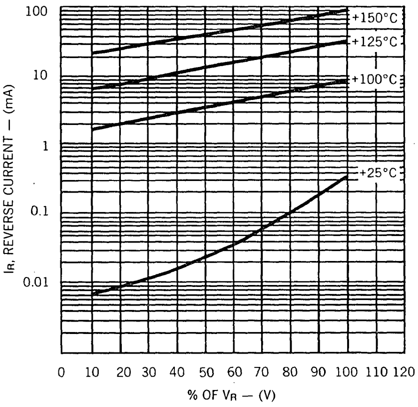
Peak Output Current vs Case Temperature (Either Leg)



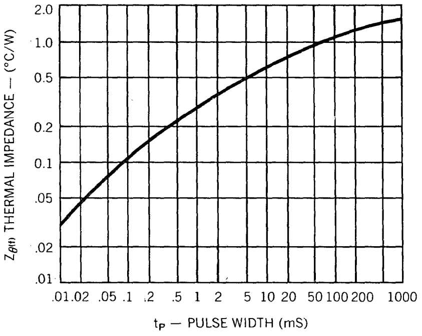
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Voltage



Thermal Impedance vs Pulse Width (Each Leg)



POWER SCHOTTKY RECTIFIERS
60A Pk, Up to 45V

USD3030S
USD3040S
USD3045S

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Extremely Low V_F

DESCRIPTION

The USD3030S Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and low recovered charge translates to extremely high efficiency making them particularly suited for low voltage switching type power supplies.

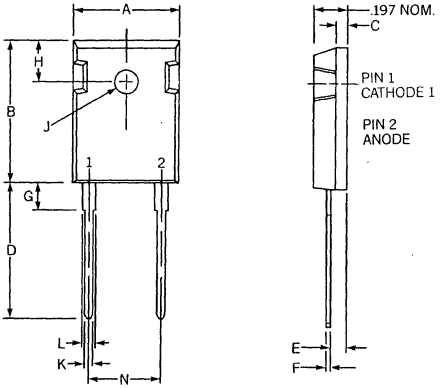
ABSOLUTE MAXIMUM RATINGS

		USD3030S	USD3040S	USD3045S
Working Peak Reverse Voltage	V_{RWM}	30V	40V	45V
D.C. Blocking Voltage	V_R	30V	40V	45V
Peak Repetitive Surge Voltage	V_{RSM} @ I_{RM}	36V	48V	54V
Maximum Average D.C. Output Current @ T_C = 115°C	$I_{F(AV)}$	30A		
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}	450A		
Peak Reverse Transient Current	I_{RM}	2A		
Thermal Resistance Junction to Case	$R_{\theta J\text{-}C}$	1.5°C/W.		
Thermal Resistance Junction to Ambient	$R_{\theta J\text{-}A}$	40°C/W.		
Operating and Storage Temperature Range	T_{OP}, T_{STG}	−55°C to +150°C.		

ELECTRICAL SPECIFICATIONS

Type	V_{RWM}	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ V_{RWM}		Maximum Capacitance C_T at V_R = 5.0V	Voltage Rate of Change (dv/dt)
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
USD3030S USD3040S USD3045S	30V 40V 45V	.75 @ 30A .93 @ 60A	.70 @ 30A .85 @ 60A	20mA	50mA	2000pF	1000V/μs

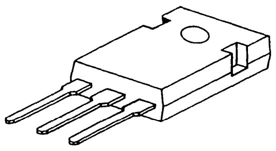
MECHANICAL SPECIFICATIONS

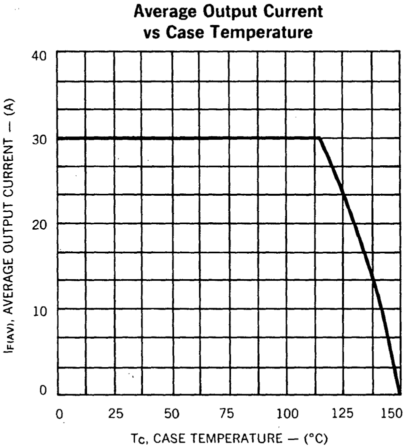


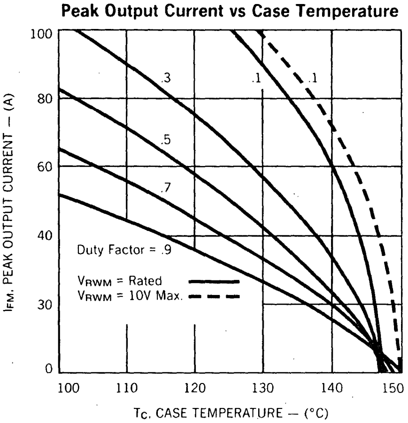
DIM.	INCHES	
	MIN.	MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
N	.430 Nom.	

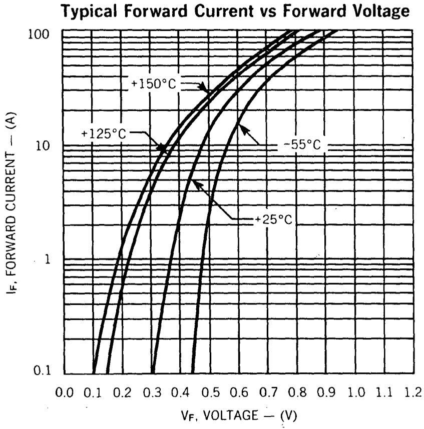
1. Mounting surface common to cathode

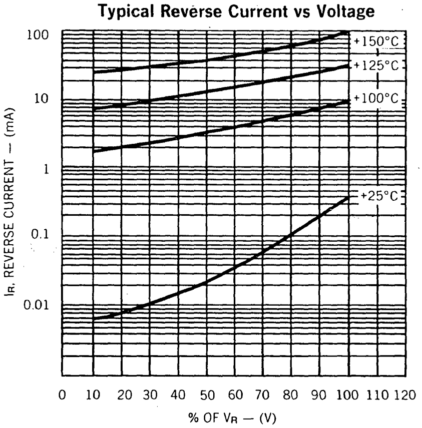
TO-3P

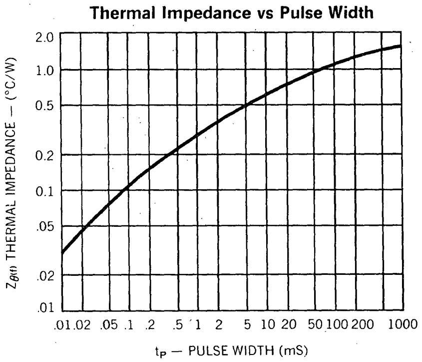



Average Output Current
vs Case Temperature
40
30
20
10
0
IF(AV), AVERAGE OUTPUT CURRENT — (A)
0
25
50
75
100
125
150
TC, CASE TEMPERATURE — (°C)


Peak Output Current vs Case Temperature
100
80
60
40
30
0
IFM, PEAK OUTPUT CURRENT — (A)
.3
.1
.1
.5
.7
Duty Factor = .9
VRWM = Rated
VRWM = 10V Max.
100
110
120
130
140
150
TC, CASE TEMPERATURE — (°C)


Typical Forward Current vs Forward Voltage
100
10
1
0.1
IF, FORWARD CURRENT — (A)
+150°C
+125°C
-55°C
+25°C
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
VF, VOLTAGE — (V)


Typical Reverse Current vs Voltage
100
10
1
0.1
0.01
IR, REVERSE CURRENT — (mA)
+150°C
+125°C
+100°C
+25°C
0
10
20
30
40
50
60
70
80
90
100
110
120
% OF VR — (V)


Thermal Impedance vs Pulse Width
2.0
1.0
0.5
0.2
0.1
.05
.02
.01
Zθ(t) THERMAL IMPEDANCE — (°C/W)
.01
.02
.05
.1
.2
.5
1
2
5
10
20
50
100
200
1000
tP — PULSE WIDTH (mS)

POWER SCHOTTKY RECTIFIERS

45A Av, Up to 45V

USD4530C
USD4540C
USD4545C

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Extremely Low V_F

DESCRIPTION

The USD4530C Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and low recovered charge translates to extremely high efficiency making them particularly suited for low voltage switching type power supplies.

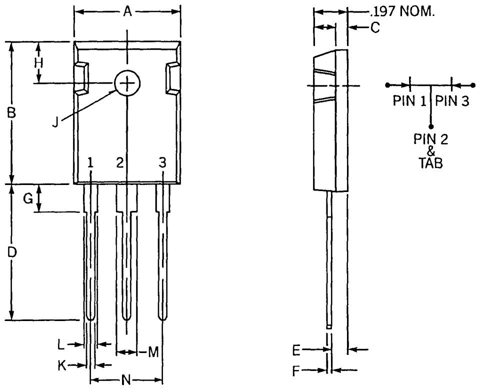
ABSOLUTE MAXIMUM RATINGS, either leg unless noted

		USD4530C	**USD4540C**	**USD4545C**
Working Peak Inverse Voltage	V_{RWM}, V_{RRM}	30V	40V	45V
D.C. Blocking Voltage	V_R	30V	40V	45V
Peak Repetitive Surge Voltage	V_{RSM} @ I_{RM}	36V	48V	54V
Maximum Average D.C. Output Current @ T_C = 125°C, full wave operation (see curves)	$I_{F(AV)}$	45A		
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}	450A		
Peak Reverse Transient Current	I_{RM}	2A		
Thermal Resistance Junction to Case	$R_{\theta J\text{-}C}$	1.0°C/W		
Thermal Resistance Junction to Case; both legs together, full wave	$R_{\theta J\text{-}C}$	0.7°C/W		
Thermal Resistance Junction to Ambient either leg, or both legs together	$R_{\theta J\text{-}A}$	40°C/W		
Operating and Storage Temperature Range	T_{OP}, T_{STG}	−55°C to +150°C		

ELECTRICAL SPECIFICATIONS

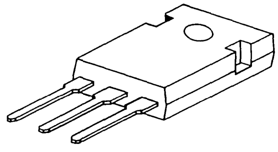
Type	V_{RWM}	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ V_{RWM}		Maximum Capacitance C_T	Voltage Rate of Change
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C	at V_R = 5.0V	(dv/dt)
USD4530C USD4540C USD4545C	30V 40V 45V	.63 @ 23A .73 @ 45A	.60 @ 23A .70 @ 45A	20mA	75mA	4000pF	1000V/μs

MECHANICAL SPECIFICATIONS



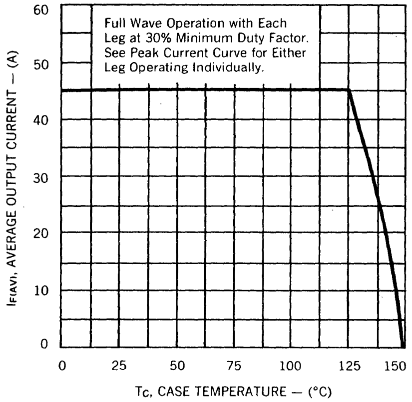
DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
M	.113	.123
N	.430 Nom.	

TO-3P

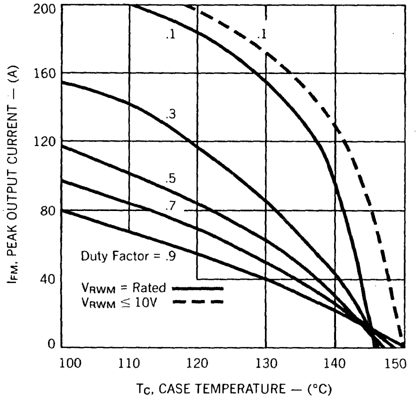


SEMICONDUCTOR PRODUCTS
UNITRODE

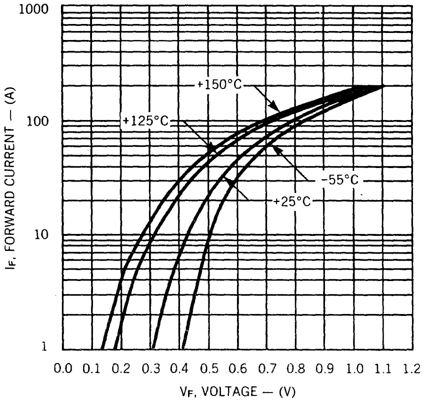
Average Output Current vs Case Temperature



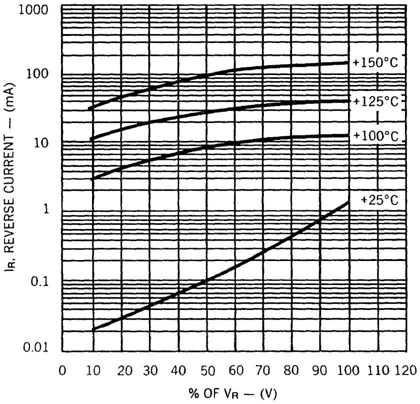
Peak Output Current vs Case Temperature (Either Leg)



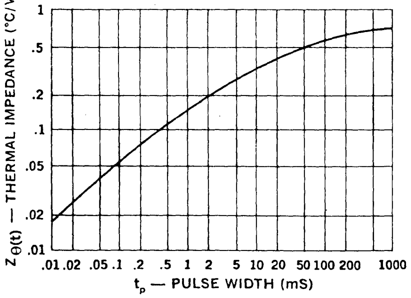
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Voltage



Thermal Impedance vs Pulse Width (Each Leg)



POWER SCHOTTKY RECTIFIERS

90A Pk, Up to 45V

USD4530S
USD4540S
USD4545S

FEATURES

- Economical Convenient TO-3P Package
- Insulated Mounting Hole
- Can Be Clip Mounted
- Mechanically Rugged
- Low Thermal Resistance
- Extremely Low V_F

DESCRIPTION

The USD4530S Series, in the economical, convenient TO-3P package, is specifically designed for operation in power switching circuits to frequencies in excess of 100kHz. The very low forward voltage and low recovered charge translates to extremely high efficiency making them particularly suited for low voltage switching type power supplies.

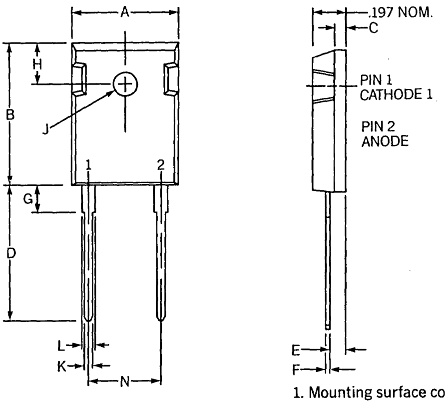
ABSOLUTE MAXIMUM RATINGS

		USD4530S	USD4540S	USD4545S
Working Peak Reverse Voltage	V_{RWM}	30V	40V	45V
D.C. Blocking Voltage	V_R	30V	40V	45V
Peak Repetitive Surge Voltage	V_{RSM} @ I_{RM}	36V	48V	54V
Maximum Average D.C. Output Current @ T_C = 115°C	$I_{F(AV)}$	45A		
Non-Repetitive Sinusoidal Surge Current, 8.3mS	I_{FSM}	450A		
Peak Reverse Transient Current	I_{RM}	2A		
Thermal Resistance Junction to Case	$R_{\theta J\text{-}C}$	.8°C/W		
Thermal Resistance Junction to Ambient	$R_{\theta J\text{-}A}$	40°C/W		
Operating and Storage Temperature Range	T_{OP}, T_{STG}	−55°C to +150°C		

ELECTRICAL SPECIFICATIONS

Type	V_{RWM}	Maximum Forward Voltage (V_F)		Maximum Reverse Current (I_R) @ V_{RWM}		Maximum Capacitance C_T at V_R = 5.0V	Voltage Rate of Change (dv/dt)
		T_J = 25°C	T_J = 125°C	T_J = 25°C	T_J = 125°C		
USD4530S USD4540S USD4545S	30V 40V 45V	.73 @ 45A 1.00 @ 90A	.70 @ 45A .95 @ 90A	20mA	75mA	4000pF	1000V/μs

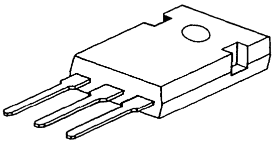
MECHANICAL SPECIFICATIONS



DIM.	INCHES MIN.	INCHES MAX.
A	.620	.640
B	.825	.845
C	.060	.080
D	.780	.800
E	.087	.102
F	.019	.029
G	.150	.170
H	.212	.222
J	.140	.144
K	.042	.052
L	.074	.084
N	.430 Nom.	

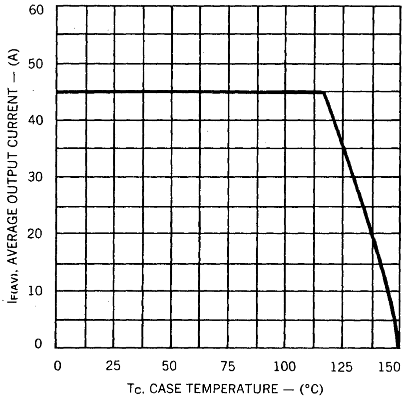
1. Mounting surface common to cathode

TO-3P

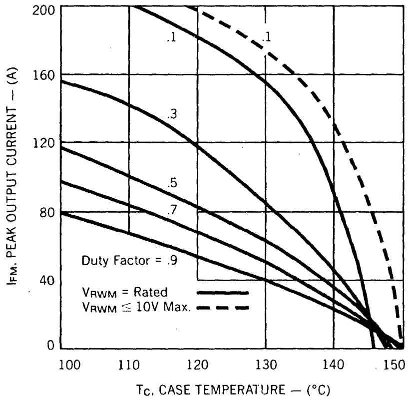


SEMICONDUCTOR PRODUCTS
UNITRODE

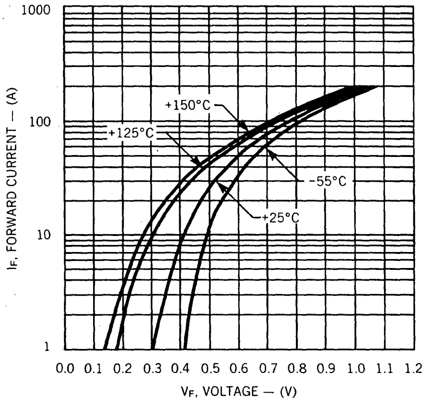
Average Output Current vs Case Temperature



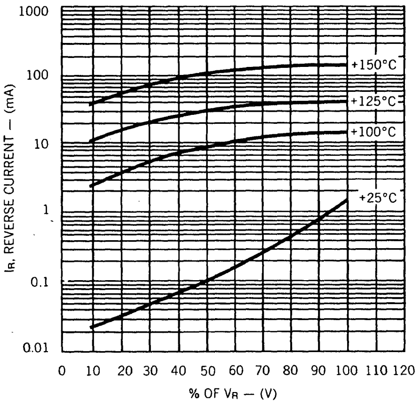
Peak Output Current vs Case Temperature



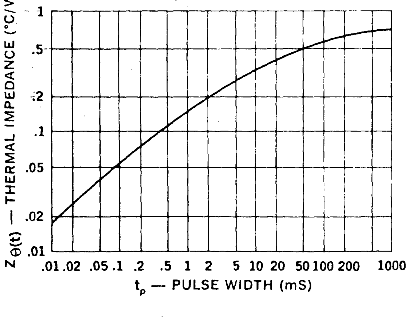
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs Voltage



Thermal Impedance vs Pulse Width



POWER SCHOTTKY RECTIFIERS

150 Amp Pk, Up to 25V

USD7520
USD7525

FEATURES

- **Extremely Low Forward Voltage (0.425V at 60A, 125°C)**
- High Efficiency for Low Voltage Supplies (3V types)
- Low Recovered Charge
- Rugged Package Design (DO-5)
- Low Thermal Resistance (0.7°C/W)
- High Surge Current (1000A)
- Low Reverse Current (150mA at Rated V_R at 125°C)

DESCRIPTION

This series of Schottky barrier power rectifiers is specifically designed to be used as output rectifiers and catch diodes for 3V power supplies. The Unitrode high conductivity design, using a heavy copper top post and 4 point crimp, ensures cool thermal operation and low dynamic impedance. Rugged design absorbs stress that can damage glass-to-metal seal during installation and use.

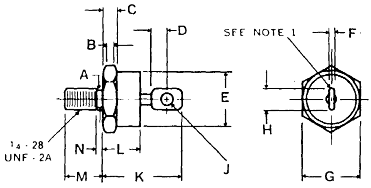
ABSOLUTE MAXIMUM RATINGS

ABSOLUTE MAXIMUM RATINGS	USD7520	USD7525
Working Peak Reverse Voltage, V_{RWM}	20V	25V
DC Blocking Voltage, V_R	20V	25V
Peak Repetitive Surge Voltage, V_{RSM} @ I_{RM}	24V	30V
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20kHz, 50% Duty Cycle), I_{FRM} (T_C = 130°C)	150A	
Average Rectified Forward Current, $I_{F(AV)}$ (T_C = 130°C)	75A	
Non-Repetitive Peak Surge Current (8.3mS), I_{FSM}	1000A	
Peak Reverse Transient Current, I_{RM}	2A	
Storage Temperature Range, T_{Stg}	−55°C to +200°C	
Operating Junction Temperature, T_J	+175°C	
Thermal Resistance Junction-to-Case, $R_{\theta JC}$	0.7°C/W	

ELECTRICAL CHARACTERISTICS (T_{CASE} = 25°C unless noted.)

CHARACTERISTICS	SYMBOL	LIMIT		UNITS	CONDITIONS
		20V	25V		
Maximum Instantaneous Reverse Current	i_R	20 (100)	20 (150)	mA	$V_R = V_{RWM}$ (T_C = 125°C) Pulse Width = 300μS Duty Cycle = 1 percent
Maximum Instananeous Forward Voltage	V_F	0.425 0.450 0.550		V V V	i_F = 60A, T_C = 125°C i_F = 75A, T_C = 125°C i_F = 150A, T_C = 125°C
Maximum Capacitance	Ct	5000		pF	V_R = 5.0V
Maximum Voltage Rate of Change	dv/dt	1000		V/μS	V_R = rated

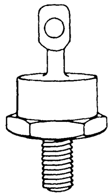
MECHANICAL SPECIFICATIONS



USD7520
USD7525

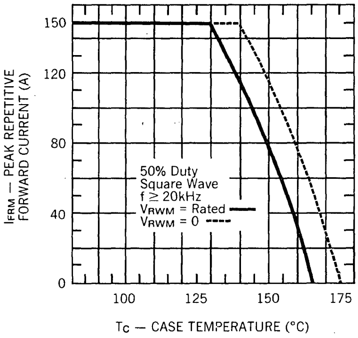
	ins.	mm
A	.225 ± .005	5.72 ± 0.13
B	.060 MIN.	1.52 MIN.
C	.156 ± .020	3.96 ± 0.51
D	.156 MIN. FLAT	3.96 MIN. FLAT
E	.667 DIA. MAX.	16.94 DIA. MAX.
F	.090 MAX.	2.29 MAX.
G	.677 ± .010	17.20 ± 0.25
H	.375 MAX.	9.53 MAX.
J	.140 MIN. DIA.	3.56 MIN. DIA.
K	1.000 MAX.	25.40 MAX.
L	.450 MAX.	11.43 MAX.
M	.438 ± .015	11.13 ± 0.38
N	.078 MAX.	1.98 MAX.

DO-5

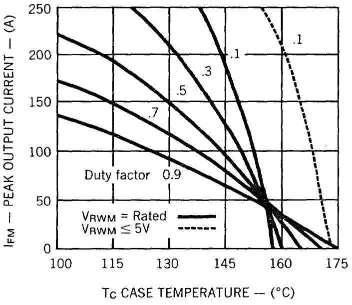


Notes:
1. Cathode is stud.
2. All metal surfaces tin plated.
3. Maximum unlubricated stud torque: 30 inch pounds (35 kg. cm).
4. Angular orientation of terminal is undefined.

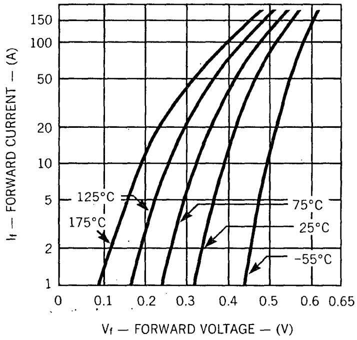
Maximum Current vs Case Temperature



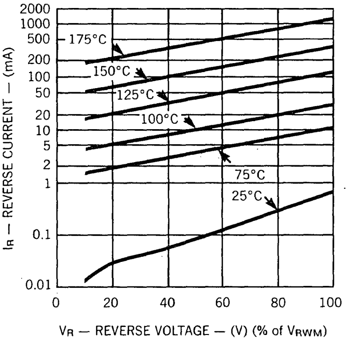
Peak Output Current vs Case Temperature



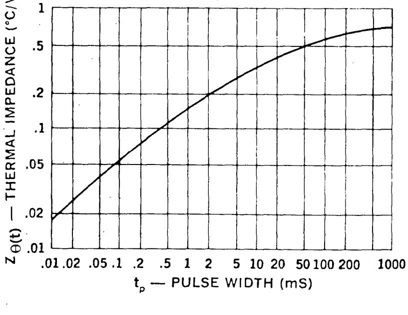
Typical Forward Current vs Forward Voltage



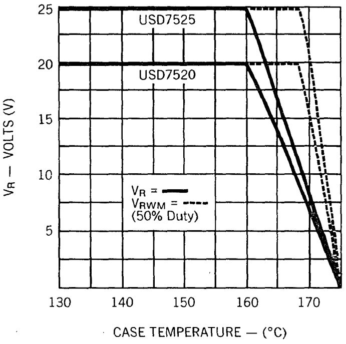
Typical Reverse Current vs Reverse Voltage



Thermal Impedance vs. Pulse Width



Maximum Reverse Voltage vs Case Temperature



RECTIFIERS
Standard Recovery, 1 Amp to 2 Amp

UT236-UT347
UT249-UT363
UT251-UT364
UT261-UT268

FEATURES
- Continuous Rating: to 2A
- Controlled Avalanche
- Surge Rating: to 30A
- PIV: to 1000V
- Miniature Package

DESCRIPTION
These miniature power rectifiers offer the user extreme reliability for high-rel military supplies.

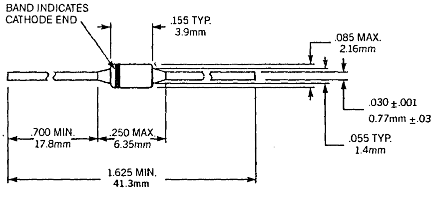
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	1 Amp Series	1.25 Amp Series	1.5 Amp Series	2 Amp Series
100V	UT236	UT249	UT251	UT261
200V	UT234	UT242	UT252	UT262
400V	UT235	UT244	UT254	UT264
500V	UT237	UT245	UT255	UT265
600V	UT238	UT247	UT257	UT267
800V	UT361	UT362	UT258	UT268
1000V	UT347	UT363	UT364	

	1 AMP SERIES	1.25 AMP SERIES	1.5 AMP SERIES	2 AMP SERIES
Maximum Average D.C. Output Current				
@ $T_A = 25°C$	1.0A	1.25A	1.5A	2.0A
@ $T_A = 100°C$	0.5A	0.65A	0.75A	1.0A
Non-Repetitive Sinuosoidal Surge (8.3ms)	20A	20A	25A	30A
Operating Temperature Range	—195°C to +175°C			
Storage Temperature Range	—195°C to +175°C			
Thermal Resistance	See lead temperature derating curve			

MECHANICAL SPECIFICATIONS

UT236-UT347 UT249-UT363 UT251-UT364 UT261-UT268

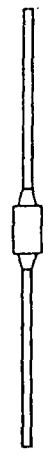


Part Identification: Orange band indicates "UT." Part number printed on body.

Polarity: Denoted by orange band.

Weight: 0.26 grams, typical.

BODY A



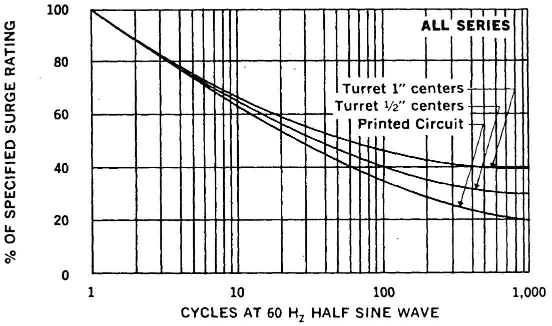
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

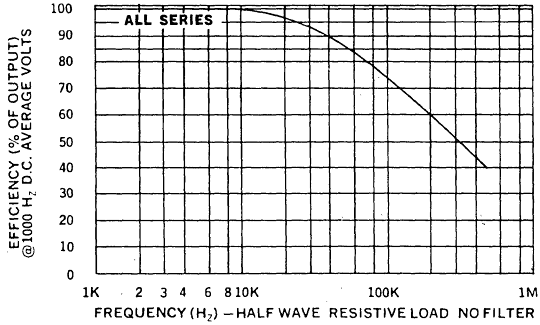
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV	
			25°C	100°C
UT261	100V	1V @ 900mA	2μA	75μA
UT262	200V			
UT264	400V			
UT265	500V			
UT267	600V			
UT268	800V			
UT251	100V	1V @ 750mA	2μA	75μA
UT252	200V			
UT254	400V			
UT255	500V			
UT257	600V			
UT258	800V			
UT364	1000V			
UT249	100V	1V @ 500mA	2μA	75μA
UT242	200V			
UT244	400V			
UT245	500V			
UT247	600V			
UT362	800V			
UT363	1000V			
UT236	100V	1V @ 400mA	2μA	75μA
UT234	200V			
UT235	400V			
UT237	500V			
UT238	600V			
UT361	800V			
UT347	1000V			

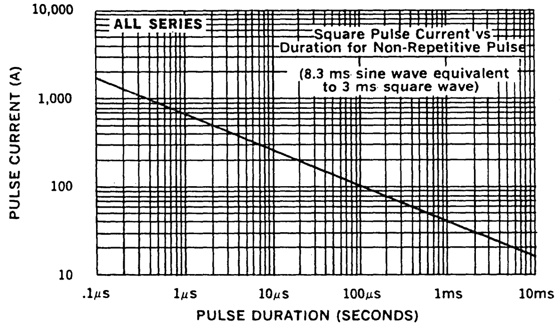
Allowable Forward Surge vs Number of Cycles



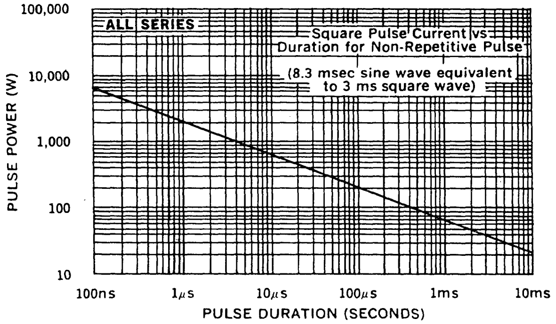
Efficiency vs Frequency at Rated Current (Sine Wave)



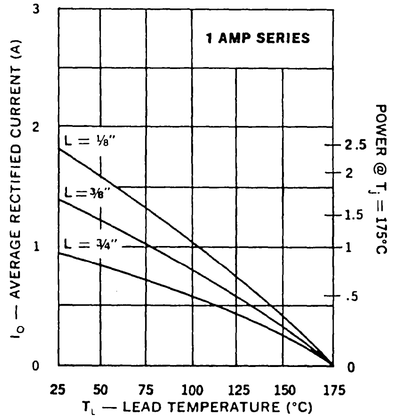
Forward Pulse Current vs Pulse Duration



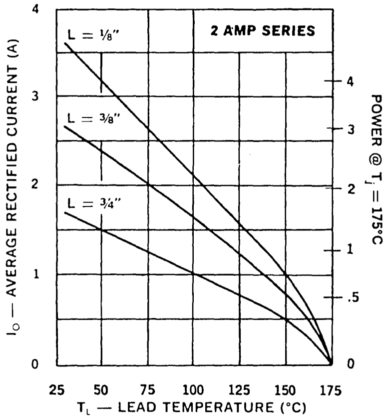
Reverse Pulse Power vs Pulse Duration



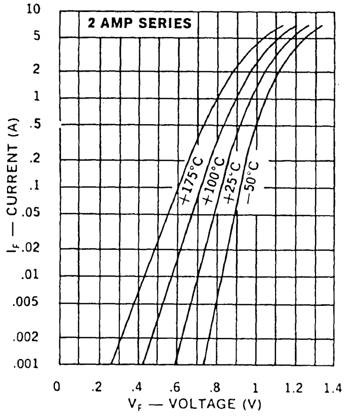
Maximum Current
vs Lead Temperature



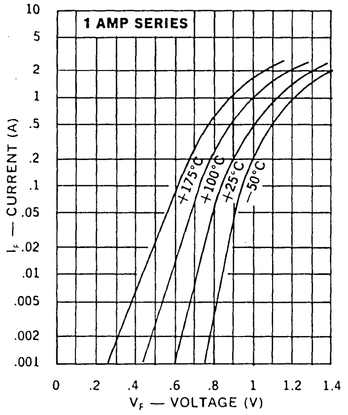
Maximum Current
vs Lead Temperature



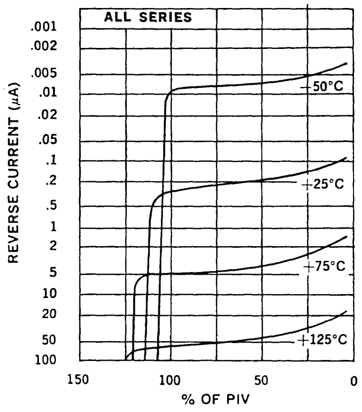
Typical Forward Current
vs Forward Voltage



Typical Forward Current
vs Forward Voltage



Typical Leakage Current vs. PIV



RECTIFIERS
Standard Recovery, 2 Amp to 4 Amp

UT2005-UT2060
UT3005-UT3060
UT4005-UT4060

FEATURES
- Continuous Rating: to 4A
- Controlled Avalanche
- Surge Rating: to 100A
- PIV: to 600 V
- Miniature Package

DESCRIPTION
High average power and surge capability make these series of devices attractive in many high-rel applications.

All Unitrode rectifiers have a sleeve of pure hard glass fused to the silicon junction. Since the silicon sees only this glass, electrical characteristics are permanently stable. This voidless, monolithic package is totally unaffected by the most severe moisture or temperature testing.

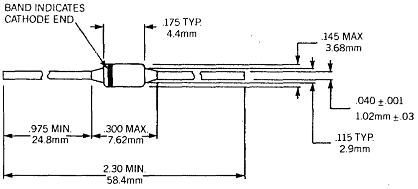
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	2 Amp Series	3 Amp Series	4 Amp Series
50V	UT2005	UT3005	UT4005
100V	UT2010	UT3010	UT4010
200V	UT2020	UT3020	UT4020
400V	UT2040	UT3040	UT4040
600V	UT2060	UT3060	UT4060

	2 AMP SERIES	3 AMP SERIES	4 AMP SERIES
Maximum Average D.C. Output Current			
@ $T_A = 25°C$	2.0A	3.0A	4.0A
@ $T_A = 100°C$	1.0A	1.5A	2.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	60A	80A	100A
Operating Temperature Range		—195°C to +175°C	
Storage Temperature Range		—195°C to +200°C	
Thermal Resistance		See lead temperature derating curve	

MECHANICAL SPECIFICATIONS

UT2005-UT2060 UT3005-UT3060 UT4005-UT4060

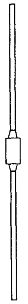


Part Identification: Orange band indicates "UT." Part number printed on body.

Polarity: Denoted by orange band.

Weight: 0.75 grams, typical.

BODY B



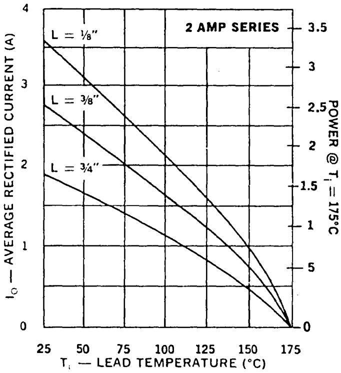
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

SEMICONDUCTOR PRODUCTS
UNITRODE

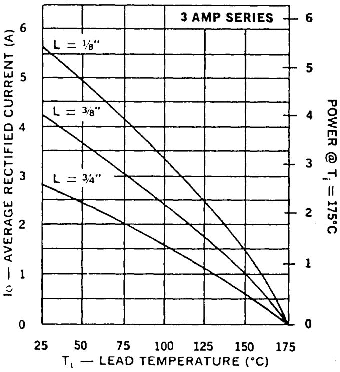
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV	
			25°C	100°C
UT4005	50V	1V @ 3A	5µA	100µA
UT4010	100V			
UT4020	200V			
UT4040	400V			
UT4060	600V			
UT3005	50V	1V @ 2A	5µA	100µA
UT3010	100V			
UT3020	200V			
UT3040	400V			
UT3060	600V			
UT2005	50V	1V @ 1A	5µA	100µA
UT2010	100V			
UT2020	200V			
UT2040	400V			
UT2060	600V			

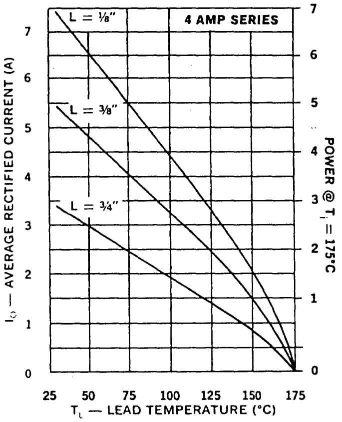
Maximum Current vs Lead Temperature



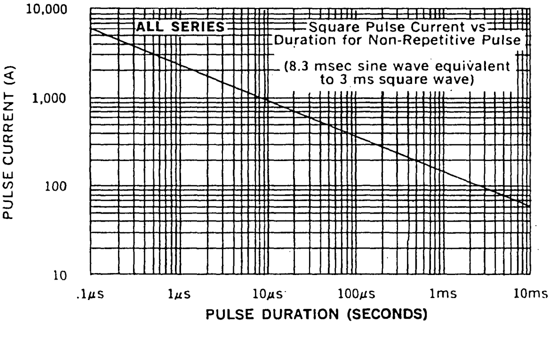
Maximum Current vs Lead Temperature



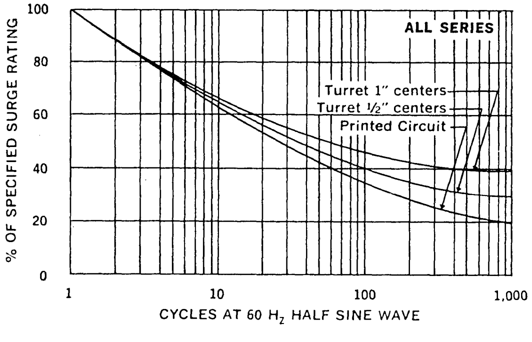
Maximum Current vs Lead Temperature



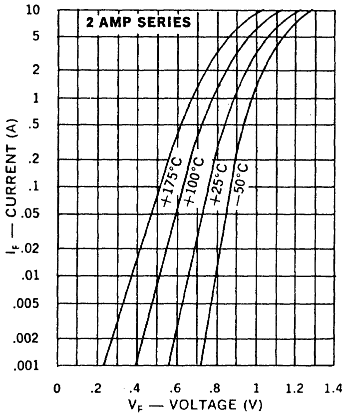
Forward Pulse Current vs Pulse Duration



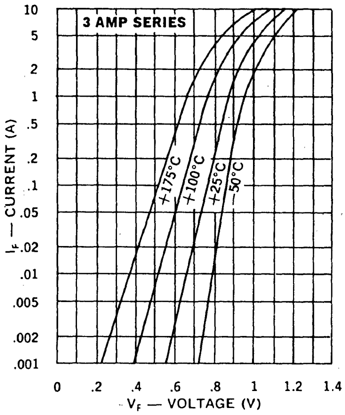
Allowable Forward Surge vs Number of Cycles



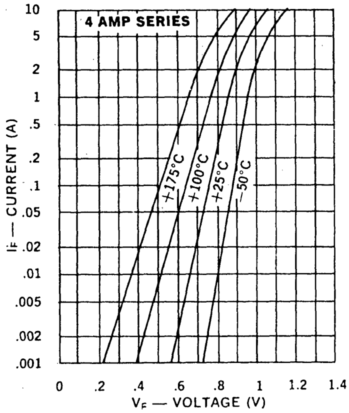
Typical Forward Current vs Forward Voltage



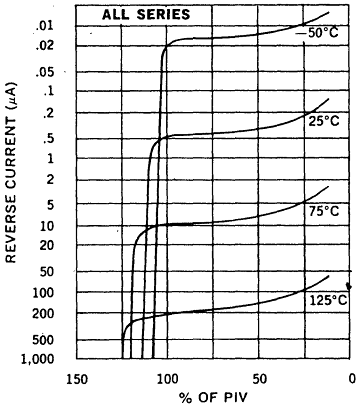
Typical Forward Current vs Forward Voltage



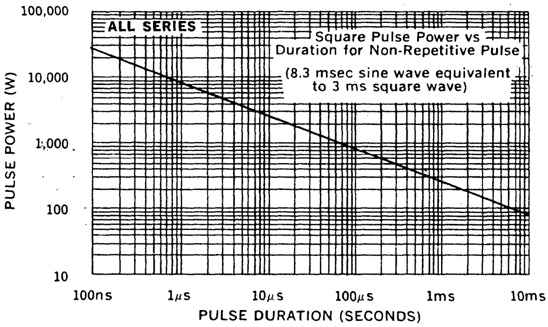
Typical Forward Current vs Forward Voltage



Typical Reverse Current vs PIV



Reverse Pulse Power vs Pulse Duration



RECTIFIERS

Standard Recovery, 7.5 Amp to 12 Amp

UT5105-UT5160
UT6105-UT6160
UT8105-UT8160
UT5105HR2-UT5160HR2
UT6105HR2-UT6160HR2
UT8105HR2-UT8160HR2

FEATURES

- Rating: 12A
- Controlled Avalanche
- Miniature Package
- Surge Rating: 200A

DESCRIPTION

These series of high current rectifiers offers opportunity for size and weight reduction in high power supplies.

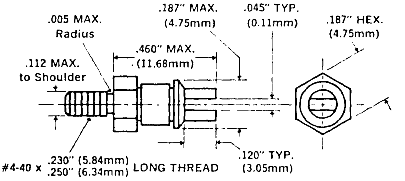
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	12 Amp Series	9 Amp Series	7.5 Amp Series
50V	UT8105/8105HR2	UT6105/6105HR2	UT5105/5105HR2
100V	UT8110/8110HR2	UT6110/6110HR2	UT5110/5110HR2
200V	UT8120/8120HR2	UT6120/6120HR2	UT5120/5120HR2
400V	UT8140/8140HR2	UT6140/6140HR2	UT5140/5140HR2
600V	UT8160/8160HR2	UT6160/6160HR2	UT5160/5160HR2

	12 AMP SERIES	9 AMP SERIES	7.5 AMP SERIES
Maximum Average D.C. Output Current @ $T_C = 100°C$	12.0A	9.0A	7.5A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	200A	175A	150A
Operating and Storage Temperature Range	—65°C to +175°C		
Thermal Resistance, Junction to Case	7.5°C/Watt		
Current Derating	See current vs. case temperature curve		

MECHANICAL SPECIFICATIONS

UT5105-UT5160 **UT6105-UT6160** **UT8105-UT8160**
UT5105HR2-UT5160HR2 **UT6105HR2-UT6160HR2** **UT8105HR2-UT8160HR2**



Part Identification: Numerals and polarity letter indicate UTR type number, e.g., UTR 4405.

Polarity: Cathode to Stud is standard. Reverse polarity denoted by "R" suffix.

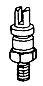
Finish: Metal parts gold plated per MIL-G-45204, Type II.

Weight: 1.5 grams, typical.

Also available with insulated stud. Reference Design Note 17.

Installation
Maximum unlubricated stud torque: 28 inch-ounces.
Mounting hardware supplied.
Do not use a screwdriver in the turret slot for installation purposes, or damage may result.

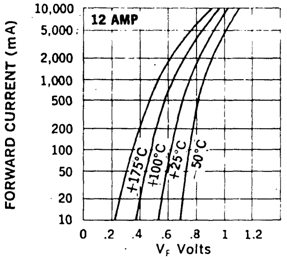
BODY C — Stud Mount



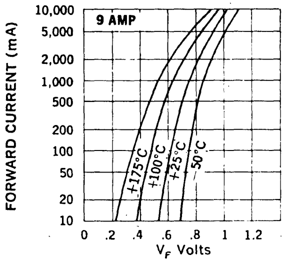
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage	Maximum Forward Voltage	Max. Reverse Current at PIV	
			25°C	100°C
UT8105/8105HR2	50V	1V @ 8A	10μA	300μA
UT8110/8110HR2	100V			
UT8120/8120HR2	200V			
UT8140/8140HR2	400V			
UT8160/8160HR2	600V			
UT6105/6105HR2	50V	1V @ 6A	10μA	300μA
UT6110/6110HR2	100V			
UT6120/6120HR2	200V			
UT6140/6140HR2	400V			
UT6160/6160HR2	600V			
UT5105/5105HR2	50V	1V @ 5A	10μA	300μA
UT5110/5110HR2	100V			
UT5120/5120HR2	200V			
UT5140/5140HR2	400V			
UT5160/5160HR2	600V			

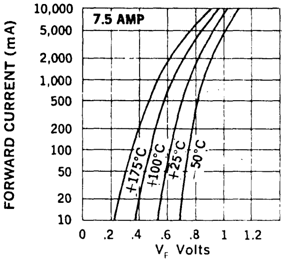
Typical Forward Voltage vs Forward Current



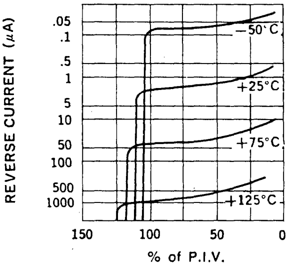
Typical Forward Voltage vs Forward Current



Typical Forward Voltage vs Forward Current



Typical P.I.V. vs Reverse Current

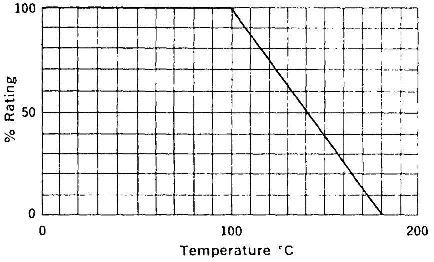


OPTIONAL HIGH RELIABILITY (HR2) SCREENING

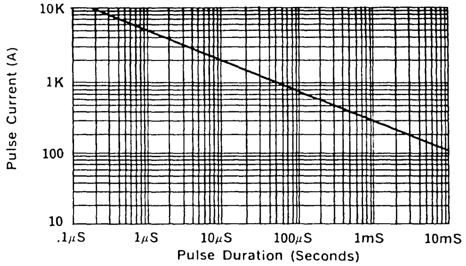
The following tests are performed on 100% of the devices specified UT5105HR2 through UT8160HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ 175°C
2. Temperature Cycling	1051	C, 20 Cycles, −65 to +175°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes.
3. Hermetic Seal a. Gross Leak	1071	E, ZYGLO
4. High Temperature Reverse Bias (HTRB)	1038	A, T_A = 150°C, V_R = 80% of rating, 48 hours
5. Interim Electrical Parameters	GO/NO GO	V_F and I_R @ 25°C
6. Power Burn-in	1038	B, T_A = 25°C, 96 Hours, I_O adjusted 150°C, ⩽ T_j ⩽ 175°C
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

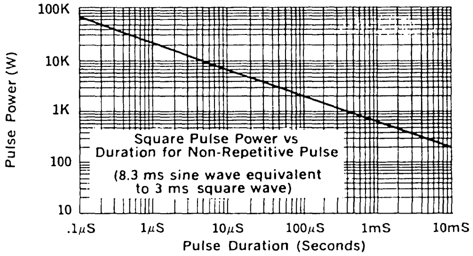
Current Rating vs Case Temperature



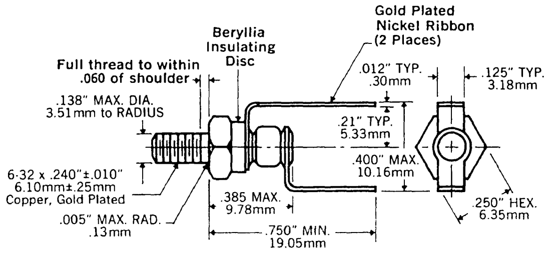
Forward Pulse Current vs. Pulse Duration



Reverse Pulse Power vs. Pulse Duration

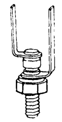


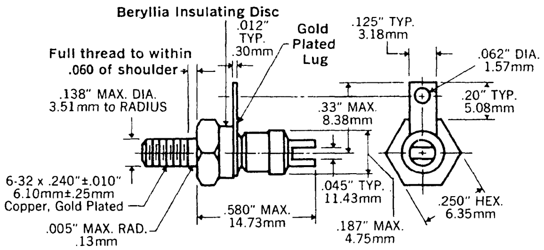
MECHANICAL SPECIFICATIONS



Dimensions in inches.

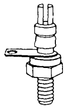
Style W





Dimensions in inches.

Style V



RECTIFIERS

Fast Recovery, 0.5 Amp to 2 Amp

UTR10-UTR60
UTR01-UTR61
UTR02-UTR62

FEATURES

- Continuous Rating: to 2A
- Controlled Avalanche
- Surge Rating: to 25A
- Fast Recovery 40kHz Operation
- PIV: to 600V
- Miniature Package

DESCRIPTION

These miniature fast recovery rectifiers permit operation at full frequencies as high as 40kHz square wave. They have the unique Unitrode Fused in Glass construction.

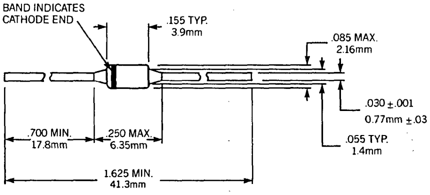
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	½ Amp Series	1 Amp Series	2 Amp Series
50V		UTR01	UTR02
100V	UTR10	UTR11	UTR12
200V	UTR20	UTR21	UTR22
300V	UTR30	UTR31	UTR32
400V	UTR40	UTR41	UTR42
500V	UTR50	UTR51	UTR52
600V	UTR60	UTR61	UTR62

	½ AMP SERIES	1 AMP SERIES	2 AMP SERIES
Maximum Average D.C. Output Current			
@ $T_A = 25°C$	0.5A	1.0A	2.0A
@ $T_A = 100°C$	0.25A	0.5A	1.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	15A	20A	25A
Operating Temperature Range	—195°C to +175°C		
Storage Temperature Range	—195°C to +200°C		
Thermal Resistance	See lead temperature derating curves		

MECHANICAL SPECIFICATIONS

UTR10-UTR60 UTR01-UTR61 UTR02-UTR62

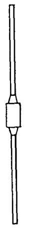


Part Identification: Green band indicates "UTR." Part number printed on body.

Polarity: Denoted by Green band.

Weight: 0.26 grams, typical.

BODY A



THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

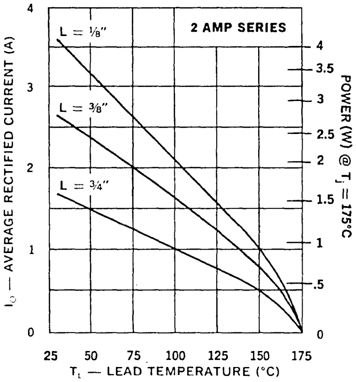
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

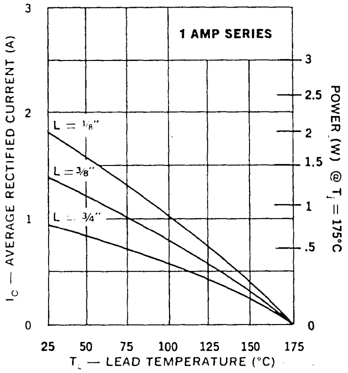
Type	PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV		Maximum Reverse Recovery Time*	Maximum Junction Capacitance @ 25°C	
			25°C	100°C		0V	—10V
UTR02	50V	1.1V @ 1000mA	3μA	100μA	250ns	150pf	60pf
UTR12	100V				250ns	100pf	40pf
UTR22	200V				250ns	80pf	32pf
UTR32	300V				300ns	70pf	28pf
UTR42	400V				350ns	60pf	24pf
UTR52	500V				400ns	50pf	20pf
UTR62	600V				400ns	40pf	16pf
UTR01	50V	1.1V @ 500mA	3μA	100μA	250ns	150pf	60pf
UTR11	100V				250ns	100pf	40pf
UTR21	200V				250ns	80pf	32pf
UTR31	300V				300ns	70pf	28pf
UTR41	400V				350ns	60pf	24pf
UTR51	500V				400ns	50pf	20pf
UTR61	600V				400ns	40pf	16pf
UTR10	100V	1.1V @ 200mA	3μA	100μA	250ns	100pf	40pf
UTR20	200V				250ns	80pf	32pf
UTR30	300V				300ns	70pf	28pf
UTR40	400V				350ns	60pf	24pf
UTR50	500V				400ns	50pf	20pf
UTR60	600V				400ns	40pf	16pf

*Recovery time is measured from 10.0mA to 10.0mA recovery to 5.0mA

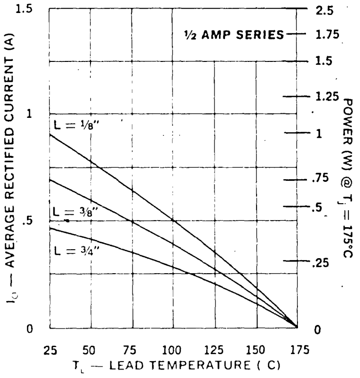
Maximum Current vs Lead Temperature



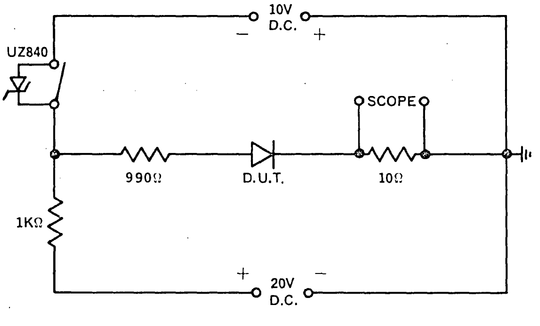
Maximum Current vs Lead Temperature



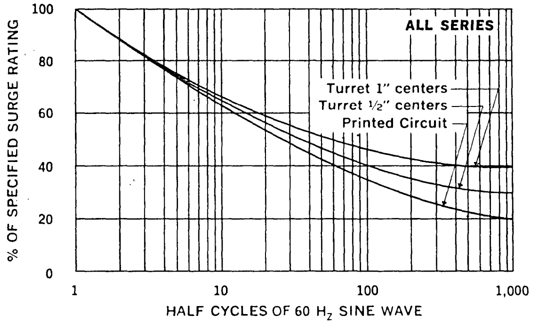
Maximum Current vs Lead Temperature



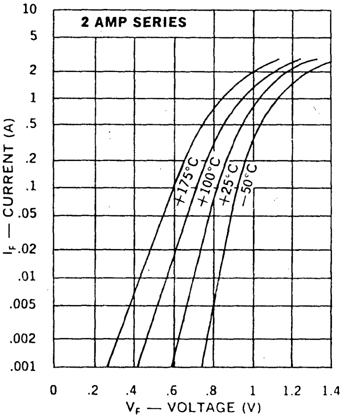
Reverse-Recovery Circuit



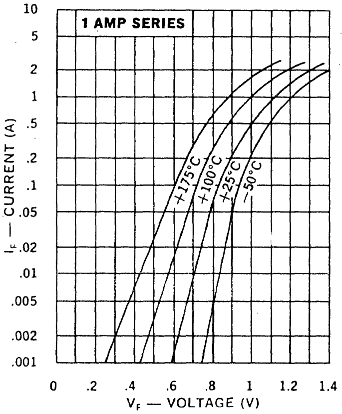
Allowable Forward Surge vs Number of Cycles



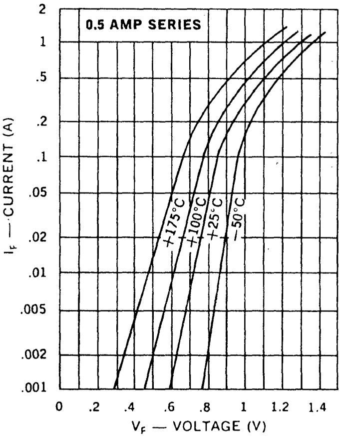
Typical Forward Current vs Forward Voltage



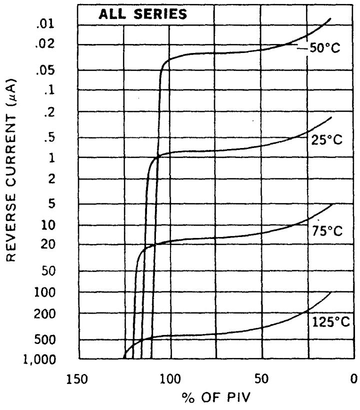
Typical Forward Current vs Forward Voltage



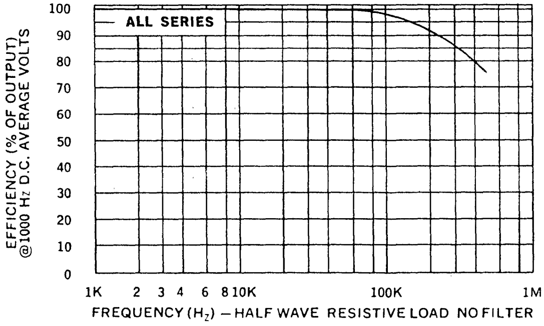
Typical Forward Current vs Forward Voltage



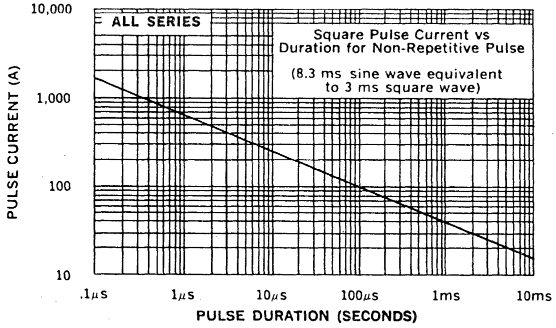
Typical Reverse Current vs PIV



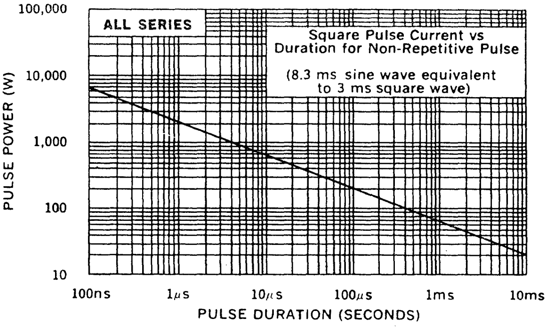
Efficiency vs Frequency at Rated Current (Sine Wave)



Forward Pulse Current vs Pulse Duration



Reverse Pulse Power vs Pulse Duration



RECTIFIERS

Fast Recovery, 2 Amp to 4 Amp

UTR2305-UTR2360
UTR3305-UTR3360
UTR4305-UTR4360

FEATURES

- Continuous Rating: to 4A
- Controlled Avalanche
- Surge Rating: to 100A
- PIV: to 600V
- Miniature Package

DESCRIPTION

Small size and high surge capability make this series of power switching rectifiers desirable for power supplies where size, weight and reliability are important.

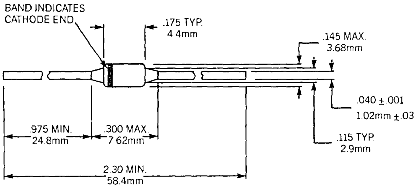
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	2 Amp Series	3 Amp Series	4 Amp Series
50V	UTR2305	UTR3305	UTR4305
100V	UTR2310	UTR3310	UTR4310
200V	UTR2320	UTR3320	UTR4320
400V	UTR2340	UTR3340	UTR4340
500V	UTR2350	UTR3350	UTR4350
600V	UTR2360	UTR3360	UTR4360

	2 AMP SERIES	3 AMP SERIES	4 AMP SERIES
Maximum Average D.C. Output Current			
@ $T_A = 25°C$	2.0A	3.0A	4.0A
@ $T_A = 100°C$	1.0A	1.5A	2.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	60A	80A	100A
Operating Temperature Range	—195°C to +175°C		
Storage Temperature Range	—195°C to +200°C		
Thermal Resistance	See lead temperature derating curve		

MECHANICAL SPECIFICATIONS

UTR4305-UTR4360 **UTR3305-UTR3360** **UTR2305-UTR2360**

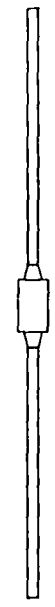


Part Identification: Green band indicates "UTR." Part number printed on body.

Polarity: Denoted by Green band.

Weight: 0.75 grams, typical.

BODY B



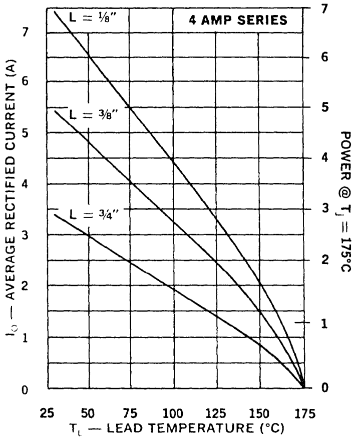
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

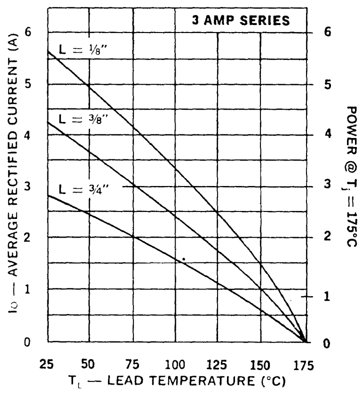
Type	PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV		Maximum Reverse Recovery Time*	Maximum Junction Capacitance @ 25°C	
			25°C	100°C		0V	—10V
UTR4305 UTR4310 UTR4320 UTR4340 UTR4350 UTR4360	50V 100V 200V 400V 500V 600V	1.1V @ 4A	5μA	100μA	250ns 250ns 250ns 400ns 400ns 400ns	600pf 400pf 320pf 240pf 200pf 160pf	240pf 160pf 128pf 96pf 80pf 64pf
UTR3305 UTR3310 UTR3320 UTR3340 UTR3350 UTR3360	50V 100V 200V 400V 500V 600V	1.1V @ 3A	5μA	100μA	250ns 250ns 250ns 300ns 350ns 400ns	600pf 400pf 320pf 240pf 200pf 160pf	240pf 160pf 128pf 96pf 80pf 64pf
UTR2305 UTR2310 UTR2320 UTR2340 UTR2350 UTR2360	50V 100V 200V 400V 500V 600V	1.1V @ 2A	5μA	100μA	250ns 250ns 250ns 300ns 350ns 400ns	600pf 400pf 320pf 240pf 200pf 160pf	240pf 160pf 128pf 96pf 80pf 64pf

*Recovery time is measured from 1A to 1A recovering to 0.5A.

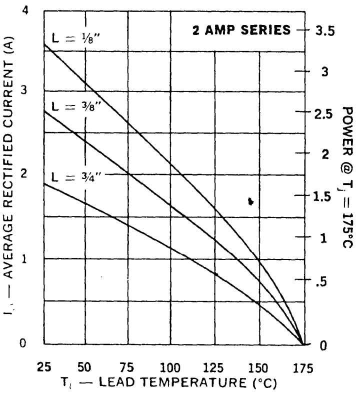
Maximum Current vs Lead Temperature



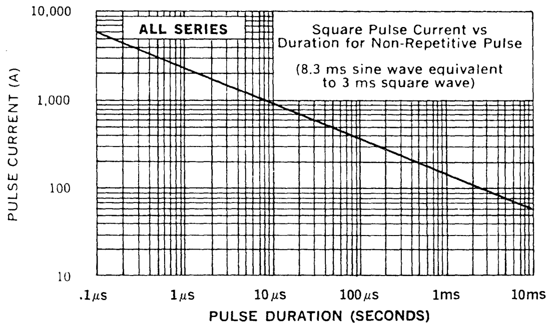
Maximum Current vs Lead Temperature



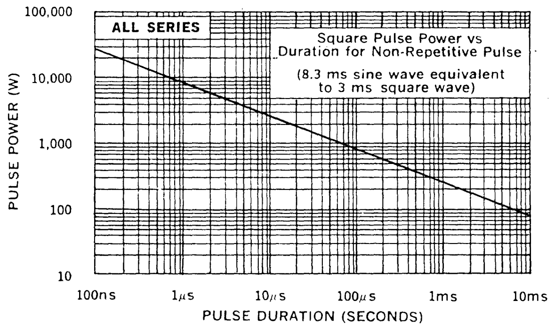
Maximum Current vs Lead Temperature



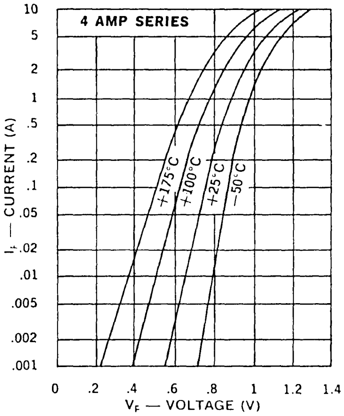
Forward Pulse Current vs Pulse Duration



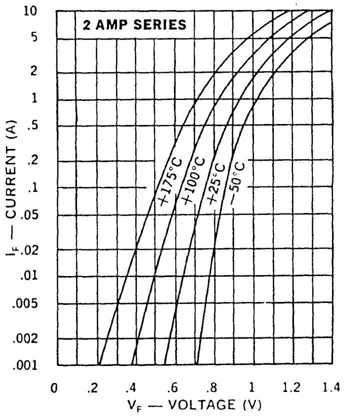
Reverse Pulse Power vs Pulse Duration



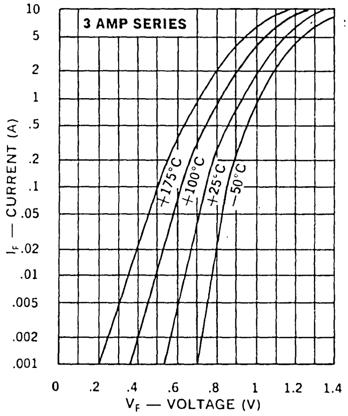
Typical Forward Current vs Forward Voltage



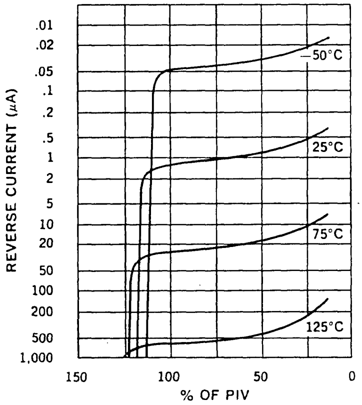
Typical Forward Current vs Forward Voltage



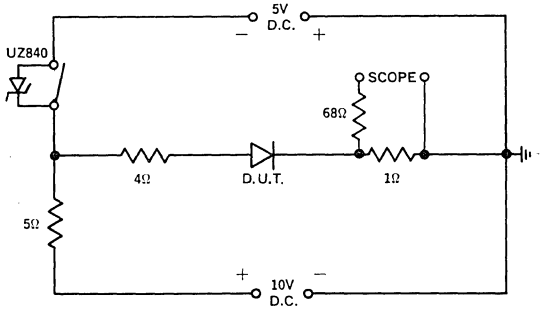
Typical Forward Current vs Forward Voltage



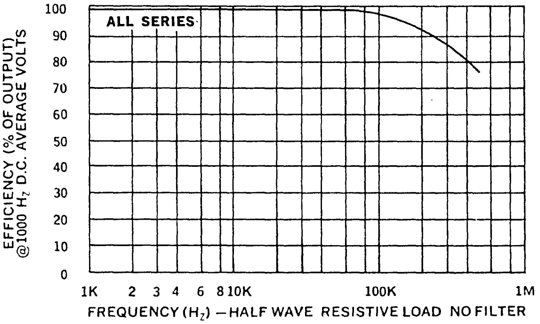
Typical Reverse Current vs PIV



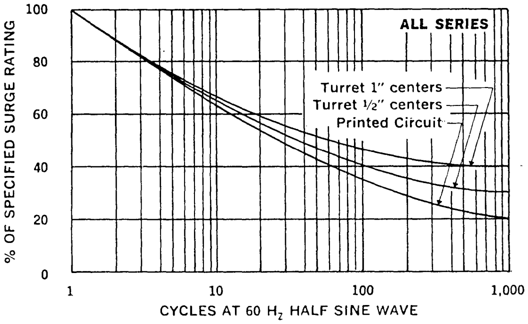
Reverse Recovery Circuit



Efficiency vs Frequency at Rated Current (Sine Wave)



Allowable Forward Surge vs Number of Cycles



RECTIFIERS

Fast Recovery, 6 Amp to 9 Amp

UTR4405-UTR4440
UTR5405-UTR5440
UTR6405-UTR6440
UTR4405HR2-UTR4440HR2
UTR5405HR2-UTR5440HR2
UTR6405HR2-UTR6440HR2

FEATURES

- Continuous Rating: to 9A
- Controlled Avalanche
- Surge Rating: to 150A
- Fast Recovery, 40kHz Operation
- PIV: to 400V
- Miniature Package

DESCRIPTION

The same basic construction as all Unitrode diodes, but using a miniature stud mounting and larger junction area, provides a 9 Amp continuous and 150 Amp surge rating in a package only one fifth the weight and one quarter the volume of conventional types.

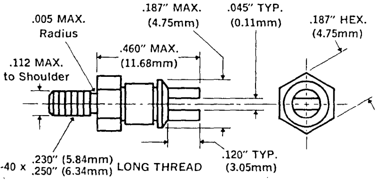
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	6 Amp Series	7.5 Amp Series	9 Amp Series
50V	UTR4405/4405HR2	UTR5405/5405HR2	UTR6405/6405HR2
100V	UTR4410/4410HR2	UTR5410/5410HR2	UTR6410/6410HR2
200V	UTR4420/4420HR2	UTR5420/5420HR2	UTR6420/6420HR2
400V	UTR4440/4440HR2	UTR5440/5440HR2	UTR6440/6440HR2

	6 Amp Series	7.5 Amp Series	9.0 Amp Series
Maximum Average D.C. Output Current @ T_C = 100°C	6.0A	7.5A	9.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	120A	135A	150A
Operating Temperature Range		−195°C to +175°C	
Storage Temperature Range		−195°C to +200°C	
Thermal Resistance		7.5°C/W	

MECHANICAL SPECIFICATIONS

UTR4405-UTR4440	**UTR5405-UTR5440**	**UTR6405-UTR6440**
UTR4405HR2-UTR4440HR2	**UTR5405HR2-UTR5440HR2**	**UTR6405HR2-UTR6440HR2**



Part Identification: Numerals and polarity letter indicate UTR type number, e.g., UTR 4405.

Polarity: Cathode to Stud is standard. Reverse polarity denoted by "R" suffix.

Finish: Metal parts gold plated per MIL-G-45204, Type II.

Weight: 1.5 grams, typical.

Also available with insulated stud. Reference Design Note 17.

Installation
Maximum unlubricated stud torque: 28 inch-ounces.
Mounting hardware supplied.
Do not use a screwdriver in the turret slot for installation purposes, or damage may result.

BODY C — Stud Mount

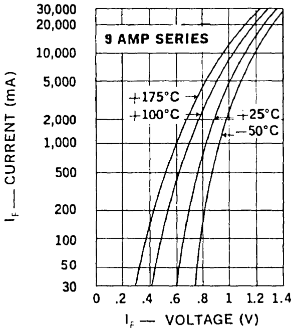
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

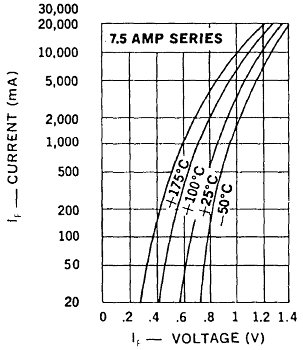
Type	PIV	Maximum Forward Voltage Drop	Maximum Reverse Current @ PIV		Maximum Reverse Recovery Time*
			25°C	100°C	
UTR6405/6405HR2 UTR6410/6410HR2 UTR6420/6420HR2 UTR6440/6440HR2	50V 100V 200V 400V	1.1V @ 6.0A	10μA	300μA	300ns 300ns 400ns 500ns
UTR5405/5405HR2 UTR5410/5410HR2 UTR5420/5420HR2 UTR5440/5440HR2	50V 100V 200V 400V	1.1V @ 5.0A	10μA	300μA	300ns 300ns 400ns 500ns
UTR4405/4405HR2 UTR4410/4410HR2 UTR4420/4420HR2 UTR4440/4440HR2	50V 100V 200V 400V	1.1V @ 4.0A	10μA	300μA	300ns 300ns 400ns 500ns

*Recovery time is measured from 1A to 1A, recovering to 0.5A.

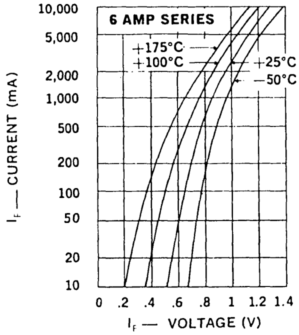
Typical Forward Voltage vs Forward Current



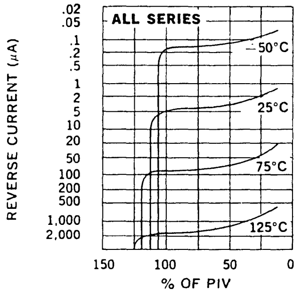
Typical Forward Voltage vs Forward Current



Typical Forward Voltage vs Forward Current



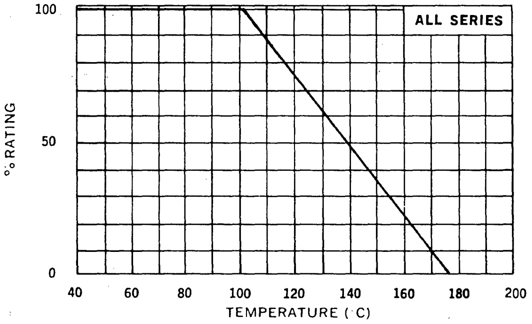
Typical Reverse Current vs PIV

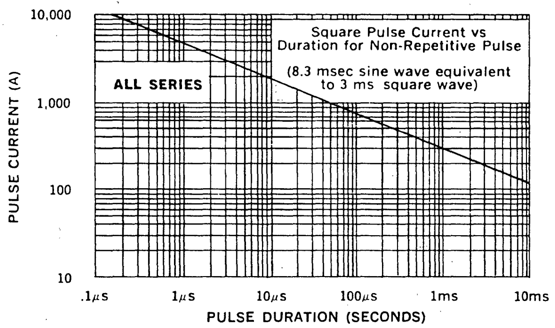


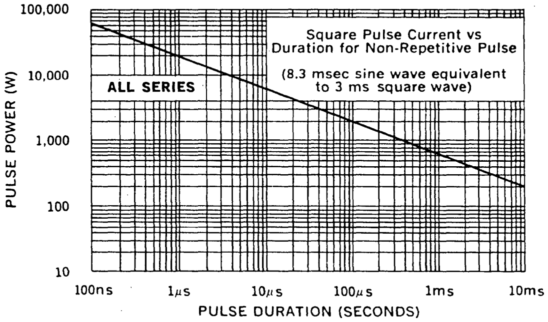
OPTIONAL HIGH RELIABILITY (HR2) SCREENING

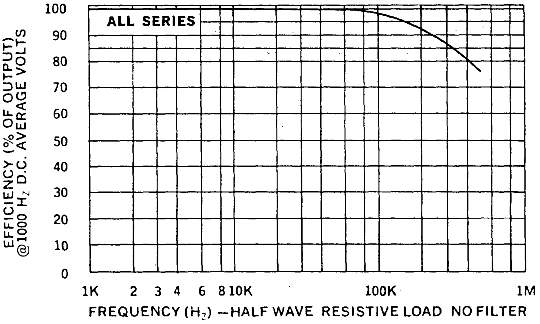
The following tests are performed on 100% of the devices specified UTR4405HR2 through UTR6440HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ 175°C
2. Temperature Cycling	1051	C, 20 Cycles, −65 to +175°C. No dwell required @ 25°C, t ⩾ min. extremes
3. Hermetic Seal a. Gross Leak	1071	E, ZYGLO
4. High Temperature Reverse Bias (HTRB)	1038	A, T_A = 150°C, V_R = 80% of rating, 48 hours
5. Interim Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C
6. Power Burn-in	1038	B, T_A = 25°C, 96 Hours, I_O adjusted 150°C, ⩽ T_j ⩽ 175°C
7. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C PDA = 10% (Final Electricals)

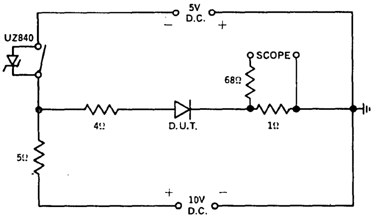

Current Rating vs Case Temperature


Forward Pulse Current vs Pulse Duration

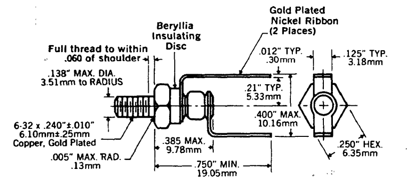

Reverse Pulse Power vs Pulse Duration


Efficiency vs Frequency at Rated Current (Sine Wave)

Reverse Recovery Circuit

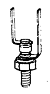


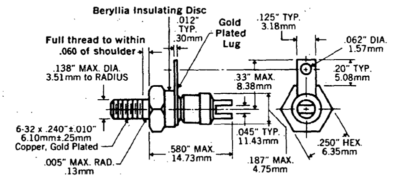
MECHANICAL SPECIFICATIONS



Dimensions in inches.

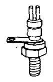
Style W





Dimensions in inches.

Style V



RECTIFIERS

Super-Fast Recovery, 1 Amp and 2 Amp

UTX105-UTX125
UTX205-UTX225

FEATURES

- Continuous Rating: to 2A
- Controlled Avalanche
- Surge: to 25A
- Recovery Time less than 75ns
- Miniature Package

DESCRIPTION

These miniature super-fast recovery rectifiers permit operation at full power at frequencies as high as 100kHz square wave. They may be used as half wave rectifiers or as legs of a bridge.

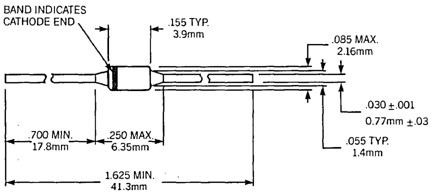
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	1 Amp Series	2 Amp Series
50V	UTX105	UTX205
100V	UTX110	UTX210
150V	UTX115	UTX215
200V	UTX120	UTX220
250V	UTX125	UTX225

	1 AMP SERIES	2 AMP SERIES
Maximum Average D.C. Output Current		
@ $T_A = 25°C$	1.0A	2.0A
@ $T_A = 100°C$	0.5A	1.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	20A	25A
Operating Temperature Range	—195°C to +175°C	
Storage Temperature Range	—195°C to +200°C	
Thermal Resistance	See Lead Temperature Derating Curve	

MECHANICAL SPECIFICATIONS

UTX105-UTX125 UTX205-UTX225



Part Identification: Green band indicates "UTX." Part number printed on body.

Polarity: Denoted by green band.

Weight: 0.26 grams, typical.

BODY A

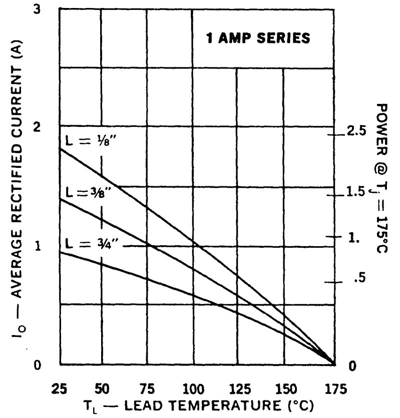
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

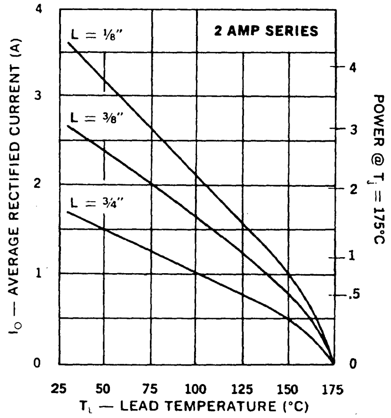
Type	PIV	Maximum Voltage Forward Drop	Leakage Current @ PIV		Max. Reverse Recovery Time*
			25°C	100°C	
UTX 205 UTX 210 UTX 215 UTX 220 UTX 225	50V 100V 150V 200V 250V	1.0V @ 1 Adc	3μA	50μA	75ns
UTX 105 UTX 110 UTX 115 UTX 120 UTX 125	50V 100V 150V 200V 250V	1.0V @ 0.5 Adc	3μA	50μA	75ns

*Recovery time is measured from 10.0mA to 10.0mA recovery to 5.0mA.

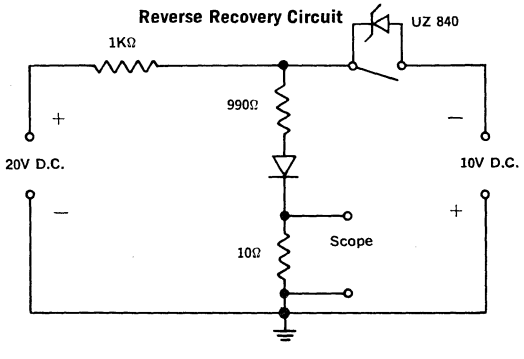
Maximum Current vs Lead Temperature



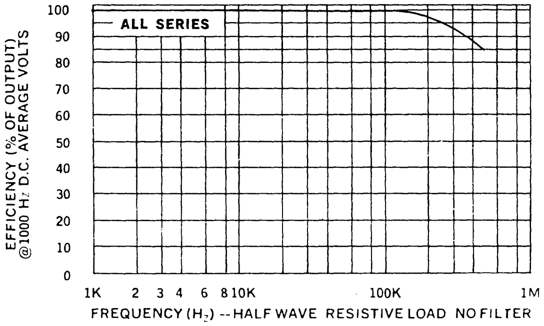
Maximum Current vs Lead Temperature



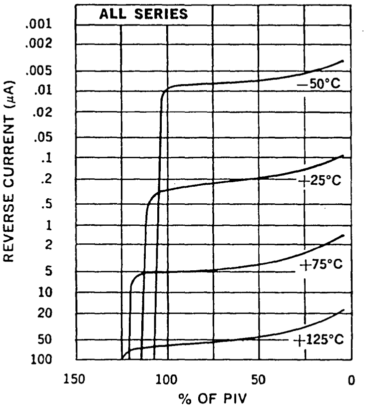
Reverse Recovery Circuit



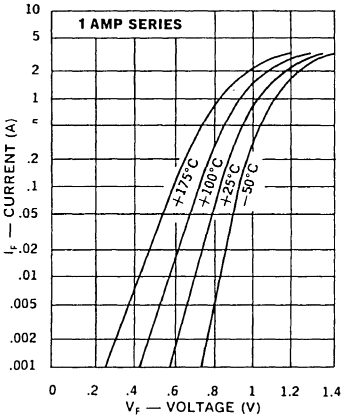
Efficiency vs Frequency at Rated Current (Sine Wave)



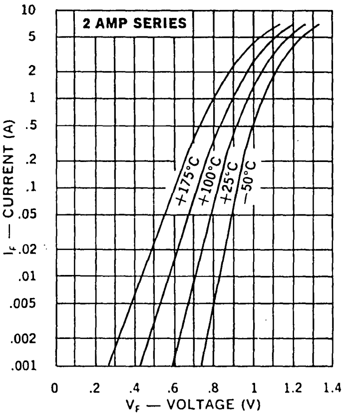
Typical Leakage Current vs. PIV



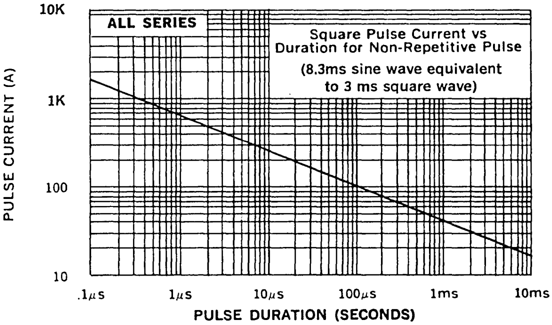
Typical Forward Current vs Forward Voltage



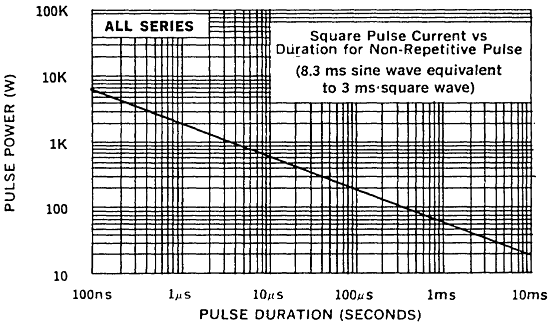
Typical Forward Current vs Forward Voltage



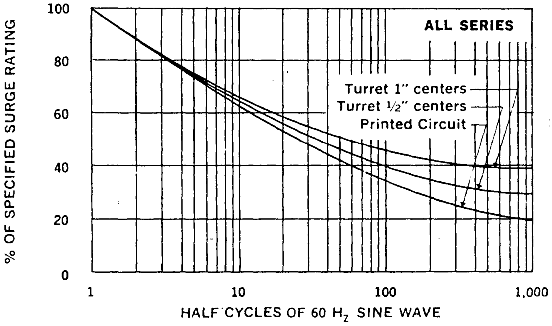
Forward Pulse Current vs Pulse Duration



Reverse Pulse Power vs Pulse Duration



Allowable Forward Surge vs Number of Cycles



RECTIFIERS
Super-Fast Recovery, 3 Amp and 4 Amp

UTX 3105-UTX 3120
UTX 4105-UTX 4120

FEATURES
- Continuous Rating: to 4A
- Controlled Avalanche
- Surge: to 80A
- Recovery Time less than 100ns
- Miniature Package

DESCRIPTION
These miniature super-fast recovery rectifiers permit operation at full power at frequencies as high as 100kHz square wave. They have the same unique Unitrode construction as the familiar 2 amp UTX series, but are scaled up in size to provide higher continuous and surge current capability.

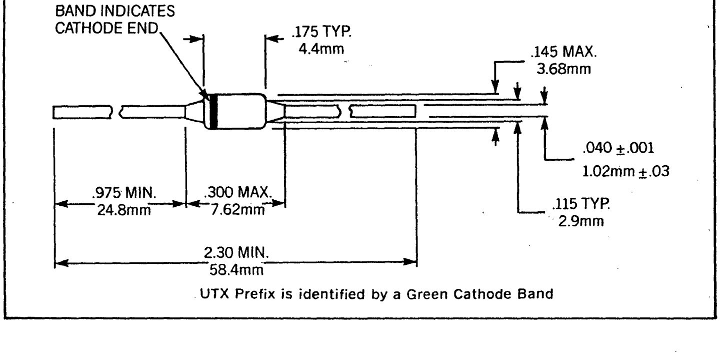
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	3 Amp Series	4 Amp Series
50V	UTX 3105	UTX 4105
100V	UTX 3110	UTX 4110
150V	UTX 3115	UTX 4115
200V	UTX 3120	UTX 4120

	3 AMP SERIES	4 AMP SERIES
Maximum Average D.C. Output Current		
@ $T_A = 25°C$	3.0A	4.0A
@ $T_A = 100°C$	1.5A	2.0A
Non-Repetitive Sinusoidal Surge Current (8.3ms)	60A	80A
Operating Temperature Range	—195°C to +175°C	
Storage Temperature Range	—195°C to +200°C	
Thermal Resistance	See Lead Temperature Derating Curve	

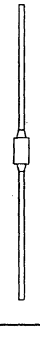
MECHANICAL SPECIFICATIONS

UTX 3105-UTX 3120 UTX 4105-UTX 4120



UTX Prefix is identified by a Green Cathode Band

BODY B



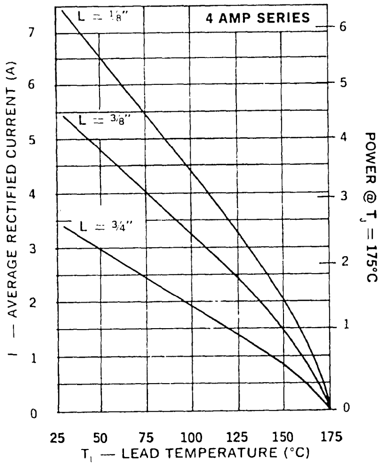
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

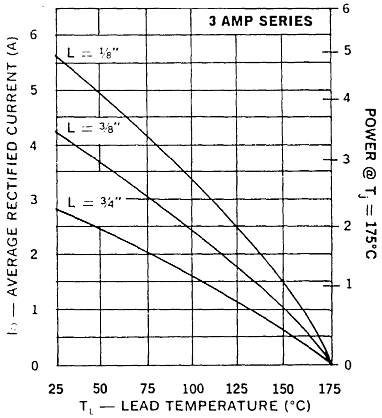
Type	PIV	Maximum Forward Voltage Drop*	Maximum Leakage Current @ PIV 25°C	Maximum Leakage Current @ PIV 100°C	Maximum Reverse Recovery Time**
UTX 4105	50V	1V @ 3 Adc	5μA	75μA	100ns
UTX 4110	100V				
UTX 4115	150V				
UTX 4120	200V				
UTX 3105	50V	1V @ 2 Adc	5μA	75μA	100ns
UTX 3110	100V				
UTX 3115	150V				
UTX 3120	200V				

*Forward voltage is measured at least 1 second after application of current.
**Recovery time is measured from 1A to 1A recovering to 0.5A.

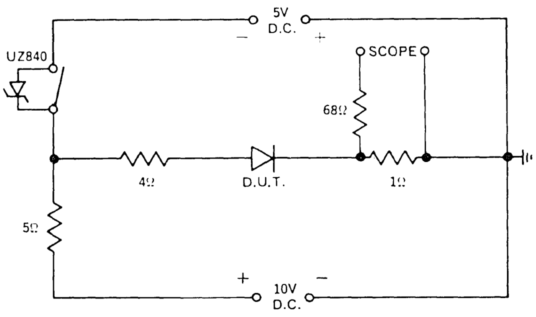
Maximum Current vs Lead Temperature



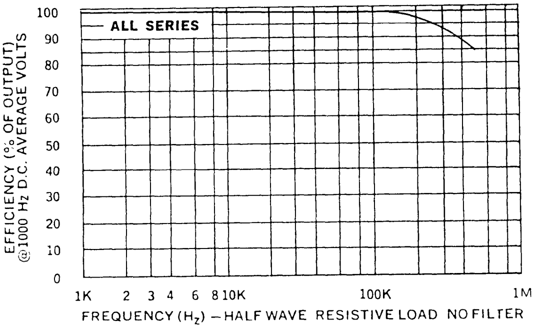
Maximum Current vs Lead Temperature



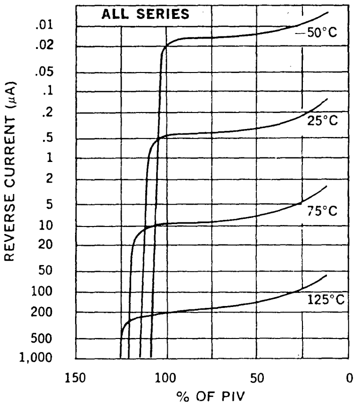
Reverse Recovery Circuit



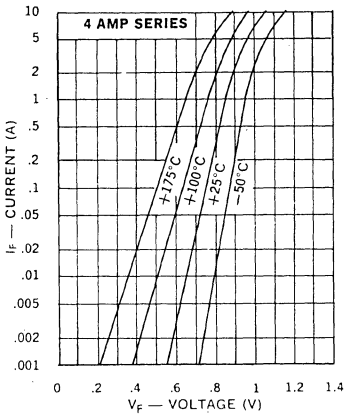
Efficiency vs Frequency at Rated Current (Sine Wave)



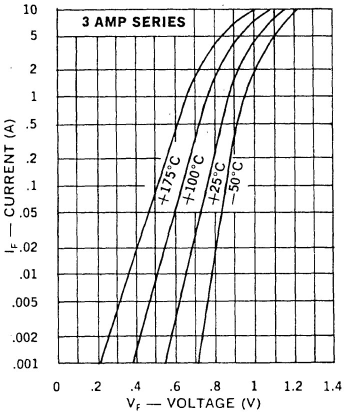
Typical Leakage Current vs PIV



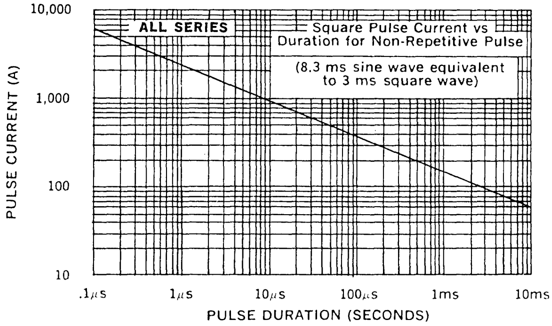
Typical Forward Current vs Forward Voltage



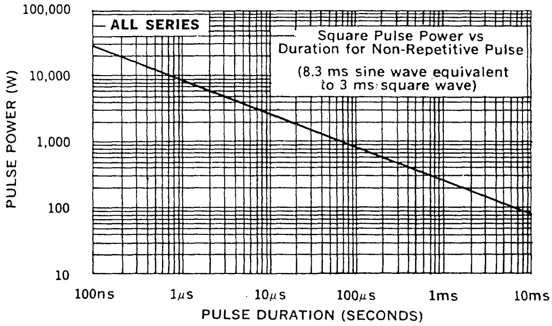
Typical Forward Current vs Forward Voltage



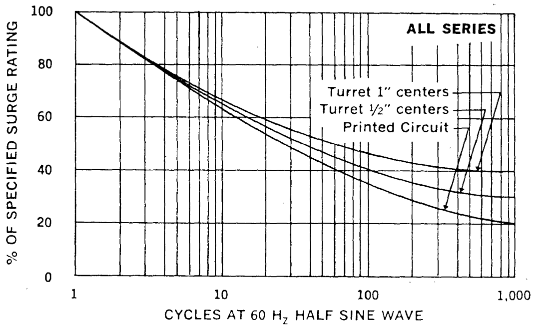
Forward Pulse Current vs Pulse Duration



Reverse Pulse Power vs Pulse Duration



Allowable Forward Surge vs Number of Cycles

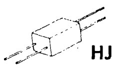


RECTIFIER BRIDGES & MODULES 3

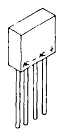
RECTIFIER BRIDGES

Single Phase Full-Wave Bridges

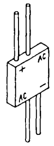
PRODUCT SELECTION GUIDE



HJ, HK, HL, HM, HN, HO, HP



S



G, GA, GH

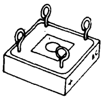
STANDARD RECOVERY

Peak Inverse Voltage Per Leg	AVERAGE D.C. OUTPUT CURRENT					
	≤.25A	.25—.75A	.75—1.5A	1.5—2.5A	4—10A	10—25A
100V			673-1 **G or S**	697-1 **GA**	680-1 **NA**	679-1 **NB** SPA25* **MC**
200V			673-2 **G or S**	697-2 **GA**	680-2 **NA** 469-1** **MD**	679-2 **NB** SPB25* **MC**
300V			673-3 **G or S**	697-3 **GA**	680-3 **NA**	679-3 **NB**
400V			673-4 **G or S**	697-4 **GA**	680-4 **NA** 469-2** **MD**	679-4 **NB** SPC25* **MC**
500V			673-5 **G or S**	697-5 **GA**	680-5 **NA**	679-5 **NB**
600V			673-6 **G or S**	697-6 **GA**	680-6 **NA** 469-3** **MD**	679-6 **NB** SPD25* **MC**
1.2kV		673-7 **GH**				
1.8kV		673-75 **HJ**				
2.4kV		673-8 **HK**				
2.5kV						
3.0kV		673-85 **HL**				
3.6kV	673-9 **HM**					
4.0kV						
4.2kV	673-10 **HN**					
4.8kV	673-11 **HO**					
5.0kV	673-12 **HO**					
7.5kV						
10kV						
15kV						

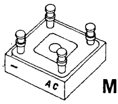
*Available as JAN
**Available as JAN, JANTX

RECTIFIER BRIDGES

Single Phase Full-Wave Bridges



NA, NB



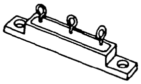
MA, MB, MC, MD

FAST RECOVERY

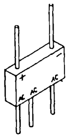
Peak Inverse Voltage Per Leg	AVERAGE D.C. OUTPUT CURRENT							
	≤.25A	.25—.75A	.75—1.5A	1.5—2.5A	4—10A	10—25A		25—35A
50V							803-1 **MB**	802-1 **MA**
100V			676-1 **G or S**	698-1 **GA**	684-1 **NA**	683-1 **NB**	803-2 **MB**	802-2 **MA**
125V							803-3 **MB**	802-3 **MA**
150V							803-4 **MB**	802-4 **MA**
200V			676-2 **G or S**	698-2 **GA**	684-2 **NA**	683-2 **NB**		
300V			676-3 **G or S**	698-3 **GA**	684-3 **NA**	683-3 **NB**		
400V			676-4 **G or S**	698-4 **GA**	684-4 **NA**	683-4 **NB**		
500V			676-5 **G or S**	698-5 **GA**	684-5 **NA**	683-5 **NB**		
600V			676-6 **G or S**	698-6 **GA**	684-6 **NA**	683-6 **NB**		
1.2kV		676-12 **HJ**						
1.8kV		676-18 **HK**						
2.4kV		676-24 **HL**						
2.5kV								
3.0kV		676-30 **HM**						
3.6kV	676-36 **HN**							
4.0kV								
4.2kV	676-42 **HO**							
4.8kV	676-48 **HP**							
5.0kV	676-50 **HP**							
7.5kV								
10kV								
15kV								
Reverse Recovery Time (max.)	500ns	500ns	500ns	500ns	500ns	500ns	50ns	50ns

RECTIFIER BRIDGES

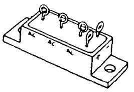
Three Phase Full-Wave Bridge



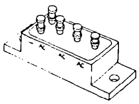
ND



F



NC



ME

STANDARD RECOVERY

Peak Inverse Voltage Per Leg	AVERAGE D.C. OUTPUT CURRENT			
	1–3A	4.5–15A	15–25A	
50V				
100V	700-1 **F**	695-1 **NC**	678-1 **NC**	
125V				
150V				
200V	700-2 **F**	695-2 **NC**	678-2 **NC**	483-1* **ME**
300V	700-3 **F**	695-3 **NC**	678-3 **NC**	
400V	700-4 **F**	695-4 **NC**	678-4 **NC**	483-2* **ME**
500V	700-5 **F**	695-5 **NC**	678-5 **NC**	
600V	700-6 **F**	695-6 **NC**	678-6 **NC**	483-3* **ME**
2.5kV				
5.0kV				
7.5kV				
10kV				

*Available as JANTX

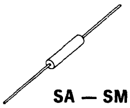
FAST RECOVERY

Peak Inverse Voltage Per Leg	AVERAGE D.C. OUTPUT CURRENT				
	1–3A	4.5–15A	15–25A		25–40A
50V				801-1 **ME**	800-1 **ME**
100V	701-1 **F**	696-1 **NC**	682-1 **NC**	801-2 **ME**	800-2 **ME**
125V				801-3 **ME**	800-3 **ME**
150V				801-4 **ME**	800-4 **ME**
200V	701-2 **F**	696-2 **NC**	682-2 **NC**		
300V	701-3 **F**	696-3 **NC**	682-3 **NC**		
400V	701-4 **F**	696-4 **NC**	682-4 **NC**		
500V	701-5 **F**	696-5 **NC**	682-5 **NC**		
600V	701-6 **F**	696-6 **NC**	682-6 **NC**		
2.5kV					
3.0kV					
4.0kV					
5.0kV					
Reverse Recovery Time (max.)	500ns	500ns	500ns	50ns	50ns

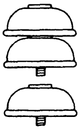
DOUBLERS & CENTER-TAP RECTIFIERS

STANDARD RECOVERY ND

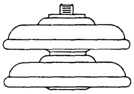
Peak Inverse Voltage Per Leg	Average D.C. Output Current
	2–15A
100V	681-1 **ND**
200V	681-2 **ND**
300V	681-3 **ND**
400V	681-4 **ND**
500V	681-5 **ND**
600V	681-6 **ND**



SA — SM



DD

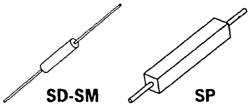


DG

STANDARD RECOVERY

Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT						
	.250-.50A	.50-.75A	.75-1A	1-1.5A	2.5-5A	5-6A	6-7A
1.0kV							
1.2kV				US12 **SA**			
1.5kV			US15 **SA**				
1.8kV		US18 **SA**					
2.0kV		US20 **SA**					
2.5kV		US25 **SB**		USB2.5 **DH**	UDB2.5 **DD**	UDE2.5 **DD**	UGE2.5 **DG**
3.0kV		US30 **SB**					
3.5kV	US35 **SC**						
4.0kV	US40 **SC**						
4.5kV	US45A **SD**						

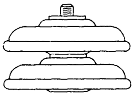
RECTIFIER MODULES



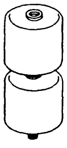
Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT										
	.100-.250A	.250-.50A	.50-.75A	.75-1A	1-1.5A	1.5-2A	2-2.5A	2.5-3A	3-4A	4-5A	5-6A
5.0kV		US50A **SD**	USB5 **DH** USS5 **DH**			UDA5 **DD** UDB5 **DD** 1N5600* **DE**				UDE5 **DG** UGB5 **DD**	UGE5 **DG** 1N5603* **DF**
6.0kV		US60A **SD**			KXS60 **SM**						
7.0kV		US70A **SD**									
7.5kV		USS7.5 **DH**	USB7.5 **DH**		UDA7.5 **DD** UDB7.5 **DD**			UGB7.5 **DG**	UGE7.5 **DG**		
8.0kV	US80A **SE**										
10kV	US100A **SE**	USB10 **DH** USS10 **DH**	688-10 **BE**	UDA10 **DD** 1N5597* **DE**			UGB10 **DG**				
12kV	US120A **SE**	688-12 **BE**									
12.5kV											

*Available as JAN

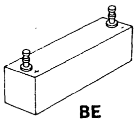
RECTIFIER MODULES



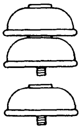
DF DG



DH



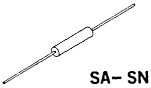
BE



DD DE

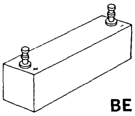
STANDARD RECOVERY

Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT		
	.100-.250A	.250-.50A	.50-.75A
15kV	US150A **SF** USS15 **DH**	688-15 **BE**	UDA15 **DD**
17.5kV			
18kV	US180A **SF**	688-18 **BE**	
20kV	US200A **SF**	688-20 **BE**	
22.5kV			
25kV	688-25 **BE**		

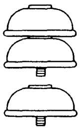


FAST RECOVERY

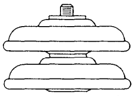
Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT					
	.100-.250A	.250-.50A	.50-.75A	.75-1.5A	2-2.5A	4-6A
1.0kV						
1.2kV				USR12 **SA**		
1.5kV			USR15 **SA**			
1.8kV			USR18 **SA**			
2.0kV			USR20 **SB**			
2.5kV		USR25 **SB**		UFB2.5 **DH**	UDD2.5 **DD**	UDF2.5 **DD** UGF2.5 **DG**
3.0kV		USR30 **SC**				
3.5kV		USR35 **SC**				
4.0kV		USR40A **SD**				
4.5kV	USR45A **SD**					
Reverse Recovery Time (Max.)	500ns 250ns*	500ns 250ns†	500ns 250ns*	500ns 250ns*	500ns 250ns* 150ns†	500ns



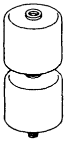
BE



DD



DG



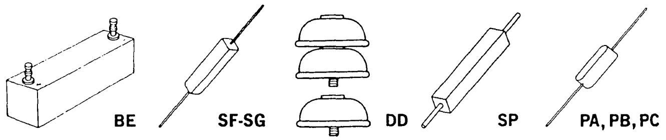
DH

FAST RECOVERY

Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT							
	.100-.250A	.250-.50A	.50-.75A	.75-1A	1-1.5A	1.5-2A	2-2.5A	2.5-4A
5.0kV	USR50A **SD**	UFS5 **DH**	UFB5 **DH**		UDC5 **DD** UDD5 **DD**			UDF5 **DD** UGD5 **DG** UGF5 **DG**
6.0kV	USR60A **SD**							
7.0kV	USR70A **SE**							
7.5kV		UFB7.5 **DH** UFS7.5 **DH**		UDC7.5 **DD** UDD7.5 **DD**			UGD7.5 **DG** UGF7.5 **DG**	
8.0kV	USR80A **SE**							
10kV	USR100A **SE**	UFS10 **DH**	UDC10 **DD** 688-10R **BE**			UGD10 **DG**		
12kV	USR120A **SF**	688-12R **BE**						
12.5kV								
Reverse Recovery Time (Max.)	500ns	500ns	500ns	500ns	500ns	500ns	500ns	500ns

RECTIFIER MODULES

PRODUCT SELECTION GUIDE



FAST RECOVERY

Peak Inverse Voltage	AVERAGE D.C. OUTPUT CURRENT	
	.100-.250A	.250-.75A
15kV	USR150A **SF**	UDC15 **DD** 688-15R **BE**
17.5kV		
18kV	USR180A **SF**	688-18R **BE**
20kV	688-20R **BE**	
22.5kV		
25kV	688-25R **BE**	
Reverse Recovery Time (Max.)	500ns	500ns 150ns

OPTIONAL HIGH RELIABILITY (HR2) SCREENING
(Consult factory for applicable part numbers)

SCREEN	MIL-STD-750 METHOD	CONDITIONS
PERFORM ON DISCRETE DIODES PRIOR TO ENCAPSULATION		
1. High Temperature Storage	1032	24 Hours @ T_A + 175°C
2. Temperature Cycling	1051	C, 10 Cycles, −65 to +175°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes.
3. Hermetic Seal a. Gross	1071	E, ZYGLO
4. High Temperature Reverse Bias (HTRB)	1038	A, 48 Hours, T_A = 125°C, V_R = 80% of rating
5. Interim Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C, PDA = 10% (Final Electricals)
BRIDGE MODULE SCREENING		
1. Temperature Cycling	1051	F, 10 Cycles, −55 to +150°C. No dwell required @ 25°C, t ⩾ 10 min. @ extremes.
2. Final Electrical Parameters	GO/NO GO	V_F + I_R @ 25°C
3. External Visual		

RECTIFIER ASSEMBLIES
Single Phase Bridges, 10 Amp, Military Approved

JAN & JANTX 469-1
JAN & JANTX 469-2
JAN & JANTX 469-3

FEATURES
- Qualified to MIL-S-19500/469
- Current Rating: to 10A
- PIV: from 200 to 600V
- Surge Ratings of 100A
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Aluminum Heat Sink Case, Electrically Insulated

DESCRIPTION
This series of military high-current single-phase bridge offer the utmost in reliability as required in military system designs. The TX series is assembled with diodes which have been subjected to 100% screening tests.

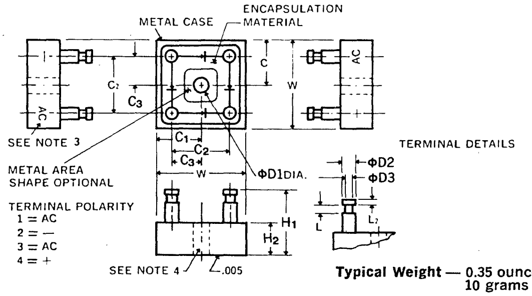
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	200 to 600V
Maximum Average D.C. Output Current	
@ $T_C = +55°C$	10A
@ $T_C = +100°C$	6A
Non-Repetitive Sinusoidal Surge (8.3ms)	
@ $T_C = +55°C$	100A
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient	25°C/W
Junction to Case	5°C/W

Ltr	Dimensions			
	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
C_1	.367	.375	9.32	9.53
C_2	.350	.450	8.89	11.43
C_3	.175	.225	4.45	5.72
ϕD_1	.139	.149	3.53	3.78
ϕD_2	.091	.101	2.31	2.57
ϕD_3	.066	.076	1.68	1.93
H_1		.570		14.48
H_2		.370		9.40
L_1	.088	.098	2.24	2.49
L_2	.020	.030	.51	.76
W	.735	.750	18.67	19.05

MECHANICAL SPECIFICATIONS

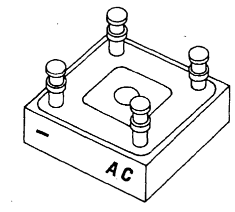
JAN & JANTX 469-1, JAN & JANTX 469-2, JAN & JANTX 469-3



Typical Weight — 0.35 ounces
10 grams

See table above

MD



NOTES:
1. Metric equivalents (to the nearest .01 mm) are given for general information only and are based upon 1 inch = 25.4 mm.
2. Terminals shall be tinned.
3. Polarity shall be marked on the bridge body adjacent to terminals. Terminal numbers are for reference and do not have to be marked on the bridge; however, terminal (1) shall be indicated by a mechanical index such as a line, flattened corner, etc., visible from the top (terminal surface) of the device.
4. Point at which T_C is read shall be in metal part of a case as shown on drawing.

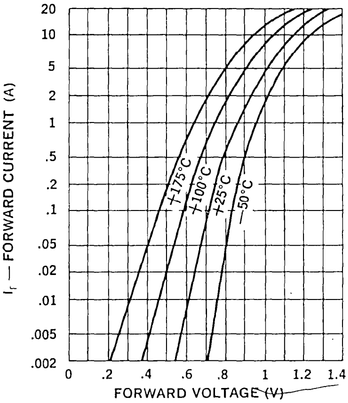
SEMICONDUCTOR PRODUCTS
UNITRODE

Electrical Specification (at 25°C unless noted)

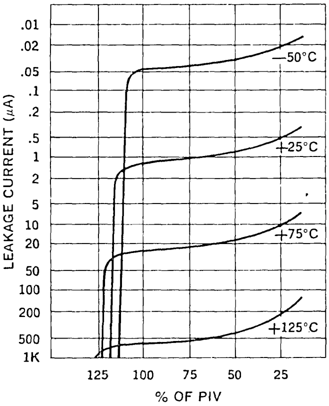
Type	PIV Per Leg	Minimum Reverse Breakdown Voltage Per Leg @ 50μA	Maximum Forward Voltage Drop Per Leg*	Maximum Reverse Recovery Time†	Maximum Leakage Current Per Leg @ PIV	
					$T_C = 25°C$	$T_C = 100°C$
	Volts	Volts		μS	μA	μA
JAN & JANTX 469-1	200	240	1.35V @ 15.7A(pk)	2	2	125
JAN & JANTX 469-2	400	460				
JAN & JANTX 469-3	600	660				

*Maximum forward voltage drop is measured at a pulse width of 8.3ms.
†Measured in a reverse-recovery circuit switching from 0.5A forward to 1.0A reverse current recovering to 0.25A.

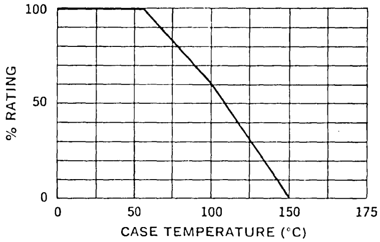
Typical Forward Voltage Per Leg vs. Forward Current

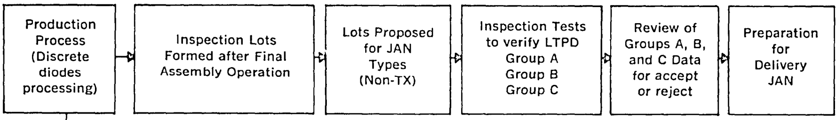


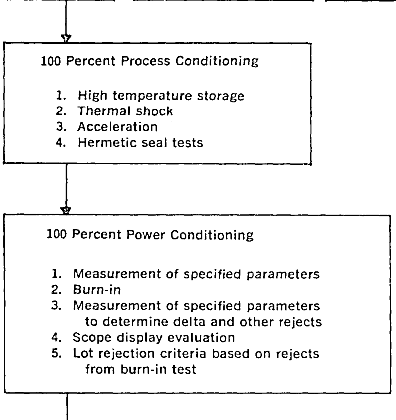
Typical Leakage Current vs. PIV

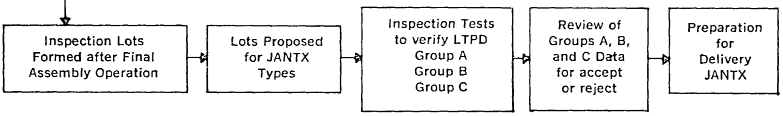


Current Derating Curve

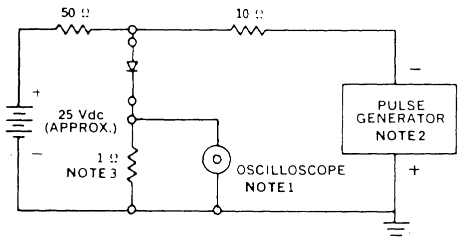








Reverse-Recovery Circuit



NOTES:
1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIER ASSEMBLIES
Three Phase Bridges, 25 Amp, Military Approved

JANTX 483-1
JANTX 483-2
JANTX 483-3

FEATURES
- Qualified to MIL-S-19500/483
- Current Rating: 25A
- PIV: from 200 to 600V
- Surge Ratings: 150A
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Aluminum Heat Sink Case, Electrically Insulated

DESCRIPTION
This military high-current three phase bridge series is assembled with diodes which have been subjected to TX type screening tests. This series of bridges offers the utmost in high reliability as normally required in military system design.

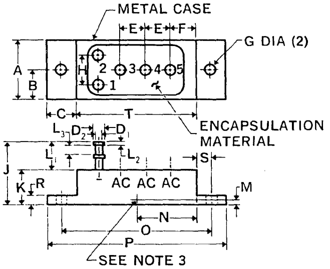
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	200 to 600V
Maximum Average D.C. Output Current	
@ $T_C = 55°C$	25A
@ $T_C = 100°C$	18.5A
Non-Repetitive Sinusoidal Surge (8.3ms)	
@ $T_C = 55°C$	150A
Operating and Storage Temperature Range, T_C	−65°C to +150°C
Thermal Resistance Junction to Ambient	20°C/W
Junction to Case	2.5°C/W

DIMENSIONS				
LTR	INCH		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	.730	.770	18.54	19.56
B	.355	.395	9.02	10.03
C	.355	.395	9.02	10.03
D_1	.141	.151	3.58	3.84
D_2	.108	.118	2.74	3.00
E	.355	.395	9.02	10.03
F	.230	.270	5.84	6.86
G	.149	.189	3.78	4.80
H	.355	.395	9.02	10.03
J		.82		20.83
K	.39	.51	9.91	12.95
L_1	.240	.320	6.10	8.13
L_2	.015	.030	.38	.76
L_3	.100	.125	2.54	3.18
M	.040	.060	1.02	1.52
N	.72	.78	18.29	19.81
O	1.84	1.90	46.74	48.26
P	2.22	2.28	56.39	57.91
R	.09	.15	2.29	3.81
S	.168	.208	4.27	5.28
T	1.47	1.53	37.34	38.86

MECHANICAL SPECIFICATIONS

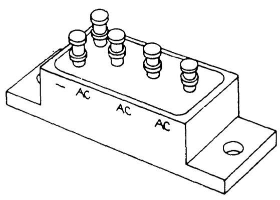
JANTX 483-1 JANTX 483-2 JANTX 483-3



See Table Above

Typical Weight — 1.0 ounces
30 grams

ME



NOTES:
1. Terminals shall be tinned.
2. Polarity shall be marked as shown on drawing.
3. Point at which T_C is read (shall be in metal part of case).

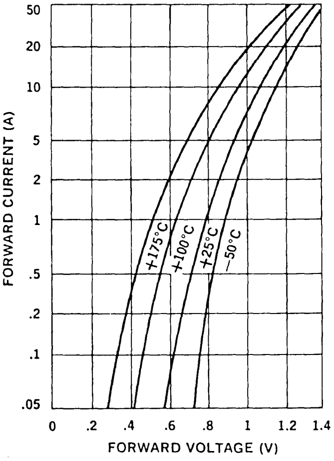
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

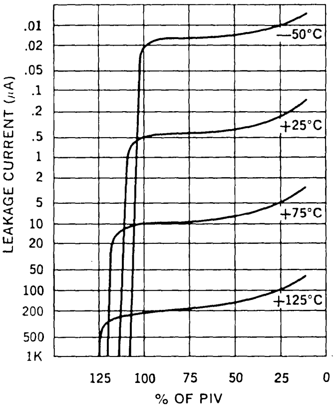
Type	PIV Per Leg	Breakdown Voltage Per Leg @ 50μA	Maximum Forward Voltage Drop Per Leg*	Maximum Leakage Current Per Leg @ PIV	
				$T_C = 25°C$	$T_C = 100°C$
	Volts	Volts		μA	μA
JANTX 483-1	200	240	1.3V @ 39A (pk)	2	200
JANTX 483-2	400	480			
JANTX 483-3	600	660			

* Maximum forward voltage drop is measured at a pulse width of 8.3ms, duty cycle ≤2%.

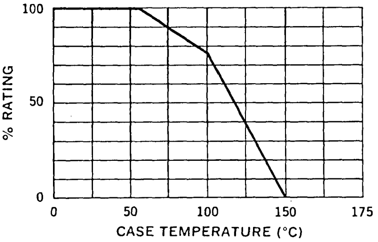
Typical Forward Voltage Per Leg vs. Forward Current

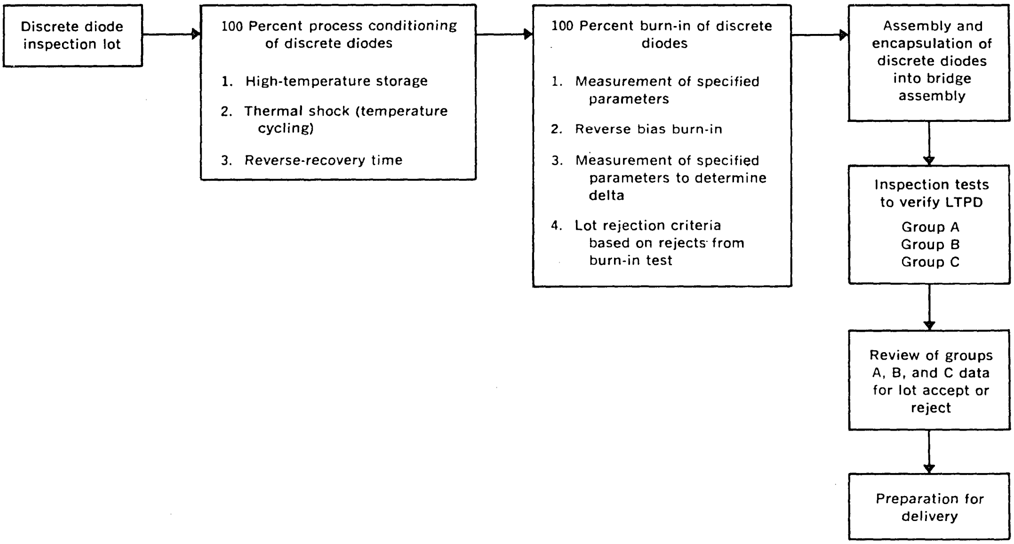


Typical Leakage Current vs. PIV



Current Derating Curve





RECTIFIER ASSEMBLIES

673, 676 SERIES

Single Phase Bridges, 1.5Amp, Standard and Fast Recovery

FEATURES

- Miniature Package
- Surge Ratings: to 25A
- PIV's: from 100 to 600V
- Recovery Times: to 500ns
- Controlled Avalanche Characteristics
- Only Fused-in-Glass Diodes Used

DESCRIPTION

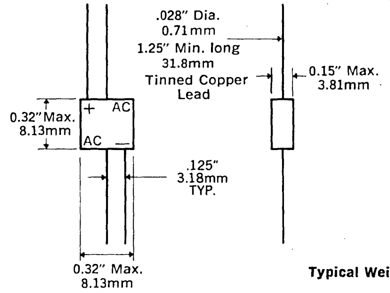
These miniature transfer-molded single-phase power bridges are designed for universal application in power supplies. One basic bridge assembly comes in a choice of lead configurations for mounting in wired chassis or on printed boards.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	100 to 600V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3mS)	See Electrical Specifications
Operating and Storage Temperature Range	—65°C to +150°C
Thermal Resistance Junction to Ambient	50°C/W

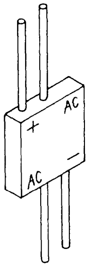
MECHANICAL SPECIFICATIONS

673, 676 SERIES

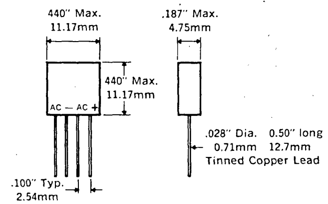


Typical Weight G: 0.05 ounces
1.4 grams

G BODY



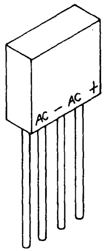
673, 676 SERIES



When specifying S body, add suffix S i.e., 673-1S

Typical Weight S: 0.11 ounces
3.1 grams

S BODY



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

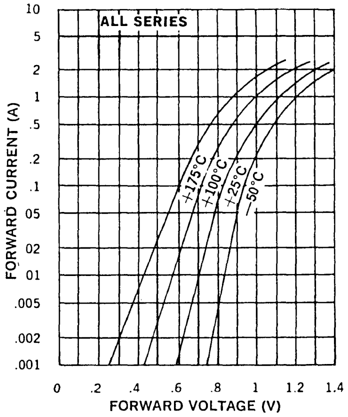
Part number is printed on the body.

SEMICONDUCTOR
PRODUCTS
UNITRODE

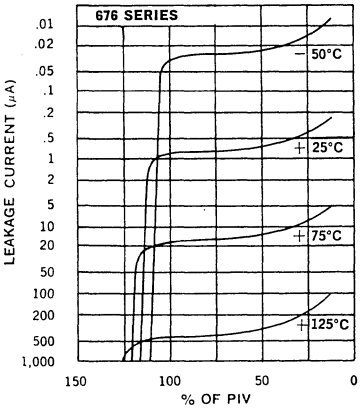
Electrical Specifications (at 25°C unless noted)							Maximum Ratings	
Type		PIV Per Leg	Maximum Forward Drop Per Leg	Leakage Current Per Leg		Maximum Reverse Recovery Time†	Maximum Average D.C. Output Current T_A = 25°C	Non-Repetitive Sinusoidal Surge (8.3mS)
				T_A = 25°C	T_A = 100°C			
		Volts		µA	µA	ns	Amps	Amps
Standard	673-1	100	1.1V @ 1.0A	2	100	—	1.5	25
Recovery	673-2	200						
	673-3	300						
	673-4	400						
	673-5	500						
	673-6	600						
Fast	676-1	100	1.1V @ 0.5A	3	150	500	1.0	20
Recovery	676-2	200						
	676-3	300						
	676-4	400						
	676-5	500						
	676-6	600						

†Measured in a reverse recovery circuit switching from 10mA forward to 10mA reverse current recovering to 5mA.

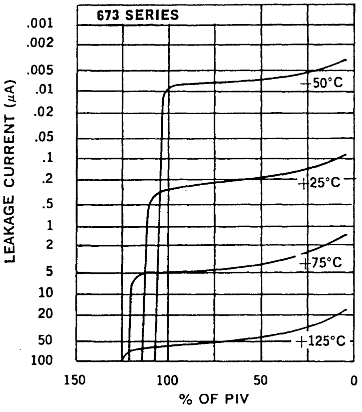
Typical Forward Voltage Per Leg vs. Forward Current

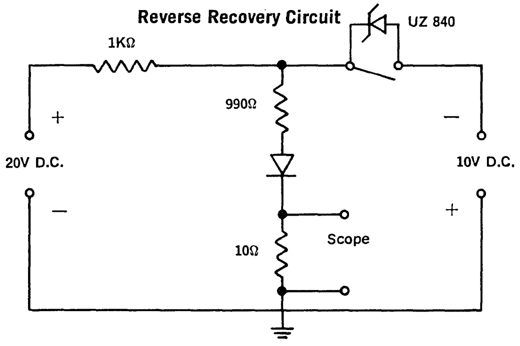


Typical Leakage Current vs. PIV

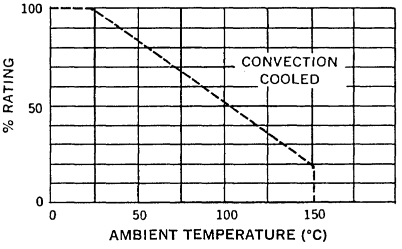


Typical Leakage Current vs. PIV




Reverse Recovery Circuit

Current Derating Curve



RECTIFIER ASSEMBLIES

Single Phase Bridges, High Voltage 0.125-0.6 Amp, Standard and Fast Recovery

673, 676 SERIES
(1200-5000V)

FEATURES
- Miniature High Voltage Bridges
- Continuous Ratings: to 0.6A
- Surge Ratings: to 15A
- PIV's: from 1200 to 5000V
- Recovery Times: to 500ns
- Controlled Avalanche Characteristics
- Only Fused in Glass Diodes Used

DESCRIPTION

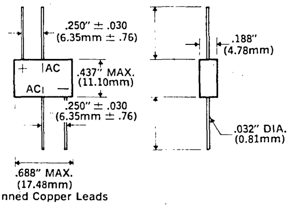
These miniature molded high-voltage single phase bridges are designed for universal application in power supplies. The miniature package is shatterproof and is capable of handling extremes in temperature, vibration and shock. These bridges, therefore are ideally suited for miniaturized, tightly packaged equipment operating in extreme environments.

ABSOLUTE MAXIMUM RATINGS

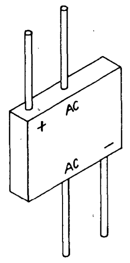
Peak Inverse Voltage	1200 to 5000V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range	−65°C to +150°C
Thermal Resistance Junction-to-Ambient	50°C/W

MECHANICAL SPECIFICATIONS

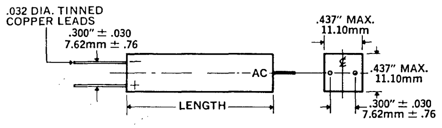
673-7



Body H



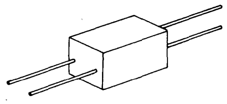
673, 676 SERIES



MAX. LENGTHS

J	K	L	M	N	O	P
.562" 14.27mm	.688" 17.48mm	.875" 22.23mm	1.125" 28.58mm	1.25" 31.75mm	1.375" 34.92mm	1.625" 41.28mm

BODY J through P



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative Output	—

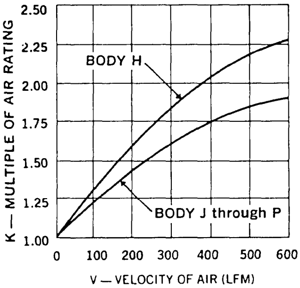
Part number is printed on the body.

SEMICONDUCTOR
PRODUCTS
UNITRODE

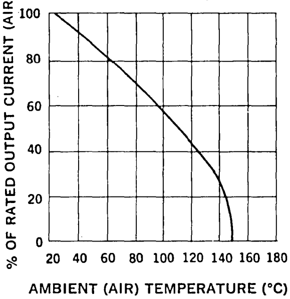
		Electrical Specifications at 25°C						Maximum Ratings		
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time*	Body Size	Maximum Average D.C. Output Current		Non-repetitive Sinusoidal Surge (8.3ms)
				T_A = 25°C	T_A = 100°C			T_A = 25°C Air	T_A = 50°C Oil	
		Volts		µA	µA	ns		Amps	Amps	Amps
Standard Recovery	673-7	1200	2.2V @ 0.4A	2	100		H	0.6	1.5	15
	673-75	1800	3.3V @ 0.4A				J	0.5	1.25	
	673-8	2400	4.4V @ 0.4A				K	0.4	1.0	
	673-85	3000	5.5V @ 0.3A				L	0.3	0.75	
	673-9	3600	6.6V @ 0.2A				M	0.2	0.5	
	673-10	4200	7.7V @ 0.2A				N	0.18	0.45	
	673-11	4800	8.8V @ 0.15A				O	0.16	0.4	
	673-12	5000	9.0V @ 0.15A				O	0.16	0.4	
Fast Recovery	676-12	1200	3.3V @ 0.3A	5	150	500	J	0.4	1.0	10
	676-18	1800	4.4V @ 0.2A				K	0.35	0.85	
	676-24	2400	5.5V @ 0.2A				L	0.325	0.8	
	676-30	3000	7.7V @ 0.2A				M	0.25	0.625	
	676-36	3600	8.8V @ 0.15A				N	0.175	0.425	
	676-42	4200	9.9V @ 0.15A				O	0.15	0.375	
	676-48	4800	11V @ 0.15A				P	0.135	0.325	
	676-50	5000	11V @ 0.15A				P	0.125	0.3	

†Measured in a reverse recovery circuit switching from 10mA forward to 10mA reverse current recovering to 5mA.

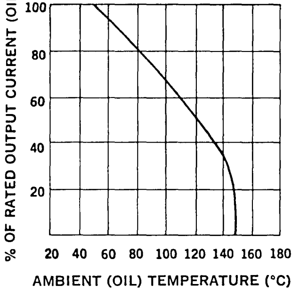
Output Current Ratio vs Velocity of Air Flow



Output Current vs Ambient (Air) Temperature

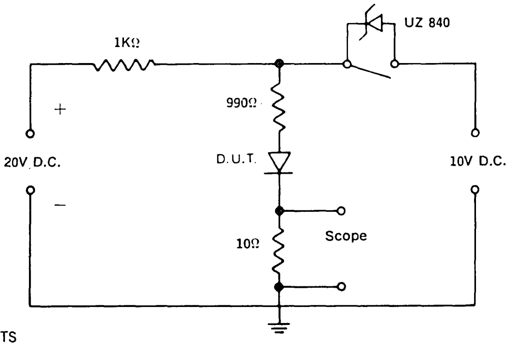


Output Current vs Ambient (Oil) Temperature

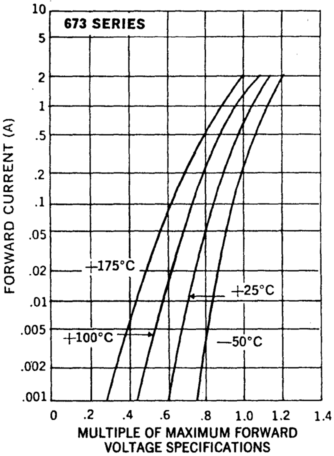


Application example: The rectifier is to be used in a cabinet at 60°C with ambient air moving at 400 LFM. The rating is reduced (Fig. 2) by a factor of 0.81 due to the elevated temperature, but is enhanced by 2.X (Fig. 1) due to the air flow. Hence the DC output current is 0.81 x 2, or 1.6 times the 25°C air rating.

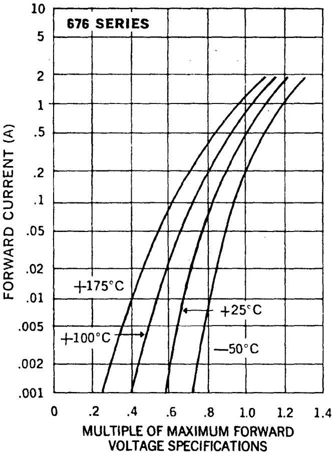
Reverse-Recovery Circuit



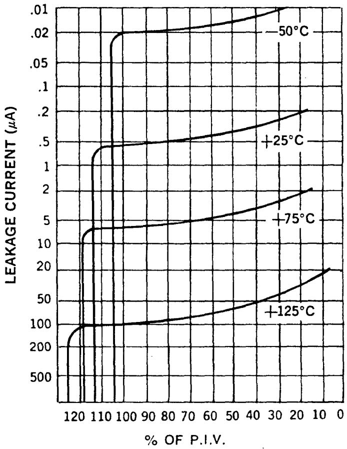
Typical Forward Voltage vs Forward Current



Typical Forward Voltage vs Forward Current



Typical Leakage Current vs. Voltage



RECTIFIER ASSEMBLIES
Three Phase Bridges, 15-25 Amp, Standard and Fast Recovery Magnum®

678, 682, 695
696 SERIES

FEATURES
- Current Rating: to 25A
- PIVs: from 100 to 600V
- Only Fused-in-Glass Diodes Used
- Recovery Times: to 500ns
- Controlled Avalanche Characteristics
- Surge Ratings: to 150A
- Aluminum Heat Sink Case, Electrically Insulated

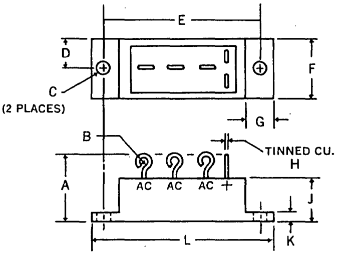
DESCRIPTION
This series of three phase MAGNUM® bridges offer the ultimate in high current power supply applications. The fast recovery series allows operation at full power at high frequencies (up to 40KHz squarewave), often used in choppers, inverters and converters in aircraft, missiles, etc., equipment.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	100 to 600V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient, All Series	20°C/W
Junction to Case, 678, 682 Series	1.5°C/W
Junction to Case, 695, 696 Series	3.0°C/W

MECHANICAL SPECIFICATIONS

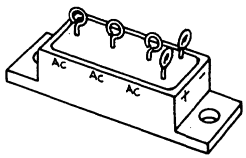
678, 682, 695, 696 SERIES



	ins.	mm.
A	.820 MAX.	20.83 MAX.
B	.09 DIA. TYP.	2.29 DIA. TYP.
C	.164-.174 DIA.	4.17-4.42 DIA.
D	.365-.385	9.27-9.78
E	1.870-1.880	47.50-47.75
F	.740-.760	18.80-19.30
G	.370-.390	9.40-9.91
H	.040 TYP.	1.02 TYP.
J	.486-.506	12.34-12.85
K	.115-.135	2.92-3.43
L	2.240-2.260	56.90-57.40

Typical Weight — 30 grams

NC



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

Part number is printed on the body.

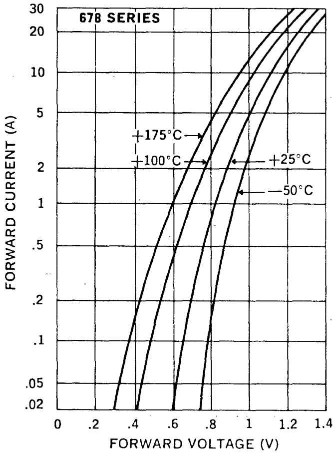
SEMICONDUCTOR PRODUCTS
UNITRODE

Magnum® is a registered trademark of Unitrode Corporation

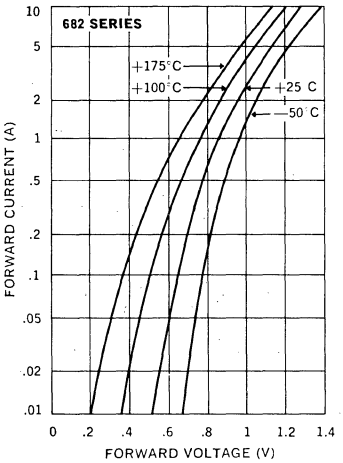
Electrical Specifications (at 25°C unless noted)							Maximum Ratings		
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time*	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
				$T_A = 25°C$	$T_A = 100°C$		$T_C = 55°C$	$T_C = 100°C$	$T_A = 100°C$
		Volts		µA	µA	ns	Amps	Amps	Amps
Standard Recovery	678-1	100	1.2V @ 10A	10	200	—	25	18.5	150
	678-2	200							
	678-3	300							
	678-4	400							
	678-5	500							
	678-6	600							
Standard Recovery	695-1	100	1.2V @ 2A	5	150	—	15	9	80
	695-2	200							
	695-3	300							
	695-4	400							
	695-5	500							
	695-6	600							
Fast Recovery	682-1	100	1.2V @ 6A	10	200	500	20	14	150
	682-2	200							
	682-3	300							
	682-4	400							
	682-5	500							
	682-6	600							
Fast Recovery	696-1	100	1.2V @ 2A	5	150	500	15	9	60
	696-2	200							
	696-3	300							
	696-4	400							
	696-5	500							
	696-6	600							

*Measured in a reverse recovery circuit switching from 1.0A forward to 1.0A reverse current recovering to 0.5A.

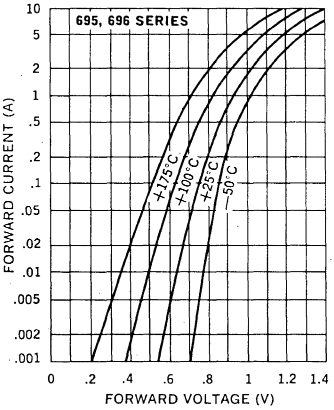
Typical Forward Voltage Per Leg vs. Forward Current



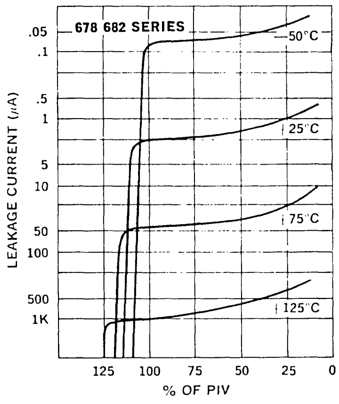
Typical Forward Voltage Per Leg vs. Forward Current



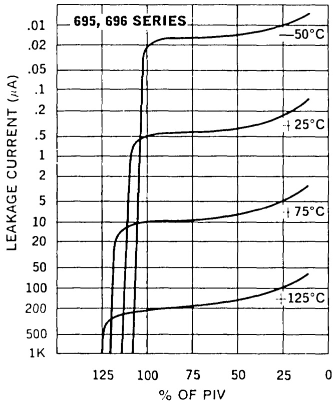
Typical Forward Voltage Per Leg vs. Forward Current



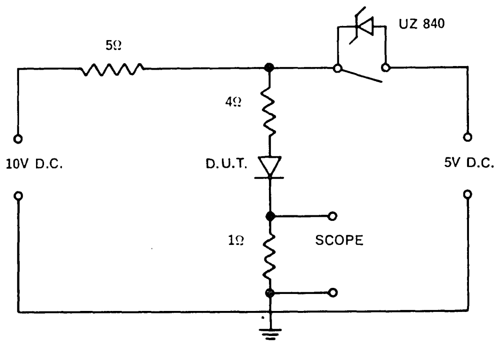
Typical Leakage Current vs. PIV



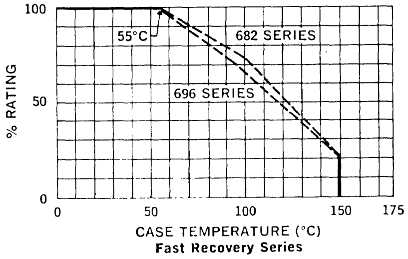
Typical Leakage Current vs. PIV



Reverse Recovery Circuit

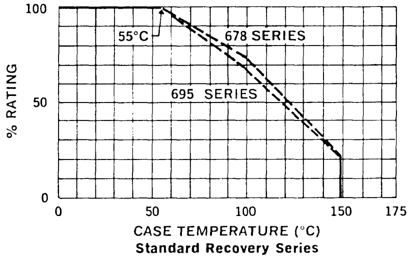


Current Derating Curve



Fast Recovery Series

Current Derating Curve



Standard Recovery Series

RECTIFIER ASSEMBLIES

679, 680, 683, 684 SERIES

Single Phase Bridges, 10-25 Amp, Standard and Fast Recovery Magnum™

FEATURES

- Current Ratings: to 25A
- Recovery Time: to 500ns
- PIVs: from 100 to 600V
- Surge Ratings: to 150A
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Aluminum Heat Sink Case, Electrically Insulated

DESCRIPTION

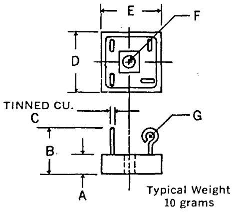
This series of single phase MAGNUM™ bridge offers the designer the ultimate in high current power supply applications. The fast recovery series allows operation at full power at high frequencies, up to 40kHz square wave, which is often used in chopper, inverters and converters in aircraft, missiles, etc., equipment.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	100 to 600V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient, 679, 683 Series	20°C/W
Junction to Ambient, 680, 684 Series	25°C/W
Junction to Case, 679, 683 Series	2.0°C/W
Junction to Case, 680, 684 Series	4.0°C/W

MECHANICAL SPECIFICATIONS

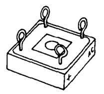
680, 684 SERIES



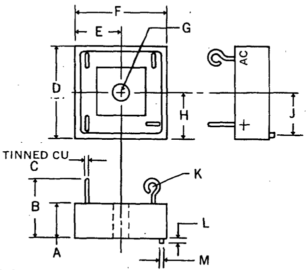
	ins.	mm.
A	.250 MAX.	6.10 MAX.
B	.57 MAX.	14.45 MAX.
C	.040 TYP.	1.02 TYP.
D	.750 MAX.	19.05 MAX.
E	.750 MAX.	19.05 MAX.
F	.140 DIA.	3.56 DIA.
G	.09 DIA. TYP.	2.29 DIA. TYP.

Typical Weight — 0.35 ounces
10 grams

NA



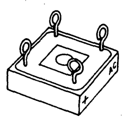
679, 683 SERIES



	ins.	mm.
A	.328 MAX.	8.33 MAX.
B	.750 MAX.	19.05 MAX.
C	.040 TYP.	1.02 TYP.
D	1.125 MAX.	28.58 MAX.
E	.562	14.27
F	1.125 MAX.	28.58 MAX.
G	.193	4.90
H	.562	14.27
J	.500	12.70
K	.09 DIA. TYP.	2.29 DIA. TYP.
L	.062	1.57
M	.062	1.57

Typical Weight — 0.7 ounces
20 grams

NB



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

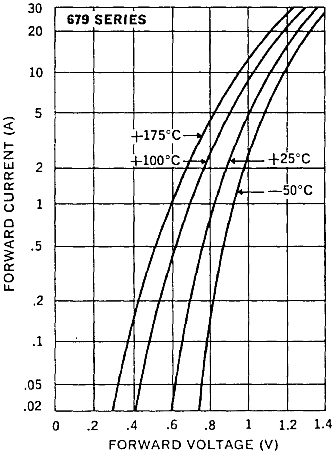
Part number is printed on the body.

SEMICONDUCTOR PRODUCTS
UNITRODE

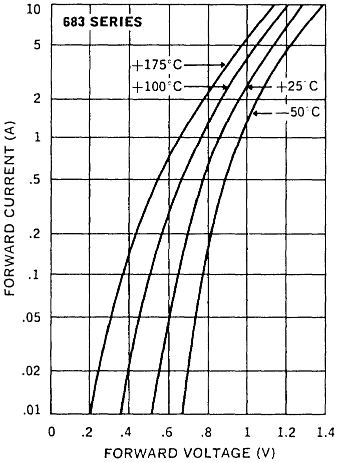
Electrical Specifications (at 25°C unless noted)							Maximum Ratings		
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time*	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
				T_A = 25°C	T_A = 100°C		T_C = 55°C	T_C = 100°C	T_A = 100°C
		Volts		µA	µA	ns	Amps	Amps	Amps
Standard Recovery	679-1	100	1.2V @ 10A	10	200	—	25	18.5	150
	679-2	200							
	679-3	300							
	679-4	400							
	679-5	500							
	679-6	600							
Standard Recovery	680-1	100	1.2V @ 2A	2	50	—	10	6	50
	680-2	200							
	680-3	300							
	680-4	400							
	680-5	500							
	680-6	600							
Fast Recovery	683-1	100	1.2V @ 6A	10	200	500	20	14	150
	683-2	200							
	683-3	300							
	683-4	400							
	683-5	500							
	683-6	600							
Fast Recovery	684-1	100	1.2V @ 2A	5	100	500	10	6	50
	684-2	200							
	684-3	300							
	684-4	400							
	684-5	500							
	684-6	600							

*Measured in a reverse recovery circuit switching from 1.0A forward to 1.0A reverse current recovering to 0.5A.

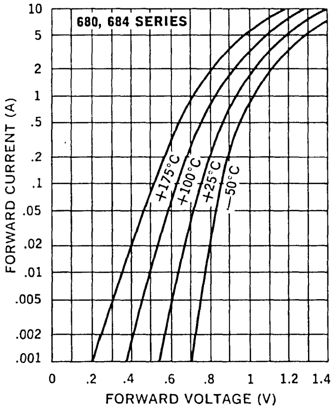
Typical Forward Voltage Per Leg vs. Forward Current



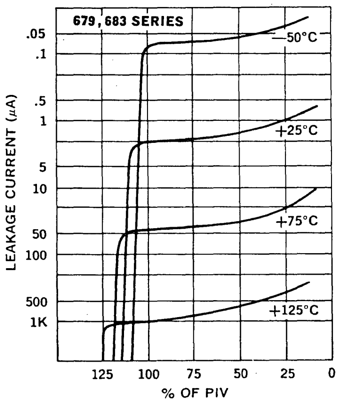
Typical Forward Voltage Per Leg vs. Forward Current



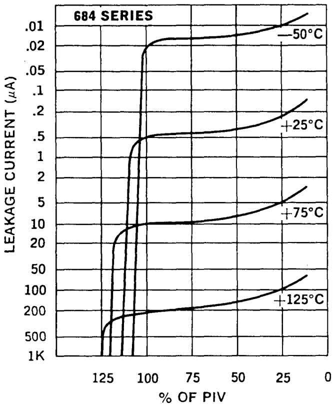
Typical Forward Voltage Per Leg vs. Forward Current



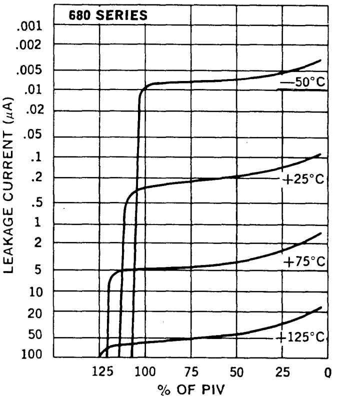
Typical Leakage Current vs. PIV



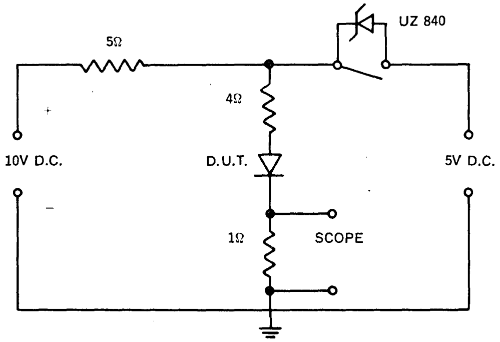
Typical Leakage Current vs. PIV



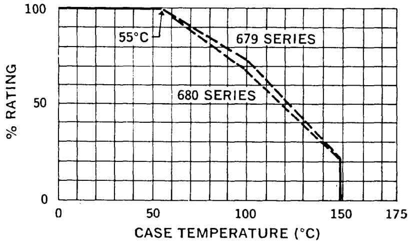
Typical Leakage Current vs. PIV



Reverse Recovery Circuit

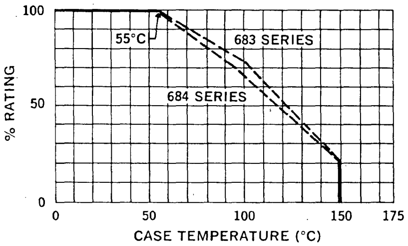


Current Derating Curve



Standard Recovery Series

Current Derating Curve



Fast Recovery Series

RECTIFIER ASSEMBLIES

681, 689 SERIES

Doubler and Center Tap, 15 Amp, Standard and Fast Recovery, Magnum®

FEATURES

- Current Ratings: to 15A
- Aluminum Heat Sink Case, Electrically Insulated
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- PIV: 100 to 600V
- Surge Ratings of 150A

DESCRIPTION

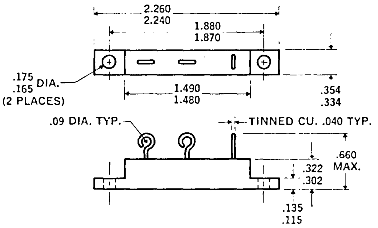
This series of MAGNUM® doublers and center tap rectifiers offers high current and high thermal conductivity needed in high current power supply applications. The MAGNUM® package is virtually indestructable and lends its use to high environmental stresses, as seen in aircraft, missile and satellite equipment.

ABSOLUTE MAXIMUM RATINGS

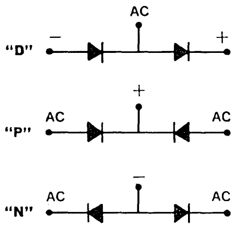
Peak Inverse Voltages	100 to 600V
Maximum Average D.C. Output Current	
@ $T_C = +55°C$	15A
@ $T_C = +100°C$	10A
Non-Repetitive Sinusoidal Surge (8.3ms)	
@ $T_A = +100°C$	150A
Operating and Storage Temperature Range, T_C	−65°C to +150°C
Thermal Resistance Junction to Ambient	20°C/W
Junction to Case	6.0°C/W

MECHANICAL SPECIFICATIONS

681, 689 SERIES

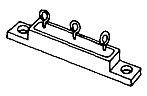


Orientation of terminals shown for "D". For "P" or "N" center terminal is at 90° from the AC terminals.



Typical Weight — 0.35 ounces
10 grams

ND



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

Part number is printed on the body.

† Add suffix P, N, or D for terminal configuration P, N, or D. For example, for center tap configuration, P, order 681-IP.

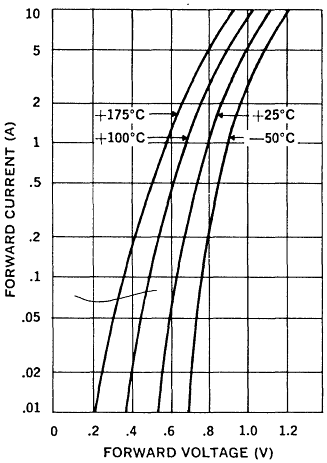
SEMICONDUCTOR PRODUCTS
UNITRODE

Electrical Specifications (at 25°C unless noted)

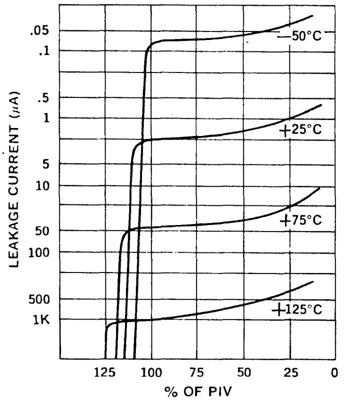
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Reverse Recovery Time*	Maximum Leakage Current Per Leg @ PIV	
					$T_A = 25°C$	$T_A = 100°C$
		Volts		nS	μA	μA
Standard Recovery	681-1	100	1.2V @ 10A		10	200
	681-2	200				
	681-3	300				
	681-4	400				
	681-5	500				
	681-6	600				
Fast Recovery	689-1	100	1.2V @ 10A	500	10	200
	689-2	200				
	689-3	300				
	689-4	400				
	689-5	500				
	689-6	600				

*Measured in a reverse recovery circuit from 1A forward to 1A reverse current recovery to 0.5A.

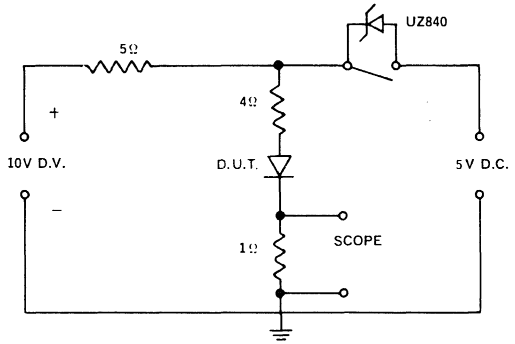
Typical Forward Voltage Per Leg vs. Forward Current



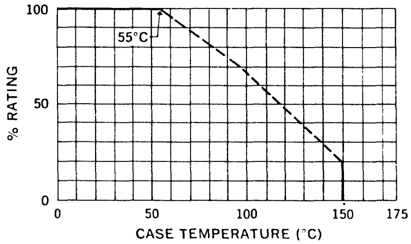
Typical Leakage Current vs. PIV



Reverse-Recovery Circuit



Current Derating Curve



RECTIFIER ASSEMBLIES

High Voltage Stacks, Standard and Fast Recovery

688 SERIES

FEATURES

- PIV: from 10kV to 25kV
- Surge Ratings of 20A
- Recovery Time Available: to 500ns
- Current Ratings: to 0.6A
- Bonded Plate for Maximum Heat Transfer
- Controlled Avalanche Characteristics
- Only Fused-in-Glass Diodes Used

DESCRIPTION

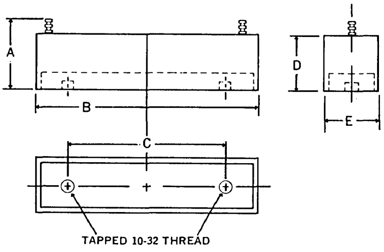
This series of high power stacks has a unique packaging design that provides characteristics not obtainable in conventional molded epoxy packages. This series, therefore, is ideally suited for high-voltage, high-power applications.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	10kV to 25kV
Maximum Average D.C. Output Current	See Electrical Specifications
Non-repetitive Sinusoidal Surge (8.3ms)	20A
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient	25°C/W
Junction to Case	10°C/W

MECHANICAL SPECIFICATIONS

688 SERIES

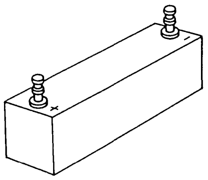


	ins.	mm.
A	1.140 MAX.	28.96 MAX.
B	2.985-3.015	75.82-76.58
C	2.110-2.140	53.59-54.36
D	.740-.770	18.80-19.56
E	.720-.750	18.29-19.05

Add suffix R to denote Fast Recovery version. For example, for recovery time, $t_{rr} = 500ns$; order 688-10R.

Typical Weight — 2.5 ounces
70 grams

BE



MARKING

Cathode — Positive Output	+
Anode — Negative	—

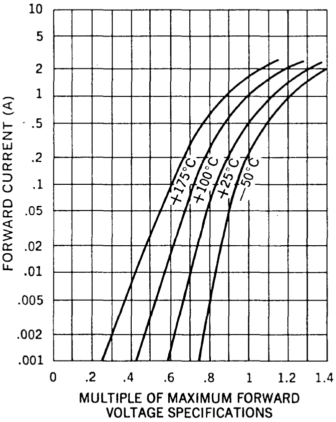
Part number is printed on the body.

SEMICONDUCTOR PRODUCTS
UNITRODE

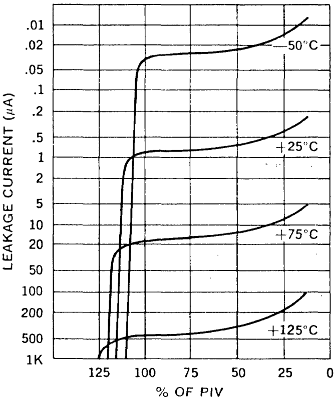
Electrical Specifications (at 25°C unless noted)						Maximum Ratings
Type		PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV		Maximum Average D.C. Output Current
				$T_A = 25°C$	$T_A = 100°C$	$T_C = 100°C$
		kV		µA	µA	Amps
Standard And Fast Recovery*	688-10	10	17V @ 0.4A	2	100	0.60
	688-12	12	20V @ 0.4A			0.50
	688-15	15	25V @ 0.4A			0.40
	688-18	18	30V @ 0.4A			0.35
	688-20	20	34V @ 0.4A			0.30
	688-25	25	42V @ 0.4A			0.20

*Add suffix R to denote Fast Recovery version.

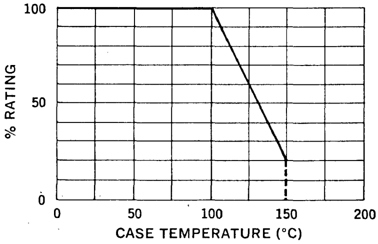
Typical Forward Voltage Per Leg vs. Forward Current



Typical Leakage Current vs. PIV



Current Derating Curve



RECTIFIER ASSEMBLIES

Single Phase Bridges, 7.5 Amp, Standard and Fast Recovery

697, 698 SERIES

FEATURES

- Miniature High Current Assemblies
- Continuous Ratings: to 7.5A
- Surge Ratings: to 80A
- PIV's: from 100V to 600V
- Recovery Times: to 500ns
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics

DESCRIPTION

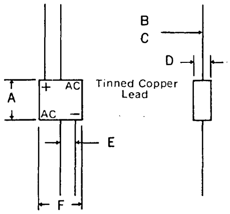
These miniature molded high-current single-phase bridges are designed for universal application in power supplies. One basic bridge fills current requirements up to 7.5A, with PIV's from 100 to 600 volts and recovery times of standard, and 500ns max.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	100 to 600V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range	—65°C to +150°C
Thermal Resistance Junction to Ambient	32°C/W
Junction to Case	10°C/W

MECHANICAL SPECIFICATIONS

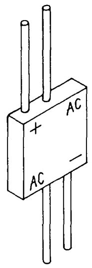
697, 698 SERIES



	ins.	mm.
A	0.50±.01	12.70±.25
B	.032 DIA.	0.81 DIA.
C	1.0 MIN.	25.4 MIN.
D	.250 MAX.	6.35 MAX.
E	.150 TYP.	3.81 TYP.
F	0.50±.01	12.70±.25

Typical Weight — 0.14 ounces
4.0 grams

GA



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

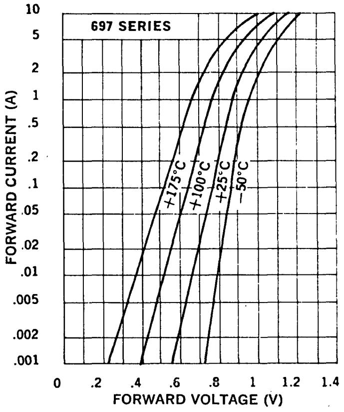
Part number is printed on the body.

SEMICONDUCTOR PRODUCTS
UNITRODE

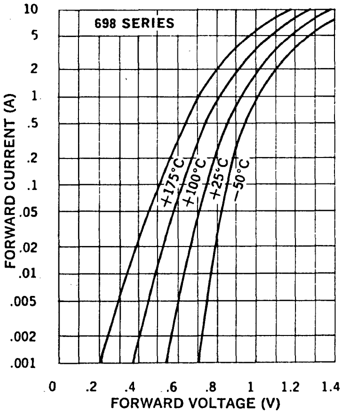
Electrical Specifications (at 25°C unless noted)							Maximum Ratings		
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time†	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
				T_A = 25°C	T_A = 100°C		T_A = 25°C	T_C = 55°C	
		Volts		μA	μA	ns	Amps	Amps	Amps
Standard Recovery	697-1	100	1.0V @ 2A	5	200		2.5	7.5	80
	697-2	200							
	697-3	300							
	697-4	400							
	697-5	500							
	697-6	600							
Fast Recovery	698-1	100	1.1V @ 2A	5	200	500	2.25	7.0	70
	698-2	200							
	698-3	300							
	698-4	400							
	698-5	500							
	698-6	600							

†Measured in a reverse recovery circuit switching from 1A forward to 1A reverse current recovering to .5A.

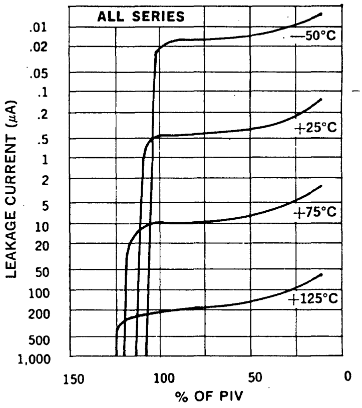
Typical Forward Voltage Per Leg vs. Forward Current



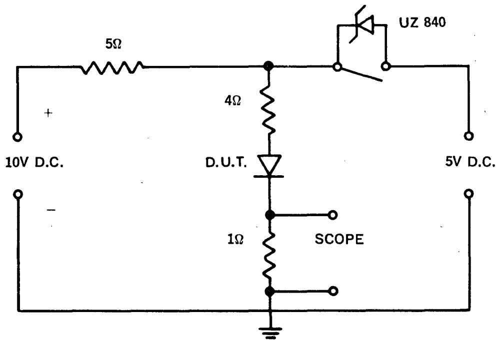
Typical Forward Voltage Per Leg vs. Forward Current



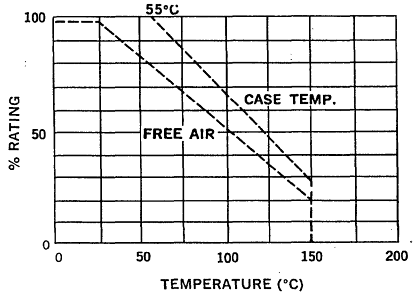
Typical Leakage Current vs. PIV



Reverse Recovery Circuit



Current Derating Curve



RECTIFIER ASSEMBLIES

700, 701 SERIES

Three Phase Bridges, 2.5 Amp, Standard and Fast Recovery

FEATURES

- Miniature Package
- Recovery Time: to 500ns
- Surge Ratings: to 25A
- PIV: from 100 to 600V
- Controlled Avalanche Characteristics
- Only Fused-in-Glass Diodes Used

DESCRIPTION

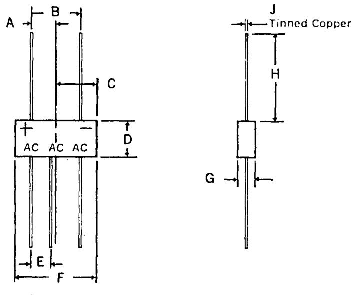
These miniature transfer-molded high-voltage three-phase power bridges are designed for universal application in power supplies. One basic bridge fills current requirements up to 2.5A, with PIV's from 100 to 600 volts and recovery times of standard and 500ns.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	100 to 600V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range	—65°C to +150°C
Thermal Resistance Junction-to-Ambient	25°C/W

MECHANICAL SPECIFICATIONS

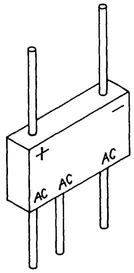
700, 701 SERIES



	ins.	mm.
A	.310	7.87
B	.621	15.77
C	.512 REF.	13.0 REF.
D	.460 MAX.	11.68 MAX.
E	.255	6.48
F	1.030 MAX.	26.16 MAX.
G	.220 MAX.	5.59 MAX.
H	.875	22.23
J	.028 DIA.	0.71 DIA.

Typical Weight — 0.12 ounces
3.5 grams

F



MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

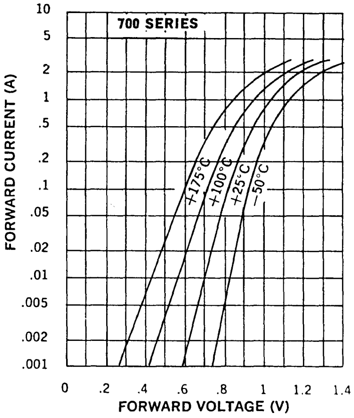
Part number is printed on the body.

SEMICONDUCTOR PRODUCTS
UNITRODE

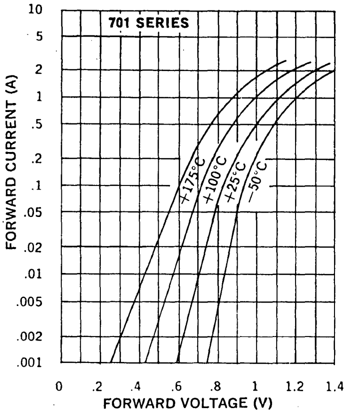
Electrical Specifications (at 25°C unless noted)							Maximum Ratings	
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time†	Maximum Average D.C. Output Current	Non-Repetitive Sinusoidal Surge (8.3ms)
				$T_A = 25°C$	$T_A = 100°C$		$T_A = 55°C$	
		Volts		μA	μA	ns	Amps	Amps
Standard Recovery	700-1	100	1.0V @ 0.5A	2	100		2.5	25
	700-2	200						
	700-3	300						
	700-4	400						
	700-5	500						
	700-6	600						
Fast Recovery	701-1	100	1.1V @ 0.5A	2	100	500	2.25	20
	701-2	200						
	701-3	300						
	701-4	400						
	701-5	500						
	701-6	600						

†Measured in a reverse recovery circuit switching from 10mA forward to 10mA reverse current recovering to 5mA.

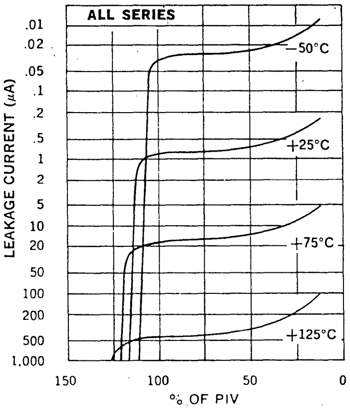
Typical Forward Voltage Per Leg vs. Forward Current



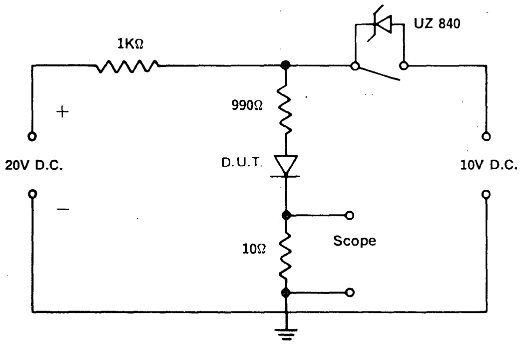
Typical Forward Voltage Per Leg vs. Forward Current



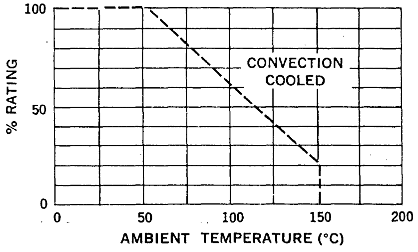
Typical Leakage Current vs. PIV



Reverse Recovery Circuit



Current Derating Curve



RECTIFIER ASSEMBLIES
Three Phase Bridges, 20-40 Amp, High Efficiency, ESP

800, 801 SERIES

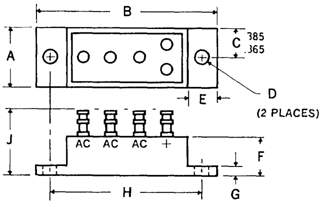
FEATURES
- Current Ratings: to 40A
- Recovery Time: 50ns
- Surge Ratings: to 250A
- PIVs: from 50 to 150V
- Only Fused-in-Glass Diodes Used
- Exceptionally High Efficiency
- Aluminum Heat Sink Case, Electrically Insulated

DESCRIPTION
This series of three phase bridges offers the highest efficiency possible for applications where nothing else will do. The series allows operation at full power at high frequencies.

ABSOLUTE MAXIMUM RATINGS
Peak Inverse Voltages	50 to 150V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient, All Series	20°C/W
Junction to Case, 800 Series	1.5°C/W
Junction to Case, 801 Series	3.0°C/W

MECHANICAL SPECIFICATIONS

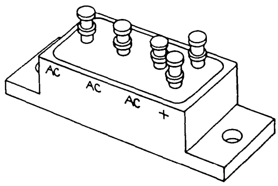
800, 801 SERIES



	ins.	mm.
A	.740-.760	18.80-19.30
B	2.240-2.260	56.90-57.40
C	.365-.385	9.27-9.78
D	.164-.174 DIA.	4.17-4.42 DIA.
E	.370-.390	9.40-9.91
F	.486-.506	12.34-12.85
G	.115-.135	2.92-3.43
H	1.870-1.880	47.50-47.75
J	.820 MAX.	20.83 MAX.

Typical Weight — 1.0 ounce
30 grams

ME



MARKING
Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

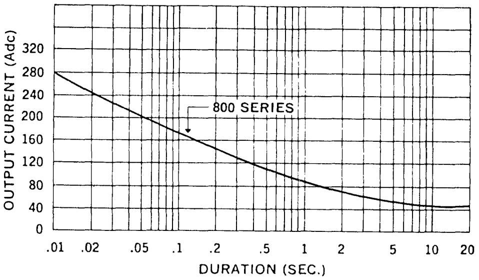
Part number is printed on the body.

SEMICONDUCTOR PRODUCTS
UNITRODE

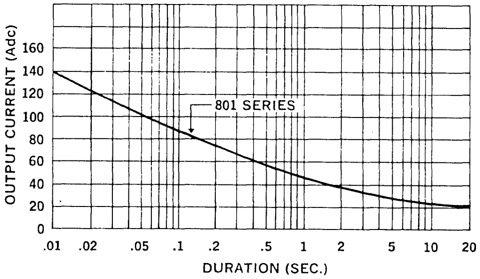
Electrical Specifications (at 25°C unless noted)							Maximum Ratings			
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Reverse Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time*	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
				$T_A = 25°C$	$T_A = 100°C$		$T_C = 55°C$	$T_C = 100°C$	$T_A = 100°C$
		Volts		μA	μA	ns	Amps	Amps	Amps
ESP Recovery	800-1	50	.95V @ 10A	20	1000	50	40	25	250
	800-2	100							
	800-3	125							
	800-4	150							
ESP Recovery	801-1	50	.95V @ 6A	10	300	50	20	16	125
	801-2	100							
	801-3	125							
	801-4	150							

*Measured in a reverse recovery circuit switching from 1A forward to 1A reverse current recovering to 0.5A.

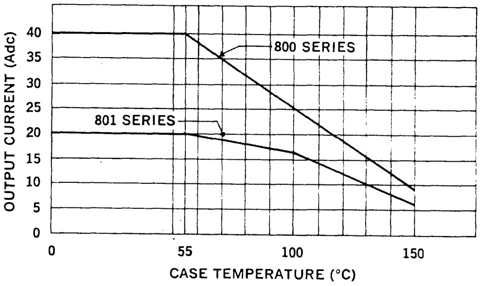
Forward Surge Current vs. Duration



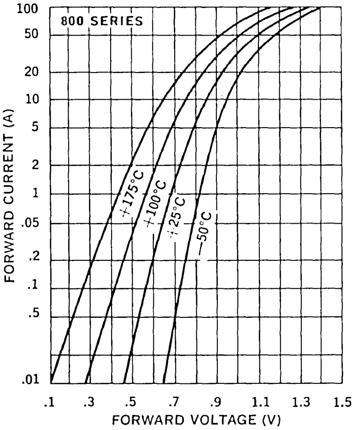
Forward Surge Current vs. Duration



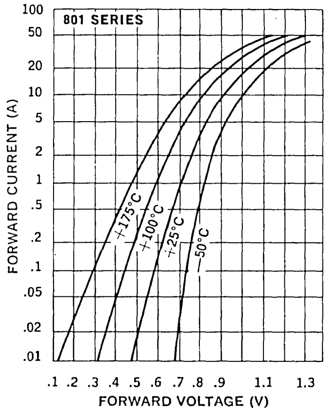
Current Derating Curve



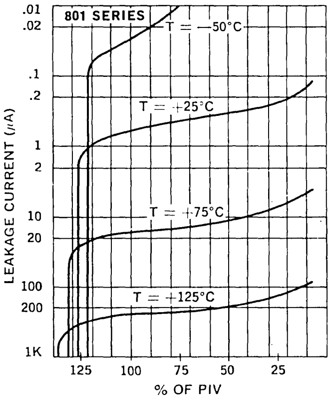
Typical Forward Voltage Per Leg vs. Forward Current



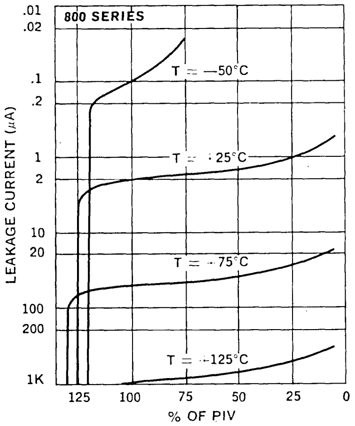
Typical Forward Voltage Per Leg vs. Forward Current



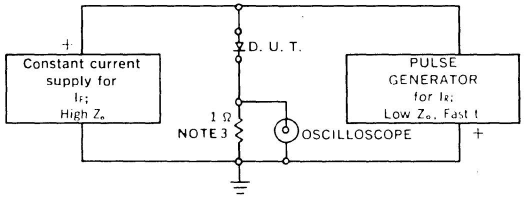
Typical Leakage Current vs. PIV



Typical Leakage Current vs. PIV



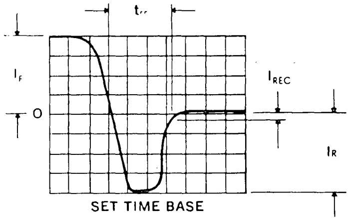
Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time $\leq$ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time $\leq$ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Characteristic Waveform



SET TIME BASE FOR 5 NS/CM

RECTIFIER ASSEMBLIES

Single Phase Bridges, 20-35 Amp, High Efficiency ESP Series

802, 803 SERIES

FEATURES

- Current Ratings: to 35A
- Recovery Time: 50ns
- Surge Ratings: to 250A
- PIVs: from 50 to 150V
- Only Fused-in-Glass Diodes Used
- Exceptional High Efficiency
- Aluminum Heat Sink Case, Electrically Insulated

DESCRIPTION

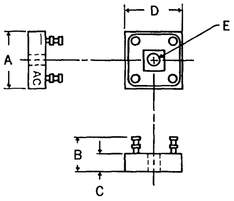
This series of single phase bridges offer the highest efficiency possible for applications where nothing else will do. The series allow operation at full power at very high frequency.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	50 to 150V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient, 802 Series	20°C/W
803 Series	25°C/W
Junction to Case, 802 Series	2.0°C/W
803 Series	4.0°C/W

MECHANICAL SPECIFICATIONS

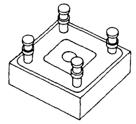
803 SERIES



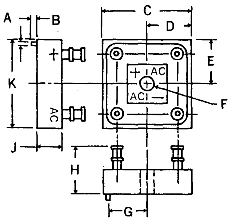
	ins.	mm.
A	.735-.755	18.67-19.18
B	.570 MAX.	14.48 MAX.
C	.250 MAX.	5.74-6.25
D	.735-.755	18.67-19.18
E	.139-.149 DIA.	3.30-3.81

Typical Weight — 0.35 ounces
10 grams

MA



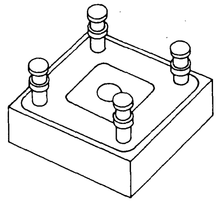
802 SERIES



	ins.	mm.
A	.056-.066	1.42-1.68
B	.052-.072	1.32-1.83
C	1.115-1.135	28.32-28.83
D	.552-.572	14.02-14.53
E	.552-.572	14.02-14.53
F	.180-.200 DIA.	4.57-5.08 DIA.
G	.490-.510	12.45-12.95
H	.750 MAX.	19.05 MAX.
J	.302-.322	7.67-8.18
K	1.115-1.135	28.32-28.83

Typical Weight — 0.70 ounces
20 grams

MB

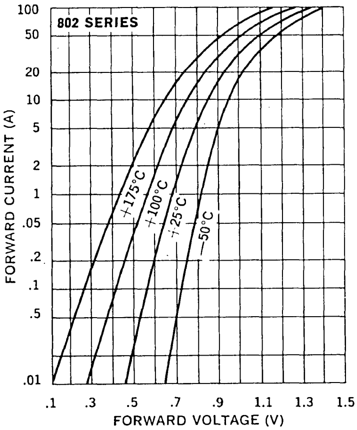


SEMICONDUCTOR PRODUCTS
UNITRODE

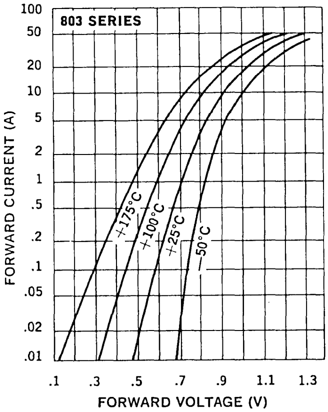
Electrical Specifications (at 25°C unless noted)							Maximum Ratings		
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Reverse Leakage Current Per Leg @ PIV		Maximum Reverse Recovery Time*	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
				$T_A = 25°C$	$T_A = 100°C$		$T_C = 55°C$	$T_C = 100°C$	$T_A = 100°C$
		Volts		µA	µA	ns	Amps	Amps	Amps
ESP Recovery	802-1	50	.95V @ 10A	20	1000	50	35	22.5	250
	802-2	100							
	802-3	125							
	802-4	150							
ESP Recovery	803-1	50	.95V @ 6A	10	300	50	20	16	125
	803-2	100							
	803-3	125							
	803-4	150							

*Measured in a reverse recovery circuit switching from 1A forward to 1A reverse current recovering to 0.5A.

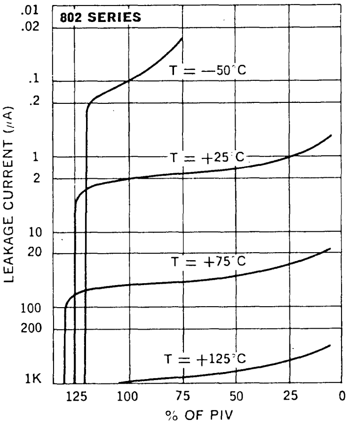
Typical Forward Voltage Per Leg vs. Forward Current



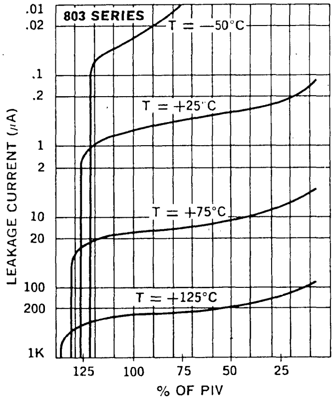
Typical Forward Voltage Per Leg vs. Forward Current



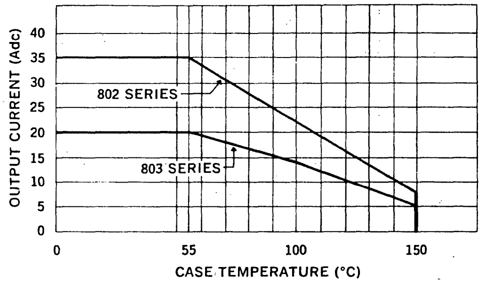
Typical Leakage Current vs. PIV



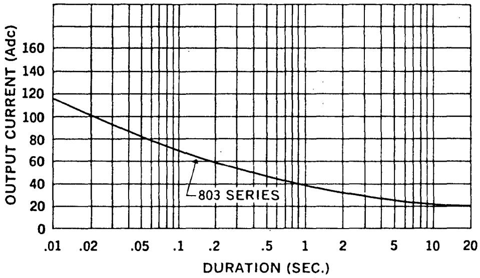
Typical Leakage Current vs. PIV



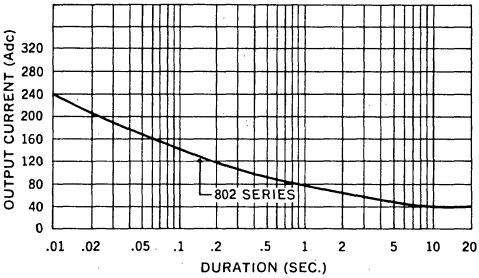
Current Derating Curve



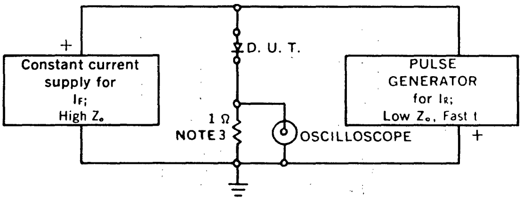
Forward Surge Current vs. Duration



Forward Surge Current vs. Duration



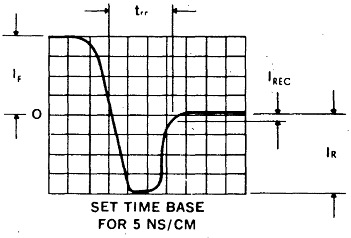
Reverse-Recovery Circuit



NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

Characteristic Waveform



RECTIFIER ASSEMBLIES

804 SERIES

Doublers and Center Tap, 20 Amp, High Efficiency, ESP

FEATURES

- Current Rating: to 20A
- Aluminum Heat Sink Case, Electrically Insulated
- Recovery Time: 50ns
- Surge Ratings of 250A
- PIVs: from 50 to 150V
- Only Fused-in-Glass Diodes Used
- Exceptional High Efficiency

DESCRIPTION

This series of doublers and center tap rectifiers offer the ultimate in high efficiency application. The rectifiers are particularly suited to switching regulator supplies where very fast recovery time and low forward drop are of prime importance.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	50 to 150V
Maximum Average D.C. Output Current	
@ $T_C = +55°C$	20A
@ $T_C = +100°C$	14A
Non-Repetitive Sinusoidal Surge (8.3ms)	
@ $T_A = +100°C$	250A
Operating and Storage Temperature Range, T_C	—65°C to +150°C
Thermal Resistance Junction to Ambient	20°C/W
Junction to Case	6.0°C/W

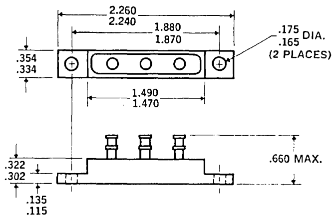
Electrical Specifications (at 25°C unless noted)

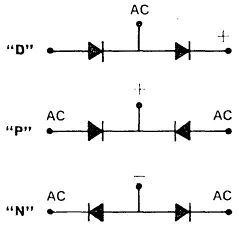
Type		PIV Per Leg	Maximum Forward Voltage Drop Per Leg	Maximum Leakage Current (μA) Per Leg @ PIV		Maximum Reverse Recovery Time*
				T_A = 25°C	T_A = 100°C	
		Volts		μA	μA	ns
ESP	804-1	50	.95V @ 10A	10	500	50
Recovery	804-2	100				
	804-3	125				
	804-4	150				

*Measured in a reverse recovery circuit switching from 1A forward to 1A reverse current recovering to 0.5A.

MECHANICAL SPECIFICATIONS

804 SERIES

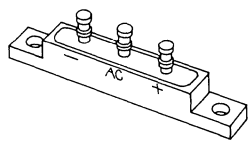




Dimensions in inches.

Typical Weight — 0.35 ounces
10 grams

MF



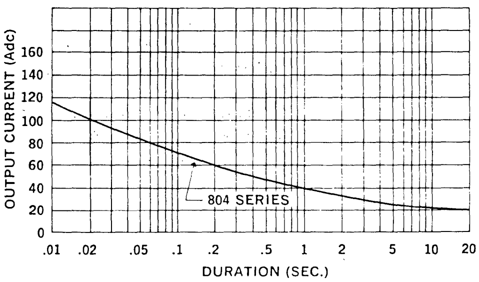
MARKING

Alternating Current Input	A.C.
Cathode — Positive Output	+
Anode — Negative	—

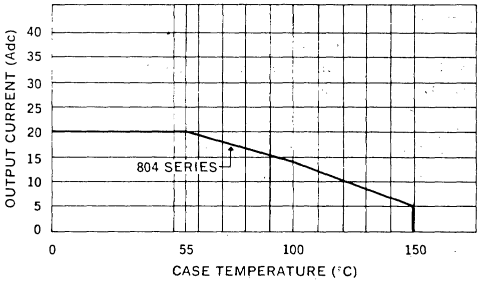
Part number is printed on the body.

† Add suffix P, N, or D for terminal configuration P, N, or D.
For example, for center tap configuration, P, order 804-IP

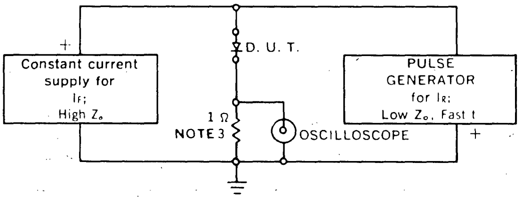
Forward Surge Current vs. Duration



Current Derating Curve



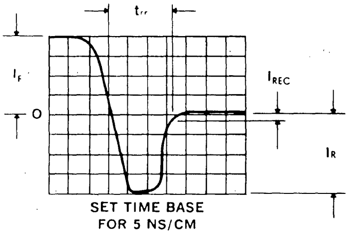
Reverse-Recovery Circuit



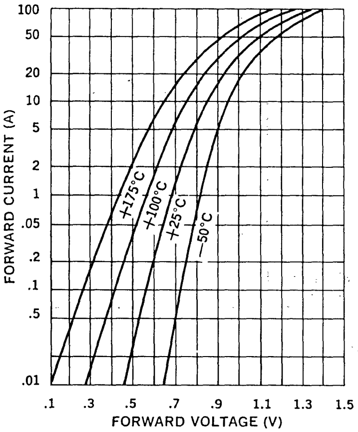
NOTES:

1. Oscilloscope: Rise time ⩽ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ⩽ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

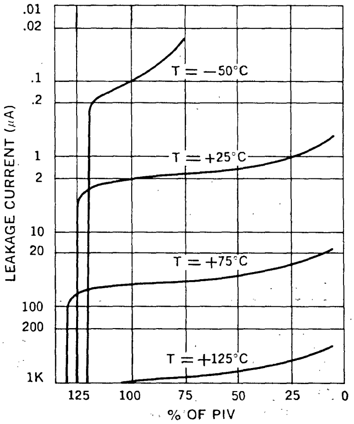
Characteristic Waveform



Typical Forward Voltage Per Leg vs. Forward Current



Typical Leakage Current vs. PIV



RECTIFIER ASSEMBLIES
High Voltage Stacks, 1 Amp to 5 Amp, Military Approved

JAN 1N5597
JAN 1N5600
JAN 1N5603

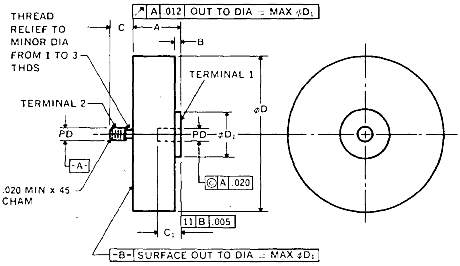
FEATURES
- Qualified to MIL-S-19500/404A
- PIV: to 10kV
- Surge Ratings: to 200A
- Current Ratings: to 5A
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Modular Package For Easy Stacking

DESCRIPTION
This series of military high-voltage high-current stacks offers the utmost in reliability as required in military system designs. The rectifiers are assembled with diodes which have been subjected to TX type screening tests.

ABSOLUTE MAXIMUM RATINGS

	JAN 1N5597	JAN 1N5600	JAN 1N5603
Peak Inverse Voltage	10kV	5kV	5kV
Maximum Average D.C. Output Current @ $T_C = 75°C$	1A	2A	5A
Non-Repetitive Sinusoidal Surge (8.3ms) @ $T_C = 75°C$	30A	80A	200A
Operating and Storage Temperature Range, T_C	−65°C to +150°C		

MECHANICAL SPECIFICATIONS



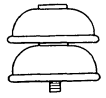
JAN 1N5597 JAN 1N5600

Ltr	Dimensions in inches with metric equivalents (mm) in parentheses		NOTES
	Minimum	Maximum	
A	.73 (18.54)	.83 (21.08)	8
B		.080 (2.03)	
C	.240 (6.10)	.264 (6.71)	2,6
C_1	.265 (6.73)	.400 (10.16)	4
ϕD	1.85 (46.99)	1.95 (49.53)	
$ϕD_1$	.57 (14.48)	.67 (17.02)	

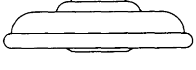
JAN 1N5603

Ltr	Dimensions in inches with metric equivalents (mm) in parentheses		NOTES
	Minimum	Maximum	
A	.970 (24.64)	1.020 (25.91)	8
B	.050 (1.27)	.080 (2.03)	
C	.307 (7.80)	.317 (8.05)	3
C_1	.318 (8.08)	.400 (10.16)	5,7
ϕD	3.450 (87.63)	3.650 (92.71)	
$ϕD_1$	.95 (24.13)	1.250 (31.75)	

DE



DF

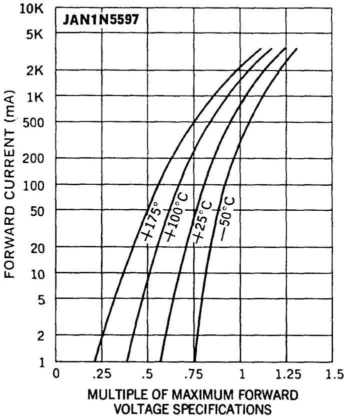


1. All marking shall be on cathode side of module.
2. Threaded stud ¼-28UNF-2A.
3. Threaded stud ⅜-24UNF-2A.
4. Threaded insert ¼-28UNF-2B.
5. Threaded insert ⅜-24UNF-2B.
6. Cathode connected to terminal 2.
7. Cathode connected to terminal 1.
8. Module contour within dimension A is not specified.

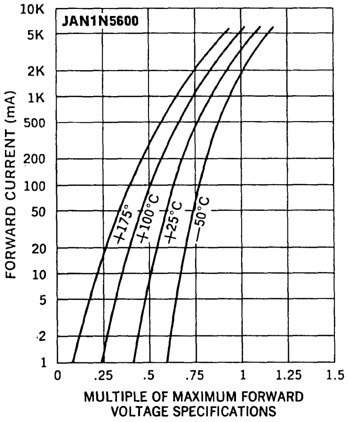
Electrical Specifications (at 25°C unless noted)

Type	PIV	Forward Voltage Drop		Maximum Leakage Current @ PIV		Capacitance @ V_R = 100V		Maximum Reverse Transient Energy Absorption
		Min.	Max.	T_A = 25°C	T_A = 100°C	Min.	Max.	
	kV			µA	µA	pf	pf	joules
JAN 1N5597	10	13V @ 1A	19V @ 1A	1	75	5	30	2
JAN 1N5600	5	6V @ 2A	10V @ 2A	5	100	7	30	6
JAN 1N5603	5	6V @ 5A	10V @ 5A	5	100	15	40	12

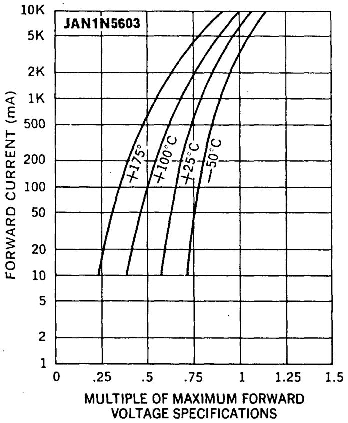
Typical Forward Voltage vs. Forward Current



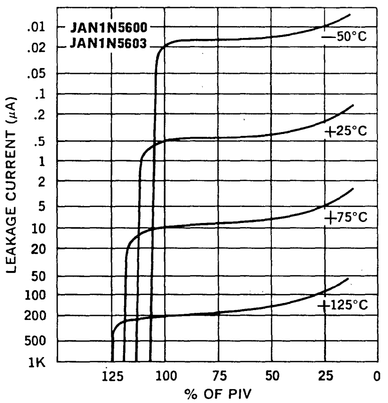
Typical Forward Voltage vs. Forward Current

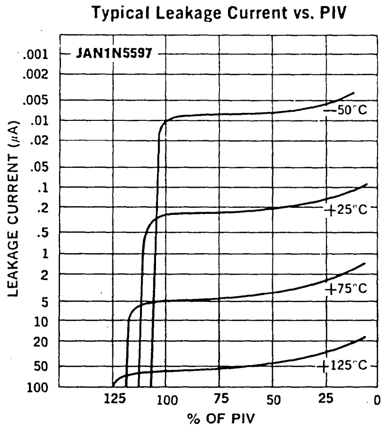


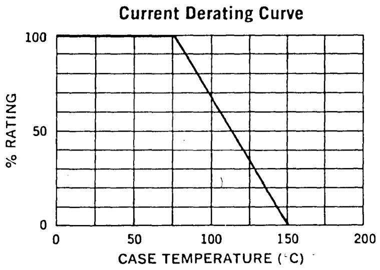
Typical Forward Voltage vs. Forward Current

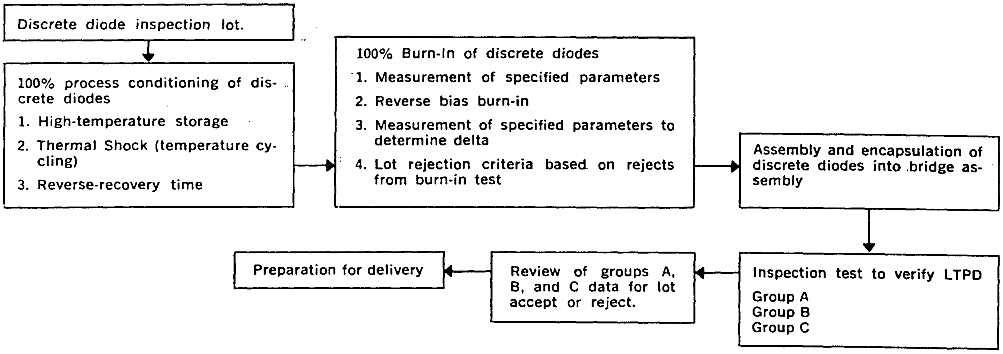


Typical Leakage Current vs. PIV




Typical Leakage Current vs. PIV


Current Derating Curve


Discrete diode inspection lot.

100% process conditioning of discrete diodes
1. High-temperature storage
2. Thermal Shock (temperature cycling)
3. Reverse-recovery time

100% Burn-In of discrete diodes
1. Measurement of specified parameters
2. Reverse bias burn-in
3. Measurement of specified parameters to determine delta
4. Lot rejection criteria based on rejects from burn-in test

Assembly and encapsulation of discrete diodes into bridge assembly

Inspection test to verify LTPD
Group A
Group B
Group C

Review of groups A, B, and C data for lot accept or reject.

Preparation for delivery

RECTIFIER ASSEMBLIES
Single Phase Bridges, 25 Amp, Military Approved

JAN SPA25
JAN SPB25
JAN SPC25
JAN SPD25

FEATURES
- Qualified to MIL-S-19500/446
- Current Rating: to 25A
- PIV: from 100 to 600V
- Surge Ratings of 150A
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Aluminum Heat Sink Case, Electrically Insulated

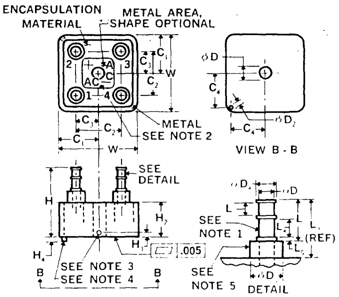
DESCRIPTION
This series of military high-current single-phase bridges offer the utmost in reliability as required in military system designs. This series is assembled with diodes which have been subjected to 100% screening tests.

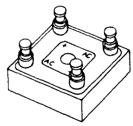
ABSOLUTE MAXIMUM RATINGS
Peak Inverse Voltage .... 100 to 600V
Maximum Average D.C. Output Current
@ $T_C = 55°C$ 25A
@ $T_C = 100°C$ 15A
Non-Repetitive Sinusoidal Surge (8.3ms)
@ $T_C = 55°C$ 150A
Operating and Storage Temperature Range, T_C .... —65°C to +150°C
Thermal Resistance Junction to Ambient .... 20°C/W
Junction to Case .... 2.5°C/W

Ltr	Dimensions			
	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
C_1	.552	.572	14.02	14.53
C_2	.624	.760	15.85	19.30
C_3	.312	.380	7.92	9.65
C_4	.495	.512	12.57	13.00
ϕD_1	.189	.195	4.80	4.95
ϕD_2	.057	.067	1.45	1.70
ϕD_3	.108	.118	2.74	3.00
ϕD_4	.141	.151	3.58	3.84
ϕD_5	.225	.235	5.72	5.97
H_1	.669	1.060	17.53	26.92
H_2	.300	.500	7.62	12.70
H_3	.040	.060	1.02	1.52
H_4	.042	.062	1.07	1.57
L_1	.370	.560	9.40	14.22
L_2	.307	.365	7.80	9.27
L_3	.089	.099	2.26	2.49
L_4	.132	.142	3.35	3.61
L_5	.026	.036	.66	.91
W	1.104	1.144	28.04	29.06

MECHANICAL SPECIFICATIONS

SPA25 SPB25 SPC25 SPD25





NOTES:
1. Terminals shall be hot tin dipped or silver plated.
2. Polarity shall be marked on terminal side of device.
3. Point at which Tc is read (must be in metal part of case).
4. Locating pin shall be adjacent to positive terminal.
5. Insulating sleeve shall be alumina (AL_2O_3) or equivalent.

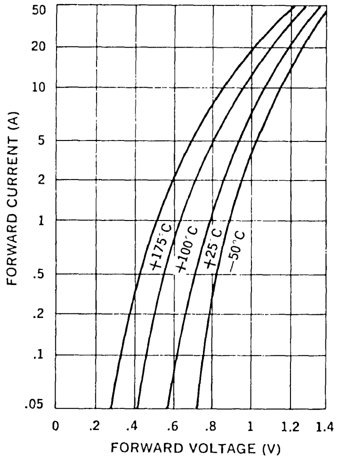
SEMICONDUCTOR PRODUCTS
UNITRODE

Electrical Specifications (at 25°C unless noted)

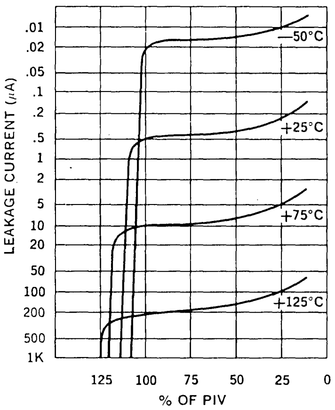
Type	PIV Per Leg	Peak Forward Voltage Drop*		Maximum Reverse Recovery Time†	Maximum Leakage Current Per Leg @ PIV	
					Tc = 25°C	Tc = 100°C
	Volts	Minimum	Maximum	µS	µA	µA
JAN SPA25 JAN SPB25 JAN SPC25 JAN SPD25	100 200 400 600	0.9V @ 39A(pk)	1.4V	2	2	150

*Peak forward voltage drop is measured at a pulse width of 8.3ms.
†Measured in a reverse recovery circuit switching from 0.5A forward to 1.0A reverse current recovery to 0.5A.

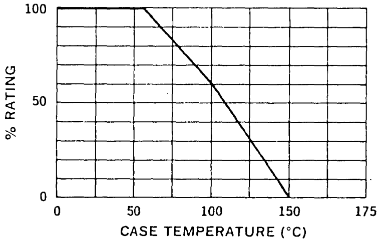
Typical Forward Voltage Per Leg vs. Forward Current

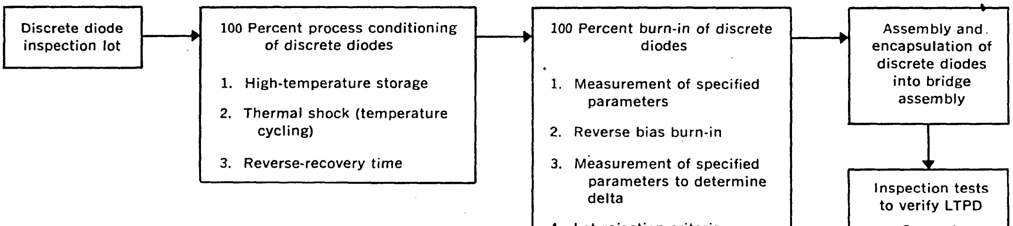


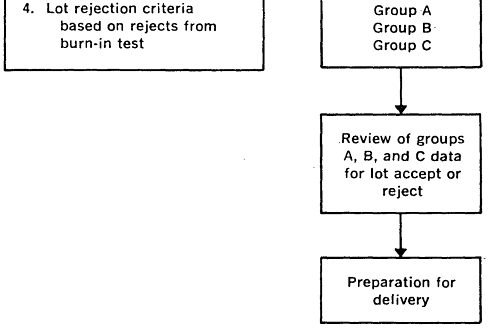
Typical Leakage Current vs. PIV



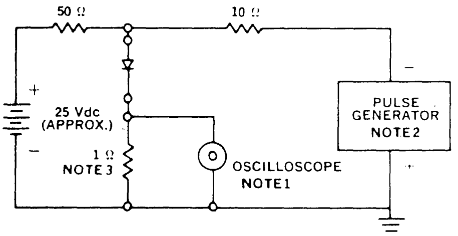
Current Derating Curve







Reverse-Recovery Circuit



NOTES:
1. Oscilloscope: Rise time ≤ 3ns; input impedance = 50Ω.
2. Pulse Generator: Rise time ≤ 8ns; source impedance 10Ω.
3. Current viewing resistor, non-inductive, coaxial recommended.

RECTIFIER ASSEMBLIES
High Voltage Doorbell® Modules, Standard and Fast Recovery

UDA, UDB, UDC, UDD , UDE, UDF SERIES

FEATURES
- PIV: from 2.5kV to 15kV
- Stackable to 600kV
- Current Ratings: to 7.7A
- Controlled Avalanche Characteristics
- Only Fused-in-Glass Diodes Used
- Recovery Time: to 500ns
- Modular Package For Easy Stacking

DESCRIPTION

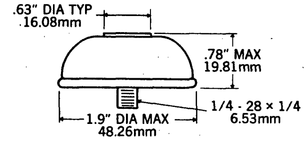
This series of high-voltage, high-current stacks that incorporate a unique modular design makes it ideally suited for high power applications such as in radar systems as charger, hold-off and clipper diodes.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	
UDA, UDC Series	5kV to 15kV
UDB, UDD Series	2.5 kV to 7.5kV
UDE, UDF Series	2.5 kV to 5kV
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	—65°C to +150°C

MECHANICAL SPECIFICATIONS

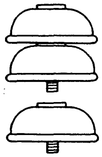
UDA, UDB, UDC, UDD, UDE, UDF SERIES



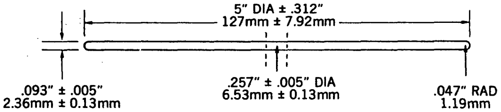
1. Polarity — Cathode connected to base.
2. Part Number — On base of unit.

Typical Weight — 2.1 ounces
60 grams

DD



EXTENDER PLATE D



Typical Weight — 2.75 ounces
78 grams

SEMICONDUCTOR PRODUCTS
UNITRODE

Doorbell® is a registered trademark of Unitrode Corporation

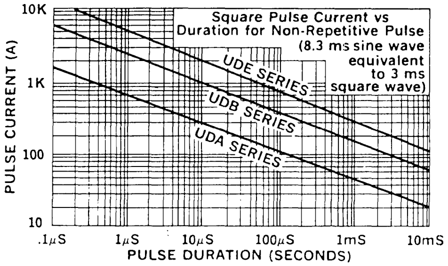
Electrical Specifications (at 25°C unless noted)						Maximum Ratings				
Type		PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV	Maximum Reverse Recovery Time	Maximum Average D.C. Output Current			Non-Repetitive Sinusoidal Surge (8.3ms) $T_C = 100°C$	Maximum Reverse Transient Energy Absorption
						$T_C = 75°C$ Air	$T_C = 60°C$ Air with Extender Plate**	$T_C = 50°C$ Oil		
		kV		μA	ns	Amps	Amps	Amps	Amps	joules
Standard Recovery	UDE-2.5	2.5	5V @ 3.00A	10		‡ 6.00	7.00	7.70	200	8
	UDB-2.5	2.5	4V @ 1.50A	5		3.00	3.75	4.25	100	4
	UDE-5	5	10V @ 2.20A	10		‡ 4.50	5.00	5.50	200	14
	UDB-5	5	8V @ 1.00A	5		2.00	2.50	2.75	100	8
	UDA-5	5	8V @ 0.82A	2	—	1.65	2.00	2.20	30	1.5
	UDB-7.5	7.5	12V @ 0.70A	5		1.33	1.65	2.00	100	12
	UDA 7.5	7.5	12V @ 0.60A	2		1.25	1.55	1.75	30	2.5
	UDA-10	10	16V @ 0.50A	2		1.00	1.25	1.40	30	3
	UDA-15	15	25V @ 0.33A	2		0.67	0.80	0.90	30	5
Fast Recovery	UDF-2.5	2.5	6V @ 2.20A	10		4.50	5.00	5.30	150	8
	UDD-2.5	2.5	6V @ 1.20A	5		2.25	2.80	3.30	80	4
	UDF-5	5	11V @ 1.60A	10		3.30	4.00	4.40	150	14
	UDD-5	5	11V @ 0.75A	5		1.50	1.85	2.00	80	8
	UDC-5	5	10V @ 0.70A	2	500*	1.20	1.50	1.70	25	1.5
	UDD-7.5	7.5	17V @ 0.50A	5	350†	1.00	1.25	1.50	80	12
	UDC-7.5	7.5	15V @ 0.50A	2		0.90	1.10	1.25	25	2.5
	UDC-10	10	20V @ 0.37A	2		0.75	0.90	1.00	25	3
	UDC-15	15	30V @ 0.25A	2		0.50	0.60	0.70	25	5

*Measured in a reverse recovery circuit switching from 1.0A forward to 1.0A reverse current recovering to 0.5A.
†Measured in a reverse recovery circuit switching from 0.5A forward to 1.0A reverse current recovering to 0.25A.

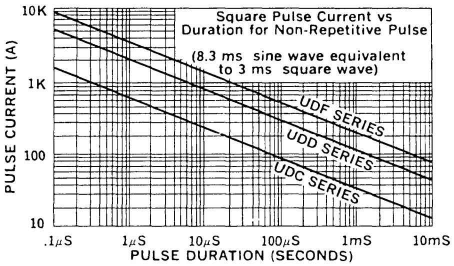
**These ratings are based on using "extender plates" that provide additional surface area to radiate heat. Because of possible corona effects caused by scratches on these plates, extreme care is necessary in their handling and they are not recommended where the working voltage exceeds 7.5KV/module. They should be carefully polished prior to installation.

‡These ratings are based on $T_C = 100°C$.

