EAI 231R-V

ANALOG COMPUTER

INFORMATION MANUAL

INFORMATION MANUAL
For
The EAI 231R-V
ANALOG COMPUTING SYSTEM

AUGUST 1964

Preface

All general-purpose analog computers use the same basic operating principles and programming techniques. The flexibility and ease with which these principles and techniques are made available to the programmer, however, differ markedly from one machine to another. For this reason, this manual has been prepared as an introduction to the EAI 231R-V Analog Computer — describing the system, its components, accessories, peripheral equipment and the multitude of features that establishes it as the most complete analog computing system available. No attempt has been made to cover either the programming or operation of the machine, nor its performance specifications. Additional manuals and data sheets are available on request to provide further detailed information.

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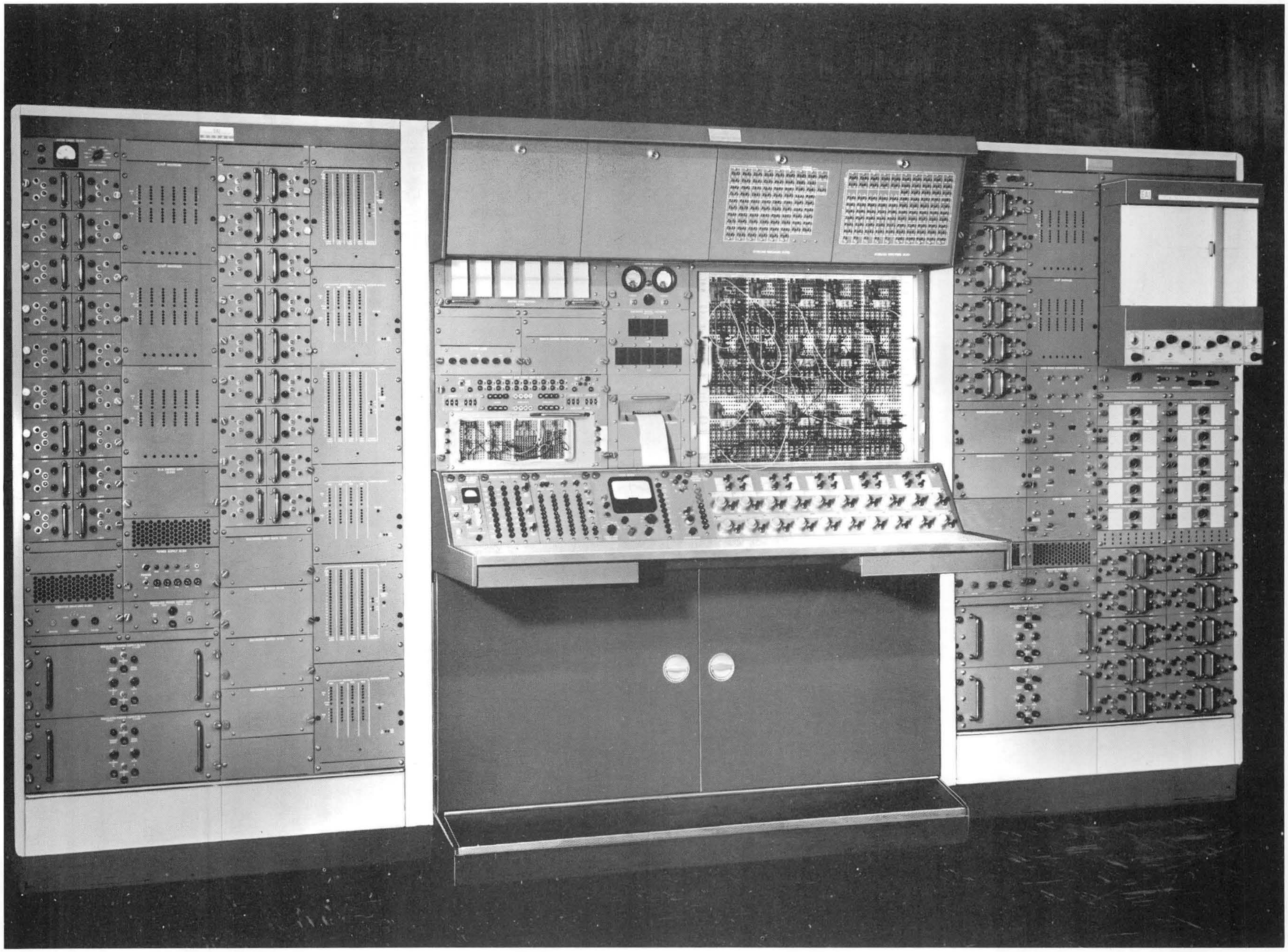


Figure 1. EAI 231R-V Analog Computing System

INTRODUCTION

Complex system designs dictate the constant need for thorough investigations of system behavior over wide ranges of operating conditions. Such investigations generally consist of an interwoven series of experiments and analyses to determine the effect of individual parameters on overall performance. Since the cost and complexity of modern systems preclude the use of scale models or prototypes for this purpose, the design-engineer/scientist must rely on a mathematical model, or statement of laws governing system behavior.

Electronic computers provide the engineer with a means to obtain accurate solutions – rapidly – to these mathematical relationships without the uncertainty of results inherent in other procedures. The computer makes it possible to perform controlled experiments and design modifications in a fast, safe, economic manner – by simulation. Because of this, computer simulation has become an integral part of, and a routine technique in, complex system design and development.

The success of this procedure is dependent on the selection of a scientific computer that is suited to the needs of the simulation. Speed and accuracy requirements vary with the system to be investigated and the information required. The capability to simulate only static or steady-state conditions – as well as complete system dynamics – must also be considered.

The dynamic behavior of a physical system is characteristically described by differential equations, which lend themselves to high-speed solutions by an electronic differential analyzer – or general-purpose analog computer. The solution speed of the analog computer becomes even more important when a portion of the actual physical system is involved, or when "real-time" simulation is necessary.

As systems become more complex, the mathematical models require more sophisticated simulation techniques and methods of analysis – thus the computer must provide capabilities for utilizing new techniques. The need for more complete mathematical descriptions of systems has placed particular emphasis on the computer solution of partial differential equations. Advanced solution techniques for such equations, which make use of sequential or iterative operations, have made it necessary to extend the computing speed range of the analog computer to permit "compressed time" or faster than "real-time" simulation. Use of the analog computer to perform automatic system optimization in accordance with specific design criteria imposes further requirements – such as logical decision-making and control.

The technology of the space age has brought about a need for analysis of systems which involve both discrete and continuous phenomena. Simulation of such systems dictates the need for a computer capable of performing the continuous (analog) and the discrete (digital) operations. Simulation of the combined dynamic and steady-state characteristics of a system, particularly if the latter requires logical decisions or extreme precision, further suggests the use of a "hybrid" computer to effectively integrate the capabilities of analog and digital equipments.

To meet this challenge EAI introduced the 231R-V General-Purpose Analog Computing System. This system exhibits the accuracy and stability necessary for real-time simulation, and at the same time provides the solution-speed and control flexibility necessary for iterative and hybrid computation. The 231R-V is the latest in the 231R series of analog computing systems, and as such, makes use of a basic design which has achieved an unmatched record for performance and reliability. Incorporating all of the proven features of previous PACE computers, the 231R-V adds many advanced features specifically designed to meet the simulation requirements of industrial and government research and development groups.

Among the many new features offered by the 231R-V is the EAI Analog Memory and Logic System, which allows the computer to perform the functions of mode control, signal switching and storage under program control at repetitive operation speeds. Electronic mode control, individual integrator time-scale selection, and high-speed analog memory make possible multi-speed and iterative operation of the computer. The modular design of the 231R-V allows the customer to initially establish a modest-sized installation and later expand as the work load and problem complexity dictate. Provisions for mode control slaving and signal communication between multiple 231R Computing Systems permit expansions necessary to cope with the largest simulation problems.

Since the 231R-V also forms the analog section of EAI HYDAC Hybrid Digital Analog Computer Systems, it represents the logical first step in establishing a complete hybrid computing facility. The 231R-V was developed specifically for the advanced analog computing techniques required by hybrid computation, and is an integral part of the HYDAC 2000 and HYDAC 2400 computing systems. Because of this, the customer has the added assurance that he can expand to these capabilities when necessary and thereby avoid obsoleting his computing facility.

The experience compiled in the development of special military systems and industrial control equipment represents the foundation of EAI's ability to develop computing equipment uniquely suited to the requirements of modern technology. Application experience gained through the computation centers operated by the EAI Research and Computation Division, which serve as proving grounds for new computing equipment and methods, has proved that the 231R-V exhibits the programming convenience and flexibility necessary for efficient operation of a simulation laboratory.

EAI Computation Centers offer a complete curriculum of training courses in the proper maintenance, operation, and programming of analog and hybrid computers. Advanced courses are given on analog and hybrid computation, covering such fields as chemical process, aerospace and biochemical simulation. The computation center installations are also available to industry to provide the latest in scientific computers and programming techniques for tasks ranging from operations research to the solution of partial differential equations.

As the leading supplier of general-purpose analog and hybrid computing systems, EAI also offers the most extensive supporting services to assure the success of a computing facility. The largest field service organization in the analog computer industry is available to supply information and assistance to customer maintenance personnel, or to provide complete maintenance service under a contract tailored to the specific customer's requirements.

Backed by the EAI creed of quality and service, plus the assurance of constant system optimization gained through years of experimentation and modernization, users of the 231R-V are guaranteed the finest precision simulation equipment and computing services available.

TABLE I. EQUIPMENT COMPLEMENT OF FULLY EXPANDED 231R-V

	Qty.
OPERATIONAL AMPLIFIERS	
Summer-Integrators	30
Summers	29
Summers with Track and Store Network	16
Summer-Inverters	5
Inverters associated with Diode Function Generators	40
Inverters associated with Electronic Multipliers	30
Inverters associated with Electronic Resolvers	12
Additional Amplifiers associated with Electronic Multipliers	30
Additional Amplifiers associated with Electronic Resolvers	24
Total	216
COEFFICIENT POTENTIOMETERS	
Manual Attenuators	20
Manual or Servo-Set Attenuators	150
Total	170
ELECTRONIC MULTIPLIERS	30
NONLINEAR COMPONENT POSITIONS (See Note 1)	6
ELECTRONIC RESOLVERS (See Note 2)	3
DIODE FUNCTION GENERATORS (Manual or Servo-Set)	20
DIODE LIMITERS (Bridge or Feedback)	15
COMBINATION TRACK & HOLD UNITS (See Note 3)	10
DIGITAL-ANALOG SWITCHES	12
ELECTRONIC COMPARATORS (With Function Relays)	10
POTENTIOMETER PADDING UNITS (See Note 4)	9
MODE LOGIC PROGRAMMING COMPONENTS	
Interval Timers	2
Function Switches	6
Mode Relay Drivers	10
Repetitive Drives (See Note 5)	4
Logic Gates	11
PASSIVE ELEMENTS (See Note 6)	
Resistors	10
Capacitors	10
Total	20
FUNCTION SWITCHES	20
EXTERNAL TRUNK LINES	
Input and Output Trunks on Analog Patch Panel	200
Input and Output Trunks on Mode Logic Patch Panel	40
Total	240
INTER-PANEL TRUNKS (See Note 7)	8
HYDAC DIGITAL OPERATIONS SYSTEM INTERFACE TERMINATIONS	
Electronic Comparators	16
Digital-Analog Switches	30
Mode Relay Drivers	8
ELECTRONIC DIGITAL VOLTMETER	1
VACUUM-TUBE VOLTMETER	1
AUTOMATIC DIGITAL INPUT-OUTPUT SYSTEM (ADIOS)	1
HIGH-SPEED PRINTER	1
GAUSSIAN NOISE GENERATOR	1
EIGHT-CHANNEL RECORDERS	2
X-Y PLOTTERS	3
CURVE-FOLLOWER FUNCTION GENERATORS	3
HIGH-SPEED REPETITIVE OPERATION DISPLAY CONSOLE (EIGHT-CHANNEL)	1
MONITOR OSCILLOSCOPE	1

NOTE 1. A Non-linear Component Position may accommodate any of the following equipment:
(a) one Servo-Multiplier
(b) one Servo-Resolver-Multiplier
(c) four 180° Sine-Cosine Generators
(d) three 360° Sine-Cosine Generators
(e) six Fixed Function Generators (Log X, X^2, X^4) in any combination
(f) three Electronic Multipliers

NOTE 2. Each Electronic Resolver contains four Electronic Multipliers and one Sine-Cosine Generator that may be used independently of the Resolver. It is also possible to have two additional Electronic Resolvers in place of two of the Non-linear Component Positions.

NOTE 3. The individual Combination Track and Hold Unit consists of an Electronic Comparator and two Track and Hold networks which may be used as digital-to-analog switches.

NOTE 4. Additional Potentiometer Padding Units may be supplied as customer needs dictate.

NOTE 5. The three Repetitive Drives, 250cps, 500cps and 2500cps, are available when the computing system contains a High-Speed Repetitive Operation Display Console.

NOTE 6. Patch cords containing resistors, capacitors and diodes are available as needed.

NOTE 7. These trunks connect the Analog and Mode Logic Patch Panels, and are voltage-limited to maintain logic level outputs at the Mode Logic Panel.