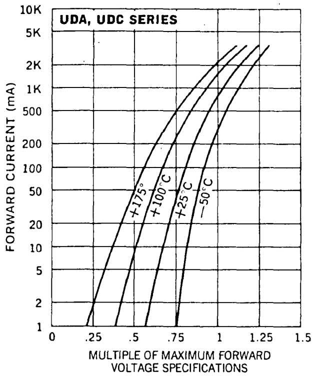
Forward Pulse Current vs. Pulse Duration



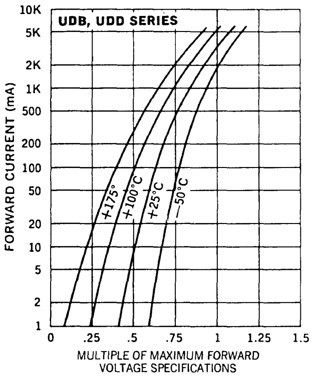
Forward Pulse Current vs. Pulse Duration



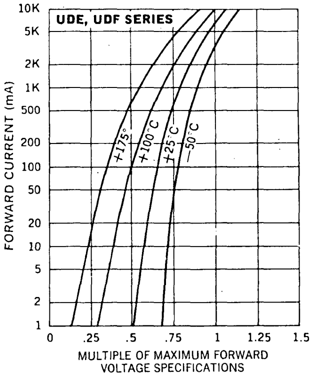
Typical Forward Voltage vs. Forward Current



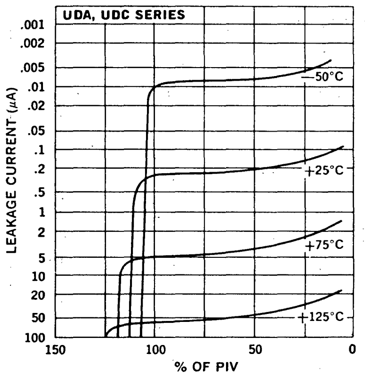
Typical Forward Voltage vs. Forward Current



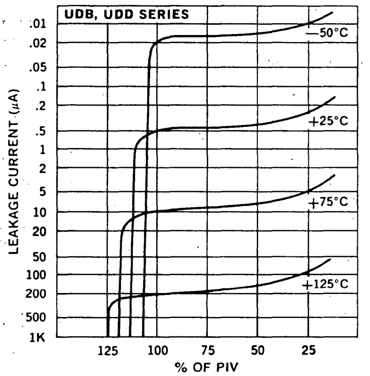
Typical Forward Voltage vs. Forward Current



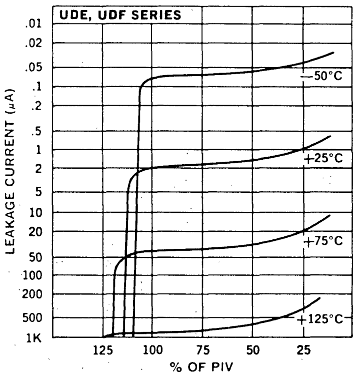
Typical Leakage Current vs. PIV



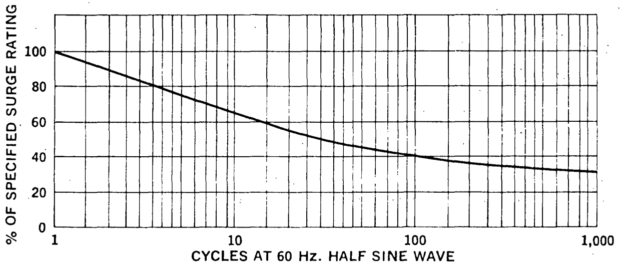
Typical Leakage Current vs. PIV



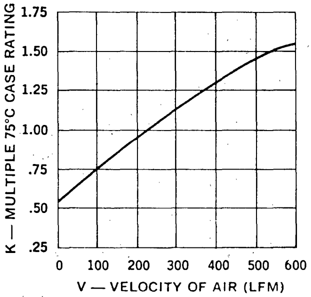
Typical Leakage Current vs. PIV



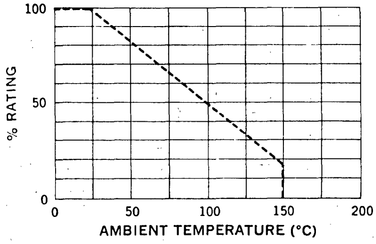
Multiple Surge Rating vs. Duration



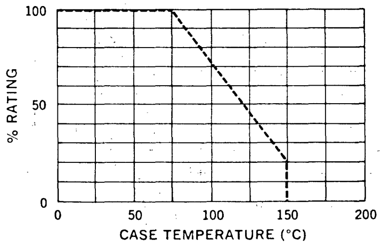
Output Current Ratio
vs. Velocity of Air Flow



Current Derating Curve

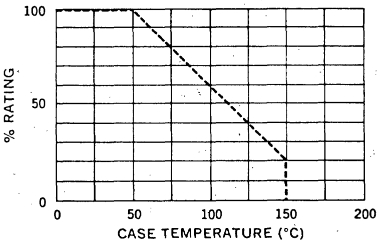


Current Derating Curve



Air Cooled

Current Derating Curve



Oil Immersed

RECTIFIER ASSEMBLIES

High Voltage Stacks, Standard and Fast Recovery

UFB, UFS, USB, USS SERIES

FEATURES

- Controlled Avalanche Characteristics
- Only Fused-in-Glass Diodes Used
- High Forward and Reverse Surge Capability
- Transfer Molded for Voidless Construction
- Modular for Easy Stacking
- PIV: from 2.5 kV to 15 kV
- Recovery Times: to 500ns
- Continuous Ratings: to 2.3A

DESCRIPTION

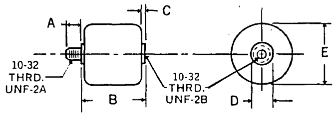
These assemblies uniquely combine a versatile stackable design with all the requirements for reliable high voltage operation. All modules are suitable for bridge or series operations.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage, USS Series	5.0 kV to 15 kV
Peak Inverse Voltage, USB Series	2.5 kV to 10 kV
Peak Inverse Voltage, UFS Series	5.0 kV to 10 kV
Peak Inverse Voltage, UFB Series	2.5 kV to 7.5 kV
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range	—65°C to +150°C

MECHANICAL SPECIFICATIONS

UFB, UFS, USB, USS SERIES

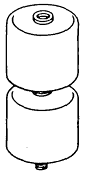


	ins.	mm.
A	.230-.235	5.84-5.97
B	.980-1.10	24.89-27.94
C	.020-.040	0.51-1.02
D	.320-.330	8.13-8.38
E	.97-1.00	24.64-25.40

Typical Weight: USS & UFS Series — 1.0 ounce
28 grams

USB & UFB Series — 1.1 ounce
31 grams

DH



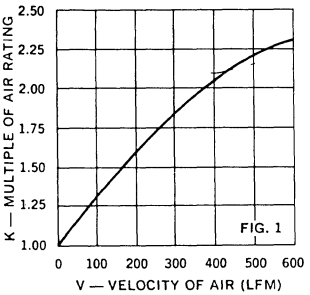
MARKING

Type number marked on unit.

Polarity — Cathode connected to stud.

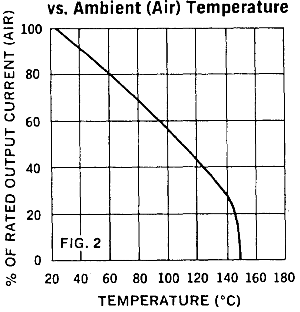
Electrical Specifications (at 25°C unless noted)							Maximum Ratings		
Type		PIV	Maximum Forward Voltage Drop	Leakage Current @ PIV	Maximum Reverse Recovery Time	Maximum Reverse Transient Energy Absorption	Maximum Average D.C. Output Current		Non-Repetitive Sinusoidal Surge (8.3ms)
							$T_A = 25°C$ AIR	$T_A = 50°C$ OIL	
		kV		μA	ns	joules	Amps	Amps	Amps
Standard Recovery	USS 5	5.0	9V @ 0.6A	5	—	1.5	0.60	1.1	25
	USS 7.5	7.5	13V @ 0.5A			2.5	0.45	0.91	
	USS 10	10	17V @ 0.3A			3.0	0.35	0.71	
	USS 15	15	25V @ 0.2A			5.0	0.25	0.51	
Standard Recovery	USB 2.5	2.5	5V @ 1.1A	10	—	3.0	1.1	2.3	80
	USB 5	5.0	9V @ 0.7A			6.0	0.68	1.5	
	USB 7.5	7.5	13V @ 0.5A			9.0	0.53	1.2	
	USB 10	10	17V @ 0.4A			12	0.43	1.0	
Fast Recovery	UFS 5	5.0	12V @ 0.5A	5	500* 350†	1.5	0.50	0.90	20
	UFS 7.5	7.5	18V @ 0.4A			2.5	0.38	0.75	
	UFS 10	10	23V @ 0.3A			3.0	0.30	0.58	
Fast Recovery	UFB 2.5	2.5	6V @ 0.9A	10	500* 350†	3.0	0.90	2.0	70
	UFB 5	5.0	12V @ 0.6A			6.0	0.58	1.3	
	UFB 7.5	7.5	18V @ 0.4A			9.0	0.45	1.0	

*Measured in a reverse recovery circuit switching from 1A forward to 1A reverse current recovering to 0.5A.
†Measured in a reverse recovery circuit switching from .5A foward current to 1A reverse current, recovery to .25A.



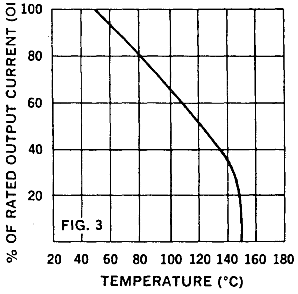
Output Current Ratio vs. Velocity of Air Flow

FIG. 1



Output Current vs. Ambient (Air) Temperature

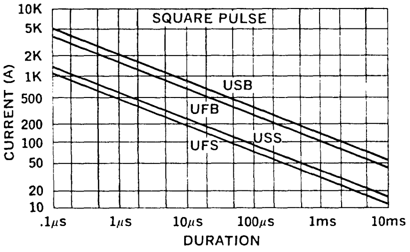
FIG. 2



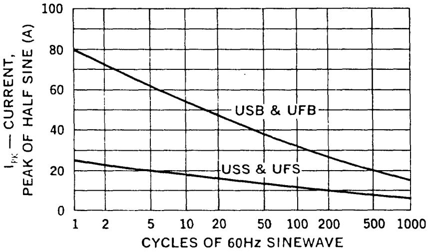
Output Current vs. Ambient (Oil) Temperature

FIG. 3

Application example: The rectifier is to be used in a cabinet at 60°C with ambient air moving at 400 LFM. The rating is reduced (Fig. 2) by a factor of 0.81 due to the elevated temperature, but it is enhanced by 2X (Fig. 1) due to the air flow. Hence the DC output current is 0.81 x 2, or 1.6 times the 25°C air rating.

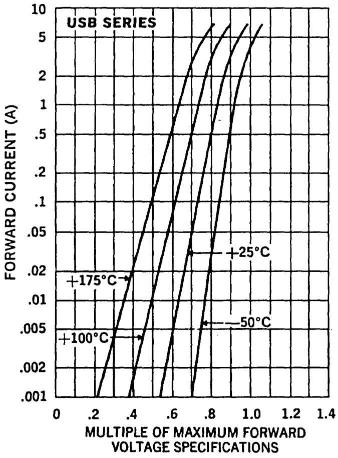


Forward Pulse Current vs. Duration

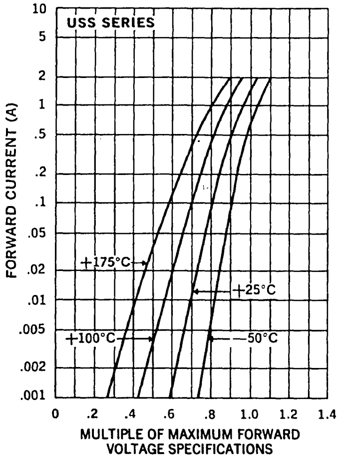


Multiple Surge Current vs. Duration

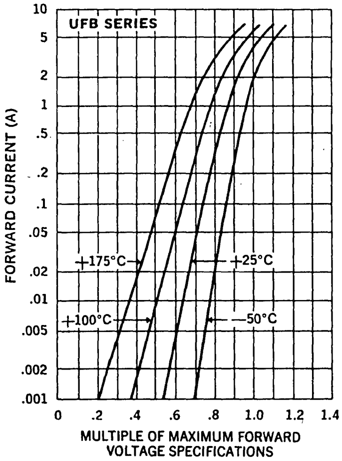
Typical Forward Voltage vs. Forward Current



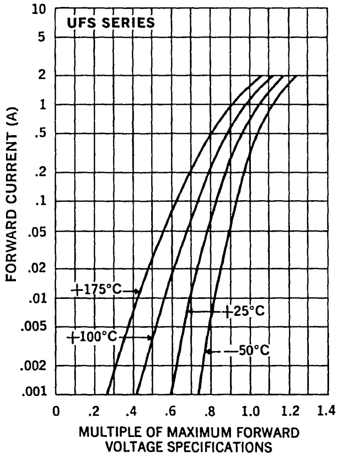
Typical Forward Voltage vs. Forward Current



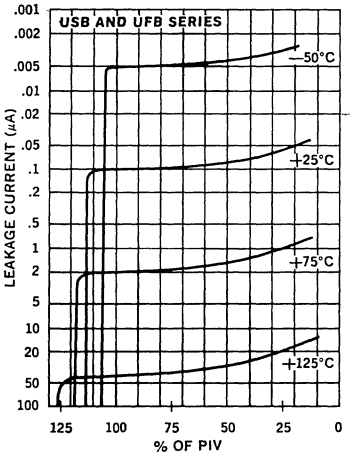
Typical Forward Voltage vs. Forward Current



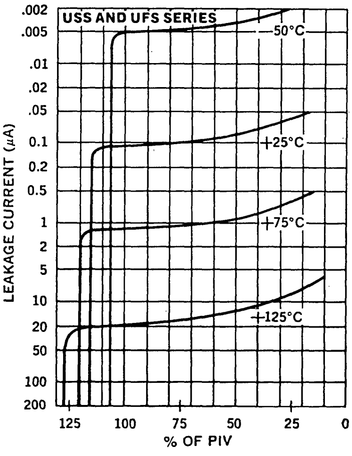
Typical Forward Voltage vs. Forward Current



Typical Leakage Current vs. PIV



Typical Leakage Current vs. PIV



RECTIFIER ASSEMBLIES

High Voltage Doorbell® Modules
Standard and Fast Recovery

UGB, UGD, UGE, UGF SERIES

FEATURES

- Current Ratings: to 10A
- PIV: 2.5 kV to 10kV
- Recovery Times: to 500ns
- Only Fused-in-Glass Diodes Used
- Controlled Avalanche Characteristics
- Stackable to 600kV
- Modular Package for Easy Stacking

DESCRIPTION

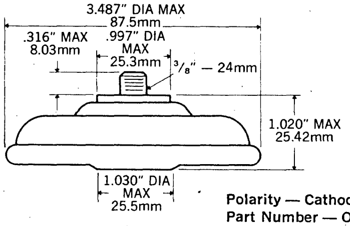
This series of high-voltage, high-current stacks that incorporate a unique modular design makes it particularly well-suited for high power applications such as in radar systems as charge, hold-off and clipper diodes.

ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	
UGB, UGD Series	5 kV to 10 kV
UGS, UGF Series	2.5 kV to 7.5 kV
Maximum Average D.C. Output Current	See Electrical Specifications
Non-repetitive Sinusoidal Surge (8.3ms)	See Electrical Specifications
Operating and Storage Temperature Range, T_C	−65°C to +150°C

MECHANICAL SPECIFICATIONS

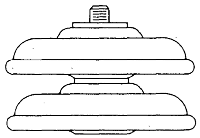
UGB, UGD, UGE, UGF SERIES



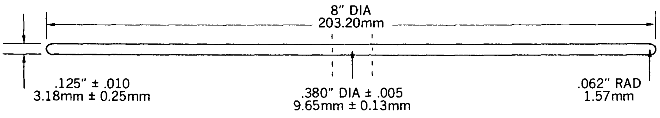
Polarity — Cathode connected to base.
Part Number — On base of unit.

Typical Weight — 7.0 ounces
200 grams

DG



EXTENDER PLATE G



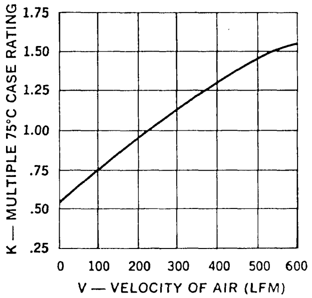
Typical Weight — 9.25 ounces
265 grams

Doorbell® is a registered trademark of Unitrode Corporation

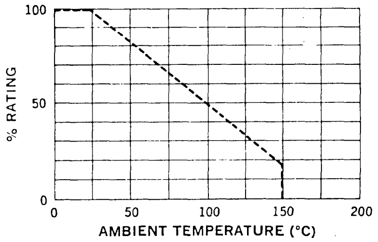
Electrical Specifications (at 25°C unless noted)						Maximum Ratings				
Type		PIV	Maximum Forward Voltage Drop	Maximum Leakage Current @ PIV	Maximum Reverse Recovery Time	Maximum Average D.C. Output Current			Non-repetitive Sinusoidal Surge (8.3ms)	Maximum Reverse Transient Energy Absorption
						$T_C = 75°C$ Air	$T_C = 60°C$ Air with Extender Plate**	$T_C = 50°C$ Oil	$T_C = 100°C$	
		kV		µA	ns	Amps	Amps	Amps	Amps	joules
Standard Recovery	UGE-2.5	2.5	5V @ 3.30A	10		6.60	8.25	10.00	200	8
	UGE-5	5	10V @ 2.50A	15		5.00	6.25	7.50	200	14
	UGB-5	5	9V @ 2.20A	5	—	4.40	5.50	6.60	100	7
	UGE-7.5	7.5	13V @ 1.60A	10		3.30	4.10	5.00	200	20
	UGB-7.5	7.5	13V @ 1.50A	5		3.00	3.75	5.00	100	10
	UGB-10	10	17V @ 1.10A	5		2.30	2.85	3.50	100	14
Fast Recovery	UGF-2.5	2.5	6V @ 2.50A	10		5.00	6.25	8.00	150	8
	UGF-5	5	11V @ 1.80A	10		3.75	4.70	6.00	150	14
	UGD-5	5	11V @ 1.60A	5	500*	3.30	4.10	4.80	80	7
	UGF-7.5	7.5	17V @ 1.20A	10	350†	2.50	3.10	4.00	150	20
	UGD-7.5	7.5	17V @ 1.10A	5		2.25	2.80	3.50	80	10
	UGD-10	10	22V @ 0.85A	5		1.75	2.20	2.50	80	14

*Measured in a reverse recovery circuit switching from 1.0A forward to 1.0A reverse current recovering to 0.5A.
†Measured in a reverse recovery circuit switching from 0.5A forward to 1.0A reverse current recovering to 0.25A.

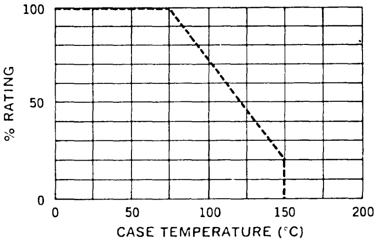
**These ratings are based on using "extender plates" that provide additional surface area to radiate heat. Because of possible corona effects caused by scratches on these plates, extreme care is necessary in their handling and they are not recommended where the working voltage exceeds 7.5KV/module. They should be carefully polished prior to installation.



Output Current Ratio vs. Velocity of Air Flow

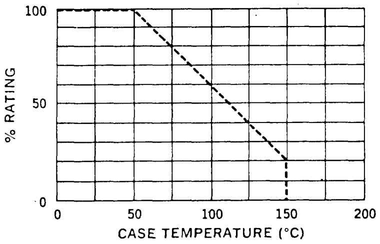


Current Derating Curve



Current Derating Curve

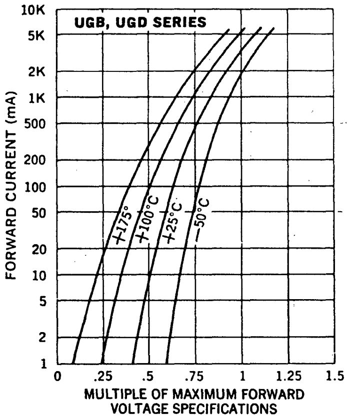
Air Cooled



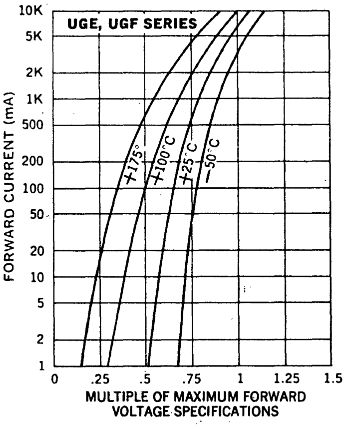
Current Derating Curve

Oil Immersed

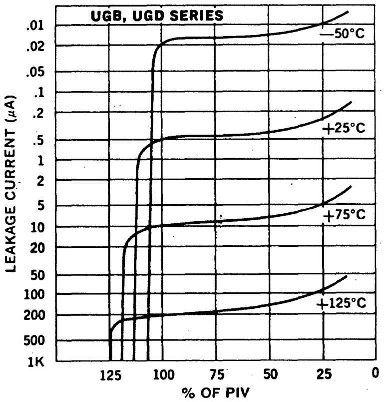
Typical Forward Voltage vs. Forward Current



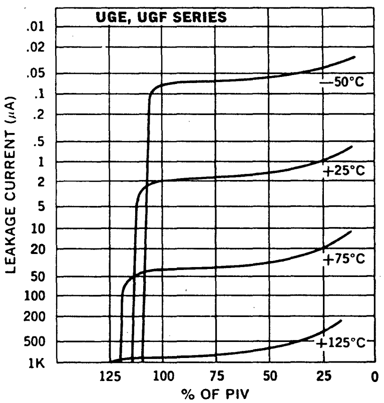
Typical Forward Voltage vs. Forward Current



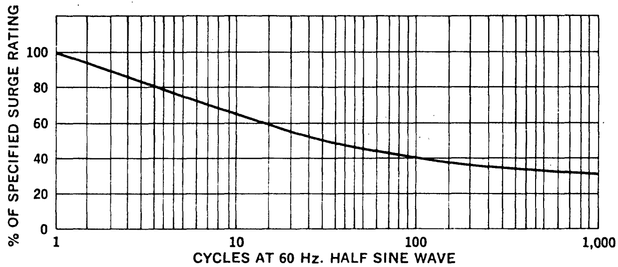
Typical Leakage Current vs. PIV



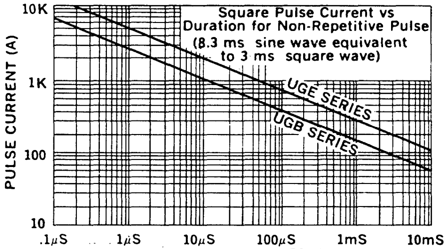
Typical Leakage Current vs. PIV



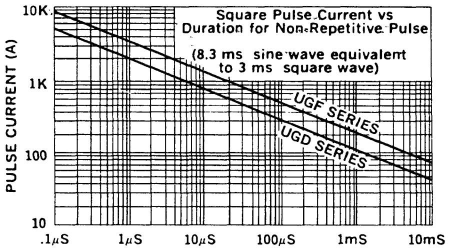
Multiple Surge Rating vs. Duration



Forward Pulse Current vs. Pulse Duration



Forward Pulse Current vs. Pulse Duration



RECTIFIER ASSEMBLIES

High Voltage Stacks, .125 Amp to 1 Amp, Standard and Fast Recovery

US12–US200A
USR12–USR180A

FEATURES

- Controlled Avalanche Characteristics
- Recovery Times: to 500ns
- Transfer Molded for Voidless Encapsulation
- High Forward and Reverse Surge Capability
- PIV: from 1200 to 20,000V
- Only Fused-in-Glass Diodes Used

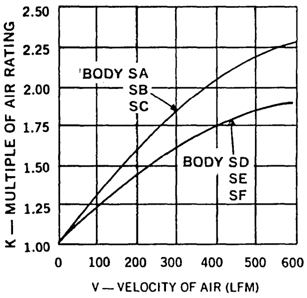
DESCRIPTION

This series of High Voltage, Medium Current Stacks are assembled from hermetically sealed, controlled avalanche individual diodes. Therefore, they offer the ultimate in reliability for such applications as clipper diodes, back swing diodes and hold-off diodes in pulse modulators.

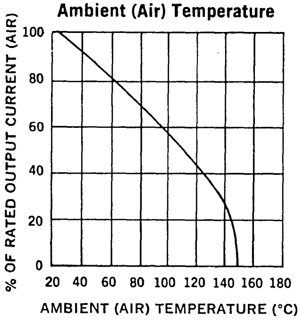
ABSOLUTE MAXIMUM RATINGS

Peak Inverse Voltage	1200 to 20,000V
Maximum Average D.C. Output Current	See Electrical Specifications
Non-Repetitive Sinusoidal Surge (8.3ms)	20A
Operating and Storage Temperature Range	−65°C to +150°C

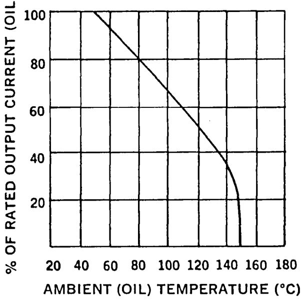
Output Current Ratio vs Velocity of Air Flow



Output Current vs Ambient (Air) Temperature



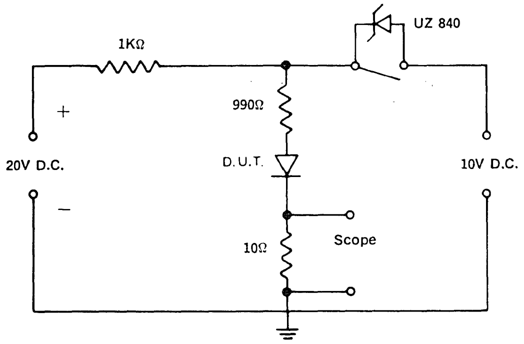
Output Current vs Ambient (Oil) Temperature



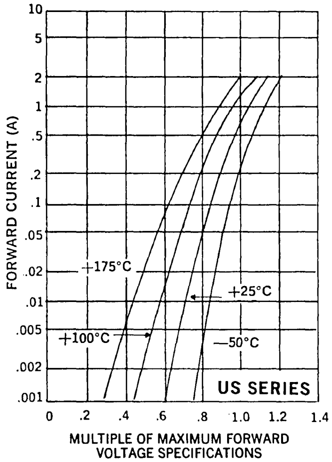
Electrical Specifications (at 25°C unless noted)							Maximum Ratings	
Type	PIV	Maximum Leakage Current at PIV		Maximum Forward Voltage Drop	Maximum Reverse Recovery Time†	Body Size	Max. Avg. D.C. Output Current	
		$T_A = 25°C$	$T_A = 100°C$				$T_A = 25°C$ (Air)	$T_A = 50°C$ (Oil)
	V	μA	μA		ns		mA	mA
Standard Recovery								
US 12	1200	2	100	2.0V @ 400mA	——	SA	1000	2500
US 15	1500	2	100	3.0V @ 400mA		SA	800	2000
US 18	1800	2	100	3.0V @ 400mA		SA	700	1750
US 20	2000	2	100	4.0V @ 400mA		SA	600	1500
US 25	2500	2	100	5.0V @ 400mA	——	SB	600	1500
US 30	3000	2	100	6.0V @ 400mA		SB	500	1250
US 35	3500	2	100	7.0V @ 200mA	——	SC	400	1000
US 40	4000	2	100	7.0V @ 200mA		SC	350	850
US 45A	4500	2	100	8.0V @ 200mA	——	SD	330	750
US 50A	5000	2	100	9.0V @ 200mA		SD	330	750
US 60A	6000	2	100	10.0V @ 200mA		SD	300	620
US 70A	7000	2	100	12.0V @ 200mA		SD	300	620
US 80A	8000	2	100	14.0V @ 100mA	——	SE	250	500
US 100A	10000	2	100	17.0V @ 100mA		SE	250	500
US 120A	12000	2	100	21.0V @ 100mA		SE	200	400
US 150A	15000	2	100	26.0V @ 100mA	——	SF	200	400
US 180A	18000	2	100	31.0V @ 100mA		SF	180	360
US 200A	20000	2	100	34.0V @ 100mA		SF	180	360
Fast Recovery								
USR 12	1200	5	150	3.3V @ 400mA	500	SA	750	1850
USR 15	1500	5	150	4.0V @ 400mA	500	SA	600	1500
USR 20	2000	5	150	5.5V @ 400mA	500	SB	500	1250
USR 25	2500	5	150	6.6V @ 400mA	500	SB	400	1000
USR 30	3000	5	150	7.7V @ 400mA	500	SC	400	1000
USR 35	3500	5	150	8.8V @ 200mA	500	SC	350	850
USR 40A	4000	5	150	9.9V @ 200mA	500	SD	300	750
USR 45A	4500	5	150	11.0V @ 100mA	500	SD	250	625
USR 50A	5000	5	150	13.0V @ 100mA	500	SD	250	625
USR 60A	6000	5	150	15.4V @ 100mA	500	SD	220	500
USR 70A	7000	5	150	17.6V @ 100mA	500	SE	220	500
USR 80A	8000	5	150	20.0V @ 100mA	500	SE	200	400
USR 100A	10000	5	150	24.0V @ 100mA	500	SE	200	400
USR 120A	12000	5	150	31.0V @ 100mA	500	SF	150	300
USR 150A	15000	5	150	33.0V @ 100mA	500	SF	150	300
USR 180A	18000	5	150	35.0V @ 100mA	500	SF	125	250

†Measured in a reverse recovery circuit switching from 10mA forward to 10mA reverse current recovering to 5mA.

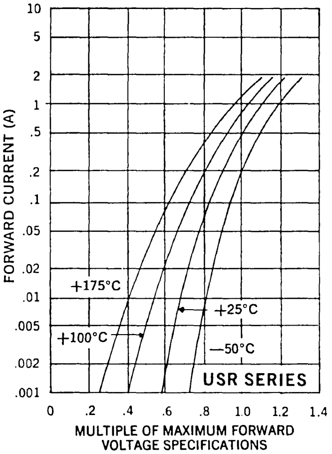
Reverse Recovery Circuit



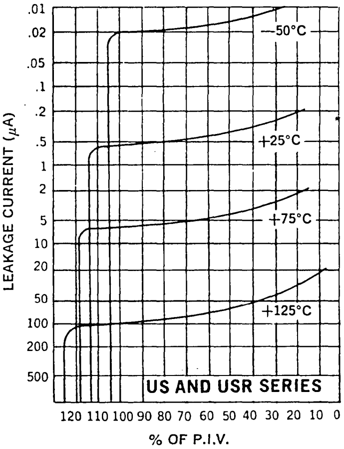
Typical Forward Current vs. Forward Voltage



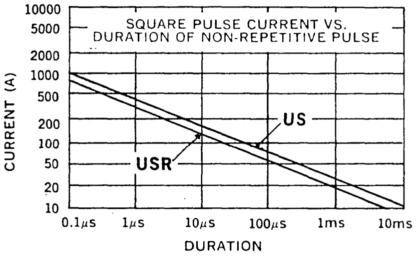
Typical Forward Current vs. Forward Voltage



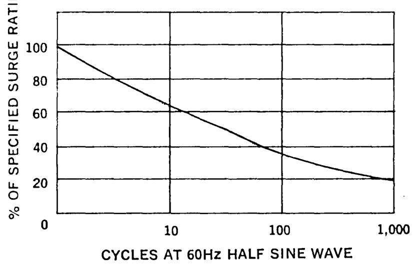
Typical Leakage Current vs. Voltage



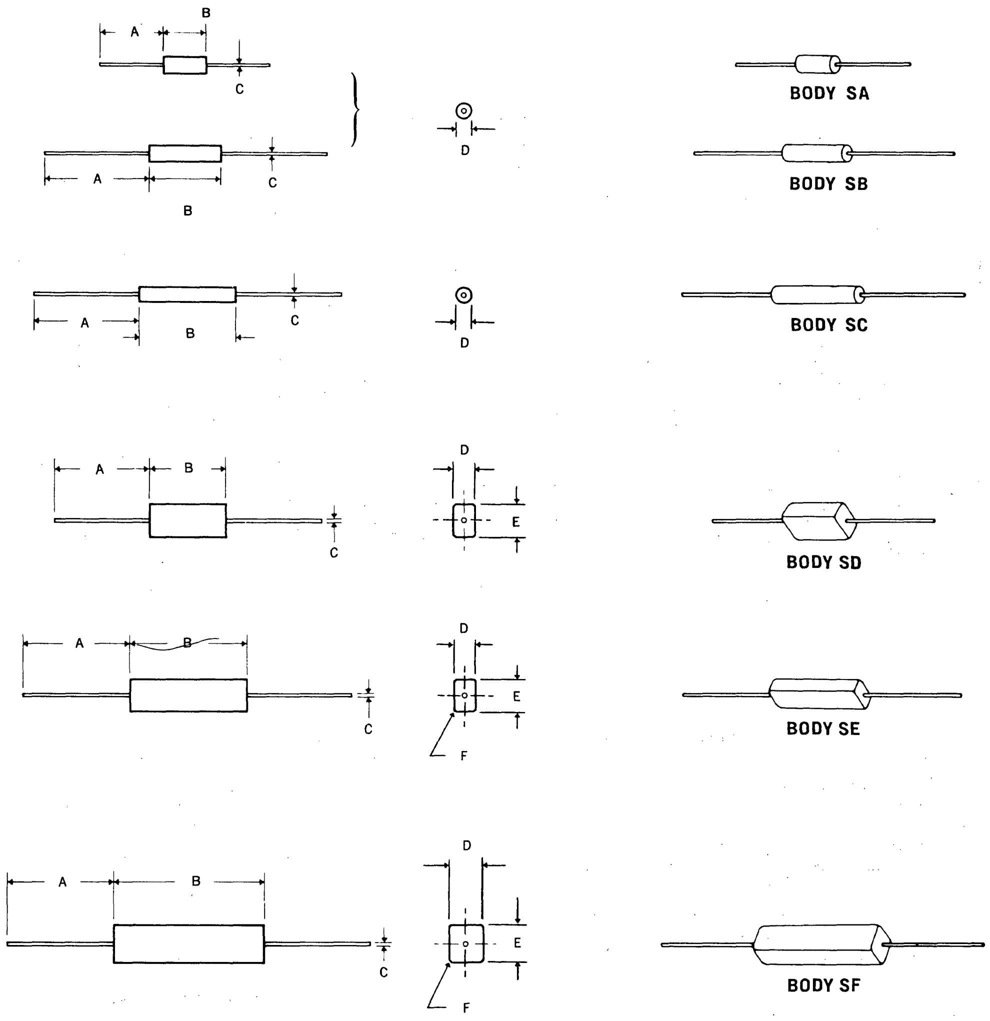
Forward Pulse Current vs Duration



Multiple Forward Surge Rating



MECHANICAL SPECIFICATIONS



	SA		SB		SC		SD		SE		SF	
	ins.	mm.	ins.	mm.	ins.	mm.	ins.	mm.	ins.	mm.	ins.	mm.
A	.75 MIN.	19.05 MIN.	1.25 MIN.	31.75 MIN.	1.25 MIN.	31.75 MIN.	1.25 MIN.	31.75 MIN.	1.25 MIN.	31.75 MIN.	1.25 MIN.	31.75 MIN.
B	.50 MAX.	12.70 MAX.	0.85 MAX.	21.59 MAX.	1.125 MAX.	28.58 MAX.	.875 MAX.	22.23 MAX.	1.375 MAX.	34.93 MAX.	1.75 MAX.	44.45 MAX.
C	.028 DIA.	.71 DIA.	.032 DIA.	.81 DIA.	.032 DIA.	.81 DIA.	.032 DIA.	.81 DIA.	.032 DIA.	.81 DIA.	.032 DIA.	.81 DIA.
D	.187 MAX.	4.75 MAX.	.187 MAX.	4.75 MAX.	.187 MAX.	4.75 MAX.	.250 MAX.	6.35 MAX.	.250 MAX.	6.35 MAX.	.400 MAX.	10.16 MAX.
E							.375 MAX.	9.53 MAX.	.375 MAX.	9.53 MAX.	.400 MAX.	10.16 MAX.
F									.078	1.98	.078	1.98

POWER ZENERS AND TRANSIENT VOLTAGE SUPPRESSORS 4

Product Selection Guides

POWER ZENERS AND TRANSIENT VOLTAGE SUPPRESSORS

Transient Voltage Suppressors

Package Style	Part No.	Stand-Off Voltage V_R (V)	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA (V)	Max. Peak Pulse Current I_{PP} (A)	Max. Clamping Voltage* V_C @ I_{PP} (V)	Peak Power for 1mS (W)
A Body	TVS305	5.0	5.0	17	8.7	150
	TVS310	10.0	11.1	8.9	16.8	
	TVS312	12.0	13.8	7.1	21.0	
	TVS315	15.0	16.7	5.9	25	
	TVS318	18.0	20.4	4.9	31	
	TVS324	24.0	28.4	3.6	42	
	TVS328	28.0	30.7	3.2	46	
	TVS348	48.0	54	1.7	82	
	TVS360	60.0	67	1.4	105	
	TVS410	100.0	111	.91	160	
	TVS420	200.0	234	.42	360	
	TVS430	300.0	342	.28	520	
B Body	TVS505	5.0	6.0	53.7	9.3	500
	TVS510	10.0	11.1	30.3	16.5	
	TVS512	12.0	13.8	23.8	21.0	
	TVS515	15.0	16.7	19.8	25.2	
	TVS518	18.0	20.4	16.3	30.5	
	TVS524	24.0	28.4	11.9	42.0	
	TVS528	28.0	30.7	10.7	46.5	
	1N6461**	5.0	5.6 @ 25mA	56	9	500
	1N6462**	6.0	6.5 @ 20mA	46	11	
	1N6463**	12.0	13.6 @ 5mA	22	22.6	
	1N6464**	15.0	16.4 @ 5mA	19	26.5	
	1N6465**	24.0	27.0 @ 2mA	12	41.4	
	1N6466**	30.5	33.0 @ 1mA	11	47.5	
	1N6467**	40.3	43.7 @ 1mA	8	63.5	
	1N6468**	51.6	54.0 @ 1mA	6	78.5	
CCL	1N5610*		33.0	32.0	47.5	1500
	1N5611*		43.7	24.0	63.5	
	1N5612*		54.0	19.0	79.5	
	1N5613*		191.0	5.7	265.0	

Transient Voltage Suppressors Glass Axial, Bidirectional

Part No.	Stand-Off Voltage V_R (V)	Min. Breakdown Voltage $BV_{(min.)}$ @ 1mA (V)	Max. Peak Pulse Current I_{PP} (A)	Max. Clamping Voltage V_C @ I_{PP} (V)	Peak Pulse Power 8 × 20μs Waveform (W)
EPS5	5	6.0	89.4	9.5	1000
EPS8	8	8.8	62.1	13.7	1000
EPS12	12	13.8	40.3	21.6	1000
EPS15	15	16.7	33.9	26.0	1000
EPS16	17	18.7	30.8	29.2	1000
EPS24	24	28.4	22.0	41.0	1000
EPS28	28	30.7	19.2	47.8	1000
EPS33	33	36.3	16.4	56.7	1000
EPS42	48	54.0	11.2	84.3	1000

POWER ZENERS AND TRANSIENT VOLTAGE SUPPRESSORS

Transient Voltage Suppressors Glass Axial, Bidirectional

Part No.	Stand-Off Voltage V_R (V)	Min. Breakdown Voltage $BV_{(min.)}$ @ 1mA (V)	Max. Peak Pulse Current I_{PP} (A)	Max. Clamping Voltage V_C @ I_{PP} (V)	Peak Pulse Power for 1ms (W)
1N6102A	5	6.46	47.6	10.5	500
1N6107A	8	10.45	32.0	15.6	500
1N6111A	12	15.2	22.4	22.3	500
1N6113A	15	19.0	18.0	27.7	500
1N6115A	17	22.8	15.0	33.3	500
1N6118A	24	31.4	10.9	45.7	500
1N6120A	28	37.1	9.3	53.6	500
1N6122A	33	44.7	7.7	64.6	500
1N6125A	48	64.6	5.1	97.1	500

B

Bi-directional Zeners

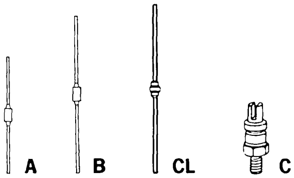
Power		1W	3W	5W
Package Style		AA		BB
Voltage, V (10% Tolerance)	7.5	UDZ8807	UDZ807	UDZ5807
	8.2	UDZ8808	UDZ808	UDZ5808
	9.1	UDZ8809	UDZ809	UDZ5809
	10	UDZ8810	UDZ810	UDZ5810
	12	UDZ8812	UDZ812	UDZ5812
	15	UDZ8815	UDZ815	UDZ5815
	18	UDZ8818	UDZ818	UDZ5818
	20	UDZ8820	UDZ820	UDZ5820
	24	UDZ8824	UDZ824	UDZ5824
	27	UDZ8827	UDZ827	UDZ5827
	30	UDZ8830	UDZ830	UDZ5830
	33	UDZ8833	UDZ833	UDZ5833
	36	UDZ8836	UDZ836	UDZ5836
	40	UDZ8840	UDZ840	UDZ5840
	45	UDZ8845	UDZ845	UDZ5845
	60	UDZ8860	UDZ860	UDZ5860

AA

BB

POWER ZENERS AND TRANSIENT VOLTAGE SUPPRESSORS

PRODUCT SELECTION GUIDE



POWER ZENERS

Power		1W	1.5W	3W	3W	5W	5W	6W	10W
Package Style		**A**	**A**	**A**	**A**	**B**	**B**	**CL**	**C**
VOLTAGE V_Z (5% Tolerance)	5.6V						1N5968*		
	6.2V						1N5969*		
	6.8V	UZ8706	1N4461*	1N5063	UZ706[1]	UZ4706	1N4954*	UZ7706L[1]	UZ7706[1]
	7.5V	UZ8707	1N4462*	1N5064	UZ707[1]	UZ4707	1N4955*	UZ7707L[1]	UZ7707[1]
	8.2V	UZ8708	1N4463*	1N5065	UZ708[1]	UZ4708	1N4956*	UZ7708L[1]	UZ7708[1]
	9.1V	UZ8709	1N4464*	1N5066	UZ709[1]	UZ4709	1N4957*	UZ7709L[1]	UZ7709[1]
	10V	UZ8710	1N4465*	1N5067	UZ710[1]	UZ4710	1N4958*	UZ7710L[1]	UZ7710[1]
	11V	UZ8711	1N4466*	1N5068			1N4959*	UZ7711L[1]	UZ7711[1]
	12V	UZ8712	1N4467*	1N4883	UZ712[1]	UZ4712	1N4960*	UZ7712L[1]	UZ7712[1]
	13V	UZ8713	1N4468*	1N5069	UZ713[1]	UZ4713	1N4961*	UZ7713L[1]	UZ7713[1]
	14V	UZ8714		1N5070	UZ714[1]		1N5118	UZ7714L[1]	UZ7714[1]
	15V	UZ8715	1N4469*	1N5071	UZ715[1]	UZ4715	1N4962*	UZ7715L[1]	UZ7715[1]
	16V	UZ8716	1N4470*	1N5072	UZ716[1]	UZ4716	1N4963*	UZ7716L[1]	UZ7716[1]
	18V	UZ8718	1N4471*	1N5073	UZ718[1]	UZ4718	1N4964*	UZ7718L[1]	UZ7718[1]
	20V	UZ8720	1N4472*	1N4884	UZ720[1]	UZ4720	1N4965*	UZ7720L[1]	UZ7720[1]
	22V	UZ8722	1N4473*	1N5074	UZ722[1]	UZ4722	1N4966*	UZ7722L[1]	UZ7722[1]
	24V	UZ8724	1N4474*	1N5075	UZ724[1]	UZ4724	1N4967*	UZ7724L[1]	UZ7724[1]
	27V	UZ8727	1N4475*	1N5076	UZ727[1]	UZ4727	1N4968*	UZ7727L[1]	UZ7727[1]
	30V	UZ8730	1N4476*	1N5077	UZ730[1]	UZ4730	1N4969*	UZ7730L[1]	1N7730[1]
	33V	UZ8733	1N4477*	1N5078	UZ733[1]	UZ4733	1N4970*	UZ7733L[1]	UZ7733[1]
	36V	UZ8736	1N4478*	1N5079	UZ736[1]	UZ4736	1N4971*	UZ7736L[1]	UZ7736[1]
	39V		1N4479*	1N5080		UZ4739	1N4972*		
	40V	UZ8740		1N5081	UZ740[1]		1N5119	UZ7740L[1]	UZ7740[1]
	43V		1N4480*	1N5082		UZ4743	1N4973*		
	45V	UZ8745		1N5083	UZ745[1]		1N5120	UZ7745L[1]	UZ7745[1]
	47V		1N4481*	1N5084		UZ4747	1N4974*		
	50V	UZ8750		1N5085	UZ750[1]		1N5121	UZ7750L[1]	UZ7750[1]
	51V		1N4482*	1N5086		UZ4751	1N4975*		
	56V	UZ8756	1N4483*	1N5087	UZ756[1]	UZ4756	1N4976*	UZ7756L[1]	UZ7756[1]
	60V	UZ8760		1N5088	UZ760[1]		1N5122	UZ7760L[1]	UZ7760[1]
	62V		1N4484*	1N5089		UZ4762	1N4977*		
	68V		1N4485*	1N5090		UZ4768	1N4978*		
PULSE POWER **		100W	140W	230W	230W	720W	900W	2000W	2000W

* Available as JAN, JANTX & JANTXV

1. Available with High Reliability (HR2) Screening. See individual datasheet.

POWER ZENERS AND TRANSIENT VOLTAGE SUPPRESSORS

POWER ZENERS

Power		1W	1.5W	3W	3W	5W	5W	6W	10W
Package Style		**A**	**A**	**A**	**A**	**B**	**B**	**CL**	**C**
VOLTAGE V_Z (5% Tolerance)	70V	UZ8770		1N5091	UZ770[1]		1N5123	UZ7770L[1]	UZ7770[1]
	75V	UZ8775	1N4486*	1N5092	UZ775[1]	UZ4775	1N4979*	UZ7775L[1]	UZ7775[1]
	80V	UZ8780		1N5093	UZ780[1]		1N5124	UZ7780L[1]	UZ7780[1]
	82V		1N4487*	1N5094		UZ4782	1N4980*		
	90V	UZ8790		1N4096	UZ790[1]		1N5125	UZ7790L[1]	UZ7790[1]
	91V		1N4488*	1N4095		UZ4791	1N4981*		
	100V	UZ8110	1N4489*	1N4097	UZ110[1]	UZ4110	1N4982*	UZ7110L[1]	UZ7110[1]
	110V	UZ8111	1N4490*	1N5096	UZ111[1]	UZ4111	1N4983*		
	120V	UZ8112	1N4491*	1N5097	UZ112[1]	UZ4112	1N4984*		
	130V	UZ8113	1N4492*	1N5098	UZ113[1]	UZ4113	1N4985*		
	140V	UZ8114		1N5099	UZ114[1]				
	150V	UZ8115	1N4493*	1N4098	UZ115[1]	UZ4115	1N4986*		
	160V	UZ8116	1N4494*	1N5100	UZ116[1]	UZ4116	1N4987*		
	170V	UZ8117		1N5101	UZ117[1]		1N5127*		
	180V	UZ8118	1N4495*	1N5102	UZ118[1]	UZ4118	1N4988*		
	190V	UZ8119		1N5103	UZ119[1]		1N5128		
	200V	UZ8120	1N4496*	1N5104	UZ120[1]	UZ4120	1N4989*		
	220V			1N5105	UZ122[1]		1N4990*		
	240V			1N5106	UZ124[1]		1N4991*		
	260V			1N5107	UZ126[1]		1N5129		
	270V			1N5108			1N4992*		
	280V			1N5109	UZ128[1]		1N5130		
	300V			1N5110	UZ130[1]		1N4993*		
	320V			1N5111	UZ132[1]		1N5131		
	330V			1N5112			1N4994*		
	340V			1N5113	UZ134[1]		1N5132		
	360V			1N5114	UZ136[1]		1N4995*		
	380V			1N5115	UZ138[1]		1N5133		
	390V			1N5116			1N4996		
	400V			1N5117	UZ140[1]		1N5134		
PULSE POWER **		100W	140W	230W	230W	720W	900W	2000W	2000W

* Available as JAN, JANTX & JANTXV

1. Available with High Reliability (HR2) Screening. See individual datasheet.

POWER ZENERS

1.5 Watt, Military

1N4461-1N4496
JAN, JANTX & JANTXV

FEATURES

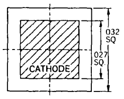
- 5 Times Greater Surge Rating than JAN1N3016 Series
- Low Reverse Current: to 50nA
- ¼ Size of Conventional 1 Watt Zeners

DESCRIPTION

Fused-in-glass, metallurgically bonded 1.5 watt zeners, qualified to MIL-S-19500/406.

ABSOLUTE MAXIMUM RATINGS

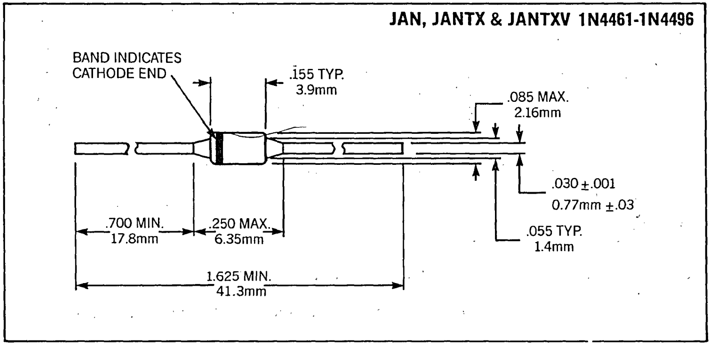
Zener Voltage, V_Z	6.8 to 200V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	−65°C to +175°C

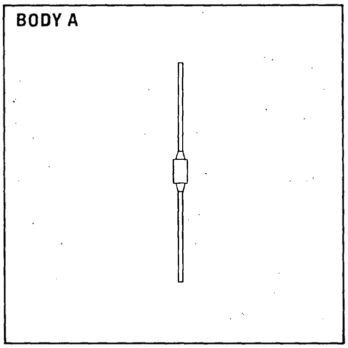


BACKSIDE ANODE

CHIP THICKNESS		METALLIZATION	
1N4461	.0054	TOP	AL
1N4478	.0063	BACK	AU
1N4479	.0085		
1N4496	.0096		

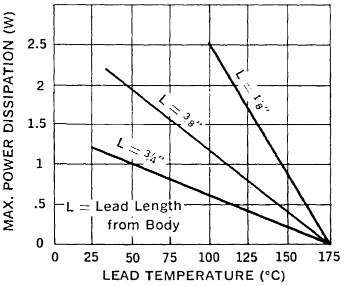
MECHANICAL SPECIFICATIONS



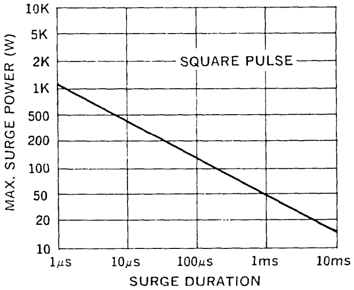


THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

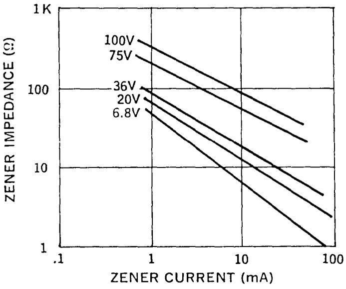
Power Dissipation vs. Lead Temperature Derating Curve



Max. Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



SEMICONDUCTOR PRODUCTS
UNITRODE

	Electrical Specifications at 25°C								Maximum Ratings	
			Max. Zener Impedance §				Maximum Reverse Leakage Current			
Type	Nominal Zener Voltage † V_Z @ I_{ZT}	Test Current I_{ZT}	Z_Z @ I_{ZT}	Z_{ZK} @ I_{ZK}	I_{ZK}	Voltage ** Regulation ΔBV Max	I_R @ V_R	V_R	Maximum Cont. Current I_{ZM}	Maximum Surge Current‡ I_S
±5% Tolerance	Volts	mA	Ohms	Ohms	mA	Volts	μA	Volts	mA	Amps
1N4461	6.8	37	2.5	200	1.0	.30	5.0	4.08	210	5.0
1N4462	7.5	34	2.5	400	.5	.35	1.0	4.50	191	4.5
1N4463	8.2	31	3.0	400	.5	.40	.50	4.92	174	3.9
1N4464	9.1	28	4.0	500	.5	.45	.30	5.46	157	3.4
1N4465	10	25	5.0	500	.25	.50	.30	8.0	143	3.0
1N4466	11	23	6.0	550	.25	.55	.30	8.8	130	2.6
1N4467	12	21	7.0	550	.25	.60	.20	9.6	119	2.4
1N4468	13	19	8.0	550	.25	.65	.10	10.4	110	2.2
1N4469	15	17	9.0	600	.25	.75	.05	12.0	95	1.8
1N4470	16	15.5	10.0	600	.25	.80	.05	12.8	90	1.6
1N4471	18	14	11.0	650	.25	.83	.05	14.4	79	1.4
1N4472	20	12.5	12.0	650	.25	.95	.05	16.0	71	1.2
1N4473	22	11.5	14	650	.25	1.0	.05	17.6	65	1.1
1N4474	24	10.5	16	700	.25	1.1	.05	19.2	60	.90
1N4475	27	9.5	18	700	.25	1.3	.05	21.6	53	.80
1N4476	30	8.5	20	750	.25	1.4	.05	24.0	48	.75
1N4477	33	7.5	25	800	.25	1.5	.05	26.4	43	.66
1N4478	36	7.0	27	850	.25	1.7	.05	28.8	40	.60
1N4479	39	6.5	30	900	.25	1.8	.05	31.2	37	.54
1N4480	43	6.0	40	950	.25	1.9	.05	34.4	33	.48
1N4481	47	5.5	50	1000	.25	2.1	.05	37.6	30	.45
1N4482	51	5.0	60	1100	.25	2.3	.05	40.8	28	.42
1N4483	56	4.5	70	1300	.25	2.5	.05	44.8	26	.39
1N4484	62	4.0	80	1500	.25	2.7	.05	49.6	23	.35
1N4485	68	3.7	100	1700	.25	3.0	.05	54.4	21	.32
1N4486	75	3.3	130	2000	.25	3.3	.05	60.0	19	.29
1N4487	82	3.0	160	2500	.25	3.6	.05	65.6	17	.26
1N4488	91	2.8	200	3000	.25	4.0	.05	72.8	16	.23
1N4489	100	2.5	250	3100	.25	4.4	.25	80.0	14	.20
1N4490	110	2.0	300	4000	.25	5.0	.25	88.0	13	.19
1N4491	120	2.0	400	4500	.25	5.5	.25	96.0	12	.18
1N4492	130	1.9	500	5000	.25	6.0	.25	104	11	.16
1N4493	150	1.7	700	6000	.25	7.0	.25	120	9.5	.14
1N4494	160	1.6	1000	6500	.25	8.0	.25	128	8.9	.12
1N4495	180	1.4	1300	7000	.25	10.0	.25	144	7.9	.10
1N4496	200	1.2	1500	8000	.25	12.0	.25	160	7.2	.08

† All Zener voltages are measured with an automated test set using a 35 millisecond test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§ Zener impedance is derived from the 60 cycle AC Voltage created when AC current with RMS value of 10% of DC Zener test current is superimposed on the test current.

** ΔBV is obtained by measuring the voltage change when the test current is changed from 10% to 50% of Iz max under DC conditions. During this measurement the leads are heat sunk .375 inch from the body and maintained at 25°C.

‡ Ratings shown are for peak sinusoidal surge current of 8.3 ms duration, non-repetitive. The 8.3 ms square pulse rating is 71% of the value shown. Rating exceeds JEDEC Registered Specification.

POWER ZENERS
5 Watt, Military

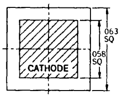
1N4954-1N4996
1N5968-1N5969
JAN, JANTX & JANTXV

FEATURES
- 2 Times Greater Surge Rating than Conventional 10 Watt Zeners
- Small Physical Size

DESCRIPTION
Fused-in-glass, metallurgically-bonded 5 watt zeners, qualified to MIL-S-19500/356.

ABSOLUTE MAXIMUM RATINGS

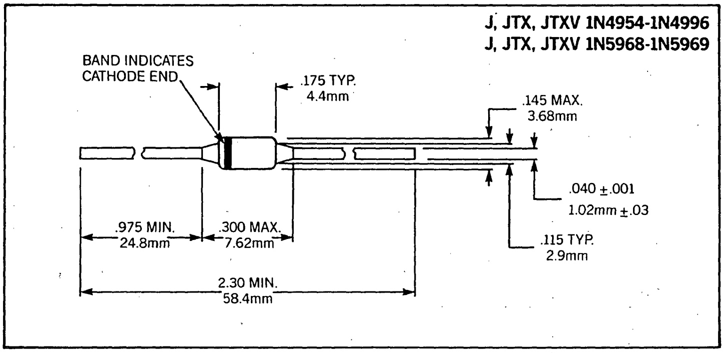
Zener Voltage, V_Z	5.6 to 390V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	−65°C to +175°C

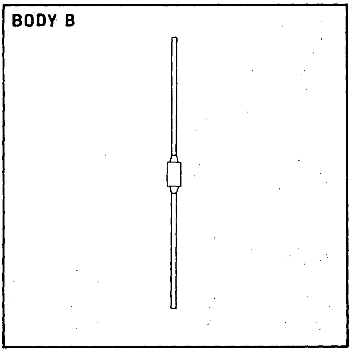


BACKSIDE ANODE

CHIP THICKNESS		METALLIZATION	
1N4954 – 1N4971	.0058 / .0065	TOP	AL
1N4972 – 1N4996	.0085 / .0095	BACK	AU

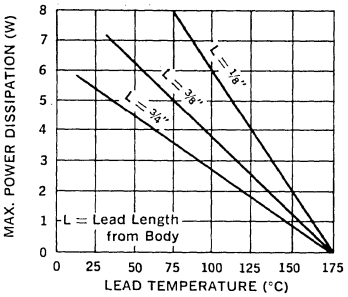
MECHANICAL SPECIFICATIONS



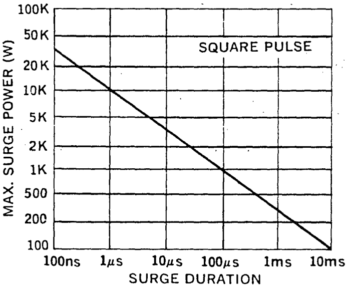


THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

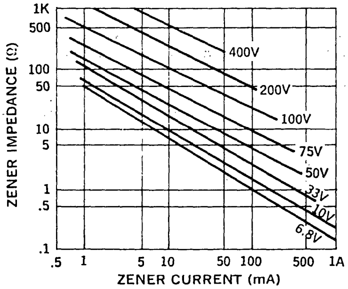
Power Dissipation vs. Lead Temperature Derating Curve



Max. Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



SEMICONDUCTOR PRODUCTS
UNITRODE

Electrical Specifications at 25°C										Maximum Ratings	
Type	Nominal Zener Voltage† V_Z @ I_{ZT}	Test Current I_{ZT}	Maximum Zener Impedance § Z_Z @ I_{ZT}	Maximum Zener Impedance § Z_{ZK}†† @ I_{ZK} = 1mA	Voltage Regulation ΔBV §§	Maximum Reverse Leakage Current I_R††	Maximum Reverse Leakage Current I_R	Maximum Reverse Leakage Current V_R	Maximum Temperature Coeff. T_C @ I_{ZT}	Maximum Continuous Current ★ I_{ZM}	Maximum Surge Current‡ I_S
±5% Tolerance	Volts	mA	Ohms	Ohms	Volts	μA		Volts	%/°C	mA	Amps
1N5968*	5.6	220	1.0	400	0.4	5000	5000	4.28	.04	865	20
1N5969*	6.2	220	1.0	1000	0.5	1000	1000	4.74	.04	765	20
1N4954*	6.8	175	1.0	1000	0.7	150	300	5.2	.05	700	40
1N4955*	7.5	175	1.5	800	0.7	100	200	5.7	.06	630	32
1N4956*	8.2	150	1.5	600	0.7	50	100	6.2	.06	580	24
1N4957*	9.1	150	2.0	400	0.7	25	50	6.9	.06	520	22
1N4958*	10.0	125	2.0	125	0.8	25	25	7.6	.07	475	20
1N4959*	11	125	2.5	130	0.8	10	15	8.4	.07	430	19
1N4960*	12	100	2.5	140	0.8	10	10	9.1	.07	395	18
1N4961*	13	100	3.0	145	0.8	10	10	9.9	.08	365	16
1N4962*	15	75	3.5	150	1.0	5	5	11.4	.08	315	12
1N4963*	16	75	3.5	155	1.1	5	5	12.2	.08	294	10
1N4964*	18	65	4.0	160	1.2	5	5	13.7	.085	264	9.0
1N4965*	20	65	4.5	165	1.5	2	2	15.2	.085	237	8.0
1N4966*	22	50	5.0	170	1.8	2	2	16.7	.085	216	7.0
1N4967*	24	50	5.0	175	2.0	2	2	18.2	.090	198	6.5
1N4968*	27	50	6.0	180	2.0	2	2	20.6	.090	176	6.0
1N4969*	30	40	8	190	2.5	2	2	22.8	.090	158	5.5
1N4970*	33	40	10	200	2.8	2	2	25.1	.095	144	5.0
1N4971*	36	30	11	220	3.0	2	2	27.4	.095	132	4.5
1N4972*	39	30	14	230	3.0	2	2	29.7	.095	122	4.0
1N4973*	43	30	20	240	3.3	2	2	32.7	.095	110	3.5
1N4974*	47	25	25	250	3.5	2	2	35.8	.095	100	3.2
1N4975*	51	25	27	270	4.0	2	2	38.8	.095	92	3.0
1N4976*	56	20	35	320	4.4	2	2	42.6	.095	84	2.8
1N4977*	62	20	42	400	5.0	2	2	47.1	.100	76	2.5
1N4978*	68	20	50	500	5.5	2	2	51.7	.100	70	2.2
1N4979*	75	20	55	620	6.0	2	2	56.0	.100	63.0	2.0
1N4980*	82	15	80	720	6.6	2	2	62.2	.100	58.0	1.8
1N4981*	91	15	90	760	7.5	2	2	69.2	.100	52.5	1.6
1N4982*	100	12	110	800	8.0	2	2	76.0	.100	47.5	1.4
1N4983*	110	12	125	1000	9.0	2	2	83.6	.100	43.0	1.2
1N4984*	120	10	170	1150	10	2	2	91.2	.100	39.5	1.00
1N4985*	130	10	190	1250	11	2	2	98.8	.105	36.6	0.80
1N4986*	150	8	330	1500	13	2	2	114.0	.105	31.6	0.75
1N4987*	160	8	350	1650	14	2	2	121.6	.105	29.4	0.70
1N4988*	180	5	450	1750	16	2	2	136.8	.110	26.4	0.60
1N4989*	200	5	500	1850	18	2	2	152	.110	23.6	0.50
1N4990*	220	5	550	2000	19	2	2	167	.115	21.6	0.50
1N4991*	240	5	650	2050	22	2	2	182	.115	19.8	0.40
1N4992*	270	5	800	2100	25	2	2	206	.120	17.5	0.35
1N4993*	300	4	950	2150	28	2	2	228	.120	15.6	0.30
1N4994*	330	4	1175	2200	32	2	2	251	.120	14.4	0.25
1N4995*	360	3	1400	2300	35	2	2	274	.120	13.0	0.22
1N4996	390	3	1800	2500	40	2	2	297	.120	12.0	0.20

* Available as JAN, JANTX & JANTXV.

† All zener voltages are measured with an automated test set using a 35 msec test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§ Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

§§ ΔBV is obtained by measuring the voltage change when the test current is changed from 10% to 50% of Iz max under DC conditions. During this measurement the leads are heat sunk .375 inch from the body and maintained at 25°C.

★ Maximum current based on 5 Watt Rating. See lead temperature derating curves for proper mounting methods.

‡ Figures shown are for peak sinusoidal surge current of 8.3 msec duration, non-repetitive. The 8.3 ms square pulse rating is 71% of the value shown.

†† These specifications apply only to JAN and JANTX

POWER ZENERS

Transient Suppressor Diodes

JAN, JANTX, JANTXV 1N5610-1N5613

FEATURES

- 1500 Watts for 1ms Pulse Power Capability
- Small Physical Size
- Designed to be Used in Mil-Std-704A Applications

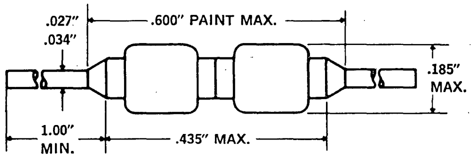
DESCRIPTION

Zener diodes with high surge capability qualified to MIL-S-19500/434.

ABSOLUTE MAXIMUM RATINGS (at 25°C except where otherwise noted)

	1N5610	1N5611	1N5612	1N5613
Zener Voltage	See Electrical Specifications			
Forward Surge Current	200A	200A	200A	200A
Zener Surge Current, at 25°C	32.0A	24.0A	19.0A	5.7A
Surge Current, at 150°C	5.5A	4.8A	3.2A	1.0A
Surge Power	See Graph			
Storage and Operating Temperature	—65°C to +175°C			

JAN, JANTX, JANTXV 1N5610-1N5613



Polarity: Cathode indicated by band.
Weight: 1.5 gram (approximate).
Mounting Position: Any. **Leads:** Tinned Copper.
Marking: Type number marked on unit.

Double C BODY

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Min. Zener Voltage § Vz @ ImA	Max. Zener Voltage† Vz @ Is		Max. Reverse Leakage Current I_R @ V_R		Max. Forward Voltage‡ @ 100 Amps	Typical Temperature Coefficient
	Volts	Volts	Amps	µA	Volts	Volts	%/°C
1N5610*	33.0	47.5	32.0	5.0	30.5	4.8	.093
1N5611*	43.7	63.5	24.0	5.0	40.3	4.8	.094
1N5612*	54.0	78.5	19.0	5.0	49.0	4.8	.096
1N5613*	191.0	265.0	5.7	5.0	175.0	4.8	.100

Notes: * Available as JAN, JANTX and JANTXV.
§ Duration of applied current ≤ 300ms, duty cycle ≤ 2%.
† Utilizing a pulse which decays exponentially to 50% of the peak value in 1ms. See graph entitled "Pulse Waveform".
‡ Peak Sinusoidal surge current of 8.3ms duration, non-repetitive.

APPLICATIONS

Voltage transients can be suppressed with series elements, shunt elements, or a combination of both. These elements may be passive or active. For low and medium power applications, a series resistor and zener clamp offer several attractive features:

1. Simplicity of design
2. High reliability
3. Fast response time

The 1N5610 series of surge suppressors will suppress the following transients defined by *MIL-S-704A* without the use of any series limiting resistance beyond that provided by the source:

1. All 600V transients (category #1 on chart below)
2. All 80V transients except those generated by the main voltage regulator (category #2 on chart below)
3. The overvoltage transients generated by the *main voltage regulator* (category #3 on chart below) will also be suppressed by the 1N5610 series if:
   a. A 20 ohm series limiting resistor is used, or
   b. No series resistance is used but the zener is protected within 500 µs by using, for example, an SCR crowbar

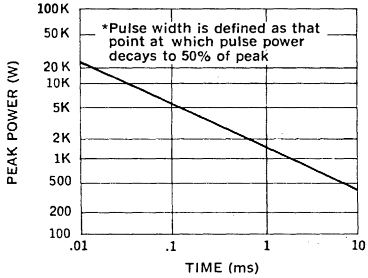
The above statements are based on the source impedances and dv/dt characteristics as given in ARINC* Specification #413. This report entitled "Guidance for Aircraft Electrical Power Utilization and Transient Protection" serves to further define *MIL-STD-704A* for large aircraft electrical systems.

Category	Source of Transient	Maximum Amplitude	Duration	Min. Source Impedance	dv/dt
1.	Inductive Switching	600 V	≤ 10 µs	50 ohms	
2.	BUS Switching	80 V	≤ 10 ms	15 ohms	
3.	Main Voltage Regulator	80 V	≥ 10 ms	0.2 ohms	50V/ms

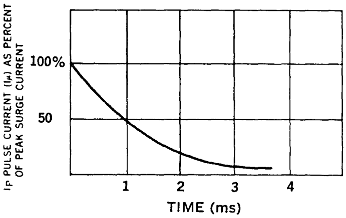
These Surge Suppressors are useful in a variety of other applications where semiconductor devices must function reliably in an environment subject to extremely high but short term surges.

* ARINC stands for Aeronautical Radio, Inc. (Annapolis, Maryland 21401)

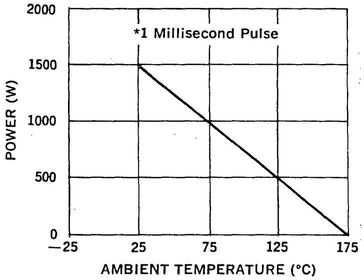
Peak Power Rating vs. Pulse Width*



Pulse Waveform



Peak Power Rating* vs. Ambient Temperature



TRANSIENT VOLTAGE SUPPRESSOR

Bidirectional, 4000 Watts Peak, Military

1N6102A Series

FEATURES

- Bidirectional
- 4000W for 8 × 20 microsec pulse
- 500W for 1 millisec pulse
- Clamping time in pico seconds
- Voidless hermetically sealed glass package
- Metallurgically bonded construction
- Designed to meet MIL-S-19500/516A

DESCRIPTION

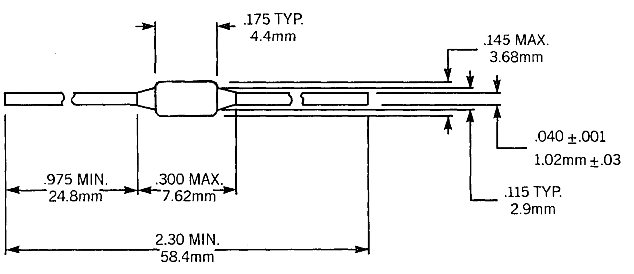
These bidirectional, high speed, voltage suppression devices are ideally suited for applications where fast response is essential. The use of passivated die metallurgically bonded on both sides asssures long term reliability. This series is especially useful in protecting microprocessor, MOS, CMOS, TTL, Schottky TTL, ECL, I^2L and linear integrated circuits from spurious transient disturbances.

ABSOLUTE MAXIMUM RATINGS AT 25°C

Stand-Off Voltage . . . . 5 to 48V (See Characteristics Table)
Peak Pulse Power
(8 × 20 microsec pulse) . . . . 4000W (See Figure 1)
Peak Pulse Power (1 millisec pulse) . . . . 500W (See Figure 2)
Peak Pulse Current . . . . See Characteristics Table
Breakdown Voltage . . . . See Characteristics Table
Power Continuous
(T_L = 75°C, L = 3/8") 3W
Storage and Operating Temperature . . . . −55°C to +175°C

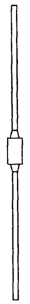
MECHANICAL SPECIFICATIONS

1N6102A Series



These devices also available in surface mount package. See Section 11

B BODY



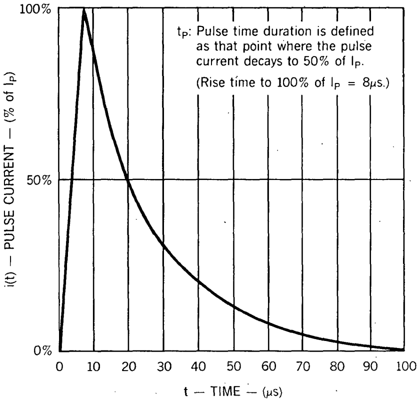
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL CHARACTERISTICS AT 25°C

Type	Stand-Off Voltage V_R	Breakdown Voltage BV			Test Current I_{BR}	Working Peak Voltage V_{RWM}	Maximum Leakage Current I_R @ V_R	Maximum Clamping Voltage Vcc Max. @ I_P*	Maximum Peak Current I_P	Maximum Temp. Coef. of BV
	(V)	min. (V)	nom. (V)	max. (V)	(mA)	(V)	(μA)	(V)	(A)	(%/°C)
1N6102A	5	6.46	6.8	7.14	175	5.2	100	10.5	47.6	.050
1N6107A	8	10.45	11.0	11.55	125	8.4	1	15.6	32.0	.070
1N6111A	12	15.20	16.0	16.80	75	12.2	1	22.3	22.4	.080
1N6113A	15	19.0	20.0	21.0	65	12.2	1	27.7	18.0	.085
1N6115A	17	22.8	24.0	25.2	50	18.2	1	33.3	15.0	.090
1N6118A	24	31.4	33.0	34.6	40	25.1	1	45.7	10.9	.095
1N6120A	28	37.1	39.0	40.9	30	29.7	1	53.6	9.3	.095
1N6122A	33	44.7	47.0	49.3	25	35.8	1	64.6	7.7	.095
1N6125A	48	64.6	68.0	71.4	20	51.7	1	97.1	5.1	.100

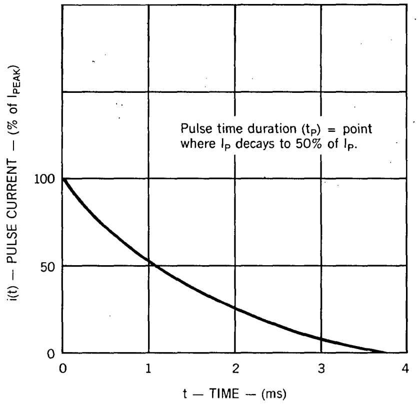
*See Figure 2.

Figure 1. Current Impulse Waveform



t_P: Pulse time duration is defined as that point where the pulse current decays to 50% of I_P.
(Rise time to 100% of I_P = 8μs.)

Figure 2. Pulse Waveform



Pulse time duration (t_P) = point where I_P decays to 50% of I_P.

Figure 3. Derating Curve

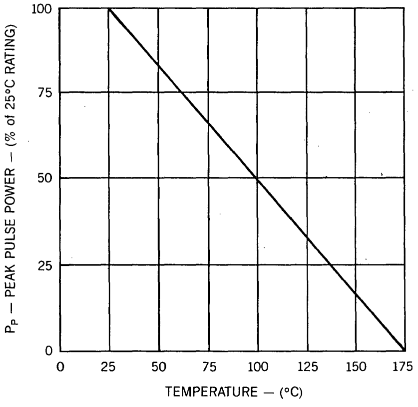
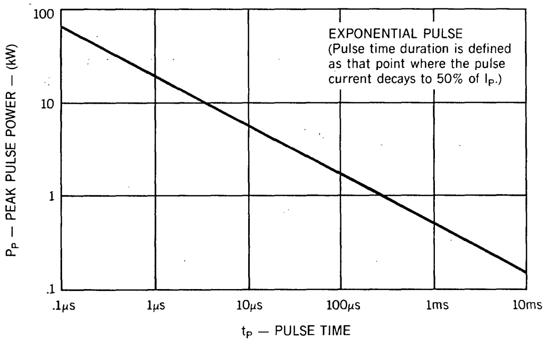
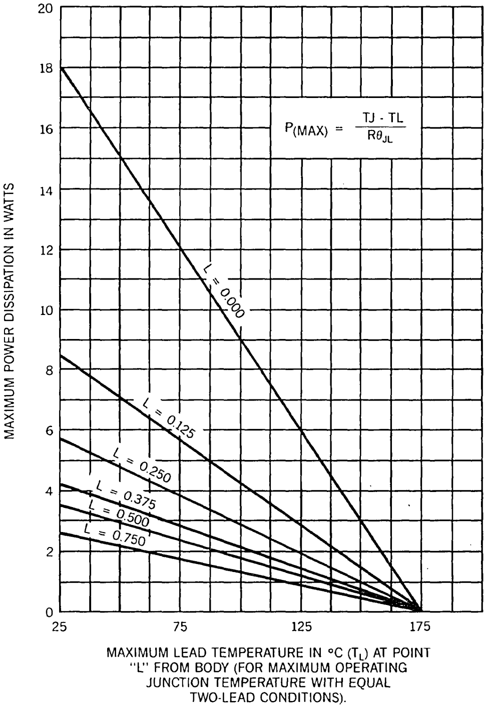


Figure 4. Peak Pulse Power vs. Pulse Duration



EXPONENTIAL PULSE
(Pulse time duration is defined as that point where the pulse current decays to 50% of I_P.)

**Figure 5.
Maximum Power vs. Lead Temperature**



L		$R\theta_{JL}$
INCHES	(MM)	°C/W
0.000		8.3
0.125	(3.17)	17.5
0.250	(6.35)	26.5
0.375	(9.53)	33.5
0.500	(12.70)	42.0
0.750	(19.05)	55.0

**Figure 6. Steady-State Derating Curve
for Free-Air Mounting**

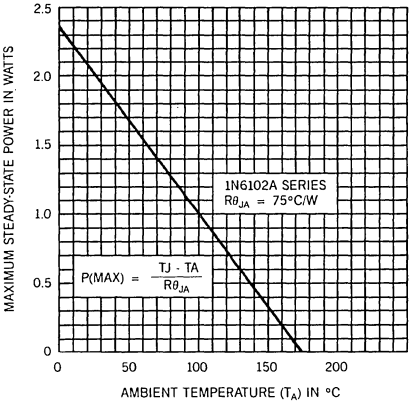
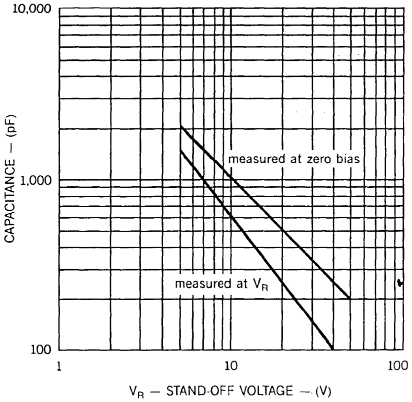


**Figure 7.
Typical Capacitance vs. Stand-Off Voltage**



TRANSIENT VOLTAGE SUPPRESSORS

500W, Military

1N6461-1N6468
JAN, JANTX & JANTXV

FEATURES

- 500W Power Capability for 1ms pulse
- Glass Encapsulated Device
- Clamping Time in Picoseconds

DESCRIPTION

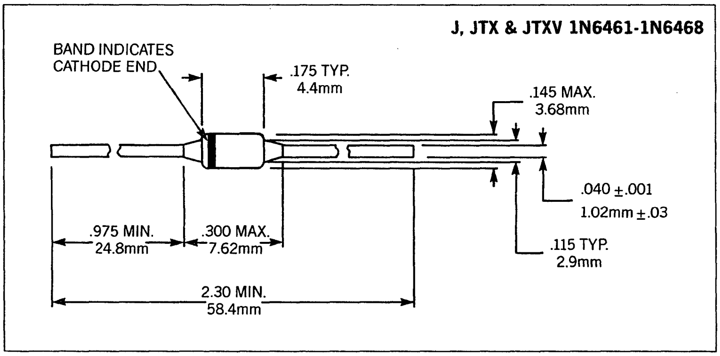
Transient voltage suppressor of noncavity design and qualified to MIL-S-19500/551. Metallurgically bonded for high reliabilty.

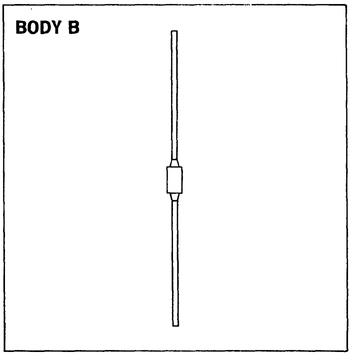
ABSOLUTE MAXIMUM RATINGS @ 25°C

Stand-off Voltage, V_R	5.0V to 51.6V
Peak Pulse Power (1ms)*, P_{PR}	500W
Forward Surge Current @ tp = 8.33ms, I_{FSM}	80A(pk)
Peak Pulse Current	see table
Breakdown Voltage	see table
Power, Continuous (Derate @ 16.7mW/°C above T_A = 25°C), P_R	2.5W
Storage Temperature	−55°C to +200°C
Operating Temperature	−55°C to +175°C

*See Figure 2 for Peak Pulse Power vs. Pulse Duration.

MECHANICAL SPECIFICATIONS

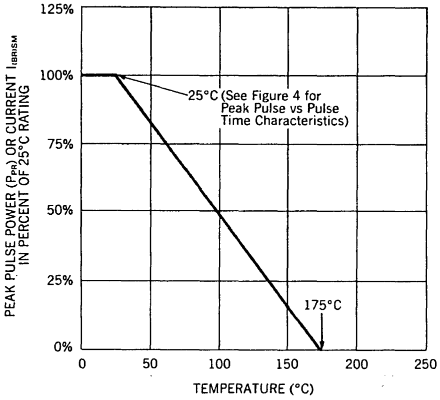




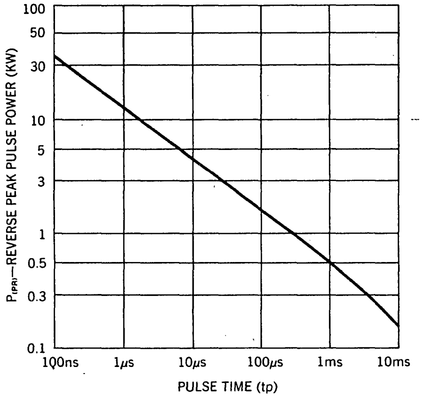
THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

ELECTRICAL SPECIFICATIONS @ 25°C

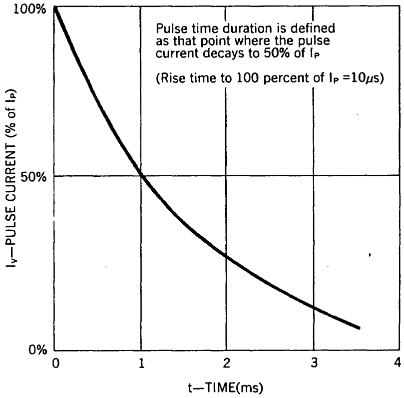
Part No.	Stand-off Voltage V_R	Min. Breakdown Voltage @ I_{BR}	Test Current I_{BR} @ tp = 300ms Duty Cycle ≤ 2%	Max. Leakage Current I_R @ V_R	Max. Peak Pulse Current I_{pp}		Max. Clamping Voltage ($V_{C\ MAX.}$) @ Ipp for tp = 1ms	Max. Clamping Voltage @ Ipp (tp = 1ms) Inverse Voltage $-V_{C\ Max.}$	Max. Temperature Coefficient ∝ $V_{(BR)}$
					tp = 1ms tr = 10μs (Fig. 3)	tp = 20μs tr = 8μs (Fig. 4)			
	V	V	mA	μA	A(pk)	A(pk)	V	V	%/°C
1N6461	5.0	5.6	25	3000	56	315	9.0	-3.5	0.040
1N6462	6.0	6.5	20	2500	46	258	11.0	-3.2	0.040
1N6463	12.0	13.6	5	500	22	125	22.6	-3.8	0.050
1N6464	15.0	16.4	5	500	19	107	26.5	-3.8	0.060
1N6465	24.0	27.0	2	50	12	69	41.4	-3.6	0.084
1N6466	30.5	33.0	1	3	11	63	47.5	-3.6	0.093
1N6467	40.3	43.7	1	2	8	45	63.5	-3.5	0.094
1N6468	51.6	54.0	1	2	6	35	78.5	-3.4	0.096



1. Derating Curve



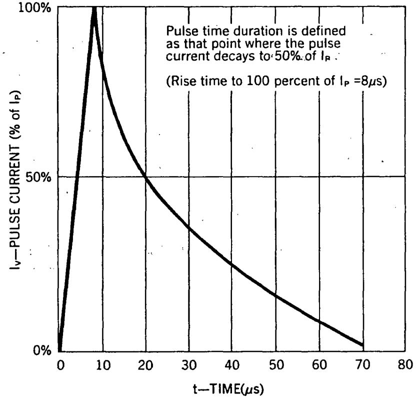
2. Peak Pulse Power vs. Pulse Duration



3. Current Impulse Waveform

Pulse time duration is defined as that point where the pulse current decays to 50% of I_P

(Rise time to 100 percent of I_P =10μs)



4. Current Impulse Waveform

Pulse time duration is defined as that point where the pulse current decays to 50% of I_P.

(Rise time to 100 percent of I_P =8μs)

TRANSIENT VOLTAGE SUPPRESSOR

Bidirectional, 5 to 48V, 1000 Watts Peak

EPS5 Series

FEATURES
- Bidirectional
- 1000W for 8 × 20 microsec pulse
- Clamping time in pico seconds
- Extremely low leakage current
- Voidless hermetically sealed glass package
- Metallurgically bonded construction

DESCRIPTION

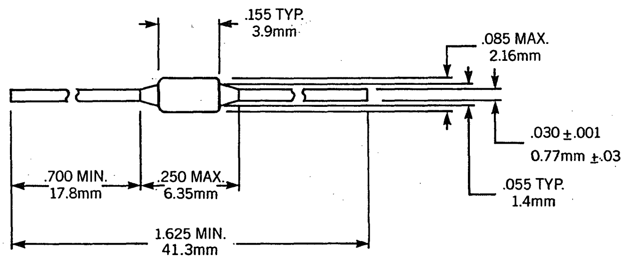
These bidirectional, high speed, voltage protection devices are ideally suited for applications where fast response is essential. The use of passivated die metallurgically bonded on both sides asssures long term reliability. This series is especially useful in protecting microprocessor, MOS, CMOS, TTL, Schottky TTL, ECL, I^2L and linear integrated circuits from spurious transient disturbances including NEMP (Nuclear Electromagnetic Pulse) and electrostatic discharge.

ABSOLUTE MAXIMUM RATINGS AT 25°C (PER LEG)

Stand-Off Voltage . . . . 5 to 48V (See Characteristics Table)
Peak Pulse Power
(8 × 20 microsec pulse) . . . . 1000W (See Figure 1)
Peak Pulse Power (1 millisec pulse) . . . . 150W (See Figure 2)
Peak Pulse Current . . . . See Characteristics Table
Breakdown Voltage . . . . See Characteristics Table
Power Continuous
(T_L = 75°C, L = ⅜″) 2.5W
Storage and Operating Temperature . . . . −65°C to +175°C

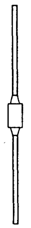
MECHANICAL SPECIFICATIONS

EPS5 Series



These devices also available in surface mount package. See Section 11

A BODY



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL CHARACTERISTICS AT 25°C

Type	Stand-Off Voltage V_R	Minimum Breakdown Voltage BV(min) @ 1mA	Maximum Leakage Current I_R @ V_R	Maximum Peak Current* I_P	Maximum Clamping Voltage* V_C @ 10A	Maximum Temp. Coef. of BV
	(V)	(V)	(μA)	(A)	(V)	(%/°C)
EPS5	5	6.0	50	89.4	9.5	.030
EPS8	8	9.0	2	62.1	13.7	.040
EPS12	12	13.8	1	40.3	21.6	.050
EPS15	15	16.7	1	33.9	26.0	.055
EPS17	17	19.0	1	30.8	29.2	.060
EPS24	24	28.4	1	22.0	43.2	.070
EPS28	28	31.0	1	19.2	47.8	.075
EPS33	33	36.8	1	16.4	56.7	.080
EPS48	48	54.0	1	11.2	84.3	.090

*See Figure 1.

Figure 1. Current Impulse Waveform

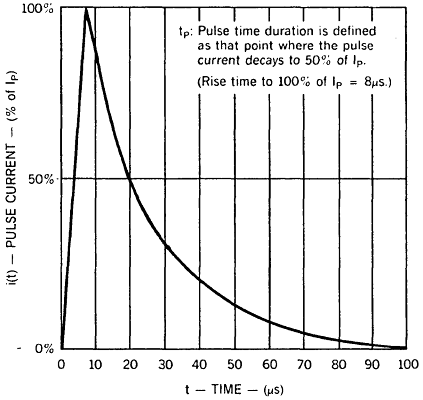


Figure 2. Peak Pulse Power vs. Pulse Duration

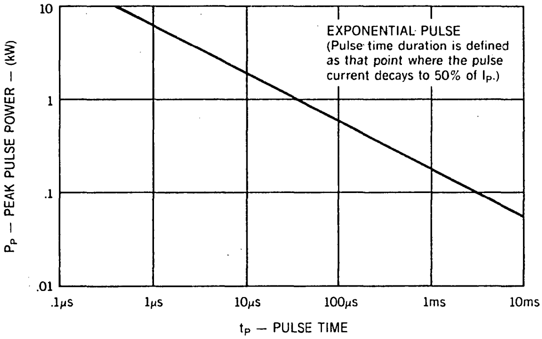


Figure 3. Derating Curve

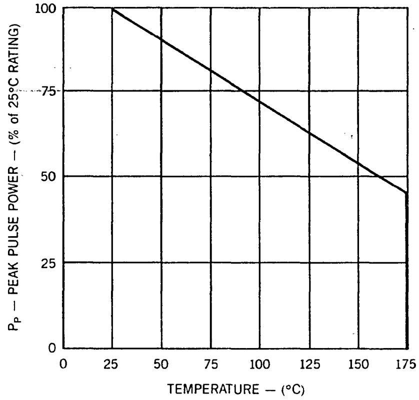
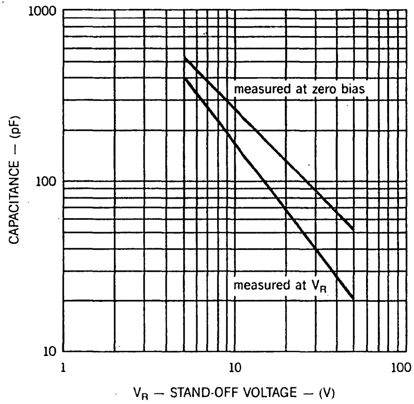


Figure 4. Typical Capacitance vs. Stand-Off Voltage



TRANSIENT VOLTAGE SUPPRESSORS

TVS305-TVS430
TVS505-TVS528

FEATURES
- Up to 500W for 1mS Pulse Power Capability
- Clamping Time in Picoseconds
- Direct Applicability for all popular Microprocessors and IC families
- Metallurgically bonded assembly system to assure long term reliability
- Miniature glass encased hermetically sealed package

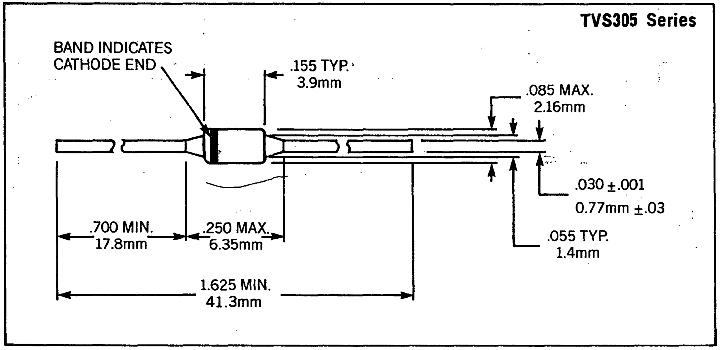
DESCRIPTION
Unitrode's TVS series of transient voltage suppressors feature oxide passivated zener type chips with full-faced metallurgical bonds on both sides to achieve high surge capability and negligible electrical degradation under repeated surge conditions. The series is especially useful in protecting microprocessor, MOS, CMOS, TTL, Schottky TTL, ECL, I²L and linear integrated circuits from spurious transient disturbances.

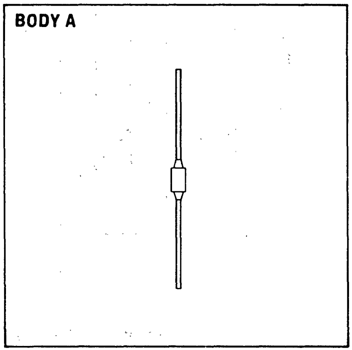
ABSOLUTE MAXIMUM RATINGS @ 25°C

	TVS305-TVS430	TVS505-TVS528
Stand-off Voltage, V_R	5 to 300V	5.0V to 28.0V
Peak Pulse Power (1mS)*	150W	500W
Forward Surge Current (8.3mS half sinewave)	15A	50A
Peak Pulse Current	See Table	See Table
Breakdown Voltage	See Table	See Table
Power, Continuous	3W	5W
Storage and Operating Temperature	−65 to +175°C	−65 to +175°C

*See Figures 3 and 4 for Peak Pulse Power vs Pulse Duration.

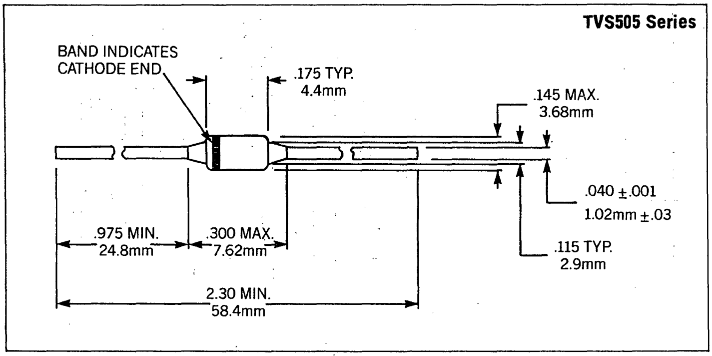
MECHANICAL SPECIFICATIONS

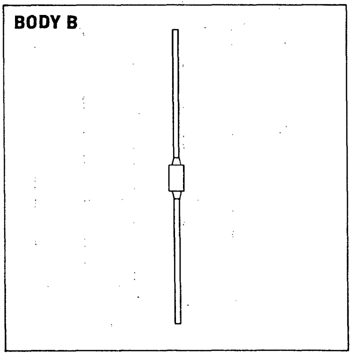




THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

MECHANICAL SPECIFICATIONS





THESE DEVICES ALSO AVAILABLE IN SURFACE MOUNT PACKAGE. SEE SECTION 11.

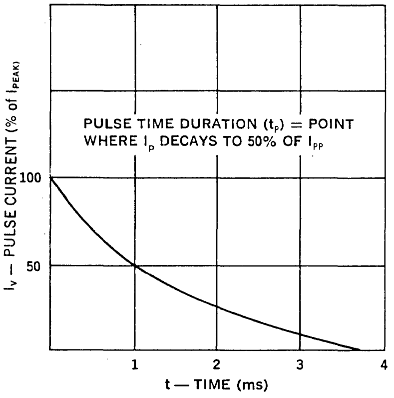
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS @ 25°C

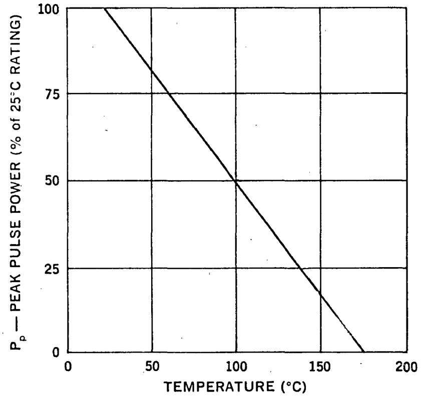
TVS Part No.	Stand -Off Voltage V_R	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA	Max. Leakage Current I_R @ V_R	Max. Peak Pulse Current* I_{PP}	Max. Clamping Voltage* V_C @ I_{PP}	Max. Clamping Voltage* V_C @ 1A	Max. Clamping Voltage* V_C @ 5A	Max. Clamping Voltage* V_C @ 10A
	V	V	μA	A	V	V	V	
TVS305	5.0	6.0	50	17	8.7	—	—	—
TVS310	10.0	11.1	2	8.9	16.8	—	—	—
TVS312	12	13.8	1	7.1	21.0	—	—	—
TVS315	15	16.7	1	5.9	25	—	—	—
TVS318	18	20.4	1	4.9	31	—	—	—
TVS324	24	28.4	1	3.6	42	—	—	—
TVS328	28	30.7	1	3.2	46	—	—	—
TVS348	48	54	1	1.7	82	—	—	—
TVS360	60	67	1	1.4	105	—	—	—
TVS410	100	111	1	.91	160	—	—	—
TVS420	200	234	1	.42	360	—	—	—
TVS430	300	342	1	.28	520	—	—	—
TVS505	5.0	6.0	300	53.7	9.3	7.4	—	7.9
TVS510	10.0	11.1	5	30.3	16.5	13.2	—	14.4
TVS512	12.0	13.8	5	23.8	21.0	16.5	—	18.5
TVS515	15.0	16.7	5	19.8	25.2	19.7	—	22.2
TVS518	18.0	20.4	5	16.3	30.5	23.8	26.0	—
TVS524	24.0	28.4	5	11.9	42.0	32.4	37.0	—
TVS528	28.0	30.7	5	10.7	46.5	35.9	41.0	—

*For 1mS pulse: see Figure 1.

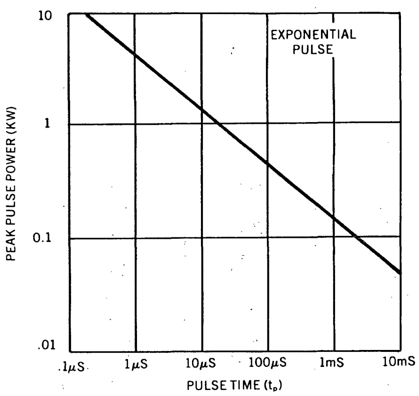
1. **Pulse Waveform**



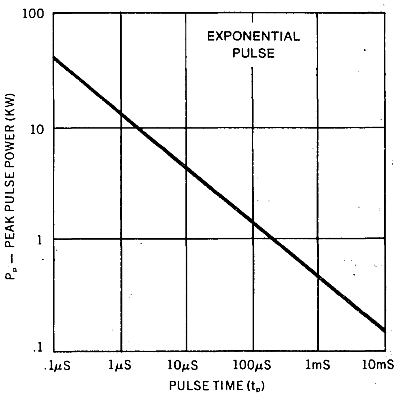
2. **Derating Curve**



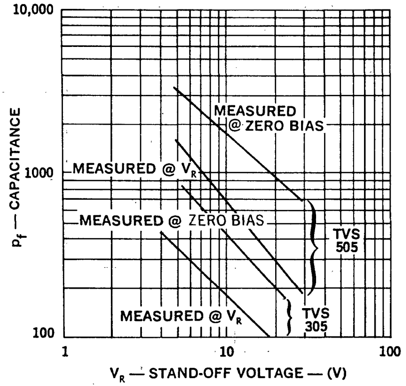
3. Peak Pulse Power vs. Pulse Duration



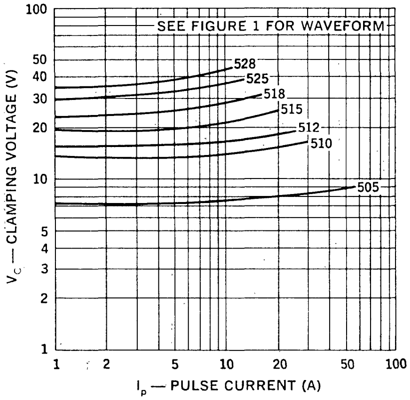
4. Peak Pulse Power vs. Pulse Duration



5. Capacitance vs. Stand-Off Voltage



6. Clamping Voltage vs. Pulse Current



CHOOSING AND SPECIFYING THE PROPER TVS

The following terms are generally used in specifying Transient Voltage Suppressors (TVS):

1. Stand-off Voltage (V_R) is the highest reverse voltage at which the TVS will be non-conducting.
2. Minimum Breakdown Voltage (BV min) is the reverse voltage at which the TVS conducts 1 milli-amp. This is the point where the TVS begins to limit the transient.
3. Maximum Clamping Voltage (V_C max) is the maximum voltage the TVS will allow during a transient "spike."

Figure 7 graphically shows all three terms.

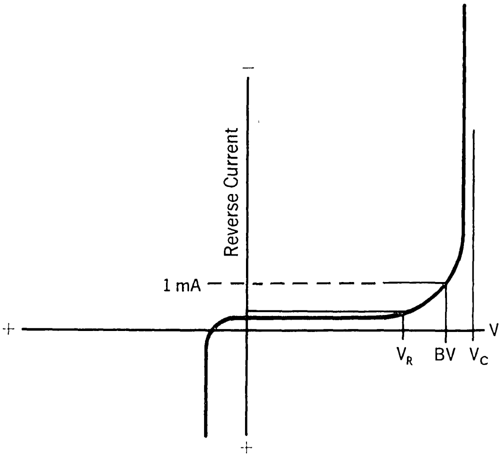


Figure 7

The three most important factors in choosing the appropriate TVS for an application in their order of importance are:

1. Pulse power (P_P) — Choose the TVS series that will handle the Transient Pulse Power. Transient Pulse Power is equal to the clamping voltage (V_C) times the peak pulse current (i_{PP}). The pulse duration vs. pulse power graph on the TVS data sheet can then be used to determine the maximum allowable pulse duration. (Figure 3 or 4).
2. Standoff voltage (V_R) — From the TVS series selected, choose the device with the stand-off voltage equal to or greater than the normal circuit operating voltage.
3. Maximum Clamping Voltage (V_{CMAX}) — Determine the clamping voltage of the device chosen for the transient given and be sure it is below the voltage that might damage any components.

For further information see Unitrode Application Note U-79, "Guidelines for Using Transient Voltage Suppressors."

AC POWER ZENERS
1, 3 and 5 Watt Types

UDZ807 SERIES
UDZ5807 SERIES
UDZ8807 SERIES
UDZ807HR2 SERIES
UDZ5807HR2 SERIES

FEATURES
- Zener Characteristics in Both Directions
- 7.5 to 60V
- High Surge Ratings
- Small Physical Size

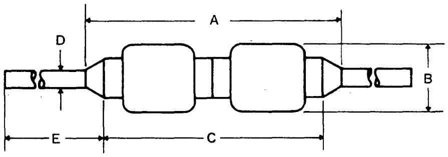
DESCRIPTION
These devices consist of two fused-in-glass zeners brazed cathode to cathode to provide zener action in both directions.

ABSOLUTE MAXIMUM RATINGS

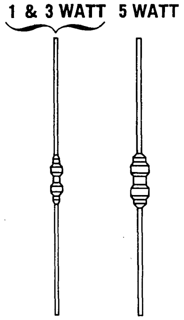
Zener Voltage	7.5 to 60V
Continuous Current	See Tables
Surge Current (8.3ms)	See Tables
Surge Power	See Graph
Power	See Data Sheets for Related Series (UZ8807, UZ807 and UZ5807)
Storage and Operating Temperature	—65°C to +175°C

MECHANICAL SPECIFICATIONS

UDZ807 SERIES UDZ5807 SERIES UDZ8807 SERIES
UDZ807HR2 SERIES UDZ5807HR2 SERIES



MARKING: "D," followed by last 3 to 4 digits and part number.
Example: 7.5 volt ±10%, 1 watt type would be marked: "D8807".



Dimensions

1 Watt UDZ8807 Series

	ins.	mm
A	.450 MAX.	11.43 MAX.
B	.085 MAX.	2.16 MAX.
C	.275 TYP.	6.99 TYP.
D	.028 ± .001	.71 ± .03
E	.700 MIN.	17.78 MIN.

3 Watt UDZ807/UDZ807HR2 Series

	ins.	mm
A	.450 MAX.	11.43 MAX.
B	.085 MAX.	2.16 MAX.
C	.275 TYP.	6.99 TYP.
D	.028 ± .001	.71 ± .03
E	.700 MIN.	17.78 MIN.

5 Watt UDZ5807/UDZ5807HR2

	ins.	mm
A	.500 MAX.	12.70 MAX.
B	.145 MAX.	3.68 MAX.
C	.325 TYP.	8.26 TYP.
D	.040 ± .001	1.02 ± .03
E	.975 MIN.	24.77 MIN.

	Electrical Specifications at 25°C						**Maximum Ratings****	
Type	Nominal Zener Voltage† V_Z @ I_{ZT}	Test Current I_{ZT}	Max. Zener Imped § Z_Z @ I_{ZT}	Maximum Leakage Current	@ Reverse Voltage · ±10%	±5%	Maximum Cont. Current I_{ZM}	Maximum Surge Current‡ I_S
±10% Tolerance*	Volts	mA	Ohms	μA	Volts	Volts	mA	Amps
1 WATT ZENERS — Specifications apply for both directions.								
UDZ8807	7.5	34	6	50	4.9	5.2	125	5
UDZ8808	8.2	31	7	30	5.4	5.7	115	4.5
UDZ8809	9.1	28	8	10	5.9	6.2	105	3.9
UDZ8810	10	25	8.5	3	6.6	6.9	95	3.37
UDZ8812	12	23	9	1	8.6	9.1	85	2.25
UDZ8815	15	17	14	0.5	10.8	11.4	63	1.65
UDZ8818	18	14	20	0.5	12.9	13.7	52	1.12
UDZ8820	20	12.5	23	0.5	14.4	15.2	47	1.12
UDZ8824	24	10.5	25	0.5	17.3	18.2	40	0.825
UDZ8827	27	9.5	35	0.5	19.4	20.6	35	0.825
UDZ8830	30	8.5	40	0.5	21.6	22.8	31	0.825
UDZ8833	33	7.5	45	0.5	23.7	25.1	28	0.675
UDZ8836	36	7.0	50	0.5	25.9	27.4	26	0.562
UDZ8840	40	6.5	62	0.5	28.8	30.4	24	0.562
UDZ8845	45	6	75	0.5	32.4	34.2	22	0.450
UDZ8860	60	4	125	0.5	43.2	45.6	15	0.337
3 WATT ZENERS — Specifications apply for both directions.								
UDZ807HR2	7.5	75	3	500	4.9	5.2	400	10
UDZ808HR2	8.2	75	4	300	5.4	5.7	360	8
UDZ809HR2	9.1	75	4	200	5.9	6.2	330	7
UDZ810HR2	10	75	5	100	6.6	6.9	300	5
UDZ812HR2	12	65	5	10	8.6	9.1	250	4
UDZ815HR2	15	50	6	10	10.8	11.4	200	3
UDZ818HR2	18	40	8	5	12.9	13.7	170	2
UDZ820HR2	20	40	9	5	14.4	15.2	150	2
UDZ824HR2	24	30	10	5	17.3	18.2	125	1.5
UDZ827HR2	27	25	12	1	19.4	20.6	110	1.5
UDZ830HR2	30	25	15	1	21.6	22.8	100	1.5
UDZ833HR2	33	20	21	1	23.7	25.1	90	1.2
UDZ836HR2	36	20	21	1	25.9	27.4	85	1
UDZ840HR2	40	20	27	1	28.8	30.4	75	1
UDZ845HR2	45	15	37	1	32.4	34.7	65	0.8
UDZ860HR2	60	10	70	1	43.2	45.6	50	0.6

*For ±5% voltage tolerance change the 3rd number from the right from 8 to 7 i.e. UDZ8807 to UDZ8707, etc.

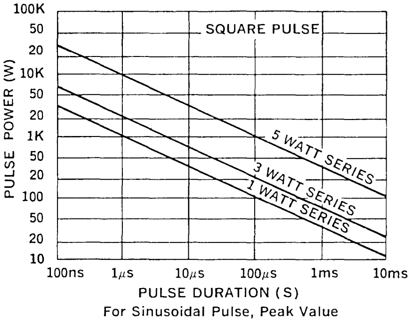
†All zener voltages are measured with an automated test set using a 35ms test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

**D.C. Ratings are based on the lead temperature conditions shown in the data sheets covering the UDZ8807, UDZ807, and UDZ5807 series devices. Other conditions will affect the power ratings of all the families except the 1 watt zener family. However, the surge values given apply for any mounting conditions including printed circuit board mounting.

‡Figures shown are for peak sinusoidal surge current of 8.3ms duration using 60 cycle AC. The 8.3ms square pulse rating is 71% of the value shown.

Typical Reverse Surge Power vs. Surge Duration



For Sinusoidal Pulse, Peak Value is 1.4 Times Value Shown

Type	Electrical Specifications at 25°C						Maximum Ratings**	
	Nominal Zener Voltage† V_Z @ I_{ZT}	Test Current I_{ZT}	Max. Zener Imped § Z_Z @ I_{ZT}	Maximum Leakage Current	@ Reverse Voltage ±10%	±5%	Maximum Cont. Current I_{ZM}	Maximum Surge Current‡ I_S
±10% Tolerance*	Volts	mA	Ohms	μA	Volts	Volts	mA	Amps
5 WATT ZENERS — Specifications apply for both directions.								
UDZ5807HR2	7.5	175	1.8	500	4.9	5.2	620	40
UDZ5808HR2	8.2	150	1.8	400	5.4	5.7	570	32
UDZ5809HR2	9.1	150	2.5	200	5.9	6.2	510	24
UDZ5810HR2	10	125	2.5	100	6.6	6.9	470	22
UDZ5812HR2	12	100	2.5	50	8.6	9.1	385	18
UDZ5815HR2	15	75	3.5	15	10.8	11.4	300	12
UDZ5818HR2	18	65	4	10	12.9	13.7	255	9
UDZ5820HR2	20	65	4.5	10	14.4	15.2	220	8
UDZ5824HR2	24	50	5	10	17.3	18.2	180	6.5
UDZ5827HR2	27	50	6	10	19.4	20.6	155	6
UDZ5830HR2	30	40	8	10	21.6	22.8	140	5.5
UDZ5833HR2	33	40	10	5	23.7	25.1	130	5
UDZ5836HR2	36	30	11	5	25.9	27.4	120	4.5
UDZ5840HR2	40	30	14	5	28.8	30.4	105	4
UDZ5845HR2	45	30	20	5	32.4	34.2	95	3.5
UDZ5860HR2	60	20	40	5	43.2	45.6	75	2.5

*For ±5% voltage tolerance change the 3rd number from the right from 8 to 7 i.e. UDZ8807 to UDZ8707, etc.

†All zener voltages are measured with an automated test set using a 35ms test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

**D.C. Ratings are based on the lead temperature conditions shown in the data sheets covering the UDZ8807, UDZ807, and UDZ5807 series devices. Other conditions will affect the power ratings of all the families except the 1 watt zener family. However, the surge values given apply for any mounting conditions including printed circuit board mounting.

‡Figures shown are for peak sinusoidal surge current of 8.3ms duration using 60 cycle AC. The 8.3ms square pulse rating is 71% of the value shown.

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UDZ5807HR2 through UDZ5890HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature Storage	1032	T_A = 175°C, 24 Hours
2. Temperature Cycling	1051	C, 20 Cycles, −65 to +175°C. No dwell required @ 25°C, t ≥ 10 min. at extremes.
3. Hermetic Seal @ Gross Leak	1071	E, ZYGLO
4. Interim Electrical Parameters	GO/NO GO	V_Z + I_R @ 25°C
5. Power Burn-in	1038	B, 96 Hours, T_A = 25°C, I_Z adjusted so that 150°C ≤ T_j ≤ 175°C. This test performed in each direction
6. Final Electrical Parameters	GO/NO GO	V_Z + I_R @ 25°C PDA = 20% (Final Electricals)

POWER ZENERS
3 Watt

UZ706 SERIES
UZ806 SERIES
UZ706HR2 SERIES
UZ806HR2 SERIES

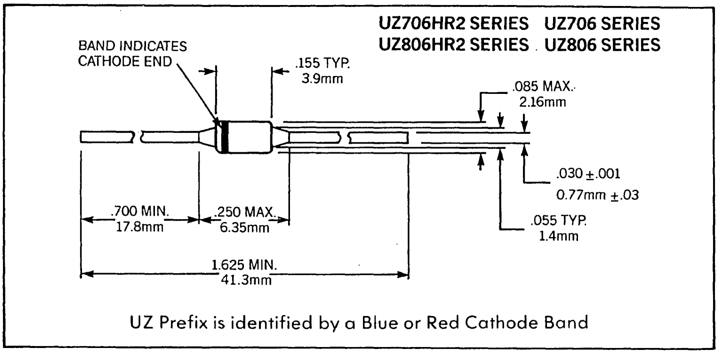
FEATURES
- 10 Times Greater Surge Rating than Conventional 1 Watt Types
- Small Physical Size

DESCRIPTION
Fused-in-glass metallurgically bonded 3 watt zener diodes.

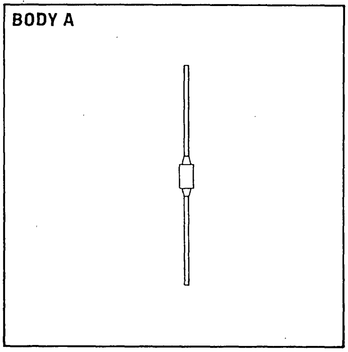
ABSOLUTE MAXIMUM RATINGS

Zener Voltage, V_Z	6.8 to 400V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	—65°C to +175°C

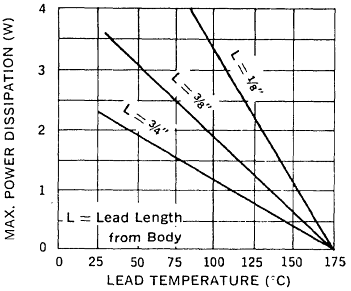
MECHANICAL SPECIFICATIONS



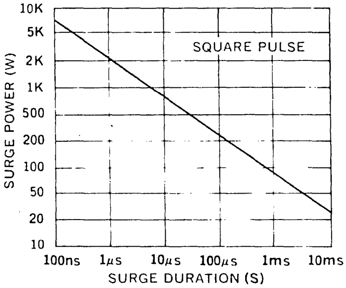
UZ Prefix is identified by a Blue or Red Cathode Band



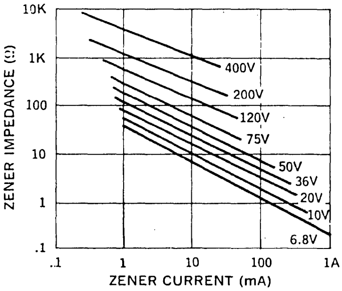
Power Dissipation vs. Lead Temperature Derating Curve



Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



OPTIONAL HIGH RELIABILITY (HR2) SCREENING

The following tests are performed on 100% of the devices specified UZ706 through UZ140HR2.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 175°C
2. Temperature Cycling	1051	C, 20 Cycles, −65 to +175°C. No dwell required @ 25°C ⩾ 10 min. at extremes
3. Hermetic Seal @ Gross Leak	1071	E, ZYGLO
4. Interim Electrical Parameters	GO/NO GO	V_Z + I_R @ 25°C
5. Power Burn-in	1038	B, 96 Hours, T_A = 25°C, I_Z adjusted so that 150°C ⩽ T_j ⩽ 175°C
6. Final Electrical Parameters	GO/NO GO	V_Z + I_R @ 25°C PDA = 10% (Final Electricals)

Type*		Electrical Specifications at 25°C							Maximum Ratings	
		Nominal Zener Voltage †	Test Current	Max. Zener Impedance §	Maximum Reverse Leakage Current			Typ. Temp. Coefficient	Maximum Continuous Current ★	Maximum Surge Current‡
		V_Z @ I_{ZT}	I_{ZT}	Z_Z @ I_{ZT}	I_R @ V_R	± 5% V_R	± 10% V_R	T_C @ I_{ZT}	I_{ZM}	I_S
±5% Tolerance	Jedec** Registration	Volts	mA	Ohms	µA	Volts	Volts	%/°C	mA	Amps
UZ706/706HR2	1N5063	6.8	75	2	500	5.2	4.9	.04	440	10.0
UZ707/707HR2	1N5064	7.5	75	2	300	5.7	5.4	.04	400	8.0
UZ708/708HR2	1N5065	8.2	75	3	200	6.2	5.9	.05	360	7.0
UZ709/709HR2	1N5066	9.1	75	3	100	6.9	6.6	.05	330	6.0
UZ710/710HR2	1N5067	10.0	75	4	40	7.6	7.2	.06	300	5.0
UZ712/712HR2	1N4883	12	65	5	10	9.1	8.6	.07	250	4.0
UZ713/713HR2	1N5069	13	50	6	10	9.9	9.3	.07	230	4.0
UZ714/714HR2	1N5070	14	50	6	10	10.6	10.1	.07	210	4.0
UZ715/715HR2	1N5071	15	50	6	10	11.4	10.8	.07	200	3.0
UZ716/716HR2	1N5072	16	50	7	5	12.2	11.5	.07	185	3.0
UZ718/718HR2	1N5073	18	40	8	5	13.7	12.9	.08	170	2.0
UZ720/720HR2	1N4884	20	40	9	5	15.2	14.4	.08	150	2.0
UZ722/722HR2	1N5074	22	30	10	5	16.7	15.8	.08	135	2.0
UZ724/724HR2	1N5075	24	30	10	5	18.2	17.3	.08	125	1.5
UZ727/727HR2	1N5076	27	25	12	1	20.6	19.4	.09	110	1.5
UZ730/730HR2	1N5077	30	25	15	1	22.8	21.6	.090	100	1.5
UZ733/733HR2	1N5078	33	20	21	1	25.1	23.7	.090	90	1.2
UZ736/736HR2	1N5079	36	20	21	1	27.4	25.9	.090	85	1.0
UZ740/740HR2	1N5081	40	20	27	1	30.4	28.8	.095	75	1.0
UZ745/745HR2	1N5083	45	15	37	1	34.2	32.4	.095	65	0.8
UZ750/750HR2	1N5085	50	15	50	1	38.0	36.0	.095	60	0.8
UZ756/756HR2	1N5087	56	10	70	1	42.6	40.3	.095	55	0.7
UZ760/760HR2	1N5088	60	10	70	1	45.7	43.2	.095	50	0.6
UZ770/770HR2	1N5091	70	10	90	1	53.3	50.5	.095	45	0.6
UZ775/775HR2	1N5092	75	10	100	1	56.0	54.0	.095	40	0.5
UZ780/780HR2	1N5093	80	10	115	1	60.8	57.7	.095	35	0.4
UZ790/790HR2	1N4096	90	8.0	150	1	68.5	64.8	.095	30	0.4
UZ110/110HR2	1N4097	100	5.0	175	1	76.0	72.0	.100	30	0.4
UZ111/111HR2	1N5096	110	5.0	250	1	83.6	79.2	.100	25	0.3
UZ112/112HR2	1N5097	120	5.0	325	1	91.2	86.4	.100	25	0.2
UZ113/113HR2	1N5098	130	5.0	375	1	98.8	93.6	.100	20	0.20
UZ114/114HR2	1N5099	140	5.0	550	1	106	101	.100	20	0.20
UZ115/115HR2	1N4098	150	5.0	650	1	114	108	.100	20	0.20
UZ116/116HR2	1N5100	160	4.0	700	1	122	115	.100	20	0.15
UZ117/117HR2	1N5101	170	4.0	750	1	129	122	.100	18	0.15
UZ118/118HR2	1N5102	180	4.0	850	1	137	129	.100	18	0.10
UZ119/119HR2	1N5103	190	4.0	900	1	144	137	.100	15	0.10
UZ120/120HR2	1N5104	200	4.0	950	1	152	144	.100	15	0.10
UZ122/122HR2	1N5105	220	3.0	1100	1	167	158	.100	15	0.09
UZ124/124HR2	1N5106	240	3.0	1300	1	182	173	.105	12	0.09
UZ126/126HR2	1N5107	260	3.0	1500	1	198	187	.105	12	0.08
UZ128/128HR2	1N5109	280	3.0	1700	1	213	202	.105	10	0.08
UZ130/130HR2	1N5110	300	3.0	1900	1	228	216	.105	10	0.07
UZ132/132HR2	1N5111	320	2.0	2100	1	243	230	.105	9	0.07
UZ134/134HR2	1N5113	340	2.0	2400	1	258	245	.110	9	0.06
UZ136/136HR2	1N5114	360	2.0	2700	1	274	259	.110	8	0.06
UZ138/138HR2	1N5115	380	2.0	3000	1	289	274	.110	8	0.06
UZ140/140HR2	1N5117	400	2.0	3500	1	304	288	.110	7	0.06

* Specify 20% voltage tolerance by changing first numeral of type number from 7 to 9. (UZ709 becomes UZ909) or from 1 to 3 (UZ111 becomes UZ311).
Specify 10% voltage tolerance by changing first numeral of type number from 7 to 8. (UZ709 becomes UZ809) or from 1 to 2 (UZ111 becomes UZ211).

** Jedec registration applies to ±5% tolerance zeners only.

† All zener voltages are measured with an automated test set using a 35 ms test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§ Zener impedance is derived from the 60-cycle AC voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

★ Maximum current based on 3 watt rating. See lead temperature derating curves for proper mounting methods.

‡ Figures shown are for a peak sinusoidal surge current of 8.3ms duration using 60 cycle AC. The 8.3ms square pulse rating is 71% of the value shown.

POWER ZENERS
5 Watt, Industrial

UZ4706 SERIES
UZ4806 SERIES

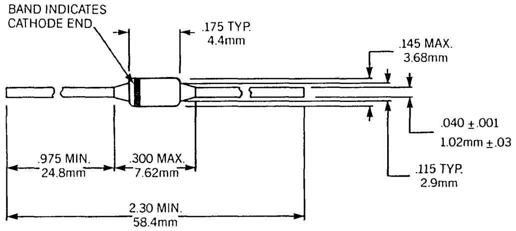
FEATURES
- 2 Times Greater Surge Rating than Plastic Types
- Small Physical Size
- Impervious to Moisture

DESCRIPTION
Fused-in-glass 5 watt zeners with the same electrical specs as the 1N5342-1N5388 series.

ABSOLUTE MAXIMUM RATINGS
Zener Voltage, V_Z .... 6.8 to 200V
Continuous Current .... See Table
Surge Current (8.3ms) .... See Table
Surge Power .... See Graph
Power .... See Lead Temperature Derating Curve
Storage and Operating Temperature .... −65°C to +175°C

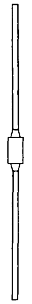
MECHANICAL SPECIFICATIONS

UZ4706 SERIES UZ4806 SERIES

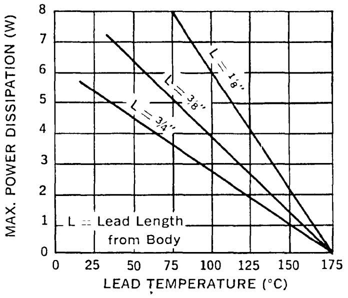


UZ Prefix is identified by a Blue or Red Cathode Band

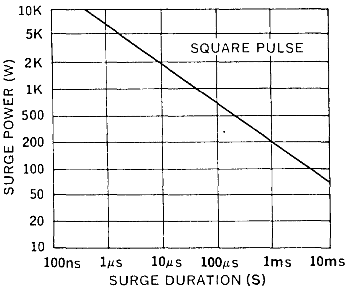
BODY B



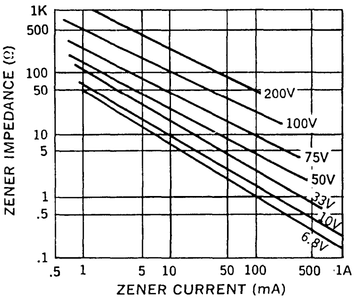
Power Dissipation vs. Lead Temperature Derating Curve



Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



SEMICONDUCTOR PRODUCTS
UNITRODE

Type		Electrical Specifications at 25°C							Maximum Ratings	
		Nominal Zener Voltage † V_Z @ I_{ZT}	Test Current I_{ZT}	Max. Zener Impedance §		Reverse Voltage			Maximum Cont. Current I_{ZM}	Maximum Surge Current ‡ I_S
				Z_Z @ I_{ZT}	Z_{ZK} @ I_{ZK} = ImA	Maximum Leakage Current	@ Reverse Voltage ±10%	±5%		
±5% Tolerance	±10% Tolerance	Volts	mA	Ohms	Ohms	µA	Volts	Volts	mA	Amps
UZ4706	UZ4806	6.8	175	1	1000	500	4.9	5.2	675	32
UZ4707	UZ4807	7.5	175	1.5	800	400	5.4	5.7	620	26.5
UZ4708	UZ4808	8.2	150	1.5	600	200	5.9	6.2	570	19.2
UZ4709	UZ4809	9.1	150	2	400	100	6.6	6.9	510	17.6
UZ4710	UZ4810	10	125	2	125	75	7.2	7.6	470	16
UZ4712	UZ4812	12	100	2.5	140	50	8.6	9.1	385	14.4
UZ4713	UZ4813	13	100	3	145	25	9.3	9.9	350	12.8
UZ4715	UZ4815	15	75	3.5	150	15	10.8	11.4	300	9.6
UZ4716	UZ4816	16	75	3.5	155	10	11.5	12.2	275	8
UZ4718	UZ4818	18	65	4	160	10	12.9	13.7	255	7.2
UZ4720	UZ4820	20	65	4.5	165	10	14.4	15.2	220	6.4
UZ4722	UZ4822	22	50	5	170	10	15.8	16.7	195	5.6
UZ4724	UZ4824	24	50	5	175	10	17.3	18.2	180	5.2
UZ4727	UZ4827	27	50	6	180	10	19.4	20.6	155	4.8
UZ4730	UZ4830	30	40	8	190	10	21.6	22.8	140	4.4
UZ4733	UZ4833	33	40	10	200	5	23.7	25.1	130	4.0
UZ4736	UZ4836	36	30	11	220	5	25.9	27.4	120	3.6
UZ4739	UZ4839	39	30	14	230	5	28.1	29.7	105	3.2
UZ4743	UZ4843	43	30	20	240	5	31	32.7	100	2.8
UZ4747	UZ4847	47	25	25	250	5	33.8	35.8	96	2.6
UZ4751	UZ4851	51	25	27	270	5	36.7	38.8	85	2.4
UZ4756	UZ4856	56	20	35	320	5	40.3	42.6	81	2.2
UZ4762	UZ4862	62	20	42	400	5	44.6	47.1	73	2.0
UZ4768	UZ4868	68	20	50	500	5	49.0	51.7	61	1.8
UZ4775	UZ4875	75	20	55	620	5	54.0	56	60	1.6
UZ4782	UZ4882	82	15	80	720	5	59.0	62.2	55	1.4
UZ4791	UZ4891	91	15	90	760	5	65.5	69.2	50	1.3
UZ4110	UZ4210	100	12	100	800	5	72.0	76.0	45	1.1
UZ4111	UZ4211	110	12	125	1000	5	79.2	83.6	40	1.0
UZ4112	UZ4212	120	10	170	1150	5	86.4	91.2	38	.8
UZ4113	UZ4213	130	10	190	1250	5	93.6	98.8	35	.64
UZ4115	UZ4215	150	8	330	1500	5	108	114.0	31	.60
UZ4116	UZ4216	160	8	350	1650	5	115	121.6	30	.56
UZ4118	UZ4218	180	5	450	1750	5	129	136.8	25	.48
UZ4120	UZ4220	200	5	500	1850	5	144	152.0	22	.40

Maximum V_F @ 1.0 Amp = 1.2 Volts for all types

†All zener voltages are measured with an automated test set using a 35 ms test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

‡Figures shown are for peak sinusoidal surge current of 8.3 ms duration using 60 cycle AC. The 8.3ms square pulse rating is 71% of the value shown.

POWER ZENERS
5 Watt

UZ5706 SERIES
UZ5806 SERIES

FEATURES
- 2 Times Greater Surge Rating than Conventional 10 Watt Zeners
- Small Physical Size

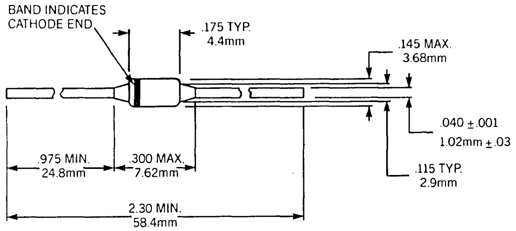
DESCRIPTION
Fused-in-glass, metallurgically-bonded 5 watt zeners.

ABSOLUTE MAXIMUM RATINGS

Zener Voltage, V_Z	6.8 to 400V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	—65°C to +175°C

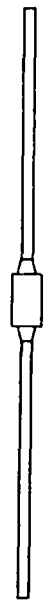
MECHANICAL SPECIFICATIONS

UZ5706 SERIES UZ5806 SERIES

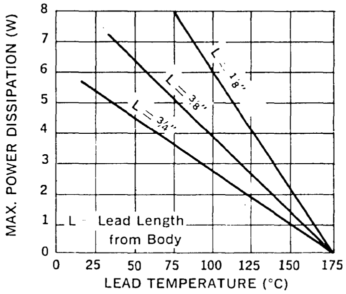


UZ Prefix is identified by a Blue or Red Cathode Band

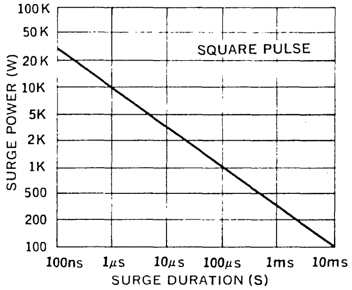
BODY B



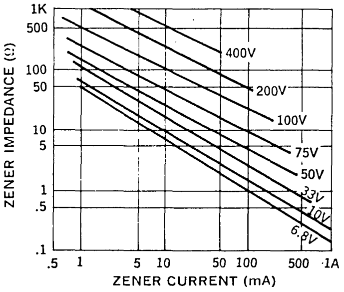
Power Dissipation vs. Lead Temperature Derating Curve



Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



SEMICONDUCTOR PRODUCTS
UNITRODE

Type *		Electrical Specifications at 25°C							Maximum Ratings	
		Nominal Zener Voltage † V_Z @ I_{ZT}	Test Current I_{ZT}	Max. Zener Impedance § Z_Z @ I_{ZT}	Maximum Reverse Leakage Current			Typ. Temp. Coeff. T_C @ I_{ZT}	Maximum Continuous Current ★ I_{ZM}	Maximum Surge Current ‡ I_S
					I_R	± 5% V_R	± 10% V_R			
±5% Tolerance	±10% Tolerance	Volts	mA	Ohms	µA	Volts	Volts	%/°C	mA	Amps
UZ5706	UZ5806	6.8	175	1.0	500	5.2	4.9	.05	675	40
UZ5707	UZ5807	7.5	175	1.5	400	5.7	5.4	.06	620	32
UZ5708	UZ5808	8.2	150	1.5	200	6.2	5.9	.06	570	24
UZ5709	UZ5809	9.1	150	2.0	100	6.9	6.6	.06	510	22
UZ5710	UZ5810	10.0	125	2.0	75	7.6	7.2	.07	470	20
UZ5712	UZ5812	12	100	2.5	50	9.1	8.6	.07	385	18
UZ5713	UZ5813	13	100	3.0	25	9.9	9.3	.08	350	16
UZ5714	UZ5814	14	100	3.0	20	10.6	10.1	.08	320	14
UZ5715	UZ5815	15	75	3.5	15	11.4	10.8	.08	300	12
UZ5716	UZ5816	16	75	3.5	10	12.2	11.5	.08	275	10
UZ5718	UZ5818	18	65	4.0	10	13.7	12.9	.085	255	9.0
UZ5720	UZ5820	20	65	4.5	10	15.2	14.4	.085	220	8.0
UZ5722	UZ5822	22	50	5.0	10	16.7	15.8	.085	195	7.0
UZ5724	UZ5824	24	50	5.0	10	18.2	17.3	.090	180	6.5
UZ5727	UZ5827	27	50	6.0	10	20.6	19.4	.090	155	6.0
UZ5730	UZ5830	30	40	8	10	22.8	21.6	.09	140	5.5
UZ5733	UZ5833	33	40	10	5	25.1	23.7	.09	130	5.0
UZ5736	UZ5836	36	30	11	5	27.4	25.9	.095	120	4.5
UZ5740	UZ5840	40	30	14	5	30.4	28.8	.095	105	4.0
UZ5745	UZ5845	45	30	20	5	34.2	32.4	.095	95	3.5
UZ5750	UZ5850	50	25	25	5	38.0	36.0	.095	85	3.0
UZ5756	UZ5856	56	20	35	5	42.6	40.3	.095	80	2.8
UZ5760	UZ5860	60	20	40	5	45.7	43.2	.100	75	2.5
UZ5770	UZ5870	70	20	50	5	53.3	50.5	.100	65	2.3
UZ5775	UZ5875	75	15	55	5	56.0	54.0	.100	60	2.0
UZ5780	UZ5880	80	15	80	5	60.8	57.7	.100	55	1.8
UZ5790	UZ5890	90	15	90	5	68.5	64.8	.100	50	1.6
UZ5110	UZ5210	100	10	100	5	76.0	72.0	.100	45	1.4
UZ5111	UZ5211	110	10	125	5	83.6	79.2	.100	40	1.2
UZ5112	UZ5212	120	10	170	5	91.2	86.4	.100	38	1.0
UZ5113	UZ5213	130	10	190	5	98.8	93.6	.105	35	0.80
UZ5114	UZ5214	140	8	230	5	106.0	101.0	.105	33	0.80
UZ5115	UZ5215	150	8	330	5	114.0	108.0	.105	31	0.75
UZ5116	UZ5216	160	8	350	5	122.0	115.0	.105	30	0.70
UZ5117	UZ5217	170	8	380	5	129.0	122.0	.105	27	0.65
UZ5118	UZ5218	180	5	450	5	137	129	.110	25	0.60
UZ5119	UZ5219	190	5	470	5	144	137	.110	24	0.55
UZ5120	UZ5220	200	5	500	5	152	144	.110	22	0.50
UZ5122	UZ5222	220	5	550	5	167	158	.115	20	0.45
UZ5124	UZ5224	240	5	650	5	182	173	.115	18	0.40
UZ5126	UZ5226	260	5	750	5	198	187	.120	17	0.35
UZ5128	UZ5228	280	4	850	5	213	202	.120	16	0.30
UZ5130	UZ5230	300	4	950	5	228	216	.120	15	0.25
UZ5132	UZ5232	320	4	1100	5	243	230	.120	14	0.24
UZ5134	UZ5234	340	4	1200	5	258	245	.120	13	0.23
UZ5136	UZ5236	360	3	1400	5	274	259	.120	12	0.22
UZ5138	UZ5238	380	3	1500	5	289	274	.120	12	0.21
UZ5140	UZ5240	400	3	1800	5	304	288	.120	11	0.20

Temperature Range: Operating and Storage −65°C to +175°C.

* Specify 20% tolerance by changing the second numeral of type number from 8 to 9 (UZ5809 becomes UZ5909) or from 2 to 3 (UZ5211 becomes UZ5311).

† All zener voltages are measured with an automated test set using a 35 millisecond test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§ Zener impedance is derived from the 60-cycle AC voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

★ Maximum current based on 5 watt rating. See lead temperature derating curves for proper mounting methods.

‡ Figures shown are for a peak sinusoidal surge current of 8.3ms duration using 60 cycle AC. The 8.3ms square pulse rating is 71% of the value shown.

Several of the above types now have JEDEC 1N type numbers. The following cross-reference table lists the appropriate 1N numbers; specifications are same as above.

JEDEC #	UNITRODE TYPE	JEDEC #	UNITRODE TYPE	JEDEC #	UNITRODE TYPE
1N5118	UZ5714	1N5124	UZ5780	1N5130	UZ5128
1N5119	UZ5740	1N5125	UZ5790	1N5131	UZ5132
1N5120	UZ5745	1N5126	UZ5114	1N5132	UZ5134
1N5121	UZ5750	1N5127	UZ5117	1N5133	UZ5138
1N5122	UZ5760	1N5128	UZ5119	1N5134	UZ5140
1N5123	UZ5770	1N5129	UZ5126		

POWER ZENERS
6 Watt, Military, 10 Watt Military

UZ7706L and UZ7806L SERIES
UZ7706 and UZ7806 SERIES

FEATURES
- High Surge Rating
- Small Physical Size
- Leaded and Stud Packages Available

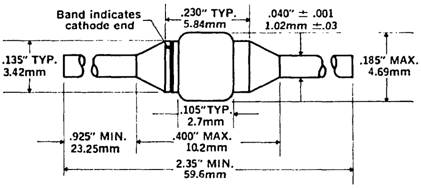
DESCRIPTION
Fused-in-glass, metallurgically bonded 6 watt leaded zeners and 10 watt stud-type zeners.

ABSOLUTE MAXIMUM RATINGS

Zener Voltage, V_Z		6.8 to 100V
Continuous Current		See Table
Surge Current (8.3ms)		See Table
Surge Power		See Graph
Power	UZ7706L & UZ7806L	See Lead Temperature Derating Curve
	UZ7706 & UZ7806 @100°C Case	10W
Storage and Operating Temperature		—65°C to +175°C

MECHANICAL SPECIFICATIONS

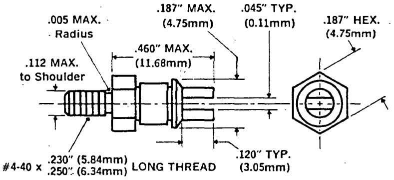
UZ7706L and UZ7806L SERIES



UZ Prefix is identified by a Blue or Red Cathode Band

BODY C — Lead Mount

UZ7706 and UZ7806 SERIES



POLARITY: Cathode to Stud is standard. Reverse polarity denoted by "R" suffix.

FINISH: Metal parts gold plated per MIL-G-45204, Type II.

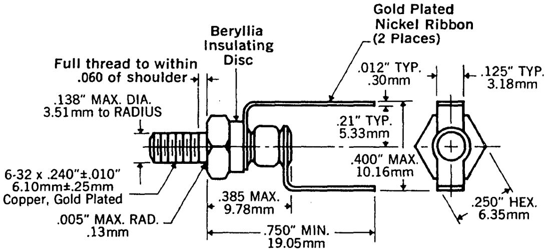
WEIGHT: 1.5 grams (max.)

INSTALLATION PRECAUTIONS: Maximum unlubricated stud torque: 28 inch-ounces. Do not use a screwdriver in the turret slot for installation purposes, or damage may result.

Also available with insulated stud. Reference Design Note-17.

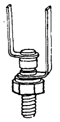
BODY C — Stud Mount

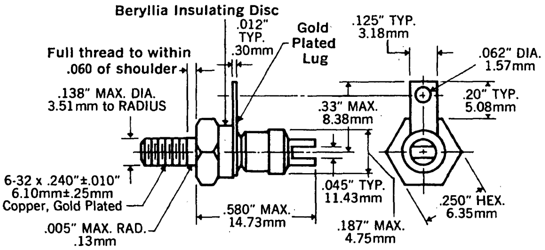
MECHANICAL SPECIFICATIONS



Dimensions in inches.

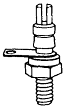
Style W



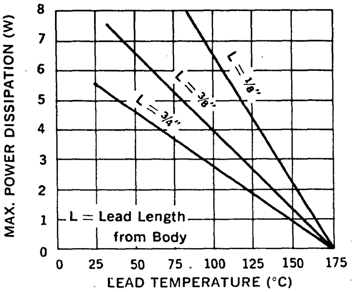


Dimensions in inches.

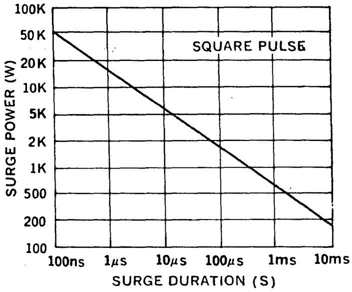
Style V



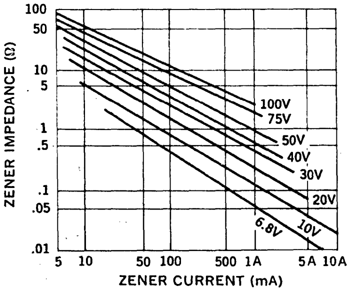
Power Dissipation vs. Lead Temperature Derating Curve



Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



Type *		Electrical Specifications at 25°C							Maximum Ratings	
		Nominal Zener Voltage † V_Z @ I_{ZT}	Test Current I_{ZT}	Max. Zener Impedance § Z_Z @ I_{ZT}	Maximum Reverse Leakage Current			Typ. Temp. Coeff. T_C @ I_{ZT}	Maximum Continuous Current ★ I_{ZM}	Maximum Surge Current ‡ I_S
					I_R @ V_R	± 5% V_R	± 10% V_R			
±5% Tolerance	±10% Tolerance	Volts	mA	Ohms	μA	Volts	Volts	%/°C	mA	Amps
UZ7706	UZ7806	6.8	350	0.6	1000	5.2	4.9	.04	1350	50
UZ7707	UZ7807	7.5	325	0.7	800	5.7	5.4	.04	1250	41
UZ7708	UZ7808	8.2	300	0.8	200	6.2	5.9	.05	1150	31
UZ7709	UZ7809	9.1	275	1.0	150	6.9	6.6	.05	1020	29
UZ7710	UZ7810	10.0	250	1.0	100	7.6	7.2	.06	950	26
UZ7712	UZ7812	12	200	1.3	75	9.1	8.6	.07	770	23
UZ7713	UZ7813	13	200	1.5	50	9.9	9.3	.07	700	21
UZ7714	UZ7814	14	175	1.5	40	10.6	10.1	.07	640	20
UZ7715	UZ7815	15	150	2.0	30	11.4	10.8	.07	600	17
UZ7716	UZ7816	16	150	2.5	20	12.2	11.5	.07	550	15
UZ7718	UZ7818	18	130	3.5	20	13.7	12.9	.08	500	13
UZ7720	UZ7820	20	120	4.0	20	15.2	14.4	.08	440	12
UZ7722	UZ7822	22	100	4.5	20	16.7	15.8	.08	390	11
UZ7724	UZ7824	24	100	5.0	20	18.2	17.3	.08	360	10
UZ7727	UZ7827	27	90	6.0	20	20.6	19.4	.09	310	9
UZ7730	UZ7830	30	80	8	20	22.8	21.6	.090	280	8.5
UZ7733	UZ7833	33	70	10	10	25.1	23.7	.090	260	7.5
UZ7736	UZ7836	36	60	12	10	27.4	25.9	.090	240	7.0
UZ7740	UZ7840	40	60	15	10	30.4	28.8	.095	210	6.4
UZ7745	UZ7845	45	50	20	10	34.2	32.4	.095	180	5.5
UZ7750	UZ7850	50	50	22	10	38.0	36.0	.095	170	4.6
UZ7756	UZ7856	56	40	30	10	42.6	40.3	.095	160	4.1
UZ7760	UZ7860	60	40	35	10	45.6	43.2	.095	150	3.7
UZ7770	UZ7870	70	35	40	10	53.2	50.4	.095	130	3.3
UZ7775	UZ7875	75	30	45	10	56.0	54.0	.095	120	3.1
UZ7780	UZ7880	80	30	60	10	60.8	57.6	.095	110	2.9
UZ7790	UZ7890	90	25	75	10	68.4	64.8	.095	100	2.6
UZ7110	UZ7210	100	20	90	10	76.0	72.0	.100	90	2.3

For optional high reliability screening, see UZ706-UZ140HR data sheet.

Power Rating: Stud Mounted: 10 Watts at 100°C Case derate linerally to zero at 175°C Case.
Lead Mounted: See lead temperature derating curve.
Temperature Range: Operating and storage −65°C to 175°C.

* Specify 20% tolerance by changing the second numeral of type number from 8 to 9 (UZ7809 becomes UZ7909) or from 2 to 3 (UZ7210 becomes UZ7310). Specify leaded version by adding an L suffix (UZ7809 becomes UZ7809L).

† All zener voltages are measured with an automated test set using a 35 msec test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§ Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

★ Ratings Based on 100°C Case temperature; for leaded devices multiply by 0.6.

‡ Figures shown are for a peak sinusoidal surge current of 8.3ms duration, non-repetitive. The 8.3ms square pulse rating is 71% of the value shown.

POWER ZENERS
1 Watt, Industrial

UZ8706 SERIES
UZ8806 SERIES

FEATURES
- High Surge Ratings
- A Quarter the Size of Conventional 1 Watt Zeners
- Impervious to Moisture

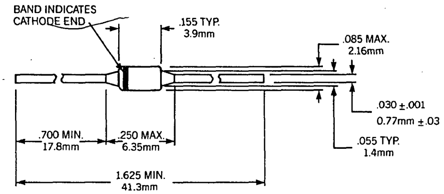
DESCRIPTION
One watt zener diodes, hermetically sealed in glass.

ABSOLUTE MAXIMUM RATINGS

Zener Voltage, V_Z	6.8 to 200V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	—65°C to +175°C

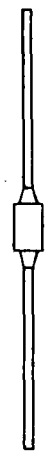
MECHANICAL SPECIFICATIONS

UZ8706 SERIES UZ8806 SERIES

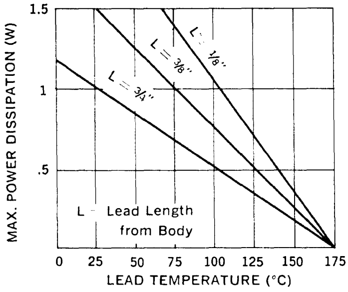


UZ Prefix is identified by a Blue or Red Cathode Band

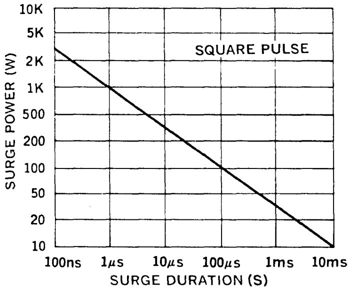
BODY A



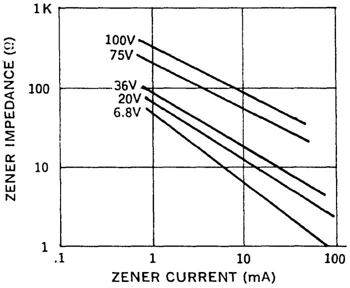
Power Dissipation vs. Lead Temperature Derating Curve



Surge Power vs. Surge Duration



Typical Zener Impedance vs. Zener Current



SEMICONDUCTOR PRODUCTS
UNITRODE

Type		Electrical Specifications at 25°C							Maximum Ratings	
		Nominal Zener Voltage †	Test Current	Max. Zener Impedance §	Maximum Reverse Leakage Current			Typ. Temp. Coefficient	Maximum Continuous Current ★	Maximum Surge Current ‡
						± 5%	± 10%			
		V_Z @ I_{ZT}	I_{ZT}	Z_Z @ I_{ZT}	I_R @ V_R	V_R	V_R	T.C. @ I_{ZT}	I_{ZM}	I_S
± 5% Tolerance	± 10% Tolerance	Volts	mA	Ohms	μA	Volts	Volts	%/°C	mA	Amps
UZ 8706	UZ 8806	6.8	37	3.5	50	5.2	4.9	0.04	140	5.00
UZ 8707	UZ 8807	7.5	34	4.0	30	5.7	5.4	0.04	125	4.50
UZ 8708	UZ 8808	8.2	31	4.5	10	6.2	5.9	0.05	115	3.90
UZ 8709	UZ 8809	9.1	28	5.0	3.0	6.9	6.6	0.05	105	3.37
UZ 8710	UZ 8810	10	25	7.0	2.0	7.6	7.2	0.06	95	2.77
UZ 8712	UZ 8812	12	23	9.0	1.0	9.1	8.6	0.07	85	2.25
UZ 8713	UZ 8813	13	21	10	0.5	9.9	9.3	0.07	80	2.25
UZ 8714	UZ 8814	14	19	12	0.5	10.6	10.1	0.07	74	2.25
UZ 8715	UZ 8815	15	17	14	0.5	11.4	10.8	0.07	63	1.65
UZ 8716	UZ 8816	16	15.5	16	0.5	12.1	11.5	0.07	60	1.65
UZ 8718	UZ 8818	18	14.0	20	0.5	13.7	12.9	0.08	52	1.12
UZ 8720	UZ 8820	20	12.5	22	0.5	15.2	14.4	0.08	47	1.12
UZ 8722	UZ 8820	22	11.5	23	0.5	16.7	15.8	0.08	43	1.12
UZ 8724	UZ 8824	24	10.5	25	0.5	18.2	17.3	0.08	40	0.825
UZ 8727	UZ 8827	27	9.5	35	0.5	20.5	19.4	0.09	35	0.825
UZ 8730	UZ 8830	30	8.5	40	0.5	22.8	21.6	0.09	31	0.825
UZ 8733	UZ 8833	33	7.5	45	0.5	25.1	23.7	0.09	28	0.675
UZ 8736	UZ 8836	36	7.0	50	0.5	27.3	25.9	0.09	26	0.562
UZ 8740	UZ 8840	40	6.5	62	0.5	30.4	28.8	0.095	24	0.562
UZ 8745	UZ 8845	45	6.0	75	0.5	34.2	32.4	0.095	22	0.450
UZ 8750	UZ 8850	50	5.0	85	0.5	38.0	36.0	0.095	20	0.450
UZ 8756	UZ 8856	56	4.5	110	0.5	42.5	40.3	0.095	17	0.390
UZ 8760	UZ 8860	60	4.0	125	0.5	45.6	43.2	0.095	15	0.337
UZ 8770	UZ 8870	70	3.7	150	0.5	53.2	50.4	0.095	14	0.337
UZ 8775	UZ 8875	75	3.3	175	0.5	57.0	54.0	0.095	12	0.277
UZ 8780	UZ 8880	80	3.0	200	0.5	60.8	57.6	0.095	11	0.225
UZ 8790	UZ 8890	90	2.8	250	0.5	68.4	64.8	0.095	10	0.225
UZ 8110	UZ 8210	100	2.5	350	0.5	76.0	72.0	0.10	9.5	0.225
UZ 8111	UZ 8211	110	2.3	450	0.5	83.6	79.2	0.10	8.5	0.165
UZ 8112	UZ 8212	120	2.0	550	0.5	91.2	86.4	0.10	8.0	0.112
UZ 8113	UZ 8213	130	1.9	700	0.5	98.8	93.6	0.10	7.2	0.112
UZ 8114	UZ 8214	140	1.8	850	0.5	106	100	0.10	6.8	0.112
UZ 8115	UZ 8215	150	1.7	1000	0.5	114	108	0.10	6.3	0.112
UZ 8116	UZ 8216	160	1.6	1100	0.5	121	115	0.10	5.9	0.082
UZ 8117	UZ 8217	170	1.5	1200	0.5	129	122	0.10	5.6	0.082
UZ 8118	UZ 8218	180	1.4	1300	0.5	137	129	0.10	5.2	0.056
UZ 8119	UZ 8219	190	1.3	1400	0.5	144	137	0.10	5.0	0.056
UZ 8120	UZ 8220	200	1.2	1500	0.5	152	144	0.10	4.7	0.056

†All zener voltages are measured with an automated test set using a 35 millisecond test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.

§Zener impedance is derived from the 60-cycle AC voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.

★Ratings are based on free air. T_A is 25°C. For use at 1.5 watts see derating curve.

‡Figures shown are for a peak sinusoidal surge current of 8.3 ms duration using 60 cycle AC. The 8.3 ms square pulse rating is 71% of the value shown.

SWITCHING & GENERAL PURPOSE DIODES 5

Product Selection Guides

SWITCHING, GENERAL PURPOSE DIODES

UNIBOND SWITCHING DIODES

Type	Reverse Breakdown Voltage	Average Forward Current (mA)	Forward Voltage	Reverse Recovery Time (ns)	Junction Capacitance (@ OV)
1N6638†	150V	300	1.1V @ 200 mA	4.5	2.0pf
1N6642†	100V	300	1.2V @ 100mA	5.0	5.0pf
1N6643†	75V	300	1.2V @ 100mA	6.0	5.0pf
1N4148-1†	100V	200	1.2V @ 100mA	5.0	4.0pf
1N4150-1†	75V	200	1.0V @ 200mA	4.0	2.5pf

† Available as JANTX, JANTXV.

SWITCHING

Type	Reverse Breakdown Voltage (V)	Average Forward Current (mA)	Forward Voltage (V)	Reverse Recovery Time (ns)	Junction Capacitance (pF)
1N4154	35	150	1.0 @ 30mA	2	4
1N251*	40	75	1.0 @ 5mA	150	
1N4152	40	150	.49-.52 @ 0.1mA	2	2
1N4450	40	200	.42-.54 @ 0.1mA	4	4
1N4451	40	200	.4-.5 @ 0.1mA	10	6
1N4452	40	200	.42-.54 @ 0.1mA	50	30
1N4444	70	200	.44-.55 @ 0.1mA	7	2
1N3064**	75	75	1.0 @ 10mA	4	2
1N4532***	75	125	1.0 @ 10mA	4	2
1N4534***	75	150	.74-.88 @ 20mA	4	2
1N4151	75	150	1.0 @ 50mA	2	2
1N4153***	75	150	.49-.55 @ 0.1mA	2	2
1N4305	75	150	.5-.575 @ .25mA	2	2
1N4446	75	150	1.0 @ 20mA	4	4
1N4447	75	150	1.0 @ 20mA	4	2
1N4448	75	150	1.0 @ 100mA	4	4
1N4449	75	150	1.0 @ 30mA	4	2
1N3600***	75	200	.54-.62 @ 1mA	4	2.5
1N4149	75	200	1.0 @ 10mA	4	2
1N4454***	75	200	1.0 @ 10mA	2	2
1N4500**	80	300	.64-.72 @ 10mA	6	4
1N4607	85	400	1.1 @ 400mA	10	4
1N4608	85	500	1.1 @ 500mA	10	4
1N662*	100	40	1.0 @ 10mA	500	3
1N663*	100	40	1.0 @ 100mA	500	3
1N914**	100	75	1.0 @ 10mA	5	4
1N4531***	100	125	1.0 @ 10mA	5	4
1N3070**	200	100	1.0 @ 100mA	50	5
1N4938**	200	150	1.0 @ 10mA	50	5

GENERAL PURPOSE

Type	Reverse Voltage (V)	Average Forward Current (mA)	Forward Voltage (V)	Reverse Recovery Time (ns)	Junction Capacitance (pF)
1N456	30	90	1.0 @ 40mA		
1N457*	70	75	1.0 @ 20mA		
1N483B**	80	200	1.0 @ 100mA		
1N458*	150	55	1.0 @ 7mA		
1N3595***	150	150	.83-1.0 @ 200mA	3μs	2.5
1N459*	200	40	1.0 @ 3mA		
1N643*	200	40	1.0 @ 10mA	300	3
1N485B**	200	200	1.0 @ 100mA		
1N645***	270	400	1.0 @ 400mA		20
1N647**	480	400	1.0 @ 400mA		20

* Available as JAN. ** Available as JAN, JANTX. *** Available as JAN, JANTX, JANTXV.

SWITCHING, GENERAL PURPOSE AND STABISTOR DIODES

PROELECTRON SWITCHING DIODES

Type	Reverse Voltage (V)	Average Forward Current (mA)	Forward Voltage (V)	Reverse Recovery Time (ns)	Reverse Current @ 25°C (μA)	Junction Capacitance (pF)
BAY60	25	115	1.0 @ 30mA	4	0.1 @ 25V	4
BAW75	35	300	1.0 @ 30mA	2	5 @ 35V	4
BAY41	40	225	1.0 @ 200mA	8.5	5 @ 40V	5
BAW24	50	600	1.0 @ 50mA	6	0.1 @ 40V	4
BAW25	50	600	0.8 @ 50mA	6	0.1 @ 40V	4
BAY42	60	225	1.0 @ 200mA	15	5 @ 60V	5
BAW26	75	600	1.0 @ 50mA	6	0.1 @ 60V	4
BAW27	75	600	1.0 @ 200mA	6	0.1 @ 40V	4
BAW76	75	300	1.0 @ 100mA	2	5 @ 75V	2
BAY43	80	225	1.0 @ 200mA	15	5 @ 80V	5
BAX12	90	400	1.25 @ 400mA	15	0.1 @ 90V	20

COMPUTER DIODE
General Purpose

1N251
JAN 1N251

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Peak Reverse Voltage	40V
Reverse Working Voltage	30V
Average Rectified Current	75mAdc
Surge Current, I_{ms} @ 125°C Free Air Temperature	125mA
Surge Current (JAN), 1s, 25°C	200mA
Continuous Power Dissipation	150mW
Operating Temperature Range	−55°C to +175°C
Storage Temperature Range	−55°C to +175°C

FEATURES

- Metallurgical Bond
- Qualified to MIL-S-19500/188
- Planar Passivated Chip
- DO-7 Package

DESCRIPTION

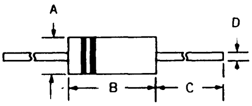
This device is particularly suited to applications where medium speed switching is required. Moisture free stability is ensured through hermetic sealing.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Reverse Current	Reverse Current	Reverse Current @ 125°C	Forward Voltage	Reverse Recovery Time
1N251	20μA @ V_R = 20V	0.1μA @ V_R = 10V	10μA @ 10V T_A = 125°C	1V @ I_F = 5mA	150ns @ I_F = 5mA, V_R = 10V R_L = 1KΩ, C_L = 10pf, I_{REC} = 0.5mA
JAN 1N251	100μA @ V_R = 30Vdc	.1μA @ V_R = 10V	10μA @ 10V T_A = 100°C	1V @ I_F = 10mA	30ns I_F =10mA, I_R =10mA R_L = 100Ω, C = 4pf

MECHANICAL SPECIFICATIONS

JAN 1N251



	INCHES	MILLIMETERS
A	.075-.130	1.90-3.30
B	.195-.300	4.95-7.62
C	1.0-1.5	25.4-38.1
D	.019-.021	.48-.53

DO-7
1N251

SEMICONDUCTOR PRODUCTS
UNITRODE

DIODE
Low Current

1N456
1N457; JAN 1N457
1N458; JAN 1N458
1N459; JAN 1N459

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/193
- Planar Passivated Chip
- DO-7 Package

DESCRIPTION
General purpose low current diode with high reliability characteristics

ABSOLUTE MAXIMUM RATINGS, AT 25°C

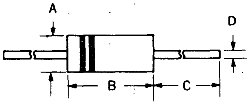
	1N456	JAN 1N457	JAN 1N458	JAN 1N459
Reverse Working Voltage	25V	60V	125V	175V
Peak Reverse Voltage	30V	70V	150V	200V
Average Output Current	90mA	75mA	55mA	40mA
Surge Current, 8.3mS	700mA	225mA	165mA	120mA
Operating Temperature Range	−65°C to +150°C			
Storage Temperature Range	−65°C to +200°C			

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Forward Voltage	Reverse Current	Reverse Current @T_A = 150°C	Peak Reverse Voltage @100µA
1N456	1.0V @ 40mA	25nA @ 25V	5µA @ 25V	30V
1N457, J	1.0V @ 20mA	25nA @ 60V	5µA @ 60V	70V
1N458, J	1.0V @ 7mA	25nA @ 125V	5µA @ 125V	150V
1N459, J	1.0V @ 3mA	25nA @ 175V	5µA @ 175V	200V

MECHANICAL SPECIFICATIONS

JAN 1N457, 1N458, 1N459



	INCHES	MILLIMETERS
A	.085 - .130	2.16 - 3.30
B	.230 - .300	5.84 - 7.62
C	1.0 - 1.5	25.40 - 38.10
D	.018 - .022	.46 - .56

DO-7
1N456
1N457
1N458
1N459

SEMICONDUCTOR PRODUCTS
UNITRODE

DIODE
General Purpose
Low Current

1N483B; JAN, JANTX 1N483B
1N485B; JAN, JANTX 1N485B

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/118
- Planar Passivated Chip
- DO-7 Package

DESCRIPTION
This Series is useful in low current rectifying applications for military, industrial and commercial equipment.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N483B	1N485B
Reverse Breakdown Voltage	80V	200V
Peak Working Voltage	70V	180V

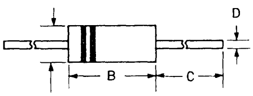
Average Output Current @ $T_A = 25°C$	200mA
$T_A = 150°C$	50mA

Current Derating 1.2 mAdc/°C from 25°C to 150°C and 1.0 mAdc/°C from 150°C to 200°C

Surge Current, 8.3mSec	2 Amps
Operating Temperature Range	—65°C to +200°C
Storage Temperature Range	—65°C to +200°C

MECHANICAL SPECIFICATIONS

J & JTX 1N483B, 1N485B



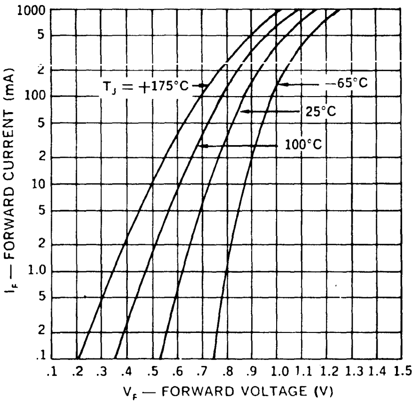
	INCHES	MILLIMETERS
A	.085-.125	2.16-3.18
B	.230-.300	5.84-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

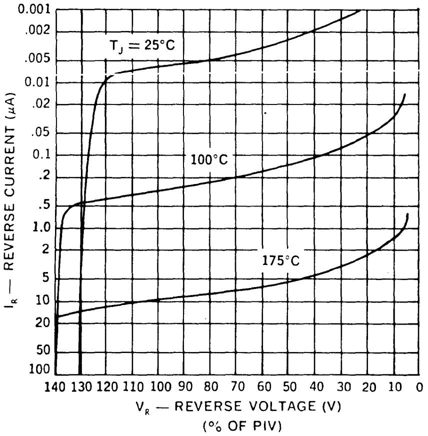
DO-7
1N483BJ, JTX
1N485BJ, JTX

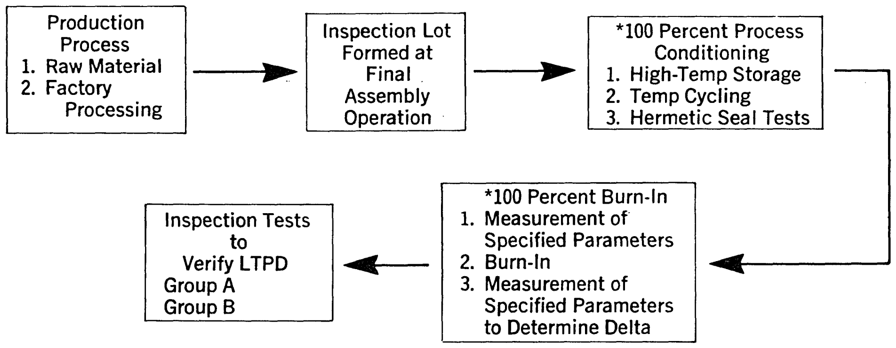
DO-35

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Reverse Current @ 25°C	Reverse Current @ 25°C	Reverse Current @ 150°C	Forward Voltage @ 100mAdc, 8.5msec dc = 2% MAX.
1N483B	25nA @ 70Vdc	100 μA(pk) @ 80V(pk)	5.0 μA @ 70Vdc	1.0V(pk)
1N485B	25nA @ 180Vdc	100 μA(pk) @ 200V(pk)	5.0 μA @ 180Vdc	


Forward Voltage vs. Forward Current


Reverse Voltage vs. Reverse Current



*Order of the tests in the blocks shall be performed as shown.

Order of procedure diagrams for TX types only.

COMPUTER DIODE
Switching

1N643; JAN 1N643
1N662; JAN 1N662
1N663; JAN 1N663

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/256
- Planar Passivated Chip
- DO-7 Package

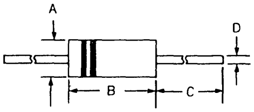
DESCRIPTION
This device is particularly suited to applications where medium speed switching is required. Moisture free stability is ensured through hermetic sealing.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N643 JAN 1N643	1N662 JAN 1N662	1N663	JAN 1N663
Peak Reverse Voltage	200V	100V	100V	100V
Reverse Working Voltage	175V	80V	80V	80V
Average Rectified Current	40mAdc	40mAdc	60mAdc	100mA
Surge Current, 8.3ms	500mA			
Operating Temperature Range	−65°C to +150°C			
Storage Temperature Range	−65°C to +175°C			

MECHANICAL SPECIFICATIONS

J 1N643, 1N662, 1N663



	INCHES	MILLIMETERS
A	.077 - .130	1.96 - 3.30
B	.195 - .300	4.95 - 7.62
C	1.0 - 1.5	25.4 - 38.1
D	.019 - .021	.48 - .53

DO-7
1N643
1N662
1N663

SEMICONDUCTOR
PRODUCTS
UNITRODE

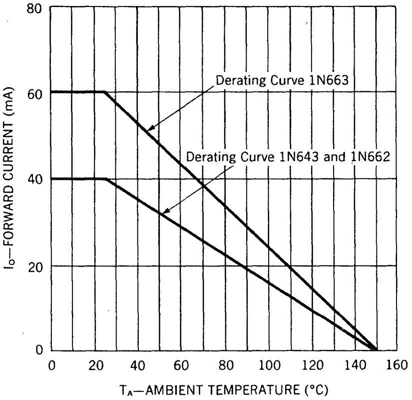
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Maximum Reverse Current @ 25°C	Maximum Reverse Current @ 25°C	Maximum Peak Reverse Current @ 25°C	Maximum Reverse Current @ 100°C
1N643	25nAdc @ V_R = 10Vdc	1μAdc @ V_R = 100Vdc	100μA_{PK} @ V_R = 200V_{PK}	15μAdc @ V_R = 100Vdc
1N662	25nAdc @ V_R = 10Vdc	5μAdc @ V_R = 50Vdc	100μA_{PK} @ V_R = 100V_{PK}	100μAdc @ V_R = 50Vdc
1N663	25nAdc @ V_R = 10Vdc	5μAdc @ V_R = 75Vdc	100μA_{PK} @ V_R = 100V_{PK}	50μAdc @ V_R = 75Vdc

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Maximum Forward Voltage @ 25°C	Capacitance	Maximum Reverse Recovery Time
1N643	1.0Vdc @ I_F = 10mAdc	3pF @ V_R = 175V	300ns @ I_F = 5mA I_R = 17.5mA I_{REC} = 0.2nA
1N662	1.0Vdc @ I_F = 10mAdc	3pF @ V_R = 80V	500ns @ I_F = 5mA I_R = 17.5mA I_{REC} = 0.4nA
1N662	1.0Vdc @ I_F = 100mAdc	3pF @ V_R = 80V	500ns @ I_F = 5mA I_R = 17.5mA I_{REC} = 0.4nA

Average Rectified Current vs. Ambient Temperature



RECTIFIERS
High Voltage, Low Current

1N645, 1N647; JAN, JANTX 1N645, 1N647
JAN, JANTX & JANTXV 1N645-1, 1N647-1

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/240
- Planar Passivated Chip
- DO-35 or DO-7 Package

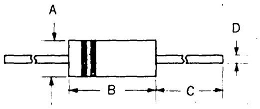
DESCRIPTION
These devices are useful in general purpose low current applications in high reliability and military equipment.

ABSOLUTE MAXIMUM RATINGS, AT 25°C	1N645 JAN 1N645 JAN 1N645-1	1N647 JAN 1N647 JAN 1N647-1
Reverse Breakdown Voltage	270V	480V
Peak Working Voltage	225V	400V
Average Output Current, 25°C*	400mA	
150°C	150mA	
Surge Current, 8.3ms, 150°C	5A	
Operating Temperature Range	−65°C to +175°C	
Storage Temperature Range	−65°C to +200°C	

*Derate 2.0mAdc/°C between 25°C and 150°C.

MECHANICAL SPECIFICATIONS

J, JTX 1N645, 1N647
J, JTX, & JTXV 1N645-1, 1N647-1



J, JTX 1N645, 1N647
J, JTX, & JTXV 1N645-1, 1N647-1

	INCHES	MILLIMETERS
A	.055-.130	1.40-3.30
B	.140-.300	3.56-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.023	.46-.58

DO-7
1N645
1N647
1N647-1

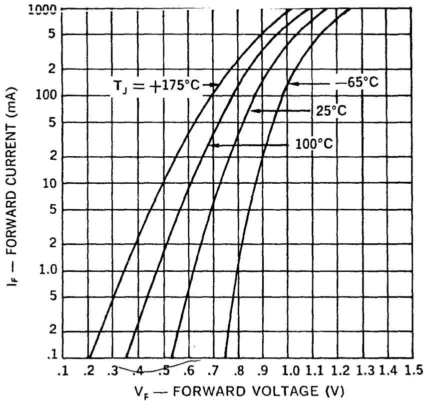
DO-35
1N645-1

SEMICONDUCTOR PRODUCTS
UNITRODE

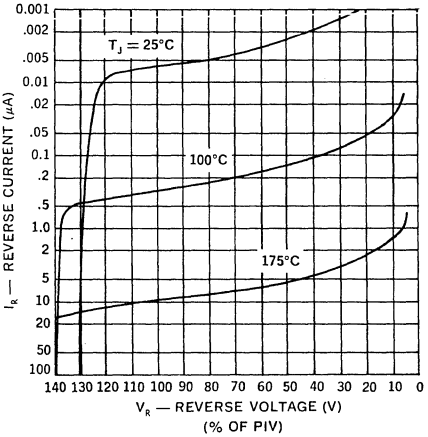
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

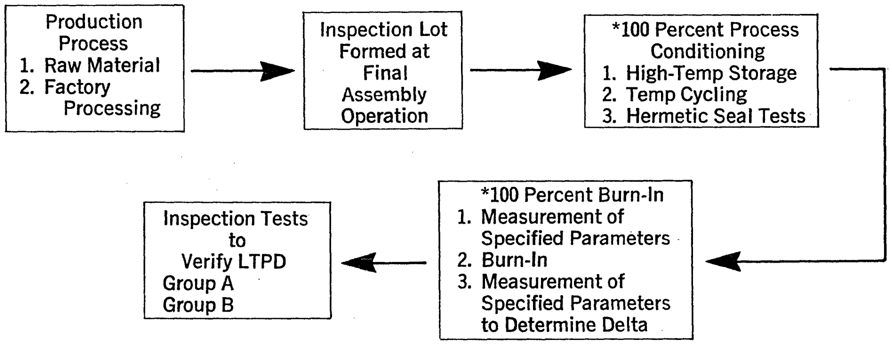
Type	Reverse Current @ 25°C	Reverse Current @ 150°C	Peak Reverse Current @ 25°C	Average Reverse Current @ 150°C	Forward Voltage @ 25°C	Capacitance
1N645 JAN 1N645	0.025μA @ 225Vdc	15μAdc @ 225Vdc	100μA (pk) @ 270V (pk)	100μAdc @ 225V (pk)	1.0Vdc @ I_F = 400mAdc 8.3ms	20pF V_R = 4 Vdc f = 1MHz V_{sig} = 50mV
JAN 1N645-1	0.050μA @ 225Vdc	25μAdc @ 225Vdc	50 (pk) @ 270V (pk)	100μAdc @ 225V (pk)		
1N647 JAN 1N647	0.025μA @ 400Vdc	15μAdc @ 400V	100μA (pk) @ 480V (pk)	100μAdc @ 400V (pk)		
JAN 1N647-1	0.050μA @ 400Vdc	25μAdc @ 400V	50 (pk) @ 480V (pk)	100μAdc @ 400V (pk)		

Forward Voltage vs. Forward Current



Reverse Voltage vs. Reverse Current





*Order of the tests in the blocks shall be performed as shown.

Order of procedure diagrams for TX types only.

COMPUTER DIODE
General Purpose Switching

1N914; JAN, JANTX 1N914
1N4148; JAN, JANTX, JANTXV 1N4148
JAN, JANTX, JANTXV 1N4148-1
1N4531; JAN, JANTX, JANTXV 1N4531

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/116
- Planar Passivated Chip
- DO-34 or DO-35 Package
- Non-JAN Available

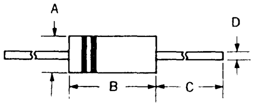
DESCRIPTION
This series is very popular for general purpose switching applications in electronic equipment.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage		100V
Peak Working Voltage		75V
Average Output Current,	1N914	75mAdc
	1N4148	200mAdc
	1N4148-1	200mAdc
	1N4531	125mAdc
Surge Current, 8.3ms		500mA
Operating Temperature Range		−65°C to +175°C
Storage Temperature Range		−65°C to +200°C

MECHANICAL SPECIFICATIONS

J, JTX 1N914
J, JTX, JTXV 1N4148
J, JTX, JTXV 1N4148-1
J, JTX, JTXV 1N4531



J, JTX & JTXV 1N4531

	INCHES	MILLIMETERS
A	.050-.065	1.27-1.65
B	.080-.120	2.03-3.05
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

J, JTX 1N914

	INCHES	MILLIMETERS
A	.058-.107	1.42-2.72
B	.140-.300	3.56-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

J, JTX, JTXV 1N4148 and 1N4148-1

	INCHES	MILLIMETERS
A	.056-.075	1.42-1.91
B	.140-.180	3.56-4.57
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.10 MAX.
D	.018-.022	.46-.56

DO-34
1N4531

DO-35
1N914
1N4148

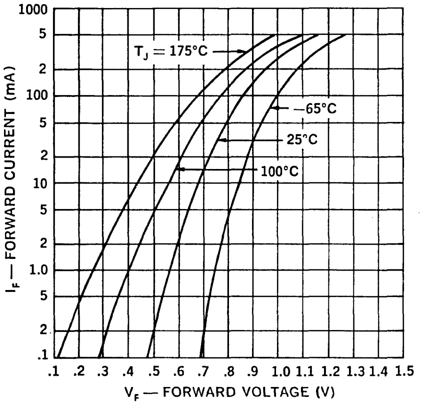
SEMICONDUCTOR
PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

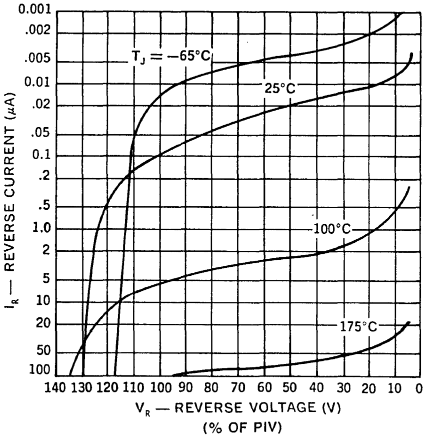
Reverse Current @ 25°C	Reverse Current @ 25°C	Peak Reverse Current @ 25°C	Reverse Current @ 150°C	Reverse Current @ 150°C
25nAdc @ $V_R = 20$Vdc	0.5μAdc @ $V_R = 75$Vdc	100μA (pk) @ $V_R = 100$V (pk)	50μAdc @ $V_R = 20$Vdc	100μAdc @ $V_R = 75$Vdc

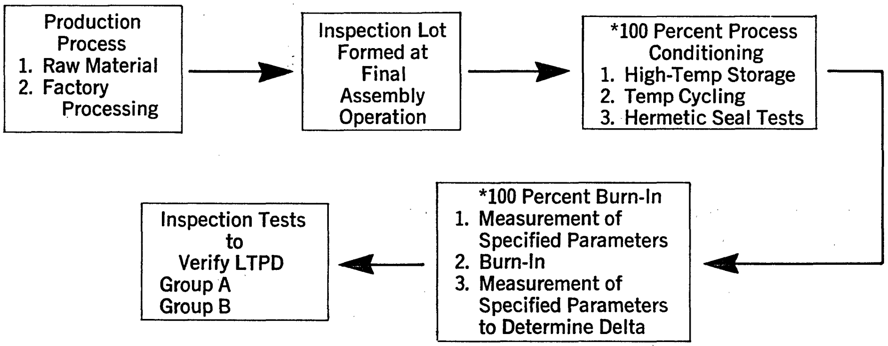
Forward Voltage	Foward Recovery Voltage	Forward Recovery Time	Reverse Recovery Time	Capacitance
1.0Vdc @ $I_F = 10$mAdc	5.0V (pk) @ $I_F = 50$mAdc	20ns @ $I_F = 50$mAdc	5ns @ $I_F = I_R = 10$mA $R_L = 100$ ohms	4.0 pF @ $V_R = 0$V, f = 1 MHz $v_{sig} = 50$mV (pk-pk) 2.8 pF @ $V_R = 1.5$V, f = 1 MHz $v_{sig} = 50$mV (pk-pk)

Forward Voltage vs. Forward Current



Reverse Voltage vs. Reverse Current





*Order of the tests in the blocks shall be performed as shown.

Order of procedure diagrams for TX types only.

COMPUTER DIODE

General Purpose Switching

JAN & JANTX 1N3064
1N4454; JAN, JANTX & JANTXV 1N4454
JAN, JANTX & JANTXV 1N4454-1
1N4532; JAN, JANTX & JANTXV 1N4532

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage		75V
Peak Working Voltage		50V
Average Output Current,	1N3064	75mA
	1N4454,-1	200mA
	1N4532	125mA
Surge Current, 1sec	1N3064	0.5A
	1N4454,-1	1A
	1N4532	0.5A
Operating Temperature Range		−65°C to +175°C
Storage Temperature Range		−65°C to +200°C

FEATURES

- Metallurgical Bond
- Qualified to MIL-S-19500/144
- Planar Passivated Chip
- DO-7, DO-34 or DO-35 Package

DESCRIPTION

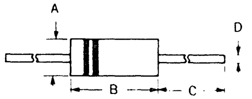
Available in DO-7, DO-34 or DO-35 packages. Unitrode offers high temperature metallurgical bond, making these devices useful in high reliability applications.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Reverse Current @ 25°C	Reverse Current @ 150°C	Reverse Breakdown Voltage @ −65°C	Reverse Recovery Time	Capacitance	Forward Voltage	Forward Recovery Voltage	Forward Recovery Time
1N3064 1N4454 1N4454-1 1N4532	0.1μAdc @ V_R = 50V	100μAdc @ V_R = 50V	75Vdc @ I_R = 5μAdc	4ns @ $I_F = I_R$ = 10mAdc R_L = 100Ω c ≤ 3pF	2pF @ V_R = 0Vdc f = 1MHz V_{sig} = 50mV (pk to pk)	1.0Vdc @ I_F = 10mAdc	5.0V (pk) @ I_F = 100mAdc $t_r \leq$ 0.4ns	30ns I_F = 100mAdc $t_r \leq$ 0.4ns

MECHANICAL SPECIFICATIONS

J & JTX 1N3064
J, JTX & JTXV 1N4454 & 1N4454-1
J, JTX & JTXV 1N4532



J, JTX & JTXV 1N4532

	INCHES	MILLIMETERS
A	.050-.065	1.27-1.65
B	.080-.120	2.03-3.05
C	1.0 MIN.-1.5 MAX.	24.0 MIN.-38.1 MAX.
D	.018-.022	.46-.56

J & JTX 1N3064

	INCHES	MILLIMETERS
A	.078-.107	1.98-2.72
B	.195-.300	4.96-7.62
C	1.0 MIN.-1.5 MAX.	24.0 MIN.-38.1 MAX.
D	.018-.022	.46-.56

J, JTX & JTXV 1N4454,-1

	INCHES	MILLIMETERS
A	.056-.075	1.42-1.91
B	.140-.180	3.55-4.57
C	1.0 MIN.-1.5 MAX.	24.0 MIN.-38.1 MAX.
D	.018-.022	.46-.56

DO-34
1N4532

DO-35
1N4454

COMPUTER DIODE
Switching

1N3070; JAN, JANTX 1N3070
1N4938; JAN, JANTX 1N4938

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage	200V
Steady-State Forward Current at (or below) 25°C Free Air Temperature	150mA
Peak Surge Current, 1sec	500mA
Peak Surge Current, 1μsec	2A
Continuous Power Dissipation at (or below) 25°C Free Air Temperature	250mW
Operating Temperature Range	−65°C to +175°C
Storage Temperature Range	−65°C to +200°C

FEATURES

- Double-plug Construction
- Qualified to MIL-S-19500/169
- Available in DO-7 or DO-35 package

DESCRIPTION

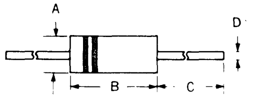
Double-plug construction affords integral positive contact by means of a thermal compression bond. Moisture free stability is ensured through hermetic sealing. The coefficients of thermal expansion of the glass case and the dumet plugs are closely matched. Hot solder dipped leads are standard.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Maximum Reverse Current @ 25°C	Maximum Reverse Current @ 150°C	Maximum Forward Voltage	Maximum Capacitance	Maximum Reverse Recovery Time
1N3070 1N4938	0.1μAdc @ 175Vdc	100μAdc @ 175Vdc	1Vdc @ I_F = 100mAdc	5pF @ V_R = 0, f = 1MHz	50ns @ I_F = 30mA I_R = 30mA I_{REC} = 1mA

MECHANICAL SPECIFICATIONS

J, JTX, JTXV 1N3070
J, JTX, JTXV 1N4938



J, JTX 1N4938

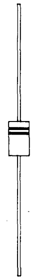
	INCHES	MILLIMETERS
A	.056-.074	1.42-1.88
B	.140-.180	3.56-4.57
C	1.0 MIN	25.4 MIN.
D	.019-.021	.48-.53

J,JTX 1N3070

	INCHES	MILLIMETERS
A	.078-.107	1.98-2.72
B	.195-.300	4.95-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

DO-7
1N3070

DO-35
1N4938



SEMICONDUCTOR
PRODUCTS
UNITRODE

COMPUTER DIODE 1N3595; JAN, JANTX & JANTXV 1N3595
150 mA, Switching

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Peak Reverse Voltage	125V
Reverse Breakdown Voltage	150V
Average Output Current	150mAdc
Surge Current, 1S	500mA
1μS	4A
Operating Temperature Range	−65°C to +175°C
Storage Temperature Range	−65°C to +200°C

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/241
- Planar Passivated Chip
- DO-7 Package

DESCRIPTION
A very useful device for medium current switching applications.

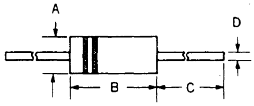
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Limits	V_{F_1} I_F = 200mAdc	V_{F_2} I_F = 100mAdc	V_{F_3} I_F = 50mAdc	V_{F_4} I_F = 10mAdc	V_{F_5} I_F = 5mAdc	V_{F_6} I_F = 1mAdc
Min	0.83Vdc	0.79Vdc	0.74Vdc	0.65Vdc	0.60Vdc	0.52Vdc
Max	1.00Vdc	0.92Vdc	0.88Vdc	0.80Vdc	0.75Vdc	0.68Vdc

Limits	I_{R_1} V_R = 125Vdc	I_{R_2} V_R = 30Vdc T_A = 125°C	I_{R_3} V_R = 125Vdc T_A = 125°C	I_{R_4} V_R = 125Vdc T_A = 150°C	C V_R = 0Vdc f = 1MHz	t_{rr} I_F = 10mAdc V_R = 35Vdc
Min	—	—	—	—	—	—
Max	1.0nAdc	0.3μAdc	0.5μAdc	3.0μAdc	8.0pF	3.0μS

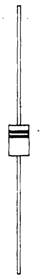
MECHANICAL SPECIFICATIONS

JAN, JANTX, JANTXV 1N3595



	INCHES	MILLIMETERS
A	.092-.130	2.34-3.30
B	.130-.300	3.30-7.62
C	1.0-1.5	25.40-38.10
D	.018-.022	.46-.56

DO-7 **IN3595**



SEMICONDUCTOR PRODUCTS
UNITRODE

COMPUTER DIODE
200mA
Low Power, Switching

1N3600; JAN, JANTX & JANTXV 1N3600
1N4150; JAN, JANTX & JANTXV 1N4150
JAN, JANTX & JANTXV 1N4150-1

FEATURES

- Metallurgical Bond
- Qualified to MIL-S-19500/231
- Planar Passivated Chip
- DO-7 or DO-35 Package
- Non-JAN Available

DESCRIPTION

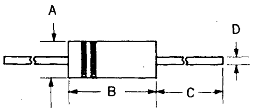
This series of switching diodes is useful in many computer switching applications, for both military and commercial systems.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage	75V
Peak Working Voltage	50V
Average Output Current	200mA
Surge Current (1sec)	0.5A
(1µsec)	4.0A
Operating Temperature Range	−65°C to +175°C
Storage Temperature Range (1N4150)	−65°C to +200°C
(1N3600)	−65°C to +175°C

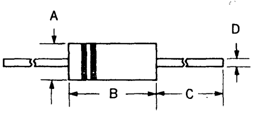
MECHANICAL SPECIFICATIONS

J, JTX & JTXV 1N3600

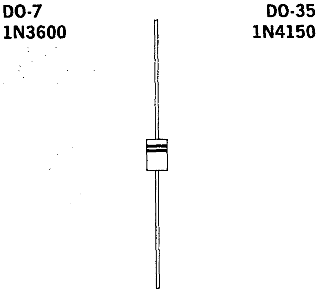


	INCHES	MILLIMETERS
A	.078-.107	1.98-2.72
B	.195-.300	4.96-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

J, JTX & JTXV 1N4150, 1N4150-1



	INCHES	MILLIMETERS
A	.056-.075	1.42-1.91
B	.140-.180	3.56-4.57
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

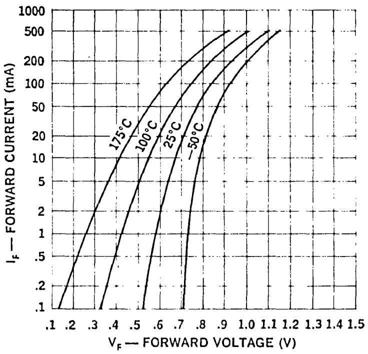


SEMICONDUCTOR PRODUCTS
UNITRODE

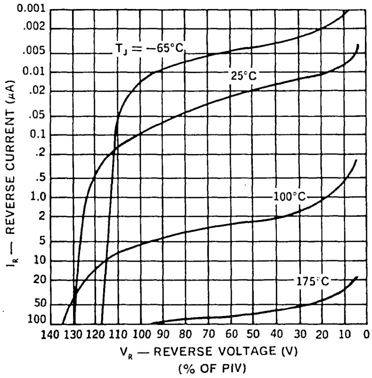
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Characteristics	Forward Voltage	Forward Voltage	Forward Voltage	Forward Voltage	Forward Voltage	Reverse Breakdown Voltage
Conditions	V_{F1} $I_F = 1$ mAdc	V_{F2} $I_F = 10$ mAdc	V_{F3} $I_F = 50$ mAdc (pulse)	V_{F4} $I_F = 100$ mAdc (pulse)	V_{F5} $I_F = 200$ mAdc (pulse)	BV $I_R = 5.0$ μAdc
Minimum Maximum	0.540 Vdc 0.620 Vdc	0.660 Vdc 0.740 Vdc	0.760 Vdc 0.860 Vdc	0.820 Vdc 0.920 Vdc	0.870 Vdc 1.00 Vdc	75 Vdc —

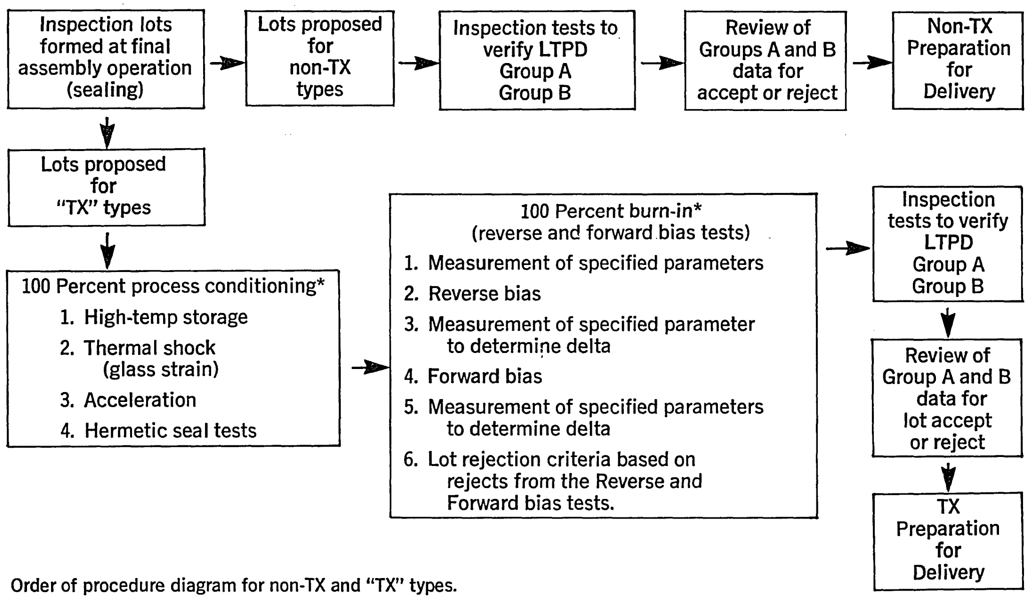
Characteristics	Reverse Current	Reverse Current	Junction Capacitance	Reverse Recovery Time	Reverse Recovery Time	Forward Recovery Time
Conditions	I_R $V_R = 50$ Vdc	I_R $V_R = 50$ Vdc $T_A = 150$°C	C $V_R = 0$ F = 1 MHz $V_{sig} = 50$ mv (p-p)	t_{rr1} $I_F = I_R =$ 10 to 200 mAdc; $R_L = 100$ ohms	t_{rr2} $I_F = I_R =$ 200 to 400 mAdc; $R_L = 100$ ohms	t_{fr} $I_F = 200$ mAdc; $t_p = 100$ nsec; $t_r = 0.4$ nsec
Maximum	0.1 μAdc	100 μAdc	2.5 pf	4 nsec	6 nsec	10 nsec



Typical Forward Current vs Voltage



Reverse Voltage vs. Reverse Current



Order of procedure diagram for non-TX and "TX" types.

COMPUTER DIODE
Switching

1N4149, 1N4151, 1N4154
1N4446, 1N4447, 1N4448
1N4449

FEATURES
- Metallurgical Bond
- Planar Passivated
- DO-35

DESCRIPTION
This series offers Metallurgical Bonding and is very popular for general purpose switching applications.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

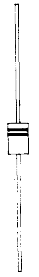
	1N4149	1N4151	1N4154	1N4446	1N4447	1N4448	1N4449
Peak Reverse Voltage	75V	75V	35V	75V	75V	75V	75V
Average Rectified Current	200mAdc						
Surge Current, 8.3 mS	500mA						
Operating Temperature Range	−65°C to +150°C						
Storage Temperature Range	−65°C to +200°C						

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage	Forward Voltage					Reverse Current V_R nA	Reverse Current @ 150°C V_R µA	Junction Capacitance @ 0V	Reverse Recovery Time t_{RR}
		@ 10mA	@ 20mA	@ 30mA	@ 50mA	@ 100mA				
1N4149	75	1.0	—	—	—	—	20 25	20 50	4pF	4nS
1N4151	75	—	—	—	1.0	—	50 50	50 50	4pF	2nS
1N4154	35	—	—	1.0	—	—	25 100	25 100	4pF	2nS
1N4446	75	—	1.0	—	—	—	20 25	20 50	4pF	4nS
1N4447	75	—	1.0	—	—	—	20 25	20 50	4pF	4nS
1N4448	75	—	—	—	—	1.0	20 25	20 50	4pF	4nS
1N4449	75	—	—	1.0	—	—	20 25	20 50	2pF	4nS

MECHANICAL SPECIFICATIONS

DO-35



SEMICONDUCTOR PRODUCTS
UNITRODE

COMPUTER DIODE
Switching

1N4152, 1N4305, 1N4444

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N4152	1N4305	1N4444
Peak Reverse Voltage	40V	75V	70V
Reverse Working Voltage	30V	50V	50V
Average Rectified Current	200mAdc		
Surge Current, 8.3 mS	500mA		
Operating Temperature Range	−65°C to +150°C		
Storage Temperature Range	−65°C to +200°C		

FEATURES

- Metallurgical Bond
- Planar Passivated
- DO-35 Package

DESCRIPTION

This series offers Metallurgical Bonding and is very popular for general purpose switching applications.

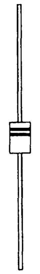
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage (V)	Forward Voltage @ 0.1mA		Forward Voltage @ 0.25mA		Forward Voltage @ 1.0mA		Forward Voltage @ 2.0mA		Forward Voltage @ 10mA		Forward Voltage @ 20mA		Forward Voltage @ 100mA	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max
1N4152	40	0.49	0.55	0.53	0.59	0.59	0.67	0.62	0.70	0.70	0.81	0.74	0.88	—	—
1N4305	75	—	—	0.505	0.575	0.55	0.65	0.61	0.71	0.70	0.85	—	—	—	—
1N4444	70	0.44	0.55	—	—	0.56	0.68	—	—	0.69	0.82	—	—	0.85	1.0

Type	Reverse Current		Reverse Current @ 150°C		Junction Capacitance @ 0V	Reverse Recovery Time t_{rr}
	V_R	(nA)	V_R	μA		
1N4152	30	50	30	50	2pF	2nS
1N4305	50	100	50	100	2pF	2nS
1N4444	50	50	50	50	2pF	7nS

MECHANICAL SPECIFICATIONS

DO-35



SEMICONDUCTOR PRODUCTS
UNITRODE

COMPUTER DIODE
150mA
Switching Diode

1N4153, JAN, JANTX & JANTXV 1N4153
1N4534, JAN, JANTX & JANTXV 1N4534

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/337
- Planar Passivated Chip
- DO-34 or DO-35 Package

DESCRIPTION
This device is particularly suited to applications where tightly controlled forward characteristics and fast recovery time are important.

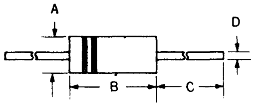
ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage	75V
Peak Working Voltage	50V
Average Output Current*	150mA
Surge Current, 1μs	2.0A
Operating Temperature Range	−65°C to +200°C
Storage Temperature Range	−65°C to +200°C

*Derate 0.86mAdc/°C for T_A above 25°C.

MECHANICAL SPECIFICATIONS

J, JTX & JTXV 1N4153
J, JTX & JTXV 1N4534

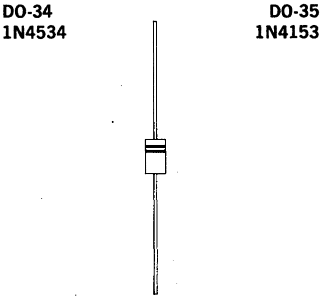


J, JTX & JTXV 1N4534

	INCHES	MILLIMETERS
A	.050-.075	1.27-1.91
B	.080-.120	2.03-3.05
C	1.0-1.5	25.4-38.1
D	.018-.022	.46-.56

J,JTX & JTXV 1N4153

	INCHES	MILLIMETERS
A	.056-.075	1.42-1.91
B	.140-.180	3.56-4.57
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

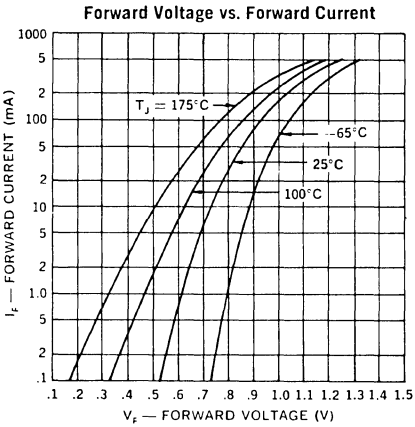


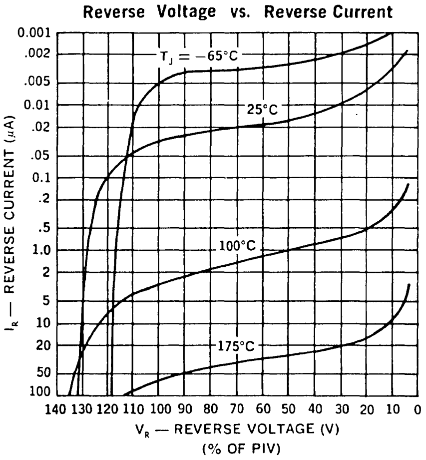
SEMICONDUCTOR PRODUCTS
UNITRODE

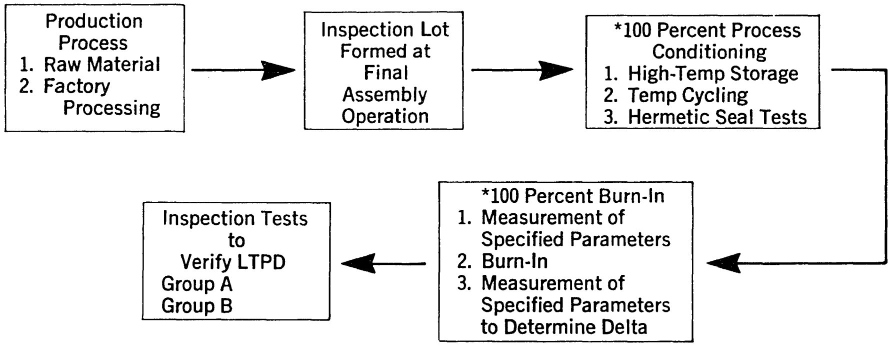
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Limit	V_{F1} $I_F = 100\ \mu$Adc	V_{F2} $I_F = 250\ \mu$Adc	V_{F3} $I_F = 1$ mAdc	V_{F4} $I_F = 2$ mAdc	V_{F5} $I_F = 10$ mAdc	V_{F6} $I_F = 20$ mAdc
Min	0.490Vdc	0.530Vdc	0.590Vdc	0.620Vdc	0.700Vdc	0.740Vdc
Max	0.550Vdc	0.590Vdc	0.670Vdc	0.700Vdc	0.810Vdc	0.880Vdc

Limit	I_R $V_R = 50$V	I_{R2} $V_R = 50$V $T_A = 150$°C	C $V_R = 0$ f = 1MHz	t_{rr} $I_F = I_R = 10$mAdc $R_L = 100$ ohms	Reverse Breakdown Voltage $I_R = 5.0\mu$Adc
Min	—	—	—	—	75V
Max	0.05μAdc	50μAdc	2.0pF	4ns	—







*Order of the tests in the blocks shall be performed as shown.

Order of procedure diagrams for TX types only.

COMPUTER DIODE
Switching

1N4450, 1N4451, 1N4453

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N4450	1N4451	1N4453
Peak Reverse Voltage	40V	40V	30V
Reverse Working Voltage	30V	30V	20V
Average Rectified Current		200mAdc	
Surge Current, 8.3 mS		500mA	
Operating Temperature Range		−65°C to +150°C	
Storage Temperature Range		−65°C to +200°C	

FEATURES

- Metallurgical Bond
- Planar Passivated
- DO-35 Package

DESCRIPTION

This series offers Metallurgical Bonding and is very popular for general purpose switching applications.

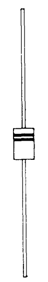
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage (V)	Forward Voltage @ 0.01mA		Forward Voltage @ 0.1mA		Forward Voltage @ 1.0mA		Forward Voltage @ 10mA		Forward Voltage @ 100mA		Forward Voltage @ 200mA		Forward Voltage @ 300mA	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max
1N4450	40	—	—	0.42	0.54	0.52	0.64	0.64	0.76	0.80	0.96	—	1.0	—	—
1N4451	40	—	—	0.40	0.50	0.51	0.61	0.62	0.72	0.75	0.875	—	—	—	1.0
1N4453	30	0.43	0.55	0.51	0.63	0.60	0.71	0.69	0.80	0.80	0.92	—	—	—	—

Type	Reverse Current		Reverse Current @ 150°C		Junction Capacitance @ 0V	Reverse Recovery Time t_{rr}
	V_R	(nA)	V_R	μA		
1N4450	30	50	30	50	4pF	4nS
1N4451	30	50	30	50	6pF	10nS
1N4453	20	50	20	50	30pF	—

MECHANICAL SPECIFICATIONS

DO-35



SEMICONDUCTOR PRODUCTS
UNITRODE

COMPUTER DIODE
High Conductance

1N4452, 1N4607, 1N4608

FEATURES
- Metallurgical Bond
- Planar Passivated
- High Conductance
- DO-35 Package

DESCRIPTION
This series offers Metallurgical Bonding and is specifically designed for high conductance switching applications such as core memories.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N4452	1N4607	1N4608
Peak Reverse Voltage	40V	85V	85V
Reverse Working Voltage	30V	50V	50V
Average Rectified Current	400mAdc		500mAdc
Surge Current, 8.3 mS	1A		
Operating Temperature Range	-65°C to +150°C		
Storage Temperature Range	-65°C to +200°C		

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage	Forward Voltage @ 0.1mA min		Forward Voltage @ 1.0mA min		Forward Voltage @ 10mA min		Forward Voltage @ 100mA min		Forward Voltage @ 250mA min		Forward Voltage @ 350mA min		Forward Voltage @ 400mA min		Forward Voltage @ 500mA min	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
1N4452	40V	0.42	0.54	0.51	0.62	0.60	0.71	0.71	0.83	—	—	—	—	—	—	—	—
1N4607	85V	0.39	0.50	0.50	0.60	0.61	0.72	0.74	0.87	0.81	0.95	—	1.0	—	1.1	—	—
1N4608	85V	0.39	0.49	0.50	0.60	0.61	0.71	0.74	0.85	0.81	0.93	0.84	0.96	—	—	—	1.1

Type	Forward Voltage @ 600mA		Forward Voltage @ 1000mA		Reverse Current		Reverse Current @ 100°C		Reverse Current @ 150°C		Junction Capacitance @ 0V	Reverse Recovery Time t_{rr}
	min	max	min	max	V_R	nA	V_R	μA	V_R	μA		
1N4452	—	1.0	0.90	1.2	30	50	—	—	30	50	—	50nS
1N4607	—	—	—	—	50	100	50	25	—	—	4pF	10nS
1N4608	—	—	—	—	50	100	50	25	—	—	4pF	10nS

* t_{rr} @ $I_f = I_r = 10mA$, $I_{rec} = 1mA$

MECHANICAL SPECIFICATIONS

DO-35

COMPUTER DIODE

500mA
Switching Diode

1N4500, JAN & JANTX 1N4500

FEATURES
- Metallurgical Bond
- Qualified to MIL-S-19500/403
- Planar Passivated Chip
- DO-35 Package

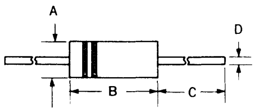
DESCRIPTION
This device is a fast switching, high conductance diode for military, space, high rel and other systems.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

Reverse Breakdown Voltage	80Vdc
Peak Working Voltage	75Vpk
Average Output Current	300mAdc
Surge Current, 1sec	0.5A
1μsec	4.0A
Operating Temperature Range	—65°C to +175°C
Storage Temperature Range	—65°C to +200°C

MECHANICAL SPECIFICATIONS

J & JTX 1N4500



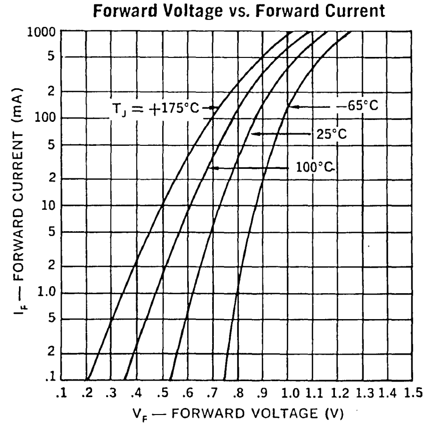
	INCHES	MILLIMETERS
A	.060-.107	1.52-2.72
B	.140-.300	3.55-7.62
C	1.0 MIN.-1.5 MAX.	25.4 MIN.-38.1 MAX.
D	.018-.022	.46-.56

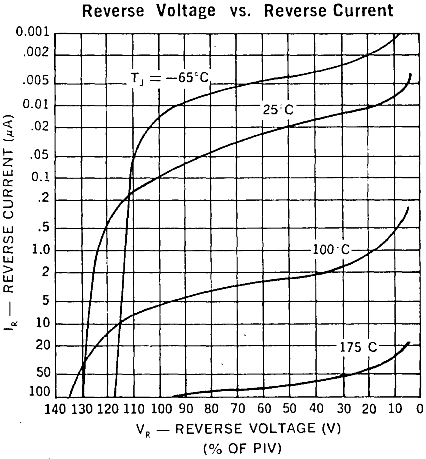
DO-35
1N4500

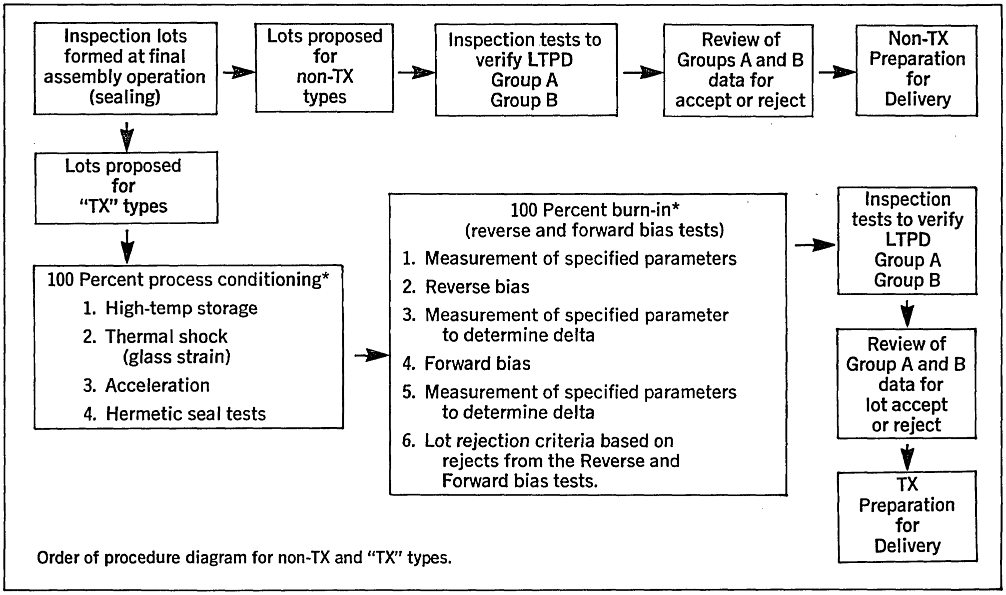
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Limits	V_{F1} $I_F = 250\mu$Adc	V_{F2} $I_F = 1.0$mAdc	V_{F3} $_F = 10$mAdc	V_{F4} $I_F = 20$mAdc	V_{F5} 1/ $I_F = 300$mAdc	C $V_R = 0$ 100 kHz $\leqslant f \leqslant$ 1 MHz $v_{sig} = 50$ mv (p-p)
	mVdc	mVdc	mVdc	mVdc	Vdc	pF
Minimum	470	520	640	670	—	—
Maximum	560	600	720	770	1.10	4.0

	I_R $V_R = 75$Vdc	B_V $I_R = 5\mu$Adc	I_R $V_R = 75$Vdc $T_A = 150$°C	t_{rr} $I_F = I_R =$ 10 mAdc: $R_L = 100$ ohms
	nAdc	Vdc	μAdc	nsec
Minimum	—	80	—	—
Maximum	100		100	6.0







Order of procedure diagram for non-TX and "TX" types.

COMPUTER DIODE
General Purpose Switching

1N4727

FEATURES
- Metalurgical Bond
- Low Capacitance
- Low Stored Charge

DESCRIPTION
This Unitrode very high speed silicon planar passivated epitaxial diode, is useful for computer circuits, high speed instrumentation and general purpose applications.

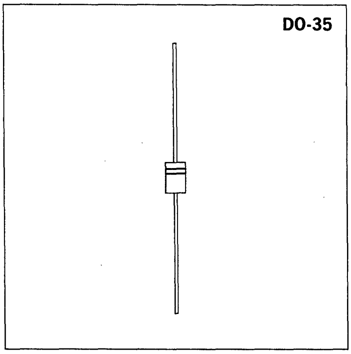
ABSOLUTE MAXIMUM RATINGS, at 25°C

Reverse Breakdown Voltage, (at I_R = 5μA) (Min.)	30V
Peak Working Voltage	20V
Average Rectified Current	75mA
Forward Steady-State DC Current	115mA
Recurrent Peak Forward Current	225mA
Peak Forward Surge Current (1μS @ 1% Duty Cycle)	2000mA
Power Dissipation (with Heatsinking .250" from end of diode body)	
@ 25°C	500mW
@ 125°C	200mW
Linear Power Derating Factor	
Ambient Temperature between 25°C and 125°C	3.0mW/°C
Ambient Temperature above 125°C	4.0mW/°C
Operating Temperature	−65°C to +175°C
Storage Temperature	−65°C to +200°C

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Limits	Forward Voltage	Reverse Current		Capacitance	Stored Charge
	I_F = 10mA	V_R = 20V	V_R = 20V T_A = 100°C	V_R = 0V f =1MHz	I_F = 10mA
Typ.	0.79V	0.02μA	3.0μA	1.5pf	24pC
Max.	0.85V	0.1μA	10.0μA	4.0pf	40pC

MECHANICAL SPECIFICATIONS



SEMICONDUCTOR
PRODUCTS
UNITRODE

COMPUTER DIODE
SWITCHING, **UNIBOND** SERIES

1N6638, JTX, JTXV 1N6638U, JTX, JTXV
1N6642, JTX, JTXV 1N6642U, JTX, JTXV
1N6643, JTX, JTXV 1N6643U, JTX, JTXV

FEATURES

- Metallurgical Bond
- Qualified to MIL-S-19500/578
- Planar Passivated Chip
- Available in MELF Configuration
- Thermally Matched Construction
- Non-Cavity Design

DESCRIPTION

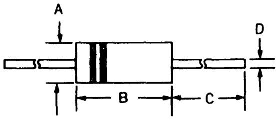
This specification details the capabilities of a superior mechanically rugged diode. Designed to replace silver button 1N4148-1 and 1N4150-1 small signal diodes used in harsh environments such as coated, potted or multilayer circuit board applications.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	1N6638	1N6642	1N6643
Peak Reverse Voltage	150V	100V	75V
Reverse Working Voltage	125V	75V	50V
Average Rectified Current	300mAdc	300mAdc	300mAdc
Surge Current, 8.3ms	2.5A	2.5A	2.5A
Operating Temperature Range		−65°C to +200°C	
Storage Temperature Range		−65°C to +200°C	
Power Dissipation @ T_A = 25°C with $R_{\theta LA}$ @ ℓ = ⅜ inches, 100°C/W			750mW
Power Derating Factor			4.25mW/°C
Thermal Resistance, Junction to Lead, ⅜ inch			120°C/W

MECHANICAL SPECIFICATIONS

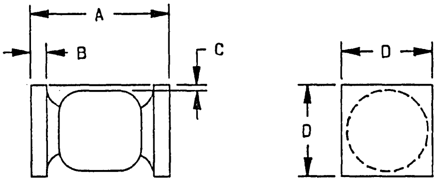
1N6638, 1N6642, 1N6643



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	.056	.075	1.42	1.91
B	.140	.180	3.56	4.57
C	1.0	1.5	25.4	38.10
D	.018	.022	.46	.56

DO-35

1N6638U, 1N6642U, 1N6643U



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	.165	.195	4.19	4.95
B	.019	.028	0.48	0.71
C	.003	—	0.08	—
D	.070	.085	1.78	2.16

SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type*	Maximum Reverse Current				Minimum Breakdown Voltage @100μA	Maximum Forward Voltage		
	@ V_R as noted		at 150°C			@ I_F (pulsed) noted		at 150°C
1N6638	25nA @ 20Vdc	0.5μA @ 125Vdc	40μA @20V	100μA @ 125Vdc	$150V_{pk}$	0.8Vdc @ 10mA	1.1Vdc @ 200mA	0.65Vdc @10mA
1N6642	25nA @ 20Vdc	0.5μA @ 75Vdc	50μA @ 20Vdc	100μA @ 75Vdc	$100V_{pk}$	1.0Vdc @ 10mA	1.2Vdc @ 100mA	0.8Vdc @ 10mA
1N6643	50nA @ 20Vdc	0.5μA @ 50Vdc	75μA @20Vdc	160μA @ 50Vdc	$75V_{pk}$	1.0Vdc @ 10mA	1.2Vdc @ 100mA	—

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type*	Maximum Forward Voltage @ −55°C	Maximum Capacitance @ 1MHz with V_{sig} = 50mV (pk-pk)	Maximum Forward Recovery Voltage and Time (@ I_F = 50 with I_F = 50mA, t_r = 1ns)		Maximum Reverse Recovery Time (@ $I_F = I_R$ = 10mA, i_{REC} = 1mA)
1N6638	1.2Vdc @ 200mA	2pf @ $V_R = 0$ 1.4pf @ V_R = 1.4Vdc	$5.0V_{pk}$	20ns	4.5ns
1N6642	1.2Vdc @ 100mA	5.0pf @ $V_R = 0$ 2.8pf @ V_R = 1.4Vdc	$5.0V_{pk}$	20ns	5.0ns
1N6643	1.4Vdc @ 100mA	5.0pf @ $V_R = 0$ 2.8pf @ V_R = 1.4Vdc	$5.0V_{pk}$	20ns	6.0ns

*Military U-suffix (surface mount) types have the same specifications.

MECHANICAL INTEGRITY:

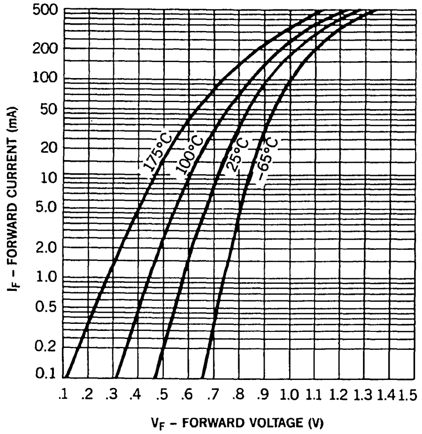
These devices have been specifically designed to eliminate intermittent opens over the entire operating temperature range which might result from thermal or mechanical stress.

Intended to replace 1N4148-1 and 1N4150-1 types in harsh environments, these devices have a unique die and package design. The die is manufactured using a process that provides anode contact over the complete pin diameter and equal to the cathode contact area.

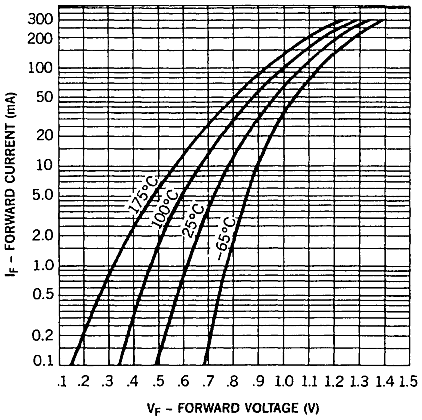
The terminal pins, silicon die and glass are thermally matched. The passivated die is sealed in a non-cavity glass body.

This device is capable of passing the most severe mechanical tests of MIL-STD-750 including monitored lead pull, mission profile testing and a hard potting environment.

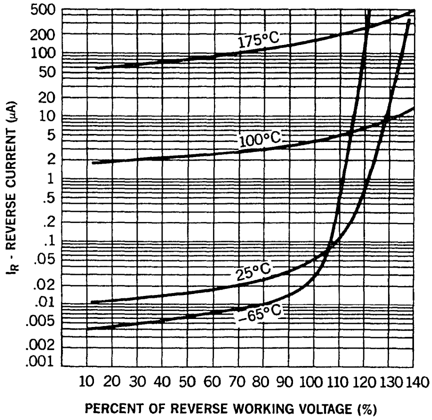
Typical Forward Current
vs Forward Voltage
1N6638



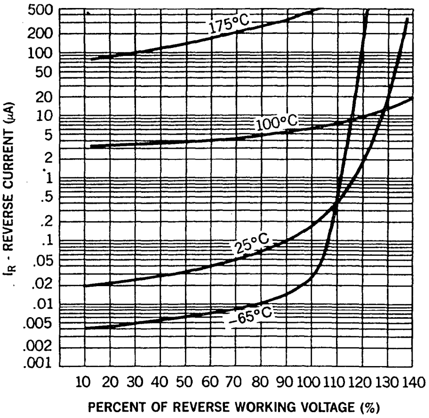
Typical Forward Current
vs Forward Voltage
1N6642, 1N6643



Typical Reverse Current
vs Reverse Voltage
1N6638, 1N6642



Typical Reverse Current
vs Reverse Voltage
1N6643



COMPUTER DIODE
Switching

BAW24-BAW27
BAW75-BAW76

FEATURES
- Metallurgical Bond
- Planar Passivated
- DO-35

DESCRIPTION
This series offers Metallurgical Bonding and is very popular for general purpose switching applications.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	BAW24	BAW25	BAW26	BAW27	BAW75	BAW76
Peak Reverse Voltage	50V	50V	75V	75V	35V	75V
Average Rectified Current	600mA	600mA	600mA	600mA	300mA	300mA
Peak Forward Current	400mA	400mA	400mA	400mA	500mA	500mA
Operating Temperature Range	—65°C to +150°C					
Storage Temperature Range	—65°C to +200°C					

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

	Peak Inverse Voltage	Forward Voltage (Max V)				Reverse Current		Junction Capacitance @ OV	Reverse Recovery Time t_{RR}
Type	(V)	@ 30mA	@ 50mA	@ 100mA	@ 200mA	(V_R)	(μA)	(pF)	(nS)
BAW24	50	—	1.0	—	—	40	0.1	4	6
BAW25	50	—	0.8	—	—	40	0.1	4	6
BAW26	75	—	—	1.0	—	60	0.1	4	6
BAW27	75	—	—	—	1.0	40	0.1	4	6
BAW75	35	1.0	—	—	—	35	5.0	4	4
BAW76	75	—	—	1.0	—	75	5.0	2	4

MECHANICAL SPECIFICATIONS

DO-35

COMPUTER DIODE
Switching

BAY41-BAY43
BAY60
BAX12

FEATURES
- Metallurgical Bond
- Planar Passivated
- DO-35

DESCRIPTION
This series offers Metallurgical Bonding and is very popular for general purpose switching applications.

ABSOLUTE MAXIMUM RATINGS, AT 25°C

	BAY41	BAY42	BAY43	BAY60	BAX12
Peak Reverse Voltage	40V	60V	80V	25V	90V
Average Rectified Current	225mA	225mA	225mA	115mA	400mA
Peak Forward Current	600mA	600mA	600mA	225mA	800mA
Operating Temperature Range	−65°C to +150°C				
Storage Temperature Range	−65°C to +200°C				

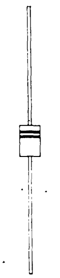
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Type	Peak Inverse Voltage	Maximum Forward Voltage						Reverse Current		Junction Capacitance @ 0V	Reverse Recovery Time T_{rr} Condition 10/10/1
		@ 10mA	@ 30mA	@ 50mA	@ 100mA	@ 200mA	@ 400mA				
	V	V	V	V	V	V	V	V_R	µA	pF	ns
BAY41	40	—	—	—	—	1.0	—	40	5	5	8.5
BAY42	60	—	—	—	—	1.0	—	60	5	5	15
BAY43	80	—	—	—	—	1.0	—	80	5	5	15
BAY60	25	—	1.0	—	—	—	—	25	.1	4	4
BAX12*	90	.75	—	.84	.90	1.0	1.25	90	100	20	15

*Maximum reverse energy 5mW/second.

MECHANICAL SPECIFICATIONS

DO-35



PIN DIODES 6

PIN DIODES

PRODUCT SELECTION GUIDE

For applications information, see PIN Diode Designers' Handbook and Catalog (PD-500C)

SWITCHING PIN DIODES

Type	Voltage Rating Range	Capacitance (100V, 1MHz) C_T max.	Forward Resistance (100mA, 100MHz) R_S max.	Parallel Resistance (100V, 100MHz) R_P min.	Average Thermal Resistance θ_A max.	Average Power Dissipation P_A max.	Peak Power Dissipation P_p max.	Carrier Lifetime $I_F = 10mA$ τ min.
	(V)	(pF)	(Ω)	(KΩ)	(°C/W)	(W)	(KW)	(μS)
UM4000	100-1000	3.0	0.5	10	6	25	100	5.0
UM4900	100-600	3.0	0.5	10	4	37	100	5.0
UM6000	100-1000	0.5	1.7	300	25	6	25	1.0
UM6200	100-400	1.1	0.4	350	25	6	10	0.6
UM6600	100-1000	0.4	2.5	300	35	4	13	1.0
UM7000	100-1000	0.9	1.0	200	15	10	60	2.5
UM7100	100-800	1.2	0.6	150	15	10	35	2.0
UM7200	100-400	2.2	0.25	70	15	10	20	1.5

HIGH POWER ATTENUATOR & MODULATOR PIN DIODES

Type	Voltage Ratings Range	Total Capacitance (0V, 100MHz) C_T max.	RF Resistance (100mA, 100MHz) R_S max.	RF Resistance (10μA, 100MHz) R_S min.	Average Thermal Resistance θ_A max.	Average Power Dissipation P_A max.	Carrier Lifetime $I_F = 10mA$ τ min.
	(V)	(pF)	(Ω)	(Ω)	(°C/W)	(W)	(μs)
UM4300	100-1000	2.2	1.5	1000	8	18	6.0
UM7300	100-1000	0.7	3.0	3000	20	7.5	4.0

LOW CAPACITANCE SWITCH AND ATTENUATOR PIN DIODES

Type	Voltage Rating (I_R=10μA)	Total Capacitance (50V, 1MHz) C_T max.	RF Resistance (10μA, 100 MHz) R_S min.	RF Resistance (20mA, 100 MHz) R_S max.	RF Resistance (100mA, 100MHz) R_S max.	Carrier Lifetime (I_R = 10mA) τ min.
	(V)	(pF)	(Ω)	(Ω)	(Ω)	(μs)
1N5767 (5082-3080)	100	0.4	1000 3000 typ.	8 4 typ.	2.5 1.5 typ.	1

LOW DISTORTION ATTENUATOR PIN DIODES

Type	Voltage Rating I_R=10μA	Total Capacitance C_T max.	RF Resistance (100mA, 100MHz) R_S max.	RF Resistance (10μA, 100 MHz) R_S min.	Forward Current (R_S = 75Ω F = 100MHz) Typ.	Carrier Lifetime (I_F=10mA) Typ.
	(V)	(pF)	(Ω)	(Ω)	I_F (mA)	τ (μS)
1N5957	100	0.4 (50V, 1MHz)	3.5	1500	1.0	2
UM9301	75	0.8 (0V, 100MHz)	3.0	3000	1.1	4

TWO WAY RADIO ANTENNA SWITCHES

Type	Voltage Rating (I_R=10μA)	Total Capacitance (0V, 100MHz) C_T max.	RF Resistance (50mA, 100MHz) R_S max.	Transmit Harmonic Distortion f_a = 50MHz I = 20mA	Receive Third Order Distortion (Pin-10mW, 0V Bias) f_a = 50MHz f_b = 51MHZ Max.	Average Power Dissipation P_A Max.
	(V)	(pF)	(Ω)	(dB)	(dB)	(W)
UM9401 and UM9402	50	1.5	1.0	−80	−60	5.5
UM9415	50	4.0	1.0	−80	−60	10

PIN DIODES

PRODUCT SELECTION GUIDE

For applications information, see PIN Diode Designers' Handbook and Catalog (PD-500C)

LOW RESISTANCE ANTENNA SWITCHING PIN DIODES

Type	Voltage Rating (I_R = 10μA)	Total Capacitance (50V, 1MHz) C_T max	RF Resistance (10mA, 100MHz) R_S max	Forward Bias Third Order I_M Distortion I = 10mA f_a = 43MHz f_b = 44MHz max	Reverse Bias Third Order I_M Distortion V = 50V f_a = 43MHz f_b = 44MHz max	Average Power Dissipation P_A max
	(V)	(pF)	(Ω)	(dB)	(dB)	(W)
UM9701	100	1.8	.8	-90	-90	2.5

MICROSTRIP PACKAGED PIN DIODES

Type	Series Resistance R_S max. (Ω)	Parallel Resistance R_P min. (KΩ)	Total Capacitance C_T max. (pF)	Carrier Lifetime τ min. (μS)	Voltage Rating (V)	Forward Voltage V_F typ. (V)
	100mA, 1GHz	0V, 1GHz	0V, 1GHz	I_F = 10mA	I_R = 10μA	I_F = 100mA
UM9601-UM9604	0.6	5	1.2	2.0	100, 400	.85
UM9605-UM9608	1.7	7	0.5	1.0	100, 400	.95

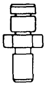
RADIATION DETECTOR

Type	Photocurrent 10^6 Rad (Si)/s, 50V Flash X-Ray, 2.5 MeV mA min.	Maximum Photocurrent	Reverse Current 50V μA max.	Capacitance f = 1 MHz, V = 50V pF max.
UM9441	4.0	3A dc, 3A²s pulsed	1.0	10

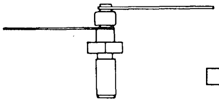
PACKAGE STYLES

A Style
Basic Diode

B Style
Round Axial Leads



***C Style**
Stud

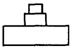


***D Style**
Insulated Stud

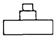
E Style
Ribbon Axial Leads

*Not available for UM6000, UM6600, UM6200.

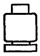
For UM9600 Series



Cup
UM9601/2



Cup
UM9605/6



Flange
UM9603/4

Flange
UM9607/8

Drawings are not actual size.

The following series are available in surface mount packaging: UM7000, UM7200, UM7300, UM9301, UM9401, UM9415 and are also available with Round or Square End Caps.

PIN DIODES

PRODUCT SELECTION GUIDE

VOLTAGE RATINGS

Series	100V	200V	400V	600V	800V	1000V
UM4000	✓	✓		✓		✓
UM4300	✓	✓		✓		✓
UM4900	✓	✓		✓		
UM6000	✓	✓		✓		✓
UM6200	✓	✓	✓			
UM6600	✓	✓		✓		✓
UM7000	✓	✓		✓		✓
UM7100	✓	✓	✓		✓	
UM7200	✓	✓	✓			
UM7300	✓	✓		✓		✓

ORDERING INFORMATION

Part numbers of Switching and High Power Attenuator PIN diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the voltage rating in hundreds of volts. The remaining letters denote the package style. Reverse polarity is available for C, and D, style and denoted by adding second letter R.

For Example: UM|60|06|B|

Series 6000 | 600 Volts | Style B

Generic Pin Diode Type	Typical V_{BR}	Voltage Ratings (V_R)
UM4300, UM7300	3000V	100, 200, 600, 1000 V
UM4000, UM6000, UM7000	2000V	100, 200, 600, 1000 V
UM7100	1200V	100, 200, 400, 800 V
UM6200, UM7200	600V	100, 200, 400 V

Typical PIN Diode Switching Speeds (T_{RF})

Generic Pin Diode Type	To 10 mA from 100V	To 50 mA from 100V	To 100mA from 100V
UM4000, UM6000, UM7000	5.0μs	2.5μs	1.5μs
UM7100	2.0μs	0.8μs	0.5μs
UM6200, UM7200	0.4μs	0.2μs	0.1μs

UM PIN DIODE PACKAGE MATRIX

Terminal Plug Diameter (inches)

I — Region Thickness (inches) Min.

	.030	.045	.090
.002	6200	7200, 9701	CALL FACTORY
.004	CALL FACTORY	9401, 7100, 9601	CALL FACTORY
.005	CALL FACTORY	CALL FACTORY	CALL FACTORY
.007	6000, IN5767	7000	4900, 4000, 9415
.009	IN5957	CALL FACTORY	CALL FACTORY
.013	CALL FACTORY	7300, 9301	4300

Increasing Distortion ↑ ↓ **Increasing Breakdown Voltage V_{BR}**

Decreasing C_T ←

→ **Decreasing R_S**

OPTIONAL HIGH RELIABILITY (HR2) SCREENING

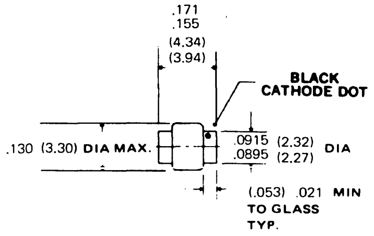
The following tests are performed on 100% of the devices specified with "UM" prefix.

SCREEN	MIL-STD-750 METHOD	CONDITIONS
1. High Temperature	1032	24 Hours @ T_A = 175°C
2. Temperature Cycling	1051	C, 20 Cycles, −65 to +175°C. No dwell required @ 25°C, t ⩾ 10 min. at extremes
3. Hermetic Seal a. Gross	1071	E, ZYGLO
4. Interim Electrical Parameters	GO/NO GO	I_R @ 25°C
5. High Temperature Reverse Bias (HTRB)	1038	A, 96 Hours. T_A = 125°C, V_R = 80% of rating (max. 200V)
6. Final Electrical Parameters	GO/NO GO	I_R @ 25°C, PDA = 10% (final electricals) Sample test C_T + RS @ L.T.P.D. = 10

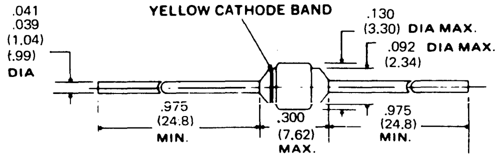
MECHANICAL SPECIFICATIONS
UM4000 SERIES
UM4300 SERIES

Dimensions — English/Metric

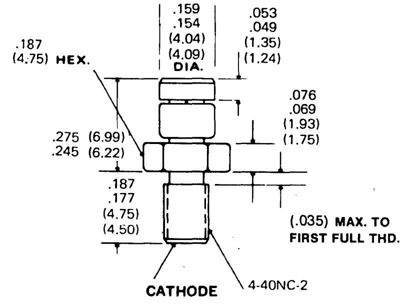
STYLE A



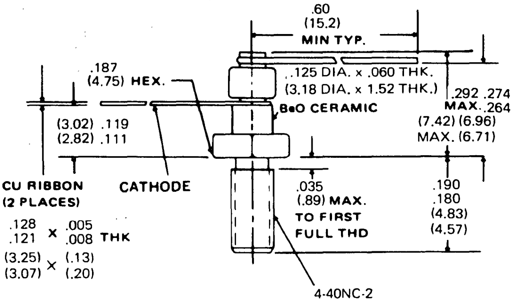
STYLE B



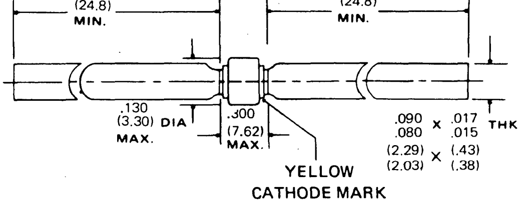
STYLE C
STUD



STYLE D
INSULATED STUD

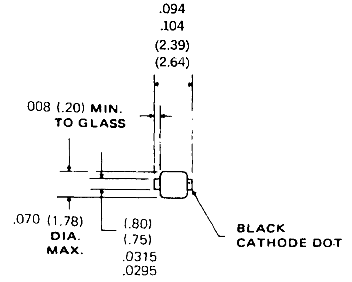


STYLE E
RIBBON LEADS

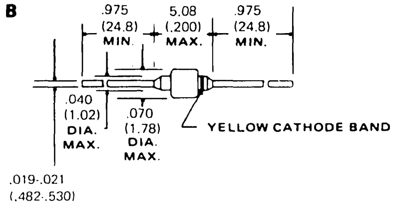


MECHANICAL SPECIFICATIONS

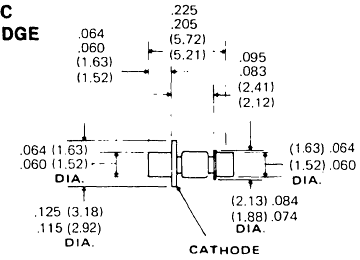
STYLE A



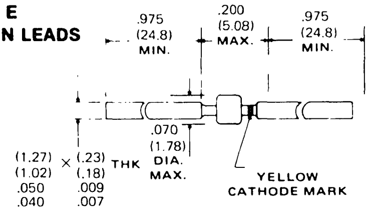
STYLE B



STYLE C
CARTRIDGE



STYLE E
RIBBON LEADS

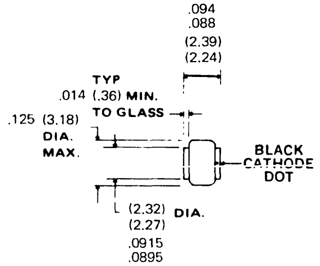


MECHANICAL SPECIFICATIONS (continued)

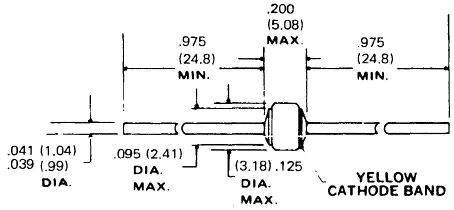
UM 4900 Series

Dimensions — English/Metric

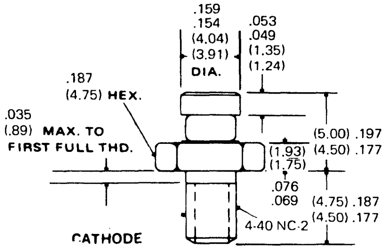
STYLE A



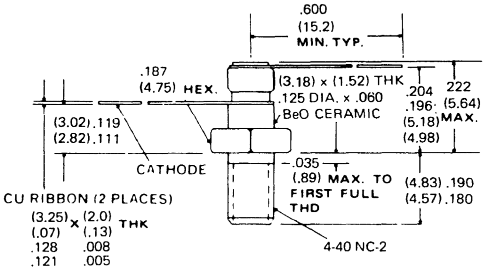
STYLE B



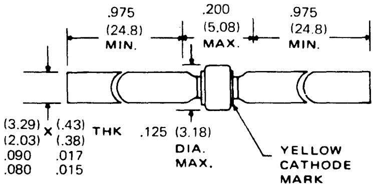
STYLE C
STUD



STYLE D
INSULATED STUD



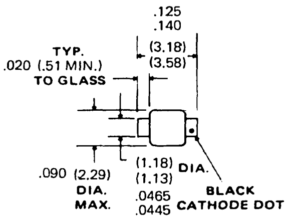
STYLE E
RIBBON LEADS



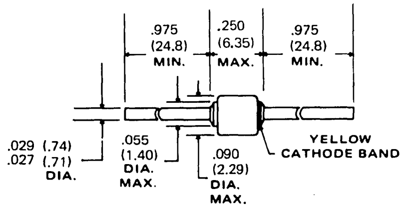
MECHANICAL SPECIFICATIONS (continued)
UM7000 UM7100 UM7200 SERIES
UM7300 SERIES

Dimensions — English/Metric

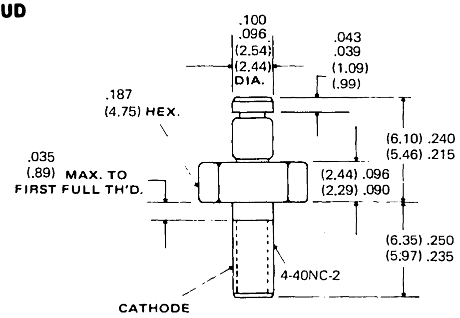
STYLE A



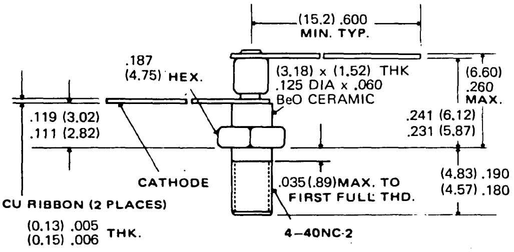
STYLE B



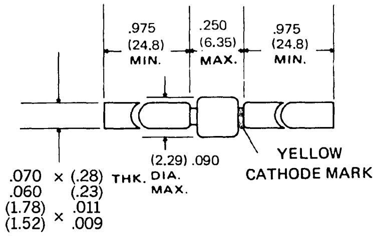
STYLE C
STUD



STYLE D
INSULATED STUD



STYLE E
RIBBON LEADS



PIN DIODE

1N5767 (5082 - 3080)SERIES
1N5957 SERIES

Features

- Useful attenuation from 1 μA to 100 mA bias.
- Capacitance below 0.4 pF.
- Low distortion in switches and attenuators.
- Rugged Unitrode construction.

Description

The 1N5767 and 1N5957 PIN diodes are based upon low capacitance PIN chips designed with long minority carrier lifetime, and thick intrinsic width. Thus operation as low as 1 MHz is possible with low distortion. Additionally, the low diode capacitance allows useful operation well into the microwave frequency range.

The 1N5767 (5082-3080) is a general purpose low power PIN diode designed for both switch and attenuator applications.

The 1N5957 is primarily used as an attenuator PIN diode and is particularly suitable wherever current controlled, wide dynamic range resistance elements are required. The 1N5957 has also been characterized for the 75Ω attenuator, commonly employed in CATV systems.

MAXIMUM RATINGS

Reverse Voltage **(V_R) — Volts** **(I_R = 10 μA)**	100V

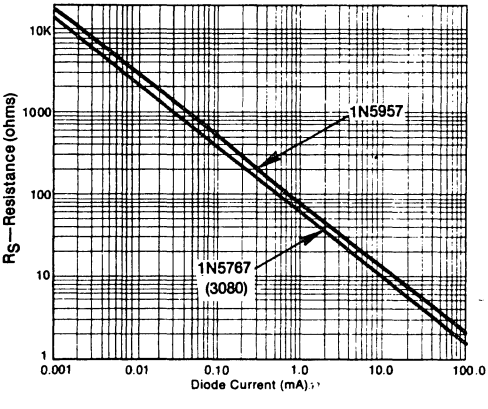
Average Power Dissipation: (25°C) Free Air (P_A)	400 mW (Derate linearly to 175°C)

Operating and Storage Temperature Range	−65°C to +175°C

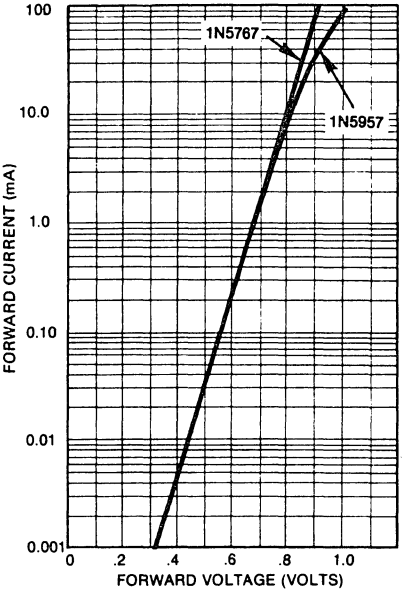
Electrical Specifications (25 °C)

Test	Symbol	1N5767 (5082-3080)	1N5957	Conditions
Total Capacitance (Max)	C_T	0.4 pF	0.4 pF	50V, 1 MHz
Series Resistance	R_S	1000Ω(min) 2000Ω(typ)	1500Ω(min) 3000Ω(typ)	10 μA, 100 MHz
Series Resistance	R_S	8Ω(max) 4Ω(typ)	8Ω(max) 6Ω(typ)	20 mA, 100 MHz
Series Resistance	R_S	2.5Ω(max) 1.5Ω(typ)	3.5Ω(max) 2.0Ω(typ)	100 mA, 100 MHz
Carrier Lifetime (Min)	τ	1.0 μS	1.5(min) 2(typ)	I_F = 10 mA
Reverse Current (Max)	I_R	10 μA	10 μA	V_R = Rating
Current for R_S = 75Ω (typ)	I_{75}	0.7 mA	0.8 mA-1.2 mA	R_S = 75Ω
Return Loss (typ)	—	30 dB	30 dB	Diode terminates 75Ω line
Second Order Distortion (typ)	—	−40 dB	−50 dB	Bridged tee attenuator atten. = 10 dB
Third Order Distortion (typ)	—	−60 dB	−65 dB	P_{in} = 50 dBmV f_1 = 10 MHz, f_2 = 13 MHz

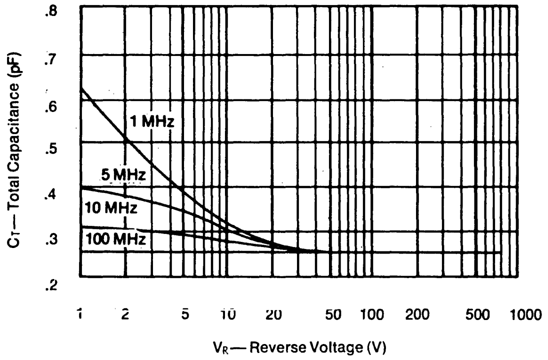
RESISTANCE VS FORWARD CURRENT (TYPICAL)



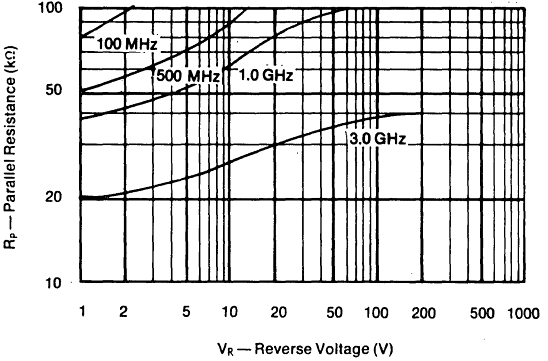
FORWARD VOLTAGE VS FORWARD CURRENT (TYPICAL)



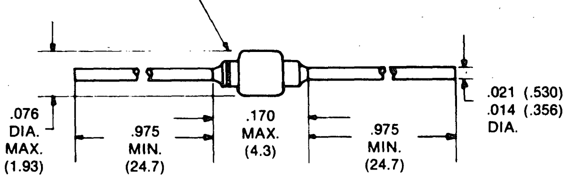
TOTAL CAPACITANCE VS REVERSE VOLTAGE



PARALLEL RESISTANCE VS REVERSE VOLTAGE



MECHANICAL SPECIFICATIONS



Dimensions: Inches (Millimeters)

PIN DIODE

UM4000 SERIES
UM4900 SERIES

Features

- Power dissipation to 37.5W
- Voltage ratings to 1000V
- Series resistance rated at 0.5Ω
- Carrier lifetime greater than 5μs

Description

The UM4000 and UM4900 series feature high power PIN diodes with long carrier lifetimes and thick I-regions. They are especially suitable for use in low distortion switches and attenuators, in the HF through S band frequencies. While both series are electrically equivalent, the UM4900 series have higher power ratings due to a shorter thermal path between chip and package. High charge storage and long carrier lifetime enable high RF levels to be controlled with relatively low bias current. Similarly, peak RF voltages can be handled well in excess of applied reverse bias voltage.

Both series have been fully qualified in high power UHF phase shifters and megawatt peak-power duplexers, accumulating thousands of hours of proven performance. Both types have been used in the design of antenna selectors and couplers, where inductive and capacitive elements are switched in and out of filter or cavity networks.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM4000		UM4900	
		P_D	θ	P_D	θ
A	25°C Pin Temperature	25W	6°C/W	37.5W	4°C/W
B&E (Axial Leads)	½ in. (12.7mm) Total Length to 25°C Contact	12W	12.5°C/W	12W	12.5°C/W
B&E (Axial Leads)	Free Air	2.5W	—	2.5W	—
C (Studded)	25°C Stud Temperature	25W	6°C/W	37.5W	4°C/W
D (Insulated Stud)	25°C Stud Temperature	18.75W	8°C/W	25W	6°C/W

Peak Power Dissipation Rating

All Packages	1 μs Pulse (Single) at 25 °C Ambient	100 KW

Operating and Storage Temperature Range: −65°C to +175°C

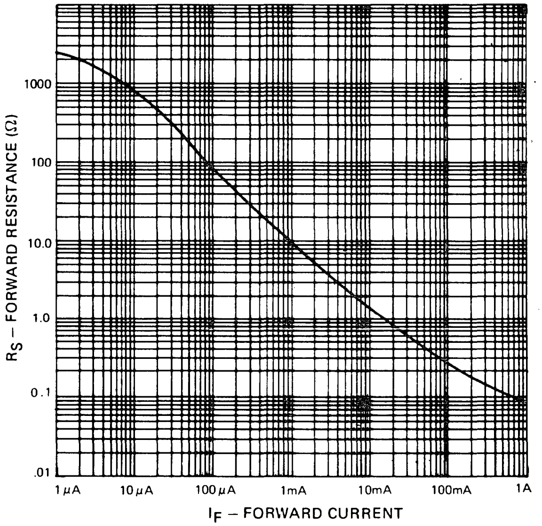
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μ Amps)	Types	
100	UM4001	UM4901
200	UM4002	UM4902
400	—	—
600	UM4006	UM4906
1000	UM4010	—

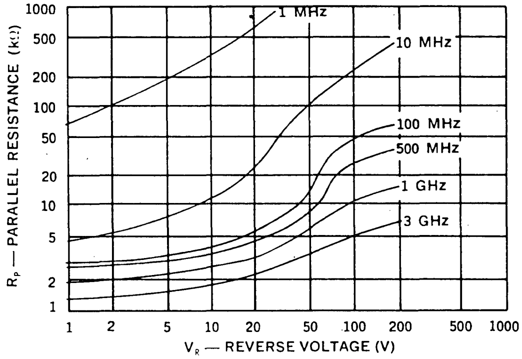
Electrical Specifications (25 °C)

Test	Symbol	UM4000 UM4900	Conditions
Total Capacitance (Max)	C_T	3 pF	100V, 1MHz
Series Resistance (Max)	R_S	0.5Ω	100mA, 100MHz
Parallel Resistance (Min)	R_P	10 KΩ	100V, 100MHz
Carrier Lifetime (Min)	τ	5μs	I_F = 10mA
Reverse Current (Max)	I_R	10μA	V_R = Rating
I-Region Width (Min)	W	150μm	—

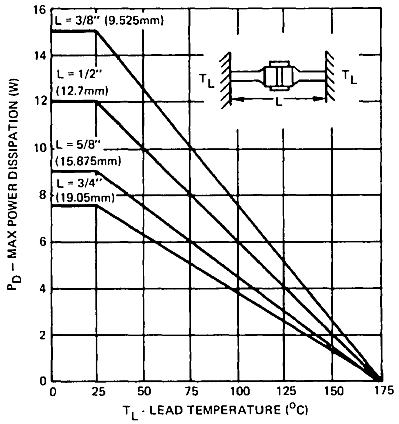
TYPICAL FORWARD RESISTANCE
VS
FORWARD CURRENT
(F = 100 MHz)



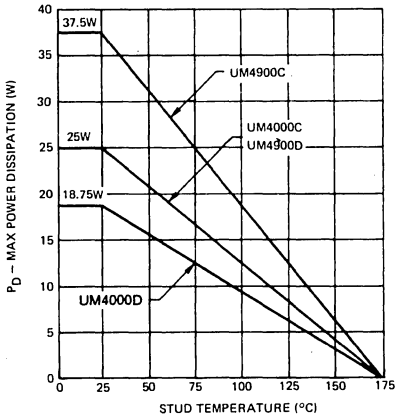
TYPICAL PARALLEL RESISTANCE CHARACTERISTIC



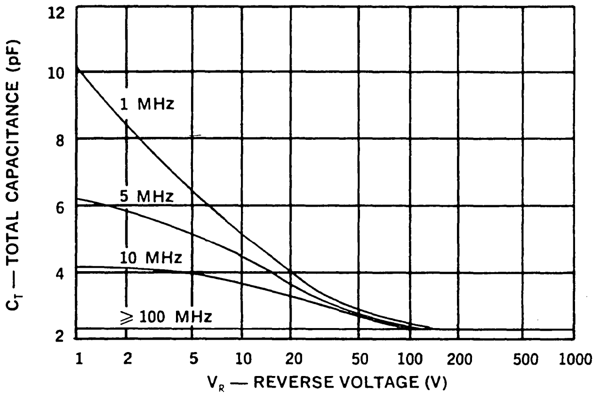
POWER RATING AXIAL LEADED DIODE



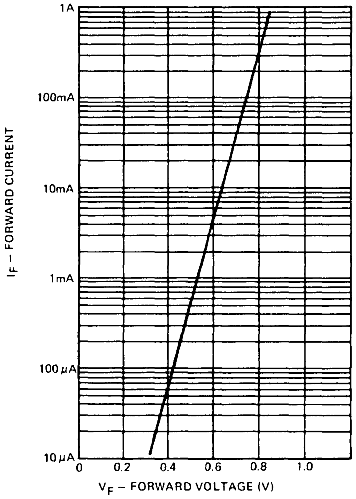
POWER RATING STUD MOUNTED DIODES



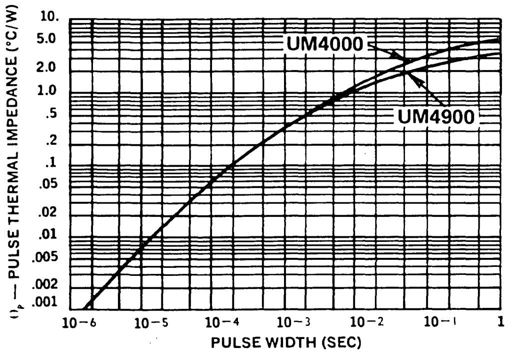
TYPICAL CAPACITANCE CHARACTERISTIC



DC CHARACTERISTICS FORWARD VOLTAGE VS FORWARD CURRENT (TYPICAL)



THERMAL IMPEDANCE



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode large end cap) is available for the C style and denoted by adding second letter R.

For Example: UM|40|06|CR|

|Series 4000| |100 Volts| |Style C|Reverse Polarity|

PIN DIODE

UM4300 SERIES
UM7300 SERIES

For Attenuator Applications

Features

- Extremely low distortion performance
- Useful frequency range extends below 500 KHz
- Power dissipation to 20W (UM4300)
- Capacitance as low as 0.7 pF (UM7300)
- Voltage ratings to 1000V

Description

The UM4300 and UM7300 series combine a diode chip of extremely thick intrinsic region with a low thermal resistance construction. This results in diodes uniquely applicable to very low distortion linear attenuators and specialized switching functions. The UM4300 series, with large cross-sectional chip area offers the highest power capability, of the two series. The UM7300 series offers lower capacitance.

Both diode series are intended for use in linear attenuators operating from HF to beyond 1 GHz. Low distortion at low frequencies is a result of transit time frequencies below 5 MHz.

Operated as RF switches, either diode series can be operated at low dc reverse bias voltages, to hold off much higher RF voltage levels.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM4300		UM7300	
		P_D	θ	P_D	θ
A	25°C Pin Temperature	20W	7.5°C/W	7.5W	20°C/W
B&E (Axial Leads)	½ in. (12.7mm) Total Lead Length to 25°C Contact	10W	15°C/W	4W	37.5°C/W
B&E (Axial Leads)	Free Air	2.5W	—	1.5W	—
C (Studded)	25°C Stud	20W	7.5°C/W	7.5W	20°C/W
D (Insulated Stud)	25°C Stud	15W	10°C/W	6W	25°C/W

Peak Power Dissipation Rating

All packages	1μs Pulse (Single) at 25°C Ambient	500 KW	100 KW

Operating and Storage Temperature Range: −65°C to +175°C

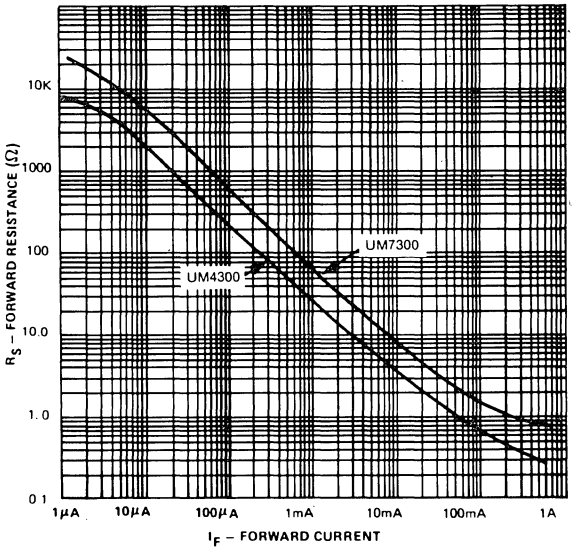
Voltage Ratings (25°C)

Reverse Voltage (V_R) — Volts (I_R = 10 μA)	Types	
100V	UM4301	UM7301
200V	UM4302	UM7302
600V	UM4306	UM7306
1000V	UM4310	UM7310

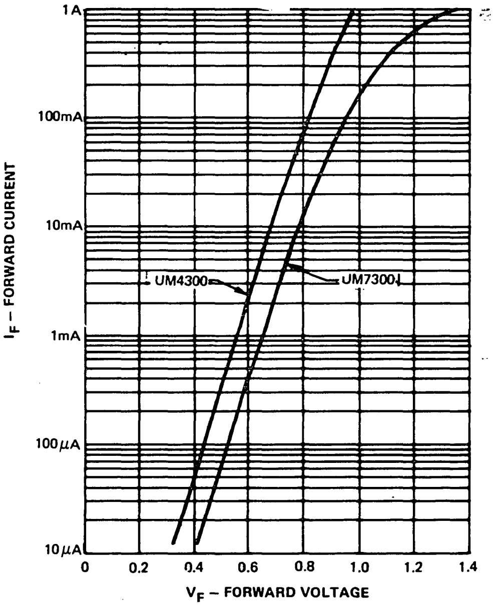
Electrical Specifications (25°C)

Test	Symbol	UM4300	UM7300	Conditions
Total Capacitance (Max)	C_T	2.2 pF	0.7 pF	100V, 100MHz
Series Resistance (Max)	R_S	1.5Ω	3.0Ω	100mA, 100MHz
Series Resistance (Min)	R_S	1000Ω	3000Ω	10 μA, 100MHz
Carrier Lifetime (Min)	τ	6μs	4.0μS	I_F = 10mA
Leakage Current (Max)	I_R	10μA	10μA	V_R = Rating
I-Region Width (Min)	W	250μm	250μm	—

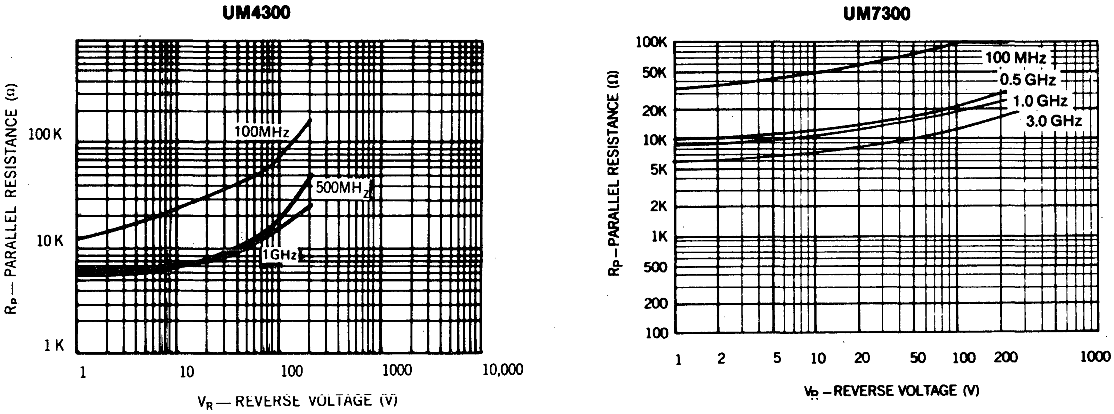
TYPICAL FORWARD RESISTANCE VS FORWARD CURRENT (F = 100 MHz)



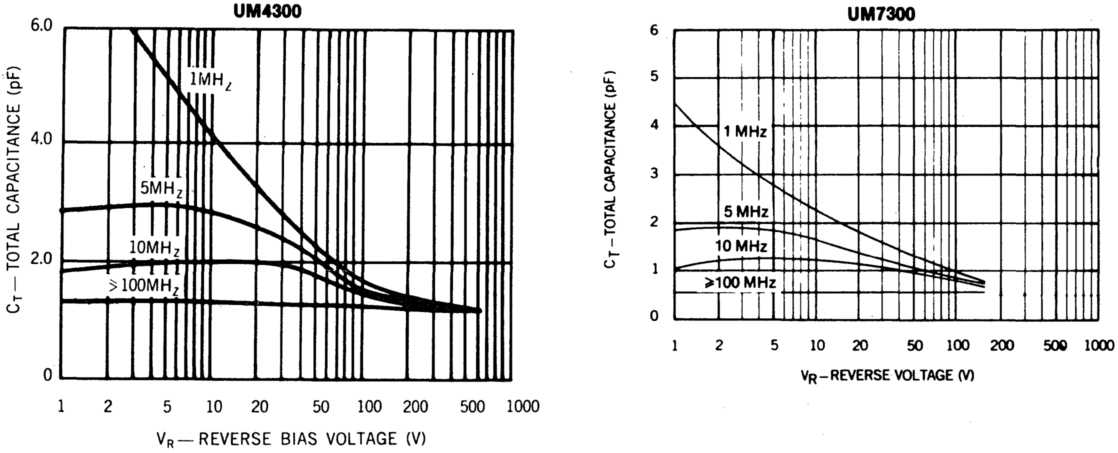
TYPICAL DC CHARACTERISTIC FORWARD VOLTAGE VS FORWARD CURRENT



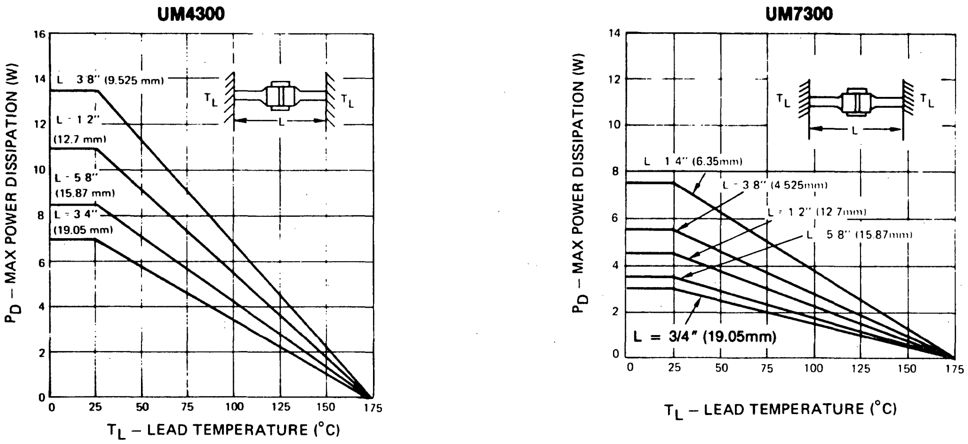
PARALLEL RESISTANCE VS REVERSE VOLTAGE



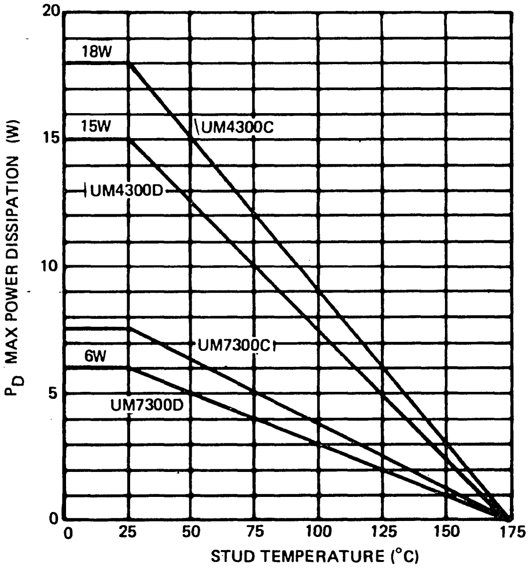
TOTAL CAPACITANCE VS REVERSE VOLTAGE



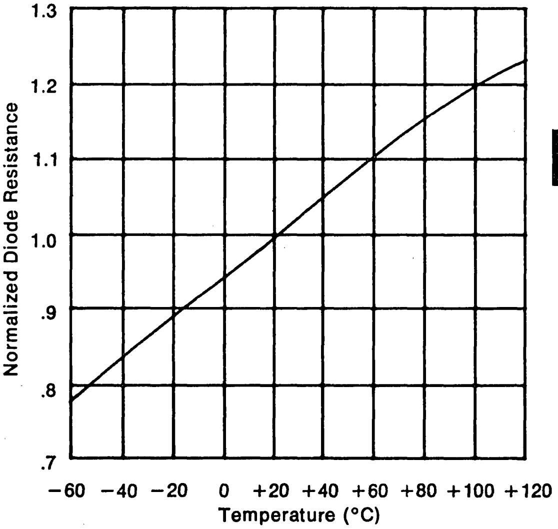
POWER RATING AXIAL LEADED DIODE



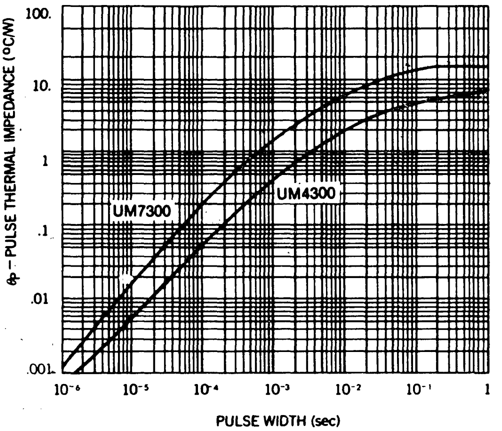
UM4300/UM7300 POWER RATING STUD MOUNTED DIODES



NORMALIZED R_S VS TEMPERATURE



PULSE THERMAL IMPEDANCE VS PULSE WIDTH



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode on stud end) is available in C or D Styles and denoted by adding second letter R.

For Example: UM|73|01|C|

Series 7300 | 100 volts | Style C

Reverse polarity available in C style. Part number designated by adding R.

PIN DIODE

UM6000 SERIES
UM6200 SERIES
UM6600 SERIES

Features

- Capacitance specified as low as 0.4 pF (UM6600)
- Resistance specified as low as 0.4Ω (UM6200)
- Voltage ratings to 1000V
- Power dissipation to 6W

Description

These series of PIN diodes are designed for applications requiring small package size and moderate average power handling capability. The low capacitance of the UM6000 and UM6600 allows them to be used as series switching elements to 1 GHz. The low resistance of the UM6200 is useful in applications where forward bias current must be minimized.

Because of its thick I-region width and long lifetime the UM6000 and UM6600 have been used in distortion sensitive and high peak power applications, including receiver protectors, TACAN, and IFF equipment. Their low capacitance allows them to be useful as attenuator diodes at frequencies greater than 1 GHz. The UM6200 has been used successfully in switches in which low insertion loss at low bias current is required.

The "A" style package for this series is the smallest Unitrode PIN diode package. It has been used successfully in many microwave applications using coaxial, microstrip, and stripline techniques at frequencies beyond X-Band. The "B" and "E" style, leaded packages offer the highest available power dissipation for a package this small. They have been used extensively as series switch elements in microstrip circuits. The "C" style package duplicates the physical outline available in conventional ceramic-metal packages but incorporates the many reliability advantages of the Unitrode construction.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	UM6000 UM6600		UM6200	
		P_D	θ	P_D	θ
A&C	25°C Pin Temperature	6W	25°C/W	4W	37.5°C/W
B&E (Axial Leads)	½ in. (12.7mm) Total Lead Length to 25°C Contact	2.5W	60°C/W	2.0W	75°C/W
B&E (Axial Leads)	Free Air	0.5W	—	0.5W	—

Peak Power Dissipation Rating

All Packages	1 μs Pulse (Single) at 25°C Ambient	UM6000 - 25 KW UM6200 - 10 KW	UM6600 - 13 KW

Operating and Storage Temperature Range: −65°C to +175°C

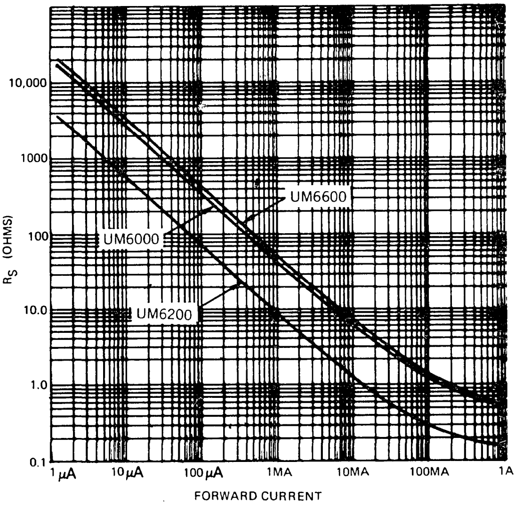
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 μA)	Types		
100V	UM6001	UM6201	UM6601
200V	UM6002	UM6202	UM6602
400V	—	UM6204	—
600V	UM6006	—	UM6606
1000V	UM6010	—	UM6610

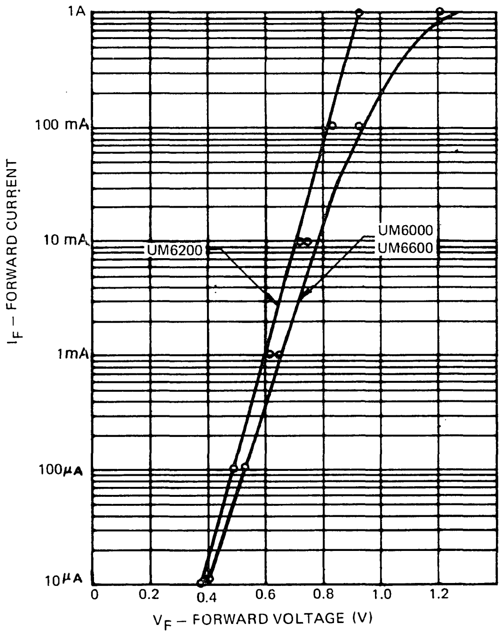
Electrical Specifications (25 °C)

Test	Symbol	UM6600	UM6000	UM6200	Conditions
Total Capacitance (Max)	C_T	0.4 pF	0.5 pF	1.1 pF	100V, 1MHz
Series Resistance (Max)	R_S	2.5Ω	1.7Ω	0.4Ω	100mA, 100MHz
Parallel Resistance (Min)	R_P	300 KΩ	300 KΩ	350 KΩ	100V, 100MHz
Carrier Lifetime (Min)	τ	1.0 μs	1.0 μs	0.6 μs	I_F = 10 mA
Reverse Current (Max)	I_R	10 μA	10 μA	10 μA	V_R = Rating
I-Region Width (Min)	W	150 μm	150 μm	40 μm	—

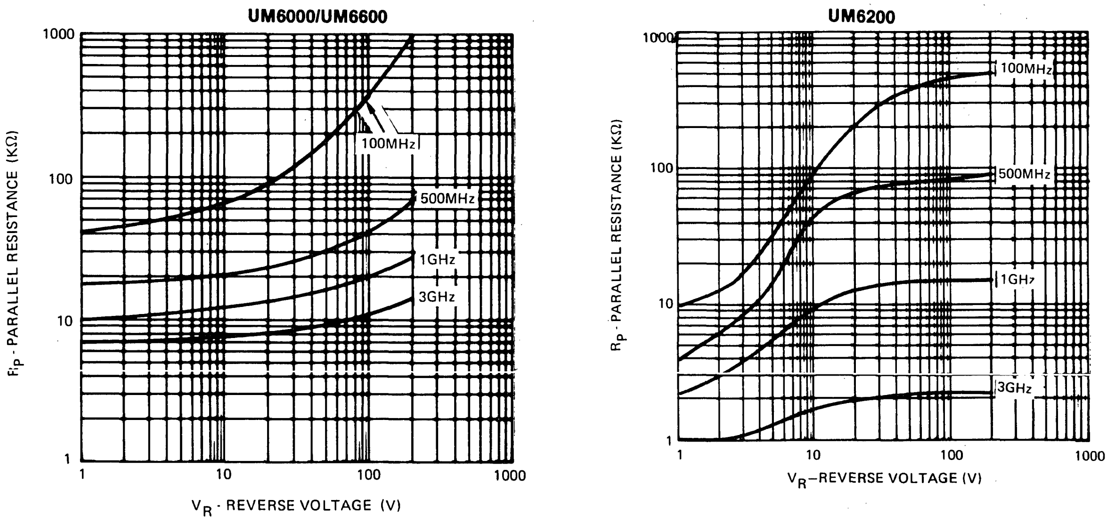
TYPICAL SERIES RESISTANCE VS FORWARD CURRENT (F = 100MHz)



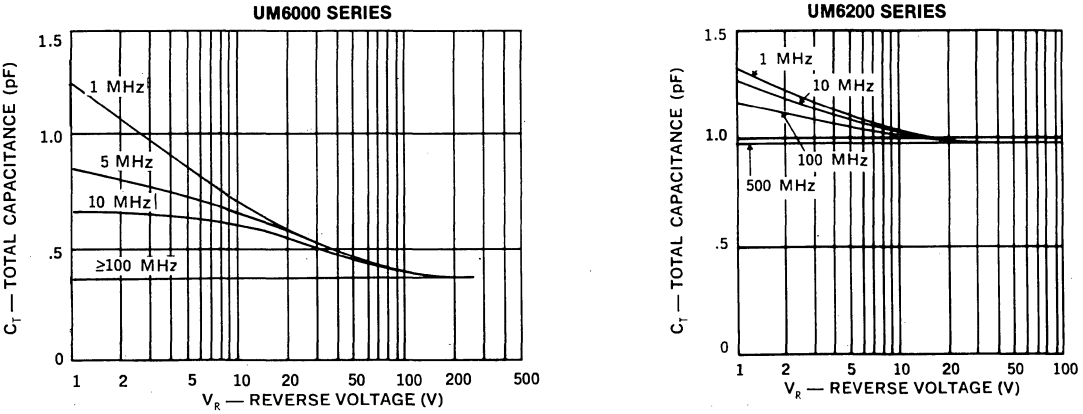
DC CHARACTERISTICS FORWARD VOLTAGE VS CURRENT



TYPICAL R_p VS VOLTAGE & FREQUENCY



TYPICAL CAPACITANCE VS VOLTAGE AND FREQUENCY

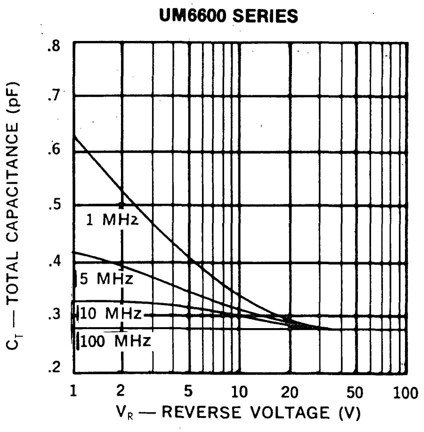


ORDERING INSTRUCTIONS

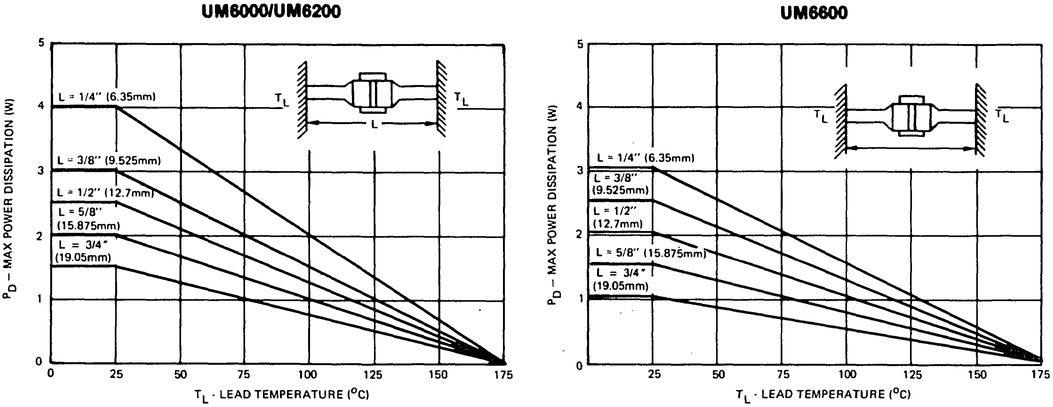
Part numbers of Unitrode PIN diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode large end cap) is available for the C style and denoted by adding second letter R.

For Example: UM |60|06 |CR|

|Series 6000| |600 Volts| |Style C|Reverse Polarity|



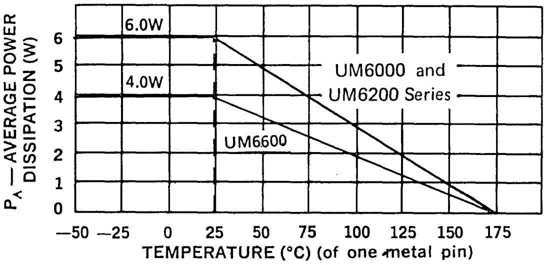
POWER RATING — AXIAL LEADED DIODE



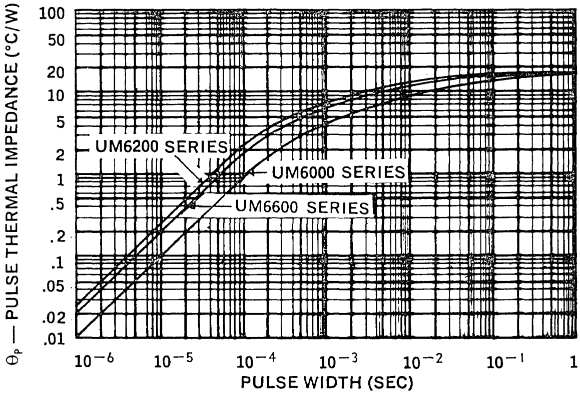
UM6000/UM6200

UM6600

POWER RATING



PULSE THERMAL IMPEDANCE VS PULSE WIDTH



PIN DIODE

UM7000 SERIES
UM7100 SERIES
UM7200 SERIES

Features

- Voltage ratings to 1000V (UM7000)
- Wide variety of package styles
- Rated average power dissipation to 10W
- Cost effective in volume applications

Description

The UM7000 and UM7100 series offer moderately high power handling in combination with reasonably low levels of both series resistance and capacitance. The UM7200 series offers the lowest series resistance, but the highest capacitance of the group. The differences in specified performance, for each of the series, results from different I-region thicknesses. The three series have broad applicability in many RF and microwave switch and attenuator circuits. Additionally, the UM7100 in leaded versions, is usually the most cost-effective diode choice in high volume usage.

MAXIMUM RATINGS

Average Power Dissipation and Thermal Resistance Ratings

Package	Condition	P_D	θ
A	25 °C Pin Temperature	10W	15 °C/W
B&E (Axial Leads)	½ in. (12.7mm) Total Lead Length to 25° C Contact	5.5W	27.5 °C/W
B&E (Axial Leads)	Free Air	1.5W	—
C (Studded)	25 °C Stud Temperature	10W	15 °C/W
D (Insulated Stud)	25 °C Stud Temperature	7.5W	20 °C/W

Peak Power Dissipation Rating

All Packages	1 μs Pulse (Single) at 25 °C Ambient	UM7000 - 60 KW UM7100 - 35 KW UM7200 - 20 KW

Operating and Storage Temperature Range: −65 °C to +175 °C

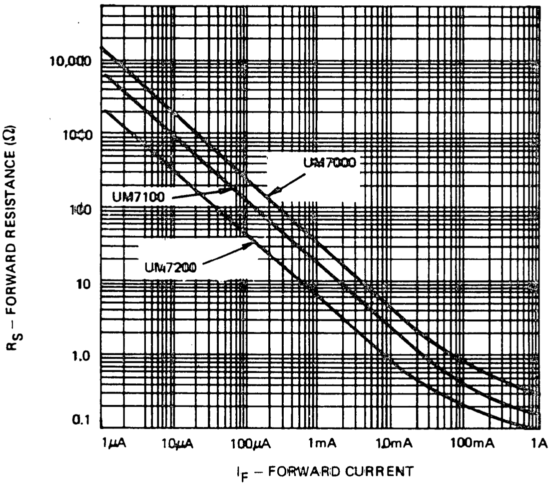
Voltage Ratings (25 °C)

Reverse Voltage (V_R) — Volts (I_R = 10 µA)	Types		
100V	UM7001	UM7101	UM7201
200V	UM7002	UM7102	UM7202
400V	—	UM7104	UM7204
600V	UM7006	—	—
800V	—	UM7108	—
1000V	UM7010	—	—

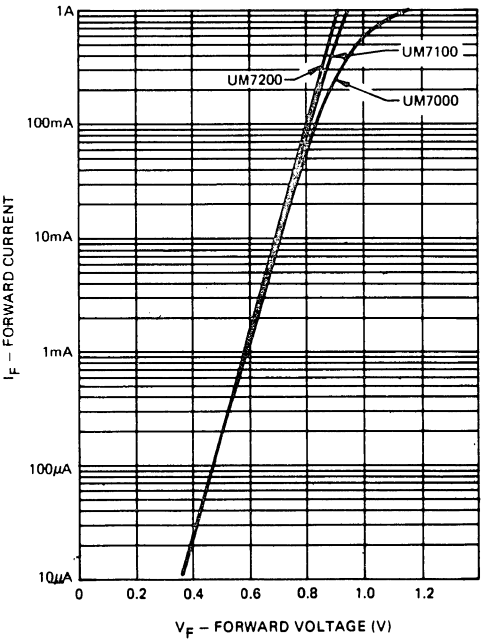
Electrical Specifications (25 °C)

Test	Symbol	UM7000	UM7100	UM7200	Conditions
Total Capacitance (Max)	C_T	0.9 pF	1.2 pF	2.2 pF	100V, 1MHz
Series Resistance (Max)	R_S	1.0Ω	0.6Ω	0.25Ω	100mA, 100MHz
Parallel Resistance (Min)	R_P	200 KΩ	150 KΩ	70 KΩ	100V, 100MHz
Carrier Lifetime (Min)	τ	2.5 µs	2.0 µs	1.5 µs	I_F = 10 mA
Reverse Current (Max)	I_R	10 µA	10 µA	10 µA	V_R = Rating
I-Region Width (Min)	W	150 µm	80 µm	40 µm	—

TYPICAL FORWARD RESISTANCE
VS FORWARD CURRENT
(F = 100 MHz)

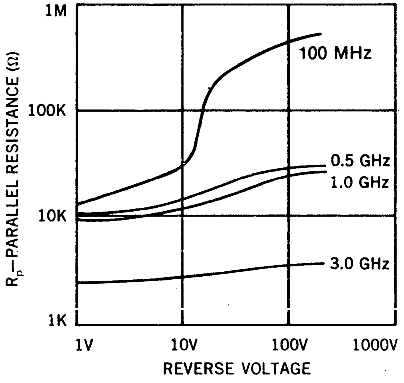


TYPICAL DC CHARACTERISTIC
FORWARD VOLTAGE
VS FORWARD CURRENT
UM7000/UM7100/UM7200



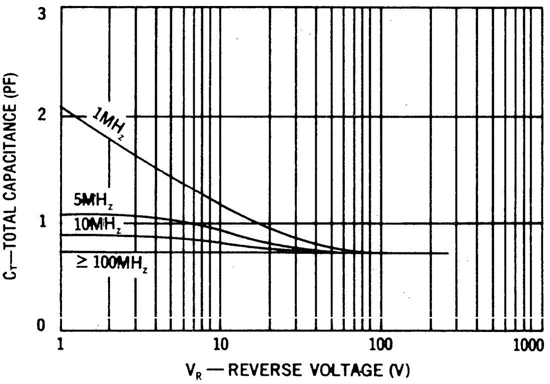
TYPICAL Rp CHARACTERISTIC

UM 7000 SERIES

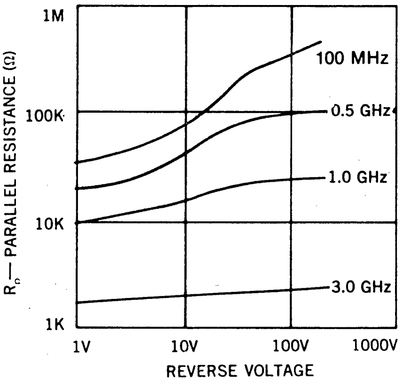


TYPICAL C_T CHARACTERISTIC

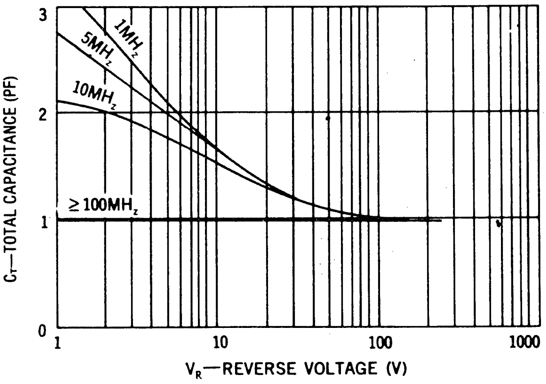
UM 7000 SERIES



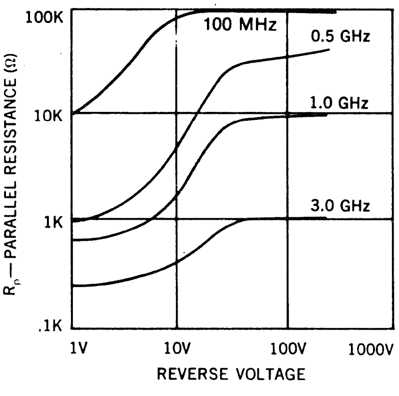
UM7100 SERIES



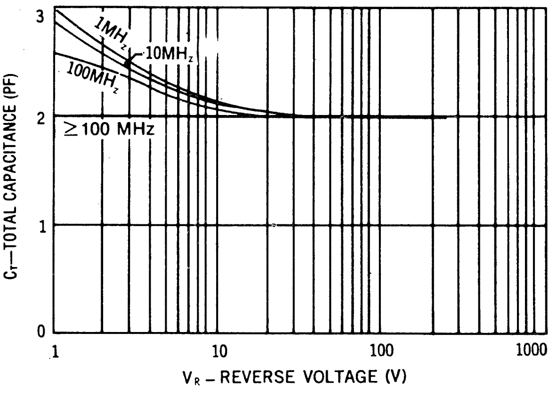
UM 7100 SERIES



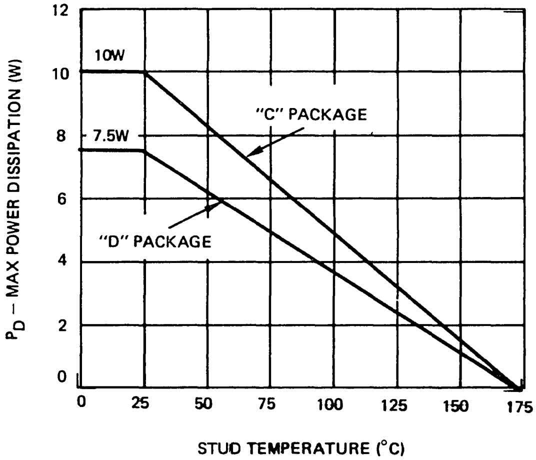
UM 7200 SERIES



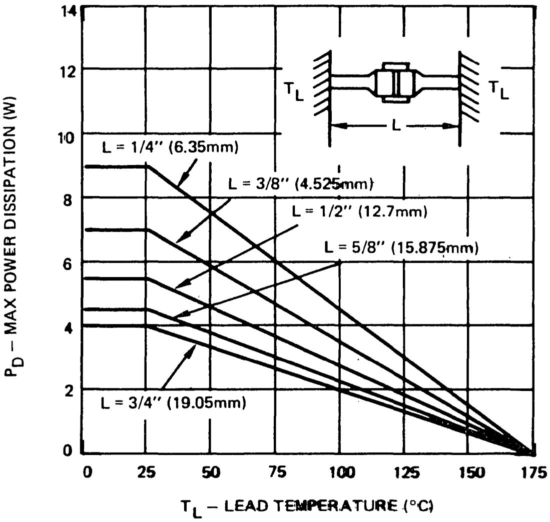
UM 7200 SERIES



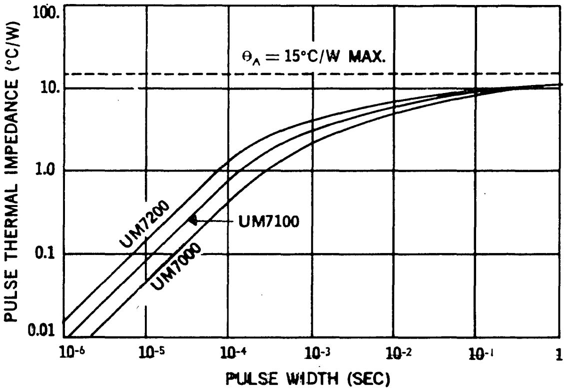
POWER RATING STUD MOUNTED DIODES



POWER RATING — AXIAL LEADED DIODES



PULSE THERMAL IMPEDANCE VS PULSE WIDTH



ORDERING INSTRUCTIONS

Part numbers of Unitrode PIN Diodes consist of the letters UM followed by four digits and one or two letters. The first two digits indicate the diode series, the next two digits specify the minimum breakdown voltage in hundreds of volts. The remaining letters denote the package style. Reverse polarity (anode on stud end) is available in C or D Styles and denoted by adding second letter R.

For Example: UM |70|01|C|

|Series 7000| |100 volts| |Style C|

PIN DIODE

UM9301

COMMERCIAL ATTENUATOR DIODE

Features

- Specified low distortion
- Low rectification properties at low reverse bias
- Resistance specified at 3 current points
- High reliability fused-in-glass construction

Description

The UM9301 PIN Diode utilizes a special overall chip geometry with an extremely thick intrinsic "I" region, to offer unique capabilities in both RF switch and attenuator applications. Volume production also makes the diode an economical choice suitable for many commercial low power equipments.

The UM9301 has been designed for use in bridged TEE attenuator circuits commonly utilized for gain and slope control in CATV amplifiers. Low distortion and high dynamic range are characteristic of the diodes' outstanding performance.

The UM9301 is also appropriate for switch applications, when little or no bias voltage is available. Frequent applications occur in portable 12 volt-powered communications equipments, operating at frequencies as low as 2 MHz.

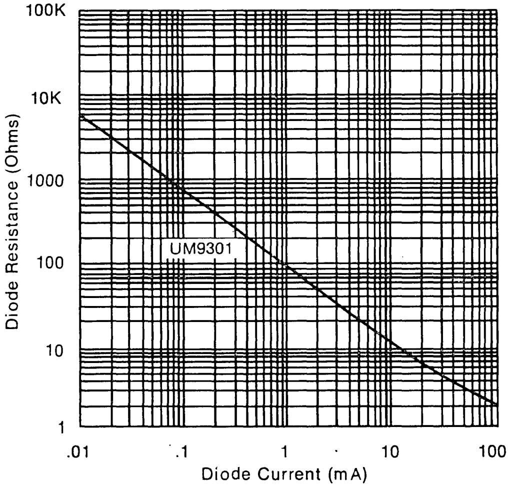
MAXIMUM RATINGS

Reverse Voltage **(V_R) — Volts** **(I_R = 10 μA)**	75V
Average Power Dissipation @ (P_A) Leads ½ in. (12.7mm) Total to 25°C Contact	1.0W (Derate linearly to 175°C)
Operating and Storage Temperature Range	−65°C to +175°C

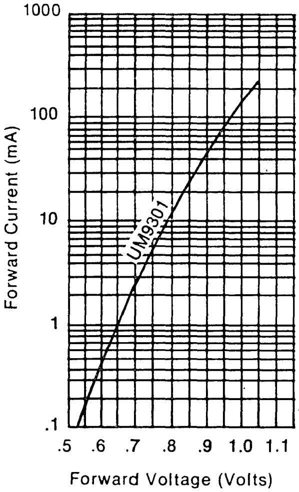
Electrical Specifications (25 °C)

Test	Min	Typ	Max	Units	Conditions
Diode Resistance R_S	 3000	1.7 80 5000	3.0 150	Ω Ω Ω	I = 100 mA, f = 100 MHz I = 1 mA, f = 100 MHz I = 0.01 mA, f = 100 MHz
Current for R_S = 75Ω I_R	0.5	1.1	2.0	mA	f = 100 MHz
Capacitance C_T			0.8	pF	V = 0V, f = 100 MHz
Return Loss	25			dB	Frequency Range: 10 - 300MHz R_S = 75Ω @ 100 MHz Diode Terminates 75Ω line
Second Order Distortion		55	50	−dB	f_1 = 10 MHz, f_2 = 13 MHz P = 50 dBmV, See Test Circuit
		70		−dB	F_1 = 67 MHz, F_2 = 77 MHz P = 50 dBmV, See Test Circuit
Third Order Distortion		75	65	−dB	F_1 = 10 MHz, F_2 = 13 MHz P = 50 dBmV, See Test Circuit
		95		−dB	Triple Beat; 205 + 67 − 77 MHz P = 50 dBmV, See Test Circuit
Cross Modulation Distortion		75		−dB	12 Channel Test P = 50 dBmV, See Test Circuit Dix Hills Test Set
Reverse Current I_R			10	μA	V = 75V
Carrier Lifetime τ	4.0			μs	I = 10 mA

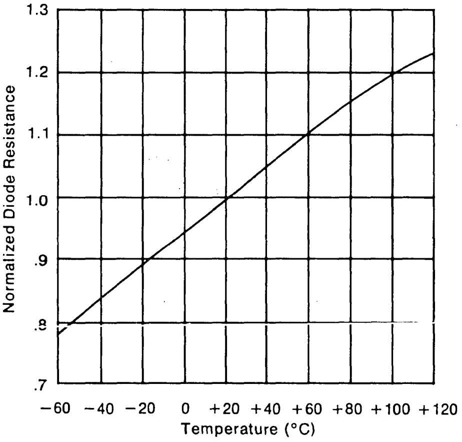
DIODE RESISTANCE VS DIODE CURRENT (TYPICAL)



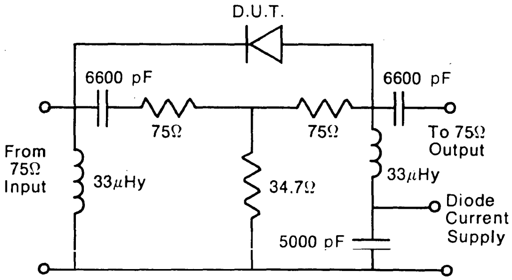
FORWARD CURRENT VS FORWARD VOLTAGE (TYPICAL)



NORMALIZED R_S VS TEMPERATURE



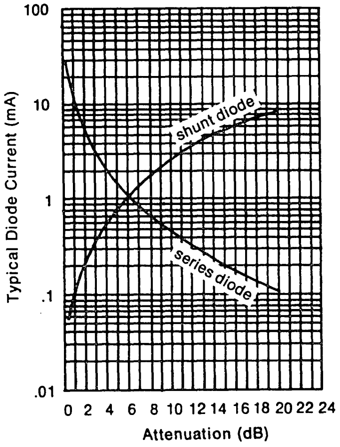
TEST CIRCUIT FOR DISTORTION MEASUREMENTS



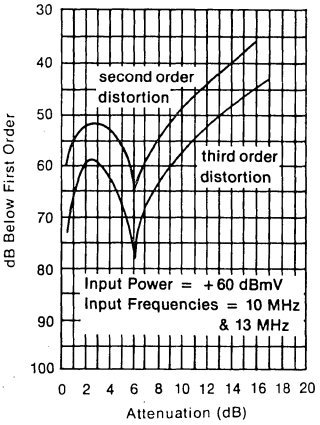
Note: Diode Current adjusted for 10dB Attenuation

TYPICAL BRIDGED TEE ATTENUATOR PERFORMANCE

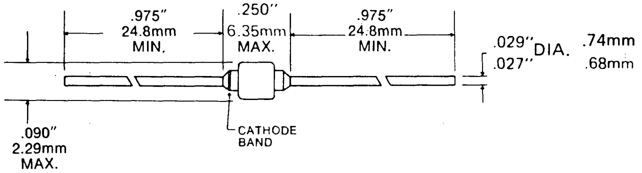
DIODE CURRENT VS ATTENUATION UM9301



DISTORTION ATTENUATION



MECHANICAL SPECIFICATIONS



PIN DIODE

UM9401
UM9402
UM9415

COMMERCIAL TWO-WAY RADIO ANTENNA SWITCH DIODES

Features

- Specified low distortion
- Unitrode ruggedness and reliability
- Low bias current requirements
- Priced for high quantity applications

Description:

Unitrode offers a series of PIN diodes specifically designed and characterized for solid state antenna switches in commercial two-way radios. Antenna switches using the UM9401 and UM9415 series PIN diodes provide high isolation, low loss and low distortion characteristics formerly possible only with electromechanical relay type switches.

The UM9401 and UM9402 diodes can handle above 100W of transmitter power, while the UM9415 will handle over 1000W. The extensive characterization of these PIN diodes in antenna switch applications has resulted in guaranteed low distortion specifications under transmit and receive conditions. These diodes also feature low forward bias resistance and high zero bias impedance which are required for low loss, high isolation and wide bandwidth antenna switch performance.

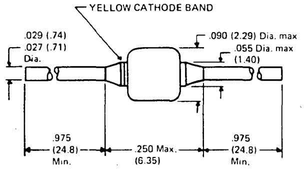
MAXIMUM RATINGS

	UM9401	UM9402	UM9415
Reverse Voltage (V_R) — Volts (I_R = 10 μA)	50V	50V	50V

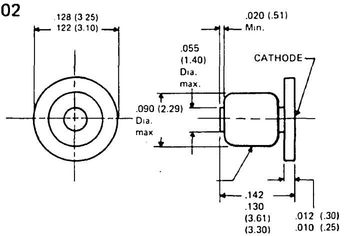
Average Power Dissipation (P_A)			
Lead Length – ½ in. (12.7mm) Total to 25°C Contacts	5.5W	—	10W
25°C (Package Flange) Temperature	—	10W	—
Free Air	1.5W		2.5W

Operating and Storage Temperature Range	– 65°C to + 175°C

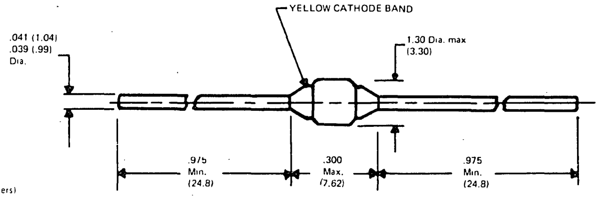
UM9401



UM9402



UM9415



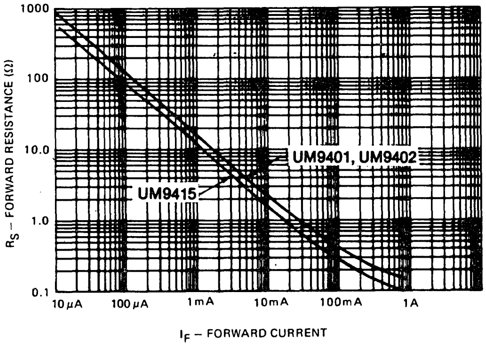
Dimensions: inches (millimeters)

SEMICONDUCTOR PRODUCTS
UNITRODE

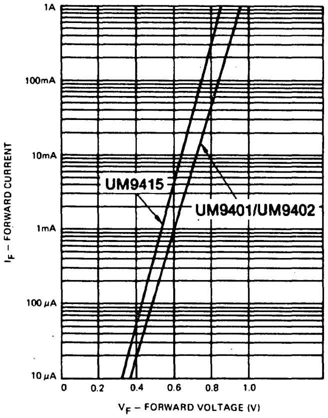
Electrical Specifications (at 25 °C)

Test	Symbol	UM9401/UM9402			UM9415			Units	Conditions
		Min	Typ	Max	Min	Typ	Max		
Series Resistance	R_S		0.75	1.0		0.75	1.0	Ω	f = 100MHz typical I = 50 mA
Diode Capacitance	C_T		1.1	1.5			4	pF	f = 100 MHz V = 0V
Parallel Resistance	R_P	5K	10K		1K	2K		Ω	f = 100 MHz V = 0V
Carrier Lifetime	τ	1.0	2.0		5			μS	I = 10 mA
Transmit Harmonic Distortion	$\frac{R_{2A}}{A}, \frac{R_{3A}}{A}$			80			80	−dB	P_{IN} = 50W f = 50 MHz, I = 50 mA.
Receive Third Order Distortion	$\frac{R_{2AB}}{A}$			60			60	−dB	P_{IN} = 10 mW, 0V Bias f_A = 50 MHz, f_B = 51 MHz
Reverse Leakage Current	I_R			10			10	μA	V = 50V
Forward Voltage	V_F			1.0			1.0	V	I_F = 50 mA

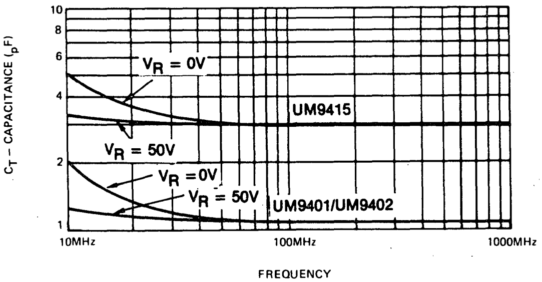
TYPICAL FORWARD RESISTANCE VS FORWARD CURRENT (F = 100 MHz)



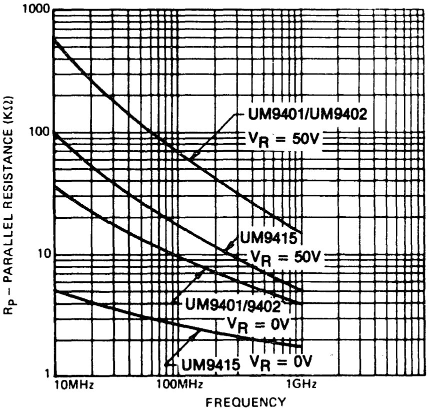
TYPICAL DC CHARACTERISTIC



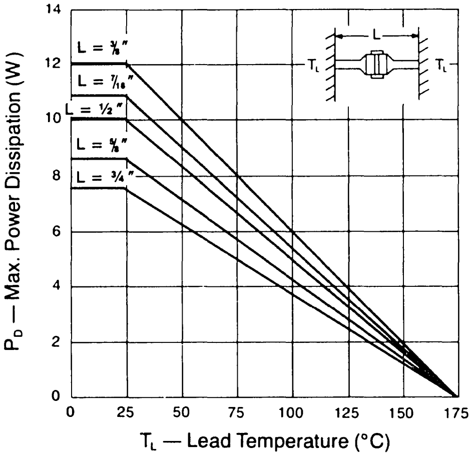
TYPICAL CAPACITANCE CHARACTERISTIC



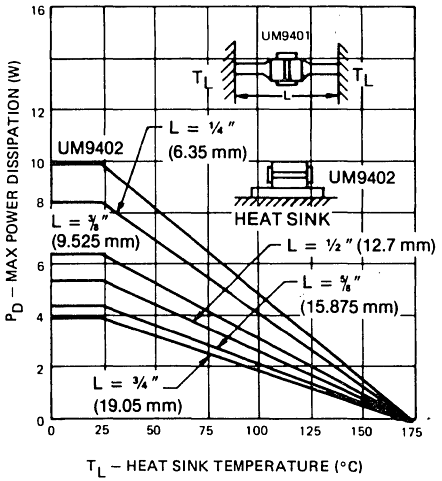
TYPICAL R_p CHARACTERISTICS



POWER RATING
UM9415

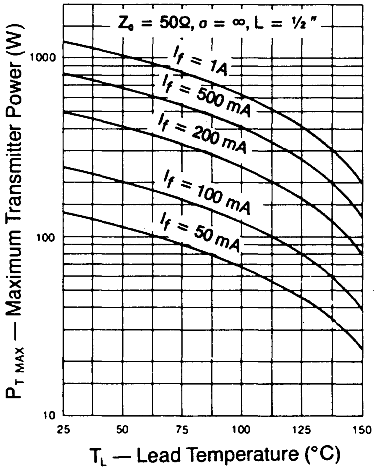


POWER RATING
UM9401/9402

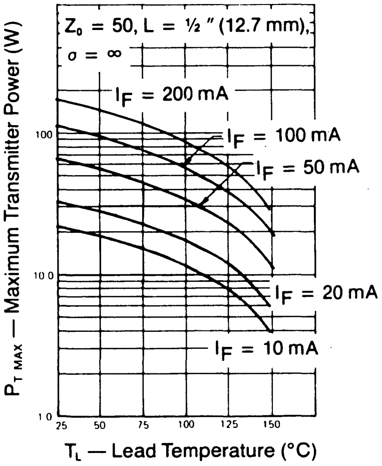


MAXIMUM TRANSMITTER POWER

UM9415



UM9401/UM9402



Maximum Transmitter Power

The maximum CW transmitter power, $P_{T(max)}$, a PIN diode antenna switch can handle depends on the diode resistance, R_S, power dissipation, P_D, antenna SWR, σ, and nominal impedance, Z_0. The expression relating these parameters is as follows:

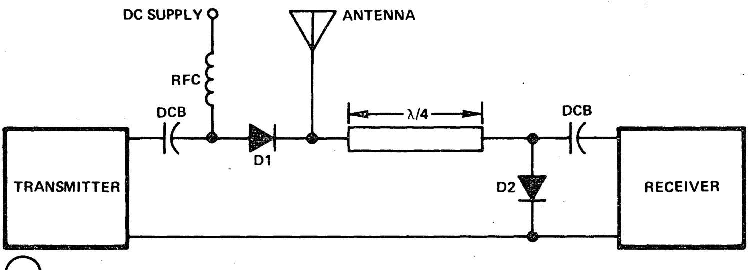
$$P_{T(max)} = \frac{P_D \times Z_0}{R_D} \left(\frac{\sigma + 1}{2\sigma}\right)^2 \text{ [Watts]}$$

Characteristic curves are shown in the data section which give both the maximum and typical diode resistance, R_S as a function of forward current. The maximum power dissipation rating of the PIN diode depends both on the length of the diode leads and the temperature of the contacts to which the leads are connected. A graph defining the maximum power dissipation at various combinations of overall lead length (L) and lead temperature (T_L) is given in the data section. From these curves and the above equation, the power handling capability of the PIN diode may be computed for a specific application.

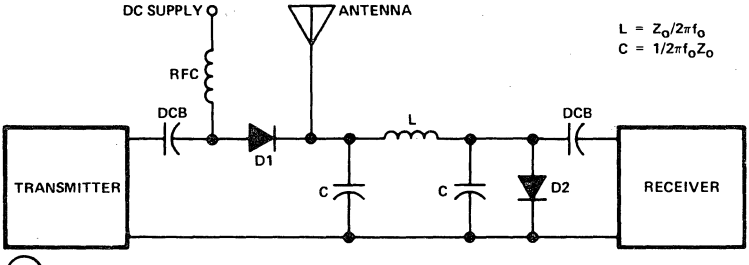
Curves are also presented which show the maximum transmitter power that an antenna switch using UM9401s and UM9415s can safely handle for various forward currents and lead temperatures. These curves are based on a typical design condition of a ½ in. total overall lead length, 50Ω line impedance and a totally mismatched antenna ($\sigma = \infty$). For the case of a perfectly matched antenna, the maximum transmitter power can be increased by a factor of 4.

Design Information

A circuit configuration for a two-way radio antenna switch using PIN diodes consists of a diode placed in series with the transmitter and a shunt diode placed a quarter wavelength from the antenna in the direction of the receiver as shown. For low frequency operation, the quarter wave line may be simulated by lumped elements. Typical performance of antenna switches using PIN diodes forward biased at 100 mA is less than 0.2 dB insertion loss and 30 dB isolation during transmit; at zero bias the receive insertion loss is less than 0.3 dB. This performance is achievable across a ±20% bandwidth at center frequencies ranging from 10 to 500 MHz.



ⓐ



ⓑ

PIN RADIATION DETECTORS

UM9441

Features

- High Photocurrent Sensitivity
- High Reliability Construction
- Fast Rise Time
- Wide Dynamic Range
- Hardness to Neutron Bombardment
- Low Operating Voltage

Description

Silicon PIN devices are effective detectors of nuclear and electromagnetic radiation. This includes gamma radiation, electrons, and X-rays. The detectors can be used across the temperature range of −55 °C to +175 °C instead of being restricted to use at low temperatures.

The absorbed radiation produces electron-hole pairs in the space charge region. These charges are swept out by the applied field and result in a current flow proportional to the rate of absorbed radiation.

The Unitrode UM9441 series utilizes high resistivity material and is designed to have a uniform area mesa structure to define the active volume. The current sensitivity of these devices is proportional only to the I-region volume and is independent of temperature so long as applied voltage exceeds the saturation voltage. This structure also minimizes the effects of permanent damage caused by neutrons and other high energy radiation. Experiments on devices of the UM9441 design show no degradation in gamma sensitivity resulting from a total dose of 10^{14} neutrons/cm^2 of 1 MeV equivalent.

Package

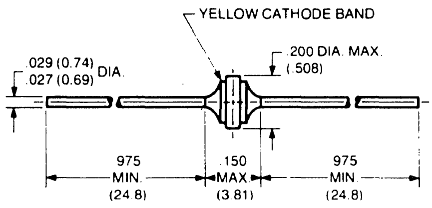
The UM9441 is an axially leaded device constructed by metallurgically bonding the PIN chip in between two molybdenum refractory pins that are typically 0.125 inches in diameter and 0.050 inches long. Hyper-pure glass is then fused over this bond to form a voidless seal. Leads are then brazed to ends of molybdenum pins. This results in a high-reliability package using materials so well thermally matched that the UM9441 can withstand temperature shock or cycling from −196 °C to +300 °C.

ABSOLUTE MAXIMUM RATINGS

Reverse Voltage 100V
Photocurrent .... 3Adc, 3A^{2}s pulsed
Storage Temperature ... −55 °C to +200 °C
Operating Temperature . −55 °C to +175 °C

MECHANICAL SPECIFICATIONS

UM9441

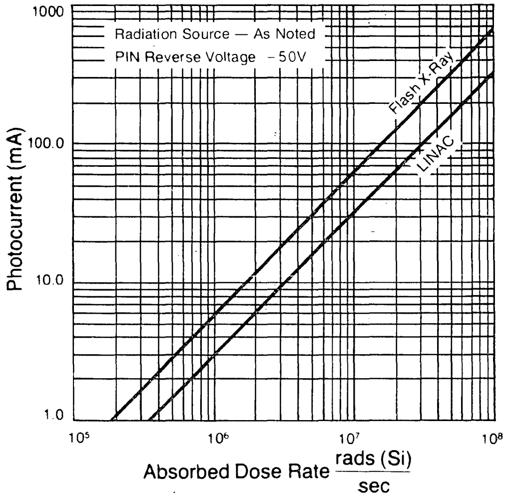


Dimensions in inches (millimeters)

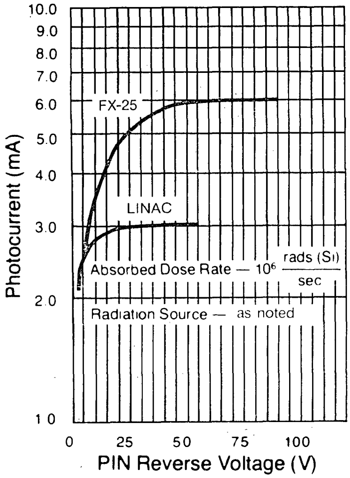
Electrical Specifications (at 25°C)

Test	Min	Typ	Max.	Units	Test Conditions
Photocurrent	4.0	6.0		mA	$V_R = 50V$ $10^6 \frac{\text{rads (Si)}}{\text{sec.}}$ 2.5 MeV Flash X-Ray Ion Physics Corp. FX-25
Capacitance			10	pF	F = 1 MHz, V = 50V
Reverse Current			1.0	μA	$V_R = 50V$
Minority Carrier Lifetime	2.0			μS	$I_f = 10mA$

TYPICAL PHOTOCURRENT SENSITIVITY



TYPICAL VOLTAGE SENSITIVITY



RELIABILITY

The UM9441 is consistent with Unitrode's reputation as a manufacturer of high reliability semiconductors. Unitrode is equipped to perform JAN type testing, base-lining and documental conformance to a wide range of reliability testing. This commitment to reliability has enabled Unitrode to be a qualified supplier of semiconductor devices to many high-reliability programs such as:

APOLLO	MINUTEMAN
DRAGON	SPRINT
HAWK	TRIDENT
MARINER	VIKING

PIN DIODE

For Microstrip 900MHz Antenna Switches and Microwave Applications

Features

- Low Inductance Shunt Mount Package
- Characterized for Microstrip
- Unitrode Ruggedness and Reliability
- High Power Handling Capability
- Low Bias Current Requirement
- Excellent Distortion Properties
- Cost Effective in High Quantity Applications

Description

The UM9601-UM9608 series of PIN diodes was developed for shunt mount applications in microstrip circuits. Good switch performance is demonstrated at frequencies from UHF to 4GHz and higher. This performance is achieved using discrete low inductance Unitrode PIN diodes assembled with special hardware to permit good electrical and mechanical compatibility with microstrip transmission lines.

Design information is presented for preparation of microstrip circuit boards to accommodate these PIN diodes. A detailed design for a 900MHz quarter-wave antenna switch is given. This switch which employs a low cost UM9401 axial leaded PIN diode in conjunction with a UM9601, performs with 30dB receiver isolation over a 100MHz bandwidth and with transmitter insertion loss of less than 0.4dB. This switch can safely handle transmitter power levels up to 100 watts at infinite antenna SWR.

The Unitrode UM9601 series PIN diodes are constructed using a fused-in-glass process which results in a highly reliable, hermetic package. The process utilizes symmetrical, full faced metallurgical bonds to both surfaces of the silicon chip. This construction greatly minimizes the normal parasitic inductance and capacitance found in conventional glass or ceramic packaged diodes which employ straps, springs or whiskers.

The use of discrete UM9601-UM9608 diodes greatly minimizes handling problems commonly associated with passivated PIN diode chips while maintaining good microwave performance. In addition the power handling capibility of the UM9601-UM9608 series is considerably higher than PIN diode chips can provide.

Environmentally, the UM9601-UM9608 series PIN diodes can withstand thermal cycling from −195°C to +300°C and exceed all military environmental specification for shock, vibration, acceleration, and moisture resistance.

Typical Microwave Performance

	UM9601-UM9604			UM9605-UM9608		
Frequency	SPST Insertion Loss 0 Bias	SPST Isolation 100mA	SPNT* Isolation 100mA	SPST Insertion Loss 0 Bias	SPST Isolation 100mA	SPNT* Isolation 100mA
GHz	dB	dB	dB	dB	dB	dB
0.5	0.20	30	36	0.20	25	31
1.0	0.25	26	32	0.20	22	28
1.5	0.35	22	28	0.20	20	26
2.0	0.50	18	24	0.25	17	22
3.0	1.00	15	21	0.25	15	21
4.0	1.50	13	19	0.40	14	20

* Performance based on SPST Measurements In 0.025" (.635mm) Microstrip Test Circuit.

Note: All dimensions in inches and (millimeters).

Maximum Ratings

	UM9601 - UM9604		UM9605 - UM9608	
	P_D	θ	P_D	θ
Flange at 25° C	7.5W	20° C/W	4W	37.5° C/W
Free Air	1.5W	—	0.5W	—

Peak Power 1μS Single Pulse at 25° C Ambient	25KW	10KW

Operating and Storage Temperature	−65° C to +175° C

Reverse Voltage Ratings @ 10μA

100V	400V
UM9601	UM9602
UM9603	UM9604
UM9605	UM9606
UM9607	UM9608

Electrical Specifications (at 25° C)

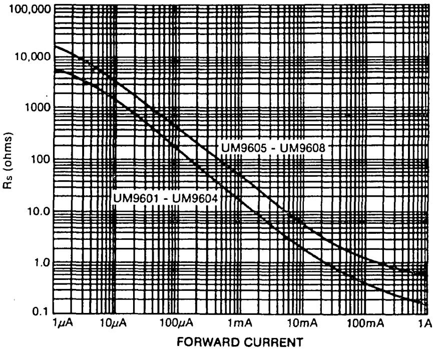
Test	Symbol	UM9601-UM9604 Min	UM9601-UM9604 Typ	UM9601-UM9604 Max	UM9605-UM9608 Min	UM9605-UM9608 Typ	UM9605-UM9608 Max	Units	Condition
Series Resistance	R_S	—	0.4	0.6	—	1.5	1.7	Ω	I = 100mA f = 100MHz
Parallel Resistance	R_P	100K	—	—	150K	—	—	Ω	V = 100V f = 100MHz
Total Capacitance	C_T	—	—	1.2	—	—	0.5	pF	V = 100V f = 1MHz
Carrier Lifetime	τ	2.0	—	—	1.0	—	—	μS	I_F = 10mA
Forward Voltage	V_F	—	0.85	—	—	0.95	—	V	I_F = 100mA
I-Region Width	W	80	—	—	150	—	—	μm	

Selection Guide

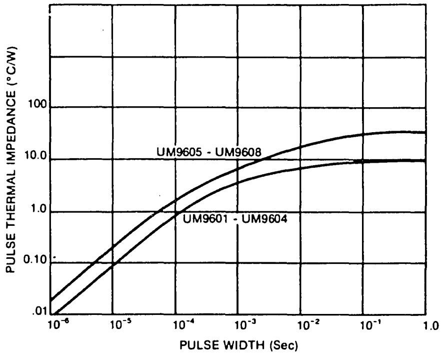
The following chart serves as a general guide for indicating the most likely diode from the series for a given application.

Applications	Recommended Types
1. High isolation switches to 2GHz at low dc drive 2. Quarter-wave antenna switches to 100 watts. 3. Priced for high volume commercial applications.	UM9601 (Affixes to microstrip ground plane.) UM9603 (Affixes to microstrip backing plate.)
High voltage rating version of UM9601 and UM9603 respectively for peak power handling to 3KW.	UM9602, UM9604
1. Low insertion loss switches to 4GHz. 2. Low distortion antenuator applications.	UM9605 (Affixes to microstrip ground plane.) UM9607 (Affixes to microstrip backing plate.)
High voltage version of UM9605 and UM9607 for peak power handling to 10KW.	UM9606, UM9608

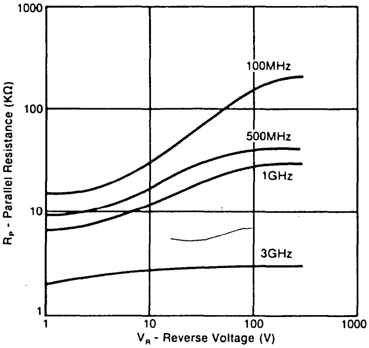
Typical Series Resistance vs Forward Current (F = 100MHz)



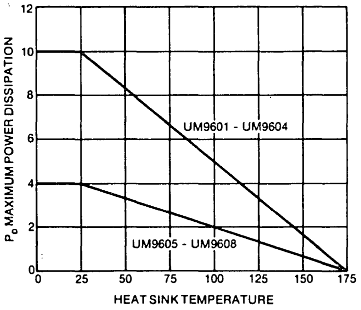
Pulse Thermal Impedance



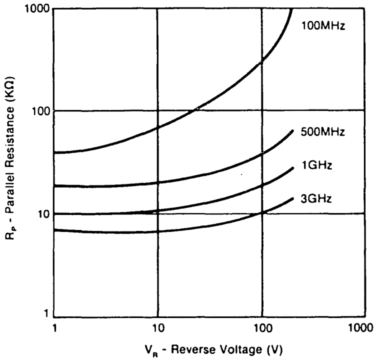
Typical R_P vs Voltage and Frequency UM9601 - UM9604



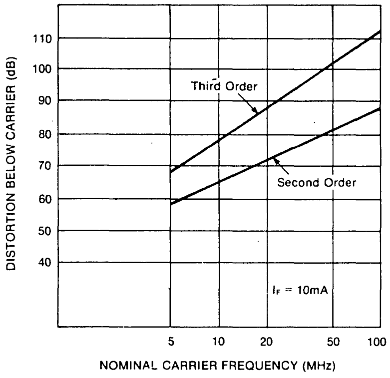
Power Rating



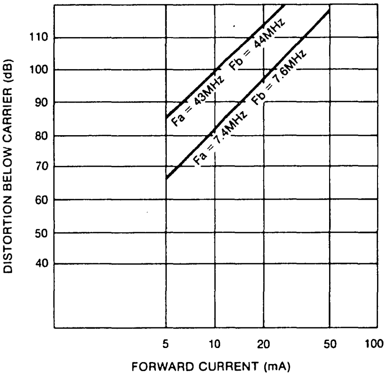
Typical R_P vs Voltage and Frequency UM9605 - UM9608



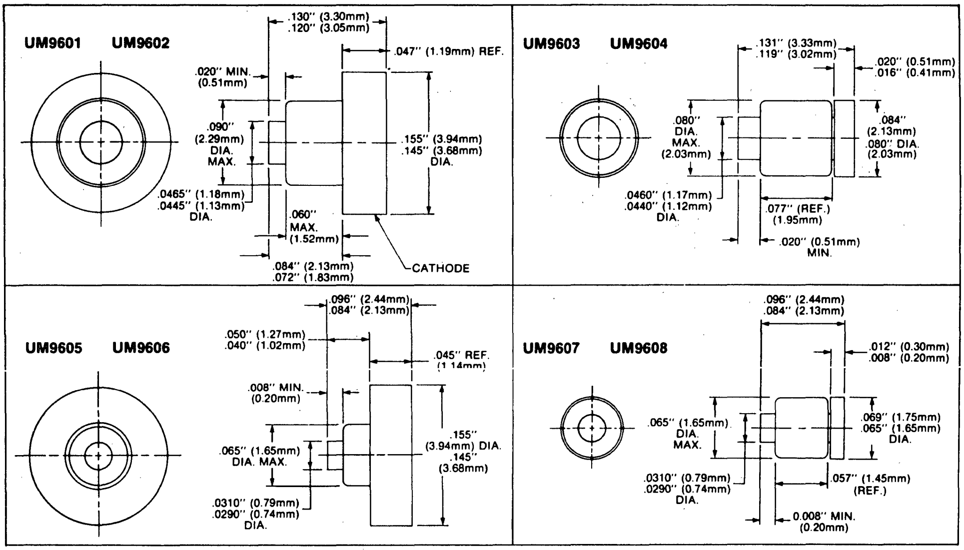
Typical Forward Bias Intermodulation Distortion vs Nominal Carrier Frequency at 20dBm per Channel



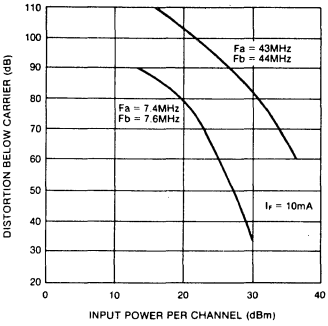
Typical Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Forward Bias Current at 20dBm per Channel



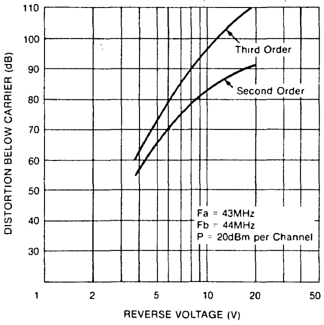
Mechanical Specifications



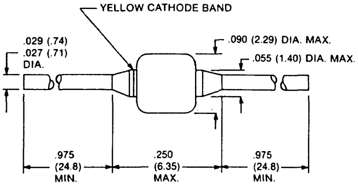
Typical Forward Bias Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Input Power per Channel



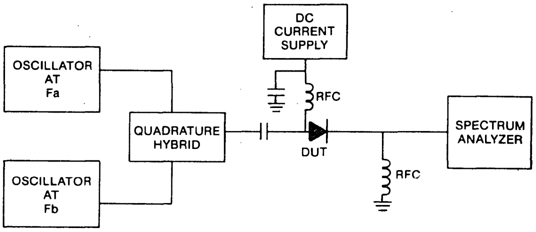
Typical Reverse Bias Intermodulation Distortion



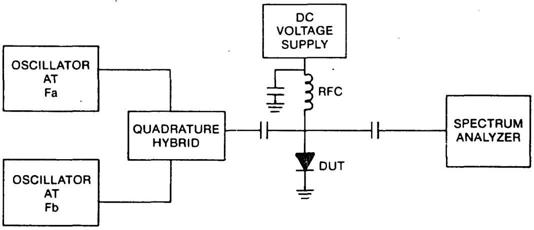
Mechanical Specifications



Forward Bias Distortion Test Set



Reverse Bias Distortion Test Set



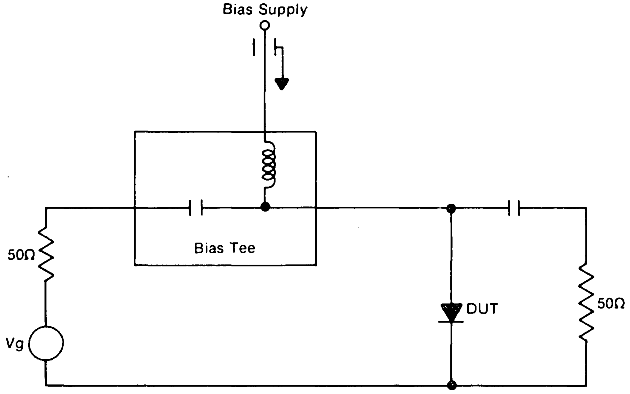
Microwave Characterization

The UM9601-UM9608 series has been designed and characterized as shunt switch elements at frequencies to 4GHz in microstrip circuits. Performance curves are given which demonstrate switch performance in 0.025" (.635mm) alumina microstrip.

The performance data were derived by evaluating externally biased microstrip circuits in which a UM9601 diode was installed. Each circuit consisted of a 1 inch length of 50 ohm nominal impedance 0.025" (.635mm) thick alumina microstrip and two SMA connectors. The data shown include the board and connector loss. Measurements performed using 0.050" (1.27mm) alumina substrates show similar performance at frequencies to 1.5GHz.

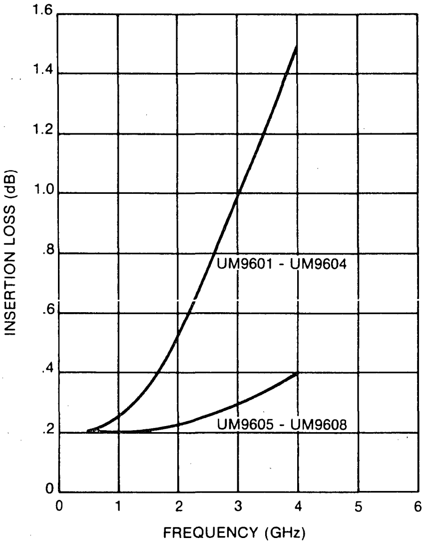
These circuits simulate simple SPST switches. Many designs require multithrow switches. It is important to recognize that a multithrow switch will have 6dB higher isolation than indicated for SPST switches. Also, a multithrow switch using shunt mounted PIN diodes require the diodes be placed a quarter-wavelength from the common port.

A further improvement in switch performance may be achieved by using 2 shunt PIN diodes in each arm spaced a quarter-wavelength from each other. In this case the isolation of each section will be twice the dB value of a SPST switch. The insertion loss due to the diodes should be less than twice the insertion loss of an SPST section due to the transforming effect of the quarter-wave line on the capacitance of a single diode.

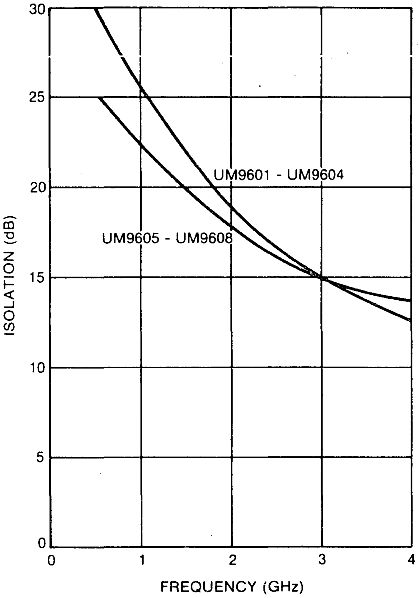


Microwave Test Circuit

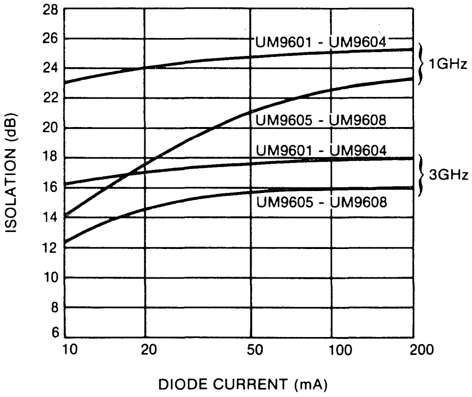
Typical Insertion Loss vs Frequency 0.025″ (0.635mm) Alumina Microstrip SPST Switch Diode at Zero Bias



Typical Isolation vs Frequency 0.025″ (0.635mm) Alumina Microstrip SPST Switch Diode Current = 100mA



Isolation vs Frequency and Diode Current 0.025″ (0.635mm) Alumina Microstrip SPST Switch

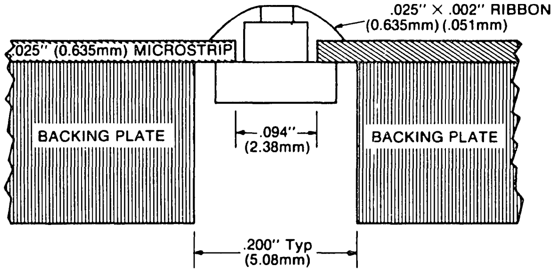


Installation in Microstrip

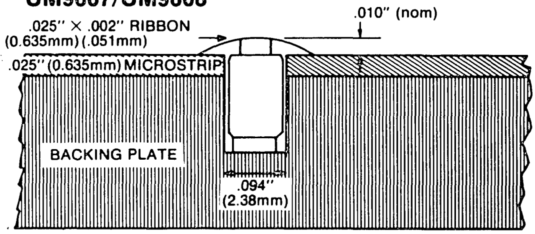
The cup type flange on the UM9601, UM9602, UM9605 and UM9606 is designed to be affixed to the ground plane surface of a microstrip board as shown. The UM9603, UM9604, UM9607 and UM9608 were designed to be affixed to a backing plate as shown. It was experimentally determined that at frequencies greater than 2GHz the anode of the diode should be approximately 0.010" (.254mm) above the top surface of the microstrip for lowest insertion loss.

For solder adhesion the microstrip may be heated to solder melting temperature (up to 300° C) with no damage to the diode. Conductive epoxy may also be employed. The thermal resistance of solder mounted UM9601-UM9604 in their test boards was less than 20° C/W; for the UM9605-UM9608 thermal resistance was less than 30° C/W.

UM9601/UM9602
UM9605/UM9606 **Microstrip Mount**



UM9603/UM9604
UM9607/UM9608 **Microstrip Mount**



Design Example - 900MHz Antenna Switch

An example of a practical circuit design using a UM9601 diode is a quarter-wave antenna switch covering the frequency of 800-900MHz. The circuit design for this switch is shown and was constructed using 0.025" (0.645mm) alumina microstrip.

This antenna switch uses a series mounted diode and a shunt mounted diode. The UM9601 was selected for the shunt mounted device (SPST performance at 1GHz: 0.2dB insertion loss and 25dB isolation) and because it is the lowest cost diode in the UM9601-UM9608 series. A UM9401 axial lead diode was chosen for the series mounted device.

The performance of this switch is displayed in the graphs and in the following table. It should be noted that the loss values are actual measured numbers including losses due to the capacitors, bias networks, connectors as well as the board. In a typical radio application where the antenna switch circuit board is integrated in the same microstrip board that contains transmitter and receiver elements the connector loss is eliminated. This will result in lower overall insertion loss values than indicated here.

The CW power handling capacity is determined by the allowable power dissipation of the series mounted UM9401. Using a gap in the line of 0.190" (4.82mm) and lead soldered attached spacing of 0.250" (0.635mm) the power rating of the UM9401 is 6 watts at a 25° C ambient. This was determined by performing a thermal resistance measurement on the circuit mounted UM9401. The relationship that derives the maximum transmitter power, P_T, is:

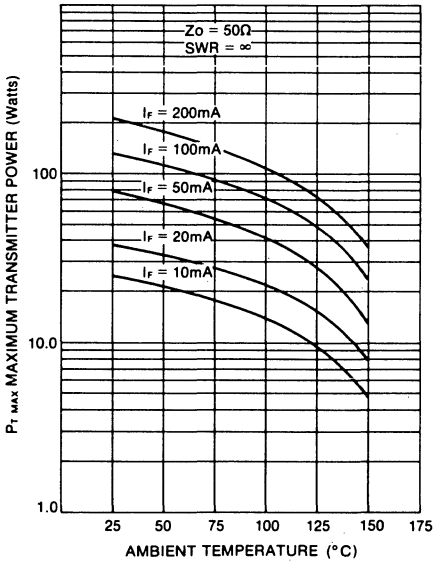
$$P_T = \frac{P_{DISS}}{R^S} \cdot Z_o \left(\frac{\sigma + 1}{2\sigma}\right)^2$$

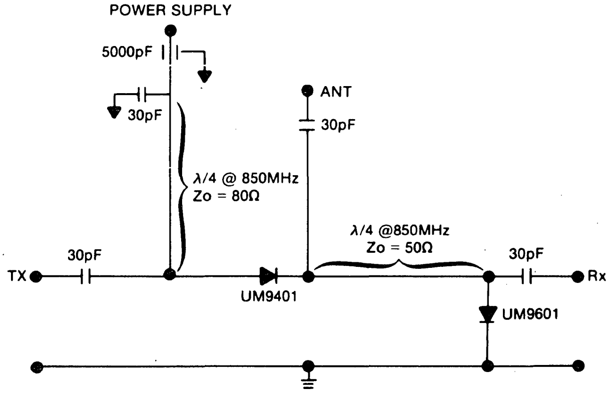
where σ = maximum antenna SWR

Using resistance values for the UM9401 and UM9601 the maximum transmitter power curve is given and shows that this circuit is able to handle 100 watts of transmitter power at 100mA forward biased and totally mismatched antenna at an ambient temperature of 60° C. For a perfectly matched antenna the power handling increases to 400 watts under the same bias and ambient temperature conditions.

Distortion is an important consideration in the selection of a PIN diode antenna switch design. The UM9401 and UM9601 PIN diodes are designed for low distortion applications. The level of distortion produced by this 900MHz antenna switch when operated in the transmit state (forward bias of 100mA) is expected to be at least 90dB below the carrier for a 50 watt transmitter level. In the receiver state (zero bias) the intermodulation distortion caused by two in-band signals at 0dBm are estimated to be at least 100dB below this level.

Maximum Transmitter Power vs Forward Current for UM9601/UM9401 900MHz Microstrip Antenna Switch





Circuit Diagram

Antenna Switch Performance

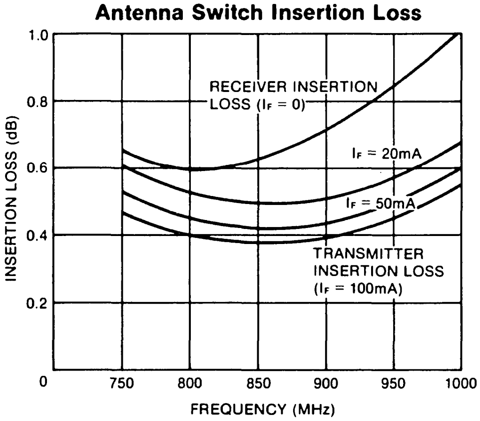
Frequency Range 800-900MHz

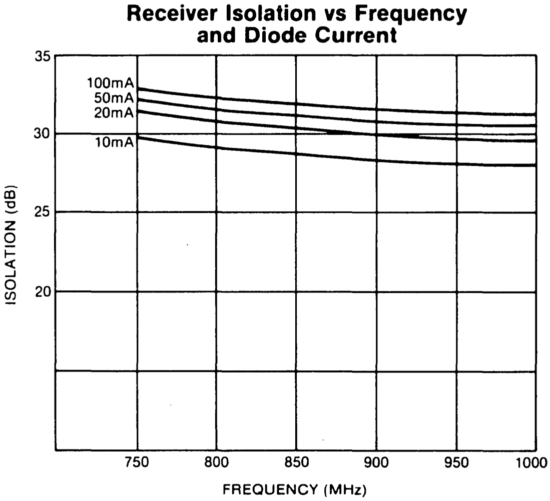
I. Transmit State
(I = 100mA, T_A = 60°C)

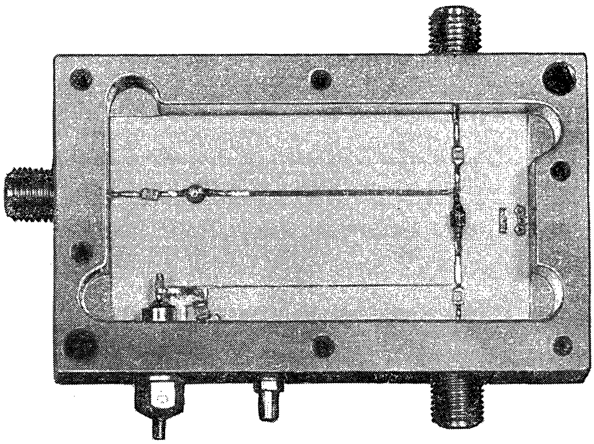
A. Maximum Transmitter Power - 100 watts (antenna SWR = ∞)
B. Maximum Transmitter Power - 400 watts (antenna SWR = 1)
C. Transmitter Insertion Loss - 0.4dB
D. Receiver Isolation - 31dB
E. Harmonic Distortion - −90dB (P_T = 100 watts)

II. Receive State
(Zero Bias)

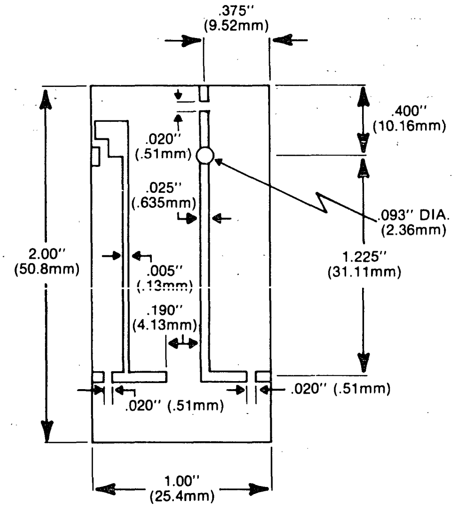
A. Receiver Insertion Loss - 0.6-0.7dB
B. Intermodulation Distortion - −100dB P_{in} = 0dBm



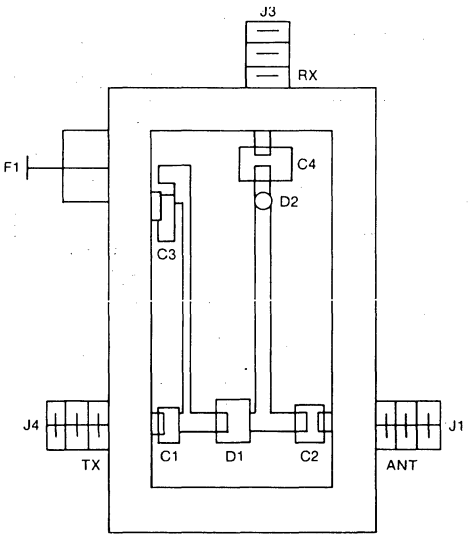




Photograph of 800-900MHz antenna switch test module using UM9401 and UM9601 PIN Diodes. In typical transceiver applications, the antenna switch circuit board is integrated.



Substrate Drawing



Assembly Drawing

Parts List

F1	5000pF Feed through Filter	Erie 1270-016
C1-C4	30pF Chip Capacitor	Vitramon VJ0805A300KF
D1	PIN Diode	Unitrode UM9401
D2	PIN Diode	Unitrode UM9601
J1-J3	SMA Connector	Cablewave 971-028
	Substrate	Vectronics Microwave 79-9081-0401

PIN DIODE

UM9701

Low Resistance, Low Distortion, RF Switching Diode

Features

- Low Forward Resistance
- High Reverse Resistance
- Specified Low Distortion
- High Voltage Capability
- Good Power Handling
- Unitrode Ruggedness and Reliability

Description

The UM9701 PIN diode was designed for low resistance at low forward bias current and low reverse bias capacitance. This unique Unitrode design results in both forward and reverse bias.

These PIN diodes are characterized for low current drain RF and microwave switch applications particularly for digital filter switch designs. The construction and geometry of these devices provide good voltage and power handling capability.

These devices are constructed using a metallurgical full face bond to both surfaces of the silicon chip. A glass enclosure houses this bond in a reliable and hermetic package. The axial leads are attached to the refractory pins and do not touch the glass enclosure.

Environmentally these, and all Unitrode PIN diodes, can withstand thermal cycling from −195° C to +300° C and exceed all military environmental specifications for shock, vibration, acceleration, and moisture resistance.

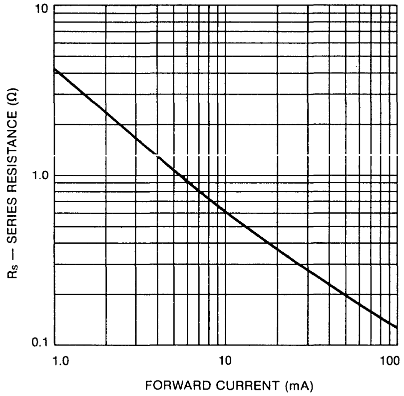
Maximum Ratings

Reverse Voltage	100V
Average Power Dissipation Free Air at 25° C	500mW (Derate linearly to 175° C)
Average Power Dissipation ½" (12.7 mm) Total Lead Length to 25° C Contacts	2.5W (Derate linearly to 175° C)
Operating and Storage Temperature	−65° C to +175° C

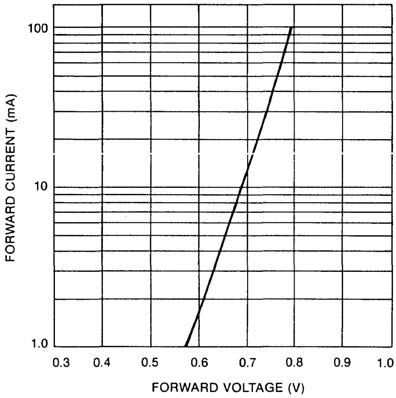
Electrical Specifications

Test	Symbol	UM9701	Condition
Series Resistance (MAX)	R_S	0.8Ω	f = 100MHz, I = 10mA
Total Capacitance (MAX)	C_T	1.8pF	f = 1MHz, V = 50V
Parallel Resistance (MIN)	R_P	100kΩ	f = 100MHz, V = 50V
Carrier Lifetime (MIN)	τ	1.5μs	I = 10mA
Reverse Current (MAX)	I_R	10μA	V = 100V
Forward Voltage (MAX)	V_F	0.8V	I = 10mA
Forward Bias Third Order IM Distortion (MAX)	$R \frac{2ab}{a}$	−90dB	I = 10mA Pa = Pb = +20dBm fa = 43MHz, fb = 44MHz
Reverse Bias Third Order IM Distortion (MAX)	$R \frac{2ab}{a}$	−90dB	V = 50V Pa = Pb = +20dBm fa = 43MHz, fb = 44MHz

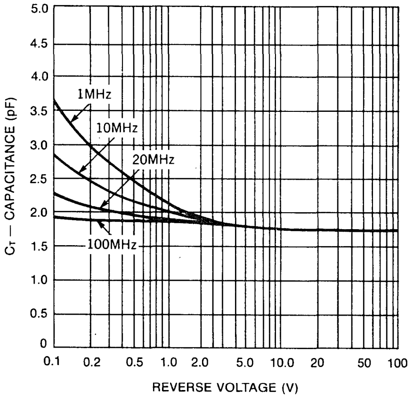
Typical Series Resistance vs Forward Current (F = 100MHz)



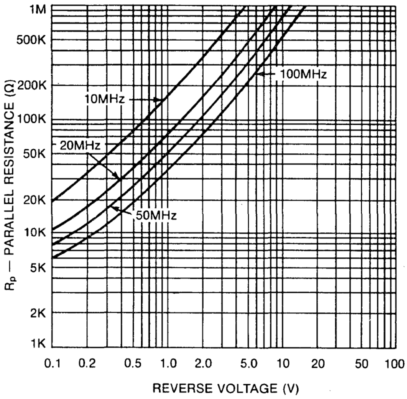
Typical DC Characteristic



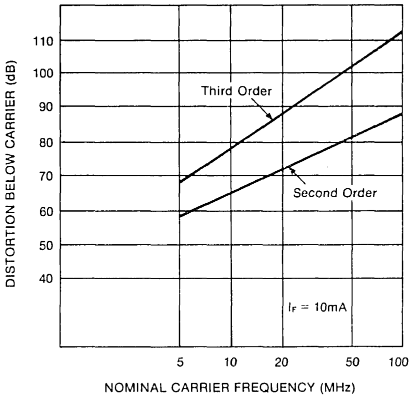
Typical Capacitance Characteristic



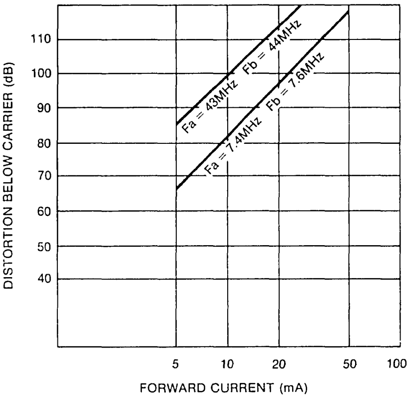
Typical Parallel Resistance Characteristic



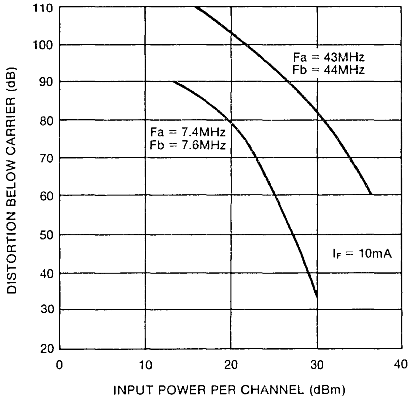
Typical Forward Bias Intermodulation Distortion vs Nominal Carrier Frequency at 20dBm per Channel



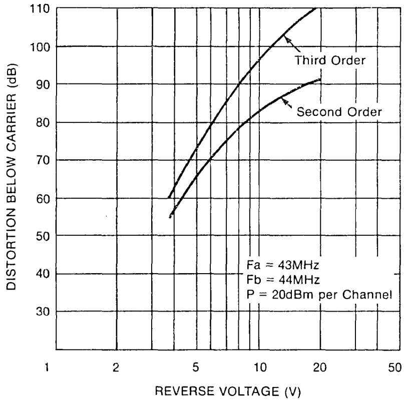
Typical Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Forward Bias Current at 20dBm per Channel



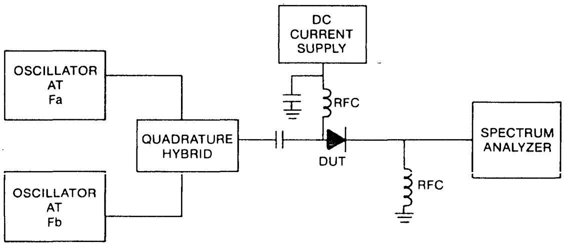
Typical Forward Bias Third Order Intermodulation Distortion $\left(R\ \frac{2ab}{a}\right)$ vs Input Power per Channel



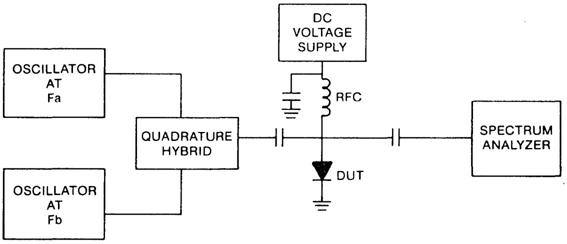
Typical Reverse Bias Intermodulation Distortion



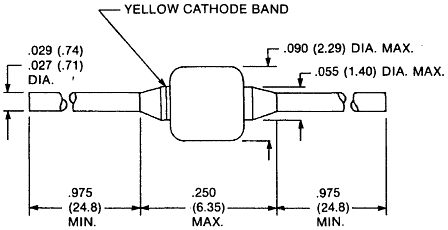
Forward Bias Distortion Test Set



Reverse Bias Distortion Test Set

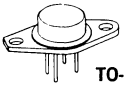


Mechanical Specifications

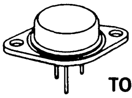


POWER HYBRIDS 7

POWER HYBRIDS



TO-66



TO-3

Type	Output Current, Pk.	Input/Output Voltage	Polarity	Fall Time		On-State Voltage (V) @ (A)	Pkg.
				Volt. (ns)	Cur. (ns)		
PIC600	5A	60	Pos.	75	150	1.5 @ 2	**4 PIN TO-66 (Isolated)**
PIC601		80	Pos.				
PIC602		100	Pos.				
PIC610		60	Neg.				
PIC611		80	Neg.				
PIC612		100	Neg.				
PIC660	10A	60	Pos.	150	250	1.5 @ 5	**4 PIN TO-66 (Isolated)**
PIC661		80	Pos.				
PIC662		100	Pos.				
PIC670		60	Neg.	250	250		
PIC671		80	Neg.				
PIC672		100	Neg.				
PIC625	15A	60	Pos.	175	300	1.5 @ 7	**4 PIN TO-66 (Isolated)**
PIC626		80	Pos.				
PIC627		100	Pos.				
PIC635		60	Neg.	300	300		
PIC636		80	Neg.				
PIC637		100	Neg.				
PIC645	20A	60	Pos.	150	300	1.5 @ 7	**3 PIN TO-3**
PIC646		80	Pos.				
PIC647		100	Pos.				
PIC655		60	Neg.	300	300		
PIC656		80	Neg.				
PIC657		100	Neg.				

HI-REL PICS

Unitrode offers as standard parts, high reliability versions of the PIC600 series power hybrid circuit screened to Unitrode specifications UL101/102. Listed below is a part number cross reference.

Basic Device	Test Specification	Test Level T1	Test Level T2
PIC600-602	UL101	PIC7501-7503	PIC7519-7521
PIC610-612	UL101	PIC7504-7506	PIC7522-7524
PIC625-627	UL101	PIC7507-7509	PIC7525-7527
PIC635-637	UL101	PIC7510-7512	PIC7528-7530
PIC645-647	UL102	PIC7513-7515	PIC7531-7533
PIC655-657	UL102	PIC7516-7518	PIC7534-7536
PIC660-661	UL101	PIC7555-7557	PIC7561-7563
PIC670-672	UL101	PIC7558-7560	PIC7564-7566

Each PIC75XX device is 100% screened to the following requirements per specification UL101/102.

UL101/102 SCREENING TABLE

1. Hermetic Seal Test — Fine Leak
2. Hermetic Seal Test — Gross Leak
3. High Temperature Storage
4. Temperature Cycling
5. Reverse Bias Clamped Inductive Test
6. High Temperature Reverse Bias
7. Power Burn-In

Test level T1 provides "attributes" data (GO/NO-GO testing after high temperature reverse bias and power burn-in) with shipment.

Test level T2 provides "variables" data (read and record data with delta criteria before and after high temperature reverse bias and power burn-in) with shipment.

A Group A sample test of mechanical, electrical and switching speed specifications is performed on each lot.

A Certificate of Compliance is provided with each shipment.

POWER INTEGRATED CIRCUIT

Switching Regulator 5 Amp Positive and Negative Power Output Stages

PIC600
PIC601
PIC602
PIC610
PIC611
PIC612

FEATURES

- Designed and characterized for switching regulator applications
- Cost saving design reduces size, improves efficiency, reduces noise and RFI (See note 4.)
- High operating frequency (to > 100kHz) results in smaller inductor-capacitor filter and improved power supply response time
- High operating efficiency: Typical 2A circuit performance —
  Rise and Fall time <75ns
  Efficiency >85%
- No reverse recovery spike generated by commutating diode (See note 4. and Fig. 2.)
- Electrically isolated, 4-Pin, TO-66 hermetic case (500V, 1μA, all leads common)

DESCRIPTION

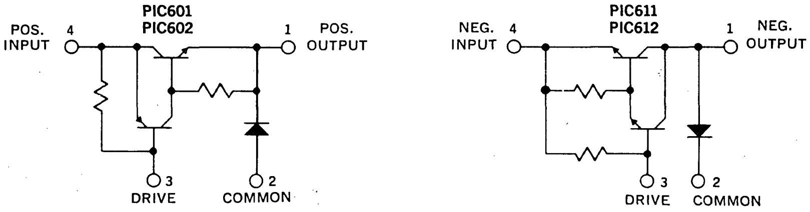
The Unitrode ESP Switching Regulator is a unique hybrid transistor circuit, specifically designed, constructed and specified for use in high current switching regulator applications. The designer is thus relieved of one of the most time consuming, tedious and critical aspects of switching regulator design: choosing the appropriate switching transistors and commutating diode, and empirically determining the optimum drive and bias conditions.

Switching regulators, when compared to conventional regulators, result in significant reductions in size, weight, and internal power losses and a major decrease in overall cost. Using the Unitrode PIC600 series, the designer can achieve further improvements in size, weight, efficiency, and costs. At the same time, because of the PIC600 series design and packaging, the designer is aided in overcoming two of the most significant drawbacks to switching regulators: noise generation and slow response time; there is, in fact, no diode reverse recovery spike (see note 4.).

The PIC600 series switching regulators are designed and characterized to be driven with standard integrated circuit voltage regulators. They are completely characterized over their entire operating range of —55°C to +125°C. The devices are enclosed in a special 4-pin TO-66 package, hermetically sealed for high reliability. The hybrid circuit construction utilizes thick film resistors on a beryllia substrate for maximum thermal conductivity and resultant low thermal impedance. All of the active elements in the hybrid are fully passivated.

Application Notes U-68 and U-76 provide a detailed description of the hybrid circuit and design guidance for specific circuit applications.

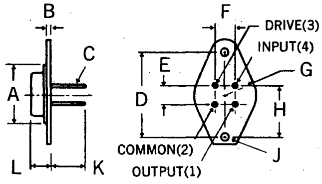
SCHEMATIC



MECHANICAL SPECIFICATIONS

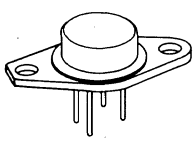
PIC600 PIC601 PIC602 PIC610 PIC611 PIC612

NOTES:
1. Case is electrically isolated.
2. Loads may be soldered to within $^1/_{16}$" of base provided temperature-time exposure is less than 260°C for 10 seconds.



	ins.	mm
A	.620 MAX.	15.75 MAX.
B	.050-.075	1.27-1.91
C	.028-.034	0.71-0.86
D	.958-.962	24.33-24.43
E	.190-.210	4.83-5.33
F	.190-.210	4.83-5.33
G	.350 MAX. RAD.	8.89 MAX. RAD.
H	.570-.590	14.48-14.99
J	.142-.152 DIA.	3.61-3.86 DIA.
K	.360 MIN.	9.14 MIN.
L	.250-.340	6.35-8.64

4-Pin TO-66



SEMICONDUCTOR PRODUCTS
UNITRODE

ABSOLUTE MAXIMUM RATINGS

	PIC600	PIC601	PIC602	PIC610	PIC611	PIC612
Input Voltage, V_{4-2}	60V	80V	100V	—60V	—80V	—100V
Output Voltage, V_{1-2}	60V	80V	100V	—60V	—80V	—100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	—5V	—5V	—5V
Output Current, I_1	5A	5A	5A	—5A	—5A	—5A
Drive Current, I_3	—0.2A	—0.2A	—0.2A	0.2A	0.2A	0.2A

Thermal Resistance	
Junction to Case, θ_{J-C}	
Power Switch	4.0°C/W
Commutating Diode	4.0°C/W
Case to Ambient, θ_{C-A}	60.0°C/W
Operating Temperature Range, T_C	—55°C to +125°C
Maximum Junction Temperature, T_J	+150°C
Storage Temperature Range	—65°C to +150°C

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	PIC600, 601, 602 Min.	Typ.	Max.	PIC610, 611, 612 Min.	Typ.	Max.	Units	Conditions
Current Delay Time	t_{di}	—	20	40	—	20	40	ns	V_{in} = 25V(—25V)
Current Rise Time	t_{ri}	—	50	75	—	50	75	ns	V_{out} = 5V(—5V)
Voltage Rise Time	t_{rv}	—	30	50	—	30	50	ns	I_{out} = 2A(—2A)
Voltage Storage Time	t_{sv}	—	700	—	—	700	—	ns	I_3 = —20mA(20mA) NOTE 5
Voltage Fall Time	t_{fv}	—	50	75	—	50	75	ns	See Figure 2.
Current Fall Time	t_{fi}	—	70	150	—	70	150	ns	See notes 1., 2., 4.
Efficiency (Notes 2. & 4.)	η	—	85	—	—	85	—	%	
On-State Voltage (Note 3.)	$V_{4-1(on)}$	—	1.0	1.5	—	—1.0	—1.5	V	I_4 = 2A(—2A), I_3 = —.02A(.02A) NOTE 5
On-State Voltage (Note 3.)	$V_{4-1(on)}$	—	2.5	3.5	—	—2.5	—3.5	V	I_4 = 5A(—5A), I_3 = —.02A(.02A) NOTE 5
Diode Forward Voltage (Note 3.)	$V_{2-1(on)}$	—	.8	1.0	—	—.8	—1.0	V	I_2 = 2A(—2A)
Diode Forward Voltage (Note 3.)	$V_{2-1(on)}$	—	1.0	1.5	—	—1.0	—1.5	V	I_2 = 5A(—5A)
Off-State Current	I_{4-1}	—	0.1	10	—	—0.1	—10	μA	V_4 = Rated input voltage
Off-State Current	I_{4-1}	—	10	—	—	—10	—	μA	V_4 = Rated input voltage, T_A = 100°C
Diode Reverse Current	I_{1-2}	—	1.0	10	—	—1.0	—10	μA	V_1 = Rated output voltage
Diode Reverse Current	I_{1-2}	—	500	—	—	500	—	μA	V_1 = Rated output voltage, T_A = 100°C

NOTES:

1. In switching an inductive load, the current will lead the voltage on turn on and lag the voltage on turn-off (see Figure 2.). Therefore, Voltage Delay Time (t_{DV}) $\cong t_{di} + t_{ri}$ and Current Storage Time (t_{si}) $\cong t_{sv} + t_{fv}$.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1., in which the efficiency is measured, is representative of typical operating conditions for the PIC600 switching regulators.
3. Pulse test: Duration = 300μs, Duty Cycle ≤ 2%.
4. As can be seen from the switching waveforms shown in Figure 2., no reverse of forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliabilty, since the power switch only carries current during turn-on.
5. To insure safe operation I_3 should be $\geq |20mA|$ during T_{ON}. Operation at $I_3 < |20mA|$ can permanently damage device.

POWER DISSIPATION CONSIDERATIONS

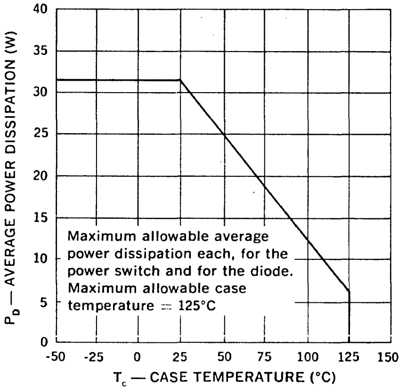
The total power losses in the switching regulator is the sum of the switching losses, and the power switch and diode D.C. losses. Once total power dissipation has been determined, the Power Dissipation curve, or thermal resistance data may be used to determine the allowable case or ambient temperature for any operating condition.

The switching losses curve presents data for a frequency of 20KHz. To find losses at any other frequency, multiply by f/20KHz.

The D.C. losses curve presents data for a duty cycle of .2. To find D.C. losses at any other duty cycle, multiply by D/.2 for the power switch and by (1-D)/.8 for the diode.

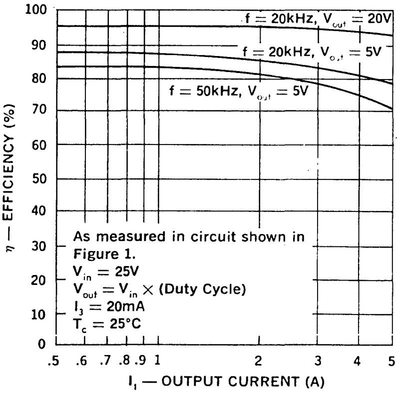
At frequencies much below 10KHz the above method for determining the allowable case or ambient temperature becomes invalid and a detailed transient thermal analysis must be performed. Please see Design Note 6 (DN-6) for further information.

Power Dissipation



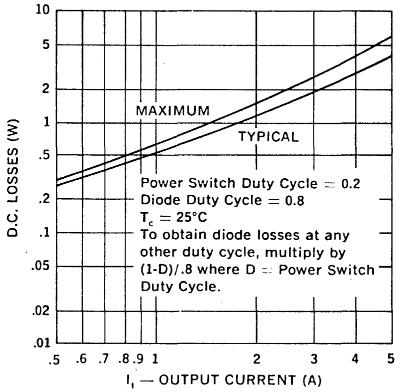
Maximum allowable average power dissipation each, for the power switch and for the diode. Maximum allowable case temperature = 125°C

Efficiency



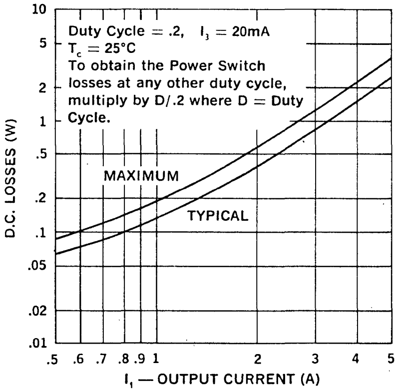
As measured in circuit shown in Figure 1.
V_{in} = 25V
V_{out} = V_{in} × (Duty Cycle)
I_3 = 20mA
T_c = 25°C

Diode D.C. Losses



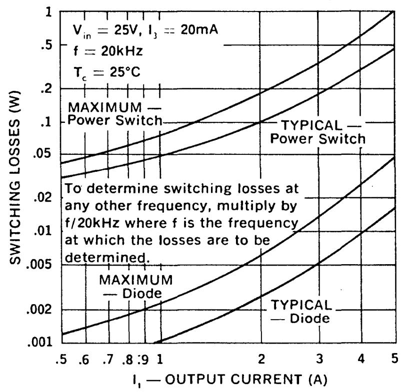
Power Switch Duty Cycle = 0.2
Diode Duty Cycle = 0.8
T_c = 25°C
To obtain diode losses at any other duty cycle, multiply by (1-D)/.8 where D = Power Switch Duty Cycle.

Power Switch D.C. Losses



Duty Cycle = .2, I_3 = 20mA
T_c = 25°C
To obtain the Power Switch losses at any other duty cycle, multiply by D/.2 where D = Duty Cycle.

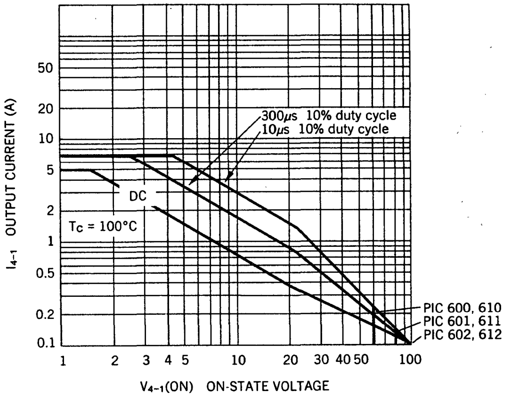
Switching Losses



V_{in} = 25V, I_3 = 20mA
f = 20kHz
T_c = 25°C

To determine switching losses at any other frequency, multiply by f/20kHz where f is the frequency at which the losses are to be determined.

Maximum Safe Operating Area
PIC 600, 601, 602-610, 611, 612



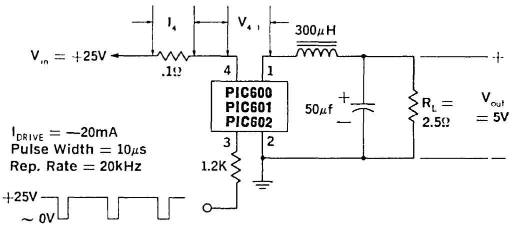


Figure 1. PIC600, 601, 602 Switching Speed Circuit

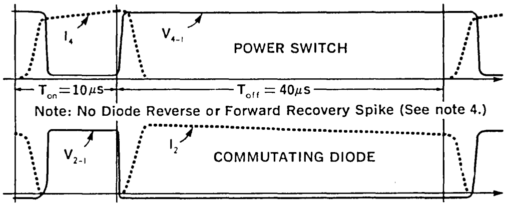
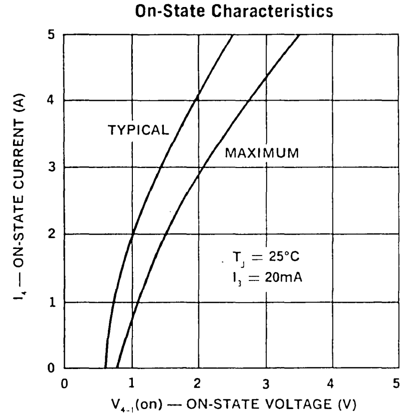
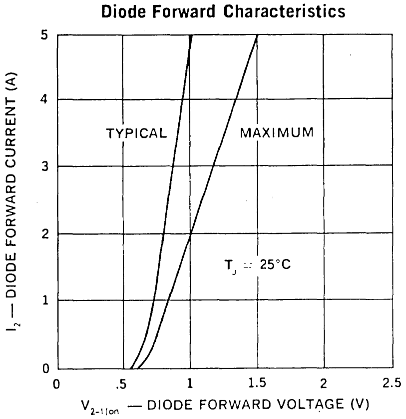
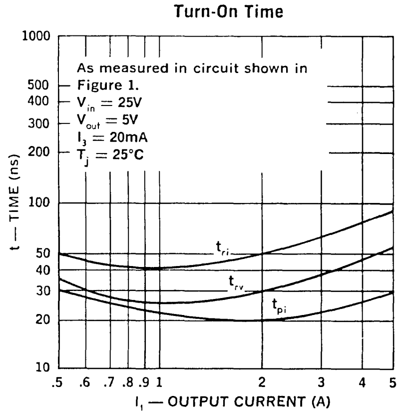


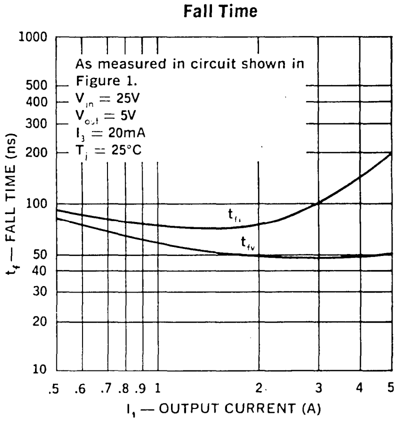
Figure 2. PIC600, PIC601, PIC602 Switching Waveforms

Note: PIC610, PIC611, PIC612 Test Circuit and waveforms are identical but of opposite polarity ($V_{in} = -25V$, $V_{out} = -5V$, $I_{DRIVE} = +20mA$).









POWER INTEGRATED CIRCUIT

Switching Regulator 15 Amp Positive and Negative Power Output Stages

PIC625
PIC626
PIC627
PIC635
PIC636
PIC637

FEATURES

- Designed and characterized for switching regulator applications
- Cost saving design reduces size, improves efficiency, reduces noise and RFI (See note 4.)
- High operating frequency (to >100kHz) results in smaller inductor-capacitor filter and improved power supply response time
- High operating efficiency: Typical 7A circuit performance —
  Rise and Fall time <300 ns
  Efficiency >85%
- No reverse recovery spike generated by commutating diode (See note 4. and Fig. 2.)
- Electrically isolated, 4-Pin, TO66 hermetic case (500V, 1μA, all leads common)

DESCRIPTION

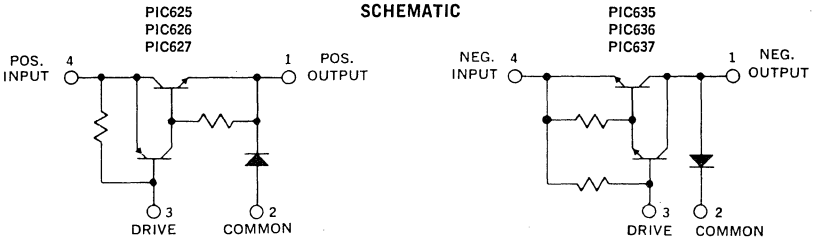
The Unitrode ESP Switching Regulator is a unique hybrid transistor circuit, specifically designed, constructed and specified for use in high current switching regulator applications. The designer is thus relieved of one of the most time consuming, tedious and critical aspects of switching regulator design: choosing the appropriate switching transistors and commutating diode, and empirically determining the optimum drive and bias conditions.

Switching regulators, when compared to conventional regulators, result in significant reductions in size, weight, and internal power losses and a major decrease in overall cost. Using the Unitrode PIC600 series the designer can achieve further improvements in size, weight, efficiency, and costs. At the same time, because of the PIC600 series design and packaging, the designer is aided in overcoming two of the most significant drawbacks to switching regulators: noise generation and slow response time; there is, in fact, no diode reverse recovery spike (See note 4.).

The PIC600 series switching regulators are designed and characterized to be driven wih standard integrated circuit voltage regulators. They are completely characterized over their entire operating range of —55°C to +125°C. The devices are enclosed in a special 4-pin TO66 package, hermetically sealed for high reliability. The hybrid circuit construction utilizes thick film resistors on a beryllia substrate for maximum thermal conductivity and resultant low thermal impedance. All of the active elements in the hybrid are fully passivated.

Application Notes U-68 and U-76 provide a detailed description of the hybrid circuit and design guidance for specific circuit applications.

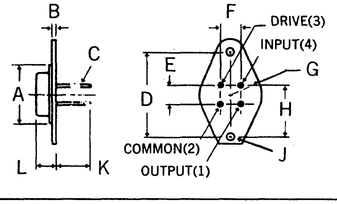
SCHEMATIC



MECHANICAL SPECIFICATIONS

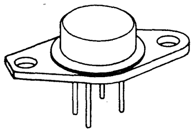
PIC625 PIC626 PIC627 PIC635 PIC636 PIC637

NOTES:
1. Case is electrically isolated.
2. Loads may be soldered to within $^1/_{16}$" of base provided temperature-time exposure is less than 260°C for 10 seconds.



	ins.	mm
A	.620 MAX	15.75 MAX.
B	050-.075	1.27-1 91
C	.028- 034	0.71-0.86
D	.958-.962	24.33-24.43
E	.190-.210	4.83-5.33
F	.190-.210	4.83-5.33
G	.350 MAX. RAD	8.89 MAX RAD
H	570- 590	14 48 14 99
J	.142-.152 DIA	3 61-3 86 DIA
K	360 MIN	9.14 MIN
L	250-.340	6 35-8.64

4-Pin TO-66



SEMICONDUCTOR PRODUCTS
UNITRODE

ABSOLUTE MAXIMUM RATINGS

	PIC625	PIC626	PIC627	PIC635	PIC636	PIC637
Input Voltage, $V_{4\text{-}2}$	60V	80V	100V	—60V	—80V	—100V
Output Voltage, $V_{1\text{-}2}$	60V	80V	100V	—60V	—80V	—100V
Drive-Input Reverse Voltage, $V_{3\text{-}4}$	5V	5V	5V	—5V	—5V	—5A
Output Current, I_1	15A	15A	15A	—15A	—15A	—15A
Drive Current, I_3	—0.4A	—0.4A	—0.4A	0.4A	0.4A	0.4A
Thermal Resistance						
Junction to Case, $\theta_{J\text{-}C}$						
Power Switch	4.0°C/W					
Commutating Diode	4.0°C/W					
Case to Ambient, $\theta_{C\text{-}A}$	60.0°C/W					
Operating Temperature Range, T_C	—55°C to +125°C					
Maximum Junction Temperature, T_j	+150°C					
Storage Temperature Range	—65°C to +150°C					

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

		PIC625/626/627			PIC635/636/637				
Test	Symbol	Min.	Typ.	Max.	Min.	Typ.	Max.	Units	Conditions
Current Delay Time	t_{di}	—	35	60	—	35	60	ns	$V_{in} = 25V(-25V)$
Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	$V_{out} = 5V(-5V)$
Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	$I_{out} = 7A(-7A)$
Voltage Storage Time	t_{sv}	—	900	—	—	900	—	ns	$I_3 = -30mA(30mA)$ NOTE 5
Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 2
Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See notes 1, 2, 4
Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
On-State Voltage (Note 3)	$V_{4\text{-}1(on)}$	—	1.0	1.5	—	—1.0	—1.5	V	$I_4 = 7A(-7A)$, $I_3 = -.03A(.03A)$ NOTE 5
On-State Voltage (Note 3)	$V_{4\text{-}1(on)}$	—	2.5	3.5	—	—2.5	—3.5	V	$I_4 = 15A(-15A)$, $I_3 = -.03A(.03A)$ NOTE 5
Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1(on)}$	—	.85	1.25	—	—.85	—1.25	V	$I_2 = 7A(-7A)$
Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1(on)}$	—	.95	1.75	—	—.95	—1.75	V	$I_2 = 15A(-15A)$
Off-State Current	$I_{4\text{-}1}$	—	0.1	10	—	—0.1	—10	μA	V_4 = Rated input voltage
Off-State Current	$I_{4\text{-}1}$	—	10	—	—	—10	—	μA	V_4 = Rated input voltage, $T_A = 100°C$
Diode Reverse Current	$I_{1\text{-}2}$	—	1.0	10	—	—1.0	—10	μA	V_1 = Rated output voltage
Diode Reverse Current	$I_{1\text{-}2}$	—	500	—	—	500	—	μA	V_1 = Rated output voltage, $T_A = 100°C$

NOTES:

1. In switching an inductive load, the current will lead the voltage on turn-on and lag the voltage on turn-off (see Figure 2). Therefore; Voltage Delay Time (t_{DV}) ≅ t_{di} + t_{ri} and Current Storage Time (t_{si}) ≅ t_{sv} + t_{fv}.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1, in which the efficiency is measured, is representative of typical operating conditions for the PIC600 series switching regulators.
3. Pulse test: Duration = 300μs, Duty Cycle ≤ 2%.
4. As can be seen from the switching waveforms shown in Figure 2, no reverse of forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliability, since the power switch only carries current during turn-on.
5. To insure safe operation I_3 should be ≥|30mA| during T_{ON}. Operation at I_3 <|30mA| can permanently damage device.

POWER DISSIPATION CONSIDERATIONS

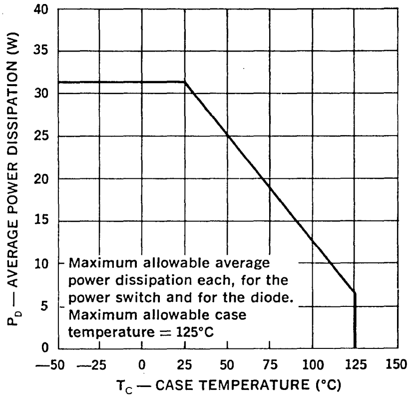
The total power losses in the switching regulator is the sum of the switching losses, and the power switch and diode D.C. losses. Once total power dissipation has been determined, the Power Dissipation curve, or thermal resistance data may be used to determine the allowable case or ambient temperature for any operating condition.

The switching losses curve presents data for a frequency of 20KHz. To find losses at any other frequency, multiply by f/20KHz.

The D.C. losses curve presents data for a duty cycle of .2. To find D.C. losses at any other duty cycle, multiply by D/.2 for the power switch and by (1-D)/.8 for the diode.

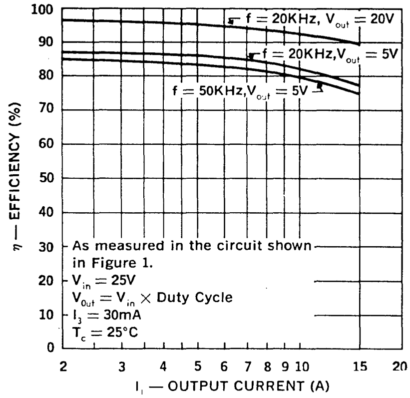
At frequencies much below 10KHz the above method for determining the allowable case or ambient temperature becomes invalid and a detailed transient thermal analysis must be performed. Please see Design Note 6 (DN-6) for further information.

Power Dissipation



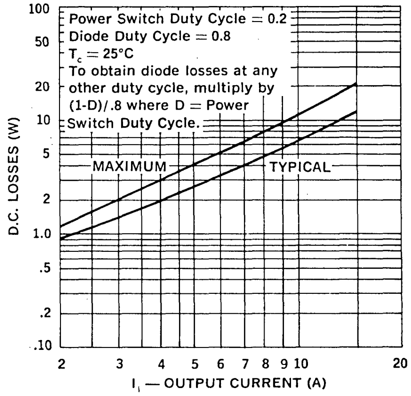
Maximum allowable average power dissipation each, for the power switch and for the diode. Maximum allowable case temperature = 125°C

Efficiency



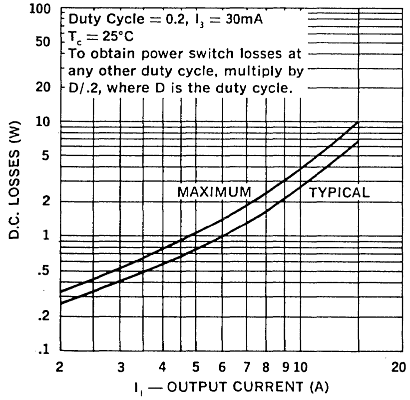
As measured in the circuit shown in Figure 1.
V_{in} = 25V
V_{out} = V_{in} × Duty Cycle
I_3 = 30mA
T_c = 25°C

Diode D.C. Losses



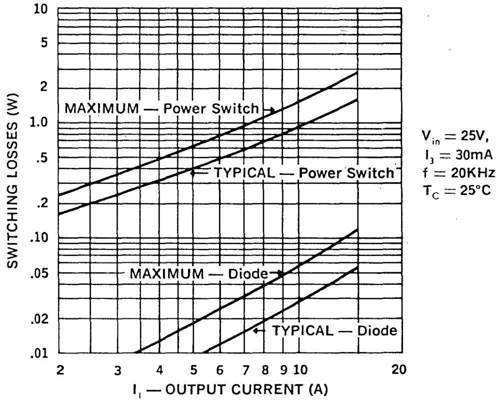
Power Switch Duty Cycle = 0.2
Diode Duty Cycle = 0.8
T_c = 25°C
To obtain diode losses at any other duty cycle, multiply by (1-D)/.8 where D = Power Switch Duty Cycle.

Power Switch D.C. Losses



Duty Cycle = 0.2, I_3 = 30mA
T_c = 25°C
To obtain power switch losses at any other duty cycle, multiply by D/.2, where D is the duty cycle.

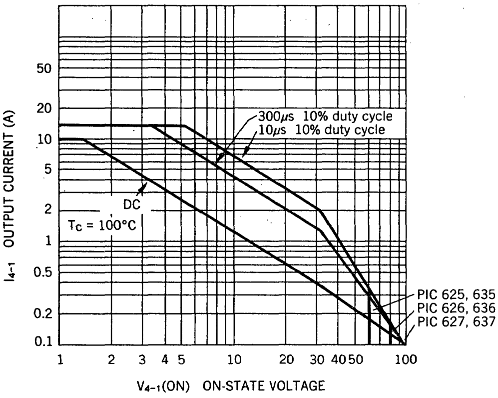
Switching Losses



V_{in} = 25V,
I_3 = 30mA
f = 20KHz
T_C = 25°C

To determine switching losses at any other frequency, multiply by f/20KHz where f is the frequency at which the losses are to be determined.

Maximum Safe Operating Area
PIC 625, 626, 627-635, 636, 637



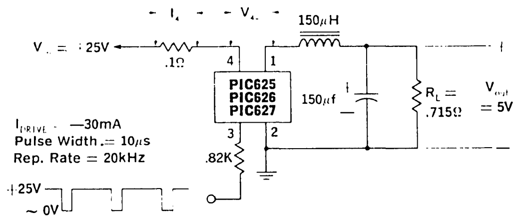


Figure 1. PIC625, 626, 627 Switching Speed Circuit

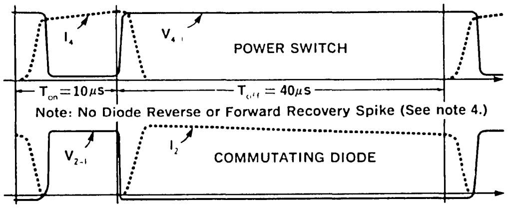
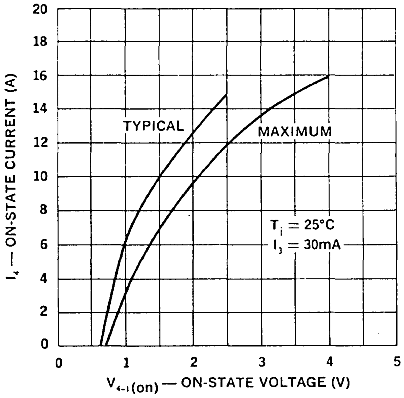


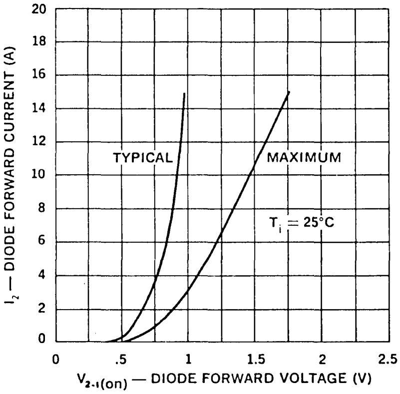
Figure 2. PIC625, 626, 627 Switching Waveforms

Note: PIC635, PIC636, PIC637 Circuit and waveforms are identical but of opposite polarity ($V_{in} = -25V$, $V_{out} = -5V$, $I_{DRIVE} = +30mA$.)

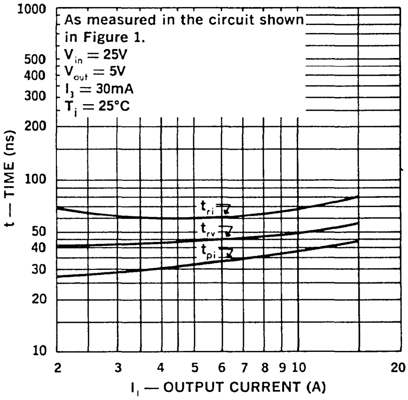
On-State Characteristics



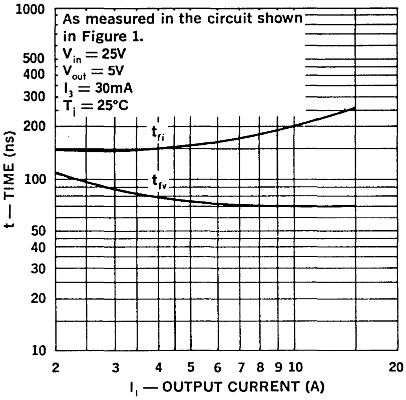
Diode Forward Characteristics



Turn-on Time



Fall Time



POWER INTEGRATED CIRCUIT

Switching Regulator 15 Amp Positive and Negative Power Output Stages

PIC645
PIC646
PIC647
PIC655
PIC656
PIC657

FEATURES

- Designed and characterized for switching regulator applications
- Cost saving design reduces size, improves efficiency, reduces noise and RFI (See note 4.)
- High operating frequency (to >100kHz) results in smaller inductor-capacitor filter and improved power supply response time
- High operating efficiency: Typical 7A circuit performance —
  Rise and Fall time <300 ns
  Efficiency >85%
- No reverse recovery spike generated by commutating diode (See note 4. and Fig. 2.)

DESCRIPTION

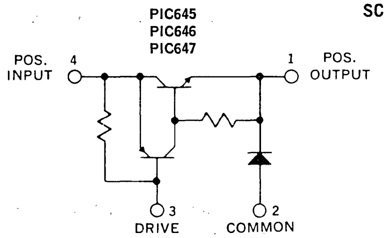
The Unitrode ESP Switching Regulator is a unique hybrid transistor circuit, specifically designed, constructed and specified for use in high current switching regulator applications. The designer is thus relieved of one of the most time consuming, tedious and critical aspects of switching regulator design: choosing the appropriate switching transistors and commutating diode, and empirically determining the optimum drive and bias conditions.

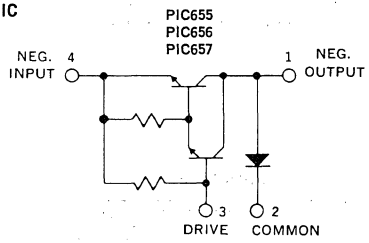
Switching regulators, when compared to conventional regulators, result in significant reductions in size, weight, and internal power losses and a major decrease in overall cost. Using the Unitrode PIC600 series the designer can achieve further improvements in size, weight, efficiency, and costs. At the same time, because of the PIC600 series design and packaging, the designer is aided in overcoming two of the most significant drawbacks to switching regulators: noise generation and slow response time; there is, in fact, no diode reverse recovery spike (See note 4.).

The PIC600 series switching regulators are designed and characterized to be driven with standard integrated circuit voltage regulators. They are completely characterized over their entire operating range of —55°C to +125°C. The devices are enclosed in a special 3 pin TO-3 package, hermetically sealed for high reliability. The hybrid circuit construction utilizes thick film resistors on a beryllia substrate for maximum thermal conductivity and resultant low thermal impedance. All of the active elements in the hybrid are fully passivated.

Application Notes U-68 and U-76 provide a detailed description of the hybrid circuit and design guidance for specific circuit applications.

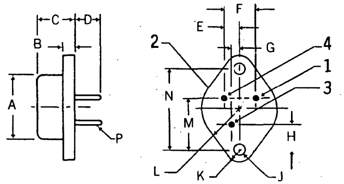
SCHEMATIC





MECHANICAL SPECIFICATIONS

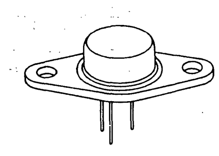
PIC645 PIC646 PIC647 PIC655 PIC656 PIC657



NOTE:
Loads may be soldered to within $^{1}/_{16}$″ of base provided temperature-time exposure is less than 260°C for 10 seconds.

	ins.	mm
A	.875 MAX.	22.23 MAX.
B	.135	3.43
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.205-.225	5.21-5.72
F	.420-.440	10.67-11.18
G	.145-.165	3.68-4.19
H	.395-.405	10.03-10.29
J	.151-.161 DIA.	3.84-4.09 DIA.
K	.188 MAX. RAD.	4.78 MAX. RAD.
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.708-.728	17.98-18.49
N	1.177-1.197	29.90-30.40
P	.038-.043 DIA.	.97-1.09 DIA.

3 Pin TO-3



SEMICONDUCTOR PRODUCTS
UNITRODE

ABSOLUTE MAXIMUM RATINGS

	PIC645	PIC646	PIC647	PIC655	PIC656	PIC657
Input Voltage, V_{4-2}	60V	80V	100V	—60V	—80V	—100V
Output Voltage, V_{1-2}	60V	80V	100V	—60V	—80V	—100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	—5V	—5V	—5V
Continuous Output Current, I_1	15A	15A	15A	—15A	—15A	—15A
Peak Output Current	20A	20A	20A	—20A	—20A	—20A
Drive Current, I_3	—0.4A	—0.4A	—0.4A	0.4A	0.4A	0.4A

Thermal Resistance

Junction to Case, θ_{J-C}

Power Switch .... 2°C/W

Commutating Diode .... 2°C/W

Case to Ambient, θ_{C-A} .... 30.0°C/W

Operating Temperature Range, T_C .... —55°C to +125°C

Maximum Junction Temperature, T_j .... +150°C

Storage Temperature Range .... —65°C to +150°C

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	PIC645/646/647			PIC655/656/657			Units	Conditions
		Min.	Typ.	Max.	Min.	Typ.	Max.		
Current Delay Time	t_{di}	—	35	60	—	35	60	ns	$V_{in} = 25V(-25V)$
Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	$V_{out} = 5V(-5V)$
Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	$I_{out} = 7A(-7A)$
Voltage Storage Time	t_{sv}	—	900	—	—	900	—	ns	$I_3 = -30mA(30mA)$ NOTE 5
Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 2
Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See notes 1, 2, 4
Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
On-State Voltage (Note 3)	$V_{4-1(on)}$	—	1.0	1.5	—	—1.0	—1.5	V	$I_4 = 7A(-7A)$, $I_3 = -.03A(.03A)$ NOTE 5
On-State Voltage (Note 3)	$V_{4-1(on)}$	—	2.5	3.5	—	—2.5	—3.5	V	$I_4 = 15A(-15A)$, $I_3 = -.03A(.03A)$ NOTE 5
Diode Fwd. Voltage (Note 3)	$V_{2-1(on)}$	—	.85	1.25	—	—.85	—1.25	V	$I_2 = 7A(-7A)$
Diode Fwd. Voltage (Note 3)	$V_{2-1(on)}$	—	.95	1.75	—	—.95	—1.75	V	$I_2 = 15A(-15A)$
Off-State Current	I_{4-1}	—	0.1	10	—	—0.1	—10	μA	V_4 = Rated input voltage
Off-State Current	I_{4-1}	—	10	—	—	—10	—	μA	V_4 = Rated input voltage, $T_A = 100°C$
Diode Reverse Current	I_{1-2}	—	1.0	10	—	—1.0	—10	μA	V_1 = Rated output voltage
Diode Reverse Current	I_{1-2}	—	500	—	—	500	—	μA	V_1 = Rated output voltage, $T_A = 100°C$

NOTES:

1. In switching an inductive load, the current will lead the voltage on turn-on and lag the voltage on turn-off (see Figure 2). Therefore, Voltage Delay Time (t_{DV}) $\cong t_{di} + t_{ri}$ and Current Storage Time (t_{si}) $\cong t_{sv} + t_{fv}$.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1, in which the efficiency is measured, is representative of typical operating conditions for the PIC600 series switching regulators.
3. Pulse test: Duration = 300μs, Duty Cycle $\leq$ 2%.
4. As can be seen from the switching waveforms shown in Figure 2, no reverse of forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliability, since the power switch only carries current during turn-on.
5. To insure safe operation I_3 should be $\geq |30mA|$ during T_{ON}. Operation at $I_3 < |30mA|$ can permanently damage device.

POWER DISSIPATION CONSIDERATIONS

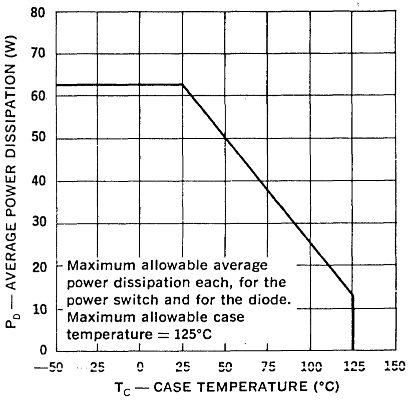
The total power losses in the switching regulator is the sum of the switching losses, and the power switch and diode D.C. losses. Once total power dissipation has been determined, the Power Dissipation curve, or thermal resistance data may be used to determine the allowable case or ambient temperature for any operating condition.

The switching losses curve presents data for a frequency of 20KHz. To find losses at any other frequency, multiply by f/20KHz.

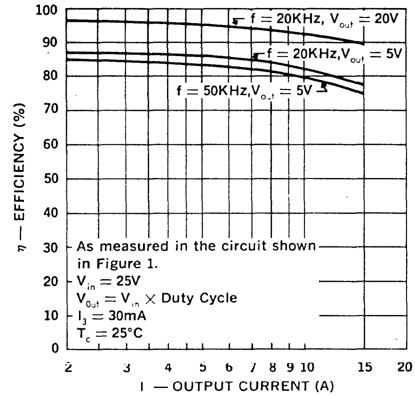
The D.C. losses curve presents data for a duty cycle of .2. To find D.C. losses at any other duty cycle, multiply by D/.2 for the power switch and by (1-D)/.8 for the diode.

At frequencies much below 10KHz the above method for determining the allowable case or ambient temperature becomes invalid and a detailed transient thermal analysis must be performed. Please see Design Note 6 (DN-6) for further information.

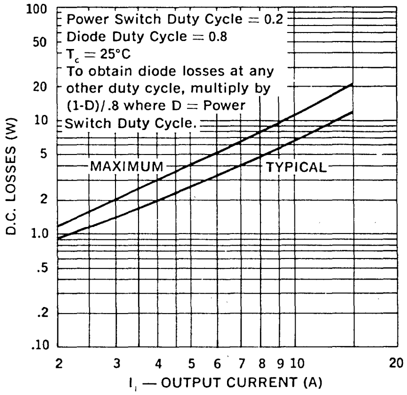
Power Dissipation



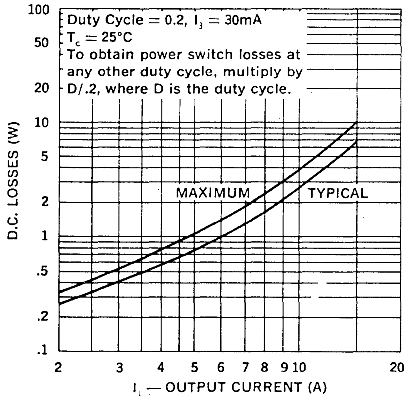
Efficiency



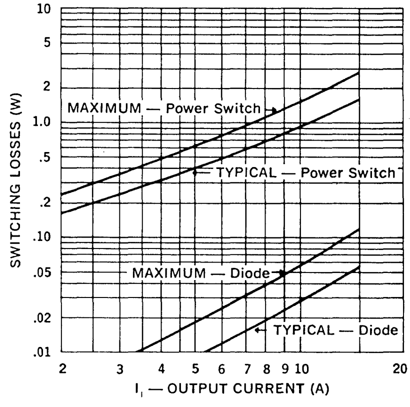
Diode D.C. Losses



Power Switch D.C. Losses



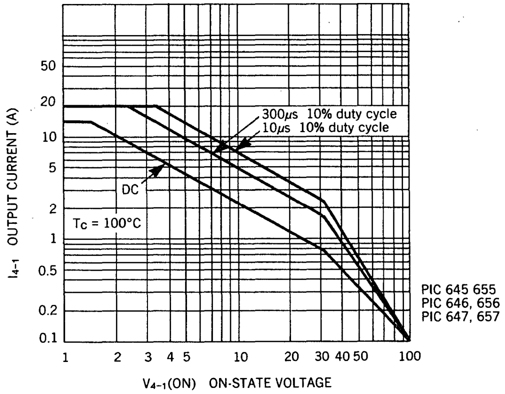
Switching Losses



V_{in} = 25V, I_3 = 30mA
f = 20KHz
T_C = 25°C

To determine switching losses at any other frequency, multiply by f/20KHz where f is the frequency at which the losses are to be determined.

Maximum Safe Operating Area
PIC 645, 646, 647-655, 656, 657



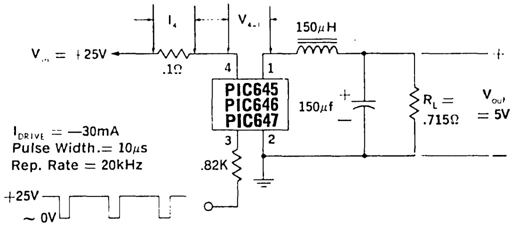


Figure 1. PIC645, 646, 647 Switching Speed Circuit

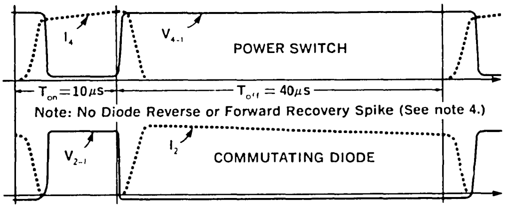
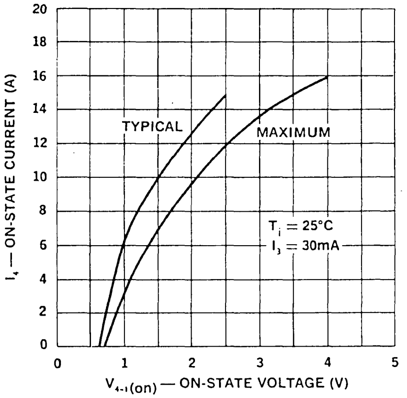


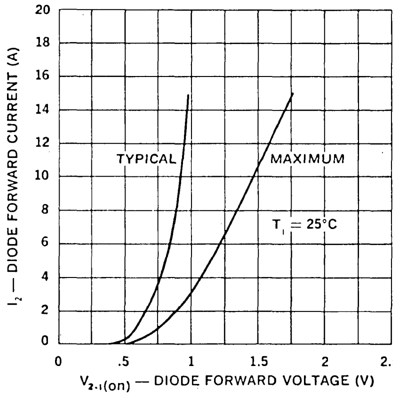
Figure 2. PIC645, 646, 647 Switching Waveforms

Note: PIC655, PIC656, PIC657 Circuit and waveforms are identical but of opposite polarity (V_{in} = —25V, V_{out} = —5V, I_{DRIVE} = +30mA.)

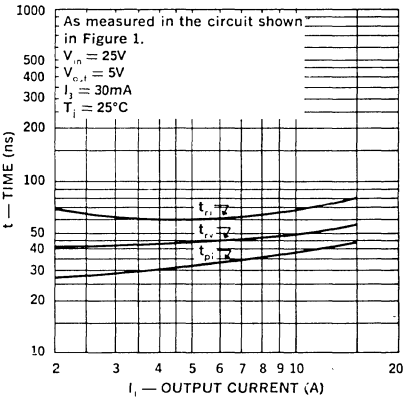
On-State Characteristics



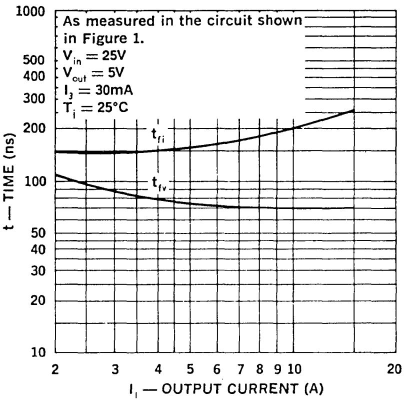
Diode Forward Characteristics



Turn-on Time



Fall Time



POWER INTEGRATED CIRCUIT

Switching Regulator 10 Amp Positive and Negative Power Output Stages

PIC660
PIC661
PIC662
PIC670
PIC671
PIC672

FEATURES

- Designed and characterized for switching regulator applications
- Cost saving design reduces size, improves efficiency, reduces noise and RFI (See note 4.)
- High operating frequency (to >100kHz) results in smaller inductor-capacitor filter and improved power supply response time
- High operating efficiency: Typical 5A circuit performance —
  Rise and Fall time <300ns
  Efficiency >85%
- No reverse recovery spike generated by commutating diode (See note 4. and Fig. 2.)
- Electrically isolated, 4-Pin, TO-66 hermetic case (500V, 1μA, all leads common)

DESCRIPTION

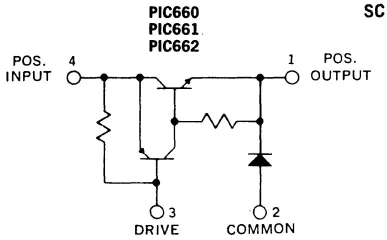
The Unitrode Switching Regulator is a unique hybrid transistor circuit, specifically designed, constructed and specified for use in high current switching regulator applications. The designer is thus relieved of one of the most time consuming, tedious and critical aspects of switching regulator design: choosing the appropriate switching transistors and commutating diode, and empirically determining the optimum drive and bias conditions.

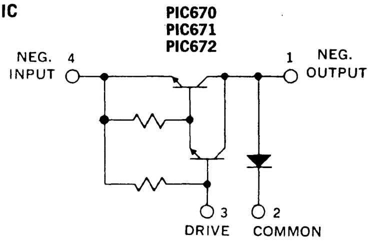
Switching regulators, when compared to conventional regulators, result in significant reductions in size, weight, and internal power losses and a major decrease in overall cost. Using the Unitrode PIC600 series the designer can achieve further improvements in size, weight, efficiency, and costs. At the same time, because of the PIC600 series design and packaging, the designer is aided in overcoming two of the most significant drawbacks to switching regulators: noise generation and slow response time; there is, in fact, no diode reverse recovery spike (See note 4.).

The PIC600 series switching regulators are designed and characterized to be driven with standard integrated circuit voltage regulators. They are completely characterized over their entire operating range of —55°C to +125°C. The devices are enclosed in a special 4-Pin TO-66 package, hermetically sealed for high reliability. The hybrid circuit construction utilizes thick film resistors on a beryllia substrate for maximum thermal conductivity and resultant low thermal impedance. All of the active elements in the hybrid are fully passivated.

Application Notes U-68 and U-76 provide a detailed description of the hybrid circuit and design guidance for specific circuit applications.

SCHEMATIC

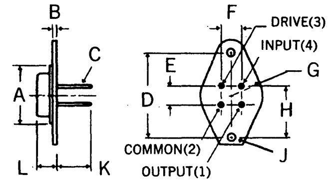




MECHANICAL SPECIFICATIONS

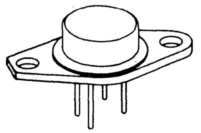
PIC660 PIC661 PIC662 PIC670 PIC671 PIC672

NOTES:
1. Case is electrically isolated.
2. Loads may be soldered to within $^1/_{16}''$ of base provided temperature-time exposure is less than 260°C for 10 seconds.



	ins.	mm
A	.620 MAX	15 75 MAX.
B	.050-.075	1 27-1 91
C	.028- 034	0.71-0.86
D	958- 962	24.33-24.43
E	.190-.210	4.83-5.33
F	.190- 210	4 83-5.33
G	.350 MAX. RAD	8 89 MAX. RAD
H	.570- 590	14 48-14 99
J	.142-.152 DIA	3 61-3 86 DIA
K	.360 MIN	9.14 MIN
L	.250- 340	6 35-8.64

4-Pin TO-66



SEMICONDUCTOR PRODUCTS
UNITRODE

ABSOLUTE MAXIMUM RATINGS

	PIC660	PIC661	PIC662	PIC670	PIC671	PIC672
Input Voltage, V_{4-2}	60V	80V	100V	-60V	-80V	-100V
Output Voltage, V_{1-2}	60V	80V	100V	-60V	-80V	-100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	-5V	-5V	-5V
Output Current, I_1	10A	10A	10A	-10A	-10A	-10A
Drive Current, I_3	-0.4A	-0.4A	-0.4A	0.4A	0.4A	0.4A

Thermal Resistance
  Junction to Case, θ_{J-C}
    Power Switch .... 4.0°C/W
    Commutating Diode .... 4.0°C/W
  Case to Ambient, θ_{C-A} .... 60.0°C/W.
Operating Temperature Range, T_C .... —55°C to +125°C.
Maximum Junction Temperature, T_j .... +150°C.
Storage Temperature Range .... —65°C to +150°C

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	PIC660/661/662 Min.	Typ.	Max.	PIC670/671/672 Min.	Typ.	Max.	Units	Conditions
Current Delay Time	t_{di}	—	35	60	—	35	60	ns	$V_{in} = 25V(-25V)$
Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	$V_{out} = 5V(-5V)$
Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	$I_{out} = 5A(-5A)$
Voltage Storage Time	t_{sv}	—	900	—	—	900	—	ns	$I_3 = -30mA(30mA)$ NOTE 5
Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 2
Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See notes 1, 2, 4
Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
On-State Voltage (Note 3)	$V_{4-1(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	$I_4 = 5A(-5A)$, $I_3 = -.03A(.03A)$ NOTE 5
On-State Voltage (Note 3)	$V_{4-1(on)}$	—	2.5	3.5	—	−2.5	−3.5	V	$I_4 = 10A(-10A)$, $I_3 = -.03A(.03A)$ NOTE 5
Diode Fwd. Voltage (Note 3)	$V_{2-1(on)}$	—	.85	1.25	—	−.85	−1.25	V	$I_2 = 5A(-5A)$
Diode Fwd. Voltage (Note 3)	$V_{2-1(on)}$	—	.95	1.75	—	−.95	−1.75	V	$I_2 = 10A(-10A)$
Off-State Current	I_{4-1}	—	0.1	10	—	−0.1	−10	μA	V_4 = Rated input voltage
Off-State Current	I_{4-1}	—	10	—	—	−10	—	μA	V_4 = Rated input voltage, $T_A = 100°C$
Diode Reverse Current	I_{1-2}	—	1.0	10	—	−1.0	−10	μA	V_1 = Rated output voltage
Diode Reverse Current	I_{1-2}	—	500	—	—	500	—	μA	V_1 = Rated output voltage, $T_A = 100°C$

NOTES:

1. In switching an inductive load, the current will lead the voltage on turn-on and lag the voltage on turn-off (see Figure 2). Therefore, Voltage Delay Time (t_{DV}) ≅ t_{di} + t_{ri} and Current Storage Time (t_{si}) ≅ t_{sv} + t_{fv}.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1, in which the efficiency is measured, is representative of typical operating conditions for the PIC600 series switching regulators.
3. Pulse test: Duration = 300μs, Duty Cycle ≤ 2%.
4. As can be seen from the switching waveforms shown in Figure 2, no reverse of forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliability, since the power switch only carries current during turn-on.
5. To insure safe operation I_3 should be ≥|30mA| during T_{ON}. Operation at I_3 <|30mA| can permanently damage device.

POWER DISSIPATION CONSIDERATIONS

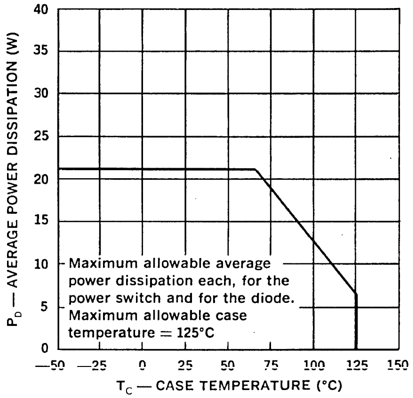
The total power losses in the switching regulator is the sum of the switching losses, and the power switch and diode D.C. losses. Once total power dissipation has been determined, the Power Dissipation curve, or thermal resistance data may be used to determine the allowable case or ambient temperature for any operating condition.

The switching losses curve presents data for a frequency of 20KHz. To find losses at any other frequency, multiply by f/20KHz.

The D.C. losses curve presents data for a duty cycle of .2. To find D.C. losses at any other duty cycle, multiply by D/.2 for the power switch and by (1-D)/.8 for the diode.

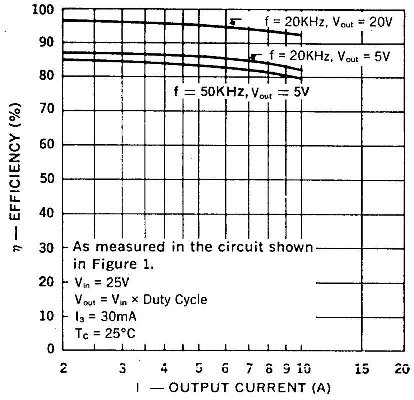
At frequencies much below 10KHz the above method for determining the allowable case or ambient temperature becomes invalid and a detailed transient thermal analysis must be performed. Please see Design Note 6 (DN-6) for further information.

Power Dissipation



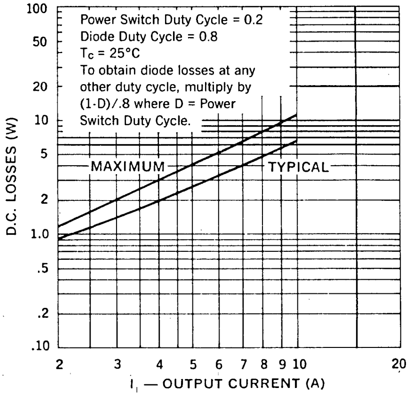
Maximum allowable average power dissipation each, for the power switch and for the diode. Maximum allowable case temperature = 125°C

Efficiency



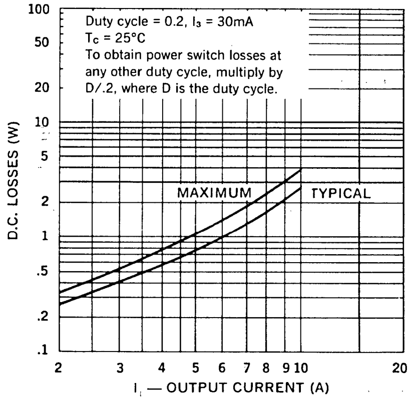
As measured in the circuit shown in Figure 1.
V_{in} = 25V
$V_{out} = V_{in} \times$ Duty Cycle
I_3 = 30mA
T_C = 25°C

Diode D.C. Losses



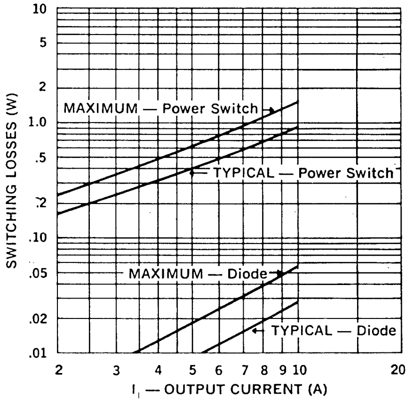
Power Switch Duty Cycle = 0.2
Diode Duty Cycle = 0.8
T_C = 25°C
To obtain diode losses at any other duty cycle, multiply by (1-D)/.8 where D = Power Switch Duty Cycle.

Power Switch D.C. Losses



Duty cycle = 0.2, I_3 = 30mA
T_C = 25°C
To obtain power switch losses at any other duty cycle, multiply by D/.2, where D is the duty cycle.

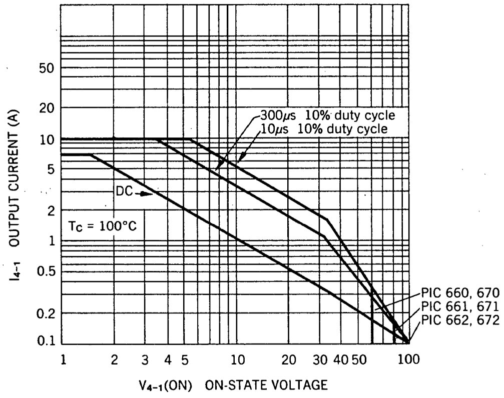
Switching Losses



V_{in} = 25, V, I_3 = 30mA
f = 20KHz
T_C = 25°C

To determine switching losses at any other frequency, multiply by f/20KHz where f is the frequency at which the losses are to be determined.

Maximum Safe Operating Area
PIC 660, 661, 662-670, 671, 672



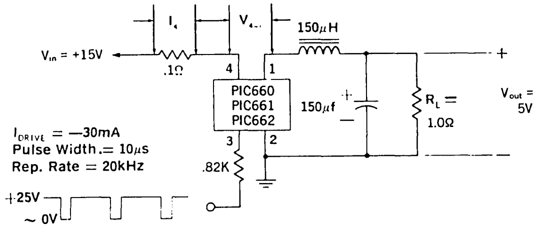


Figure 1. PIC660, 661, 662 Switching Speed Circuit

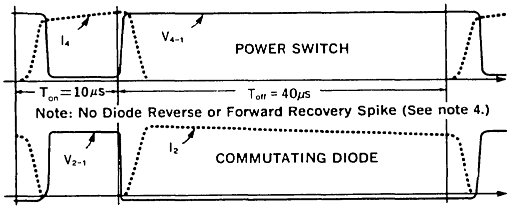
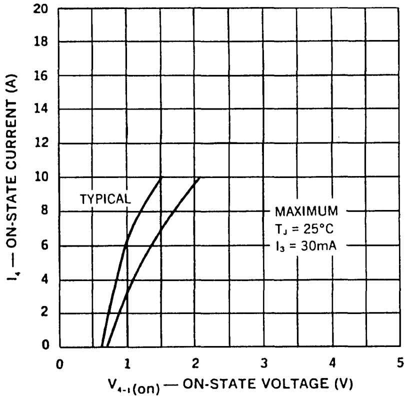


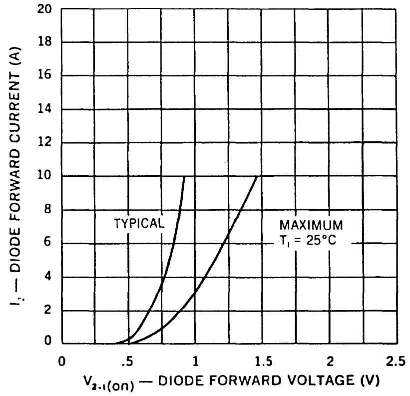
Figure 2. PIC660, 661, 662 Switching Waveforms

Note: PIC670, PIC671, PIC672 Circuit and waveforms are identical but of opposite polarity (V_{in} = −15V, V_{out} = −5V, I_{DRIVE} = +30mA.)

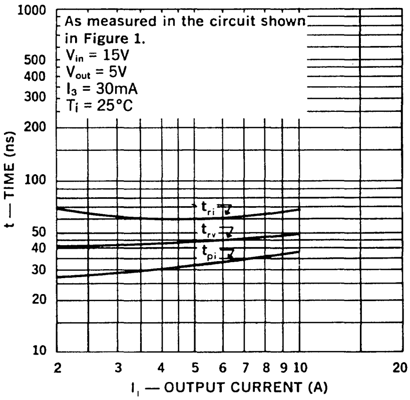
On-State Characteristics



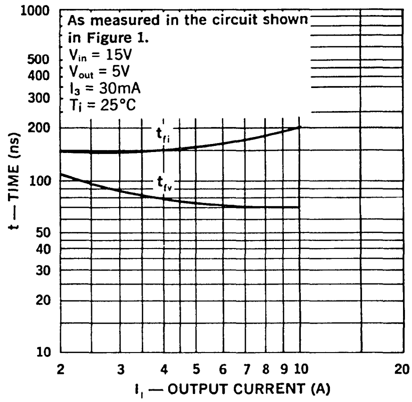
Diode Forward Characteristics



Turn-on Time



Fall Time



Semiconductor Devices, Silicon Hybrid Switching Regulators High Reliability Types

	Test Level T_1	Test Level T_2
PIC 600/601/602	PIC 7501/7502/7503	PIC 7519/7520/7521
PIC 610/611/612	PIC 7504/7505/7506	PIC 7522/7523/7524
PIC 625/626/627	PIC 7507/7508/7509	PIC 7525/7526/7527
PIC 635/636/637	PIC 7510/7511/7512	PIC 7528/7529/7530
PIC 660/661/662	PIC 7555/7556/7557	PIC 7561/7562/7563
PIC 670/671/672	PIC 7558/7559/7560	PIC 7564/7565/7566

Contents

SEMICONDUCTOR PRODUCTS
UNITRODE

1.0 SCOPE

This specification defines the detail requirements for High Reliability Hybrid Switching Regulators. Very extensive 100% testing for parameter stability has been included in the Quality Assurance Provisions.