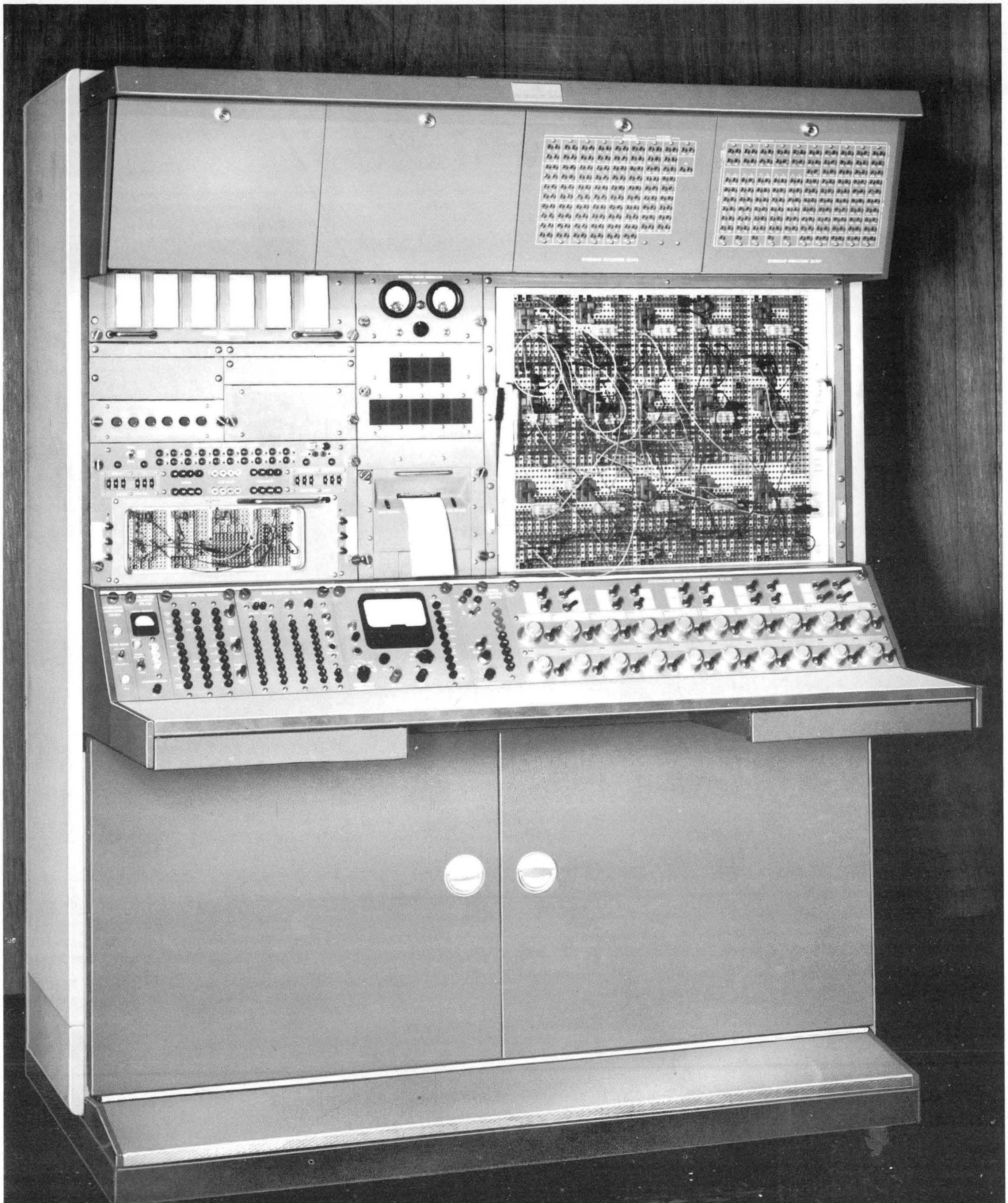


Figure 2. Control Console

CONTROL CONSOLE

The PACE 231R-V Analog Computing System (Figure 1) is a general-purpose computer for simulating dynamic systems . . . yielding new standards for speed, accuracy, reliability and economy in the scientific computing field. Over two hundred operational amplifiers enable the 231R-V to handle everything from routine engineering calculations to the most complex and sophisticated problems in system design. The modular arrangement of elements in this computing system permits field expansion of an installation to cope with increasing problem complexities as needed.

DESCRIPTION

The programming and control center of the 231R-V is a three-bay console-type cabinet (Figure 2) containing the operating controls and program patching system for the entire computer. In addition, the linear computing components, i.e., integrators, summers, coefficient attenuators, etc., together with their associated power supplies and temperature-stabilized network oven, are included in this cabinet. Completely useable as a self-contained linear computing system, the control console may be later expanded to include the capability for solving more complex non-linear problems. Multipliers, function generators and other non-linear components are contained in separate cabinets which are physically joined to the console, the interconnecting cables being routed through an integral cable duct at the rear of the cabinets.

Table I lists the equipment complement of a fully-expanded 231R-V System. Further expansion may be accomplished by the addition of a second control console with its associated expansions.

Special consideration has been given to human-engineering the 231R-V Control Console for maximum operator convenience and efficiency. All programming and control functions are centrally located at the console. Controls which include the readout selector pushbuttons, Digital Attenuator System input keyboard, vacuum-tube voltmeter, and mode control pushbuttons, are conveniently grouped on a sloping panel (Figure 3) which spans the front of the console. All controls and indicators are clearly labeled according to the functions which they serve. Also mounted on this panel are twenty function switches and twenty manual coefficient attenuators, to facilitate program checkout and problem parameter adjustment. Immediately above the control panel are the program patching system, digital voltmeter, printer, and the Analog Memory and Logic System control unit with its associated patching system. Mounted below the control panel, a shelf with storage drawers provides a convenient work area for the operator. The entire control and patching area of the console is illuminated with indirect fluorescent lighting.

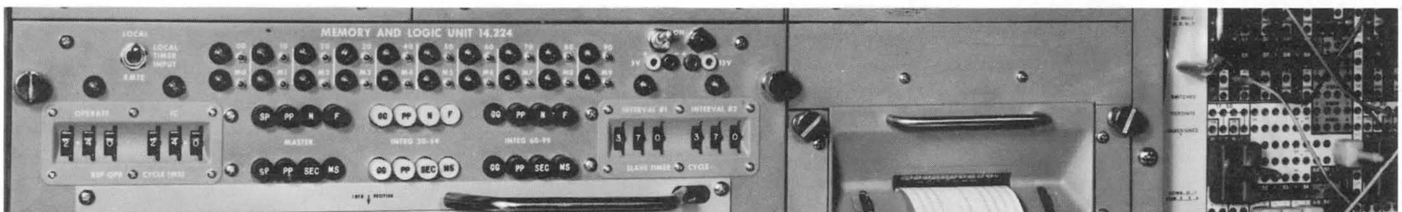


Figure 3. Control Panel

Figure 4. Program Patching System

PROGRAM PATCHING SYSTEM

Since a significant portion of the overall computing cycle for a general-purpose analog computer is devoted to programming, emphasis has been placed on the design of the 231R-V Program Patching System (Figure 4). It features a 3,450-hole removable pre-patch panel and patch-bay which permit program patching without interruption of computer operation. Patching changes may be made without removing the panel from the computer; moreover, patch panels may be interchanged in seconds with complete assurance of electrical continuity on all contacts.

The all-metal pre-patch panel of the 231R-V is precision-machined for accurate alignment with the patch-bay – the use of an aluminum alloy insuring a durable, lightweight, easy-to-handle panel. Low-cost construction makes practical the purchase of a number of spare panels for long-term program storage. Patching terminations (Figure 5) are color-coded and labeled with large, clear lettering to facilitate error-free patching. A unique, modular format, which arranges locations of computing-component group terminations to conform with a typical patching sequence, permits maximum use of bottle plugs – thus reducing patch cord clutter. Write-in areas on the panel enable identification of stored programs. A complete variety of fully-shielded patch cords, bottle plugs and other patching accessories are available for use with the pre-patch panel. Patch cords containing resistors, capacitors, diodes, and special networks may also be supplied.