1.1a Absolute Maximum Ratings

	T_1	T_1	T_1	T_1	T_1	T_1
	PIC7501	**PIC7502**	**PIC7503**	**PIC7504**	**PIC7505**	**PIC7506**
	T_2	T_2	T_2	T_2	T_2	T_2
	PIC7519	**PIC7520**	**PIC7521**	**PIC7522**	**PIC7523**	**PIC7524**
	(PIC600)	**(PIC601)**	**(PIC602)**	**(PIC610)**	**(PIC611)**	**(PIC612)**
Input Voltage, V_{4-2}	60V	80V	100V	−60V	−80V	−100V
Output Voltage, V_{1-2}	60V	80V	100V	−60V	−80V	−100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	−5V	−5V	−5V
Output Current, I_1	5A	5A	5A	−5A	−5A	−5A
Drive Current, I_3	−0.2A	−0.2A	−0.2A	0.2A	0.2A	0.2A
Thermal Resistance						
Junction to Case, θ_{J-C}						
Power Switch	4.0°C/W					
Commutating Diode	4.0°C/W					
Case to Ambient, θ_{C-A}	60.0°C/W					
Operating Temperature Range, T_C	−55°C to +125°C					
Maximum Junction Temperature, T_j	+150°C					
Storage Temperature Range	−65°C to +150°C					

1.1b Absolute Maximum Ratings

	T_1	T_1	T_1	T_1	T_1	T_1
	PIC7507	**PIC7508**	**PIC7509**	**PIC7510**	**PIC7511**	**PIC7512**
	T_2	T_2	T_2	T_2	T_2	T_2
	PIC7525	**PIC7526**	**PIC7527**	**PIC7528**	**PIC7529**	**PIC7530**
	(PIC625)	**(PIC626)**	**(PIC627)**	**(PIC635)**	**(PIC636)**	**(PIC637)**
Input Voltage, V_{4-2}	60V	80V	100V	−60V	−80V	−100V
Output Voltage, V_{1-2}	60V	80V	100V	−60V	−80V	−100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	−5V	−5V	−5V
Output Current, I_1	15A	15A	15A	−15A	−15A	−15A
Drive Current, I_3	−0.4A	−0.4A	−0.4A	0.4A	0.4A	0.4A
Thermal Resistance						
Junction to Case, θ_{J-C}						
Power Switch	4.0°C/W					
Commutating Diode	4.0°C/W					
Case to Ambient, θ_{C-A}	60.0°C/W					
Operating Temperature Range, T_C	−55°C to +125°C					
Maximum Junction Temperature, T_j	+150°C					
Storage Temperature Range	−65°C to +150°C					

1.1c Absolute Maximum Ratings

	Positive Output			Negative Output		
	T_1	T_1	T_1	T_2	T_2	T_2
	PIC7555	PIC7556	PIC7557	PIC7558	PIC7559	PIC7560
	T_2	T_2	T_2	T_2	T_2	T_2
	PIC7561 (PIC660)	PIC7562 (PIC661)	PIC7563 (PIC662)	PIC7564 (PIC670)	PIC7565 (PIC671)	PIC7566 (PIC672)
Input Voltage, $V_{4\text{-}1}$	60V	80V	100V	−60V	−80V	−100V
Output Voltage, $V_{1\text{-}2}$	60V	80V	100V	−60V	−80V	−100V
Drive-Input Reverse Voltage, $V_{3\text{-}1}$	5V	5V	5V	−5V	−5V	−5V
Peak Output Current, I_{1pk}	10A	10A	10A	−10A	−10A	−10A
Drive Current, I_3	−0.4A	−0.4A	−0.4A	0.4A	0.4A	0.4A
Thermal Resistance						
Junction to Case, $\theta_{J\text{-}C}$						
Power Switch	4.0°C/W					
Commutating Diode	4.0°C/W					
Case to Ambient, $\theta_{C\text{-}A}$	60.0°C/W					
Operating Temperature Range, T_C	−55°C to +125°C					
Maximum Junction Temperature, T_j	+150°C					
Storage Temperature Range	−65°C to +150°C					

1.1d Electrical Specifications (at 25°C unless noted)

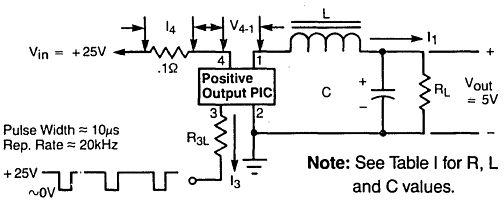
	Test	Symbol	PIC7501-3 PIC7519-21			PIC7504-6 PIC7522-24			Units	Conditions
			Min.	Typ.	Max.	Min.	Typ.	Max.		
1	Current Delay Time	t_{di}	—	20	40	—	20	40	ns	V_{in} = 25V (−25V)
2	Current Rise Time	t_{ri}	—	50	75	—	50	75	ns	V_{out} = 5V (−5V)
3	Voltage Rise Time	t_{rv}	—	30	50	—	30	50	ns	I_{out} = 2A (−2A)
4	Voltage Storage Time	t_{sv}	—	900	—	—	900	—	ns	I_3 = −20mA (20mA) (Note 5)
5	Voltage Fall Time	t_{fv}	—	50	75	—	50	75	ns	See Figure 1
6	Current Fall Time	t_{fi}	—	70	150	—	70	150	ns	See Notes 1, 2, 4
7	Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
8	On-State Voltage (Note 3)	$V_{4\text{-}1\,(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	I_4 = 2A (−2A), I_3 = −0.02A (0.02A)
9	On-State Voltage (Note 3)	$V_{4\text{-}1\,(on)}$	—	2.5	3.5	—	−2.5	−3.5	V	I_4 = 5A (−5A), I_3 = −0.02A (0.02A)
10	Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1\,(on)}$	—	0.8	1.0	—	−0.8	−1.0	V	I_2 = 2A (−2A)
11	Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1\,(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	I_2 = 5A (−5A)
12	Off-State Current	$I_{4\text{-}1}$	—	0.1	10	—	−0.1	−10	μA	V_4 = Rated input voltage
13	Off-State Current	$I_{4\text{-}1}$	—	0.01	1.0	—	−0.1	−1.0	mA	V_4 = Rated input voltage, T_A = 100°C
14	Diode Reverse Current	$I_{1\text{-}2}$	—	1.0	10	—	−1.0	−10	μA	V_1 = Rated output voltage
15	Diode Reverse Current	$I_{1\text{-}2}$	—	0.5	1.0	—	−0.5	−1.0	mA	V_1 = Rated output voltage, T_A = 100°C

Notes:

1. In switching an inductive load, the current will lead the voltage on turn-on and lag the voltage on turn-off (see Figure 1). Therefore, Voltage Delay Time (t_{DV}) ≅ t_{di} + t_{ri} and Current Storage Time (t_{si}) ≅ t_{sv} + t_{fv}.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1, in which the efficiency is measured, is representative of typical operating conditions for the PIC600 series switching regulators.
3. Pulse test: Duration = ≤ 400μs. Duty Cycle ≤2%.
4. As can be seen from the switching waveforms shown in Figure 1, no reverse or forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliability, since the power switch only carries current during turn-on.
5. To insure safe operation, absolute value of I_3 should be a minimum of 20mA during $t_{(on)}$. Operation with I_3 below 20mA can permanently damage the device.
6. To insure safe operation, absolute value of I_3 should be a minimum of 30mA during $t_{(on)}$. Operation with I_3 below 30mA can permanently damage the device.

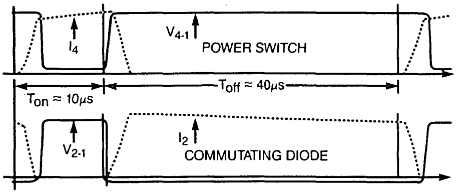
			PIC7507-9 PIC7525-27			PIC7510-12 PIC7528-30				
	Test	Symbol	Min.	Typ.	Max.	Min.	Typ.	Max.	Units	Conditions
1	Current Delay Time	t_{di}	—	35	60	—	35	60	ns	V_{in} = 25V (−25V)
2	Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	V_{out} = 5V (−5V)
3	Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	I_{out} = 7A (−7A)
4	Voltage Storage Time	t_{sv}	—	1200	—	—	1200	—	ns	I_3 = −30mA (30mA) (Note 6)
5	Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 1
6	Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See Notes 1, 2, 4
7	Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
8	On-State Voltage (Note 3)	$V_{4\text{-}1\,(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	I_4 = 7A (−7A), I_3 = −0.03A (0.03A)
9	On-State Voltage (Note 3)	$V_{4\text{-}1\,(on)}$	—	2.5	3.5	—	−2.5	−3.5	V	I_4 = 15A (−15A), I_3 = −0.03A (0.03A)
10	Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1\,(on)}$	—	0.85	1.25	—	−0.85	−1.25	V	I_2 = 7A (−7A)
11	Diode Fwd. Voltage (Note 3)	$V_{2\text{-}1\,(on)}$	—	0.95	1.75	—	−0.95	−1.75	V	I_2 = 15A (−15A)
12	Off-State Current	$I_{4\text{-}1}$	—	0.1	10	—	−0.1	−10	μA	V_4 = Rated input voltage
13	Off-State Current	$I_{4\text{-}1}$	—	0.01	1.0	—	−0.1	−1.0	mA	V_4 = Rated input voltage, T_A = 100°C
14	Diode Reverse Current	$I_{1\text{-}2}$	—	1.0	10	—	−1.0	−10	μA	V_1 = Rated output voltage
15	Diode Reverse Current	$I_{1\text{-}2}$	—	0.5	1.0	—	−0.5	−1.0	mA	V_1 = Rated output voltage, T_A = 100°C

			PIC7555-7 PIC7561-3			PIC7558-60 PIC7564-6				
	Test	Symbol	Min.	Typ.	Max.	Min.	Typ.	Max.	Units	Conditions
1	Current Delay Time	t_{di}	—	35	60	—	35	60	ns	V_{in} = 25V (−25V)
2	Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	V_{out} = 5V (−5V)
3	Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	I_{out} = 5A (−5A)
4	Voltage Storage Time	t_{sv}	—	1200	—	—	1200	—	ns	I_3 = 30mA (−30mA) (Note 6)
5	Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 1
6	Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See Notes 1, 2, 4
7	Efficiency	η	—	85	—	—	85	—	%	See Notes 2 and 4
8	On-State Voltage	$V_{4\text{-}1\,(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	I_4 = 5A (−5A), I_3 = −30mA (30mA), Notes 3, 5
9	On-State Voltage	$V_{4\text{-}1\,(on)}$	—	2.5	3.5	—	−2.5	−3.5	V	I_4 = 10A (−10A), I_3 = −30mA (30mA), Notes 3,5
10	Diode Fwd. Voltage	$V_{2\text{-}1\,(on)}$	—	0.85	1.25	—	−0.85	−1.25	V	I_2 = 5A (−5A)
11	Diode Fwd. Voltage	$V_{2\text{-}1\,(on)}$	—	0.95	1.75	—	−0.95	−1.75	V	I_2 = 10A (−10A)
12	Off-State Current	$I_{4\text{-}1}$	—	0.1	10	—	−0.1	−10	μA	V_4 = Rated input voltage
13	Off-State Current	$I_{4\text{-}1}$	—	.01	1	—	−.01	−1	mA	V_4 = Rated input voltage, T_A = 100°C
14	Diode Reverse Current	$I_{1\text{-}2}$	—	1.0	10	—	−1.0	−10	μA	V_1 = Rated output voltage
15	Diode Reverse Current	$I_{1\text{-}2}$	—	0.5	1.0	—	−0.5	−1.0	mA	V_1 = Rated output voltage, T_A = 100°C



Note: See Table I for R, L and C values.

Positive Output Switching Speed Circuit



Note: No Diode Reverse or Forward Recovery Spike (See note 4.).

Positive Output Switching Waveforms

Note: Negative test circuit and waveforms are identical but of opposite polarity (V_{in} = −25V, V_{out} = −5V).

Figure 1.

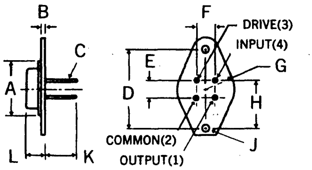
Table I.
Component Values for Switching Speed Circuit

I_3 required	R_{3L}
20mA	1.2 kohms ±5% tolerance
30mA	820 ohms ±5% tolerance

I_4 current	R_L	L	C
2A	2.5 ohms ± 1% 10 watt	300 μH	50 μF 100V electrolytic
5A	1 ohm ± 1% 50 watt	150 μH	150μF 100V electrolytic
7A	0.714 ohms ± 1% 35 watt	150 μH	150μF 100V electrolytic

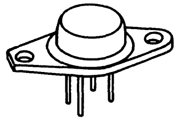
MECHANICAL SPECIFICATIONS

Notes: 1. Case is electrically isolated.
2. Loads may be soldered to within 1/16″ of base provided temperature-time exposure is less than 260°C for 10 seconds.

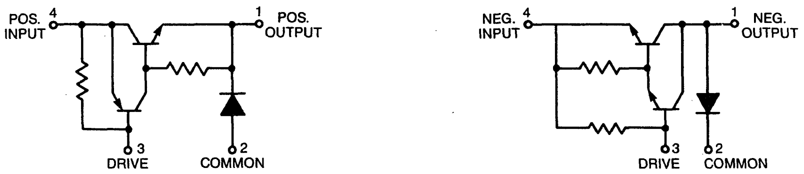


	ins.	mm
A	.620 MAX.	15.75 MAX.
B	.050-.075	1.27-1.91
C	.028-.034	0.71-0.86
D	.958-.962	24.33-24.43
E	.190-.210	4.83-5.33
F	.190-.210	4.83-5.33
G	.350 MAX. RAD.	8.89 MAX. RAD.
H	.570-.590	14 48-14 99
J	.142-.152 DIA.	3.61-3.86 DIA.
K	.360 MIN.	9.14 MIN.
L	.250-.340	6.35-8.64

4-Pin TO-66



SCHEMATIC



PIC7501-3, PIC7519-21
PIC7507-9, PIC7525-27
PIC7555-57, PIC7561-65

PIC7504-6, PIC7522-24
PIC7510-12, PIC7528-30
PIC7558-60, PIC7564-66

Figure 2. Physical Dimensions and Biasing Diagrams

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of invitations for bids, form a part of this specification to the extent specified herein.

MIL-S-19500 — General Specifications for Semiconductor Devices

MIL-S-19491 — Preparation for Delivery of Semiconductor Devices

3.0 REQUIREMENTS

3.1 Design and Construction

The Hybrid devices supplied under this specification shall have a design and construction such that they will meet all of the requirements specified herein. The dimensions and physical characteristics shall be as specified in Figure 2.

3.2 Performance Characteristics

The performance characteristics of the Hybrid device supplied under this specification shall be as specified in Group A inspection defined in Table III.

3.3 Quality Assurance

The Quality Assurance Provisions shall be as defined in paragraph 4.0.

3.4 Test Methods

Test methods shall be as specified herein.

3.5 Marking

The markings on the devices supplied shall be permanent and legible and shall include the Manufacturer's name or trademark, a Manufacturing Date Code in accordance with MIL-S-19500 and the specific device type number.

3.6 Preparation for Delivery

The Hybrid devices supplied under this specification shall be prepared for delivery in accordance with level C of MIL-S-19491 unless otherwise directed in the specific contract or purchase order.

3.7 Ordering Data

Procurement documents should specify the following:

a. Specific item type number
b. Number and date of this specification
c. Quality Assurance Test level required
d. Any special packaging if required

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General Provisions

4.1.1 Inspection Responsibility — The supplier is responsible for the performance of all inspection requirements and acceptability of results as specified herein for the Test Level identified in the contract or purchase order.

4.1.2 Controlled Manufacture — The devices supplied under this specification shall be manufactured under controlled conditions using formally defined quality assurance methods and systems.

4.1.3 Manufacturing Traceability — Each device supplied under this specification shall be traceable to a specific process group, to permit tracing of its full manufacturing history. Process group records shall indicate the exact date that each manufacturing operation was performed and identify materials and process procedures which were used. The manufacturer shall keep these records on file for at least five years.

4.1.4 Definitions

4.1.4.1 Inspection Lot — An "inspection lot" is a collection of devices from which a sample is withdrawn and inspected to determine compliance with the acceptibility criterion. It shall consist of one or more "inspection sublots" of the device types defined in this specification. The maximum inspection lot size shall be 5000 units.

4.1.4.2 Inspection Sublot — An "inspection sublot" shall consist of a collection of devices of a single type which have been manufactured under the same conditions and with the same materials.

4.1.4.3 Shipment Lot — A "shipment lot" shall consist of devices taken from an accepted inspection lot for the purpose of shipment on a specific contract or order.

4.1.4.4 Group A Inspection — Group A inspection shall consist of the examinations and tests specified in Table I, and shall be performed on a sublot basis.

4.1.4.5 Controlled Inventory — The controlled inventory shall consist of lots which have successfully passed the acceptance inspection and are being held in storage prior to actual shipment. A controlled inventory shall have adequate safeguards to insure that no defective or untested devices can be included in it. It shall be accessible only to those individuals who are formally identified as authorized personnel.

4.2 Acceptance Inspection

The acceptance inspection requirements shall be as defined by the applicable test level. The procedures of MIL-S-19500 shall apply to Group A inspection. Inspection lots which have been inspected and accepted shall be kept in a controlled inventory. Shipment lots shall be formed using devices taken from accepted inspection lots.

4.2.1 Test Level T2 Requirements — Test level T2 shall consist of the following requirements.

4.2.1.1 The supplier shall perform the Parameter Stability Testing defined in paragraph 4.3 on each device to be supplied. Prior to starting the Blocking Stability test defined in paragraph 4.3.6, each device shall be serialized for individual identity. Variables test data for the controlled electrical parameters shall be recorded before and after stressing. The same procedure shall apply for the Power Stress stability test defined in paragraph 4.3.8.

4.2.1.2 The supplier shall perform the Group A inspections in accordance with the defined LTPD requirements on each inspection sublot. Electrical parameter testing as specified shall be performed by variables with test data recorded.

4.2.1.3 With each shipment lot, the supplier shall provide a Certificate of Compliance to test level T2 of this specification.

4.2.2 Test Level T1 Requirements — Test level T1 shall consist of the following requirements.

4.2.2.1 The supplier shall perform the Parameter Stability Testing defined in paragraph 4.3 on each device to be supplied. Electrical parameter testing as specified shall be performed by attributes.

4.2.2.2 The supplier shall perform the Group A inspections in accordance with the defined LTPD requirements on each inspection sublot. Electrical parameter testing as specified shall be performed by attributes with test data recorded.

4.2.2.3. With each shipment lot, the supplier shall provide a Certification of Compliance to test level T1 of this specification.

4.3 Parameter Stability Tests

Each hybrid device to be supplied under this specification shall receive the following tests in addition to other standard testing performed by the manufacturer.

4.3.1 Temperature Storage — Each Hybrid device shall be subjected, in a non-operating state, to a temperature of 150°C for a minimum period of 48 hours.

4.3.2 Temperature Cycling — Each Hybrid device shall be temperature cycled from −55°C to 150°C for a minimum of 10 cycles. Each cycle shall consist of at least 15 minutes at each temperature extreme with a maximum transition time of 5 minutes between each temperature extreme.

4.3.3 Hermetic Seal Test — Fine Leak — Each Hybrid device shall be tested for a case leakage rate of 1 x 10^{-8} cc/sec or smaller using a helium mass spectrometer or equivalent method. Devices with a case leakage rate greater than specified shall be removed from the lot.

4.3.4 Hermetic Seal Test — Gross Leak — Each Hybrid device shall be tested for gross leaks using fluorocarbon gross leak test or equivalent method. Devices with any indication of case leakage shall be removed from the lot.

4.3.5 Reverse Bias Clamp Inductive Test —

V_{4-2} = Rated Input Voltage
f ≈ 25kHz, E_{out} = 5V
T_C = 25°C, see Figure 4
I_{out} — See Table II
t = 1 sec max

4.3.6 High Temperature Reverse Bias — Each Hybrid device will be high temperature reversed biased in the circuit shown in Figure 3. The conditions of this test are as follows:

T_A = +125°C
Time = 16 hours $^{+8}_{-0}$ hours
Circuit and voltages as shown in Figure 3.

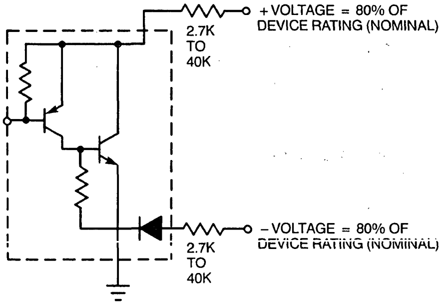
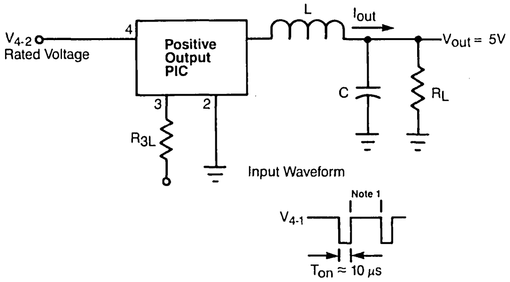


Figure 3. High Temperature Reverse Bias Circuit

4.3.7 The following measurements will be made before and after the high temperature reverse bias test. The unit measurements shall be recorded or the devices will be celled in order to compare and guarantee the delta (△) requirements depending on the test level to which the lot is being prepared.

Part Type	Test 1.1.D	Maximum Readings Initial & Final	Delta Change	Symbol
PIC7501/7502/7503/7519/7520/7521	8	1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7507/7508/7509/7525/7526/7527	8	1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7555/7556/7557/7561/7562/7563	8	1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7504/7505/7506/7522/7523/7524	8	−1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7507/7508/7509/7528/7529/7530	8	−1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7558/7559/7560/7564/7565/7655	8	−1.5V	±0.3V	$V_{4-1\ (on)}$
PIC7501/7502/7503/7519/7520/7521	10	1.0V	±0.25V	$V_{2-1\ (on)}$
PIC7507/7508/7509/7525/7526/7527	10	1.25V	±0.3V	$V_{2-1\ (on)}$
PIC7555/7556/7557/7561/7562/7563	10	1.25V	±0.3V	$V_{2-1\ (on)}$
PIC7504/7505/7506/7522/7523/7524	10	−1.0V	±0.25V	$V_{2-1\ (on)}$
PIC7507/7508/7509/7528/7529/7530	10	−1.25V	±0.3V	$V_{2-1\ (on)}$
PIC7558/7559/7560/7564/7565/7655	10	−1.25V	±0.3V	$V_{2-1\ (on)}$
PIC7501/7502/7503/7519/7520/7521	12	10μA	±1.0 or ±100%*	I_{4-1}
PIC7507/7508/7509/7525/7526/7527	12	10μA	±1.0 or ±100%*	I_{4-1}
PIC7555/7556/7557/7561/7562/7563	12	10μA	±1.0 or ±100%*	I_{4-1}
PIC7504/7505/7506/7522/7523/7524	12	−10μA	±1.0 or ±100%*	I_{4-1}
PIC7507/7508/7509/7528/7529/7530	12	−10μA	±1.0 or ±100%*	I_{4-1}
PIC7558/7559/7560/7564/7565/7655	12	−10μA	±1.0 or ±100%*	I_{4-1}
PIC7501/7502/7503/7519/7520/7521	14	10μA	±2.0 or ±100%*	I_{2-1}
PIC7507/7508/7509/7525/7526/7527	14	10μA	±2.0 or ±100%*	I_{2-1}
PIC7555/7556/7557/7561/7562/7563	14	10μA	±2.0 or ±100%*	I_{2-1}
PIC7504/7505/7506/7522/7523/7524	14	−10μA	±2.0 or ±100%*	I_{2-1}
PIC7507/7508/7509/7528/7529/7530	14	−10μA	±2.0 or ±100%*	I_{2-1}
PIC7558/7559/7560/7564/7565/7655	14	−10μA	±2.0 or ±100%*	I_{2-1}

* Whichever is greater.



Note 1: Adjust T_{off} to obtain specified I_{out}.

Note 2: Negative output test circuits and waveforms are identical but of opposite polarity.

Note 3: See Table II for component values.

Figure 4. Reverse Bias Clamp Inductive Test Circuit

4.3.8 Power Stress — Each Hybrid device shall be burned-in using the circuit shown in Figure 5. The conditions are as follows:

T_A = +25°C
Time = 40 hours minimum
Circuit and conditions as shown in Figure 5.

4.3.9 The readings before and after burn-in shall be as specified in paragraph 4.3.7 above.

Table II.
Component Values for Clamped Inductive Test
(Refer to Figure 4)

Device Type	R_{3L}	L/C	R_L	I_{OUT}
PIC 7501, 7504 PIC 7519, 7522	3K	300/100	2.5	2
PIC 7502, 7505 PIC 7520, 7523	4K	300/100	2.5	2
PIC 7503, 7506 PIC 7521, 7524	5K	300/100	2.5	2
PIC 7507, 7525 PIC 7510, 7528 PIC 7555, 7561 PIC 7558, 7564	2K	150/100	1	5
PIC 7508, 7526 PIC 7511, 7529 PIC 7556, 7562 PIC 7559, 7565	2.7K	150/100	1	5
PIC 7509, 7527 PIC 7512, 7530 PIC 7557, 7563 PIC 7560, 7566	3.3K	150/100	1	5

Table III. Group A Inspection

Examination or Test	Symbol	Electrical Spec Test Number	Sample Size (LTPD)	Max. Acc. No.
Subgroup 1				
Visual and Mechanical	—	—	22 (10)	0
Subgroup 2 25°C Tests				
On-State Voltage	$V_{4\text{-}1\ on}$	8	45	0
On-State Voltage	$V_{4\text{-}1\ on}$	9	(5)	
Diode Forward Voltage	$V_{2\text{-}1\ on}$	10		
Diode Forward Voltage	$V_{2\text{-}1\ on}$	11		
Off-State Current	$I_{4\text{-}1}$	12		
Diode Reverse Current	$I_{1\text{-}2}$	14		
Subgroup 3 T_A = +100°C Tests				
Off-State Current	$I_{4\text{-}1}$	13	45	0
Off-State Current	$I_{1\text{-}2}$	15	(5)	
Subgroup 4 25°C Tests				
Current Delay Time	t_{dI}	1		
Current Rise Time	t_{rI}	2		
Voltage Rise Time	t_{rV}	3	45	0
Voltage Fall Time	t_{fV}	5	(5)	
Current Fall Time	t_{fI}	6		

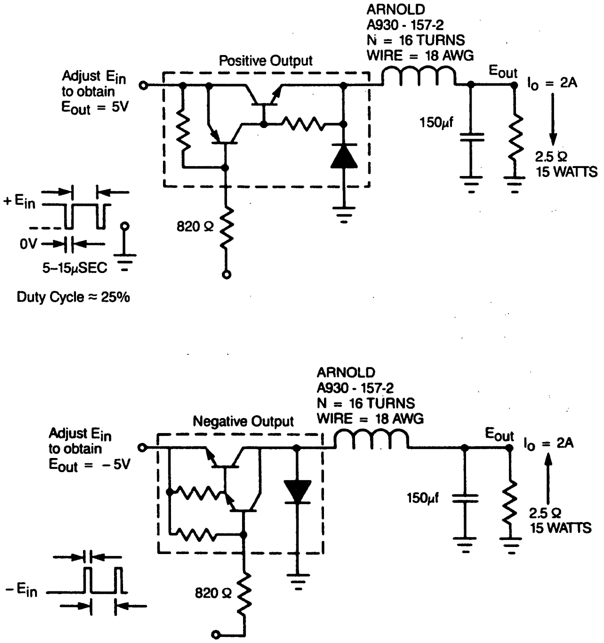


Figure 5. Burn-in Circuits

Semiconductor Devices, Silicon
Hybrid Switching Regulators
High Reliability Types

	Test Level T_1	Test Level T_2
PIC 645/646/647	PIC 7513/7514/7515	PIC 7531/7532/7533
PIC 655/656/657	PIC 7516/7517/7518	PIC 7534/7535/7536

Contents

1.0 SCOPE

This specification defines the detail requirements for High Reliability Hybrid Switching regulators. Very extensive 100% testing for parameter stability has been included in the Quality Assurance Provisions.

1.1a Absolute Maximum Ratings

	T_1 PIC7513 T_2 PIC7531 (PIC645)	T_1 PIC7514 T_2 PIC7532 (PIC646)	T_1 PIC7515 T_2 PIC7533 (PIC647)	T_1 PIC7516 T_2 PIC7534 (PIC655)	T_1 PIC7517 T_2 PIC7535 (PIC656)	T_1 PIC7518 T_2 PIC7536 (PIC657)
Input Voltage, V_{4-2}	60V	80V	100V	−60V	−80V	−100V
Output Voltage, V_{1-2}	60V	80V	100V	−60V	−80V	−100V
Drive-Input Reverse Voltage, V_{3-4}	5V	5V	5V	−5V	−5V	−5V
Continuous Output Current, I_1	15A	15A	15A	−15A	−15A	−15A
Peak Output Current	20A	20A	20A	−20A	−20A	−20A
Drive Current, I_3	−0.4A	−0.4A	−0.4A	0.4A	0.4A	0.4A
Thermal Resistance						
Junction to Case, θ_{J-C}						
Power Switch	2°C/W					
Commutating Diode	2°C/W					
Case to Ambient, θ_{C-A}	30.0°C/W					
Operating Temperature Range, T_C	−55°C to +125°C					
Maximum Junction Temperature, T_j	+150°C					
Storage Temperature Range	−65°C to +150°C					

			PIC7513/14/15 PIC7531/32/33			PIC7516/17/18 PIC7534/35/36				
	Test	Symbol	Min.	Typ.	Max.	Min.	Typ.	Max.	Units	Conditions
1	Current Delay Time	t_{di}	—	35	60	—	35	60	ns	$V_{in} = 25V\ (-25V)$
2	Current Rise Time	t_{ri}	—	65	150	—	65	175	ns	$V_{out} = 5V\ (-5V)$
3	Voltage Rise Time	t_{rv}	—	40	60	—	40	60	ns	$I_{out} = 7A\ (-7A)$
4	Voltage Storage Time	t_{sv}	—	1200	—	—	1200	—	ns	$I_3 = -30mA\ (30mA)$ (Note 5)
5	Voltage Fall Time	t_{fv}	—	70	175	—	100	300	ns	See Figure 1
6	Current Fall Time	t_{fi}	—	175	300	—	175	300	ns	See Notes 1, 2, 4
7	Efficiency (Notes 2 and 4)	η	—	85	—	—	85	—	%	
8	On-State Voltage (Note 3)	$V_{4-1\,(on)}$	—	1.0	1.5	—	−1.0	−1.5	V	$I_4 = 7A\ (-7A),\ I_3 = -0.03A\ (0.03A)$
9	On-State Voltage (Note 3)	$V_{4-1\,(on)}$	—	2.5	3.5	—	−2.5	−3.5	V	$I_4 = 15A\ (-15A),\ I_3 = -0.03A\ (0.03A)$
10	Diode Fwd. Voltage (Note 3)	$V_{2-1\,(on)}$	—	0.85	1.25	—	−0.85	−1.25	V	$I_2 = 7A\ (-7A)$
11	Diode Fwd. Voltage (Note 3)	$V_{2-1\,(on)}$	—	0.95	1.75	—	−0.95	−1.75	V	$I_2 = 15A\ (-15A)$
12	Off-State Current	I_{4-1}	—	0.1	10	—	−0.1	−10	μA	V_4 = Rated input voltage
13	Off-State Current	I_{4-1}	—	10	1000	—	−10	1000	μA	V_4 = Rated input voltage, $T_A = 100°C$
14	Diode Reverse Current	I_{1-2}	—	1.0	10	—	−1.0	−10	μA	V_1 = Rated output voltage
15	Diode Reverse Current	I_{1-2}	—	500	1000	—	−500	−1000	μA	V_1 = Rated output voltage, $T_A = 100°C$

Notes:

1. In switching an inductive load, the current will lead the voltage on turn-on and lag the voltage on turn-off (see Figure 1). Therefore, Voltage Delay Time (t_{DV}) $\cong t_{di} + t_{ri}$ and Current Storage Time (t_{si}) $\cong t_{sv} + t_{fv}$.
2. The efficiency is a measure of internal power losses and is equal to Output Power divided by Input Power. The switching speed circuit of Figure 1, in which the efficiency is measured, is representative of typical operating conditions for the PIC600 series switching regulators.
3. Pulse test: Duration = $\leqslant 400\ \mu$sec.
4. As can be seen from the switching waveforms shown in Figure 1, no reverse or forward recovery spike is generated by the commutating diode during switching! This reduces self-generated noise, since no current spike is fed through the switching regulator. It also improves efficiency and reliability, since the power switch only carries current during turn-on.
5. To insure safe operation, the absolute value of I_3 should be a minimum of 30 mA during $t_{(on)}$. Operation with I_3 below 30 mA can permanently damage the device.

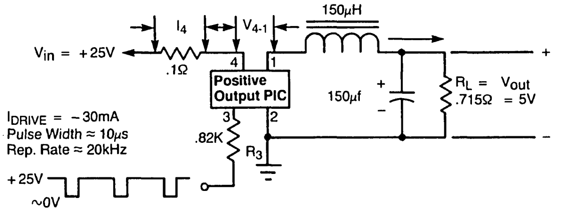
Power Dissipation Considerations

The total power losses in the switching regulator is the sum of the switching losses, and the power switch and diode D.C. losses. Once total power dissipation has been determined, the Power Dissipation curve, or thermal resistance data may be used to determine the allowable case or ambient temperature for any operating condition.

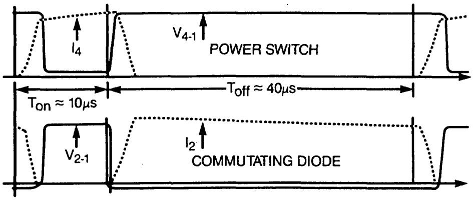
The switching losses curve presents data for a frequency of 20 kHz. To find losses at any other frequency, multiply by f/20 kHz.

The D.C. losses curves present data for a duty cycle of 0.2. To find D.C. losses at any other duty cycle, multiply by D/0.2 for the power switch and by (1-D)/0.8 for the diode.

At frequencies much below 10 kHz the above method for determining the allowable case or ambient temperature becomes invalid and a detailed transient thermal analysis must be performed. Unitrode will supply transient thermal impedance information on request.



Positive Output Switching Speed Circuit



Note: No Diode Reverse or Forward Recovery Spike (See note 4.)!

Positive Output Switching Waveforms

Note: Negative output circuit and waveforms are identical but of opposite polarity
(V_{in} = −25V, V_{out} = −5V, I_{DRIVE} = +30mA).

Figure 1.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on the date of invitations for bids, form a part of this specification to the extent specified herein.

MIL-S-19500 — General Specification for Semiconductor Devices
MIL-S-19491 — Preparation for Delivery of Semiconductor Devices

3.0 REQUIREMENTS

3.1 Design and Construction

The Hybrid devices supplied under this specification shall have a design and construction such that they will meet all of the requirements specified herein. The dimensions and physical characteristics shall be as specified in Figure 2.

3.2 Performance Characteristics

The performance characteristics of the Hybrid device supplied under this specification shall be as specified in Group A inspection defined in Table I.

3.3 Quality Assurance

The Quality Assurance Provisions shall be defined in paragraph 4.0.

3.4 Test Methods

Test methods shall be as specified herein.

3.5 Marking

The markings on the devices supplied shall be permanent and legible and shall include the Manufacturer's name or trademark, a Manufacturing Date Code in accordance with MIL-S-19500 and the specific device type number.

3.6 Preparation for Delivery

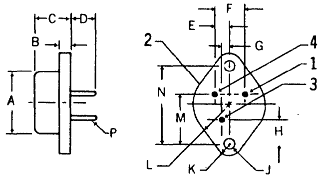
The Hybrid devices supplied under this specification shall be prepared for delivery in accordance with level C of MIL-S-19491 unless otherwise directed in the specific contract or purchase order.

3.7 Ordering Data

Procurement document should specify the following:

a. Specific item type number
b. Number and date of this specification
c. Quality Assurance Test level required
d. Any special packaging if required

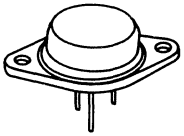
MECHANICAL SPECIFICATIONS



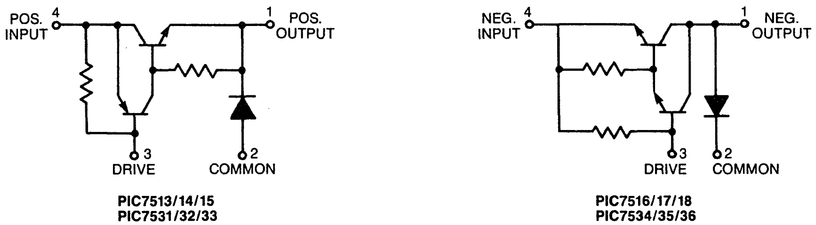
Note: Loads may be soldered to within 1/16" of base provided temperature-time exposure is less than 260°C for 10 seconds.

	ins.	mm
A	.875 MAX.	22.23 MAX.
B	.135	3.43
C	.250-.450	6.35-11.43
D	.312 MIN.	7.92 MIN.
E	.205-.225	5.21-5,72
F	.420-.440	10.67-11.18
G	.145-.165	3.68-4.19
H	.395-.405	10.03-10.29
J	.151-.161 DIA.	3.84-4.09 DIA.
K	.188 MAX. RAD.	4.78 MAX. RAD.
L	.525 MAX. RAD.	13.34 MAX. RAD.
M	.708-.728	17.98-18.49
N	1.177-1.197	29.90-30.40
P	.038-.043 DIA.	.97-1.09 DIA.

3 Pin TO-3



SCHEMATIC



PIC7513/14/15
PIC7531/32/33

PIC7516/17/18
PIC7534/35/36

Figure 2. Physical Dimensions and Biasing Diagrams

4.0 QUALITY ASSURANCE PROVISIONS

4.1 General Provisions

4.1.1 Inspection Responsibility — The supplier is responsible for the performance of all inspection requirements and acceptability of results as specified herein for the Test Level identified in the contract or purchase order.

4.1.2 Controlled Manufacture — The devices supplied under this specification shall be manufactured under controlled conditions using formally defined quality assurance methods and systems.

4.1.3 Manufacturing Traceability — Each device supplied under this specification shall be traceable to a specific process group, to permit tracing of its full manufacturing history. Process group records shall indicate the exact date that each manufacturing operation was performed and identify materials and process procedures which were used. The manufacturer shall keep these records on file for at least five years.

4.1.4 Definitions

4.1.4.1 Inspection Lot — An "inspection lot" is a collection of devices from which a sample is withdrawn and inspected to determine compliance with the acceptability criterion. It shall consist of one or more "inspection sublots" of the device types defined in this specification. The maximum inspection lot size shall be 5000 units.

4.1.4.2 Inspection Sublot — An "inspection sublot" shall consist of a collection of devices of a single type which have been manufactured under the same conditions and with the same materials.

4.1.4.3 Shipment Lot — A "shipment lot" shall consist of devices taken from an accepted inspection lot for the purpose of shipment on a specific contract or order.

4.1.4.4 Group A Inspection — Group A inspection shall consist of the examinations and tests specified in Table I, and shall be performed on a sublot basis.

4.1.4.5 Controlled Inventory — The controlled inventory shall consist of lots which have successfully passed the acceptance inspection and are being held in storage prior to actual shipment. A controlled inventory shall have adequate safeguards to insure that no defective or untested devices can be included in it. It shall be accessible only to those individuals who are formally identified as authorized personnel.

4.2 Acceptance Inspection

The acceptance inspection requirements shall be as defined by the applicable test level. The procedures of MIL-S-19500 shall apply to Group A inspection. Inspection lots which have been inspected and accepted shall be kept in a controlled inventory. Shipment lots shall be formed using devices taken from accepted inspection lots.

4.2.1 Test Level T2 Requirements — Test level T2 shall consist of the following requirements.

4.2.1.1 The supplier shall perform the Parameter Stability Testing defined in paragraph 4.3 on each device to be supplied. Prior to starting the Blocking Stability test defined in paragraph 4.3.6, each device shall be serialized for individual identity. Variables test data for the controlled electrical parameters shall be recorded before and after stressing. The same procedure shall apply for the Power Stress stability test defined in paragraph 4.3.8.

4.2.1.2 The supplier shall perform the Group A inspections in accordance with the defined LTPD requirements on each inspection sublot. Electrical parameter testing as specified shall be performed by variables with test data recorded.

4.2.1.3 With each shipment lot, the supplier shall provide a Certificate of Compliance to test level T2 of this specification.

4.2.2 Test Level T1 Requirements — Test level T1 shall consist of the following requirements.

4.2.2.1 The supplier shall perform the Parameter Stability Testing defined in paragraph 4.3 on each device to be supplied. Electrical parameter testing as specified shall be performed by attributes.

4.2.2.2 The supplier shall perform the Group A inspections in accordance with the defined LTPD requirements on each inspection sublot. Electrical parameter testing as specified shall be performed by attributes with test data recorded.

4.2.2.3 The supplier shall provide a Certificate of Compliance to test level T1 of this specification with each shipment lot.

4.3 Parameter Stability Tests

Each Hybrid device is to be supplied under this specification and shall receive the following tests in addition to other standard testing performed by the manufacturer.

4.3.1 Temperature Storage — Each Hybrid device shall be subjected, in a non-operating state, to a temperature of 150°C for a minimum period of 48 hours.

4.3.2 Temperature Cycling — Each Hybrid device shall be temperature cycled from −55°C to 150°C for a minimum of 10 cycles. Each cycle shall consist of at least 15 minutes at each temperature extreme with a maximum transition time of 5 minutes between each temperature extreme.

4.3.3 Hermetic Seal Test — Fine Leak — Each Hybrid device shall be tested for a case leakage rate of 1×10^{-8} cc/sec or smaller using a helium mass spectrometer or equivalent method. Devices with a case leakage rate greater than specified shall be removed from the lot.

4.3.4 Hermetic Seal Test — Gross Leak — Each Hybrid device shall be tested for gross leaks using fluorocarbon gross leak test or equivalent method. Devices with any indication of case leakage shall be removed from the lot.

4.3.5 Reverse Bias Clamp Inductive Test —

V_{4-2} = Rated Input Voltage
I_4 = 5A., f = 25 kHz, E_{out} = 5V
T_C = 25°C, see Figure 4

4.3.6 High Temperature Reverse Bias — Each Hybrid device will be high temperature reversed biased in the circuit shown in Figure 3. The conditions of this test are as follows:

T_A = +125°C
Time = 16 hours $^{+8}_{-0}$ hours
Circuit and voltages as shown in Figure 3 for the appropriate device.

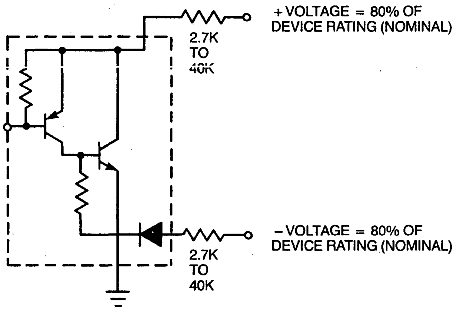
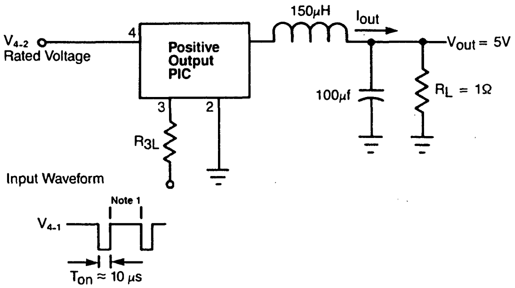


Figure 3. High Temperature Reverse Bias Circuit



Note 1: Adjust T_{off} to obtain specified I_{out}.

Note 2: Negative output test circuits and waveforms are identical but of opposite polarity.

Note 3: R_{3L} = 2KΩ for the PIC 7513/16/31/34
R_{3L} = 2.7KΩ for the PIC 7514/17/32/35
R_{3L} = 3.3KΩ for the PIC 7515/18/33/36

Figure 4. Reverse Bias Clamp Inductive Test Circuit

4.3.7 The following measurements will be made before and after the high temperature reverse bias test. The unit measurements shall be recorded or the devices will be celled in order to compare and guarantee the delta (Δ) requirements depending on the test level the lot is being prepared to.

Type Number	Test 1.1a	Maximum Readings Initial & Final	Delta Change	Symbol
PIC7513/14/15/31/32/33	8	1.5V	±0.3V	$V_{4-1\,(on)}$
PIC7516/17/18/34/35/36	8	– 1.5V	±0.3V	$V_{4-1\,(on)}$
PIC7513/14/15/31/32/33	10	1.25V	±0.3V	$V_{2-1\,(on)}$
PIC7516/17/18/34/35/36	10	– 1.25V	±0.3V	$V_{2-1\,(on)}$
PIC7513/14/15/31/32/33	12	10μA	±1.0 or ±100%[1]	I_{4-1}
PIC7516/17/18/34/35/36	12	– 10μA	±1.0 or ±100%[1]	I_{4-1}
PIC7513/14/15/31/32/33	14	10μA	±2.0 or ±100%[1]	I_{1-2}
PIC7516/17/18/34/35/36	14	– 10μA	±2.0 or ±100%[1]	I_{1-2}

[1] Whichever is greater.

4.3.8 Power Stress — Each Hybrid device shall be burned-in using the circuit shown in Figure 5. The conditions are as follows:

T_A = +25°C
Time = 40 hours minimum
Circuit and conditions as shown in Figure 5.

4.3.9 The readings before and after burn-in shall be as specified in paragraph 4.3.7.

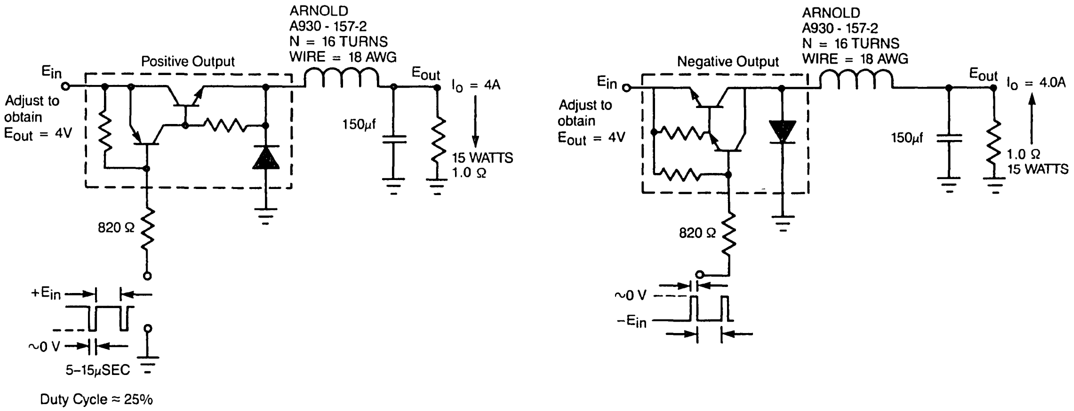


Figure 5. Burn-in Circuits

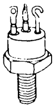
Table I. Group A Inspection

Examination or Test	Symbol	Electrical Spec Test Number	Sample Size (LTPD)	Max. Acc. No.
Subgroup 1				
Visual and Mechanical	—	—	22 (10)	0
Subgroup 2 25°C Tests				
On-State Voltage	$V_{4\text{-}1\ on}$	8	45	0
On-State Voltage	$V_{4\text{-}1\ on}$	9	(5)	
Diode Forward Voltage	$V_{2\text{-}1\ on}$	10		
Diode Forward Voltage	$V_{2\text{-}1\ on}$	11		
Off-State Current	$I_{4\text{-}1}$	12		
Diode Reverse Current	$I_{1\text{-}2}$	14		
Subgroup 3 T_A = +100°C Tests				
Off-State Current	$I_{4\text{-}1}$	13	45	0
Off-State Current	$I_{1\text{-}2}$	15	(5)	
Subgroup 4 25°C Tests				
Current Delay Time	t_{dI}	1		
Current Rise Time	t_{rI}	2		
Voltage Rise Time	t_{rV}	3	45	0
Voltage Fall Time	t_{fV}	5	(5)	
Current Fall Time	t_{fI}	6		

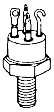
POWER TRANSISTORS & DARLINGTONS 8

NPN BIPOLAR POWER SWITCHING TRANSISTORS

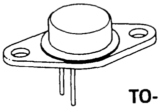
.5-30A, 60-500V



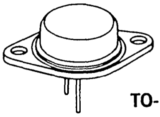
TO-59



TO-111



TO-66



TO-3

LOW VOLTAGE

Maximum Collector Current			5AMP				40AMP
Package Style		**TO-5**	**TO-59**		**TO-111**		**TO-3**
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO(SUS)}$	40V						UBT430
	60V	UPT612					
	80V	UPT613	2N2151** 2N2880* 2N3998*	2N3999*	2N3749* 2N3996*	2N3997*	
	100V	UPT614 UPT615					
h_{FE} Minimum		30 @ 1A	40 @ 1A	80 @ 1A	40 @ 1A	80 @ 1A	50 @ 20A
V_{CE}(sat) Max.		1V @ 5A	.25V @ 1A (1V @ 1A for 2N2151)				.1V @ 10A
t_f Maximum		0.1µs (typical)	0.3µs (2N2880) 0.8µs (2N3998)	1.0µs	0.3µs (2N3749) 0.8µs (2N3996)	1.0µs	0.12µs

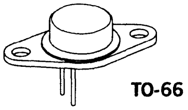
HIGH VOLTAGE

Maximum Collector Current		2 AMP		3 AMP
Package Style		**TO-66**		**TO-66**
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\ (SUS)}$	150V	UPT321		UPT521
	200V	UPT322	2N5660*	UPT522
	250V	UPT323		UPT523
	275V			
	300V	UPT324 UPT325	2N5661*	UPT524 UPT525
	350V			
	400V			
	500V			
h_{FE} Minimum		30 @ .5A	40 @ .5A (2N5660) 25 @ .5A (2N5661)	25 @ 1A
V_{CE} (sat) Max.		1V @ 2A	.4V @ 1A	1V @ 3A
t_f Maximum		0.3µs (typical)	0.4µs (2N5660) 0.6µs (2N5661)	0.4µs (typical)

*Available as JAN, JANTX, JANTXV.
**Available as JAN, JANTX.

NPN BIPOLAR POWER SWITCHING TRANSISTORS

.5-30A, 60-500V



TO-66

TO-5

LOW VOLTAGE

Maximum Collector Current		10 AMP
Package Style		**TO-5**
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\,(SUS)}$	70V	2N4150*
	75V	
	80V	
	90V	
	100V	
	120V	
h_{FE} Minimum		50 @ 5A
V_{CE} (sat) Max.		0.6V @ 5A
t_f Maximum		0.5μs

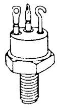
HIGH VOLTAGE

Maximum Collector Current		5 AMP				
Package Style		**TO-5**		**TO-66**		
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\,(SUS)}$	150V					UPT721
	200V	2N5666*		2N5664*		UPT722
	250V					UPT723
	275V					
	300V		2N5667*		2N5665*	UPT724 UPT725
	350V					
	400V					
	450V					
h_{FE} Minimum		40 @ 1A	25 @ 1A	40 @ 1A	25 @ 1A	25 @ 1A
V_{CE} (sat) Max.				0.4V @ 3A		1V @ 3A
t_f Maximum		0.8μs	1.0μs	0.8μs	1.0μs	0.5μs (typical)

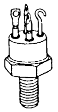
*Available as JAN, JANTX, JANTXV.

NPN BIPOLAR POWER SWITCHING TRANSISTORS

.5-30A, 60-500V



TO-59



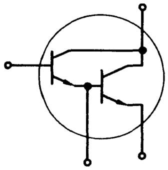
TO-111

LOW VOLTAGE

Maximum Collector Current		10 AMP	
Package Style		**TO-59**	**TO-111**
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\ (SUS)}$	70V		
	75V		
	80V	2N5658	2N5659
	90V		
	100V		
	120V		
h_{FE} Minimum		50 @ 5A	
V_{CE} (sat) Max.		0.5V @ 5A	
t_f Maximum		0.5μs	

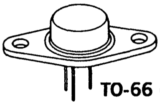
POWER DARLINGTONS

PRODUCT SELECTION GUIDE



External bias types — for fast switching or other special purpose applications

TO-33



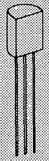
TO-66 (3-Pin)

NPN Power Darlingtons

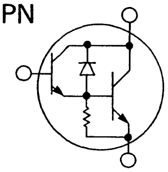
Maximum Collector Current		2A				5A			
Package Style		**TO-33**		**TO-66 (3-Pin)**		**TO-33**		**TO-66 (3-Pin)**	
COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\ (sus)}$	60V	U2T301		U2T401					
	80V					2N6350* U2T101		2N6352* U2T201	
	150V		U2T305		U2T405		2N6351* U2T105		2N6353* U2T205
h_{FE} Minimum		1000 @ 2A		1000 @ 2A		2000 @ 5A	1000 @ 5A	2000 @ 5A	1000 @ 5A
V_{CE}(sat) Maximum		1.5V @ 2A	2.5V @ 2A	1.5V @ 2A	2.5V @ 2A	1.5V @ 5A	2.5V @ 5A	1.5V @ 5A	2.5V @ 5A
t_f Typical		0.3μs				0.5μs			

*Available as JAN, JANTX, and JANTVX types

Plastic NPN Power Darlingtons

 **TO-92**	Maximum Collector Current		5A (PEAK)
	Package Style		**TO-92**
	COLLECTOR-EMITTER SUSTAINING VOLTAGE $V_{CEO\ (SUS)}$		NPN
		60V	U2TA506
		80V	U2TA508
		100V	U2TA510
	h_{FE} Minimum		500 @ 3A
	V_{CE} (sat) Maximum		1.5V @ 3A
	t_f Typical		0.8μs

NPN



Plastic Package types with integral bias resistance and shunt diode for maximum economy in standard applications

POWER TRANSISTORS

2 Amp, 80V, Planar NPN

JAN & JANTX 2N2151

FEATURES

- Meets MIL-S-19500/277
- Collector-Base Voltage: up to 150V
- D.C. Collector Current: 2A
- Beta Guaranteed at 3 Current Levels
- Characterized for Safe Operating Area

DESCRIPTION

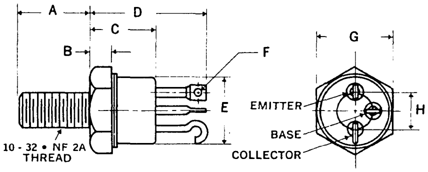
Unitrode power transistors provide a unique combination of low saturation voltage, high gain and fast switching. They are ideally suited for power supply pulse amplifier and similar high efficiency power switching applications.

ABSOLUTE MAXIMUM RATINGS

Collector-Base Voltage, V_{CBO}	150V
Collector-Emitter Voltage, V_{CEO}	100V
Emitter-Base Voltage, V_{EBO}	8V
D.C. Collector Current, I_C	2A
Base Current, I_B	2A
Power Dissipation	
100°C Case	30W
Operating Temperature Range	—55°C to 175°C
Storage Temperature Range	—65°C to 200°C

MECHANICAL SPECIFICATIONS

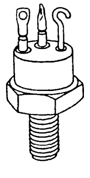
JAN & JANTX2N2151



	INCHES	MILLIMETERS
A	.400-.455	10.16-11.56
B	.090-.150	2.28-3.81
C	.320-.468	8.13-11.88
D	.570-.763	14.48-19.38
E	.318-.380	8.07-9.65
F	$.055 \pm {.010 \atop .015}$	$1.40 \pm {.254 \atop .381}$
G	.424-.437	10.77-11.10
H	.185-.215	4.70-5.46

Note: Collector connected to case

TO-59



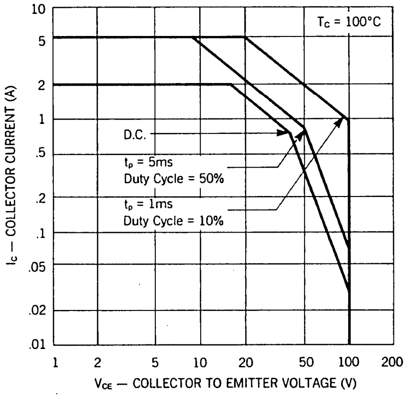
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

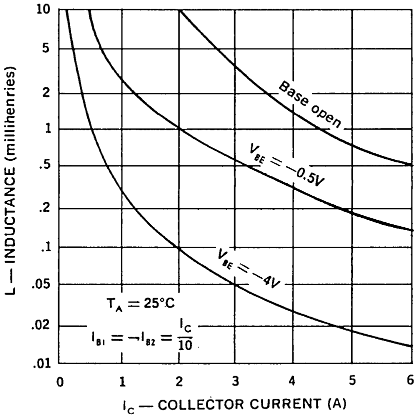
Test	Symbol	Min.	Max.	Units	/277C Sub-group	Method	MIL-STD-750 Test Conditions
25°C							
Collector-Base Breakdown Voltage	BV_{CBO}	150	—	Vdc	A-2	3001	$I_C = 100uAdc$, Cond. D
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}	100	—	Vdc	A-2	3011	$I_C = 50mAdc$, Cond. D
Collector-Emitter Cutoff Current	I_{CES}	—	5	uAdc	A-2	3041	$V_{CE} = 120Vdc$, $V_{BE} = 0$, Cond. C
Collector-Emitter Cutoff Current	I_{CEX}	—	5	uAdc	A-2	3041	$V_{CE} = 120Vdc$, $V_{EB} = 1Vdc$, Cond. A
Collector-Emitter Cutoff Current	I_{CEO}	—	10	uAdc	A-2	3041	$V_{CE} = 80Vdc$, Cond. D
Collector-Base Cutoff Current	I_{CBO}	—	5	uAdc	A-2	3036	$V_{CB} = 120Vdc$, Cond. D
Emitter-Base Cutoff Current	I_{EBO}	—	2	uAdc	A-2	3061	$V_{EB} = 8Vdc$, Cond. D
D.C. Current Gain (Note 1)	h_{FE}	40	120	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	40	120	—	A-3	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	40	—	—	A-3	3076	$I_C = 0.1Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	0.1	1.0	Vdc	A-3	3071	$I_C = 1Adc$, $I_B = 0.1Adc$
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	1.2	Vdc	A-3	3066	$I_C = 1Adc$, $I_B = 0.1Adc$, Cond. A
Base-Emitter Voltage (Note 1)	V_{BE}	—	1.2	Vdc	A-3	3066	$I_C = 1Adc$, $V_{CE} = 5Vdc$, Cond. B
A.C. Current Gain	h_{fe}	40	160	—	A-5	3206	$I_C = 0.1Adc$, $V_{CE} = 30Vdc$, $f = 1kHz$
Gain-Bandwidth Product	f_T	10	70	MHz	A-5	3306	$I_C = O.1Adc$, $V_{CE} = 30Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	160	pf	A-5	3236	$V_{CB} = 20Vdc$, $I_E = 0$, $f = 1MH_Z$
Thermal Resistance	$\theta_{J\text{-}C}$	—	2.5	$^{o}C/W$	C-1	3151	
100°C							
Forward-Biased Second Breakdown	$I_{S/B}$	2	—	Adc	B-9	—	$V_{CE} = 15Vdc$, $t = 60$ sec, see curve
Forward-Biased Second Breakdown	$I_{S/B}$	200	—	mAdc	B-9	—	$V_{CE} = 57Vdc$, $t = 60$ sec, see curve
Forward-Biased Second Breakdown	$I_{S/B}$	25	—	mAdc	B-9	—	$V_{CE} = 100Vdc$, $t = 60$ sec, see curve
Unclamped Inductive Sweep	$E_{S/B}$	20	—	mj	B-5	—	$I_C = 2Adc$, $L = 10mh$
Clamped Inductive Sweep	$E_{S/B}$	80	—	mj	B-6	—	$I_C = 2Adc$, $L = 40mh$, $V_{clamp} = 150V$
150°C							
Collector-Emitter Cutoff Current	I_{CES}	—	100	uAdc	A-4	3041	$V_{CE} = 120Vdc$, $V_{BE} = 0$, Cond. C
Collector-Emitter Cutoff Current	I_{CEX}	—	100	uAdc	A-4	3041	$V_{CE} = 120Vdc$, $V_{EB} = 1Vdc$
Emitter-Base Cutoff Current	I_{EBO}	—	20	uAdc	A-4	3061	$V_{EB} = 8Vdc$, Cond. D
—55°C							
D.C. Current Gain (Note 1)	h_{FE}	20	—	—	A-4	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$

Note: 1. Pulse width = 300μs; duty cycle $\leq$ 2%.

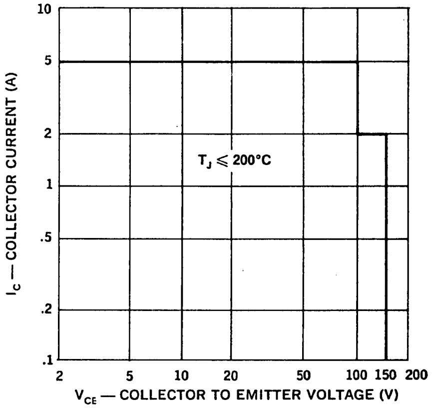
Forward Bias
Safe Operating Area



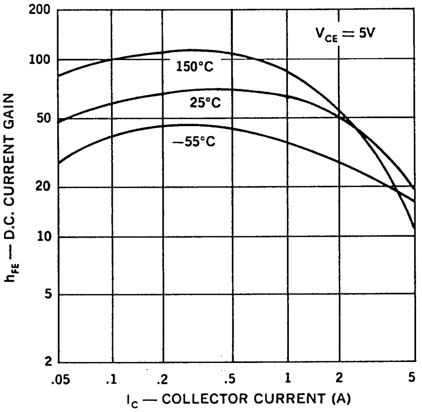
Unclamped Reverse Bias
Second Breakdown



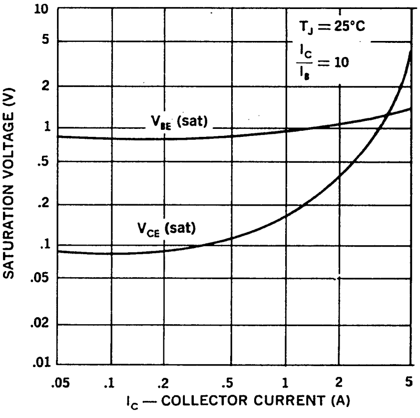
Reverse Bias
Safe Operating Area
Clamped Inductive Switching



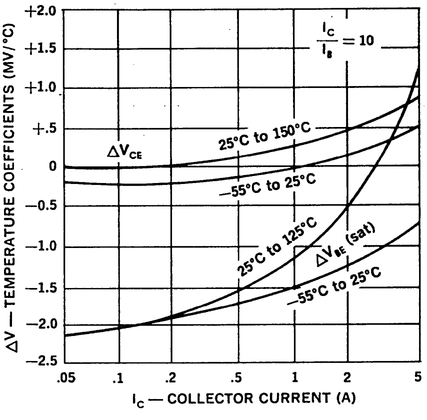
D.C. Current Gain



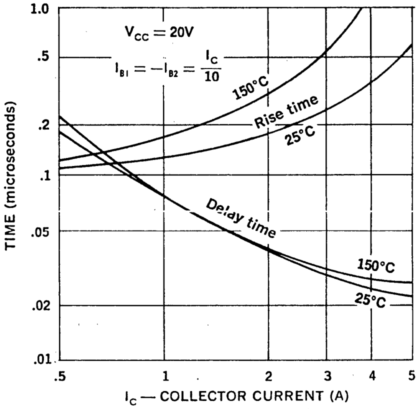
Saturation Voltages



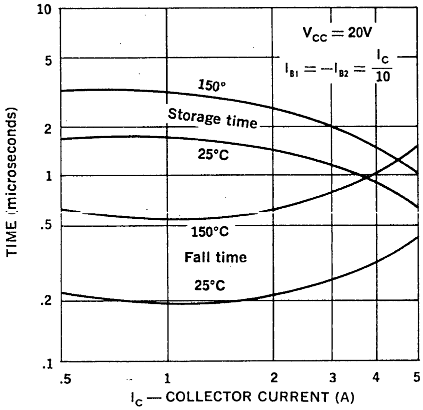
Saturation Voltage
Temperature Coefficients



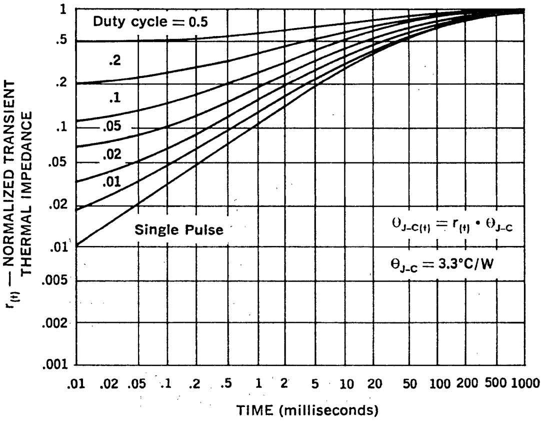
Switching Speed Characteristics



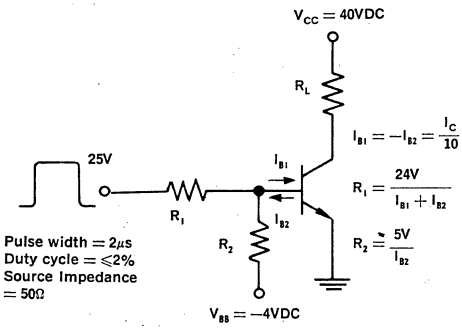
Switching Speed Characteristics



Thermal Response



Switching Speed Circuit



POWER TRANSISTORS
5 Amp, 80V, Planar, NPN

JAN, JANTX, & JANTXV 2N2880
JAN, JANTX, & JANTXV 2N3749

FEATURES
- Meets MIL-S-19500/315
- Collector-Base Voltage: 110V
- Fast Switching: t_r, t_f = 300nSec max
- Low Saturation Voltage: 0.25V max @ 1A

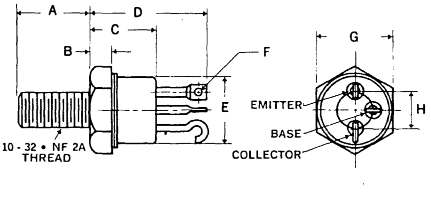
DESCRIPTION
Unitrode power transistors provide a unique combination of low saturation voltage, high gain and fast switching. They are ideally suited for power supply, pulse amplifier and similar high efficiency power switching applications.

ABSOLUTE MAXIMUM RATINGS

Collector-Base Voltage, V_{CBO}	110V
Collector-Emitter Voltage, V_{CEO}	80V
Emitter-Base Voltage, V_{EBO}	8V
D.C. Collector Current, I_C	5A
Power Dissipation	
25°C Ambient	2W
100°C Case	30W
Operating and Storage Temperature Range	−65°C to +200°C

MECHANICAL SPECIFICATIONS

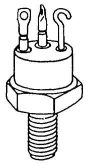
JAN, JANTX, & JANTXV 2N2880



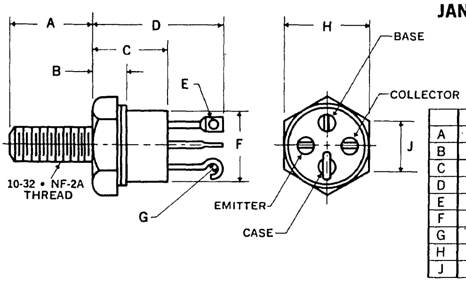
	INCHES	MILLIMETERS
A	.400-.455	10.16-11.56
B	.090-.150	2.28-3.81
C	.320-.468	8.13-11.88
D	.570-.763	14.48-19.38
E	.318-.380	8.07-9.65
F	.055 ± .010 .015	1.40 ± .254 .381
G	.424-.437	10.77-11.10
H	.185-.215	4.70-5.46

Note: Collector connected to case

TO-59

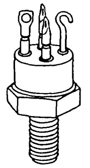


JAN, JANTX, & JANTXV 2N3749



	INCHES	MILLIMETERS
A	.400 - .455	10.16 - 11.55
B	.090 - .250	2.28 - 6.35
C	.320 - .468	8.13 - 11.88
D	.570 - .763	14.48 - 19.38
E	.065 - .090	1.65 - 2.28
F	.313 - .318	7.95 - 8.07
G	.070 - .090	1.77 - 2.28
H	.423 - .438	10.74 - 11.12
J	.135 - .215	3.43 - 5.46

TO-111



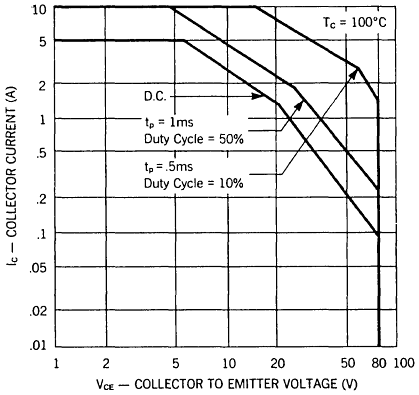
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

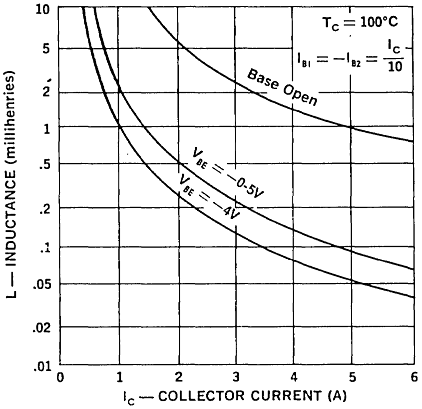
TEST	SYMBOL	MIN.	MAX.	UNITS	/315 Sub group	MIL-STD-750	
						METHOD	TEST CONDITIONS
Visual and Mechanical	—	—	—		A-1	2071	See Mechanical Data
Collector-Base Voltage	BV_{CBO}	110	—	Vdc	A-2	3001	I_C = 10μAdc, Cond. D
Collector-Emitter Voltage (1.)	BV_{CEO}	80	—	Vdc	A-2	3011	I_C = 0.1Adc, Cond. D
Emitter-Base Voltage	BV_{EBO}	8	—	Vdc	A-2	3026	I_E = 10μAdc, Cond. D
Collector-Emitter Cutoff Current	I_{CEO}	—	100	μAdc	A-2	3041	V_{CE} = 60Vdc, Cond. D
Collector-Emitter Cutoff Current	I_{CEX}	—	10	μAdc	A-2	3041	V_{CE} = 110Vdc, V_{EB} = 0.5Vdc, Cond. A
Collector-Base Cutoff Current	I_{CBO}	—	0.4	μAdc	A-2	3036	V_{CB} = 80Vdc, Cond. D
Emitter-Base Cutoff Current	I_{EBO}	—	0.4	μAdc	A-2	3061	V_{EB} = 6Vdc, Cond. D
D.C. Current Gain (1.)	h_{FE}	40	—	—	A-3	3076	I_C = 50mAdc, V_{CE} = 5Vdc
D.C. Current Gain (1.)	h_{FE}	40	120	—	A-3	3076	I_C = 1Adc, V_{CE} = 5Vdc
D.C. Current Gain (1.)	h_{FE}	15	—	—	A-3	3076	I_C = 5Adc, V_{CE} = 5Vdc
Collector Saturation Voltage (1.)	$V_{CE\,(sat)}$	—	0.25	Vdc	A-3	3071	I_C = 1Adc, I_B = 0.1Adc
Collector Saturation Voltage (1.)	$V_{CE\,(sat)}$	—	1.5	Vdc	A-3	3071	I_C = 5Adc, I_B = 0.5Adc
Base Saturation Voltage (1.)	$V_{BE\,(sat)}$	—	1.2	Vdc	A-3	3066	I_C = 1Adc, I_B = 0.1Adc
Base On-Voltage (1.)	$V_{BE\,(on)}$	—	1.2	Vdc	A-3	3066	I_C = 1Adc, V_{CE} = 2Vdc
A.C. Current Gain	h_{FE}	40	120	—	A-4	3206	I_C = 50mAdc, V_{CE} = 5Vdc, f = 1KHz
Gain Bandwidth Product	f_T	20	120	MHz	A-4	3306	I_C = 1Adc, V_{CE} = 10Vdc, f = 10MHz
Output Capacitance	C_{ob}	—	150	pf	A-4	3236	V_{CB} = 10Vdc, I_E = 0, f = 1MHz
Switching Parameters							
Delay Time	t_d	—	60	ns	A-4	—	See Switching Speed Circuit
Rise Time	t_r	—	300	ns	A-4	—	
Storage Time	t_s	—	1.7	μs	A-4	—	
Fall Time	t_f	—	300	ns	A-4	—	
Isolation Resistance (2N3749)	R_{ISO}	10^9	—	ohms		1016	Collector, Base, Emitter shorted
Thermal Resistance	θ_{JC}	—	3.33	°C/W	C-1	3151	
100°C							
Forward-Biased Second Breakdown	$I_{S/B}$	5	—	Adc	B-5	3051	V_{CE} = 6Vdc, t = 60Sec, T_C = 100°C
Forward-Biased Second Breakdown	$I_{S/B}$	80	—	mAdc	B-5	3051	V_{CE} = 80Vdc, t = 60Sec, T_C = 100°C
Clamped Reverse-Biased Second Breakdown	$E_{S/B}$	12.5	—	mj	B-7	—	I_C = 5A, L = 1mH, V_{Clamp} = 110V, T_C = 100°C
Unclamped Reverse-Biased Second Breakdown	$E_{S/B}$	12.5	—	mj	B-6	3053	I_C = 5A, L = 1mH Base Open
Unclamped Reverse-Biased Second Breakdown	$E_{S/B}$	12.8	—	mj	B-6	3053	I_C = 1.6A, L = 10mH Base Open
150°C							
Collector-Emitter Cutoff Current	I_{CEX}	—	50	μA	A-5	3041	V_{CE} = 80Vdc, V_{EB} = 0.5Vdc Cond. A, T_A = 150°C
−65°C							
D.C. Current Gain (1.)	h_{FE}	15	—	—	A-5	3076	I_C = 1Adc, V_{CE} = 5Vdc T_A = −65°C

Note 1. Pulse Width = 300μSec, duty cycle ⩽ 2%

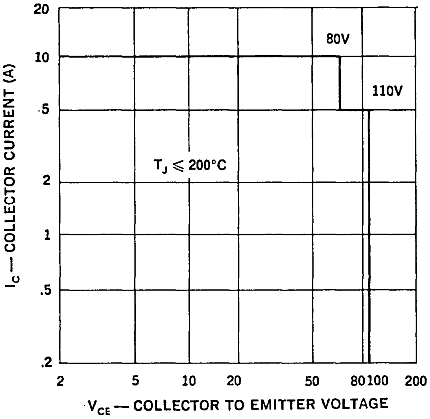
Forward Bias Safe Operating Area



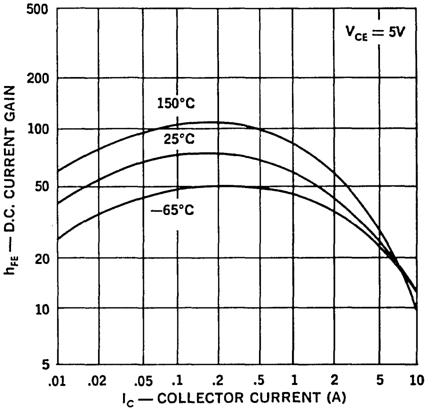
Unclamped Reverse Bias Second Breakdown



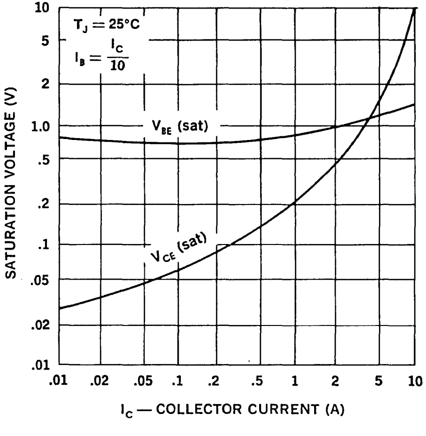
Reverse Bias Safe Operating Area Clamped Inductive Switching



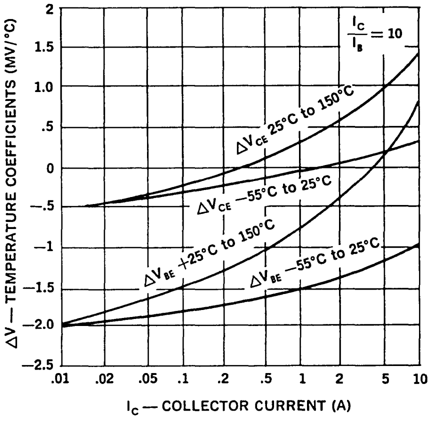
D.C. Current Gain 2N2880-2N3749



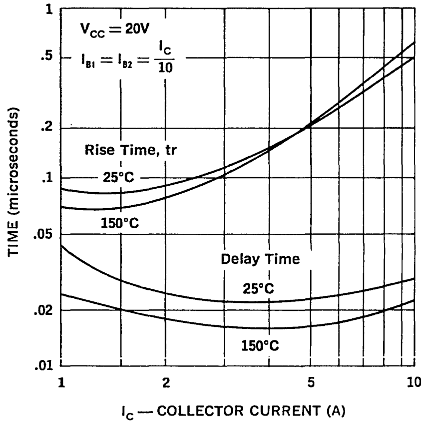
Saturation Voltages



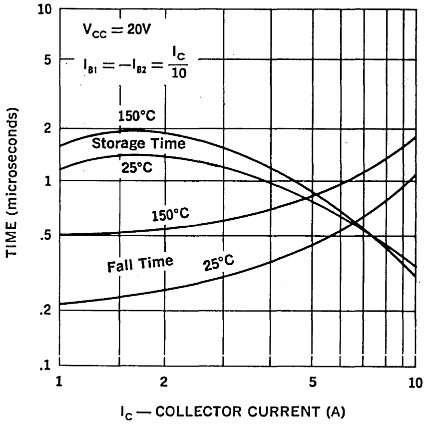
Saturation Voltage Temperature Coefficients



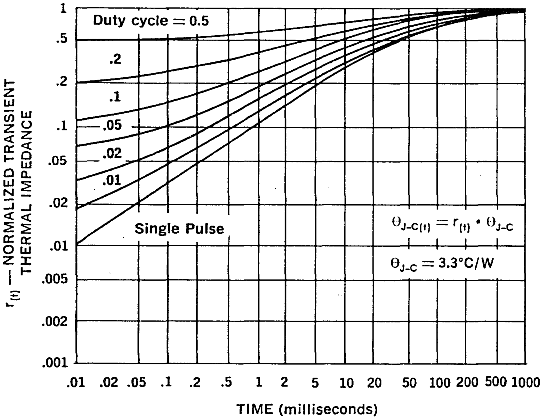
Switching Speed Characteristics



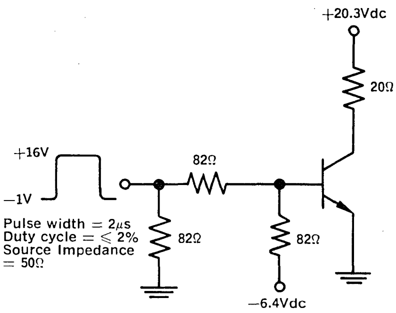
Switching Speed Characteristics



Thermal Response



Switching Speed Circuit



NOTES:

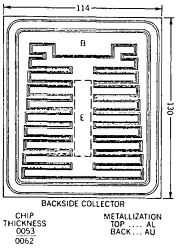
1. $I_C \approx 1A$, $I_{B1} \approx -I_{B2} \approx 100mA$
2. The values of collector current and base current are nominal. The actual values will vary slightly with transistor parameters.

POWER TRANSISTORS
3 Amp, 80V, Planar NPN

JAN, JANTX, & JANTXV 2N3418
JAN, JANTX, & JANTXV 2N3419
JAN, JANTX, & JANTXV 2N3420
JAN, JANTX, & JANTXV 2N3421

FEATURES

- Meets MIL-S-19500/393
- Collector-Base Voltage: up to 125V
- Peak Collector Current: 5A
- High Power Dissipation in TO-5: 15W @ $T_C = 100°C$
- Fast Switching



DESCRIPTION

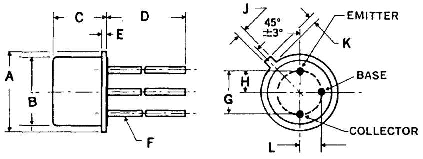
Unitrode power transistors provide a unique combination of low saturation voltage, high gain, and fast switching. They are ideally suited for power supply, pulse amplifier and similar high frequency power switching applications.

ABSOLUTE MAXIMUM RATINGS

	JAN, JANTX, & JANTXV 2N3418 2N3420	JAN, JANTX, & JANTXV 2N3419 2N3421
Collector-Base Voltage, V_{CBO}	85V	125V
Collector-Emitter Voltage, V_{CEO}	60V	80V
Emitter-Base Voltage, V_{EBO}	8V	8V
D.C. Collector Current, I_C	3A	3A
Peak Collector Current, I_C	5A	5A
Power Dissipation		
25°C Ambient	1.0W	1.0W
100°C Case	15W	15W
Operating and Storage Temperature Range	−65°C to +200°C	

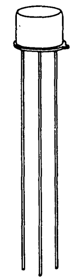
MECHANICAL SPECIFICATIONS

JAN, JANTX, & JANTXV 2N3418-2N3421



	INCHES	MILLIMETERS
A	.335-.370	8.51-9.40
B	.305-.335	7.75-8.51
C	.240-.260	6.09-6.60
D	1.5 MIN.	38.10 MIN.
E	.010-.030	.254-.762
F	$.017 \pm {}^{.002}_{.001}$	$.432 \pm {}^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.787±.076
K	.029-.045	.736-1.14
L	.100	2.54

TO-5

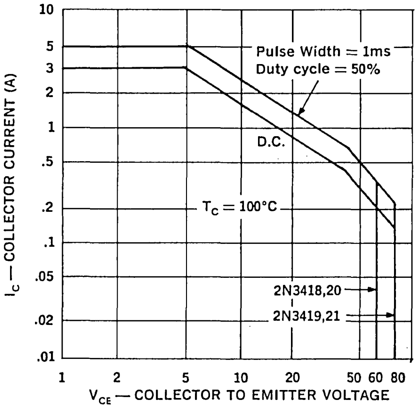


ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

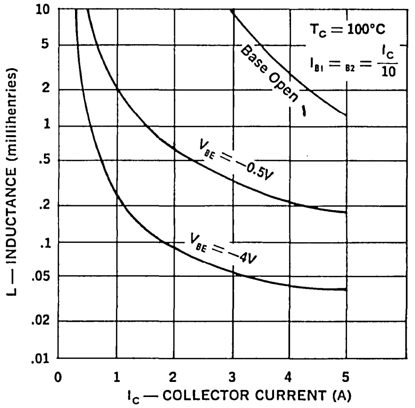
TEST	SYMBOL	MIN.	MAX.	UNITS	/393 Sub-group	MIL - STD - 750	
						METHOD	TEST CONDITIONS
Visual and Mechanical	—	—	—	—	A-1	2071	See Mechanical Data
Collector-Emitter Breakdown Voltage (1.)	BV_{CEO}				A-2	3011	$I_C = 50mAdc$, Cond. D
2N3418, 2N3420		60	—	Vdc			
2N3419, 2N3421		80	—	Vdc			
Collector-Emitter Cutoff Current	I_{CEX}				A-2	3041	$V_{EB} = 0.5Vdc$, Cond. A
2N3418, 2N3420		—	0.5	μAdc			$V_{CE} = 80Vdc$
2N3419, 2N3421		—	0.5	μAdc			$V_{CE} = 120Vdc$
Collector-Emitter Cutoff Current	I_{CEO}				A-2	3041	Cond. D
2N3418, 2N3420		—	5.0	μAdc			$V_{CE} = 45Vdc$
2N3419, 2N3421		—	5.0	μAdc			$V_{CE} = 60Vdc$
Emitter-Base Cutoff Current	I_{EBO}	—	0.5	μAdc	A-2	3061	$V_{EB} = 6Vdc$, Cond. D
Emitter-Base Cutoff Current	I_{EBO}	—	10	μAdc	A-2	3061	$V_{EB} = 8Vdc$, Cond. D
D.C. Current Gain (1.)	h_{FE}				A-3	3076	$I_C = 100mAdc, V_{CE} = 2Vdc$
2N3418, 2N3419		20	—	—			
2N3420, 2N3421		40	—	—			
D.C. Current Gain (1.)	h_{FE}				A-3	3076	$I_C = 1Adc, V_{CE} = 2Vdc$
2N3418, 2N3419		20	60	—			
2N3420, 2N3421		40	120	—			
D.C. Current Gain (1.)	h_{FE}				A-3	3076	$I_C = 2Adc, V_{CE} = 2Vdc$
2N3418, 2N3419		15	—	—			
2N3420, 2N3421		30	—	—			
D.C. Current Gain (1.)	h_{FE}				A-3	3076	$I_C = 5Adc, V_{CE} = 5Vdc$
2N3418, 2N3419		10	—	—			
2N3420, 2N3421		15	—	—			
Collector-Emitter Saturation Voltage (1.)	$V_{CE(sat)}$	—	0.25	Vdc	A-3	3071	$I_C = 1Adc, I_B = 0.1Adc$
Collector-Emitter Saturation Voltage (1.)	$V_{CE(sat)}$	—	0.5	Vdc	A-3	3071	$I_C = 2Adc, I_B = 0.2Adc$
Base-Emitter Saturation Voltage (1.)	$V_{BE(sat)}$	0.6	1.2	Vdc	A-3	3066	$I_C = 1Adc, I_B = 0.1Adc$
Base-Emitter Saturation Voltage (1.)	$V_{BE(sat)}$	0.7	1.4	Vdc	A-3	3066	$I_C = 2Adc, I_B = 0.2Adc$
Gain Bandwidth Product	f_T	40	160	MHz	A-4	3306	$I_C = 0.1Adc, V_{CE} = 10Vdc, f = 20MHz$
Output Capacitance	C_{ob}	—	150	pf	A-4	3236	$V_{CB} = 10Vdc, I_E = 0, f = 1MHz$
Switching Parameters							
Turn-on Time	t_{on}	—	0.3	μS	A-4	—	$I_C = 1Adc, I_{B1} = -I_{B2} = 0.1Adc$
Turn-off Time	t_{off}	—	1.2	μS	A-4	—	See Switching Speed Circuit
100°C							
Forward Biased Second Breakdown	$I_{S/b}$	3	—	Adc	B-6	3005	$V_{CE} = 5Vdc, t = 60sec, T_C = 100°C$
Forward Biased Second Breakdown	$I_{S/b}$	1	—	Adc	B-6	3005	$V_{CE} = 15Vdc, t = 60sec, T_C = 100°C$
Forward Biased Second Breakdown	$I_{S/b}$	0.4	—	Adc	B-6	3005	$V_{CE} = 37Vdc, t = 60sec, T_C = 100°C$
Forward Biased Second Breakdown	$I_{S/b}$				B-6	3005	$t = 60sec, T_C = 100°C$
2N3418, 2N3420		185	—	mAdc			$V_{CE} = 60Vdc$
2N3419, 2N3421		120	—	mAdc			$V_{CE} = 80Vdc$
Unclamped Reverse Biased Second Breakdown	$E_{S/b}$	45	—	mj	B-7	—	$I_C = 3Adc, L = 10mH$, Base Open
Clamped Reverse Biased Second Breakdown	$E_{S/b}$	180	—	mj	B-8	—	$I_C = 3Adc, L = 40mH$, V clamp = Rated V_{CBO}
150°C							
Collector-Emitter Cutoff Current	I_{CEX}				A-5	3041	$V_{EB} = 0.5Vdc$, Cond. A, $T_A = 150°C$
2N3418, 2N3420		—	50	μAdc			$V_{CE} = 80Vdc$,
2N3419, 2N3421		—	50	μAdc			$V_{CE} = 120Vdc$,
−55°C							
D.C. Current Gain (1.)	h_{FE}	10	—	—	A-5	3076	$I_C = 1Adc, V_{CE} = 2Vdc, T_A = -55°C$

Note: 1. Pulse width = 300μSec, duty cycle ≤ 2%.

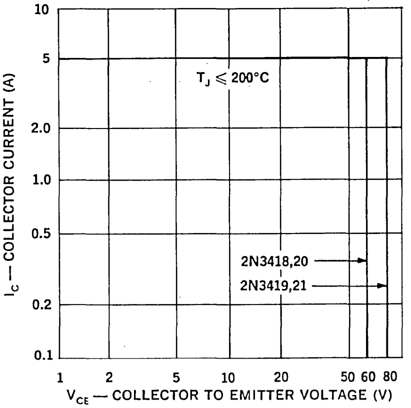
Forward Bias Safe Operating Area



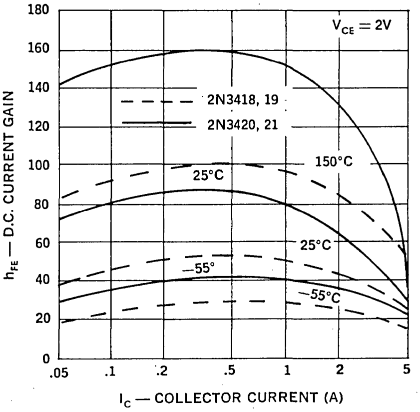
Unclamped Reverse Bias Second Breakdown



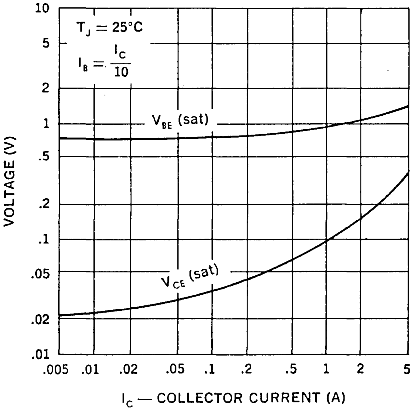
Reverse Bias Safe Operating Area Clamped Inductive Switching



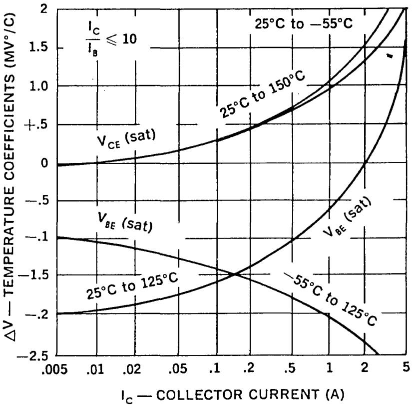
D.C. Current Gain Vs. Collector Current



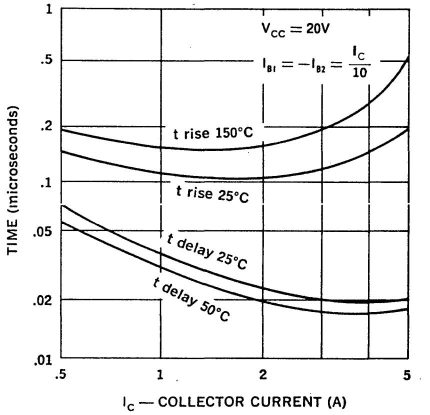
Saturation Voltage



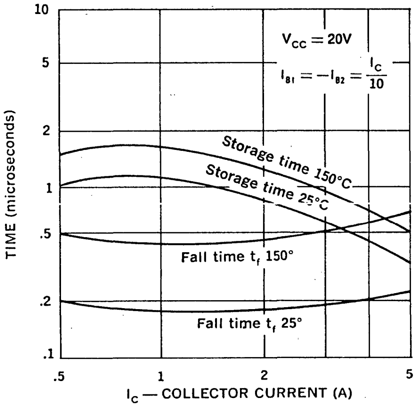
Saturation Voltage Temperature Coefficients



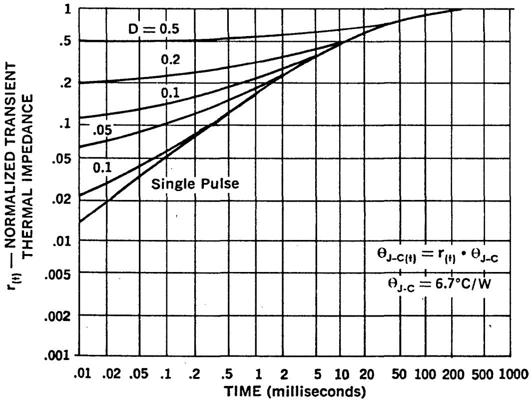
Switching Speed Characteristics



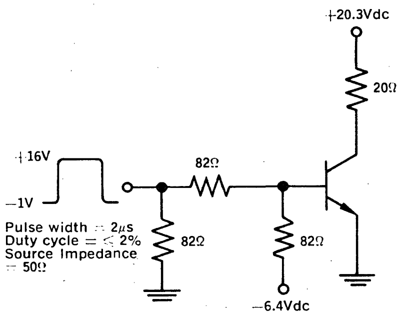
Switching Speed Characteristics



Thermal Response



Switching Speed Circuit



POWER TRANSISTORS

5 Amp, 80V, Planar NPN

JAN, JANTX, & JANTXV 2N3996
JAN, JANTX, & JANTXV 2N3997
JAN, JANTX, & JANTXV 2N3998
JAN, JANTX, & JANTXV 2N3999

FEATURES

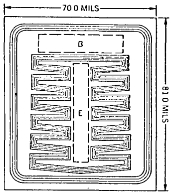
- Meets MIL-S-19500/374*
- Collector-Base Voltage: Up to 100V
- D.C. Collector Current: 5A
- Fast Switching
- Beta Guaranteed at 3 Current Levels

DESCRIPTION

Unitrode power transistors provide a unique combination of low saturation voltage, high gain and fast switching. They are ideally suited for power supply pulse amplifier and similar high efficiency power switching applications.

ABSOLUTE MAXIMUM RATINGS

Collector-Base Voltage, V_{CBO}	100V
Collector-Emitter Voltage, V_{CER}	80V
Emitter-Base Voltage, V_{EBO}	8V
D.C. Collector Current, I_C	5A
Peak Collector Current, I_C	10A
Power Dissipation	
25°C Ambient	2W
100°C Case	30W
Operating and Storage Temperature Range	—65°C to 200°C



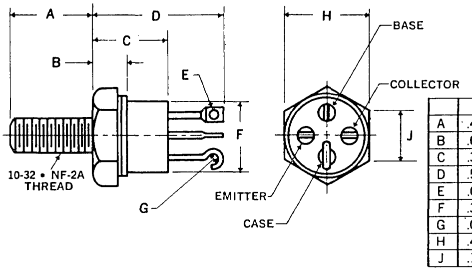
BACKSIDE COLLECTOR

CHIP THICKNESS .0045 / .0053

METALLIZATION
TOP .... AL
BACK ... AU

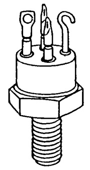
MECHANICAL SPECIFICATIONS

JAN, JANTX, & JANTXV 2N3996, 2N3997

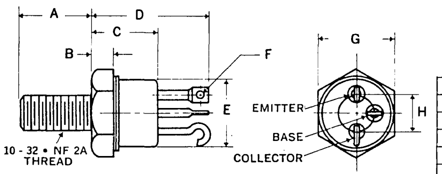


	INCHES	MILLIMETERS
A	.400 - .455	10.16 - 11.55
B	.090 - .250	2.28 - 6.35
C	.320 - .468	8.13 - 11.88
D	.570 - .763	14.48 - 19.38
E	.065 - .090	1.65 - 2.28
F	.313 - .318	7.95 - 8.07
G	.070 - .090	1.77 - 2.28
H	.423 - .438	10.74 - 11.12
J	.135 - .215	3.43 - 5.46

TO-111



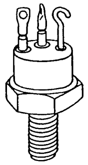
JAN, JANTX, & JANTXV 2N3998, 2N3999



	INCHES	MILLIMETERS
A	.400-.455	10.16-11.56
B	.090-.150	2.28-3.81
C	.320-.468	8.13-11.88
D	.570-.763	14.48-19.38
E	.318-.380	8.07-9.65
F	.055 ± .010 .015	1.40 ± .254 .381
G	.424-.437	10.77-11.10
H	.185-.215	4.70-5.46

Note: Collector connected to case

TO-59



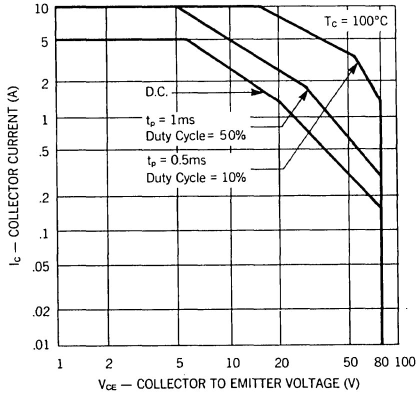
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)†

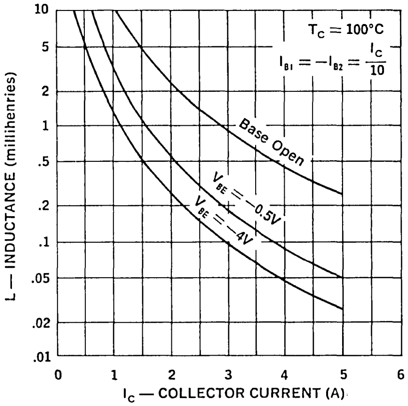
		2N3996* 2N3998*		2N3997* 2N3999*			
Test	**Symbol**	**Min.**	**Max.**	**Min.**	**Max.**	**Units**	**Test Conditions**
D.C. Current Gain	h_{FE}	30	—	60	—	—	$I_C = 50mA, V_{CE} = 2V$
D.C. Current Gain (Note 1)	h_{FE}	40	120	80	240	—	$I_C = 1A, V_{CE} = 2V$
D.C. Current Gain (Note 1)	h_{FE}	15	—	20	—	—	$I_C = 5A, V_{CE} = 5V$
D.C. Current Gain, −55°C (Note 1)	h_{FE}	10	—	20	—	—	$I_C = 1A, V_{CE} = 2V$
Collector Saturation Voltage (Note 1)	$V_{CE\,(sat)}$	—	0.25	—	0.25	V	$I_C = 1A, I_B = 100mA$
Collector Saturation Voltage (Note 1)	$V_{CE\,(sat)}$	—	2	—	2	V	$I_C = 5A, I_B = 500mA$
Base Saturation Voltage (Note 1)	$V_{BE\,(sat)}$	0.6	1.2	0.6	1.2	V	$I_C = 1A, I_B = 100mA$
Base Saturation Voltage (Note 1)	$V_{BE\,(sat)}$	—	1.6	—	1.6	V	$I_C = 5A, I_B = 500mA$
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}	80	—	80	—	V	$I_C = 50mA, I_B = 0$
Emitter-Base Cutoff Current	I_{EBO}	—	0.2	—	0.2	μA	$V_{BE} = 5V, I_C = 0$
Emitter-Base Cutoff Current	I_{EBO}	—	10	—	10	μA	$V_{BE} = 8V, I_C = 0$
Collector Cutoff Current	I_{CES}	—	5	—	5	μA	$V_{CE} = 90V, R_{BE} = 0$
Collector Cutoff Current	I_{CEO}	—	10	—	10	μA	$V_{CE} = 60V, I_B = 0$
Collector Cutoff Current, 150°C	I_{CES}	—	50	—	50	μA	$V_{CE} = 90, R_{BE} = 0$
Collector Capacitance	C_{ob}	—	150	—	150	pf	$V_{CB} = 10V, I_E = 0, f = 1MHz$
A.C. Current Gain (High Frequency)	h_{FE}	4	—	4	—	—	$I_C = 1A, V_{CE} = 5V, f = 10MHz$
Switching Speeds Turn-on Time	t_{on}	—	0.3	—	0.3	μs	$I_C = 1A$
Turn-off Time	t_{off}	—	1.5	—	2	μs	$I_{b1} = 100mA, I_{b2} = -100mA$
Isolation Resistance (2N3996, 7 only)	R_{ISO}	10^9	—	10^9	—	Ω	

Notes: * Also applicable to JAN and JANTX versions.
1. Pulse width = 300μS; duty cycle ≤2%
† All values in this table are JEDEC registered.

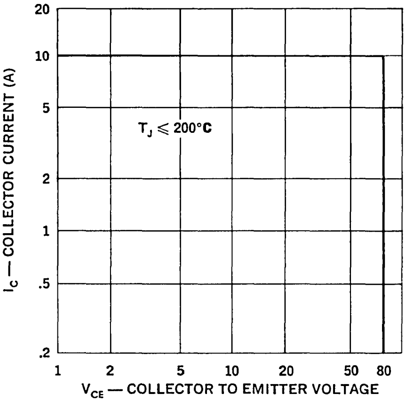
Forward Bias Safe Operating Area



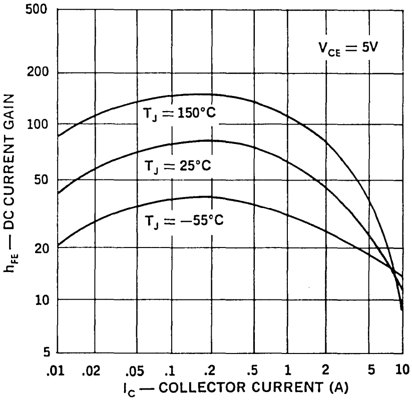
Unclamped Reverse Bias Second Breakdown



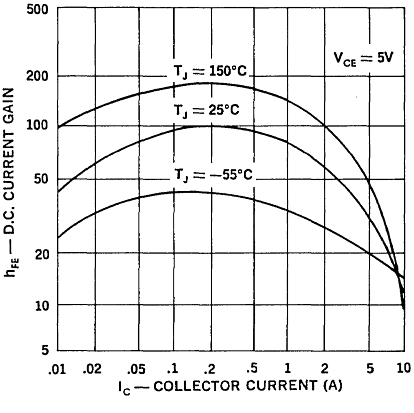
Reverse Bias Safe Operating Area Clamped Inductive Switching



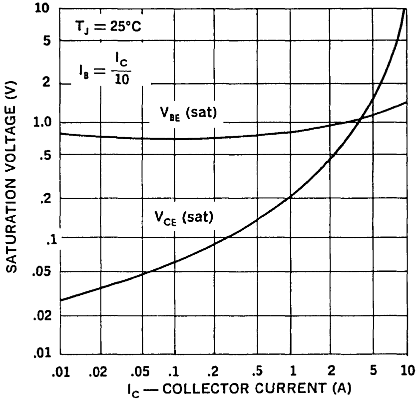
D.C. Current Gain 2N3996-2N3998



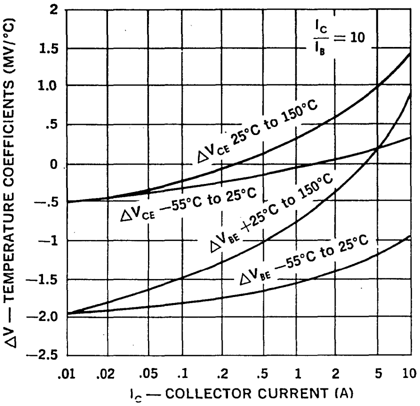
D.C. Current Gain 2N3997-2N3999



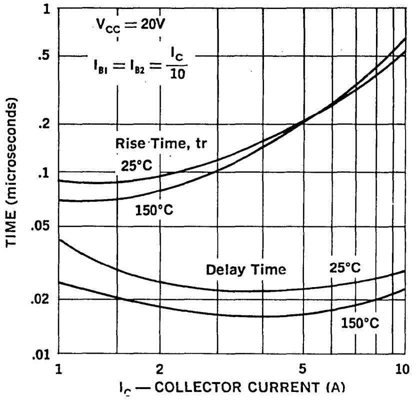
Saturation Voltage



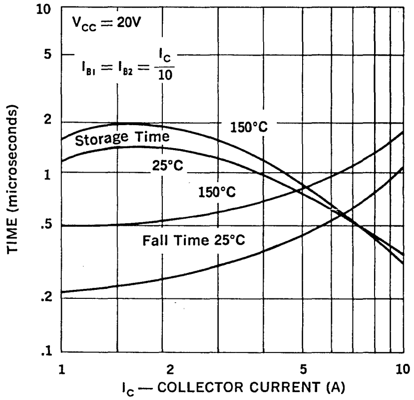
Saturation Voltage Temperature Coefficients



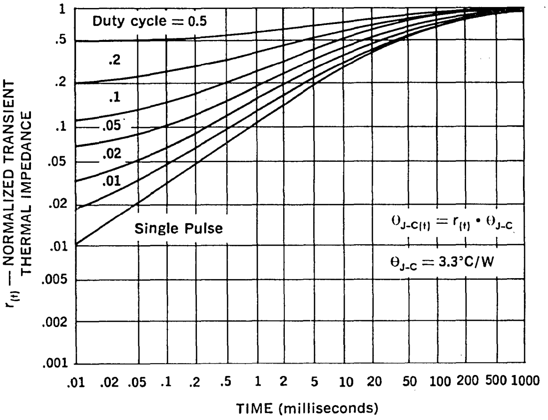
Switching Speed Characteristics



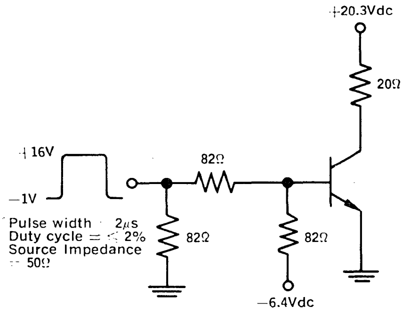
Switching Speed Characteristics



Thermal Response



Switching Speed Circuit



NOTES:

1. $I_C \approx 1A$, $I_{B1} \approx -I_{B2} \approx 100mA$
2. The values of collector current and base current are nominal. The actual values will vary slightly with transistor parameters.

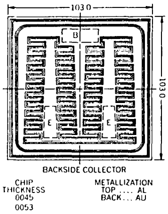
POWER TRANSISTORS

10 Amp, 70V, Planar NPN

JAN, JANTX & JANTXV 2N4150

FEATURES

- Meets MIL-S-19500/394
- Collector-Base Voltage: up to 100V
- Peak Collector Current: 10A
- Fast Switching
- Low Saturation Voltage



DESCRIPTION

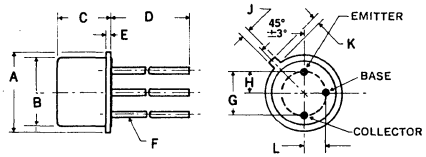
Unitrode power transistors provide a unique combination of low saturation voltage, high gain and fast switching. They are ideally suited for power supply pulse amplifier and similar high efficiency power switching applications.

ABSOLUTE MAXIMUM RATINGS

Collector-Base Voltage, V_{CBO}	100V
Collector-Emitter Voltage, V_{CEO}	70V
Emitter-Base Voltage, V_{EBO}	7V
Peak Collector Current, I_C	10A
Power Dissipation	
25°C Ambient	1.5W
100°C Case	5W
Operating and Storage Temperature Range	—65°C to 200°C

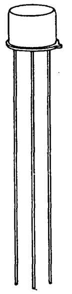
MECHANICAL SPECIFICATIONS

JAN, JANTX & JANTXV 2N4150



	INCHES	MILLIMETERS
A	.335-.370	8.51-9.40
B	.305-.335	7.75-8.51
C	.240-.260	6.09-6.60
D	1.5 MIN.	38.10 MIN.
E	.010-.030	.254-.762
F	$.017 \pm {}^{.002}_{.001}$	$.432 \pm {}^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.787±.076
K	.029-.045	.736-1.14
L	.100	2.54

TO-5



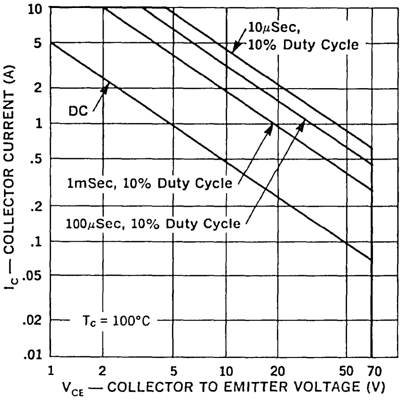
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

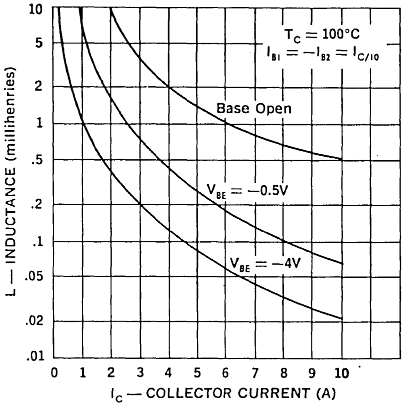
Test	Symbol	Min.	Max.	Units	/394 Sub group	Method	MIL-STD-750 Test conditions
Visual and Mechanical					A-1	2071	See Mechanical Data
25°C							
Collector-Base Breakdown Voltage	BV_{CBO}	100	—	Vdc	A-2	3001	$I_C = 10uAdc$; Cond. D
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}	70	—	Vdc	A-2	3011	$I_C = 0.1Adc$; Cond. D
Emitter-Base Breakdown Voltage	BV_{EBO}	7	—	Vdc	A-2	3026	$I_E = 10uAdc$; Cond. D
Collector-Emitter Cutoff Current	I_{CEO}	—	10	μAdc	A-2	3041	$V_{CE} = 60Vdc$; Cond. D
Collector-Emitter Cutoff Current	I_{CEX}	—	10	μAdc	A-2	3041	$V_{CE} = 100Vdc$, $V_{EB} = 0.5Vdc$; Cond. A
Collector-Base Cutoff Current	I_{CBO}	—	0.1	μAdc	A-2	3036	$V_{CB} = 80Vdc$; Cond. D
Emitter-Base Cutoff Current	I_{EBO}	—	0.1	μAdc	A-2	3061	$V_{EB} = 5Vdc$; Cond. D
D.C. Current Gain (Note 1)	h_{FE}	40	120	—	A-3	3076	$I_C = 5Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	10	—	—	A-3	3076	$I_C = 10Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	50	—	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	0.6	Vdc	A-4	3071	$I_C = 5Adc$, $I_B = 0.5Adc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	2.5	Vdc	A-4	3071	$I_C = 10Adc$, $I_B = 1Adc$
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	1.5	Vdc	A-4	3066	$I_C = 5Adc$, $I_B = 0.5Adc$; Cond. A
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	2.5	Vdc	A-4	3066	$I_C = 10Adc$, $I_B = 1Adc$; Cond. A
A.C. Current Gain	h_{fe}	40	160	—	A-4	3206	$I_C = 50mAdc$, $V_{CE} = 5Vdc$, $f = 1KHz$
Gain-Bandwidth Product	f_T	15	75	MHz	A-4	3306	$I_C = 0.2Adc$, $V_{CE} = 10Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	350	pf	A-4	3236	$V_{CB} = 10Vdc$, $I_E = 0$, $f = 1MHz$
Thermal Resistance	θ_{J-C}	—	20	$^{o}C/W$	C-1	3151	
Switching Speeds Delay Time	t_d	—	50	ns	A-4	—	$V_{CC} = 20V$ $I_C = 5A$ $I_{B1} = I_{B2}$, $I_{B1} = 0.5A$
Rise Time	t_r	—	500	ns	A-4	—	
Storage Time	t_s	—	1.5	μs	A-4	—	
Fall Time	t_f	—	500	ns	A-4	—	
100°C							
Forward-Biased Second Breakdown	$I_{S/B}$	5	—	Adc	B-6	3005	$V_{CE} = 1Vdc$, t = 60Sec,
Forward-Biased Second Breakdown	$I_{S/B}$	70	—	mAdc	B-6	3005	$V_{CE} = 70Vdc$, t = 60Sec,
Unclamped Reverse Biased Second Breakdown	$E_{S/B}$	12.5	—	mj	B-7	—	$I_C = 5Adc$, $L = 1mh$
Clamped Reverse Biased Second Breakdown	$E_{S/B}$	500	—	mj	B-8	—	$I_C = 5Adc$, $L = 40mh$, $V_{clamp} = 70V$
150°C							
Collector-Emitter Cutoff Current	I_{CEX}	—	100	μAdc	A-5	3041	$V_{CE} = 80Vdc$, $V_{EB} = 0.5Vdc$, Cond. A
−55°C							
D.C. Current Gain (Note 1)	h_{FE}	20	—	—	A-5	3076	$I_C = 5Adc$, $V_{CE} = 5Vdc$

Note:
1. Pulse width = 300μS; duty cycle ≤2%.

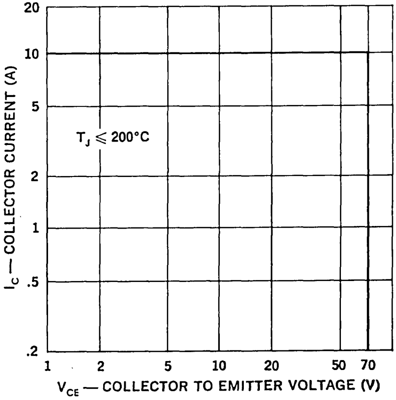
Forward Bias Safe Operating Area



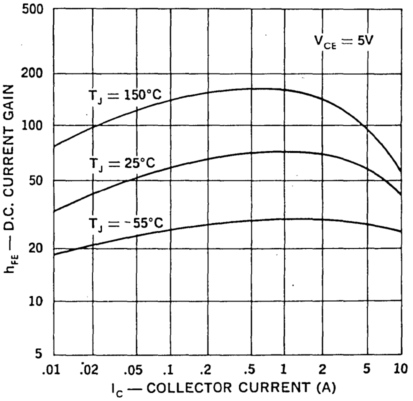
Unclamped Reverse Bias Second Breakdown



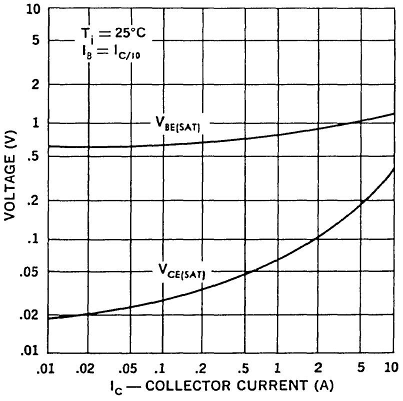
Reverse Bias Safe Operating Area Clamped Inductive Switching



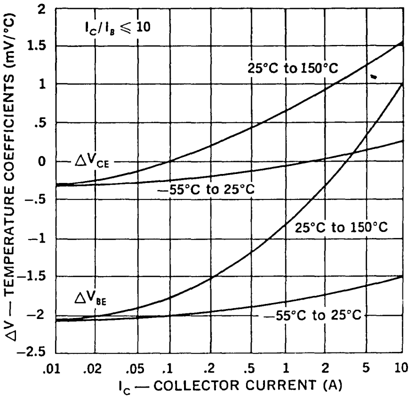
D.C. Current Gain



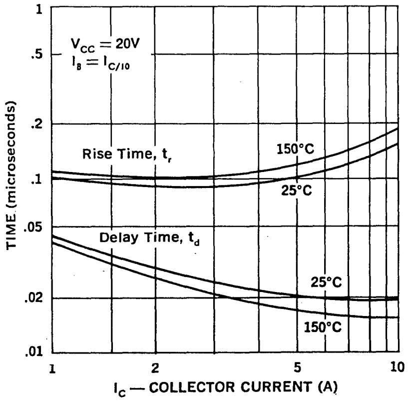
Saturation Voltages



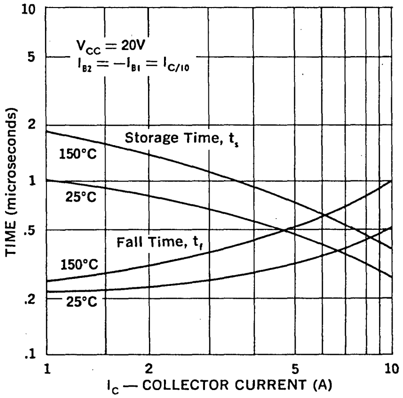
Saturation Voltage Temperature Coefficients



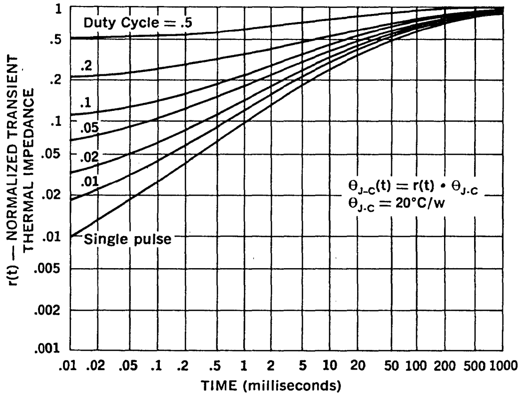
Switching Speed Characteristics



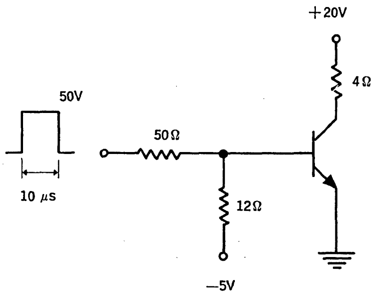
Switching Speed Characteristics



Thermal Response



Switching Speed Circuit

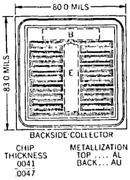


$I_C = 5A$, $I_{B1} = -I_{B2} = .5A$

POWER TRANSISTORS
2 Amp, 300V, Planar NPN

JAN, JANTX, & JANTXV 2N5660
JAN, JANTX, & JANTXV 2N5661
JAN, JANTX, & JANTXV 2N5662
JAN, JANTX, & JANTXV 2N5663

FEATURES
- Meets MIL-S-19500/454
- Collector-Base Voltage: up to 400V
- D.C. Collector Current: 5A
- Peak Collector Current: 10A
- Fast Switching



DESCRIPTION
Unitrode high voltage transistors provide a unique combination of low saturation voltage, fast switching, and excellent gain. They are ideally suited for off-line power supply designs and other applications where the increased voltage rating adds to system reliability.

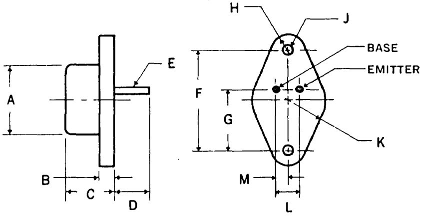
8

ABSOLUTE MAXIMUM RATINGS

	JAN, JANTX, & JANTXV 2N5660	JAN, JANTX, & JANTXV 2N5661	JAN, JANTX, & JANTXV 2N5662	JAN, JANTX, & JANTXV 2N5663
Collector-Base Voltage, V_{CBO}	250V	400V	250V	400V
Collector-Emitter Voltage, V_{CEO}	200V	300V	200V	300V
Emitter-Base Voltage, V_{EBO}	6V	6V	6V	6V
D.C. Collector Current, I_C	2A	2A	2A	2A
Peak Collector Current, I_C	5A	5A	5A	5A
Power Dissipation				
25°C Ambient	2.0W	2.0W	1.2W	1.2W
100°C Case	20W	20W	15W	15W
Operating and Storage Temperature Range	—65°C to 200°C			

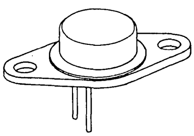
MECHANICAL SPECIFICATIONS

JAN, JANTX, & JANTXV 2N5660 JAN, JANTX, & JANTXV 2N5661

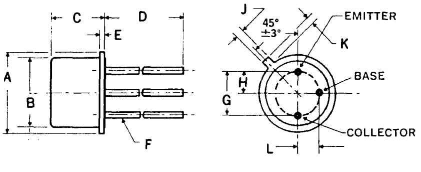


	INCHES	MILLIMETERS
A	.620 MAX.	15.75 MAX.
B	.050 - .075	1.27 - 1.90
C	.250 - .340	6.35 - 8.63
D	.360 MIN.	9.14 MIN.
E	.028 - .034 DIA.	.711 - .863
F	.958 - .962	24.33 - 24.43
G	.570 - .590	14.47 - 14.98
H	.145 MAX. RAD.	3.68 MAX. RAD.
J	.142 - .152 DIA.	3.60 - 3.86 DIA.
K	.350 MAX. RAD.	8.89 MAX. RAD.
L	.190 - .210	4.82 - 5.33
M	.093 - .107	2.36 - 2.72

TO-66

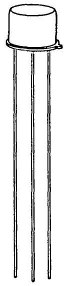


JAN, JANTX, & JANTXV 2N5662 JAN, JANTX, & JANTXV 2N5663



	INCHES	MILLIMETERS
A	.335-.370	8.51-9.40
B	.305-.335	7.75-8.51
C	.240-.260	6.09-6.60
D	1.5 MIN.	38.10 MIN.
E	.010-.030	.254-.762
F	$.017 \pm {}^{.002}_{.001}$	$.432 \pm {}^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.787±.076
K	.029-.045	.736-1.14
L	.100	2.54

TO-5



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)
2N5660, 2N5662

					/454	MIL-STD-750	
Test	Symbol	Min.	Max.	Units	Sub group	Method	Test conditions
Visual and mechanical					A-1	2071	See Mechanical Data
25°C							
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}*	250	—	Vdc	A-2	3011	$I_C = 10mAdc$; $R_{BE} = 100\Omega$; Cond. B
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}*	200	—	Vdc	A-2	3011	$I_C = 10mAdc$; Cond. D
Emitter-Base Breakdown Voltage	BV_{EBO}*	6	—	Vdc	A-2	3026	$I_E = 10\mu Adc$; Cond. D
Collector-Emitter Cutoff Current	I_{CES}*	—	0.2	μAdc	A-2	3041	$V_{CE} = 200Vdc$; Cond. C
Collector-Base Cutoff Current	I_{CBO}	—	0.1	μAdc	A-2	3036	$V_{CB} = 200Vdc$; Cond. D
Collector-Base Cutoff Current	I_{CBO}	—	1.0	mAdc	A-2	3036	$V_{CB} = 250Vdc$; Cond. D
D.C. Current Gain (Note 1)	h_{FE}*	40	—	—	A-3	3076	$I_C = 50mAdc$, $V_{CE} = 2Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	40	120	—	A-3	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	15	—	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	5	—	—	A-3	3076	$I_C = 2Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	$V_{CE}(sat)$*	—	0.4	Vdc	A-3	3071	$I_C = 1Adc$, $I_B = 0.1Adc$
Collector Saturation Voltage (Note 1)	$V_{CE}(sat)$	—	0.8	Vdc	A-3	3071	$I_C = 2Adc$, $I_B = 0.4Adc$
Base Saturation Voltage (Note 1)	$V_{BE}(sat)$*	—	1.2	Vdc	A-3	3066	$I_C = 1Adc$, $I_B = 0.1Adc$; Cond. A
Base Saturation Voltage (Note 1)	$V_{BE}(sat)$	—	1.5	Vdc	A-3	3066	$I_C = 2Adc$, $I_B = 0.4Adc$; Cond. A
Gain-Bandwidth Product	f_T*	20	70	MHz	A-4	3306	$I_C = 0.1Adc$, $V_{CE} = 5Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	45	pf	A-4	3236	$V_{CB} = 10Vdc$, $I_E = 0$, $f = 1MHz$
Thermal Resistance	θ_{J-C}				C-1	3151	
2N5660		—	5.0	°C/W			
2N5662		—	6.7	°C/W			
Switching Speeds Turn-on time	t_{on}*	—	0.25	μs	A-4	—	$I_C = 0.5Adc$
Switching Speeds Turn-off time	t_{off}*	—	0.85	μs	A-4	—	
100°C							
Forward Biased Second Breakdown							
2N5660	$I_{S/B}$	2	—	Adc	B-6	3051	$V_{CE} = 10Vdc$, $t = 1Sec$
	$I_{S/B}$	0.5	—	Adc	B-6	3051	$V_{CE} = 40Vdc$, $t = 1Sec$
	$I_{S/B}$	36	—	mAdc	B-6	3051	$V_{CE} = 200Vdc$, $t = 1Sec$
2N5662	$I_{S/B}$	2	—	Adc	B-7	3051	$V_{CE} = 7.5 Vdc$, $t = 1Sec$
	$I_{S/B}$	0.6	—	Adc	B-7	3051	$V_{CE} = 25Vdc$, $t = 1Sec$
	$I_{S/B}$	27	—	mAdc	B-7	3051	$V_{CE} = 200Vdc$, $t = 1Sec$
Unclamped Reverse Biased Second Breakdown	$E_{S/B}$	0.2	—	mj	B-8	3053	$I_C = 2Adc$, $L = 0.1 mh$
Clamped Reverse Biased Second Breakdown	$E_{S/B}$	80	—	mj	B-9	3053	$I_C = 2Adc$, $L = 40mh$, $V_{clamp} = 200V$
150°C							
Collctor-Emitter Cutoff Current	I_{CES}*	—	100	μAdc	A-5	3041	$V_{CE} = 200Vdc$, Cond. C
–65°C							
D.C. Current Gain (Note 1)	h_{FE}	15	—	—	A-6	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$

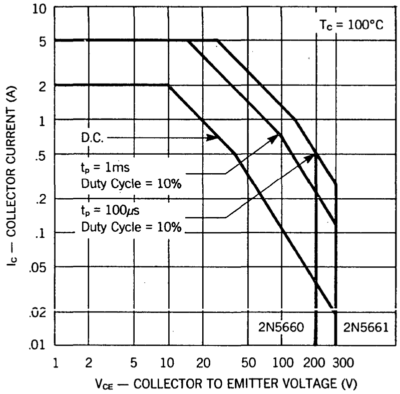
Notes:
1. Pulse width = 300μS; duty cycle ≤2%.
* Those parameters marked with a * are JEDEC registered and devices meeting these specifications are available as commercial 2N devices.

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)
2N5661, 2N5663

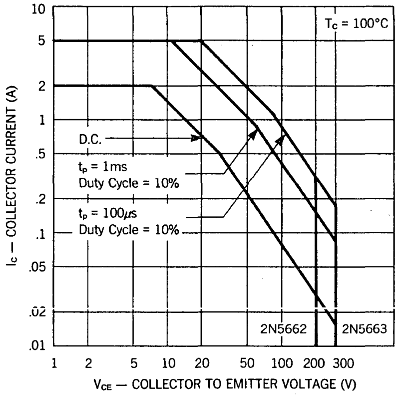
Test	Symbol	Min.	Max.	Units	/454 Sub group	MIL-STD-750	
						Method	Test conditions
Visual and mechanical					A-1	2071	See Mechanical Data
25°C							
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}*	400	—	Vdc	A-2	3011	$I_C = 10mAdc$; $R_{BE} = 100\Omega$; Cond. B
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}*	300	—	Vdc	A-2	3011	$I_C = 10mAdc$; Cond. D
Emitter-Base Breakdown Voltage	BV_{EBO}*	6	—	Vdc	A-2	3026	$I_E = 10\mu Adc$; Cond. D
Collector-Emitter Cutoff Current	I_{CES}	—	0.2	μAdc	A-2	3041	$V_{CE} = 300 Vdc$; Cond. C
Collector-Base Cutoff Current	i_{CBO}	—	0.1	μAdc	A-2	3036	$V_{CB} = 300Vdc$; Cond. D
Collector-Base Cutoff Current	I_{CBO}	—	1.0	mAdc	A-2	3036	$V_{CB} = 400Vdc$; Cond. D
D.C. Current Gain (Note 1)	h_{FE}*	25	—	—	A-3	3076	$I_C = 50mAdc$, $V_{CE} = 2Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	25	75	—	A-3	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	15	—	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	5	—	—	A-3	3076	$I_C = 2Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	$V_{CE}(sat)$*	—	0.4	Vdc	A-3	3071	$I_C = 1Adc$, $I_B = 0.1Adc$
Collector Saturation Voltage (Note 1)	$V_{CE}(sat)$	—	0.8	Vdc	A-3	3071	$I_C = 2Adc$, $I_B = 0.4Adc$
Base Saturation Voltage (Note 1)	$V_{BE}(sat)$*	—	1.2	Vdc	A-3	3066	$I_C = 1Adc$, $I_B = 0.1Adc$; Cond. A
Base Saturation Voltage (Note 1)	$V_{BE}(sat)$	—	1.5	Vdc	A-3	3066	$I_C = 2Adc$, $I_B = 0.4Adc$; Cond. A
Gain-Bandwith Product	f_T*	20	70	MHz	A-4	3306	$I_C = 0.2Adc$, $V_{CE} = 10Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	45	pf	A-4	3236	$V_{CB} = 10Vdc$, $I_E = 0$, $f = 1MHz$
Thermal Resistance	Θ_{J-C}				C-1	3151	
2N5661		—	5.0	°C/W			
2N5663		—	6.7	°C/W			
Switching Speeds Turn-on time	t_{on}*	—	0.25	μs	A-4	—	$I_C = 0.5Adc$
Turn-off time	t_{off}*	—	1.2	μs	A-4	—	
100°C							
Forward Biased Second Breakdown							
2N5661	$I_{S/B}$	2	—	Adc	B-6	3051	$V_{CE} = 10Vdc$, $t = 1Sec$
	$I_{S/B}$	0.5	—	Adc	B-6	3051	$V_{CE} = 40Vdc$, $t = 1Sec$
	$I_{S/B}$	19	—	mAdc	B-6	3051	$V_{CE} = 300Vdc$, $t = 1Sec$
2N5663	$I_{S/B}$	2	—	Adc	B-7	3051	$V_{CE} = 7.5 Vdc$, $t = 1Sec$
	$I_{S/B}$	0.6	—	Adc	B-7	3051	$V_{CE} = 25Vdc$, $t = 1Sec$
	$I_{S/B}$	14	—	mAdc	B-7	3051	$V_{CE} = 300Vdc$, $t = 1Sec$
Unclamped Reverse Biased Second Breakdown	$E_{S/B}$	0.2	—	mj	B-8	3053	$I_C = 2Adc$, $L = 0.1 mh$
Clamped Reverse Biased Second Breakdown	$E_{S/B}$	80	—	mj	B-9	3053	$I_C = 2Adc$, $L = 40mh$, $V_{clamp} = 300V$
150°C							
Collector-Emitter Cutoff Current	I_{CES}	—	100	μAdc	A-5	3041	$V_{CE} = 300Vdc$, Cond. C
–65°C							
D.C. Current Gain (Note 1)	h_{FE}	10	—	—	A-6	3076	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$

Notes:
1. Pulse width = 300μS; duty cycle ≤2%.
* Those parameters marked with a * are JEDEC registered and devices meeting these specifications are available as commercial 2N devices.

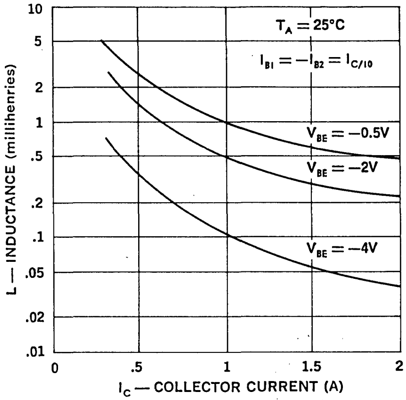
Forward Bias Safe Operating Area 2N5660, 2N5661



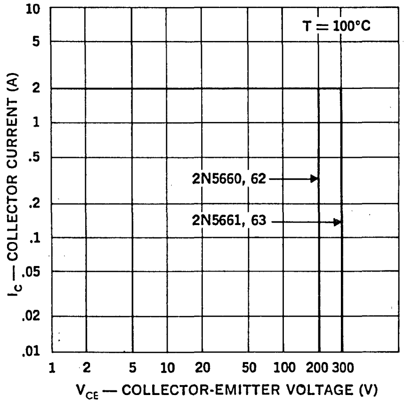
Forward Bias Safe Operating Area 2N5662, 2N5663



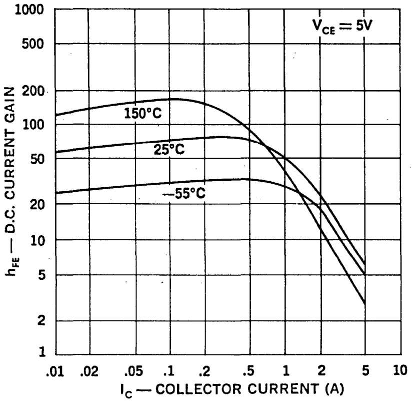
Unclamped Reverse Bias Second Breakdown



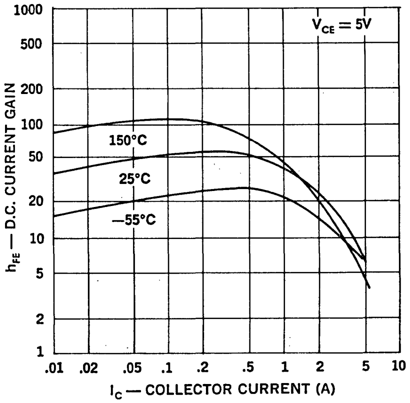
Reverse Bias Safe Operating Area Clamped Inductive Switching



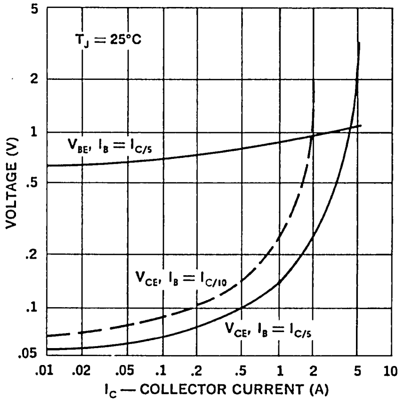
D.C. Current Gain 2N5660, 2N5662



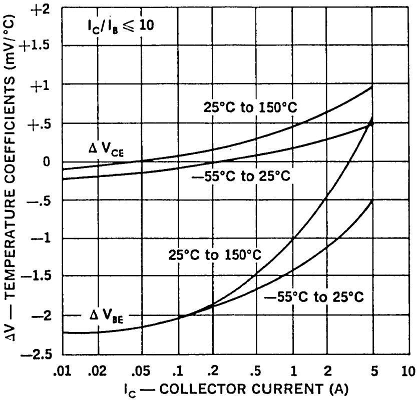
D.C. Current Gain 2N5661, 2N5663



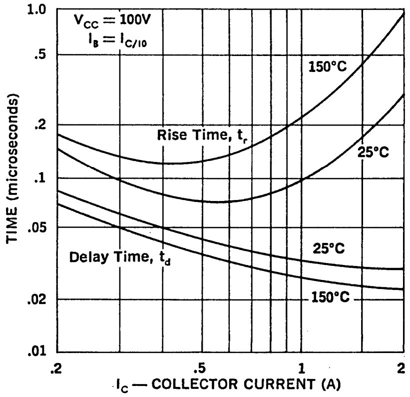
Saturation Voltages



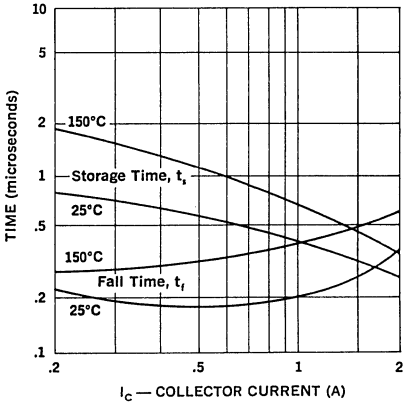
Saturation Voltage Temperature Coefficients



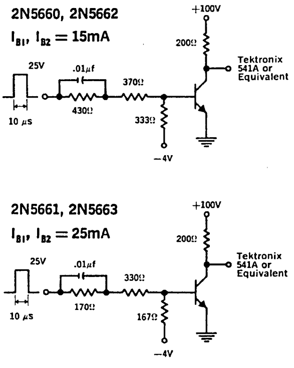
Switching Speed Characteristics



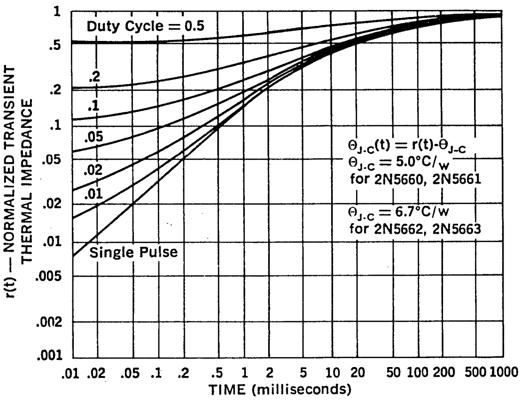
Switching Speed Characteristics



Switching Speed Circuits



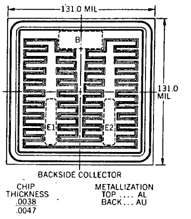
Thermal Response



POWER TRANSISTORS
5 Amp, 300V, Planar NPN

JAN, JANTX, & JANTXV 2N5664
JAN, JANTX, & JANTXV 2N5665
JAN, JANTX, & JANTXV 2N5666
JAN, JANTX, & JANTXV 2N5667

FEATURES
- Meets MIL-S-19500/455
- Collector-Base Voltage: up to 400V
- D.C. Collector Current: 5A
- Peak Collector Current: 10A
- Fast Switching

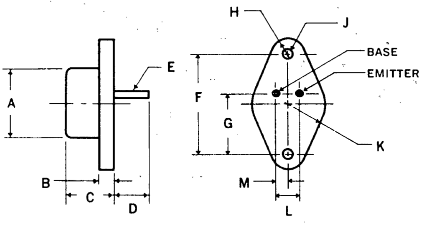


DESCRIPTION
Unitrode high voltage transistors provide a unique combination of low saturation voltage, fast switching, and excellent gain. They are ideally suited for off-line power supply designs and other applications where the increased voltage rating adds to system reliability.

ABSOLUTE MAXIMUM RATINGS	JAN, JANTX, & JANTXV 2N5664	JAN, JANTX, & JANTXV 2N5665	JAN, JANTX, & JANTXV 2N5666	JAN, JANTX, & JANTXV 2N5667
Collector-Base Voltage, V_{CBO}	250V	400V	250V	400V
Collector-Emitter Voltage, V_{CEO}	200V	300V	200V	300V
Emitter-Base Voltage, V_{EBO}	6V	6V	6V	6V
D.C. Collector Current, I_C	5A	5A	5A	5A
Peak Collector Current, I_C	10A	10A	10A	10A
Power Dissipation				
25°C Ambient	2.5W	2.5W	1.2W	1.2W
100°C Case	30W	30W	15W	15W
Operating and Storage Temperature Range	—65°C to 200°C			

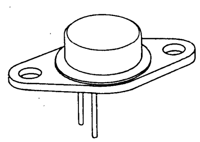
MECHANICAL SPECIFICATIONS

JAN, JANTX, & JANTXV 2N5664 JAN, JANTX, & JANTXV 2N5665

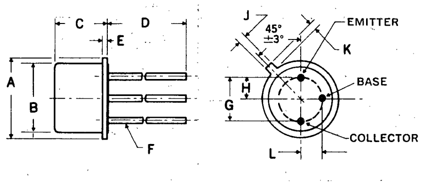


	INCHES	MILLIMETERS
A	.620 MAX.	15.75 MAX.
B	.050 - .075	1.27 - 1.90
C	.250 - .340	6.35 - 8.63
D	.360 MIN.	9.14 MIN.
E	.028 - .034 DIA.	.711 - .863
F	.958 - .962	24.33 - 24.43
G	.570 - .590	14.47 - 14.98
H	.145 MAX. RAD.	3.68 MAX. RAD.
J	.142 - .152 DIA.	3.60 - 3.86 DIA.
K	.350 MAX. RAD.	8.89 MAX. RAD.
L	.190 - .210	4.82 - 5.33
M	.093 - .107	2.36 - 2.72

TO-66

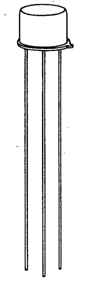


JAN, JANTX, & JANTXV 2N5666 JAN, JANTX, & JANTXV 2N5667



	INCHES	MILLIMETERS
A	.335-.370	8.51-9.40
B	.305-.335	7.75-8.51
C	.240-.260	6.09-6.60
D	1.5 MIN.	38.10 MIN.
E	.010-.030	.254-.762
F	$.017 \pm {}^{.002}_{.001}$	$.432 \pm {}^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.787±.076
K	.029-.045	.736-1.14
L	.100	2.54

TO-5



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)
2N5664, 2N5666

						MIL-STD-750	
Test	Symbol	Min.	Max.	Units	/455 Sub group	Method	Test conditions
Visual and mechanical					A-1	2071	See Mechanical Data
25°C							
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}*	250	—	Vdc	A-2	3011	$I_C = 10mAdc$; $R_{BE} = 100\Omega$, Cond. B
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}*	200	—	Vdc	A-2	3011	$I_C = 10mAdc$; Cond. D
Emitter-Base Breakdown Voltage	BV_{EBO}*	6.0	—	Vdc	A-2	3026	$I_E = 10\mu Adc$; Cond. D
Collector-Emitter Cutoff Current	I_{CES}	—	0.2	μAdc	A-2	3041	$V_{CE} = 200Vdc$; Cond. C
Collector-Base Cutoff Current	I_{CBO}	—	0.1	μAdc	A-2	3036	$V_{CB} = 200Vdc$; Cond. D
Collector-Base Cutoff Current	I_{CBO}	—	1.0	mAdc	A-2	3036	$V_{CB} = 250Vdc$; Cond. D
D.C. Current Gain (Note 1)	h_{FE}*	40	—	—	A-3	3076	$I_C = 0.5Adc$, $V_{CE} = 2Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	40	120	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	15	—	—	A-3	3076	$I_C = 3Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	5	—	—	A-3	3076	$I_C = 5Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)*	—	0.4	Vdc	A-3	3071	$I_C = 3Adc$, $I_B = 0.3Adc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.0	Vdc	A-3	3071	$I_C = 5Adc$, $I_B = 1Adc$
Base Saturation Voltage (Note 1)	V_{BE} (sat)*	—	1.2	Vdc	A-3	3066	$I_C = 3Adc$, $I_B = 0.3Adc$; Cond. A
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	1.5	Vdc	A-3	3066	$I_C = 5Adc$, $I_B = 1Adc$; Cond. A
Gain-Bandwith Product	f_T*	20	70	MHz	A-4	3306	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	120	pf	A-4	3236	$V_{CB} = 10Vdc$, $I_E = 0$, $f = 1MHz$
Thermal Resistance	Θ_{J-C}				C-1	3151	
2N5664		—	3.3	°C/W			
2N5666		—	6.7	°C/W			
Switching Speeds Turn-on Time	t_{on}*	—	0.25	μs	A-4	—	$I_C = 1Adc$
Switching Speeds Turn-off Time	t_{off}*	—	1.5	μs	A-4	—	
100°C							
Forward Biased Second Breakdown 2N5664	$I_{S/B}$	5	—	Adc	B-6	3051	$V_{CE} = 6Vdc$, $t = 1sec$
	$I_{S/B}$	0.75	—	Adc	B-6	3051	$V_{CE} = 40Vdc$, $t = 1sec$
	$I_{S/B}$	43	—	mAdc	B-6	3051	$V_{CE} = 200Vdc$, $t = 1sec$
2N5666	$I_{S/B}$	5	—	Adc	B-7	3051	$V_{CE} = 3Vdc$, $t = 1sec$
	$I_{S/B}$	0.4	—	Adc	B-7	3051	$V_{CE} = 37.5Vdc$, $t = 1sec$
	$I_{S/B}$	27	—	mAdc	B-7	3051	$V_{CE} = 200Vdc$, $t = 1sec$
Unclamped Reverse Biased Second Breakdown	$E_{S/B}$	0.81	—	mj	B-8	3053	$I_C = 5Adc$, $L = .065mh$
Clamped Reverse Biased Second Breakdown	$E_{S/B}$	500	—	mj	B-9	3053	$I_C = 5Adc$, $L = 40mh$, $V_{clamp} = 200V$
150°C							
Collector-Emitter Cutoff Current	I_{CES}	—	100	μAdc	A-5	3041	$V_{CE} = 200Vdc$, Cond. C
−65°C							
D.C. Current Gain (Note 1)	h_{FE}	15	—	—	A-6	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$

Notes:
1. Pulse width = 300μS; duty cycle ≤2%.
* Those parameters marked with a * are JEDEC registered and devices meeting these specifications are available as commercial 2N devices.

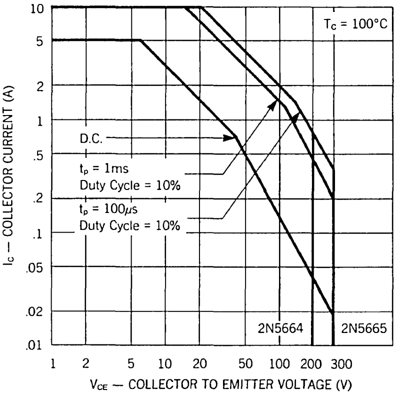
8

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)
2N5665, 2N5667

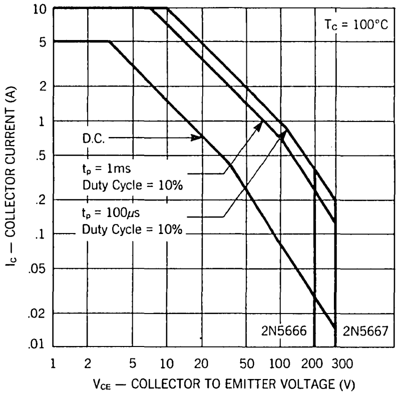
Test	Symbol	Min.	Max.	Units	/455 Sub group	MIL-STD-750	
						Method	Test conditions
Visual and mechanical					A-1	2071	See Mechanical Data
25°C							
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}*	400	—	Vdc	A-2	3011	$I_C = 10mAdc$; $R_{BE} = 100\,\Omega$, Cond. B
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}*	300	—	Vdc	A-2	3011	$I_C = 10mAdc$; Cond. D
Emitter-Base Breakdown Voltage	BV_{EBO}*	6	—	Vdc	A-2	3026	$I_E = 10\mu Adc$; Cond. D
Collector-Emitter Cutoff Current	I_{CES}	—	0.2	μAdc	A-2	3041	$V_{CE} = 300Vdc$; Cond. C
Collector-Base Cutoff Current	I_{CBO}	—	0.1	μAdc	A-2	3036	$V_{CB} = 300Vdc$; Cond. D
Collector-Base Cutoff Current	I_{CBO}	—	1.0	mAdc	A-2	3036	$V_{CB} = 400Vdc$; Cond. D
D.C. Current Gain (Note 1)	h_{FE}*	25	—	—	A-3	3076	$I_C = 0.5Adc$, $V_{CE} = 2Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	25	75	—	A-3	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}*	15	—	—	A-3	3076	$I_C = 3Adc$, $V_{CE} = 10Vdc$
D.C. Current Gain (Note 1)	h_{FE}	5	—	—	A-3	3076	$I_C = 5Adc$, $V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)*	—	0.4	Vdc	A-3	3071	$I_C = 3Adc$, $I_B = 0.6Adc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.0	Vdc	A-3	3071	$I_C = 5Adc$, $I_B = 1Adc$
Base Saturation Voltage (Note 1)	V_{BE} (sat)*	—	1.2	Vdc	A-3	3066	$I_C = 3Adc$, $I_B = 0.6Adc$; Cond. A
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	1.5	Vdc	A-3	3066	$I_C = 5Adc$, $I_B = 1Adc$; Cond. A
Gain-Bandwith Product	f_T*	20	70	MHz	A-4	3306	$I_C = 0.5Adc$, $V_{CE} = 5Vdc$, $f = 10MHz$
Output Capacitance	C_{ob}	—	120	pf	A-4	3236	$V_{CB} = 10Vdc$, $I_E = 0$, $f = 1MHz$
Thermal Resistance	θ_{J-C}				C-1	3151	
2N5665		—	3.3	°C/W			
2N5667		—	6.7	°C/W			
Switching Speeds Turn-on time	t_{on}*	—	0.25	μs	A-4	—	$I_C = 1Adc$
Turn-off time	t_{off}*	—	2.0	μs	A-4	—	
100°C							
Forward Biased Second Breakdown 2N5665	$I_{S/B}$	5	—	Adc	B-6	3051	$V_{CE} = 6Vdc$, $t = 1sec$
	$I_{S/B}$	0.75	—	Adc	B-6	3051	$V_{CE} = 40Vdc$, $t = 1$ sec
	$I_{S/B}$	21	—	mAdc	B-6	3051	$V_{CE} = 300Vdc$, $t = 1sec$
2N5667	$I_{S/B}$	5	—	Adc	B-7	3051	$V_{CE} = 3Vdc$, $t = 1sec$
	$I_{S/B}$	0.4	—	Adc	B-7	3051	$V_{CE} = 37.5Vdc$, $t = 1sec$
	$I_{S/B}$	14	—	mAdc	B-7	3051	$V_{CE} = 300Vdc$, $t = 1sec$
Unclamped Reverse Biased Second Breakdown	$E_{S/B}$	0.81	—	mj	B-8	3053	$I_C = 5Adc$, $L = .065mh$
Clamped Reverse Biased Second Breakdown	$E_{S/B}$	500	—	mj	B-9	3053	$I_C = 5Adc$, $L = 40mh$, $V_{clamp} = 300V$
150°C							
Collector-Emitter Cutoff Current	I_{CES}	—	100	μAdc	A-5	3041	$V_{CE} = 300Vdc$, Cond. C
—65°C							
D.C. Current Gain (Note 1)	h_{FE}	10	—	—	A-6	3076	$I_C = 1Adc$, $V_{CE} = 5Vdc$

Notes:
1. Pulse width = 300μS; duty cycle ≤2%.
* Those parameters marked with a * are JEDEC registered and devices meeting these specifications are available as commercial 2N devices.

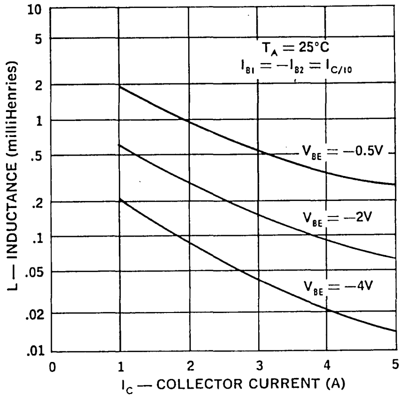
**Forward Bias
Safe Operating Area
2N5664, 2N5665**



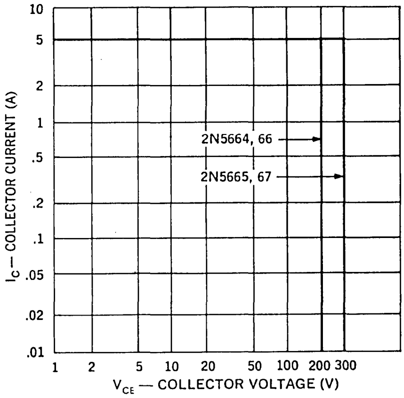
**Forward Bias
Safe Operating Area
2N5666, 2N5667**



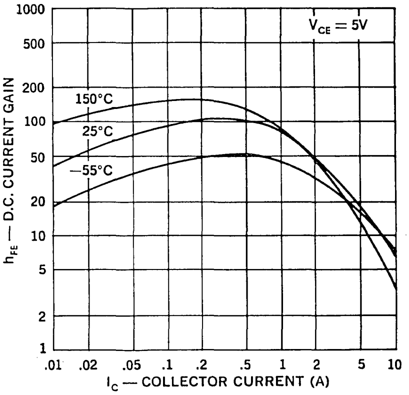
**Unclamped Reverse Bias
Second Breakdown**



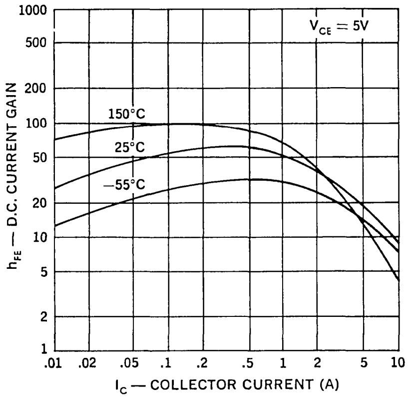
**Reverse Bias
Safe Operating Area
Clamped Inductive Switching**



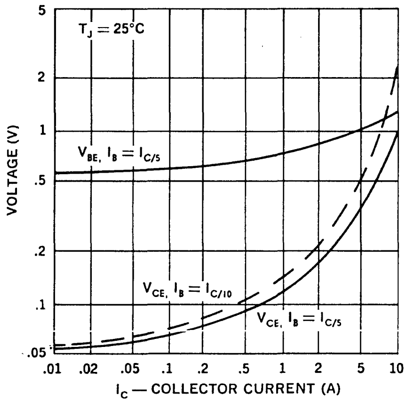
**D.C. Current Gain
2N5664, 2N5666**



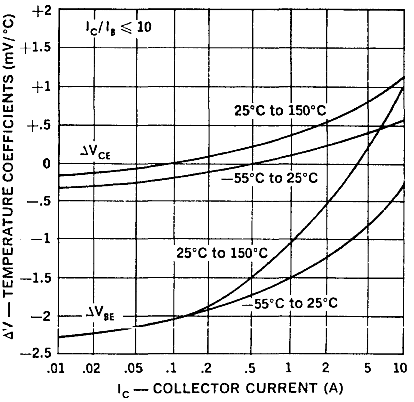
**D.C. Current Gain
2N5665, 2N5667**



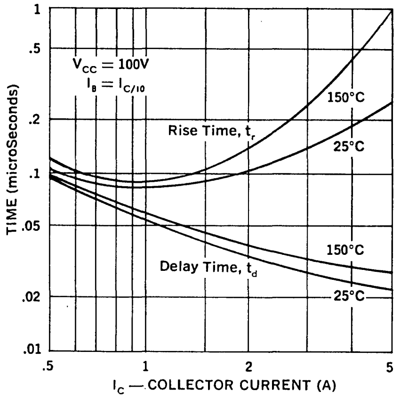
Saturation Voltages



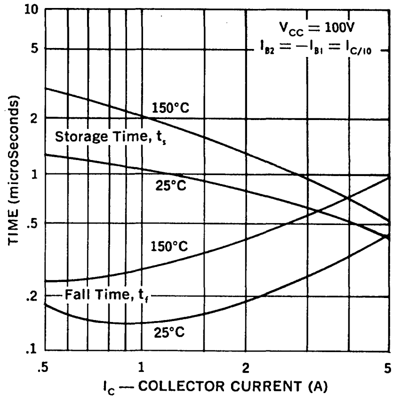
Saturation Voltage Temperature Coefficients



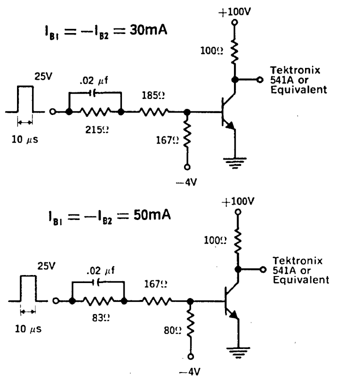
Switching Speed Characteristics



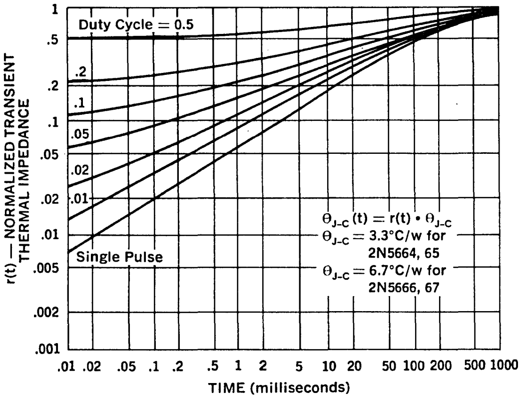
Switching Speed Characteristics



Switching Speed Circuits



Thermal Response



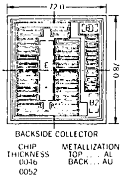
POWER DARLINGTONS

5 Amp, 150V, NPN

JAN, JANTX & JANTXV 2N6350
JAN, JANTX & JANTXV 2N6351
JAN, JANTX & JANTXV 2N6352
JAN, JANTX & JANTXV 2N6353

FEATURES

- High Current Gain: up to 2000 min. @ $I_C = 5A$
- Low Saturation Voltage: as low as 1.5V max. @ $I_C = 2A$
- Peak Current: to 10A
- JAN/JANTX/JANTXV versions meet MIL-S-19500/472



DESCRIPTION

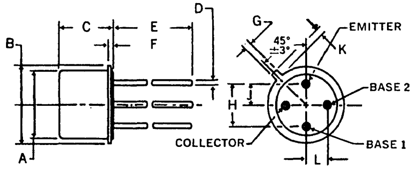
Unitrode NPN Darlingtons consist of a two transistor circuit on a single monolithic planar chip. The 2N6350 series is characterized for fast switching applications.

ABSOLUTE MAXIMUM RATINGS

	TO-33		3 PIN TO-66	
	JAN, JANTX & JANTXV 2N6350	JAN, JANTX & JANTXV 2N6351	JAN, JANTX & JANTXV 2N6352	JAN, JANTX & JANTXV 2N6353
Collector—Emitter Voltage	80V	150V	80V	150V
Emitter—Base Voltages				
V_{EB2}	6V	6V	6V	6V
V_{EB1}	12V	12V	12V	12V
D.C. Collector Current	5A	5A	5A	5A
Peak Collector Current	10A	10A	10A	10A
Base 1 Current	0.5A	0.5A	0.5A	0.5A
Power Dissipation				
25°C Ambient	1W	1W	2W	2W
100°C Case	5W	5W	25W	25W
Thermal Resistance				
Junction-to-Case	20°C/W		4.0°C/W	
Operating and StorageTemperature Range	−65°C to +200°C		−65°C to +200°C	

MECHANICAL SPECIFICATIONS

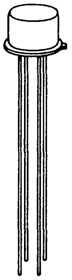
JAN, JANTX & JANTXV 2N6350 JAN, JANTX & JANTXV 2N6351



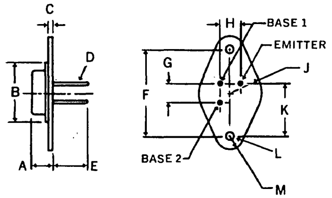
	ins.	mm
A	.305-.335	7 75-8 51
B	335- 370	8.51-9 40
C	240- 260	6 10-6 60
D	$017 \pm {002 \atop 001}$	$.432 \pm {.051 \atop .025}$
E	1.5 MIN.	38.10 MIN
F	018 MAX.	0 46 MAX
G	031 ± 003	0 79 ± 08
H	200	1.02
J	.100	2 54
K	029- 045	0 74-1 14
L	100	2 54

COLLECTOR CONNECTED TO CASE

TO-33



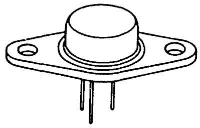
JAN, JANTX & JANTXV 2N6352 JAN, JANTX & JANTXV 2N6353



	ins	mm
A	.250-.340	6.35-8.64
B	.620 MAX.	15 75 MAX.
C	.050-.075	1.27-1.91
D	.028- 034	0.71-0.86
E	.360 MIN.	9.14 MIN.
F	.958-.962	24.33-24 43
G	.190-.210	4.83-5.33
H	.190-.210	4 83-5.33
J	.350 MAX. RAD.	8.89 MAX. RAD
K	.570-.590	14.48-14.99
L	.142-.152	3.61-3.86
M	.145 MAX. RAD.	3.68 MAX. RAD.

COLLECTOR CONNECTED TO CASE

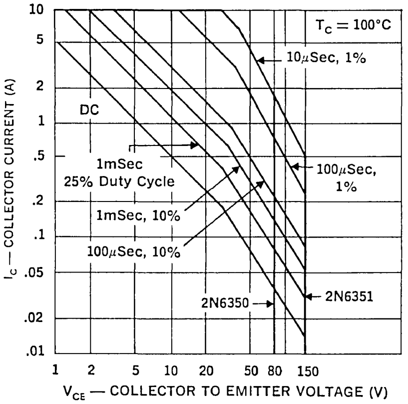
3 PIN TO-66



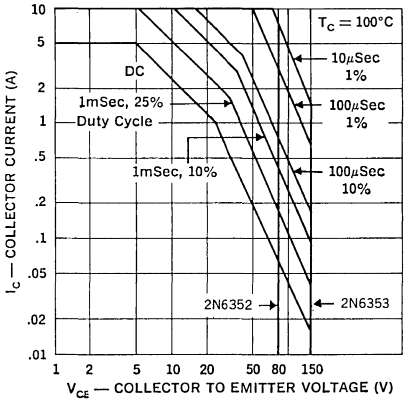
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

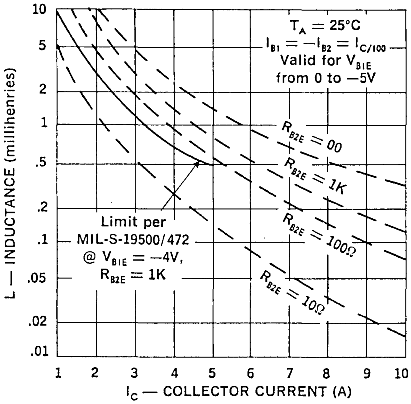
Test	Symbol	Min.	Max.	Units	MIL-STD-750	
					Method	Test Conditions
Visual and Mechanical					2071	See Mechanical Data
25°C						
Collector–Emitter Breakdown Voltage	BV_{CER}				3011	$I_C = 25mA$, $R_{BE1} = 2.2K$, $R_{BE2} = 100$ Ohms
2N6350, 2N6352		80		Vdc		
2N6351, 2N6353		150		Vdc		
Emitter Base Breakdown Voltage, Base 1	BV_{EBO1}	12		Vdc	3026	$I_E = 12mA$ Base 2 Open
Emitter Base Breakdown Voltage, Base 2	BV_{EBO2}	6		Vdc	3026	$I_E = 12mA$ Base 1 Open
Collector — Emitter Cutoff Current	I_{CEX}		1.0	μAdc	3041	$V_{CE} = BV_{CER}$ Rating
D.C. Current Gain	h_{FE}				3076	$V_{CE} = 5Vdc$; $I_C = 1.0A$ (pulse)
2N6350, 2N6352		2000				$R_{BE2} = 1K$
2N6351, 2N6353		1000				
D.C. Current Gain	h_{FE}				3076	$V_{CE} = 5Vdc$; $I_C = 5.0Adc$ (pulse)
2N6350, 2N6352		2000	10000			$R_{BE2} = 100$ Ohms
2N6351, 2N6353		1000	10000			
D.C. Current Gain	h_{FE}				3076	$V_{CE} = 5Vdc$; $I_C = 10Adc$ (pulse)
2N6350, 2N6352		400				$R_{BE2} = 100$ Ohms
2N6351, 2N6353		200				
Collector Saturation Voltage	V_{CE} (sat)				3071	$I_C = 5.0Adc$, $R_{BE2} = 100$ Ohms
2N6350, 2N6352			1.5	Vdc		$I_{B1} = 5mAdc$ (pulse)
2N6351, 2N6353			2.5	Vdc		$I_{B1} = 10mAdc$ (pulse)
Base Saturation Voltage	V_{BE1} (on)		2.5	Vdc	3066	$I_C = 5.0Adc$ (pulse), $V_{CE} = 5Vdc$ $R_{BE2} = 100$ Ohms
A.C. Current Gain	$\lvert h_{FE} \rvert$	5	25		3066	$V_{CE} = 10Vdc$, $I_C = 1.0Adc$, $f = 10MHz$ $R_{BE2} = 100$ Ohms
Output Capacitance	C_{OBO1}		120	pf	3236	$V_{CB1} = 10Vdc$, $100KHz \leqslant f \leqslant 1MHz$ Base 2 open
Turn-on Time	t_{on}		0.5	μs	3251	$V_{CC} = 30Vdc$; $I_C = 5.0Adc$ See Switching Speed Circuit
Turn-off Time	t_{off}		1.2	μs	3251	$V_{CC} = 30Vdc$; $I_C = 5.0Adc$ See Switching Speed Circuit
150°C						
Collector-Emitter Cutoff Current	I_{CEX}		1.0	mAdc	3041	$V_{EB1} = 2Vdc$, $R_{BE2} = 100$ Ohms $V_{CE} = BV_{CER}$ Rating
−65°C						
D.C. Current Gain	h_{FE}				3076	$V_{CE} = 5Vdc$, $I_C = 5.0Adc$ (pulse)
2N6350, 2N6352		400				$R_{BE2} = 100$ Ohms
2N6351, 2N6353		200				



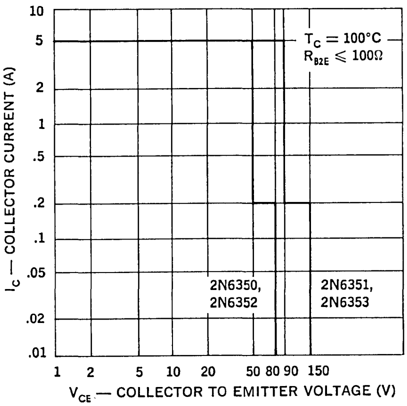
Forward Bias Safe Operating Area 2N6350, 2N6351



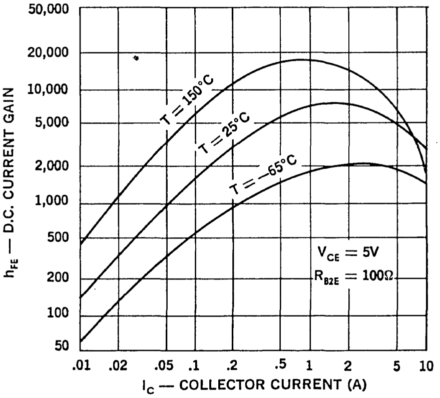
Forward Bias Safe Operating Area 2N6352, 2N6353



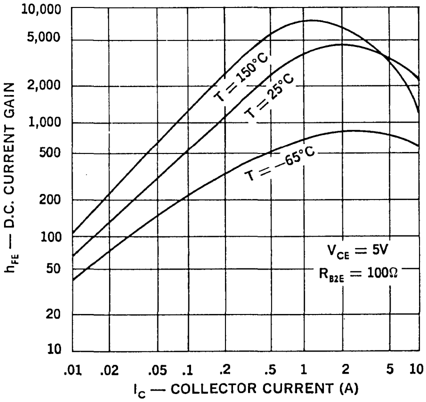
Unclamped Reverse Bias Second Breakdown



Reverse Bias Safe Operating Area Clamped Inductive Switching

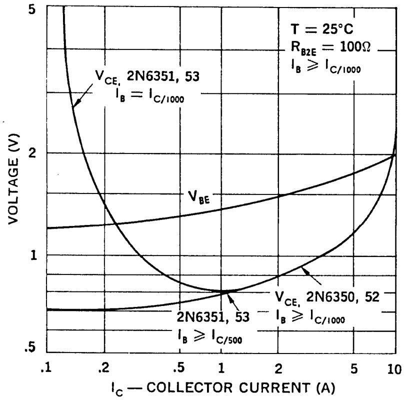


D.C. Current Gain 2N6350, 2N6352

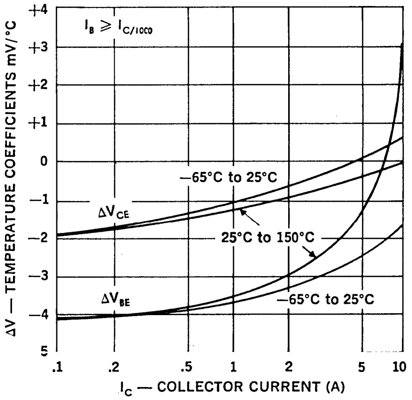


D.C. Current Gain 2N6351, 2N6353

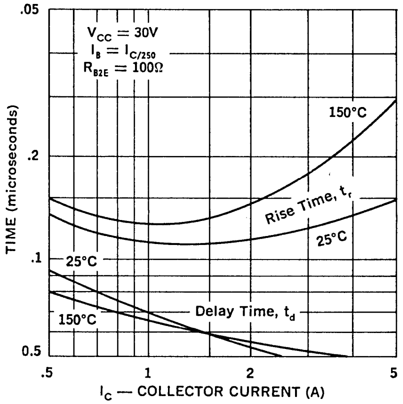
Saturation Voltages



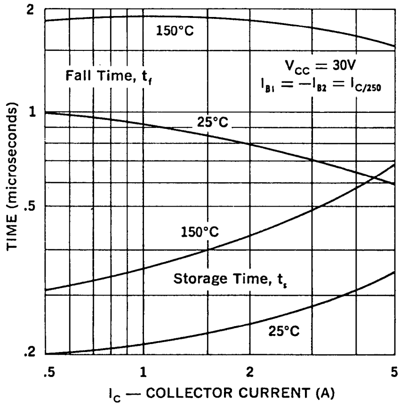
Saturation Voltage Temperature Coefficients



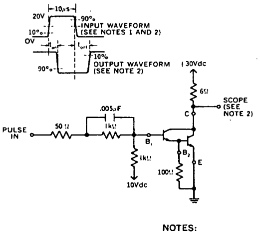
Switching Speed Characteristics



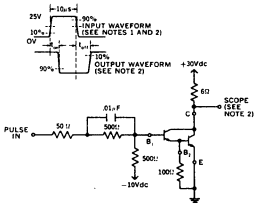
Switching Speed Characteristics



2N6350 & 52 Switching Speed Circuit



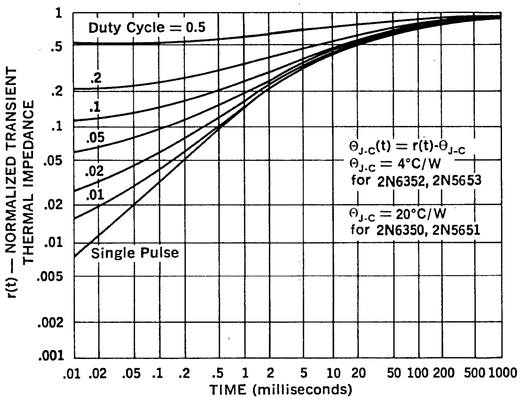
2N6351 & 3 Switching Speed Circuit



NOTES:

1. The input waveform is supplied by a pulse generator with the following characteristics: $t_r \leqslant 15$ ns, $t_f \leqslant 15$ ns, $Z_{out} = 50\Omega$, PW = 10 μs, Duty cycle ⩽ 2%.
2. Output waveforms are monitored on an oscilloscope with the following characteristics: $t_r \leqslant 15$ ns, $Z_{in} \geqslant 10$ MΩ, $C_{in} \leqslant 11.5$ pF.
3. Resistors shall be noninductive types.
4. The DC power supplies may require additional by-passing in order to minimize ringing.

Thermal Response



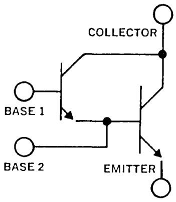
POWER DARLINGTONS

10 Amp, 150V, Planar NPN

U2T101
U2T105
U2T201
U2T205

FEATURES

- High Current Gain: up to 2000 min @ $I_C = 5A$
- Low Saturation Voltage: as low as 1.5V max @ $I_C = 5A$
- High Voltage: up to 150V min V_{CER}
- Monolithic Design Incorporating Multiple-Emitter Techniques
- Triple-Diffused Planar Construction



DESCRIPTION

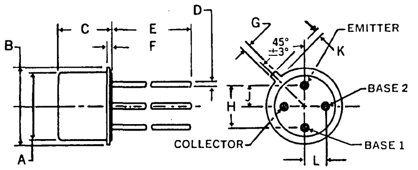
Unitrode NPN Darlingtons consist of a two transistor circuit on a single monolithic planar chip.

ABSOLUTE MAXIMUM RATINGS

	TO-33		3 PIN TO-66	
	U2T101	U2T105	U2T201	U2T205
Collector-Emitter Voltage	80V	150V	80V	150V
Emitter Base Voltages,				
V_{EB2}	6V	6V	6V	6V
V_{EB1}	12V	12V	12V	12V
D.C. Collector Current	5A	5A	5A	5A
Peak Collector Current	10A	10A	10A	10A
Base 1 Current	0.5A	0.5A	0.5A	0.5A
Power Dissipation				
25°C Ambient	1W	1W	2.5W	2.5W
100°C Case	5W	5W	25W	25W
Thermal Resistance, Junction to Case	20°C/W		4°C/W	
Operating and Storage Temperature Range	—65°C to 200°C		—65°C to 200°C	

MECHANICAL SPECIFICATIONS

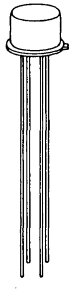
U2T101 U2T105



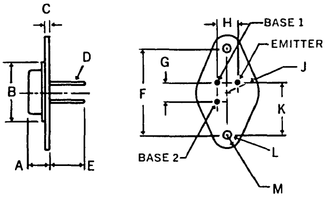
	ins.	mm
A	.305-.335	7 75-8 51
B	335- 370	8 51-9.40
C	240- 260	6 10-6 60
D	017 ± 002 001	.432 ± .051 .025
E	1 5 MIN	38 10 MIN
F	018 MAX	0 46 MAX
G	031 ± 003	0 79 ± 08
H	200	1 02
J	100	2 54
K	029- 045	0 74-1 14
L	100	2 54

COLLECTOR CONNECTED TO CASE

TO-33



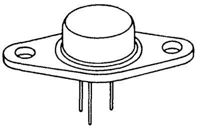
U2T201 U2T205



	ins	mm
A	.250- 340	6 35-8 64
B	.620 MAX	15 75 MAX
C	050- 075	1 27-1.91
D	028- 034	0 71-0 86
E	360 MIN.	9 14 MIN
F	.958- 962	24 33-24 43
G	190- 210	4 83-5.33
H	190- 210	4 83-5 33
J	350 MAX RAD	8 89 MAX RAD
K	.570-.590	14 48-14 99
L	142- 152	3 61-3 86
M	145 MAX. RAD	3 68 MAX RAD

COLLECTOR CONNECTED TO CASE

3 Pin TO-66



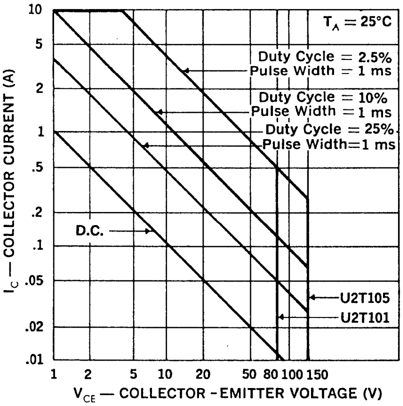
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

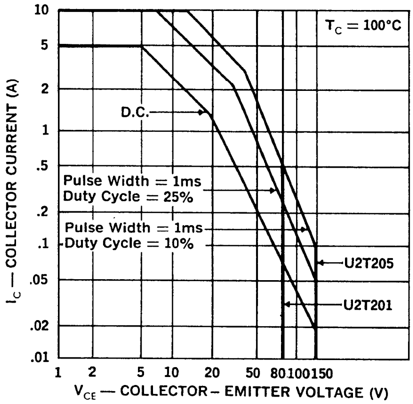
Test	Symbol	U2T101 & U2T201 Min.	U2T101 & U2T201 Max.	U2T105 & U2T205 Min.	U2T105 & U2T205 Max.	Units	Test Conditions
D.C. Current Gain (Note 1)	h_{FE}	2000	—	1000	—	—	$I_C = 1.0A$, $V_{CE} = 2V$, $R_{B2E} = 1K$
D.C. Current Gain (Note 1)	h_{FE}	2000	—	1000	—	—	$I_C = 5A$, $V_{CE} = 5V$, $R_{B2E} = 100$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.5	—	2.5	V	$I_C = 5A$, $R_{B2E} = 100$ U2T101, 201: $I_{B1} = 5mA$ U2T105, 205: $I_{B1} = 10mA$
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}	80	—	150	—	V	$I_C = 25mA$, $R_{B1E} = 2.2K$, $R_{B2E} = 100$
Collector Cutoff Current	I_{CER}	—	1.0	—	1.0	μA	$R_{B1E} = 2.2K$, $R_{B2E} = 100$ U2T101, 201: $V_{CE} = 80V$ U2T105, 205: $V_{CE} = 150V$
Collector Cutoff Current	I_{CER}	—	1.0	—	1.0	mA	$R_{B1E} = 2.2K$, $R_{B2E} = 100$, $T = 150°C$ U2T101, 201: $V_{CE} = 80V$ U2T105, 205: $V_{CE} = 150V$
Collector Capacitance	C_{obo}	—	100	—	100	pf	$V_{CB} = 10$, $I_E = 0$, $f = 1MHz$
A.C. Current Gain	h_{fe}	5	—	5	—	—	$I_C = 1.0A$, $V_{CE} = 10V$, $f = 10MHz$, $R_{B2E} = 100$
Switching Speeds Delay Time	t_d	100 Typ.		100 Typ.		ns	$V_{CC} = 30V$, $I_C = 5A$, U2T101, 201: I_B (on) = I_B (off) = 5mA, U2T105, 205: I_B (on) = I_B (off) = 10mA, $R_{B2E} = 100$
Rise Time	t_r	300 Typ.		400 Typ.		ns	
Storage Time	t_s	600 Typ.		500 Typ.		ns	
Fall Time	t_f	500 Typ.		500 Typ.		ns	

Note: 1. Pulse width = 300 μs; duty cycle $\leqslant 2\%$.

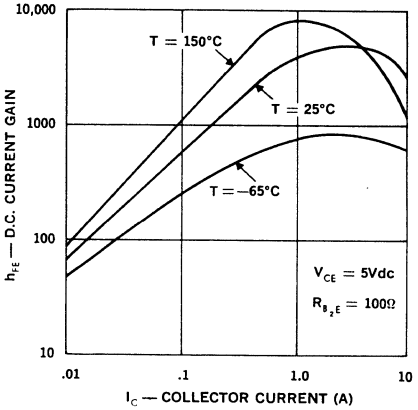
Maximum Safe Operating Area U2T101 & 105



Maximum Safe Operating Area U2T201 & 205



D.C. Current Gain vs. Collector Current U2T101, U2T105, U2T201, U2T205



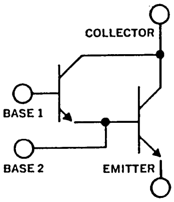
POWER DARLINGTONS

5 Amp, 150V, Planar NPN

U2T301 U2T401
U2T305 U2T405

FEATURES

- High Current Gain: 1000 min. @ $I_C = 2A$
- Low Saturation Voltage: as low as 1.5V max. @ $I_C = 2A$
- High Voltage: up to 150V min. V_{CER}
- Monolithic Design Incorporating Multiple-Emitter Techniques
- Triple-Diffused Planar Construction



DESCRIPTION

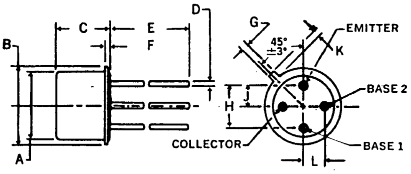
Unitrode NPN Darlingtons consist of a two transistor circuit on a single monolithic planar chip.

ABSOLUTE MAXIMUM RATINGS

	TO-33		3 PIN TO-66	
	U2T301	U2T305	U2T401	U2T405
Collector-Emitter Voltage	60V	150V	60V	150V
Emitter Base Voltages,				
V_{EB2}	6V	6V	6V	6V
V_{EB1}	12V	12V	12V	12V
D.C. Collector Current	2A	2A	2A	2A
Peak Collector Current	5A	5A	5A	5A
Base 1 Current	0.5A	0.5A	0.5A	0.5A
Power Dissipation				
25°C Ambient	1W	1W	2W	2W
100°C Case	4W	4W	16W	16W
Thermal Resistance				
Junction to Case	25°C/W		6°C/W	
Operating and Storage Temperature Range	—65°C to 200°C		—65°C to 200°C	

MECHANICAL SPECIFICATIONS

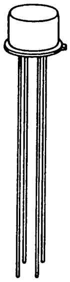
U2T301 U2T305



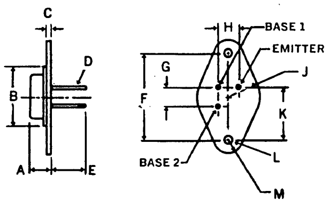
	ins.	mm
A	.305-3.35	7 75-8 51
B	.335-.370	8.51-9.40
C	.240-.260	6.10-6 60
D	$.017 \pm ^{.002}_{.001}$	$.432 \pm ^{.051}_{.025}$
E	1.5 MIN.	38.10 MIN.
F	018 MAX	0.46 MAX.
G	.031 ± 003	0.79 ± 08
H	.200	1.02
J	.100	2.54
K	.029-.045	0 74-1.14
L	.100	2.54

COLLECTOR CONNECTED TO CASE

TO-33



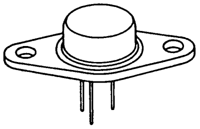
U2T401 U2T405



	ins	mm
A	.250-.340	6.35-8.64
B	.620 MAX.	15.75 MAX.
C	.050-.075	1.27-1.91
D	.028-.034	0.71-0.86
E	.360 MIN.	9.14 MIN.
F	.958-.962	24.33-24.43
G	.190-.210	4.83-5.33
H	.190-.210	4.83-5.33
J	.350 MAX. RAD.	8.89 MAX. RAD.
K	.570-.590	14.48-14.99
L	.142-.152	3.61-3.86
M	.145 MAX. RAD.	3.68 MAX. RAD.

COLLECTOR CONNECTED TO CASE

3 Pin TO-66



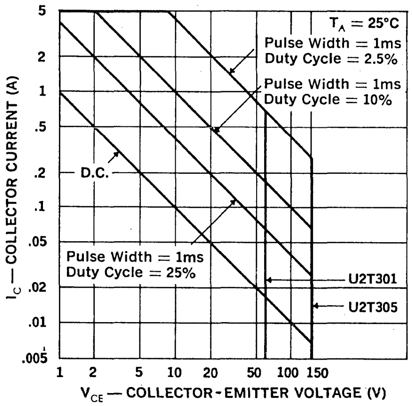
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

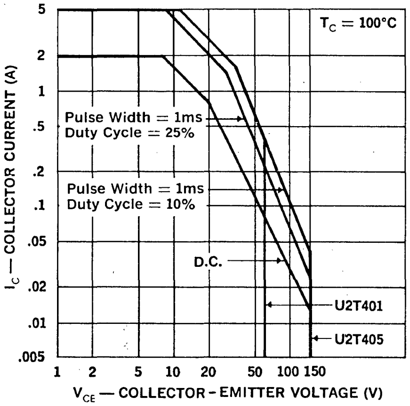
Test	Symbol	U2T301 & U2T401		U2T305 & U2T405		Units	Test Conditions
		Min.	Max.	Min.	Max.		
D.C. Current Gain (Note 1)	h_{FE}	1000	—	1000	—	—	$I_C = 1A$, $V_{CE} = 2V$, $R_{B2E} = 1K$
D.C. Current Gain (Note 1)	h_{FE}	1000	—	1000	—	—	$I_C = 2A$, $V_{CE} = 5V$, $R_{B2E} = 100$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.5	—	2.5	V	$I_C = 2A$, $R_{B2E} = 100$, $I_{B1} = 4mA$
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CER}	60	—	150	—	V	$I_C = 25mA$, $R_{B1E} = 2.2K$, $R_{B2E} = 100$
Collector Cutoff Current	I_{CER}	—	1.0	—	1.0	μA	$R_{B1E} = 2.2K$, $R_{B2E} = 100$ U2T301, 401: $V_{CE} = 60V$ U2T305, 405: $V_{CE} = 150V$
Collector Cutoff Current	I_{CER}	—	1.0	—	1.0	mA	$R_{B1E} = 2.2K$, $R_{B2E} = 100$, $T = 150°C$ U2T301, 401: $V_{CE} = 60V$ U2T305, 405: $V_{CE} = 150V$
Collector Capacitance	C_{obo}	—	60	—	60	pf	$V_{CB1} = 10V$, $I_E = 0$, $f = 1MHz$
A.C. Current Gain	h_{fe}	5	—	5	—	—	$I_C = 0.5A$, $V_{CE} = 10V$, $f = 10MHz$, $R_{B2E} = 100$
Switching Speeds Delay Time	t_d	100 Typ.		100 Typ.		ns	$V_{CC} = 30V$, $I_C = 2A$, I_B (on) $= I_B$ (off) $= 4mA$ $R_{B2E} = 100$
Rise Time	t_r	200 Typ.		300 Typ.		ns	
Storage Time	t_s	800 Typ.		800 Typ.		ns	
Fall Time	t_f	300 Typ.		300 Typ.		ns	

Note: 1. Pulse width = 300 μs; duty cycle ≤2%.

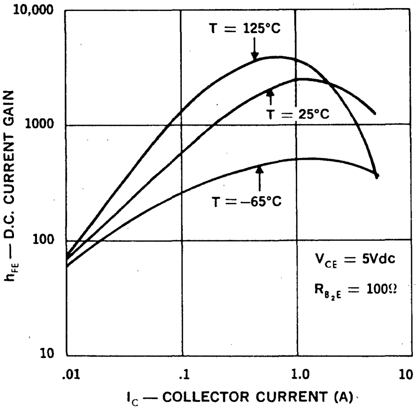
Maximum Safe Operating Area U2T301 & 305



Maximum Safe Operating Area U2T401 & 405



D.C. Current Gain vs. Collector Current U2T301, U2T305, U2T401, U2T405



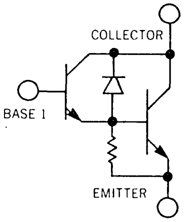
POWER DARLINGTONS

3 Amp, 100V, Planar NPN, Plastic

U2TA506
U2TA508
U2TA510

FEATURES

- High Current Gain: 500 min. @ $I_C = 3A$
- Low Saturation Voltage: as low as 1.5V max. @ $I_C = 3A$
- Economic Plastic Molded Construction



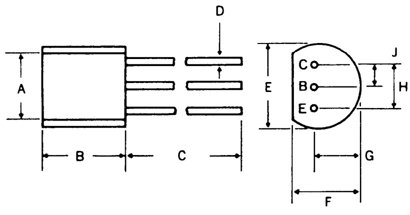
DESCRIPTION

Unitrode NPN Darlingtons consist of a two transistor circuit on a single monolithic planar chip, including integral bias resistance and protective diode. It is ideally suited for pulse power applications in power supplies, printers, solid state relays and displays.

ABSOLUTE MAXIMUM RATINGS

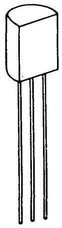
	U2TA506	U2TA508	U2TA510
Collector-Base Voltage, V_{CBO}	80V	100V	120V
Collector-Emitter Voltage, V_{CEO}	60V	80V	100V
Emitter-Base Voltage, V_{EBO}		5V	
D.C. Collector Current, I_C		.75A	
Peak Collector Current, I_C		5A	
Base Current, I_B		.6A	
Power Dissipation			
25°C Case		2.2W	
25°C Ambient		871mW	
Thermal Resistance, Θ_{J-C}		62.5°C/W	
Thermal Resistance, Θ_{J-A}		155°C/W	
Storage Temperature Range		−55 to +150°C	
Maximum Junction Temperature		+175°C	

U2TA506 U2TA508 U2TA510



	INCHES	MILLIMETERS
A	.135 MIN.	3.42 MIN.
B	.170 - .210	4.31 - 5.33
C	.500 MIN.	12.70 MIN.
D	.016 - .019	.406 - .482
E	.175 - .205	4.44 - 5.21
F	.125 - .165	3.17 - 4.19
G	.080 - .105	2.03 - 2.66
H	.095 - .105	2.41 - 2.66
J	.045 - .055	1.14 - 1.40

TO-92



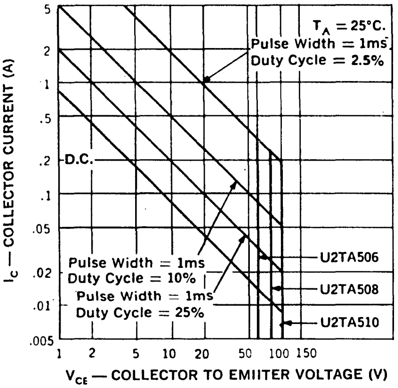
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

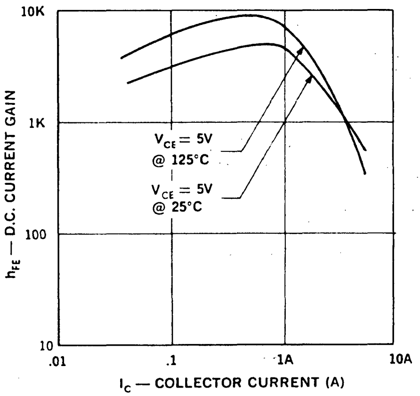
Test	Symbol	Min.	Max.	Units	Test Conditions
D.C. Current Gain (Note 1)	h_{FE}	1000	—	—	$I_C = 1A, V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	500	—	—	$I_C = 3A, V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	300 Typ.		—	$I_C = 5A, V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.5	Vdc	$I_C = 3A, I_B = 30mA$
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}			Vdc	$I_C = 10mAdc$
U2TA506		60	—		
U2TA508		80	—		
U2TA510		100	—		
Collector-Emitter Cutoff Current	I_{CER}	—	10	μAdc	V_{CE} = rating, R = 100Ω
Collector-Emitter Cutoff Current	I_{CER}	—	1	mAdc	V_{CE} = rating, R = 100Ω, T_A = 125°C
Emitter-Base Cutoff Current	I_{EBO}	—	50	μAdc	$V_{EB} = 5Vdc$
Output Capacitance	C_{ob}	—	50	pf	$V_{CB} = 10Vdc, I_E = 0, f = 1MHz$
A.C. Current Gain	h_{fe}	4.0 Typ.		—	$I_C = 1Adc, V_{CE} = 5Vdc, f = 10MHz$
Rise Time	t_r	600 Typ.		ns	$I_C = 2A$
Storage Time	t_s	1500 Typ.		ns	V_{CC} = rating, $I_{B\,(on)} = I_{B\,(off)}$ = 4mA
Fall Time	t_f	800 Typ.		ns	

Note 1: Pulse width = 300μs; duty cycle ≤ 2%.
Note 2: For thermal considerations for operating U2TA506, U2TA508 and U2TA510, refer to Application Note U-77.

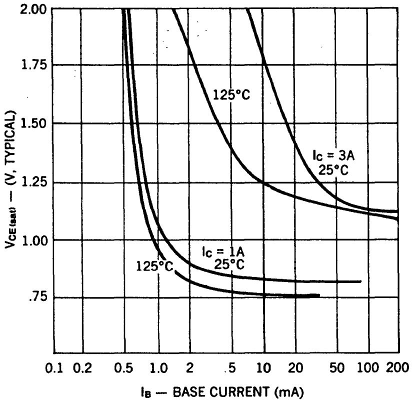
Maximum Safe Operating Area U2TA506, 508 & 510



D.C. Current Gain vs. Collector Current



Saturation Voltage vs Base Current



LOW VOLTAGE NPN TRANSISTOR

UBT430

40Amp, 50V, Planar NPN
Low Saturation Voltage (.3V @ 30A); High Efficiency

FEATURES

- Very Low On Resistance — Typically 7 milliohms
- Reverse Blocking Voltage — V_{ECS} = 20V
- Low Temperature Coefficient of On Resistance
- Fast Switching Times Make Operation at High Frequency·Easy
- High Gain Reduces Base Losses

DESCRIPTION

The UBT430 is a planar NPN bipolar transistor that has been designed to optimize performance for low voltage circuits. It features a very low saturation voltage of only .30V max at 30A, and .10V at 10A. Because of its excellent switching speed (rise and fall times typically under 100ns and storage times under 500ns) it offers excellent performance even in high frequency switching circuits.

This is the ideal transistor to use for emitter switching in off-line switching power supplies. The low drop of this device also makes it the best choice for a battery back-up circuit. Considerable improvement in efficiency can be achieved by using the UBT430 transistor in boost regulators operating off a 5V line and low voltage buck regulators.

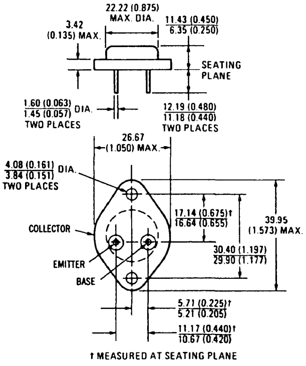
Design Note DN-20 provides additional information on the application of the UBT430 transistor.

ABSOLUTE MAXIMUM RATINGS

Continuous Collector Current	I_C	40A
Peak Emitter Current	I_M	150A
Inductive Collector Current Clamped	I_{LM}	80A
Continuous Base Current	I_B	8A
Peak Base Current	I_{BM}	50A
Collector-Emitter Voltage	V_{CES}	50V
Emitter-Base Voltage	V_{EBO}	20V
Thermal Resistance	$R\theta$	1°C/W
Power Dissipation		150W @ 25°C
Derating Factor		1W/°C
Operating Temperature Range		−65°C to +175°C

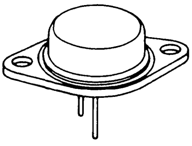
MECHANICAL SPECIFICATIONS

UBT430



Dimensions in Millimeters and (Inches)

TO-204AE (TO-3 modified, 60 mil. pin)

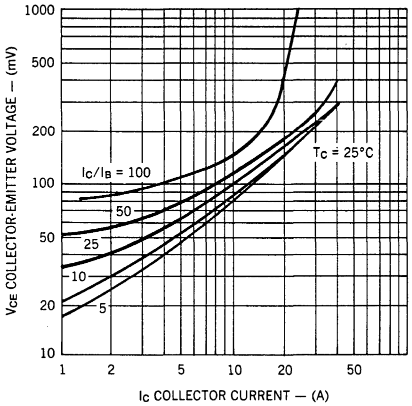


SEMICONDUCTOR PRODUCTS
UNITRODE

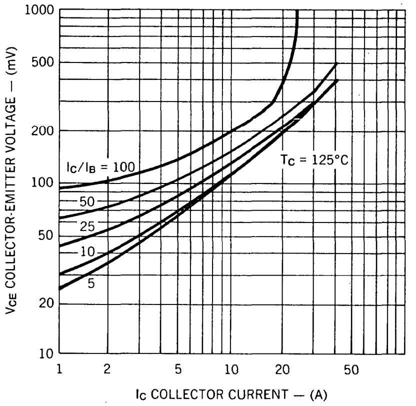
ELECTRICAL CHARACTERISTICS (at 25°C unless noted)

TEST		SYMBOL	MIN.	TYP.	MAX.	UNIT	CONDITIONS
Collector Saturation Voltage		$V_{CE(sat)}$		0.07	0.1	V	I_C = 10A, I_B = .5A
				0.21	0.3		I_C = 30A, I_B = 1.2A
				0.30	0.4		I_C = 30A, I_B = 1.2A, T = 125°C
On-Resistance		$R_{CE(ON)}$		7	10	mΩ	I_C = 30A, I_B = 1.2A
Current Gain		H_{FE}	50	100			I_C = 20A, V_{CE} = .5V
Base Saturation Voltage		$V_{BE(sat)}$		1.2	1.5	V	I_C = 30A, I_B = 1.2A
Collector-Emitter Sustaining Voltage		$V_{CEO(sus)}$	17	20		V	I_C = 100mA
Resistive Switching Speed	Rise Time	t_r		85	120	ns	I_C = 20A, I_{B1} = I_{B2} = 2A, V_{CC} = 10V
	Storage Time	t_s		300	500	ns	I_C = 20A, I_{B1} = I_{B2} = 2A, V_{CC} = 10V
	Fall Time	t_f		75	120	ns	I_C = 20A, I_{B1} = I_{B2} = 2A, V_{CC} = 10V
Inductive Switching Speed	Voltage Storage Time	t_{sv}		400	600	ns	I_C = 20A, I_{B1} = I_{B2} = .8A, V_{CC} = 10V, L = 10μH
	Current Fall Time	t_{fi}		85	120	ns	I_C = 20A, I_{B1} = I_{B2} = .8A, V_{CC} = 10V, L = 10μH
Collector-Emitter Cutoff Current		I_{CES}			100	μA	V_{CE} = 50V
					1	mA	V_{CE} = 50V, T = 125°C
Emitter-Base Cutoff Current		I_{EBO}			200	μA	V_{EB} = 20V
					1	mA	V_{EB} = 20V, T = 125°C

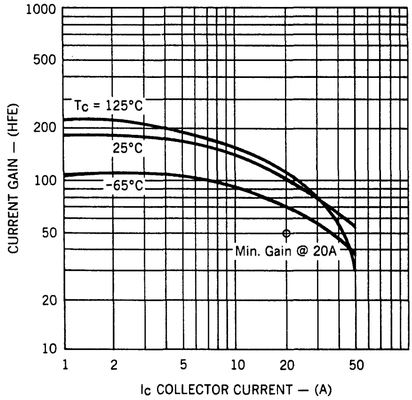
Collector-Emitter Voltage vs Collector Current at Various Forced Gains



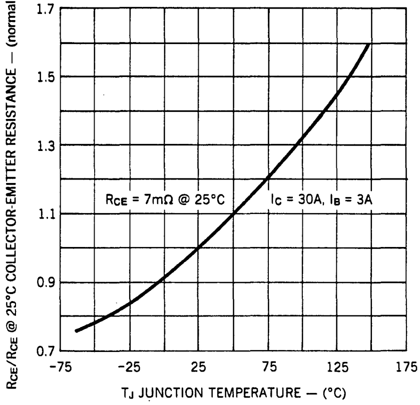
Collector-Emitter Voltage vs Collector Current at Various Forced Gains



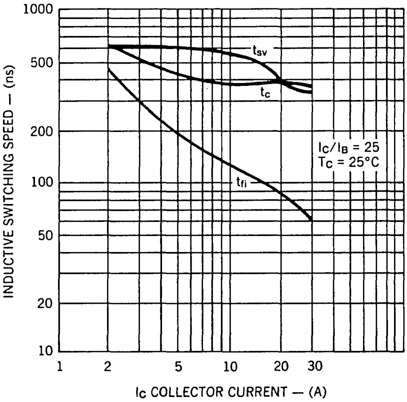
Gain vs Collector Current @ V_{CE} = 0.5V at Various Temperatures



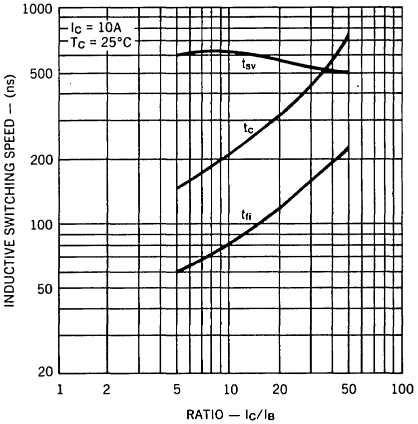
Collector-Emitter Resistance vs Junction Temperature



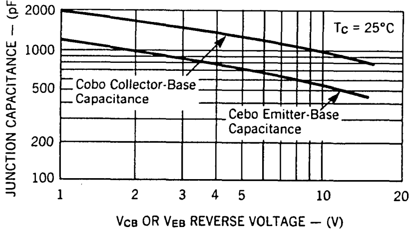
Inductive Switching Time vs Collector Current

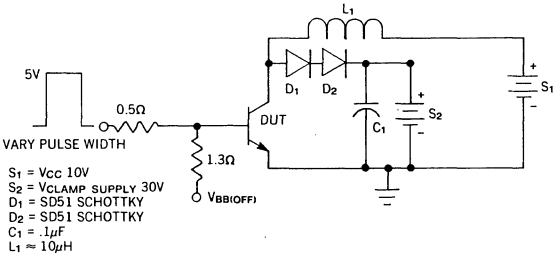


Inductive Switching Time vs Base Drive Current



Junction Capacitance

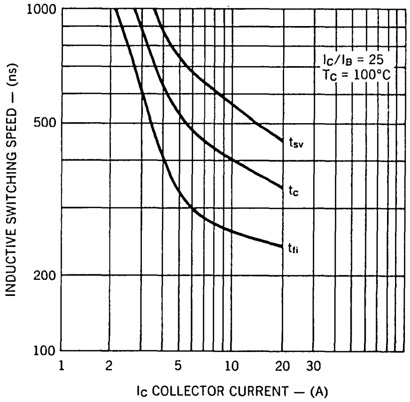




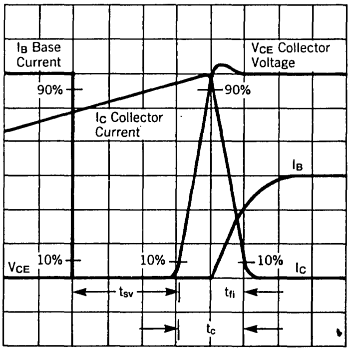
S_1 = V_{CC} 10V
S_2 = $V_{CLAMP\ SUPPLY}$ 30V
D_1 = SD51 SCHOTTKY
D_2 = SD51 SCHOTTKY
C_1 = .1µF
L_1 ≈ 10µH

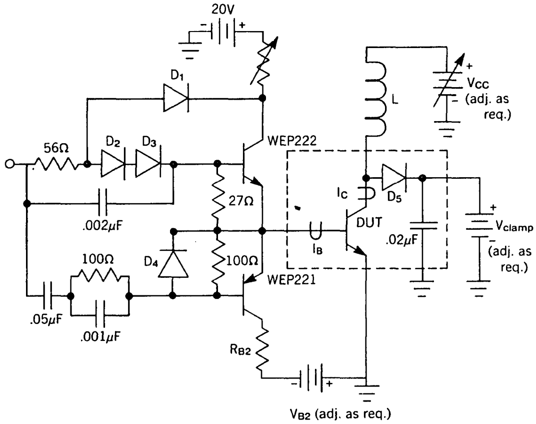
FIGURE #1 TEST CIRCUIT FOR I_{LPK}

Inductive Switching Time vs Collector Current



Clamped Inductive Switching Waveforms and Definitions Inductive Turn Off

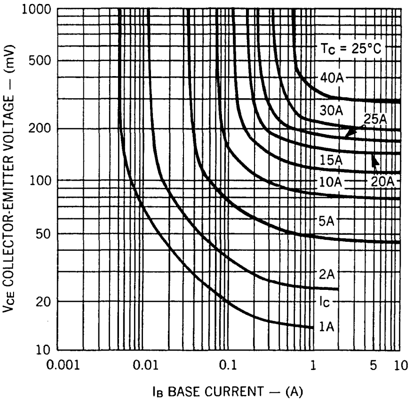




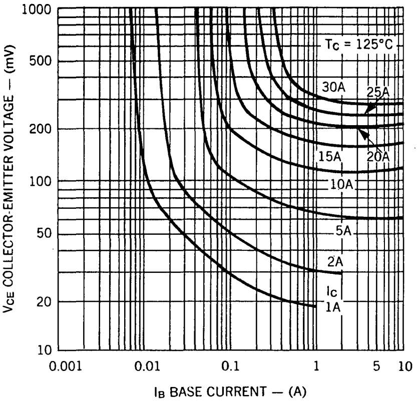
NOTES:
1. All resistors are in ohms.
2. All capacitors are in microfarads.
3. D_1 — D_4 are 1N914 diodes.
4. D_5 is 1N6391 or equivalent.
5. L is selected as required (5 to 15 microhenries).
6. Adjust R_{B2} and/or V_{B2} for desired I_{B2}.
7. Circuit; DUT and adjacent circuit is critical due to fast switching time Ringing voltage produced by Ldi/dt effects may be reduced by proper layout of PC board.

FIGURE #2 INDUCTIVE SWITCHING CIRCUIT WITH CLAMPED COLLECTOR

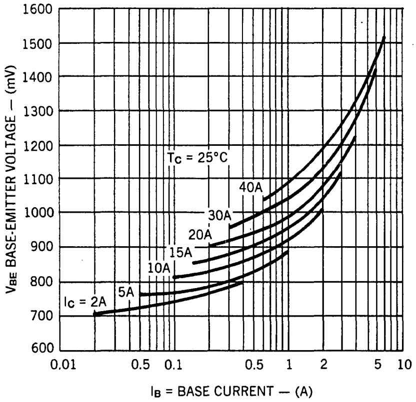
Collector-Emitter Voltage vs Base Current



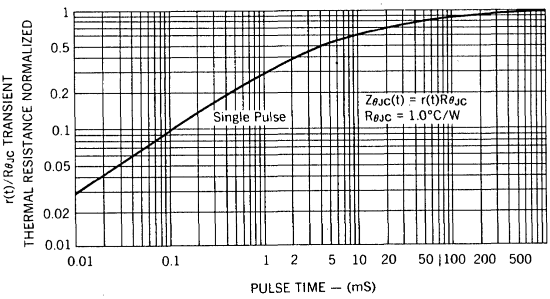
Collector-Emitter Voltage vs Base Current



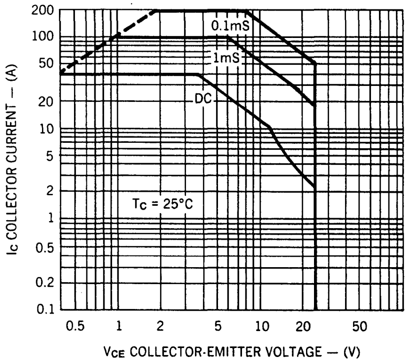
Base Emitter Voltage vs Base Current at Various Collector Currents



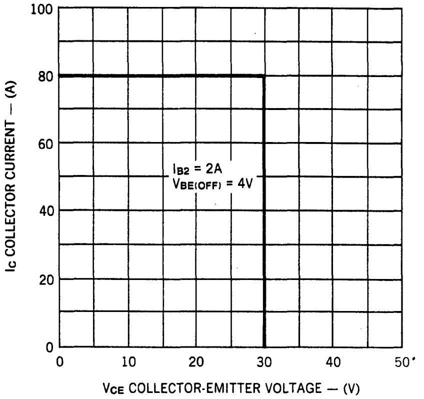
Transient Thermal Resistance vs Time



Forward Bias Safe Operating Area (SOA)



Reverse Bias Safe Operating Area



POWER TRANSISTORS
0.1 Amp, 500V, Planar NPN, Plastic

UPTB520
UPTB530
UPTB540
UPTB550

FEATURES
- Designed for High Speed Switching Applications
- Collector-Emitter Voltage: up to 500V
- Peak Collector Current: to .2A
- Economical Plastic Molded Construction

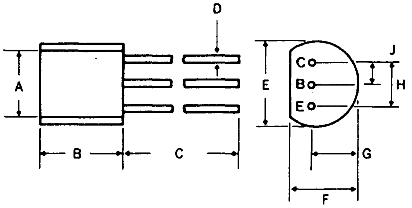
DESCRIPTION
Unitrode high voltage power transistors provide a unique combination of low saturation voltage, high gain and fast switching. They are ideally suited for pulse power applications in power supplies, thermal printers, solid state relays and pulse amplifiers.

ABSOLUTE MAXIMUM RATINGS

	UPTB520	UPTB530	UPTB540	UPTB550
Collector-Base Voltage, V_{CBO}	250V	350V	450V	550V
Collector-Emitter Voltage, V_{CEO}	200V	300V	400V	500V
Emitter-Base Voltage, V_{EBO}	5V	5V	5V	5V
D.C. Collector Current, I_C	.1A	.1A	.1A	.1A
Peak Collector Current, I_C	.2A	.2A	.2A	.2A
Base Current, I_B	.1A	.1A	.1A	.1A
Power Dissipation				
25°C Case	2.4W			
25°C Ambient	750mW			
Thermal Resistance, θ_{J-C}	62.5°C/W			
Thermal Resistance, θ_{J-A}	200°C/W			
Storage Temperature Range	−55°C to +150°C			
Maximum Junction Temperature	+175°C			

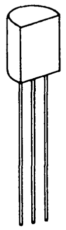
MECHANICAL SPECIFICATIONS

UPTB520 UPTB530 UPTB540 UPTB550



	INCHES	MILLIMETERS
A	.135 MIN.	3.42 MIN.
B	.170 - .210	4.31 - 5.33
C	.500 MIN.	12.70 MIN.
D	.016 - .019	.406 - .482
E	.175 - .205	4.44 - 5.21
F	.125 - .165	3.17 - 4.19
G	.080 - .105	2.03 - 2.66
H	.095 - .105	2.41 - 2.66
J	.045 - .055	1.14 - 1.40

TO-92



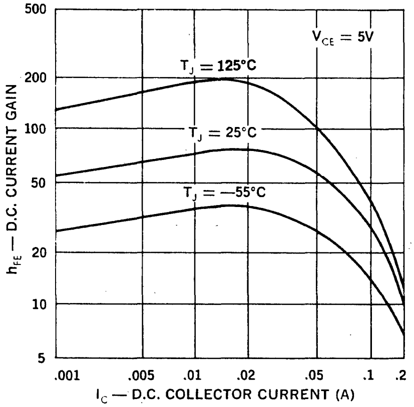
SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

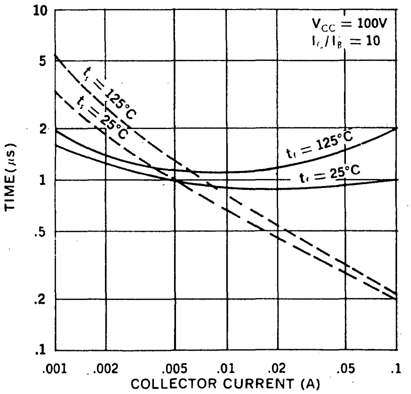
Test	Symbol	Min.	Max.	Units	Test Conditions
D.C. Current Gain (Note 1)	h_{FE}	20	—	—	$I_C = 25mA, V_{CE} = 5Vdc$
D.C. Current Gain (Note 1)	h_{FE}	5	—	—	$I_C = 100mA, V_{CE} = 5Vdc$
Collector Saturation Voltage (Note 1)	V_{CE} (sat)	—	1.2	Vdc	$I_C = 50mA, I_B = 10mA$
	V_{CE} (sat)		1.0	Vdc	$I_C = 20mA, I_B = 2mA$
Base Saturation Voltage (Note 1)	V_{BE} (sat)	—	1.5	Vdc	$I_C = 50mA, I_B = 10mA$
Collector-Base Breakdown Voltage (Note 1)	BV_{CBO}			Vdc	$I_C = 10\mu Adc$
UPTB520		250	—		
UPTB530		350	—		
UPTB540		450	—		
UPTB550		550	—		
Collector-Emitter Breakdown Voltage (Note 1)	BV_{CEO}			Vdc	$I_C = 1mAdc$
UPTB520		200	—		
UPTB530		300	—		
UPTB540		400	—		
UPTB550		500	—		
Collector-Emitter Cutoff Current	I_{CES}	—	10	μAdc	V_{CE} = rated BV_{CEO}, $V_{BE} = 0$
Collector-Emitter Cutoff Current	I_{CES}	—	1	mAdc	V_{CE} = rated BV_{CEO}, T = 125°C, $V_{BE} = 0$
Emitter-Base Cutoff Current	I_{EBO}	—	50	μAdc	$V_{EB} = 5Vdc$
Output Capacitance	C_{ob}	—	50	pf	$V_{CB} = 10Vdc, I_E = 0, f = 1MHz$
Gain-Bandwidth Product	f_T	15	—	MHz	$I_C = 1Adc, V_{CE} = 5Vdc, f = 10MHz$
Rise Time	t_r	100 Typ.		ns	$I_C = 100mA$
Delay Time	t_d	50 Typ.		ns	
Storage Time	t_s	200 Typ.		ns	
Fall Time	t_f	1000 Typ.		ns	

Note: 1. Pulse width = 300μs; duty cycle ≤ 2%.
Note: 2. For thermal considerations for operating UPTB520, UPTB530, UPTB540 and UPTB550, refer to Application Note U-77.

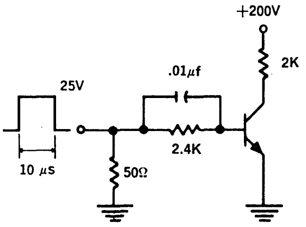
D.C. Current Gain vs. Collector Current



Switching Speeds



Switching Speed Circuit



SCRs & THYRISTORS 9

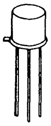
Product Selection Guides

THYRISTORS (SCRs & PUTs)

PRODUCT SELECTION GUIDE

 TO-18	SCR	$I_{T(RMS)}$		.5A			
		V_{DRM} (V)	30		2N3027*	2N3030*	ID100
			60	AA114	2N3028*	2N3031*	ID101
			100		2N3029*	2N3032*	ID102
			150				ID103
			200	AA116			ID104
			300	AA110			ID105
			400	AA111			ID106
		I_{GT}		200µA	200µA	20µA	200µA
		I_H		2mA	5mA	4mA	5mA

 TO-9	SCR	$I_{T(RMS)}$		1.25A	
		V_{DRM} (V)	30	2N1876	2N1870A**
			60	2N1877	2N1871A**
			100	2N1878	2N1872A**
			150	2N1879	2N1873A
			200	2N1880	2N1874A**
		I_{GT}		20µA	200µA
		I_H		3mA	5mA

 TO-39	SCR	$I_{T(RMS)}$		1.6A				
		V_{DRM} (V)	30				2N2322	
			60	AD100	2N5724	2N2323A***	2N2323***	1D200
			100	AD101	2N5725	2N2324A***	2N2324***	ID201
			150			2N2325A	2N2325	ID202
			200	AD102	2N5726	2N2326A***	2N2326***	ID203
			300	AD103	2N5727	2N2328A***	2N2328***	ID300
			400	AD104	2N5728		2N2329***	ID301
		I_{GT}		2µA	20µA	20µA	200µA	200µA
		I_H		2mA	2mA	2mA	2mA	3mA

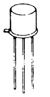
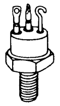
*Available as JAN and JANTX types.

**Available as JAN type.

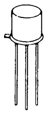
***Available as JAN, JANTX, JANTXV types.

THYRISTORS (SCRs & PUTs)

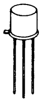
ULTRAFAST SWITCHING

 TO-18	SCR	V_{DRM} (V)	$I_{T(RMS)}$	.4A	
			60V	GA200 GA300	GA200A GA300A
			100V	GA201 GA301	GA201A GA301A
			t_{on}	20ns (TYP.)	20nS (TYP.)
			t_q	2.0μS	.5μS
 TO-59	SCR	V_{DRM} (V)	$I_{T(RMS)}$	6A	
			60V	GB200 GB300	GB200A GB300A
			100V	GB201 GB301	GB201A GB301A
			t_{on}	20ns (TYP.)	20nS (TYP.)
			t_q	2.0μS	.5μS

RADIATION HARDENED SCRs

 TO-18	On-State Current $I_{T(RMS)}$		0.4A
	Package Style		TO-18
	REPETITIVE PEAK OFF-STATE VOLTAGE, V_{DRM} and REVERSE VOLTAGE, V_{RRM}	30V	GA100
		60V	GA101
		80V	GA102
	Key Parameters		I_{GT} (Post 3X10^{14} NVT) 20mA
			I_H (Post 3X10^{14} NVT) 30mA

PUTs — PROGRAMMABLE UNIJUNCTION TRANSISTORS

 TO-18	Peak Recurrent Forward Current		8A	
	Package Style		TO-18	
	MIN. VALLEY CURRENT, I_V MAX. PEAK POINT CURRENT, I_P	$I_V = 25\mu A$ @ $R_G = 10K$ $I_P = .15\mu A$ @ $R_G = 1Meg$	U13T2	CONSULT FACTORY
		$I_V = 70\mu A$ @ $R_G = 10K$ $I_P = 2\mu A$ @ $R_G = 1Meg$	U13T1	
		$I_V = 1mA$ @ $R_G = 200\Omega$ $I_P = .15\mu A$ @ $R_G = 1Meg$	2N6120	
		$I_V = 1.5mA$ @ $R_G = 200\Omega$ $I_P = 2\mu A$ @ $R_G = 1Meg$	2N6119 2N6137*	
	Forward and Reverse Voltage; V_{AK}, V_{AKR}		40V	100V

* Available as JAN and JANTX types.

SCRs
1.25 Amp, Planar

2N1870A-2N1874A, J

FEATURES
- Available as Either "JAN" or Standard Types
- Operating D.C. Current Range: 5 to 1250mA
- Pulse Currents: to 30A
- Voltage Ratings: to 200V
- Maximum Trigger Current: 0.2mA
- Maximum Trigger Voltage: 0.8V
- All Leads Isolated from Case
- Maximum θ_{J-C}: 20°C/W

DESCRIPTION
These are premium PNPN controlled switches intended for use in applications requiring a high degree of reliability assurance. The JAN types are specified under MIL-S-19500/198, and are included in MIL-STD-701 as recommended types for military usage.

This series is useful in a wide variety of applications including: safety, arming and detonating circuits; timing and programming circuits; protective and warning circuits; driving relays; driving indicator lamps, encoding and decoding circuits; replacing relays, thyratrons, and magamps; servo motor control; pulse generation; plus many others.

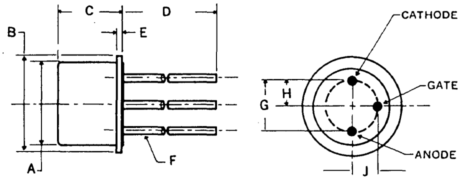
ABSOLUTE MAXIMUM RATINGS

	2N1870A JAN2N1870A	2N1871A JAN2N1871A	2N1872A JAN2N1872A	2N1873A —	2N1874A JAN2N1874A
Repetitive Peak Off-State Voltage, V_{DRM}	30V	60V	100V	150V	200V
Repetitive Peak Reverse Voltage, V_{RRM}	30V	60V	100V	150V	200V

D.C. On-State Current, I_T	
100°C Ambient	250mA
100°C Case	1.25A
Repetitive Peak On-State Current, I_{TRM}	up to 30A
Peak One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	15A
Peak Gate Current, I_{GM}	250mA
Average Gate Current, $I_{G(AV)}$	25mA
Reverse Gate Voltage, V_{GR}	5V
Thermal Resistance, Junction to Case, $R\theta_{J-C}$	20°C/W
Operating and Storage Temperature Range	—65°C to +150°C

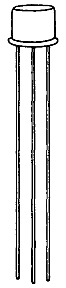
MECHANICAL SPECIFICATIONS

2N1870A-2N1874A



	ins.	mm.
A	275- 335	6.99-7.75
B	..290-.370	7.37-9 40
C	200- 260	5.08-6 60
D	1 5 MIN.	38.10 MIN.
E	.010- 030	.25-.76
F	.017 ± .002 001	.432 ± .051 .025
G	.200	5 08
H	.100	2.54
J	.100	2.54

TO-9



ELECTRICAL SPECIFICATIONS (at 25°C unless noted)†

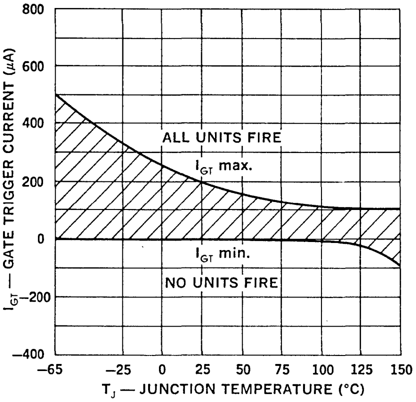
Test	Symbol	Min.	Typical	Max.	Units	Test Conditions
Subgroup 1 (Visual and Mechanical)						
Subgroup 2 (25°C Tests)						
Off-State Current	I_{DRM}	—	0.5	10	μA	$R_{GK} = 1K, V_{DRM} = +$ Rating
Reverse Current	I_{RRM}	—	0.5	10	μA	$R_{GK} = 1K, V_{RRM} = -$ Rating
Gate Trigger Voltage	V_{GT}	0.4	0.55	0.8	V	$R_{GS} = 100$ ohms, $V_D = 5V$
Gate Trigger Current	I_{GT}	—	30	200	μA	$R_{GS} > 10K$ ohms, $V_D = 5V$
On-State Voltage	V_{TM}	—	1.8	2.5	V	$I_{TM} = 2A$ (pulse test)
Off-State Voltage — Critical of Rise	dv_c/dt	100	—	—	V/μs	Specified test circuit
Reverse Gate Current	I_{GR}	—	0.5	10	μA	$V_{GRM} = 5V$, anode open
Holding Current	I_H	0.3	—	5.0	mA	$I_G = -150\mu A, V_D = 5V$
Subgroup 3 (125°C Tests)						
High Temp. Off-State Current	I_{DRM}	—	15	100	μA	$R_{GK} = 1K, V_{DRM} = +$ Rating
High Temp. Reverse Current	I_{RRM}	—	15	100	μA	$R_{GK} = 1K, V_{RRM} = -$ Rating
High Temp. Gate Non-Trigger Voltage	V_{GD}	0.2	—	—	V	$R_{GS} = 100$ ohms, $V_D = 5V$
High Temp. Holding Current	I_H	0.2	—	—	mA	$I_G = -150\mu A, V_D = 5V$
Subgroup 4 (—65°C Tests)						
Low Temp. Gate Trigger Voltage	V_{GT}	—	—	1.0	V	$R_{GK} = 100$ ohms, $V_D = 5V$
Low Temp. Gate Trigger Current	I_{GT}	—	—	500	μA	$R_{GK} > 10K$ ohms, $V_D = 5V$
Low Temp. Holding Current	I_H	—	—	15	mA	$I_G = -150\mu A, V_{AA} = 5V$

†All values in this table are JEDEC registered.

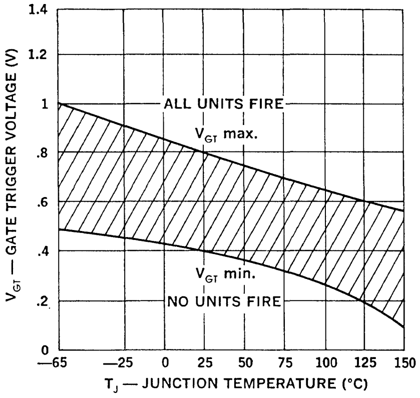
Note: Voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1 K or smaller, or other adequate gate bias is used.

Triggering and Bias Stabilization

1. Gate Trigger Current

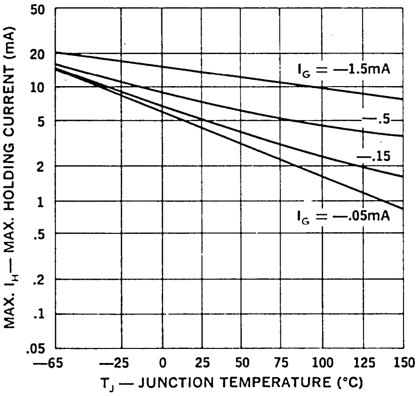


2. Gate Trigger Voltage

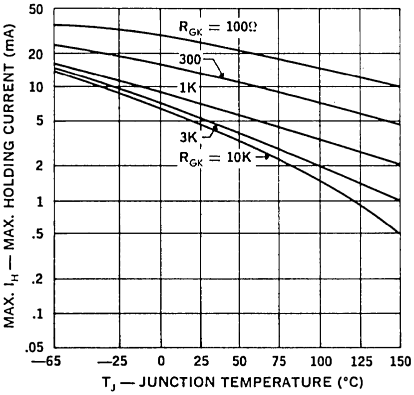


Holding Current

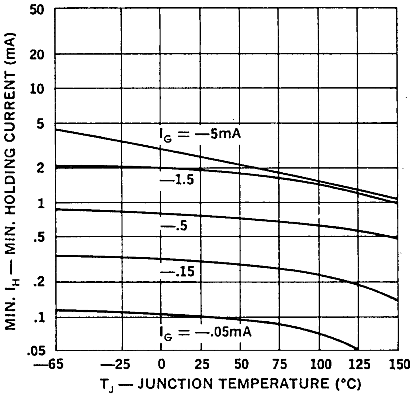
1. Max. Holding Current (Current Bias)



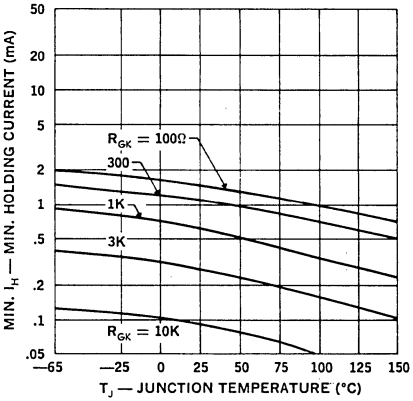
2. Max. Holding Current (Resistor Bias)



3. Min. Holding Current (Current Bias)

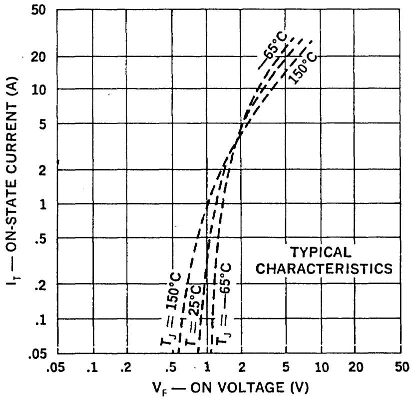


4. Min. Holding Current (Resistor Bias)

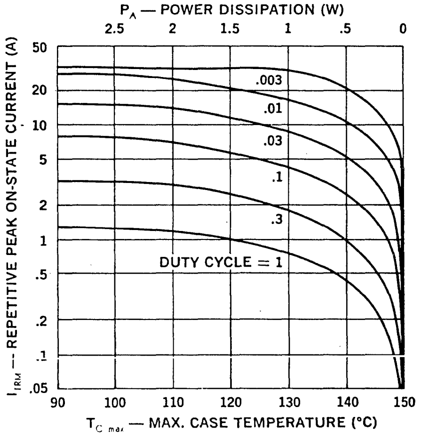


Current Ratings — Thermal Design

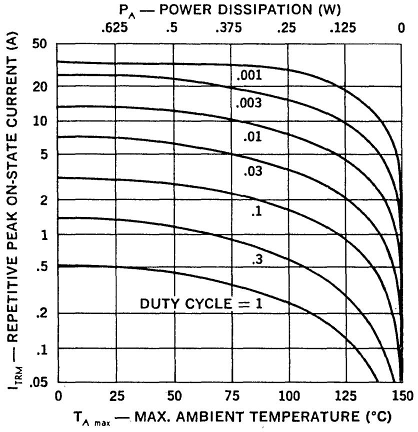
1. On-State Current vs. Voltage



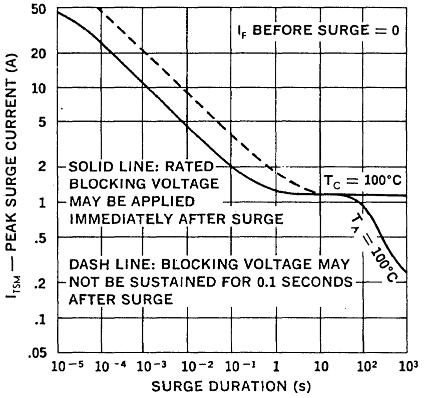
2. Peak Current vs. Case Temperature



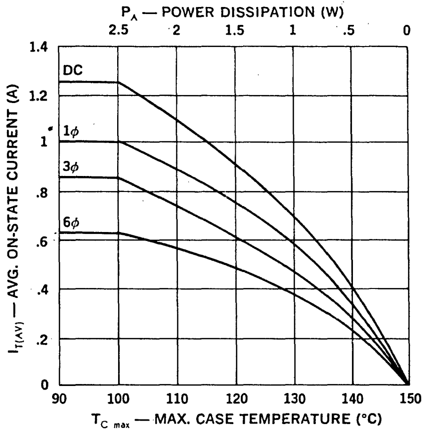
3. Peak Current vs. Ambient Temperature



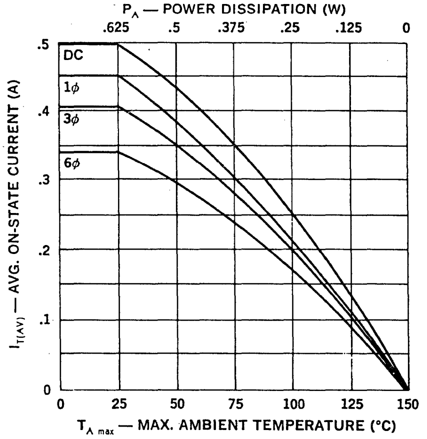
4. Surge Current vs. Time



5. Average Current vs. Case Temperature



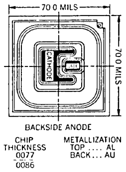
6. Average Current vs. Ambient Temperature



SCRs
1.6 Amp, Planar

2N2323-2N2329, J, JTX, JTXV
2N2323A-2N2328A, J, JTX, JTXV
2N2323S-2N2329S, J, JTX, JTXV
2N2323AS-2N2328AS, J, JTX, JTXV

FEATURES
- Available as JAN, JANTX, & JANTXV Types
- JAN Types Available in TO-5
- 1.6A D.C. Current
- Peak Currents: to 30A
- Voltage Ratings: to 400V
- 20μA Max. Trigger Current ("A" types)
- 0.6V Max. Trigger Voltage ("A" types)



DESCRIPTION
These are premium thyristor switches intended for use in high performance industrial, military and space applications requiring a high degree of reliability assurance. This series is useful in a wide variety of applications including timing and programming circuits, protective and warning circuits, driving relays, driving indicator lamps, encoding and decoding circuits, replacing relays, thyratrons, and magamps, servo motor control, pulse generation, plus many others. The high surge current rating (15A - 1 cycle) makes this series particularly useful for squib firing.

The following JAN, JANTX and JANTXV types are specified under Mil-S-19500/276A and are included in Mil-STD-701 as recommended types for military usage:

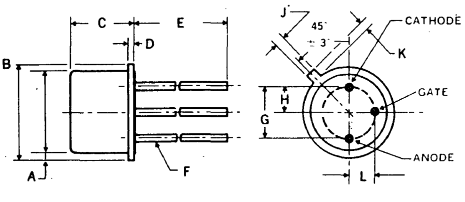
ABSOLUTE MAXIMUM RATINGS

	2N2323 JAN2N2323S JANTX2N2323S JANTXV2N2323S 2N2323A JAN2N2323AS JANTX2N2323AS JANTXV2N2323AS	2N2324 JAN2N2324S JANTX2N2324S JANTXV2N2324S 2N2324A JAN2N2324AS JANTX2N2324AS JANTXV2N2324AS	2N2325 2N2325A	2N2326 JAN2N2326S JANTX2N2326S JANTXV2N2326S 2N2326A JAN2N2326AS JANTX2N2326AS JANTXV2N2326AS	2N2327 2N2327A	2N2328 JAN2N2328S JANTX2N2328S JANTXV2N2328S 2N2328A JAN2N2328AS JANTX2N2328AS JANTXV2N2328AS	2N2329 JAN2N2329S JANTX2N2329S JANTXV2N2329S
Repetitive Peak Off-State Voltage, V_{DRM}	50V	100V	150V	200V	250V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	50V	100V	150V	200V	250V	300V	400V
Non-Repetitive Peak Reverse Voltage, V_{RSM} (< 5ms)	75V	150V	225V	300V	350V	400V	500V

D.C. On-State Current, I_T	
80°C Ambient	300mA
85°C Case	1.6A
One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	15A
Repetitive Peak On-State Current, I_{TM}	30A
Gate Power Dissipation, P_{GM}	0.1W
Gate Power Dissipation, $P_{GM(AV)}$	0.01W
Peak Gate Current, I_{GM}	100mA
Reverse Gate Voltage	6V
Reverse Gate Current, I_{GR}	3mA
Storage Temperature Range	—65°C to +150°C
Operating Temperature Range	—65°C to +125°C

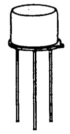
MECHANICAL SPECIFICATIONS

2N2323-2N2329, J, JTX, JTXV 2N2323S-2N2328S, J, JTX, JTXV
2N2323A-2N2328A, J, JTX, JTXV 2N2323AS-2N2328AS, J, JTX, JTXV



	INCHES	MILLIMETERS
A	.315-.335	8.00-8.51
B	.350-.370	8.89-9.39
C	.240-.260	6.35-6.60
D	.010-.030	0.25-0.76
E	.5 MIN	12.70 MIN
F	.016-.019	.406-.483
G	.190-.210	4.83-5.33
H	.085-.105	2.16-2.67
J	.028-.034	.711-.864
K	.029-.045	.737-1.14
L	.100	2.54

TO-205AD (TO-39)



ELECTRICAL SPECIFICATIONS

Test	Symbol	Min.	Typical	Max.	Units	Test Conditions
Visual and Mechanical						MIL-STD-750, Method 2071
25°C						
Off-State Current	I_{DRM}	—	0.1	10	μA	V_{DRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Reverse Current	I_{RRM}	—	0.1	10	μA	V_{RRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Gate Trigger Current	I_{GT}					
"A" Types		—	2	20	μA	V_D = 6V, R_L = 100Ω
non-"A" Types		—	50	200	μA	V_D = 6V, R_L = 100Ω
Gate Trigger Voltage	V_{GT}					
"A" Types		0.35	0.52	0.60	V	V_D = 6V, R_{GK} = 2K, R_L = 100Ω
non-"A" Types		0.35	0.55	0.80	V	V_D = 6V, R_{GK} = 1K, R_L = 100Ω
On-State Voltage	V_{TM}	—	2.0	2.2	V	I_{TM} = 4A (pulse test)
Holding Current	I_H	—	0.3	2.0	mA	V_D = 6V, R_{GK} = 1K (2K for "A" Types)
Reverse Gate Current	I_{GR}	—	1	200*	μA	V_{GR} = 6V
Delay Time	t_d	—	0.6	—	μs	I_G = 10mA, I_T = 1A, V_D = 30V
Rise Time	t_r	—	0.4	—	μs	I_G = 10mA, I_T = 1A, V_D = 30V
Circuit Commutated Turn-Off Time	t_q	—	20	—	μs	I_T = 1A, I_R = 1A, R_{GK} = 1K
125°C						
Off-State Current	I_{DRM}	—	1	100	μA	V_{DRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Reverse Current	I_{RRM}	—	1	100	μA	V_{RRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Gate Trigger Voltage	V_{GT}	0.1	0.3	—	V	V_D = Rated V_D, R_{GK} = 1K (2K for "A" Types)
Holding Current	I_H					
"A" Types		0.1†	—	—	mA	V_D = 6V, R_{GK} = 2K
non-"A" Types		0.15†	—	—	mA	V_D = 6V, R_{GK} = 1K
Off-State Voltage — Critical Rate of Rise	dv/dt					
"A" Types		0.7*			V/μs	V_D = Rating, R_{GK} = 2K
non-"A" Types		1.8*			V/μs	V_D = Rating, R_{GK} = 1K
−65°C						
Off-State Current	I_{DRM}	—	.05	5.0*	μA	V_{DRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Reverse Current	I_{RRM}	—	.05	5.0*	μA	V_{RRM} = Rating, R_{GK} = 1K (2K for "A" Types)
Gate Trigger Current	I_{GT}					
"A" Types		—	50	75	μA	V_D = 6V, R_L = 100Ω
non-"A" Types		—	100	350	μA	V_D = 6V, R_L = 100Ω
Gate Trigger Voltage	V_{GT}					
"A" Types		—	0.7	0.8*	V	V_D = 6V, R_{GK} = 2K, R_L = 100Ω
				0.9†	V	V_D = 6V, R_{GK} = 2K, R_L = 100Ω
non-"A" Types		—	0.75	1.0	V	V_D = 6V, R_{GK} = 1K, R_L = 100Ω
Holding Current	I_H	—	—	3.0†	mA	V_D = 6V, R_{GK} = 1K (2K for "A" Types)

* JAN and JANTX Types only.
† Industrial Types only.

JAN and JANTX Acceptance Tests

100% Screening TX-Types

High Temperature Storage
Temperature Cycling
Constant Acceleration
Fine & Gross Hermetic Seal
Electrical Test
Burn-in
Electrical Test

Group B Tests

Subgroup 1 — Reverse Gate Current
Surge Current
Non-Repetitive Reverse Voltage

Subgroup 2 — Low Temp. Reverse Blocking Current
Low Temp. Forward Blocking Current
Low Temp. Gate Trigger Voltage
Low Temp. Gate Trigger Current

Subgroup 3 — Temperature Cycling
Thermal Shock
Moisture Resistance
Solderability

Subgroup 4 — Blocking Life Test

Group C Tests

Subgroup 1 — Physical Dimensions

Subgroup 2 — Shock
Constant Acceleration
Vibration, Variable Frequency

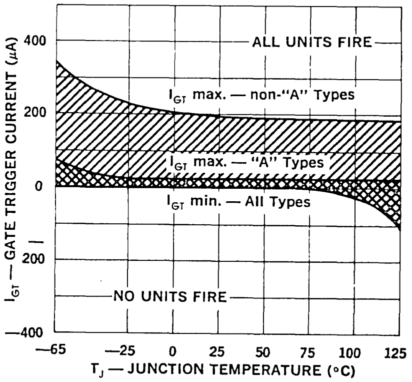
Subgroup 3 — Barometric Pressure, Reduced

Subgroup 4 — Salt Atmosphere

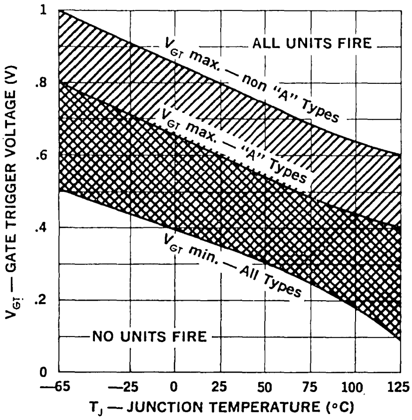
Subgroup 5 — Terminal Strength

Subgroup 6 — Intermittent Operating Life Test

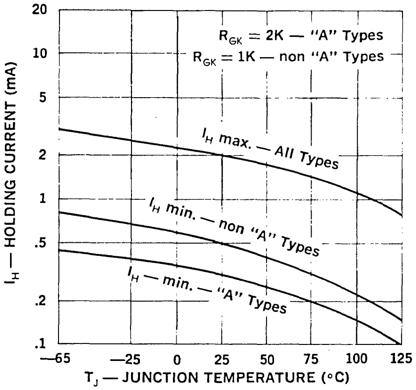
Gate Trigger Current



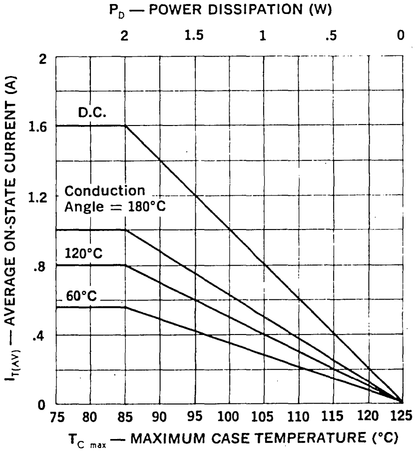
Gate Trigger Voltage



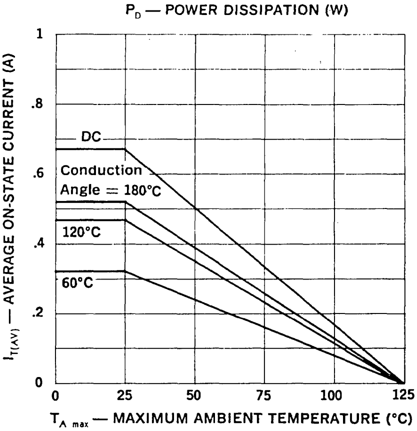
Holding Current



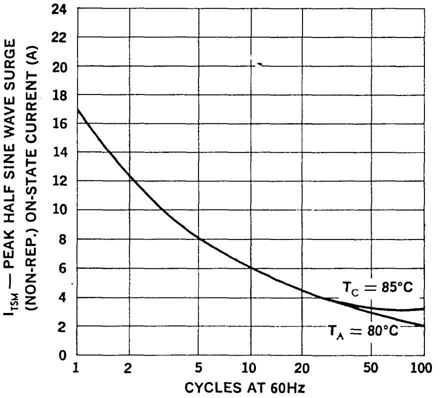
Average Current vs. Case Temperature



Average Current vs. Ambient Temperature



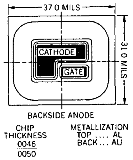
Surge Current



SCRs

0.5 Amp, Planar

JAN & JANTX 2N3027-2N3032



FEATURES

- JAN and JANTX Types Available
- Fully Characterized for "Worst Case" Design
- Passivated Planar Construction for Maximum Reliability and Parameter Uniformity
- Low On-State Voltage and Fast Switching at High Current Levels
- Typical Turn-On Time: 0.12μs
- Typical Recovery Time: 0.7μs
- Pulse Currents: to 30A

DESCRIPTION

The 2N3027 series of planar SCRs (controlled switches) are intended for use in military and space applications requiring a high degree of reliability. They offer a unique combination of extremely fast switching, precise triggering, high pulse power, small size, intrinsic parameter stability, and high radiation tolerance.

The JAN and JANTX types are specified under MIL-S-19500/419, and are included in MIL-STD-701 as recommended types for military usage.

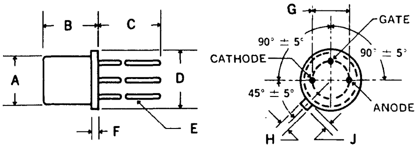
ABSOLUTE MAXIMUM RATINGS

	JAN & JANTX 2N3027 JAN & JANTX 2N3030	JAN & JANTX 2N3028 JAN & JANTX 2N3031	JAN & JANTX 2N3029 JAN & JANTX 2N3032
Repetitive Peak Off-State Voltage, V_{DRM}	30V	60V	100V
Repetitive Peak Reverse Voltage, V_{RRM}	30V	60V	100V
D.C. On-State Current, I_T			
100°C Case	500mA		
75°C Ambient	250mA		
Repetitive Peak On-State Current, I_{TRM}	30A		
Surge (Non-Rep.) On-State Current, I_{TSM}			
50ms	5A		
8ms	8A		
Peak Gate Current, I_{GM}	250mA		
Average Gate Current, $I_{G(AV)}$	25mA		
Reverse Gate Voltage	5V		
Reverse Gate Current	3mA		
Storage Temperature Range	−65°C to +200°C		
Operating Temperature Range	−65°C to +150°C		

Note: Blocking voltage ratings apply over the operating temperature range, provided the gate is connected to the cathode through an appropriate resistor, or adequate gate bias is used. (See section on bias stabilization.)

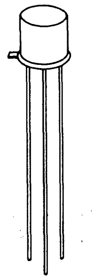
MECHANICAL SPECIFICATIONS

JAN & JANTX 2N3027-2N3032



	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	.017 ± .002 DIA. .001 DIA.	.432 ± .051 .025
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted) 2N3027 — 2N3028 — 2N3029

Parameter	Symbol	Min.	Typical	Max.	Units	Test Conditions
SUBGROUP 1						MIL-STD-750
Visual and Mechanical	—	—	—	—	—	Method 2071
SUBGROUP 2 (25°C Tests)						
Off-State Current	I_{DRM}	—	.002	0.1	µA	R_{GK} = 1K, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	.002	0.1	µA	R_{GK} = 1K, V_{RRM} = Rating
Reverse Gate Voltage	V_{GR}	5	8	—	V	I_{GR} = 0.1mA
Gate Trigger Current	I_{GT}	−5	8	200	µA	R_{GS} = 10K, V_D = 5V
Gate Trigger Voltage	V_{GT}	.40	.55	.80	V	R_{GS} = 100Ω, V_D = 5V
On-State Voltage	V_T	0.8	1.2	1.5	V	I_T = 1A (pulse test)
Holding Current	I_H	0.3	0.7	5.0	mA	R_{GK} = 1K, V_D = 5V
SUBGROUP 3 (25°C Tests)						
		30	60	—		R_{GK} = 1K, V_D = 30V (2N3027)
Off-State Voltage — Critical Rate of Rise	dv_c/dt	15	30	—	V/µs	R_{GK} = 1K, V_D = 60V (2N3028)
		10	25	—		R_{GK} = 1K, V_D = 100V (2N3029)
Gate Trigger-on Pulse Width	$t_{pg\,(on)}$	—	.07	0.2	µs	I_G = 10mA, I_T = 1A, V_{DM} = 30V
Delay Time	t_d	—	.08	—	µs	I_G = 10mA, I_T = 1A, V_D = 30V
Rise Time	t_r	—	.04	—	µs	I_G = 10mA, I_T = 1A, V_D = 30V
Circuit Commutated Turn-off Time	t_g	—	0.7	2.0	µs	I_T = 1A, I_R = 1A, R_{GK} = 1K
SUBGROUP 4 (150°C Tests)						
High Temp. Off-State Current	I_{DRM}	—	2	20	µA	R_{GK} = 1K, V_{DRM} = Rating
High Temp. Reverse Current	I_{RRM}	—	20	50	µA	R_{GK} = 1K, V_{RRM} = Rating
High Temp. Gate Trigger Voltage	V_{GT}	.10	.15	0.6	V	R_{GS} = 100Ω, V_D = 5V
High Temp. Holding Current	I_H	.05	.20	1.0	mA	R_{GK} = 1K, V_D = 5V
SUBGROUP 5 (−65°C Tests)						
Low Temp. Gate Trigger Voltage	V_{GT}	0.6	0.75	1.1	V	R_{GS} = 100Ω, V_D = 5V
Low Temp. Gate Trigger Current	I_{GT}	0	150	1.2	mA	R_{GS} = 10K, V_D = 5V
Low Temp. Holding Current	I_H	0.5	3.5	10	mA	R_{GK} = 1K, V_D = 5V

ELECTRICAL SPECIFICATIONS (at 25°C unless noted) 2N3030 — 2N3031 — 2N3032

Parameter	Symbol	Min.	Typical	Max.	Units	Test Conditions
SUBGROUP 1						MIL-STD-750
Visual and Mechanical	—	—	—	—	—	Method 2071
SUBGROUP 2 (25°C Tests)						
Off-State Current	I_{DRM}	—	.002	0.1	µA	R_{GK} = 1K, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	.002	0.1	µA	R_{GK} = 1K, V_{RRM} = Rating
Reverse Gate Voltage	V_{GR}	5	8	—	V	I_{GR} = 0.1mA
Gate Trigger Current	I_{GT}	−5		20	µA	R_{GS} = 10K, V_D = 5V
Gate Trigger Voltage	V_{GT}	0.44		0.6	V	R_{GS} = 100Ω, V_D = 5V
On-State Voltage	V_T	0.8	1.2	1.5	V	I_T = 1A (pulse test)
Holding Current	I_H	0.3	1.0	4.0	mA	R_{GK} = 1K, V_D = 5V
SUBGROUP 3 (25°C Tests)						
		30	60	—		R_{GK} = 1K, V_D = 30V (2N3030)
Off-State Voltage — Critical Rate of Rise	dv_c/dt	15	30	—	V/µs	R_{GK} = 1K, V_D = 60V (2N3031)
		10	25	—		R_{GK} = 1K, V_D = 100V (2N3032)
Gate Trigger-on Pulse Width	$t_{pg\,(on)}$	—	.05	0.1	µs	I_G = 10mA, I_T = 1A, V_D = 30V
Delay Time	t_d	—	0.1	—	µs	I_G = 10mA, I_T = 1A, V_D = 30V
Rise Time	t_r	—	.05	—	µs	I_G = 10mA, I_T = 1A, V_D = 30V
Circuit Commutated Turn-off Time	t_g	—	0.7	2.0	µs	I_T = 1A, I_R = 1A, R_{GK} = 1K
SUBGROUP 4 (150°C Tests)						
High Temp. Off-State Current	I_{DRM}	—	2	20	µA	R_{GK} = 1K, V_{DRM} = Rating
High Temp. Reverse Current	I_{RRM}	—	20	50	µA	R_{GK} = 1K, V_{RRM} = Rating
High Temp. Gate Trigger Voltage	V_{GT}	.10	.15	0.4	V	R_{GS} = 100Ω, V_D = 5V
High Temp. Holding Current	I_H	.05	.30	2.0	mA	R_{GK} = 1K, V_D = 5V
SUBGROUP 5 (−65°C Tests)						
Low Temp. Gate Trigger Voltage	V_{GT}	0.44	0.8	0.95	V	R_{GS} = 100Ω, V_D = 5V
Low Temp. Gate Trigger Current	I_{GT}	0	0.4	0.5	mA	R_{GS} = 10K, V_D = 5V
Low Temp. Holding Current	I_H	0.5	5.0	8	mA	R_{GK} = 1K, V_D = 5V

High Reliability Processing

The 2N3027-2N3032 series provides a complete range of high reliability processing from the standard devices that undergo extensive electrical testing, through JAN and JANTX levels. 100% processing, Group B, and Group C tests for JAN and JANTX devices is shown below. For further details, see MIL-S-19500/419(EL).

100% Screening TX-Types

High Temperature Storage
Temperature Cycling
Constant Acceleration
Fine & Gross Hermetic Seal
Electrical Test
Burn-in
Electrical Test

Group B Tests

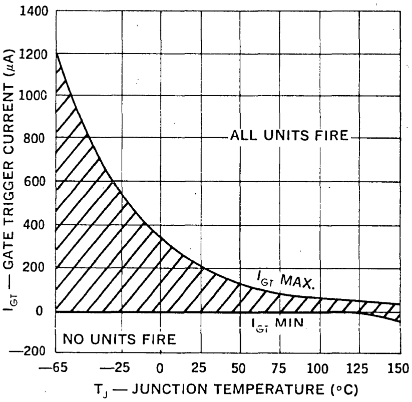
Subgroup 1 — Physical Dimensions
Subgroup 2 — Solderability
Temperature Cycling
Thermal Shock
Constant Acceleration
Moisture Resistance
Subgroup 3 — Surge Current
Subgroup 4 — Blocking Life Test
Subgroup 5 — Storage Life Test
Subgroup 6 — Operating Life Test

Group C Tests

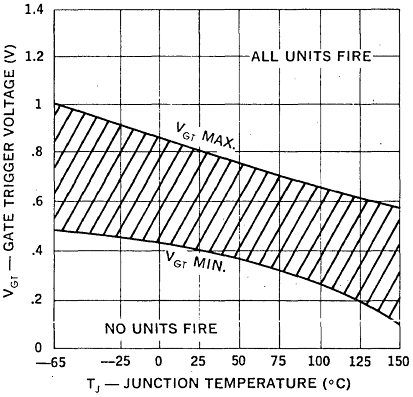
Subgroup 1 — Shock
Vibration, Variable Frequency
Subgroup 2 — Salt Atmosphere
Subgroup 3 — Terminal Strength
Subgroup 4 — High Temp. Anode Voltage — Critical rate or rise
Subgroup 5 — Storage Life Test
Subgroup 6 — Operating Life Test

TYPICAL CHARACTERISTICS
2N3027 — 2N3028 — 2N3029

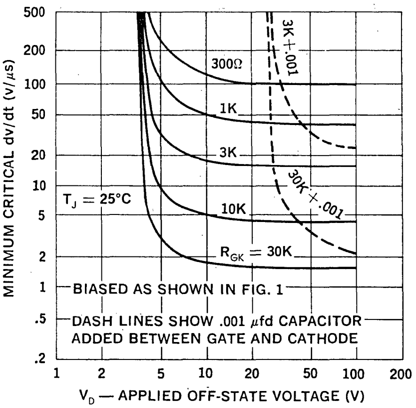
1 Gate Trigger Current



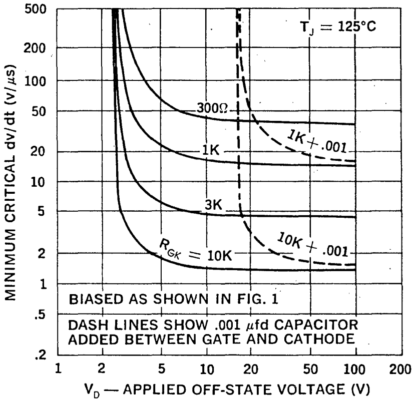
2 Gate Trigger Voltage



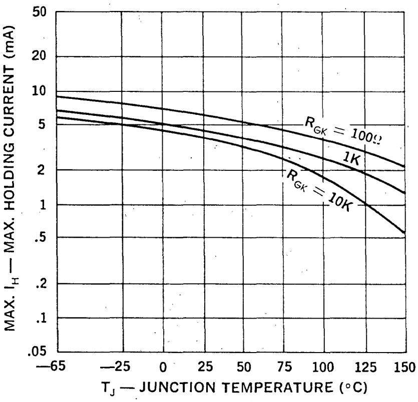
3 Min. Critical dv/dt (25°C — R Bias)



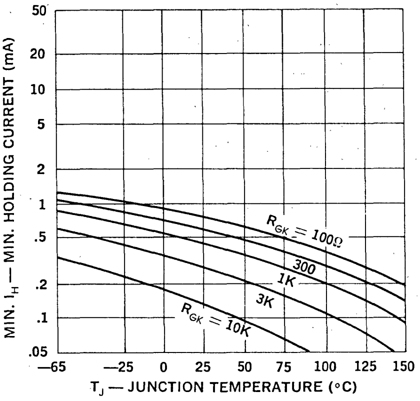
4 Min. Critical dv/dt (125°C — R Bias)



5 Max. Holding Current (Resistor Bias)

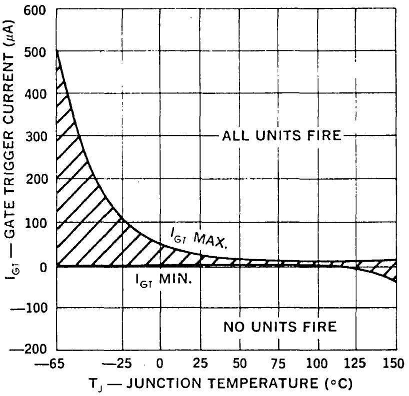


6 Min. Holding Current (Resistor Bias)

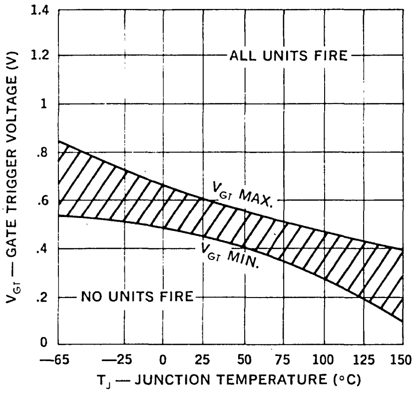


TYPICAL CHARACTERISTICS
2N3030 — 2N3031 — 2N3032

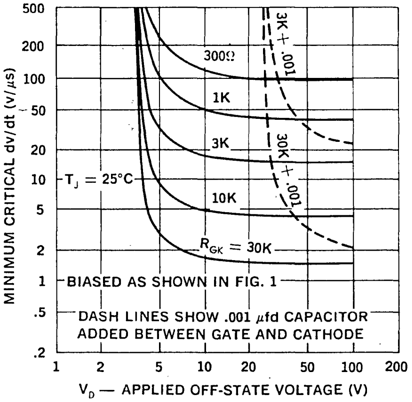
1 Gate Trigger Current



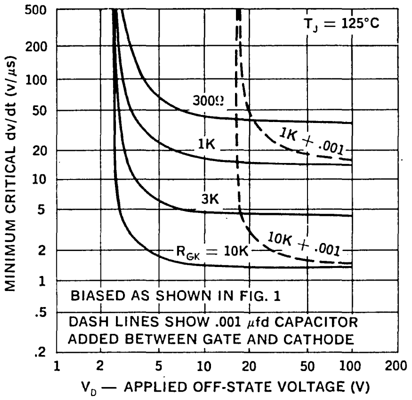
2 Gate Trigger Voltage



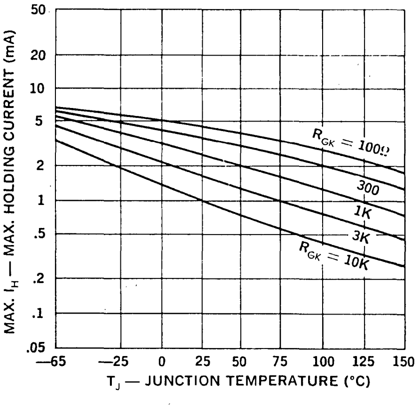
3 Min. Critical dv/dt (25°C — R Bias)



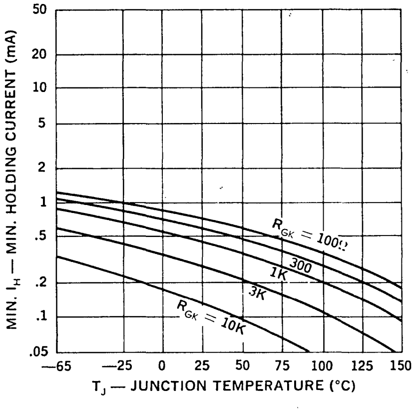
4 Min. Critical dv/dt (125°C — R Bias)



5 Max. Holding Current (Resistor Bias)

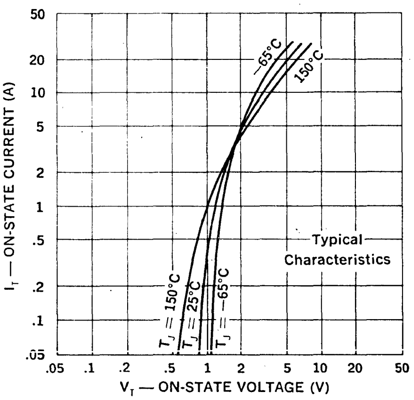


6 Min. Holding Current (Resistor Bias)

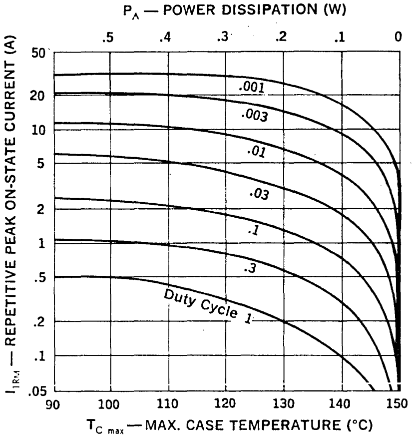


CURRENT RATINGS

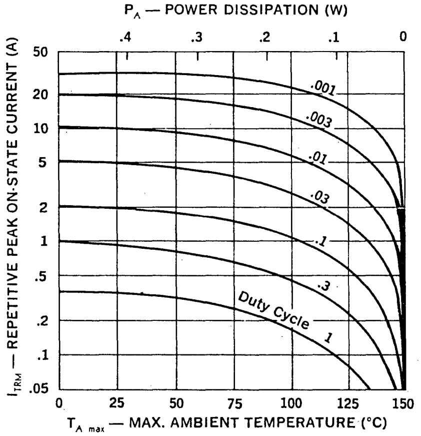
C1 Forward on Current vs. Voltage



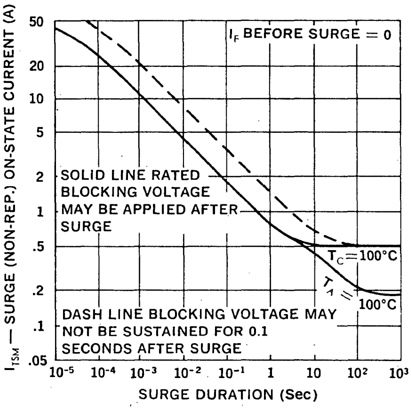
C2 Peak Current vs. Case Temperature



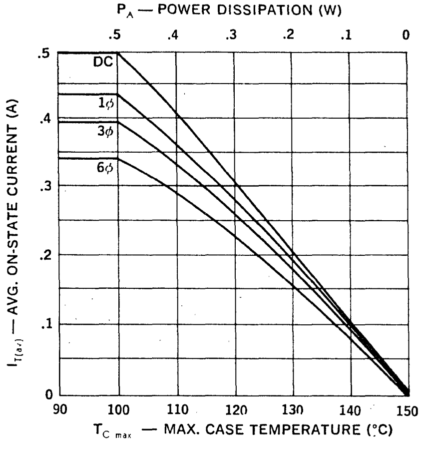
C3 Peak Current vs. Ambient Temperature
TO-18 Ratings (see note)



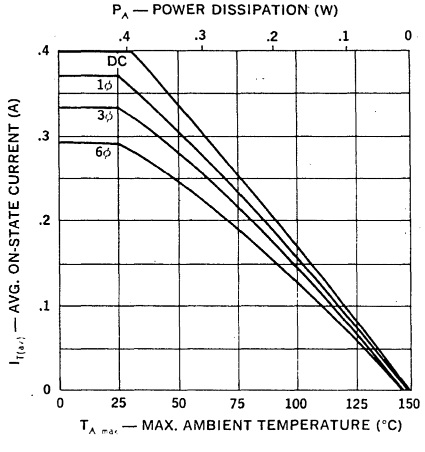
C4 Surge Current vs. Time



C5 Average Current vs. Case Temperature

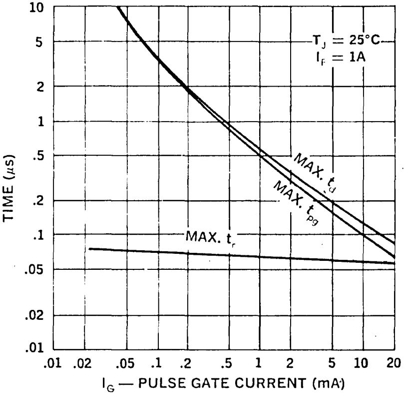


C6 Average Current vs. Ambient Temperature
TO-18 Ratings (see note)

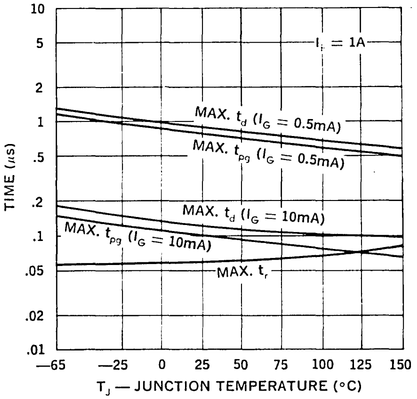


SWITCHING SPEEDS

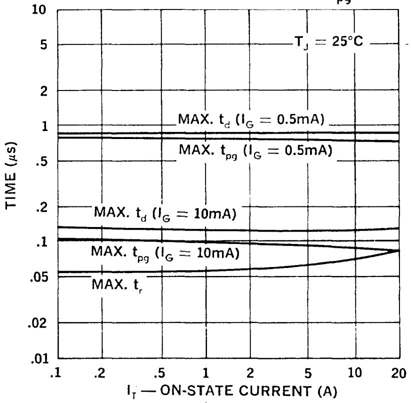
S1 Maximum Delay Time t_d, Rise Time t_r, and Gate Trigger Pulse Width t_{pg} (on)



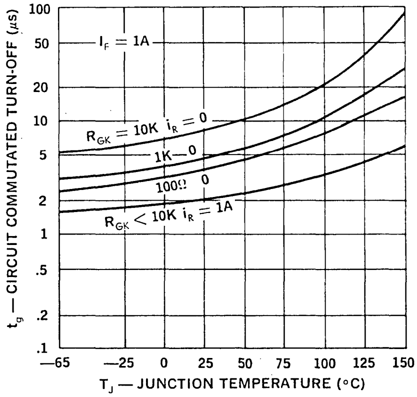
S2 Maximum Delay Time t_d, Rise Time t_r, and Gate Trigger Pulse Width t_{pg} (on)



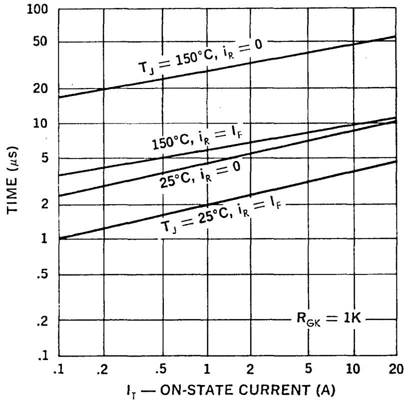
S3 Maximum Delay Time t_d, Rise Time t_r, and Gate Trigger Pulse Width t_{pg} (on)



S4 Maximum Circuit Commutated Turn-off Time t_q



S5 Maximum Circuit Commutated Turn-off Time t_q



SCRs

1.6 Amp, Planar

2N5724-2N5728

FEATURES

- Maximum Gate Trigger Current: 20μA
- Closely Controlled Gate Trigger Voltage: .44 to .6V
- Operating Current Range: 2mA to 1.6A
- Voltage Ratings: to 400V
- Low On-State Voltage
- Specified for dv/dt and Switching Time

DESCRIPTION

These devices are intended for general purpose usage in Military/aerospace or severe industrial environments. Major design parameters are specified at the temperature extremes, thus permitting worst case design on the basis of guaranteed values. These devices undergo 100% preconditioning, which includes high temperature storage and temperature cycling followed by a fine leak test as a regular part of the manufacturing procedure.

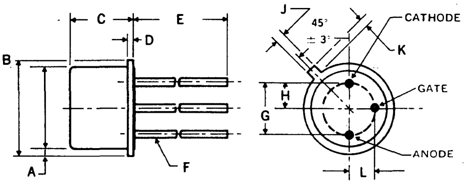
The high voltage types of the 2N5724 series are especially useful as pulse modulator switches in low to medium power pulse modulator applications. Specific parameters such as rise time, delay time, holding current, and recovery time can be selected for optimum performance in a pulse modulator circuit.

ABSOLUTE MAXIMUM RATINGS

	2N5724	2N5725	2N5726	2N5727	2N5728
Repetitive Peak Off-State Voltage, V_{DRM}	60V	100V	200V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	60V	100V	200V	300V	400V
Non-Repetitive Peak Off-State Voltage, V_{DSM}	500V				
D.C. On-State Current, I_T					
75°C Ambient	450mA				
85°C Case	1.6A				
Repetitive Peak On-State Current, I_{TRM}	up to 30A				
Peak One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	15A				
Peak Gate Current, I_{GM}	250mA				
Average Gate Current, $I_{G(AV)}$	25mA				
Reverse Gate Current, I_{GR}	3mA				
Reverse Gate Voltage, V_{GR}	6V				
Operating and Storage Temperature Range	–65°C to +150°C				

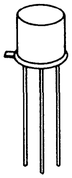
MECHANICAL SPECIFICATIONS

2N5724-2N5728



	ins.	mm.
A	.305-.335	7.75-8.51
B	.335-.370	8.51-9.40
C	.240-.260	6.35-6.60
D	.010-.030	.25-.76
E	.5 MIN.	12.70 MIN.
F	$.017 \pm {.002 \atop .001}$	$.432 \pm {.051 \atop .025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.79±.08
K	.029-.045	.74-1.14
L	.100	2.54

TO-205AD (TO-39)



SEMICONDUCTOR PRODUCTS
UNITRODE

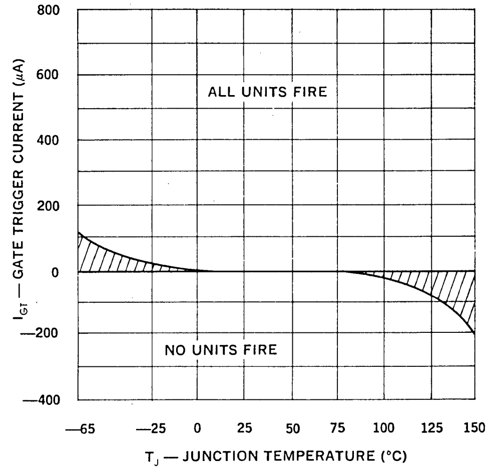
ELECTRICAL SPECIFICATIONS

Test	Symbol	Min.	Typical	Max.	Units	Test Conditions
SUBGROUP 1						
Visual and Mechanical	—	—	—	—	—	
SUBGROUP 2 (25°C TESTS)						
Off-State Current	I_{DRM}	—	.05	0.1	μA	$R_{GK} = 1K$, $V_{DRM} =$ Rating
Reverse Current	I_{RRM}	—	.05	0.1	μA	$R_{GK} = 1K$, $V_{RRM} =$ Rating
Reverse Gate Voltage	V_{GR}	5	8	—	V	$I_{GR} = 0.1mA$
Gate Trigger Current	I_{GT}	—	2	20	μA	$R_{GS} = 10K$, $V_D = 5V$
Gate Trigger Voltage	V_{GT}	0.44	0.5	0.6	V	$R_{GS} = 100\Omega$, $V_D = 5V$
On-State Voltage	V_T	—	2.3	2.5	V	$I_T = 5A$ (pulse test)
Holding Current	I_H	0.3	0.8	2.0	mA	$R_{GK} = 1K$, $V_D = 5V$
SUBGROUP 3 (25°C TESTS)						
Off-State Voltage — Critical Rate of Rise	dv/dt	100	150	—	v/μs	$R_{GK} = 1K$, $V_D = 30V$
Gate Trigger — on Pulse Width	t_{pg} (on)	—	0.1	0.5	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Delay Time	t_d	—	0.1	—	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Rise Time	t_r	—	0.3	—	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Circuit Commutated Turn-off Time						
2N5724, 2N5725, 2N5726,	t_q	—	15	30	μs	$I_T = 1A$, $i_R = 1A$, $R_{GK} = 1K$
2N5727, 2N5728		—	30	50	μs	
SUBGROUP 4 (150°C TESTS)						
High Temp. Off-State Current	I_{DRM}	—	50	200	μA	$R_{GK} = 1K$, $V_{DRM} =$ Rating
High Temp. Reverse Current	I_{RRM}	—	80	200	μA	$R_{GK} = 1K$, $V_{RRM} =$ Rating
High Temp. Gate Trigger Voltage	V_{GT}	0.10	0.15	—	V	$R_{GS} = 100\Omega$, $V_D = 5V$
High Temp. Holding Current	I_H	0.10	0.15	—	mA	$R_{GK} = 1K$, $V_D = 5V$
SUBGROUP 5 (—65°C TESTS)						
Low Temp. Gate Trigger Voltage	V_{GT}	—	0.7	0.9	V	$R_{GS} = 100\Omega$, $V_D = 5V$
Low Temp. Gate Trigger Current	I_{GT}	—	50	125	μA	$R_{GS} = 10K$, $V_D = 5V$
Low Temp. Holding Current	I_H	—	1.2	3.0	mA	$R_{GK} = 1K$, $V_D = 5V$

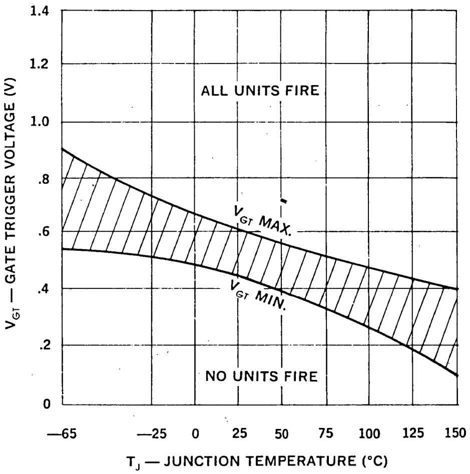
Note 1 See rating curves for full rating information.

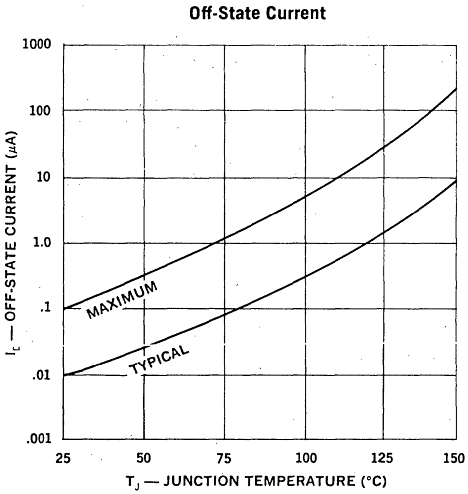
Note 2 Blocking voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1K or smaller, or other adequate gate bias is used.

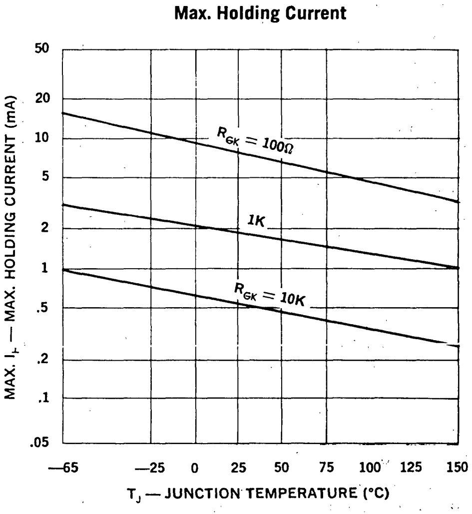
Gate Trigger Current

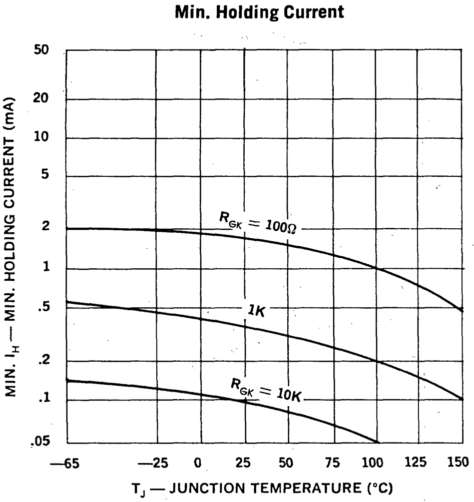


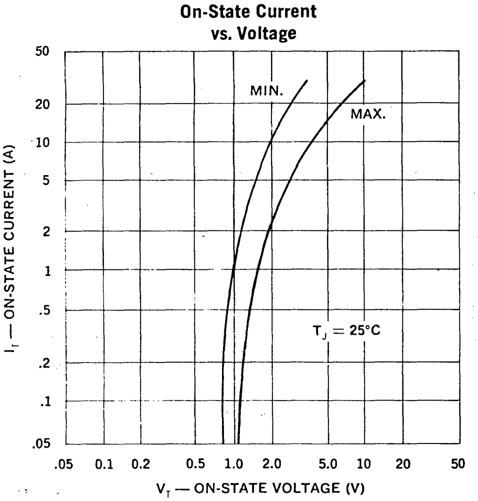
Gate Trigger Voltage



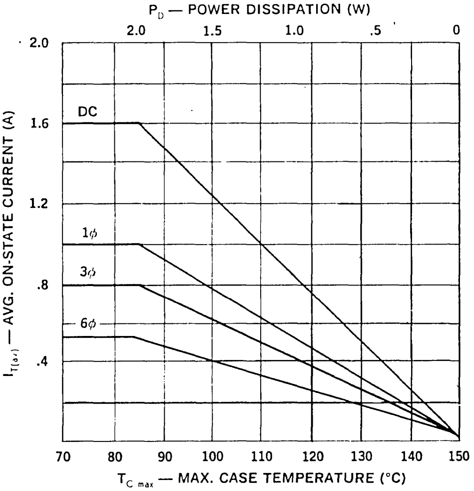

Off-State Current
1000
100
10
1.0
.1
.01
.001
25
50
75
100
125
150
MAXIMUM
TYPICAL
I_C — OFF-STATE CURRENT (μA)
T_J — JUNCTION TEMPERATURE (°C)


Max. Holding Current
50
20
10
5
2
1
.5
.2
.1
.05
—65
—25
0
25
50
75
100
125
150
R_GK = 100Ω
1K
R_GK = 10K
MAX. I_H — MAX. HOLDING CURRENT (mA)
T_J — JUNCTION TEMPERATURE (°C)

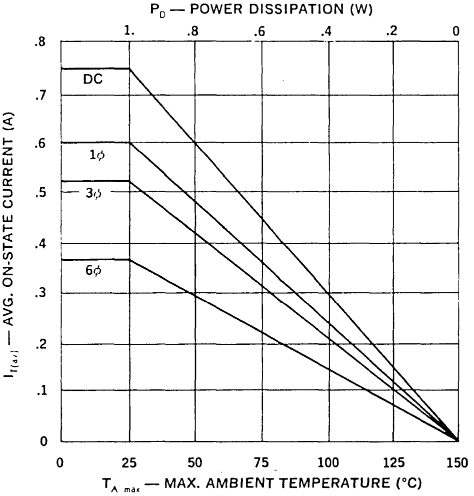

Min. Holding Current
50
20
10
5
2
1
.5
.2
.1
.05
—65
—25
0
25
50
75
100
125
150
R_GK = 100Ω
1K
R_GK = 10K
MIN. I_H — MIN. HOLDING CURRENT (mA)
T_J — JUNCTION TEMPERATURE (°C)


On-State Current vs. Voltage
50
20
10
5
2
1
.5
.2
.1
.05
.05
0.1
0.2
0.5
1.0
2.0
5.0
10
20
50
MIN.
MAX.
T_J = 25°C
I_T — ON-STATE CURRENT (A)
V_T — ON-STATE VOLTAGE (V)

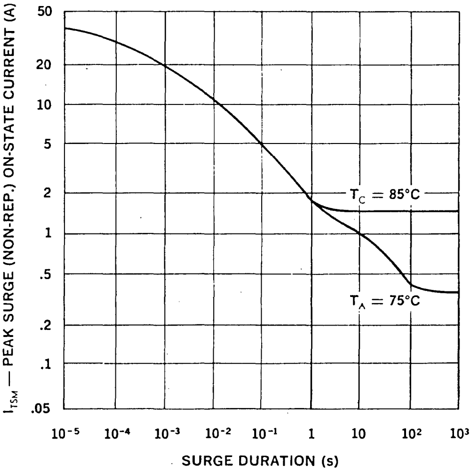
Avg. Current vs. Case Temperature



Avg. Current vs. Ambient Temperature



Surge Current



PUTs

Planar, TO-18, Hermetic

2N6119-2N6120

FEATURES

- Hermetically Sealed TO-18 Metal Can
- Programmable Eta, R_{BB}, I_P and I_V
- Maximum Peak Point Current: 150nA
- Minimum Valley Current to 1.5mA
- Nano-Amp Leakage
- Passivated Planar Construction for Maximum Reliability and Parameter Uniformity

DESCRIPTION

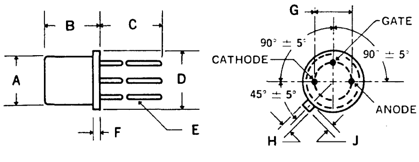
Functionally equivalent to standard unijunction transistors, Unitrode's Programmable Unijunction Transistors offer the distinct advantage of versatile programming. External resistors can be added to meet the designer's needs in programming Eta, R_{BB}, I_P and I_V functions. This series also features a hermetically sealed TO-18 package for optimum reliability in all environmental conditions. Applications include pulse and timing circuits, SCR trigger circuits, relaxation oscillators and sensing circuits. For additional information see Unitrode Application Note U-66.

ABSOLUTE MAXIMUM RATINGS

Anode-to-Cathode Voltage, V_{AK}	±40V
Gate-to-Cathode Forward Voltage, V_{GK}	40V
Gate-to-Anode Reverse Voltage, V_{GAR}	40V
Gate-to-Cathode Reverse Voltage, V_{GKR}	—5V
Peak Recurrent Forward Current	
10μs, 1% Duty Cycle	8A
100μs, 1% Duty Cycle	5A
Power Dissipation	
25°C Ambient	400mW
Derating Factor	3.2mW/°C
Storage Temperature	—55°C to +125°C
Operating Temperature Range	—55°C to +125°C

MECHANICAL SPECIFICATIONS

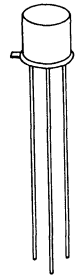
2N6119-2N6120



GATE CONNECTED TO CASE

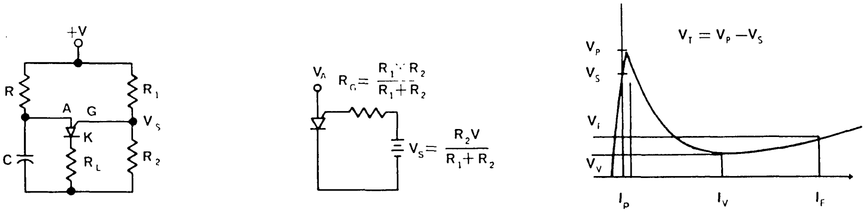
	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	$.017 \pm ^{.002\ \mathrm{DIA.}}_{.001\ \mathrm{DIA.}}$	$.432 \pm ^{.051}_{.025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	Fig.	2N6119		2N6120		Units	Test Conditions
			Min.	Max.	Min.	Max.		
Peak Current	I_P	1	— —	5 2	— —	1.0 0.15	μA μA	$R_G = 10k, V_S = 10V$ $R_G = 1$ Meg.
Valley Current	I_V	1	70 — 1.5	— 50 —	25 — 1.0	— 25 —	μA μA mA	$R_G = 10k, V_S = 10V$ $R_G = 1$ Meg. $R_G = 200\Omega$
Offset Voltage	V_T	1	0.2 0.2	0.6 1.6	0.2 0.2	0.6 0.6	V V	$R_G = 10k, V_S = 10V$ $R_G = 1$ Meg.
Gate-to-Anode Leakage	I_{GAO}	2	— —	10 100	— —	10 100	nA nA	$T = 25°C, V_S = 40V$ $T = 75°C$
Gate-to-Cathode Leakage	I_{GKS}	3	—	100	—	100	nA	$V_S = 40V$
Forward Voltage	V_F	4	—	1.0	—	1.0	V	$I_F = 50mA$
Pulse Output Voltage	V_o	5	9	—	9	—	V	
Pulse Output Rate of Rise	t_r	5	—	80	—	80	ns	



a) Typical Circuit b) Equivalent Test Circuit c) Characteristic Curves

Figure 1

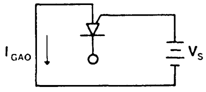


Figure 2

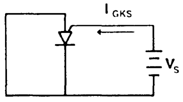


Figure 3

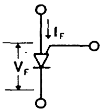


Figure 4

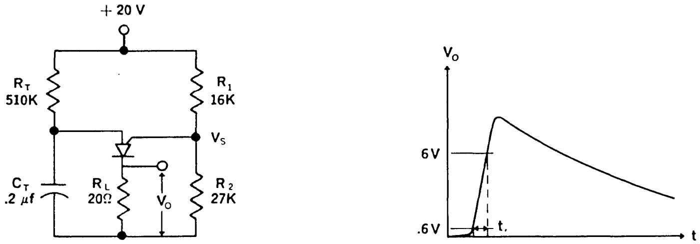
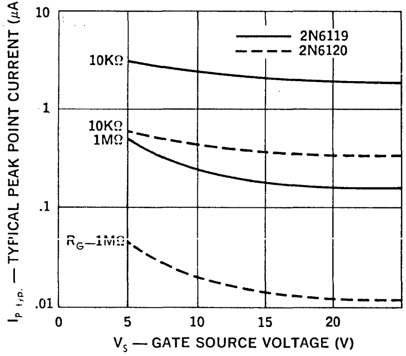
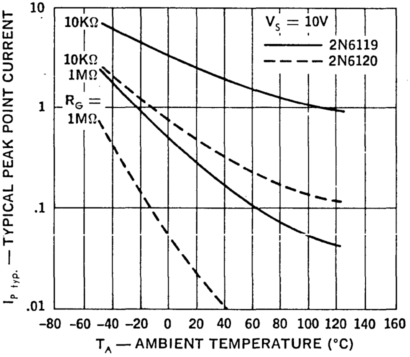


Figure 5

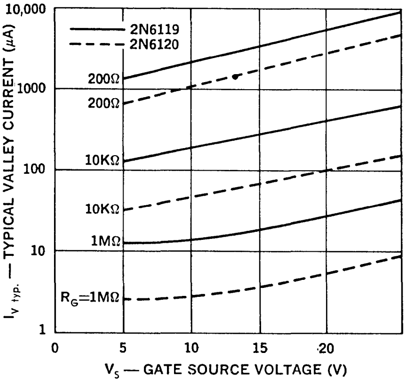
Typical Peak Point Current vs. Gate Source Voltage



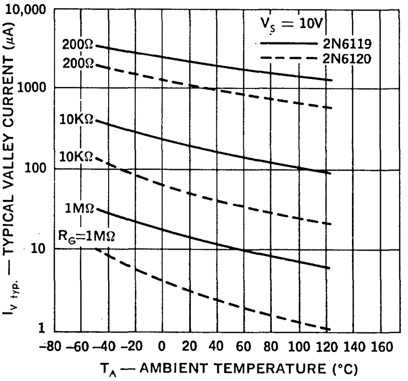
Typical Peak Point Current vs. Ambient Temperature



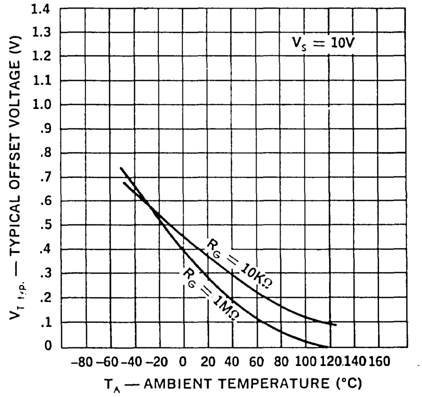
Typical Valley Current vs. Gate Source Voltage



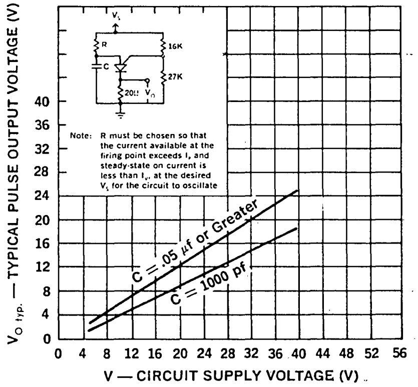
Typical Valley Current vs. Ambient Temperature



Typical Offset Voltage vs. Ambient Temperature

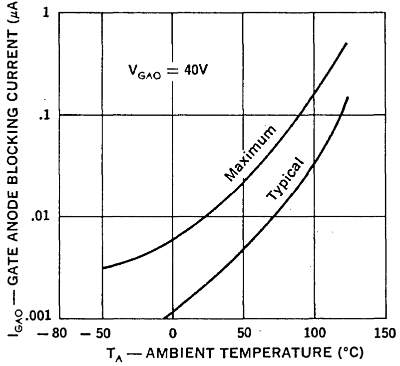


Typical Pulse Output vs. Circuit Supply Voltage

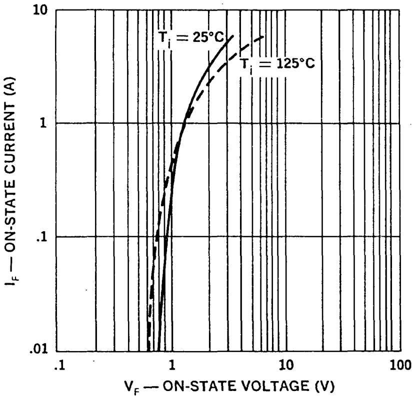


Note: R must be chosen so that the current available at the firing point exceeds I_P and steady-state on current is less than I_V, at the desired V_S for the circuit to oscillate

Gate-Anode Blocking Current vs. Ambient Temperature



Typical On-State Current vs. Voltage



PUTs

2N6137

Military, Planar, TO-18, Hermetic

FEATURES

- Available as JAN and JANTX types per MIL standard 19500/493
- $-55°C$ to $+125°C$ Temperature Range for Timing and Oscillator Circuits
- $I_P \leqslant 10\mu A$ at $T = -55°C$
  $I_V \geqslant 40\mu A$ at $T = +125°C$
- Programmable η, R_{BB}, I_P and I_V
- Peak Recurrent Current: of 5A
- Low On-State Voltage Drop
- Hermetically Sealed Metal Case and Planar Passivated Construction for Maximum Reliability and Parameter Stability.

DESCRIPTION

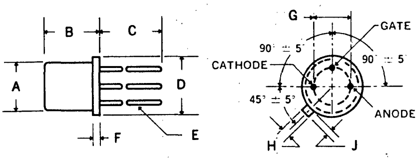
The Programmable Unijunction Transistor is functionally equivalent to a standard unijunction transistor with the advantage that external resistors can be used to program η, R_{BB}, I_P, and I_V, depending upon the designer's needs. The Unitrode device, in addition to allowing programmable versatility, is completely planar passivated and packaged in a TO-18 hermetically sealed package, which offers an order of magnitude improvement in inherent reliability over many similar devices. Applications include pulse and timing circuits, SCR trigger circuits, relaxation oscillators, and sensing circuits. For further application information see Unitrode Application Note U-66.

ABSOLUTE MAXIMUM RATINGS

Anode-to-Cathode Forward Voltage, V_{AK}	40V
Anode-to-Cathode Reverse Voltage, V_{AKR}	40V
Gate-to-Cathode Forward Voltage, V_{GK}	40V
Gate-to-Anode Reverse Voltage, V_{GAR}	40V
Gate-to-Cathode Reverse Voltage, V_{GKR}	5V
Peak Recurrent Forward Current, 10μs 1% Duty Cycle	5A
Peak Gate Current, I_{GM}	250mA
Average Gate Current, $I_{G(AV)}$	50mA
Power Dissipation	
25°C Ambient	300mW
Derating Factor	2.4mW/°C
Storage Temperature Range	$-55°C$ to $+125°C$
Operating Temperature Range	$-55°C$ to $+125°C$

MECHANICAL SPECIFICATIONS

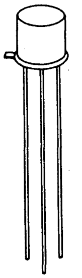
2N6137



GATE CONNECTED TO CASE

	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	$.017 \pm {}^{.002\text{ DIA.}}_{.001\text{ DIA.}}$	$.432 \pm {}^{.051}_{.025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18

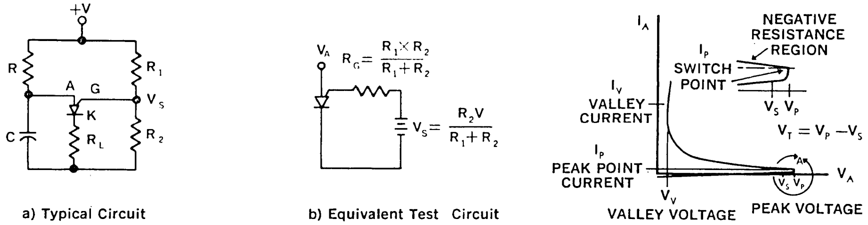


SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)†

Test	Symbol	Figure	Minimum	Typical	Maximum	Units	Test Conditions
SUBGROUP 1 Visual and Mechanical	—	—	—	—	—	—	—
SUBGROUP 2							
Gate-anode blocking current	I_{GAO}	2	—	2	10	nA	V_{GA} = Rating
Gate-cathode blocking current	I_{GKS}	3	—	5	100	nA	V_{GK} = Rating
SUBGROUP 3							
Peak-point anode current	I_P	1	— —	1 2.5	2 5	μA μA	R_G = 1 Meg R_G = 10K } V_s = 10V
Peak-point offset voltage	V_T	1	0.2 0.2	0.26 0.35	1.6 0.6	V V	R_G = 1 Meg R_G = 10K } V_s = 10V
Valley-point anode current	I_V	1	— 70 1.5	15 200 2	50 — —	μA μA mA	R_G = 1 Meg R_G = 10K } V_s = 10V R_G = 200Ω
SUBGROUP 4							
Forward on-state voltage	V_F	4	—	0.85	1.0	V	I_F = 50mA
Peak pulse voltage	V_o	5	9	12	—	V	
Peak pulse voltage rise time	t_r	5	—	50	80	ns	
SUBGROUP 5							
Gate-anode blocking current (125°C Test)	I_{GAO}	2	—	150	500	nA	V_{GA} = Rating
Valley-point anode current (125°C Test)	I_V	1	40	100	—	μA	R_G = 10K, V_s = 10V
Peak-point anode current (—55°C Test)	I_P	1	—	7.5	10	μA	R_G = 10K, V_s = 10V

† All values in table are JEDEC registered



a) Typical Circuit

b) Equivalent Test Circuit

Figure 1

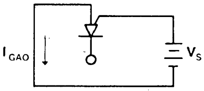


Figure 2

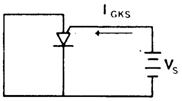


Figure 3

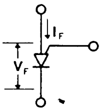


Figure 4

Note: Conditions for oscillation

$$\frac{V_{BB} - V_P}{R} > I_P$$

$$\frac{V_{BB} - V_V}{R} < I_V$$

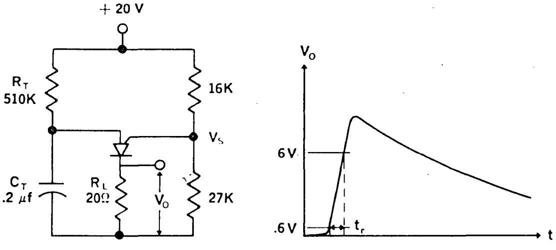
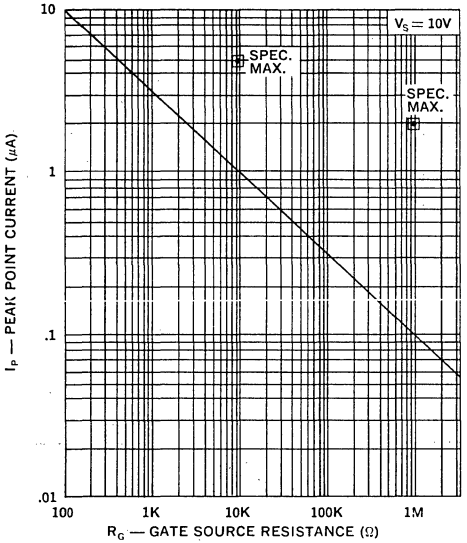
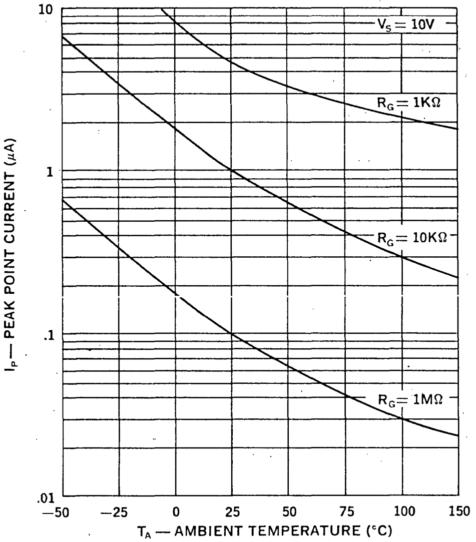


Figure 5

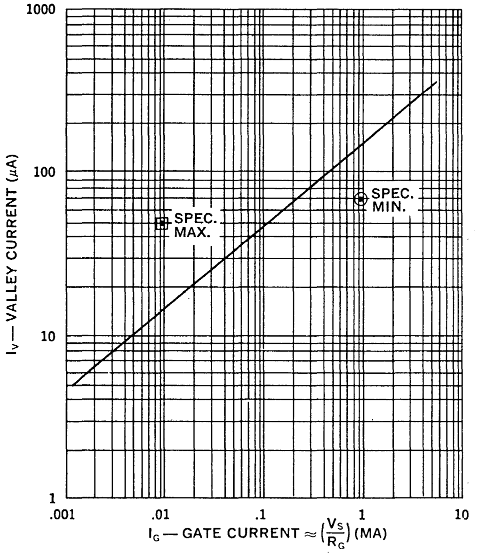
Peak Point Current vs. Gate Source Resistance



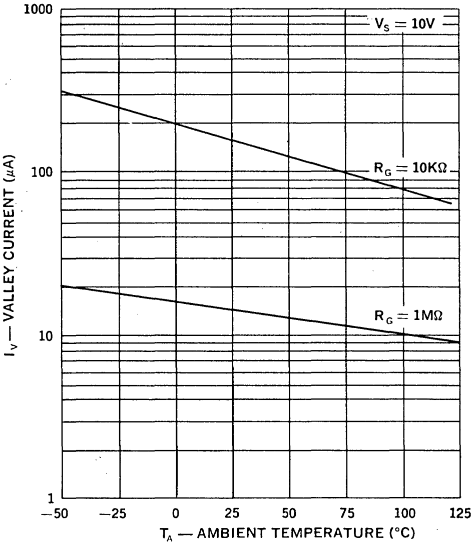
Peak Point Current vs. Ambient Temperature



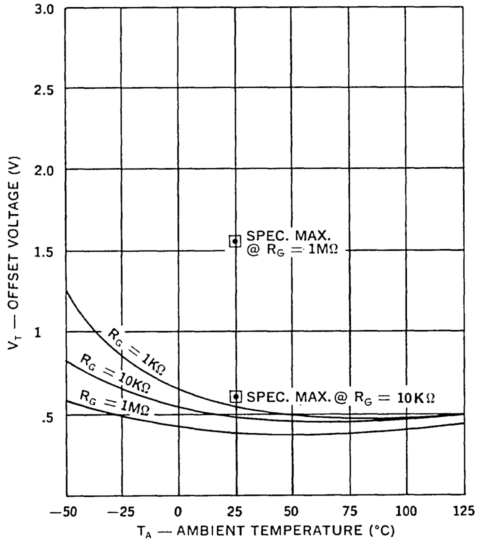
Valley Current vs. Gate Current



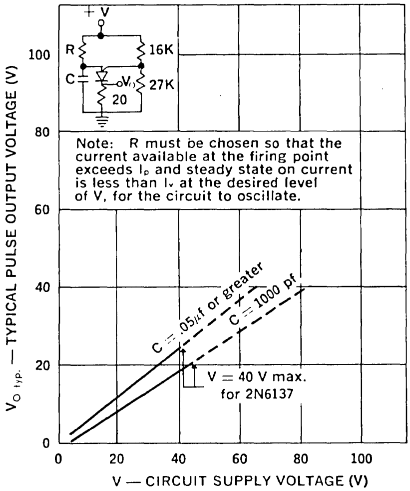
Valley Current vs. Ambient Temperature



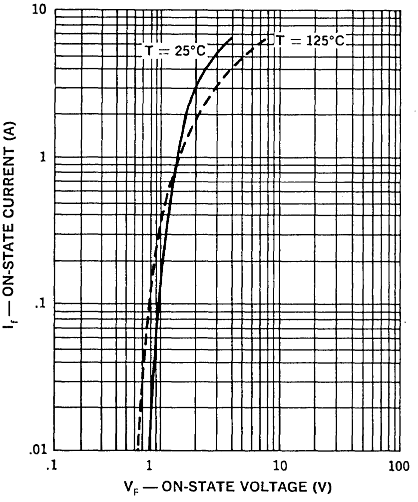
Offset Voltage vs. Ambient Temperature



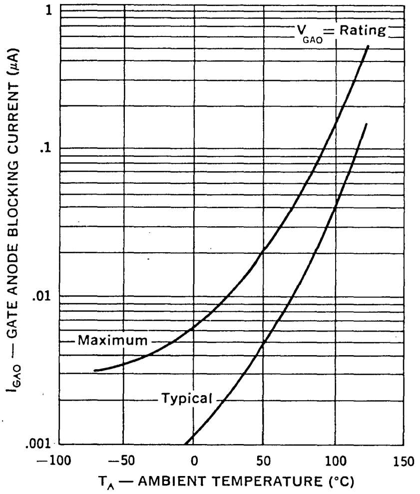
Typical Pulse Output Voltage vs. Circuit Supply Voltage



Typical Current vs. On-State Voltage



Gate-Anode Blocking Current vs. Ambient Temperature



SCRs
.5A, Planar

AA100-AA104
AA107-AA111
AA114-AA118

FEATURES

- Maximum Gate Trigger Current: 2, 20 or 200μA
- Tight Gate Trigger Voltage Range: .44 to .6V
- Voltage Ratings: to 400V
- Specified for dv/dt and Switching Time

DESCRIPTION

This data sheet describes Unitrode's AA Series 0.5A SCRs designed for low-current sensing applications. Units are available in a complete range of blocking voltages from 60 to 400 volts.

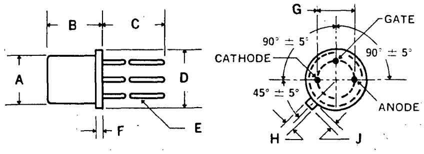
The AA100 series offers a maximum gate trigger current of 2.0 microamps making it the most sensitive device of its type. The AA107 series has a maximum I_{GT} of 20μA while this parameter is specified at 200μA for the AA114 series.

ABSOLUTE MAXIMUM RATINGS

	AA100 AA107 AA114	AA101 AA108 AA115	AA102 AA109 AA116	AA103 AA110 AA117	AA104 AA111 AA118
Repetitive Peak Off-State Voltage, V_{DRM}	60V	100V	200V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	60V	100V	200V	300V	400V
Non-Repetitive Peak Reverse Voltage, V_{RSM}	80V	150V	300V	400V	500V
Non-Repetitive Peak Off-State Voltage, V_{DSM}	500V				
D.C. On-State Current, I_T					
75°C Ambient	250mA				
100°C Case	500mA				
Repetitive Peak On-State Current, I_{TRM}	up to 30A				
Peak One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	5A				
Peak Gate Current, I_{GM}	250mA				
Average Gate Current, $I_{G(AV)}$	25mA				
Reverse Gate Voltage V_{GR}	6V				
Operating and Storage Temperature Range	$-65°C$ to $+150°C$				

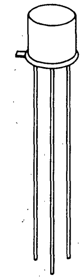
MECHANICAL SPECIFICATIONS

AA100-AA104 AA107-AA111 AA114-AA118



	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	$.017 \pm {.002 \atop .001}$ DIA.	$.432 \pm {.051 \atop .025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



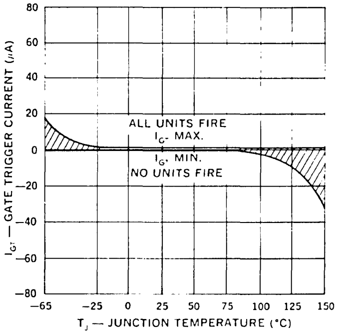
SEMICONDUCTOR
PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

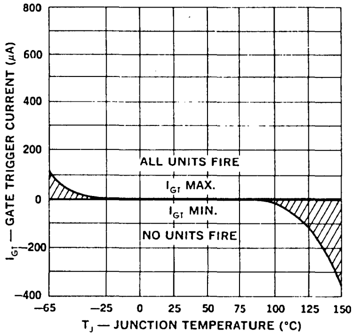
Parameter	Symbol	Min.	Typical	Max.	Units	Test Conditions
SUBGROUP 1						
Visual & Mechanical	—	—	—	—	—	—
SUBGROUP 2 (25°C TESTS)						
Off-State Current	I_{DRM}	—	.01	0.1	μA	$R_{GK} = 1K$, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	.01	0.1	μA	$R_{GK} = 1K$, V_{RRM} = Rating
Reverse Gate Current	I_{GR}	—	0.1	0.2	μA	$V_{GR} = 2V$
Gate Trigger Current	I_{GT}					$R_{GS} = 10K$, $V_D = 5V$
AA100-104		—	0.2	2.0	μA	
AA107-111		—	2.0	20	μA	
AA114-118		—	20	200	μA	
Gate Trigger Voltage	V_{GT}	0.44	0.52	0.60	V	$R_{GS} = 100\Omega$, $V_D = 5V$
On-State Voltage	V_T	—	1.1	1.5	V	$I_T = 1.0$ A (pulse)
Holding Current	I_H	0.3	0.5	2.0	mA	$R_{GK} = 1K$
SUBGROUP 3 (25°C TESTS)						
Off-State Voltage — Critical Rate of Rise	dv/dt	50	100	—	V/μs	$R_{GK} = 1K$, $V_D = 30V$
Gate Trigger — on Pulse Width	t_{pg} (on)	—	0.5	2.0	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Delay Time	t_d	—	0.6	—	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Rise Time	t_r	—	0.4	—	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Circuit Commutated Turn-off Time	t_q	—	20	50	μs	$I_T = 1A$, $I_R = 1A$, $R_{GK} = 1K$
SUBGROUP 4 (125°C TESTS)						
Off-State Current	I_{DRM}	—	10	20	μA	$R_{GK} = 1K$, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	30	100	μA	$R_{GK} = 1K$, V_{RRM} = Rating
Gate Trigger Voltage	V_{GT}	0.15	0.2	—	V	$R_{GS} = 100\Omega$, $V_D = 5V$
Holding Current	I_H	0.2	0.4	1.5	mA	$R_{GK} = 1K$

Note: Blocking voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1000 ohms or smaller, or other adequate bias is used.

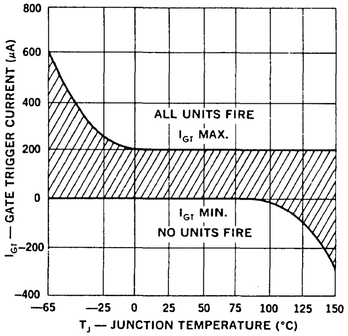
Gate Trigger Current
AA100 Series



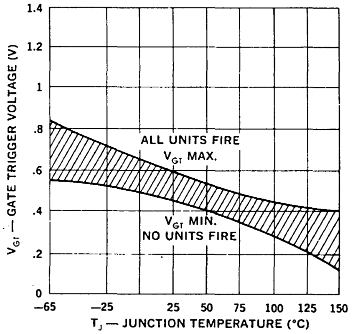
Gate Trigger Current
AA107 Series



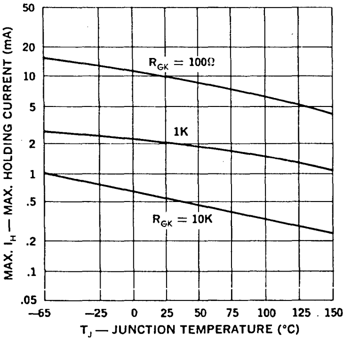
Gate Trigger Current
AA114 Series



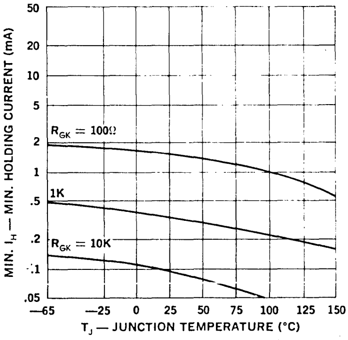
Gate Trigger Voltage



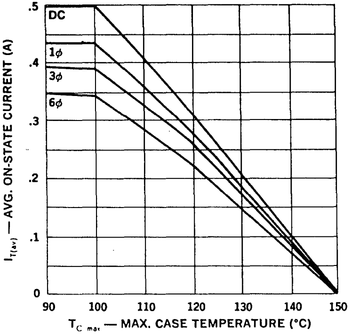
Max. Holding Current



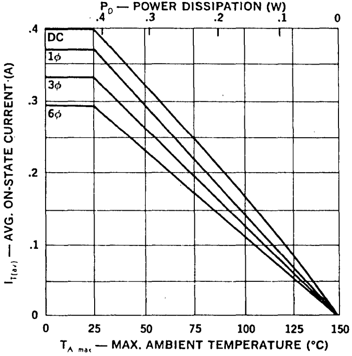
Min. Holding Current



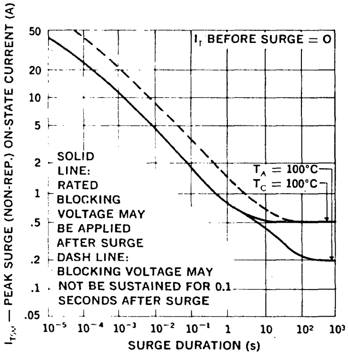
Avg. Current vs. Case Temperature



Avg. Current vs. Ambient Temperature



Surge Current



SCRs
1.6 Amp, Planar

AD100-AD104
AD107-AD111
AD114-AD118

FEATURES
- Maximum Gate Trigger Current: 2, 20 or 200μA
- Tight Gate Trigger Voltage Range: .44 to .6V
- Voltage Ratings: to 400V
- Specified for dv/dt and Switching Time

DESCRIPTION
This data sheet describes Unitrode's AD Series 1.6A SCRs designed for medium-current control and sensing applications. Units are available in a complete range of blocking voltages from 60 to 400 volts.

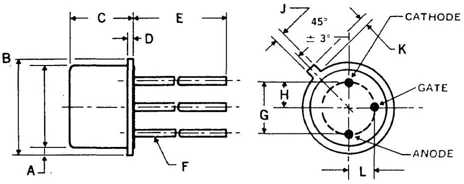
The AD100 series offers a maximum gate trigger current of 2.0 microamps making it the most sensitive device of its type. The AD107 series has a maximum I_{GT} of 20μA while this parameter is specified at 200μA for the AD114 series.

ABSOLUTE MAXIMUM RATINGS

	AD100 AD107 AD114	AD101 AD108 AD115	AD102 AD109 AD116	AD103 AD110 AD117	AD104 AD111 AD118
Repetitive Peak Off-State Voltage, V_{DRM}	60V	100V	200V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	60V	100V	200V	300V	400V
Non-Repetitive Peak Reverse Voltage, V_{RSM}	80V	150V	300V	400V	500V
Non-Repetitive Peak Off-State Voltage, V_{DSM}	500V				
D.C. On-State Current, I_T					
75°C Ambient	450mA				
85°C Case	1.6A				
Repetitive Peak On-State Current, I_{TRM}	up to 30A				
Peak One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	15A				
Peak Gate Current, I_{GM}	250mA				
Average Gate Current, $I_{G(AV)}$	25mA				
Reverse Gate Voltage, V_{GR}	6V				
Operating and Storage Temperature Range	$-65°C$ to $+150°C$				

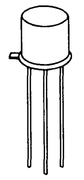
MECHANICAL SPECIFICATIONS

AD100-AD104 AD107-AD111 AD114-AD118



	ins.	mm.
A	.305-.335	7.75-8.51
B	.335-.370	8.51-9.40
C	.240-.260	6.35-6.60
D	.010-.030	.25-.76
E	.5 MIN.	12.70 MIN.
F	$.017 \pm {}^{.002}_{.001}$	$.432 \pm {}^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.79±.08
K	.029-.045	.74-1.14
L	.100	2.54

TO-205AD (TO-39)

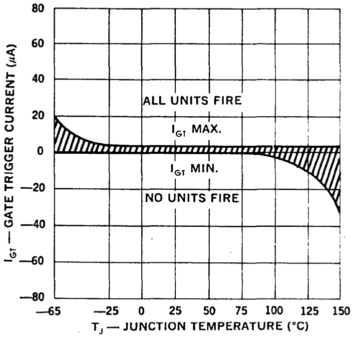


ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

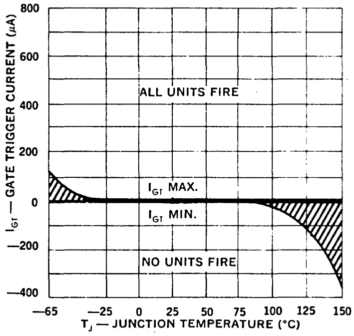
Parameter	Symbol	Min.	Typical	Max.	Units	Test Conditions
SUBGROUP 1 Visual & Mechanical	—	—	—	—	—	
SUBGROUP 2 (25°C TESTS)						
Off-State Current	I_{DRM}	—	.01	0.1	μA	$R_{GK} = 1K$, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	.01	0.1	μA	$R_{GK} = 1K$, V_{RRM} = Rating
Reverse Gate Current	I_{GR}	—	0.1	0.2	μA	$V_{GR} = 2V$
Gate Trigger Current	I_{GT}					$R_{GS} = 10K$, $V_D = 5V$
AD100-104		—	0.2	2.0	μA	
AD107-111		—	2.0	20	μA	
AD114-118		—	20	200	μA	
Gate Trigger Voltage	V_{GT}	0.44	0.52	0.60	V	$R_{GS} = 100\Omega$, $V_D = 5V$
On-State Voltage	V_T	—	1.1	1.5	V	$I_T = 1.0$ Amp (pulse)
Holding Current	I_H	0.3	0.5	2.0	mA	$R_{GK} = 1K$
SUBGROUP 3 (25°C TESTS)						
On-State Voltage-Critical Rate of Rise	dv/dt	50	100	—	V/μs	$R_{GK} = 1K$, $V_D = 30V$
Gate Trigger-on Pulse Width	t_{pg} (on)	—	0.5	2.0	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Delay Time	t_d	—	0.6	—	μs	$i_G = 10mA$, $i_T = 1A$, $V_D = 30V$
Rise Time	t_r	—	0.4	—	μs	$I_G = 10mA$, $I_T = 1A$, $V_D = 30V$
Circuit Commutated Turn-off Time	t_g	—	20	50	μs	$I_T = 1A$, $I_R = 1A$, $R_{GK} = 1K$
SUBGROUP 4 (125°C TESTS)						
Off-State Current	I_{DRM}	—	10	100	μA	$R_{GK} = 1K$, V_{DRM} = Rating
Reverse Current	I_{RRM}	—	30	100	μA	$R_{GK} = 1K$, V_{RRM} = Rating
Gate Trigger Voltage	V_{GT}	0.15	0.2	—	V	$R_{GS} = 100\Omega$, $V_D = 5V$
Holding Current	I_H	0.2	0.4	1.5	mA	$R_{GK} = 1K$

Note: Blocking voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1000 ohms or smaller, or other adequate bias is used.

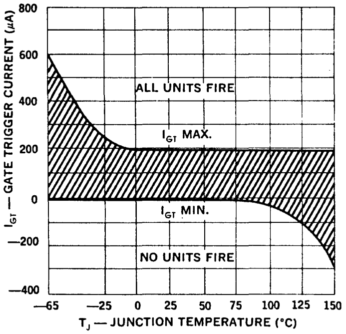
Gate Trigger Current
AD100 Series



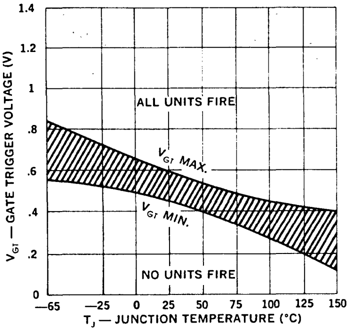
Gate Trigger Current
AD107 Series



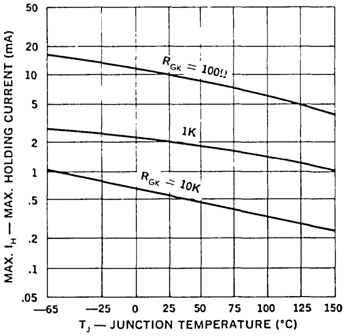
Gate Trigger Current
AD114 Series



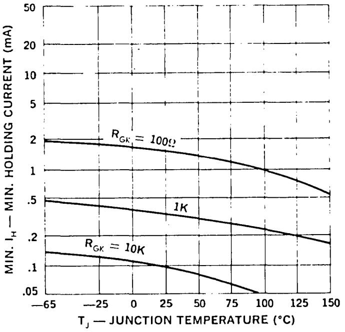
Gate Trigger Voltage



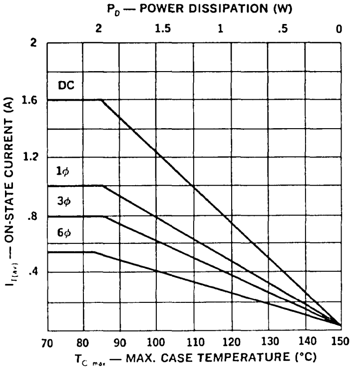
Max. Holding Current



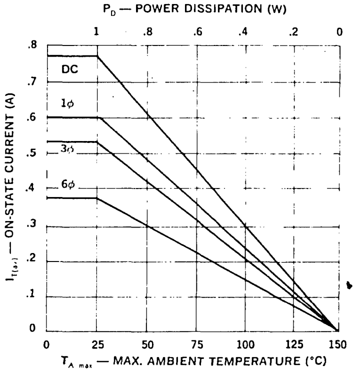
Min. Holding Current



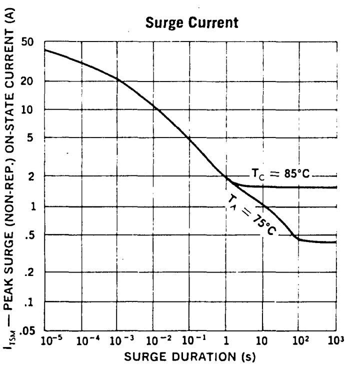
Avg. Current vs. Case Temperature



Avg. Current vs. Ambient Temperature



Surge Current



SCRs
Nuclear Radiation Resistant, Planar

GA100
GA101
GA102

FEATURES
- Optimized for Radiation Resistance
- Fully Characterized for "Worst Case" Design
- Post Radiation Design Limits Specified
- Passivated Planar Construction for Maximum Reliability and Parameter Uniformity
- Pulse Currents: to 30A
- Max. Trigger Current 20mA after 3 X 10^{14} NVT
- Max. Holding Current 30mA after 3 X 10^{14} NVT

DESCRIPTION
The GA100 Series of Radiation Hard SCRs have been designed to provide significantly greater radiation tolerance than conventional SCRs or Transistors with the same current handling ability. This Series is capable of operation after exposure to 10^{15} NVT.

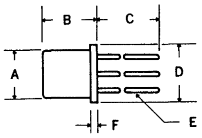
The radiation resistant characteristics of the GA100 series devices make them particularly desirable for use under radiation environments in squib firing circuits; inverters and converters; pulse generators; relay drivers; and modulator discharge switches.

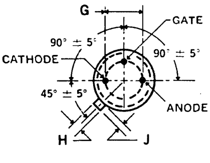
ABSOLUTE MAXIMUM RATINGS

	GA100	GA101	GA102
Repetitive Peak Off-State Voltage, V_{DRM}	30V	60V	80V
D.C. On-State Current, I_T			
75°C Ambient	200mA		
100°C Case	400mA		
Repetitive Peak On-State Current, I_{TRM}	up to 30A		
Surge (non-rep.) On-State Current, I_{TSM} (Sq. Pulse-50ms)	5A		
Peak Gate Current, I_{GM}	250mA		
Average Gate Current, $I_{G(AV)}$	25mA		
Reverse Gate Voltage, V_{GR}	5V		
Reverse Gate Current, I_{GR}	3mA		
Storage Temperature Range	—65°C to +200°C		
Operating Temperature Range	—65°C to +150°C		

MECHANICAL SPECIFICATIONS

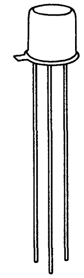
GA100 GA101 GA102





	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	.017 ± $^{.002 \text{ DIA.}}_{.001 \text{ DIA.}}$	.432 ± $^{.051}_{.025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

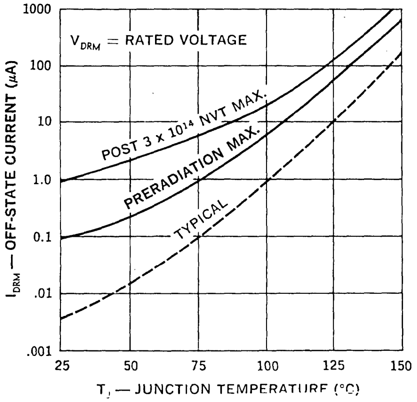
Test	Symbol	Preradiation Limits			Post 3 x 10^{14} NVT Design Limits		Units	Test Conditions
		Min.	Typ.	Max.	Min.	Max.		
SUBGROUP 1 Visual and Mechanical	—	—	—	—	—	—	—	MIL-STD-750 Method 2071
SUBGROUP 2 (25°C Tests)								
Off-State Current	I_{DRM}	—	.005	0.1	—	1.0	μA	$R_{GK} = 220\Omega$, V_{DRM} = Rating
Reverse Gate Current	I_{GR}	—	.01	0.1	—	1.0	μA	$V_{GR} = 2V$
Input Trigger Current (Note 2)	I_{ST}	1.8	2.3	3.5	—	20	mA	$R_{GK} = 220\Omega$, $V_D = 5V$
Gate Trigger Voltage	V_{GT}	0.4	0.5	0.7	—	1.5	V	$R_{GK} = 220\Omega$, $V_D = 5V$
On-State Voltage	V_T	0.8	1.1	1.5	—	3.0	V	$i_T = 1A$ (pulse test)
Holding Current	I_H	0.3	0.7	10	—	30	mA	$R_{GK} = 220\Omega$
SUBGROUP 3 (25°C Tests)								
Off-State Voltage-Critical Rate of Rise	dv_c/dt	20	40	—	—	—	v/μs	$R_{GK} = 220\Omega$, $V_D = 30V$
Gate Trigger-on Pulse Width	t_{pg} (on)	—	.02	.05	—	0.1	μs	$I_G = 25mA$, $I_T = 1A$, $V_D = 30V$
Delay Time	t_d	—	.02	—	—	—	μs	$I_G = 25mA$, $I_T = 1A$, $V_D = 30V$
Rise Time	t_r	—	.05	—	—	—	μs	$I_G = 25mA$, $I_T = 1A$, $V_D = 30V$
Circuit Commutated Turn-off Time	t_q	—	1.5	2.5	—	1.0	μs	$I_T = 1A$, $i_R = 1A$, $R_{GK} = 220\Omega$
SUBGROUP 4 (125°C Tests)								
High Temp Off-State Current	I_{DRM}	—	10	100	—	100	μA	$R_{GK} = 220\Omega$, V_{DRM} = Rating
High Temp Gate Trigger Voltage	V_{GT}	0.1	.17	—	0.1	—	V	$R_{GK} = 220\Omega$, $V_D = 5V$

Notes: 1. Off-State voltage ratings apply over the operating temperature range provided the gate is connected to the cathode through an appropriate resistor, or other adequate bias is used.
2. Total Input Trigger Current, including current required by 220Ω gate bias resistance.

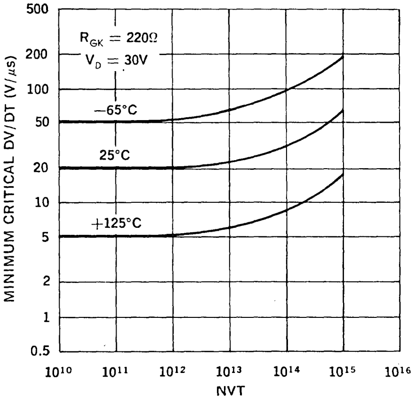
DESIGN CONSIDERATIONS

1. Curve 1 shows the off-state current, I_{DRM} of the SCR as a function of temperature. I_{DRM} is increased by radiation damage, but is not a design consideration at the recommended gate bias levels.
   In order to optimize for radiation tolerance, reverse blocking capability has not been retained as a design feature. Devices with reverse blocking capability can be provided.
2. Minimum critical dv/dt levels are defined in Curve 2. The dv/dt capability is improved after radiation because of reduced triggering sensitivity. dv/dt is therefore a design consideration only prior to radiation.
3. Curves 3 and 4 show the limits of Gate Trigger Voltage and Total Input Trigger Current prior to radiation. Maximum design limits after a total radiation dosage of 3 x 10^{14} NVT is also shown. Curves 5 and 6 show the maximum limits of Gate Trigger Voltage and Total Input Trigger Currents as a junction of neutron dosage. The minimum level of Trigger current prior to radiation is established by the shunting effect of a 220 ohm resistor between gate and cathode. After radiation the device is less sensitive and Total Trigger Current will increase to a level relatively independent of the bias resistance. The 220 ohm resistor is recommended since it raises the minimum preradiation trigger current to a level that is closer to the past radiation limit and minimizes the percentage change in this parameter.
4. Current ratings shown in Curves 10, 11, and 12 apply after the device has been subjected to 3 x 10^{14} NVT. Current ratings prior to radiation are greater than the values indicated.
5. Gamma radiation produces a reversible ionization (leakage) current within the device which is directly proportional to the Gamma flux level. When the Gamma flux level is in the range of 10 to 100 Roentgens per microsecond for burst durations greater than 1 microsecond, the device will self trigger ON. For the radiation bursts associated with nuclear explosions, the Gamma flux level will invariably cause device triggering at radiation levels significantly below the levels that would produce detectable permanent device damage due to cumulative neutron dosage. In applications where the burst effect triggering cannot be tolerated, it is necessary to reset the device after the radiation burst. Special circuit approaches such as additional SCRs to crowbar or otherwise cancel the output function may be used.

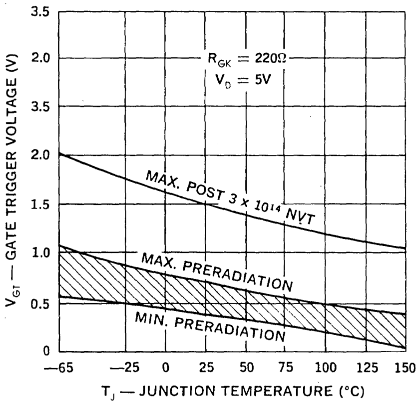
1. Off-State Current



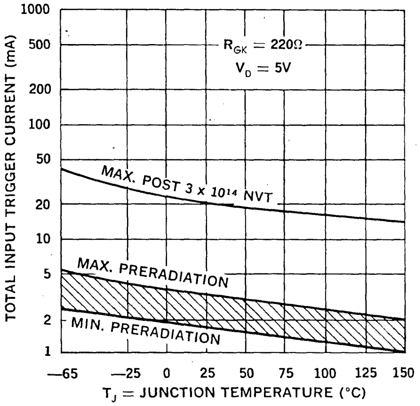
2. Minimum Critical DV/DT vs. Neutron Dosage



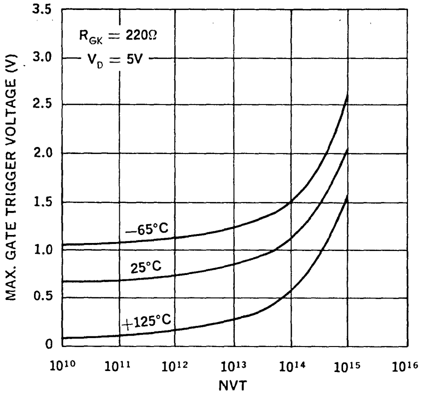
3. Gate Trigger Voltage



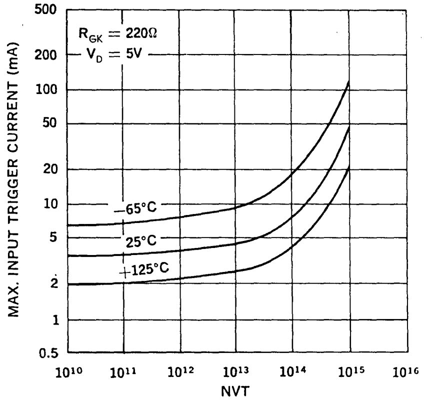
4. Input Trigger Current



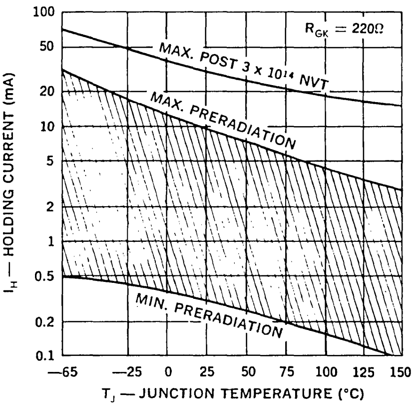
5. Max. Gate Trigger Voltage vs. Neutron Dosage



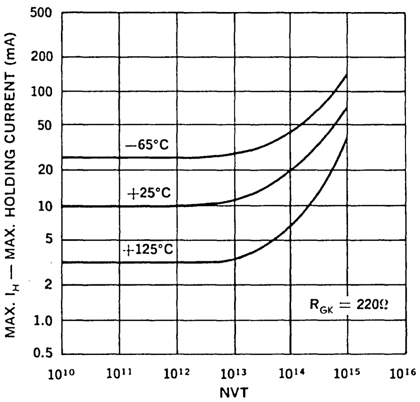
6. Max. Input Trigger Current vs. Neutron Dosage



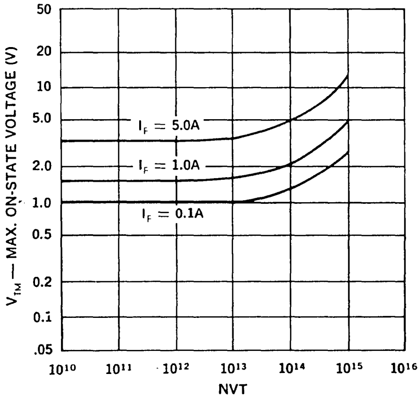
7. Holding Current



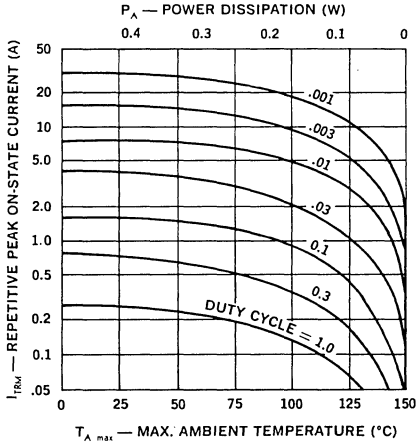
8. Max. Holding Current vs. Neutron Dosage



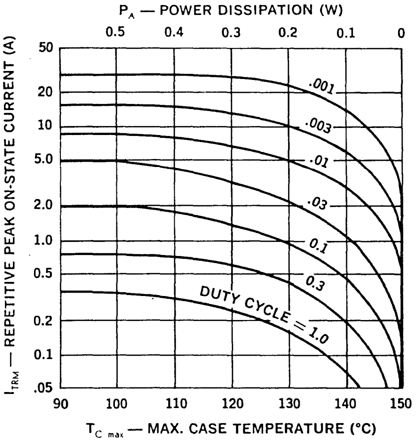
9. Max. On-State Voltage vs. Neutron Dosage



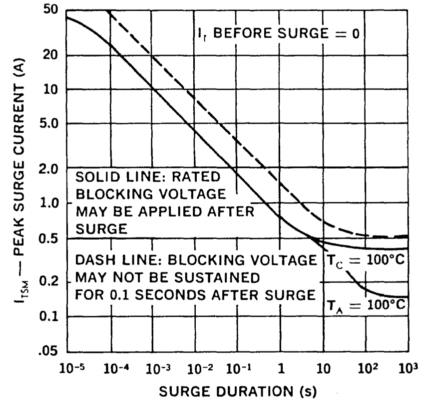
10. Peak Current vs. Ambient Temperature



11. Peak Current vs. Case Temperature



12. Surge Current vs. Time



SCRs
Nanosecond Switching, Planar

GA200 GB200
GA200A GB200A
GA201 GB201
GA201A GB201A

FEATURES
- Rise Time: 10ns
- Delay Time: 10ns
- Recovery Time: 0.5 μs
- Pulse Current: to 100A
- Turn-on with 20ns, 10 mA Gate Pulse

DESCRIPTION
The Unitrode Nanosecond Thyristor Switch combines the turn-on speed of logic level transistors with the high current switching capability inherent in SCRs. With this device engineers can now design circuits capable of switching pulse currents of 1A in less than 10ns or up to 30A in less than 20ns.

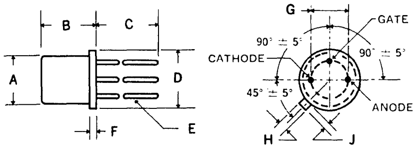
The GA/GB200 series is specifically designed for use as switching elements in high speed, low-to-medium power radar pulse modulators. Other applications include switching elements for phased array radars, laser pulse drivers, harmonic wave-form generators, line drivers and high current replacements for avalanche transistors. For applications requiring higher voltage levels, Unitrode has developed several "series string" circuits which allow the series connection of virtually an unlimited number of devices for voltages as high as 2000V with no significant decrease in speed. These circuits are described in Unitrode's Design Note #14.

ABSOLUTE MAXIMUM RATINGS

	GA200 GA200A	GA201 GA201A	GB200 GB200A	GB201 GB201A
Repetitive Peak Off-State Voltage, V_{DRM}	60V	100V	60V	100V
Repetitive Peak On-State Current, I_{TRM}	up to 100A		up to 100A	
D.C. On-State Current, I_T				
70°C Ambient	200mA		—	
70°C Case	400mA		6A	
Peak Gate Current, I_{GM}	250mA		250mA	
Average Gate Current, $I_{G(AV)}$	25mA		50mA	
Reverse Gate Current, I_{GR}	3mA		3mA	
Reverse Gate Voltage, V_{GR}	5V		5V	
Thermal Resistance, $R_{\theta\ CA}$	300°C/W			
Storage Temperature Range	−65°C to +200°C			
Operating Temperature Range	−65°C to +150°C			

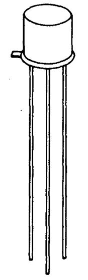
MECHANICAL SPECIFICATIONS

GA200 GA200A GA201 GA201A

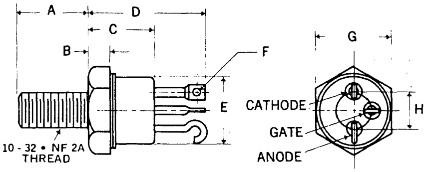


	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	$.017 \pm ^{.002\text{ DIA.}}_{.001\text{ DIA.}}$	$.432 \pm ^{.051}_{.025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



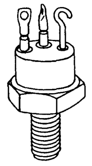
GB200 GB200A GB201 GB201A



	INCHES	MILLIMETERS
A	.400-.455	10.16-11.56
B	.090-.150	2.28-3.81
C	.320-.468	8.13-11.88
D	.570-.763	14.48-19.38
E	.318-.380	8.07-9.65
F	$.055 \pm ^{.010}_{.015}$	$1.40 \pm ^{.254}_{.381}$
G	.424-.437	10.77-11.10
H	.185-.215	4.70-5.46

NOTE: Anode connected to case.

TO-59



SEMICONDUCTOR
PRODUCTS
UNITRODE

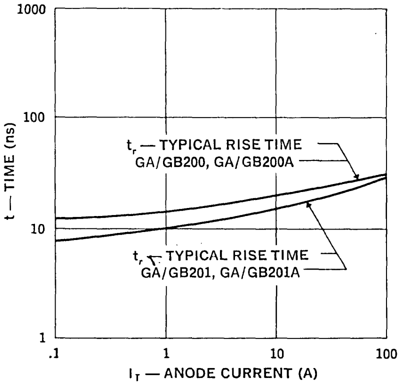
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	Min.	Typ.	Max.	Units	Test Conditions
Delay Time	t_d	— —	20 10	30 —	ns ns	$I_G = 20mA, I_T = 1A$ $I_G = 30mA, I_T = 1A$
Rise Time GA200, 200A, GB200, 200A	t_r	— —	15 25	25 —	ns ns	$V_D = 60V, I_T = 1A$ (1) $V_D = 60V, I_T = 30A$ (1)
Rise Time GA201, 201A, GB201, 201A	t_r	— —	10 20	20 —	ns ns	$V_D = 100V, I_T = 1A$ (1) $V_D = 100V, I_T = 30A$ (1)
Gate Trigger on Pulse Width	$t_{pg(on)}$	—	.02	.05	μs	$I_G = 10mA, I_T = 1A$
Circuit Commutated Turn-off Time GA200, 201, GB200, 201	t_q	—	0.8	2.0	μs	$I_T = 1A, I_R = 1A, R_{GK} = 1K$
GA200A, 201A, GB200A, 201A	t_q	—	0.3	0.5	μs	
Off-State Current	I_{DRM}	—	.01	0.1	μA	V_{DRM} = Rating, $R_{GK} = 1K$
		—	20	100	μA	V_{DRM} = Rating, $R_{GK} = 1K$, 150°C
Reverse Current	I_{RRM}	—	1.0	10	mA	$V_{RRM} = 30V, R_{GK} = 1K$ (2)
Reverse Gate Current	I_{GR}	—	.01	0.1	mA	$V_{GRM} = 5V$
Gate Trigger Current	I_{GT}	—	10	200	μA	$V_D = 5V, R_{GS} = 10K$
Gate Trigger Voltage	V_{GT}	0.4	.6	0.75	V	$V_D = 5V, R_{GS} = 100\Omega, T = 25°C$
		0.10	0.2	—	V	$T = +150°C$
On-State Voltage	V_T	—	1.1	1.5	V	$I_T = 2A$
Holding Current	I_H	0.3	2.0	5.0	mA	$V_D = 5V, R_{GK} = 1K, T = 25°C$
		0.05	0.2	—	mA	$T = +150°C$
Off-State Voltage-Critical Rate of Rise	dv/dt	20	40	—	V/μs	$V_D = 30V, R_{GK} = 1K$

Notes: 1. I_G = 10mA; Pulse Test, Duty Cycle <1%.

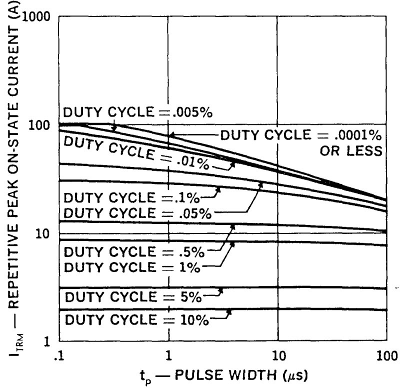
2. Pulse test intended to guarantee reverse anode voltage capability for pulse commutation. Device should not be operated in the Reverse blocking mode on a continuous basis.

Switching Speed (Typical) GA/GB200 Series

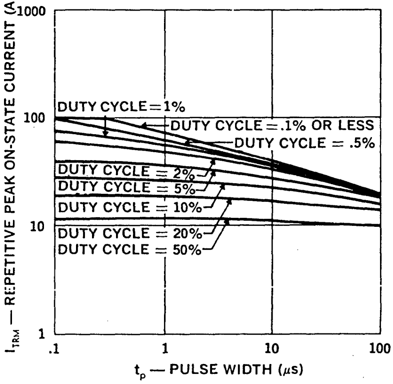


NOTES: 1. V_D = Rated V_{DRM}
2. $T_A = 25°C$
3. $I_G = 20mA$
4. t_d = 20ns TYPICALLY FOR ALL TYPES INDEPENDENT OF ANODE CURRENT

Peak Current vs. Pulse Width GA200 Series

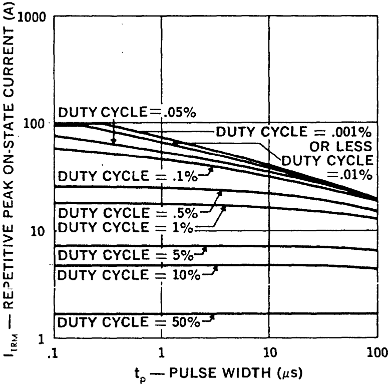


NOTES: 1. DATA BASED ON ON-STATE VOLTAGE GRAPH AT T_j = 150°C. BLOCKING VOLTAGE MAY BE APPLIED IMMEDIATELY AFTER TERMINATION OF CURRENT PULSE.
2. T_A = 75°C



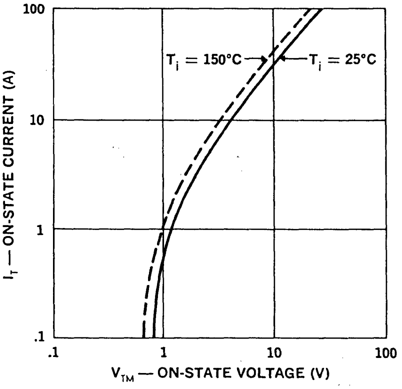
Peak Current vs. Pulse Width
GB200 Series

NOTES: 1. DATA BASED ON ON-STATE VOLTAGE GRAPH AT $T_j = 150°C$. BLOCKING VOLTAGE MAY BE APPLIED IMMEDIATELY AFTER TERMINATION OF CURRENT PULSE.
2. $T_C = 75°C$

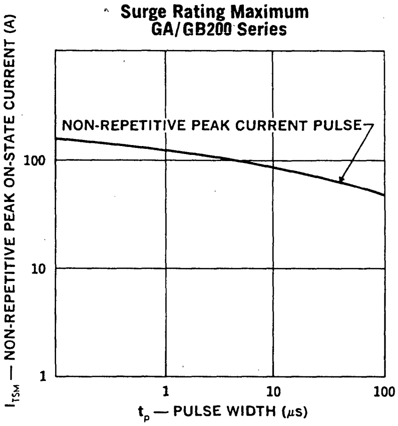


Peak Current vs. Pulse Width
GB200 Series

NOTES: 1. DATA BASED ON ON-STATE VOLTAGE GRAPH AT $T_j = 150°C$. BLOCKING VOLTAGE MAY BE APPLIED IMMEDIATELY AFTER TERMINATION OF CURRENT PULSE.
2. $T_A = 75°C$

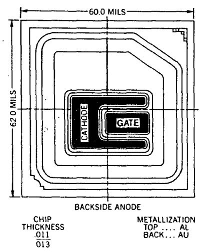


On-State Current vs. Voltage
GA/GB200 Series



Surge Rating Maximum
GA/GB200 Series

NOTES: 1. BLOCKING VOLTAGE MAY NOT BE APPLIED FOR .001 SEC. AFTER TERMINATION OF SURGE PULSE AS JUNCTION TEMPERATURE WILL EXCEED 150°C.
2. $T_C = 75°C$



SCRs
Commercial Nanosecond Switching Planar

GA300 GB300
GA300A GB300A
GA301 GB301
GA301A GB301A

FEATURES

- Rise Time: 10ns
- Delay Time: 10ns
- Recovery Time: 0.5μs
- Pulse Current: to 100A
- Turn-on with 20ns, 10mA gate pulse

DESCRIPTION

Unitrode's Nanosecond Thyristor Switch combines the turn-on speed of logic level transistors with the high current switching capability inherent in SCRs. With this device, engineers can now design circuits capable of switching pulse currents of 1A in less than 10ns or up to 30A in less than 20ns.

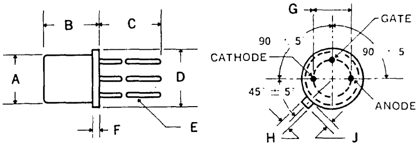
The GA300, GB300 Series is specifically designed for use as the switching element in high speed laser diode pulse drivers. Other applications include electronic crowbars, harmonic wave-form generators, line drivers and general purpose replacements for avalanche transistors. For applications requiring higher voltage levels, Unitrode has developed several "series string" circuits which allow the series connection of an unlimited number of devices for voltages as high as 2000V with no significant decrease in speed. These circuits are described in Unitrode's Design Note #14.

ABSOLUTE MAXIMUM RATINGS

	GA300 GA300A	GA301 GA301A	GB300 GB300A	GB301 GB301A
Repetitive Peak Off-State Voltage, V_{DRM}	60V	100V	60V	100V
Repetitive Peak On-State Current, I_{TRM}	up to 100A		up to 100A	
Peak Gate Current, I_{GM}	250mA		250mA	
Average Gate Current, $I_{G(AV)}$	25mA		50mA	
Reverse Gate Current, I_{GR}	3mA		3mA	
Reverse Gate Voltage, V_{GR}	5V		5V	
Storage Temperature Range	−65°C to +150°C			
Operating Temperature Range	0°C to +125°C			

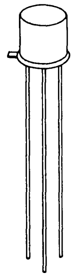
MECHANICAL SPECIFICATIONS

GA300 GA300A GA301 GA301A

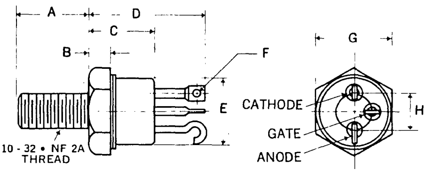


	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	.017 ± .002 DIA. .001 DIA.	.432 ± .051 .025
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



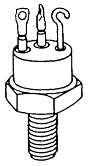
GB300 GB300A GB301 GB301A



	INCHES	MILLIMETERS
A	.400-.455	10.16-11.56
B	.090-.150	2.28-3.81
C	.320-.468	8.13-11.88
D	.570-.763	14.48-19.38
E	.318-.380	8.07-9.65
F	.055 ± .010 .015	1.40 ± .254 .381
G	.424-.437	10.77-11.10
H	.185-.215	4.70-5.46

NOTE: Anode connected to case.

TO-59



SEMICONDUCTOR PRODUCTS
UNITRODE

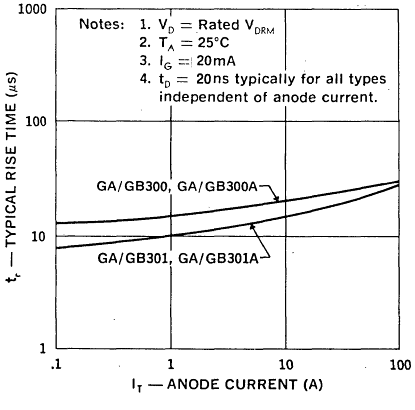
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	Min.	Typical	Max.	Units	Test Conditions
Delay Time	t_d	—	20	30	ns	$I_G = 20mA$, $I_T = 1A$
			10	—		$I_G = 30mA$, $I_T = 1A$
Rise Time (Note 1) GA300, 300A, GB300, 300A	t_r	—	15	25	ns	$V_D = 60V$, $I_T = 1A$ (Note 1)
			25	—		$V_D = 60V$, $I_T = 30A$
Rise Time (Note 1) GA301, 301A, GB301, 301A	t_r	—	10	20	ns	$V_D = 100V$, $I_T = 1A$ (Note 1)
			20	—		$V_D = 100V$, $I_T = 30A$
Circuit Commutated Turn-off Time GA300, 301, GB300, 301	t_q	—	0.8	2.0	μs	$I_T = 1A$, $I_R = 1A$, $R_{GK} = 1K$
GA300A, 301A, GB300A, 301A			0.3	0.5	μs	$I_T = 1A$, $I_R = 1A$, $R_{GK} = 1K$
Gate Trigger-on Pulse Width	$t_{pg\ (on)}$	—	0.02	0.05	μs	$I_G = 10mA$, $I_T = 1A$
Off-state Current	I_{DRM}	—	0.01	0.1	μA	V_{DRM} = Rating, $R_{GK} = 1K$, $T = 25°C$
		—	20	100	μA	V_{DRM} = Rating, $R_{GK} = 1K$, $T = 125°C$
Reverse Current (Note 2)	I_{RRM}	—	1.0	10	mA	$V_{RRM} = 30V$, $R_{GK} = 1K$ (Note 2)
Gate Trigger Voltage	V_{GT}	0.4	0.6	0.75	V	$V_D = 5V$, $R_{GS} = 100\Omega$, $T = 25°C$
		0.10	0.2	—	V	$V_D = 5V$, $R_{GS} = 100\Omega$, $T = 125°C$
Gate Trigger Current	I_{GT}	—	10	200	μA	$V_D = 5V$, $R_{GS} = 10K$
On-state Voltage	V_T	—	1.1	1.5	V	$I_T = 2A$
Off-state Voltage — Critical Rate of Rise	dv/dt	15	30	—	V/μs	$V_D = 30V$, $R_{GK} = 1K$
Reverse Gate Current	I_{GR}	—	0.01	0.1	mA	$V_{GR} = 5V$
Holding Current	I_H	0.3	2.0	5.0	mA	$V_D = 5V$, $R_{GK} = 1K$, $T = 25°C$
		0.05	0.4	—	mA	$V_D = 5V$, $R_{GK} = 1K$, $T = 125°C$

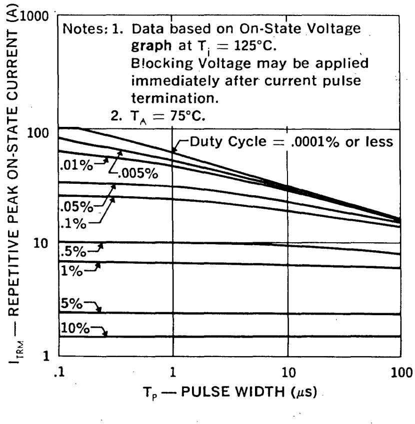
Notes: 1. $I_G = 10mA$; Pulse Test, Duty Cycle $< 1\%$.

2. Pulse test intended to guarantee reverse anode voltage capability for pulse commutation. Device should not be operated in the reverse blocking mode on a continuous basis.

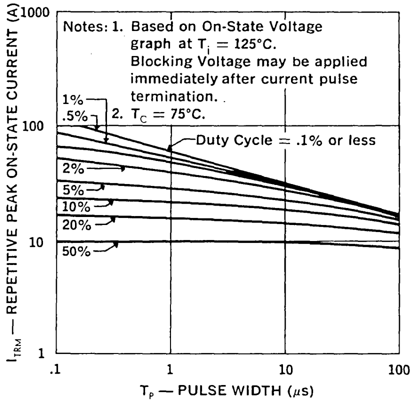
Switching Speed vs. Current
GA/GB300 Series



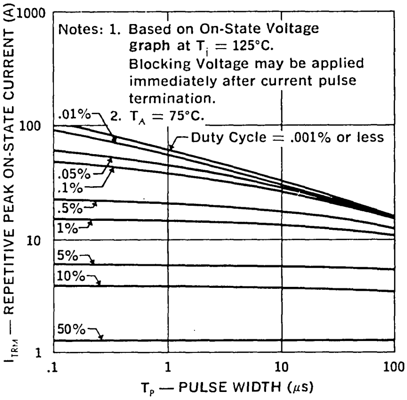
Peak Current vs. Pulse Width
GA300 Series



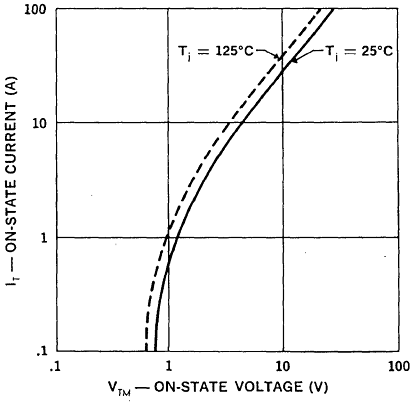
**Peak Current vs. Pulse Width
GB300 Series**



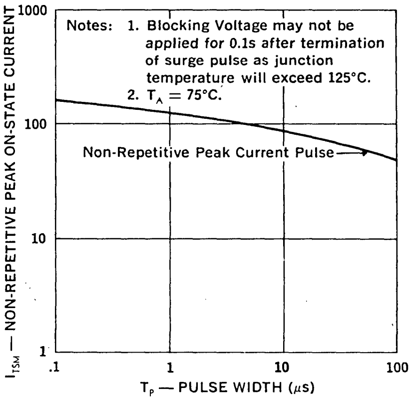
**Peak Current vs. Pulse Width
GB300 Series**



**On-State Voltage vs. Current
GA/GB300 Series**



**Surge Rating
GA/GB300 Series**



SCRs

.5 Amp, Planar

ID100-ID106

FEATURES

- Voltage Ratings: to 400V
- Maximum Gate Trigger Current: 200μA
- Hermetically Sealed TO-18 Metal Can
- Planar Passivated Construction

DESCRIPTION

This Data Sheet describes Unitrode's line of hermetically sealed industrial SCRs designed for low-voltage, low-current sensing application. The ID100 Series is packaged in a TO-18 metal case with Unitrode's unique oxide passivated junctions, offering the highest degree of reliability and parameter stability for any device in its price range.

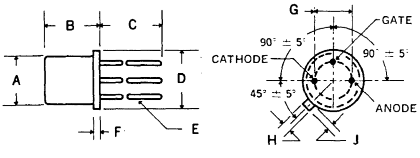
Typical applications include lamp driving, relay driving, sensor, pulse-generating and timing circuits.

ABSOLUTE MAXIMUM RATINGS

	ID100	ID101	ID102	ID103	ID104	ID105	ID106
Repetitive Peak Off-State Voltage, V_{DRM}	30V	60V	100V	150V	200V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	30V	60V	100V	150V	200V	300V	400V
On-State Current, I_T							
75°C Ambient	250mA						
100°C Case	0.5A						
Repetitive Peak On-State Current, I_{TRM}	6A						
Peak One Cycle Surge (Non-Rep.) On-State Current, I_{TSM}	up to 30A						
Peak Gate Current, I_{GM}	250mA						
Average Gate Current, $I_{G(AV)}$	25mA						
Reverse Gate Voltage, V_{GR}	6V						
Storage Temperature Range	−65°C to +150°C						
Operating Temperature Range	−65°C to +125°C						

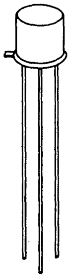
MECHANICAL SPECIFICATIONS

ID100-ID106



	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	$.017 \pm {.002 \atop .001}$ DIA.	$.432 \pm {.051 \atop .025}$
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA.	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

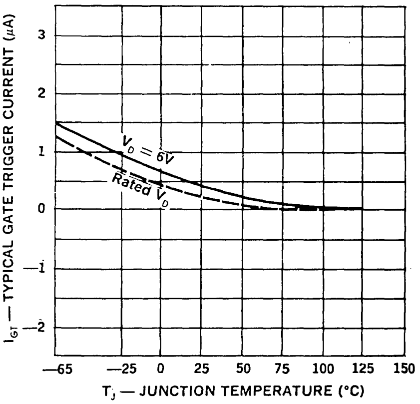
TO-18

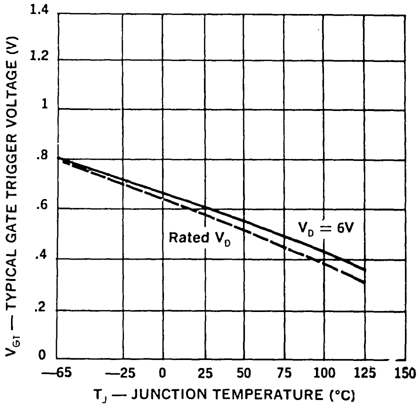


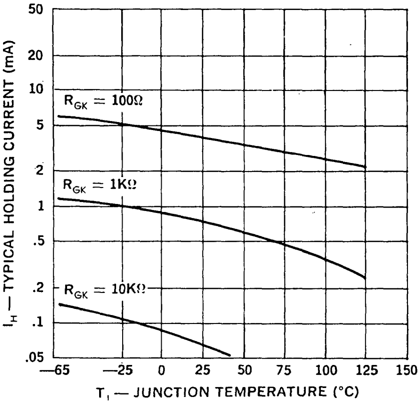
ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

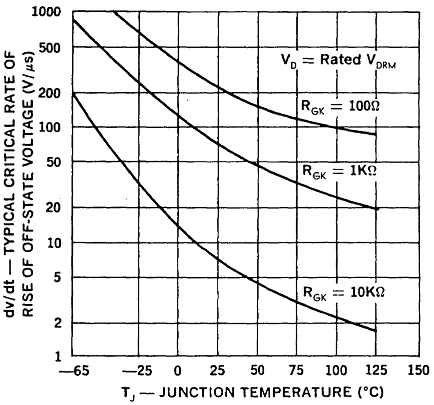
Test	Symbol	Min.	Typical	Max.	Units	Test Conditions
Off-State Current	I_{DRM}	—	5.0	50	μA	V_{DRM} = Rating, R_{GK} = 1K, T = 125°C, ID100-ID104
		—	10.0	100	μA	V_{DRM} = Rating, R_{GK} = 1K, T = 125°C, ID105-ID106
Reversing Current	I_{RRM}	—	10	50	μA	V_{RRM} = Rating, R_{GK} = 1K, T = 125°C, ID100-ID104
		—	15	100	μA	V_{RRM} = Rating, R_{GK} = 1K, T = 125°C, ID105-ID106
Gate Trigger Current	I_{GT}	—	5.0	200	μA	V_D = 5V, R_{GS} = 10K
		—	—	500	μA	V_D = 5V, R_{GS} = 10K, T = −40°C
Gate Trigger Voltage	V_{GT}	0.4	0.55	0.8	V	V_D = 5V, R_{GS} = 100Ω
		—	—	1.0	V	V_D = 5V, R_{GS} = 100Ω, T = −40°C
		0.10	—	—	V	V_D = 5V, R_{GS} = 100Ω, T = 125°C
Peak On-State Voltage	V_{TM}	—	—	1.7	V	I_{TM} = 1 Amp Pulse
Holding Current	I_H	—	1.0	5.0	mA	R_{GK} = 1K
		—	—	10.0	mA	R_{GK} = 1K, T = −40°C
Turn-on Time	t_{on}	—	0.5	—	μs	I_G = 10mA, I_T = 1A, V_D = 30V
Circuit Commutated Turn-off Time	t_q	—	8.0	—	μs	I_T = I_R = 1A, R_{GK} = 1K, ID100-ID104
		—	15.0	—	μs	I_T = I_R = 1A, R_{GK} = 1K, ID105-ID106

Note: Blocking voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1000 ohms or smaller, or other adequate bias is used.

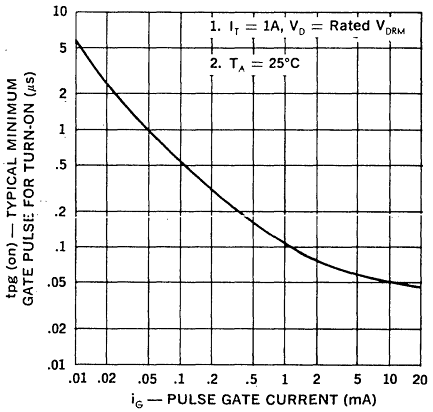

Gate Trigger Current vs. Junction Temp.


Gate Trigger Voltage vs. Junction Temp.

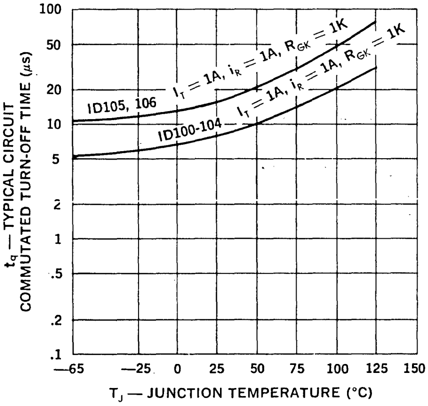

Holding Current vs. Junction Temp.


dv/dt vs. Junction Temp.

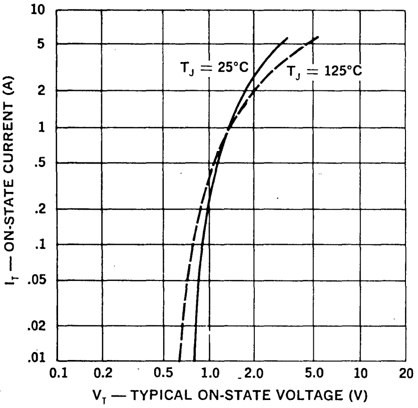
Gate Pulse for Turn-On vs. Pulse Gate Current



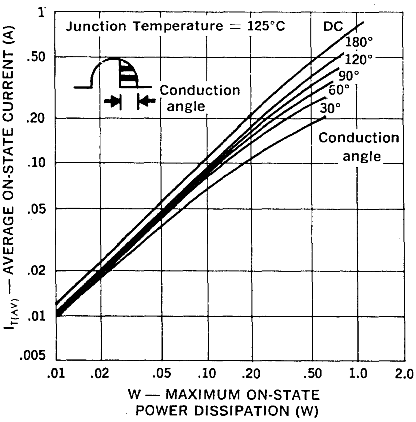
Circuit Commutated Turn-Off Time vs. Junction Temp.



Current vs. On State Voltage



Current vs. Power Dissipation



SCRs

1.6 Amp, Planar

ID200-ID203
ID300-ID301

FEATURES

- Voltage Rating: to 200V
- Max. Gate Trigger Current: 200μA
- Hermetically Sealed Metal Can
- Planar Passivated Construction

DESCRIPTION

This Data Sheet describes Unitrode's line of hermetically sealed industrial SCRs designed for high-voltage, medium-current control applications. The Series is packaged in a TO-39 metal case with Unitrode's unique oxide passivated junctions to ensure reliability and parameter stability.

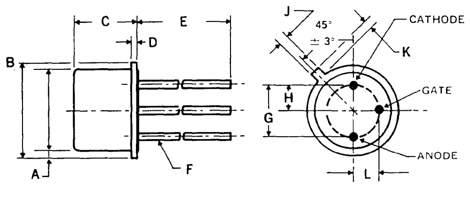
Typical applications include relay equipment, motor controls, process controllers and pulse generators.

ABSOLUTE MAXIMUM RATINGS

	ID200	ID201	ID202	ID203	ID300	ID301
Repetitive Peak Off-State Voltage, V_{DRM}	50V	100V	150V	200V	300V	400V
Repetitive Peak Reverse Voltage, V_{RRM}	50V	100V	150V	200V	300V	400V
Non-Repetitive Peak Reverse Voltage, V_{RSM} (<5ms)	75V	150V	225V	300V	400V	500V
On-State Current, $I_{T(RMS)}$						
70°C Case	1.6A					
75°C Ambient	450mA					
Peak One Cycle Surge (Non-Repetitive) On-State Current, I_{TSM}	15A					
Repetitive Peak On-State Current, I_{TRM}	up to 30A					
Rate of Rise of On-State Current, di/dt	100A/μs					
I^2t (for times > 1.5 ms)	$0.83A^2s$					
Peak Gate Current, I_{GM}	250mA					
Average Gate Current, $I_{G(AV)}$	25mA					
Reverse Gate Voltage, V_{GR}	6V					
Storage Temperature Range	−65°C to +150°C					
Operating Temperature Range	−40°C to +110°C					

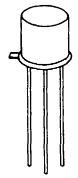
MECHANICAL SPECIFICATIONS

ID200-ID203 ID300-ID301



	ins.	mm.
A	305-.335	7.75-8.51
B	.335-.370	8.51-9.40
C	.240-.260	6.35-6.60
D	.010-.030	.25-.76
E	.5 MIN.	12.70 MIN.
F	$.017 \pm ^{.002}_{.001}$	$.432 \pm ^{.051}_{.025}$
G	.200	5.08
H	.100	2.54
J	.031±.003	.79±.08
K	.029- 045	.74-1.14
L	.100	2.54

TO-205AD (TO-39)



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	Min.	Typ.	Max.	Units	Test Conditions
Off-State Current	I_{DRM}	—	—	10	µA	V_{DRM} = Rating, R_{GK} = 1K, T = 25°C
		—	5	100	µA	V_{DRM} = Rating, R_{GK} = 1K, T = 110°C
Reverse Current	I_{RRM}	—	—	10	µA	V_{RRM} = Rating, R_{GK} = 1K, T = 25°C
		—	10	100	µA	V_{RRM} = Rating, R_{GK} = 1K, T = 110°C
Gate Trigger Current	I_{GT}	—	—	200	µA	V_D = 5V, R_{GS} = 10K, T = 25°C
		—	—	500	µA	V_D = 5V, R_{GS} = 10K, T = −40°C
On-State Voltage	V_{GT}	0.4	0.52	0.8	V	V_D = 5V, R_{GS} = 100Ω, T = 25°C
		0.5	0.7	1.0	V	V_D = 5V, R_{GS} = 100Ω, T = −40°C
		0.2	—	—	V	V_D = 5V, R_{GS} = 100Ω, T = 110°C
Peak On — Voltage	V_{TM}	—	—	2.2	V	I_T = 4 Amp Pulse, T = 25°C
Holding Current	I_H	0.3	0.7	3.0	mA	R_{GK} = 1K, T = 25°C
		0.4	—	6.0	mA	R_{GK} = 1K, T = −40°C
		0.2	—	—	mA	R_{GK} = 1K, T = 110°C
Off-State Voltage — Critical Rate of Rise	dv/dt	—	20	—	V/µs	V_{DRM} = Rated, R_{GK} = 1K, T = 110°C
Turn-on Time	t_{on}	—	1.0	—	µs	I_G = 10mA, I_T = I_A, V_D = 30V, T = 25°C
Circuit Commutated Turn-off Time	t_q	—	—	40	µs	I_T = i_R = 1A, R_{GK} = 1K, T = 25°C

Note: Blocking voltage ratings apply over the full operating temperature range, provided the gate is connected to the cathode through a resistor, 1000 ohms or smaller, or other adequate bias is used.

PUTs

Planar, TO-18 Hermetic

U13T1-U13T2

FEATURES

- Voltage Ratings: to 100V
- Maximum Peak Current: 150nA
- Valley Current: as low as 25 μA
- Low Forward Voltage Drop
- Nano-Amp Leakage
- Hermetically Sealed TO-18 Metal Can

DESCRIPTION

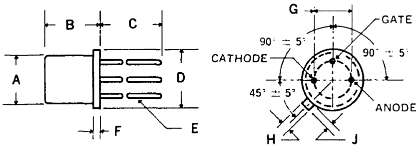
The Unitrode hermetically sealed TO-18 metal can series of programmable unijunction transistors feature blocking voltages to 100V, the highest available to designers. These PUTs are functionally equivalent to standard unijunction transistors, with the added advantages of programming versatility. External resistors can be added to program η, R_{BB}, I_p and I_v, depending upon your design requirements. All units are fully planar passivated. This series features a hermetically sealed TO-18 package for optimum reliability in all environmental conditions. Applications include pulse and timing circuits, SCR trigger circuits, relaxation oscillators, and sensing circuits. For further application information see Unitrode's Application Note U-66.

ABSOLUTE MAXIMUM RATINGS

Anode-to-Cathode Forward Voltage, V_{AK}		40V
Anode-to-Cathode Reverse Voltage, V_{AKR}		40V
Gate-to-Cathode Forward Voltage, V_{GK}		40V
Gate-to-Anode Reverse Voltage, V_{GAR}		40V
Gate-to-Cathode Reverse Voltage, V_{GKR}		5V
Peak Recurrent Forward Current		
	10 μs 1% Duty Cycle	8A
	100 μs 1% Duty Cycle	5A
Power Dissipation		
	25°C Ambient	400mW
	Derating Factor	3.2mW/°C
Storage Temperature Range		−55°C to +150°C
Operating Temperature Range		−55°C to +150°C

MECHANICAL SPECIFICATIONS

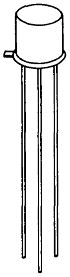
U13T1-U13T2



GATE CONNECTED TO CASE

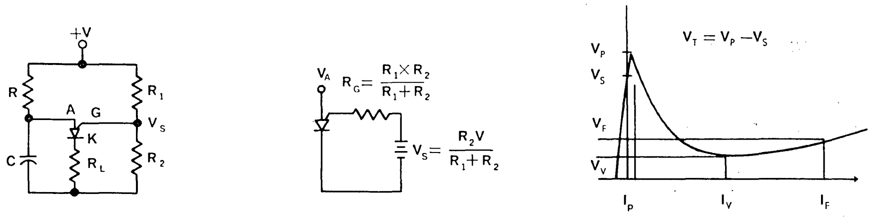
	INCHES	MILLIMETERS
A	.178-.195 DIA.	4.52-4.95 DIA.
B	.170-.210	4.31-5.33
C	.5 MIN.	12.70 MIN.
D	.209-.230 DIA.	5.31-5.84 DIA.
E	.017 ± .002 DIA. .001 DIA.	.432 ± .051 .025
F	.020 MAX.	.508 MAX.
G	.100±.010 DIA..	2.54±.254 DIA.
H	.041±.005	1.04±.127
J	.028-.048	.711-1.22

TO-18



ELECTRICAL SPECIFICATIONS (at 25°C unless noted)

Test	Symbol	Fig.	U13T1		U13T2		Units	Test Conditions
			Min.	Max.	Min.	Max.		
Peak Current	I_P	1	— —	5 2	— —	1.0 0.15	μA μA	$R_G = 10k, V_s = 10V$ $R_G = 1$ Meg.
Valley Current	I_V	1	70 —	— 50	25 —	— 25	μA μA	$R_G = 10k, V_s = 10V$ $R_G = 1$ Meg.
Offset Voltage	V_T	1	0.2 0.2	0.6 1.6	0.2 0.2	0.6 0.6	V V	$R_G = 10k, V_s = 10V$ $R_G = 1$ Meg.
Gate-to-Anode Leakage	I_{GAO}	2	— —	10 100	— —	10 100	nA nA	$T = 25°C, V_s =$ rating $T = 75°C$
Gate-to-Cathode Leakage	I_{GKS}	3	—	100	—	100	nA	$V_s =$ rating
Forward Voltage	V_F	4	—	1.5	—	1.5	V	$I_F = 50mA$
Pulse Output Voltage	V_o	5	6	—	6	—	V	
Pulse Output Rate of Rise	t_r	5	—	80	—	80	nS	



a) Typical Circuit

b) Equivalent Test Circuit

c) Characteristic Curve

Figure 1

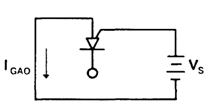


Figure 2

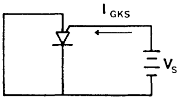


Figure 3

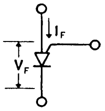


Figure 4

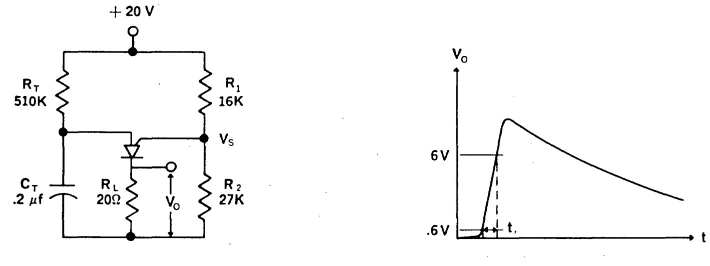
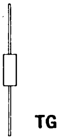


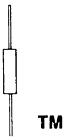
Figure 5

SENSISTORS® 10

SENSISTORS®

PRODUCT SELECTION GUIDE





Type	Resistance Range (Ω)	Resistance Range (R25°C/R125°C)	Tolerance	Package
TG1/8-J	10-10K	0.55±15%	5%	TG
TG1/8-K	10-10K	0.55±15%	10%	TG
TM1/8-J	10-39K	0.55±15%	5%	TM
TM1/8-K	10-39K	0.55±15%	10%	TM
TM1/4-J	10-10K	0.55±15%	5%	TM
TM1/4-K	10-10K	0.55±15%	10%	TM
RTH22 ES-J	10-10K	0.55±15%	5%	TM
RTH22 ES-K	10-10K	0.55±15%	10%	TM
RTH42 ES-J	10-2.7K	0.55±15%	5%	TG
RTH42 ES-K	10-2.7K	0.55±15%	10%	TG

Sensistors® is a registered trademark of Unitrode Corporation.

TYPE NUMBER DESIGNATION **TM1/8272K**

TM 1/8 272 K

STYLE
TM
TG
RTH22 ES
RTH42 ES

WATTAGE
1/8

RESISTANCE VALUE CODE
270 = 27Ω
271 = 270Ω
272 = 2,700Ω
273 = 27,000Ω

TOLERANCE
J = 5%
K = 10%

SENSISTORS®
Positive – Temperature – Coefficient Silicon Thermistors

TG1/8
TM1/8
RTH42
RTH22
TM1/4

FEATURES

- Qualified to MIL-T-23648A
- TG1/8 – Similar to RTH42 (MIL-T-23648A/19)
- TM1/8 – Similar to RTH22 (MIL-T-23648A/9)
- Large Positive Temperature Coefficient ≃ 0.7%/°C
- Wide Resistance Value Ranges Available in 5% or 10% Tolerances

DESCRIPTION

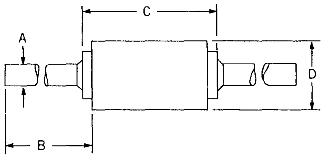
The TG1/8 thermistor is encapsulated in a glass, hermetically sealed package. The TM1/8 and TM1/4 thermistors are encapsulated in a molded package. Both have hot solder-dipped leads and are used in temperature sensing and compensation circuits. They meet or exceed all of the requirements of MIL-T-23648A.

ABSOLUTE MAXIMUM RATINGS

	TG1/8 RTH42	TM1/8 RTH22	TM1/4
Power Dissipation at (or below) 25°C Free-Air Temperature (See Figure 1)	300mW	500mW	500mW
Power Dissipation at (or below) 100°C Free Air Temperature (See Figure 1)	125mW		250mW
Operating Free-Air Temperature Range	−55°C to +125°C		−55°C to +125°C
Storage Temperature Range	−65°C to +150°C		−65°C to +150°C

MECHANICAL SPECIFICATIONS

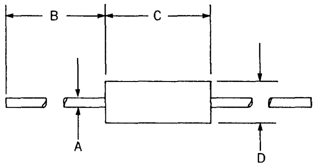
TM1/4 TG1/8
RTH42



	INCHES	MILLIMETERS
A	.020 ± .002	.508 ± .051
B	1.0 MIN.	25.4 MIN.
C	.285 ± .015	7.239 ± .381
D	.095 ± .01	2.413 ± .254

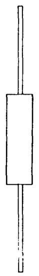
TG

TM1/4 TM1/8
RTH22



	INCHES	MILLIMETERS
A	.025 ± .003	.635 ± .076
B	1.0 MIN.	25.4 MIN.
C	.405 ± .015	10.287 ± .381
D	.14 ± .015	3.556 ± .381

TM



SEMICONDUCTOR PRODUCTS
UNITRODE

ELECTRICAL AND THERMAL CHARACTERISTICS **TG1/8 RTH42** **TM1/8 RTH22** **TM1/4**

Zero Power Resistance Ratio ($R_{25°C}/R_{125°C}$) ....0.55 ± 15% ....
Thermal Time Constant – Typical .... 35s ....
Thermal Time Constant – Maximum .... 60s ....

NOMINAL RESISTANCE AT VARIOUS TEMPERATURES

Standard Zero Power Resistance Value (Ω) at 25°C Free-Air Temperature	Type No.					Resistance (Ω) of Sensistor® at Temperature other than 25°C						
						-55°	-15°C	0°C	50°C	75°	100°C	125°C
10	TG1/8	RTH42	TM1/8	RTH22	TM1/4	6.15	7.9	8.63	11.6	13.5	15.45	17.5
12	TG1/8	RTH42	TM1/8	RTH22	TM1/4	7.38	9.48	10.356	13.92	16.2	18.54	21
15	TG1/8	RTH42	TM1/8	RTH22	TM1/4	9.225	11.85	12.945	17.4	20.25	23.175	26.25
18	TG1/8	RTH42	TM1/8	RTH22	TM1/4	11.07	14.22	15.534	20.88	24.3	27.81	31.5
22	TG1/8	RTH42	TM1/8	RTH22	TM1/4	13.53	17.38	18.986	25.52	29.7	33.99	38.5
27	TG1/8	RTH42	TM1/8	RTH22	TM1/4	16.605	21.33	23.301	31.32	36.45	41.715	47.25
33	TG1/8	RTH42	TM1/8	RTH22	TM1/4	20.295	26.07	28.479	38.28	44.55	50.985	57.75
39	TG1/8	RTH42	TM1/8	RTH22	TM1/4	23.985	30.81	33.657	45.24	52.65	60.255	68.25
47	TG1/8	RTH42	TM1/8	RTH22	TM1/4	28.905	37.13	40.561	54.52	63.45	72.615	82.25
50	TG1/8	RTH42	TM1/8	RTH22	TM1/4	30.75	39.5	43.15	58	67.5	77.25	87.5
56	TG1/8	RTH42	TM1/8	RTH22	TM1/4	34.44	44.24	48.328	64.96	75.6	86.52	98
68	TG1/8	RTH42	TM1/8	RTH22	TM1/4	41.82	53.72	58.684	78.88	91.8	105.06	119
82	TG1/8	RTH42	TM1/8	RTH22	TM1/4	47.724	63.14	69.454	95.94	112.34	129.888	147.6
100	TG1/8	RTH42	TM1/8	RTH22	TM1/4	58.2	77	84.7	117	137	158.4	180
120	TG1/8	RTH42	TM1/8	RTH22	TM1/4	69.84	92.4	101.64	140.4	164.4	190.08	216
150	TG1/8	RTH42	TM1/8	RTH22	TM1/4	87.3	115.5	127.05	175.5	205.5	237.6	270
180	TG1/8	RTH42	TM1/8	RTH22	TM1/4	100.8	135.9	150.84	212.4	252	292.14	334.8
220	TG1/8	RTH42	TM1/8	RTH22	TM1/4	123.2	166.1	184.36	259.6	308	357.06	409.2
270	TG1/8	RTH42	TM1/8	RTH22	TM1/4	151.2	203.85	226.26	318.6	378	438.21	502.2
330	TG1/8	RTH42	TM1/8	RTH22	TM1/4	184.8	249.15	276.54	389.4	462	535.59	613.8
390	TG1/8	RTH42	TM1/8	RTH22	TM1/4	218.4	294.45	326.82	460.2	546	632.97	725.4
470	TG1/8	RTH42	TM1/8	RTH22	TM1/4	263.2	354.85	393.86	554.2	658	762.81	874.2
500	TG1/8	RTH42	TM1/8	RTH22	TM1/4	280	377.5	419	590	700	811.5	930
560	TG1/8	RTH42	TM1/8	RTH22	TM1/4	308	414.4	467.6	672	795.2	927.36	1,075.2
680	TG1/8	RTH42	TM1/8	RTH22	TM1/4	374	503.2	567.8	816	965.6	1,126.08	1,305.6

NOMINAL RESISTANCE AT VARIOUS TEMPERATURES

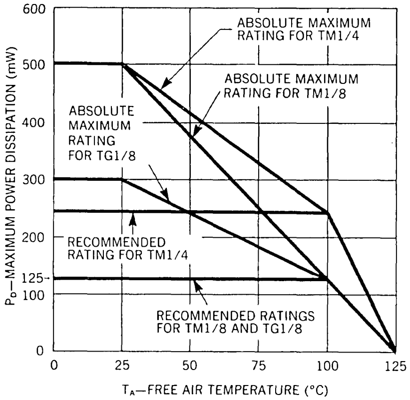
Standard Zero Power Resistance Value (Ω) at 25°C Free-Air Temperature	Type No.					Resistance (Ω) of Sensistor® at Temperature other than 25°C						
						−55°	−15°C	0°C	50°C	75°	100°C	125°C
820	TG1/8	RTH42	TM1/8	RTH22	TM1/4	451	606.8	684.7	984	1,164.4	1,357.92	1,574.4
1,000	TG1/8	RTH42	TM1/8	RTH22	TM1/4	550	740	835	1,200	1,420	1,656	1,920
1,200	TG1/8	RTH42	TM1/8	RTH22	TM1/4	660	888	1,002	1,440	1,704	1,987.2	2,304
1,500	TG1/8	RTH42	—	—	TM1/4	772.5	1,095	1,237.5	1,845	2,175	2,505	2,940
	—	—	TM1/8	RTH22	TM1/4	825	1,110	1,252.5	1,800	2,130	2,484	2,880
1,800	TG1/8	RTH42	TM1/8	RTH22	TM1/4	927	1,314	1,485	2,214	2,610	3,006	3,528
2,200	TG1/8	RTH42	TM1/8	RTH22	TM1/4	1,133	1,606	1,815	2,706	3,190	3,674	4,312
2,700	TG1/8	RTH42	TM1/8	RTH22	TM1/4	1,390.5	1,971	2,27.5	3,321	3,915	4,509	5,292
3,300	TG1/8	—	TM1/8	RTH22	TM1/4	1,699.5	2,409	2,722.5	4,059	4,785	5,511	6,468
3,900	TG1/8	—	TM1/8	RTH22	TM1/4	2,008.5	2,847	3,217.5	4,797	5,655	6,513	7,644
4,700	TG1/8	—	TM1/8	RTH22	TM1/4	2,420.5	3,431	3,877.5	5,781	6,815	7,849	9,212
5,000	TG1/8	—	TM1/8	RTH22	TM1/4	2,575	3,650	4,125	6,150	7,250	8,350	9,800
5,600	TG1/8	—	TM1/8	RTH22	TM1/4	2,884	4,088	4,620	6,888	8,120	9,352	10,976
6,800	TG1/8	—	—	—	TM1/4	3,468	4,964	5,610	8,092	9,520	10,948	12,444
	—	—	TM1/8	RTH22	TM1/4	3,502	4,964	5,610	8,364	9,860	11,356	13,328
8,200	TG1/8	—	TM1/8	RTH22	TM1/4	4,182	5,986	6,765	9,758	11,480	13,202	15,006
	—	—	TM1/8	RTH22	TM1/4	4,223	5,986	6,765	10,086	11,890	13,694	16,072
10,000	TG1/8	—	TM1/8	RTH22	TM1/4	5,100	7,300	8,250	11,900	14,000	16,100	18,300
	—	—	TM1/8	RTH22	TM1/4	5,150	7,300	8,250	12,300	14,500	16,700	19,600
12,000	—	—	TM1/8	—	—	6,180	8,760	9,900	14,760	17,400	20,040	23,520
15,000	—	—	TM1/8	—	—	7,215	10,680	12,210	18,150	21,450	20,050	28,500
18,000	—	—	TM1/8	—	—	8,658	12,816	14,652	21,780	25,740	30,060	34,200
22,000	—	—	TM1/8	—	—	10,582	15,664	17,908	26,620	31,460	36,740	41,800
27,000	—	—	TM1/8	—	—	12,987	19,224	21,978	32,670	38,610	45,090	51,300
33,000	—	—	TM1/8	—	—	15,873	23,496	26,862	39,930	47,190	55,110	62,700
39,000	—	—	TM1/8	—	—	18,759	27,768	31,746	47,190	55,770	65,130	74,100

DEVICE TOLERANCE

The actual resistance of the thermistor at T/°C may vary from the calculated value by an amount not exceeding the tolerances tabulated below.

Temperature	±5%	±10%
(°C)	(J)	(K)
−55	±15%	±20%
−15	±9%	±14%
0	±7%	±12%
25	±5%	±10%
50	±7%	±12%
75	±9%	±14%
100	±12%	±17%
125	±15%	±20%

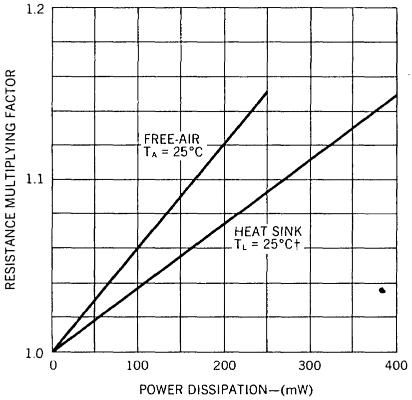
1. Dissipation Derating Curves



TYPICAL CHARACTERISTICS WITH POWER APPLIED

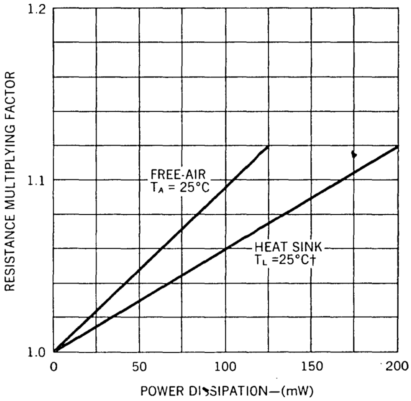
To determine resistance value with power applied, obtain a multiplying factor from the applicable curve below. The free-air curve is for the condition of heat removal by free-air convection only. The heat sink curve is for the maximum cooling rate condition of a heat sink strap, with leads attached to an infinite heat sink. Actual conditions encountered will be between these two extremes. After selecting an applicable multiplying factor from figure 2 or 3, multiply this by the 25°C zero power resistance. This product is then corrected for the actual ambient temperature by use of the appropriate temperature column in the Nominal Resistance at Various Temperatures table.

2. Percent Resistance Change vs Power Dissipation TM1/8 / RTH22 / TM1/4



†T_L is lead temperature measured 1/16 inch from the body.

3. Percent Resistance Change vs Power Dissipation TM1/8 / RTH42 / TM1/4



†T_L is lead temperature measured 1/16 inch from the body.

PART NUMBER DESIGNATION (EXAMPLE)

TM1/8272K

TM 1/8 272 K

STYLE	**WATTAGE**	**RESISTANCE VALUE CODE**	**TOLERANCE**
TM	1/8	270 = 27Ω	J = 5%
TG	1/4	271 = 270Ω	K = 10%
RTH42 ES		272 = 2,700Ω	
RTH22 ES		273 = 27,000Ω	

SURFACE MOUNT DEVICES 11

SURFACE MOUNTABLE POWER SEMICONDUCTORS

DESCRIPTION

The technology generally known as "surface mount" provides an opportunity to achieve several important benefits in many applications. Unitrode's traditional miniature, high power, metallurgically bonded, glass to metal, non-cavity, hermetically sealed axial devices are available as surface mount (MELF) products. Unitrode offers MELF versions of our rectifiers, small signal diodes, zener diodes, transient voltage suppressors and PIN diodes in 3 standard sizes with various ratings.

Unitrode offers bipolar and MOSFET transistors, and PN junction and Schottky rectifiers in ceramic leadless chip carriers. These capabilities are described in detail in the Unitrode Custom Packaging brochure.

A major advantage of this technology over other discrete component assembly methods, and even over some hybrid circuits, is reduction in size of the complete circuit. It is not unusual to achieve a four times reduction in area over a "compactly designed" conventional printed circuit (PC) board, — greater reductions are possible when compared with typical PC, hand wired or brass board designs. Another significant advantage, that of lower assembly cost, and often lower hardware cost, can be achieved with automation in high volume production for the industrial market.

Other benefits result from the inherently small size. Shorter "runs" between components achieve reduced parasitic inductance, resulting in "cleaner" high frequency circuits and switching circuits freer of spurious oscillations and/or voltage transients. Simple, uniform ground planes are readily utilized to decrease radiated electromagnetic interference (EMI) and providing better protection against outside EMI sources.

These improvements do not necessarily come at the cost of thermal properties, in fact, Unitrode's MELF devices have *lower* thermal resistance, junction to case, than equivalent axial types. Hence the current or power rating is enhanced. The conventionally mounted axial device requires heat flow through the leads to reach the mounting surface, thus adding thermal resistance. In the MELF package, low-resistance square end caps are used instead of leads, allowing the heat to reach the "outside world" with minimal resistance. R_θ is shown on the individual data sheets.

In hybrid circuits, the use of a packaged surface mount device (SMD) allows the purchase of a 100% tested component with all parameters guaranteed. This cannot be done for chip components. The advantages of higher hybrid yields and lower overall costs are obvious.

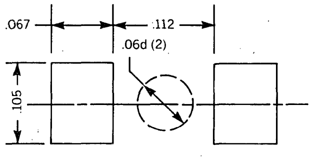
Mounting Considerations

To achieve the benefits noted above it is important to mount the devices in a manner to maintain the inherent reliability. This involves the proper choice of mounting boards or substrates and a suitable assembly process. The axial (glass MELF type) have low expansion coefficients, similar to ceramic leadless chip carriers (CLCC). Plastic chip carriers (PLCC) usually require flexible leads (J or gull-wing) when used on the same circuit board with the other types.

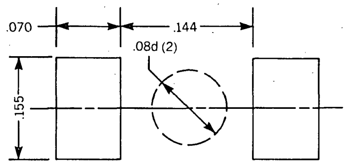
Selection of circuit board material should generally be governed by consideration of thermal-mismatch and power requirements. For Military temperature ranges or applications requiring many thousands of temperature cycles an alumina substrate is advised. A suitable material with even better thermal conductivity is Copper-Invar-Copper triplate with a thin bonded coating of insulating material such as polyimide and printed copper wiring on the component-mounting surface. This material, however, is heavier and more expensive than the alumina. High-reliability industrial or commercial users will find aluminum, coated with similar insulating and conductive wiring, suitable. The cost is considerably less than the triplate material and the ruggedness considerably greater than alumina. Where cost is the primary consideration a low expansion PC board material, such as epoxy-glass, is satisfactory for environments where the temperature range is limited. The trade off here is thermal; thermal resistance is higher than the other materials mentioned so allowable power dissipation is less.

Assembly may be accomplished with wave soldering, vapor phase reflow or infra red reflow assembly techniques. In high power, low thermal resistance (mounting surface to ambient) application the solder joint must be relatively void-free.

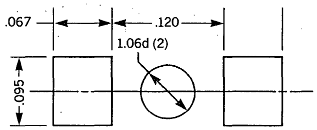
SUGGESTED FOOTPRINTS FOR MOUNTING UNITRODE MELF DEVICES (1)



A-SIZE
(standard small
square end cap outline)



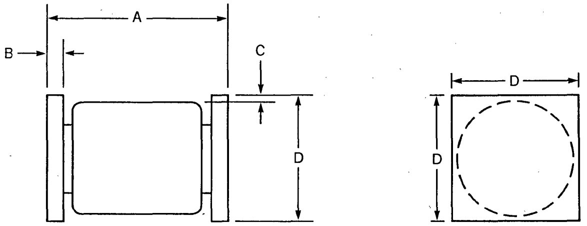
B-SIZE
(standard large
square end cap outline)



D-SIZE
(extra small
square end cap outline)

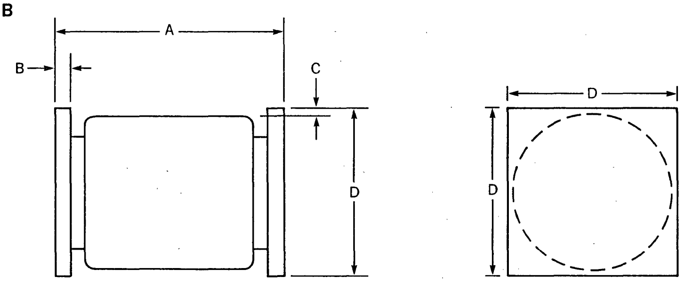
NOTES:
1. These dimensions will match the terminals and provide for additional solder fillets at the outboard ends at least as wide as the terminals themselves, assuming accuracy of device placement within .005 inches.
2. If the mounting method chosen requires use of an adhesive separate from the solder compound, a round (or square) spot of cement as shown should be centrally located.
3. Dimensions shown are in inches.

MELF A



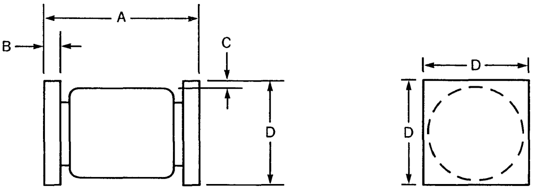
	"A" BODY	
DIM.	MIN.	MAX.
A	.168	.200
B	.019	.028
C	.003	—
D	.091	.103

MELF B



	"B" BODY	
DIM.	MIN.	MAX.
A	.200	.225
B	.019	.028
C	.003	—
D	.137	.148

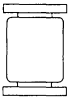
MELF D

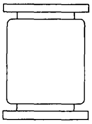


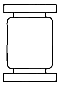
	INCHES		MM	
DIM.	MIN.	MAX.	MIN.	MAX.
A	.165	.195	4.19	4.95
B	.019	.028	0.48	0.71
C	.003	—	0.08	—
D	.070	.085	1.78	2.16

SURFACE MOUNT PACKAGES

Ultra-Fast & Standard Recovery Rectifiers


MELF A


MELF B


MELF D

UNIBOND SWITCHING DIODES

Average DC Output Current	300mA @ TEC = 110°C
Package Style	**Melf D**
150V	1N6638U
100V	1N6642U
75V	1N6643U

These also available as JTX, JTXV.

ULTRA-FAST RECTIFIERS

Average DC Output Current			2A	3A	4A	7A	8A
Package Style			**Melf A**	**Melf A**	**Melf A**	**Melf B**	**Melf B**
Peak Inverse Voltage	50V	t_{rr}	UES1001SM 25ns		UES1101SM SM5802 25ns		UES1301SM SM5807 30ns
	100V	t_{rr}	UES1002SM 25ns		UES1102SM SM5804 25ns		UES1302SM SM5809 30ns
	150V	t_{rr}	UES1003SM 25ns		UES1103SM SM5806 25ns		UES1303SM SM5811 30ns

STANDARD RECOVERY RECTIFIERS

Average DC Output Current		2A	4A	8A
Package Style		**Melf A**	**Melf A**	**Melf B**
Peak Inverse Voltage	200V	SM3611 SM4245	SM5614 SM5615	SM5550 SM5417
	400V	SM3612 SM4246	SM5616 SM5617	SM5551 SM5418
	600V	SM3613 SM4247	SM5618 SM5619	SM5552 SM5419
	800V	SM3614 SM4248	SM5620	SM5553
	1000V	SM4249		

HV PLUS RECTIFIERS

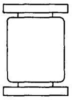
Average DC Output Current			2.25A	3.0A	4.5A	6.0A
Package Style			**Melf A**	**Melf A**	**Melf B**	**Melf B**
Peak Inverse Voltage	200V	V_F t_{rr}		SM6620 UHVP202SM 1.6V @ 2A 30 nSec		SM6626 UHVP402SM 1.5V @ 4A 30 nSec
	400V	V_F t_{rr}		SM6621 UHVP204SM 1.6V @ 2A 30 nSec		SM6627 UHVP404SM 1.5V @ 4A 30 nSec
	600V	V_F t_{rr}		SM6622 UHVP206SM 1.6V @ 2A 30 nSec		SM6628 UHVP406SM 1.5V @ 4A 30 nSec
	800V	V_F t_{rr}	SM6623 UHVP208SM 1.8V @ 1.5A 50 nSec		SM6629 UHVP408SM 1.7V @ 3A 50 nSec	

Contact factory for Rectifiers, Zeners, TVSs, and PINs not displayed in this section.

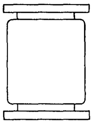
SURFACE MOUNT PACKAGES

PRODUCT SELECTION GUIDE

Power Zeners & Transient Voltage Suppressors



MELF A



MELF B

POWER ZENERS

Power		3W	10W	6W
Package Style		**Melf A**	**Melf B**	**Melf A**
Voltage V_Z (5% Tolerance)	5.6V		SM5968	
	6.2V		SM5969	
	6.8V	SM4461	SM4954	UZ706SM
	7.5V	SM4462	SM4955	UZ707SM
	8.2V	SM4463	SM4956	UZ708SM
	9.1V	SM4464	SM4957	UZ709SM
	10V	SM4465	SM4958	UZ710SM
	11V	SM4466	SM4959	
	12V	SM4467	SM4960	UZ712SM
	13V	SM4468	SM4961	UZ713SM
	14V			UZ714SM
	15V	SM4469	SM4962	UZ715SM
	16V	SM4470	SM4963	UZ716SM
	18V	SM4471	SM4964	UZ718SM
	20V	SM4472	SM4965	UZ720SM
	22V	SM4473	SM4966	UZ722SM
	24V	SM4474	SM4967	UZ724SM
	27V	SM4475	SM4968	UZ727SM
	30V	SM4476	SM4969	UZ730SM
	33V	SM4477	SM4970	UZ733SM
	36V	SM4478	SM4971	UZ736SM
	39V	SM4479	SM4972	
	40V			UZ740SM
	43V	SM4480	SM4973	
	45V			UZ745SM
	47V	SM4481	SM4974	
	50V			UZ750SM
	51V	SM4482	SM4975	
	56V	SM4483	SM4976	UZ756SM
	60V			UZ760SM
	62V	SM4484	SM4977	

POWER ZENERS

Power		3W	10W	6W
Package Style		**Melf A**	**Melf B**	**Melf A**
Voltage V_Z (5% Tolerance)	68V	SM4485	SM4978	
	70V			UZ770SM
	75V	SM4486	SM4979	UZ775SM
	80V			UZ780SM
	82V	SM4487	SM4980	
	90V			UZ790SM
	91V	SM4488	SM4981	
	100V	SM4489	SM4982	UZ110SM
	110V	SM4490	SM4983	UZ111SM
	120V	SM4491	SM4984	UZ112SM
	130V	SM4492	SM4985	UZ113SM
	140V			UZ114SM
	150V	SM4493	SM4986	UZ115SM
	160V	SM4494	SM4987	UZ116SM
	170V			UZ117SM
	180V	SM4495	SM4988	UZ118SM
	190V			UZ119SM
	200V	SM4496	SM4989	UZ120SM
	220V		SM4990	UZ122SM
	240V		SM4991	UZ124SM
	260V			UZ126SM
	270V		SM4992	
	280V			UZ128SM
	300V		SM4993	UZ130SM
	320V			UZ132SM
	330V		SM4994	
	340V			UZ134SM
	360V		SM4995	UZ136SM
	380V			UZ138SM
	390V		SM4996	
	400V			UZ140SM

TRANSIENT VOLTAGE SUPPRESSORS

Part No.			Stand-Off Voltage V_R	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA	Max. Peak Pulse Current I_{PP}	Max. Clamping Voltage V_C @ I_{PP}	Peak Power for lmS
			(V)	(V)	(A)	(V)	(W)
Package Style	Melf B	SM6461	5.0	5.6 @ 25mA	56	9	500
		SM6462	6.0	6.5 @ 20mA	46	11	
		SM6463	12.0	13.6 @ 5mA	22	22.6	
		SM6464	15.0	16.4 @ 5mA	19	26.5	
		SM6465	24.0	27.0 @ 2mA	12	41.4	
		SM6466	30.5	33.0 @ 1mA	11	47.5	
		SM6467	40.3	43.7 @ 1mA	8	63.5	
		SM6468	51.6	54.0 @ 1mA	6	78.5	

Contact factory for Rectifiers, Zeners, TVSs, and PINs not displayed in this section.

APPLICATION NOTES 12

TABLE OF CONTENTS—Application Notes

POWER SUPPLY DESIGN

APPLICATION NOTE U-68A

SWITCHING REGULATOR DESIGN GUIDE

I. The Advantages of the Switching Regulator

Unlike conventional "dissipative" series or shunt regulators, in which the power-regulating transistor operates in a continuous-conduction mode, dissipating large amounts of power at high load currents – especially when the input-output voltage difference is large – the switching regulator has high efficiency under all input and output conditions. Furthermore, since the power-transistor "switch" is always either cut off or saturated (except for a very brief transition between those two states), the switching regulator can achieve good regulation despite large changes in input voltage, and maintains high efficiency over wide ranges in load current.

Because the switching regulator regulates by varying the ON-OFF duty cycle of the power-transistor switch, and the switching frequency can be made very much higher than the line frequency, the filtering elements used in the power supply can be made small, lightweight, low in cost, and very efficient – i.e., with almost negligible power losses. It is possible to drive the switching regulator with very poorly filtered DC (in fact, in high-power applications, three-phase rectification *without* filtering of any kind is often used to develop the input DC from the power line), thereby eliminating large and expensive line-frequency filtering elements.

Finally, it is possible to design switching regulators with excellent load-transient properties, so that step increases of load current cause relatively small instantaneous changes in output voltage, recovery from which is essentially completed in a few hundred microseconds.

The switching regulator has become increasingly popular in new-equipment designs, not only in aerospace and defense applications, but in computers, industrial process control systems, instrumentation, and communication.

Compared to the dissipative regulator, the switching regulator does have some disadvantages which preclude its use in some applications. The primary power source delivers current to the switching regulator in pulses which, for efficiency reasons, have short rise and fall times. In those applications where a significant series impedance appears between the supply and the regulator, the rapid changes in current can generate considerable noise. This problem can be reduced by reducing the series impedance, increasing the switching time, or by filtering the input to the regulator.

A second problem of the switching regulator, compared to the dissipative regulator, is its response time to rapid changes in load current. The switching regulator will reach a new equilibrium only when the average inductor current reaches its new steady-state value. In order to make this time short, it is advantageous to use low inductor values, or else to use a large difference between the input and output voltage.

Improved circuits for controlling switching regulators have been developed at Unitrode, thereby eliminating some earlier design constraints and optimizing the performance attainable with available hardware. These new circuits permit taking full advantage of the economy and efficiency of the Unitrode PIC600 Series Hybrid Power Switch.

The design approach used herein is believed to be original, and to be clearly superior to earlier methods of calculating the key parameters and designing the power inductor . . . yielding explicit, accurate results in significantly less time than the approximate equations in common use.

SEMICONDUCTOR PRODUCTS
UNITRODE

II. The Switching Regulator Described and Characterized

The basic configuration of a switching regulator is shown in Figure 1. It accepts a DC voltage input, Ein, and regulates a DC ouput voltage, Eo, despite variations in Ein and load current. Although the static regulation, dynamic regulation, and ripple rejection of this type of regulator cannot be as easily optimized as they can in a continuous (so-called "dissipative") series regulator, its efficiency, power density (Watts output per cubic inch) and economy are all markedly superior to the series regulator . . . particularly for low-voltage, high-current supplies. Unlike a series regulator, it maintains high efficiency with high input voltages. Switching regulators can thus be employed with high efficiency to derive low voltage outputs from a high voltage unregulated supply.

All of these advantages derive from the method of regulating the output voltage: *by varying the duty cycle of a power-transistor switch,* rather than varying the voltage drop across a power transistor operating in the linear mode. Because the switch (Q1 in Figure 1) is always in the saturated state when it is conducting, and is otherwise completely non-conducting (except for a brief commutation time between the ON and OFF states), the power dissipated in the regulator is much lower than it would be in a series regulator for the same input and output conditions.

The basic switching regulator circuit functions as follows:

The control circuit causes transistor switch, Q1, to switch on and off at a predetermined frequency, f. During the time that Q1 is on, t_{on}, the input voltage, Ein, is applied to the input of the LC filter, causing current i_1 to increase. When Q1 is off, the energy stored in the inductor, L, maintains current flow to the load, circulating through "catch" diode D1. The input of the LC filter is now at zero Volts, i_1 decreases to its original value and the cycle repeats.

The output voltage, Eo, will equal the time average of the voltage at the input of the LC filter:

$$Eo = Ein\ t_{on}/\tau$$

where: $\tau = 1/f$

The control circuit senses and regulates Eo by controlling the duty cycle, $\alpha = t_{on}/\tau$. If Ein increases, the control circuit will cause a corresponding reduction in the duty cycle, α, so as to maintain a constant Eo.

$$Eo = \alpha\ Ein$$

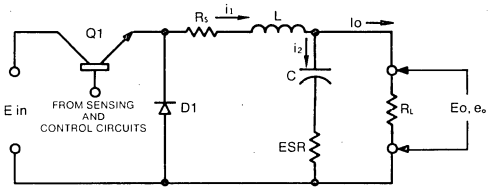
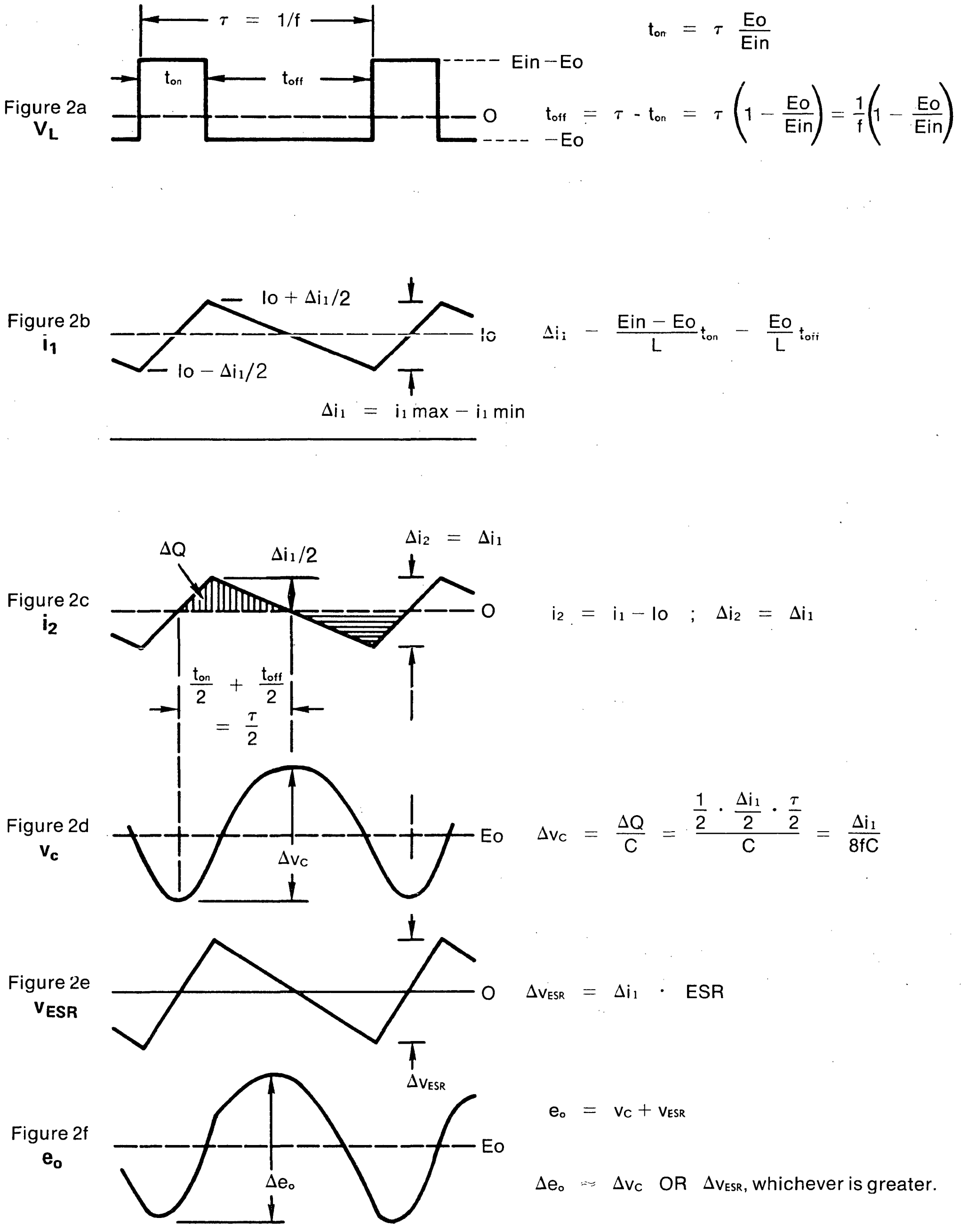


Figure 1. Switching Regulator Basic Configuration



$$t_{on} = \tau \frac{Eo}{Ein}$$

$$t_{off} = \tau - t_{on} = \tau\left(1 - \frac{Eo}{Ein}\right) = \frac{1}{f}\left(1 - \frac{Eo}{Ein}\right)$$

$$\Delta i_1 = \frac{Ein - Eo}{L} t_{on} = \frac{Eo}{L} t_{off}$$

$$\Delta i_1 = i_1 \max - i_1 \min$$

$$i_2 = i_1 - Io \; ; \; \Delta i_2 = \Delta i_1$$

$$\Delta V_C = \frac{\Delta Q}{C} = \frac{\frac{1}{2} \cdot \frac{\Delta i_1}{2} \cdot \frac{\tau}{2}}{C} = \frac{\Delta i_1}{8fC}$$

$$\Delta V_{ESR} = \Delta i_1 \cdot ESR$$

$$e_o = V_C + V_{ESR}$$

$\Delta e_o \approx \Delta V_C$ OR ΔV_{ESR}, whichever is greater.

NOTE: See Appendix A for rigorous analysis and justification

Figure 2. Switching Regulator Waveforms

Figure 2 shows some of the important waveforms and equations which define the operation of the switching regulator power circuit. The following discussion is based on several simplifying assumptions which are explained and justified or corrected in Appendix A. The most significant assumptions are to neglect the saturation voltage of Q1, the forward drop of D1, and the series loss resistance, R_S, of the inductor, L.

Figure 2a shows the voltage across inductor, L, which equals (Ein − Eo) during t_{on} and (−Eo) during t_{off}. Under equilibrium conditions, when output load current, Io, is constant, the average voltage across L must, by definition, equal zero.

Figure 2b shows the current i_1 through the inductor. Under equilibrium output current conditions, the increase in current during t_{on}, Δi_1, must equal the decrease in current during t_{off}. The average value of i_1 equals the output current, Io.

Figure 2c shows current i_2 through the capacitor, which is equal to (i_1 − Io). The average value of $i_2 = 0$, and $\Delta i_2 = \Delta i_1$. Current i_2 causes a ripple voltage to appear at the output. The output ripple voltage, e_o, has two components, a capacitive component, v_C, and a resistive component, v_{ESR}, caused by the equivalent series resistance of the capacitor.

Figure 2d shows the capacitive component, v_C, of the ripple voltage, which is the time integral of the capacitor current, i_2. Note that v_C is the integral of a triangular wave, and is not sinusoidal. Also note that v_C is in "quadrature" with i_2, in the sense that v_C min and v_C max occur at times A and B, midway in the t_{on} and t_{off} intervals, when i_2 is zero. The total charge, ΔQ flowing into C is computed graphically by finding the area of the triangular current waveform between time A and time B (Area = ½ bh; $\Delta Q = \frac{1}{2} \times \tau/2 \times \Delta i_2/2$). The peak to peak capacitive ripple component $\Delta v_C = \Delta Q/C = \Delta i_1/8fC$. (The factor 8f for a triangular current waveform is comparable to $2\pi f$ for a sinusoidal input current.)

Figure 2e shows the resistive component, v_{ESR}, of the ripple voltage which simply equals $i_2 \times$ ESR, and is in phase with i_2.

Figure 2f, the total output ripple voltage, e_o, is the sum of the waveforms in Figures 2d and 2e. Note that since v_C and v_{ESR} are in quadrature, the greater of these two components dominates, and for all practical purposes the peak to peak output ripple voltage, Δe_o, is equal to either Δv_C or Δv_{ESR} whichever is greater.

The magnitude of v_{ESR} in comparison with v_C shown in these waveforms is not exaggerated. Indeed, when designing a switching regulator to operate at frequencies greater than 20 kHz in order to achieve small size and low cost in the L and C filter elements, the ESR of the capacitor usually dominates completely. Even when high quality capacitors (low ESR) are employed, it is usually necessary to use a larger capacitance value than would otherwise be required in order to realize the ESR required to achieve the ripple objective of the design.

With conventional free running switching regulator control circuits, capacitor ESR also causes very significant departure from the design frequency, which can result in large ripple magnitude, inductor saturation, and switching transistor failure. In the circuits developed at Unitrode and presented in the next section, the frequency-variation effect caused by ESR is effectively eliminated, leaving only the ripple consideration.

Detailed design considerations for switching regulator power circuits are contained in Section IV.

III. Applications Circuits for Switching Regulators

The design and performance of conventional switching regulators are usually dominated by the ESR of the output capacitor. However, in the group of circuits described in this section, the following parametric relationships and circuit characteristics are easily and economically attained:

- The switching frequency may be selected and established at the optimum value for the switching components, and *will be independent of the value of the ESR of the output capacitor.*
- The value of t_{off} is held relatively constant, over wide ranges of load current and input voltage, and independent of the ESR of the output capacitor. Constant t_{off} results in constant ripple current and output ripple voltage.
- Settable overcurrent limiting is provided, thereby protecting both the load and the switching transistors under all conditions, and preventing saturation of the power inductor during the startup transient period, thereby minimizing startup overshoot.
- The overcurrent limiting circuit is significantly lower in dissipation than conventional current-limit-feedback arrangements.
- The drive current to the power output (switch) stage is regulated to a pre-determined value, for best efficiency and optimum switching speed. Drive current is automatically increased at low temperatures and decreased at high temperatures, thereby maintaining optimum drive conditions for the power switch.

Note that, although the use of this circuit approach permits essentially constant "t_{off}" operation even with capacitors having relatively high ESR, the output ripple voltage is increased by high ESR. (If the ripple developed across ESR is significantly larger than that developed across C, then the ripple is essentially proportional to ESR.)

Not all of the circuits that follow have all of the virtues listed above, but the exceptions will be noted. Figure 3 typifies this family of regulators. It is shown implemented by the popular LM305 regulator IC, and a Unitrode Series PIC600 Hybrid Power Switch, comprising a quasi-Darlington switching transistor, a fast recovery catch diode, and transistor bias resistors, all matched for optimum efficiency and switching speed (up to 100 kHz without derating). The configuration of Figure 3 is a *positive* output regulator, with performance characteristics as follows:

Ein = 20 to 40V
Eo = 5V ± 1%
Δe_o = 100 mV p-p (2% p-p ripple)
Io = 2 to 10A
Isc = 12A
Regulation versus Ein (20 to 40V) <25 mV
Transient Recovery Time for step change in load current from 2A to 10A, or 10A to 2A <150 μsec.
f = 50 kHz nominal
Efficiency >70%

The circuit of Figure 3 operates in the fixed-off-time mode; hence, output ripple is independent of input voltage over wide ranges. In this circuit, two feedback signal paths are provided:

- *DC Feedback.* A fraction of the DC output voltage, Eo, is fed back to the inverting input of the LM305 through voltage divider R1, R2. The DC voltage at the inverting input is compared to a reference voltage (approximately 1.8V) within the LM305, and the LM305 regulates Eo so that the voltage fed back to the inverting input is essentially equal to the built in reference voltage. The R1, R2 divider ratio therefore establishes the level of the DC output voltage, Eo. Resistor R5 improves output voltage regulation versus input voltage changes by feeding a small compensating voltage proportional to the input voltage into the inverting input of the LM305.

- *AC Feedback.* Capacitor C1 feeds back an AC voltage waveform to the inverting input of the LM305. This voltage is proportional to the output ripple voltage plus the AC voltage developed across R_l, $\Delta e_o + \Delta v_{Rl}$.

  Capacitor C2 feeds back an AC voltage to the non-inverting input of the LM305. This voltage is proportional to the output ripple voltage plus the AC voltage across R3, $\Delta e_o + v_{R3}$.

When the circuit values are properly established, the same fraction of Δe_o is fed back to both inverting and non-inverting inputs, thereby effectively cancelling. The operation of the switching regulator is thus rendered independent of the output ripple voltage developed across the C or ESR of the output capacitor.

Since the Δe_o components cancel each other, the LM305 essentially compares Δv_{Rl} at the inverting input to Δv_{R3} at the non-inverting input. Voltage Δv_{R3} is a rectangular waveform with a peak-to-peak amplitude equal to I drive × R3, where I drive is the base drive to the hybrid switching transistor provided by the LM305, and Δv_{Rl} is a triangular waveform with a peak-to-peak amplitude equal to $\Delta i_1 \times R_l$, where Δi_1 is the ripple current through inductor L. When the drive current is on, Δv_{R3} is at its peak positive amplitude. As i_1 increases, v_{Rl} increases proportionately. When the positive amplitude of Δv_{Rl} reaches Δv_{R3}, this causes the LM305 to switch off the drive current, Δv_{R3} immediately drops to its peak negative amplitude, and i_1 starts to fall. When Δv_{Rl} reaches a negative amplitude equal to Δv_{R3}, the LM305 switches the drive current back on, and the process repeats. In this manner, the LM305 controls the power switch so that Δi_1 is fixed. Since $t_{off} = \Delta i_1 \times L/Eo$, with fixed values of L and Eo, t_{off} is fixed and independent of changes in Ein or capacitor C or ESR values.

R4, connected between pins 1 and 8 of the LM305, establishes the desired level of base drive for the PIC600 Series Hybrid Power Switch, and determines the hysteresis voltage across R3.

Current-limiting action is provided by transistor Q1, the collector of which is connected to the "gate" or "inhibit" terminal of the LM305 (pin 7). When the load current is normal, Q1 is cut off and pin 7 floats; but when the voltage drop across R_l increases to a value greater than the sum of V_{BE} (Q1) and v_{R3}, Q1 turns on, cutting off the drive current from the LM305 and, ultimately, the power switch. This cutoff action is made to "latch" by the fact that, with the drive cut off, v_{R3} disappears. This keeps Q1 on, until the current through R_l drops significantly – enough to make the voltage drop across R_l fall below the V_{BE} of Q1.

The current through R_l, following such an overload cutoff action, falls linearly at the rate of Eo/L. When Q1 is cut off, drive current is restored. The circuit will then continue to switch on and off at a frequency comparable to normal operation, with the average current limited at the design limit, and power dissipation held to safe values.

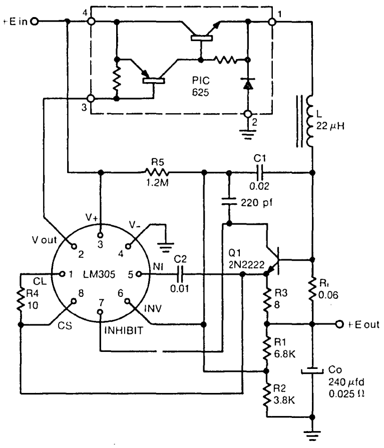


Figure 3. Positive Voltage Switching Regulator

Transient response of the switching regulator of Figure 3 is shown in Figures 4, 5, and 6.