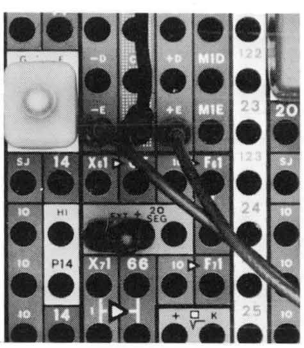


Figure 5
Close-up of Pre-Patch Panel.

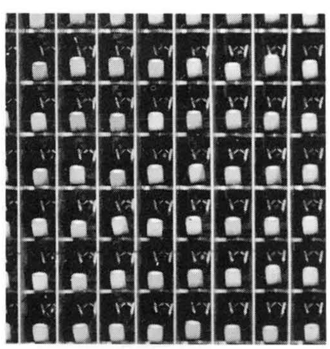


Figure 6
Close-up of Patch-Bay Contacts

With the inputs and outputs of all computing components terminating at the patch-bay, its electrical design is necessarily critical to the performance of the computer; i.e., special care must be taken to prevent cross-talk and to avoid degrading the accuracy of computing voltages. To minimize noise and allow maximum dynamic performance of computing components, the 231R-V patch-bay includes complete electrical shielding for each signal. A metal gridwork (Figure 6) on the front and rear of the patch-bay forms individually shielded cells for each contact. Moreover, each contact is mounted on a low-loss insulator bushing. To minimize the conducting paths between the pre-patch panel and amplifier networks, the patch-bay also forms the front cover of the temperature-stabilized network oven. All electrical connections to the rear of the patch-bay are made either by taper pins or banana plugs to facilitate maintenance and permit modification of patching terminations.

The latching mechanism which locates the panel in the patch-bay includes a system of cams to create a wiping action between the patch cord tips and contact springs of the patch-bay. To assure minimum contact resistance, the cord tips and patch-bay springs are gold-plated by a special process. For safety, the latching system includes provisions for automatically disconnecting all voltages from the contacts when the pre-patch panel is removed.

AUTOMATIC EXTENDED READ OUT (AERO) SYSTEM

The overall usefulness of an electronic computer is greatly determined by its input-output capabilities and its provisions for operator-machine communication. Throughout the programming phase of an analog computer it is particularly important that the operator be able to readily select and monitor voltages in the program. This is accomplished in the 231R-V by the Automatic Extended Read Out (AERO) System which offers both manual and automatic selection of components.

In addition to readout of computing component outputs, provisions are included for monitoring integrator initial derivatives and coefficient attenuator settings. A complete list of the signals selected by the AERO System is given in Table II. The voltage values of these signals may be measured with either the vacuum-tube volt-

TABLE II. SIGNALS MONITORED BY THE FULLY EXPANDED 231R-V READOUT SYSTEM

COMPONENT CATEGORY	READOUT SIGNALS
Operational Amplifiers	*Summer-Integrator Outputs* *Integrator Initial Derivatives* *Summer Outputs* *Summer-Inverter Outputs* *Outputs of Summers with Track and Store Networks* *Outputs of Inverters associated with Diode Function Generators* *Outputs of Amplifiers associated with Electronic Multipliers* *Outputs of Amplifiers associated with Electronic Resolvers*
Coefficient Potentiometers	*Potentiometer Coefficients* *Potentiometer Outputs*
Electronic Multipliers	*Electronic Multiplier Outputs* *Associated Amplifier Outputs*
Servo Multipliers	*Feedback Potentiometer Outputs* *Multiplying Potentiometer Outputs*
Servo Resolvers	*Feedback Potentiometer Outputs* *Multiplying Potentiometer Outputs* *Sine-Cosine Potentiometer Outputs*
Electronic Resolvers	*Electronic Resolver Outputs* *Sine-Cosine Generator Outputs* *Electronic Multiplier Outputs* *Outputs of Amplifiers associated with Electronic Multipliers*
Diode Function Generators	*Function Generator Outputs* *Associated Amplifier Outputs*
Electronic Comparators	*Function Relay Arms*
Trunks	*Input Trunks*

meter or electronic digital voltmeter; a high-speed digital printer provides a printed record of voltages measured by the digital voltmeter.

The AERO signal selector makes use of high-speed stepping relays equipped with gold-plated contacts to insure low-loss signal paths. These relays are addressed manually with the parallel-input keyboard (Figure 7), or automatically from the ADIOS (Automatic Digital Input-Output System) or digital section of the EAI HYDAC (Hybrid Digital-Analog Computer). When the AERO System is addressed by the HYDAC Digital Operations System, the binary-coded-decimal output of the digital voltmeter appears on the DOS pre-patch panel. Since the output of the signal selector is terminated on the 231R pre-patch panel, it may also be used to switch a number of signals to a common point in the program.

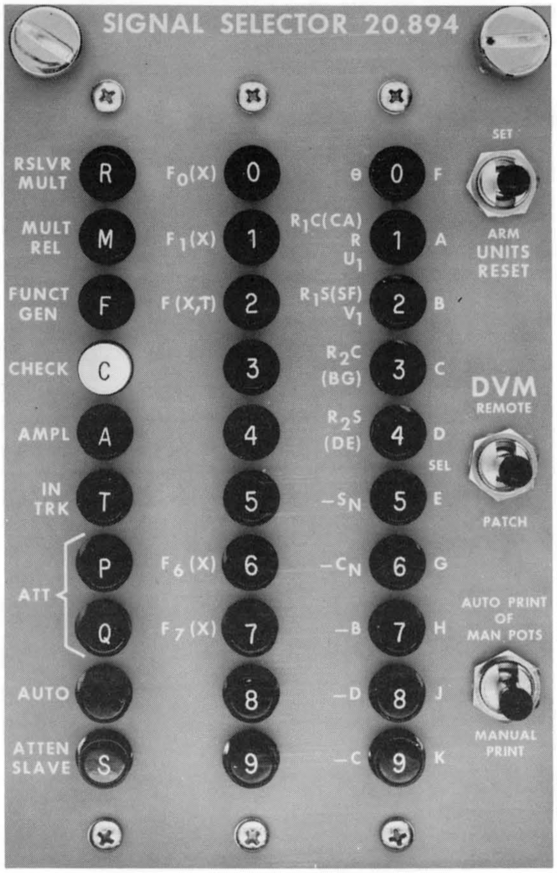
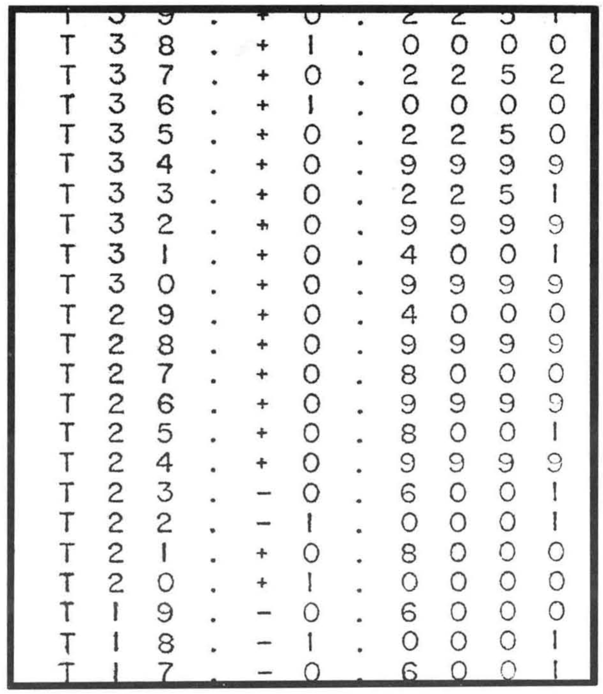