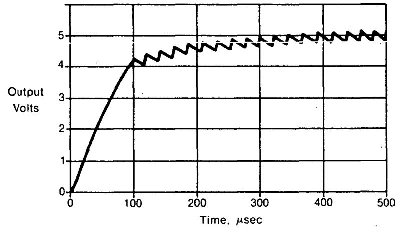


Figure 4. Ein from 0 to 25V

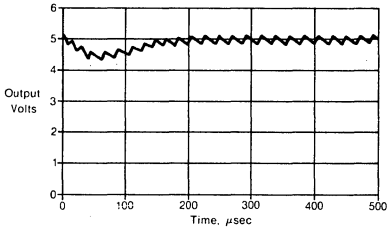


Figure 5. Io from 4A to 10A

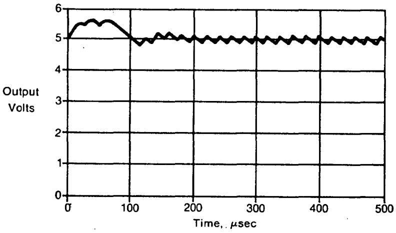


Figure 6. Io from 10A to 4A

It is usually necessary to employ a noise filtering capacitor across the input of any switching regulator. This functions to prevent the steep waveform of the rectangular current pulse associated with the power switch turning on and off from propagating into the Ein supply line. The capacitance value required is a function of the impedance characteristics of the Ein supply and intervening wiring. Watch out for underdamped resonance with the inductance of the input wiring, or transient induced ringing may occur. The input capacitor must have short leads, and the ground side should preferably be connected directly to the ground side of the output filter capacitor.

A 10A negative voltage switching regulator, utilizing an LM304 and PIC600 series, is shown in Figure 7.

A reference voltage is determined by resistor R1 and R2. The error amplifier controls the output voltage at twice the voltage across R2. Diode D1 is used to ensure a potential difference of less than 2V at the unregulated input (pin 5) with respect to the reference supply (pin 3). (If the unregulated supply terminal gets more than 2V positive with respect to reference supply, the collector isolation junction of transistor Q6 of LM304 becomes forward biased and disrupts the reference.)

Current limiting is achieved, in Figure 7, by means of reducing the reference voltage to ground with the help of transistor Q1 and resistor R8, instead of turning off the base drive to the power output switch as in Figure 3.

The functions of the rest of the components and the operation of the switching regulator are the same as described for Figure 3.

A positive switching regulator using a μA723 is shown in Figure 8.

The basic performance and circuit operation is the same as Figure 3.

The circuit shown in Figure 9 is a high voltage positive switching regulator. Because the LM305 (like almost all IC regulators) cannot be operated at supply voltage in excess of 40V, this circuit uses a fraction of Ein as a power supply for the IC circuit by means of zener diode and current limiting resistor R9. The voltage isolation between LM305 and power switch, and the regulated base drive to the power switch are provided by transistor Q2.

The basic operation of the circuit and design approach is the same as that of a low voltage positive switching regulator.

The circuit shown in Figure 10 is a negative high voltage switching regulator.

This circuit is similar to the low voltage negative switching regulator with a minor modification. Transistor Q2, resistor R10 and R11 are all used to provide regulated base drive to the power output stage and also to provide the voltage isolation between power output stage and LM305. The resistor R9 is used to limit current through zener diode under steady state and startup conditions.

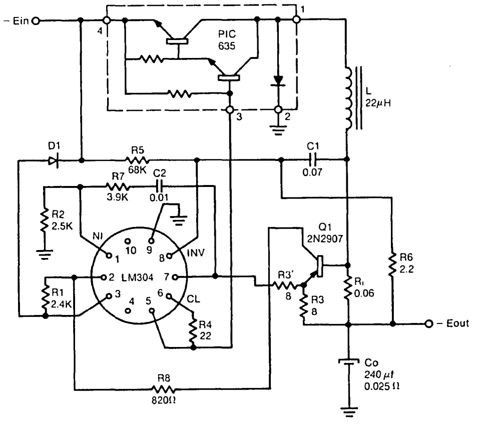


Figure 7. Negative Voltage Switching Regulator

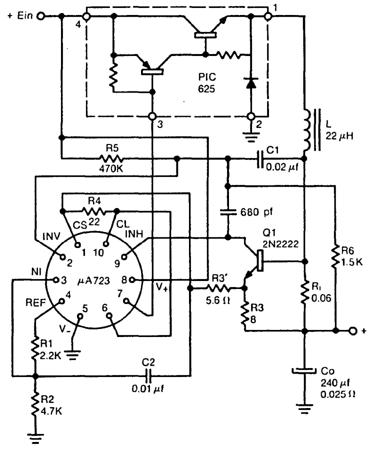


Figure 8. Positive Voltage Switching Regulator

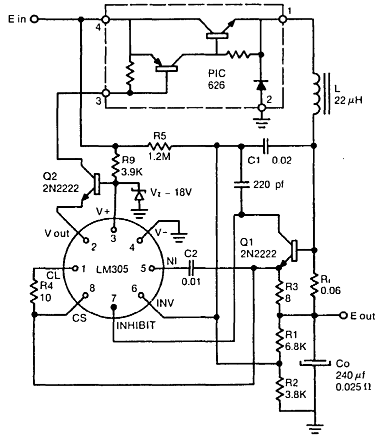


Figure 9. High Voltage Positive Switching Regulator

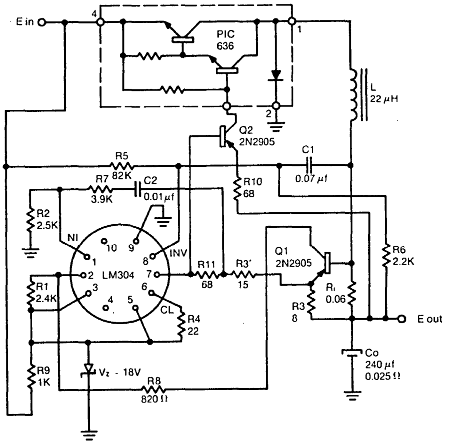


Figure 10. High Voltage Negative Switching Regulator

IV. Designing the Power Circuit

In designing a switching regulator power supply, the following parameters will normally be predefined. Specific values shown for each parameter will be used as the basis for a design example:

Eo = 5V Output Voltage
Δe_o = 100 mV Output Ripple Voltage, Peak to Peak
Io max = 10A Output Current, Full Load
Io min = 2A Output Current, Minimum Load
Ein max = 40V Input Voltage, Maximum
Ein min = 20V Input Voltage, Minimum

The first step in the design is to decide on the operating frequency of the switching regulator. No concrete rules can be given for this decision.

High frequency operation is distinctly advantageous in that the cost, weight and volume of both L and C filter elements are reduced. However, above the frequency where the capacitor ESR exceeds its capacitive reactance, no further reduction in capacitor size or cost will occur. This frequency, in the range of 1-50 kHz, depends upon the "quality" of the capacitor in terms of ESR. Above this frequency, the inductor will continue to diminish in size and cost, although when the inductor reaches a very small size, cost will level off.

Operation above 20 kHz is desirable to eliminate the possibility of audio noise.

The main factor limiting high frequency operation is the drop in efficiency caused by switching losses in the power switching transistor and "catch" diode. The higher cost of these fast switching semiconductors required to operate efficiently at high frequencies must be weighed against the reduced cost, size and weight of the L and C components to arrive at the optimum frequency for any specific application. It may be desirable to work the design through at several frequencies in order to make a decision.

In the specific application defined at the beginning of this section, the power output (Eo × Io max) is 50W. Referring to the specification for the Unitrode PIC 625/635 Hybrid Power Switch, the DC losses (Transistor V_{CEsat}, Diode V_F) under the conditions of this application amount to 10W. The following tabulation shows the switching losses and overall efficiency at several frequencies.

Frequency	**1 kHz**	**20 kHz**	**50 kHz**	**100 kHz**
Power output	50	50	50	50
DC losses	10	10	10	10
Switching losses	0.05	1	2.5	5
Total power input	60.05	61	62.5	65
Realizable efficiency	83.3%	82%	80%	77%

For our example, we will choose a frequency of 50 kHz, even though the efficiency is not significantly reduced at 100 kHz. At 100 kHz most currently available tantalum and aluminum electrolytic capacitors begin to exhibit series inductance.

Transistors and diodes which do not have the fast switching capabilities of the PIC 625/635 will become efficiency limited at much lower frequencies. Note that in this specific application, a dissipative regulator design will incur power losses in the series transistor of 350W, resulting in an efficiency of 12.5 percent!

The control circuits shown in the previous section control the on-off switching periods by sensing and controlling the ripple current, Δi_1, through the inductor L. This mode of operation results in a constant ripple current and (assuming Eo and L are fixed) constant off time, t_{off}, independent of input voltage. The relationship between t_{off}, f, Eo, and Ein is as follows (from Figure 2a):

$$t_{off} = (1 - Eo/Ein) / f$$

With t_{off} and Eo fixed by the control circuit, f will change when Ein changes, and f will be maximum when Ein is maximum. In our specific example,

f max = 50 kHz
Ein max = 40 V
Eo = 5V

so that:

$$t_{off} = (1 - 5/40) \;/\; 50{,}000 = 17.5\,\mu sec$$

Now, with t_{off} fixed at 17.5 μsec, if Ein changes to Ein min = 20V,

$$f_{min} = \frac{(1 - Eo/Ein)}{t_{off}} = \frac{(1 - 5/20)}{17.5 \times 10^{-6}} = 43\text{ kHz}$$

The fact that the frequency changes slightly with Ein is really not important, as stated earlier, because constant t_{off} operation results in more constant output ripple than constant frequency operation.

Having determined (or assumed) the maximum operating frequency and calculated t_{off}, we next proceed to find specific values for L and C. L and C together form a low pass filter which reduces the rectangular waveform at the filter input to a DC output voltage, Eo, with a small amount of ripple, Δe_o, superimposed. To achieve a specified Δe_o requires a specific LC product, independent of load current. Theoretically, this LC product can be achieved with any L/C ratio – small L and large C, or large L and small C (or very large L and no C at all, using instead the load resistance R_L as one element of an L/R filter). There are, however, several practical economic and performance considerations that apply to selecting specific L and C values.

It is favorable to push in the direction of small L and large C for the following reasons:

1. Under the power and frequency ranges commonly encountered in switching regulator circuits, it costs more to store energy in an inductor than in a capacitor. Also, an inductor will have considerably greater weight and volume than a capacitor with equal energy storage capacity. Small L and large C, within the limits defined below, will usually result in the lowest cost, weight and size design.
2. Small L and large C results in low "surge impedance" of the filter, hence better transient behavior with step changes in load current.
3. Losses in a practical inductor are higher than in a capacitor with equal energy storage capacity (assuming low ESR). This again argues for small L, large C.

One major objection to a low L/C ratio is that it causes large and sometimes intolerable overshoot in input current and output voltage on startup, when the circuit is first energized. Input current overshoot can saturate the inductor and destroy the switching transistor. The current limiting feature of the applications circuits shown in Section III effectively controls the startup transient, thereby protecting all components and minimizing voltage overshoot. With current limiting, this problem is eliminated and no longer pertains to the selection of L and C values.

Referring to Figure 2b and its associated equations, the peak-to-peak ripple current through the inductor, Δi_1, is inversely proportional to the inductance, L. As L is made smaller, Δi_1 increases. Maximum limits on Δi_1 determine how small L is permitted to be, as follows:

1. The instantaneous current through L ranges between a maximum of $Io + \Delta i_1/2$ and a minimum of $Io - \Delta i_1/2$. If $\Delta i_1/2$ is permitted to become larger than Io, the minimum inductor current becomes a negative value. This is impossible, since neither the switching transistor nor the "catch" diode will conduct. Therefore, the switching regulator goes into a discontinuous mode of operation which is perfectly safe, but the frequency changes considerably and regulation with output current changes becomes relatively poor. The worst case consideration to insure that discontinuous operation does not occur is to make $\Delta i_1/2$ equal to the *minimum* load output current, Io min, or $\Delta i_1 = 2\ Io\ min$.

   It is not practical to apply this criterion if Io min is very small (<0.05 Io max) because Δi_1 would then be very small, forcing an impractically large L value. In applications where Io min is very small, there are two alternatives: (a) raise Io min by preloading the supply, or (b) make $\Delta i_1 = 2(0.05$ Io max$) = 0.1$ Io max realizing that when Io becomes less than 0.05 Io max, the discontinuous mode will occur.

2. The maximum peak current is equal to the full load current, Io max $+ \Delta i_1/2$. As L is decreased, the corresponding increase in Δi_1 will begin to cause a significant increase in the maximum peak current. Since the inductor must be designed not to saturate at the maximum peak current, this begins to negate the cost, size and weight advantages of making the L value smaller. Higher peak currents will have an adverse effect on efficiency and transistor drive requirements, and may require transistor and "catch" diodes with higher current ratings (and higher cost). It is, therefore, recommended that $\Delta i_1/2$ be no greater than 0.25 Io max, which will limit the maximum peak current to 1.25 Io max, or Δi_1 max $= 0.5$ Io max.

In summary:

Δi_1 = 2 Io min, within the following somewhat arbitrary limits:

Δi_1 min = 0.1 Io max

Δi_1 max = 0.5 Io max

In our example, Io min = 2A, Io max = 10A. Calculating $\Delta i_1 = 2$ Io min $= 4$A, which is acceptable since Δi_1 max $= 0.5 \times 10$A $= 5$A, and Δi_1 min $= 0.1 \times 10$A $= 1$A.

Now that t_{off} and Δi_1 have been determined, L can be calculated as follows:

$$L = \frac{Eo \times t_{off}}{\Delta i_1} = \frac{5 \times 17.5 \times 10^{-6}}{4} = 21.9\,\mu H$$

The final step is to determine the requirements for the capacitor C and ESR values which will result in the desired output ripple voltage, Δe_o. Since the two components of Δe_o : Δv_C and Δv_{ESR}, are in "quadrature", we can consider each component separately, with a worst case error of less than 20 percent when both components are equal. This much error is highly unlikely, since the ESR component usually dominates completely when operating at high frequencies.

From Figure 2d:

$$C = \frac{\Delta i_1}{8f\,\Delta v_C}$$

note that C varies inversely with f. In order to achieve Δv_C less than the desired maximum Δe_o, the minimum value for C must be determined at the lowest frequency, f_{min}, calculated previously.

$$\begin{aligned} C\ min &= \frac{\Delta i_1}{8f_{min}\,\Delta e_o\ max} \\ &= \frac{4}{8 \times 43 \times 10^3 \times 100 \times 10^{-3}} \\ &= 114\,\mu F \end{aligned}$$

From Figure 2e:

$$\begin{aligned} ESR\ max &= \frac{\Delta v_{ESR}}{\Delta i_1} = \frac{\Delta e_o\ max}{\Delta i_1} \\ &= \frac{100 \times 10^{-3}}{4} \\ &= 0.025\Omega \end{aligned}$$

With high frequency operation, capacitor ESR usually dominates, forcing the use of a C value much greater than C min in order not to exceed ESR max.

Subsequent sections deal with designing the inductor and selecting the capacitor and other components of the switching regulator.

V. Design of the Power Inductor

This simplified nomographic method facilitates selecting the smallest core that will achieve the desired characteristics of the power inductor. This procedure is useful in selecting the proper core and determining wire size, number of turns, copper losses, and temperature rise. It also permits investigating the effects of change in assumed initial conditions and in "trimming" the design.

A detailed analysis of this inductor design procedure is contained in Appendix B.

Tables 1 and 2 give core parameters for a variety of commonly used ferrite pot cores and Mo-Permalloy toroids. (Note: There is no significance to the selection of manufacturers, nor is any intended. Many manufacturers make roughly equivalent cores in these sizes, with similar magnetic properties.)

Ferrite and Mo-Permalloy powder are excellent core materials for the switching regulator inductor. Since the rms AC current through the inductor is small compared to the DC current, AC losses in the winding and core losses will be negligible compared with DC winding losses.

Selection of the proper core for a specific application is a process concerned with two factors: (1) The core must provide the desired inductance without saturating magnetically at the maximum peak overload current, i_1 max. In this respect each core has a specific $(LI^2)_{sat}$ energy storage capability. (2) The core must have a window area for the winding which admits the number of turns necessary to obtain the required inductance with a wire size which will result in acceptable DC losses in the winding at the full load output current, Io. Each core has a specific $(LI^2)_{diss}$ capability that will result in a specific power loss or temperature rise.

The significant core parameters are primarily core size and the magnetic gap in series with the flux path. Consider a very small (for the application) ferrite pot core with no air gap. The effective permeability, μ_e, will be very large because there is no gap. Relatively few turns will be required to achieve the desired inductance, and the power loss at Io will be small, but the core cannot store the required energy $L(i_1 \text{ max})^2$ without saturating. If we introduce a gap into this core, the energy storage capability increases (the extra energy is actually stored in the gap, not in the ferrite material). However, the gap causes the effective permeability to drop, which requires more turns of finer wire to achieve the desired inductance. If the core is too small, as the gap is increased to the point required to achieve the necessary energy storage capability without saturating, the DC resistance of the increased number of turns of finer wire has increased to the point where the power dissipation and temperature rise is too great. This conflict is resolved by going to a larger core with appropriate gap.

To facilitate core selection, Tables 1 and 2 contain tabulated values of $(LI^2)_{sat}$ energy storage capability (saturation limited) and $(LI^2)_{25C}$ capability (based on power dissipation resulting in 25°C temperature rise). These values have been calculated for various size cores with different gaps, by methods described in Appendix B. Also given in the tables are the power dissipation corresponding to a 25°C rise for each core size, and the effective window area for the winding, A_W'. Tabulated A_L values relate to different gaps. (A_L is the inductance index at a particular gap setting – defined as the inductance in mH for 1000 turns.)

The optimum cores for switching regulator inductor applications generally have quite large gaps, and consequent relatively low A_L values. This is fortuitous, since the core properties are then dependent mostly on the gap itself, and variations in the magnetic materials of the core are swamped out, resulting in excellent stability and linearity. Note, however, that in the ferrite pot core table, many of the lower A_L values are not supplied as stock items by the manufacturer, and the desired gap must be ground to size on a special order basis.

Mo-Permalloy powder cores are effectively "gapped" by the manufacturer by means of varying the amount of non-magnetic binder that holds the Mo-Permalloy particles together within the core, and by the size and shape of the Mo-Permalloy particles. Thus, the "gap" is actually distributed throughout the core material. These cores are supplied with many different A_L values in each size.

One of the main advantages of ferrite pot cores and ferrite E-I cores (not tabulated, but worth considering) is that the winding is easily formed on a bobbin which is subsequently assembled within the two-piece core assembly. Ferrite toroids are not recommended because of the practical difficulty of introducing a gap. Mo-Permalloy toroids are not as convenient to wind, but this is not a serious problem as most switching regulator inductor designs require few turns of relatively heavy wire.

Example of Inductor Design

The example shown below will illustrate the method of solution, as drawn on the nomograph of Figure 11.

Given:

$$\begin{aligned} L &= 21.9\,\mu H \\ Io &= 10A \\ i_1\,max &= 14A \text{ (current limited)} \\ Eo \times Io &= 50W \text{ (output of regulator)} \end{aligned}$$

Copper losses not to exceed 1% of output power, and temperature rise of inductor not to exceed 25°C.

Step 1: Draw line ① from Io = 10A on the "I" scale, to 0.0219 mH (21.9 µH) on the "L" scale through the "LI²" scale. Note that $LI_o^2 = 2.19$ millijoules.

Step 2: Draw line ② from i_1 max = 14A on the "I" scale to the 0.0219 mH on the "L" scale through the "LI²" scale. Note that $L(i_1\ max)^2 = 4.3$ millijoules.

Step 3: Find the smallest core in Tables 1 or 2 that has $(LI^2)_{25C}$ capability greater than LI_o^2 defined in step 1, and $(LI^2)_{sat}$ capability greater than $L(i_1max)^2$ defined in step 2. This appears to be a 2616-3B7 pot core with $A_L = 160$ from Table 1, or an A-291061-2 toroid from Table 2.

Step 4: Actual temperature rise of the core and power loss can be calculated as follows:

Temperature rise of pot core;

$$\begin{aligned} \text{Actual } \Delta T &= 25°C \frac{LI_o^2 \text{ (step 1)}}{(LI^2)_{25C} \text{ from core table}} \\ &= 25°C \times \frac{2.19}{2.288} \\ &= 24°C \end{aligned}$$

Power loss in inductor;

$$\begin{aligned} \text{Actual } P_W &= P_{25C} \times \frac{LI_o^2}{(LI^2)_{25C}} \\ &= 0.547 \times \frac{2.19}{2.288}\ W \\ &= 0.524W \end{aligned}$$

Actual power loss in the inductor as a percentage of the power output of the switching regulator is:

$$\frac{P_W \times 100\%}{Eo \times Io} = \frac{0.524 \times 100\%}{50} = 1.05\%$$

If power losses are not acceptable, then select a core with higher $(LI^2)_{25C}$ capability.

Step 5: In the nomogram, draw line ③ from 0.0219 mH on the "L" scale through $A_L = 160$ on "A_L" scale to the "N" scale. Note that 12 turns are required to obtain the desired inductance.

Step 6: Enter the $A_W' = 0.193$ from the table for the core selected on the "A_W'" scale. Draw ④ from "N" scale where N = 12 through $A_W' = 0.193$ to the "wire size" scale. From this scale, note that wire size is AWG 15.2. Select the next highest integer, AWG 16, in order to fit within the available window area. This will result in a slight increase in power loss and temperature rise.

The same procedure applies if a toroid is selected instead of a pot core.

If both the LI_o^2 and $L(i_1max)^2$ values calculated in steps 1 and 2 are less than the appropriate limiting (LI^2) values for the core selected, it is suggested that the L value of the application be increased until one or the other of the core limits is reached. This will permit reduction of Δi_1, and reduce the requirements of the output capacitor.

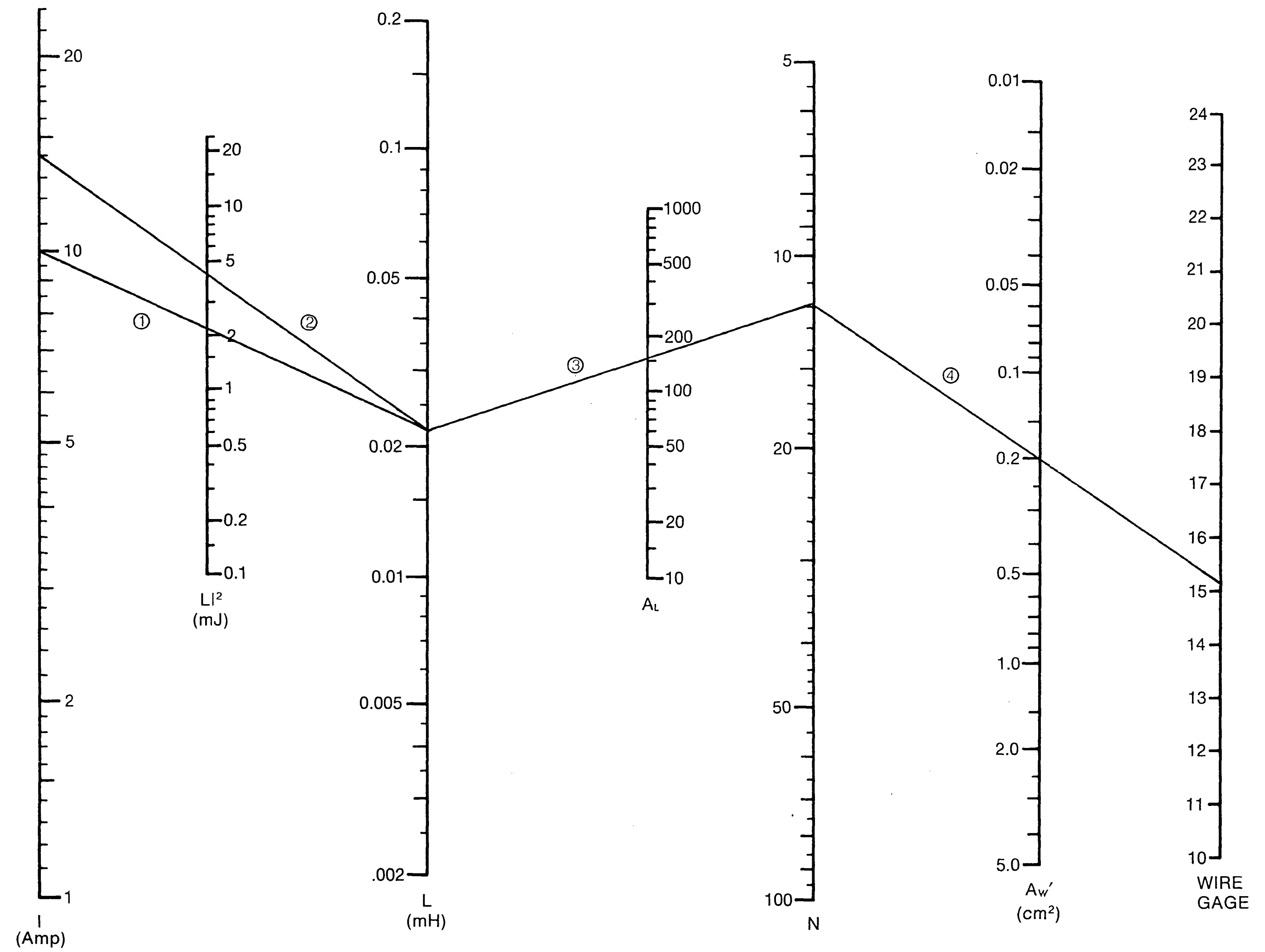


Figure 11. Inductor Design Nomograph

Table 1. Ferrite Pot Cores

Ferroxcube Part No.	Dimensions (inches)		Power Dissipation 25°C rise (watts)	Window Area 0.65 A_W (cm^2)	Inductor Index	Saturation Limit (mJ)	Dissipation Limit 25°C rise (mJ)
	(OD)	(HT)	(P_{25C})	(A_W')	(A_L)	($(LI^2)_{sat}$)	($(LI^2)_{25C}$)
1107-A100-3B7	0.445	0.264	0.100	0.034	100	0.200	0.077
1107-A160-3B7	0.445	0.264	0.100	0.034	160	0.144	0.124
1408-A100-3B7	0.559	0.334	0.158	0.063	100	0.490	0.180
1408-A160-3B7	0.559	0.334	0.158	0.063	160	0.324	0.288
1811-A160-3B7	0.716	0.428	0.259	0.122	160	1.02	0.719
2213-A160-3B7	0.858	0.538	0.358	0.193	160	2.12	1.32
2616- * -3B7	1.024	0.640	0.547	0.263	160*	5.06	2.29
2616-A250-3B7	1.024	0.640	0.547	0.263	250	3.24	3.58
3019- * -3B7	1.201	0.754	0.754	0.382	200*	8.57	4.90
3622- * -3B7	1.418	0.880	1.04	0.486	200*	18.4	7.21
4229- * -3B7	1.697	1.16	1.60	0.910	200*	31.8	17.9

*Indicates not stock item. Gap must be ground to obtain desired A_L.

Table 2. Mo-Permalloy Toroids

Arnold Part No.	Dimensions (inches)		Power Dissipation 25°C rise (watts)	Window Area 0.5 A_W (cm^2)	Inductor Index	Saturation Limit (mJ)	Dissipation Limit 25°C rise (mJ)
	(OD)	(HT)	(P_{25C})	(A_W')	(A_L)	($(LI^2)_{sat}$)	($(LI^2)_{25C}$)
A-307032-2	0.425	0.180	0.072	0.082	32	0.180	0.065
A-051027-2	0.530	0.217	0.125	0.192	27	0.296	0.199
A-189043-2	0.710	0.280	0.209	0.319	43	0.782	0.659
A-059043-2	0.930	0.330	0.346	0.703	43	1.55	2.06
A-894075-2	1.09	0.472	0.520	0.781	75	3.40	4.32
A-291061-2	1.33	0.457	0.708	1.47	61	4.54	8.97
A-298028-2	1.33	0.457	0.708	1.47	28	9.90	4.12
A-085035-2	1.60	0.605	1.04	2.14	35	20.1	8.65
A-087059-2	1.875	0.745	1.48	2.14	59	40.2	16.0

VI. Component Selection

1. *Power Switching Components*

Voltage ratings of the power switching transistor and catch diode must be greater than the maximum input voltage, Ein, including any transient voltages that may appear at the input of the switching regulator. Low transistor $V_{CE\,sat}$ and diode V_F at full load output current are important considerations to maintain high efficiency (Ref efficiency calculations – Appendix A).

Fast switching diodes and transistors are required to maintain good efficiency in high frequency switching regulators. Transistor switching losses become significant when combined rise time plus fall time exceeds approximately $0.025 \times \tau$. Thus, for 50 kHz operation, $t_r + t_f$ should be approximately 0.5 μsec or less. Transistor delay and storage times do not affect efficiency, but cause delays in turn on and turn off resulting in lowering the frequency of operation and increasing ripple. Combined $t_d + t_s$ should be less than $0.05 \times \tau$.

Unitrode manufactures a broad variety of fast switching power transistors and Darlingtons, which are listed in the Power Transistor & Darlington Product Selection Guide. Their combinational high voltage, high current, low saturation voltage and medium to fast switching characteristics make them ideal for this application.

The diode reverse recovery time must be no more than about half the current rise time through the transistor. If this requirement is not met, large amplitude reverse recovery current spikes will be drawn from the input power supply causing severe EMI problems. Large transient currents through the transistor may cause degradation or second breakdown. Referring to Figure 1, Section II, during the time that the transistor is off, the catch diode is conducting the output current, Io, and the transistor V_{CE} equals Ein. When base drive is applied to the transistor to turn it on, current through the transistor rises from 0 to Io. During this current rise time interval, t_{ri}, the diode remains in forward conduction, but the diode current declines from Io to 0, since the inductor maintains the total current at a constant value equal to Io. If the diode has recovered at the end of the t_{ri} interval, the voltage across the transistor will start to decrease and the diode will go into the reverse direction. This period of time is the transistor voltage rise time interval, t_{rv}, which is terminated when the transistor V_{CE} reaches $V_{CE\,sat}$ and the diode V_R reaches Ein. If the diode has *not* recovered at the end of the t_{ri} interval, it will remain a low impedance instead of proceeding smoothly into the reverse direction. Transistor current will increase well above Io until the diode recovers, pulling the additional current through the diode in the reverse direction.

This problem has probably caused more grief in switching regulator applications than any other, and almost completely dominates diode selection. Diode switching losses will be completely negligible if the diode is fast enough to minimize the recovery problem, i.e., two to three times faster than the transistor turn-on rate.

Unitrode UES rectifiers, listed in the Rectifier Product Selection Guide, are uniquely suited to this type of application. With low forward drop and typical recovery time of 20 nsec from forward currents as high as 50A, they cause no discernible recovery spike when used in conjunction with Unitrode's medium frequency switching transistors.

Unitrode PIC600 Hybrid Power Switches summarized in the Switching Regulator Power Circuits Product Selection Guide combine in a single package the UES rectifier and power switching transistor with its associated drive transistor and bias resistors. Power transistor, drive transistor and rectifier are matched to optimize switching speeds and $V_{CE\,sat}$. Available in NPN and PNP versions, the PIC600 series can operate at 50 kHz with only 2.5 percent loss of efficiency compared with operation at lower frequencies. Significant reduction of EMI can be achieved because of the reduction of circuit wiring.

2. *Output Filter Capacitor.*

The most difficult component selection problem for high frequency switching regulator applications is to find and specify an output capacitor with suitably low ESR. Most tantalum and aluminum electrolytic capacitor types do not have ESR specifications (probably because ESR is not very good). In some cases, the dissipation factor, DF, is given in the specification. However, DF is usually specified at 60 Hz, which is more indicative of effective *parallel* resistance, and is virtually useless in determining ESR. When DF is specified at 1 kHz or higher, it may be used to determine ESR:

$$\mathrm{ESR} = \mathrm{DF}\,(\%) \times 0.01 \times X_C = \frac{\mathrm{DF}\,(\%) \times 0.01}{2\pi f C}$$

The power circuit design example given in Section IV requires an output capacitor with C_{min} of 114 μfd and ESR_{max} of 0.025Ω. The capacitor which comes closest to meeting this requirement (after a limited search) is solid tantalum, Mallory THF, 120 μfd @ 10V. This capacitor has a max DF of 8% at 1 kHz, which defines $\mathrm{ESR}_{max} = 0.106\Omega$. ESR is typically 0.05$\Omega$. Two of these capacitors in parallel are required, based on typical ESR, to achieve an ESR of 0.025Ω; four in parallel are required, based on ESR_{max} of the capacitor. The aluminum electrolytic which comes closest (again based on a limited search) is the Sprague 672D series, 1000 μfd @ 12V, which has an ESR_{max} of 0.065Ω @ 50 kHz. Typical ESR is 0.025Ω. In either case, a much larger C value is required in order to achieve the desired ESR. This does have the advantage of reducing transient voltage changes with sudden changes in load current.

It is worth noting again that with the control circuits shown in Section III (unlike conventional switching regulator control circuits), the operating frequency will remain relatively constant, regardless of ESR, although the output ripple voltage will vary directly with ESR. In some cases, it may be economically advantageous to increase the value of L (and the size and cost of the inductor) in order to reduce ripple current, $\Delta i_1 = \Delta i_2$, and thereby increase the ESR_{max} requirement.

In addition to considering the C and ESR values and appropriate voltage derating for the application, most capacitors have maximum RMS ripple current or max RMS ripple voltage ratings which should not be exceeded. Actual RMS ripple current and voltage in the application can be calculated as follows:

$$\Delta e_{o\,RMS} = \Delta e_o\ \text{p-p}/3.0$$
$$\Delta i_{RMS} = \Delta i_1\ \text{p-p}/3.5$$

In the design example of Section IV, $\Delta e_{o\,RMS} = 0.033V$, which is less than the 0.05V max ripple rating of the 10V Mallory THF capacitor, and $\Delta i_{RMS} = 1.14A$, which is less than the 2.47A max ripple current rating of the 1000 μfd, 12V Sprague 672D capacitor.

Series inductance of the capacitor is usually not significant compared to ESR at frequencies below 100 kHz. However, inductance can become dominant if good wiring practices are not followed. Specifically, the ground side of the catch diode should be returned directly and as close as possible to the ground side of the capacitor, and capacitor lead length including circuit wiring on both sides of the capacitor should be minimized.

3 *Control Amplifier and Reference.*

Control circuits for switching regulators can be designed around IC operational amplifiers and separate voltage references, or around low power voltage regulator IC's which have built-in references. Voltage regulator IC's such as the LM304, LM305, and μA723 have the added advantage that the output current they provide to drive the power switching transistor can be caused to diminish at higher temperatures, which conforms to the transistor drive requirements vs. temperature and helps to maintain optimum switching speeds over a range of temperatures. Amplifiers used in the control circuit should be uncompensated in order to obtain fast switching speeds, otherwise the delay times introduced will result in lower frequency operation and larger ripple amplitudes, and may cause circuit instability.

Appendix A
Analysis of Power Circuit

The design equations for the switching regulator power circuit used throughout this design guide were based on several simplifying assumptions, which will now be dealt with.

The simplified equations neglected the effect of "catch" diode forward drop, V_F, transistor saturation voltage, V_{sat}, and the IR drops in the inductor and current sensing resistor, $Io\ R_X$. If a design is implemented using the values of L, C, ESR, and Δi derived from the simplified equations, then t_{on}, t_{off}, f, and Δe_o will differ from the design values because of the effect of the simplifying assumptions as follows, from Figure 2b:

Simplified :

$$\Delta i_1 = \frac{(Ein - Eo)t_{on}}{L} \qquad (1)$$

Exact :

$$\Delta i_1 = \frac{(Ein - Eo - V_{sat} - Io\ R_X)t_{on}'}{L} \qquad (2)$$

Simplified :

$$\Delta i_1 = \frac{Eo\ t_{off}}{L} \qquad (3)$$

Exact :

$$\Delta i_1 = \frac{(Eo + V_D + Io\ R_X)t_{off}'}{L} \qquad (4)$$

Note that Δi_1 is fixed, because the control circuit controls this value directly. Instead of the original design values of t_{on} and t_{off}, actual values t_{on}' and t_{off}' will be observed. Since Δi_1 is fixed, we can equate Equations (1) to (2) and (3) to (4):

$$\frac{t_{on}'}{t_{on}} = \frac{(Ein - Eo)}{(Ein - Eo - V_{sat} - IoR_X)} \quad \text{and}$$

$$\frac{t_{off}'}{t_{off}} = \frac{Eo}{Eo + V_D + IoR_X}$$

Although the actual t_{off}' is less than the assumed t_{off}, t_{on}' is greater than the assumed t_{on}, so that their net effect on the operating frequency is reduced. In the worst-case, when Eo is small (5V) and Ein is high (50V), the actual frequency will be 25 percent higher than the original assumed frequency, resulting in a very slight drop in efficiency. Output ripple component Δv_C will be smaller because of the higher frequency, and Δv_{ESR} will not change because Δi_1 is fixed. Component tolerances will result in larger deviations than those caused by the use of the simplified equations.

The only other assumption that could have possible significance is that the transistor switching times are negligible at the highest frequency of operation. The validity of this assumption is normally assured by selecting appropriate devices (see Section VI). This also applies to the speed of the control circuit. If delay time through the control circuit in addition to transistor turn-on and turn-off times is significant with respect to the total period, τ, the consequent delay in turning the power circuit on and off will cause a proportional increase in Δi_1 and Δe_o, and a proportional decrease in frequency.

Efficiency Calculations: The efficiency of a switching regulator depends upon the factors given in the following equation:

$$\text{Efficiency} = \frac{\text{Pout}}{\text{Pin}} \times 100\%$$

$$= \frac{\text{Eo} \times \text{Io}}{\text{Eo} \times \text{Io} + P_T + P_D + p_T + p_D + P_L + P_I + p_C + P_C}$$

Note that the worst case for each factor does not necessarily occur under the same conditions.

1. *DC Losses – Transistor.* (Worst case when Ein is lowest because t_{on} is largest.)

$$P_T = V_{CE\,sat} \times \text{Io} \times \frac{t_{on}}{\tau}$$

where: $\frac{t_{on}}{\tau} - \frac{\text{Eo}}{\text{Ein}}$

2. *DC Losses – Diode.* (Worst case when Ein is highest.)

$$P_D = V_F \times \text{Io} \times \frac{t_{off}}{\tau}$$

where: $\frac{t_{off}}{\tau} = 1 - \frac{\text{Eo}}{\text{Ein}}$

3. *Switching Losses – Transistor.* (Worst case when Ein is high. $t_d + t_s$ do not contribute to power losses.)

$$p_T = \text{Ein} \times \text{Io} \frac{t_r + t_f}{2\tau}$$

where: $t_r = t_{rv} + t_{ri}, \; t_f = t_{fv} + t_{fi}$

4. *Switching Losses – Diode.*

This is a very complex calculation if diode recovery time is not much smaller than the transistor rise time, because the diode will short-circuit the power supply prior to turn-off, affecting the transistor dissipation, possibly causing second breakdown, and generating intolerable EMI. By using a diode whose recovery time is not more than half the transistor rise time, all these problems become negligible.

5. *DC Losses – Inductor.* (AC losses are negligible when Δi_1 is small compared to Io.)

$$P_L = \text{Io}^2 \times R_S$$

where: R_S is equal to effective series resistance of inductor.

6. *DC Losses – Current Sense Resistor.* (AC losses negligible when Δi_1 is small compared to Io.)

$$p_I = \text{Io}^2 \times R_I$$

7. *AC Losses – Capacitor.* (Usually negligible.)

$$p_C = \frac{\Delta i_1{}^2}{12} \times \text{ESR}$$

8. *Control Circuit Losses.* (Base drive to switching transistor is dominant, but usually negligible.)

$$P_C = \text{Ein} \times I_b \times \frac{t_{on}}{\tau} = \text{Eo} \times I_b$$

where: $\frac{t_{on}}{\tau} = \frac{\text{Eo}}{\text{Ein}}$

Appendix B
Analysis of Power Inductor Design

This appendix describes the methods used to develop the core tables given in Section V and the nomographic method for design of the power inductor. Core parameters for any cores not listed in the tables can be derived from the equations given.

The following equations provide the basis for this design approach. Equation (1a) defines the value of inductance, L, in terms of basic core parameters and the total number of turns, N, wound on the core:

$$L = N^2 \times 0.4\pi\mu\frac{A_e}{\ell_e} \times 10^{-5} \quad \text{mH} \qquad (1a)$$

where:
μ = effective permeability of core
ℓ_e = effective magnetic path length – cm
A_e = effective magnetic cross section – cm^2

For most standard cores, the above calculation has been simplified by listing the compound parameter A_L, called the "inductor index", as follows:

$$L = N^2 A_L \times 10^{-6} \quad \text{mH} \qquad (1b)$$

where: $A_L = 0.4\pi\mu\frac{A_e}{\ell_e} \times 10$ mH for 1000 turns

Multiplying both sides of Equation (1b) by I^2,

$$LI^2 = (NI)^2 A_L \times 10^{-6} \quad \text{millijoules} \qquad (2)$$

Core Saturation Limits.

Any specific core has a maximum ampere-turn, NI, capability limited by magnetic saturation of the core material. $(NI)_{sat}$ is listed in some core catalogs, in which case the maximum $(LI^2)_{sat}$ capability of the core can be calculated from Equation (2). $(NI)_{sat}$ is related to the saturation flux density, B_{sat}, as follows:

$$(NI)_{sat} = 10\frac{B_{sat} A_e}{A_L} \quad \text{ampere-turns} \qquad (3)$$

Substituting Equation (3) into (2),

$$(LI^2)_{sat} = \frac{B_{sat}^2 A_e^2 \times 10^{-4}}{A_L} \quad \text{millijoules} \qquad (4)$$

Values of $(LI^2)_{sat}$ are given for each core represented in Tables 1 and 2 of Section III. Equation (2) *or* (4) was employed, using values for either B_{sat} or NI which would result in a reduction of A_L (and L) of 20 percent under maximum overload conditions, according to the core manufacturer's data. The core selected for an application must have an $(LI^2)_{sat}$ value greater than $L(i_1 \max)^2$ to insure that the core will not saturate under maximum peak overload current conditions.

Power Dissipation and Temperature Rise Limits.

In switching regulator applications, the AC current component is small compared to the DC current through the power inductor. Power dissipation in the inductor is almost entirely DC losses in the winding. DC resistance of the winding, R_s, is calculated from the following:

$$R_s = \rho \frac{\ell_w}{A_x} N \quad \text{ohms} \qquad (5)$$

where:

ℓ_w = mean length of turn – cm

A_x = effective area of wire – cm²

ρ = resistivity of wire – Ω-cm

Core geometry provides a certain window area, A_W, for the winding, but only a fraction of this area can be occupied by the actual conductor. The *effective* window area, A_W' is taken as 0.5 A_W for toroids, and 0.65 A_W for pot cores. This allows for wasted area of uniformly wound round wire with HF insulation, allows for the fact that the central fourth of the window area of a toroid cannot practically be filled, and allows for a single section bobbin in the case of the pot core. The number of turns, area of wire, and effective window area of a fully wound core are related by:

$$A_x = \frac{A_W'}{N} \text{cm}^2 \qquad (6)$$

Substituting Equation (6) into (5):

$$R_s = \rho \frac{\ell_W}{A_W'} N^2 \quad \text{ohms} \qquad (7)$$

Multiplying both sides of Equation (7) by I^2, the power dissipation in the winding, P_l, is:

$$P_L = I^2 R_s = I^2 \rho \frac{\ell_W}{A_W'} N^2 \quad \text{Watts} \qquad (8)$$

Substituting for N from Equation (1b), and rearranging:

$$LI^2 = P_L \frac{A_L A_W'}{\rho \ell_W} \times 10^{-6} \quad \text{millijoules} \qquad (9)$$

Equation (9) shows that the LI^2 capability is directly related to, and is limited by the maximum permissible power dissipation. Using a value for P_l that will result in a 25°C rise in the temperature of the inductor, values of $(LI^2)_{25C}$ are calculated for each core in Tables 1 and 2 of Section III. For these calculations, resistivity, ρ, is assumed to be 1.9×10^{-6} Ω-cm, the resistivity of copper wire at 65°C. The power dissipation that will result in a 25°C rise is calculated and tabulated for each core as follows:

$$\Delta T = 850 \frac{P_l}{A_s} \quad {}^\circ\text{C} \qquad (10)$$

where:

ΔT = temperature rise

A_s = surface area of inductor – cm²

The factor 850 in the above equation represents a temperature rise of 850°C for 1W power dissipation from 1 cm² surface area, empirically determined for natural convection cooling. The surface area, A_s, used in the calculation is taken as the top and sides of the inductor, ignoring the mounted bottom surface. Substituting a temperature rise of 25°C:

$$P_{25C} = \frac{25 \times A_s}{850} \quad \text{Watts} \qquad (11)$$

Appendix C
Analysis of Application Circuits

The design equations for the critical components and operating parameters of Figure 3, Section III, are given below, for the following design objectives:

$$\begin{aligned} Eo &= +5V \\ \Delta e_o &= 100\,mV\ p\text{-}p \\ Ein &= 20V\ min,\ 40V\ max \\ Io &= 2A\ min,\ 10A\ max \\ \text{Current Limit} &= 14A\ max\ peak \end{aligned}$$

Using the procedure described in Section IV, the following parameters were established:

$$\begin{aligned} f &= 50\,kHz\ (nominal) \\ t_{off} &= 17.5\,\mu sec \\ L &= 22\,\mu H \\ C &= 120\,\mu F\ min \\ \text{ESR of capacitor} &= 0.025\,\Omega max \\ \Delta i_1 &= 4A \end{aligned}$$

From the manufacturer's design data for the LM305, we know that: the internal reference voltage, V_{ref}, is 1.8V, nominal; the impedance of the inverting input is very high; the threshold level of the drive-current-limiting circuit is 0.30V; and the impedance of the non-inverting input (Rin) is 2.4K, nominal.

From the Unitrode data for the PIC625 Hybrid Power Switch, the drive current (I drive) required for Io = 10A is 30 mA. The V_{BE} of Q1 is taken as 0.6V.

First, we may calculate the values R1 and R2 of the output divider. We will make the effective parallel resistance of R1 and R2 equal to 2.4K, so that the impedance at the inverting input will be approximately the same as the noninverting input of the LM305:

$$\frac{R2}{R1 + R2} = \frac{Vref}{Eo} = \frac{1.8}{5}$$

$$\frac{R1\ R2}{R1 + R2} = Rin = 2.4K$$

The resulting values are R1 = 6.8K, R2 = 3.8K. R2 may be trimmed for precise setting of Eo.

C1 and C2 function to provide negative and positive AC feedback, and should be large enough to result in small losses to the AC signals. Assuming that Rin = (R1 × R2)/(R1 + R2), the value of C1 should be twice the value of C2, so that the negative feedback will be dominant over positive feedback at all frequencies, thereby ensuring circuit stability. The following relationships satisfy these conditions:

$$C2 \geqq \frac{1}{Rin \times f} \quad ; \quad C1 = 2 \times C2$$

where: f = the nominal switching frequency.

These equations are satisfied by C2 ≈ 0.01 μF and C1 = 0.02 μF. Making C1 and C2 too large will have an adverse effect on transient recovery time of the switching regulator.

R4 is calculated from the threshold voltage of the LM305 drive current limiting circuit and the required base drive current.

$$R4 = \frac{V\ threshold}{I\ drive} = \frac{0.3V}{0.03A} = 10\Omega$$

Current sampling resistor R_I is determined by the desired short circuit current limit and the V_{BE} of Q1. As described in Section III, under *current overload conditions,* current i_1 ranges between two values. The maximum instantaneous overload current is defined by: $i_1 \times R_I = V_{BE} + V_{R3}$. The minimum instantaneous overload current is defined by: $i_1 \times R_I = V_{BE}$.

Since Δi_1 has been previously defined as 4A p-p, if we assume a minimum value of 10A for i_1 under overload conditions, then the maximum peak overload value for i_1 will be 14A, and the average value of i_1 = Io under overload conditions is 12A.

$$R_I = \frac{V_{BE}}{i_1\ (min\ overload)} = \frac{0.6V}{10A} = 0.06\Omega$$

Power dissipation in R_I will be 6W under full load conditions, and 8.64W under overload conditions.

R3 determines Δi_1 under overload conditions as well as for normal operation of the switching regulator:

$$R3 \times I_{drive} = R_I \times \Delta i_1$$

$$R3 = \frac{R_I \times \Delta i_1}{I_{drive}} = \frac{0.06 \times 4}{0.030} = 8\Omega$$

The value of R5 is determined empirically to optimize regulation versus changes in Ein. With R5 omitted, Eo changes approximately 70 mV when Ein is changed from 20V to 40V. With R5 = 1.2 MΩ, the change in Eo is reduced to less than 25 mV.

THE IMPORTANCE OF RECTIFIER CHARACTERISTICS IN SWITCHING POWER SUPPLY DESIGN

With the increasing interest in switching regulated power supplies designers have directed much of their effort to selecting transistors with low switching losses and adequate power handling capability. While recognizing that they must use fast recovery rectifiers, less attention has been given to "how fast" or "what type of recovery characteristic" is desired. More detailed knowledge of rectifier behavior allows determination of the magnitude of increased losses and stress on the transistor by the non-ideal diode. By choosing the best available rectifier, transistor stress can be minimal, thereby resulting in higher reliability. Other benefits are:

A. Improved power supply efficiency
B. Lower noise
C. Lower cost and/or
D. Smaller size and weight

The performance of fast recitifiers in the most popular switching circuits is discussed below.

"Switcher" inputs use available DC voltages, or rectifiers directly off the AC line. This DC "input" is converted by semiconductor switches operating at high frequency in circuits such as buck, flyback or boost regulators and in pulse-width-modulated or square wave inverters.

Inverter output rectifiers and regulator "catch" diodes are subject to unusual stresses due to the fast switching rates and very low impedance seen by the diode during the reverse transient (diode turn-off) and a momentary high impedance during diode turn-on.

These new square wave switching supplies are limited in efficiency and frequency by transistor stress and switching losses, some of which is due to diode switching characteristics. Faster transistors and diodes are helping to increase efficiency and/or frequency. At low output voltages, and lower frequency the DC characteristics ($V_{CE(sat)}$ and V_F) have the major influence on efficiency. However, as frequency and/or input voltage increase the switching characteristics become increasingly important.

BUCK REGULATOR ANALYSIS

Ideal Diode — For better understanding consider the buck regulator and resulting waveforms, using an *ideal* diode and assuming linear current rise and fall in the power transistor during switching. Similar considerations apply to other types of switching regulator circuits.

The transistor "on" time, t controls the conversion such that,

$$(1)\ V_o = \frac{t}{\tau} V_i$$

where τ is the period. t is determined by the control circuit which senses output voltage and controls transistor base drive.

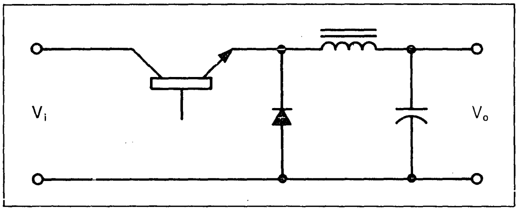


Figure 1a

In this regulator the inductor current is essentially constant as it flows alternately through the transistor or "catch" diode. The sum of the transistor current and diode current must always equal the current in the inductor, which cannot change instantaneously.

At t_0 the diode is conducting inductor current while the transistor is blocking the input voltage.

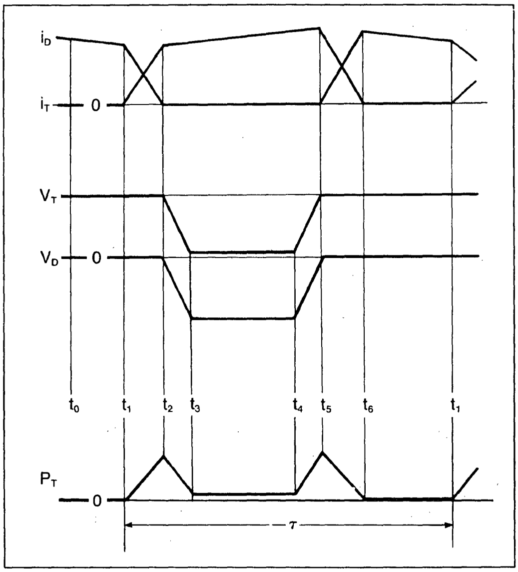


Figure 1b

t_1 to t_2 is the current rise time t_{ri} of the transistor. Since inductor current is not changing, the diode current must decrease. The forward biased diode maintains full input voltage across the transistor.

At t_2 the transistor is conducting all the inductor current so the diode turns off and voltage across the transistor starts to decrease toward $V_{CE\ (sat)}$.

t_2 to t_3 is the voltage rise time, t_{rv} of the transistor.

From t_3 to t_4 the transistor is saturated and conducting the inductor current i_L.

At t_4 the transistor starts to turn off and V_{CE} increases.

t_4 to t_5 is the voltage fall time t_{fv} of the transistor. During this time the transistor must conduct the entire inductor current because the diode is still reverse biased. At t_5 the diode is forward biased and the transistor is blocking the full input voltage. Diode current starts to increase and the transistor current decreases, the sum equalling i_L.

t_5 to t_6 is the current fall time t_{fi} of the transistor. Diode current increases in a complementary manner. From t_6 to t_1 the transistor is off and the diode is conducting all the inductor current.

To simplify the illustration assume the inductor current constant and equal to I_o. Transistor dissipation P_T is the sum of transient switching and DC losses. Neglecting losses due to DC leakages, which are generally negligible:

$$(2)\quad P_T = \frac{V_i\, I_o}{2}\,\frac{(t_{ri} + t_{rv} + t_{fv} + t_{fi})}{T} + \frac{V_{CE\ (sat)}\, I_o\, (t_4 - t_3)}{T}$$

$$(3)\quad P_T = \frac{I_o}{T}\left\{\frac{V_i}{2}(t_{ri} + t_{rv} + t_{fv} + t_{fi}) + V_{CE(sat)}\ (t_4 - t_3)\right\}$$

Practical diode — Now consider how the non-ideal diode with reverse recovery, junction capacitance, forward recovery and DC loss affects the circuit of Figure 1a.

In Figure 1c the solid lines are the waveforms using a practical diode in a buck regulator circuit. Comparing them with the dotted lines of the ideal diode previously considered we see three significant differences during transient switching and one during DC conduction:

1. The peak collector current increases (above I_o) during a period of high dissipation t_2 to t_2'.
2. Rise times t_{ri} and t_{rv} are increased. $(t_2' - t_1) > (t_2 - t_1)$ and $(t_3' - t_2') > (t_3 - t_2)$.
3. Maximum collector voltage peaks up above V_i briefly at t_5.
4. The diode has DC loss (from t_6 to t_1) and switching loss (principally from t_2' to t_3').

From the P_T curve of Figure 1c it is obvious that transistor power dissipation increases above that of (3) due to the "real" diode, — see the hatched regions.

The magnitude of these detrimental factors depends on the choice of rectifier. Before considering losses more fully let us examine the switching periods in greater detail.

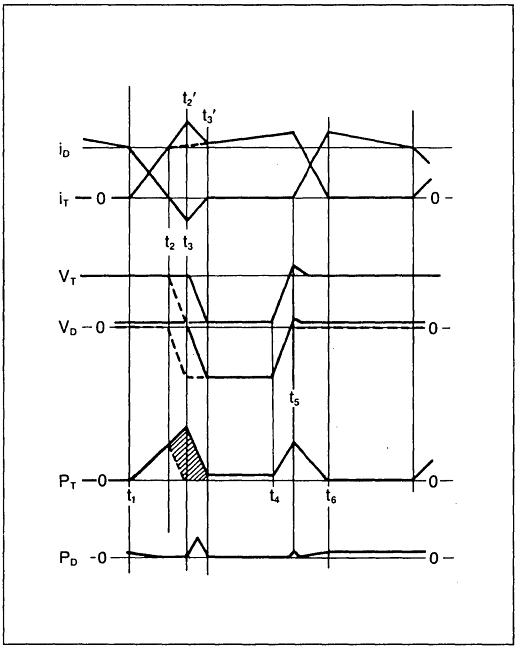


Figure 1c

TRANSISTOR TURN-ON BEHAVIOR

The transistor "turn-on transient", when the diode is switching from forward conduction to reverse blocking, results in the following transistor and diode waveforms:

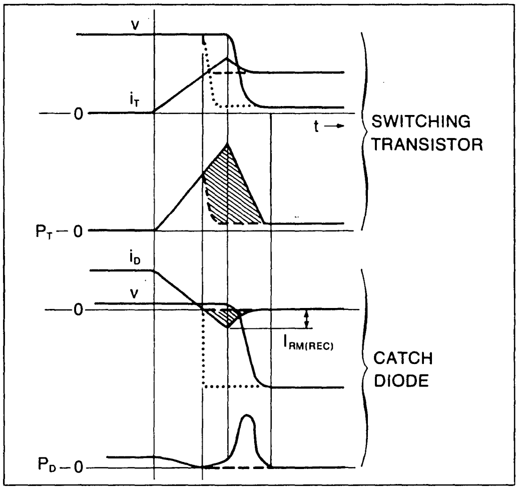


Figure 2

Dashed lines show what the current and power would be if the *diode* were ideal to the extent of having no reverse recovery time or junction capacitance. (Dotted lines show the voltage for the ideal diode case.) The reverse diode current caused by diode capacitance and recovered charge is shown by the cross hatched area of the i_D curve. The transistor must conduct this reverse diode current as well as the inductor current. The grey area represents additional transistor dissipation due solely to the diode recovered charge and capacitance.

Faster switching transistors will not necessarily result in reduced switching losses. Unless a diode with recovery time 2 or 3 times faster than the transistor current rise time is used, a faster transistor will increase the peak recovery current in the diode and thus increase overall switching losses. Furthermore, a diode with a "soft" recovery characteristic will cause more dissipation than an "abrupt" type with the same peak recovery current. The relationship of recovery characteristic to switching rate is discussed in Appendix B. With many switching transistors now available a 200 nS fast-recovery rectifier will have a peak recovery current $I_{RM(REC)}$ greater than shown in the i_D waveform of Figure 2, where it is about ⅓ of the forward current. This rather modest additional collector current (of 33% above that limited by an ideal diode) can cause increased transistor power dissipation of 100 to 150% during the turn-on period. Other serious problems can occur from high peak currents, such as noise transients in the line, the transistor coming-out of saturation and forward-biased second breakdown.

Rectifiers are now available with recovery characteristics to keep these problems minimal. Their use is required for a switching supply of maximum reliability and efficiency.

TRANSISTOR TURN-OFF BEHAVIOR:

When the transistor turns off, the diode turn-on characteristic usually has little effect on power dissipation but may cause voltage spiking, with resulting noise and the possibility of exceeding the transistor voltage ratings. Diode characteristics and conditions under which these transients occur are discussed in Appendix C. The voltage spike is due to the forward recovery characteristic and, when present, will occur as shown (dotted) in Figure 3. To correct it a snubber (series RC across the diode) may be needed. However, the choice of an optimum diode will minimize or eliminate this need.

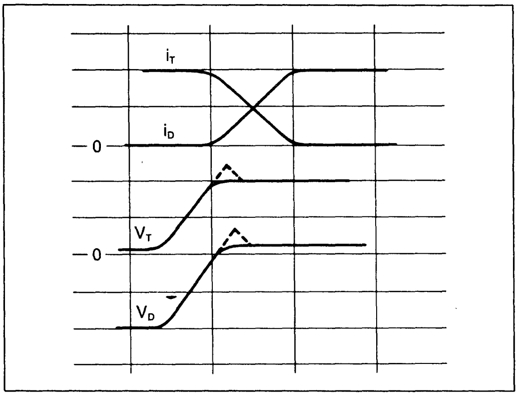


Figure 3

POWER LOSSES IN THE SEMICONDUCTOR DEVICES

DC Losses in the buck regulator occur alternately when the diode is forward conducting and when the transistor is turned on. Referring to Figure 1 these intervals are t_6 to t_1 and t_3 to t_4 respectively. During *either* interval the dissipation is independent of input voltage, V_i, or output voltage, V_o, depending only on load current and device voltage drop. *Total circuit DC losses* are a function of V_o/V_i because a) this ratio relates to "on" time and b) transistor $V_{CE(sat)}$ will probably not equal diode V_F. Neglecting switching intervals the dissipation due to DC losses is:

$$(4)\quad P_{DC} = V_F I_O \frac{V_i - V_o}{V_i} + V_{CE\,(sat)} I_O \frac{V_o}{V_i}$$

Loss of efficiency due to DC losses is greatest when V_o is low, with diode loss being more significant when V_i is relatively high and transistor loss dominating when V_i is close to V_o.

Transient (switching) losses in the regulator vary considerably with voltage, being highest at "high line" V_i (see Eq. 3). Furthermore, high voltage transistors and rectifiers generally have longer switching times than low voltage types. Speed and "recovery characteristic" (see Appendix B), and consequently losses, can vary greatly between different device types and manufacturing processes. A relationship for calculating approximate transient dissipation of practical devices during the transistor turn-on interval is given in Appendix B. The other component (turn-off interval) can be similarly developed but it is not significantly affected by diode selection. However, when transistors and/or drive techniques are chosen for shorter fall times overall losses are reduced *and* the benefits of optimum diode selection become more significant. Proper diode (and transistor) selection is important in all switching supplies, but the higher the voltage (and frequency) the more significant will be the effect of selection on switching losses.

OTHER SWITCHING CIRCUITS

The pulse-width-modulated inverter (PWM) supply (Figure 4a) has much in common with the buck regulator. Output rectifiers also perform the catch diode function. Current waveforms are shown in Figure 4b, with overshoot due to diode reverse recovery and capacitance. Here again slow diodes cause additional transistor stress, usually not reduced significantly by transformer impedance. Leakage reactance will often require the use of a snubber, to protect the transistor.

Transistor "on" time t and the turns-ratio control the conversion such that

$$(5)\ V_o = \frac{2t\ N_s}{\tau N_p} V_i$$

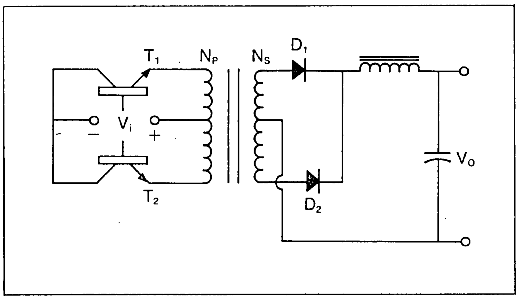


Figure 4a

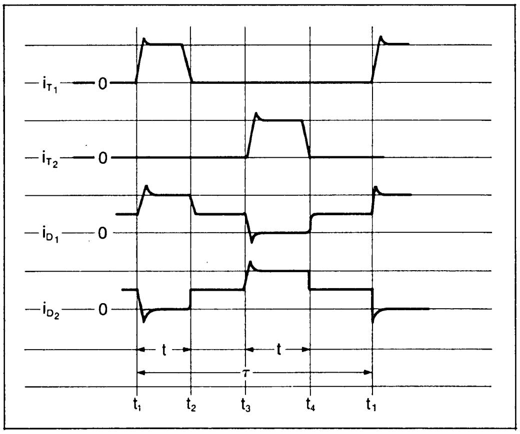


Figure 4b

From t_1 to t_2 transistor T_1 and diode D_1 conduct, with diode current equal to inductor current i_L.

At t_2 the transistor turns off and the inductor "pulls" i_L equally through D_1 and D_2.

At t_3 transistor T_2 turns on, driving full i_L through D_2 and causing D_1 to be reversed biased. D_2 current is increased by the recovery current of D_1, and T_2 current also increases proportionally.

From t_4 to t_1 both transistors are again off and at t_1 the events of t_3 occur on the opposite device pair.

One difference between the inverter and the regulator is that here the DC diode losses are more significant because they (D_1 and/or D_2) are conducting the full cycle regardless of V_i to V_o ratio. Another difference is that here the diode recovery is from half, rather than full, load current.

The square wave inverter can be considered, in terms of device operation, a special case of the PWM where 2t approaches τ. Regulation is achieved by varying V_i.

EMI, RFI, NOISE —

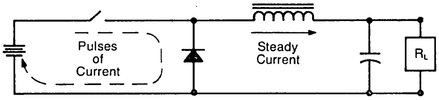
Given any inductance in a circuit "loop" of wiring, a rapid current change will generate a voltage transient, V = L di/dt, and the energy in such a transient will vary with the square of the current, $E = \frac{1}{2}LI^2$. The interference and voltage spiking will be easier to filter if the energy is low and has predominantly high frequency components.

We can establish a priority of factors for reducing EMI:

1. $I_{RM(REC)}$ should be as low as possible, — accomplish by diode selection (see Appendix B and Fig. 7).
2. L (circuit loop) should be minimum, — accomplish by layout and interconnect geometry. (See Fig. 5).
3. Use a "soft recovery" diode (See Appendix B). However, this is an item of possible trade-off since such a device may have longer t_{rr}, higher $I_{RM(REC)}$ and, thus, create much higher switching loss.

An ultra-fast device with moderate recovery (vs. abrupt or soft) will often be the best choice.

REDUCE EMI BY LOWERING CIRCUIT WIRING INDUCTANCE:



Low L needed in loop shown in grey. Avoid ground loop noise by returning input capacitor directly to diode.

Figure 5a

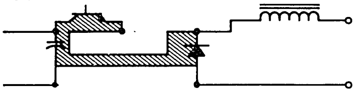


Figure 5b

SELECTING THE BEST SWITCHING RECTIFIER

Ratings and characteristics have different priorities and significance when they are to be applied to these power switching circuits. Selection should be based on the following:

1. Peak inverse voltage, PIV of "catch" diodes must at least equal the highest input voltage, while PIV of center-tap output rectifiers must be at least twice the maximum output voltage in a square wave inverter and much greater in the pulse width modulated inverter. More significant perhaps are the transient voltages in practical fast switching circuits partly due to wiring inductance and rectifier's own recovery. Unless these are intentionally clipped, damped, or "designed out" it is advisable to use a safety factor of 2 or 3. PIV selected should apply over a range from lowest ambient to the highest expected junction temperature.

2. Reverse recovery time t_{rr} must be much lower than the rise time of the transistor with which it will be used, — preferably by at least 3 times when measured at conditions similar to circuit operation. Selection is complicated because rectifiers are normally specified at conditions less severe than in power switching circuits. Furthermore, correlation between test conditions is not always the same (see Table I of Appendix B).

Following preliminary selection from available data the devices should be compared in a circuit developing the highest current, junction temperature and rate of current switching (− di/dt) expected.

The desired goal is to minimize peak recovery current $I_{RM(REC)}$ and switching loss. Note that these are the same order of magnitude with Schottky rectifiers (due to high capacitance, principally) as with the fastest PN rectifiers. The figures below illustrate these points. Figure 6 shows the variation of peak current with switching rate, using the Unitrode UES 801 in a special test circuit. Figure 7 shows the difference in $I_{RM(REC)}$ and t_{rr} when representative fast recovery DO-5 devices are measured in a JEDEC test circuit at different temperatures. In Figure 8 the incremental collector current (the peak value in excess of 30 A) for a 30 A buck regulator using 50, 100, and 200 nS catch diodes is plotted as a function of transistor rise time (and resulting di/dt). Figures 9a, b, and c show the loss of efficiency due to transistor turn-on dissipation as a function of operating frequency, with 3 transistor rise times and 3 diode recovery times, in a regulator operated with 40 V in and 10 V out. Similar figures can be developed for other conditons using the model and assumptions in Appendix B.

3. Forward voltage should be as low as possible to optimize efficiency, especially for inverter output rectifiers and regulators with high V_i/V_o ratios. Loss of efficiency due to V_F is most significant at low output voltages. Figure 10, which relates this loss to device choice over the range of available forward voltages, applies to output rectifiers of inverter supplies with popular output voltages.

Schottky rectifiers have the lowest V_F and are therefore widely used as output rectifiers for 5 V supplies. Their limitations in PIV, transient voltage capability and temperature must be considered when applying them in other applications.

Selection should be based on conditions where losses are most significant, — at rated supply output current and anticipated junction temperature. The approximate range of V_F, at rated current and 25°C, as well as at more typical operating conditions, is shown in Figure 11 for representative fast rectifier types. Note that the Unitrode UES series is closest to the Schottky, especially at expected operating conditions.

4. Maximum average rectified output current at maximum expected case or ambient temperature must always be considered. Note however, that standard current rating is based on a half sine waveform. These square wave applications at average current equal to this rating will usually dissipate somewhat lower power, and, thus, be used conservatively. However, regulators with $V_i \lesssim 1.5\ V_o$ should use a catch diode with a higher rating than the average current it conducts at full load.

5. Peak voltage $V_{F(DYN)}$ during forward recovery will be of significance when using transistors with fast fall times at close to the V_{CE} rating. This is further discussed in Appendix C. See Table II for typical performance of representative devices. At lower values of di/dt the peak voltages will be lower.

6. Surge current (8.3 mS) is not of great significance because transistor saturation limits fault current. If the power supply is designed to provide rapid charging of a large output capacitor the "overload" requirement for the charge time (perhaps 0.1 to 2 seconds or so) must be considered.

$I_{RM(REC)}$ & t_{rr} vs $\frac{di}{dt}$

CONDITIONS I_{FM} = 10A, LINEAR SLOPE. UNITRODE UES 801 RECTIFIER.

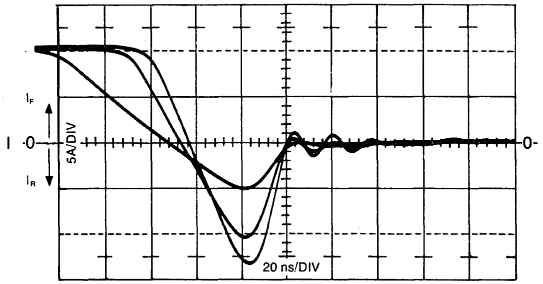


Figure 6

$I_{RM(REC)}$ & t_{rr} of DO5 FAST RECTIFIERS

CONDITIONS: I_{FM} = 30A $-\frac{dI}{dt}$ = 30A/µS (30V JEDEC)

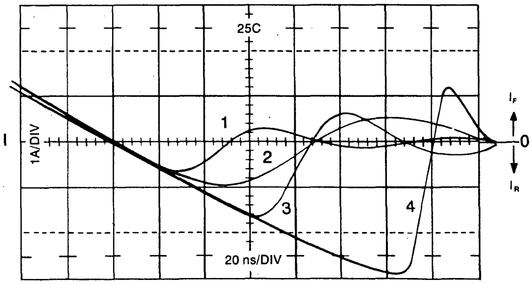


Figure 7a

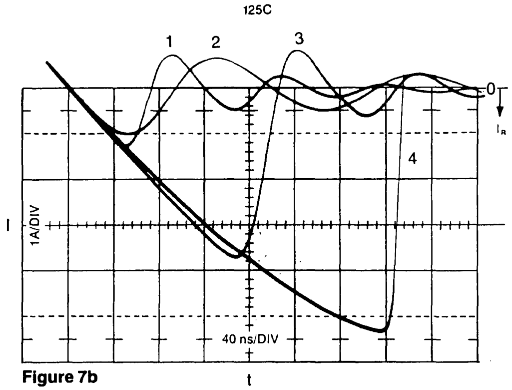


Figure 7b

DEVICE TYPE	$I_{RM(REC)}$ 25°C (A)	$I_{RM(REC)}$ 125°C (A)	t_{rr} 25°C (nS)	t_{rr} 125°C (nS)	t_{rr} MAX. At Low Current Cond'ns.
1	0.6	1.3	50	72	50
2	1.0	1.0	86	95	—
3	1.7	3.7	86	185	100
4	2.9	5.4	142	296	200

1 Unitrode UES 803
2 USD545
3 100nS rectifier.
4 200nS rectifier.

Figure 7c

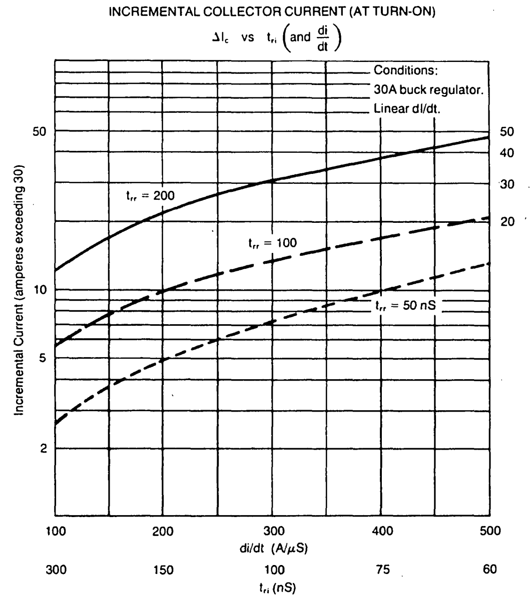
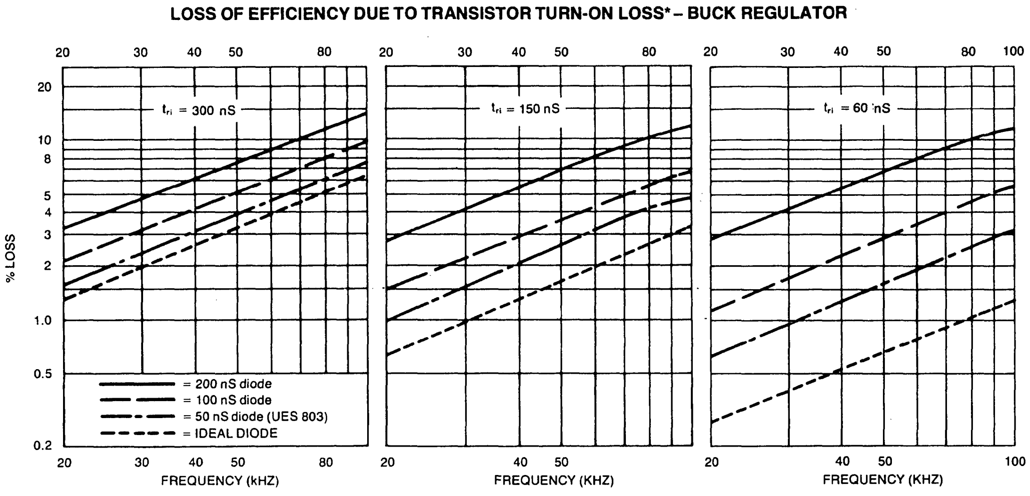
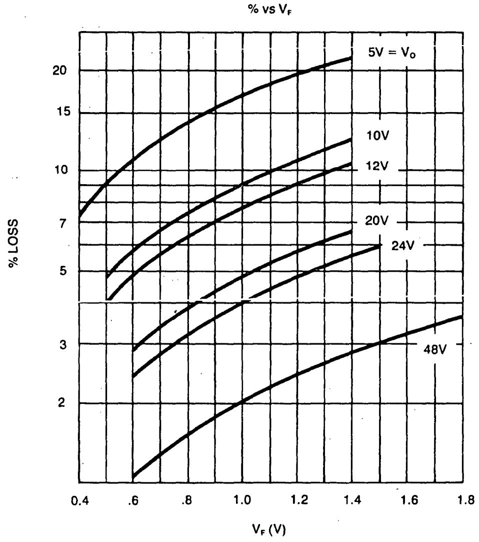


Figure 8



* Calculations of total switching losses (diode and transistor) per model in Appendix B for a 30A buck regulator with V_{in} = 40V and V_{OUT} = 10V.

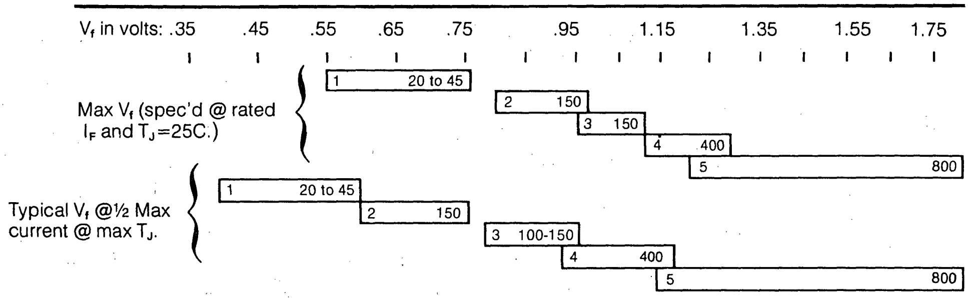
Figure 9



LOSS OF EFFICIENCY DUE TO FORWARD VOLTAGE OF INVERTER OUTPUT RECTIFIERS.

Figure 10

V_f available (approximate range) for low to medium V_{RM} applications



KEY: N XY

1 = Schottky. USD series.

2 = Unitrode UES 150 V series.

3 = Other devices for low forward voltage.

4 = Typical fast recovery (200 nS) devices.

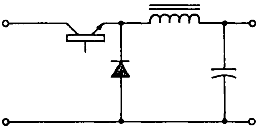
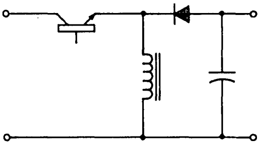
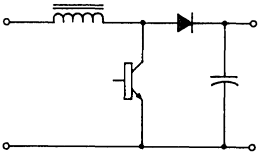
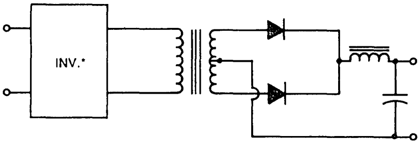
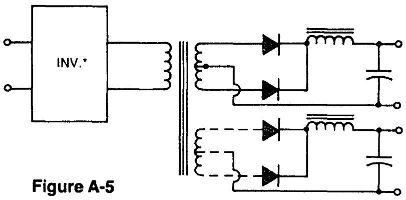
5 = Fast devices to 800 V.

N = Device Class

XY=V_{RW}
(Max. at T_J noted above).

Figure 11

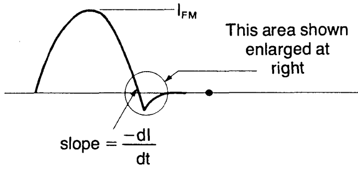
Appendix A
"Off-Line" Supplies

BASIC CIRCUIT	TYPE	FEATURES
Figure A-1 	a) Buck Regulator	$V_o < V_{in}$. Output non-isolated. Easy to filter output. Noisy input.
Figure A-2 	b) Flyback Regulator	V_o opposite polarity from V_{in}. (Unless isolated). Output can be isolated. Output can be stepped up to HV. Noisy input and output.
Figure A-3 	c) Boost Regulator	$V_o > V_{in}$. Output non-isolated. Hard to filter output. Quiet input.
 **Figure A-4**	d) PWM (Variable Duty Cycle) Inverter.	Used with single V_o, - also common for lab supplies. Provides isolation. Does not need separate catch diode, - rectifiers serve this function, possibly with small HV diodes in primary for magnetizing current.
 **Figure A-5**	e) Square Wave Inverter (50% Duty)	Regulation provided by previous input. Regulates one of (possible) multiple outputs. Uses high transistor count. Provides isolation. Does not need separate catch diode, - rectifiers serve this function, possibly with small HV diodes in primary for magnetizing current.

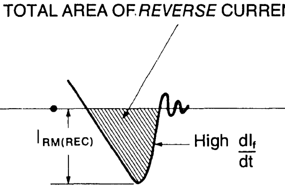
(*) INV. = Bridge, center-tap, or half-bridge inverter.

Appendix B
Reverse Recovery Behavior and Dissipation

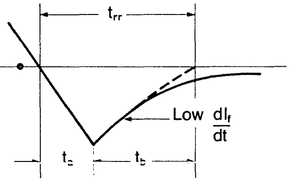
1. Waveforms and definition of terms:



JEDEC test - standard slope = 25A/μS
Figure B-1



"ABRUPT"
Figure B-2



"SOFT"
Figure B-3

2. Discussion of Variables:

Any PN junction diode operating in the forward direction contains stored charge in the form of excess minority carriers. The amount of stored charge is proportional to the forward current level.

The diode or rectifier in a switching regulator is switched from forward conduction to reverse at a specific ramp rate (−dI/dt) determined by the external circuit, usually by the turn-on time of the associated switching transistor. During the first portion of the reverse recovery period, t_a, charge stored in the diode is able to provide more current than the circuit demands, so that the device appears to be a short circuit. Transition from t_a to t_b occurs when stored charge has been depleted to the point where it can no longer supply the increasing current demanded by the circuit. The device becomes a high impedance and during t_b the reverse voltage is permitted to increase. Reverse current, no longer circuit determined, dwindles as excess stored charge depletes to zero. Stored charge is depleted by the reverse current flow and also by recombination within the device.

At (−dI/dt) rates which are slow relative to the rate of recombination of the specific device relatively little stored charge is swept out. Recovery time, t_{rr} is determined mainly by the recombination rate, independent of (−dI/dt). Peak reverse recovery current $I_{RM(REC)}$, and total charge associated with reverse current, $Q_{R(REC)}$ are almost directly proportional to (−dI/dt) (Region I, Figure B-4). The recovery characteristic with slow (−dI/dt) rates tends to be soft.

When the (−dI/dt) rate is fast compared to recombination rate (transistor turn-on faster than diode recovery time), t_{rr} decreases as −dI/dt increases, because more of the available stored charge is swept out sooner, leaving little to be depleted by recombination. As (−dI/dt) increases, peak recovery current increases and can become much greater than the original forward current level. However, $Q_{R(REC)}$ levels off as (−dI/dt) increases because it can only approach but not exceed the total stored charge which is a function of the original forward current level (Region II, Figure B-4).

Higher voltage devices have poorer recovery characteristics because they require thicker regions of higher resistivity, resulting in greater volume of stored charge and longer recombination rates.

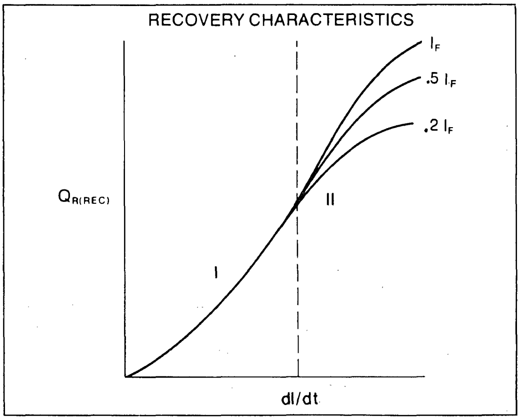


Figure B-4

With a given I_F and dI/dt the $Q_{R(REC)}$, $I_{RM(REC)}$, and t_{rr} all increase with temperature. Recovery characteristic changes as well (generally becoming more abrupt if reverse current is not circuit limited, and softer if limited). Furthermore, $Q_{R(REC)}$ increases and recovery generally softens if higher circuit voltage is applied to a given diode.

3. Comparison of devices at popular test conditions:
Table I, below, shows measured t_{rr} values (in nanoseconds) using ultra-fast and fast recovery DO-5 rectifiers.

I_F (A)	**I_R (A)**	**$-di/dt$ (A/µS)**	**T (°C)**	**$I_{R(REC)}$** (t_{rr} Measured to (A))	**UNITRODE UES803**	**MANUFACTURER**			
						B	**C**	**D**	**E**
0.5	1.0	step	25	0.25	38	50	42	—	—
1.0	1.0	step	25	0.10	45	75	50	63	120
1.0	1.0	step	125	0.10	60	90	122	135	300
	(85V JEDEC circuit)								
30	—	30	25	0	75	120	85	105	150
30	—	30	125	0	100	150	140	210	300
30	—	100	25	0	45	72	66	92	—
30	—	100	125	0	65	114	106	160	—
MAX t_{rr} per manufacturer's stated condition					50	50 to 100			200

Table I

4. Turn-on switching losses, assuming linear V and I transitions:

With an ideal diode, switching losses are entirely in the transistor as follows (from Eq. 2).

$$\text{(B1)}\ P_{(tri)} = V_{in} \cdot \frac{I_C}{2} \cdot \frac{t_{ri}}{\tau}$$

$$\text{(B2)}\ P_{(trv)} = \frac{V_{in}}{2} \cdot I_C \cdot \frac{t_{rv}}{\tau}$$

A practical diode with finite t_{rr} and $I_{RM(REC)}$ will cause *additional* switching losses as follows:

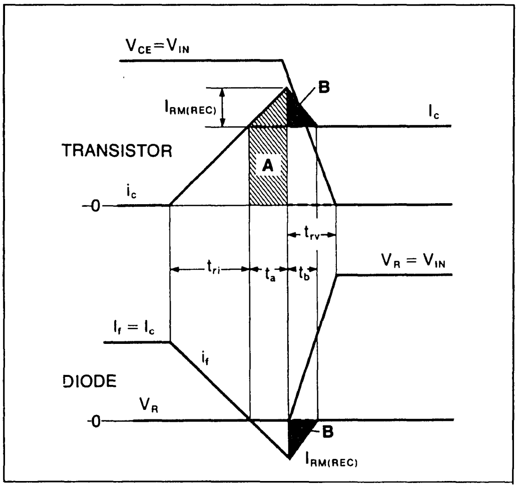


Figure B-5

Diode recovery time component t_a effectively increases transistor rise time, and delays the voltage transition, t_{rv}. During time t_a, the diode conducts reverse current but remains a low impedance. Transistor V_{CE} remains equal to V_{in} while collector current continues to rise above I_C to $I_C + I_{RM(REC)}$. The entire amount of charge shown in shaded area A results in increased switching loss in the *transistor only* (increase in diode loss is negligible):

$$\text{(B3)}\ P_{(t_a)} = V_{in} \left(I_C + \frac{I_{RM(REC)}}{2}\right) \frac{t_a}{\tau}$$

$$\text{(B4)}\quad t_a = t_{ri} \left(\frac{I_{RM(REC)}}{I_c}\right)$$

$$\text{(B5)}\ P_{(t_a)} = V_{in} \left(I_c + \frac{I_{RM(REC)}}{2}\right)\left(\frac{t_{ri}}{\tau}\ \frac{I_{RM(REC)}}{I_c}\right)$$

$$\text{(B6)}\ P_{(t_a)} = V_{in} \cdot I_{RM(REC)} \left(1 + \frac{I_{RM(REC)}}{2 I_c}\right) \frac{t_{ri}}{\tau}$$

If diode $I_{RM(REC)}$ is half of I_C (1.5:1 current overshoot in transistor) total transistor switching losses during current turn-on ($t_{ri} + t_a$) will be 2.25 times greater than with an ideal diode (Eq. B1).

During diode recovery time component t_b, the diode continues to conduct reverse current, but becomes a high impedance, permitting the transistor voltage transition, t_{rv}, to take place. Diode reverse current during t_b causes increased switching losses in the transistor and/or the diode. It is difficult to quantify these losses in the diode and transistor separately, since transistor V_{CE} is decreasing and diode V_R is increasing during all or part of period t_b. However, the total increase in losses in both diode and transistor during t_b is:

$$\text{(B7)}\ P_{(t_b)} = V_{in} \cdot \frac{I_{RM(REC)}}{2} \cdot \frac{t_b}{\tau}$$

$$\left(\text{area B} = \frac{I_{RM(REC)}}{2} \cdot t_b\right)$$

Note: $P_{(t_b)}$ loss is in *addition* to the ideal diode case transistor losses, $P_{(t_{rv})}$ (Eq. B2). With a very fast diode, t_b will be much shorter than t_{rv}, and most of the $P_{(t_b)}$ loss will occur in the transistor, although it will be negligible. With a slow diode, where t_b is much longer than t_{rv}, $P_{(t_b)}$ loss will be significant and will occur mostly in the diode.

$P_{(t_a)}$ is usually much greater than $P_{(t_b)}$. Since all of $P_{(t_a)}$ is dissipated in the transistor, it can be seen that most of the increased switching losses caused by diode reverse recovery are borne by the switching transistor, not by the rectifier.

Appendix C
Forward Recovery Behavior and Characterization

When used in some circuits, any diode may exhibit the phenomenon known as forward recovery. Under these conditions, the device has an impedance which, for a short time after initial application of forward current, is higher than its normal "on" value. The magnitude and duration of this transient impedance will depend on circuit conditions and device design, varying from no effect in many circuits to a few microseconds in the worst case. When present, the effect is generally less with fast-recovery rectifiers, and much less with "computer-type" switching diodes.

Circuits with very fast current rise time, in the direction of forward conduction, will allow this phenomenon to appear. Generally, these will be low-inductance circuits which allow the current to rise from zero to rated forward current in less than the reverse recovery time for fast stud-mounted rectifiers, and in less than 0.1 x t_{rr} for lead mounted fast devices.

When such a source has a high voltage, of at least 10 times V_F, the forward recovery phenomenon exhibits an initial higher-than-steady-state forward voltage. The rise time of current is not limited by the diode and the peak voltage decays to the specified measurement level in the "forward recovery time" t_{fr}. The peak voltage $V_{F(DYN)}$ will be strongly influenced by the current rise time di/dt, and current I_F.

When a fast-rise source has an open circuit (compliance) voltage of less than several times the diode V_F, the forward recovery phenomenon may exhibit a delay in the rise of forward current. In this case the peak diode voltage is limited by the source, and the "turn-on" time is the rise time to 90% of I_F.

A comparison of the Unitrode UES 803 with a typical 200 nS rectifier is shown in Table II below.

	Unitrode UES 803		**DO5 200 nS**	
Test Condition	$V_{F(DYN)}$ **(v)**	t_{fr} **(nS)**	$V_{F(DYN)}$ **(v)**	t_{fr} **(nS)**
I_F to 1A in 8 nS	1.2	20	12	300
I_F to 1A in 125nS and continuing to 50A with t_r = 10μS	0.9	—	2.8	350

Table II

APPLICATION NOTE U-76

FLYBACK AND BOOST SWITCHING REGULATOR DESIGN GUIDE

Section One – Flyback Regulator

I. Definition

The flyback switching regulator described in this application note accepts a DC voltage input and provides a regulated output voltage of opposite polarity. This method of conversion, compared to a conventional DC to DC converter, provides advantages of high efficiency, low cost, circuit simplicity, and a rather wide, easily selectable choice of the regulated output voltage. The switching transistor is not stressed to second breakdown in either the forward or reverse bias modes. Thus, it provides a reliable method of converting the input voltage. The disadvantage of the flyback switching regulator described here is that it provides no isolation and requires a large output filter capacitor. Primary usage of this type of regulator is in low current and/or high voltage applications.

II. Design Approaches to Flyback Regulator

The principal difference between a flyback regulator and a buck regulator (Ref. Unitrode Design Guide U-68) is the manner in which energy is transferred to the output capacitor. In a buck regulator, energy is provided continuously, while in a flyback regulator, energy is pumped in a discontinuous fashion. The flyback regulator can be operated in two modes.

A. Continuous Mode (see Figure 1a)

In this mode of operation, a large inductor is required to insure that the inductor current never goes to zero. Although the current through the inductor flows continuously, the charging current to the filter capacitor is in the form of discontinuous current pulses. This large peak-to-peak current waveform requires a much larger filter capacitor than the buck regulator. Component cost is higher than with the discontinuous mode of operation because of the large inductance required, and transient response is worse.

B. Discontinuous Mode (see Figure 1b, 1c)

In this mode, the regulator is designed such that at maximum output load current and minimum input voltage, the transistor starts conducting as soon as the catch diode stops conducting. At a lower output current or higher input voltage there is a dead time when neither device conducts.

The output voltage can be regulated by varying the duty cycle of the transistor switch.

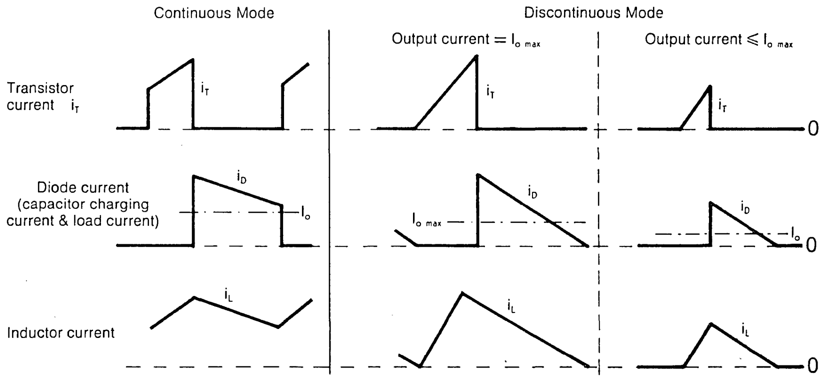


Figure 1a Figure 1b Figure 1c

Figure 1. Current Waveforms

III. The Flyback Switching Regulator Described and Characterized

The basic circuit configuration and generalized current waveforms are shown in Figure 2. When transistor Q_1 is turned on, the supply voltage, E_{IN}, is applied across power inductor L. The current through the inductor rises linearly to a peak current level I_p:

$$I_p = \frac{E_{IN} \times t_T}{L} \qquad \text{A.}$$

This results in an energy transfer from the input supply to the power inductor:

$$W = \frac{1}{2} L I_p^2 \qquad \text{B.}$$

When the transistor turns off, a voltage is induced across inductor L which forces the current to flow through diode D_1. All of the energy stored in the inductor is transferred to the output capacitor and load R_L, and the inductor current diminishes linearly from I_p to zero according to the relationship:

$$I_p = \frac{E_o \times t_D}{L} \qquad \text{C.}$$

The power delivered to the load is equal to the peak energy stored in the inductor times the number of pump cycles per second:

$$P_{out} = E_o \times I_o = \frac{1}{2} L I_p^2 \times f \qquad \text{D.}$$

The voltage induced in the inductor is such that E_o is opposite in polarity from E_{IN}. The relationship between E_o and E_{IN} is established by combining equations A and C, eliminating I_p and L:

$$\frac{E_o}{E_{IN}} = \frac{t_T}{t_D} \qquad \text{E.}$$

DC output current I_o is equal to the average current through the diode:

$$I_o = \frac{I_P}{2} \times \frac{t_D}{\tau} = \frac{I_P}{2} \times t_D \times f$$

The output voltage can be regulated by operating at a fixed frequency and varying the transistor on time, t_T. However, because of the inherent "pumping" action of the flyback regulator, the output voltage diminishes while the switching transistor is on, and increases when the transistor is off. This characteristic makes it difficult to control on a fixed frequency basis.

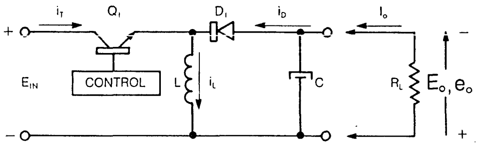


Figure 2a. Flyback Switching Regulator

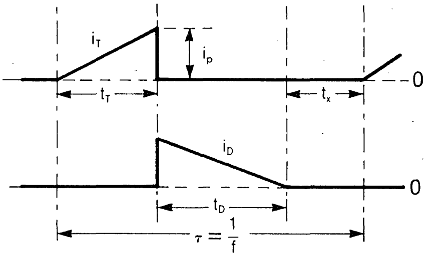
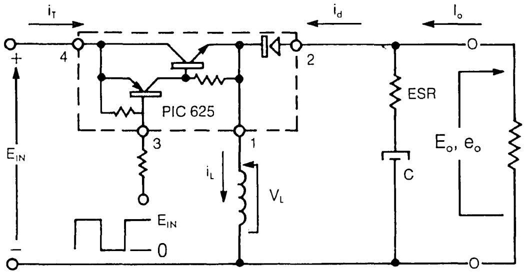


Figure 2b. Generalized Current Waveforms of a Flyback Switching Regulator

The simplest approach to controlling the flyback regulator in the discontinuous mode is to establish a fixed peak current through the inductor, which determines a fixed diode conduction time, t_D. Frequency then varies directly with output current, and transistor on-time varies inversely with input voltage. This is the approach used in this application note, resulting in a simple and economical control circuit.

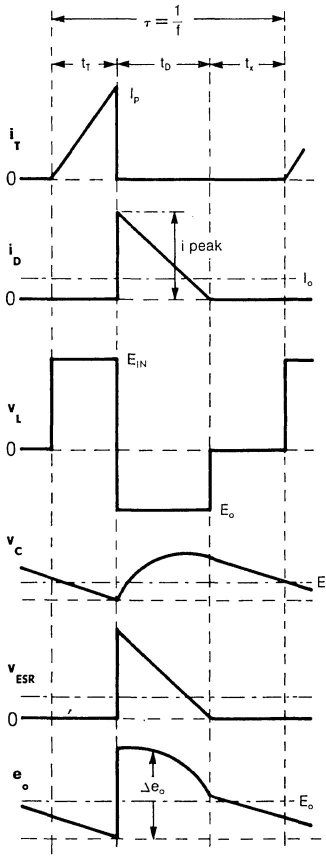
IV. Worst Case Design Conditions

Design equations based on the fixed peak current mode of operation are shown in Figure 3. The worst case condition exists when input voltage is low while output current is at maximum. Under these worst case conditions, frequency is maximum and t_x is zero because the pass transistor turns on as soon as diode stops conducting.



GIVEN:
$E_{IN\,(min)}$
E_o
$I_{o\,(max)}$
f_{max}
Δe_o

WORST CASE:
$E_{IN} = E_{IN\,(min)}$
$I_o = I_{o\,(max)}$
$t_x = 0$



$$I_p = 2\, I_{o\ max}\,(E_o/E_{IN\,(min)} + 1) = \text{constant}$$

$$t_D = \frac{1}{f_{max}\,(E_o/E_{IN\,(min)} + 1)} = \text{constant}$$

$$L = \frac{t_D \times E_o}{I_p} = \frac{t_T \times E_{IN}}{I_p}$$

$$f = \frac{1}{\tau} = f_{max}\,\frac{I_o}{I_{o\,(max)}}$$

$$C_{min} = \frac{I_p \times t_D}{2\,\Delta e_o}$$

(worst case $I_o \rightarrow 0$)

$$ESR_{max} = \frac{\Delta e_o}{I_p}$$

Figure 3. Flyback Regulator

12

V. Circuit Design and Description

In designing a flyback switching regulator power supply, the following parameters will normally be predefined. Numerical values are given and computed for the example shown in Figure 4.

E_o = 5V output
Δe_o = 100 mV output ripple voltage peak to peak
$I_o max$ = 2.5A
$E_{IN} min$ = 9V (minimum)
$E_{IN} max$ = 15V (maximum)

Since the output voltage is derived from pulses of current, it is desirable to keep the operating frequency as high as possible in order to obtain small size and lower cost of the filter inductor and capacitor. However, above 5-10 kHz, capacitor impedance is usually dominated by its equivalent series resistance, ESR, rather than C value. Since the ESR remains essentially constant regardless of operating frequency, operation at higher frequencies does not enable the size and cost of the capacitor to be further reduced.

Also, at higher frequencies, transistor switching losses become significant. Thus, a maximum operating frequency of 25 kHz is chosen for this design.

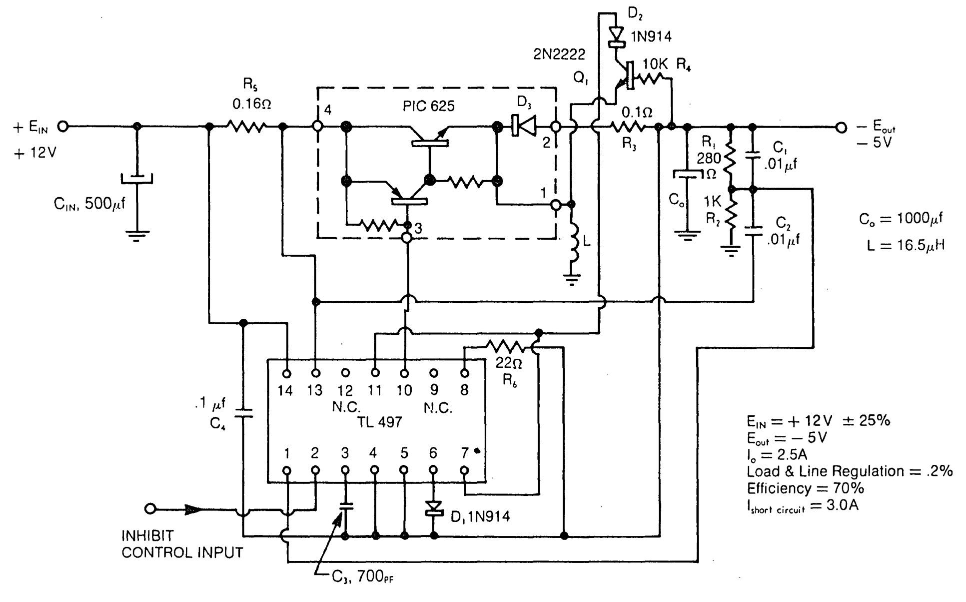


Figure 4. Flyback Regulator, +12V Input, −5V Output

Referring to Figure 3, the design calculations are:

$$I_p = 2 I_o max (E_o/E_{IN}min + 1) = 2 \times 2.5 (5/9 + 1)$$
$$= 7.8A \text{ (constant)}$$

$$t_D = \frac{1}{f_{max} (E_o/E_{IN}min + 1)} = \frac{1}{25 \times 10^3 (5/9 + 1)}$$
$$= 25.7 \mu s \text{ (constant)}$$

$$L = \frac{t_D \times E_o}{I_p} = \frac{25.7 \times 10^{-6} \times 5}{7.8}$$
$$= 16.47 \mu H$$

$$C_{min} = \frac{I_p \times t_D}{2 \Delta e_o} = \frac{7.8 \times 25.7 \times 10^{-6}}{2 \times 0.1}$$
$$= 1002 \mu F$$

$$ESR_{max} = \frac{\Delta e_o}{I_p} = \frac{0.1}{7.8} = 0.0128 \Omega$$

The operating frequency will change in proportion to load current, I_o:

$$f = f_{max} \times \frac{I_o}{I_{o\ max}}$$

The PIC625 hybrid power output stage incorporates a fast PNP quasi-darlington switching transistor and UES catch diode. The quasi-darlington switch requires 30 mA of drive current. This drive current is provided with diode D_1 and Resistor R_6 in conjunction with the Integrated circuit TL497. (Refer to Figure 4)

$$I_{DRIVE} = \frac{V_{be}}{R_6} = \frac{0.65}{R_6}$$
$$\therefore \ R_6 = 22 \Omega$$

The output voltage is preset by divider network R_1 and R_2, according to the relationship:

$$E_o = \left[1 + \frac{R_2}{R_1}\right] V_{REF}$$

where $V_{REF} = 1.22V$. Assuming a nominal value for $R_2 = 1K$, then:

$$R_1 = 320 \Omega$$

R_1 may be trimmed to obtain the precise output voltage.

The TL497 control circuit operates in the current limiting mode under normal operating condition. Thus, the peak current value, I_p, is determined by the current limiting resistor R_5. Capacitor C_3 is required to prevent the TL497 from terminating the transistor on-time prematurely. This causes an 8 μs delay, once over-current is detected at the short circuit sense input (pin 13 of TL497) before the transistor switch turns off. The delay time is the time required to charge capacitor C_3 to the predetermined voltage level before drive current to the pass transistor is removed. The current limit threshold voltage is about 1.2 volts.

$$R_5 = \frac{1.2V}{I_p}$$
$$= \frac{1.2}{7.8A}$$
$$= 0.153 \Omega$$

The function of transistor Q_1, diode D_3 and resistor R_3 and R_4 is to provide short circuit protection. The transistor Q_1 prevents turn-on of the pass transistor as long as the catch diode continues to conduct. Thus, it limits the maximum current and operating frequency under short circuit conditions. D_2 and R_4 providing voltage isolation to transistor Q_1.

C_2 is required for circuit stabilization; capacitor C_1 provides AC coupling of ripple voltage to the control circuit. C_{IN} and C_o are filter capacitors.

Unitrode Switching Regulator Design Guide U-68 covers the design of a buck regulator, and contains a section on power inductor design which is applicable to the flyback and boost regulators.

Section Two — Boost Switching Regulator

The boost switching regulator is described briefly in this application note. It accepts a DC voltage input and provides a regulated output voltage which must be greater than input voltage.

The basic circuit configuration of a boost regulator is shown in Figure 5. When the transistor switch is turned on, the supply voltage E_{IN} is applied across power inductor L. The diode is reverse biased by voltage E_o. Energy is transferred from the input supply to the power inductor. When the transistor is turned off, the energy stored in the inductor L induces a voltage such that the diode conducts and transfers the energy to the load and the output capacitor. In addition to the energy stored in the inductor, additional energy is transferred from the input directly to the output during the diode conduction time.

This pumping action, similar to the flyback regulator, also makes it desirable to operate the boost regulator in the discontinuous mode with a fixed peak current through the inductor. However, unlike the flyback regulator, in the boost regulator the diode conduction time is not fixed, but varies according to the input voltage:

$$t_D = \frac{L\,I_p}{E_o - E_{IN}}$$

Output voltage is regulated by controlling the duty cycle:

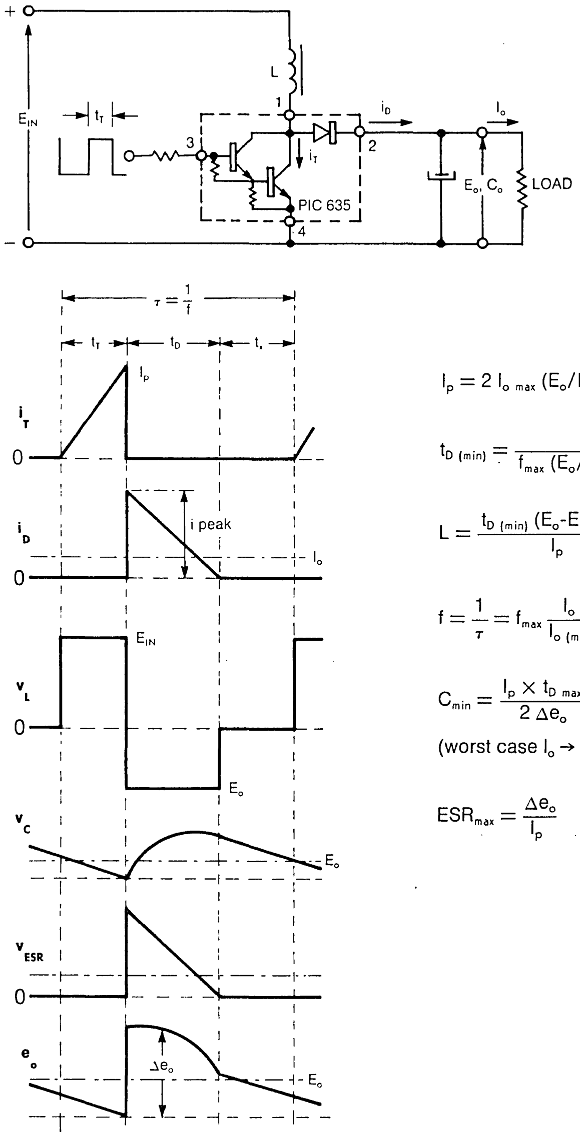
$$\frac{E_o}{E_{IN}} = \frac{t_T}{t_D} + 1$$

Since the ripple voltage across the output capacitor is directly proportional to diode conduction time, t_D, capacitor requirements are determined by the maximum t_D:

$$t_D\,\text{max} = \frac{L\,I_p}{E_o - E_{IN}\,(\text{max})}$$

The Figure 6 is a complete schematic diagram of a boost switching regulator. It accepts +12V of DC input voltage and provides regulated +24V of output voltage.

The design procedure and circuit description is similar to the flyback switching regulator.



GIVEN:
$E_{IN\,(max)}$
$E_{IN\,(min)}$
E_o
$I_{o\,(max)}$
$f_{(max)}$
Δe_o

WORST CASE:
$E_{IN} = E_{IN\,(min)}$
$I_o = I_{o\,(max)}$
$t_x = 0$

$$I_p = 2\, I_{o\,max}\,(E_o/E_{IN\,(min)}) = \text{constant}$$

$$t_{D\,(min)} = \frac{1}{f_{max}\,(E_o/E_{IN\,(min)})}$$

$$L = \frac{t_{D\,(min)}\,(E_o\text{-}E_{IN\,min})}{I_p}$$

$$f = \frac{1}{\tau} = f_{max}\,\frac{I_o}{I_{o\,(max)}} \times \frac{E_o\text{-}E_{IN}}{E_o\text{-}E_{IN\,(min)}}$$

$$C_{min} = \frac{I_p \times t_{D\,max}}{2\,\Delta e_o}$$

(worst case $I_o \to 0$)

$$ESR_{max} = \frac{\Delta e_o}{I_p}$$

Figure 5. **Boost Regulator**

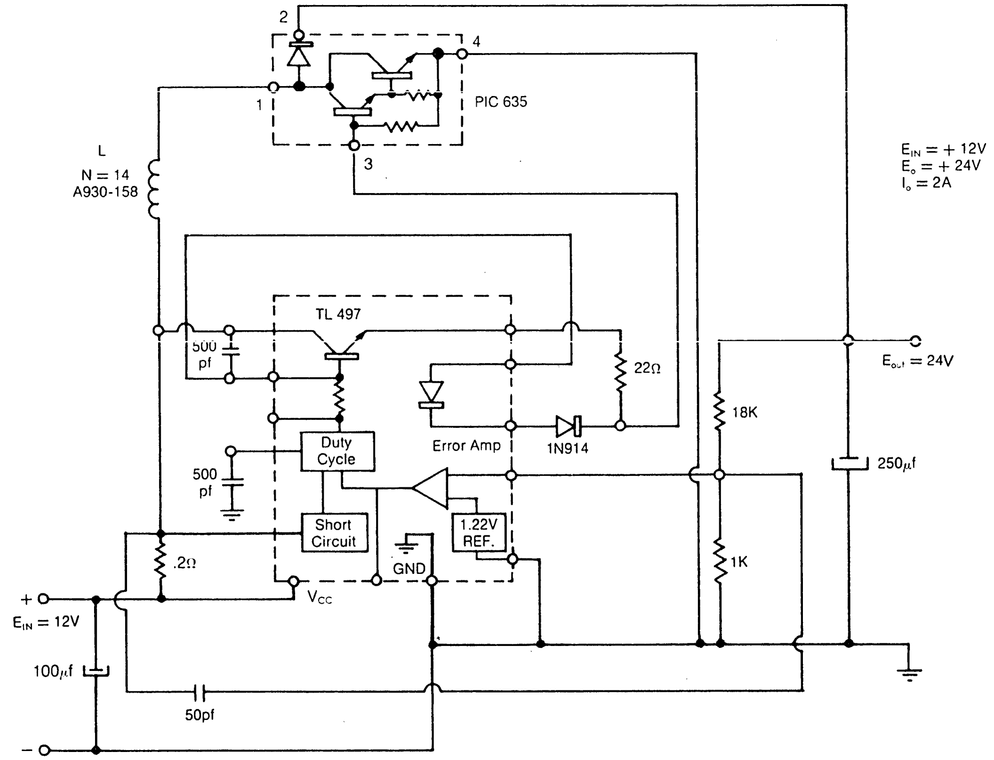


Figure 6. Boost Switching Regulator

Appendix A — Derivation of Design Equations

The basic circuit configuration of the flyback switching regulator is shown in Figure 3. Assuming a fixed value of peak current, I_p, and output volts, E_o, the following equations are evident:

$$E_{IN}\, t_T = E_o\, t_D = I_p \times L \tag{1.}$$

$$t_T = t_D \times E_o / E_{IN} \tag{1a.}$$

$$\tau = t_T + t_D + t_X = 1/f \tag{2.}$$

Worst case $\tau = \tau_{min}$, $f = f_{max}$, $t_X = 0$, $E_{IN} = E_{IN}$ min. Substituting Equation 1a:

$$\tau_{min} = \frac{1}{f_{max}} = t_D\,(E_o/E_{IN}\,\text{min} + 1) \tag{2a.}$$

$$\therefore\ t_D = \frac{1}{f_{max}\,(E_o/E_{IN}\,\text{min} + 1)} \tag{2b.}$$

Since in Equation 1, E_o, I_p and L are all constant values for a given application, t_D is also a constant value.

By inspection of Figure 3 output current waveforms:

$$I_o = \frac{I_p}{2} \times \frac{t_D}{\tau} = \frac{I_p}{2} \times t_D \times f \tag{3.}$$

Taking worst case conditions and substituting Equation 2b:

$$I_o\,\text{max} = \frac{I_p}{2} \times f_{max} \times \frac{1}{f_{max}\,(E_o/E_{IN}\,\text{max} + 1)} \tag{3a.}$$

$$\therefore\ I_p = 2\, I_o\,\text{max}\,(E_o/E_{IN}\,\text{max} + 1) \tag{3b.}$$

Rearranging Equation 1:

$$L = \frac{t_D \times E_o}{I_p} \tag{1b.}$$

The ripple voltage, Δv_c, across the output filter capacitor:

$$\Delta v_c = \frac{\Delta Q}{C} \tag{4.}$$

The worst case net charge into the capacitor is equal to the area under the diode current waveform

$$\Delta Q_{max} = \frac{I_p \times t_D}{2} \tag{4a.}$$

Substituting into Equation 4 and rearranging:

$$\therefore\ C_{min} = \frac{I_p \times t_D}{2\,\Delta e_o} \tag{4b.}$$

The ripple voltage, v_{ESR} across the capacitor series resistance, ESR.

$$v_{ESR} = I_p \times ESR \tag{5.}$$

$$\therefore\ ESR_{max} = \frac{\Delta e_o}{I_p} \tag{5a.}$$

The frequency, f, will vary as a function of load current. Rearranging Equation 3:

$$\frac{I_o}{f} = \frac{I_p}{2} \times t_D = I_o\,\text{max}/f_{max} \tag{6.}$$

$$\therefore\ f = f_{max} \times \frac{I_o}{I_{o\,max}} \tag{6a.}$$

and

$$f_{min} = f_{max} \times \frac{I_{o\,min}}{I_{o\,max}}$$

APPLICATION NOTE U-77

THERMAL DESIGN CONSIDERATIONS FOR OPERATING UNITRODE'S TO-92 TRANSISTORS AND DARLINGTONS IN PULSED-POWER APPLICATIONS

Introduction

Unitrode's power Darlingtons (U2TA506, U2TA508, U2TA510) and power transistors (UPTA510, UPTA520, UPTA530 and UPTB520, UPTB530, UPTB540, UPTB550) in economical TO-92 plastic packages are ideally suited for use in pulsed power applications, such as lamp driving or printer driving where the inrush or pulse drive current can be as high as several amperes. When compared with transistors or Darlingtons in conventional power packages, the Unitrode TO-92 devices offer cost savings of 50% or more, take up significantly less board space, and lend themselves to tape and reeling and automatic insertion. They also offer the advantage of a maximum operating junction temperature ($T_{J(max)}$ of 175°C versus 150°C or 125°C) for other plastic packaged devices.

Thermal considerations are of prime concern when the TO-92 power transistors and Darlingtons are used in pulsed power applications. This Design Guide provides a method for determining the junction temperature and maximum allowable peak power dissipation for the U2TA506, U2TA606 and the UPTA510 and UPTB520 series when they are operated at frequencies of 10kHz or less, where the switching losses are negligible and can be ignored. This method is valid for the vast majority of pulse applications.

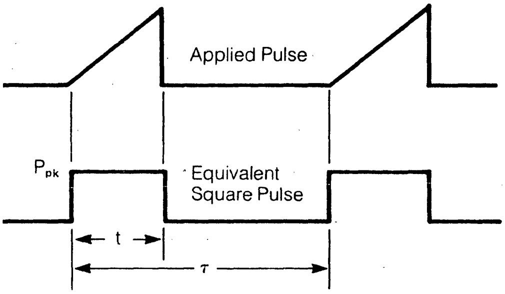
Thermal Analysis

A detailed transient thermal analysis is required to determine the peak junction temperature and maximum allowable power dissipation since the junctions of the transistor or Darlington are subjected to temperature excursions due to the applied, periodic power pulses.

A) Effective Pulsed Thermal Impedance

The effective pulsed thermal impedance (Θ_p) of a device subjected to a periodic train of power pulses can be calculated as follows:

$$\Theta_p = (\Theta_{j\text{-}A})(D) + (1-D)(r(t+\tau)) - r(\tau) + r(t) \ \ldots\ldots\ (1)$$



Where: t = pulse width
τ = period
D = t/τ (Duty Cycle)
$r(t+\tau)$ = transient thermal impedance at time $t + \tau$
$r(t)$ = transient thermal impedance at time t
$\Theta_{j\text{-}A}$ = DC junction to ambient thermal impedance
P_{pk} = The peak power of a square power pulse with equivalent energy to that of the actual power pulse.

Figure 1. Power Pulses

The DC junction to ambient thermal impedance ($\Theta_{j\text{-}A}$) is 200°C/W maximum for the UPTA510 and UPTB520 series and is 155°C/W maximum for the U2TA506 series.

The transient thermal impedance for the U2TA506, UPTA510 and UPTB520 series can be obtained from the curves presented in Figure 2:

SEMICONDUCTOR PRODUCTS
UNITRODE

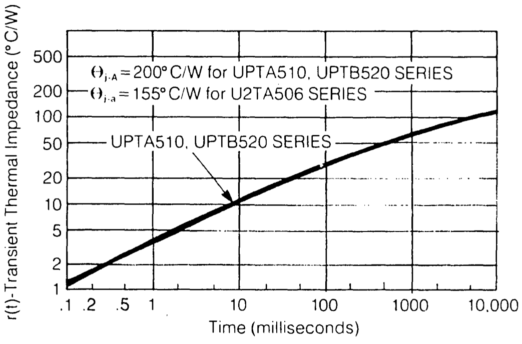


Figure 2. Junction to Ambient Transient Thermal Impedance

B) Peak Junction Temperature

The peak junction temperature of a device subjected to a periodic train of power pulses can be calculated using the previously derived effective pulsed thermal impedance as follows:

$$T_{j\,(peak)} = T_{Ambient} + (P_{pk})\,(\Theta_p) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In the case of a single shot pulse the term for Θ_p reduces to

$$\Theta_p = r\,(t)$$

and the equation used to calculate peak junction temperature becomes

$$T_{j\,(peak)} = T_{Ambient} + (P_{pk})\,(r(t)) \quad \ldots\ldots\ldots\ldots\ldots (3)$$

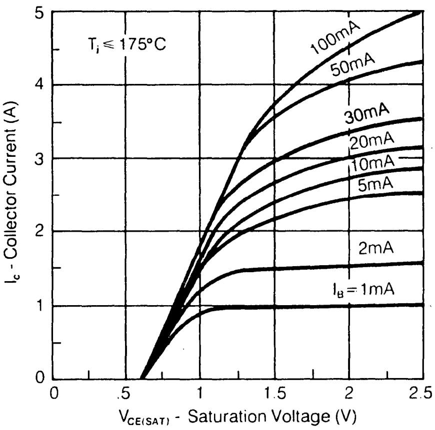


Figure 3. U2TA506 Series. Maximum Base to Emitter Saturation Voltage vs. Collector Current

Allowable Peak Power Dissipation

The allowable peak power dissipation can be derived from the following equation:

$$P_{pk(max)} = \frac{T_{j\,(max)} - T_{Ambient}}{\Theta_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where $T_{J(max)}$ is the maximum allowable junction temperature. For the U2TA506; UPTA510 and UPTB520 series the maximum junction temperature is 175°C.

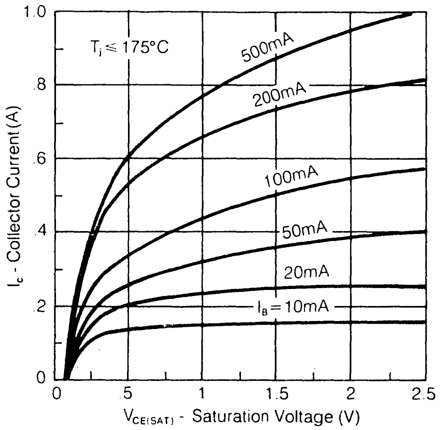


Figure 4. UPTA510 Series. Maximum Saturation Voltage vs. Collector Current

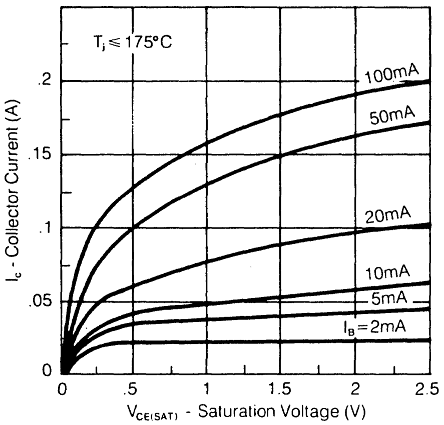


Figure 5. UPTB520 Series Maximum Saturation Voltage vs. Collector Current

Peak Power

The peak power can be expressed as follows:

$$P_{pk} = (V_{CE(SAT)})(I_{pk}) + (V_{BE(SAT)})(I_B) \ldots\ldots\ldots\ldots (5)$$

Where I_{pk} is the peak collector current of a square pulse of current equivalent to the applied current pulse, $V_{CE(SAT)}$ is the transistor or Darlington saturation voltage at I_{pk}, $V_{BE(SAT)}$ is the base-to-emitter saturation voltage and I_B is the base current. Figures 3, 4, and 5 are plots of $V_{CE(SAT)}$ for the U2TA506, UPTA510 and UPTB520 series Darlingtons and transistors. Figures 6 and 7 are plots of the $V_{CE(SAT)}$. These curves can be used in determining P_{pk}.

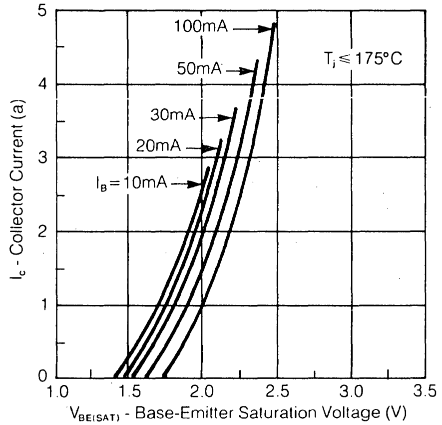


Figure 6. U2TA506 Series Maximum Base to Emitter Saturation Voltage vs. Collector Current

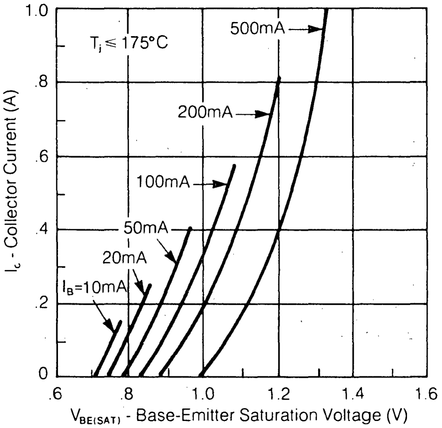


Figure 7. UPTA510, UPTB520 Series. Maximum Base to Emitter Saturation Voltage vs. Collector Current

Design Examples

1. An incandescent lamp is controlled by a U2TA506 Darlington operating from a 12V battery. When switched on the lamp draws an inrush current of 3A which decays exponentially to a steady-state value of 300mA. The time constant of the inrush current is 50 milliseconds and the worst case ambient temperature is 55°C. The Darlington's base drive is 30mA dc.

Problem:

Calculate the peak junction temperature due to the inrush pulse and the steady-state junction temperature.

Solution:

The inrush current can be approximated by a square wave of 3A peak and 50 milliseconds duration. The equivalent square pulse of current will have the same energy as the exponential pulse if the $V_{CE(SAT)}$ of the Darlington is assumed to remain constant. Since the $V_{CE(SAT)}$ will actually drop as the inrush current exponentially decays, the result obtained from using the square wave approximation will be conservative.

Using equations (3) and (5)

$$T_{j(peak)} = T_{Ambient} + (P_{pk})(r(t)) \ldots\ldots\ldots\ldots (3)$$

$$\begin{aligned} \text{Where: } T_{Ambient} &= 55°C \\ r(t) &= r(50mSec) = 17.5°C/W \text{ (from Figure 2)} \\ P_{pk} &= (V_{CE(SAT)})(I_{pk}) + (V_{BE(SAT)})(I_B) \ldots (5) \\ &= (1.5V)(3A) + (2.15V)(30mA) \\ &\quad \text{(from Figures 3 and 6)} \\ &= 4.56W \end{aligned}$$

Therefore:

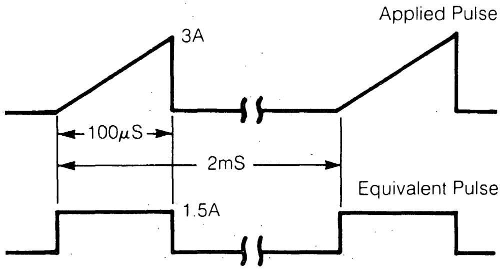
$$T_{j(peak)} = 55°C + (4.56W)(17.5°C/W) = 135°C$$

Since 135°C is 40°C less than the maximum operating junction temperature for the U2TA506 ($T_{j(max)}$ = 175°C), the Darlington is operating well within its rating.

The Steady-state junction temperature can be determined as follows:

$$\begin{aligned} T_{j(ss)} &= (P_{(ss)})(\Theta_{j\text{-}A}) + T_{Ambient} \\ &= ((.3A)(.73V) + (.03A)(1.60V))(155°C/W) + 55°C \\ &= 96°C \end{aligned}$$

2. A U2TA508 is used to drive a solenoid load in an impact printer. The collector current waveform is as shown below along with the equivalent square pulse:



The Darlington is switching in a clamped mode so the energy stored in the solenoid inductance during the on-time is dissipated in the clamp and not in the Darlington. The maximum ambient temperature is 80°C and the base drive current is 20mA.

Problem:
Find the worst case junction temperature and determine if it is within the maximum rating of the U2TA508.

Solution:
Use equation (1) to determine Θ_p

$\Theta_p = (\Theta_{j\text{-}A})(D) + (1-D)(r(t+\tau)) - r(\tau) + r(t)$ ....(1)

$\Theta_{j\text{-}A}$= 155°C/W (from Figure 2)

$D = \frac{.1\text{mSec}}{2\text{mSec}} = .05$

$r(t+\tau) = r(2.1\text{mSec}) = 4.2°\text{C/W}$ (from Figure 2)

$r(\tau) = r(2\text{mSec}) = 4.1°\text{C/W}$ (from Figure 2)

$r(t) = r(.1\text{mSec}) = 1.1°\text{C/W}$ (from Figure 2)

Therefore:

$\Theta_p = (155°\text{C/W})(.05) + (.95)(4.2°\text{C/W}) - 4.1°\text{C/W} + 1.1°\text{C/W}$

$= 8.75°\text{C/W}$

Using equation (5)

$P_{pk} = (V_{CE(SAT)})(I_{pk}) + (V_{BE(SAT)})(I_B)$ .... (5)

I_{pk}= 1.5A

$V_{CE(SAT)}$ + 2V (from Figure 3)

(The $V_{CE(SAT)}$ value at 3A was chosen to give a conservative answer. If T_j is found to be greater than 175°C it may be necessary to recompute using a closer approximation of the actual $V_{CE(SAT)}$ which varies as the current increases from 0 to 3A.)

I_B= 20mA

$V_{BE(SAT)}$ = 2.1V (from Figure 6)

(Again the $V_{BE(SAT)}$ value at 3A was chosen to give a conservative result.)

Therefore:

P_{pk}= (2V) (1.5A) + (2.1V) (.02A) = 3.04W

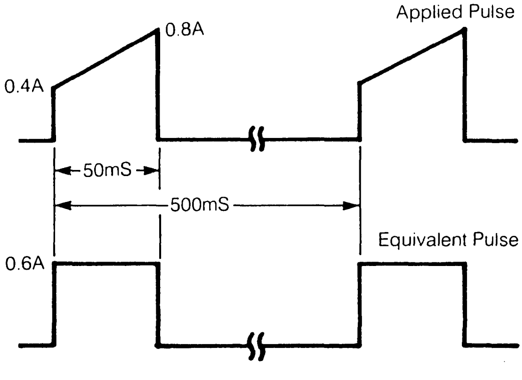
Now T_j can be determined from equation (2)

$T_j = T_{ambient} + (P_{pk})(\Theta_p)$ .... (2)

= 80°C + (3.04W) (8.75°C/W) = 107°C

This is well within the maximum rating of 175°C for the U2TA508.

3. A UPTA530 is used to drive a high voltage DC motor in a display application the current waveform as is shown below:



The base drive is 200 mA and the worst case ambient temperature is 65°C.

Problem:
Determine the junction temperature to insure it is within the maximum rating of 175°C for the UPTA530.

Solution:
Using Equation (1)

$\Theta_p = (200°\text{C/W})(.1) + (.9)(52°\text{C/W}) - 50°\text{C/W} + 21°\text{C/W}$

$= 37.8°\text{C/W}$

From equation (5) and Figures 4 and 7.

P_{pk} = (2.3V (.6A) + (1.2V)(.2A) = 1.6W

(Again $V_{CE(SAT)}$ and $V_{BE(SAT)}$ values at .8A rather than .6A were used to insure a conservative answer).

Therefore, from equation (2)

T_j = 65°C + (1.6W) (37.8°C/W) = 126°C

It becomes readily apparent from these examples that Unitrode's TO-92 transistors and Darlingtons can be operated with significant safety margin in a wide variety of pulsed-power applications.

APPLICATION NOTE **U-79**

GUIDELINES FOR USING TRANSIENT VOLTAGE SUPPRESSORS

1.0 Introduction

During transient periods, system voltages and currents are often many times greater than their steady-state values. These transients must be considered in overall electronic systems design to insure required circuit performance and reliability both during and after the transient.

Transients may result from a variety of causes. The most common of these are: normal switching operations (power supply turn-on and turn-off cycles), routine AC line fluctuations, or abrupt circuit disturbances (faults, load switching, voltage dips, magnetic coupling by electro-mechanical devices, lightning surges, etc.). Voltage transients are a major cause of component failures in semiconductors. Random high voltage transient spikes can permanently damage these voltage sensitive devices and disrupt proper system operation. Catastrophic power supply conditions should not necessarily be the designer's prime concern, since lower level transients can cause improper operation of a system even though no component failures are caused. Normal power supply on-off cycles have the potential of emitting spikes with sufficient energy to destroy an entire semiconductor device chain. Any surviving devices are also suspect. Trouble shooting, isolating, and replacing damaged devices is time consuming and costly; especially when performed in the field.

Unitrode's TVS305 and TVS505 series of transient voltage suppressors (TVS) offer the designer significant price/performance advantages over other protection methods. Their miniature size permits simple "close-in" installation in applications where circuit boards are dispersed throughout one or more electronic racks. Dispersed usage aids system trouble shooting and affords transient voltage protection where internal system disturbances such as those caused by inductive load switching could occur.

In spite of their small size, the TVS305 and TVS505 suppressor series can dissipate 500 watts and 150 watts (respectively) of peak pulse power for 1 millisecond. Response time to transients is just about instantaneous — about 1 × 10^{-12} seconds. These devices perform to their data sheet specifications without significant degradation throughout their operating life. Unitrode has performed full power pulse life tests for 100,000 pulses with negligible change in characteristics. These devices are suitable for almost any equipment and environment.

2.0 Choosing the Correct Transient Voltage Suppressor for the Application

Certain critical terms must be defined before any discussion of "how to" choose the correct TVS.

1. Stand-Off Voltage (V_R) is the highest reverse voltage at which the TVS will be non-conducting.
2. Min. Breakdown Voltage (BV_{min}) is the reverse voltage at which the TVS conducts 1 mA. This is the point where the TVS becomes a low impedance path for the transient.
3. Max. Clamping Voltage (V_{Cmax}) is the maximum voltage drop across the TVS while it is subjected to the peak pulse current, usually for 1mS.

Figure 1 graphically shows all three terms.

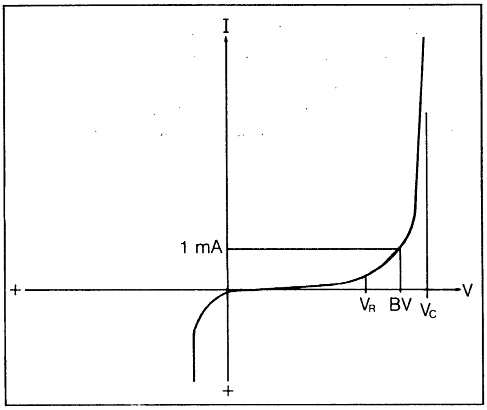


Figure 1 — TVS Characteristics

SEMICONDUCTOR PRODUCTS
UNITRODE

2.1 Determining Pulse Power Levels

Since a zener TVS has an almost constant clamping voltage throughout a transient pulse, the transient pulse power (P_p) equals the peak pulse current (I_{pp}) multiplied by the clamping voltage (V_C).

$$P_p = V_C \times I_{pp}$$

2.2 Choosing the Appropriate Transient Voltage Suppressor

The three most important factors in choosing the appropriate TVS for your application, in their order of importance are:

1. Pulse power (P_p) — Choose the TVS series that will handle the Transient Pulse Power. To determine Transient Pulse Power use the simple equation in section 2.1. If I_{pp} is not known or measurable, it can be calculated — see Sections 3 and 4. The pulse duration vs. pulse power graph on the Unitrode TVS305/TVS505 data sheet can then be used to determine the TVS series that will handle the transient. This graph for the TVS505 series is shown in Figure 2.
2. Stand-off voltage (V_R) — From the TVS series selected, choose the device with the stand-off voltage equal to or greater than your normal circuit operating voltage. This insures that the TVS will draw a negligible amount of current from the circuit during normal circuit operation. The electrical specifications for the TVS505 series are shown in Figure 3.
3. Maximum Clamping Voltage (V_{Cmax}) — Determine the clamping voltage of the device chosen for the transient given and be sure it is below the voltage that might damage any components in the protected circuit. See Figure 3.

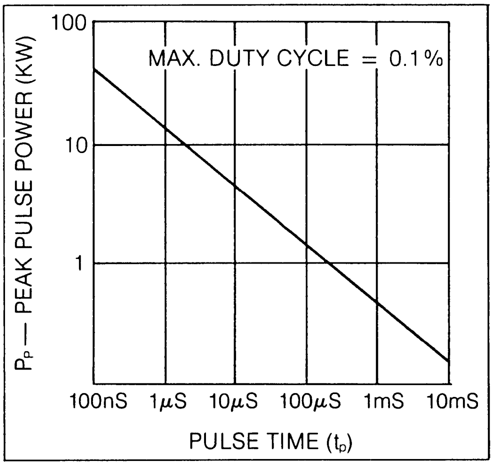


Figure 2 — Peak Pulse Power vs. Pulse Duration

TVS Part No.	Stand-off Voltage V_R	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA	Max. Leakage Current I_R @ V_R	Max. Clamping Voltage V_C @ 1A	Max. Clamping Voltage V_C @ 5A	10A	Max. Peak Pulse Current I_{pp}	Max. Clamping Voltage V_C @ I_{pp}
	V	V	μA	V	V		A	V
TVS505	5.0	6.0	300	7.4		7.9	53.7	9.3
TVS510	10.0	11.1	5	13.2		14.4	30.3	16.5
TVS512	12.0	13.8	5	16.5		18.5	23.8	21.0
TVS515	15.0	16.7	5	19.7		22.2	19.8	25.2
TVS518	18.0	20.4	5	23.8	26.0		16.3	30.5
TVS524	24.0	28.4	5	32.4	37.0		11.9	42.0
TVS528	28.0	30.7	5	35.9	41.0		10.7	46.5

Figure 3 — Electrical Specifications @ 25°C

If the actual pulse power and pulse width are different from those listed on the data sheet, the clamping voltage can be calculated. The actual calculation method is beyond the scope of this note. Instead, we offer a graphical approximation using Figure 4. The approximation is based on the ratio of the actual and rated pulse power.

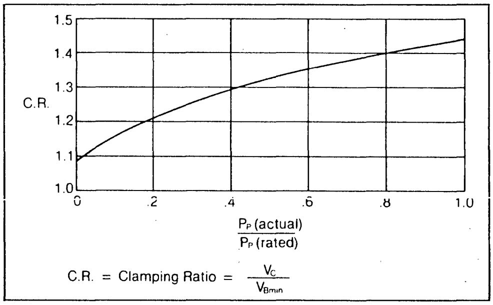


Figure 4 — Graphical Approximation for the Clamping Ratio

The procedure is as follows:

a. Calculate P_p (actual)$\approx$1.3BV_{min} I_{pp}.
b. For P_p (rated) use value from TVS data sheet curve (See Fig. 2 for example).
c. Calculate P_p (actual)/P_p (rated).
d. Use Fig. 4 to find corresponding value of C.R.
e. Calculate V_C = C.R. × BV_{min}.

2.3 Installation Considerations

1. Locate the TVS as close to the device or circuit to be protected as possible.
2. Minimize the "common path" through the TVS to minimize voltage spikes produced by fast risetime transients in lead and wiring stray inductance. See Figure 5.

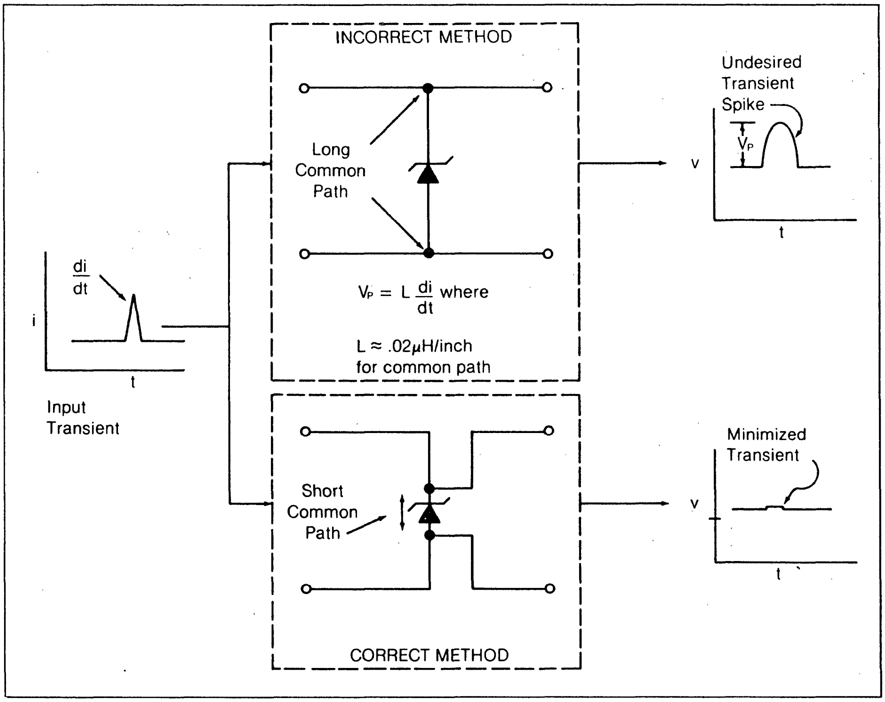


Figure 5 — Minimizing the Common Path

3.0 Transient Levels and Waveforms

3.1 Voltage, Current and Power Levels

Since TVS tests and specs may be written in terms of voltage, current or power levels, the relationships are shown in Figure 6 for (a) field conditions and (b) test conditions.

In addition to the magnitude of the voltage, current or power, the waveform or pulse width should be specified, as shown in Figure 7, for example.

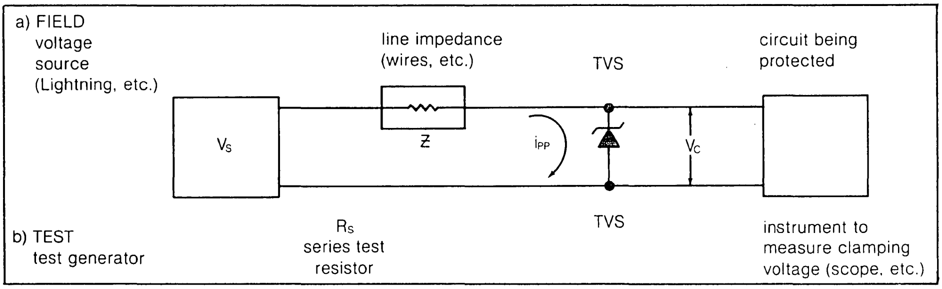


Figure 6 — Equivalent Circuit for Field and Test Conditions

3.2 Typical Transient Levels

Martzloff and Hahn in their paper on transients on 120 volt power lines* produced this table showing the surges recorded at a number of different locations over a two year period. The table indicates two primary causes of transients; load switching within the house and lightning storms.

Table 1*
Detailed Analysis of Recorded Surges

	Most Severe Surge			Most Frequent Surge				
House	Type†	Crest (volts)	Duration (μs or cycles)	1.5mHz Type†	Crest (volts)	Duration (μs or cycles)	Average Surges per Hour	Remarks
1	A-1.5	700	10 μs	A-1.5	300	10 μs	0.07	
2	A-2.0	750	20 μs	A-2.0	500	20 μs	0.14	fluorescent light
3	B-0.5	600	1 cycle	B-0.5	300	1 cycle	0.05	switching
4	B-0.5	400	2 cycles	B-0.5	300	2 cycles	0.2	
5	C	640	5 μs	too few to show typical			10 total	
6	B-0.3	400	1 cycle	B-0.3	250	1 cycle	0.01	
7	B-1	1800	1 cycle	B-1.0	800	1 cycle	0.03	lightning storm
8	C	1200	10 μs	B-0.5	300	4 cycles	0.1	
9	B-0.25	1500	1 cycle	same as most severe			0.2	oil burner
10	B-0.25	2500	1 cycle	B-0.25	2000	1 cycle	0.4	oil burner
11	B-0.2	1500	1 cycle	same as most severe			0.15	water pump
12	B-0.2	1700	1 cycle	B-0.2	1400	1 cycle	0.06	oil burner
13	B-0.1	350	1 cycle	too few to show typical			4 total	house next to 12
14	C	800	15 μs	—	—	—	1 total	lightning
15	B-0.25	800	3 cycles	B-0.25	600	3 cycles	0.05	rural area
16	B-0.15	400	15 μs	B-0.13	200	30 μs	0.4	surges
Street pole	B-0.5	5600	4 cycles	B-0.3	1000	1 cycle	0.1	lightning stroke nearby
Hospital	C	2700	9 μs	C	900	5 μs	0.1	lightning storm
Hospital	B-0.3	1100	1 cycle	too few to show typical			4 total	
Dept. store	B-0.5	300	1 cycle	B-0.5	300	1 cycle	0.5	
Street pole	B-0.2	1400	4 cycles	B-0.2	600	4 cycles	0.07	lightning storm

†*A*—long oscillation. *B*—damped oscillation. *C*—unidirectional. Number shows frequency in megahertz

*Reprinted from *Surge Voltages in Residential and Industrial Power Circuits* by Francois D. Martzloff, Member, IEEE, and Gerald J. Hahn. Reprinted by permission from *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-89, No. 6, July/August 1970, pp. 1049-1056. Copyright 1970, by the Institute of Electrical and Electronics Engineers, Inc. Printed in U.S.A.

3.3 Commonly Used Test Waveforms

1. The 10 × 1000μS Test Waveform used by many TVS manufacturers, also by incoming inspection departments of users, represents some commonly encountered transients. (See Figure 7).
2. The IEEE Standard (ANSI C 37.90a — 1974) for surge withstand capability. (See Figure 8).

3.4 Surge Testing

Figure 9 shows a typical test set used to produce an exponentially decaying current pulse of 1mS to 50% down. (10 × 1000μS). The 1mS waveform is used by many manufacturers to test and characterize their TVS devices for pulse power and clamping voltage.

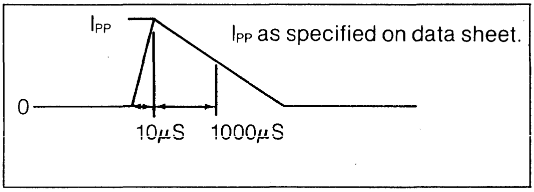


Figure 7 — Commonly Used Test Waveform

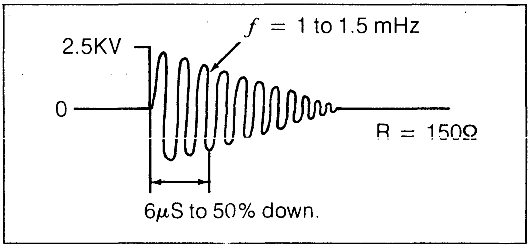


Figure 8 — More Complex Standard Waveform

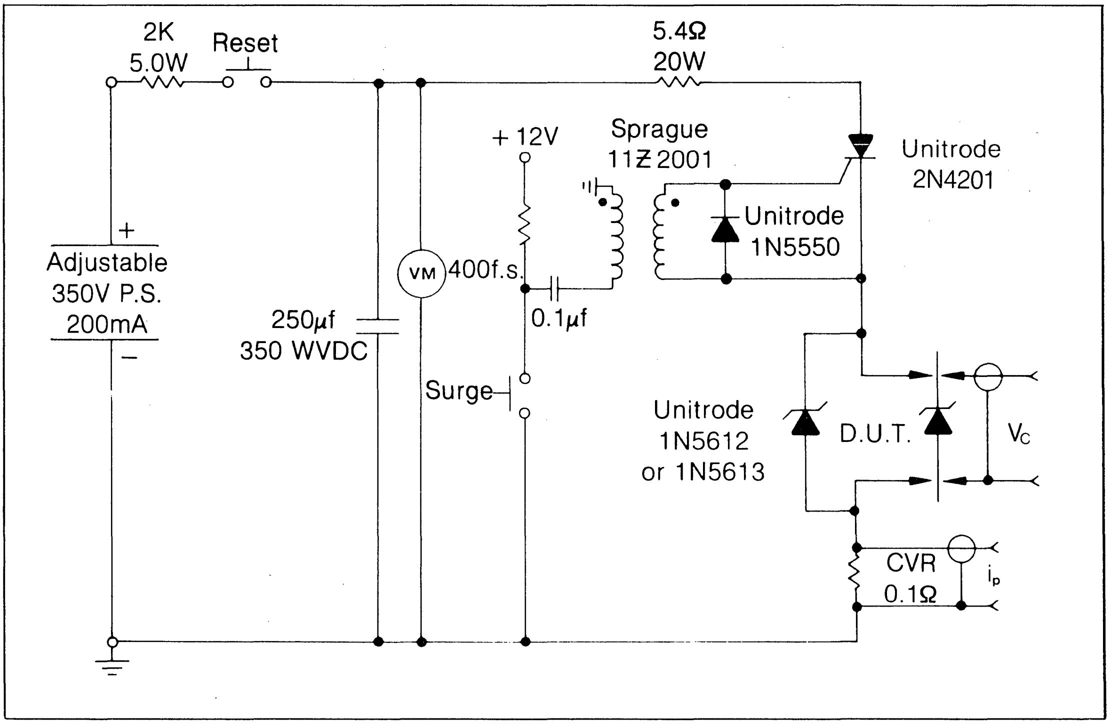


Figure 9 — Suggested Set-up for Surge Testing

4.0 Examples

4.1 Relay and Solenoid Applications

When the energy stored in the coil inductance of a relay or solenoid is released it can damage contacts or drive transistors. It can also produce EMI interference. A TVS used as shown in Figure 10 will provide reliable operation.

Just before the switch opens, the initial inductor current $I_O = \frac{V_{CC}}{R_L}$.

This is the worst case (maximum) current and assumes the switch was closed long enough for the circuit to reach steady-state.

After the contacts switch at $t = 0$, $e = -L\frac{di}{dt}$, and when using a TVS the change in coil current, $\frac{di}{dt} = \frac{V_C}{L}$. Referring to Figure 10d, $t_1 = \frac{I_O}{di/dt} = \frac{V_{cc}/R_L}{V_c/L} = \frac{V_{cc}L}{R_L\,V_c}$. Note that the higher the V_c of the TVS, the shorter the current decay time.

In order to select the proper TVS, determine:

1. Peak pulse power $P_p = I_p \times V_c$, where $I_p = I_o$.
2. Pulse time t_p (@ 50% down point of i_{TVS}) $= \frac{t_1}{2}$.
3. These values of P_p and t_p are used with graphs of pulse power vs. pulse duration provided on the TVS305 and TVS505 data sheet to select proper device. See example in Figure 2.

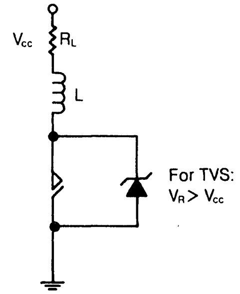


Figure 10a, DC Coil and Contacts.

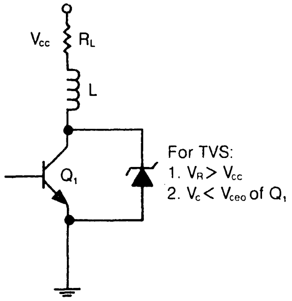


Figure 10b, DC Coil and Transistor.

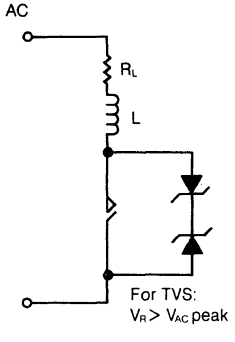


Figure 10c, AC Coil and Contacts.

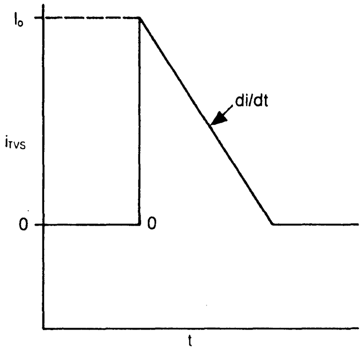


Figure 10d, Simplified Current Waveform in the TVS.

NOTE: In some cases, because of accessibility, the TVS must be located across the coil; in that case a diode should be used in series with the TVS, connected back to back as shown in Figure 11.

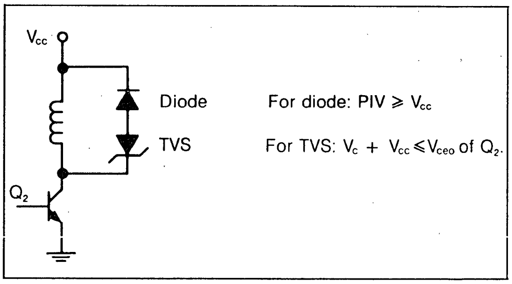


Figure 11 — Using TVS Across Coil

Sample Calculations:

For example, using the circuit of Figure 10a, and sample values of:

$V_{cc} = 14V$, $L = 1mH$, and $R_L = 2\Omega$;

For $V_{cc} = 14V$, the next higher V_R is 15V. (Note that $V_c = 22.2V$ at 10A).

STEP 1: $I_o = \frac{V_{cc}}{R_L} = \frac{14V}{2\Omega} = 7A$

$P_p = I_p \times V_c = 7.0A \times 22.2V = 155W$

STEP 2: $t_1 = \frac{V_{cc}/R_L}{V_c/L} = \frac{14/2}{22.2/10^{-3}} = 0.32mS$

so $t_p = \frac{0.32mS}{2} = 0.16mS = 160\mu S$

STEP 3: From Figure 2, P_{pmax} for $t_p = 160\mu S$ is 1200W, which is well above the circuit value of 155W.

4.2 Protecting Switching Power Supplies

The designer needs to protect against:

1. Load transients
2. Line transients
3. Internally generated transients including those produced by internal faults or failures.

Transients can produce failures because of their own high energy level; and also they can cause improper operation and component failure.

Figure 12 shows a simplified schematic of a typical switching power supply.

Referring to Figure 12, the TVS devices shown protect the following circuit components:

1. the rectifiers.
2. the HV switching transistors.
3. the output rectifiers.
4. the control circuitry.

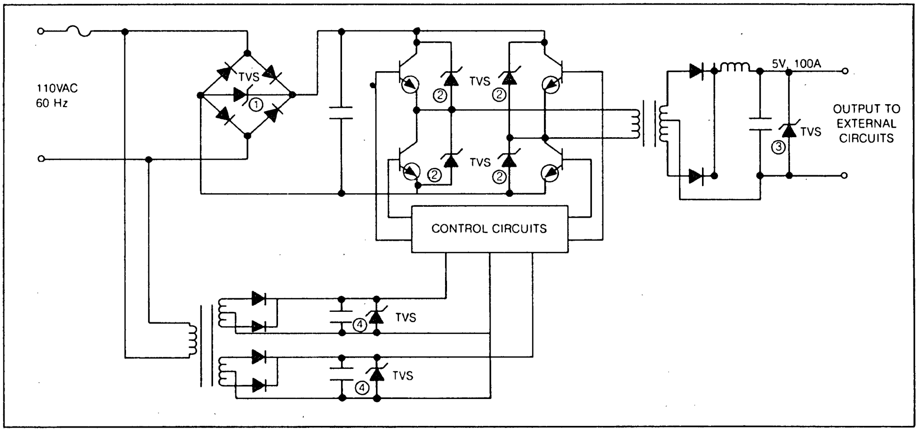


Figure 12 — Typical Switching Power Supply

4.3 Protecting Microprocessor Based Systems

While most microprocessor and IC semiconductor manufacturers design some form of diode-resistive input clamping network on the chip itself, transient voltage protection offered is very minimal — on the order of a few watts of pulse power. Manufacturers are also reluctant to make device performance and reliability claims when power supply operation extends beyond the maximum rated level of the individual device for even relatively short durations such as those that may be encountered during on-off transitions. Therefore, there is a need for some external protective device to suppress voltage transients, as shown in Figure 13.

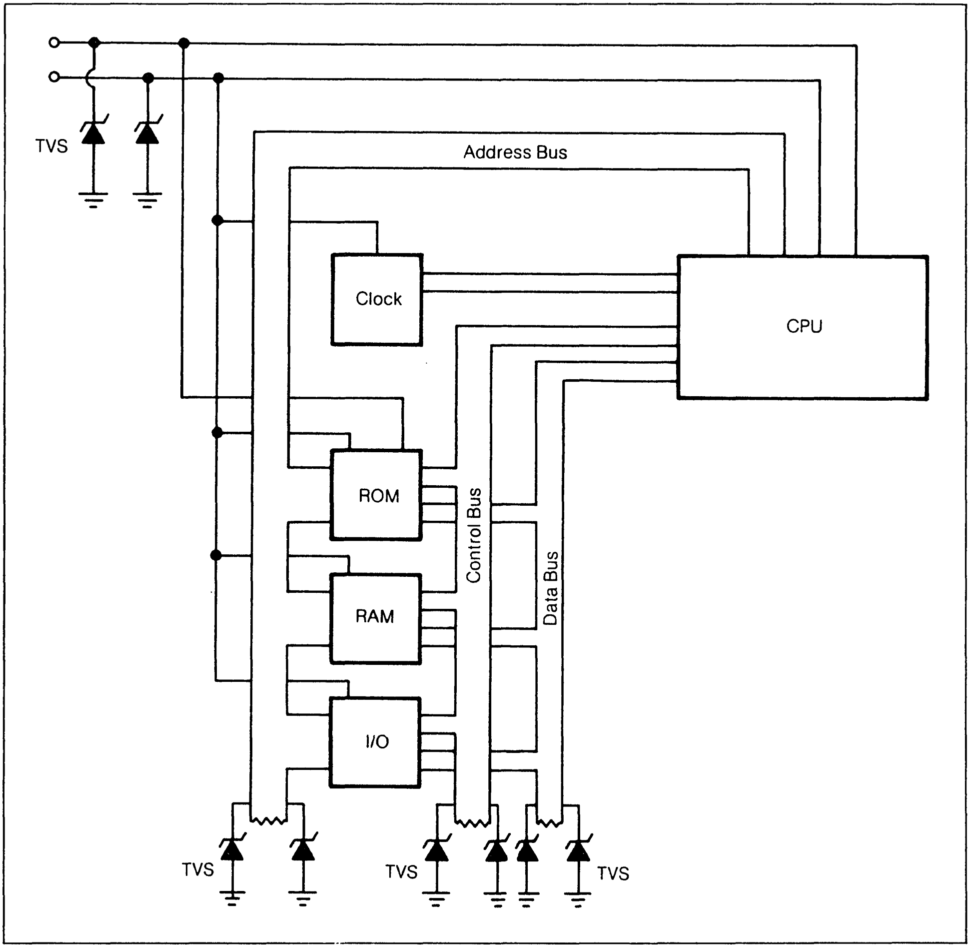


Figure 13 — Protecting Microprocessors

5.0 Alternative Protection Devices

Other protective devices such as MOVs, spark gaps, and crowbars have one common disadvantage when compared to zener TVS products; the response time is from nanoseconds to as much as tens of microseconds as compared to 1 pS for an avalanche zener diode. Even 50nS is long enough to allow a transient to destroy the small junctions used in most integrated circuits, logic, fast transistors, etc.

In circuits where transient pulses are fairly common, device degradation becomes a significant problem. TVS products do not significantly degrade even after 100,000 transients.

In many cases, the zener TVS and one of the alternative devices can complement each other. For example, when used with an SCR crowbar, the zener TVS will keep the voltage during a transient to an acceptable level until the crowbar, which may take 10μS to short the line, can protect the load circuits, and in the case of a heavy transient protect the smaller TVS as well.

APPLICATION NOTE U-82

HYBRID CIRCUITS FOR LOW VOLTAGE SWITCHED-MODE CONVERTERS

ABSTRACT

Hybrid circuits offer many advantages over the conventional discrete approach in switched-mode converters. This paper deals with the construction of the hybrid circuit and its thermal considerations. It examines the efficiency of a buck regulator employing a saturated transistor versus the optimized darlington configuration. Also considered are the effects of reverse recovery of the rectifier and base spreading resistance of the transistor on the efficiency of a switching regulator. Finally, applications of standard hybrid circuits for switched-mode converters are discussed.

I. INTRODUCTION

Recently a rapid increase in the use of hybrid circuits in switched-mode power converters is evident due to their inherent advantages. Some of these advantages are: dc and high frequency electrical isolation, ease in heat sinking multiple power components within the single hybrid package, reduced stray parasitics, and finally, lower overall cost compared to the discrete approach.

The hybrid circuit approach requires careful consideration of thermal design for maximum reliability and proper selection of silicon chips for best electrical performance. This paper provides an overview of the construction of a typical power hybrid switching regulator circuit and its thermal design considerations. Also considered are the effects of the reverse recovery time of the rectifier and the base spreading resistance r_{BB}',of the power switching transistor on the efficiency of the switching regulator. Applications and advantages are also discussed for types of hybrid circuits which are designed for low voltage applications and other types designed for "off-line" switched mode converters.

II. CONSTRUCTION

The power hybrid circuit PIC600 is the power output stage of a buck type switching regulator as shown in Figure 1. It consists of a high speed darlington-connected transistor pair, a commutating diode and two thick film biasing resistors. These components are housed in a 4 pin electrically isolated TO-66 package.

The manufacturing procedure for these devices is divided into two stages. First, a BeO substrate is chosen because of its excellent thermal conductivity, — 70% as good as copper. The interconnection paths, pad areas for the wire bonds and the thick film resistors are screen printed onto the BeO substrate and then fired in high temperature furnaces. For optimum performance, the tolerances of the thick film resistors are maintained within 10% of their design values. The semiconductor devices used in the circuit are all silicon planar passivated devices and are gold eutectic mounted. Aluminum ultrasonic wire bonding is used for interconnections.

In the second stage the BeO substrate is soft soldered to the header for good heat transfer. A copper slug is interfaced between the BeO substrate and nickel plated steel header. The copper slug is used to relieve mechanical stress between the BeO substrate and the header and to provide heat spreading resulting in lower thermal resistance.

III. THERMAL CONSIDERATIONS

The design of the power hybrid circuit requires careful consideration to optimize important thermal requirements; thermal cycling, resistance, and partitioning. To obtain maximum thermal resistance, overlapping heat flow should be avoided. As shown in Figure 2, heat flow from silicon chips #2 and #3 overlaps, thus reducing the thermal capability. No overlapping heat flow occurs from chip #1.

Thermal resistance of the package can be calculated by the formula:

$$R_T = \rho \frac{t}{A}$$

where t is the thickness of material through which heat flows, ρ is the thermal resistivity of the material and A is the average area through which heat flows.

In making a conservative calculation, it is assumed that heat flux diverges at approximately a 45° angle for all the materials except the copper slug (62.5°) due to high conductivity.

The thermal resistance calculation of a hybrid circuit is shown in Figure 2. The copper slug between the BeO and header reduces the thermal resistance of the package (by about .32°C/W) by spreading the heat flow through a large area of the steel header.

This calculation assumes that no voids are present at the interfaces.

IV. COMPONENT AND CIRCUIT SELECTION

Achieving maximum efficiency in a buck-type regulator requires proper selection of electrical characteristics of the transistor switch and catch diode. Optimum efficiency can be obtained with a

Schottky rectifier because it has lower forward drop than most PN junction devices. The Schottky rectifier is a majority carrier device and has zero reverse recovery time. However, the Schottky's high junction capacitance (10 times greater than PN junction devices) produces the same effect as the t_{rr} of PN junction devices. Junction capacitance does not change appreciably with temperature, so the effective reverse recovery time remains the same with respect to temperature. Since commercially available Schottky rectifiers have only a 45V PIV rating, the absolute maximum input voltage of the buck type regulator is limited to only 45V.

Ultra fast PN junction devices are available with the same effective reverse recovery as Schottky rectifiers with a higher (up to 400V) PIV capability. The somewhat higher forward drop of the PN junction devices does not degrade efficiency at higher voltages.

The way in which a device recovers from forward conduction is also important. In high voltage (>1000V) power supplies, it is desirable to have abrupt reverse recovery time for optimum efficiency. In low voltage, high current power supplies a soft reverse recovery rectifier is better suited from the RFI viewpoint.

Figure 3 shows the effect of a diode recovery time on transistor power dissipation. The reverse recovery time of the catch diode requires the transistor to conduct higher peak current for a longer duration in the active region. This significantly increases RFI and also increases the power dissipation in the transistor, and may cause second breakdown.

For reliable circuit operation, t_{rr} should be much less than the current rise time of the transistor. This ensures minimum current overshoot in the transistor and also minimizes the amount of time the transistor spends in the active region during turn-on, resulting in lower power dissipation and increased efficiency. However, to obtain maximum efficiency, all switching times, (including current rise time) should be as fast as possible. The rectifier should be selected such that its t_{rr} is one third or less of the current rise time of the transistor. In switching regulator applications, it is also essential that the storage and fall times be as low as possible.

When turn-off is achieved without the assistance of I_{B2}, it is important that the power output transistor have the following characteristics for best performance:

1. Larger emitter periphery area with a triple diffused or double diffused epitaxial construction to provide lowest effective collector series resistance to prevent forward biasing of the collector-base junction.
2. The base spreading resistance, r_{BB}', of the device should be lower than the external biasing resistor. This will provide low storage time and fast fall time.

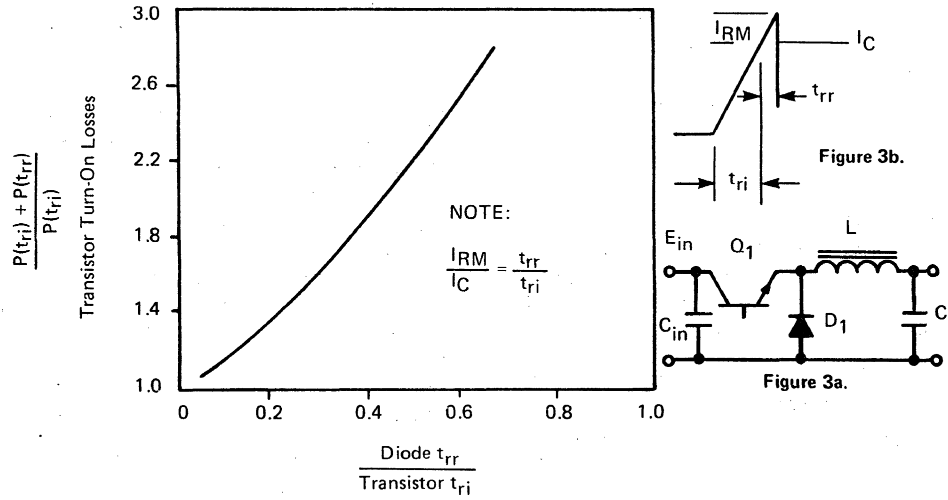


Figure 3b.

Figure 3a.

Figure 3. Importance of Reverse Recovery Time of a Rectifier

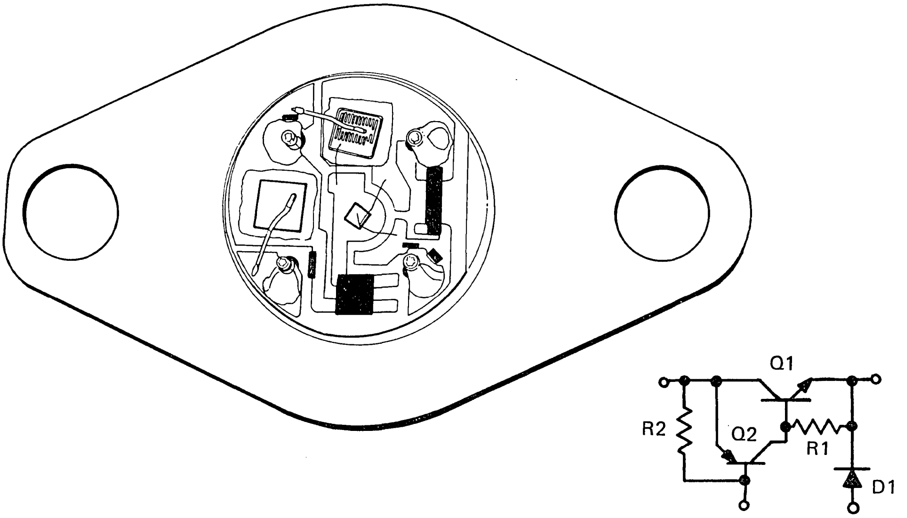
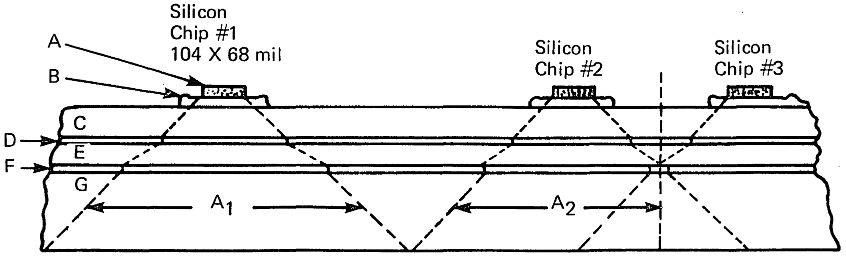


Figure 1. Unitrode power hybrid circuit (PIC600)



DEFINITION:

Material	Temp. Coef. 10^{-6} °C	ρ Rest. °C-in/W	t Thickness in mils		R_T* of PIC625
A – Silicon	4.2	.303	5		.214
B – Si Au Eut.	14	.182	3		.0718
C – BeO	6	.152	20		.249
D – Solder	23	.8	4		.187
E – Copper	16	.104	10		.04614
F – Solder	23	.8	3		.0836
G – Steel	11	.884	65		1.043
				Total	1.8954

*$R_T = \rho \left(\frac{t}{A}\right)$

Figure 2. Heat Flux Line in a Hybrid Circuit

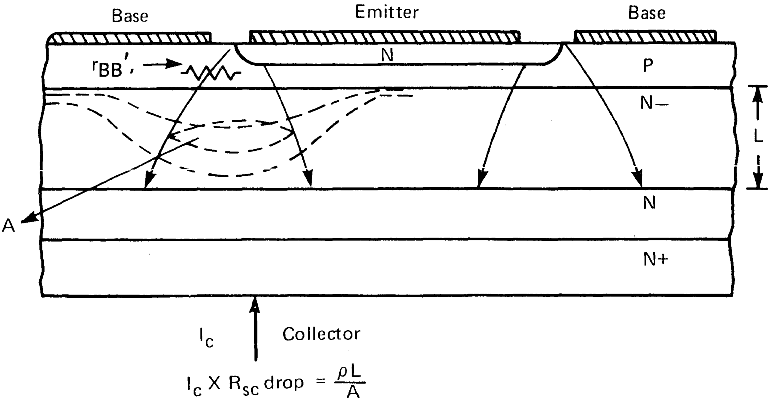


Figure 4. Effect of $r_{BB'}$ on Switching Times and Dynamic Saturation

The resistor turn-on biasing method works satisfactory up to 10A for a low voltage device without affecting the efficiency of the switching regulator. Another advantage of the resistive turn-off circuit is that it limits current crowding during turn-off thus increasing the reliability of the circuit. Since the driver transistor operates in a saturated mode, the device should have a high gain-bandwidth product to minimize overall storage time.

The hybrid circuit PIC600 consists of two transistors connected in a darlington configuration. The internal biasing resistors of these transistors are sufficient for fast turn-off without requiring any I_{B2}.

The table shown in Figure 5 compares the efficiency of a saturated transistor (2N4150) versus the hybrid darlington as the switching element in a 50 kHz buck regulator. In each case, the output device has the same size silicon chip.

Pass Transistor	Power Losses (Watts) $T_j = 25°C$	Efficiency	
		$\frac{E_O}{E_{in}} = 0.5$	$\frac{E_O}{E_{in}} = 0.2$
2N4150 (Saturated)	D.C. Losses . . . . 0.7 Switching Losses . . . . 2.27 Drive Losses . . . . 0.13 Diode Losses 4.76	84.79%	81.66%
PIC625 (Darlington)	D.C. Losses . . . . 1.4 Switching Losses . . . . 1.53 Drive Losses . . . . 0.15 Diode Losses 4.76	82.8%	81.69%

Conditions:
$f = 50KHz$
$E_O = 5V$
$I_O = 7A$
Same size output device for both cases.

Figure 5. Comparison Between Saturated and Darlington Pass Transistors in a Buck Type Switching Regulator

In the saturated transistor approach, the transistor is driven with a forced Beta of 5 during turn-on and turn-off. However, in the darlington configuration, no turn-off base drive is employed. Typical measured switching times and saturation voltages are used to calculate losses.

From the table in Figure 5, it is evident that the hybrid darlington approach provides best results in terms of efficiency when the ratio between the output and input voltage is less than 0.25. In a darlington configuration, if the output device is kept out of saturation, then the rise, fall and storage times will be reduced compared with the saturated transistor. Even at higher output/input voltage ratios the loss in efficiency because of higher $V_{CE(SAT)}$ is minimal compared to the complexity and cost of a drive circuit required for a saturated transistor.

The plot in Figure 6 shows dc power dissipation of a PIC625 at various duty cycles and temperatures. The efficiency of the regulator depends heavily upon output voltage. Switching losses of the PIC625 under conditions shown in Figure 6 are:

25°C – 0.875W
-55°C – 0.525W
125°C – 1.476W

V. APPLICATIONS

Different applications of power hybrid circuits are discussed in this section.

Low Voltage Hybrid Circuits (<100V)

Some applications of low voltage hybrid circuits are: low and high current positive and negative buck-type regulators, bidirectional motor driver circuits, PWM push-pull and half bridge converters. Each is discussed briefly as follows:

a. Buck Type Switching Regulator

The schematic of the low cost, free running buck switching regulator is shown in Figure 7. When the output voltage is lower than the reference voltage, transistor Q_2 is off and transistor Q_1 is on and provides the base drive to the power hybrid circuit PIC600. The current in inductor L_1 increases linearly and continues to charge the output capacitor C_o. When the output voltage exceeds the zener voltage of diode D_1 (plus some fixed fraction of V_{BE} of transistor Q_2) transistor Q_2 turns on and removes base drive current from transistor Q_1 and hybrid circuit PIC600. Resistor R_6 and capacitor C_1 are used to provide fast switching times. The output voltage is trimmed with resistor R_3.

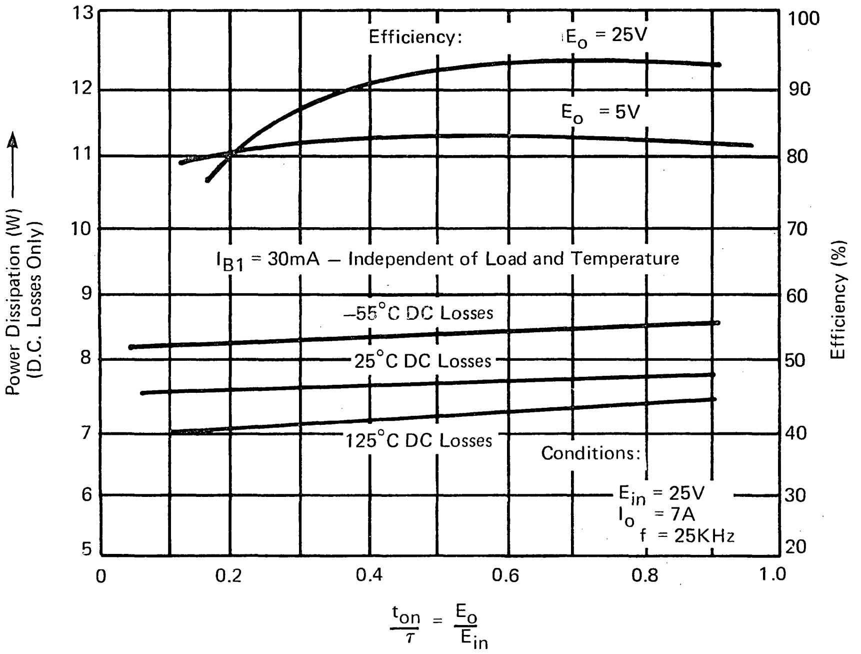


Figure 6. Losses and Efficiency – PIC625

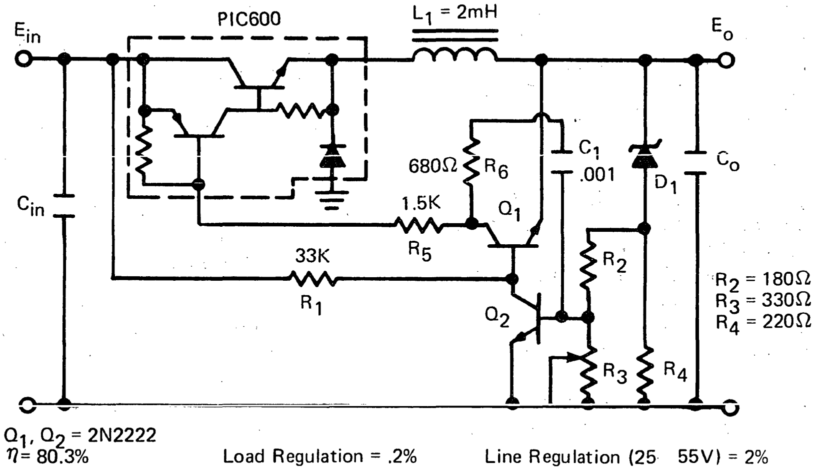


Figure 7. Low Cost Buck Regulator

b. High Frequency Switching Regulator

Low voltage hybrid circuits can be operated as high as 250 kHz due to their fast switching times. When these devices are used above 100 kHz, the storage time of the driver transistor must be reduced. This can be done by using a Baker clamp with resistor R_1 and diode D_1 as shown in Figure 8.

The advantages of operating a buck regulator at higher frequencies are:

- Lower filter cost
- Reduced size and weight
- Improved transient response
- Output ripple voltage less dependent upon ESR of capacitor
- Simpler EMI and RFI filtering

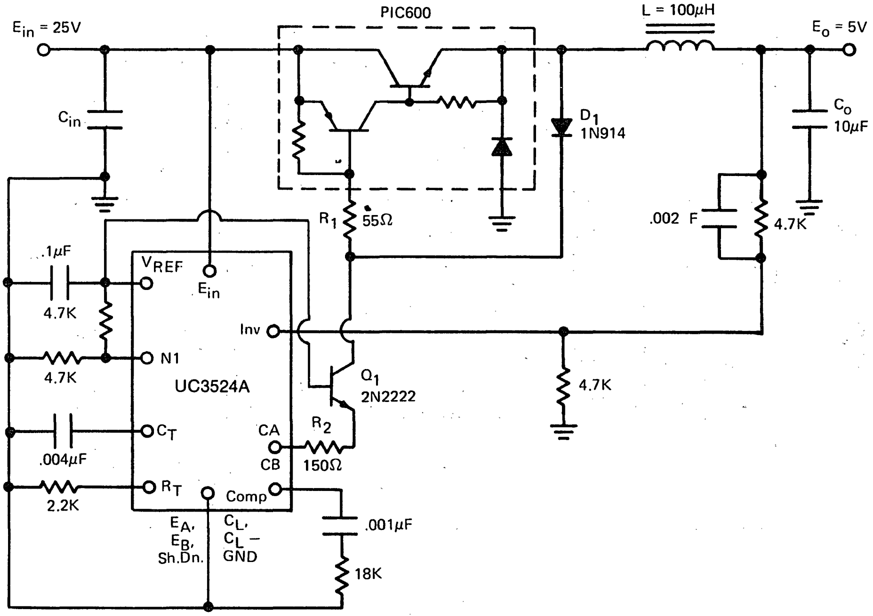


Figure 8. Operating a PWM Buck Regulator Above 100KHz

c) Extending Output Current Capability up to 20A

The output current capability of a buck regulator can be extended by (1) paralleling the output devices as shown in Figure 9 and (2) the use of a high current device as shown in Figure 10.

The advantages of paralleling output devices are that it allows the device to operate with a relatively simple drive circuit and provides simplicity of heat sinking. On the other hand, proper current sharing during the on-time period and turn-off time is required. The circuit shown in Figure 9 provides the circuit technique to do just that. The only drawback is that it requires a dead-band period which must be greater than 0.1L, where L is the inductance value of the common mode choke L_1.

PWM Push-Pull Converter

The circuit schematic shown in Figure 11 is a width modulated push-pull converter. It utilizes the Unitrode PIC636 power hybrid circuit.

Flux symmetry[5] in the transformer core is provided by introducing an air gap in only one leg of the EE core configuration. The voltage developed across resistor R_1 and capacitor C_1 is proportional to the flux density in the center leg of the EE core. This developed voltage is fed back into the control circuit at the output of the error amplifier. The output pulsewidth is corrected by the developed voltage across C_1 and R_1, providing flux symmetry in the power transformer.

Bidirectional Motor Drive Circuit

These power hybrid circuits can be employed to drive inductive loads, such as DC motors, stepper motors, and hammer drivers. Small inductors L_1 and L_2 limit cross-conduction current during switching times of the two hybrid circuits. The excellent switching properties of the hybrid circuit allow the circuit to be operated with high efficiency up to 100 kHz, improving transient response of the circuit.

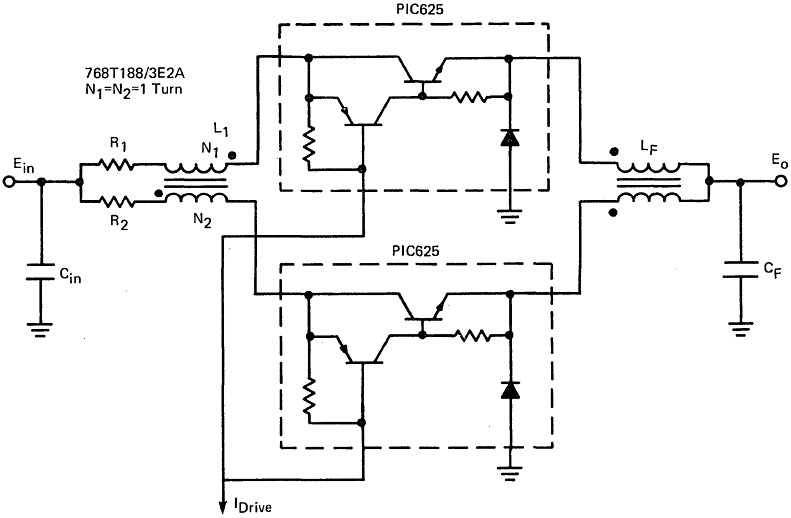


Figure 9. Current Sharing with a Common Mode Choke

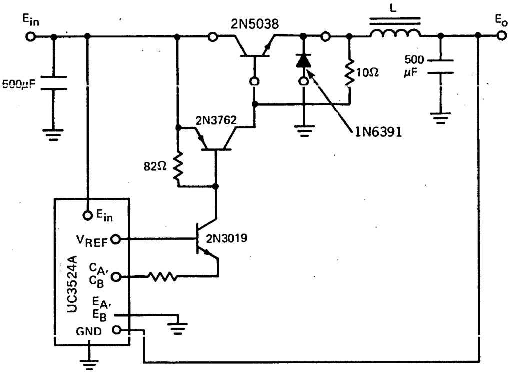


Figure 10. Simplified Schematic of 20A Buck Type High Efficiency Switching Regulator

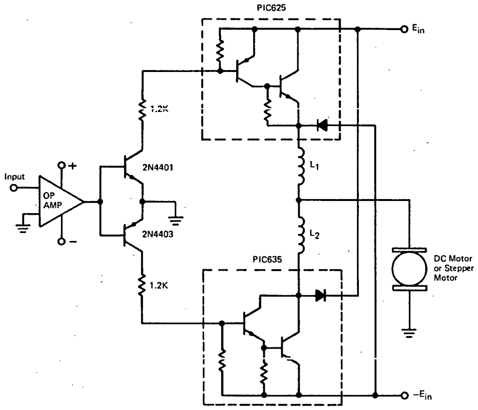


Figure 12. Bidirectional Motor Drive Circuit

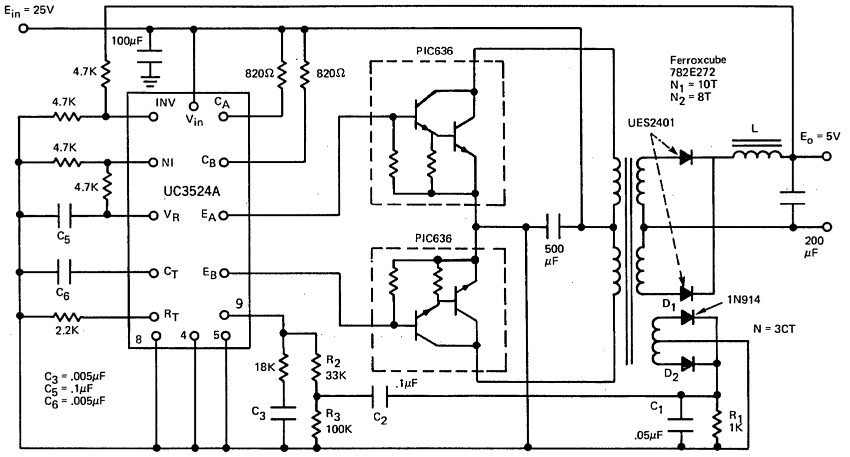


Figure 11. PWM Push-Pull Converter

VI. CONCLUSION

A wide variety of power hybrid circuits in standard packages for switched-mode converter applications have been developed by Unitrode. Power components were carefully selected for optimum electrical performance. In many instances these hybrid circuits not only provide superior electrical performance but also reduce the overall cost of the power supply by reducing production labor and repair cost.

APPLICATION NOTE U-83

INCORPORATE ACTIVE INRUSH CURRENT LIMITING TO IMPROVE RELIABILITY AND EFFICIENCY OF POWER SUPPLIES

Active inrush-current limiters—unlike fuses and circuit breakers—prevent dangerous situations instead of only reacting to them. Apply limiting techniques, and you need not employ extra-hefty rectifiers just to ensure rectifier survival during turn on.

The input filter capacitor employed in many power-supply designs creates a potential problem—high inrush current. Fortunately, though, adding a few extra components can prevent inrush current and its associated circuit damage.

How does the input capacitor cause such problems? Intentionally chosen for high storage capacity and low equivalent series resistance (ESR), it behaves like a nearly perfect short circuit when the supply first turns on. The resulting short-duration peak inrush current can reach levels much greater than the tolerable single-cycle ratings of the supply's semiconductor rectifiers (thus destroying them) and still not contain sufficient total energy to open protective fuses or circuit breakers. Additionally, the supply's rapidly rising voltage and current levels could cause dv/dt- or di/dt-sensitive devices in neighboring hardware to fail or malfunction.

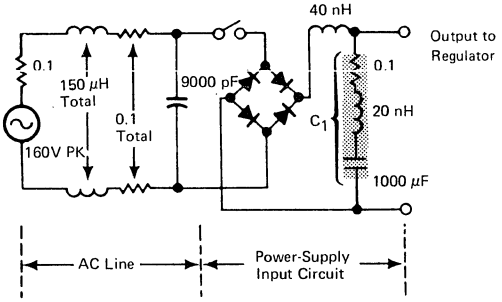
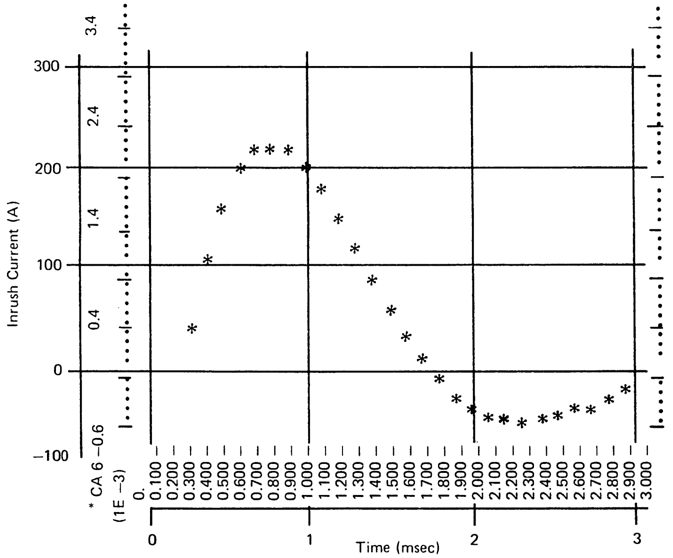


Figure 1. Based upon this generalized model, *analysis indicates the inrush-current problem's magnitude. Chosen for its low ESR, the input filter capacitor (C_1) behaves like a nearly perfect short circuit when the supply first turns on.*



```
                 ECAP
                 TRANSIENT ANALYSIS

C
B1               N(0,1), R = .1
B2               N(1,2), L = 150E - 6
B3               N(2,3), R = .1
B4               N(3,0), C = 7000E - 12
B5               N(3,4), R = .001
B6               N(4,5), L = 40E - 9
B7               N(5,6), R = .1
B8               N(6,7), L = 10E - 6
B9               N(7,0), C = 1000E - 6
E1               (1), 0, 0, 0, 160
                 TIME STEP = 100E - 6
                 FINISH TIME = 3E - 3
                 1ERROR = 1
                 PRINT NV, CA
                 PLOT, (SCALED), CA(6)
                 BINARY, NV, CA
```

Figure 2. Peaks greater than 200A *are predicted by ECAP for the circuit model shown in Figure 1.*

Turn on an analysis before you turn on a power supply

Computer analysis proves useful

To appreciate the inrush-current problem, consider an estimate of its magnitude before examining possible control techniques. Figure 1 depicts a model of the ac-input and rectifier/filter sections for a typical power supply. Although shown in a straight off-the-power-mains configuration, the model should be valid for any other design with the same output-power capability.

An ECAP computer analysis performed for this circuit assumed worst-case conditions: switch closure at 160V (peak voltage). The results (Figure 3) of a typical design. The current pulse's high level and short duration could generate severe, localized hot spots in rectifier junctions or cause false triggering of rate-sensitive devices elsewhere in the circuit.

A standard approach to current limiting is depicted in Figure 4a—a resistor. It's simple, reliable and easy to design in, but efficient it isn't. At any current level, it dissipates power that would otherwise be available to the load. The resistor does perform a surge-current-limiting function, however.

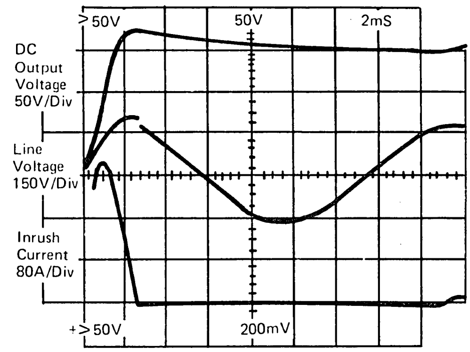


Figure 3. Measured inrush current *appears close to that predicted in Figure 2. This large current inrush could cause junction hot spots and generate troublesome EMI.*

Alternatively, a thermistor-controlled current limiter (Figure 4b) alleviates the resistor's efficiency problems to some extent, but it aggravates the dropout-recovery problem. The same cold-to-hot resistance variation that permits turn-on current limiting and high efficiency at low operating currents fails in dropout-recovery situations: The thermistor's long thermal time constant prohibits fast recovery.

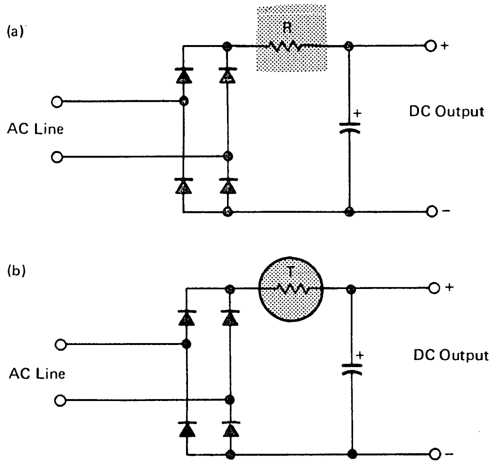
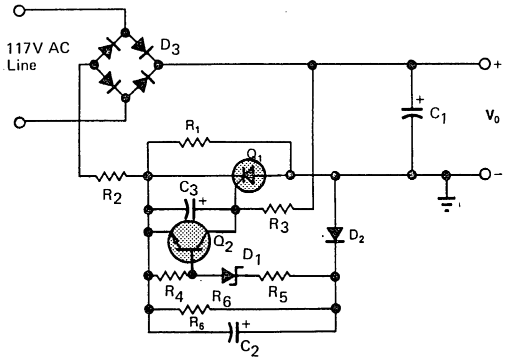


Figure 4. Two common methods *of inrush limiting employ either a resistor (a) or a thermistor (b). But if the resistor is large enough to effectively control surge currents, it also significantly reduces efficiency. The thermistor, while more efficient, offers little protection during dropout recovery because of its long thermal time constant.*



NOTES

R_1: 3, 5W	C_1: 1000 µF	Q_1: 400,V10A
R_2: 0.2, 10W	C_2: 10 µF	Q_2: UPT312
R_3: 3k, 5W	C_3: 2 µF	
R_4: 1k	D_1: UZ4715	
R_5: 1k, 2W	D_2: 1N4245	
R_6: 2k	D_3: UT680-4	

Figure 5. SCR soft starting *bypasses the current-limiting resistor (R_1) only when the peak-detected voltage across Q_1 drops below the zener breakdown, i.e., when C_1 becomes almost fully charged through R_1.*

SCR spells efficiency

In view of resistor and thermistor drawbacks, active soft-start designs offer a best-of-both-worlds solution—effective inrush limiting, fast recovery and high operating efficiency. This type of circuit, shown in Figure 5, essentially incorporates a current-limiting resistor (R_1) and a bypass switch (Q_1). At turn on, Q_1 is OFF, and the surge current (I_S) develops a voltage across R_1. This voltage is peak detected by D_2 and stored in C_2. When the voltage exceeds D_1's zener breakdown—an event that should occur almost instantaneously—Q_2 turns on, disabling Q_1's gate-triggering network (R_3C_3). As the power supply's filter capacitor C_1 charges up, the inrush peaks diminish until the detected I_SR_1 voltage falls below D_1's zener breakdown. Q_2 then turns off, and the R_3C_3 network charges up and fires Q_1, bypassing R_1.

This circuit recovers rapidly enough to limit inrush currents that could occur as a result of even short line dropouts. When the ac input voltage goes to zero, the voltage across Q_1 also goes to zero, and Q_1 turns off. When the input voltage reappears, Q_2 keeps Q_1's gate circuit OFF until R_1 has allowed C_1 to become almost fully charged.

Figure 6 graphically depicts this design's inrush-limiting ability. Note how the I_SR_1 voltage level (upper trace) tracks the diminishing inrush-current pulses (lower trace) for the first three cycles. At the 17-msec point (slightly after the third current pulse), the peak detected voltage has dropped below the zener breakdown point, and Q_1 switches on, bypassing R_1. Then R_2 limits inrush currents.

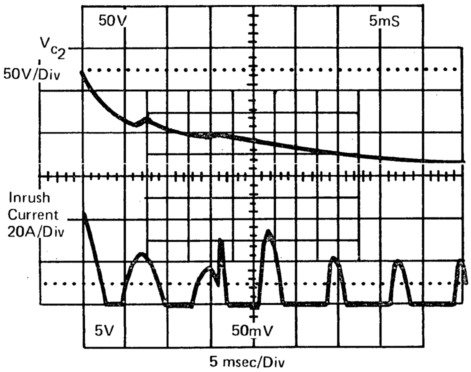


Figure 6. Inrush-current pulses of decreasing magnitude *(bottom trace) lower the SCR's hold-off voltage (upper trace). After 17 msec, the SCR fires.*

After determining your design's maximum continuous dc output current (I_O) and inrush limit (I_S), you can select an appropriate SCR. (The major SCR considerations are the peak repetitive blocking voltages and the maximum average plus peak current levels.) Typical SCRs exhibit a gate-turn-on voltage (V_{GT}) of about 0.6V; typical power-supply circuits exhibit a di/dt of about 1A/μsec—two quantities required for calculating the values of the other critical components:

$$R_1 = \sqrt{2}V_{AC}/I_S$$

$$R_2 = P_{R_2}/I_O^2$$

$$V_Z = I_SR_2$$

$$C3 \geqslant (2\sqrt{2}\, V_{AC}V_Z)/(R_3V_{GT}R_1(di/dt)).$$

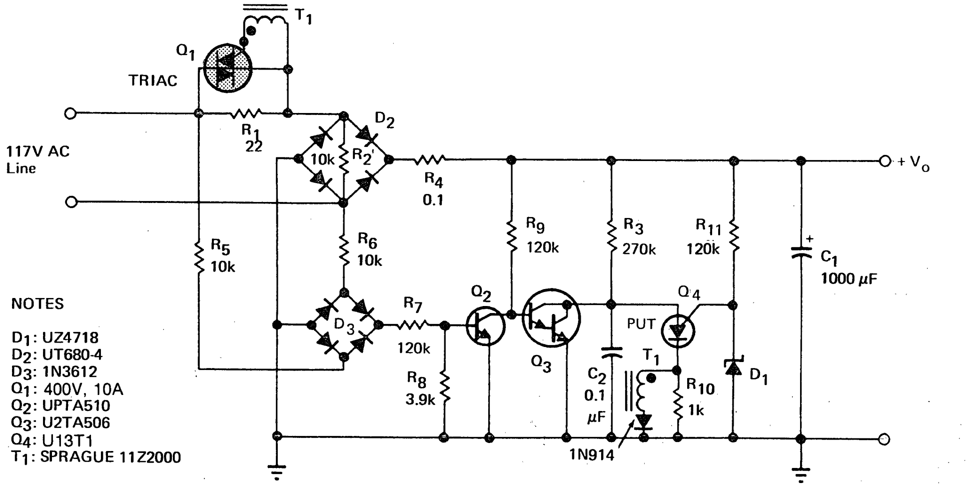


Figure 7. Phase controlling a triac *limits inrush-current pulses' amplitude and duration. Cycle-by-cycle triggering — handled by the PUT comparator — ensures instant recovery from line dropouts.*

Switch out the limiting resistor when the inrush is over

In the second equation, specify P_{R_2} as the maximum power your requirements allow across R_2.

Another effective inrush-current limiter is the phase-controlled triac design shown in Figure 7, which operates by controlling the conduction time of the current surges. Initially, the dc voltage (V_O) across C_1 builds up slowly because of R_1's current-limiting action. This dc voltage helps establish a reference (via R_{11} and zener diode D_1) for the programmable unijunction transistor (PUT) Q_4 and charges the phase-control timing capacitor C_2 (via R_3). The PUT fires when its trigger point is reached, turning the triac on. Thus, when V_O is initially low, C_2 charges slowly, and the triac triggers on late in the half cycle. As V_O rises Q_1 turns on earlier in each cycle until nearly 100% conduction is achieved.

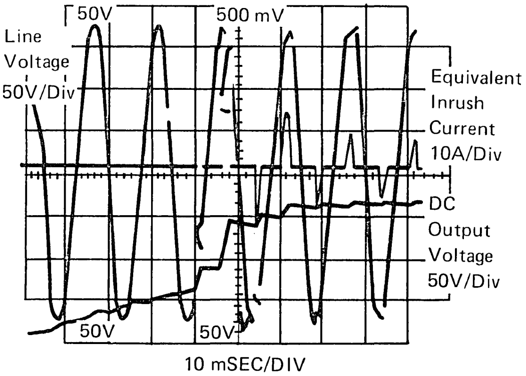


Figure 8. Triac conduction *follows the gradually increasing dc output voltage, decreasing the would-be inrush current. When the output voltage reaches design level, the triac is bypassing the current limiter nearly 100% of the time.*

The remaining circuit components (D_3, Q_2, Q_3, etc) discharge timing capacitor C_2 on each half cycle, thereby assuring cycle-by-cycle current limiting and fast recovery from dropouts. Figure 8 depicts the relationship between the ac input voltage, the dc output voltage and the varying conduction angle of the triac.

DESIGN GUIDE — POWER SCHOTTKY RECTIFIERS IN A SWITCHING REGULATOR

1. Introduction

Present technology is stimulating the development of more efficient power supplies. The switching regulated power supply is fast becoming the most popular type especially in industrial and military applications because it offers higher efficiency than a linear power supply.

Schottky rectifiers are widely used in switched-mode converters due to their inherently lower forward voltage characteristics compared with PN junction devices. Losses in the power supply are reduced considerably by the use of Schottky rectifiers, resulting in increased efficiency, improved reliability, and reduced size, weight and cost of the switched-mode converter.

In a +5V T^2L logic power supply, the efficiency of a switched-mode converter is reduced 11 to 15% due to rectifier losses. The trend is for information processing circuits to be operated at even lower voltages, making the forward characteristic of a Schottky rectifier even more important.

Since the Schottky rectifier is a majority carrier device, there is no reverse recovery characteristic caused by minority carrier storage when the devices switch from forward conduction to the blocking state. However, due to the large junction capacitance, Schottky rectifiers will exhibit reverse recovery time like a fast PN junction rectifier.

This application note describes, in brief, the theory of Schottky rectifiers and compares Schottky rectifier characteristics using different barrier metals and their effects on switching regulator efficiency.

The discussion also covers the parasitic elements in the Schottky rectifier and considers the effects of these elements in switched-mode converters. Design rules are derived for optimum snubber networks to protect against transient voltages and minimize RFI. Guidelines are provided for selecting the proper Schottky rectifier for different types of switched-mode converters.

2. Basic Structure

The basic construction of a Schottky rectifier is shown in Figure 1. The starting material is a heavily doped N+ silicon wafer on which an N-type epitaxial layer is deposited. The resistivity of this layer determines the reverse blocking voltage capability of the rectifier. The Schottky barrier is formed by depositing a metal layer on the N-type epitaxial layer, and the junction formed between the metal and the semiconductor is an abrupt junction.

The most commonly used barrier metals or alloys are chromium, platinum, nickel platinum, molybdenum tungsten. A performance comparison of different barrier metals is summarized in Table 1. The chromium barrier provides low forward voltage with a very high leakage current. However, the tungsten barrier provides low leakage current with high forward voltage. Since efficiency is a major consideration in switched-mode converters, the nickel platinum barrier provides the best choice due to its low forward drop with a minimum of leakage current.

3. Theory And Discussion of Parasitic Elements in a Schottky Rectifier

The energy bands of a metal and semiconductor separated by a vacuum are shown in Figure 2a. This system is not in equilibrium. However, if an electrical connection is made between the semiconductor and metal, charge is allowed to flow from the semiconductor to the metal. Equilibrium will be established and the Fermi levels will become aligned.

When intimate contact is made between the metal and semiconductor, Figure 2b, the Fermi levels will line up and there will be an accumulation of positive charges at the surface of the semiconductor. A barrier will exist for electron flow from the metal to semiconductor and the barrier height will be the difference between the work function of the metal and the semiconductor.

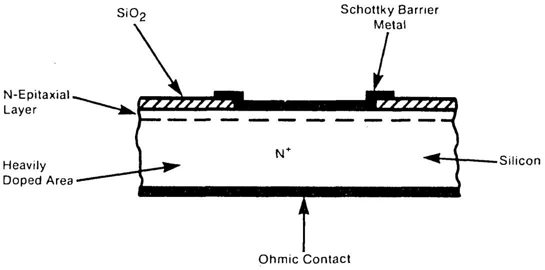


Figure 1 - Cross–Section of a Schottky Barrier Power Rectifier

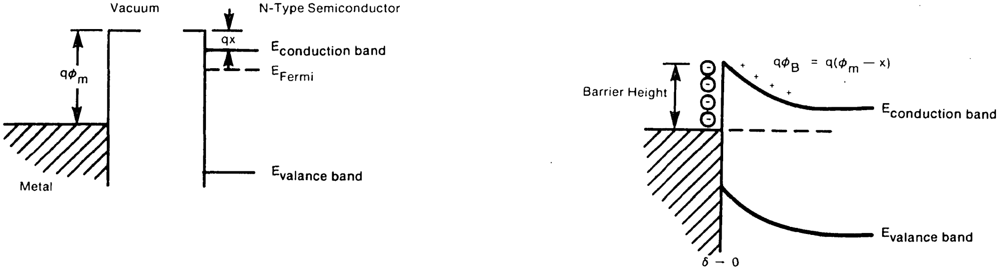


Figure 2a

Figure 2b

Figure 2 - Energy Band Diagram of Metal Semiconductor Contact

TABLE 1 — PERFORMANCE COMPARISON OF DIFFERENT BARRIERS

SPECIFICATIONS				POWER LOST IN EACH RECTIFIER	
METAL BARRIER	V_F @ 20A (V) 125°C**	V_F @ 100A (V) 125°C**	LEAKAGE CURRENT (mA) 125°C**	LOSSES DUE TO LEAKAGE (W)*	V_F LOSSES @ 100A (W)*
Chromium	0.35	0.78	280	1.80	33.20
	0.45	0.75	65	0.46	34.07
Platinum	0.51	0.80	10	0.071	35.23
Ni-Platinum	0.433	0.73	30	0.2145	32.70
Tungsten	0.51	0.82	10	0.071	36.79

* Power dissipation calculations are based on 125° C operating junction temperature and a high line input voltage for an off-line PWM converter.

** V_F voltages are for 160 mil^2 die.

3.1 Forward Biased Junction

When the barrier or a junction is forward biased, the energy level of the conduction band in the semiconductor is raised, which allows electrons to flow into the metal as shown in Figure 3a. A small barrier does remain, but the electron energy distribution is sufficient to overcome this remaining barrier. Increased forward bias will overcome the barrier and current flow will be limited only by the series resistance of the device. Most of the forward drop at high current occurs in the high resistivity epitaxial layer which determines the reverse blocking voltage capability.

Schottky rectifier forward drop can be expressed by the following equation:

$$V_F = \frac{\Phi}{q} + \frac{KT}{q} \ln \left(\frac{I_F}{A \times RT^2} \right) + \frac{I_F \cdot \rho \cdot d}{A} \qquad (3.1)$$

+ Voltage drop in ohmic contact of package

Where: I_F = Forward current (A)
A = Barrier area (cm^2)
$\frac{KT}{q}$ = 0.026 at room temperature
Φ = Barrier height - e_v
ρ = Resistivity of epitaxial layer (Ω-cm)
d = Thickness of epitaxial layer (cm)
R = Richardson constant
T = Absolute temperature (° K)

The term $[I_F \cdot \rho \cdot (d/A)]$ in the above equation is the forward drop in the high resistivity epitaxial layer and it is a significant portion of the forward drop at high current levels.

Since holes cannot exist in the metal, none can be injected into it. As a result, conduction is entirely due to electrons. This eliminates the minority carrier related reverse recovery time.

3.2 Reverse Biased Junction

When the device is reverse biased, the conduction band in the semiconductor is lowered by the applied reverse biased voltage as shown in Figure 3b. For any conduction to occur, electrons must surmount the potential barrier created at the metal-semiconductor junction. Some electrons in the metal gain sufficient thermal energy from the lattice structure to overcome the barrier while others are able to tunnel through the barrier. This leakage current is temperature dependent.

3.3 Junction Capacitance

The barrier metal and uniformly doped N-type epitaxial layer create an abrupt junction. This results in at least 5 times higher junction capacitance when compared with similar slightly graded ultra-fast PN junction devices. The depletion capacitance of a Schottky rectifier under reverse biased conditions can be expressed by the equation:

$$C = A \cdot \sqrt{\frac{(43 \cdot 10^{-6})N_D}{V_R + 0.6 + (KT/q)}} \qquad (3.2)$$

Where: N_D = Carrier concentration of an epitaxial layer
$\frac{KT}{q}$ = 0.026 at room temperature
V_R = Applied reverse biased voltage

As can be seen from the equation, the junction capacitance is inversely proportional to the square root of the applied reverse voltage and is practically independent of temperature at reverse voltages greater than 1V. When the device switches from forward biased condition to the reverse blocking state, current is required to charge the depletion capacitance. The time required to charge up capacitance is determined by the circuit impedance. This charging current has the same effect as the reverse recovery current of a Unitrode fast recovery "UES" PN junction rectifier!

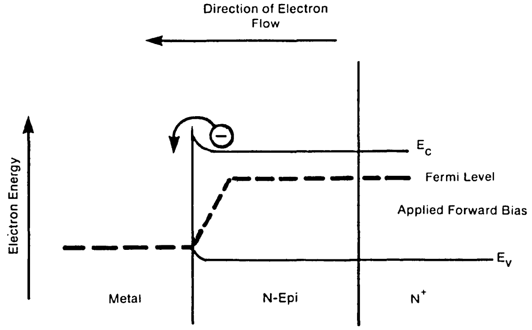


Figure 3a - Rectifier — Forward Biased

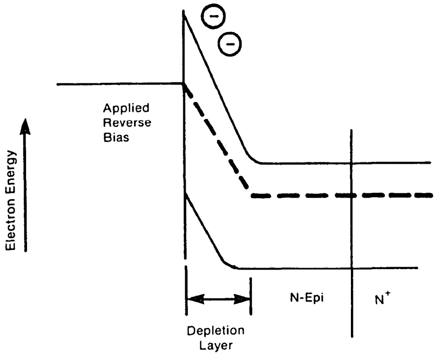


Figure 3b - Rectifier — Reverse Biased

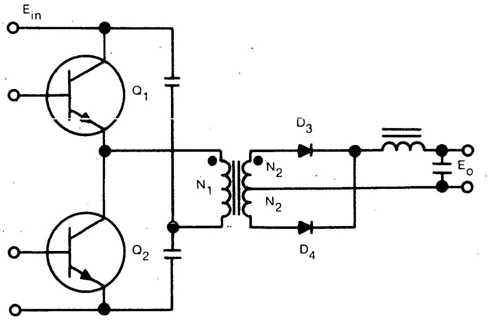
In a switched-mode converter, the apparent reverse recovery time is determined by the leakage inductance of the transformer and the junction capacitance of the Schottky rectifier. Since capacitance does not vary with temperature, the apparent recovery time and current overshoot remain constant with temperature. Ringing resonance of leakage inductance and Schottky capacitance can cause voltage overshoot. In a high frequency switched-mode converter where the transformer is designed with very low leakage inductance, careful consideration must be given in selecting the Schottky rectifier because of dv/dt limitations.

4. Applications of a Schottky Rectifier in Switched-Mode Converters

The simplified power output stage of a half-bridge switched-mode converter is shown in Figure 4a. When switching transistors Q_1 and Q_2 are in the "off" condition, diodes D_3 and D_4 conduct in the forward direction to provide a current path for inductor L_1. Each diode carries half of the load current. When transistor Q_1 turns on, current in diode D_3 starts to change from half the load current to full load current, while current in diode D_4 starts to change from half the load current into the "off" condition. Current transition time in the rectifier will depend on the current rise time of the transistor and the leakage inductance of power transformer T_2. When current in rectifier D_3 increases to full load current, current in rectifier D_4 decreases to zero.

Since a Schottky rectifier is a majority carrier device, it should turn off instantaneously. However, because of the larger junction capacitance of the Schottky rectifier compared with PN junction devices, transistor Q_1 supplies additional current to the secondary winding to charge up this larger junction capacitance. Note that the junction capacitance of the Schottky rectifier varies with reverse bias voltage as shown in Figure 5. Also the capacitance is five times that of equivalent PN junction devices.

As current is increased, the voltage across the junction capacitance of the rectifiers builds up toward the full reverse blocking state. The primary current will be higher than the output load current divided by the transformer turns ratio. During this period, energy is stored in the leakage inductance due to the excessive current on the primary side. As the



$\frac{N1}{N2}$	N. transformer turns ratio
R_{PW}	Series resistance of primary windings
R_{SW}	Series resistance of one half secondary winding
L	Leakage inductance of transformer
C_{PW}	Primary windings distributed capacitance
C_{SW}	One half secondary winding capacitance
C_{ob}	Output capacitance of switching transistor
C_j	Junction capacitance of rectifier

Figure 4a - Typical Half-Bridge PWM Switching Converter

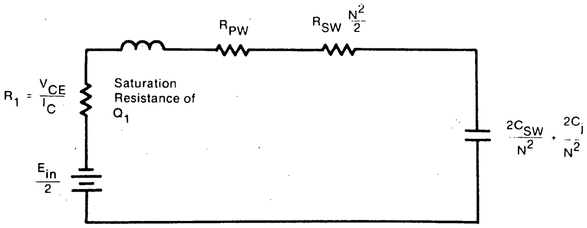


Figure 4b - Equivalent Circuit During Charging of a Junction Capacitance of a Schottky

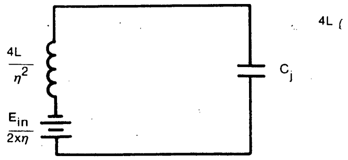


Figure 4c - Simplified Equivalent Circuit Referred Back to Secondary Side

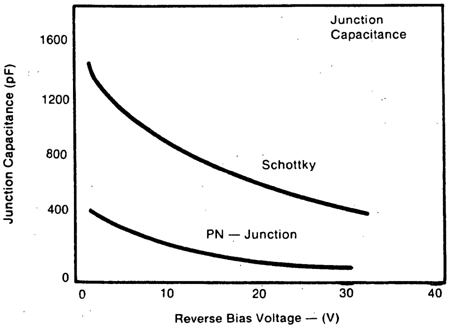


Figure 5 - Comparison of Junction Capacitance ultra-fast PN-Junction vs. Comparable Schottky Rectifier

voltage across the rectifier reaches full switching voltage, energy stored in the leakage inductance continues to charge up the junction capacitance of the rectifier above the switching voltage reflected back in the secondary. These voltages can force the device into the breakdown region if the proper snubber circuit is not employed.

4.1 Snubber Network Design

The equivalent circuit referred back to the primary side when the junction capacitance is charging up is shown in Figure 4b. The junction capacitance of the Schottky and the leakage inductance of transformer T_2 form a resonant circuit. The winding resistances, R_{PW} and R_{SW}, and saturation resistance, R_1, provide very little damping to this LC tuned circuit. Therefore, its effect on damping can be neglected. The interwinding capacitance of the power transformer is much lower than the junction capacitance of the Schottky rectifier and may be neglected. The simplified circuit referred back to the secondary side is shown in Figure 4c.

Since Schottkys are prone to excessive heating and possible damage in the breakdown mode, a proper snubber is required. The design of the snubber network minimizes voltage spikes and snubber losses. The snubber network also helps to reduce conducted and radiated RFI.

The optimum snubber network should be designed on the basis of critical damping of the LC tuned circuit and limiting the maximum excursion of the voltage below the PIV ratings of the rectifier.

Shown below is the LC tuned circuit with resistor R_{snb} paralleled across the junction capacitance of the Schottky rectifier for a critically damped condition.

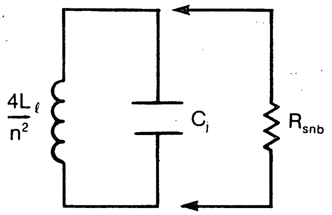


Figure 6 - Damping Resistor R_{snb} Added Across the LC Tuned Circuit for Critical Damping

The loaded Q_L should be 0.5 for a critically damped case to prevent any ringing of the voltage and to provide minimum losses in the snubber resistor. LC tuned circuits will have only real roots. Loaded Q_L can be described by the equation:

$$Q_L = 0.5 = \frac{R_{snb}}{X_L} \qquad (4.1)$$

Where: $X_L = j\omega L$

$$\therefore R_{snb} = 0.5 \cdot \omega \cdot L$$

$$= 0.5 \left(\frac{1}{\sqrt{(4L_\ell/n^2)C_j}} \right) \left(\frac{4L_\ell}{n^2} \right)$$

$$R_{snb} = \frac{1}{n}\sqrt{\frac{L_\ell}{C_j}} \qquad (4.2)$$

Where: C_j = Junction capacitance of rectifier
L_ℓ = Leakage inductance of power transformer

A capacitor is required in series with the resistor in order to block the dc voltage present. The blocking capacitor should be at least ten times the rectifier junction capacitance:

$$C_{snb} - 10(C_j) \qquad (4.3)$$

To transfer the power effectively from the input power source to the output load, the time constant (R_{snb} x C_{snb}) should at at most one-tenth the minimum pulse width of the switched-mode converter. This occurs at maximum input voltage. Therefore:

$$R_{snb} \cdot C_{snb} \leq \frac{(1/20)}{f} (E_{in_{min}}/E_{in_{max}}) \qquad (4.4)$$

Where: f is the operating frequency of the switching regulator.

The power dissipation in the snubber resistor R_{snb} can be calculated by the equation:

For Half-Bridge:

$$PR_{snb} = ½C_{snb} \left[\frac{E_{in_{max}}}{n} \right]^2 \cdot f \qquad (4.5)$$

For Push-Pull for Full-Bridge:

$$P_{R_{snb}} = \tfrac{1}{2} C_{snb} \left[\frac{2(E_{in_{max}})}{n} \right]^2 \cdot f \qquad (4.6)$$

Where: $E_{in_{max}}$ = Maximum input voltage
n = Primary to secondary turns ratio of power transformer

Every inch of wire represents 20 nanohenries of inductance. When the output current is high, the energy stored in the lead and package inductance in the secondary circuit can generate high voltage spikes across the rectifier during reverse recovery time. To reduce these spikes, two snubber networks are required. One should be placed across each Schottky rectifier as shown in Figure 7 below.

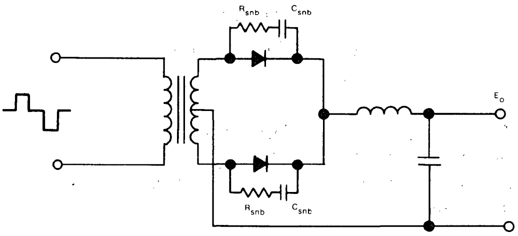


Figure 7 - High Current Outputs

For low current outputs, the snubber network can be connected across the secondary winding as shown in Figure 8.

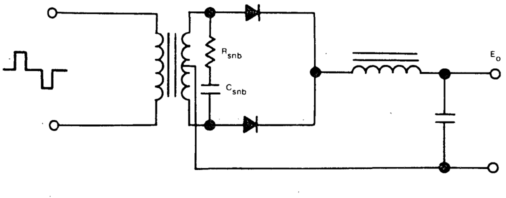


Figure 8 - Low Current Outputs

4.2 *Reverse Recovery Time and Overshoot Current, $I_{RM(REC)}$*

Reverse recovery time is defined as the time required to change a rectifier from the forward conduction state to the reverse blocking state. Although a Schottky rectifier is a majority carrier device, it takes time to "recover" because of its high junction capacitance. In a switched-mode converter, reverse recovery time is, to a large extent, determined by the parasitic leakage inductance of the transformer which resonates with the junction capacitance of the Schottky rectifier. Design equations for reverse recovery time and current overshoot can be derived as shown below.

Reverse Recovery Time:

From basic equations of an LC tuned circuit:

$$\omega = \frac{1}{\sqrt{LC}}$$

Substituting $f = 1/\tau$ and rearranging:

$$\tau = 2\pi\sqrt{LC}$$

Since $\tau/2 = t_{rr}$ by definition:

$$t_{rr} = \pi\sqrt{LC} \qquad (4.7)$$

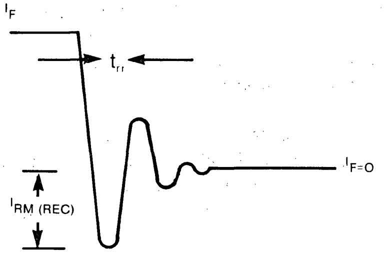


Figure 9 - Reverse Recovery Time of a Rectifier

Assuming the rise time of the transistor is much faster than t_{rr} of the rectifier, and substituting L_ℓ= leakage inductance of the transformer and C_j = junction capacitance of the Schottky rectifier. Neglecting the interwinding capacitance of the transformer, the reverse recovery time (when no snubber network is employed across the rectifier) can be calculated by the equation:

t_{rr} due to junction capacitance:

$$t_{rr} = \frac{2\pi}{n}\sqrt{L_\ell(C_j)} \qquad (4.8)$$

Where: n = Primary to secondary turns ratio

The ringing frequency can be calculated by the equation:

$$f = \frac{n}{4\pi\sqrt{L_\ell (C_j)}} \quad (4.9)$$

From the characteristic impedance of the LC tuned circuit, overshoot current, I_{RM}, in the Schottky rectifier can be calculated by:

$$I_{RM(REC)} = \frac{E_{in}}{2}\sqrt{\frac{C_j}{L_\ell}} \quad (4.10)$$

4.3 Practical Example

A detailed diagram of a 150W, multiple output switching regulated power supply is shown in Figure 10. The power supply is designed to operate with a line input voltage of 117V ac, 60 Hz or 220V ac, 50 Hz. The regulated output voltages are +5V @ 1A, +12V @ 1.2A, -12V @ 1A and -5V @ 1A. The output voltage is regulated by power switching hybrid circuits Q_1 and Q_2 which are housed in four pin electrically isolated packages.

Since the case is electrically isolated from the active devices, it provides the following advantages:

a) lower conducted and radiated RFI

b) ease in mounting — two devices can be mounted on the same heat sink.

The selected switching transistor provides fast switching time (<100ns) and the diode in the hybrid circuit provides low reverse recovery (<50ns) and forward recovery time. The proportional base drive current to the switching transistor is supplied by the current transformer T_1.

One of the output voltages (+5V) is regulated with a pulse width modulated (PWM) control chip Unitrode's UC3524. The auxiliary voltage to power the control circuit should be electrically isolated from the line voltage. Conventionally, the 60 Hz transformer is utilized to provide isolation and the transformer output voltage is rectified and regulated to supply bias voltage to the control circuit. Transistors, Q_3 and Q_4, provide a low cost approach in developing bias voltage for the control circuit without the use of a 60 Hz transformer. The operation of the circuit is described in detail below.

When the 117V ac input line voltage is applied to the switched-mode converter, capacitors C_1 and C_2 charge up to full input voltage. Meanwhile capacitor C_T charges up slowly through resistor R_T. When the voltage across C_T reaches the anode-gate voltage of the programmable unijunction transistor Q_4, it will turn on and dump the stored charge from capacitor C_T into one of the proportional base drive windings of the transformer T_1. The polarity of the windings is such that it will turn on only transistor Q_2, transferring energy from input capacitor C_2 into the output capacitor C_3 (isolated from the input line) through power transformer T_2. The control circuit LM3524 starts to switch transistor Q_2. At the instant when transistor Q_2 turns on, capacitor C_T will be isolated from current transformer T_1 with the help of transistor Q_3. The programmable unijunction transistor Q_4 now remains off. The capacitor C_3 is now continuously charging up through the secondary winding of the transformer.

The output circuit of the switched-mode converter utilizes coupled inductor L_1 to provide better tracking among all the output voltages and improve transient response. Coupled inductor L_2 (which is not in the control loop) maintains the sawtooth current in the +5V winding of L_1 (which is in the control loop) providing stability in the control circuit.

Calculations of Snubber Network:

In the 150W switching regulator shown in Figure 10, first calculate the current overshoot $I_{RM(REC)}$, the ringing frequency and the apparent reverse recovery time without the snubber network. Then determine the resistor and capacitor values (for critically damped case) of the network across the Schottky rectifier.

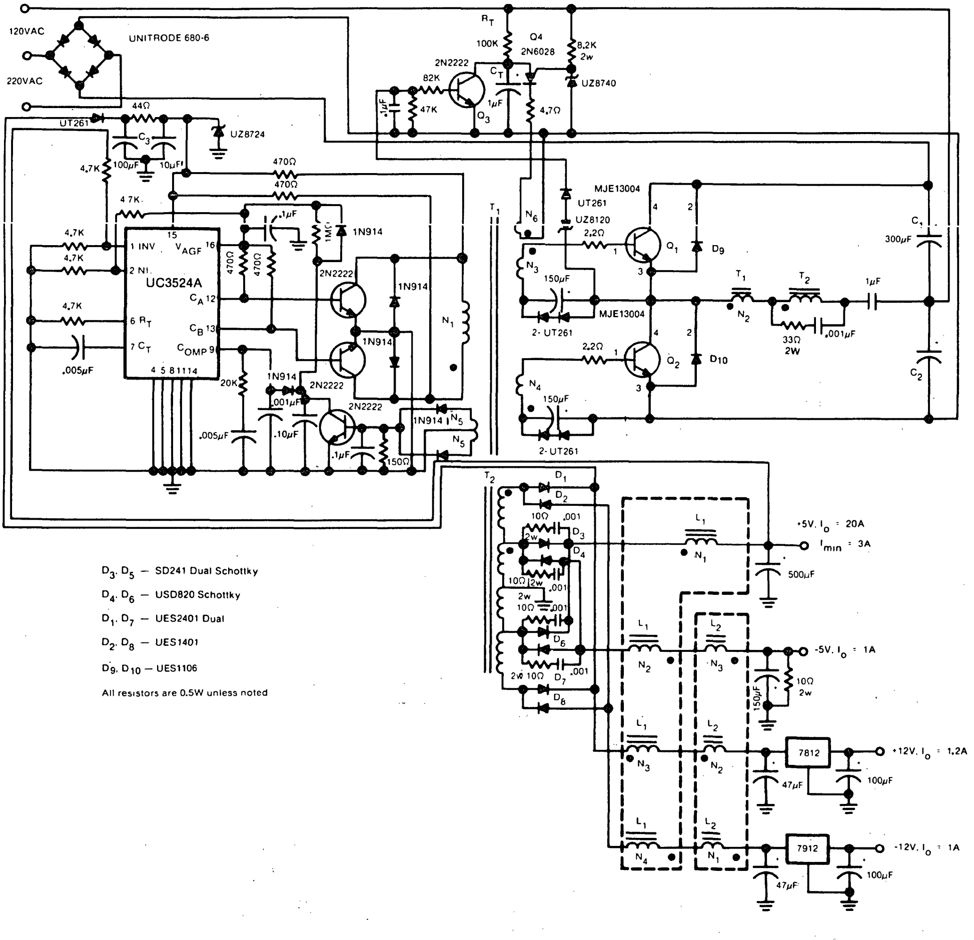
Given: L_ℓ, Leakage inductance of power transformer = 22μH

C_j, Junction capacitance of Schottky = 850pF

f, Operating frequency = 30 KHz

n, Primary to secondary turns ratio = 14

$E_{in_{min}}/E_{in_{max}}$, Ratio of maximum input voltage to minimum input voltage = 400/200 = 2



D3, D5 — SD241 Dual Schottky

D4, D6 — USD820 Schottky

D1, D7 — UES2401 Dual

D2, D8 — UES1401

D9, D10 — UES1106

All resistors are 0.5W unless noted

Figure 10 - 150 Watt Multiple Output "OFF Line" Switched-Mode Converter

Solution:

Current overshoot, $I_{RM(REC)}$, from Equation 4.10:

$$I_{RM(REC)} = \frac{E_{in}}{2}\sqrt{\frac{C_j}{l_\ell}}$$

$$= \frac{320V}{2}\sqrt{\frac{850 \times 10^{-12}}{22 \times 10^{-6}}}$$

$$= 1A$$

The ringing frequency from equation 4.9:

$$f = \frac{n}{4\pi\sqrt{L_\ell(C_j)}}$$

$$= \frac{14}{4\pi\sqrt{(22 \times 10^{-6})(850 \times 10^{-12})}}$$

$$= 8.1 \text{ MHz}$$

The apparent reverse recovery time from equation 4.8:

$$t_{rr} = \frac{2\pi}{n}\sqrt{C_j(L_\ell)}$$

$$= \frac{2\pi}{14}\sqrt{(850 \times 10^{-12})(22 \times 10^{-6})}$$

$$= 67\text{ns}$$

The value of the snubber resistor from Equation 4.2:

$$R_{snb} = \frac{1}{n}\sqrt{\frac{L_\ell}{C_j}}$$

$$= \frac{1}{14}\sqrt{\frac{22 \times 10^{-6}}{850 \times 10^{-12}}}$$

$$= 10.9\Omega$$

The value of the snubber capacitor from Equation 4.3:

$$C_{snb} = 10(C_j)$$

$$= 10(850 \times 10^{-12})$$

$$= 0.01\mu F$$

The power dissipation in snubber resistor, R_{snb}, from Equation 4.5:

$$PR_{snb} = \tfrac{1}{2}C_{snb}\left[\frac{E_{in_{max}}}{n}\right]^2 \cdot f$$

$$= \tfrac{1}{2}(0.01 \times 10^{-6})\left[\frac{400}{14}\right]^2 \cdot 30 \times 10^3$$

$$= 0.121W$$

∴ The snubber resistor R_{snb} should have at least 0.5W rating.

The criteria for the snubber network should satisfy the conditions below:

$$R_{snb}(C_{snb}) \leq \frac{1}{20f}\left[\frac{E_{in_{min}}}{E_{in_{max}}}\right]$$

$$10\Omega(0.01 \times 10^{-6}) \leq \frac{1}{20(30\times10^{3})} \cdot \frac{1}{2}$$

$$0.1\mu s \leq 0.993\mu s$$

The voltage across the Schottky rectifier with and without the snubber network in a 150W off-line switched-mode converter is shown in Figures 11a and 11b. Note that the voltage across the Schottky rectifier with a snubber network has no voltage overshoot. Thus, it prevents failure of the Schottky due to large voltage transients during transistor turn-on. The ringing frequency is about 10 MHz without the snubber and is close to calculated values.

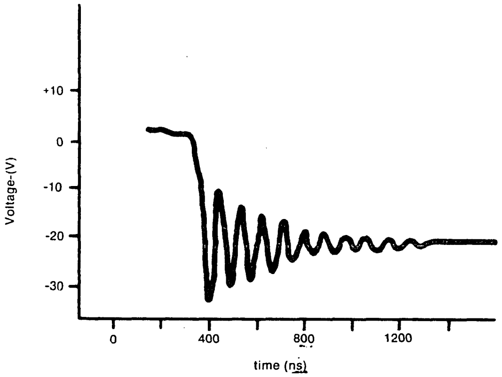


Figure 11a - Voltage Across Rectifier Without Snubber Network

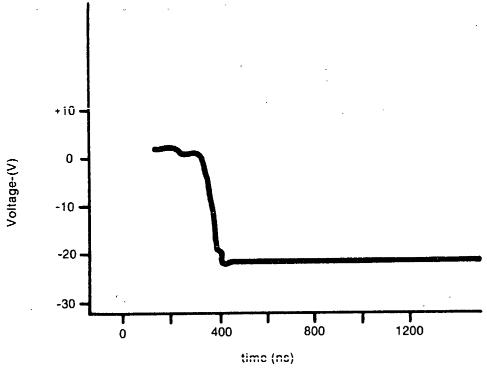


Figure 11b - Voltage Across Rectifier With Snubber Network 10Ω - 0.1μF

4.4 *Thermal Stability Considerations*

The reverse leakage current of a Schottky rectifier is much higher than PN junction devices because of the Schottky's lower barrier height. The magnitude of this leakage current doubles approximately every ten degrees Centigrade. Since it is temperature sensitive, the thermal stability of the system should be checked over to avoid thermal runaway. In a PWM switched-mode converter (i.e. push-pull, half-bridge, etc.) the rectifier can be operated at 50% duty cycle in the reverse blocking state while the remaining 50% of the time it will operate in the forward conduction mode under worst case conditions. However, forward drop is also a temperature sensitive parameter and this should also be considered when thermal stability calculations are made.

The criteria for thermal stability is defined as: "the rate of change in power pumped into a device with respect to temperature (dP_{in}/dt) should be less than the rate of change in power removed (in the applicable thermal environment) in the form of heat from the device with respect to temperature (dP_{out}/dt)".

In a switched-mode converter, the power dissipated in the device and the power removed can be expressed by:

$$V_R \cdot \frac{I_L(\tau - t_{on})}{\tau} + I_F \cdot V_F \cdot \frac{t_{on}}{\tau} \leq \frac{T_J - T_A}{R_{\theta J\text{-}A}} \qquad (4.11)$$

Where: V_R = Applied reverse voltage

I_L = Leakage current at temperature

t_{on} = Rectifier on-time

τ = 1/f, where f is the operating frequency

I_F = Forward current

V_F = Forward voltage at forward current (at temperature)

T_J = Junction temperature

Since both I_L and V_F are temperature sensitive parameters, we can express I_L and V_F as functions of temperature in the above equation for thermal stability and obtain:

$$\left[\left\{\frac{(\tau - t_{on})}{\tau} \cdot V_R \cdot I_o \cdot 2^{\frac{(T_J - T_A)}{y}}\right\} + \left\{I_F \cdot \frac{t_{on}}{\tau} \cdot [V_{F_0} + X(T_J - T_A)]\right\}\right] \leq \frac{T_J - T_A}{R_{\theta JA}} \qquad [4.12]$$

Where: I_o = Leakage current at room temperature

V_{F_0} = Forward voltage drop at room temperature

x = Temperature coefficient for forward voltage at operating current

y = Temperature difference for which leakage current doubles.

Differentiating the above equation:

$$\frac{(\tau - t_{on})}{\tau} \cdot V_R \cdot I_o \cdot 2^{\frac{(T_J - T_A)}{y}} \cdot \frac{1}{y} \cdot \ln 2 + I_F \cdot \frac{t_{on}}{\tau} \cdot X \leq \frac{1}{R_{\theta J\text{-}A}} \qquad [4.13]$$

Defining $I_o \cdot 2^{\frac{(T_J - T_A)}{y}}$ as the critical current, $I_{R(crit)}$ at maximum temperature, and solving for $I_{R(crit)}$ we obtain:

$$I_{R(crit)} \leq y \left[\frac{(\tau/R_{\theta J\text{-}A}) - I_F \cdot t_{on} \cdot X}{.693\,(\tau - t_{on})V_R}\right] \qquad [4.14]$$

Design Example

In the practical example previously discussed, the maximum reverse voltage across the rectifiers is 30V. Each rectifier is mounted on a heat sink. The thermal resistance of the heat sink is 1° C/W. The Schottky rectifier, SD241, has a maximum thermal resistance of 1.4° C/W from case to junction. Its reverse leakage current doubles every ten degrees Centigrade, while the forward voltage at I_F=20A decreased by 1mV/° C as the junction temperature increases. The designer desires to limit the maximum operating junction temperature of the Schottky rectifier to 125° C under worst case conditions

Calculate the maximum reverse leakage current allowed for these rectifiers at 125° C to prevent thermal instability

Calculation:

$$\begin{aligned} R_{\theta JA} &= (R_{\theta H} + R_{\theta J\text{-}C})\ ^\circ\text{C/W} \\ &= 1^\circ\text{C/W} + 1.4^\circ\text{C/W} \\ &= 2.4^\circ\text{C/W} \\ t_{on} &= 16.6\mu s \\ t_{off} &= 16.6\mu s \\ \tau = t_{on} + t_{off} &= 33.2\mu s \end{aligned}$$

Using equation 4.14:

$$I_{R(crit)} \leq 10^\circ\text{C x}$$

$$\left[\frac{(33.2 \text{ x } 10^{-6})/(2.4^\circ\text{C/W}) - (20\text{A})(16.6 \text{ x } 10^{-6})(-1 \text{ x } 10^{-3}\text{V})}{.693(33.2 \text{ x } 10^{-6}\text{ sec} - 16.6 \text{ x } 10^{-6})(30\text{V})}\right]$$

$$\leq 410\text{mA}$$

From the SD241 specification, the maximum reverse leakage current at 125° C is 100mA; therefore this system will be thermally stable.

4.5 Paralleling Rectifiers

When the output current required is greater than the maximum rated forward current of commercial rectifiers, it becomes necessary to parallel the devices. In some instances, it may be preferable to parallel devices even when a single device of higher current ratings is available. The advantages of paralleling these devices are:

1) Heat is easier to remove when compared to a single device with a higher current rating because the heat is spread between two or more devices.
2) The transformer is easier to wind since the wire size is smaller, using a separate winding for each rectifier.
3) Smaller chip size will have less chance of voids in the chip bond to the package, thus, the reliability of the system is improved.

The disadvantage of paralleling rectifiers is that some kind of circuit technique is required to share the current among the paralleled devices. If the current is not shared equally, the junction temperature of the device which conducts the higher current will increase. The forward voltage of the device will decrease due to its increased temperature and will conduct an even larger share of the load current. If adequate matching is not provided, this regenerative process continues; and if not checked in time, the junction temperature will exceed the maximum rating and the device will be damaged.

In switched-mode converter applications, current sharing can be accomplished by using separate windings for each rectifier and by matching forward drops. The series resistance of each winding acts as a current ballasting impedance.

5. Guidelines for Selecting the Schottky Rectifier in Pulse Width Mode (PWM) Switched-Mode Converter Applications

The minimum required dc blocking voltage of the Schottky rectifier and its maximum power dissipation can be calculated for different types of switched-mode power supplies summarized in Tables II and III. After calculating the maximum power dissipation, the designer can determine the required thermal resistance of the rectifier and the heat sink using the equation:

$$R_{\theta H} + R_{\theta JC} = \frac{T_{jmax} - T_{Amax}}{P_{max}} \qquad [5.1]$$

Where: $R_{\theta JC}$ = Thermal resistance of rectifier
$R_{\theta H}$ = Thermal resistance of heat sink
T_{jmax} = Maximum operating junction temperature of device
T_{Amax} = Maximum ambient temperature

When calculations are made for maximum power dissipation in a rectifier, the voltage drop V_F and leakage current I_R should be taken at the maximum operating junction temperature.

During start up and for step changes in the output load current, the voltage across the rectifier should be limited to below its maximum dc blocking voltage to avoid failures due to transient voltage across the Schottky.

TABLE 1 — GUIDELINES FOR DETERMINING THE RATING OF A RECTIFIER IN A PWM SWITCHED-MODE CONVERTER

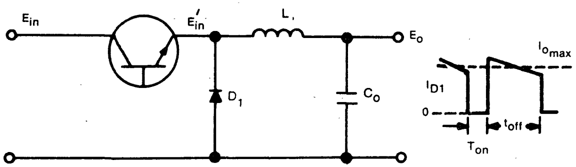
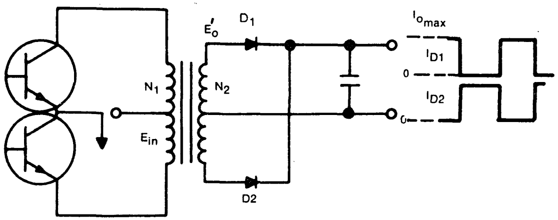
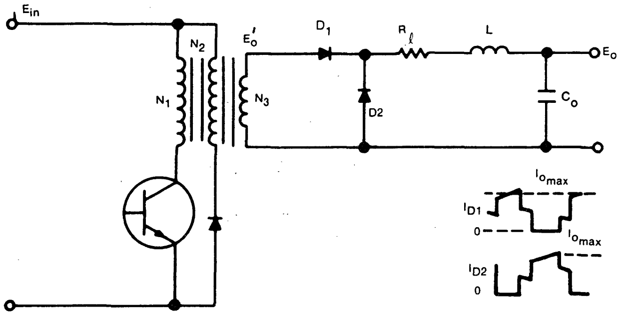
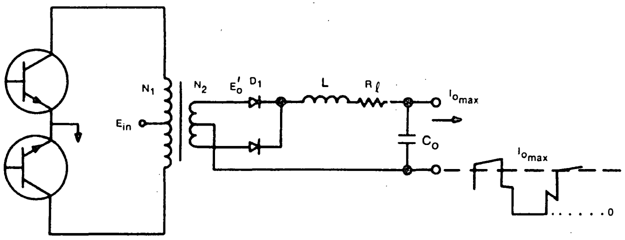
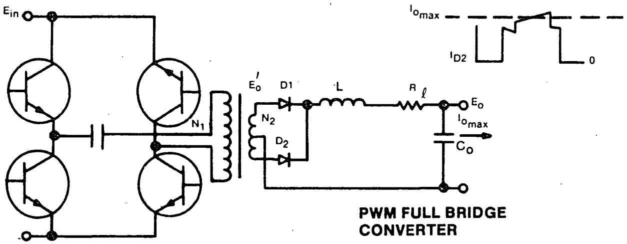
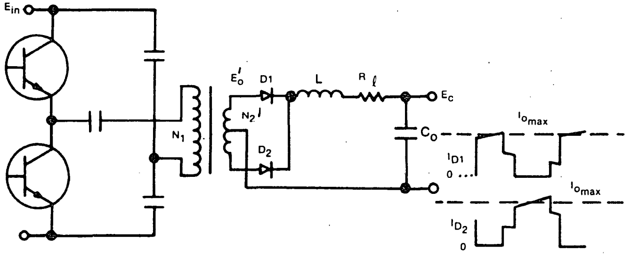
TYPES OF SWITCHING REGULATORS	OUTPUT VOLTAGE	STEADY STATE -- POWER DISSIPATION IN RECTIFIERS	MINIMUM DC BLOCKING VOLTAGE REQUIRED
BUCK REGULATOR  	$E_o = E_{in}' \times \frac{t_{on}}{\tau}$ $E_o \approx E_{in} \times \frac{t_{on}}{\tau}$	Power dissipation in Diode D_1 due to forward conduction: $P_{D1_F} = I_{o_{max}} \times V_F \cdot \frac{E_{in_{max}} - E_o}{E_{in_{max}}}$ Power dissipation due to leakage current, I_R: $P_{D1_R} \leq I_R \times E_o$, I_R @ $E_{in_{max}}$	For Diode D_1: $1.2 \times E_{in_{max}}$
PUSH-PULL CONVERTER (50% Duty Cycle)  	$E_o' = E_o + V_F$ $E_o = E_{in} \times \frac{N_2}{N_1}$	Power dissipation in Rectifier D_1 or D_2 due to forward conduction: P_{D1_F} or $P_{D2_F} = \frac{I_{o_{max}} \times V_F}{2}$ Power dissipation due to leakage current, I_R: P_{D1_R} or $P_{D2_R} = 2.0 \times E_{in_{max}} \times \frac{N_2}{N_1} \times I_R$	For D_1 or D_2: $2.4 (E_{in_{max}}) \times \frac{N_2}{N_1}$
PWM FORWARD CONVERTER  	$E_o' = E_o + V_F + I_{o_{max}} \times R$ $E_o = E_{in_{min}} \frac{N_3}{N_1 + N_2}$ Where: E_o = dc Output Voltage E_o' = Output of Secondary Winding When D_1 is conducting	Power dissipation due to forward conduction in Rectifier D_1: $P_{D1_F} = I_{o_{max}} \times V_F \frac{N_1}{N_1 + N_2}$ Power dissipation in Rectifier D_2: $P_{D2_F} = I_{o_{max}} \times V_F \left[1 - \frac{N_1}{N_1 + N_2} \cdot \frac{E_{in_{max}}}{E_{in_{min}}}\right]$ Power dissipation due to reverse leakage current: $P_{D1_R} = E_{in_{min}} \cdot I_R \cdot \frac{N_3}{N_1 + N_2}$ $P_{D2_R} = I_R \times \frac{N_3}{N_1 + N_2} \times E_{in_{min}}$	For D_1: $1.2 \times E_{in_{max}} \times \frac{N_3}{N_2}$ For D_2: $1.2 \frac{E_{in_{max}} \times N_3}{N_1}$

TABLE II

TYPES OF SWITCHING REGULATORS	OUTPUT VOLTAGE	STEADY STATE — POWER DISSIPATION IN RECTIFIERS	MINIMUM DC BLOCKING VOLTAGE REQUIRED
PWM PUSH-PULL CONVERTER   **PWM FULL BRIDGE CONVERTER**	$E_o' = E_o + V_F + I_{o_{max}} \times R_\ell$ $E_o = E_{in_{min}} \times \frac{N_2}{N_1}$ For Push-Pull and Full Bridge	Power dissipation in Rectifier D_1or D_2due to forward conduction: P_{D1_F} or $P_{D2_F} = \frac{I_{o_{max}} \times (V_F @ I_{o_{max}})}{2} \times \frac{E_{in_{min}}}{E_{in_{max}}}$ $+ \frac{I_{o_{max}} (V_F @ \frac{I_{o_{max}}}{2})}{2} \times \frac{E_{in_{max}} - E_{in_{min}}}{E_{max}}$ Power dissipation due to leakage current: P_{D1_R} or $P_{D2_R} = I_R(E_{in_{min}}) (N_1/N_2)$ NOTE: $I_R @ 2(E_o + V_F + I_{o_{max}} \times R\ell) \times \frac{E_{in_{max}}}{E_{in_{min}}}$	For D_1 or D_2: $2.4 (E_o + V_F + R$ $\times I_{o_{max}}) \times \frac{E_{in_{max}}}{E_{in_{min}}}$
PWM HALF-BRIDGE CONVERTER  	$E_o' = E_o + V_F \times I_{o_{max}} \times R_\ell$ $E_o = \frac{E_{in_{min}}}{2} \times \frac{N_2}{N_1}$ For Half-Bridge	SAME AS ABOVE	SAME AS ABOVE

6 Conclusion

Complete design guidelines for Schottky rectifiers used in switched-mode converters have been provided. The Schottky, when compared to a fast PN junction rectifier, offers the advantages of lower forward voltage and a faster reverse recovery time which is independent of temperature. Efficiency is improved at least 3 to 5% when Schottky rectifiers are used in place of PN junction devices for power rectification in switched-mode converters. Schottky rectifiers are available with a maximum reverse blocking voltage up to only 50 to 60V. Thus, applications of Schottky devices are limited to low output voltages (+5V) in PWM switched-mode converters (except for buck type and 50% duty cycle converters). When the rectifier requires voltage blocking capability of greater than 60V, fast PN junction devices like UES800 series rectifier offers the optimum choice without sacrificing speed and forward voltage.

SCHOTTKY RECTIFIERS

AVERAGE DC OUTPUT CURRENT		4A	6A	8A	12A[1]	12A
PEAK REVERSE VOLTAGE	PKG	TO-39 HERMETIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)	TO-220 PLASTIC (2 LEAD)	TO-220 PLASTIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)
30V	TYPE					
	V_F					
	I_{FSM}					
35V	TYPE		USD635	USD735	USD635C	USD835
	V_F		.48 @ 6A	.48 @ 8A	.60 @ 12A	.51 @ 12A
	I_{FSM}		150A	200A	150A	200A
40V	TYPE		USD640	USD740	USD640C	USD840
	V_F		.48 @ 6A	.48 @ 8A	.60 @ 12A	.45 @ 12A
	I_{FSM}		150A	200A	150A	200A
45V	TYPE	1N6492 USD245C	USD645	USD745	USD645C	USD845
	V_F	.45 @ 2A	.48 @ 6A	.48 @ 8A	.60 @ 12A	.45 @ 12A
	I_{FSM}	80A	150A	200A	150A	200A
50V	TYPE		USD650	USD750	USD650C	USD850
	V_F		.48 @ 6A	.48 @ 8A	.60 @ 12A	.45 @ 12A
	I_{FSM}		150A	200A	150A	200A

SCHOTTKY RECTIFIERS

AVERAGE DC OUTPUT CURRENT	16A[2]	16A	25A	30A	30A[3]	30A[3]
PKG / PEAK REVERSE VOLTAGE	TO-220 PLASTIC (3 LEAD)	TO-220 PLASTIC (2 LEAD)	DO-4 STUD	TO-3P (2 LEAD)	TO-3P (3 LEAD)	TO-3
30V TYPE V_F I_{FSM}				USD3030S .70 @ 30A 450A	USD3030C .71 @ 30A 400A	
35V TYPE V_F I_{FSM}	USD735C .60 @ 16A 200A	USD935 .53 @ 16A 250A				USD335C[6] .6 @ 20A 400A
40V TYPE V_F I_{FSM}	USD740C .60 @ 16A 200A	USD940 .53 @ 16A 250A		USD3040S .70 @ 30A 450A	USD3040C .71 @ 30A 400A	
45V TYPE V_F I_{FSM}	USD745C .60 @ 16A 200A	USD945 .53 @ 16A 250A	1N6391[5] .68 @ 50A 600A	USD3045S .70 @ 30A 450A	USD3045C .71 @ 30A 400A	USD345C[6] SD241[6] .6 @ 20A 400A
50V TYPE V_F I_{FSM}	USD750C .60 @ 16A 200A	USD950 .53 @ 16A 250A				

NOTES:
1. Center-tap 6A per leg.
2. Center-tap 8A per leg.
3. Center-tap 15A per leg.
4. V_{RRM} @ 25°C is 45V, V_{RRM} @ 150°C is 35V.
5. Available as JAN, JANTX, JANTXV.
6. Available with High-Reliability (HR2) Screening.
7. Center-tap 23A per leg.

SCHOTTKY RECTIFIERS

AVERAGE DC OUTPUT CURRENT	45A	45A[7]	50A	60A	75A	75A
PKG / PEAK REVERSE VOLTAGE	TO-3P (2 LEAD)	TO-3P (3 LEAD)	DO-5 STUD	DO-5 STUD	DO-5 STUD	DO-5 STUD
20V TYPE V_F I_{FSM}					USD520 .6 @ 60A 1000A	USD7520 .425 @ 60A 1000A
25V TYPE V_F I_{FSM}						USD7525 .425 @ 60A 1000A
30V TYPE V_F I_{FSM}	USD4530S .70 @ 45A 450A	USD4530C .70 @ 45A 450A	1N6097 .86 @ 157A 800A			
35V TYPE V_F I_{FSM}					USD535 .6 @ 60A 1000A	
40V TYPE V_F I_{FSM}	USD4540C .70 @ 45A 450A	USD4540C .70 @ 45A 450A	1N6098 .86 @ 157A 800A			
45V TYPE V_F I_{FSM}	USD4545S .70 @ 45A 450A	USD4545C .70 @ 45A 450A		1N6392[5] SD51[4] .6 @ 60A 800A	USD545 .6 @ 60A 1000A	
50V TYPE V_F I_{FSM}					USD550 .6 @ 60A 1000A	

NOTES:
1. Center-tap 6A per leg.
2. Center-tap 8A per leg.
3. Center-tap 15A per leg.
4. V_{RRM} @ 25°C is 45V, V_{RRM} @ 150°C is 35V.
5. Available as JAN, JANTX, JANTXV.
6. Available with High-Reliability (HR2) Screening.
7. Center-tap 23A per leg.

USING BIPOLAR SYNCHRONOUS RECTIFIERS IMPROVES POWER SUPPLY EFFICIENCY

INTRODUCTION

In an off-line, switching regulated, low voltage power supply for applications such as high density CMOS logic, high speed ECL logic, etc., the power dissipated in the output rectifiers accounts for 20-30% of the total input power. These rectifier losses could be reduced significantly with a synchronous rectifier technique. The bipolar synchronous rectifier (BISYN™) provides a cost-effective approach compared to power MOSFET synchronous rectifiers. A low saturation resistance ($R_{CE(sat)}$) on the order of a few milli-ohms is accomplished by cancelling two forward biased junctions while in saturation. The BISYN is designed for low (<5.0V) voltage outputs and has the following features:

a) Low saturation voltage with high forced gain.

b) Ultra-fast switching times.

c) First and third quadrant switching capability.

The BISYN not only provides low forward voltage but also has a lower temperature co-efficient compared to power MOSFETs. Thus, it maintains the high efficiency of a switching regulated power supply. The storage time of a BISYN is on the order of 300-400 nano seconds. However, the circuit presented in this paper eliminates even this storage time limitation of the BISYN. The device characteristics are also briefly described.

The rectifier losses of the Schottky, power MOSFET, and BISYN are compared when used as output rectifiers. The half-wave and center-tapped full-wave BISYN output circuit for a switching regulated power supply is presented.

CONVERSION EFFICIENCY

The power conversion efficiency for a switching regulated power supply is a measure of heat generated and lost in the system. The temperature rise in the system affects the reliability. Note that the failure rate increases rapidly (log function) with an increase in operating junction temperature. Lower efficiency not only affects the reliability but also increases the operating cost of the system. Higher efficiency results in a compact and lighter power supply with simple thermal management requirements. In a typical line-operated switch-mode converter, as shown in Figure 1, the power lost in the output rectifiers accounts for 20-30% of the total input power. The circuit shown is a single ended forward converter. Energy from the input bulk capacitor C_{IN} is transferred to output filter inductor L and the load, through a power transformer T_1 and rectifier diode D_1, when transistor Q_1 is on.

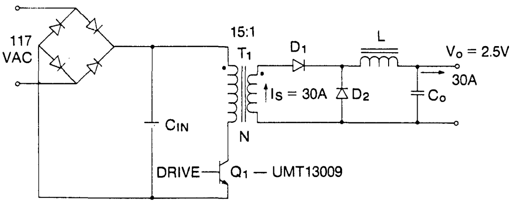


FIGURE 1. SINGLE ENDED FORWARD CONVERTER.

However, when transistor Q_1 is off, diode D_1 becomes reverse biased and the output load receives the energy from the output filter inductor L_1 through rectifier diode D_2. During this period the transformer core is reset with an equal and opposite volt-second product. Note that maximum conduction duty for transistor Q_1 is 50% and that one of the rectifiers (D_1 or D_2) is always conducting. From Figure 1, the fraction of input power lost in the rectifier can be calculated as follows:

$$\text{Output Power } P_O = V_o \times I_o = (2.5)(30) = 75\text{W} \qquad (1)$$

$$\text{Transistor } Q_1 \text{ DC losses} = [V_{CE(sat)}] \times \left[\frac{I_o}{\text{Turns ratio}}\right] [\text{Duty cycle}] \qquad (2)$$

$$P_{Tdc} = (1.0\text{V})\left(\frac{30\text{A}}{15}\right)(0.5) = 1.0\text{W}$$

Assuming transistor switching losses are equal to DC losses.

$$\text{Total transistor losses} \quad P_T = 2 \times P_{Tdc} = 2\text{W} \qquad (3)$$

Since one of the rectifiers always conducts; the total rectifier losses

$$P_D = I_o \quad V_F = (30\text{A})(1\text{V}) = 30\text{W} \qquad (4)$$

Therefore the fraction of input power lost in the output rectifiers;

$$P_{FR} = \frac{P_D}{P_o + P_D + P_T} = \frac{30}{75 + 30 + 2} = 0.28 \qquad (5)$$

The above calculation shows that rectifier losses are a significant portion of total power lost in a low voltage output supply. The reduction in efficiency due to these rectifier losses can be represented in terms of forward voltage drop by a simple equation:

Loss of efficiency due to rectifier, %

$$\approx \frac{V_F}{V_O + V_F} \times 100\%$$

$$\approx \frac{1.0}{2.5 + 1.0} \times 100\% = 28.6\% \qquad (6)$$

Note that the temperature dependent forward offset voltage V_F and and output voltage influences the efficiency of a switching power supply. The rectifier losses are minimized with the low forward voltage of a Schottky rectifier; but it still represents 20% of the total input power lost in these rectifiers when used in 2.5V supply. From the above equation, it is obvious that there is a nearly fixed fraction of input power lost in the output rectifiers regardless of load current. To improve the efficiency of the switching power supply, one must select an alternative such as synchronous rectification using either a power MOSFET or a BISYN.

The typical application of a synchronous rectifier using a power MOSFET is shown in Figure 2.

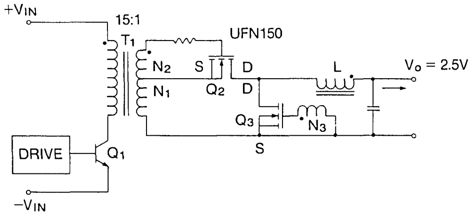


FIGURE 2. POWER MOSFET SYNCHRONOUS RECTIFIER.

During the on-time of primary transistor Q_1, power MOSFET Q_2 is turned on with a voltage generated across winding N_2, this allows secondary current to flow through the low source-to-drain resistance $R_{DS(on)}$. When primary transistor Q_1 is off, the power MOSFET Q_2 reverts to its blocking state. The MOSFET Q_3 turns on and facilitates a path for inductor current. Some inductor energy through winding N_3 is used to turn on power MOSFET Q_3. Since a power MOSFET is a majority carrier device, the turn-off delay is negligible. The switching losses are negligible due to its fast switching times. The fraction of power lost in this synchronous rectifier:

$$P_{FR} = (1 - \eta) = \frac{R_{DS(on)}\, I_o}{V_o = R_{DS(on)}\, I_o} \qquad (7)$$

Unlike conventional rectifiers, the rectifier loss and consequently the efficiency of the power supply is a function of output current. The power supply efficiency can be increased by utilizing a power MOSFET with a low on-resistance. Unfortunately, the power MOSFET synchronous rectifier is not a cost-efficient approach because:

1) Twice the silicon chip area is required when compared with a BISYN for the same forward voltage drop at room temperature.
2) $R_{DS(on)}$ of a power MOSFET increases three times faster with temperature than R_{CE} of a BISYN.

As such the power MOSFET requires three to four times as large a silicon chip for the same output current and performance as the BISYN.

BIPOLAR SYNCHRONOUS RECTIFIER

Unlike a bipolar transistor, BISYNs offer features such as low saturation resistance (8 milliohms for 4.5mm sq. chip) with light base drive (forced gain ≥ 25) and symmetrical voltage blocking capability for both positive and negative input voltages. The device is specifically designed for synchronous rectifier applications with low output voltages such as required for high density CMOS logic and high speed ECL.

Like a power MOSFET, the saturation resistance of the BISYN has a positive temperature co-efficient; however, it is three times smaller in magnitude. Thus it maintains high efficiency even at elevated temperatures. The switching times are optimized through a lightly doped, narrow base region. The storage time and fall time of the device is on the order of 300 and 80 nano seconds, respectively.

Unlike a power MOSFET, the BISYN has both positive and negative input voltage blocking capability. This opens the door for new applications, such as a synchronous PWM regulator in which the output voltage is regulated with a BISYN by controlling the conduction period in synchronization with the primary switching voltage.

The cross-sectioned area of a BISYN and waveforms of its electrical characteristics are shown in Figures 3 through 6.

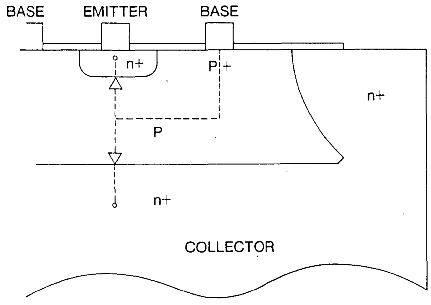


FIGURE 3. CROSS SECTION OF BISYN TRANSISTOR (TWO BIPOLAR JUNCTIONS TEND TO CANCEL EACH OTHER IN THE ON-STATE).

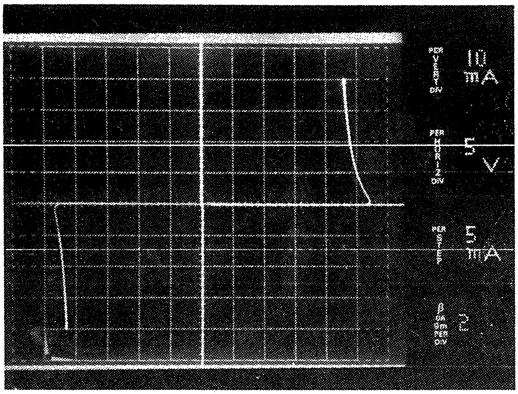


FIGURE 4. SYMMETRICAL REVERSE CHARACTERISTICS OF A BISYN RECTIFIER.

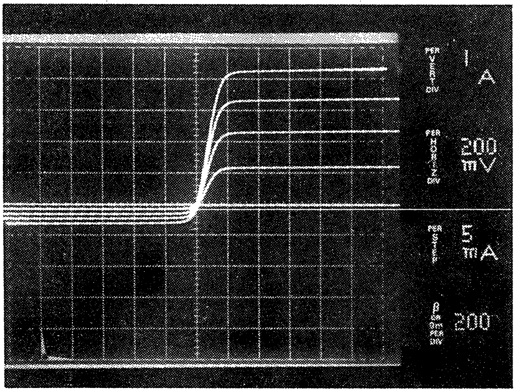


FIGURE 5. FIRST AND THIRD QUADRANT V_{CE} vs I_C CHARACTERISTICS OF A BISYN RECTIFER.

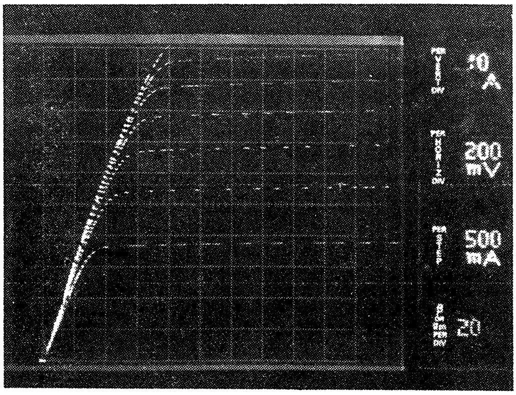


FIGURE 6. FIRST QUADRANT V_{CE} vs I_C CHARACTERISTICS.

A BISYN is a classical low voltage bipolar transistor. When both junctions are forward biased, the forward drops cancel each other and provide a low drop from collector to emitter. The saturation resistance of a BISYN is less than 2 milliohms while the rest of the 6 milliohms is contributed by metallization, wire bond and package resistances. This is the main reason for low composite temperature coefficient of saturation resistance. Both positive and negative collector to emitter voltage blocking capability of the device, with base open, are shown in Figure 4. The first and third quadrant V_{CE} vs. I_C characteristics of the BISYN are displayed in Figure 5. It is obvious that the DC gain is as high as 200 in the first quadrant and 40 in the third quadrant; and is practically independent of collector to emitter voltage. First quadrant V_{CE} vs I_C characteristics up to 100A are presented in Figure 6. The saturation resistance $R_{CE(sat)}$, independent of collector current, is less than 8 milliohms; and the device has a high gain (30) even at 100 amperes.

PERFORMANCE COMPARISON AMONG SCHOTTKY, POWER MOSFET & BISYN

The power losses of a Schottky, a power MOSFET and a BISYN when used as a rectifier are compared in Figure 8.

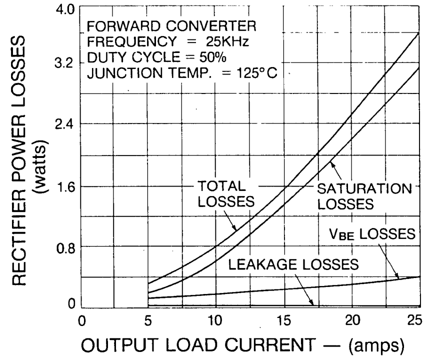


FIGURE 7. RECTIFIER POWER LOSSES.

The devices are *normalized* to the same size chip and reverse blocking voltage. For example, the commercially available power MOSFET IRFZ40 has 28 milliohms $R_{DS(on)}$ and B_{VDSS} = 40V ratings. The chip size is about the same as that of a BISYN, however, the normalized MOSFET with B_{VDSS} = 25V, not commercially available, will have only 18 milliohms $R_{DS(on)}$ and is used as a comparison with the BISYN. Similarly, the power Schottky rectifier is a 25V Schottky (not yet commercially available). Again the area of the silicon chips is normalized against the BISYN area.

Let us first define the losses in the BISYN.

The power losses can be expressed by the equation:

$$P_{LBI} = [R_{CE(sat)}\, I_o^2]\,[D] + [V_{BE(on)} \frac{I_o}{B_F}]\,[D] + [I_R\, V_R]\,[1-D]$$

Where: I_o: output current

D: BISYN on Duty cycle

B_F: Forced gain to keep BISYN in saturation

I_R: Emitter to collector leakage current I_{ECX}

V_R: Emitter to collector voltage

From the above equation, it is obvious that the lower the saturation resistance and higher the forced beta, the lower the rectifier losses. The individual components of power loss at 125°C junction for the BISYN are presented in Figure 7. The worst case BISYN rectifier losses are realized at elevated temperatures. Unlike the Schottky rectifier, the power losses are a square function of the output load current instead of linear function.

The rectifier losses in a secondary output circuit are compared for a Schottky, a power MOSFET and a BISYN at a typical operating junction temperature (75°C) in a single ended forward converter, as shown in Figure 8. All the curves are normalized for devices with equal blocking voltage and silicon chip area.

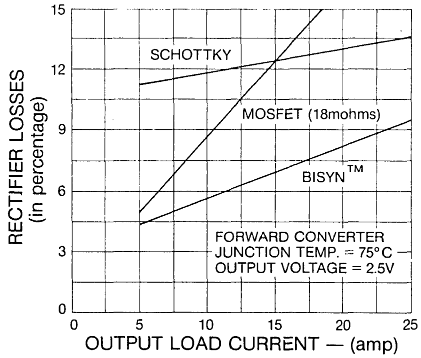


FIGURE 8. COMPARISON — TOTAL SECONDARY RECTIFIER LOSSES.

The BISYN rectifier uses a 4.5mm sq. silicon chip. For a 2.5V output supply, and output load current below 4A, the power MOSFET offers high efficiency because there are no $V_{BE(on)}$ losses. At elevated temperatures the output current crossover point favoring the BISYN will be even lower due to the higher temperature co-efficient of $R_{DS(on)}$ for the MOSFET. At high output currents use of a BISYN reduces the power losses to half of the losses of Schottky rectifiers.

For most low voltage applications the BISYN provides the most cost-effective and efficient approach for secondary rectification.

BISYN SYNCHRONOUS RECTIFIER APPLICATIONS

Two popular types of synchronous rectifiers are detailed in this section.

1) Single Ended Forward Converter; Half-Wave Synchronous Rectifier

In a single ended forward converter, the output voltage is developed by half wave rectification in the secondary circuit as previously shown in Figure 1. The rectifier diode D_2, which carries filter inductor current, must recover fast, when primary switch Q_1 is closed to prevent problems due to shorting the secondary through diode D_1. During the recovery period high peak current will be reflected back to the primary side. Besides EMI generation, the high peak current will increase the power dissipation in the switch Q_1 and can damage the power switch. Therefore, diode D_2 must have very short reverse recovery time. However, the BISYN utilized for diode D_2 had long recovery time (storage time), on the order of 300-400 nano seconds. This necessitated development of a unique circuit as shown in Figure 9, which eliminates the storage time limitation.

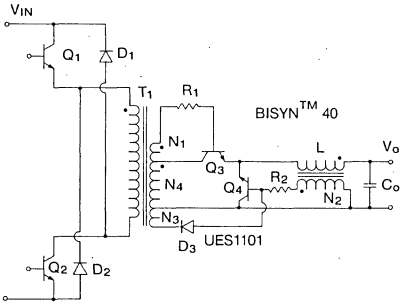


FIGURE 9. BIPOLAR SYNCHRONOUS RECTIFIER IN A TWO TRANSISTOR FORWARD CONVERTER.

The operation of the circuit is as follows. During the on-time of transistors Q_1 and Q_2, BISYN Q_3 is biased on and delivers output load current through filter inductor L. The polarity of voltage developed across winding N_2 is such that BISYN Q_4 remains in a blocking state. Diode D_3 is also biased off. When transistors Q_1 and Q_2 turn off, some of the energy stored in the magnetizing and leakage inductance enhances the recovery process of BISYN Q_3. The recovery time (300-400 nano seconds) of BISYN Q_3 extends the reset time of the core. However, in a typical design, half of the switching period is allocated for core reset time. Thus, the storage time has no significant effect on operation. The

BISYN Q_4 starts conducting filter inductor current as soon as the voltage across the secondary collapses. BISYN Q_4 receives base drive energy from the filter inductor L, through winding N_2. The diode D_3 still remains reverse biased.

When transistors Q_1 and Q_2 turn on again, the voltage across winding N_3 is clamped to approximately zero by diode D_3 and the forward biased collector to base junction of BISYN Q_4. This junction acts as a voltage source ($\approx$0.7V) as long as BISYN Q_4 is conducting during the storage time. The turn-on of BISYN Q_3 is held off due to lack of base drive because winding N_3 is shorted, through diode D_3 and the collector-base junction of BISYN Q_4. Meanwhile, the current through the shorted turns (the rate of rise of which is limited by leakage inductance) is utilized to commutate BISYN Q_4 off rapidly. Diode D_3 is then reverse biased and BISYN Q_3 turns on through winding N_1.

The effect of the turn-off circuit (consisting of winding N_3 and diode D_3) on secondary current is demonstrated in Figure 9a. The upper waveform shows secondary current identical to the lower waveform except for high peak current.

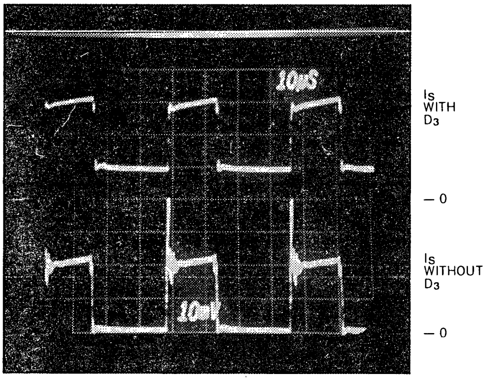


FIGURE 9a. SECONDARY CURRENT EFFECT OF DIODE D_3. VERTICAL SCALE: 5A/cm.

The oscillograms 9b and c demonstrate that there are practically no switching losses in a single ended forward converter.

2) Push-Pull Converter; Center-Tapped Full Wave Synchronous Rectifier

The center-tapped push-pull BISYN synchronous rectifier circuit is shown in Figure 10.

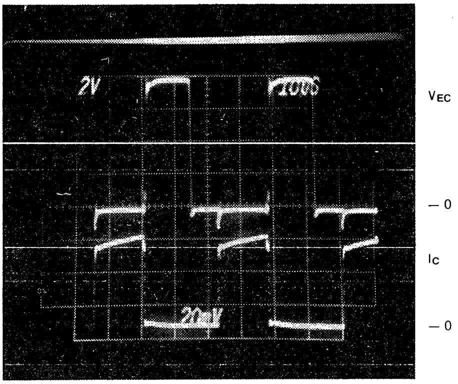


FIGURE 9b. TURN-ON WAVEFORMS. VERTICAL SCALE: 2V/cm.

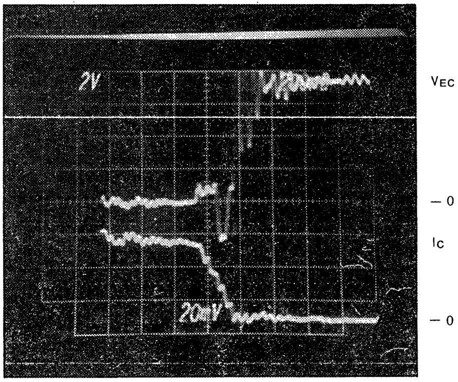


FIGURE 9c. TURN-OFF WAVEFORM. VERTICAL SCALE: 2V/cm.

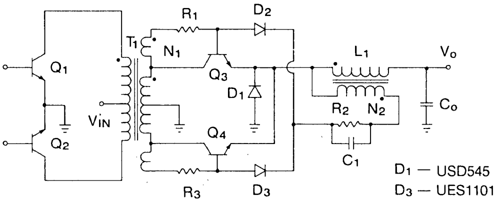


FIGURE 10a. BIPOLAR SYNCHRONOUS RECTIFIER IN A CENTER-TAP OUTPUT CONFIGURATION.

During the on-time of primary transistor Q_1, BISYN Q_3 is on. At this time all other devices in the secondary circuit are in the off state. The energy from the primary side is being transferred to the secondary through the transformer and the BISYN Q_3. When primary transistor Q_1 turns off, current flow in the secondary winding ceases and the voltage across the secondary winding collapses. The catch diode D_1 provides the path for inductor current. The filter inductor energy causes current flow through diode D_2 and speeds up the turn-off process of BISYN Q_3. When Q_3 recovers, diode D_2 becomes reverse biased. The induced voltage, caused by stored magnetizing energy in the core, will turn on BISYN Q_4 and remains on until magnetizing current drops below diode D_3 current. When both transistors Q_1 and Q_2 are off, Q_3 remains off. The catch diode D_1 provides the current path for the filter inductor. Since BISYN Q_3 is off prior to turn-on of primary transistors Q_2, recovery time of the BISYN is of no consequence other than limiting maximum dead-band period of the circuit. The input voltage and current waveforms of the BISYN are shown in Figure 10a.

SYNCHRONOUS PWM REGULATORS

In a typical switching regulated power supply only one of the outputs is regulated through a closed loop; while other auxiliary outputs may provide rough regulation. When these outputs require tighter regulation, usually linear or switching regulators are utilized.

In a synchronous PWM regulator, the regulated auxiliary output is derived in one step through rectification and regulation of the secondary winding output voltage. A BISYN is the only device which can perform this function because of its unique third quadrant characteristics. Also, its low saturation resistance maintains high efficiency. The output voltage is regulated by gating the input pulsating DC voltage (from secondary winding) to the LC filter, in synchronism with the primary switching cycle. The detailed schematic of the regulator is shown in Figure 11.

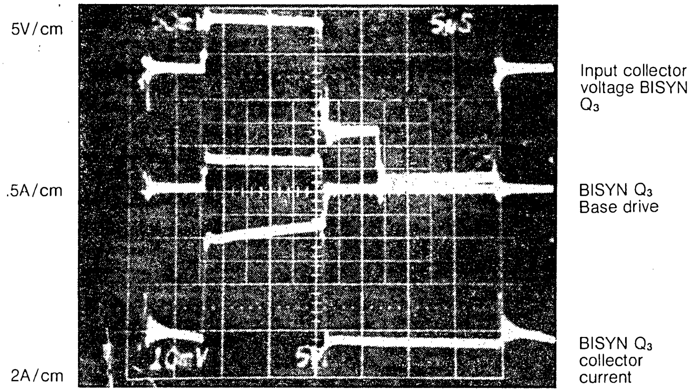


FIGURE 10b. WAVEFORMS. CENTER-TAP RECTIFIERS.

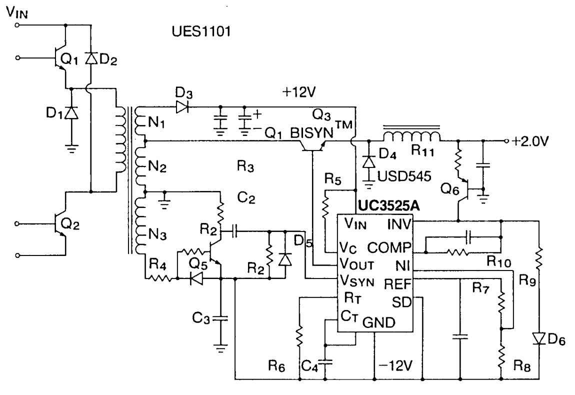


FIGURE 11. BISYN SYNCHRONOUS PWM VOLTAGE REGULATOR.

Note that there is no standard commercially available PWM circuit which can perform these functions without some additional circuitry. The biasing requirements of the BISYN Q_3 necessitate the use of a positive and negative supply voltage for the PWM control chip. A commonly required ±12V output voltage can serve as a bias supply for the PWM circuit. However, in this circuit the PWM supply voltage is developed directly from the secondary winding as shown in the previous figure.

The BISYN is controlled by one of the totem-pole outputs of the control chip 3525A. The drive current (200mA) is limited by resistor R_5 during on-time. However, during initial turn-on, it receives a large peak value of bias drive current because the emitter of BISYN Q_3 is maintained at a negative 0.7V potential by catch diode D_3 which carries the filter inductor current. The turn-on waveform shown in Figure 12a demonstrates that turn-on drive current is three times higher than steady state base drive current.

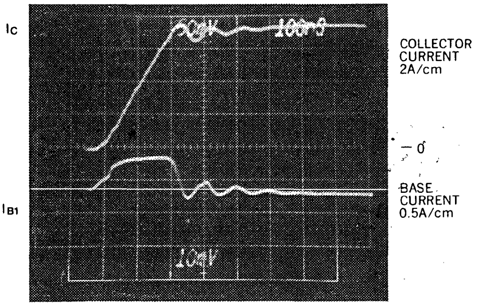


FIGURE 12a. RISE TIME.

The totem-pole output of the control chip also provides high negative base drive current (Figure 12b) during turn-off times, and also maintains proper biasing voltage to the base of the BISYN Q_3 during off-time.

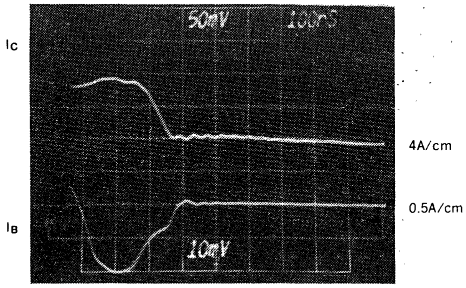


FIGURE 12b. FALL TIME.

A level shifter is required to feed back the output voltage sample because the control chip ground reference is different from the output voltage. The circuit consists of transistor Q_6, diode D_6 and resistors R_9 and R_{11}. A diode D_6 temperature compensates for the V_{BE} of transistor Q_6. The transistor Q_6 in conjunction with resistor R_{11} converts the output voltage into an output voltage dependent current source. The output voltage, referenced to the negative supply rail, is developed across resistor R_9 and diode D_6.

The sync pulses, referenced to the negative supply voltage, are developed with transistors Q_5, diode D_5 and the associated R_C circuit. The resistor R_2 and capacitor C_2 function as a differentiator circuit, while D_5 clamps the negative voltage excursion to prevent a malfunction of the control chip. The free running frequency is set about two times higher than the primary transistors switching frequency by capacitor C_4 and resistor R_4.

SUMMARY

In addition to synchronous rectifier, the application of a BISYN is demonstrated for voltage regulation with improved transient response through a synchronous PWM regulation technique. This is possible due to its unique third quadrant characteristics, unlike power MOSFETs. Ultra fast switching times allow the switching regulator to be operated up to 250kHz.

The BISYN has extremely low (<8 milliohm) saturation resistance with a small size (4.5mm sq.) chip. Thus it provides an efficient and cost-effective approach for synchronous rectifiers and synchronous PWM regulators when compared to power MOSFETs and Schottky rectifiers. The output current capability can be extended by paralleling these devices, which is possible because of the positive temperature co-efficient.

ACKNOWLEDGEMENT

I want to thank Lloyd Dixon for his insight into problems that required solving using bipolar transistors in these applications and David Reilly for constructing and assisting in the evaluation of these circuits. And finally, to Fred Blatt for his contributions.

BIBLIOGRAPHY

Chenming Hu, *Trends in Switching Power Semiconductor Devices*. International Electronic Device and Material Symposium.

MOSFETs, Schottky Diodes vie for low voltage Supply Designs. EDN, June 28, 1984.

P. L. Hower and G. Kepler - Unitrode Corp. Solid State Devices, *A Bipolar Transistor for Synchronous Rectifier*.

Low Voltage FETs slash on-resistance to boost power density, Electronic Design, July 12, 1984.

BISYN™ is a trademark of Unitrode Corporation.

APPLICATION NOTE **U-105**

HOW TO MEASURE K_T and K_V WITHOUT MEASURING TORQUE OR ANGULAR VELOCITY

INTRODUCTION

Motor manufacturers must be able to supply a good deal of technical details concerning the mechanical, electrical, and thermal specifications of their motors to enable the equipment designer to optimize their use. Among these specifications, there are two that state a motor's performance in converting electrical into mechanical energy, namely the torque constant K_T, and the voltage constant K_V.

The torque constant relates the torque produced at the motor shaft to the applied current, and is measured in units of torque per ampere. Thus, a motor having a K_T of 2 Nm/A will produce a torque of 2 Nm when driven with a current of 1 ampere. (The Newton-meter, Nm, is equal to 141.612 in oz.) To measure K_T, one applies a known current to the motor winding — or windings — and measures the resulting shaft torque.

The voltage constant is a measure of the motor's back emf, which is the voltage generated in the windings as a consequence of the rotor's movement. This back emf increases directly as the angular velocity increases, and is usually given in units of volts per thousand revolutions per minute, or V/KRPM, in this country. But there are certain advantages in stating this parameter in terms of volts per radian per second, or Vsec/rad. To measure it, you must measure voltage and angular velocity. This, by the way, applies to DC tachometers as well. Torque and angular velocity are not easy to measure, and measuring current in the amperes range is at best inconvenient. Can one obtain reliable values for K_T and K_V through a simple measurement that is easy and inexpensive to make? A positive answer to this question is given below.

It was James Watt, the Scottish engineer and inventor (1738-1819), who first thought of defining the output power of his steam engines in terms of horse-power. There was a demand for these engines to replace the working horses that were used in the various industrial operations of the time, such as textile, flour mills, etc. In those early days of the Industrial Revolution, Watt and his helpers must have been up to their necks in problems that ranged from strength of materials, fuel selection and handling, lubrication, corrosion, mechanics, dynamics, thermodynamics, noise, and safety, to the effects of mineral deposits in boilers, and so on. And then, there was the problem of how to rate the engine's power so that a given customer could be assured that his engine, once installed, would be adequate for the job.

Power is the work done per unit time. In the English system, this can be measured, for example, in foot-pounds per minute (ft lb/min). Borrowing some typical horses, and with the aid of harness, weights, ropes, pulleys, and a handful of whips, Watt determined by actual measurement that a horse can do work at the rate of 33,000 ft lb/min — on the average. This number is used to this day to define the unit of mechanical work known as the horsepower:

1HP = 33,000 ft lb/min
or
1HP = 550 ft lb/sec

Suppose a certain motor can produce torque of T ft lb at a speed of M rpm. The work done in one revolution is 2π T ft lb, and the rate of doing this work is 2π TM ft lb/min. This, divided by James Watt's measured horse equivalent, will be the motor's horsepower rating.

$$\text{HP} = \frac{2\pi T_E M}{33{,}000}$$

HP → horsepower
T_E → ft lb
M → RPM
33,000 → ft lb/HP min

If, instead of M (RPM) we prefer to use ω (rad/sec) for the angular velocity, this relationship becomes

$$\text{HP} = \frac{T_E\omega}{550}$$

ω → rad/sec
550 → ft lb/HP sec

Again, if we express the torque in metric units of Newton-meters, at 1.356 Nm/ft lb, we get:

$$\text{HP} = \frac{T_M\omega}{745.7}$$

T_m → Nm
ω → rad/sec
745.7 → Nm/HP sec

Finally if we express power in Watts instead of horsepower, using 745.7 watts/HP, we have:

$$W = T_M\omega$$

W → Watts

which tells us where the number of watts per horsepower comes from. Consequently, the shaft power in watts is simply the product of the torque in Nm and the angular velocity in rad/sec. And since W = VI we can write:

$$VI = T_M\omega$$

V → Volts

and

$$\frac{V}{\omega} = \frac{T_M}{I}$$

I → amperes
ω → rad/sec

This is an interesting result, for it states that the quantity $\frac{V}{\omega}$, in volts per rad/sec is identical to the quantity $\frac{T_M}{I}$ in Nm per ampere. Thus, in any electric motor, since

$$\frac{V}{\omega} = K_V \text{ and } \frac{T_M}{I} = K_T \qquad K_V = K_T$$

K_V → volt sec/rad
K_V → Nm/A

By the way, expressing the torque in in. oz, and the shaft speed in KRPM, we get, as you can verify,

$$VI = \frac{T_e M_K}{1.352} \qquad T_e \rightarrow \text{in oz.} \quad M_K \rightarrow \text{KRPM}$$

so that

$$K_{TE} = 1.352\ K_{VE} \qquad K_{TE} \rightarrow \text{in oz/A} \quad K_{VE} \rightarrow \text{volts/KRPM}$$

This brings us from James Watt's steam engines and his customer's horses all the way to the modern electric motor, and the fixed ratio between torque constant and voltage constant turns out to be just a matter of definition. Both K_V and K_T have the same mks dimensions: $ML^2T^{-1}Q^{-1}$. If you know one, you also know the other; once you have measured one, you are through.

Measuring the voltage or torque constant of a permanent magnet brush motor or tachometer, for example, can be an extremely simple affair, requiring almost no equipment. Note that the units of K_V are volt sec/rad, which suggests that a measurement by means of an integrating circuit should be possible. In fact, if you integrate the voltage generated at the terminals as you turn the shaft through a given angle, you will have it.

Figure 1 shows a possible circuit.

The operational amplifier used should have very low input current and should be carefully balanced to minimize drift. All you need do is this:

A) Push the reset switch initially to discharge C and set the output voltage e_o to zero.

B) Rotate the motor shaft by a known angle, such as T turns.

C) Measure the voltage e_o.

D) The motor's voltage constant will be:

$$K_V = \frac{e_oRC}{2\pi T} \text{ volt sec/rad}$$

or,

$$K_{VE} = \frac{16.67\ e_oRC}{T} \text{ volt/KRPM}$$

E) The motor's torque constant in Nm/A will be the same number as K_V.

To convert K_V (volt sec/rad) to K_{VE} (volt/KRPM);

$K_{VE} = K_V \times (104.72)$

To convert K_T (Nm/A) to K_{TE} (in oz/A);

$K_{TE} = K_T \times (141.612)$

An interesting thing about this method is that it makes no difference how fast you rotate the shaft during the measurement — provided that your integrator drift is negligible. Furthermore, if you overshoot your angle, simply turn the shaft back to the right place before you read the output voltage.

This method gives a true and accurate measurement of two important motor parameters, without any need to measure current, torque, or angular velocity. In principle, and with a few more parts, it should be adaptable to measurements of hybrid steppers and brushless DC motors as well.

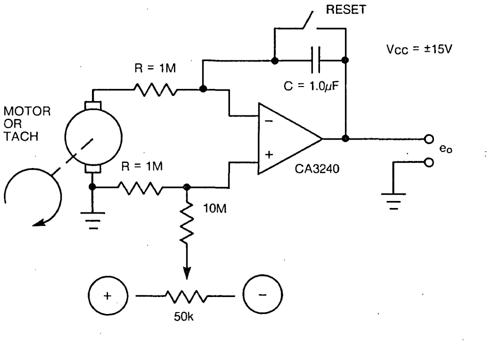


FIGURE 1. ACTIVE INTEGRATOR FOR MEASURING K_V. THE OP-AMP SHOULD BE WELL BALANCED TO MINIMIZE DRIFT.

APPLICATION NOTE **U-108**

SCHOTTKY RECTIFIERS FOR LOW-VOLTAGE OUTPUTS

ABSTRACT

Schottky rectifier device designs are reviewed with the aim of obtaining minimum power loss for output rectifier applications operating in the 2 to 3 volt range. The performance of a new low V_F Schottky design is described.

INTRODUCTION

Schottky rectifiers are routinely used as output rectifiers in switching power supplies. For output voltages of 5 volts or more, the efficiencies achieved are satisfactory for most applications. As output voltages decrease to the 2 to 3 volt range needed for the latest MOS ICs and to 2V needed for bipolar ECL, we need to look critically at the Schottky rectifier to see whether there is anything that can be done to reduce the losses in this device.

In this paper the circuit and device are treated together as one problem. The circuit operating conditions are taken as parameters and the device design is varied with the aim of achieving minimum rectification loss. The intention is to present results in terms which are familiar to most device users and circuit designers. Device physics nomenclature and analyses are kept to a minimum.

The paper concludes with a discussion of a new low V_F Schottky rectifier design which is currently in production. The implications of improved cooling techniques on the optimum Schottky design are also discussed.

DEVICE DESIGN

A cross-section of a typical Schottky rectifier is shown in Figure 1. Recent Schottky designs make use of a p-n junction "guard ring" which is the p-type region that is used to terminate the edge of the Schottky. A major reason for incorporating the guard ring is to provide a transient voltage suppressor with good energy absorption capability as close as possible to the main Schottky junction.

Device Variables

Consider the behavior under reverse bias. If the current flowing over the guard ring is I_1, and I_2 is the current in the Schottky portion, then the two components will behave with voltage as indicated in Figure 2. The guard ring is designed to give a breakdown voltage BV_1 slightly less than BV_2, the breakdown voltage of the Schottky junction. With this approach, transient reverse current, e.g. due to transformer leakage inductance, which would be destructive if carried by the I_2 path will be safely shunted by the p-n junction.

There are five variables which are generally used to describe each design. These are:

N_d, W_n: doping and thickness of the n-type epitaxial layer

x_j: metallurgical junction depth of the p-type diffusion

A_J: area of the Schottky junction

φ_B: barrier height (V) for the Schottky junction

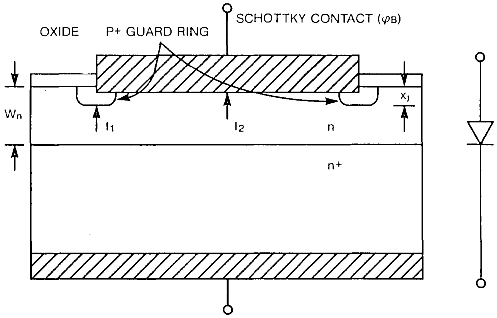


FIGURE 1. SCHOTTKY RECTIFIER CROSS-SECTION.

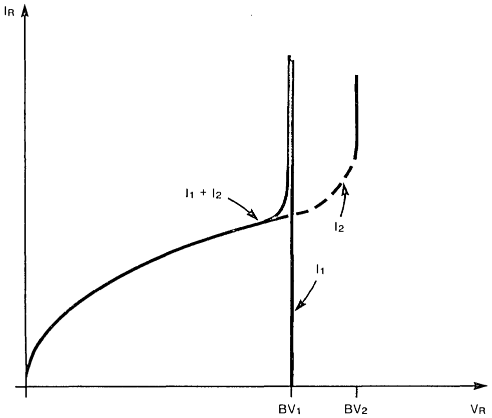


FIGURE 2. REVERSE I-V CHARACTERISTICS SHOWING THE CURRENT COMPONENTS I_1 AND I_2 of FIGURE 1.

The vertical dimensions W_n and x_j together with N_d determine the breakdown voltage and thereby the reverse voltage rating of the rectifier. These variables are usually chosen to meet a given BV requirement and at the same time minimize the series resistance contributed by the epitaxial layer.

The (electron) barrier height φ_B is defined here in volts, and it refers to the energy band diagram shown in Figure 3, where $q\varphi_B$ is the distance in eV from the metal fermi level at the surface to the conduction band edge in the silicon. The barrier height is a function of the metal used for the barrier material which is normally deposited by RF sputtering. Metals such as platinum, tungsten, nickel, chromium, and molydenum which form a silicide are preferred for the barrier material.

The choice of barrier height represents a compromise between trying to achieve a low forward drop (small φ_B) and the ability to survive high temperatures without thermal runaway (large φ_B). The influence of barrier height on rectification losses is considered later in the paper.

From a manufacturing standpoint, it is desirable to limit the number of variations of the list of five variables while still providing a product line that meets market needs. Usually what is done is to fix everything except A_J which is then varied by selecting various die sizes to meet a range of forward current ratings.

The next level of adjustment involves designing to meet a different reverse voltage while still keeping the same barrier height. This is the type of design variation considered at the end of the paper.

Adjusting φ_B can be done, but it represents the most costly of the changes available in terms of capital equipment and process development. Therefore, manufacturers need to be convinced of a satisfactory market size before they undertake a change in barrier material.

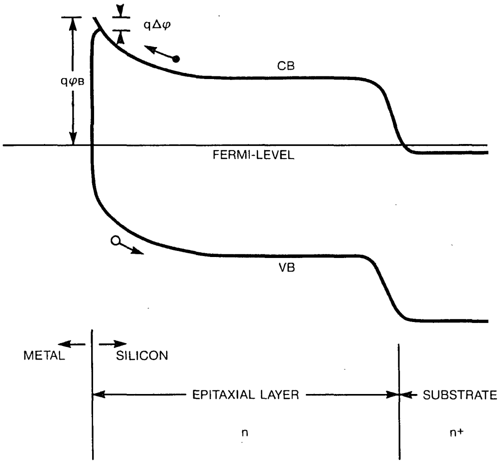


FIGURE 3. ENERGY BAND DIAGRAM AT EQUILIBRIUM ($V_F = 0$).

Circuit Conditions

For a given application, each rectifier is subjected to current and voltage waveforms which determine P_L, the average power dissipated by one rectifier. This power flows through the device package and associated heat sink to the surrounding ambient which is at temperature T_A. The junction temperature T_J is given by

$$T_J = T_A + P_L \cdot R_{\theta JA} \qquad (1)$$

where $R_{\theta JA}$ is the net junction-to-ambient thermal resistance.

A full-wave or push-pull type of output circuit with each rectifier conducting 1/2 of the period is taken to be representative of a typical Schottky application. For an inductive input filter, the wave forms can be approximated as shown in Figure 4. Actual waveforms will show a recovery type of behavior during turn-off which can become important at switching frequencies comparable to 1MHz. For this analysis, we are ignoring switching losses

For each application we assume that these quantities are defined:

I_F: the peak rectified forward current

V_R: peak reverse voltage

T_A: ambient temperature

$R_{\theta JA}$: junction-to-ambient thermal resistance. This value includes the junction-to-case thermal resistance of the package.

If we use (1) to convert T_A and $R_{\theta JA}$ input data to T_J, then this list is equivalent to defining three quantities which must be met by a design which is a function of the five device variables. That is, there are two degrees of freedom in selecting the device design. The usual procedure is to try to minimize both the power losses P_L and the device size, which is roughly equivalent to minimizing the device cost.

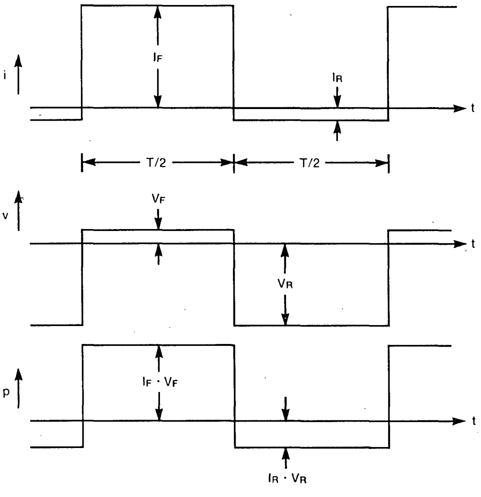


FIGURE 4. CURRENT, VOLTAGE, AND POWER WAVEFORMS.

The scheme followed in this paper is to determine how the power losses change as a function of $R_{\theta JA}$ and T_A, with various device variables or suitable combinations of variables taken as parameters.

Device Model

Accurate predictions of device performance can only be achieved if one has an accurate device model. We have found that the usual Schottky model of an ideal barrier in series with a fixed resistance works well for a wide range of situations, but it is also frequently necessary to account for conductivity modulation of the n-layer. This modulation is not due to the guard ring, which injects a relatively small amount of excess charge, but is due to the Schottky barrier itself (1). For a given barrier this effect becomes more important when N_d is small (higher BVs) or when the junction temperature is raised.

The curves of Figure 5 show the comparison between measured and calculated forward I-V characteristics for a BV = 55V Schottky, which is similar to a Unitrode USD545 ($A_J = 0.176\ cm^2$). The dashed line shows the calculated I-V curve assuming a fixed series resistance, that is, no conductivity modulation. Note that there is a significant discrepancy between this and the solid curve at high currents and 125°C.

When there is significant conductivity modulation, most of the current is still carried by electrons. The major effects of hole injection are to reduce the series resistance of the n-layer and to increase the magnitude of recovered charge during turn-off [1], [2]. For these reasons high-voltage Schottky rectifiers (BV $\gtrsim$100V) tend to look more like p-i-n rectifiers than a Schottky. The junction vs. Schottky rectifier trade-off study of Page [3] does not take into account conductivity modulation, and it is probably worthwhile to re-examine some of the conclusions of this paper. For the device designs discussed here, conductivity modulation effects are generally negligible except for the larger values of φ_B at high junction temperatures.

Reverse Current

Figure 6 shows a plot of high-temperature leakage current for a device similar to that of Figure 5. The increase in leakage current with reverse voltage is due to "barrier lowering" or Schottky effect [4], in which the magnitude of $\Delta\varphi$ indicated in Figure 3 increases with V_R.

Barrier lowering effects can be greatly reduced by using an embedded grid of p-type regions under the Schottky to achieve the "pinch rectifier" proposed by Baliga [5]. Unfortunately the dimensions of these p-regions have to be rather small compared to W_n to avoid a severe increase in series resistance that penalizes high-current performance. This means p-regions with lateral metallurgical dimensions of about 1μm or less for the device designs being considered here. Dimensions in this range can be achieved by the more advanced microwave and VLSI technologies, but the cost of using such an approach should be weighed against the fact that the major benefit appears to be a reduction in high temperature leakage current by about two or threefold.

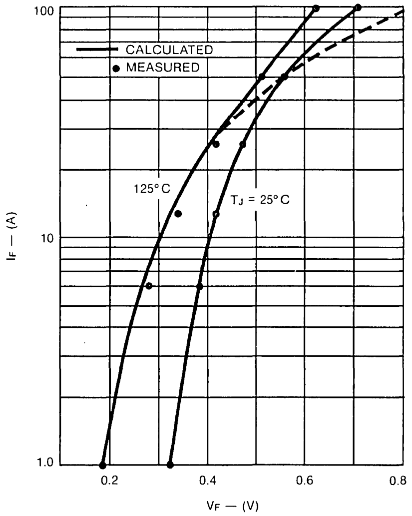


FIGURE 5. COMPARISON OF MEASURED AND CALCULATED FORWARD I-V CHARACTERISTICS FOR A USD545.

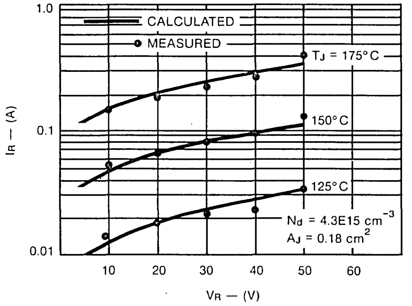


FIGURE 6. REVERSE I-V CHARACTERISTIC FOR A DEVICE SIMILAR TO THAT OF FIGURE 5. φ_B = 0.695V.

Thermal Instability

The major consequence of the temperature dependence of I_R is that the reverse power increases with T_J and at some point the combination of the device and its heat sink become thermally unstable. Some device data sheets reflect this situation by giving a $T_{J\,MAX}$ value, but this number can only approximate the onset of thermal instability.

One way to describe the problem is shown in Figure 7. Here the solid curves represent the power $I_R \cdot V_R$ which will be "generated" by the Schottky junction under reverse bias V_R. The waveforms of Figure 4 are assumed with negligible forward power. The dashed curves are plots of (1) which gives the value of T_J that must occur if P_R is to flow through $R_{\theta JA}$ to some ambient temperature T_A.

If the system is to be stable, the heat sinking system must be capable of removing more power than the junction can generate. That is, the dashed curve must lie above the solid curve for some value of T_J. In the example shown, it can be seen that for a T_A of 75°C, there is no problem with thermal instability for a wide range of $R_{\theta JA}$ values.

The second set of dashed curves shows the situation when T_A is increased to 175°C, which is the T_{JMAX} for the USD545. In this case, $R_{\theta JA}$ must be less than 2°C/W if the system is to be stable. These curves correspond to a φ_B = 0.695V. If φ_B is decreased, for example, to reduce forward power losses, then the solid curves will shift upward. Over the temperature range shown, P_R will double for a decrease of about 22mV in φ_B. Thus if barrier height is to be used as a method of decreasing losses, more effective cooling methods must accompany this change. These tradeoffs are considered in more detail in the next section.

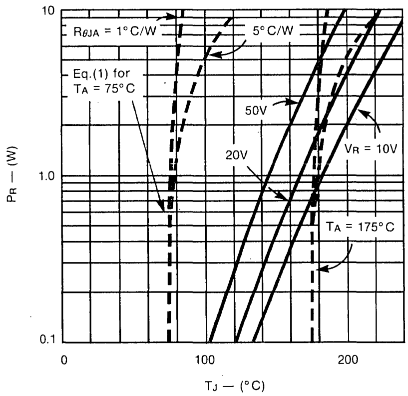


FIGURE 7. REVERSE POWER VS. JUNCTION TEMPERATURE FOR A USD545 (SOLID CURVES). T_J PREDICTED BY (1) FOR DIFFERENT CONDITIONS (DASHED CURVES).

POWER LOSS COMPARISONS

One way to see the benefits and penalties of various changes in the device design is to use the model to calculate total power losses under a variety of conditions. To be strictly correct, the influence of each of the five device variables should be examined separately; however, the problem is simplified by combining W_n, x_j, and N_d into a function which minimizes the series resistance for a given breakdown voltage. A slightly different procedure has been used to analyze a foward converter [6], but the results obtained are in general agreement with the method used here.

P_L vs. $R_{\theta JA}$ Curves

The results of this type of comparison are conveniently displayed as plots of total power lost P_L vs. $R_{\theta JA}$. Various combinations of device variables and input conditions are used to give an accurate picture of the tradeoffs involved.

For the first set of comparisons (Figures 8-13) the following conditions are used:

A_J = 0.176 cm^2, which is the same as for the USD545.

N_d = 1.4E16 cm^3, x_j = 1.1μm, W_n = 1.9 μm, corresponding to a breakdown voltage (BV_1 of Figure 2) of 25V.

This value of breakdown voltage is approximately one-half that of the USD545. The ratio V_R to output voltage V_R/V_O, ignoring any inductive voltage spikes, is typically less than about 5 for a forward converter and 2.5 for a push-pull output. If we consider an output voltage of 2.5V, then a BV of 25V will provide a margin of at least 12V for any inductive spikes. Probably the BV could be reduced even further, and for this reason the tradeoff is considered later in Figure 14. In this connection it should be noted that the guard ring is capable of absorbing inductive spikes, but the corresponding power will contribute to the temperature rise of the Schottky.

Efficiency will depend on the output voltage being considered and can be calculated using

$$\text{Efficiency} = \frac{I \cdot V_O}{I \cdot V_O + 2 \cdot P_L} \qquad (2)$$

Influence of Forward Current

The relation between power loss P_L and forward current is shown in Figure 8, where the waveforms of Figure 3 are assumed. P_L is approximately proportional to I_F, with the change being slightly greater than calculated from this rule due to an additional term which varies logarithmically with current. The slight negative slope of the curves in Figure 8 is due to the decrease in V_F that occurs as T_J increases. For each curve, P_L is calculated as $R_{\theta JA}$ is increased from zero. The plot is terminated when thermal instability is reached.

For the plots of Figures 9-13, I_F is fixed at 100A. Figure 8 can be used to extrapolate most of these results, at least up to the point where a minimum in P_L is reached.

It should also be noted that $R_{\theta JA}$ will always be greater than the junction-to-case thermal resistance $R_{\theta JC}$ For the USD545 which uses a DO-5 package, $R_{\theta JC}$ is about 0.7°C/W. Typical heat sinks are several times this value. If $R_{\theta JA}$ is to approach values less than 1°C/W, liquid cooling must be used.

Influence of T_A

Figures 9 and 10 show how P_L behaves vs. $R_{\theta JA}$ for different ambient temperatures. Points to the right of the minimum in P_L are stable, but there is no advantage in operating in this range. These results show that for a given barrier height there will be a minimum power dissipation that can be achieved.

This minimum can be further reduced by decreasing φ_B as shown in Figure 10; however, ambient temperature must also be reduced significantly in order to avoid thermal instability. That is, approximately 6W could be saved, in this example, by going from a combination of T_A = 75°C/W, $R_{\theta JA}$ = 4°C/W (point 'a') to T_A = 25°C, $R_{\theta JA}$ = 1°C/W (point 'b'). The second pair of numbers would probably require liquid cooling, which is currently used in some mainframe computer designs.

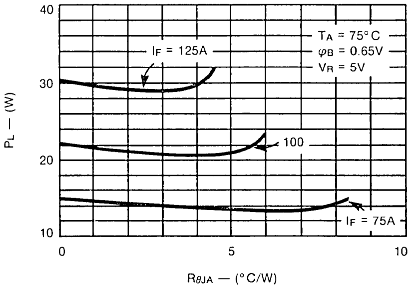


FIGURE 8. POWER LOSS VS. THERMAL RESISTANCE FOR DIFFERENT FORWARD CURRENTS. $A_J = 0.176\ cm^2$.

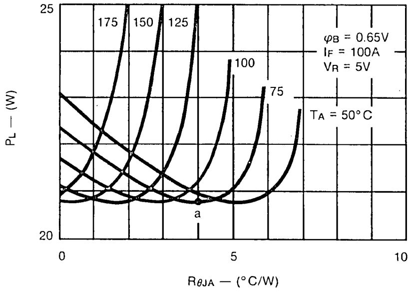


FIGURE 9. POWER LOSS VS. THERMAL RESISTANCE FOR DIFFERENT AMBIENT TEMPERATURES.

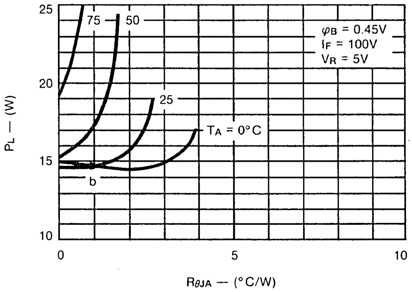


FIGURE 10. SIMILAR TO FIGURE 9, BUT FOR A LOWER BARRIER HEIGHT.

Influence of Barrier Height

Figures 11-13 show power loss curves with φ_B as the parameter for three different values of ambient temperature. These figures provide additional quantitative detail to the arguments advanced in connection with Figures 9 and 10.

Surface mount conditions represent extremes in the other direction. For example, Figure 13 shows that a T_A of 100°C and $R_{\theta JA}$ of 7°C/W can still be accommodated by a Schottky giving a respectable P_L of 21W provided φ_B is increased to 0.75V. In this case, increasing the barrier height is beneficial.

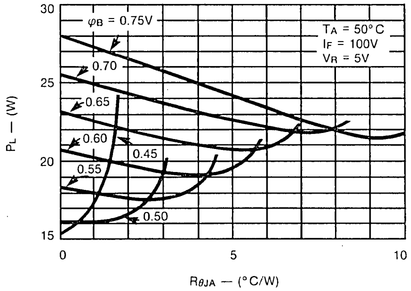


FIGURE 11. POWER LOSS VS. THERMAL RESISTANCE FOR DIFFERENT BARRIER HEIGHTS.

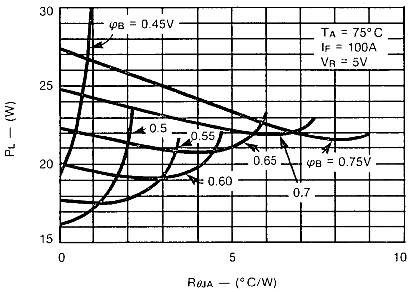


FIGURE 12. SIMILAR TO FIGURE 11, BUT FOR AN AMBIENT TEMPERATURE OF 75°C.

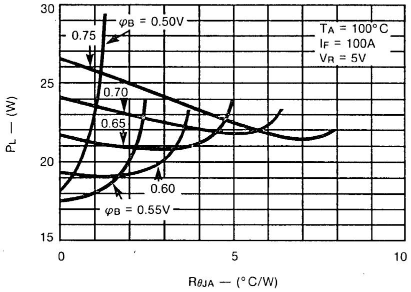


FIGURE 13. SIMILAR TO FIGURE 11, BUT FOR AN AMBIENT TEMPERATURE OF 100°C.

Influence of Breakdown Voltage

It is desirable to minimize the series resistance of the epitaxial layer by keeping the avalanche breakdown voltage BV small. Note that this BV is equivalent to the BV_1 defined in Figure 2. The effect of changing BV on power losses is shown in Figure 14. Two sets of conditions are assumed corresponding to "low" and "high" temperature designs. The device A_J is 0.176 cm^2, the same as the USD545.

For small values of BV, the series resistance of the substrate, backside contact, and package begin to dominate the total. For the USD545 size, these resistances add up to about 0.65 mohm which contributes 3.2W to P_L. As BV increases the epitaxial layer resistance becomes important and P_L shows a strong increase. For BV greater than about 50V, the P_L curves show only small increases. This is because N_d has decreased to a point where conductivity modulation of the n-layer reduces its effective series resistance.

The nominal BV of the USD545 is about 55V. If this is decreased to the 25 to 30V range, Figure 14 indicates that P_L is decreased by about 10W. This is a substantial savings in power dissipation. For the low temperature design, the decrease in P_L is even larger.

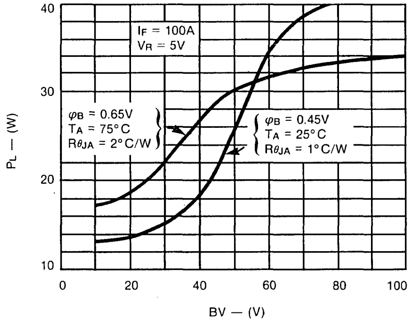


FIGURE 14. POWER LOSS VS. BREAKDOWN VOLTAGE FOR HIGH AND LOW TEMPERATURE DESIGNS.

Influence of Die Size

Increasing the die area will decrease the series resistance and also reduce the voltage drop accross the Schottky junction. Figure 15 shows how the power losses will decrease with increasing A_J. Note that the physical die dimension will be slightly larger than $\sqrt{A_J}$ to account for the guard ring diffusion and other "overhead" dimensions such as the width of saw streets.

Figure 15 shows that some decrease in power losses can be achieved by increasing die area. For small A_J, say less than $10mm^2$, series resistance dominates and rather dramatic improvements can be made by increasing A_J. As A_J becomes comparable to the size of the USD545 ($17.6mm^2$), the V_F becomes dominated by the Schottky junction. For this situation the terminal V_F will change logarithmically with A_J, and an order of magnitude increase in A_J is needed to reduce V_F by 60mV at 25°C.

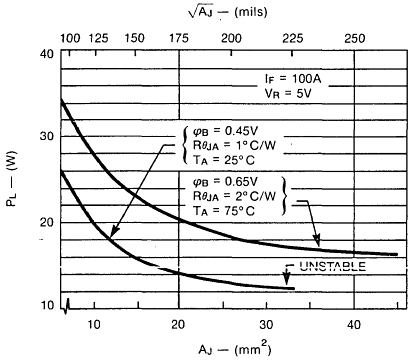


FIGURE 15. POWER LOSS VS. (SCHOTTKY) JUNCTION AREA FOR A HIGH AND LOW TEMPERATURE DESIGN.

LOW V_F DESIGN

Using the results of the analysis given in the previous section, we have developed a new Schottky rectifier which is currently in production. For this design, A_J is increased to $28mm^2$, and BV is decreased to a nominal value of 30V. The power savings over the USD545 represent about a 30 to 40 percent decrease in power losses, depending on the forward current and other operating conditions.

Figure 16 shows the typical forward characteristic for the new design. As one might expect, there is little influence of conductivity modulation.

The difference in P_L values comparing the new design with the USD545 is the power saved ΔP. A plot of ΔP vs. forward current is shown in Figure 17. As defined here, ΔP is per device and therefore the total power saved in the output rectifier circuit will be 2ΔP. For the plot of Figure 17, V_R is 5V, and two values of thermal resistance have been assumed.

It can be seen that the curve increases more strongly than linearly with I_F which indicates that the series resistance is important. At large values of I_F, reverse power becomes important and the curve tends to bend over as shown.

DISCUSSION

Although the Schottky rectifier has many strong points for low-voltage output applications, other approaches are of interest. For example, MOSFET synchronous rectifiers have received a great deal of attention in the technical literature. More recently it has been demonstrated that a bipolar transistor may be a better choice for this application [7].

The possibility of using germanium rectifiers should also be considered (8). Low V_F junction diodes are possible in this material, but it is more limited in temperature and has lower breakdown fields than for silicon. The comparison of this type of rectifier with a silicon Schottky is an interesting topic which deserves further study.

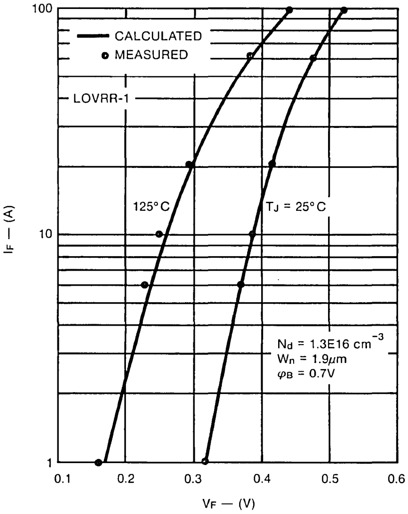


FIGURE 16. FORWARD I-V CHARACTERISTIC FOR A NEW LOW V_F DESIGN.

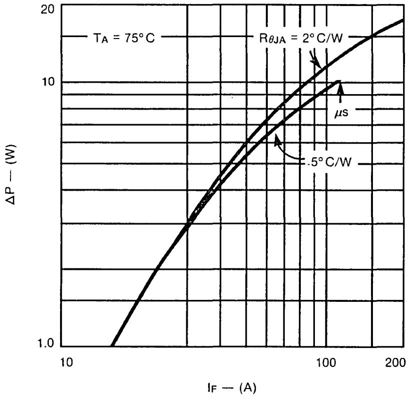


FIGURE 17. POWER SAVED (PER DEVICE) COMPARING A USD545 VS. THE NEW DESIGN.

Comparison with Bipolar Synchronous Rectifiers

Synchronous rectifiers are of interest because their I-V characteristic is linear down to zero volts, unlike the Schottky or p-n junction which have an apparent "offset" voltage. Offsetting this advantage is the need for a more complicated circuit, including additional components and transformer windings. The UBS430 BISYN™ bipolar transistor has a relatively low on-resistance of about 7mΩ, which is the smallest value obtainable for any commercial device in a TO-3 package. This resistance is still relatively large when compared with the series resistance of a Schottky, which is typically in the range of 1 to 2mΩ.

This means that the BISYN will have smaller power losses up to some current which is approximately equal to I_X, the current where the forward characteristics intersect (7). For the UBS430, I_X is in the range of 40 to 60A.

Figure 18 shows a plot of ΔP (per device), where the bipolar is compared against two different Schottky rectifiers, the USD545, and the new lower BV design described in this paper. The curves reach a peak at approximately $I_X/2$. As noted previously, the total power saved in the output circuit is 2ΔP.

Our view is that the present BISYN designs offer a useful alternative for currents less than approximately 30A, but it will take a new packaging approach to bring the synchronous rectifier to the point where it can compete with the Schottky at currents in the 60 to 200A range.

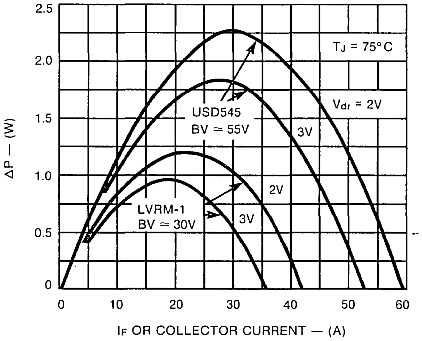


FIGURE 18. POWER SAVED (PER DEVICE) COMPARING THE UBS430 BISYN™ BIPOLAR WITH A USD545 AND THE NEW LOW V_F SCHOTTKY.

CONCLUSION

The new Schottky rectifier design described in this paper represents the next logical extension that can be made from the present designs. Power loss savings are in the 30 to 40 percent range. Other alternatives for decreasing power losses require a new choice for barrier material and the accompanying considerations of cooling requirements. Attainable reductions in power losses have been estimated. With these results it is believed that device users will be able to determine various benefits and penalties as they consider new circuit applications.

REFERENCES

[1] Y. Amemiya and Y. Mizushima, "Bipolar-mode Schottky contact and applications to high-speed diodes,". IEEE Trans. on Elec. Dev., v. ED-31, pp. 35-42, Jan. 1984.

[2] B. Carsten, "Reverse recovery characteristics of high speed rectifiers," Powerconversion and Intelligent Motion, v. 12, pp. 42-48, Feb. 1986.

[3] D.J. Page, "Theoretical performance of the Schottky barrier power rectifier," Solid-State Elect., v. 15, pp. 505-515, 1972.

[4] S.M. Sze, *Physics of Semiconductor Devices*, 2nd Ed., pp. 250-254, John Wiley, 1981.

[5] B.J. Baliga, "The pinch rectifier: A low-forward-drop high-speed power diode," IEEE Elec. Dev. Ltrs., v. EDL-5, pp. 194-196, June 1984.

[6] T. Kawakami, Y. Amemiya, Y. Mizushima, "Schottky diode design for low-voltage rectification," Solid-State Elec., v. 28, pp. 885-891, Sep. 1985.

[7] P.L. Hower, G.M. Kepler, and R. Patel, "Design, performance, and application of a new bipolar synchronous rectifier, Proc. IEEE Power Electronics Specialists Conf. 1985, pp. 247-256.

[8] R. Kassiotis, "Why not germanium?," Powertechnics, v. 1, p. 13, Nov. 1985.

DETERMINING THE CHANGE IN ZENER VOLTAGE WHEN THE CURRENT IS CHANGED

A common question concerning zener diodes is "what will be the zener voltage at a current different from the current now specified?"

The difficulty is that the impedance of a zener is not a constant, and changes with the current, so the zener voltage is a non-linear function of current.

Here is a useful equation that gives a good approximation to the change in zener voltage when the current is changed from one value to another value.

$$\Delta V_Z \doteqdot k_Z \ln\left(\frac{I_2}{I_1}\right)$$

where $k_Z = I_Z \times Z_Z$ and I_Z is chosen approximately midway between I_1 and I_2

The equation does not include the effect of pulse or dc-heating on the zener voltage. If appreciable junction heating is involved the thermal model must also be used.

Here is an example of how the equation is used.

Question: If the voltage of a UZ5733 is specified as 33V at 40mA, what will be its voltage when measured at 5mA?

Using the graph of Z_Z versus I_Z on the data sheet for this device, and choosing a value of I_Z at 20mA,

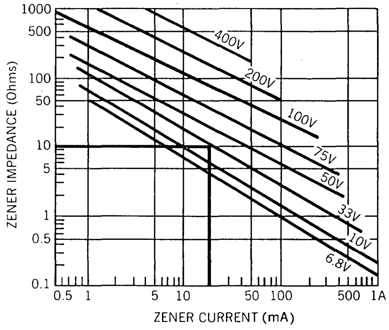
$Z_Z = 10\Omega$

So $k_Z = I_Z \times Z_Z = 20\text{mA} \times 10\Omega = 0.20\text{V}$

$$\Delta V_Z \doteqdot k_Z \ln\left(\frac{I_2}{I_1}\right) = 0.20 \times \ln\left(\frac{5\text{mA}}{40\text{mA}}\right) = 0.20 \times \ln(0.125) = 0.20\text{V}\,(-2.08) = -0.42\text{V}$$

Thus the zener voltage at 5mA will be 33V — 0.42V = 32.6V

UZ5706 Series
Typical Zener Impedance
vs Zener Current

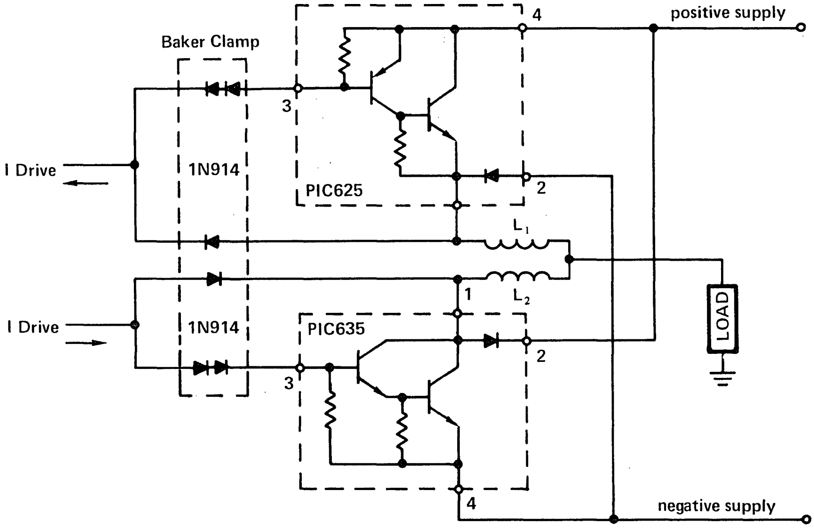


MINIMIZING STORAGE TIME WHEN USING UNITRODE SWITCHING REGULATOR POWER OUTPUT CIRCUITS (PIC600 SERIES)

In some applications (such as a reversing motor drive, for example: stepper motor) where storage time is an important consideration in the design, the normal storage time of PIC600 series (approximately 600ns) can be reduced to acceptable level.

At lower output currents, the excess storage time is a result of the driver stage operating well under saturation, while at higher output currents it is a result of the output transistor operating into quasi-saturation region.

The storage time can be reduced to less than 100ns by utilizing a Baker Clamp technique as shown in the circuit below:



The Baker Clamp will increase the $V_{CE(sat)}$ losses but this disadvantage will be more than offset by the improved switching speed.

The Baker Clamp circuit varies the drive current of the PIC600 series for optimum switching speed at any given load current. The drive current required to the Baker Clamp can be unregulated, as long as it is greater than 30mA.

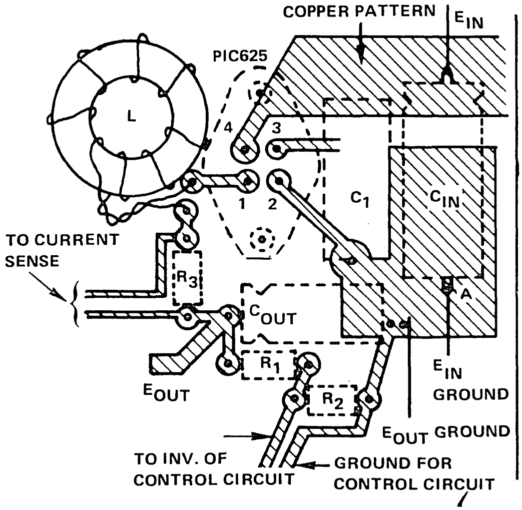
The small value of the inductor L_1 and L_2 (5 to 10 μH) stops cross conduction during the switching of PIC600 series.

AVOIDING SPURIOUS OSCILLATION WHEN USING UNITRODE SWITCHING REGULATOR POWER OUTPUT CIRCUITS (PIC600 SERIES)

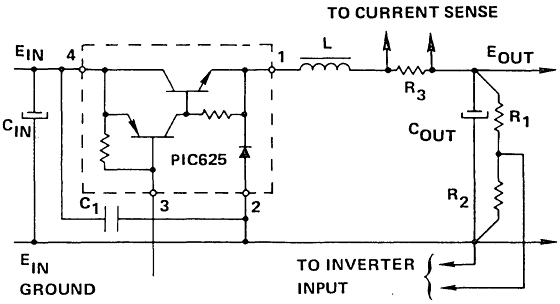
Avoid spurious oscillation due to ground loops and RFI when using a Unitrode Switching Regulator Power Output Circuit (PIC600 Series) in a switching regulator.

The Unitrode switching regulator power output stage (PIC600 Series) is a high frequency fast switching device. Its control circuitry must also operate at high frequency and high gain. Therefore, it is necessary to avoid any ground loops and RFI for stable circuit operation.

The high frequency roll-off of the control circuit should be adjusted properly with a compensation network. The typical layout of the power circuit is shown in the figure below.



PC BOARD LAYOUT OF POWER CIRCUIT



CIRCUIT DIAGRAM

Capacitor C_1 (0.2 μf) reduces the RFI generated due to the reverse recovery current spike of the catch diode, and should be physically located near pin 4 and pin 2 of the PIC625. The capacitor should be a high frequency by-pass capacitor, such as Polystyrene.

The current sense resistor R_3 should be a non-inductive (carbon) type. The current sense signal should be picked up right across this resistor.

If the switching regulator is operated at the higher end of the input voltage, the inductor should be shielded with an electrostatic shield, grounded to Point A. The case of PIC625 should also be connected to Point A.

OPERATING THE SWITCHING REGULATOR OUTPUT CIRCUIT (PIC600 SERIES) AT LOW FREQUENCIES

The Unitrode switching regulator power output circuit consists basically of a power transistor switch and a catch diode. The appropriate data sheets in the Unitrode Semiconductor Databook provide the necessary information for determining junction temperature and power dissipation at frequencies above 10 kHz.

This Design Note provides a method for determining the junction temperature and maximum allowable power dissipation for the transistor switch and catch diode when the switching regulator is operated at frequencies under 10 kHz, where the switching losses are negligible and can be safely ignored.

The method of determining safe power dissipation requires a detailed transient thermal analysis, since the junctions of the transistor and diode are subjected to temperature excursions due to the applied pulse power.

When the device is subjected to a train of periodical power pulses, the maximum power dissipation and junction temperature can be calculated from the effective pulse thermal resistance (θ_p) as follows:

$$\theta_p = R_T \times D + (1-D)\ r(t+\tau) - r(\tau) + r(t)$$

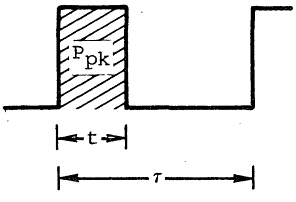


Figure 1. Power Pulses

where: t = pulse width

τ = period

Duty cycle $D = \frac{t}{\tau}$

Peak Power, P_{pk} is peak of an equivalent square power pulse

$r(t+\tau)$ = transient resistance at time $t+\tau$

$r(t)$ = transient thermal resistance at time t

R_T = DC thermal resistance (from data sheets)

SEMICONDUCTOR PRODUCTS
UNITRODE

1. Calculating the Junction Temperatures (Pulse Train)

A. Power Transistor Switch

The peak junction temperature of the transistor switch under repetitive peak power pulse conditions is calculated as follows:

$$T_{j(peak)} = T_{CASE} + P_{pk} \times \theta_p$$

$$T_{j(peak)} = T_{CASE} + V_{CE} \times I_C \times \left[R_T \frac{t_T}{\tau} + \left(1 - \frac{t_T}{\tau}\right) x\ r(t_T + \tau) - r(\tau) + r(t_T) \right]$$

The transient thermal impedances $r(t_T + \tau)$, $r(\tau)$, $r(t_T)$ are obtained from the transient thermal impedance plot for the transistor (see Figure 2),

t_T = transistor on-time

B. Catch Diode

The peak junction temperature of the catch diode under repetitive peak power pulse condition is calculated as follows:

$$T_{j(peak)} = T_{CASE} + I_F \times V_F \left[R_T \times \frac{t_D}{\tau} + \left(1 - \frac{t_D}{\tau}\right) r(t_D + \tau) - r(\tau) + r(t_D) \right]$$

12

where:

t_D = diode on-time

The Transient thermal impedances $r(t_D + \tau)$, $r(\tau)$, $r(t_D)$, are obtained from the transient thermal impedance plot for the catch diode (see Figure 2).

C. Power Dissipation

The maximum allowable power dissipation in either the transistor or the diode is determined by the maximum junction temperature of 150°C:

$$P_{pk(max)} = \frac{150°C - T_{CASE}}{\theta_P}$$

2. Calculating the Junction Temperature (Single Shot Power Pulse)

For a non-repetitive power pulse, the rise of junction temperature can be calculated as follows:

$$T_j = P_{pk} \times r(t) + T_{CASE}$$

For a pulse with less than 100 millisec, the case temperature is assumed to remain at ambient temperature.

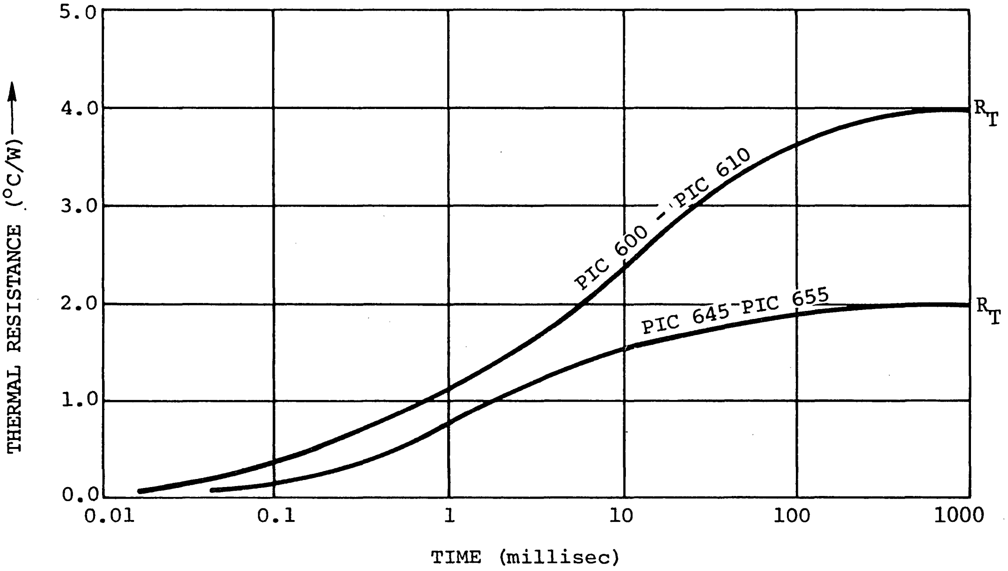


Figure 2. Transient Thermal Resistance — Power Transistor or Catch Diode

SQUIB-FIRING CIRCUIT PROVIDES FOR RELIABLE FIRING, FROM LOW LEVEL INPUTS

The design of reliable squib-firing circuitry often presents particular problems. Squib functions are typically quite critical, and the initial triggering source for these systems is, by nature, usually minute.

Conventional transistor squib-firing circuits usually require several gain stages, together with a power transistor to handle the squib-firing current. Mechanical squib switches, on the other hand, cannot be operated repetitively to allow for complete testing of the device and associated circuitry during check-out.

The high sensitivity planar Silicon Controlled Rectifier (SCR) can be triggered directly from low-level input circuitry, with significant reduction in circuit complexity and size. Reliability is thus considerably enhanced.

The unique characteristics of the planar SCR have resulted in wide usage of this semiconductor component in squib-firing circuits for rocket engine ignition, detonation, and explosive bolt applications. Compared with conventional transistor techniques or mechanical squib switches, this proven approach has significant reliability advantages, with circuit simplicity, size reduction, mechanical ruggedness and elimination of electrical contacts.

An SCR, with surge current ratings at 100 °C of 5 amperes-50 milliseconds or 20 amperes-1 millisecond can easily handle the current required for firing most squibs. Input circuits can be designed to trigger reliably at levels below 100 microamperes and 1.0 Volt, making the SCR particularly well-suited for direct drive from low level control logic circuits and simple RC time delay networks. In addition, the bistable properties of the SCR enable it to be triggered on by a pulse input—remaining in the "ON" state until reset. This inherent "memory" is frequently used to advantage in arming circuits.

Two circuits typical of squib firing applications are shown in Figures 1 and 2. Both will operate from −65 °C to over 125 °C.

In Figure 1, Capacitor C_1 is charged to +28 Volts through R_1 and stores energy for firing the squib. A positive pulse of 1 mA applied to the gate of SCR_1 will cause it to conduct, discharging C_1 into the squib load X_1. With the load in the cathode circuit, the cathode rises immediately to +28 Volts as soon as the SCR is triggered on. Diode D_1 decouples the gate from the gate trigger source, allowing the gate to rise in potential along with the cathode so that the negative gate-to-cathode voltage rating is not exceeded. This circuit will reset itself after test firing, since the available current through R_1 is less than the holding current of the SCR. After C_1 has been discharged, the SCR automatically turns off—allowing C_1 to recharge.

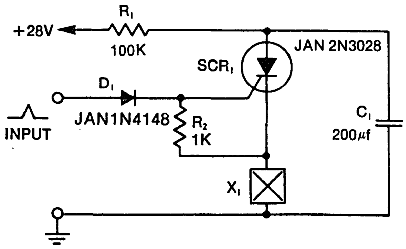


FIGURE 1

In Figure 2, energy for firing the squib is supplied directly from the +28 Volt supply. Caution must be exercised when arming this type of circuit. If anode voltage is applied too rapidly, the SCR may fire. This dv/dt effect acts through the SCR anode-gate capacitance (15 pf), which couples current to the SCR gate (in proportion to anode dv/dt). The effect is negligible if dv/dt is under 1 Volt/μs—as in Figure 1, where it is limited by the charging of C_1. Faster rates of rise can be safely handled by increasing the SCR gate bias.

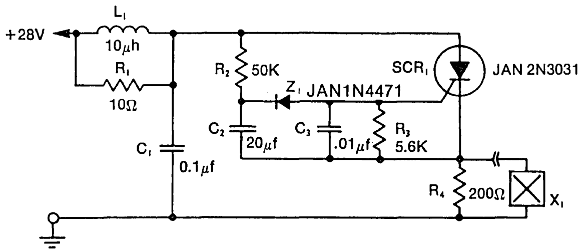


FIGURE 2

In Figure 2, the LRC input network limits the anode dv/dt to a safe value—below 30 Volts/μs. R_1 provides critical damping to prevent voltage overshoot. While a simple RC filter section could be used, the high current required by the squib would dictate a small value of resistance and a much larger capacitor. Resistor R_3 provides DC bias stabilization, while C_3 provides stiff gate bias during the transient interval when anode voltage is applied.

In this circuit the SCR is fired one second after arming by means of the simple R_2 C_2 Z_1 time delay network. R_4 provides a load for the SCR for testing the circuit with the squib disconnected—limiting the current to a level well within the continuous rating of the SCR. The circuit can be reset by opening the +28 Volt supply and then re-arming.

NANOSECOND SCR SWITCH FOR RELIABLE HIGH CURRENT PULSE GENERATORS AND MODULATORS

The design of reliable modulator and pulse generator circuitry often presents the design engineer with seemingly conflicting requirements. In order to obtain fast rise times, "hard tubes" or hydrogen thyratrons are often used. This results in a large system which consumes considerable power and has relatively low conversion efficiency. Reliability, jitter, and stability are also common problems in these systems.

To improve reliability, as well as decrease standby power consumption and improve conversion efficiency, semiconductor devices are a natural choice. However, at the voltage and current levels most often encountered in these applications, conventional semiconductors are usually too slow.

The nanosecond SCR switch developed by Unitrode allows the designer to upgrade high current, high voltage modulator and pulse generator circuitry. A single device (GA201 or GA301*) is capable of operating in circuits with supply voltages up to 100 Volts DC and pulsed load currents in excess of 50 Amperes. It can be triggered directly from logic level signals (1 Volt, 200 microamps) and exhibits a rise time of less than 10 nanoseconds to 1 Ampere with only 10 milliamps of drive signal. Single switches operated in this mode can be used as high current replacements for avalanche transistors, modulators, and harmonic wave form generators.

Special circuity has been developed to apply these nanosecond switches in applications where supply voltages exceed the forward blocking capability of a single device. The simplest of these is shown in Figure 1.

The 1 meg-ohm resistors act as a voltage-sharing network to insure that no single device is overvoltaged because of unequal leakage currents. Turn-on is accomplished by applying a trigger signal to the primary of the pulse transformer, T1. The capacitor, which has been charged to the supply voltage through R_C, discharges through R_L, and the string of SCRs. This circuit is useful until the number of stages used requires a pulse transformer that becomes objectionably bulky. Beyond that point the circuit of Figure 2 or 3 is used.

Figure 2 illustrates an approach that uses a pulse transformer to trigger only part of the string, while the rest of the devices in the string are supplied with gate drive through the zener diodes. With a supply voltage of 360 Volts DC, a 95 Volt ±5% zener diode across each SCR in the string prevents unequal voltage distribution. When SCR_3 and SCR_4 are triggered, 360 Volts appear across SCR_1 and SCR_2 causing zener diodes Z_1 and Z_2 to conduct. Since D_1 and D_2 are back-biased, the current must flow through the gate-to-cathode junctions of SCR_1 and SCR_2, thus driving them on. Up to eight stages can be stacked in this manner using a pulse transformer to drive only the bottom two SCRs in the string. Driving three SCRs with a pulse transformer allows stacking sixteen stages, which can switch a 1440 Volt load using a pulse transformer that needs to have a dielectric isolation rating of less than 300 Volts.

Figure 3 uses no pulse transformer and can be extended to virtually any number of stages. When SCR_1 is triggered, the cathode of SCR_2 drops from +100 to essentially 0 Volts. Capacitor C_1 discharges into the gate of SCR_2 causing it to conduct, and this process is repeated for SCR_3 and SCR_4. This circuit has the added feature of providing negative bias to the SCRs during recharge of the load in order to minimize the effect of dv/dt. As the voltage rises on the anode of SCR_4, current flows through the path consisting of C_4, R_4, C_3, R_3, C_2, R_2, etc. This provides negative bias for the gate-to-cathode junctions of the SCR in the string, making them less sensitive to dv/dt triggering. This allows the use of rapid recharge circuits which permits operation at higher repetition rates. Either resonant recharge or active (SCR) rapid recharge techniques may be used with these circuits.

*GA201 recommended for military, GA301 for commercial applications.

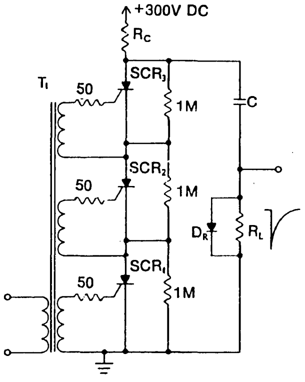


FIGURE 1

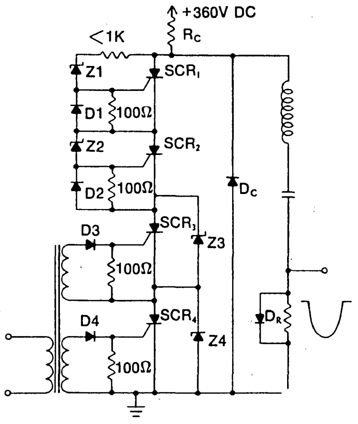


FIGURE 2

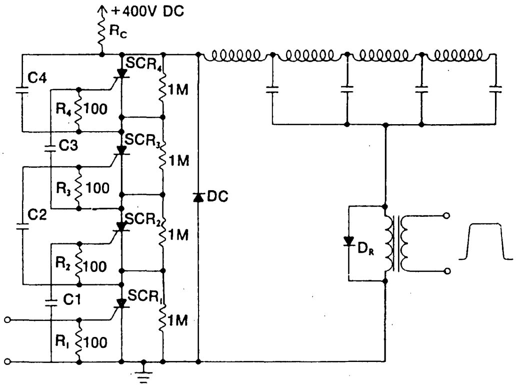


FIGURE 3

If the energy storage element(s) and load consist only of R and C components, the charging resistor must be large enough to limit the DC current to a value less than the minimum holding current of the SCRs in the string. When the load contains an inductive component, as is usually the case in modulator circuits, the network can be designed to "ring" in order to reverse-bias the SCR string momentarily, permitting the SCRs to regain their forward blocking capability even though R_C allows more than the minimum holding current to flow. Diode D_R may be used in all circuits so that the recharge current will not flow through the output element. In Figures 2 and 3, D_R shunts the reverse "ringing" current around the output element. Diode D_C must be used in circuits that contain inductive elements to protect the string from being excessively back-biased due to circuit ringing.

DESIGN NOTE DN-15

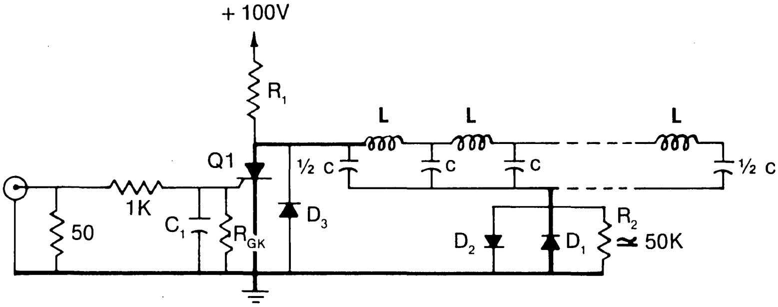
NANOSECOND SCR FOR LASER DIODE PULSE DRIVER

The use of pulsed gallium-arsenide lasers requires a reliable high speed, high current switch to drive these devices. In the past the only solid state devices that could be used in this application were avalanche transistors and fast medium power transistors. Avalanche transistors presented reliability problems, while the standard medium power transistors available were too slow. The GA200 series "Nanosecond SCR" with a rise time capability of 10 nsec to 1 Amp or 20 nsec to 30 Amps provides a solution to both the reliability and the speed problems and appears to be ideal for this type of application.

The circuit shown in Figure 1 utilizes a GA201 device along with a lumped constant delay line to generate the desired square current pulse. For simplicity, a single capacitor could be used instead of the delay line. The delay line, however, has the advantage of producing a square pulse that provides sharp turn-off, which limits the excess power dissipation that would occur in the laser diode if the pulse fell exponentially. The impedance of the delay line ($= \sqrt{L/C}$) is chosen to produce a slight mismatch, which produces overshoot on the trailing edge of the pulse. This overshoot acts as a reverse bias on the anode of the SCR, assisting in turning it off. A typical value for the delay line impedance would be 1 to 2 ohms, which approximates the impedance of the load formed by the SCR and laser diode in series. The time duration of the pulse ($= \sqrt{L/C}$ per section) can be made as short as desired with a value of 50 to 100 nsec being typical.

With the SCR in the off state, the delay line will charge to the supply voltage (100 Volts with GA201). A gate current at the input of as little as 200 μA will trigger the SCR. The delay line will then discharge, producing a square current pulse through the gallium-arsenide laser diode. R_1 and R_{GK} are chosen so that the current, after the delay line discharges, will be less than the holding current of the GA201 (= 3 mA with R_{GK} = 100 ohms.) C_1 should be about .001μf and is necessary to prevent false triggering through noise or through dv/dt commutation. D_2 provides a charging path for the delay line, while $R_2 \cong 50K$ provides a stable ground reference. Diode D_3 insures that the reverse breakover voltage of the GA201 will not be exceeded during the turn-off period.

The forward current level will depend upon the total impedance of the GA201 and the laser diode and the charging voltage used. With a 100 Volt device and a practical minimum circuit impedance of about 1 ohm, it is possible to develop peak currents of up to 100 Amps. (See Figure 2 for Time vs Current curve for GA200/CB200 Series.) Pulse of 60 Amps with rise times of approximately 30 nsec have actually been achieved. For improved performance at high current levels, the SCRs may be operated in parallel or in series. Parallel operation is achieved by providing equal series resistors to the gates of the devices and driving them from the same source. By overdriving the gates with 50 to 100 mA, simultaneous turn-on is guaranteed. Parallel operation results in lower forward voltage drop and faster rise time at high current levels. Series stringing techniques can be used in circuits with a higher total impedance where higher voltages are needed to obtain the desired current levels. For a description of series operation see Design Note 14.



Q1—GA201/GB201, GA301/GB301

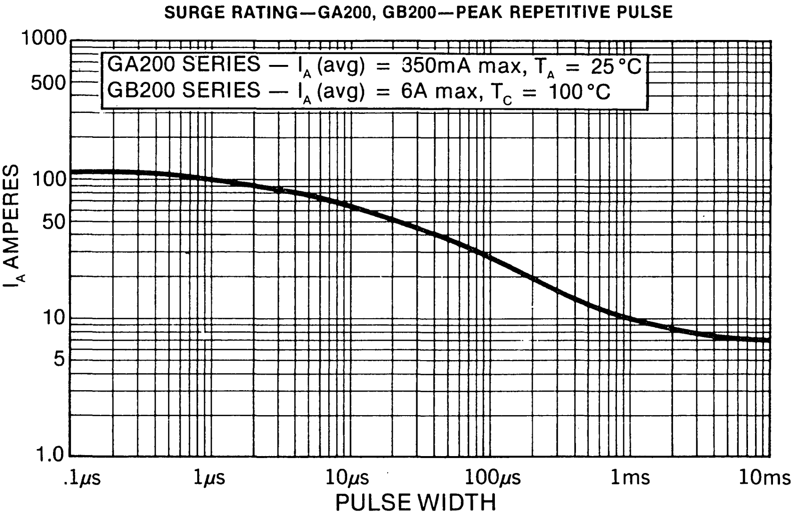
D_1 —Gallium-Arsenide Laser Diode

D_2 —JAN 1N5802 or 1N5807* (Alternative: UES1101 or UES1301)

D_3 —JAN 1N5804 or 1N5809* (Alternative: UES1102 or UES1302)

Note: Heavy lines indicate braided connections for reduced inductance and resistance.

Figure 1



Note: For MIL and high Rel series applications, use GA/GB 200/201 and JAN Diodes.

For high rep rate (high average current), use GB series with 1N5809 or UES1302 rectifiers.

GA300 and UES series are intended for commercial applications.

Figure 2

NEW HIGH EFFICIENCY CIRCUIT DESIGNS UTILIZING LOW SATURATION DROP TRANSISTOR

The new UBT430 transistor with $V_{CE(sat)}$ drops of .10V at 10A, 3V at 3A gives the circuit design engineer the opportunity to develop new circuits with greatly enhanced efficiency. This design note describes some of these circuits in detail.

High Efficiency Battery Back-up System

The circuit shown in Figure 1 is a high efficiency battery back-up system. Since the UBT430 has low saturation drop (with a high gain) the power dissipation in the control switch circuit is reduced by 40-50% when compared with low forward drop of a Schottky rectifier.

The voltage sense circuit monitors the line voltage and output voltage. When the voltage drops below a pre-determined value, transistor Q_2 turns on and drives the control switch Q_1. At an output current of 20A, the power dissipation in the transistor switch Q_1 is only 3W while an equivalent Schottky rectifier will dissipate about 8.6W.

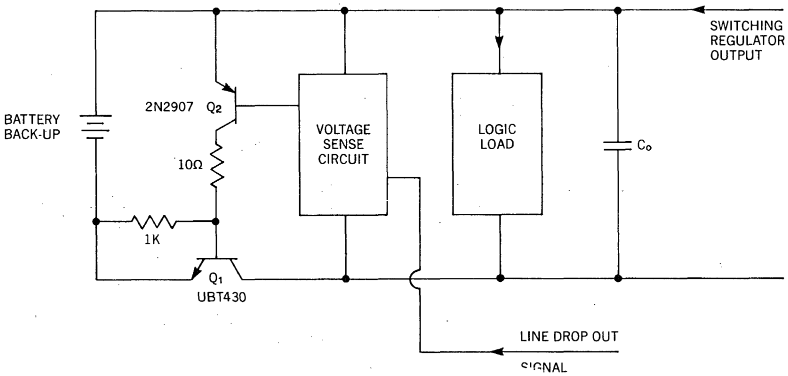


FIGURE 1. HIGH EFFICIENCY BATTERY BACK-UP SYSTEM

Current-Mode Controlled 50W High Efficiency Switching Regulator

The circuit shown in Figure 2 is a low cost, current-mode controlled 50W, high efficiency switching regulator. This circuit utilizes the 8 Pin UC3843 current-mode control chip. The totem-pole output of the UC3843 delivers 250mA of drive current to output switch Q_2.
switch 10A with a $V_{CE(sat)}$ of less than 80mV. The fast turn-off times (<400ns) are achieved through a speed-up capacitor C_4. With a 5V output an efficiency of better than 80% can be realized. The UC3843 is designed for low voltage applications with an under-voltage lockout feature. The use of current-mode control removes one of the poles from the control loop making loop compensation easier. Current-mode control also provides small signal voltage feed forward characteristics, which reduces the gain requirement of the error amplifier.

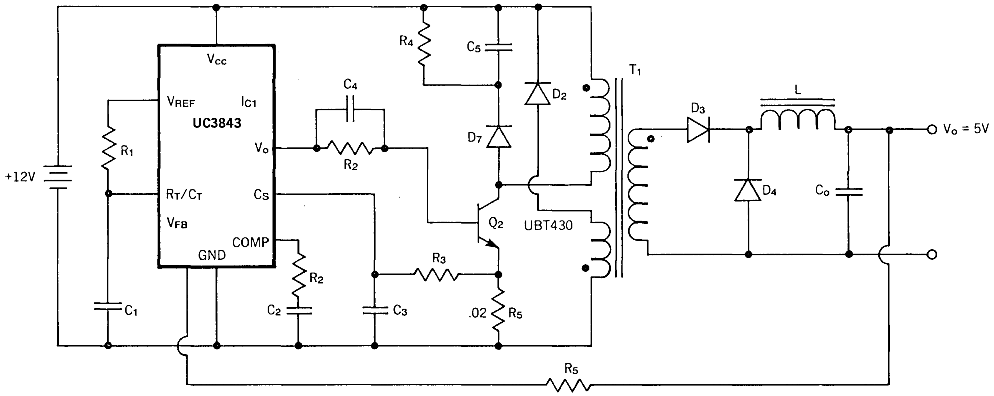


FIGURE 2. CURRENT-MODE CONTROLLED 50W HIGH EFFICIENCY SWITCHING REGULATOR

High Efficiency Emitter Control Switch

The circuit shown in Figure 3 is an emitter controlled switch. Transistor Q_2 (UBT430) is controlled with a totem-pole output switch of control chip UC3843. The power loss in the emitter control switch is an order of magnitude less than high voltage switch Q_1. The turn-off time of high voltage switch Q_1 is extremely fast because the negative base drive current is equal to collector current. The zener diode D_2 clamps the voltage across the base and provides a path for negative base drive current. The initial turn-on current is delivered from capacitors C_1 and C_2 and then is supplemented by winding N_2 through resistor R_2.

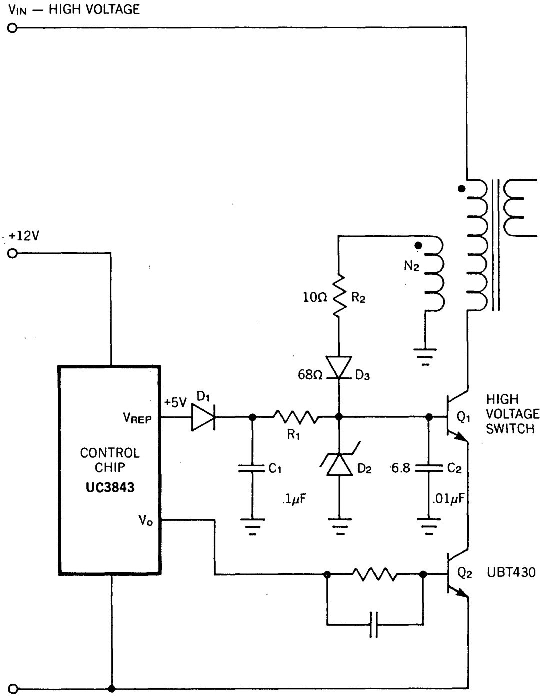


FIGURE 3. EMITTER CONTROL SWITCH

250 WATT OFF-LINE FORWARD CONVERTER DESIGN REVIEW

by

Raoji Patel

This paper gives a practical example of the design of an off-line switching power supply with forward converter topology. Topics include transformer and filter inductor design, proportional base drive, component selection, output filter design, and closing the control loop using the new Unitrode UC1524A control circuit.

POWER SUPPLY SPECIFICATIONS:

TOPOLOGY:	Forward Converter with Proportional Base Drive	
LINE INPUT:	117 Volts +/- 15% (99-135V), 60Hz	
	230 Volts +/- 15% (195-265V), 50Hz	
OUTPUT:	Voltage:	5 Volts
	Current:	5 to 50 Amperes
	Current Limit:	60 Amperes Short Circuit
	Ripple Voltage:	100mV p-p maximum
	Line Regulation:	+/- 1%
	Load Regulation:	+/- 1%
OTHER FEATURES:	Efficiency:	75%
	Line Isolation:	3750 Volts
	Switching Frequency:	40KHz

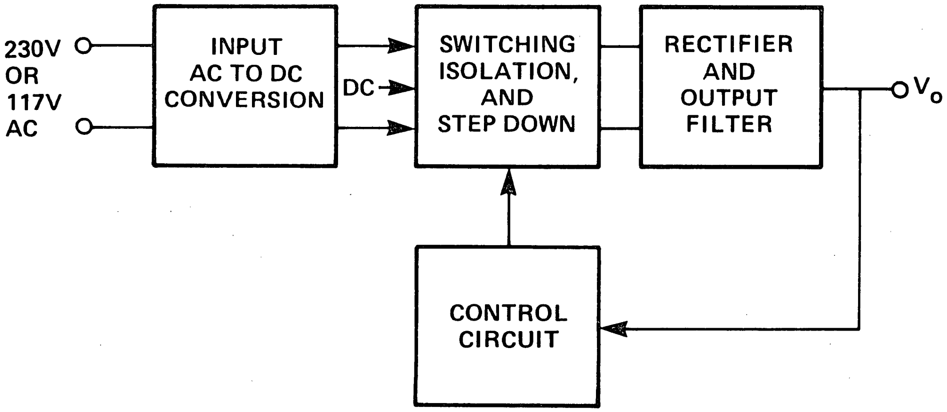


Figure 1. Block Diagram of the Switching Power Supply

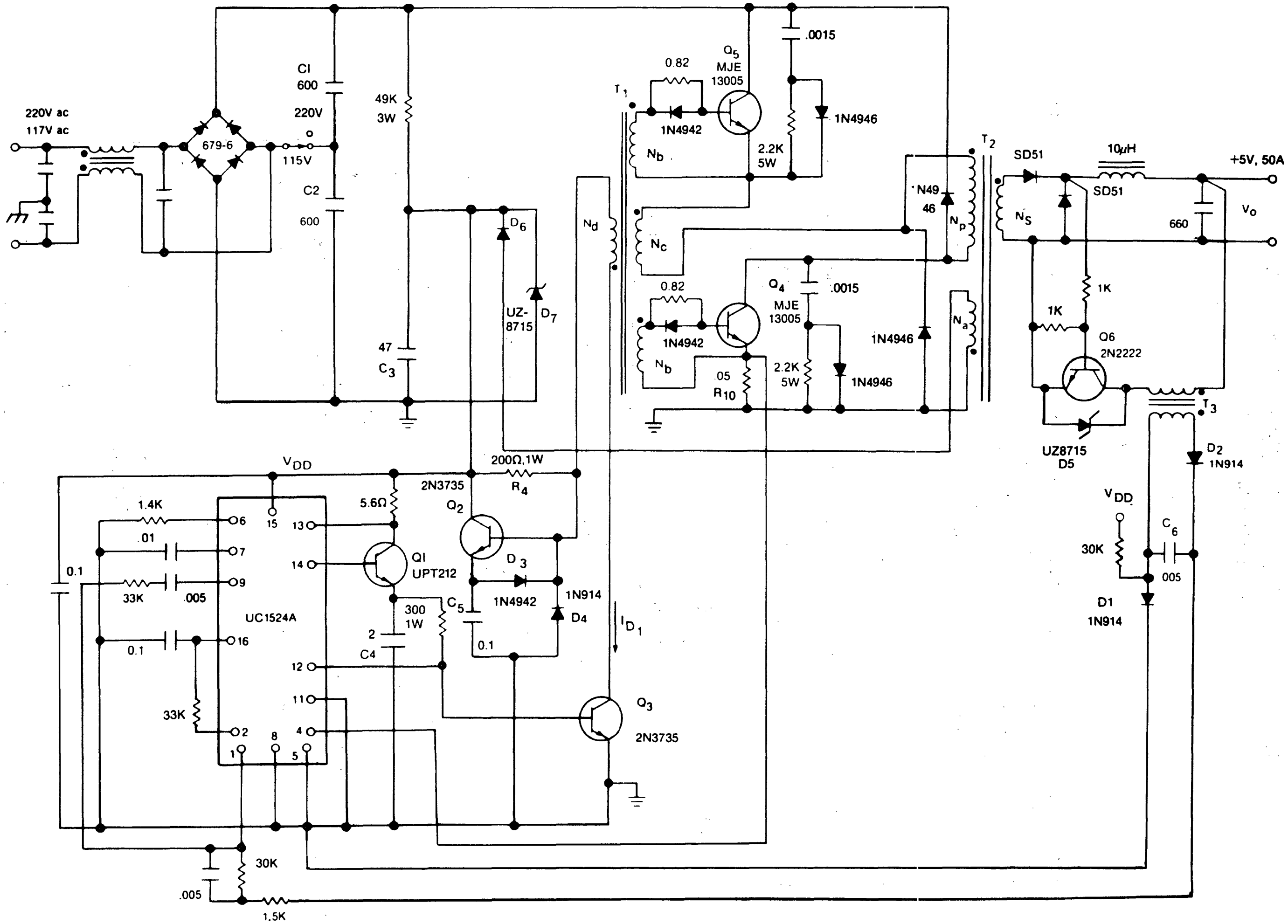


Figure 2. Complete 250 Watt Switching Power Supply

THE COMPLETE POWER SUPPLY CIRCUIT

The complete 250 watt switching power supply schematic is given in Figure 2. This supply meets all of the specification requirements defined on page 1.

LINE INPUT AC TO DC CONVERSION

The input rectifier/filter section converts the AC line voltage into a crudely filtered and unregulated DC voltage, V_{in}, which powers the downstream switching regulator. The input section is configured as a full-wave bridge when operating from the 230 volt line, and as a voltage doubler when operated from 117 volts. This provides approximately the same V_{in} range (200-380 volts) for the switching regulator with either line voltage. Minimum input voltage, V_{min}, is 200 volts at low line.

The design of the input section is covered extensively in Section I1 of the Design Reference Addenda at the end of this book. The power input required in this application equals power output (250W) divided by efficiency (75%), or 333 watts. Circuit values for this application can be obtained by multiplying the 100 watt input values given in Table I of Section I1 by $P_{in}/100 = 3.33$, using the worst case voltage doubler configuration:

$$C_1 = C_2 = 3.33(160) = 533\ \mu F \quad (\text{use } 600\ \mu F) \tag{1}$$

$$I_{chg} = 3.33(1.126) = 3.75 \text{ Amps RMS AC} \tag{2}$$

The switching regulator draws 40 KHz rectangular current pulses which discharge the input capacitors. Peak discharge current, i_{dis}, occurs at Vmin when the duty cycle, D, is maximum (50%):

$$i_{dis} = Pin/(VminD) = 333/(200\ .5) = 3.33 \text{ A peak} \tag{3}$$

The RMS AC component of the discharge current, I_{dis}, which flows through the input capacitors at worst case 50% duty cycle is:

$$Idis = (idis)/2 = 3.33/2 = 1.67 \text{ Amps RMS AC} \tag{4}$$

The total RMS AC current rating required for the input capacitors is calculated from Equation 8 of Section I1:

$$ICAP = \sqrt{Ichg^2 + Idis^2} = \sqrt{3.752 + 1.67^2} \tag{5}$$

SWITCHING CIRCUIT TOPOLOGY

The two transistor forward converter configuration shown in Figure 3 was used in this 250 watt switching power supply for the following reasons:

1. Transistor voltage ratings are half the voltage required in a comparable single transistor circuit (400V vs. 800V). Only 1/4 the silicon chip area is required for the same current rating, and the switching speeds will be twice as fast.

2. The snubber networks are for load line shaping only and are not required to absorb all the energy stored in the transformer leakage reactance. Instead, clamp diodes D_5 and D_6 conserve most of this energy by returning it to the input, improving the efficiency.

3. Closed-loop stability is easier to achieve than with a flyback converter because there is no right half plane zero.

4. Filter capacitor requirements are much less severe than in boost or flyback converters because of the output filter inductor.

5. Transformer construction is simplified because there is no need for a clamp winding (N_a is used for the auxiliary supply).

6. Reliability is improved because faster transistors result in reduced switching losses, and each transistor dissipates only one half of these reduced losses.

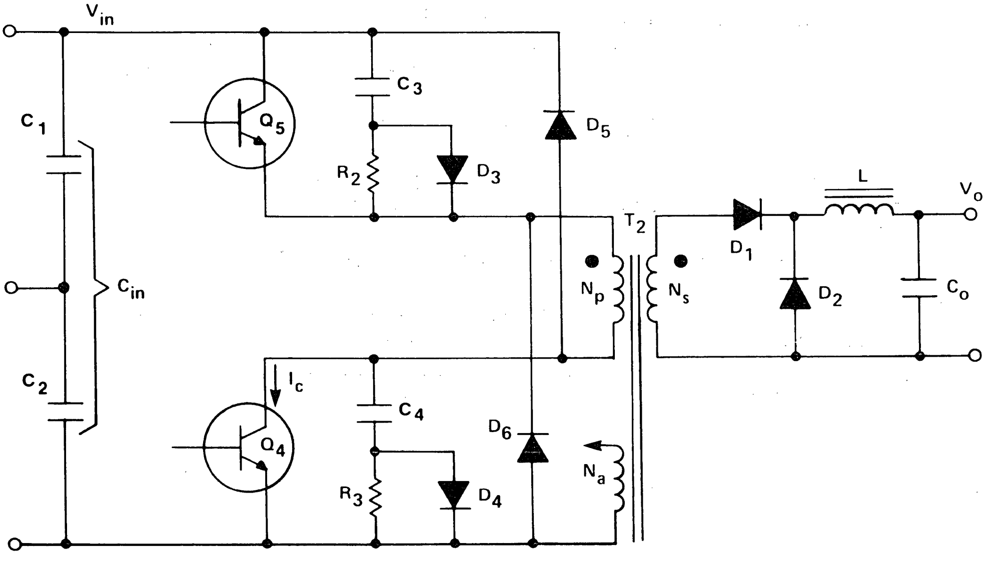


Figure 3. Two Transistor Forward Converter

Disadvantages of this topology are:

1. Two transistors are required instead of one (but cost may be less).

2. Restricted to less than 50% duty cycle to permit core reset. This results in poorer transformer utilizetion.

3. Added cost of filter inductor, which is not required for the flyback converter.

SPECIFYING THE SWITCHING TRANSISTORS

Maximum peak primary current flowing through the transistors, I_{CM}, is the same as i_{dis} from Equation 3, or 3.33 A.

The transistors should have good VCE(sat) and switching speeds at a collector current of at least 4.0 amperes, which includes an allowance for unusual conditions such as short circuit current. (Disregard spec sheet "maximum current ratings" which are inflated for competitive marketing reasons, and focus on the specified test conditions.)

The collector voltage rating must be greater than maximum V_{in}, or 380 volts in this application. Conservatively, this should be the BV_{CEO} rating, but with careful load line shaping to make certain the transistor is completely off before voltage is applied, a less conservative designer might specify BV_{CEX} greater than $V_{in(max)}$.

The UMT13007 satisfies the above requirements, with BV_{CEO} of 400V, $V_{CE(sat)}$ less than 2.0V at 5A, and worst case fall time of 400ns under the proportional base drive conditions provided.

SNUBBER NETWORK DESIGN

The turn-off snubber networks shown across each transistor in Figure 3 provide shaping of the load line to ensure that it remains below the reverse bias safe operating area (RBSOA) of the transistors. Capacitors C_3 and C_4 accomplish this by holding the voltage across each transistor low during current turn-off. The snubber capacitors thus absorb the turn-off transition energy that otherwise would have been dissipated in the transistors (see Figure 4).

$$C_3 = C_4 = \frac{I_{CM}\, t_f}{2\, V_{in(max)}} \qquad (6)$$

$$= \frac{3.33 \times .4 \times 10^{-6}}{2 \times 380} = .00175\ \mu F \qquad (\text{use } .0015\ \mu F)$$

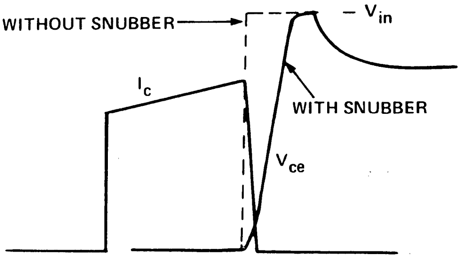


Figure 4. Effect of Snubber Network on Turn-Off Characteristic

Resistors R_2 and R_3 are designed to discharge the snubber capacitors with a discharge time constant of one-half the minimum on time, $t_{on(min)}$.

$$t_{on(min)} = \frac{D(max)}{f}\,\frac{V_{in(min)}}{V_{in(max)}} = \frac{0.5}{40{,}000}\,\frac{200}{380} = 6.58\ \mu s \qquad (7)$$

$$R2 = R3 = \frac{t_{on(min)}}{2C3} = \frac{6.58x10^{-6}}{2 \times 1.5x10^{-9}} = 2.2K$$

Maximum power dissipation in each resistor:

$$P_{R2} = P_{R3} = \frac{1}{2} C2\,V_{in(max)}^2\,f \qquad (8)$$

$$= \frac{1.5x10^{-9}}{2} \times 380^2 \times 40{,}000 = 4.3\ \text{watts}$$

POWER TRANSFORMER DESIGN

The design of the 40KHz inverter transformer is detailed in Appendix A. A primary to secondary turns ratio of 148/9, or 15.33, ensures that 5 volts output is provided with minimum Vin of 200 volts at 50% duty cycle, including voltage drops in rectifiers, transistors and windings.

Transformer winding N_a is used to provide an auxiliary supply to power the control and base drive circuits. This makes good use of the energy stored in the transformer primary inductance.

OUTPUT FILTER DESIGN

The output filter and its associated waveforms are shown in Figure 5. The filter inductor calculation is based on the maximum "off" time:

$$D(min) = D(max)\frac{V_{in(min)}}{V_{in(max)}} = 0.5\,\frac{200}{380} = .263 \qquad (9)$$

$$t_{off(max)} = \frac{1-D(min)}{f} = \frac{1-.263}{40{,}000} = 18.4\ \mu s \qquad (10)$$

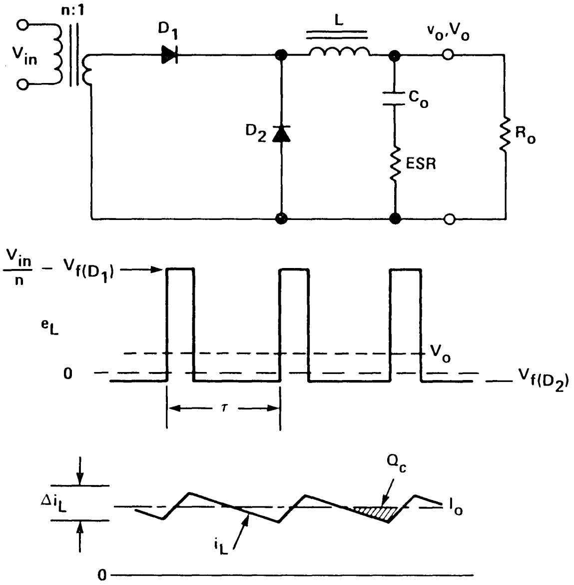


Figure 5. Output Power Filter Design

The inductance required to prevent discontinuous mode operation depends upon the minimum load current:

$$\Delta I_{L(max)} = 2I_{o(min)} = 2 \times 5 = 10A \qquad (11)$$

$$L = \frac{(V_o + V_F)t_{off(max)}}{\Delta I_{L(max)}} = \frac{(5 + 0.6)18.35}{10} = 10\ \mu H \qquad (12)$$

The capacitance required to achieve the output ripple voltage specification of 0.1 volts is:

$$C_o = \frac{1}{2}\frac{\Delta I_{L(max)}}{2}\frac{1}{2f}\frac{1}{v_o} = \frac{10}{8 \times 40{,}000 \times 0.1} = 312\ \mu F \qquad (13)$$

The maximum ESR of the capacitor is:

$$ESR = v_o/\Delta I_{L(max)} = 0.1/10 = .01\ \Omega \qquad (14)$$

To obtain the necessary ESR requires a capacitor much larger than the 312 microfarads calculated. This design will use three 220 microfarad solid tantalum capacitors, Mallory THF227M010P1G, in parallel. A single 14,000 microfarsd aluminum electrolytic capacitor, Mallory CG0143M10R2C3PL could also be used.

With the tantalum capacitor, the resonant frequency of the filter is 2KHz. With the aluminum electrolytic, the resonant frequency is reduced to 425Hz, changing the closed-loop design.

CLOSING THE CONTROL LOOP

The Unitrode UC1524A is used for the control circuit. It has additional features such as pulse by pulse current limiting and high current and voltage output capability (200mA, 60V) compared with the SG1524. The UC1524A reference is trimmed to +/- 1% which makes it possible to avoid using a voltage-setting potentiometer in many instances.

The control to output transfer function, dV_0/dV_C, shown in Figure 6, incudes the cascaded gain of the sawtooth modulator within the UC1524A control IC, the power switching circuit, and the output filter characteristic, $H_e(s)$.

In the control IC, a control voltage V_C is compared with sawtooth ramp voltage V_S (2.5 volts) to establish the drive pulse width to the power switches. For the forward converter, only one of the two alternating outputs of the UC1524A is used so as to limit the duty cycle to 50% maximum and allow for transformer core reset:

$$D = 0.5V_c/V_s = 0.5V_c/2.5 = V_c/5 \qquad (15)$$

The forward converter is a member of the buck regulator family. Transformer turns ratio n = 16.44:

$$V_o = \frac{Vin}{n} D = \frac{Vin\ Vc}{n\ 2Vs} \qquad (16)$$

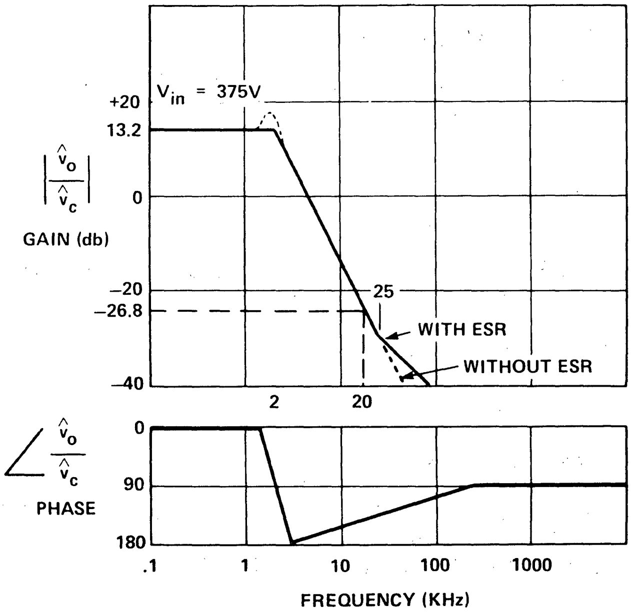


Figure 6. Control to Output Transfer Function LC Filter and Modulator

The low frequency control to output transfer characteristic is obtained by differentiating with respect to Vc:

$$\frac{\partial V_o}{\partial V_c} = \frac{V_{in}}{n\ 2V_s} = \frac{380}{15.33 \times 5} = 4.95 = 13.2\ \text{db} \qquad (17)$$

Note that gain is greatest at maximum V_{in}. The overall control to output transfer characteristic including the filter is:

$$\frac{\partial V_o}{\partial V_c} = \frac{V_{in}}{n\ 2V_s} H_e(s) \qquad (18)$$

The filter introduces a two-pole characteristic at its resonant frequency (2 KHz). Above resonance, the gain drops 40db per decade, and the phase shift becomes −180 degrees. Combined with the −180 degree phase shift of the feedback network, this will cause instability and oscillations unless compensated.

Closing the loop involves feeding back the error voltage from the output terminal of the supply ($\hat{v}_o$) to the IC control voltage port ($\hat{v}_c$) through the UC1524A error amplifier. The approach taken is to make the gain of the feedback network such that the overall loop gain crosses zero db (with adequate phase margin) at one half the switching frequency.

As shown in Figure 6, control to output gain is 13.2db at low frequencies, rolling off above 2KHz at −40db per decade, so that at 20 KHz the control to output gain is 13.2 − 40, or −26.8db. For overall loop gain of zero,the feedback network gain must be made +26.8 db at 20 KHz.

From 20KHz down to 2Kz, there is a net single zero in the feedback network which cancels one of the two filter poles and reduces the phase shift in this region to −270 degrees.

Below the filter resonant frequency the two filter poles are gone. However, the resonant frequency may be less than 2KHz because of plus tolerances on the filter capacitor. The feedback network is therefore designed to transition from a net single zero to a single pole at 1KHz, half the resonant frequency.

Figure 7 shows the gain and phase plot of the error amplifier and the overall feedback loop. Figure 8 shows the specific feedback network used to achieve this result.

The high frequency error amplifier gain is set by R_2 and R_3. An R_3 value of 33K is chosen to minimize amplifier loading:

$$Av1 = R3/R2 = 26.8\text{db} = 21.9 \qquad (19)$$

$$R2 = R3/Av1 = 33000/21.9 = 1500\ \Omega$$

The required error amplifier gain at 1KHz is:

$$Av2 = Av1 \times 1\text{KHz}/20\text{KHz} = 21.9 \times 1/20 = 1.095\ (0.8\text{db}) \qquad (20)$$

12

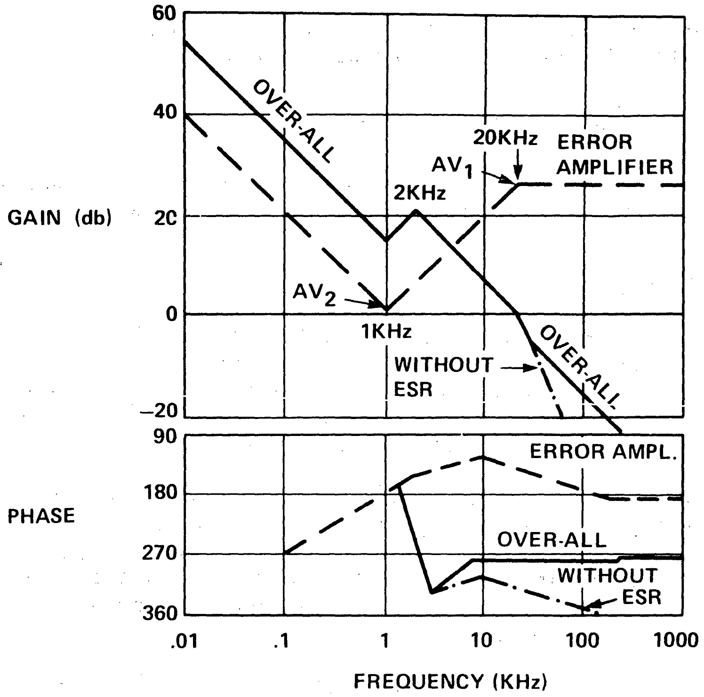


Figure 7. Open Loop Gain and Phase Plot

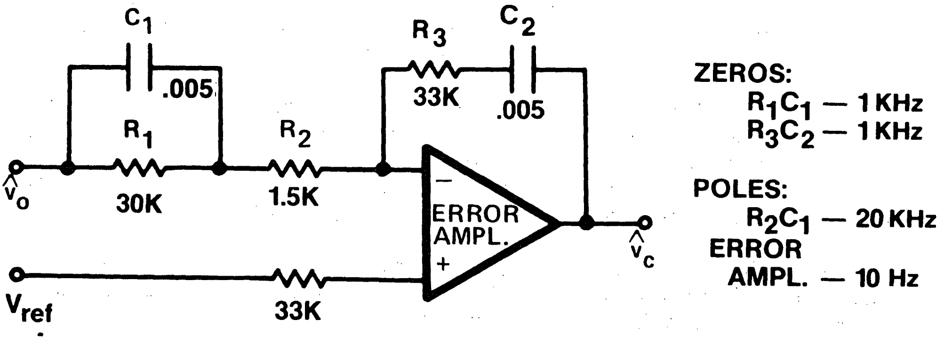


Figure 8. Error Amplifier with Compensation

The gain at 1KHz is determined by R_1, R_2 amd R_3:

$$Av2 = R3/(R1+R2) = 33K/(R1+1500) = 1.095 \quad (21)$$

$$R1 = 28.6K \quad (\text{use } 30K)$$

The two zeros at 1KHz which changes the feedback network from a net single zero to single pole are equal to:

$$f_1 = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_3 C_2} = 1\ \text{KHz} \qquad (22)$$

$$C_1 = .0053\ \mu F, \qquad C_2 = .0048\ \mu F$$

C_1 and R_1 in parallel with R_2 result in an additional pole at 20KHz. This flattens the error amplifier gain above 20 KHz. The overall phase shift will gradually increase toward 360 degrees, but it doesn't matter because the overall gain is less than one.

An additional pole occurs below 10 Hz. This is the inherent single-pole characteristic of the error amplifier's 5 megohm output impedance loaded by feedback capacitor C_2.

PROPORTIONAL BASE DRIVE

In Figure 2, transistors Q_2 and Q_3 and base drive transformer T_1 provide proportional drive to the bases of power switching transistors Q_4 and Q_5. The proportional base drive technique provides excellent performance from high voltage bipolar transistors. It provides large base current pulses for fast turn-on and turn-off, but with modest drive power requirements. Sustaining base drive is provided regeneratively from a collector current winding on the drive transformer. The transistors are never overdriven, even under light load conditions, since the sustaining base drive is proportional to the collector current. Design considerations for the proportional base drive technique are given in Section D1 in the design section at the back of this book.

Referring to the circuit of Figure 2, when Q_3 is on, R_4 establishes 75 mA magnetizing current in drive winding N_d of T_1. When Q_3 turns off, the energy stored in T_1 drives 150 mA into the base of each transistor. Collector current starting to flow in N_c provides sustaining base drive. With I_C of 3.33 A under full load conditions, an additional 667 mA of drive is provided to each base.

While Q_3 is off, capacitor C_5 charges through Q_2 in less than 1 microsecond. Then, when Q_3 turns back on, C_5 provides a negative base drive pulse of −1.5 A to each transistor, achieving turn-off in less than 1 microsecond.

Drive transformer T_1 has a drive winding inductance of 0.7 mH and is designed to saturate at 75 mA. High voltage insulation is not required because all windings are on the line side of the supply.

Core: Ferroxcube 1107P-L00-3B7 Pot Core
N_d: 20 turns AWG34
N_b: 5 turns AWG28x2 (2 wires, one for each base)
N_c: 2 turns 5xAWG28 (5 wires paralleled)

AUXILIARY POWER SUPPLY

A 15 volt auxiliary supply powers the control and driver circuits, obtaining its energy from capacitor C_3. Flyback energy is normally provided by T_2 through winding N_a and D_6 to maintain the charge on C_3 every switching cycle. However, at initial power-up it is neccessary to provide separate means to activate the V_{dd} supply. Otherwise, the control and driver circuits could not become functional and the supply could not start to switch.

The unique under-voltage lockout feature of the UC1524A facilitates this technique. All of its internal circuits are disabled (except the reference) until the Vdd voltage reaches 8 volts. This holds the standby current to less than 4mA until the 8 volt threshold is reached, and permits C3 to be initially charged through R1 from the unregulated input. Enough energy is stored in C3 to operate the control/drive circuits for several switching cycles, until flyback energy from winding N_a can take over and maintain the voltage on C_3.

It is also necessary to eliminate base drive to Q_3 during initial power-up, otherwise Q_3 will draw current through R_4 which will prevent C_3 from initially charging. This is accomplished by transistor Q_1 which disconnects base drive source capacitor C_4. When the UC1524A becomes active, its second output turns Q_1 on periodically to charge C_4.

The amount of energy stored in the power transformer is twice the drive/control circuit requirements. Excess energy is dumped into 15 volt zener diode D_7 which establishes the V_{dd} supply voltage at that level. This also provides a constant clamp voltage across the switching transistors, regardless of line voltage. With good coupling between N_a and primary winding N_p, it may be possible to eliminate clamp diodes D_{12} and D_{13}.

OUTPUT VOLTAGE SENSE AND OVERCURRENT SENSE

A small, inexpensive transformer, T_3, couples the output voltage to the line side control circuit with high voltage isolation. The transformer is wound on a Ferroxcube 204-T250-3E2A ferrite toriodal core. Primary and secondary windings are both 14 turns AWG32.

During the time the power switching transistors are on, Q_6 is on, applying V_o to the primary of T_3. Through D_2, this provides a real-time feedback voltage to the control circuit across C_6. When Q_6 is off, D_5 clamps the flyback voltage to 15 volts. Core reset is accomplished well before the end of the "off" time, since the "off" time of the forward converter is always more than 50%. All transformer windings then go to zero volts, establishing a DC coupling level. D_1 in series with the ground return compensates for the forward voltage drop and temperature coefficient of D_2.

Pulse by pulse current limiting is set by sense resistor R_{10}. Primary current is limited to 4A, corresponding to 62A load current.

Transient response of the switching supply is shown in Figure 9 with changes in load from 20A to 60A and back to 20A. This behavior is a large signal phenomenon. It doesn't matter how fast the control loop is, it is temporarily driven into the bounds because the load change is much larger than the output filter inductor current can accomodate in one cycle. Nevertheless, recovery is smooth and there is no evidence of ringing or oscillations, demonstrating the stability of the control loop. Step changes in load current that are small enough for the control loop to remain functional are barely noticable at the output.

Transient response can be improved by reducing the filter inductor and increasing the filter capacitor size, but this will increase the minimum load current required to keep the inductor current from becoming discontinuous.

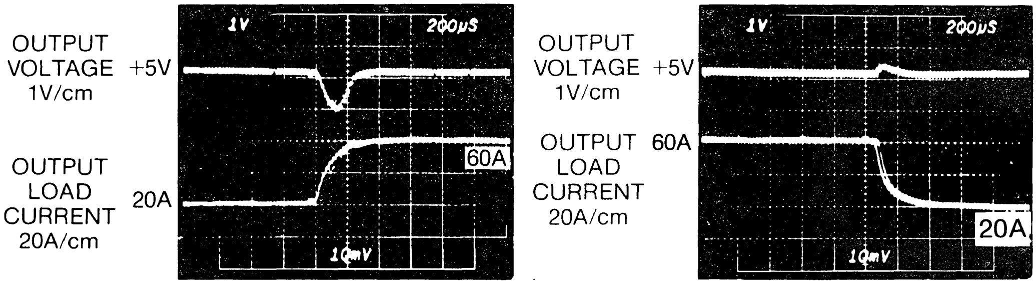


Figure 9. Step Change in Output Load

APPENDIX A
DESIGN OF THE POWER TRANSFORMER AND FILTER INDUCTOR

The design procedure used herein is defined in Design Reference Section M5. Symbols, definitions and various core and wire data are given in Reference Sections M1, M2, and M3. Equation references are to Section M5.

Flux Density Excursion

In this forward converter application, the flux excursion is entirely within the first quadrant of the B-H characteristic, from zero flux density toward saturation. With simple duty cycle control, using the UC1524A control IC, it is possible to have nearly twice the normal volt-seconds, $V_{in(max)}t_{on(max)}$, during startup or after a large step increase in load current. This means that the flux density cannot be permitted to go more than half way toward saturation under normal conditions or the core will saturate under transient conditions.

Saturation flux density for 3C8 power ferrite material is greater than 0.3 Tesla (3000 Gauss), allowing a ΔB of 0.15 T (0 to 0.15 T) in this application. (With volt-second control, available in the UC1840 control IC, a ΔB of 0.3 T would be permissible, significantly reducing the transformer size.)

Core Selection

The core area product, AP, requirements in this application are calculated using Equation 1 and Table I of Section M5 with power input of 333 watts and frequency of 40 KHz.

$$AP = A_wA_e = \left(\frac{11.1\ P_{in}}{K\ \Delta B\ f}\right)^{1.143} = \left(\frac{11.1\ 333}{0.141\ 0.15\ 40{,}000}\right)^{1.143} = 5.4\ \text{cm}^4$$

This equation is based on the assumptions that the windings occupy 40% of the window area, the primary and secondary windings are of equal area, and the windings are operated at a current density that will result in a temperature rise of 30°C with natural convection cooling.

Designing the Windings

The minimum number of primary turns required to support the volt-seconds required for normal operation is calculated from Equation 2 of Section M5:

$$N_p(min) > \frac{5000\ V_{in(min)}}{\Delta B\ A_e\ f} > \frac{5000\ 200}{0.15\ 1.83\ 40{,}000} > 91 \text{ turns}$$

From Equation 3, the primary to secondary turns ratio is:

$$n = \frac{N_p}{N_s} = \frac{0.9\ D\ [V_{in(min)} - V_{CE(sat)}]}{V_o + V_F} = \frac{0.45(200-2)}{5+0.8} = 15.36$$

Secondary turns from Equation 4:

$$N_s = \text{Integer}(N_p/n) = \text{Integer}(91/15.36) = 6 \text{ turns}$$

Recalculate the primary turns:

$$N_p = 6 \times 15.36 = 92 \text{ turns}$$

RMS primary current from Equation 6:

$$I_p = I_{in(max)}/K_t = \frac{P_{in(max)}}{V_{in(min)}\ K_t} = \frac{333}{200\ 0.71} = 2.34 \text{ A}$$

From Equation 7, the maximum current density for this size core is:

$$J_{max} = 450\ AP^{-.125} = 450(5.71)^{-.125} = 362\ \ \Omega/cm^2$$

The minimum primary wire area, A_{xp}, is:

$$A_{xp} = I_{p(max)}/J_{max} = 2.34/362 = .0065\ cm^2$$

From the Wire Table in Section M2 under 'AREA, Copper', AWG 19 is appropriate.

The maximum RMS secondary current, I_s, occurs at 50% duty cycle:

$$I_{s(max)} = I_{o(max)}/1.414 = 50/1.414 = 35.3 \text{ A}$$

Minimum secondary wire area, A_{xs}, is:

$$A_{xs} = I_{s(max)}/J_{max} = 35.3/362 = .0975\ cm^2$$

From the Wire Table, this calls for AWG 7 to 8. Ten AWG 18 wires in parallel will carry the required secondary current and provide a smooth winding with less leakage inductance and acceptable eddy curent losses. Copper strip 2.5x.04 cm could also be used.

Th number of turns required for the auxiliary winding is:

$$N_a = \frac{V_{dd}\ N_p}{V_{in(min)}} = \frac{15\ 92}{200} = 7 \text{ turns}$$

This will provide enough volt-seconds during flyback to reset the core (back to zero flux density) at 50% maximum duty cycle. AWG 32 wire is adquate to carry the V_{dd} supply current. This winding should be tightly coupled to the primary.

Double-check the wire fit in the window (neglect N_a). The total copper area of all windings should be less than 40% of the total window area of the core ($0.40x3.12 = 1.25$ cm² max).

$$A_w' > N_pA_{xp} + N_sA_{xs} = 92(.0065) + 6x10(.00823) = 1.09 \text{ cm}^2$$

Calculate Losses and Temperature Rise

The total losses in the windings is calculated from Equation 12. The mean length per turn, 1_t, for the EC52 core is 7.3 cm, and AWG 19 wire is .000353 Ω/cm from the Wire Table at 100°C.

$$P_w = 2\ I_p^2\ N_p\ 1_t\ (\Omega/\text{cm}) = 2(2.34)^2x92x7.3x.000353 = 2.59 \text{ watts}$$

The total core losses for 3C8 ferrite are obtained from Figure 1 in Section M3. The flux density axis of this graph assumes the transformer is operating with a symmetrical flux swing about the origin. The forward converter operates asymmetrically, so enter the graph with $\Delta B/2$, or .075 T. The resulting 0.01 W/cm³ must be multiplied by the core volume to obtain the total core loss, P_c.

$$P_c = .01x18.7 = .187 \text{ watts}$$

Total transformer losses are:

$$P_t = P_w + P_c = 2.59 + .187 = 2.78 \text{ watts}$$

The temperature rise of the core for natural convection cooling is calulated from Equation 14:

$$\Delta\theta = \frac{850\ Pt}{As} = \frac{850(2.78)}{91} = 25.9^oC$$

Summarizing the transformer design:

Core:	Ferroxcube EC52, 3C8 Ferrite E-E core
Np:	92 turns AWG19
Na:	7 turns AWG32
Ns:	6 turns 10xAWG18 (10 wires paralleled)

The primary and auxiliary windings are tightly coupled. The secondary is insulated with 2mil mylar tape to provide 3750 volt line isolation capability.

Filter Inductor Design

The design of the filter inductor is covered extensively in Unitrode Application Note U68A, in the Unitrode Databook. Using this approach, the inductor design is summarized as follows:

Core:	Ferroxcube 4229-3C8 Ferrite Pot Core
Winding:	7 turns 10xAWG17 (10 wires paralleled)
Losses:	2.2 watts
Temperature Rise:	35°C

HIGH FREQUENCY SERIES RESONANT POWER SUPPLY — DESIGN REVIEW

By Raoji Patel and Roger Adair

I. INTRODUCTION

In the past decade, power conversion technology has advanced from linear to switching due to the inherent high efficiency, smaller size, and lower cost of the latter technology. Recently, designers involved with conversion technology have started to consider resonant sine wave power supplies because they offer even smaller size, improved reliability, and reduced EMI.

It is possible to operate these power supplies at high frequency for two reasons. First, low-cost power MOSFETs, which, unlike bipolar transistors, have no storage time, are now available. Second, series resonant topologies are tolerant of some undesirable features of power semiconductor devices, (e.g., switching transition time and reverse recovery times.)

This paper explains the basic operation of the power output stage of a series resonant converter and examines its advantages and disadvantages compared to a conventional switching-regulated power supply. To provide a practical example, the paper details the design of an off-line series resonant power supply. The Unitrode low-cost UC3524A PWM Control Circuit is utilized to provide control for the series resonant power supply.

The 200kHz resonant power supply developed herein, as shown in Figure 1, operates from a 117V(±15%), 60Hz line and meets the following requirements:

1. Output Voltage
   A. +5V ±5% 2.5A — 5.0A
   Ripple Voltage: 100mV P-P maximum
   B. +12V ±3% 1A — 2A
   Ripple voltage: 100mV P-P maximum
   C. +24V ±5% 1A — 2A
   Ripple Voltage: 200mV P-P maximum
2. Efficiency 80% minimum.
3. Short-circuit protected.

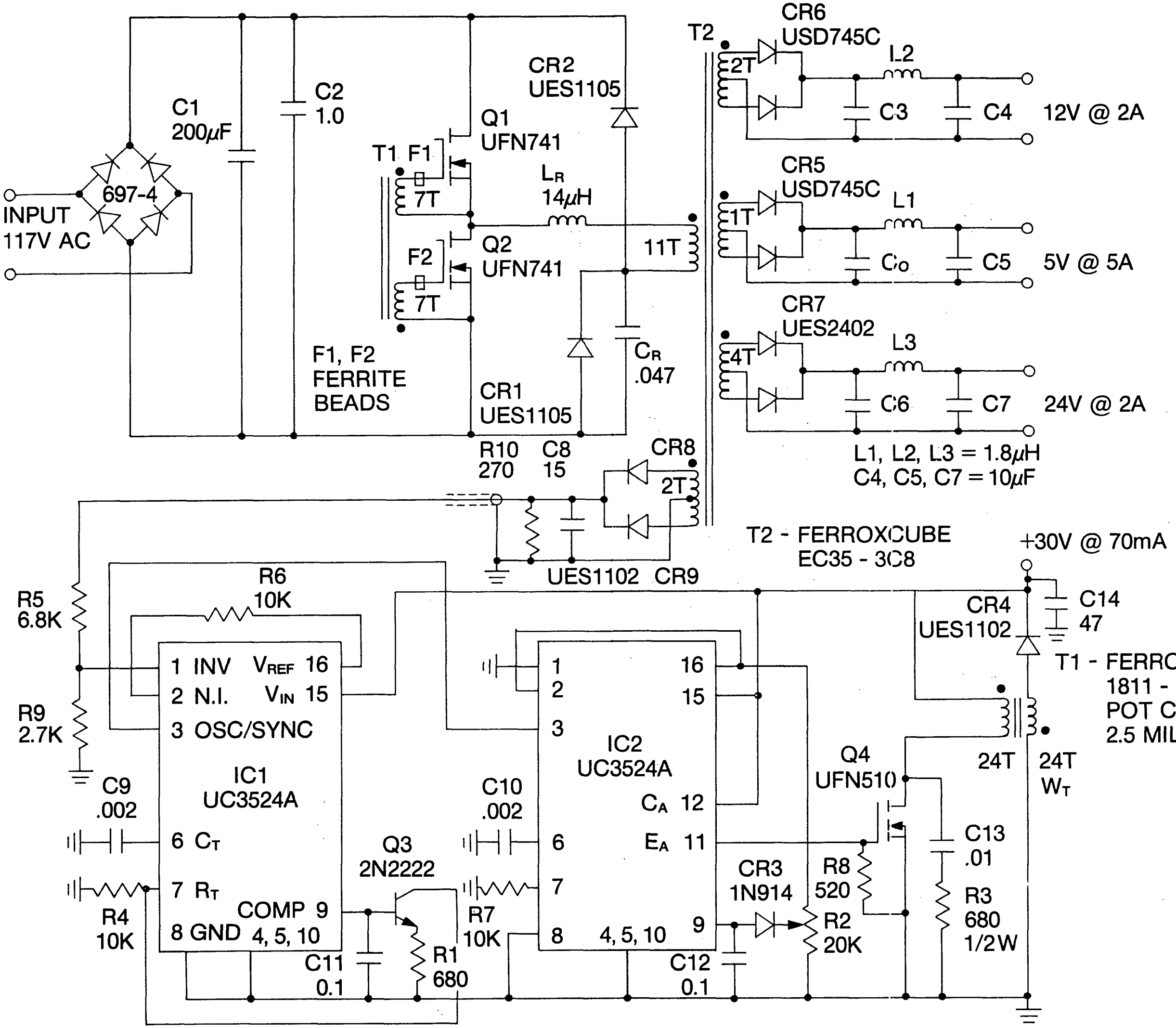


Figure 1. Schematic of Resonant Converter

Basic Principle and Operation

The power output stage and its associated waveforms at typical input voltage are shown in Figures 2 and 3. During the on-time of power switch Q1, the energy is delivered from the input supply to the output load and series resonant capacitor C_R. During the on-time of transistor Q2, the energy is transferred from capacitor C_R to the output load. Note that the rectifier diodes, CR1 and CR2, clamp the voltage across capacitor C_R by providing a current path through the V_{in} supply or ground. The AC current in the secondary winding of the transformer is rectified by rectifier diodes CR3 and CR4 and filtered with output filter capacitor C_O.

Under steady state condition, the output voltage V_o is reflected back to the primary side by NV_O, where N is the transformer turns ratio. The polarity of the reflected voltage depends upon the state of transistors Q1 and Q2. When transistor Q1 turns on, the input voltage V_{in} is applied across the series resonant network L_RC_R and the primary of the power transformer. Since voltage across the primary is fixed by its turns ratio and the output voltage, the current i_R in the primary increases in a sinusoidal manner (starting at zero) because it is controlled by the series resonant network. The voltage across capacitor C_R increases in a sinusoidal manner starting at zero, while the voltage across the inductor decreases toward zero. When the voltage across the inductor reaches zero, the current in the resonant network ceases to increase. At this instant, the peak current I_{RP} can be expressed by the equation:

$$I_{RP} = \frac{V_{in}-NV_O-V_{Ci}}{|Z_O|}$$

Where Z_O is the characteristic impedance of the series resonant network

V_{Ci} is the initial voltage across the capacitor; $V_{Ci} = 0$ for input voltage above $V_{in(min)}$

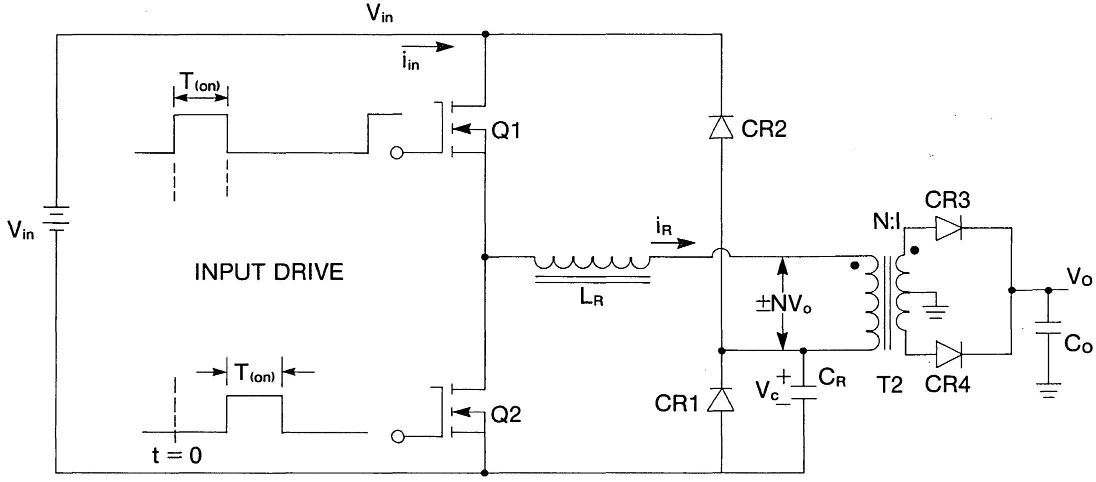


Figure 2. Power Output Stage

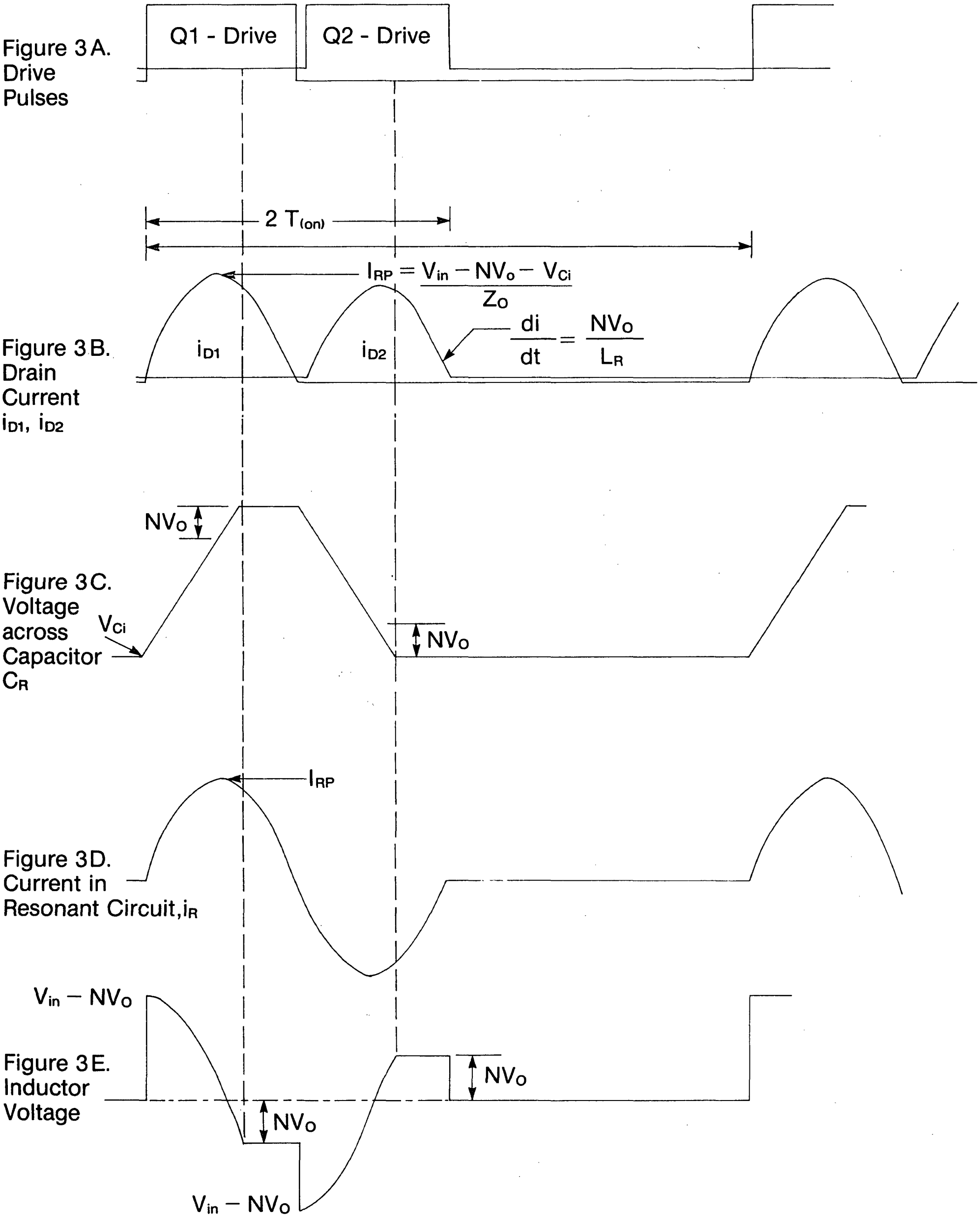


Figure 3. Voltage and Current Waveforms of the Power Output Stage of a Series Resonant Converter (with Input Volt V_{in} greater than $V_{in(min)}$)

The polarity of the voltage across series resonant inductor L_R reverses and the current starts to decrease from its peak value. The voltage across the resonant capacitor C_R continues to increase until it is clamped by diode CR2. The voltage across the series resonant inductor L_R ceases to increase when the voltage across capacitor C_R is equal to one diode drop above the input voltage V_{in}. The voltage across the inductor L_R is equal to the reflected output voltage NV_O. The current in the primary decreases in a linear manner. The slope of the current can be expressed by the equation:

$$\text{slope: } \frac{di}{dt} = \frac{NV_O}{L_R}$$

For proper operation, transistor Q1 must remain on until the current in the resonant network reaches zero. When the current in the resonant network reaches zero, the transistor Q2 is turned on and the current in the primary increases from zero, but this time in the reverse direction. The cycle repeats itself as described previously.

For maximum power transfer in a given design the selected turns ratio of the transformer should be such that the reflected output voltage across the primary is equal to half the value of the minimum input supply voltage. This can be expressed by the equation:

$$NV_O = \frac{V_{in(min)}}{2}$$

The output voltage is regulated by controlling the duty cycle, using a single cycle sine wave. Note that the required on-time of the power switches varies somewhat depending upon the input voltage variation. To maintain zero current switching, high efficiency and prevent cross conduction, the on-time should be determined at the maximum input voltage.

The maximum on-time of the power switch, referring to Figure 4A, can be calculated as follows:

Maximum on-time: $T_{on} = t_1 + t_2$

Where t_1 = time period for sinusoidal part of the current waveform.

Where t_2 = time period for linear part of the current waveform.

The time t_1 can be expressed by the equation:

$$t_1 = \frac{2\pi\sqrt{LC}}{360^\circ}\left[90^\circ + \text{SIN}^{-1}\frac{(V_{in(min)}/2)}{V_{in(max)} - \left(\frac{V_{in(min)}}{2}\right)}\right]$$

The peak current in diode CR2, to calculate the linear portion of the current waveform:

$$I_{d(pk)} = \frac{V_{in(max)} - NV_O}{|Z_O|}\text{SIN}\left\{90^\circ + \text{SIN}^{-1}\left[\frac{(V_{in(min)}/2)}{V_{in(max)} - (V_{in(min)}/2)}\right]\right\}$$

Where $Z_O = \sqrt{\frac{L_R}{C_R}}$ = Characteristic impedance of series resonant network.

Thus, the time needed for the linear portion of the current waveform:

$$t_2 = I_{d(pk)} \left[\frac{L_R}{\left(\frac{V_{in(min)}}{2} \right)} \right]$$

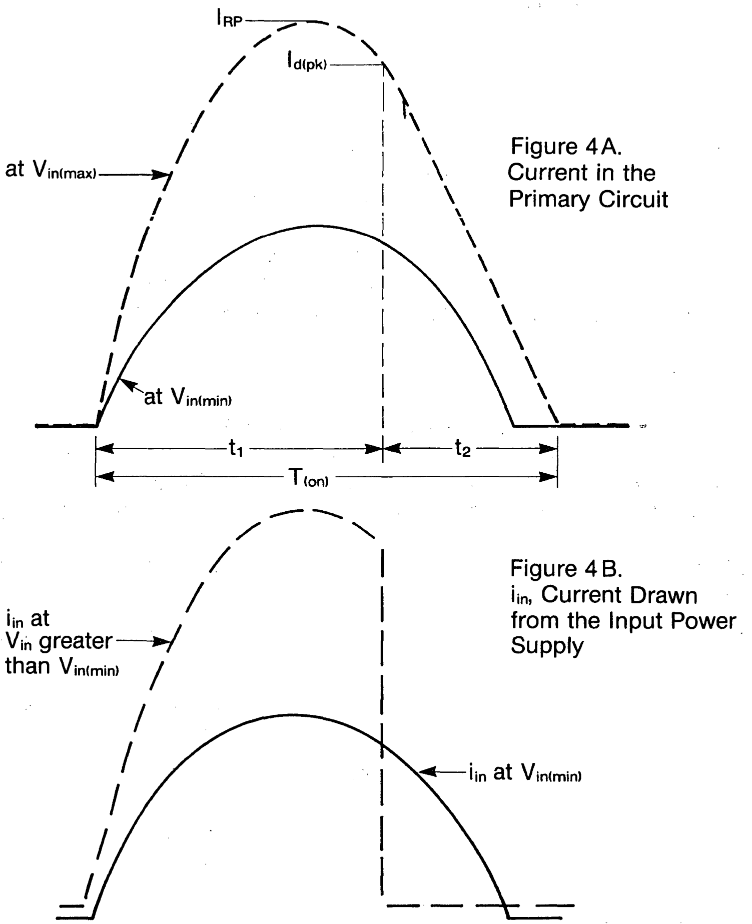


Figure 4. Current Waveforms at Minimum and Maximum Input Voltage

III. ADVANTAGES AND DISADVANTAGES OF SERIES RESONANT CONVERTERS

Advantages

The resonant sine-wave converter, when compared to buck-derived switching regulator topologies, has the following advantages.

(A) Higher overall efficiency:

  (1) There are no power losses due to the switching of the power switch or rectifier reverse recovery. Therefore, the conversion efficiency is higher.

(B) Smaller weight and volume:

  (1) Because the voltage is switched when the drain current is zero, operation at a higher frequency is possible. This results in smaller magnetic elements and filter components.

  (2) Due to the absense of switching losses, the required heat sink is smaller.

  (3) Simpler drive circuit when power MOSFETs are used.

  (4) The output filter inductor is smaller.

(C) Reduction in EMI:

  (1) No high frequency rectifier reverse recovery current spikes are reflected back to the transformer primary.

  (2) The transistor voltage is switched when current in the switch is zero. Therefore, there is no high di/dt other than at the fundamental frequency. Thus, a smaller amount of high frequency energy is radiated from the circuit.

  (3) Undesirable effects of leakage inductance (L_ℓ) in the transformer primary are minimized in a resonance converter because L_ℓ is utilized as part of the series resonance circuit. Thus, high frequency current and voltage spikes due to leakage inductance are eliminated.

  (4) Current drawn from the input filter capacitor has only the odd harmonics of the resonance frequency and their amplitude is lower.

(D) Increased reliability (high MTBF):

  (1) The resonant inductor L_R provides inherent short-circuit protection.

  (2) The inductor L_R also minimizes large current spikes in the power switch during start-up.

  (3) Zero current switching eliminates high peak power stress on the power semiconductor and localized peak junction temperature.

(4) When using a MOSFET as a power switch, there is no danger of forward bias (I_{SB}) or RBSOA.

(5) Voltage and current overshoot are minimized.

(6) Resonant converters are stable under no-load operation.

Disadvantages

(A) This topology requires the additional resonant circuit (inductor and capacitor), when compared to a buck type converter. The inductor and capacitor must carry high current, but are small in value.

(B) The required current or voltage rating of the power switch is $\sqrt{2}$ times higher compared to a switching regulator topology.

(C) Output filter capacitors must have low ESR and high ripple current ratings.

IV. HIGH FREQUENCY CONSIDERATIONS

A. Circuit Layout Guidelines

The following circuit layout guidelines should be used to optimize performance and prevent spurious oscillation or ringing, reduce radiated RFI, improve efficiency and regulation, and allow proper circuit operation.

(1) Use a short, wide ground plane and minimize the component lead inductance to that ground plane.

(2) Use separate ground returns for the power stage and the low-level control circuit.

(3) Minimize circuit lead inductance:

   (a) Keep leads short.

   (b) Minimize the loop area enclosed by wire carrying high frequency current.

   (c) When necessary, use copper straps/foils for high current.

(4) Use shielded wire in the feedback path to minimize pick-up and spurious oscillation.

(5) Be aware of package inductances, junction capacitances, heat sink capacitances, and other undesirable circuit parasitics.

(6) Use high frequency, low ESR capacitors and ferrite beads for EMI filtering.

(7) Use resistive damping when applicable. For example, a resistor or ferrite bead in the gate circuit can help to prevent spurious oscillation.

(8) Place the gap in the magnetic structure of the inductor directly under the coil winding.

B. Component Selection Guidelines

The following considerations are required when selecting or designing the components.

(1) Transformer and Inductor

Core losses are an important consideration in the design of a high-frequency converter. The core losses depend not only upon the peak flux density and the frequency, but also on the core geometry. These losses increase linearly with operating frequency, in ferrite with negligible eddy losses. Also, core losses increase as the peak operating flux density to the power of 2.5, approximately. Therefore, when the operating frequency is doubled for a given transformer (without changing the number of turns) the volt-seconds delivered to the primary and the peak operating flux density each decrease by a factor of two. The overall result is that core losses are reduced by approximately a factor of three at the higher frequency. If the transformer is redesigned to obtain the same core losses, the core will be smaller by a factor of $1/\sqrt[2.5]{3.} = 0.65$.

Use many parallel wires of small AWG size for the windings to minimize the proximity and skin effects. The proximity effect is a function of skin depth, conductor diameter, turns/layer, number of conductors per turn, and number of layers in the coil. The proximity effect produces eddy currents which distort the current distribution in the wire. Thus it increases the effective series resistance of the coil.

For low-voltage, high-current windings, copper strip or foil may be more practical than Litz wire because few turns are required. The gap in the inductor should be directly underneath the coil to minimize the radiated flux.

(2) Capacitors

Capacitors for high frequency circuits should be selected on the basis of ESR, ESL, ripple current rating (i_{RMS}) and self-resonant frequency (f_R), as well as cost and size. The resonant capacitor in the primary needs a good ESR and i_{RMS} rating. The output filter capacitors need low ESR and ESL, and high i_{RMS} and f_R. Bypass capacitors need low ESR and high f_R.

(3) Rectifiers

In this circuit, the parasitic diode of the power MOSFET should have fast forward recovery with low voltage overshoot, otherwise the other power device can be driven into breakdown during the deadband period.

In a series resonant converter, the reverse recovery of the output rectifier need not be extremely fast because of the low di/dt during diode turn-off.

V. DISCUSSION: PRACTICAL CIRCUIT

A. Power Output Stage

The output stage functions as follows. Assume both MOSFETs are off and the voltage on C_R is zero. When Q1 is turned on, the supply voltage is applied to the series resonant circuit comprised of L_R, the primary of T2, and C_R. The current starts to increase from zero in a sinusoidal manner, charging C_R and delivering energy through T2 to the load. Shortly after the peak of the sinewave current waveform is past, the voltage on C_R reaches the positive supply rail and CR2 conducts. The energy left in L_R continues to be released through T2 to the load, and the current ramps down toward zero. Note that the MOSFET voltage is switched when the current is close to zero, resulting in negligible switching loss. Also note that because of the intervening impedance of L_R, negligible reverse recovery spikes are drawn from the output rectifiers when Q1 or Q2 turn on.

The second of the two adjacent pulses produced by the drive circuit turns Q1 off and Q2 on. The above half cycle is repeated, except that the current flows in the opposite direction, thus producing the negative half-sine. Note that energy is drawn from the previously charged capacitor. C_R should be chosen for low ESR and good high frequency ripple current rating.

The output of the centertapped transformer secondary is rectified and is fed to capacitor C_O. Since the peak current in C_O is high, C_O must have low ESR and high ripple current rating.

Polypropylene type capacitors can be used. If lower cost is desired, a low ESR electrolytic of much larger capacitance (and size) may be suitable. A small low-pass filter comprised of L1 and C5 reduces the ripple appearing at the output to the desired value.

Note that the leakage inductance of the power transformer is in series with the inductance of L_R. Thus the total series resonant inductance is equal to the sum of the two. Also note the absence of snubbers across the Schottky rectifiers, permissible because of the low di/dt sinusoidal waveforms at the secondaries of the transformer.

B. Regulation and Drive Circuit

The drive circuit regulates the output voltage by varying the repetition rate of the waveform that drives the gates of the power MOSFETs. The two gates are driven by adjacent pulses of fixed pulse width. (This is not pulse width modulation.) Two of the standard PWM chips, the UC3524A, are used for the regulation circuit because they contain the necessary functions for this type of regulation.

The error amplifier and reference voltage of the first UC3524A are used in the normal manner. The output of the error amplifier, however, is used to control the amount of current at the R_T terminal of the oscillator, thus controlling the oscillator frequency. Q3, with a resistor R1 from emitter to ground, amplifies the error amplifier output. The collector of Q3 then sinks a variable amount of current out of the R_T terminal. The external C_T and R_T values set the minimum frequency. If the output power can vary by a factor of 2, then the frequency must be adjustable over a 2 to 1 range. The maximum frequency is set by the series resonant frequency of the output stage. If that is chosen at 200kHz, the minimum frequency for a 2 to 1 load change will be 100kHz.

The second IC chip is used as a one-shot. This is achieved by duty cycle limiting at the output of the error amplifier with diode CR3 and potentiometer R2. The pulse width is set equal to the width of a half sine of the output stage resonant circuit. By connecting their osc/sync pins together, the second IC is driven at the same frequency as the first IC. One of the output transistors drives the gate of Q4. Q4 drives the primary of T1 to produce a positive gate pulse for power switch Q1. When Q4 turns off, energy stored in the transformer core is returned to the 30V drive supply through "tertiary" winding W_T and CR4. Q2 is driven on at this time. The primary and tertiary windings of T1 have an equal number of turns and are clamped to the same voltage (30V) when conducting. Therefore, the time for the current to decay to zero in the tertiary winding will be the same as the time Q4 drove the primary. In this way Q2 and Q1 are operated at identical pulse widths. (Core saturation in T1 is prevented by using only one of the output transistors of the UC3524A, so the duty cycle is limited to 50%.) The snubber across Q4 (C13 and R3) damps out ringing to prevent Q1 or Q2 being turned on again after the desired double pulse is produced.

The rise and fall time of the MOSFET gate drive waveforms do not have to be ultra-fast in order to reduce switching losses, because those losses are already low due to zero current. Reasonably fast waveforms are desirable, however, to reduce deadtime between half-sine waveforms at maximum output. This minimizes the peak current in the MOSFETs, in the resonant circuit inductor and capacitor, and in the transformer and output rectifier and filter capacitors.

The circuit provides an efficiency of 81% and line and load regulation of ±5%.

VI. STABILITY CONSIDERATIONS

A simplified functional diagram of the regulator is shown in Figure 5. The small signal response of this converter is similar to that of a discontinuous-mode flyback regulator. The response of each of these topologies has only a single pole roll-off, the break frequency of which is determined by the output load R_L and the output filter capacitor C_O.