Figure 7. AERO Signal Selector



T	3	8	.	+	1	.	0	0	0	0
T	3	7	.	+	0	.	2	2	5	2
T	3	6	.	+	1	.	0	0	0	0
T	3	5	.	+	0	.	2	2	5	0
T	3	4	.	+	0	.	9	9	9	9
T	3	3	.	+	0	.	2	2	5	1
T	3	2	.	+	0	.	9	9	9	9
T	3	1	.	+	0	.	4	0	0	1
T	3	0	.	+	0	.	9	9	9	9
T	2	9	.	+	0	.	4	0	0	0
T	2	8	.	+	0	.	9	9	9	9
T	2	7	.	+	0	.	8	0	0	0
T	2	6	.	+	0	.	9	9	9	9
T	2	5	.	+	0	.	8	0	0	1
T	2	4	.	+	0	.	9	9	9	9
T	2	3	.	-	0	.	6	0	0	1
T	2	2	.	-	1	.	0	0	0	1
T	2	1	.	+	0	.	8	0	0	0
T	2	0	.	+	1	.	0	0	0	0
T	1	9	.	-	0	.	6	0	0	0
T	1	8	.	-	1	.	0	0	0	1
T	1	7	.	-	0	.	6	0	0	1

Figure 9. Printer Tape Listing

The Electronic Digital Voltmeter (EDVM) is a precision readout device which provides rapid and extremely accurate visual display of analog voltages in digital form. The high conversion speed permits almost instantaneous reading of slowly varying voltages – reducing the time required for adjusting manual coefficient attenuators and diode function generators. The EDVM (Figure 8) provides an in-plane projection-type display of the signal voltage and the address designation of the component selected. A unique input circuit maintains an extremely high input impedance to minimize current loading effects on the accuracy of the readings. Automatic polarity indication and twenty per-cent over-ranging further extend the usefulness of the EDVM.

In order to obtain a complete readout of all components in the computer, the AERO System includes an automatic scanning cycle for use with the high-speed digital printer. The printer produces an adding machine tape record (Figure 9) of component address designations and output voltage values. Print spacing may be adjusted to permit operator notation on the tape.

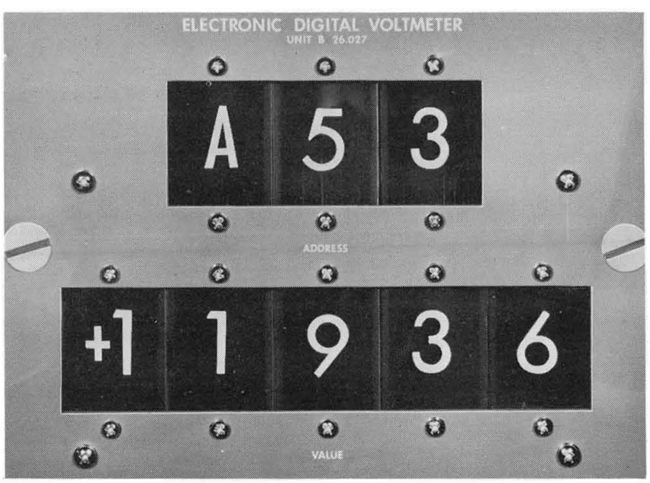


Figure 8. EDVM Display

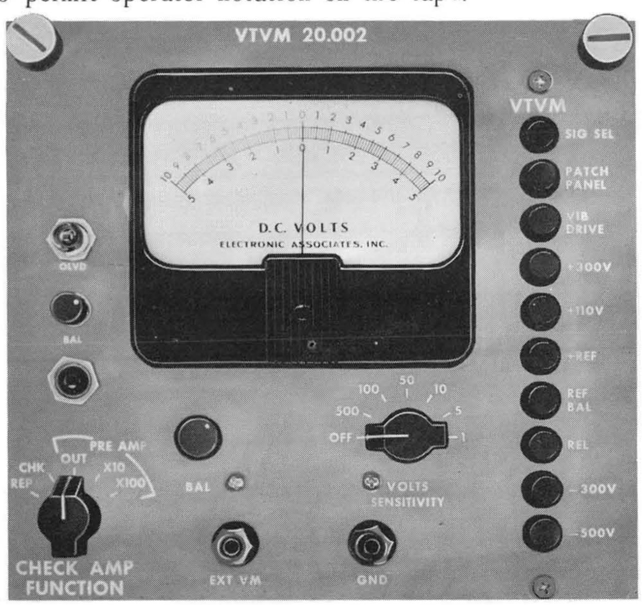


Figure 10. Vacuum-Tube Voltmeter

The control panel of the 231R-V also includes a vacuum-tube voltmeter (VTVM) with pre-amplifier for reading small signal values. The VTVM signal selector (Figure 10) monitors power supplies, reference, and the output of the AERO signal selector.

DIGITAL ATTENUATOR SYSTEM (DAS)

With increased interest in automatic operation of electronic computers, a greater number of systems are being manufactured with servo-set coefficient attenuators. EAI's 231R-V offers the Digital Attenuator System (DAS). Used in conjunction with the AERO System, the DAS enables the operator to make automatic selections and adjustments of both servo-set coefficient attenuators and diode function generators. This may be accomplished with punched-tape by the Automatic Digital Input-Output System (ADIOS), or directly from the digital section of the HYDAC System. Provisions are also included for manual adjustment by means of a parallel-input keyboard or slave potentiometer.

The servo-set potentiometers are contained in plug-in drawers which mount in the Control Console, each attenuator drawer having its own drive motor and selection system. Separate electrical and mechanical selection permits interrogation of potentiometers without mechanical engagement – eliminating the possibility of settings being altered during readout. New settings are established through the use of the servo-set potentiometer in the feedback of an electro-mechanical servo system, where the output of the potentiometer is summed with a precision input voltage in the servo amplifier.

The input to the DAS servo amplifier in the 231R-V is supplied by a Remote-Control Voltage Divider (RCVD) which makes use of relay-selected precision resistors and the computer reference voltage. The setting of the RCVD is determined by a binary-coded-decimal input to the relays. This input may be provided by a decimal keyboard (Figure 11), the tape-reader of the Automatic Digital Input-Output System (ADIOS), or from the pre-patch panel of the HYDAC Digital Operations System.

In addition to the automatic and manual adjustment of servo-set potentiometers with the RCVD, the DAS system includes a slave potentiometer (Figure 12) which may be used to vary the setting of an attenuator

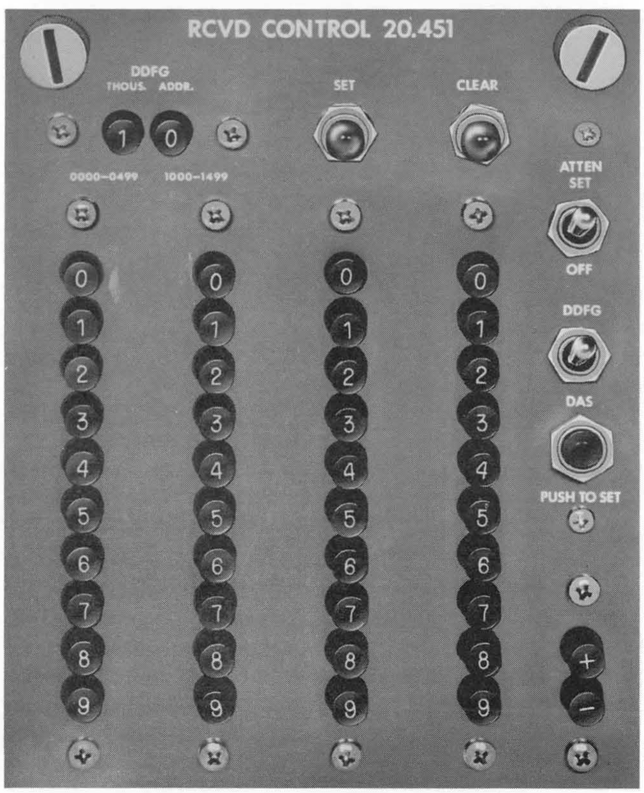


Figure 11. DAS Input Keyboard

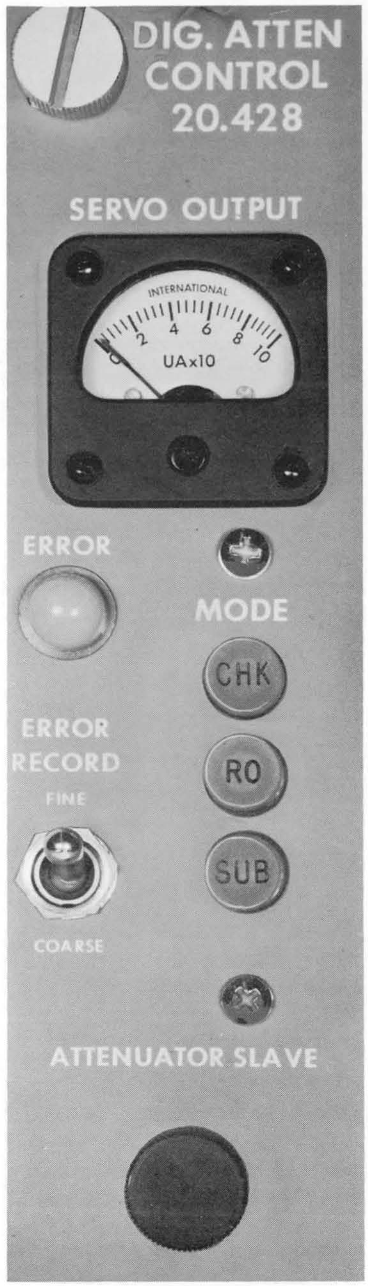


Figure 12 DAS Control Panel.

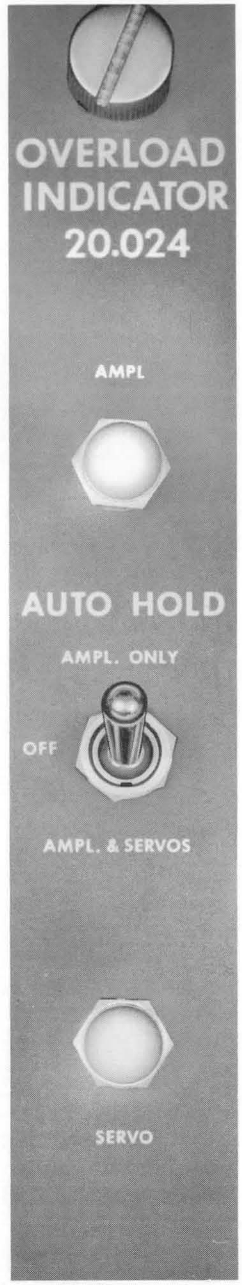


Figure 13 Automatic HOLD Control.

during computer operation. Once engaged, the slave potentiometer retains control of the addressed (selected) attenuator until another selection is made, enabling the operator to observe the effect on the problem solution. Since the input to the DAS servo amplifier may be switched to a pre-patch panel termination, it is also possible to make use of program voltages for adjusting servo-set potentiometers.

PROBLEM CHECK SYSTEM

To assure correct computer solution of a problem, it is necessary to determine that the program has been properly implemented on the computer. This is particularly important with an analog computer where manual programming can result in patching mistakes or incorrectly-adjusted coefficient attenuators.

Errors of this type may easily be located by means of a "static check" procedure, which involves comparing calculated values of the problem variables with voltages measured in the computer program. To perform a check of the entire program, however, it is necessary that all components in the program receive voltage inputs. Since there are usually several integrators which do not have programmed initial conditions, special provisions must be made available.

The 231R-V includes a static test mode which establishes a program test condition by automatically introducing initial condition voltages on all integrators which do not have programmed initial conditions. This is accomplished by means of "test reference" busses on the pre-patch panel which are energized in the static test mode. By patching the voltage outputs of these busses either directly, or through a potentiometer, to the initial condition (IC) inputs of the integrators, it is possible to insure that all computing components receive voltage inputs.

By means of the digital printer and automatic scanning cycle of the AERO system, the values of the voltages in the program may be printed out for comparison with calculated or previously measured values. Since the check output of the AERO system provides for readout of integrator initial derivatives, a complete check of the program patching and operation of the computing components is obtained. The static test programming need not be removed from the pre-patch panel since the test reference busses are de-energized in all other computer modes. This makes it possible to periodically repeat the static test procedure to verify the condition of the program.