In the simplified functional diagram, the control chip IC1 converts the output of the error amplifier into regularly spaced sync pulses for control chip IC2. For each sync pulse, the control chip IC2 and the interfacing circuit provide two identical drive pulses in sequence. The total period of these pulses is equal to $1/f_R$. The duty cycle D can be related to the error output voltage V by the equation:

$$D = \frac{f}{f_R} = \frac{(1.15)2\pi\sqrt{L_R C_R}}{R_T C_T} = \frac{(1.15)V_c(2\pi)\sqrt{L_R C_R}}{V_{REF} R_{T_E} C_T}$$

The approximate DC transfer function of the power output stage, in terms of input supply voltage V_{in} and output R_L, is:

$$V_O = \frac{V_{in}}{1 + \frac{Z_O \pi}{2 R_L D}}$$

The small signal gain varies with the input supply voltage and with output load. No special considerations are required, however, because the transfer function has only a single pole roll-off. It will provide 90° phase margin, which results in stable operation.

$$T_{(on)} = \frac{R_T'C_T'}{1.15} \geq \pi \sqrt{L_R C_R}$$

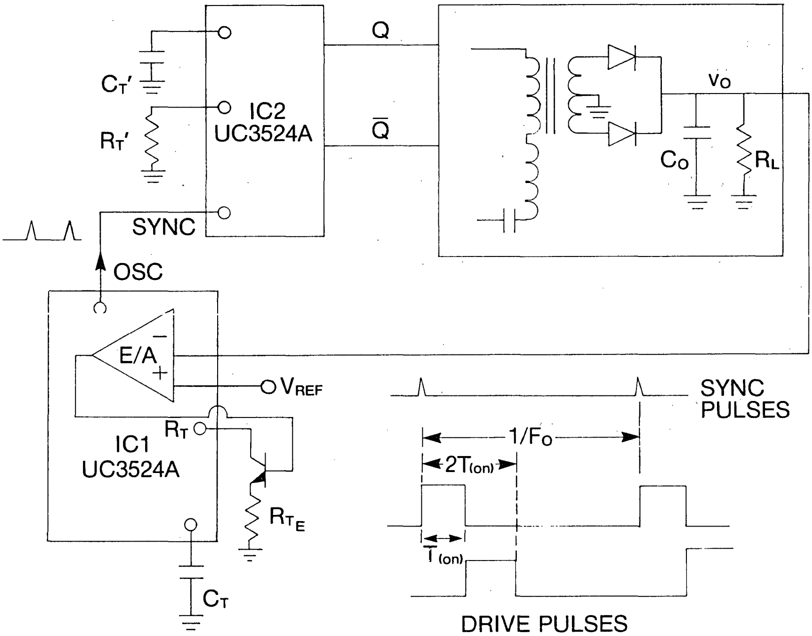


Figure 5. Simplified Functional Diagram

VII. SUMMARY

The availability of power MOSFETs, which have negligible storage times, has made practical the use of high frequency resonant sinewave converters. Switching losses are minimized by switching at approximately zero current crossings. Considerable improvements are realized in efficiency and reliability when compared to switched-mode designs.

BIBLIOGRAPHY

Amin, D. "Applying Sinewave Power Switching Techniques to the Design of High Frequency Offline Converters", *Powercon 7*, April 1980.

Babu, S. "A Practical Resonant Converter Using High Speed Power Darlington Transistors", *PCI Conference Proceedings*, March 1982.

Baker, R. "High Frequency Power Conversion with FET Controlled Resonant Charge Transfer", *PCI Conference Proceedings*, April 1983.

Myers, R. and R. Peck. "200kHz Power FET Technology in New Modular Power Supplies", *Hewlett-Packard Journal*, August 1981.

Nijhof, E. and W. Rosink. "Control Circuit Design for the Series Resonant Power Supply with GTO Switch", *Powercon 10*, April 1983.

Redl, R., B. Molnar and N. Sokal. "Class-E Resonant Regulated DC/DC Power Converters: Analysis of Operation and Experimental Results at 1.5 MHZ", *PESC Conference Proceedings*, 1983.

APPENDIX I.

Power Switch Selection and Design for a Series Resonant Circuit.

In this section, the maximum ratings of the power switch and the values of L_R and C_R in the series resonant circuit are determined.

A. Transistor Selection

At minimum input voltage $V_{in(min)}$, the converter will operate in an approximately continuous mode. Also, the voltage across the transformer primary at low line with a full load is half the input supply voltage for maximum power transfer. Note that for ease in calculation, the waveforms are approximated by a sinusoidal waveform.

The average primary current:

$$\bar{I}_{pri} = \frac{2P_{in}}{V_{in(min)}} = \frac{2(125)}{120} \approx 2.0A \qquad (I.1)$$

Therefore, the peak current at low line:

$$I_{pk(L)} = \frac{\pi}{2} \cdot \bar{I}_{pri} = \frac{\pi}{2}(2.0) = 3.14A \qquad (I.2)$$

The worse case peak current in a series resonant circuit will be at high line. Note that the same current also flows through the power switch. The maximum peak current in the transistors Q1 and Q2 can be expressed by the equation:

$$I_{pk(H)} = \frac{V_{in(max)} - \frac{V_{in(min)}}{2}}{\frac{V_{in(min)}}{2}} I_{pk(L)}$$

$$= \frac{190 - \left(\frac{120}{2}\right)}{\left(\frac{120}{2}\right)} \cdot 3.14A = 6.8A \qquad (I.3)$$

Therefore, the selected transistor must have peak current ratings of 6.8A and blocking voltage greater than the maximum input supply voltage $V_{in(max)}$.

B. Calculation of the Component Values for the Series Resonant Network

The component values for the resonant network L_R and C_R can be calculated as follows.

First, the characteristic impedance:

$$Z_O = \frac{\eta V^2_{in(min)}}{2\pi P_O} \quad \text{where } \eta \text{ is the efficiency}$$

$$= \frac{0.8(120)^2}{2\pi(100)} = 18.3\Omega \qquad (I.4)$$

The capacitor:

$$C_R = \frac{1}{2\pi f_R |Z_O|} = \frac{1}{2\pi(200 \cdot 10^3)18.3} \approx .05\mu F \qquad (I.5)$$

The inductor:

$$L_R = \frac{|Z_O|}{2\pi f_R} = \frac{18.3}{2\pi(200 \cdot 10^3)} \approx 14.5\mu H \qquad (I.6)$$

Note that the total value of the resonant inductor must include the leakage inductance of the transformer as well as any lead inductance.

C. Inductor Design

The maximum energy storage in the core occurs at high line; the maximum circuit energy storage required is:

$$W_M = \frac{1}{2} L_R I^2_{pk(H)} = \frac{1}{2}(14.5 \cdot 10^{-6})(6.8)^2 = 335 \text{ micro joules} \qquad (I.7)$$

The energy storage capability of the core must be equal to or greater than circuit energy storage W_M; therefore:

$$W_M \leq \frac{1}{2} BA_e H \ell_e 10^{-8} \qquad (I.8)$$

Use a Ferroxcube 1F30 U-core at 1500 guass; from the previous equation,

$$H\ell_e = \frac{2W_M}{BA_e} 10^8 = \frac{2(335)10^{-6}10^8}{1500(.864)} = 52 \text{ amperes/turn} \qquad (I.9)$$

Since for an inductor, all the energy is stored in the gap,

$$H\ell_g = NI_{pk(H)} = 52 \text{ A-T} \qquad (I.10)$$

The number of turns required, from above equation, is:

$$N = \frac{H\ell_e}{I_{pk(H)}} = \frac{52}{6.8} \approx 8 \text{ turns} \qquad (I.11)$$

The gap required to store the energy is:

$$\ell_g = \frac{NI}{H} = \frac{NI}{\left(\frac{B}{\mu}\right)} = \frac{52}{\left(\frac{.15}{(4\pi)10^{-7}}\right)} = .435 \text{ mm.} \qquad (I.12)$$

The windings must cover this gap to reduce fringing of the flux. The core and copper losses are maximum at high line. For this design, the total losses are equal to 1.4 watts and result in an increase in core temperature above ambient of 31°.

D. Transformer Design

The reflected output voltage across the transformer primary should be equal to half the value of the minimum input supply voltage. This will determine the primary to secondary turns ratio. For the +5V output, the turns ratio is:

$$N = \frac{V_{in(min)}}{2(V_O + V_F)} = \frac{120}{2(5 + 0.6)} = 11 \qquad (I.13)$$

The rest of the transformer design procedure is straightforward.

PROPORTIONAL BASE DRIVE OF BIPOLAR POWER TRANSISTORS IN SWITCHING POWER SUPPLIES

Proportional base drive is a simple and effective method of achieving improved performance with high voltage bipolar power switching transistors in off-line applications. As shown in Figure 1, a current transformer provides regenerative base drive current whose amplitude is proportional to the collector current being switched. The drive current ratio is established by the turns ratio of the collector and base windings.

The proportional drive method may be employed with any power switching circuit topology. Advantages over conventional fixed base current drive methods include:

1. Fixed base drive current must be large enough to handle the full load (or short-circuit load) collector current. Under lightly loaded conditions, the switching transistors are severely overdriven, resulting in long storage and fall times and more difficult turn-off. Proportional drive provides optimal performance under varying load current conditions.
2. Proportional base drive requires less drive power from the control circuit. During the "on" time of the switching transistor, base drive is provided regeneratively from the collector circuit through the current transformer. The control drive circuit is not required to provide sustaining base drive current. It must only provide short pulses of drive current to initiate turn-on and turn-off. The amplitude of these drive current pulses can easily be made large enough to obtain good switching performance from high voltage bipolar devices in off-line applications.

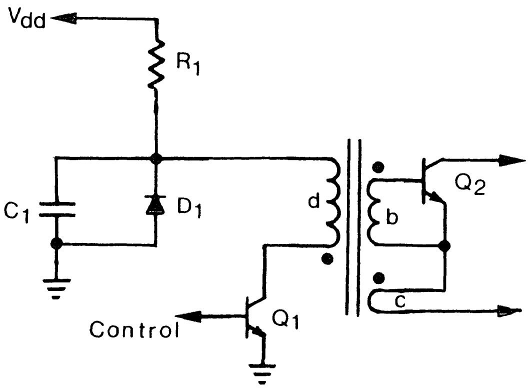


Figure 1. Proportional Base Drive Circuit

Referring to Figures 1 and 2, when driver transistor Q_1 is on, power switch Q_2 is off. Magnetizing current I_{d1} in the control drive winding N_d approaches a steady-state value equal to the drive circuit supply voltage V_{dd} divided by R_1. Capacitor C_1 is discharged and there is zero voltage across all windings of T_1.

When the output of the control circuit turns on, driver Q_1 turns off and primary current I_{d1} must cease. Energy stored in T_1 causes the voltage at the dotted ends of all windings to flyback in the positive direction. I_{d1} multiplied by turns ratio N_d/N_b becomes I_{b1}, the turn-on base drive current pulse to Q_2.

Collector current I_c starting to flow in winding N_c causes a regenerative increase in base drive to Q_2 until it is switched fully on. The final value of I_c induces a proportional base drive current, I_b, according to the turns ratio N_b/N_c.

During the time that Q_2 is on and Q_1 is off, capacitor C_1 charges through R_1 to supply voltage V_{dd}. At the end of this "on" period, driver transistor Q_1 is turned on again, applying the voltage on capacitor C_1 to the drive transformer primary. This drives the voltage on the base of Q_2 sharply negative. The turn-off base current pulse, I_{b2}, can be made larger than Q_2 collector current, resulting in very rapid turn-off of Q_2.

After Q_2 is off and I_{b2} ceases, any remaining voltage on C_1 across the drive transformer primary helps to rebuild the magnetizing current. Diode D_1 prevents the possibility of any underdamped ringing from driving the upper end of N_d negative. At the end of the "off" period, magnetizing current I_{d1} has been re-established and the cycle repeats.

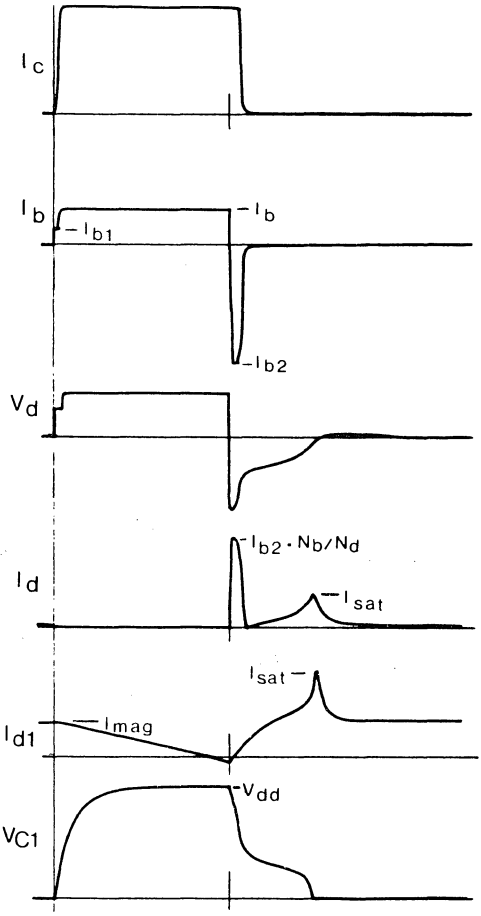


Figure 2. Waveforms

It is quite feasible to operate high voltage bipolar transistors at frequencies above 50 KHz with reasonable efficiency because of the large amplitude base drive pulses obtainable with this method. However, the circuit of Figure 1, as just described, is not capable of operation at frequencies above a few kilohertz. This is because capacitor C must charge to V_{dd} during the "on" period of Q_2, and the R_1C_1 charging time constant is far too long for this to be accomplished at 50 KHz.

This problem is solved by the addition of a rapid recharge circuit as shown in Figure 3. During the time that Q_2 is on and Q_1 is off, current through R_1 is multiplied by the current gain of Q_3, which significantly reduces the charging time of C_1. When Q_1 turns on, C_1 discharges through D_2. The base-emitter of Q_3 is reverse biased, holding it off during the entire Q_2 "off" time.

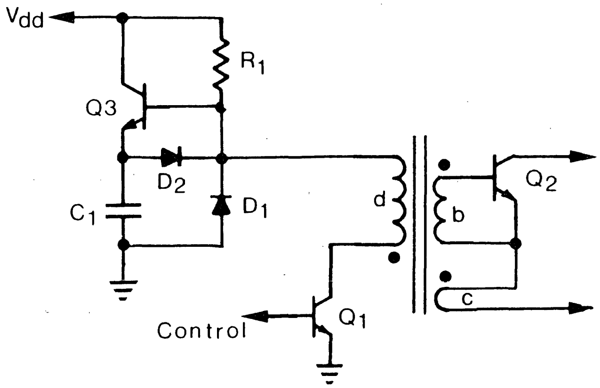


Figure 3. Improved Proportional Base Drive Circuit

DESIGN PROCEDURE:

Application parameter values must be defined, including drive requirements for the power switching transistors:

I_c	Maximum collector current
I_{b1}	Initial turn-on base drive current
I_c/I_b	Sustaining proportional base drive ratio
I_{b2}	Turn-off base drive current at max. I_c
V_{bb2}	Turn-off base drive source voltage at max. I_c
t_2	Maximum transistor turn-off time
V_{dd}	Drive circuit supply voltage
f	Operating frequency

Drive transformer base/collector turns ratio is equal to the desired proportional base drive ratio:

$$N_b/N_c = I_c/I_b \qquad (1)$$

Drive transformer driver/base turns ratio is established by the desired turn-off base source voltage and the drive circuit supply voltage, minus 1 volt diode drop:

$$N_d/N_b = (V_{dd}-1)/V_{bb2} \qquad (2)$$

When Q_1 turns off, primary magnetizing current, I_{d1}, transferred to the base winding must provide the required turn-on base drive, I_{b1}.

$$I_{d1} = I_{b1}/(N_d/N_b) \qquad (3)$$

The R_1 value required to obtain this magnetizing current is:

$$R_1 = V_{dd}/I_{d1} \qquad (4)$$

During initial turn-off, driver primary current I_{d2} must absorb the proportional base drive current and transformer magnetizing current I_{d1} in addition to the turn-off base drive current:

$$I_{d2} = \frac{I_{b2} + I_a/(N_b/N_c)}{(N_d/N_b)} + I_{d1} \qquad (5)$$

Capacitor C_1 is designed to supply the worst-case energy required to turn off Q_2:

$$W = \frac{1}{2}C_1(V_{dd}-1)^2 = (V_{dd}-1)I_{d2}\,t_2$$

$$C_1 = \frac{2\,I_{d2}\,t_2}{V_{dd}-1} \qquad (6)$$

When Q_2 is operated at very low duty cycle (such as immediately after a sudden decrease in load current), C_1 may not have time to fully charge to V_{dd} during the very short "on" time, in spite of the assistance provided by Q_3. This will probably not be a problem, because Q_2 will also not have time to store much charge and will be much easier to turn off. The time required for Q_2 to reach equilibrium charge storage is comparable to the time required to remove this charge during turn-off. The C_1 charging time constant (reduced according to the gain, H_{fe}, of Q_3) will generally be adquate if it is less than 1/2 the Q_2 turn off time, t_2. C_1 charging time constant:

$$T_{C1} = R_1C_1/H_{fe} \qquad (7)$$

DRIVE TRANSFORMER DESIGN:

Turns ratios for the drive transformer were established in equations (1) and (2). Only certain integral number of turns are permissible for each winding. For example, if N_d/N_c is 25, the permissible number of drive winding turns are 25, 50, 75, etc., corresponding to 1, 2, and 3 collector turns.

Winding I^2R losses are usually negligible. The drive transformer design is based on the following two considerations:

1. Magnetizing current I_{b1} is required for initial turn-on of the power switching transistor. During the time Q_2 is on, the magnetizing current will decrease due to voltage V_{be} across the base winding. The magnetizing current must not be allowed to decrease to less than zero, or it will cause premature turnoff under light load conditions by overcoming the small proportional drive current I_b. Referred to the primary, the drive winding inductance must be large enough to prevent I_{d1} (Equation 3) from reaching zero with voltage $V_{be}(N_d/N_b)$ during the longest possible "on" time (usually half the switching period, 1/2f):

2. Under light load conditions, relatively little charge is required to turn off Q_2. C_1 will then have substantial voltage remaining which will be applied to the drive winding during the remainder of the "off" period. This will cause the magnetizing current (and its associated energy storage) to become much larger than desired. The problem is solved by designing the drive winding to saturate at a current level slightly greater than the desired value of magnetizing current, I_{d1}. This will result in dumping any excess energy remaining in C_1 and establishing a consistent starting point on the B-H characteristic at the beginning of each "on" period.

Figure 4 shows the B-H characteristic of the core as seen from the drive winding. For the vertical axis, B times core area A_e and N_d equals $\int V_d dt$ (Faraday's Law). For the horizontal axis, H times effective core length, l, and divided by N_d equals the magnetizing current I_d, (Ampere's Law). The characteristic slope equals the drive winding inductance, L_d, and the area to the left equals the energy stored.

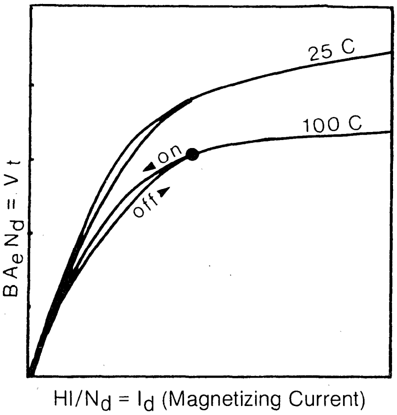


Figure 4.

The operating point shown will satisfy the two requirements above if it exceeds I_{d1} on the horizontal axis and if it exceeds $V_{be}[N_d/N_b]/2f$ on the vertical axis under worst case conditions at high temperature. Procedurally, use Faraday's Law with B close to saturation at high temperature and with the area, A_e, of the core selected. Solve for N_d:

$$\frac{V_{be}(N_d/N_b)}{2f} = B A_e N_d \tag{8}$$

Use the smallest permissible N_d equal to or greater than the value calculated above. An N_d value larger than the calculated amount simply means that the change in flux density will be less than the maximum permitted.

Next, use Ampere's law with a value for H corresponding to the B value chosen before, the smallest permissible N_d from above, and I equal to I_{d1}. Solve for the magnetic path length, l.

$$N_d I_{d1} = Hl \tag{9}$$

Compare the actual l_e value for the core selected with the value calculated above. If the actual l_e of the core is significantly larger than the calculated l, it will be necessary to use either a smaller core, or use a larger permissible number of turns, N_d. Otherwise, the operating point will not be close enough to saturation, and the B and H levels will both be too low to prevent the magnetizing current from becoming negative at the end of the "off" period.

If the actual core l_e is smaller than the calculated l, the core will be too heavily saturated, and will not store enough energy to provide the desired I_{b1}. Either go to a larger core, or introduce a small gap, lg, according to the relationship:

$$l = (l_e + \mu_a l_g), \quad \text{where } \mu_a = B/H \tag{10}$$

Driving Two Transistors. Two power switching transistors are often used in series in order to halve their high voltage V_{ce} rating requirements. It is usually desirable to drive these two transistors from a single drive circuit. This can be accomplished by means of two identical base windings in the transformer. N_b/N_c must be halved and N_d/N_b doubled from the values calculated in Eq. (1) and (2) because the total base current is twice as much as with a single transistor.

As shown in Figure 5, it is also necessary to add a small amount of resistance in series with each base in order to ensure current sharing. A resistor which drops 0.5 volts at maximum sustaining base drive, I_b, should be adequate. The added resistance does not affect the calculation of N_d in Equation (8) because its voltage drop is negligible compared to V_{be} under light load conditions, when the sustaining base drive is small. However, during turn-off, each series base resistor must be shunted by a small diode. Otherwise, a very large V_{bb2} value would be required in order to pull the desired I_{b2} out of each base. The forward drop of this diode must be added to the V_{bb2} requirement in Equation (2).

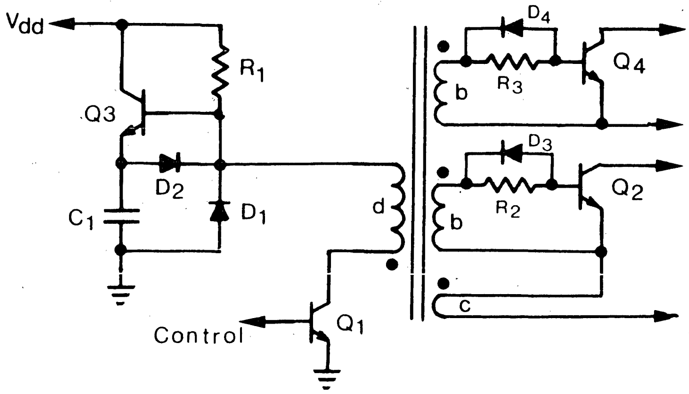


Figure 5. Two-Transistor Driver

<u>Line-side vs Output-side Control Circuit.</u> The base and collector windings of the drive transformer are normally on the input, or line side, of the power supply. When the control/driver circuits are located on the output side of the supply, high voltage insulation is required between the drive winding and the base and collector windings. This high voltage insulation, usually greater than 3000 volts, will impair the coupling between line-side and output-side windings. This results in high leakage inductance, causing voltage spikes during turn-on and turn-off which may necessitate additional snubbing or clamping the drive transistor collector and the power switching transistor base.

When the control and driver circuits are are located on the line side, the drive transformer does not require high voltage insulation. Leakage reactance can be made almost negligible, especially if multifilar windings are employed.

REFERENCES:

(1) J. Gregorich and W. Hazen, "Designing Switched-Mode Converters with a New Proportional Drive Technique," Proceedings of POWERCON 5, May 1978, pp. E2(1-8).

(2) P. Wood, "High Efficiency, Cost Effective Off-line Switching Converters," TRW Applications Note 143, April 1978, pp. 3-4

(3) R. Severns, "A New Improved and Simplified Proportional Base Drive Circuit," Proceedings of POWERCON 6, May 1979, pp. B2(1-12).

THERMAL CONSIDERATIONS FOR SEMICONDUCTOR DEVICE RELIABLITY

By Glenn Fritz

This paper is a guide to enhancing reliability and avoiding semiconductor failures in switching power supplies. Since semiconductor reliability is strongly related to junction temperature, a brief thermal design review is included. Several semiconductor failure modes are discussed, with emphasis on power supply circuits susceptible to such failure modes, methods of identifying failure mechanisms, and techniques for avoiding same.

Many semiconductor failures are the result of overheating the semiconducting silicon. Such failures can be broadly classified into two groups. First, failure can be due to excessive "average" heating, characterized by an expected distribution of high temperatures throughout the active regions, including junctions. For the purpose of this discussion, this includes repetitive transient heating within temperature ratings. Such heating is quantitatively predictable and can be controlled by appropriate device selection and heat sinking. The other failure mechanisms are related to localized overheating, and cannot be effectively addressed with the thermal models used for the average heating failure modes. A better approach to these potential problems involves relating identifiable transient circuit conditions to device ratings and safe operating area curves.

SECTION 1. AVERAGE HEATING CONSIDERATIONS

Degradation of semiconductors results from chemical reactions which change the structure of such devices on an atomic scale. The rate at which such reactions occur is found to follow the Arrhenius equation:

$$R(T) = Ce^{-E_a/KT} \qquad \text{(Eq. 1)}$$

where: $R(T)$ = temperature dependent reaction rate
C = constant
E_a = activation energy
K = Boltzmann's constant
T = temperature

Figure 1 is a typical plot of semiconductor failure rate, as a function of junction temperature, which follows Equation 1. Note that failure rate decreases rapidly as the operating junction temperature is lowered.

Semiconductor manufacturers commonly specify an absolute maximum junction temperature for any given device. This temperature is chosen to correspond to an "acceptable" failure rate for that device. However, as shown by Figure 1, improved reliability can be obtained by operating semiconductors at temperatures below their maximum rating. A tradeoff ultimately must be made between reliability and the cost and size of the semiconductor device and its associated heat sink.

Appendix A describes the thermal model usually used by designers to predict semiconductor junction temperatures and to thereby determine device and heat sink requirements. Readers unfamiliar with such a model are referred to this material. Following are illustrations of the application of this model to various power semiconductor devices commonly used in switching power supplies.

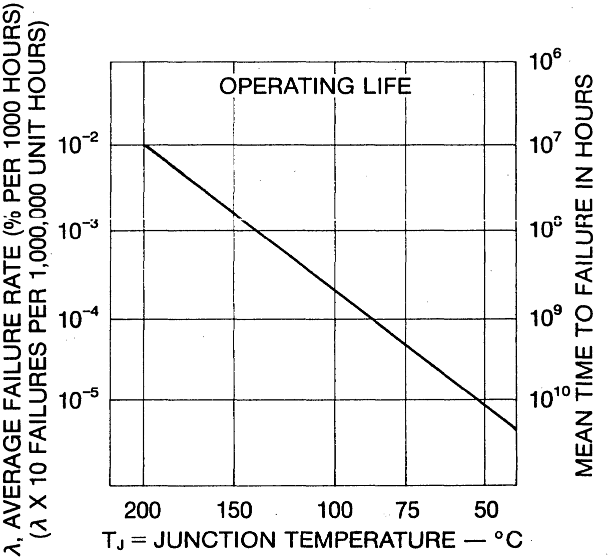


Figure 1. Approximate Arrhenius Model for Unitrode Bipolar Transistors

BIPOLAR TRANSISTORS

Power losses due to leakage current in the off state are usually negligible for bipolar transistors in switched-mode supplies. Therefore, equation A2 reduces to:

$$\overline{P} = \overline{P}_{conducting} + \overline{P}_{switching} \qquad \text{(Eq. 2)}$$

Conducting losses for bipolars can be expressed:

$$\overline{P}_{conducting} = \frac{t_{on}}{\tau} (i_c \cdot v_{ce} + i_b \cdot v_{be}) \qquad \text{(Eq. 3)}$$

where: t_{on} = transistor on time per cycle

τ = switching period

The variables i_c, v_{ce}, i_b and v_{be} in Equation 3 are mutually dependent. This is illustrated by the characteristic curves of Figures 2 and 3, which are curves typically supplied by power semiconductor manufacturers. In order to minimize conduction losses (Eq. 3) for a particular bipolar transistor, it is necessary that the designer choose an optimum base current (i_b). If i_b is too small, then the transistor will fail to saturate resulting in high power dissipation due to the v_{ce} term in Equation 3. However, too large an i_b will result in higher transistor dissipation due to the i_b term in Equation 3, and overall supply economy and efficiency might be affected adversely by losses in the high current drive circuitry. Finally, excessive i_b will result in increased minority carrier storage in the bipolar transistor base region. It will be shown below that such a "hard saturation" condition causes poorer switching performance due to increased storage and fall times (t_s, t_f).

Unfortunately, while providing general guidance for selecting a transistor and determining base drive requirements, the curves of Figures 2 and 3 are insufficient for making the choice of optimum i_b. Figure 2 gives current gain (h_{FE}) values only for non-saturation conditions ($v_{ce} = 3$ or 10V), while Figure 3 shows saturation voltage at only one gain ($i_c/i_b = 5$). A family of curves such as that shown in Figure 4 is more useful in this connection. From these curves the designer can determine just how much base current is needed to keep v_{ce} low without overdriving the transistor.

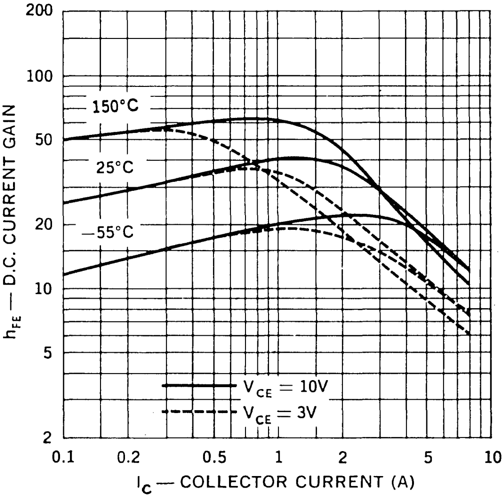


Figure 2. D.C. Current Gain for Typical Transistor

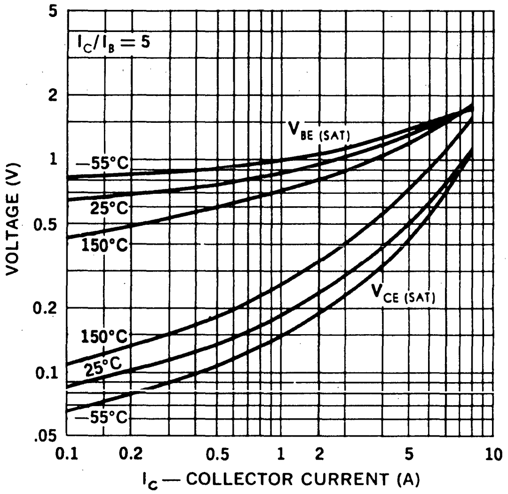


Figure 3. Saturation Voltages for Typical Transistor

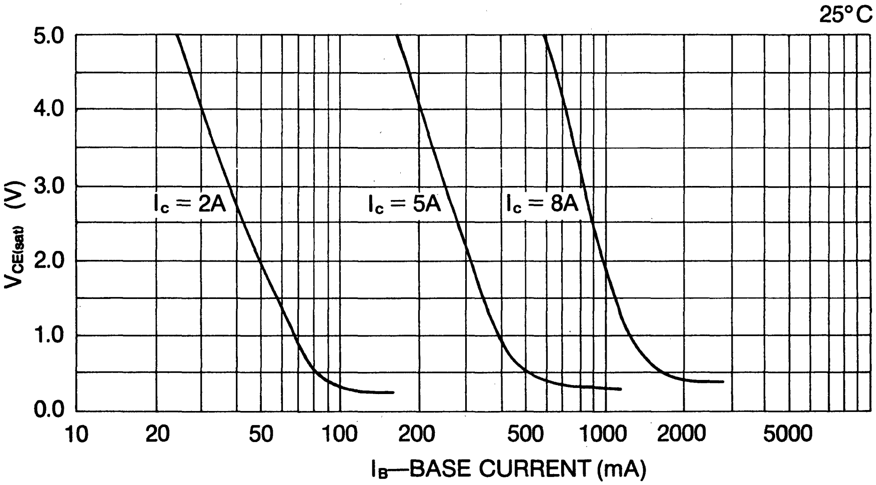


Figure 4. Typical VCE vs IC and IB for Typical Transistor

Bipolar Switching Losses

The other element contributing to average heating in bipolar transistors is power dissipation during switching (see Equation 2). Power pulses—which are large in magnitude compared to the average power, but short in duration—occur both at turn-on and turn-off of the power transistor in switched-mode supplies.

In some topologies, turn-on losses are negligible when compared to turn-off losses. Figure 5 shows a basic flyback converter, with the associated transistor i_c and v_{ce} waveforms. Transformer leakage inductance, L_ℓ, is in series with the switching transistor and prevents i_c from rising significantly until v_{ce} has fallen at turn-on. Therefore, the peak power dissipation, which is proportional to the area of the shaded region under the curves of Figure 5, is not great. During turn-off, L_ℓ again restrains i_c from changing significantly until v_{ce} has completed its transition. In this case, however, a large power pulse occurs because both i_c and v_{ce} momentarily have large values. Figure 6 shows an expanded scale of this turn-off period. In order to calculate the energy dissipated during this transition, a method of triangular approximation is well suited. The energy under the curves is given by:

$$E_{sw} \simeq \frac{1}{2} \cdot i_{c(on)} \cdot v_{ce(off)} \cdot t_f \qquad \text{(Eq. 4)}$$

where: E_{sw} = switching energy dissipated per cycle
$i_{c(on)}$ = on-state transistor current
$v_{ce(off)}$ = off-state transistor voltage
t_f = total fall time (sometimes called "crossover" time (t_c) by manufacturers)

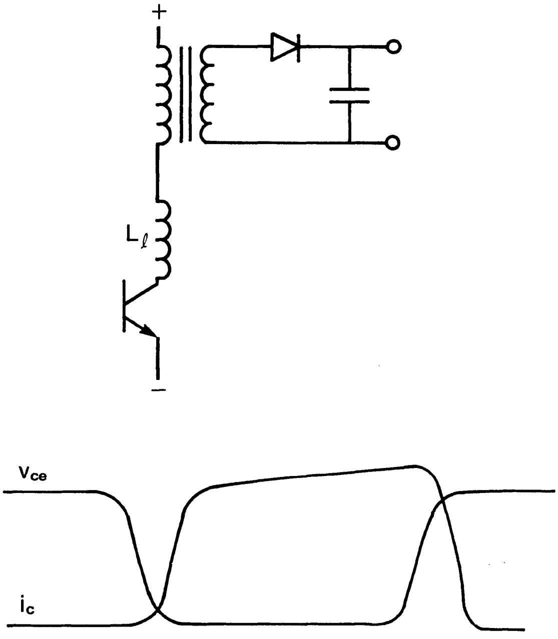


Figure 5. Flyback Topology and Associated Transistor Waveforms

The average transistor power due to switching in the flyback converter is therefore:

$$\overline{P}_{sw} = \frac{E_{sw}}{T} = \frac{1}{2} \cdot i_{c(on)} \cdot V_{ce(off)} \cdot \frac{t_f}{T} \qquad \text{(Eq. 5)}$$

If total fall time t_f is not specified, then current fall time t_{fi} can be used to calculate the area of region II in Figure 6, and the area of region I can be estimated. For a more careful study of switching losses, transition times should be measured under actual circuit conditions. Using the former method, and assuming $t_f \approx 2t_{fi}$:

$$E_{sw} \simeq i_{c(on)} \cdot V_{ce(off)} \cdot t_{fi} \qquad \text{(Eq. 6)}$$

$$\overline{P}_{sw} \simeq i_{c(on)} \cdot V_{ce(off)} \cdot \frac{t_{fi}}{T} \qquad \text{(Eq. 7)}$$

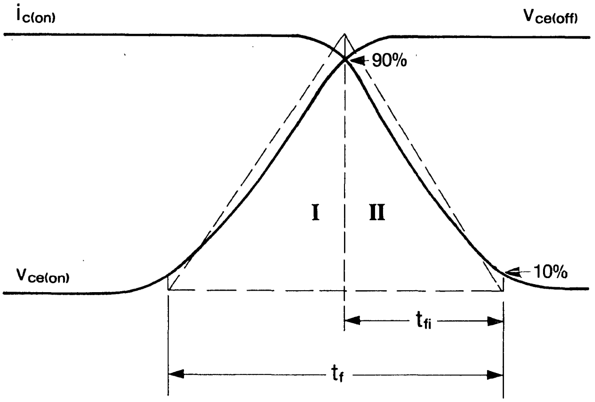


Figure 6. Bipolar Turn-Off

In the case of a buck regulator, turn-on losses are also significant. Figure 7 shows the buck topology and its associated transistor waveforms. In this case, the catch diode forces the transistor to see the full input voltage, V_{in}, at any time that diode carries any forward current. This results in the switching waveforms of Figure 7, with much energy dissipated during both turn-on and turn-off. Turn-off losses can be calculated by the same method used for the flyback regulator (Equation 7). Figure 8 shows the turn-on transition in more detail. If the catch diode recovery time is negligible, then:

$$E_{sw(turn\text{-}on)} = \frac{1}{2} \cdot i_{c(on)} \cdot V_{ce(off)} \cdot t_r \qquad \text{(Eq. 8)}$$

where t_r = current rise time (as defined in Figure 8)

Also: $$\overline{P}_{sw(turn\text{-}on)} = \frac{1}{2} \cdot i_{c(on)} \cdot V_{ce(off)} \cdot \frac{t_r}{T} \qquad \text{(Eq. 9)}$$

The effect of diode recovery time on transistor turn-on losses will be considered on subsequent pages. Total switching losses for the transistor in the buck configuration are given by (from Equations 5 and 9):

$$\overline{P}_{sw} = \overline{P}_{turn\text{-}on} + \overline{P}_{turn\text{-}off}$$

$$\overline{P}_{sw} = \frac{1}{2} \cdot i_{c(on)} \cdot v_{ce(off)} \cdot \frac{t_r}{\tau} + \frac{1}{2} \cdot i_{c(on)} \cdot v_{ce(off)} \cdot \frac{t_f}{\tau}$$

$$\overline{P}_{sw} = \frac{f_s}{2} \cdot i_{c(on)} \cdot v_{ce(off)} \cdot (t_r + t_f) \qquad \text{(Eq. 10)}$$

where: $f_s = 1/\tau$ = switching frequency

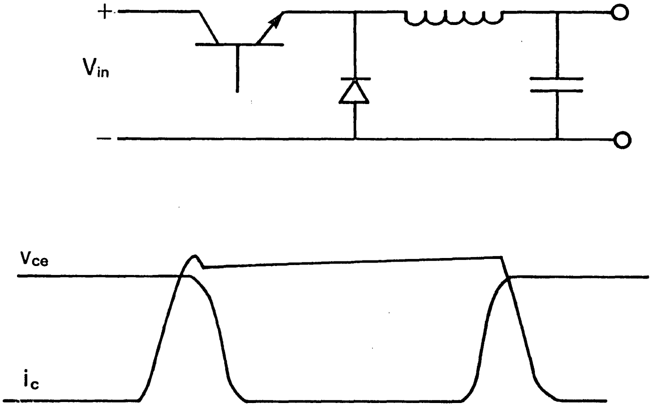


Figure 7. Buck Topology and Associated Transistor Waveforms

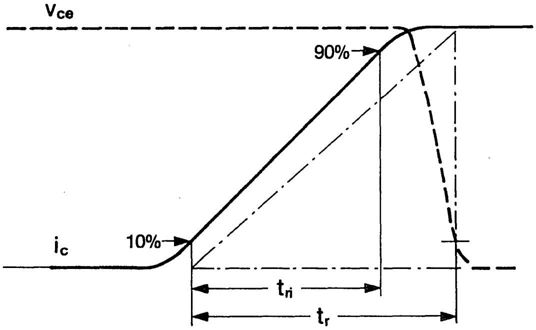


Figure 8. Bipolar Turn-On

Reducing Losses

In order to minimize bipolar transistor switching losses in any given circuit (for which $i_{c(on)}$, $v_{ce(off)}$ and f_s are fixed), the designer has two methods available. First, he can seek to minimize t_f and t_r by providing appropriate base drive. Second, designers can alter the switching waveforms by using snubber circuits.

1. Drive Circuit Optimization

Stored minority carriers in the base region are the cause of bipolar transistor storage and, to a lesser extent, fall times. Fall time, as seen above, relates directly to switching power dissipation. Storage time, while typically having little effect on power dissipation, must nevertheless be controlled in order to avoid problems of flux imbalance and poor dynamic response with some topologies.

Designers commonly use two techniques to minimize stored-charge-induced transition times. First, the amount of stored charge is kept low by driving the transistor with the lowest possible turn-on base current (i_{b1}). This current is usually chosen to drive the transistor just into "hard" saturation at maximum i_c in order to keep v_{ce} low and minimize on-state losses. Higher base currents would cause increased switching losses without significant improvement in on-state losses. When switching losses are extremely critical, as in high frequency circuits (see Equation 10), a Baker clamp is sometimes used to keep the transistor out of hard saturation altogether. Second, designers seek to remove from the base region as quickly as possible that stored charge which does develop. This is accomplished by reverse biasing the base-emitter junction during turn-off so that an electrical field is set up in the base region which acts to drive out the unwanted minority carriers. Storage and fall times are inversely related to both turn-off curent (i_{b2}) and voltage ($v_{be(off)}$), as shown in Figure 9.

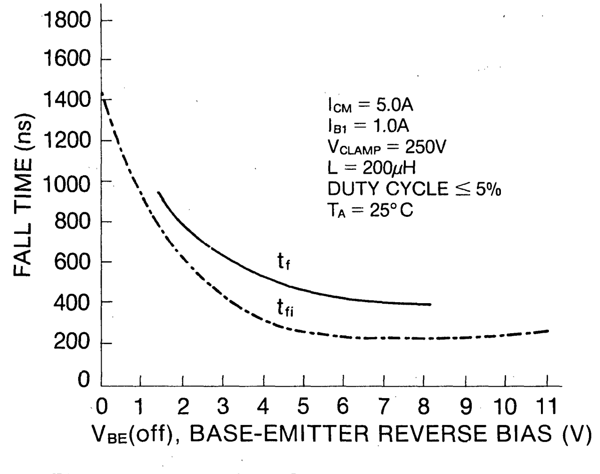


Figure 9 A. Typical Clamped Inductive Turn-Off Switching Times vs $V_{BE(off)}$

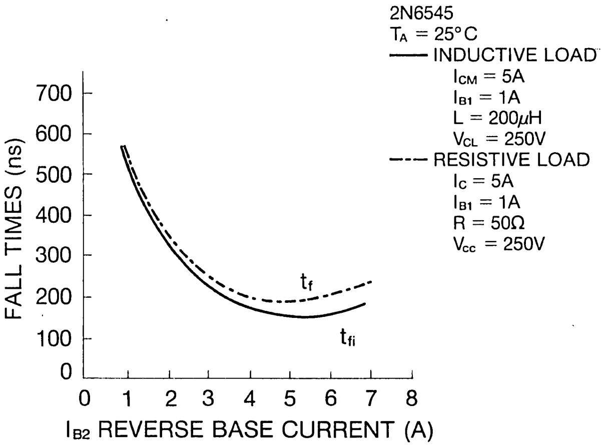


Figure 9 B. Typical Fall Times for Resistive and Clamped Inductive Loads as a Function of Reverse Base Current I_{B2}

This method must remain within the limitations of allowable on-state dissipation and base drive circuit complexity. Further improvements can result from innovative practices such as proportional base drive and "speed-up" capacitors.

2. Snubbers

Figure 10 shows a simple turn-off snubber used to limit switching power dissipation in the transistor by delaying the collector-to-emitter voltage rise until after the collector current has fallen. Power previously dissipated in the transistor is now lost in the snubber resistor R_S. This leads to improved transistor reliability, but does not increase overall circuit efficiency.

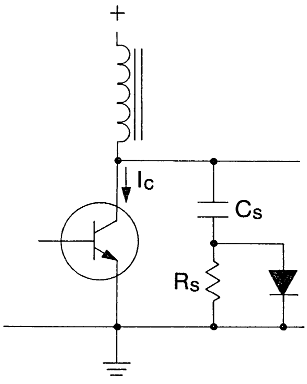


Figure 10 A. Turn-Off Snubber

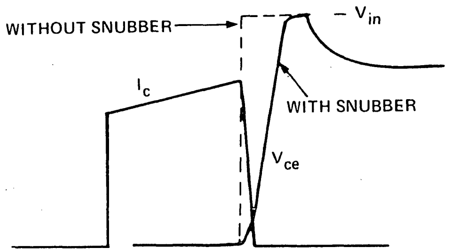


Figure 10 B. Effect of Snubber Network on Turn-Off Characteristics

Capacitor C_s holds v_{ce} low during current turn-off. Resistor R_s is designed to discharge C_s in less than the minimum transistor on time, $t_{on(min)}$. Hence, time constant R_sC_s is chosen to be one half of $t_{on(min)}$:

$$C_s = i_{c(max)} \cdot t_f / v_{ce(max)} \qquad \text{(Eq. 11)}$$

$$R_s = t_{on(min)} / 2\, C_s \qquad \text{(Eq. 12)}$$

Example - Transistor Losses in a Buck Regulator

To illustrate the relationships among transistor drive conditions, power dissipation, heat sinking, and reliability, we consider a typical transistor operated in the buck regulator circuit of Figure 7. We assume that the following worst-case conditions exist:

$V_{in(max)} = 400V$
$i_{c(max)} = 4A$
$f_s = 50kHz$
$t_{on(max)} = 10\mu s$
$T_{A(max)} = 80°C$

From Figure 4, it is apparent that 400mA of base drive is adequate to insure $v_{ce(on)} \lesssim 0.5V$ at $i_c = 4A$ and $T_J = 25°C$. Figure 3 indicates that this value could increase to 0.75V at $T_J = 150°C$, and that 1.2V is a conservative value for v_{be}. Therefore, from equation 3:

$$\overline{P}_{conducting} = 50kHz \cdot 10\mu s\,(4A \cdot 0.75V + 0.4A \cdot 1.2V) = 1.74W$$

Datasheet curves indicate that t_r and t_f will both be ~250ns. This assumes a turn-off base current (i_{B2}) of 400mA from a −5V source. From equation 10:

$$\overline{P}_{sw} = \frac{50kHz}{2} \cdot 4A \cdot 400V \cdot (250ns + 250ns) = 20W.$$

The total average power dissipation, which is clearly dominated by switching losses, is 21.7W.

$R_{\theta JC}$ for a typical transistor is specified as less than 1.4°C/W, and $R_{\theta CS}$ is ~0.2°C/W for a TO-3 package mounted with a thermally conductive paste.

Designing for a worst-case junction temperature of 150° C, we can expect a transistor MTBF of $7 \cdot 10^7$ hours (from Figure 1). The required heat sink is determined as follows, from equations A1 and A3:

$$150^\circ C = 80^\circ C + 21.7W \cdot (1.4 \frac{^\circ C}{W} + 0.2 \frac{^\circ C}{W} + R_{\theta SA})$$

$$R_{\theta SA} = 1.6 \frac{^\circ C}{W}$$

Figure A1 shows that with natural convection cooling (no fan), a 10 in^3 heat sink would be needed to fulfill this requirement. In order to reduce this volume, we consider using a turn-off snubber which can reasonably be expected to reduce total switching losses by 40% to 12W. Calculating as above, we obtain $R_{\theta SA} = 3.5\ ^\circ C/W$, requiring a 5.3 in^3 sink. The addition of a turn-off snubber can therefore decrease the required transistor heat sink volume by nearly one half. Conversely, keeping the same heat sink, the transistor can be operated cooler:

$$T_J = 80^\circ C + 13.7W \cdot (1.4 \frac{^\circ C}{W} + 0.2 \frac{^\circ C}{W} + 1.6 \frac{^\circ C}{W}) = 124^\circ C$$

Now a MTBF of $\sim 1.7 \cdot 10^8$ hours can be anticipated, so that the snubber improves transistor reliability by a factor of ~2.4.

MOSFETS

MOSFET power dissipation in a switching power supply is analogous to that of a bipolar transistor:

$$\overline{P} = \overline{P}_{conducting} + \overline{P}_{switching} \qquad \text{(Eq. 13)}$$

$$\overline{P} = \frac{t_{on}}{\tau} \cdot i_{d(on)} \cdot v_{ds(on)} + \frac{1}{2} \cdot \left(\frac{t_r + t_f}{\tau}\right) \cdot i_{d(on)} \cdot v_{ds(off)}$$

$$\overline{P} = f_s \cdot t_{on} \cdot r_{ds(on)} \cdot i^2_{d(on)} + \frac{f_s}{2} \cdot (t_r + t_f) \cdot i_{d(on)} \cdot v_{ds(off)}$$

where: $r_{ds(on)}$ = drain-to-source resistance in the on state

Values of $r_{ds(on)}$ for MOSFETs are of such a magnitude as to produce greater on-state losses than with the equivalent bipolar transistor operated in saturation. Furthermore, $r_{ds(on)}$ increases markedly with junction temperature, as illustrated in Figure 11. Note that $r_{ds(on)}$, and therefore on-state dissipation, doubles with an increase in junction temperature of 100° C.

Switching times, however, do not increase with temperature, as they do with bipolar devices. Low switching losses somewhat offset the high on-state MOSFET dissipation, particularly at high frequencies. Since MOSFETs are majority carrier devices, they are immune from stored-charge related switching constraints. MOSFET switching times are dependent on the rate at which the input capacitance, C_{iss}, can be charged or discharged by the gate drive circuit. Transition times of 10-20ns are readily achievable with MOSFETs driven from simple gate circuits. In practical power supply circuits, however, the designer must plan on somewhat slower MOSFET switching in order to avoid rectifier recovery problems. This will be discussed later.

With bipolar transistors, the power supply designer is faced with a complex trade-off among on-state losses, switching losses, drive circuit dissipation and complexity, and reliability. MOSFET designs are more straightforward, largely because on-state and switching losses can be independently optimized.

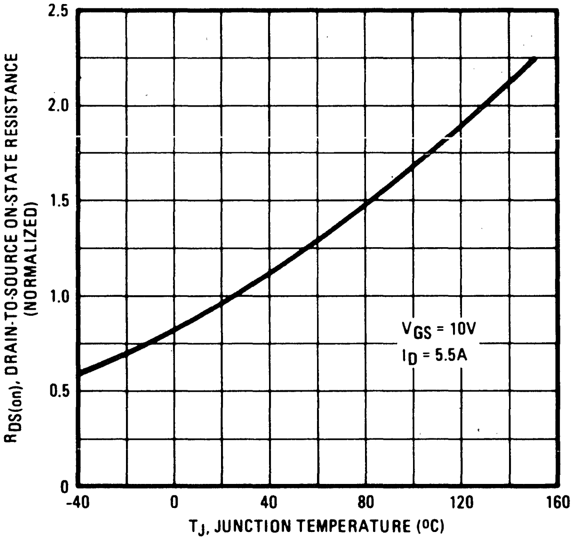


Figure 11. Normalized On-Resistance vs Temperature for UFN342

RECTIFIERS

Rectifier losses are given by the equation:

$$\overline{P} = i_f \cdot v_f \cdot \frac{t_{fb}}{T} + \frac{E_{sw}}{T} \qquad \text{(Eq. 14)}$$

where: t_{fb} = rectifier forward bias time per cycle

Expected values of v_f can easily be found from manufacturers' specifications and design curves. Calculating E_{sw}, however, requires careful consideration of rectifier reverse recovery characteristics. Figure 12 shows rectifier current and voltage waveforms during reverse recovery. Note that the voltage does not begin to fall appreciably until after the end of period t_a. Significant switching dissipation occurs only during t_b, so that:

$$E_s \simeq \frac{1}{2} \cdot v_{RM} \cdot i_{RM} \cdot t_b \qquad \text{(Eq. 15)}$$

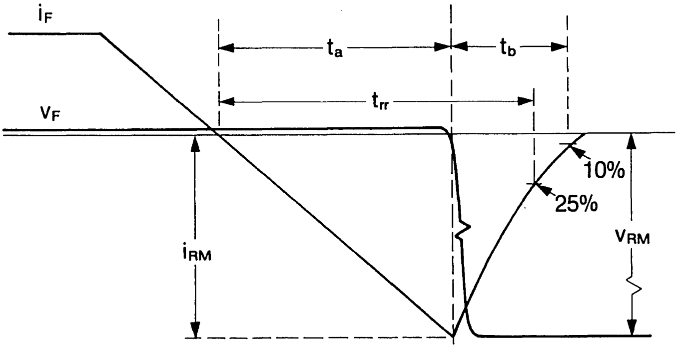


Figure 12. Rectifier Current and Voltage Waveforms During Reverse Recovery

As mentioned earlier, rectifier recovery can also cause increased power dissipation in switching transistors. In the buck regulator circuit of Figure 13 rectifier recovery results in a collector (or drain) current overshoot at turn-on. Since the collector voltage cannot fall until the rectifier is beyond transition period t_a, large power dissipation occurs in the transistor throughout that period. In Figure 14 cross-hatched area II corresponds to transistor switching dissipation in addition to the losses incurred due to t_{ri} (area I). Figure 15 shows how transistor switching losses are affected by the ratio of t_a to t_{ri}. Note that even when t_a is only $0.4 \cdot t_{ri}$, that switching losses are doubled.

Typical Circuit

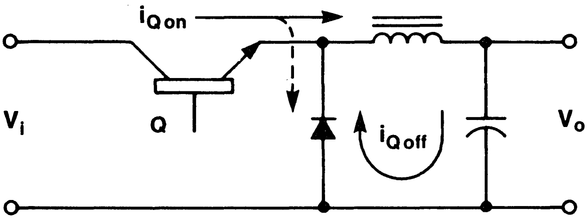


Figure 13. Buck Topology — Typical Circuit in Which Diode Recovery Affects Transistor Dissipation

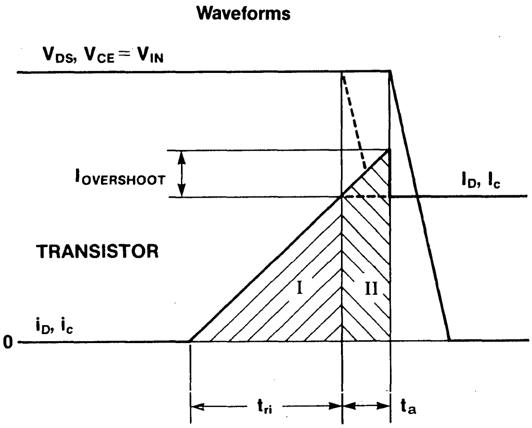


Figure 14. Additional Transistor Losses Due to t_a

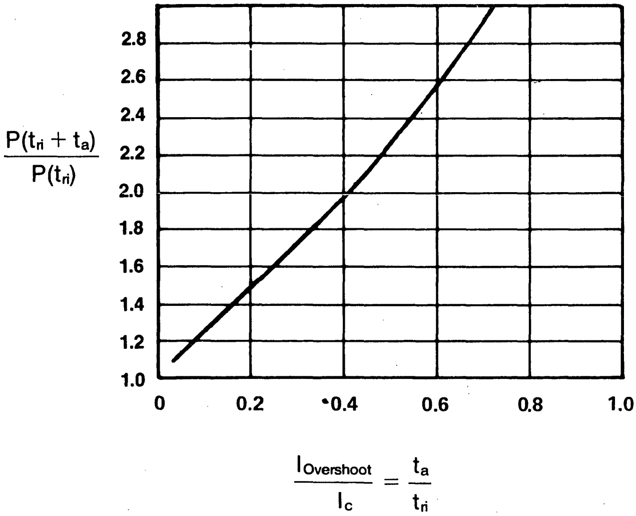


Figure 15. Relative Magnitude of Losses as a Function of t_a/t_{ri}

Rectifier manufacturers normally publish only a single t_{rr} specification, without separate indication of t_a and t_b. The ratio t_a/t_b can vary widely, but lacking other information, a value of 2 is a good approximation. But since transistor losses depend so heavily on t_a, designers may want to obtain more complete characterization as shown in Figures 16 and 17.

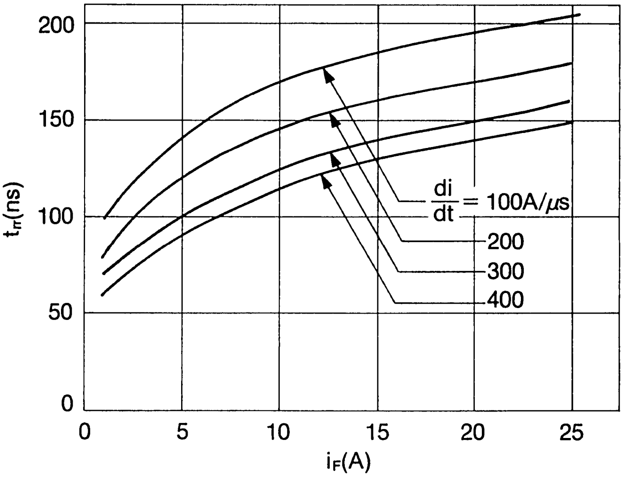


Figure 16. Typical t_{rr} vs i_F and $\frac{di}{dt}$ for a Fast Recovery Rectifier

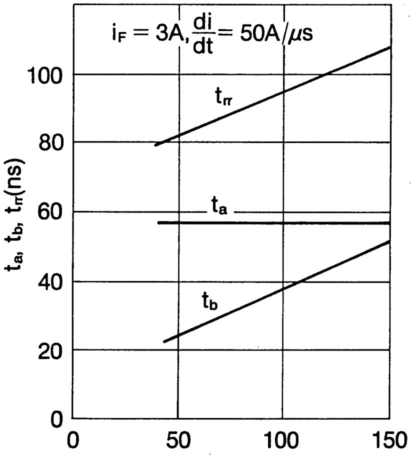


Figure 17. Typical Effect of Reverse-Bias Voltage on Relative Values of t_a and t_b During Rectifier Recovery

SECTION 2. OTHER FAILURE MODES

The previous section described how to design against unreliable semiconductor performance due to excessive average power consumption. The assumptions were made that the entire semiconductor junction or active region was at a safe temperature which varied little through the switching period. These assumptions allowed the use of the very simple time invariant thermal model of Appendix A. However, these assumptions can become invalid if a semiconductor is exposed to transient overheating conditions resulting from excessively high rates of change of current or voltage, or by extreme energy levels. Generalized time-variant thermal models can be developed for such situations, but are too complex to serve as useful design tools. Instead, designers address separately each such potential problem by relating circuit conditions to device ratings or safe operating area curves.

Voltage Spiking

One such potential problem relates to transient voltage "spiking" which can drive semiconductors into their highly-dissipative or possibly unreliable breakdown regions. This problem is particularly important when using Schottky rectifiers because their energy-handling capability when reverse biased can be significantly less than the forward biased capability. The usual approach to reliable designs when voltage spiking is possible is to limit the spike voltage, using clamps or snubbers, to a level below the rated breakdown voltage of the endangered semiconductor device.

Figure 18 shows a buck regulator circuit, in which the catch diode is susceptible to voltage spiking. During turn-on of power switch Q1, parasitic wiring inductance L_W charges to a peak current (i_{pk}) which exceeds the filter inductor current (i_L) by an amount determined by the t_a portion of the catch diode recovery time. After period t_a, the catch diode can no longer support that portion of i_{pk} which exceeds i_L, except by operating in the breakdown region. The solution is to provide an alternative current path through a snubber network as shown in Figure 18. This snubber also helps to reduce conducted and radiated RFI.

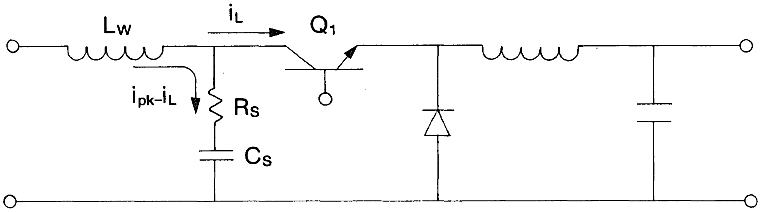


Figure 18. Snubber Prevents Catch Diode Breakdown

Bipolar $E_{s/b}$

During turn-off of an inductive load with a bipolar transistor, current crowding occurs at the center of each emitter region as illustrated in Figure 19. With conditions easily obtainable using typical switching power supply base-drive circuits, high current densities under the emitter region can cause severe localized heating. Under such conditions, the transistor can lose its ability to sustain its rated voltage and lapse into destructive second breakdown. The result is a collector-to-emitter short.

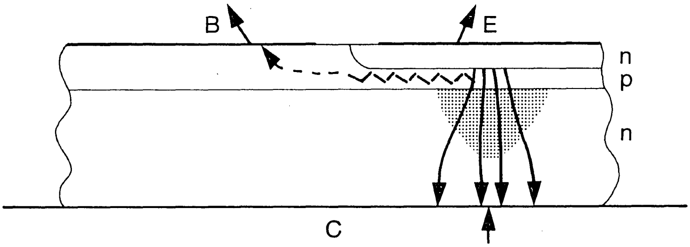


Figure 19. Reverse-Biased Current Crowding

The extent to which current flow is restricted depends largely on the turn-off reverse bias voltage and current across the base-emitter junction. Increased negative bias results in narrower current constriction. While $v_{BE(off)}$ determines the effective device area for dissipating inductive energy, the inductance value L determines the total amount of energy which is converted to heat within that area:

$$E = \frac{1}{2} L i_c^2 \text{ (for unclamped inductive switching)}$$

Therefore, transistor $E_{s/b}$ capability varies qualitatively as shown in Figure 20.

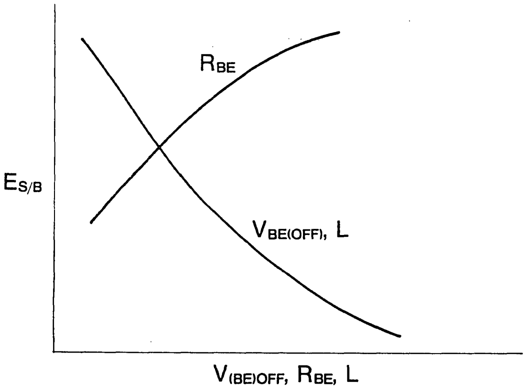


Figure 20. $E_{S/B}$ vs $V_{BE(OFF)}$, L, and R_{BE}

A device which has failed due to $E_{s/b}$ can often be identified, after the fact, by observing the damaged die with a microscope. A localized damage area which has its center near the middle of an emitter "finger" is evidence of $E_{s/b}$ failure. Figure 21 shows an example of this kind of damage.

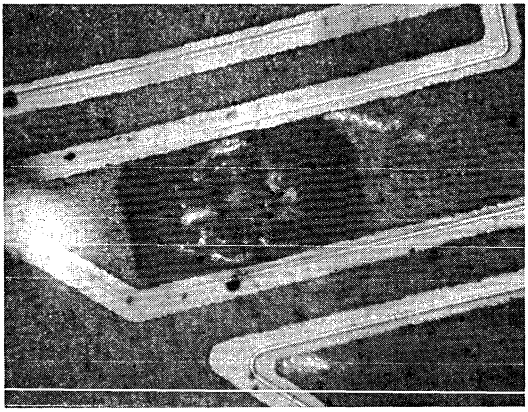


Figure 21. Photomicrograph of Damage Due to $E_{S/B}$

Transistor manufacturers supply several pieces of information which can be used as guides to preventing $E_{s/b}$ failure. First, a minimum "unclamped $E_{s/b}$" specification is sometimes given. This figure guarantees that the given amount of inductive energy can be safely dissipated by the transistor for a specific set of turn-off conditions. Designers must keep in mind, however, that $E_{s/b}$ capability will vary with base drive parameters as shown in Figure 20.

Often, in switched-mode converters, the unclamped $E_{s/b}$ capability of the power transistor is inadequate to handle the highly inductive load. In these cases, designers provide a voltage clamp which diverts inductive energy while keeping the collector-to-emitter voltage below the level sustainable by the bipolar transistor. Figure 22 illustrates the use of non-dissipative clamps in a two-transistor forward converter. Diodes D1 and D2 return inductive energy to the input supply.

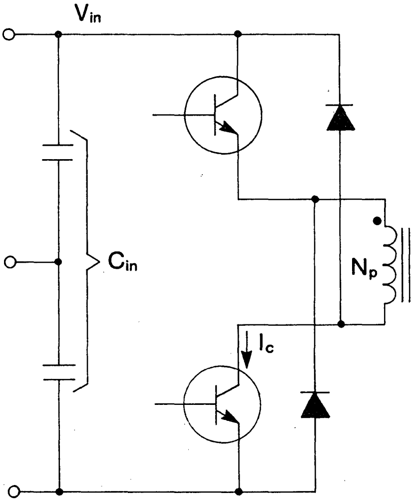


Figure 22. Two-Transistor Forward Converter With Non-Dissipative Voltage Clamps

The second manufacturers' specification relating to $E_{s/b}$ capability is a "sustaining voltage" figure ($V_{cex(sus)}$) for clamped inductive turn-off. This specification puts an upper limit on the allowable clamp voltage for reliable operation of the transistor. Again, however, this figure applies to a particular set of turn-off bias conditions.

A more general characterization is provided by the "reverse biased safe operating area" (RBSOA) curve, shown in Figure 23. This curve essentially defines clamping voltage requirements at collector currents up to the DC current rating of the device. Using this curve, designers can design against potential $E_{s/b}$ problems. Although less conservative, the $V_{cex(sus)}$ specification can be used if the turn-off bias condition applies.

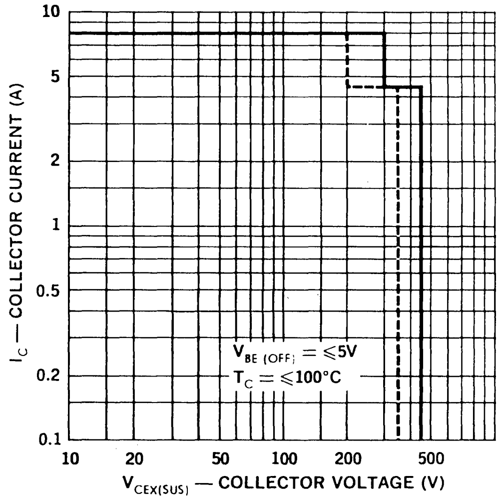


Figure 23. Reverse-Biased Safe Operating Area for a Typical Transistor

Bipolar $I_{s/b}$ and FBSOA

Figure 24 shows "forward biased safe operating area" (FBSOA) curves for a typical transistor under DC or pulsed operation. These curves are a guide to reliable transistor operation in the unsaturated "on" state and during a slow turn-on. (As such, they are often not critical in switching power supply applications.) Three distinct segments of these curves each correspond to a limit imposed by a specific potential failure mechanism.

Region I (Figure 24) is a device limitation based on the fusing characteristics of the collector bond wire. With low v_{CE}, this wire can melt due to resistive heating at current levels which will not cause damage to the semiconductor die. Operation of the transistor below its rated collector current will prevent this type of failure.

At higher voltages, power dissipation (as discussed in Section I of this paper) becomes the limiting factor for reliable operation. In region II, the FBSOA curves follow lines of constant power dissipation. The line for DC operation will vary in position somewhat as a function of thermal mounting condition.

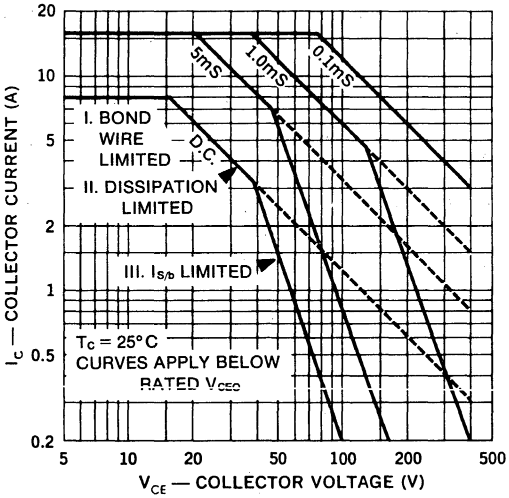


Figure 24. Forward-Biased Safe Operating Area for a Typical Transistor

Finally, in region III, FBSOA is further reduced by forward biased second breakdown ($I_{s/b}$) limitations. Under forward biased operation at high collector-to-emitter voltages, current crowding occurs beneath the periphery of each emitter finger, as shown in Figure 25. High current densities in these areas can result in "hot spots". As with the reverse biased case ($E_{s/b}$), excessive localized temperature extremes can result in destructive second breakdown. The current $I_{s/b}$ at which this can occur varies inversely with v_{CE}. Manufacturers determine the position of the FBSOA curve in region III by taking many devices to second breakdown under a number of v_{CE} and pulse width conditions. A guardband is applied to the results to ensure reliable operation within FBSOA curves.

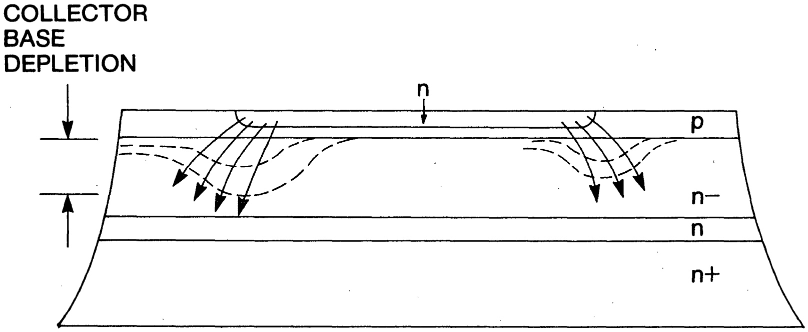


Figure 25. Forward-Biased Current Crowding

A transistor which has experienced $I_{s/b}$ failure may be identifiable by a damaged die area which centers on an emitter finger edge, as shown in Figure 26.

Figure 26. Photomicrograph of Damage Due to $I_{S/B}$

As noted, transistor operating points in switching supplies usually fall well within the area defined by the FBSOA curves. In many topologies, transformer leakage inductance delays turn-on current rise until v_{CE} has fallen, thus preventing operation near the $I_{s/b}$ limit line. With those topologies for which this is not the case, a small inductor ($<100\mu H$) can be purposely connected in series with the collector to serve as a turn-on snubber. Figure 27 illustrates this technique.

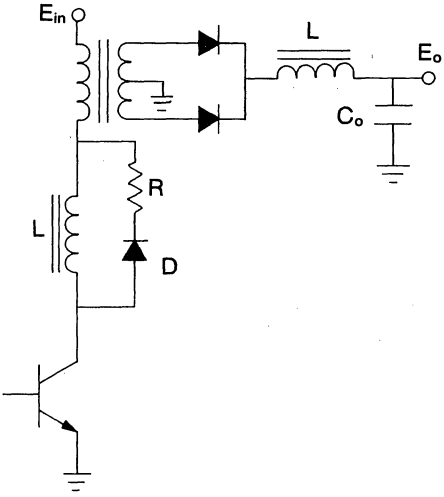


Figure 27. Turn-On Snubber

POWER MOSFET $\frac{dv_{ds}}{dt}$

A highly touted advantage of power MOSFETs is that their safe operating area curves are not limited by second breakdown considerations, as is shown by Figure 28. However, with the high currents and short pulse widths typical of switching power supplies, a MOSFET parasitic effect can limit the user's ability to utilize the entire "SOA". Figure 29 shows a parasitic npn transistor which can cause problems when a MOSFET is operated at high turn-off dv_{ds}/dt.

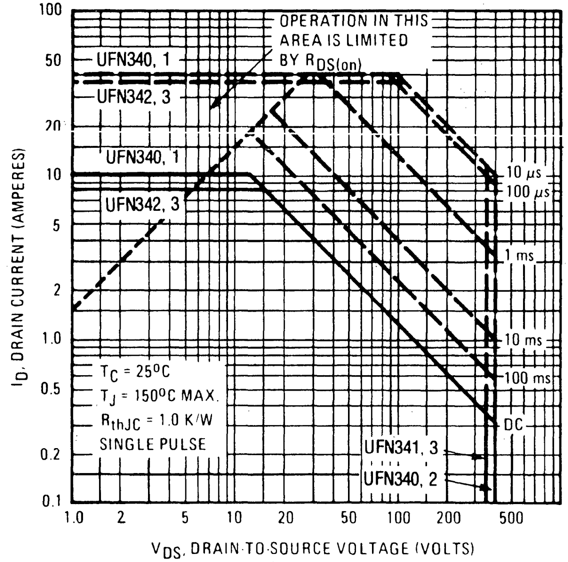


Figure 28. MOSFET Safe Operating Area

If "collector-base" junction capacitance C_{cb} cannot be charged through shorting resistance R_{be} at the desired rate of dv_{ds}/dt (= dv_{ce}/dt), the "base" voltage v_{be} will rise. This can cause turn-on action in the parasitic npn which opposes the desired MOSFET turn-off. The initial effect is delayed turn-off, but observations show that with repetitive pulses second breakdown can occur.

This undesirable effect can be minimized by keeping shorting resistance r_{be} low. Unitrode power MOSFETs use a hexagonal geometry which is optimal for achieving low r_{be}, and have far better dv_{ds}/dt capabilities than do devices with other constructions.

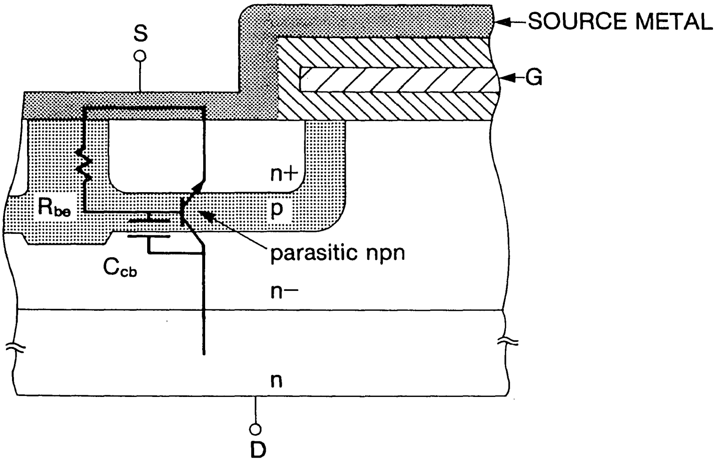


Figure 29. Power MOSFET Construction Showing Parasitic npn

Power MOSFET Gate Voltage

Power MOSFETs are constructed with a very thin (~1000A°) dielectric oxide between the gate and source. Because of its thinness, this oxide is unable to withstand large gate-to-source voltages, and most manufacturers have ±20V ratings for this parameter. MOSFET gates are highly susceptible to damage caused by transient circuit voltages or electrostatic discharge. This is particularly true of low-current devices, because their small die have low gate-to-source capacitance. Evidence of this type of failure includes high gate-to-source leakage current (I_{GSS}) and degraded transfer characteristics ($V_{GS(th)}$, g_{fs}).

A simple method of protecting against gate oxide breakdown is to clamp the gate-to-soure voltage with an avalanche breakdown transient suppressor such as the Unitrode TVS315 (see Figure 30). This device will clamp positive gate transients to approximately 18V, without leading-edge overshoot.

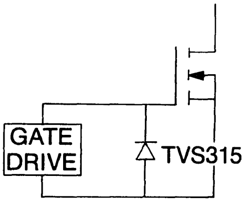


Figure 30. MOSFET Gate Protection

Selecting and Applying Rectifiers for Optimum Performance In Switching Power Supplies

Fred Blatt

Abstract:

Rectifier behavior pertaining to switched mode power supply applications is examined. Characteristics important to rectifier selection and other relevant factors are reviewed in the context of several important applications.

General Perspective

To achieve smaller and less noisy power supplies, switching power converters are being designed with shorter transition times and higher switching frequencies. Historically this has required overcoming various limitations which have impeded progress. These usually appeared sequentially; solving one problem allowed a step-wise advance. Each step might allow increasing the switching frequency or power level until another limiting cause arose. In this process the limiting characteristics of various components have eventually been overcome. Power supply circuits have also been improved and new topologies developed. Some of the advances that have taken place are:

- faster, more efficient bipolar transistors
- high efficiency ultra-fast recovery rectifiers
- power Mosfets
- integrated control circuits
- rugged Schottky rectifiers
- low ESR output capacitors
- surface-mount construction
- resonant converter designs
- high voltage ultra-fast rectifiers

Rectifier Limitations

As switching frequencies increase (and as output power at a given frequency increases), rectifiers may be a limiting component. Their recovery times can impose an extra burden on the Mosfet switch during turn-on. In resonant converters a similar situation may exist, but at much higher frequency. Clamp diodes (in bridge inverters, etc.) and output rectifiers for medium and high voltage supplies can have losses or noisy transient voltages which are more important than DC losses. These problems and their causes are reviewed herein, and some solutions are discussed.

Forward conduction losses: One limitation of swithcing power supply output rectifiers is that of forward losses. In the popular full-wave configuration, rectifiers are conducting either alternately or together at all times. The rectifiers in any buck derived topology, including push-pull and forward converters, conduct the full output current, I_O. Thus the DC loss equals $V_F \cdot I_O$. Forward conduction losses are higher in flyback converters, since conduction is for only a fraction of each cycle so that peak current (and associated V_F) are necessarily higher.

Forward conduction losses limit the overall power conversion efficiency. This is a substantial limitation when the output voltage, V_O, is low. Even a Schottky rectifier, with typical V_F of 0.6V, introduces a loss of 12% of the output power in a 5V supply, 20% in a 3V output. Designs covering the military range of input voltages typically specify a peak inverse voltage rating of 7 times V_O. This limits the use of most Schottkys to 5V outputs--those with PIV above 45V are less popular and have higher V_F approaching the high efficiency, ultra-fast PN junction devices which have the additional benefits of lower reverse loss, lower capacitance and higher operating temperature.

When used in a 15V output, a conventional fast recovery type (1.2V forward) loses 8%; the high efficiency PN loses 5.3%. In higher voltage applications, forward current is usually lower, so this DC loss is of less concern than losses from other components. However, other rectifier losses, transient voltages, and noise generation may be more significant.

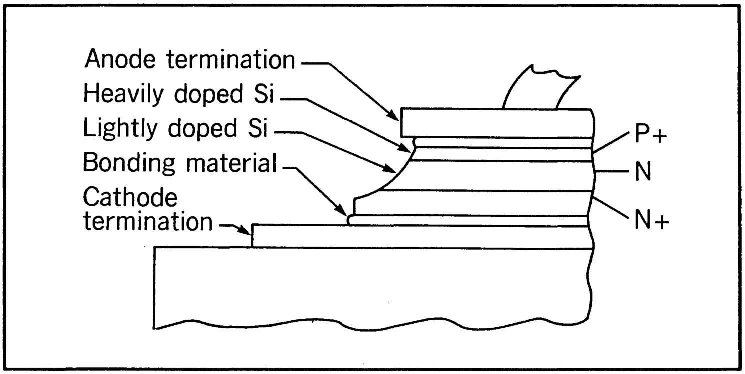


Fig. 1 - Section of Typical Power Rectifier

Reviewing semiconductor rectifier basics: In metals typically used for wiring or interconnections, electrical conductivity is high. Current flows readily because electrons move freely under the influence of a very small electric field associated with a small potential across the conductor.

Semiconductor materials such as silicon have resistivities that are *much* higher than a metal. The high resistance region of a rectifier is shown in Fig. 1 as N type silicon, and in the model of Fig. 5 as "r_V",- a variable resistance. (The N+ and P+ regions in Fig. 1 are heavily "doped" which greatly reduces their resistance.) The resistance, r_v, changes dramatically as a function of applied forward current. When a positive voltage is applied to the P+ (anode) region, minority carriers ("holes" from the P+) are injected into the N layer, greatly reducing its resistance. This mechanism is called "conductivity modulation"--it creates an excess of minority *and* majority carriers in the N region. Semiconductor devices would not be practical without this fundamental benefit.

A penalty must be paid for this benefit, however. The minority carriers contribute a charge, $Q_F = I_F \cdot t_L$, which is stored in the high resistivity N region. This charge must be removed either by recombination or by sweep-out before the device can subsequently achieve a reverse blocking capability. When the forward current (anode +) is terminated, the excess majority and minority carriers will gradually decay by recombining. The time constant of charge recombination is called the "lifetime", t_L, of the minority carriers. This lifetime will depend on the device design and wafer processing. Stored charge removal can be hastened by applying a reverse current to the device. This "sweeps out" stored charge by mechanisms opposite to those which created the charge with forward current flow.

Referring to Fig. 2, both recombination and sweep out are at work during interval t_a if appreciable reverse current, I_{RM}, is present. During interval t_b, recombination is the dominant mechanism.

Reverse recovery behavior: Popular power circuit topologies impose *current* through the rectifier which ramps up and down as a function of external circuit values. The ramp-down in current during the forward to reverse transition is shown in Fig. 2, as well as the resulting voltage across the device. This is an example of the general case where I_{RM} is limited by the rectifier lifetime, rather than by other circuit constraints. The effects of this behavior on a typical circuit (catch diode, output rectifier, high voltage clamp etc.) are discussed by analyzing the waveform in three parts: t_f, t_a, and t_b.

t_f interval: During time t_f, the *circuit* typically switches from forward to reverse polarity but the rectifier will not feel reverse voltage until near the end of t_a. di/dt and t_f are determined by circuit inductance and transistor fall time.

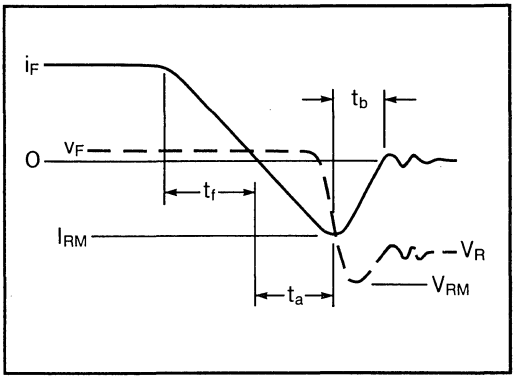


Fig. 2 - Reverse Recovery I/V Waveforms

t_a interval: During t_a the current has reversed, but the rectifier remains a very low resistance. Charge (minority carriers) stored before and during t_f must be swept out before reverse voltage can appear across the device.

During t_a the switch turns on while current is highest (output current plus I_{RM}). In a buck-derived regulator, this occurs with high voltage across the switch, causing high peak power dissipation. It will help to reduce I_{RM} by:

a. Using a faster rectifier (If not characterized under conditions similar to the intended use, be sure to compare devices under identical test conditions), and

b. Increasing t_f. This is done by not turning the Mosfet on any faster than necessary. It is often better to have more power dissipated in the switch and avoid the high I_{RM}.

Keeping I_{RM} low has the additional benefit of reduced snubber needs, lower transient voltage generation, and reducing the switch drive requirements.

With a moderate switching time relative to the recovery time of the rectifier, I_{RM} will be less than I_F. Under these conditions t_a is constant, equal to the lifetime, and not varying with di/dt, or even with I_F if the device temperature is constant. I_{RM} will thus be proportional to di/dt.

Significantly faster switching will make I_{RM} much greater than I_F and approach the condition where Q_a equals Q_F, the charge stored by I_F. In this case t_a will decrease somewhat and, although I_{RM} may be undesirably high, it will not increase as fast as di/dt.

For various switching conditions it is helpful to characterize I_{RM} vs. di/dt (or vs. current rise time), as in the data sheets for the recently introduced UHVP types. Measurements require current sensors with extremely low inductance, otherwise I_{RM} will appear incorrectly high.

t_b interval: The characteristic waveshape, soft or abrupt, as shown in Fig. 3 during t_b, will affect device heating and circuit behavior (generation of transient voltages and circuit noise). The waveshape is influenced by both device design and circuit interaction.

Device effect: Diffusion profiles including concentration gradients, resistivity and width of the high resistance region have a major influence on the t_b value and shape. Soft recovery is more common in high voltage rectifiers, where it is more difficult to implement an abrupt design .

An example of device design for a specific purpose is the "multiplier diode": long lifetime (t_a) and an abrupt characteristic are combined to produce a device capable of shock exciting a resonant tank circuit, which then rings, providing output at a multiple of the pulse driving frequency.

Although soft recovery is desireable relative to damping transients it causes more device heating which in turn increases t_a and I_{RM}. It is important that total dissipation be compatible with available heat sinking to maintain thermal stability.

Abrupt recovery devices have the advantage of dissipating less power during recovery and should thus be operable at higher frequencies than otherwise equivalent soft types. However more electrical noise may require filtering and cause a higher peak voltage, V_{RM}, which must be examined to ensure it will not impair the reliability of the switch or the rectifier by driving them into the breakdown region. These problems are controllable by snubbing; energy is then absorbed in a resistor instead of heating the rectifier, or the snubber energy is partly returned to the circuit.

Whether the goal is a soft or an abrupt characteristic, a trade-off in other features is to be expected--refer to Fig. 3.

POSITIVE AND NEGATIVE FEATURES

SOFT	ABRUPT
+ LOW TRANSIENTS	+ LOWEST LOSS
+ LOW NOISE	(Lower Tj)
	+ LESS EFFECT ON
- MORE INCREASE OF	trr AT HIGH Tj
trr AT HIGH Tj	
- HIGHER LOSSES	- TRANSIENTS
(Higher Tj)	- NOISIER

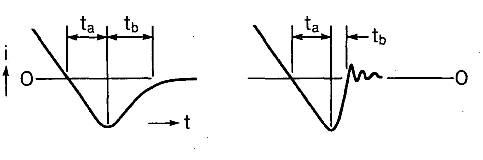


Fig. 3 - Recovery Characteristics and Features

Circuit effect: The circuit layout (loop inductance, other parasitics) influences t_b appreciably; lower inductance decreases it, making the device appear more abrupt. Transients will not increase, however, because less energy is stored in the lower inductance. Ringing frequency, where loop inductance resonates with device capacitance, will be higher.

Measurements of t_b are difficult to duplicate on different test kits. This is partly due to differences in the circuit layout, and to the choice of reverse voltage. Higher voltage results in appropriately higher t_b values. For good test repeatability, reverse voltages of 30 to 50V are often used, even though t_b may be less than expected in high voltage circuits.

TABLE I

Rectifier Power Dissipation during Reverse Recovery

						Total power		Reactive power		$\frac{P_{xc}}{P_{rr}}$
						pulse	avg			
Device Type	A	V	IRM A_{pk}	t_a ns	t_b ns	p_{rr} W_{pk}	P_{rr} W_{avg}	C_j pf	P_{xc} W_{avg}	
UES	2.5	150	1.5	15	5	45	.022	5	.0036	.16
UHVP	2	900	3	30	10	540	0.54	1.5	.039	.072
UES	6	150	4	40	12	120	0.14	15	.011	.077
UES	70	150	7	75	25	210	0.52	150	.11	.21
USD	75	45	6	60	60	54	0.32	4700	.30	.95

Conditions: I_F = rating, di/dt = 100 A/µs.
V_{RM} = 0.8 rated PIV -- no overshoot.
f = 100kHz. Typical t_{rr} such that I_{RM}, t_a, and t_b will be as noted.

Estimating P_D during t_{rr}: Dissipation during reverse recovery occurs during time t_b, causing device heating. It may be computed by integrating the instantaneous recovery power during a typical recovery interval:

$$p_{rr} = \frac{1}{t_b}\int^{tb} i \cdot v \, dt$$

Approximating with triangular waveforms this simplifies to:

$$\text{Pulse power, } p_{rr} = i_{RM} \cdot v_{RM}/4 \qquad (1)$$

$$\text{Avg. power, } P_{rr} = p_{rr} \cdot t_b/T = p_{rr}t_bf \qquad (2)$$

where f = rectifying frequency

T = 1/f = period

This P_{rr} value is the total apparent power. It includes the energy stored per cycle in the junction capacitance which is returnable to the circuit. In practice this returnable energy is usually dissipated in the transistor and snubber resistor. The power dissipated in the rectifier, P_D, is P_{rr} minus this "reactive power". For PN junction devices this will not be an appreciable part of the total. Table I shows examples for several fast devices, including a Schottky rectifier (USD). The I_{RM} for the Schottky is largely due to its high capacitance.

Note that C_j is dependent on V_R. A reasonable simplification uses $C_{j(avg)} = C_{j(@10V)}/N$, where N = 3 for UES types, 4 for UHVP, and 0.75 for Schottky USD.

$$\text{Reactive power, } P_{xc} \approx C \cdot V^2 \cdot f/2. \qquad (3)$$

Snubber design: Snubbers reduce V_{RM}, noise, and device heating. Peak recovery voltage, V_{RM}, is a result of the series resonant circuit composed of device capacitance and circuit inductance. For a Schottky rectifier in a full-wave output circuit, C is C_j and L is the transformer leakage inductance referred to the *full* secondary. In PN junction devices, charge recovered from minority carriers is a major portion of the effective C.

An optimum RC snubber can be designed for critical damping–with a loaded Q_L = 0.5. Using the optimized approach to compute the snubber component values, R_{snb} and C_{snb},

$$Q_L = R_{snb}/X_L = 0.5.$$

where X_L is the inductive reactance.

$$R_{snb} = \frac{1}{2}\left[\frac{L}{C}\right]^{1/2} \qquad (4)$$

The snubber capacitor, C_{snb} is used to block the dc voltage present (refer to Fig. 4). Its value should be at least ten times the junction capacitance:

$$C_{snb} = 10 \cdot C_j \qquad (5)$$

To transfer the power effectively from the input source to the output load, the time constant ($R_{snb}C_{snb}$) should be less than 1/10 the minimum pulse width of the converter. Since

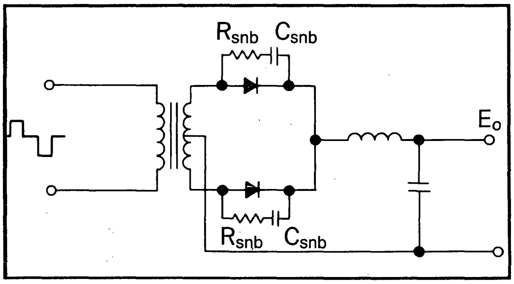


Fig. 4 - Output Circuit Snubbers

this occurs at maximum input voltage, $V_{in\ max}$,

$$R_{snb}C_{snb} \leq (V_{in\ min}/V_{in\ max})/(20f) \qquad (6)$$

and the power dissipated in the resistor is, for a half bridge:

$$P_R = \tfrac{1}{2}C_{snb}f(V_{in\ max}/n)^2 \qquad (7)$$

where n is the transformer turns ratio. In the general case where L is not known, or with any functional circuit, an experimental approach to defining snubber values may be practical. This is especially true for abrupt PN devices, where t_b is much less than t_a.

However, measuring (transient) V_{RM}, I_{RM}, and t_b can help to implement an optimum design. The loop inductance and effective capacitance, including stored charge effects, can be computed:

$$L = V_{RM}\cdot t_b/i_{RM} \qquad (8)$$

From $Q = C\cdot V = I\cdot t$ and simplifying by assuming a triangular waveform,

$$C = \tfrac{1}{2}I_{RM}(t_a + t_b)/V_{RM} \qquad (9)$$

This is the effective Cj.

Equations (4) and (5) may be used to compute the snubber values with L and C values from (8) and (9). Some fine tuning may be necessary. The intent is to increase t_b without significantly increasing i_{RM}, thus reducing v_{RM}.

Forward recovery behavior -- cause, effect and optimization: The resistance of a semiconductor diode, in the general steady state case, is dependent on the bias developed by the circuit. Resistance is lowest when conducting high forward current and highest when blocking reverse voltage.

However, if a steeply rising forward biasing current is applied to the circuit, a PN junction device will initially have a high resistance, $r_{(t)}$, the limit of which depends on device design. The forward voltage during this transient interval:

$$v_F = i_{(t)}\cdot r_{(t)}$$

The value of $r_{(t)}$ decreases with time because as soon as current starts to flow conductivity modulation begins. This is the process of injecting minority carriers -- the resistance is lowered very quickly such that the instantaneous forward voltage in many practical circuits often has little, or no, overshoot. The maximum initial $r_{(t)}$ value is:

$$r_{(t)\ max} = \rho\cdot w/A \qquad (11)$$

where ρ = resistivity of the lightly doped (or bulk) region.
w = width of the region where the resistivity = ρ
A = area of the plane through the w region.

The complete rectifier model is shown below. During the forward recovery period r_v has a major influence. L_{pkg} and C_j can play an additional, usually minor, role.

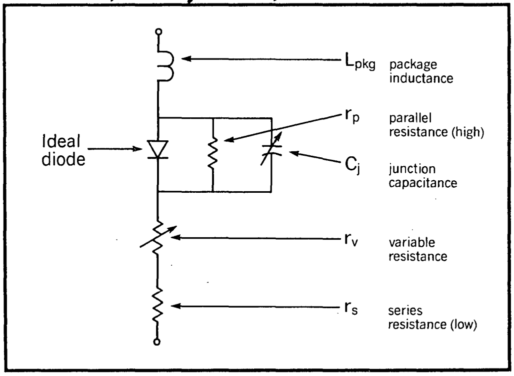


Fig. 5 - Rectifier Model

When the circuit driving forces are significant (high compliance voltage, low inductance and fast switching rate) the current turns on quickly (e.g. over 50 mA/ns) and a transient forward voltage exceeding the usual measured dc V_F value will decay to nearly this dc value during the "forward recovery time". This is usually between 10 and 200 ns, depending on device design. Forward recovery time is usually less than the reverse recovery time, although not directly related to it. Fig. 6 shows the forward recovery characteristic.

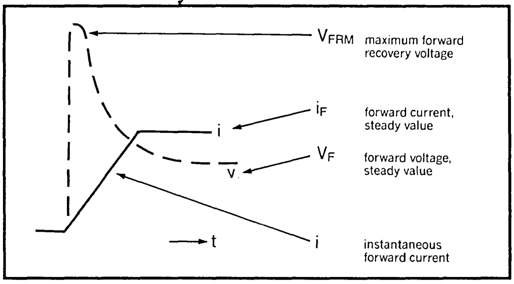


Fig. 6 - Forward Recovery Waveforms

where:

v_{FRM} = maximum forward recovery voltage
I_F = forward current, steady value
V_F = forward voltage, steady value
i = instantaneous forward current

In low voltage, low energy applications, or in circuits with compliance voltage less than v_{FRM}, this phenomenon can even delay the rise of forward current until sufficient charge has been injected (conductivity modulation) to reduce v_F. Generally this condition is limited to fast, low voltage logic circuits or to poorly chosen devices in medium power circuits.

In well-designed rectifier circuits the limiting v_{FRM} is well below the compliance voltage so there is no delay in current rise time attributable to the rectifier. This is even true for most low voltage output circuits (5V), where higher pulsed compliance voltage is available due to the inductance of circuit elements (output inductor, transformer inductances, etc).

Devices with high forward recovery voltage: Equation (11) shows that wide base width and high resistivity worsen the forward recovery characteristic. However, these are device design parameters required to achieve high reverse breakdown voltage. Fortunately these factors can be optimized for particular requirements; This is not normally done for reasons of device standardization and lower manufacturing costs.

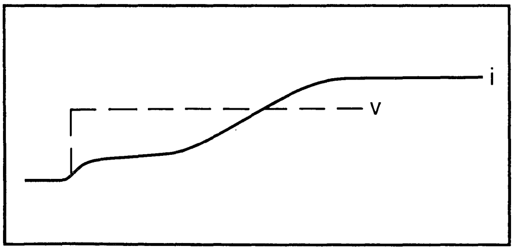


Fig. 7 - Turn-On with Low Compliance Voltage

It is particularly important to optimize ultrafast reverse recovery, high voltage device types because reducing minority carrier lifetime may significantly increase v_{FRM}. Unitrode recently introduced the UHVP product line, with optimized forward recovery and other features.

Applications likely to have forward recovery problems: Rectifier applications which experience high di_F/dt and which require high reverse blocking voltage capability are most likely to have significant forward voltage overshoot. An example is the clamp diode in an "off-line" half-bridge (or full bridge) inverter, particularly when transistor switches with fast current rise times are used.

Misapplications (usually unintended), where the best device has not been chosen, are also candidates for high v_{FRM}. It is common semiconductor industry practice to "downgrade" devices that are really designed for higher PIV. Also, users seeking high reliability often specify higher voltage devices than required. These practices cause problems not only in the high voltage clamp application—they also generate undesirable transients in low voltage output rectifier and catch diode applications. This, in turn, requires higher voltage switches and/or wider use of turn-off snubbers or transient suppressing components.

Selecting the Best Device

This section focuses on those characteristics which will optimize performance in a specific application. Thus, when there is a range of devices with appropriate current and voltage ratings to choose from, the circuit designer can rank the desireable characteristics for each major usage. First, however, we should review the effects of each characteristic:

- Low forward voltage, V_F. Keeps losses low, and efficiency high—most relevant to high current, low voltage applications.
- Low peak recovery current, i_{RM} , *and* the related (low)
- Reverse recovery time, t_{rr}. Limits Transistor peak drain/collector current and dissipation during turn-on. Important when the diode is reversed directly from

forward conduction with high di_F/dt.

- Recovery softness factor, RSF, defined as t_b/t_a. High values result in smaller voltage transients and less noise generation but more dissipation; low values give less device heating (most relevant to high voltage applications) but more snubbing may be needed.
- Low forward recovery voltage, v_{FRM}. Limits forward voltage peak when forward current is applied rapidly. Most relevant in clamp functions, especially with high PIV devices and with some ultra-fast types.
- Reverse (leakage) current, I_R. Of concern only at high junction temperature in high voltage applications. The added dissipation may cause thermal runaway or raise the junction temperature to the point where t_{rr} or reliability is undesirable.

Typical applications are shown below. Voltages in common practice are noted, relevant characteristics are ranked, and recommended device families are given.

Device Family Descriptions

UBS:	Synchronous rectifier ("BISYN")
USD:	Schottky rectifier. USDx45, 1N6391-2, 1N6492. USD7525 is low V_F, 25V.
UES:	High efficiency ultra-fast rectifier. Families to 200V & 400V, including 1N5802 – 1N5816, 1N6304 – 1N6306.
UHVP:	High voltage (families to 1000V), ultra-fast (35, 50 ns), with low v_{FRM}, low high-temp I_R, and softer recovery than UES. Includes 1N6620 – 1N6631.

Rectifier Comparisons

	UBS	USD 25V	USD 45V	UES 150V	UES 400V	UHVP
PIV	5-6	5	4	3	2	1
V_F	1a	2	3	4	5	6
t_{rr}	6	1b	1b	1	2	2-3
V_{FRM}	---	1	1	2	6	3-5
I_R	3	4c	5c	2	6c	1

Grade 1 is best

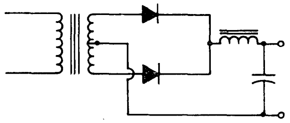
a. Above continuous I_F rating, USD is lower.

b. Effective recovery time for Schottkys.

c. High temp leakage--can result in lower max operating temp. at high voltages.

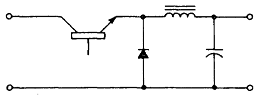
Rectifier Applications

OUTPUT RECTIFIER:



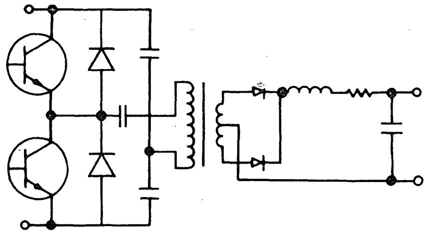
V_{out} =	4V	5	24	48	Higher
req. PIV:	25	45	150	400	600+
Rank:	V_F t_{rr}	V_F t_{rr} V_{FRM}	t_{rr} RSF V_{FRM} V_F	t_{rr} V_{FRM} RSF	t_{rr} I_R RSF V_{FRM}
Pref. Types:	UBS USD	USD	UES	UHVP UES	UHVP

CATCH DIODE:



V_{in} =	25V	85	150+
req. PIV:	45+	150+	300+
Rank:	t_{rr} V_F	t_{rr} V_{FRM} RSF	t_{rr} RSF V_{FRM} I_R
Pref. Types:	USD UES	UES	UES UHVP

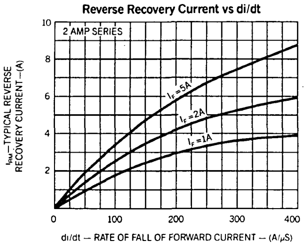
CLAMP DIODE:

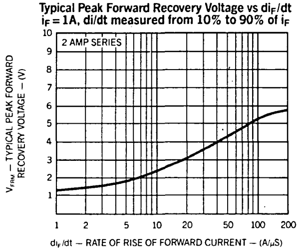


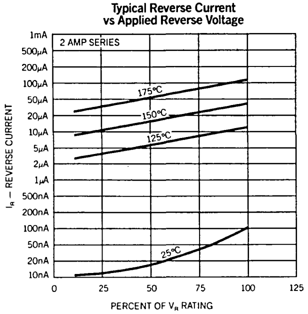
Bus Volts =	350-700V
req. PIV:	>1.3•BusV
Rank:	V_{FRM} I_R t_{rr}
Pref. Types:	UHVP

EXAMPLES OF DESIRED CHARACTERISTICS FOR RECOMMENDED DEVICES:

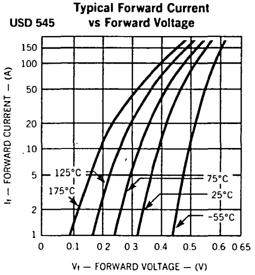
I_{RM}, V_{FRM}, and I_R of 600V, 2A UHVP (AXIAL TYPES)

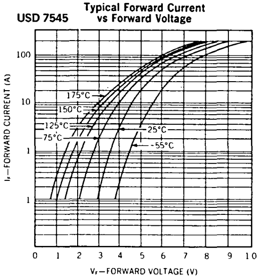


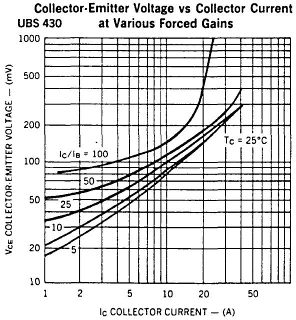




V_F of USD and UBS (CASE MOUNT TYPES)

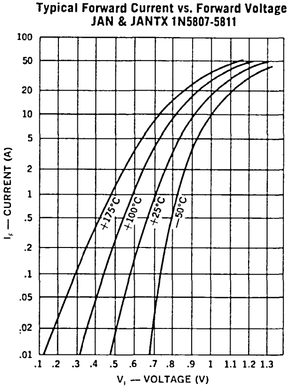


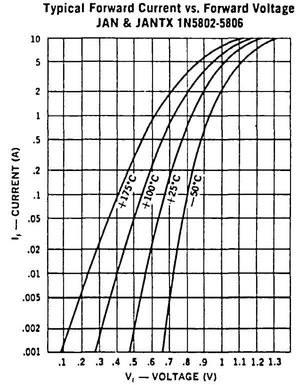


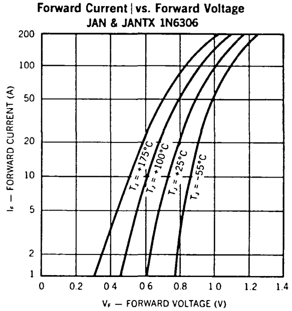


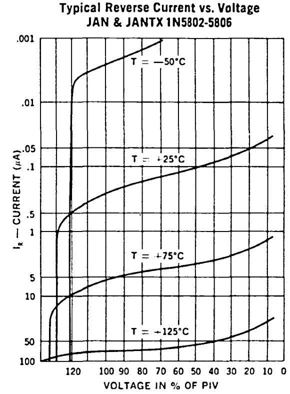
EXAMPLES OF DESIRED CHARACTERISTICS FOR RECOMMENDED DEVICES:

V_F of UES (CASE AND AXIAL MOUNT) and I_R (AXIAL)









PROTECTING CIRCUITS FROM TRANSIENT ENERGY SOURCES

Transient energy pulses are notorious among designers of all kinds of electronic hardware for their ability to cause failures in circuits of apparently conservative design. Logic circuits, for example, are subject to "glitches" and timing problems if even small transient voltages appear on supply lines. The problem is not limited to sensitive integrated circuits. Transient energy "spikes", either coupled from AC lines or internally generated in medium and high-power equipment, can generate blown fuses, misfired thyristors and other problems having various degrees of subtlety. Worse, unsuppressed transients can drive reverse biased semiconductor junctions into their highly dissipative breakdown regions. The heat generated at these junctions can then lead to the onset of second breakdown and permanent degradation or outright failure of semiconductor devices and the equipment of which they are a part. Even circuit failures of short duration or apparently minor importance can cause serious damage to the reputations of manufacturers and designers.

Fortunately, various devices exist for protecting circuits from damage due to transient energy pulses. The method chosen depends on the type of transient expected.

Transient Pulses Characterized

In terms of capability of causing damage, the key characteristics of a transient energy pulse are its total energy and energy distribution in time. A large amount of energy delivered in a short period of time is most damaging to semiconductor components. Unfortunately, total energies of transients from many sources are unpredictable. Figure 1 shows where transients produced by various common sources fall on a scale of energy predictability.

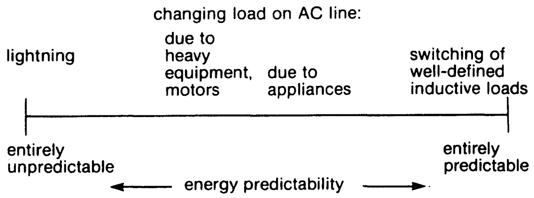


Fig. 1 Predictability of Common Transient Energy Sources

Some common transient energy pulses are quite unpredictable; still, designers want to protect their circuits from these transients as best as is practical. What, then, can be said to characterize these transients as much as is possible?

Figures 2a and 2b show generalized models which are widely useful in evaluating the effect that transient energy sources can have on circuit-protecting devices (transient suppressors). Some transient sources behave like voltage sources (Figure 2a), and can deliver to a transient suppressor currents which are limited only by the source-to-suppressor impedance. Other energy sources behave more like current sources (Figure 2b). One or the other of these models can help us to understand some of the kinds of transients shown in Figure 1.

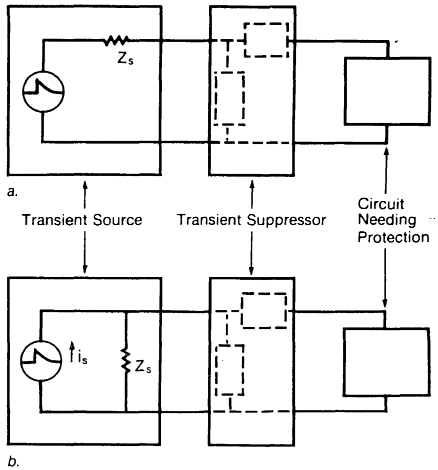


Fig. 2 Transient Source Models
a. Voltage Source b. Current Source

Lightning is a voltage source having virtually unlimited available current. Voltages of 1kV to 100kV for $1\mu s$ to $50\mu s$ are typical at the point at which lightning strikes an AC power line. The source-to-suppressor impedance can be thought of as having two resistive components:

$$Z_s = R_{line} + R_{int}$$

where R_{line} is the resistance of the AC line between the strike point and the susceptible equipment, and R_{int} is any additional line-to-suppressor resistance internal to the equipment. Commonly, $R_{int} \approx 0\Omega$; the transient suppressor is directly across the AC line in the equipment. R_{line} depends very much on where the lightning strikes, and is, therefore, extremely unpredictable.

Transients produced on AC power lines due to sudden load changes differ qualitatively from those produced by lightning, and cannot easily be interpreted as arising from voltage sources. In fact, no simple model composed of discrete components is particularly useful in describing these transients, because their nature is determined by the complex distributed impedance of the AC line. In general, it can only be stated that energy stored in inductive components of the distributed line impedance—when some load is drawing current from the line—is released as transient energy when that load is switched off of the line. The transient so generated can then be thought of as arising from a current source and as having a peak amplitude that does not exceed the peak current drawn by any single piece of equipment located near the circuit being protected. Experience shows that these transients are typically less than 100ms in duration.

Up to this point, we have been discussing transients produced on AC power lines and have reached rather tentative conclusions. Transients generated internal to the equipment being protected are another matter and can be much better described and predicted. Designers simply know much more about the equipment they are designing than they do about AC power distribution systems or long-range meteorological forecasts. The generalized models of Figure 2 can be replaced by detailed schematic diagrams showing the transient sources and their connection to sensitive components. The tools of circuit analysis can be used to predict with great precision the power dissipation, as a function of time, required of a transient suppressor.

For example: bipolar transistors are commonly used to switch inductive loads in switching power supplies. Often the circuit has the basic form of Figure 3a. In this case, the danger is that the energy stored in the inductor while the transistor is on cannot safely be dissipated by the transistor after it turns off. The common method of protecting the transistor is to provide a voltage clamp which prevents the reverse biased collector-base junction being operated beyond breakdown. This, too, is shown in Figure 3a. Inductor current i_L is forced through the transient suppressor when the transistor is off. This i_L is about the same as just before turn-off, since the current through an inductor cannot change instantaneously. After that, i_L decreases at a rate determined by the inductor voltage v_L and the inductance value L:

$$\frac{di_L}{dt} = \frac{v_L}{L}$$

If the clamp voltage V_C is assumed constant until $i_L \approx 0$, then i_L behaves as in Figure 3b. The resultant transient suppressor current, voltage and power waveforms are as in Figure 3c.

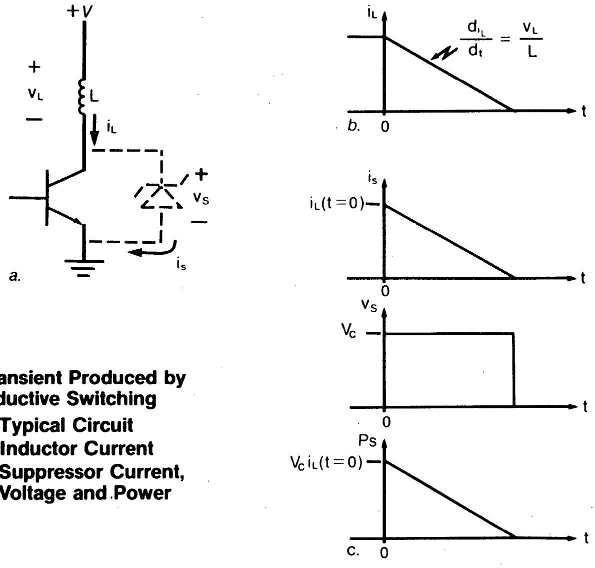


Fig. 3 Transient Produced by Inductive Switching
a. Typical Circuit
b. Inductor Current
c. Suppressor Current, Voltage and Power

This type of internally generated transient is so common and its effects so precisely definable, that the current waveform it generates has become a standard waveform for testing transient suppressors. Figure 4 shows two specific linearly decaying waveforms used by manufacturers and users of semiconductor transient voltage suppressors. (The finite slopes of the leading edges of these waveforms reflect the fact that in a real circuit, di/dt is limited by wiring inductances and transistor fall times.) These test waveforms have the additional advantage that they can be closely approximated by an easily generated exponential waveform (see Figure 5).

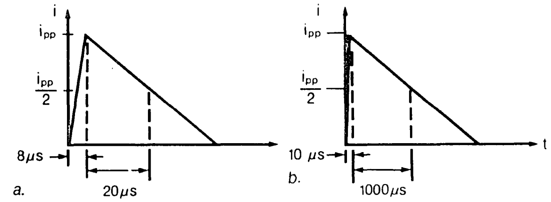


Fig. 4 **Commonly used Test Waveforms**
a. "8x20" μs
b."10 x 1000" μs

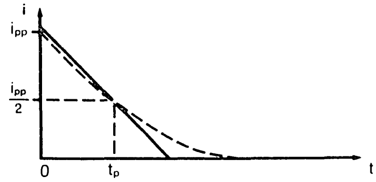


Fig. 5 Similarity of Triangular and Exponential Pulses

Desired Transient Suppressor Characteristics

In principle, it is possible to limit the transient energy that can be delivered to a sensitive component by limiting either the voltage or the current that that component can experience. In practice, however, transient current limiting is difficult to implement, and most designs employ some type of transient voltage suppressor (TVS) connected in parallel with the circuit to be protected. What, then, are the qualities required of a practical TVS?

First, a TVS must not interfere with the normal operation of the circuit; i.e., at voltages less than the maximum non-transient circuit voltage, a TVS must initially draw little current. We define that voltage at which a TVS can be guaranteed to draw less than some specified current as the stand-off voltage (V_R) for that current. A second requirement of the TVS is that it quickly clamps the voltage to a safe level when a transient does occur. Clamping voltage (V_C) is defined as the maximum voltage that will appear across the TVS under some pulsed current condition after the TVS has been fully activated. Clamping time (t_C) is the time it takes the TVS to activate. "Protected" circuits may experience voltages in excess of V_C during this defined clamping time. A figure of merit commonly used to describe TVSs is the clamping ratio (CR), defined by:

$$CR = \frac{V_C}{V_R}$$

An ideal clamp would have CR = 1.

A third TVS requirement is that it be capable of safely dissipating expected transient energy pulses. This capability is usually described in terms of allowable power dissipation as a function of pulse time.

Earlier, we discussed the predictability of various types of transients. Predictability greatly influences the process by which TVS power requirements are determined. For predictable pulses, the procedure is to minimize cost by specifying power requirements just safely in excess of the expected power for the known pulse duration. The design process is more complex for unpredictable transients. In this case, greater TVS power capability translates into great reliability. Therefore, the designer must make a trade-off between reliability and cost.

Other qualities desired of a transient voltage suppressor include freedom from the need to be "reset" after a surge and the ability to allow the protected circuit to function even during the transient period. With respect to these qualities there are two classes of TVS widely in use. *Passive* devices are those with monotonic characteristic curves, as shown in Figure 6a, while *active* TVSs are switches, with negative resistance regions on their I-V curves (Figure 6b). A passive TVS has CR > 1, does not need to be reset, and allows many circuits to function during a transient. Metal Oxide Varistors (MOVs) and semiconductor avalanche TVSs* are passive. An active TVS works by switching to a near-short condition when it senses a transient pulse, so that CR ≈ 0. Circuits protected by an active TVS do not funciton during the transient period (since they effectively become shorted out) and, in fact, will continue not to function after the transient period until the TVS "switch" is somehow turned off. Active transient suppressors include spark gap, gas tube and thyristor "crowbars". Combinations of active and passive TVSs, together with isolating elements and special reset circuits may be designed to keep circuits functional during most transients while utilizing the best features of both types of TVS.

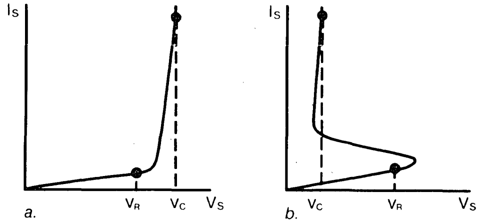


Fig. 6 Comparison of (a) Passive and (b) Active Transient Suppressor Characteristics

Comparison of Commonly Used Suppressors

Active TVSs, in addition to their need to be reset, have the added disadvantage of being bulky and costly in comparison to passive devices. Furthermore, they do not protect below V_C during the clamping time t_C. Their advantage, and the reason for their continued use, is their ability to safely handle very large pulse currents. Passive devices cannot operate at extreme current levels for two reasons. They clamp at higher voltages and are physically smaller than the active TVSs, and therefore—at any given current level—the passive devices dissipate more power and operate at higher current densities. An advantage of semiconductor TVSs is their freedom from overshoot during the transient.

MOVs have other limitations. They degrade with use, and their rated pulse currents decrease markedly as the number of lifetime pulses they are to experience increases (Figure 7). MOVs have higher clamping ratios than those of equivalent semiconductor TVSs (Figure 8). MOVs are bidirectional devices, i.e. they clamp at approximately the same voltage in each direction.

---

*Hereafter referred to as simply "semiconductor TVSs".

This can be a disadvantage when protecting many unidirectional circuits (particularly logic circuits), as will later be discussed in greater detail.

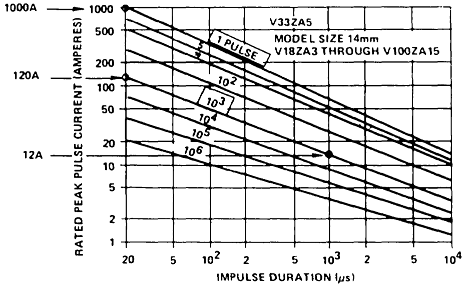


Fig. 7 MOV Lifetime Pulse Ratings

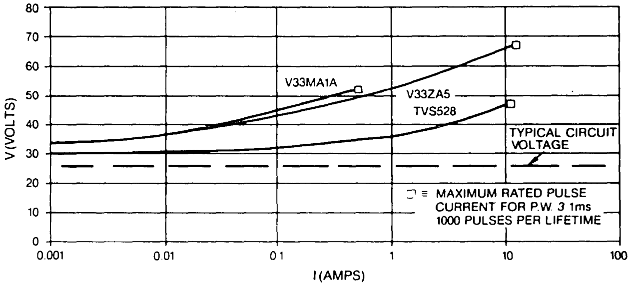


Fig. 8 Clamping Voltage Versus Current

Table I summarizes the relative merits of typical transient voltage suppressors.

	Clamping Ratio	Clamping Speed (typical)	Active or Passive	Allowable Current (for 1ms)	Available Voltages	Degradation?	Size	Cost	Typical Applications	Protection From:
Spark Gap or Gas Tube	~0*	10^{-5}s	Active	10^{3}-10^{5}A	to 20kV DC	No	Large	Very High	Phone Lines, Input to Heavy Equip.	Lightning
Thyristor Crowbar	~0*	10^{-7}-10^{-4}s	Active	to 10^{3}A	to 800V AC or DC	No	Moderate to Large	High	DC Power Supply	Output Over-voltage Protection
Metal Oxide Varistor	1—2	10^{-8}-10^{-7}s	Passive	~100A	10-260V AC (RMS)	Yes	Small to Moderate	Low to Moderate	AC Line to Equip. and Instruments	Transients due to Load Changes and Lightning
Semi-conductor TVS	1—1.5	10^{-12}s	Passive	~50A	5-400V AC or DC	No	Small	Low to Moderate	"on-board" Protection	Internally Generated Transients

**After t_C only.*

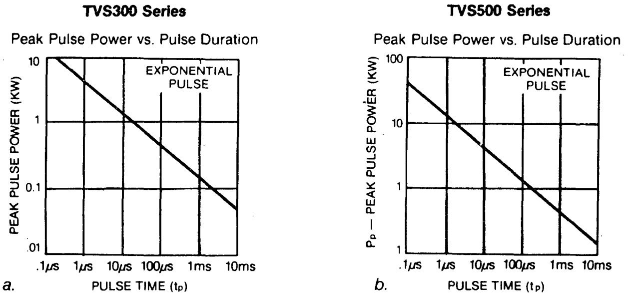
Table 1 Comparison of Transient Suppressors

Semiconductor TVS devices are preferred by power supply designers who must guard against predictable, moderate energy transients. The following section describes these devices in more detail, and offers selection guidelines and design examples.

Semiconductor TVSs

Unitrode offers several semiconductor TVS lines to commercial, industrial and military customers. Unitrode TVSs exploit the extremely rapid avalanche breakdown of a p-n junction in order to function as voltage clamps. TVS power ratings are specified for 1ms (for 50% decay) exponentially decaying pulses (ref. Figure 5). Units are available with 150W and 500W power ratings for industrial/commercial applications, and 500W and 1500W military types meet MIL-S-19500/551 and /434 respectively. Also, Unitrode markets zener diodes (1 to 10W DC) which have the same avalanche characteristics as the TVS devices, and can be used as transient suppressors.

To select the appropriate TVS for a given application, begin by determining the required stand-off voltage. V_R should be equal to or greater than the maximum non-transient voltage that is expected to appear across the TVS. Next, determine the TVS power requirements. Unitrode publishes room temperature pulsed power curves, in conjunction with junction temperature derating curves, for each TVS family (Figure 9). The pulse power rating curves (Figures 9a and 9b) apply to exponential pulses. If the expected pulse is not exponential, or approximately so, then construct an exponential pulse having the same peak power and total energy (i.e. area under the power curve) as the expected pulse (see Figure 5). Use the duration of this pulse when using the peak pulse power curves to determine which device family has adequate capability. The power and stand-off voltage considerations should point to one TVS part number.



TVS300 Series

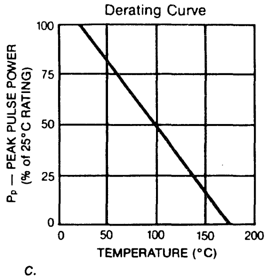
Peak Pulse Power vs. Pulse Duration

a.

TVS500 Series

Peak Pulse Power vs. Pulse Duration

b.



Derating Curve

c.

Fig. 9 Pulse Power Ratings for Unitrode TVSs

a. TVS300 Series
b. TVS500 Series
c. Junction Temperature Derating

As a final step in the selection process, determine if the clamping voltage of the tentatively selected TVS is low enough at the expected pulse current. Figure 10 is a convenient graph used to quickly determine if the clamping voltage will be adequate. If not, try a TVS with a higher power rating.

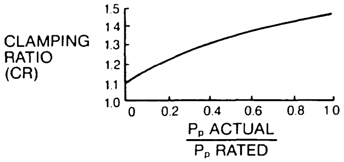


Fig. 10 Clamping Ratio vs. Peak Power for for Unitrode TVSs

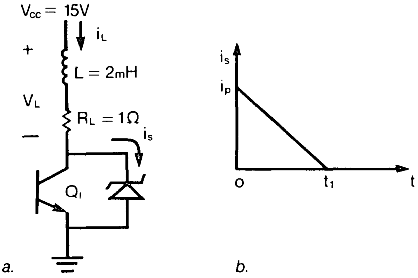


Fig. 11 A Typical TVS Application

a. Typical Circuit

b. (Idealized) Resultant Current in the TVS

To illustrate this selection process, let us consider in detail an inductive switching application of the type earlier mentioned. Figure 11a shows such an application.

Determining the required stand-off voltage rating is simple. The greatest non-transient voltage that will appear across the TVS is just the supply voltage V_{CC} = 15V. So a TVS with V_R = 15V will not interfere with the normal operation of the circuit.

As discussed before, the transient current induced in the TVS will show a linearly decaying time response (see Figure 11b). The peak current i_P is equal to the inductor current just prior to the turn-off of Q1. Making the worst-case assumptions that this system is in equilibrium before Q1 turns off, and that Q1 is then well saturated;

$$i_P = i_L (t = o-) = 15V/1\Omega = 15A$$

The peak pulse power p_P is given by:

$$p_P = i_P V_C$$

For a first estimate of this power, assume $V_C = 1.3\ V_R = 19.5V$.

Then:

$$p_P = 15A \times 19.5V = 290W$$

The time for the current pulse to decay to zero is:

$$t_1 = \frac{i_P}{\frac{di_L}{dt}} = \frac{i_P L}{V_C} = \frac{15A \times 2mH}{19.5V} = 1.5ms$$

The equivalent exponential pulse would have $t_P \approx t_1/2 = .75ms$. Referring to Figures 9a and 9b, we can see that a Unitrode TVS300 series device would not be adequate for this application, but that a TVS515 would operate with a comfortable margin for error.

Finally, we check to see if our estimate that $V_C = 1.3\ V_R$ is reasonable. To use Figure 10, we first calculate:

$$\frac{p_{P\ (ACTUAL)}}{p_{P\ (RATED)}} = \frac{290W}{600W} \approx .5$$

The clamping ratio curve then gives $V_C/V_R \approx 1.32$. Had our original estimate been less accurate, we could have re-itterated the calculations, using the clamping voltage obtained in the final step.

If available TVS devices do not meet all the needs of a particular application, consider using a Unitrode zener diode. These diodes are not characterized as conveniently as are the TVS series for use as transient suppressors. However, designers can assume that these zeners will stand off voltages up to 85% of their minimum V_Z, and that they follow the clamping voltage curve of Figure 10. Other requirements for improved P and/or CR can be serviced by series connected TVSs or zeners.

Designers often ask about the use of bidirectional semiconductor TVSs. Bidirectional suppressors should only be used when the non-transient voltage is bidirectional; i.e. when both positive and negative non-zero stand-off voltages are required. This applies regardless of the expected transient polarities. The reason for this is that the unidirectional TVS has a lower voltage clamp for negative polarity transients than does the bidirectional. Consider the protection of a bipolar transistor, as shown in Figure 12. If a bidirectional TVS is used (Figure 12a), then a negative transient current i_S will break over the transistor's emitter-base junction if the TVS has V_S greater than the breakdown voltage of that junction. On the other hand, a unidirectional TVS (Figure 12b) becomes forward biased and clamps at no more than a few volts even at very high currents. The low voltage emitter-base junction is safe in this case. Knowledge of the usefulness of this low voltage negative clamping characteristic has prompted the military to include reverse clamping voltage specifications for new 1N-type transient suppressors. (See, for instance, MIL-S-19500/551.)

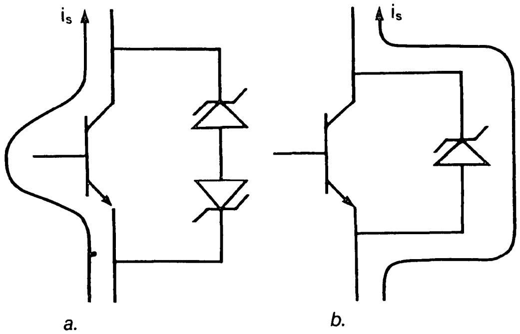


Fig. 12 (a) Bidirectional vs. (b) Unidirectional Protection for a Bipolar Transistor

The predictability of transient energy sources was earlier discussed. Often, it was found, the designer cannot accurately characterize expected transients.

It is possible, then, that a TVS could experience a pulse with energy in excess of that predicted by the designer. Faced with this potential situation, the designer should consider how the TVS behaves if overpowered.

A TVS, operating at a power level it cannot sustain, must react either to decrease the current that is flowing through it, or to decrease the voltage across which the current flows. Either the TVS tends toward an open circuit, or it becomes nearly a short circuit.

From a design standpoint, it is most often advantageous for the TVS to become a short circuit or very low resistance when subjected to a high energy transient. The primary purpose of the TVS is to protect other components. This is not accomplished if the TVS becomes highly resistive.

When overpowered by high transient field conditions, Unitrode Transient Voltage Suppressors and zener diodes fail in the "shorted" mode. The mechanism is the same "second breakdown" phenomenon observed in power transistors.

Only under very extreme pulse conditions will Unitrode TVSs fail "open". The pulse would need to have enough energy to initiate the second breakdown of the silicon junction followed by enough "follow through" energy to cause considerable heating in the now low resistance silicon.

Unitrode TVSs are of a voidless construction, so that even at very high chip temperatures the units cannot "explode" by igniting a contained gas. Cracking and chipping of the glass can occur, but this does not normally result in damage to surrounding components.

Reliability has always been important in electronic equipment; today it is even more so. Complex military and industrial systems must be built with circuit blocks of unquestioned reliability, if the overall system reliability is to be acceptable. Consumers now rightly demand long life for the products they buy. By better understanding the nature of transient energy sources and of available transient suppressors, the designer is better able to meet toughening reliability goals.

LIMITING INRUSH CURRENT TO A SWITCHING POWER SUPPLY IMPROVES RELIABILITY, EFFICIENCY

Active inrush-current limiters—unlike fuses and circuit breakers—prevent dangerous situations instead of only reacting to them. Apply limiting techniques, and you need not employ extra-hefty rectifiers just to ensure rectifier survival during turn on.

Roger Adair, Unitrode Corp

The input filter capacitor employed in many dc power-supply designs creates a potential problem—high inrush current. Fortunately, though, adding a few extra components can prevent inrush current and its associated circuit damage.

How does the input capacitor cause such problems? Intentionally chosen for high storage capacity and low equivalent series resistance (ESR), it behaves like a nearly perfect short circuit when the supply first turns on. The resulting short-duration peak inrush current can reach levels much greater than the tolerable single-cycle ratings of the supply's semiconductor rectifiers (thus destroying them) and still not contain sufficient total energy to open protective fuses or

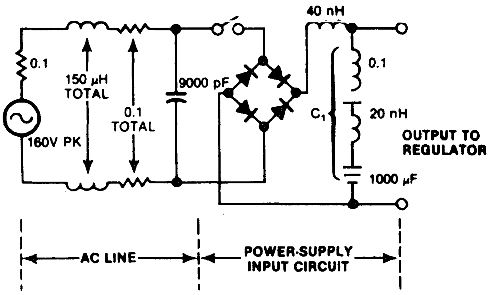
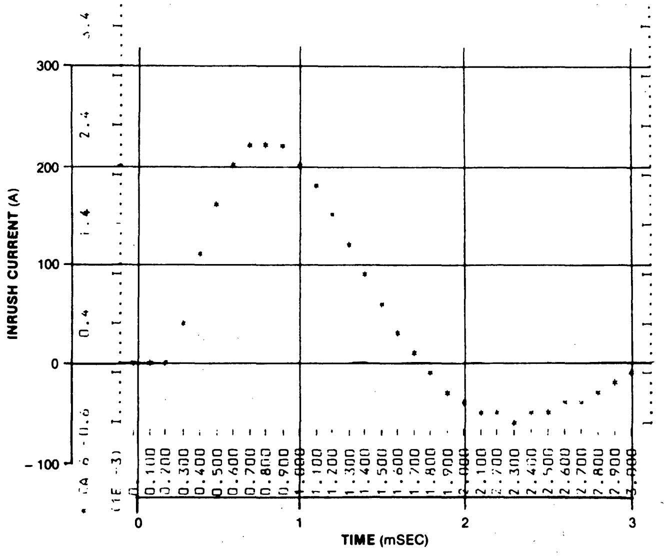


Fig 1—Based upon this generalized model, *analysis indicates the inrush-current problem's magnitude. Chosen for its low ESR, the input filter capacitor (C_1) behaves like a nearly perfect short circuit when the supply first turns on.*



```
          ECAP
          TRANSIENT ANALYSIS
C
B1        N(0,1),R=.1
B2        N(1,2),L=150E-6
B3        N(2,3),R=.1
B4        N(3,0),C=9000E-12
B5        N(3,4),R=.001
B6        N(4,5),L=40E-9
B7        N(5,6),R=.1
B8        N(6,7),L=10E-6
B9        N(7,0),C=1000E-6
E1        (1),0,0,0,160
          TIME STEP=100E-6
          FINISH TIME=3E-3
          1ERROR=1
          PRINT NV,CA
          PLOT,(SCALED),CA(6)
          BINARY,NV,CA
```

Fig 2—Peaks greater than 200A *are predicted by ECAP for the circuit model shown in* ***Fig 1.*** *Rectifier-diode reverse-recovery capability would inhibit the indicated 50A overshoot in an actual circuit design.*

Reprinted from EDN, May 20, 1980

Turn on an analysis before you turn on a power supply

circuit breakers. Additionally, the supply's rapidly rising voltage and current levels could cause dv/dt- or di/dt-sensitive devices in neighboring hardware to fail or malfunction.

Computer analysis proves useful

To appreciate the inrush-current problem, consider an estimate of its magnitude before examining possible control techniques. **Fig 1** depicts a model of the ac-input and rectifier/filter sections for a typical dc power supply. Although shown in a straight off-the-power-mains configuration, the model should be valid for any other design with the same output-power capability.

An ECAP computer analysis performed for this circuit assumed worst-case conditions: switch closure at 160V (peak voltage). The results (**Fig 2**) indicate that an inrush current greater than 200A can exist for several milliseconds.

Now compare this predicted performance with the measured characteristics (**Fig 3**) of a typical design. The current pulse's high level and short duration could generate severe, localized hot spots in rectifier junctions or cause false triggering of rate-sensitive devices elsewhere in the circuit.

A standard approach to current limiting is depicted in **Fig 4a**—a resistor. It's simple, reliable and easy to design in, but efficient it isn't. At any current level, it dissipates power that would otherwise be available to the load. The resistor does perform a surge-current-limiting function, however.

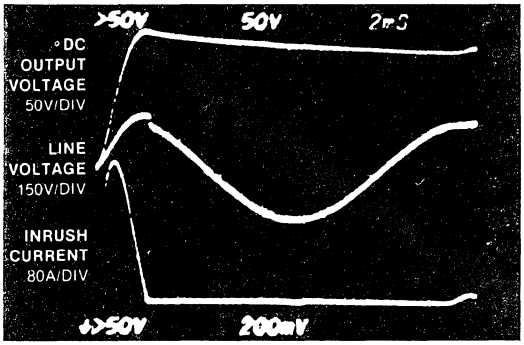


Fig 3—Measured inrush current *appears close to that predicted in* **Fig 2**. *This large current inrush could cause junction hot spots and generate troublesome EMI.*

Alternatively, a thermistor-controlled current limiter (**Fig 4b**) alleviates the resistor's efficiency problems to some extent, but it aggravates the dropout-recovery problem. The same cold-to-hot resistance variation that permits turn-on current limiting and high efficiency at low operating currents fails in dropout-recovery situations: The thermistor's long thermal time constant prohibits fast recovery.

SCR spells efficiency

In view of resistor and thermistor drawbacks, active soft-start designs offer a best-of-both-worlds

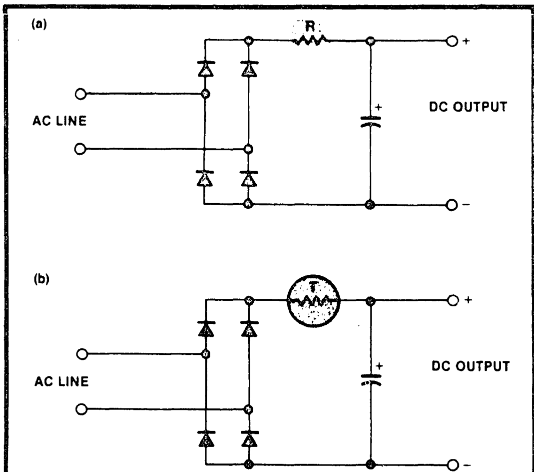
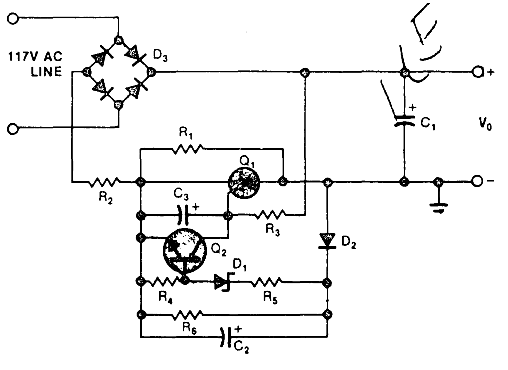


Fig 4—Two common methods *of inrush limiting employ either a resistor* **(a)** *or a thermistor* **(b)**. *But if the resistor is large enough to effectively control surge currents, it also significantly reduces efficiency. The thermistor, while more efficient, offers little protection during dropout recovery because of its long thermal time constant.*



NOTES

R_1: 3, 5W	C_1: 1000 µF	Q_1: L2R06254
R_2: 0.2, 10W	C_2: 10 µF	Q_2: UPT312
R_3: 3k, 5W	C_3: 2 µF	
R_4: 1k	D_1: UZ4715	
R_5: 1k, 2W	D_2: 1N4245	
R_6: 2k	D_3: UT680-4	

Fig 5—SCR soft starting *bypasses the current-limiting resistor (R_1) only when the peak-detected voltage across Q_1 drops below the zener breakdown, ie, when C_1 becomes almost fully charged through R_1.*

solution—effective inrush limiting, fast recovery and high operating efficiency. This type of circuit, shown in **Fig 5**, essentially incorporates a current-limiting resistor (R_1) and a bypass switch (Q_1). At turn on, Q_1 is OFF, and the surge current (I_S) develops a voltage across R_1. This voltage is peak detected by D_2 and stored in C_2. When the voltage exceeds D_1's zener breakdown—an event that should occur almost instantaneously—Q_2 turns on, disabling Q_1's gate-triggering network (R_3C_3). As the power supply's filter capacitor C_1 charges up, the inrush peaks diminish until the detected I_SR_1 voltage falls below D_1's zener breakdown. Q_2 then turns off, and the R_3C_3 network charges up and fires Q_1, bypassing R_1.

This circuit recovers rapidly enough to limit inrush currents that could occur as a result of even short line dropouts. When the ac input voltage goes to zero, the voltage across Q_1 also goes to zero, and Q_1 turns off. When the input voltage reappears, Q_2 keeps Q_1's gate circuit OFF until R_1 has allowed C_1 to become almost fully charged.

Fig 6 graphically depicts this design's inrush-limiting ability. Note how the I_SR_1 voltage level (upper trace) tracks the diminishing inrush-current pulses (lower trace) for the first three cycles. At the 17-msec point (slightly after the third current pulse), the peak detected voltage has dropped below the zener breakdown point, and Q_1 switches on, bypassing R_1. Then R_2 limits inrush currents.

After determining your design's maximum continuous dc output current (I_O) and inrush limit (I_S), you can select an appropriate SCR. (The major SCR considerations are the peak repetitive blocking voltages and the maximum average plus peak current levels.) Typical SCRs exhibit a gate-turn-on voltage (V_{GT}) of about 0.6V; typical power-supply circuits exhibit a rate sensitivity (di/dt) of about 1A/μsec—two quantities required for calculating the values of the other critical components:

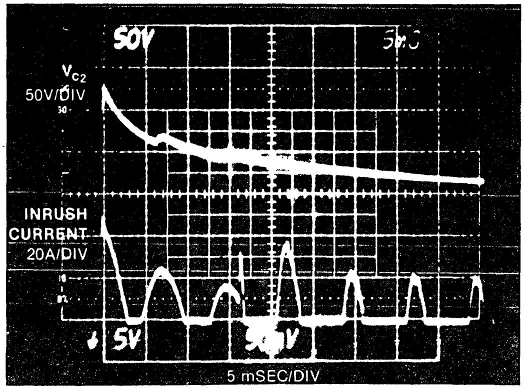


Fig 6—Inrush-current pulses of decreasing magnitude *(bottom trace) lower the SCR's hold-off voltage (upper trace). After 17 msec, the SCR fires.*

$$R_1=\sqrt{2}V_{AC}/I_S$$
$$R_2=P_{R_2}I_O^2$$
$$V_Z=I_SR_2$$
$$C3\geq(2\sqrt{2}\,V_{AC}V_Z)/(R_3V_{GT}R_1(di/dt)).$$

In the second equation, specify P_{R_2} as the maximum power your requirements allow across R_2.

Another effective inrush-current limiter is the phase-controlled triac design shown in **Fig 7**, which operates by controlling the conduction time of the current surges. Initially, the dc voltage (V_O) across C_1 builds up slowly because of R_1's current-limiting action. This dc voltage helps establish a reference (via R_{11} and zener diode D_1) for the programmable unijunction transistor (PUT) Q_4 and charges the phase-control

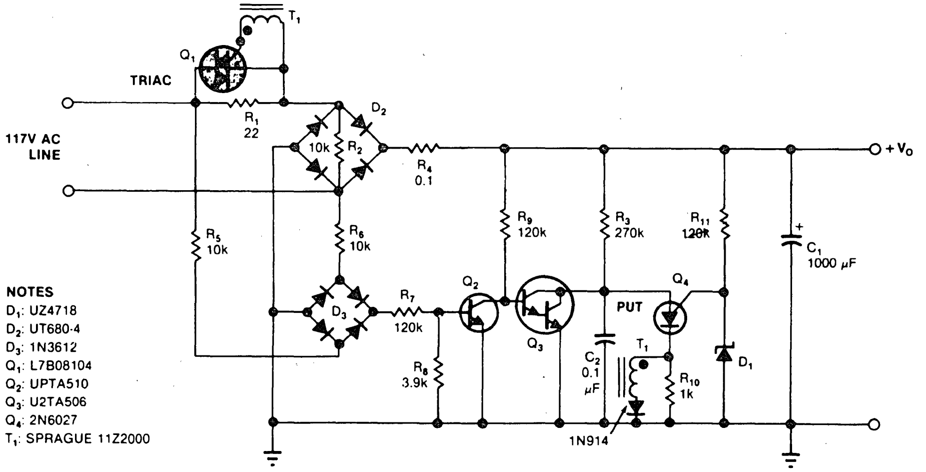


Fig 7—Phase controlling a triac *limits inrush-current pulses' amplitude and duration. Cycle-by-cycle triggering—handled by the PUT comparator—ensures instant recovery from line dropouts.*

Switch out the limiting resistor when the inrush is over

timing capacitor C_2 (via R_3). The PUT fires when its trigger point is reached, turning the triac on. Thus, when V_O is initially low, C_2 charges slowly, and the triac triggers on late in the half cycle. As V_O rises, Q_1 turns on earlier in each cycle until nearly 100% conduction is achieved.

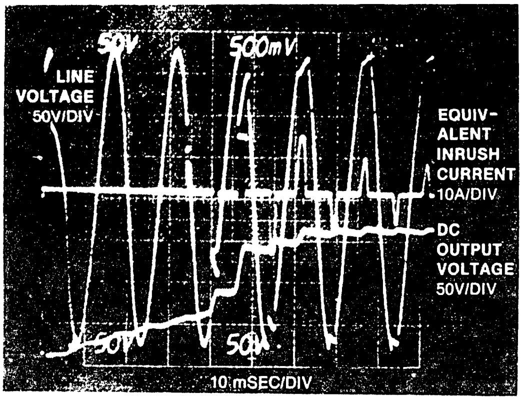


Fig 8—Triac conduction *follows the gradually increasing dc output voltage, decreasing the would-be inrush current. When the output voltage reaches design level, the triac is bypassing the current limiter nearly 100% of the time.*

The remaining circuit components (D_3, Q_2, Q_3, etc) discharge timing capacitor C_2 on each half cycle, thereby assuring cycle-by-cycle current limiting and fast recovery from dropouts. **Fig** 8 depicts the relationship between the ac input voltage, the dc output voltage and the varying conduction angle of the triac. EDN

TO-220 PACKAGE
MOUNTING AND THERMAL CONSIDERATIONS

The leads of the TO-220 rectifiers and Schottky diodes may be formed, but they are not intended to be flexible or ductile enough for unrestrained lead wrapping.

The figures show the typical device and hardware recommended. Several typical configurations of lead forming are illustrated.

The advantages of mounting the flange to the printed circuit board is that improved thermal heat transfer allows operating at higher levels of power dissipation. The individual specification sheets give the safe operating area as a function of a case temperature.

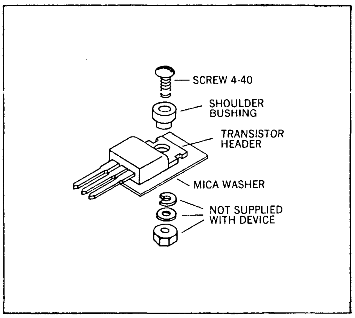


Figure A. Device and Hardware for Insulated Mounting.

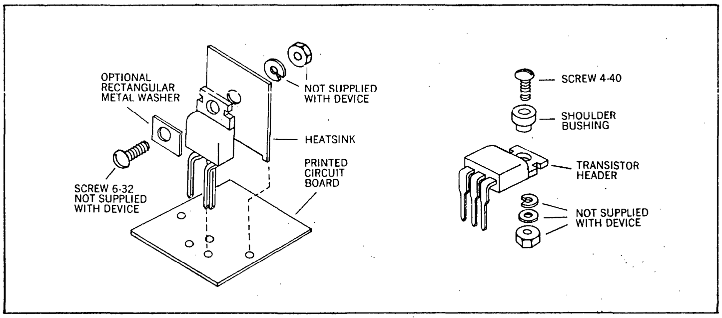


Figure B. Two Alternative Configurations for Axial Strain Relief and Electrical Isolation.

BENDING THE LEADS

Whenever the leads of the T-220 are to be formed, whether by a special fixture or by the use of long-nosed pliers, several important considerations must be followed. Internal damage to the device or lead damage may result if any or all of these precautions are not considered.

1. Minimum bend distance between the plastic body and the bend is ⅛ inch.
2. The minimum radius of the bend is $\frac{1}{16}$ inch.
3. Avoid repeating bending at the same flexure point.
4. Whenever possible, use one of the lead forming configurations which relieve strain induced by mechanical or thermal loads.
5. Leads should not be bent greater than 90 degrees.
6. Avoid axial pulling or bending that would induce axial strain. The maximum axial component is 4 pounds.
7. Forming fixtures or pliers should not touch the plastic case because axial strain of ≃ .005" could cause irreversible internal damage.
8. The leads must be fully restrained during the lead forming operation to prevent relative movement between the body and the leads.

SOLDERING INTO THE CIRCUIT

The leads on the TO-220 are solderable; however, there are a few precautions that must be observed.

1. Soldering temperature must not exceed 270°C.
2. Maximum soldering temperature must not be applied for more than 5 seconds.
3. Maximum soldering temperature should not be applied closer than ⅛ inch from the plastic body of the device.

TO-220 PACKAGE MOUNTING AND THERMAL CONSIDERATIONS

MOUNTING THE FLANGE

Flange mounting is recommended for maximum power handling applications. A 6-32 machine screw is recommended. Eyeletting (hollow rivet) is acceptable if care is taken not to distort the flange. For insulated mount, a 4-40 screw and a shoulder bushing is recommended (see figure). Suggested material for bushings are: Diallphthalate, fiber-glass-filled nylon, or fiber-glass-filled polycarbonate. Note unfilled nylon should be avoided. The flange should not be directly soldered because the use of lead-tin could produce temperatures in excess of the maximum storage temperature. See the individual specification for the device.

Check list and summary for flange mounting:

1. Use recommended hardware.
2. Always fasten the flange prior to lead soldering.
3. Do not allow the forming tool to come in contact with the plastic body.
4. Maximum mounting torque is 8 inch-pounds.
5. Avoid modifying the flange by machining and do not use oversized screws.
6. Provide axial and transverse strain relief of the leads.
7. Use recommended insulation bushings. Avoid materials that exhibit hot-creep problems.

Thermal Considerations TO-220 Power Diodes

Thermal Resistance, Case to Ambient;
Free Air, No Heatsink .... 60°C/W typical
Thermal Capacitance
of Package .... 4.8 watt-seconds/°C
Thermal Time Constant .... 305 seconds

Device Type	$I_{F\,(AV)}$	Thermal Resistance Junction Case °C/W
UES1401-4	8	2.5
UES1501-4	16	1.5
USD635-50	6	3.0
USD835-50	12	2.4
USD935-50	16	2.0

Note: When using a 2 mil MICA washer for electrical isolation, add 0.4°C/W to heatsink thermal resistance.

Thermal joint compound should be used at the interface of the TO-220 flange and the heatsink to which it is attached.

Consider a TO-220 power rectifier with a thermal resistance junction to case of 1.5°C/W. The junction temperature produced depends upon the mounting conditions and power dissipated in the circuit. The table shows junction temperature resulting from 15W of dissipation when mounted on an infinite heatsink at 100°C with different methods of interfacing.

Interface Condition Between Case and Heatsink	Thermal Resistance Case-Heatsink °C/W	Junction Temperature °C
Assumed direct, ideal metallic contact (no interference)	0.0	122
1 mil air gap*	1.2	140
Thermal compound; Tab screw torqued at 8 inch-pound	0.09	124
2 mil mica washer with thermal compound applied to both surfaces; tab screw torqued at 8 inch pound	0.58	131

* A film of air one mil in length has the thermal resistance of ≃ 1.2°C/W.

When using a small heat sink in free air one must consider the additional thermal resistance of the heat sink to ambient and operate at an appropriate power level. For example with an 18°C/W rated sink and thermal compound as above the device will have a junction temperature of 123°C when operating at 5W in an ambient of 25°C free air.

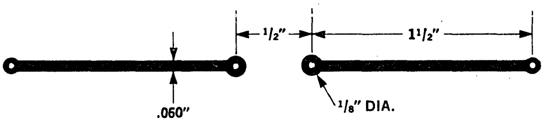
THERMAL DESIGN CONSIDERATIONS FOR LEADED DEVICES

For Lead Mounted Rectifiers and Zeners, for 5 types of mounting.

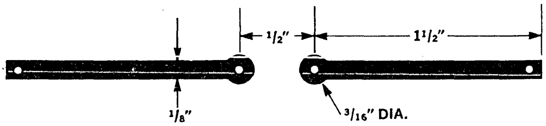
Determining The Power Rating for Your Application. The information given in this section is presented for straight-forward use by the designer. The value given in this table is $R_{\theta JA}$, the "Total" thermal resistance of the diode and mounting together; no other graphs or tables are needed.

$$P_{max} = \frac{T_{Jmax} - T_{Amax}}{R_{\theta JA}}$$

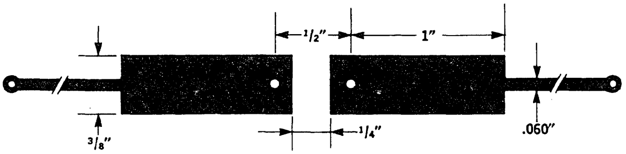
Where: P_{max} is the maximum power that can be dissipated in the device reliably. T_{Jmax} is the maximum of the operating temperature range, usually 175°C, unless derated for a military or hi rel application.
T_{Amax} is the max temp that the ambient reference (air below the device) will reach during operation.
Alternately,
Junction Temp Rise $= PR_{\theta JA}$



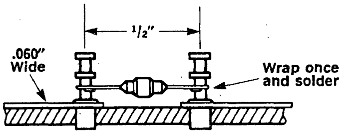
TYPE 1 PC BOARD, LIGHT



TYPE 2 PC BOARD, MEDIUM

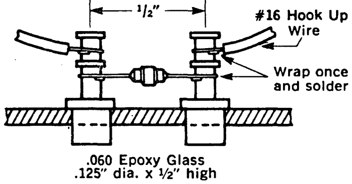


TYPE 3 PC BOARD, HEAVY



.060" dia. x 3/8" high
Terminals are per MS 17122-7

TYPE 4 PC BOARD WITH CHESSMEN TERMINALS



.125" dia. x 1/2" high
Terminals are per MS 17122-8

TYPE 5 TERMINALS AND HOOK-UP WIRES

$R_{\theta JA}$
Total Thermal Resistance in Degrees C/Watt

Type	Mounting Type				
	1	2	3	4	5
1N3611-3614	105	92	75	97	65
1N4245-4249	105	92	75	97	65
1N4461-4489	105	92	75	97	65
1N4736-4764	140	127	110	132	100
1N4942-4946	98	85	68	90	58
1N4954-4996	75	62	45	67	35
1N5063-5117	94	81	64	86	54
1N5186-5189	75	62	45	67	35
1N5186-5190	72	59	42	64	32
1N5550-5553	75	62	45	67	35
1N5614-5622	93	80	63	85	53
1N5802-5806	94	81	64	86	54
1N5807-5811	75	62	45	67	35
TVS 505-528	75	62	45	67	35
UES1101-1106	94	81	64	86	54
UES1301-1306	75	62	45	67	35
UR105-125	142	129	112	134	102
UR205-225	98	85	68	90	58
UT236-347	127	114	97	119	87
UT249-363	110	97	80	102	70
UT251-364	105	92	75	97	65
UT261-268	98	85	68	90	58
UT2005-2060	97	84	67	89	57
UT3005-3060	85	72	55	77	45
UT4005-4060	80	67	50	73	40
UTR01-61	127	114	97	119	87
UTR02-62	98	85	68	90	58
UTR10-60	176	163	146	168	136
UTR2305-2360	97	84	67	89	57
UTR3305-3360	85	72	55	77	45
UTR4305-4360	80	67	50	72	40
UTX105-125	142	129	112	134	102
UTX205-225	98	85	68	90	58
UTX3105-3120	85	72	55	77	45
UTX4105-4120	80	67	50	72	40
UZ706-140	94	81	64	86	54
UZ4706-4120	75	62	45	67	35
UZ5706-5140	75	62	45	67	35
UZ7706L-7710L	73	60	43	65	33
UZ8706-8120	140	127	110	132	100
UZS 306-440	94	81	64	86	54

TRANSIENT VOLTAGE SUPPRESSOR GUIDE

Introduction

Unitrode has been a leading supplier of discrete components for more than 25 years. Our Transient Voltage Suppressors (TVS) are used by some of the largest corporations in the world — Lockheed, IBM, Hughes, G.E., Univac, for example — in applications where high reliability and performance are important. These have included military programs such as MILSTAR, PATRIOT, and Peacekeeper.

In addition to its traditional suppressor products, Unitrode now offers a variety of bipolar and unipolar devices in custom packages, ranging from miniature plastic smaller than 1×10^{-3} cubic inches to 20-pin DIP zener arrays.

INTRODUCTION TO TRANSIENTS

Unsuppressed transients can cause circuit malfunctions or even circuit failure. Voltage transients from sources external to a circuit occur randomly, and with a frequency which is virtually impossible to predict. Transients which are created by the circuit itself can be very specifically defined. Figure 1 illustrates the range of predictability of both internally and externally generated transients.

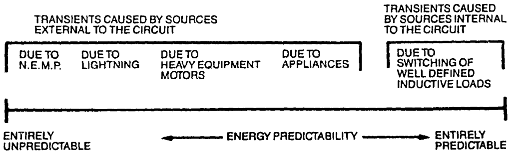
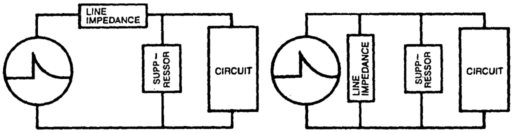


FIGURE 1.

Both types must be considered by the designer in order to achieve optimum performance and reliability.

TRANSIENT MODELS

The models in Figure 2 represent transient sources. As the diagram illustrates, externally generated transients may appear to be like a voltage or a current source. In circuits which switch inductive loads, internally generated transients appear to be from a current source.



A. TRANSIENT VOLTAGE SOURCE B. TRANSIENT CURRENT SOURCE

FIGURE 2. TRANSIENT SOURCE MODELS

When considering how to protect against transients generated from external sources, the value of impedance in series with the transient is relevant. If it is known, an approximation of the current — and therefore of the surge power handling capability of the required suppressor — can be determined. However, this impedance value is often difficult to determine accurately.

EXAMPLES OF EXTERNALLY GENERATED TRANSIENTS

An example of an externally generated transient would be lightning striking a power transmission line. The effective impedance of a typical U.S. residential branch network could be as much as 300 ohms. The peak currents associated with the high frequency components of the transient could be limited by this effective impedance.

The lower frequency components could, of course, see a much lower impedance which would be the impedance of the network associated with the 60 hertz transmitted power frequency. The value of impedance could be significantly lower if the lightning were to strike at a point close to the susceptible equipment.

In other words, the effective impedance in such a case is hard to estimate, and thus the surge current would be difficult to resolve. Figure 3 illustrates response to such a random transient.

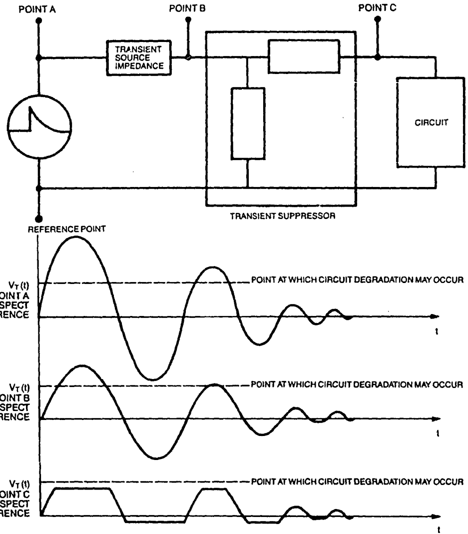


FIGURE 3.

Another type of external transient is generated when parallel inductive loads are switched on and off on the same branch of a power distribution system. These transients would appear to come from a current source.

Still another transient source of concern to many designers today is the Nuclear Electromagnetic Pulse (N.E.M.P.).

In the event of a nuclear explosion, voltage fields of very high intensity are generated. These transients are of great concern because of their far reaching effects.

For example, a nuclear explosion occuring at a height of 300 miles above the center of the United States would generate an intense electromagnetic field that would affect electrical circuits from coast to coast.

While the explosive power of such a blast is classified, it is of sufficient military concern to have started a major effort to develop E.M.P. hardened systems.

While shielding may help to provide proper protection from such transients, the effects from input and output lines would remain of concern. Ultimate protection, therefore, would have to involve effective suppression of voltage transients on these lines.

EXAMPLES OF INTERNALLY GENERATED TRANSIENTS

Internally generated transients, unlike external, can be very specifically defined. When switching inductive loads, energy built-up in the magnetic field of the inductor during the transistor on time must not be transferred to the voltage sensitive load. Such a transfer could have a serious detrimental effect on the performance of the circuit. A solution is to provide a fast acting voltage clamp which would safely limit the peak voltage across the load. An example of a voltage sensitive item would be the reverse biased collector-base junction. The value of voltage, in this case, should never exceed the applicable BV rating of the transistor.

Figure 4 shows the current and voltage waveforms associated with the application of a semiconductor transient voltage suppressor in an inductive switching situation.

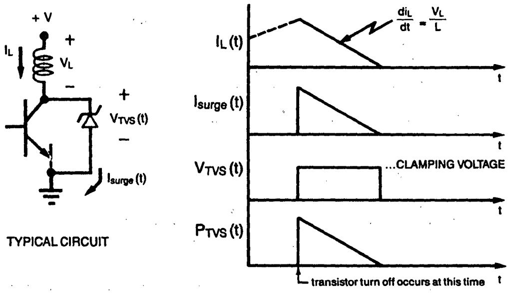


FIGURE 4.

CHOOSING AN APPROPRIATE TRANSIENT VOLTAGE SUPPRESSOR

With this brief discussion of transients behind us, it now becomes time to get a clearer understanding of how to choose an appropriate transient voltage suppressor (TVS). The key items of concern are as follows:

1. Stand-off voltage
2. Peak pulse power capability
3. Maximum clamping voltage
4. Maximum junction temperature
5. Response time

First, a definition of terms is warranted.

Stand-off Voltage

This is the circuit operating voltage which relates to the suppression device. At the stand-off voltage, the TVS will be essentially non-conducting such that the insertion loss will be minimal. A device should be chosen with a stand-off voltage equal to, or greater than, the maximum normal circuit operating voltage. The stand-off voltage of a device is clearly defined in the manufacturer's electrical specifications table.

Peak Pulse Power

The peak pulse power is equal to the clamping voltage times the peak current. A device must be chosen which has the capability to handle this peak pulse power. The pulse power vs pulse duration graph on manufacturers' datasheets can be used to determine whether a particular device would be operating within its safe operating region. (For examples of these types of curves see the individual datasheets.)

Maximum Clamping Voltage

This is the maximum voltage that will occur across the TVS for the duration of the transient. A device must be chosen which will clamp below the voltage that may damage any components. For effective use, it is necessary to define the surge current that will equate to the clamping voltage.

Maximum Junction Temperature

The junction temperature is equal to the pulsed thermal impedance times the peak pulse power, plus the junction temperature just prior to the transient pulse. An understanding of the maximum junction temperature is vital with regard to reliability of the TVS itself.

Response Time

When protecting sensitive components, the response time of the protection device is also of importance. Special attention must be paid to insuring that the protection device is inherently fast enough in its response time and that parasitic inductance is kept to a minimum. The intrinsic characteristics of a semiconductor TVS enable it to effectively respond to transients of extremely short duration, or transients of longer duration with very fast rise times. Other forms of protection are much slower in their response. A semiconductor TVS is the fastest device available, responding in pico seconds.

SELECTION CRITERIA

To properly select a device, it is essential to understand the maximum clamping voltage as accurately as possible, since this value impacts on whether proper protection has been achieved. It is also necessary to know this value to determine the peak power and peak junction temperature.

Unitrode TVSs are characterized as having a minimum breakdown voltage at some very low current, usually 1 milliampere. For reverse currents other than this, the TVS voltage will differ due to three factors:

1. TVS *dynamic impedance* varies as a function of bias current and is evident at intermediate currents (less than 1 ampere). Dynamic impedance is closely tied to the physics of the breakdown mechanism.
2. *Surge impedance* dominates the TVS's I-V characteristics at large reverse currents. The surge impedance is essentially the sum of the semiconductor bulk resistance, contact, pin, and lead resistance and varies little with bias current.

3. *Power dissipation* in the TVS, varies directly with reverse current. As a result, an increase in reverse current will create an increase in junction temperature. *Power related heating* gives rise to increased reverse voltage in TVSs because of the positive temperature coefficient of reverse voltage associated with the semiconductor junction.

Model to Determine Clamping Voltage

The expected TVS voltage under bias conditions other than the low current condition described in the data table would therefore be:

$$V_{clamp} = V_{TVS} \text{ at 1mA} + \Delta V_{TVS} \text{ (dynamic)} + \Delta V_{TVS} \text{ (surge)} + \Delta V_{TVS} \text{ (thermal)}$$

Where: ΔV_{TVS} (dynamic) = change in TVS voltage due to dynamic impedance.
ΔV_{TVS} (surge) = change in TVS voltage due to surge impedance.
ΔV_{TVS} (thermal) = change in TVS voltage due to ambient and power induced temperature excursions.
Vclamp = voltage which will occur across the TVS as a result of the surge.

ΔV_{TVS} (dynamic):
A rigorous way to obtain a value for ΔV_{TVS} (dynamic) involves the integration of the impedance-current product over the current range from the low current test point to the surge current. The results of this integration, for Unitrode axial TVSs are:

$$\Delta V_{TVS} \text{ (dynamic)} = 0.133\, (V_{TVS})^{1.08} \left[I_{surge}^{0.138 \sqrt[8]{V_{TVS}}} - I_{test}^{0.138 \sqrt[8]{V_{TVS}}} \right]$$
for 150W TVSs

$$\Delta V_{TVS} \text{ (dynamic)} = 0.029\, (V_{TVS})^{1.28} \left[I_{surge}^{0.101 \sqrt[5]{V_{TVS}}} - I_{test}^{0.101 \sqrt[5]{V_{TVS}}} \right]$$
for 500W and 600W TVSs

$$\Delta V_{TVS} \text{ (dynamic)} = 0.031\, (V_{TVS})^{1.23} \left[I_{surge}^{0.105 \sqrt[4]{V_{TVS}}} - I_{test}^{0.105 \sqrt[4]{V_{TVS}}} \right]$$
for 1500W TVSs

Where: V_{TVS} = low current breakover voltage which is defined in the data table.
I_{surge} = peak surge current.
I_{test} = low level test current; defined in manufacturers' data tables.

ΔV_{TVS} (surge):
Figure 5 shows surge impedance as a function of stand-off voltage for Unitrode axial transient voltage suppressors. The voltage increase due to surge impedance is simply:

$$\Delta V_{TVS} \text{ (surge)} = Z_S (I_{surge} - I_{test})$$

ΔV_{TVS} (thermal):
Power is dissipated at a semiconductor junction as heat and acts to raise the temperature of the junction and, in turn, the semiconductor bulk, the pins, and the leads. To understand how heat transfer occurs it is useful to consider both the thermal resistance and thermal impedance models.

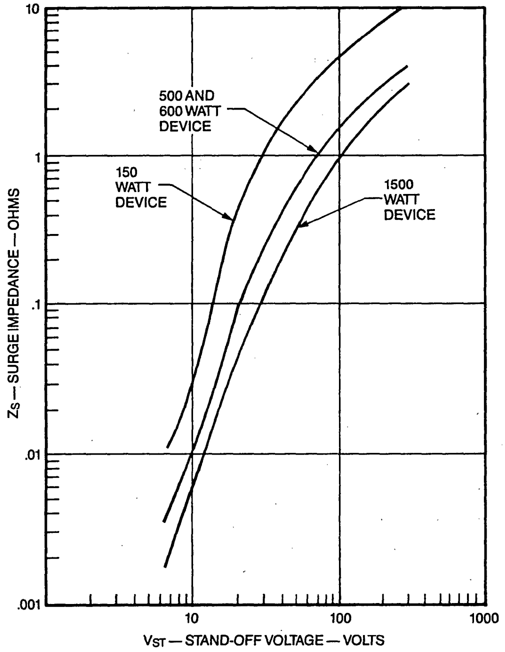


FIGURE 5.

Thermal Resistance Model

In a situation where a repetitive transient occurs at a fixed frequency, it is simple to determine the average and estimate the peak junction temperature. To determine the average junction temperature one should derive the average power dissipation by using the following relation:

Pd (average) = (Vclamp x Isurge) tp/t

Where tp = duration of the rectangular equivalent pulse
τ = period of the waveform

The average junction temperature then becomes:

$$T_j \text{ (average)} = T_A + (R_{\Theta J\text{-}A}) \times P_d \text{ (average)}$$

where: T_A = ambient temperature
$R_{\Theta J\text{-}A}$ = thermal resistance, junction to ambient

In order to assure a safe operating junction temperature, the designer must achieve a sufficiently low thermal resistance, junction to ambient.

$R_{\Theta J\text{-}A}$ is dependent on both device construction and mounting conditions. It is useful to separate these dependencies by invoking the relation:

$R_{\Theta J\text{-}A} = R_{\Theta J\text{-}L} + R_{\Theta L\text{-}A}$

Where: $R_{\Theta J\text{-}L}$ = thermal resistance junction to lead and is device construction dependent.

$R_{\Theta L\text{-}A}$ = thermal resistance lead to ambient and is mounting dependent.

For a simple conservative estimate of the peak junction temperature, the designer needs only add to the average junction temperature the excursion of junction temperature obtained by utilizing the thermal impedance model. Figure 6 offers a qualitative representation of the effects produced by a transient which occurs at a fixed frequency.

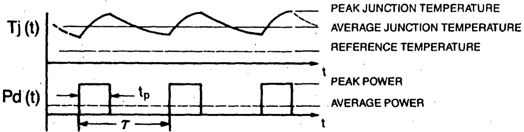


FIGURE 6.

Thermal Impedance Model

Under single pulse reverse bias conditions the thermal capacitance of the TVS becomes evident, and its thermal behavior is best characterized by a pulse-width-dependent thermal impedance. For pulse widths less than one half second in duration, heat flow from the lead to a typical mounting is minimal, and the thermal response is nearly independent of mounting conditions. In this situation:

$\Delta T_j = P_D \times Z_\Theta$

Where: P_D = pulsed power

Z_Θ = pulsed thermal impedance

Figure 7 shows pulsed thermal impedance versus pulse duration for Unitrode transient voltage suppressors. These curves give Z_Θ values for rectangular power pulses. A designer should determine the pulse energy equivalent for his specific pulse, and use the duration of that pulse when employing Figure 7.

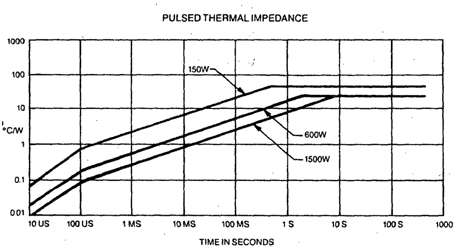


FIGURE 7.

To carry the thermal analysis one step further, and to be more rigorous, one can consider the effective thermal impedance for a given repetitive pulsing situation to be as follows:

$Z_{\Theta eff} = (R_{\Theta J\text{-}A})\,(t/\tau) + (l\text{-}t/\tau)\,[r(t + \tau)] - r(\tau) + r\,(t)$

Where: $Z_{\Theta eff}$ = effective pulsed thermal impedance

t = pulse width

τ = period

$r\,(t + \tau)$ = transient thermal impedance at time $t + \tau$

r (t) = transient thermal impedance at time t

$r\,(\tau)$ = transient thermal impedance at time τ

The peak junction temperature of a device subjected to a periodic train of power pulses can be calculated by using the following relation:

$T_{j\,(peak)} = T_{ambient} + (P_D) \times (Z_{\Theta eff})$

IMPORTANCE OF JUNCTION TEMPERATURE

A clear understanding of the junction temperature is important to the designer for two reasons:

1. The maximum junction temperature is the fundamental criterion for device reliability assurance. Unitrode transient voltage suppressors will operate with virtually no permanent degradation if the junction temperature is kept below 175°C. This criterion allows the designer to choose the proper TVS (body size/rated maximum power dissipation) for his application.
2. The thermally related change in V_{TVS} is given by

   $\Delta V_{TVS}\,(\text{thermal}) = T_j \times TC/100 \times BV_{min}$

   Where TC = temperature coefficient of reverse voltage in percent of BV_{min}/°C

   BV_{min} = minimum breakover voltage

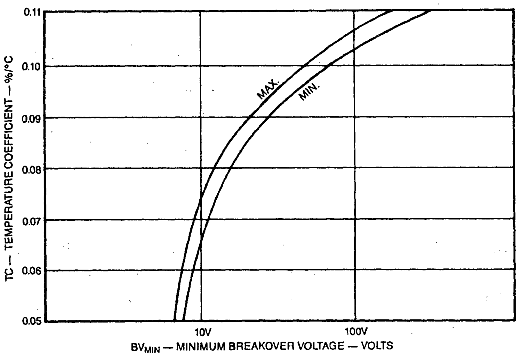


FIGURE 8.

Figure 8 shows TC as a function of stand off voltage for Unitrode transient voltage suppressors.

Although, as stated above, the junction temperature is clearly related to the long term reliability of the TVS, it must be noted that a failure mechanism not strongly related to junction temperature, but rather to current density manifests itself — when the transients are very short in duration (less than 1 micro second) and the values of current are very high. Conditions which may generate this type of transient may possibly occur in some equipment as a result of an electromagnetic pulse.

COMPARISON OF SUPPRESSOR TECHNOLOGIES

It would be helpful to the designer to have a better feel for the relative merits associated with the different types of transient suppression devices and schemes available today. A comparison of the different suppression technologies available today is presented in Table 1.

R-C snubber networks, though not shown in the table, are often used alone or in combination with other types of transient voltage suppressors. Often a snubber can be chosen which would limit the voltage across a sensitive component until the current has reached a safe level. However, in certain situations, an R-C network designed to minimize transients can have negative effects. R-C networks may cause undesirable time delays in relay or solenoid applications. The use of a semiconductor TVS would minimize the problem and the component count would be less.

In conclusion, the advantages of a semiconductor transient suppressor are as follows:

- low insertion loss
- simplification of protection circuitry
- immediate recovery after operation
- most effective clamping
- protection against fast rising transients
- circuit operation can continue for the duration of the transients

Unitrode offers a wide range of transient voltage suppressors that are suitable for many common transient suppression applications.

Table 1

	Clamping Ratio	Clamping Speed (Typical)	Active or Passive	Allowable Current (for 1ms)	Available Voltages	Degradation?	Size	Cost	Typical Applications	Protection From:
Spark Gap or Gas Tube	~0*	10^{-5}s	Active	10^3–10^5A	to 20kV DC	No	Large	Very High	Phone Lines Input to Heavy Equip.	Lightning
Thyristor Crowbar	~0*	10^{-7}–10^{-4}s	Active	to 10^3A	to 800V AC or DC	No	Moderate to Large	High	DC Power Supply	Output Over-Voltage Protection
Metal Oxide Varistor	1-2	10^{-9}–10^{-7}s	Passive	100A	10–260V AC (RMS)	Yes	Small to Moderate	Low to Moderate	AC Line to Equip. and Instruments	Transients due to Load Changes and Lightning
Semi-conductor TVS	1-1.5	10^{-12}s	Passive	50A (See Note)	5–400V AC or DC	No	Small	Low to Moderate	"on-board" Protection	Internally** Generated Transients

*After triggering on only.
**All types of transients as a final line of defense.

TABLE 1. COMPARISON OF TRANSIENT SUPPRESSORS

NOTE: Though the values in this column are useful for comparing suppressor technologies on a one to one basis it must be noted that for shorter pulse widths a semiconductor TVS is capable of sustaining hundreds of amperes. For example the smallest TVS component Unitrode presently offers was tested with a 200 nanosecond exponentially decaying waveform with a rise time of 10 nanoseconds. This device did not suffer degradation until peak values of 600 amperes had been reached. This is an extremely important point as the other technologies have response times which severely limit their effectiveness when the pulse widths and the associated current rise times are of this nature. Non-semiconductor types are excessively slow in response such that the circuit is not adequately protected. In cases where the transients are of very short duration the only viable solution is to use a semiconductor TVS.

TVS APPLICATIONS

The following suggested semiconductor TVS applications provide the designer with several methods for protecting the voltage sensitive elements of his circuit.

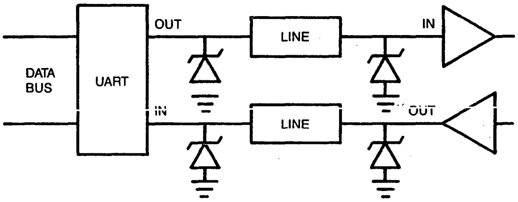


FIGURE 9. DATA LINE PROTECTION

TVS devices are used to absorb high energy transients normally associated with signal/data lines. These transients if not suppressed would destroy an ICs integrated clamp diode. The TVS devices when used for this application also suppress EMP and ESD induced transients. The destructive energy can be coupled via the I/O lines, which act like antennas passing through the faraday shielding. For multiple data line applications, TVS arrays are often utilized.

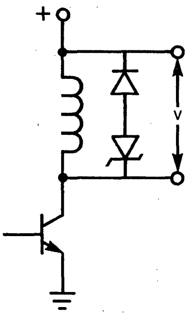


FIGURE 10. COIL RECOVERY SPEED-UP

In this application, the use of a TVS device will minimize the reset time required to discharge the current in the inductive element being switched. Since the coil recovery time is inversely proportional to the voltage across the coil, the circuit can be operated at higher frequencies.

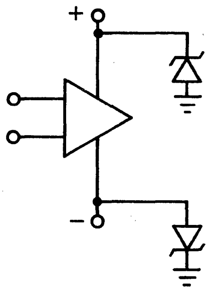


FIGURE 11. IC POWER LINE PROTECTION

Unitrode TVS devices can be used to protect ICs from ESD, lightning generated, and power supply turn on associated transients.

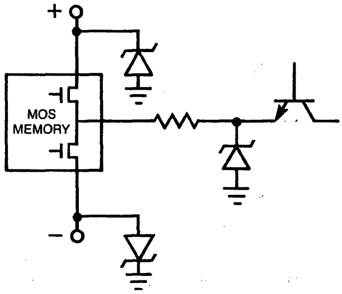


FIGURE 12. TOTEM POLE OUTPUT CIRCUIT

TVS devices are used to protect memory systems from current spikes on the output of a totem pole circuit.

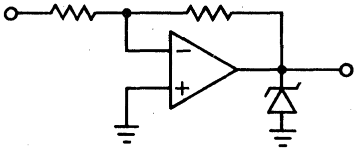


FIGURE 13. OP AMP PROTECTION

TVS devices can be used to prevent a short circuit or inductive load transients from being transmitted to the output.

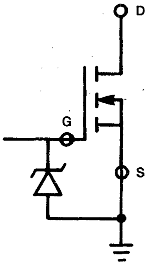


FIGURE 14. MOSFET GATE PROTECTION

MOSFET gates can be protected from transients that are delivered by the drive or coupled to the gate through the drain to gate capacitance.

TVS SELECTION GUIDE

The following selector guide tables summarize Unitrode's broad offerings in semiconductor Transient Voltage Suppressor devices. In addition to these suppressor products, Unitrode also offers a variety of unidirectional and bidirectional chips in custom packages. These products range from pin connectors to various diode/TVS combinations.

We welcome your requests to satisfy special needs. Please contact us or call your local authorized Unitrode representative.

TRANSIENT VOLTAGE SUPPRESSORS GLASS AXIAL, UNIDIRECTIONAL

Part No.	Stand-Off Voltage V_R (V)	Min. Breakdown Voltage $BV_{(min)}$ @ I_{PP} (V)	Max. Peak Pulse Current I_{PP} (A)	Max. Clamping Voltage V_C @ I_{PP} (V)	Peak Power for lmS (W)	Package Style
TVS305	5.0	5.0	17	8.7	150	**A Body** 
TVS310	10.0	11.1	8.9	16.8		
TVS312	12.0	13.8	7.1	21.0		
TVS315	15.0	16.7	5.9	25		
TVS318	18.0	20.4	4.9	31		
TVS324	24.0	28.4	3.6	42		
TVS328	28.0	30.7	3.2	46		
TVS348	48.0	54	1.7	82		
TVS360	60.0	67	1.4	105		
TVS410	100.0	111	.91	160		
TVS420	200.0	234	.42	360		
TVS430	300.0	342	.28	520		
TVS505	5.0	6.0	53.7	9.3	500	**B Body** 
TVS510	10.0	11.1	30.3	16.5		
TVS512	12.0	13.8	23.8	21.0		
TVS515	15.0	16.7	19.8	25.2		
TVS518	18.0	20.4	16.3	30.5		
TVS524	24.0	28.4	11.9	42.0		
TVS528	28.0	30.7	10.7	46.5		
1N6461**	5.0	5.6 @ 25mA	56	9	500	
1N6462**	6.0	6.5 @ 20mA	46	11		
1N6463**	12.0	13.6 @ 5mA	22	22.6		
1N6464**	15.0	16.4 @ 5mA	19	26.5		
1N6465**	24.0	27.0 @ .2mA	12	41.4		
1N6466**	30.5	33.0 @ 1mA	11	47.5		
1N6467**	40.3	43.7 @ 1mA	6	78.5		
1N6468**	51.6	54.0 @ 1mA	8	63.5		
1N5610*		33.0	32.0	47.5	1500	**CCL Body** 
1N5611*		43.7	24.0	63.5		
1N5612*		54.0	19.0	79.5		
1N5613*		191.0	5.7	265.0		

* Available as JAN, JANTX.
** Available as JAN, JANTX, JANTXV.

TRANSIENT VOLTAGE SUPPRESSORS GLASS AXIAL, BIDIRECTIONAL

The EPS5-48 series is designed to protect linear integrated circuits from spurious transient disturbances, especially NEMP and ESD events.

Part No.	Stand-Off Voltage V_R	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA	Max. Peak Pulse Current I_{PP}	Max. Clamping Voltage V_C @ I_{PP}	Peak Pulse Power 8x20μs waveform	Package Style
	(V)	(V)	(A)	(V)	(W)	
EPS5	5	6.0	89.4	9.5	1000	**A Body** 
EPS8	8	8.8	62.1	13.7	1000	
EPS12	12	13.8	40.3	21.6	1000	
EPS15	15	16.7	33.9	26.0	1000	
EPS16	17	18.7	30.8	29.2	1000	
EPS24	24	28.4	22.0	41.0	1000	
EPS28	28	30.7	19.2	47.8	1000	
EPS33	33	36.3	16.4	56.7	1000	
EPS42	48	54.0	11.2	84.3	1000	

TRANSIENT VOLTAGE SUPPRESSORS GLASS AXIAL, BIDIRECTIONAL

The 1N6102A series is designed to meet the requirements of MIL-S-19500/516A.

Part No.	Stand-Off Voltage V_R	Min. Breakdown Voltage $BV_{(min)}$ @ 1mA	Max. Peak Pulse Current I_{PP}	Max. Clamping Voltage V_C @ I_{PP}	Peak Pulse Power for 1ms	Package Style
	(V)	(V)	(A)	(V)	(W)	
1N6102A	5	6.46	47.6	10.5	500	**B Body** 
1N6107A	8	10.45	32.0	15.6	500	
1N6111A	12	15.2	22.4	22.3	500	
1N6113A	15	19.0	18.0	27.7	500	
1N6115A	17	22.8	15.0	33.3	500	
1N6118A	24	31.4	10.9	45.7	500	
1N6120A	28	37.1	9.3	53.6	500	
1N6122A	33	44.7	7.7	64.6	500	
1N6125A	48	64.6	5.1	97.1	500	

SALES OFFICES 13

SEMICONDUCTOR PRODUCTS
UNITRODE

Effective Date: June 1, 1989

UNITRODE REGIONAL OFFICES

Eastern Area Office, 580 Pleasant Street, Watertown, MA 02172, Tel. (617) 926-0404, FAX (617) 924-1235
Mid-Atlantic Office, 900 Route 9, Suite 208, Woodbridge, NJ 07095, Tel. (201) 855-8444, FAX (201) 855-8677
Mid-America Office, 2 Salt Creek Lane, Suite 200, Hinsdale, IL 60521, Tel. (312) 325-0077, FAX (312) 325-0632
South Central Office, 4975 Preston Park Blvd., Suite 775, Plano, TX 75093 Tel. (214) 985-4191 FAX (214) 985-4193
Western Office, 23801 Calabasas Rd., Suite 2038, Calabasas, CA 91302, Tel. (818) 992-6894, FAX (818) 992-4926

DOMESTIC REPRESENTATIVES

ALABAMA
Advanced Components Mktg.
Huntsville
205-881-5493

ARIZONA
Compass Mktg. & Sales, Inc.
Phoenix
602-996-0635

Compass Mktg. & Sales, Inc.
Tucson
602-293-1220

ARKANSAS
See Texas

CALIFORNIA — NORTHERN
I^2 Inc.
Santa Clara
408-988-3400

CALIFORNIA — SOUTHERN
Centaur Corp.
Irvine
714-261-2123

Centaur Corp.
San Diego
619-278-4950

Centaur Corp.
Calabasas
818-704-1655

COLORADO
Component Sales, Inc.
Denver (Englewood)
303-779-8060

CONNECTICUT
Conntech Sales
Waterbury
203-754-2823

DELAWARE
See Pennsylvania-Eastern

DISTRICT OF COLUMBIA
See Maryland

FLORIDA
Delmac Sales, Inc.
Longwood
407-831-0040

Delmac Sales, Inc.
Deerfield Beach
305-427-7788

Delmac Sales, Inc.
Clearwater
813-447-5192

GEORGIA
Advanced Comp. Mktg.
Norcross
404-448-7025

IDAHO
See Washington

ILLINOIS — NORTHERN
Oasis Sales Corp.
Elk Grove Village
312-640-1850

ILLINOIS — SOUTHERN
Contact Factory

INDIANA
Scott Electronics
Indianapolis
317-841-0010

Scott Electronics
Fort Wayne
219-489-5690

IOWA
See Minnesota

KANSAS
Spectrum Sales
Overland Park
913-648-6811

KENTUCKY
See Ohio

LOUISIANA
See Texas

MAINE
See Massachusetts

MARYLAND
Third Wave Solutions
Columbia
301-290-5990

MASSACHUSETTS
Kanan Associates
Needham
617-449-7400

Byrne Associates, (DEC only)
Maynard
617-897-3131

MICHIGAN
Greiner Associates
Grosse Pointe Park
313-499-0188

MINNESOTA
Aldridge Associates
Eden Prairie
612-944-8433

MISSISSIPPI
See Alabama

MISSOURI
Spectrum Sales
Hazelwood
314-731-5151

MONTANA
See Colorado

NEBRASKA
See Missouri

NEVADA — NORTHERN
See California — Northern

DOMESTIC REPRESENTATIVES (Continued)

NEVADA — SOUTHERN

See Arizona

NEW HAMPSHIRE

Kanan North
Hooksett
603-645-0034

NEW JERSEY — NORTHERN

ERA Inc.
Commack
516-543-0758

NEW JERSEY — SOUTHERN

See Pennsylvania — Eastern

NEW MEXICO

Compass Mktg. & Sales, Inc.
Albuquerque
505-888-0800

NEW YORK — METROPOLITAN

ERA Inc.
Commack
516-543-0758

NEW YORK — UPSTATE

Reagan/Compar Albany, Inc.
Albany
518-489-7408

Reagan/Compar Albany, Inc.
New Hartford
315-732-3775

Reagan/Compar Albany, Inc.
Fairport
716-271-2230

Reagan/Compar Albany, Inc.
Endwell
607-723-8743

Regan/Compar Albany, Inc.
Endwell
607-754-2171

Reagan/Compar Albany, Inc.
Rochester
716-271-2230

NORTH CAROLINA

Prime Components, Inc.
Raleigh
919-850-9867

NORTH DAKOTA

See Minnesota

OHIO

Thompson and Associates
Dayton
513-435-7733

Thompson and Associates
Beachwood
216-831-6277

Thompson and Associates
Orient
614-877-4304

OKLAHOMA

Nova Marketing Inc.
Tulsa
918-660-5105

OREGON

Jas. J. Backer Company
Portland
503-627-0775

PENNSYLVANIA — EASTERN

Omni Sales
Erdenheim
215-233-4600

PENNSYLVANIA — WESTERN

See Ohio

PUERTO RICO

Dynamic Sales, Inc.
Cuguas
809-746-1091

RHODE ISLAND

See Massachusetts

SOUTH CAROLINA

See North Carolina

SOUTH DAKOTA

See Minnesota

TENNESSEE

See Alabama

TEXAS

Nova Marketing, Inc.
Dallas
214-750-6082

Nova Marketing, Inc.
Austin
512-343-2321

Nova Marketing, Inc.
Houston
713-988-6082

UTAH

Harris C.S.I.
Salt Lake City
801-974-5155

VERMONT

See New Hampshire

VIRGINIA

See Maryland

WASHINGTON

Jas. J. Backer Company
Seattle
206-285-1300

WEST VIRGINIA

See Western Pennsylvania

WISCONSIN — EAST

Oasis Sales Corp.
Brookfield
414-782-6660

WISCONSIN — WEST

See Minnesota

WYOMING

See Colorado

CANADA

Kaytronics, Inc.
Quebec
514-745-5800

Kaytronics, Inc.
Concord, Ontario
416-669-2262

Kaytronics, Inc.
Surrey
604-581-5005

Kaytronics, Inc.
Kanata, Ontario
613-564-0080

DOMESTIC DISTRIBUTORS

ALABAMA

Future Electronics/Huntsville
205-882-3190

Hall-Mark/Huntsville
205-837-8700

Hamilton/Avnet/Huntsville
205-837-7210

ARIZONA

Future Electronics/Phoenix
602-968-7140

Hall-Mark/Phoenix
602-437-1200

Hamilton/Avnet/Chandler
602-961-6400

CALIFORNIA — NORTHERN

Future Electronics/San Jose
408-434-1122

Hall-Mark/San Jose
408-432-0900

Hall-Mark/Citrus Heights
916-722-8600

Hamilton/Avnet/Sacramento
916-920-3150

Hamilton/Avnet/Sunnyvale
408-743-3355

Zeus Components/San Jose
408-998-5121

CALIFORNIA — SOUTHERN

Avnet Electronics/Costa Mesa
714-754-6111

Future Electronics/Chatsworth
818-772-6240

Future Electronics/Irvine
714-250-4141

Future Electronics/San Diego
619-278-5020

Hamilton/Avnet/Ontario
714-989-8809

Hamilton/Avnet/San Diego
619-571-7510

Hall-Mark/Torrance
213-217-8400

Hall-Mark/San Diego
619-268-1201

Hall-Mark/Canoga Park
818-716-7300

Hall-Mark/Tustin
714-669-4100

Hamilton Electro Sales/Costa Mesa
714-641-4199

Hamilton/Avnet/Chatsworth
818-700-6500

Hamilton/Avnet/Gardena
213-217-6700

Zeus Components/Yorba Linda
714-921-9000

COLORADO

Future Electronics/Westminster
303-421-0123

Hall-Mark/Englewood
303-790-1662

Hamilton/Avnet/Englewood
303-799-0663

CONNECTICUT

Anthem Corporation/Meriden
203-237-2282

Future Electronics/Bethel
203-743-9594

Hall-Mark/Wallingford
203-271-2844

Hamilton/Avnet/Danbury
203-797-2800

FLORIDA

Future Electronics/Altamonte Springs
305-767-8414

Future Electronics/Clearwater
813-578-2770

Hall-Mark/Ft. Lauderdale
305-971-9280

Hall-Mark/Orlando
407-830-5855

Hall-Mark/Clearwater
813-541-7440

Hamilton/Avnet/Ft. Lauderdale
305-971-2900

Hamilton/Avnet/St. Petersburg
813-573-3930

Hamilton/Avnet/Winter Park
407-628-3888

Zeus Components/Oviedo
407-365-3000

GEORGIA

Future Electronics/Norcross
404-441-7676

Hall-Mark/Norcross
404-447-8000

Hamilton/Avnet/Norcross
404-447-7500

ILLINOIS

Future Electronics/Schaumburg
312-882-1255

Hall-Mark/Wooddale
312-860-3800

Hamilton/Avnet/Bensenville
312-860-7700

INDIANA

Hall-Mark/Indianapolis
317-872-8875

Hamilton/Avnet/Carmel
317-844-9333

IOWA

Hamilton/Avnet/Cedar Rapids
319-362-4757

KANSAS

Hall-Mark/Lenexa
913-888-4747

Hamilton/Avnet/Overland Park
913-888-8900

MARYLAND

Anthem Corporation/Columbia
301-995-6640

Future Electronics/Columbia
301-290-0060

Hall-Mark/Columbia
301-988-9800

Hamilton/Avnet/Columbia
301-995-3500

Zeus Components/Columbia
301-997-1118

MASSACHUSETTS

Anthem Corporation/Wilmington
617-272-9400

Future Electronics/Westborough
508-366-2400

Hall-Mark/Billerica
617-935-9777

Hamilton/Avnet/Peabody
508-531-7430

Zeus Components/Lexington
617-863-8800

MICHIGAN

Future Electronics/Livonia
313-261-5270

Hallmark-Detroit
313-462-1205

Hamilton/Avnet/Grand Rapids
616-243-8805

Hamilton/Avnet/Livonia
313-522-4700

MINNESOTA

Future Electronics/Eden Prairie
612-944-2200

Hall-Mark/Eden Prairie
612-941-2600

Hamilton/Avnet/Minnitonka
612-932-0600

BRANCHES

DOMESTIC DISTRIBUTORS (Continued)

MISSOURI

Future Electronics/St. Louis
314-469-6805

Hall-Mark/Earth City
314-491-5350

Hamilton/Avnet/Earth City
314-344-1200

NEW HAMPSHIRE

Hamilton/Avnet/Manchester
603-624-9400

NEW JERSEY — NORTHERN

Anthem Corporation/Fairfield
201-575-3390

Future Electronics/Fairfield
201-227-4346

Hall-Mark/Fairfield
201-575-4415

Hamilton/Avnet/Fairfield
201-575-3390

Nu Horizons Electronics/Fairfield
201-882-7950

NEW JERSEY — SOUTHERN

Future Electronics/Mt. Laurel
609-778-7600

Hall-Mark/Mt. Laurel
605-235-1900

Hamilton/Avnet/Cherry Hill
604-424-0100

NEW MEXICO

Hamilton/Avnet/Albuquerque
505-765-1500

NEW YORK

Future Electronics/Hauppauge
516-234-4000

Future Electronics/Liverpool
716-272-1120

Future Electronics/Rochester
716-272-1120

Hall-Mark/Rochester
716-425-3300

Hall-Mark/Ronkonkoma
516-737-0600

Hamilton/Avnet/Hauppauge
516-231-9800

Hamilton/Avnet/Rochester
716-475-9130

Hamilton/Avnet/Syracuse
315-437-2641

Anthem Corporation/Hauppauge
516-226-6000

Nu Horizons Electronics/No. Amityville
516-226-6000

Zeus Components/Port Chester
914-937-7400

NORTH CAROLINA

Future Electronics/Charlotte
704-529-5500

Hall-Mark/Raleigh
919-872-0712

Hamilton/Avnet/Raleigh
919-878-0810

OHIO

Hall-Mark/Solon
216-349-4632

Hall-Mark/Worthington
614-888-3313

Hamilton/Avnet/Dayton
513-439-6700

Hamilton/Avnet
216-349-5100

Hamilton/Avnet/Westerville
614-882-7004

OKLAHOMA

Hall-Mark/Tulsa
918-254-6110

OREGON

Future Electronics/Beaverton
503-645-9454

Hamilton/Avnet/Lake Oswego
503-635-8831

PENNSYLVANIA — EASTERN

Anthem Corporation/Horsem
215-443-5150

PENNSYLVANIA — WESTERN

Hamilton/Avnet/Pittsburgh
412-281-4150

TEXAS

Future Electronics/Richardson
214-437-2437

Hall-Mark/Austin
512-258-8848

Hall-Mark/Dallas
214-553-4300

Hall-Mark/Houston
713-781-6100

Hamilton/Avnet/Austin
512-837-8911

Hamilton/Avnet/Houston
713-240-7733

Hamilton/Avnet/Irving
214-550-7755

Zeus Components/Richardson
214-783-7010

UTAH

Future Electronics/Salt Lake City
801-972-8489

Hall-Mark/W. Valley City
801-972-1008

Hamilton/Avnet/Salt Lake City
801-972-2800

WASHINGTON

Future Electronics/Redmond
206-881-8199

Hall-Mark/Seattle
206-547-0415

Hamilton/Avnet/Redmond
206-881-6697

WISCONSIN

Future Electronics/Waukesha
414-786-1884

Hall-Mark/New Berlin
414-797-7844

Hamilton/Avnet/Maukehsa
414-784-4510

CANADA

Future Electronics/Calgary
403-235-5325

Future Electronics/Edmonton
403-438-2858

Future Electronics/Montreal
514-694-7710

Future Electronics/Ottawa
613-820-8313

Future Electronics/Quebec
418-682-8092

Future Electronics/Toronto
416-638-4771

Future Electronics/Vancouver
604-294-1166

Future Electronics/Winnipeg
204-786-7711

Hamilton/Avnet/Calgary
403-250-9380

DOMESTIC DISTRIBUTORS (Continued)

Hamilton/Avnet/Montreal
514-335-1000

Hamilton/Avnet/Nepean
613-226-1700

Hamilton/Avnet/Mississauga
416-667-7432

Hamilton/Avnet/Burnaby
604-437-6667

INTERNATIONAL

Hamilton/Avnet/Gardena
213-327-3693

Hamilton/Avnet/Westbury
516-997-6868

SEMICONDUCTOR PRODUCTS
UNITRODE

Effective Date: June 1, 1989

UNITRODE SALES OFFICES

Corporate International and Asian Regional Sales Office, 5 Forbes Road, Lexington, MA 02173 Tel. (617) 861-6540, Telex 95-1064
Unitrode Electronics GmbH, Hauptstrasse 68, 8025 Unterhaching, West Germany Tel. 089/6190 04/05/06, Telex 841-05-22-109, Fax: 49-89-617984
Unitrode (U.K.) Limited, 6 Cresswell Park, Blackheath, London SE3 9RD, United Kingdom Tel. 01-318-1431/4, Telex 896270 UNTRUK G, Fax: 01-318-2549
Unitrode S.R.L., Via Dei Carracci, 5, 20149 Milano, Italy Tel. 02/439-6831, 434 604, Telex 310085 UNITRD I
Unitrode-Ireland, Ltd., Industrial Estate, Shannon, County Clare, Ireland Tel. 353-61-62377, Telex 26233
Unitrode Electronics Asia, Ltd., Suite 939, New World Office Bldg., 24 Salisbury Rd., Kowloon, Hong Kong Tel (3) 722-1101, Telex 39826 UTRD HX, Fax 852-3-697596

INTERNATIONAL AGENTS — DISTRIBUTORS

AUSTRALIA

VSI Electronics (Australia) Pty. Ltd.
P.O. Box 578
Crows Nest N.S.W. 2056
Tel: 439-4655
TELEX: 22846
FAX: 612-439-6435

AUSTRIA

Dahms Elektronik
Wienerstrasse 287
A-8051 Graz
Tel: (0316) 64.0.30
TELEX: 031099
FAX: 0316/6403029

BELGIUM

Lemaire/Rodelco
Limburg Stirum 243
1810 Wemmel
Tel: (32) 2460 0560
TELEX: 24610 Lemair B
FAX:

BRAZIL

Hi Tech Comercial & Industrial Ltda.
Av. Eng. Luiz Carlos Berrini,
801, Cj. 121
Cidade Moncors
04 571 Sao Paulo
Tel: (011) 533-9566
TELEX: 11-53288 HT HB BR
FAX: 55-11-61-3770

DENMARK

REPRESENTATIVE
See Sweden

DISTRIBUTOR
Delco A/S
Hejrevang 13
DK-3450 Allerod
Tel: (45) 2277733
FAX: (45) 2277770

EASTERN EUROPE

Dahms Elektronik
Pilgramstrasse 11
A-1050 Wien
Tel: (0222) 543321
TELEX: 134583

Dahms Elektronik
Wienerstrasse, 287
A-8051 Graz
Tel: (0316) 64.0.30
TELEX: 031099

FINLAND

REPRESENTATIVE
See Sweden

DISTRIBUTOR
Turion OY
Graniittitie 9
00711 Helsinki
Tel: (358) 0372144
TELEX: 124388 Turio SF
FAX: (358) 0373558

FRANCE

REPRESENTATIVE

Unirep
Zone d'activités "Les Godets"
C.E. N.433
91374 Verrieres le Buisson Cedex
Tel: (1) 69200364
TELEX: 603131
FAX: 1 69200061

DISTRIBUTORS

Ericson Composants
Boite Postale N.203
78051 Saint-Quentin Yvelines Cedex
Tel: (1) 30582424
TELEX: 697347
FAX: 1 30583096

Ericson Composants
41, Avenue des Freres Lumiere
69680 Chassieux
Tel: (16) 78401006
TELEX: 375444
FAX: 1678907570

C.C.I.
Boite Postale N.92
Zone Industrielle
5, Rue Marcelin Berthelot
92160 Antony Cedex
Tel: (1) 46662182
TELEX: 203881
FAX: 1 42372430

C.C.I.
67 Rue Bataille
69008 Lyon
Tel: 78742375
TELEX: 375456
FAX: 16 78760891

Syscom Electronique
A.Z. des Coteaux du Sud
31.33 Rue des Refugniks
94006 Creteils Cedex
Tel: 1 43778488
TELEX: 2 62566
FAX: 1 43775349

GERMANY

Unitrode Electronics GmbH
Hauptstrasse 68
8025 Unterhaching
Tel: 089/619004-006
TELEX: 522109
FAX: 49-89-617984

Heitek GmbH
Postfach 1222
Lannerstr. 31
Unterhaching
Tel: 089/6115052
FAX: 089/619999

EBV Elektronik GmbH
Oberweg 6
8025 Unterhaching
Tel: 089/611051
TELEX: 524535
FAX: 089-61105230

EBV Elektronik GmbH
Viersenerstrasse 24
4040 Neuss
Tel: 02101/530072
TELEX: 8517605
FAX: 02101-593087

EBV Elektronik GmbH
Schenckstrasse 90
6000 Frankfurt/M. 99
Tel: 069/785037
TELEX: 413590
FAX: 069-7894458

INTERNATIONAL AGENTS — DISTRIBUTORS (Continued)

EBV Elektronik GmbH
Kibitzrain 18
3006 Burgwedel 1
Tel: 05139/80870
TELEX: 923694
FAX: 5139-5199

EBV Elektronik GmbH
Weimarstrasse, 48
7000 Stuttgart 1
Tel: 0711/619100
TELEX: 722271
FAX: 0711-613750

EBV/DISTRON GmbH
Beihaimstrasse 3
1000 Berlin 10
Tel: 030-342 1041-44
TELEX: 185475
FAX: 030-3419003

Metronik GmbH
Leonhardsweg 2
8025 Unterhaching
Tel: 089/611080
TELEX: 17-897434
FAX: 089/6116468

Metronik GmbH
Buckhoerner Moor 81
2000 Norderstedt
Tel: 040-5228031
TELEX: 2162488
FAX: 040-5228093

Metronik GmbH
Siemensstrasse 4-6
6805 Heddesheim
Tel: 06203/4701
TELEX: 465035
FAX: 06203-45543

Metronik GmbH
Laufamholzstrasse 118
8500 Nürnberg
Tel: 0911/590061-62
TELEX: 626205
FAX: 0811-542936

Metronik GmbH
Semerteichstrasse 92
4600 Dortmund 30
Tel: 0231/423037-38
TELEX: 8227082
FAX: 0231-418232

Metronik GmbH
Löwenstrasse 37
7000 Stuttgart 70
Tel: 0711/764033
TELEX: 7255228
FAX: 0711-7655181

Frehsdorf GmbH
Carl-Zeiss-Strasse 3
2085 Quickborn
Tel: 04106/70050
TELEX: 213693
FAX: 04106700537

Frehsdorf GmbH
Schlüterstrasse 39
1000 Berlin 12
Tel: 030/8839040
TELEX: 185418
FAX: 030-8823204

Frehsdorf GmbH
Herbststrasse, I
8200 Rosenheim
Tel: 08031-37085
TELEX: 525865
FAX: 08031-14560

Freshdorf, GmbH
Pfingstweide 6
6360 Friedberg
Tel: 06031-61057
TELEX: 17-6031947
FAX: 06034-92916

INDIA

American Components, Inc.
3350 Scott Blvd, Bldg. 15
Santa Clara, CA 95054
Tel: 408-427-2440
TELEX: 4937118 ACIUI
FAX: 408-492-0406

IRELAND

New England Technical Sales Ltd.
The Diamond
Malahide, Co. Dublin
Tel: (0001) 450-635
TELEX: 31407 NETS, EI
FAX: (0001) 453625

New England Technical Sales Ltd.
5 Dalton Drive
Salthill
Galway
Tel: 061-353-91-25784
TELEX: 31407
FAX: (353) 91-24885

DISTRIBUTION

Lyco
Estuary House
New Street,
Malahide
Co. Dublin
Tel: (353) 1 452020
FAX: (353) 1 452414

ISRAEL

S.T.G. International Ltd.
10 Huberman Street
P.O. Box 1276
Tel-Aviv 61012
Tel: 03-248231
TELEX: 922-342229
FAX: 972-3-234309

ITALY

Unitrode S.r.l.
Via dei Carraci, 5
20149 Milano MI
Tel: (02) 498 2278
Tel: (02) 498 5121
TELEX: 310085 UNITRD I

REPRESENTATIVES

C.F. S.n.c.
Via Badia di Cava, 62
00142 Roma RM
Tel: (06) 542 3392
FAX: 06542 5279

Dimac Elettronica S.r.l.
Via S.M. alle Selve, 4
20046 Biassono MI
Tel: (039) 491 514
TELEX: 316518 DIMAC I
FAX: (039) 491 773

DISTRIBUTORS

Eurelettronica A.P.A.
Via E. Fermi, 8
20090 ASSAGO MI
Tel: 02 488 0022
TELEX: 350037 EUREL 1
FAX: 02 488 0275

Fanton Bologna S.r.l.
Via O. Simoni, 5
40011 ANZOLA dell 'EMILIA BO
Tel: 051 734 700
TELEX: 216613 FANTOB I
FAX: 051 732216

Fanton Firenze S.r.l.
Loc Le Sieci
50065 FONTASSIEVE (Fi)
Tel: 055- 8328418
FAX: 055-8328420

Fanton Milano S.r.l.
Via Melegnano, 20
20019 Settimo Milanese MI
Tel: (02) 328 7312
TELEX: 350853 FAN MI I
FAX: 02 328 7948

Fanton Electronic System S.r.l.
Via Savelli, 1
35129 Padova PD
Tel: (049) 77 5822
TELEX: 430192 FANTON I
FAX: 049-8070521

Fanton Torino S.r.l.
Via Cimabue, 5
10137 Torino TO
Tel: (011) 309 7347
TELEX: 224129 FANTON I
FAX: 011 305 069

INTERNATIONAL AGENTS — DISTRIBUTORS (Continued)

Fanton Roma S.r.l.
Viale Leonardo daVinci 309
00145 ROMA
Tel: 06-5421471
TELEX: 620484 CSR I
FAX: 06-5425210

JAPAN

Internix Inc.
Shinjuku Hamada Bldg. 7-4-7
Nishi-Shinjuku
Shinjuku-Ku
Tokyo 160
Tel: 3-369-1105
FAX: 3-366-8566

Jepico Corporation
Shinjuku Dai-ich/Seimei Bldg.
Nishi-Shinjuku 2-7-1
Shinjuku-Ku
Tokyo 163
Tel: 3-348-0611
FAX: 3-348-0623

KOREA R.O.K.

MS International Corp.
CPO Box 6780
Room 1205 Haechun Building
831 Yucksam-dong
Kangnam-Ku, Seoul
Tel: 553-0901
TELEX: K24965 MSIPARK
FAX: 553-0046

NETHERLANDS

Koning en Hartman
Elektrotechniek B.V.
Energieweg1
2600 AC DELFT
P.O. Box 125
Tel: (31) 15609906
TELEX: 38250 Koha NL
FAX: (31) 15619194

NEW ZEALAND

Professional Electronics
22 A Milford Road
Auckland
Tel: 493-029, 499-048
TELEX: NZ21084
FAX: 64-9-493-45

NORWAY

REPRESENTATIVE

See Sweden

DISTRIBUTOR

Neco A/S
Jerikoveien 22
Box 29-Lindeberg Gaard
1007 OSLO 10
Tel: (47) 2301230
TELEX: 19247 BRAKE N
FAX: (47) 2301694

SINGAPORE

Desner Electronic PTE, Ltd.
190 Middle Road, #16-07
Fortune Centre
Singapore 0718
Tel: 337-3188
TELEX: RS 39191 DTD
FAX: 3373180

SOUTH AFRICA

Electrolink (Pty) Ltd.
Fleetway House
Martin Hammerschlag Way
Foreshore Capetown
Tel: 215350
TELEX: 98-206
FAX: 27-21-4196256

SPAIN

Monolithic S.A.
Av. Hospital Militar 78-80 ENTLO
08023 Barcelona
Tel: (3) 2194016-4154-4212
TELEX: 08026
FAX: (3) 2141193

SWEDEN

REPRESENTATIVE

Repretech Scandanavia AB
Box 2042
172 02 Sundbyberg
Tel: (46) 8-7330475
FAX: (46) 8-7330558

DISTRIBUTOR

Nordquist & Berg
Engundavagan 7
Box 1458 S-171
28 Solna
Tel: (46) 87646710
TELEX: 10407 NORDSWE S
FAX: (46) 87644730

SWITZERLAND

Elkom AG
Durisolstr. 12
5612 Villmergen
Tel. 057-211145
FAX: 057-229658

TAIWAN

Wanroc, Inc.
8F-2, 15, Hsin-I Road
Sec. 2, Taipei, 011-886
Tel: (02) 394-5236
FAX: (02) 397-1696

UNITED KINGDOM

REPRESENTATIVES

Albur Electronics
4 Peddlars Grove
Yateley, Camberley,
Surrey GU17 7AS
Tel: 0252-871882
FAX: 0252-890313

E C & E
22 Honeyborne Road
Sutton Coldfield,
West Midlands
B75 6BT
Tel: 021-378-1128
FAX: 021-311-1426

Millfield
Little Chesterford
Saffron Walden,
Essex
CB10 1UD
Tel: 0799-30434
FAX: 0799-31119

NETS
(New England Technical Sales)
Unit 17
M.E.T. Enterprise Workshops
Dalziel Street,
Motherwell,
Scotland ML1 1PJ
Tel: 0698-61904
FAX: 0698-69320

Pristine Marketing
3 High Street
Lenham,
Kent
ME17 2QD
Tel: 0622-858100
FAX: 0622-858103

DISTRIBUTORS

VSI Electronics (UK) Ltd.
Roydonbury Industrial Park
Horsecroft Road
Harlow, Essex
CM19 5BY
Tel: 0279-29666
TELEX: 81387 VSI UK G
FAX: 0279-418068

Unitrode Corporation
580 Pleasant Street
Watertown, MA 02172
Tel: (617) 926-0404
FAX: (617) 924-1235

DB600 Printed in U.S.A.