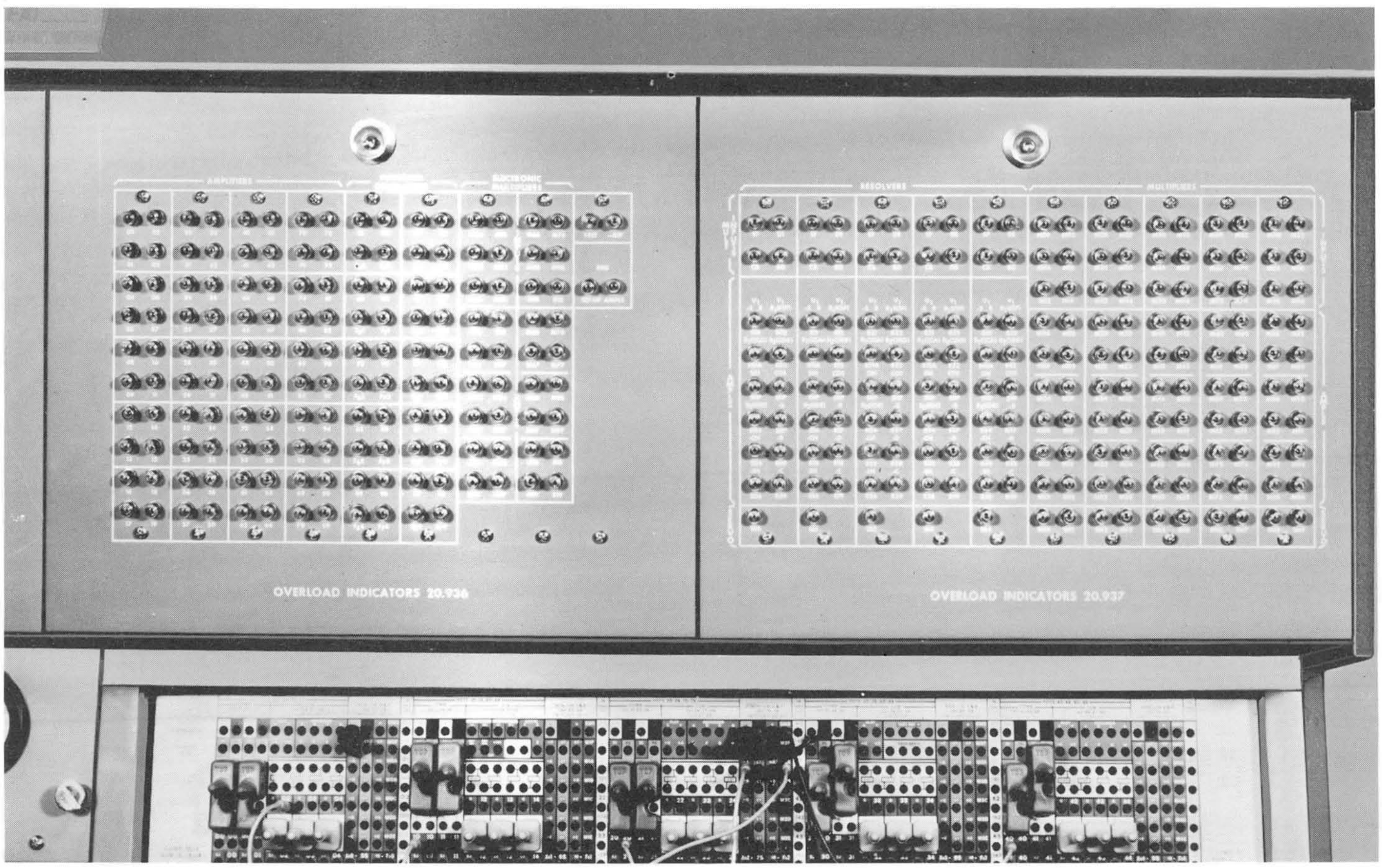


Figure 14. Central Overload Indicator

The read-out mode of the Automatic Digital Input-Output System (ADIOS), which permits a comparison of problem voltages with pre-determined values on punched tape, makes it possible to automatically perform the static problem check. The ADIOS typewriter then provides a printed record of the static check complete with calculated and measured values of the problem variables. The ERRORS-ONLY read-out mode of the ADIOS also makes it possible to rapidly locate programming errors. A similar "problem check" may be accomplished with the HYDAC Digital Operations System.

OVERLOAD INDICATOR SYSTEM

Since an electronic device is subject to the saturation or overloading of active components, it is important that the operator be aware of any such condition —— which could result in incorrect operation of the equipment. This is particularly true of an analog computer where, during the course of problem parameter variations, program voltages may exceed the voltage handling capabilities of the components. So that the operator is made aware of such conditions, the 231R Overload Indicator System provides visual and audible indications of component overloads.

The Overload Indicator System uses overload alarm busses which are activated by component overload-indicating signals. In operational amplifiers, for example, the indicating signal is actually a departure of the amplifier summing-junction voltage from ground potential. For servo multipliers and resolvers, a null error indicates that the dynamic limitations of the unit are being exceeded. In addition to the overload indication for operational amplifiers associated with non-linear components, the Overload Indicator System also includes provisions for indicating the overload of squaring and sine/cosine function generators associated with the electronic multipliers and resolvers.

The overload alarm busses drive an audio amplifier with adjustable tone and volume controls as well as indicator lights (Figure 13) on the computer control panel. The AUTOMATIC HOLD system, which causes the computer to go into the HOLD mode on overload of an operational amplifier or non-linear component, may be used to sustain the overload condition to permit the operator to ascertain the cause of the overload. In addition to the overall computer overload indication, each operational amplifier is equipped with its own indicator light. Central overload indicator panels (Figure 14) with individual lights for all amplifiers and non-linear components in the computer may also be supplied.

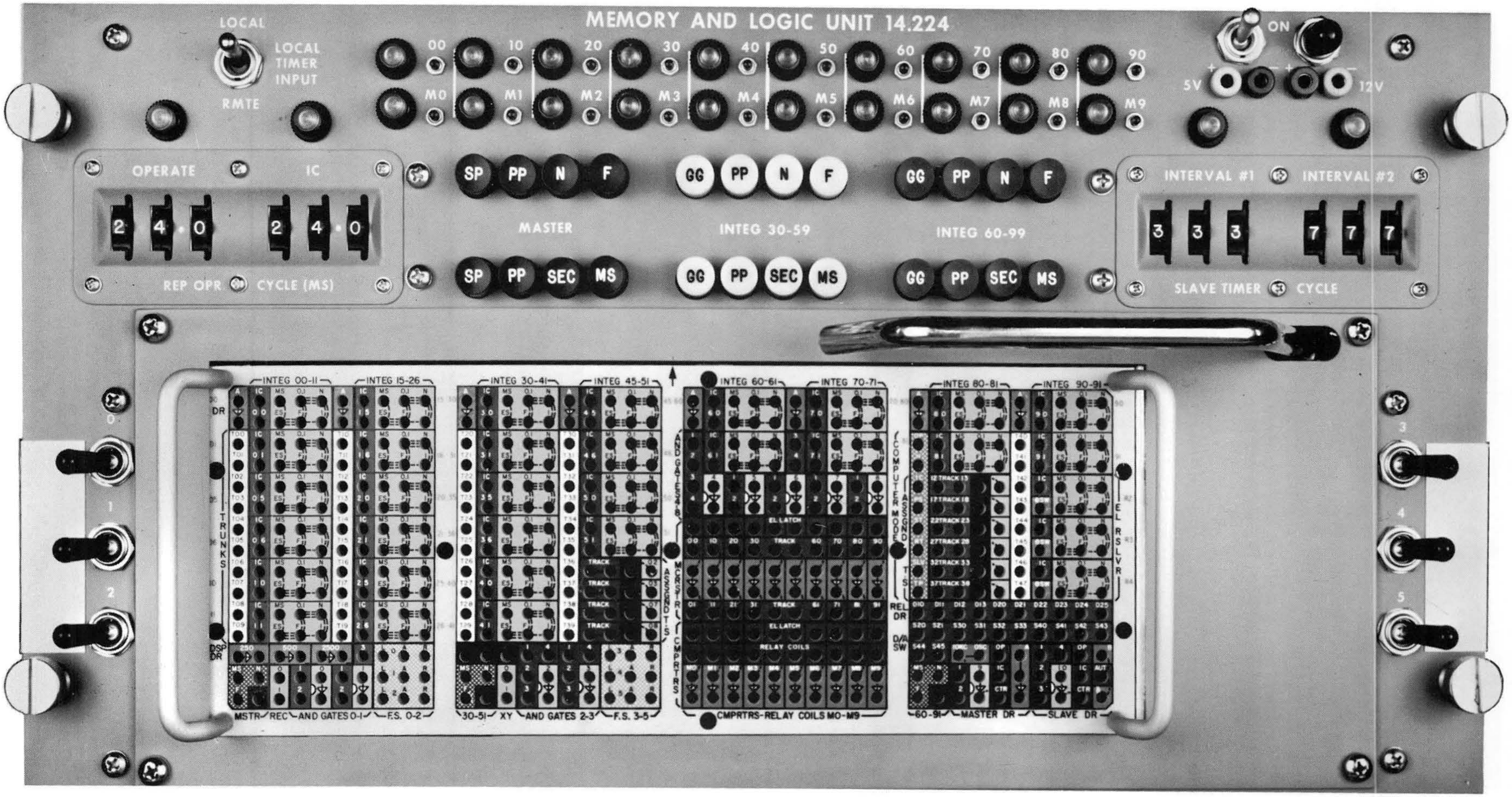


Figure 15. Analog Memory and Logic System Control Unit

MODE CONTROL

Iterative operation of a General Purpose Analog Computer requires sophisticated control of the operating modes. Furthermore, it must be possible to perform the functions of mode selection, signal switching, and storage under program control at repetitive operation speeds. Present programming techniques, based on sampling the results of high-speed calculations for "real-time" problem solutions give rise to a need for multiple time-base operation; moreover, sequential computer operation has brought the need for discreet or digital devices in the analog computer. Such new programming techniques and components are all related to the computer network complex which represents the internal functions and extensions of the computer mode control. The following is a description of the many facets of mode control.

The operating mode of a analog computer is directly associated with the independent variable of the machine; therefore, only those components in the computer which are time-dependent are directly affected by the computer operating mode. Of the components utilized in operational amplifier networks, (i.e. resistors, capacitors, and diodes), only the capacitors are time-dependent. It follows that only those components with capacitor networks, (integrating amplifiers and analog memory units), are related to the computer operating modes. Since the analog memory unit is a unique form of integrator, it may be said that the operating modes affect only integrators. Then, rather than referring to the mode of an analog computer, it is more correct to refer to the modes of the integrators — either individually or as a group.

Operating Considerations

Although a large-scale analog computer may include provisions for as many as eight or ten different modes, there are actually only three distinct operating modes. In normal sequence they are:

1. INITIAL CONDITION (IC) — this mode describes the status of the program prior to initiating a solution. In simulating a dynamic system it describes the condition of the system at time t=0; i.e., the initial value of the independent variable.

2. OPERATE — where the independent variable is permitted to change linearly while the computer executes the solution. The duration of this mode depends on the time scaling and the complexity of the computed information required.

3. HOLD — at any point during the Operate period the solution may be temporarily halted by the HOLD mode to permit examination of the solution status.

Iterative solution techniques require that the analog computer automatically repeat solutions by making use of a Repetitive Operation Mode. In this mode the integrators cycle between Operate and Initial Condition at a constant rate. Many of the more advanced computer programs call for operations at different repetitive rates simultaneously – requiring provisions for more than one repetitive drive.

Analog memory units (or storage integrators) effectively have only two modes – TRACK and HOLD, which are similar to the Initial Condition and Hold Modes for a normal integrator. In the Track Mode the output of the memory unit follows its input until a programmed "sample" command causes it to store the value of the variable in the Hold Mode. Sampling commands may be synchronized with the repetitive operation of the normal integrators, or may be generated by the program through the use of electronic comparators. Programming techniques have been developed for generating time delays, counting, and accumulating with analog memory units.

Other computer modes are generally only variations of the three modes described above – permitting remote operation of the computer, or facilitating check-out of the computer and program. See Table III for descriptions of the modes provided by the 231R-V.

Design Considerations

There are many technical considerations in the design of an analog computer Mode Control System which are critical to the performance of the machine. For example, in the case of repetitive operation, the time required for an integrator to switch from Initial Condition to Operate largely determines the maximum repetitive rate. Since this speed is dependent on the type of switching device employed in the integrator network, which must be a fraction of either the Initial Condition or Operate periods, high-speed repetitive operation dictates that the computer employ electronic or solid-state switches. The current leakage or off-set voltage inherent with any electronic switch, however, limits the computing accuracy which may be achieved.

To obtain maximum possible accuracy for "real-time" operation of the computer, positive making and breaking of contacts as well as low contact resistance of mode control relays is necessary. The requirements for "real-time" as well as high-speed repetitive operation, therefore, suggest that integrators be equipped with both solid-state and relay switches for maximum mode control flexibility.

INTEGRATOR MODE CONTROL

231R-V's equipped with the Analog Memory and Logic System have two sets of mode switches for each integrator. For "real-time" operation, high-speed relays with low resistance contacts are carefully selected to provide the uniform throw-time necessary for switching coincidence between integrators. For high-speed or iterative operation, solid-state switches designed for low leakage characteristics are substituted electrically for these relays.

A separate Mode Logic Patch Panel (MLPP) permits independent selection and control of either type of mode switch for each integrator. At the MLPP, appropriate integrator time constants may also be selected for use with the relay and solid-state mode switches. These time constants and the associated programming are shown in Table IV. A pushbutton time-scale selec-

TABLE III. 231R-V OPERATING AND PROGRAMMING MODES

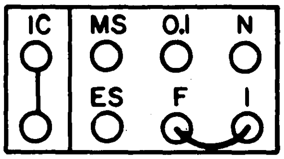
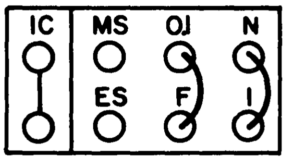
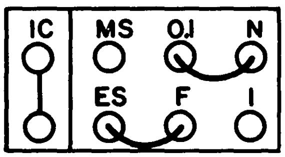
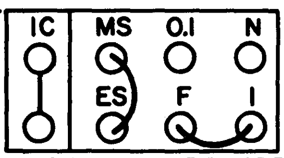
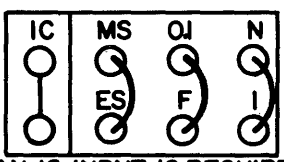
COMPUTER MODES	FUNCTIONS
Pot Set	*Represents an 'at rest' condition for the computer in that summing junctions are disconnected from unassigned amplifier grids, and reference voltage is removed from the patch panel. Potentiometer settings may be made under normal problem loading without creating unwanted problem overloads.*
Attenuator Set	*Operates in conjunction with the computer Digital Attenuator System to perform the selection and adjustment of coefficient potentiometers. It is programmable from punched paper tape or the manual keyboard.*
Attenuator Check	*Enables the Digital Attenuator System circuitry to check the settings of coefficient potentiometers; also programmable from punched paper tape or the manual keyboard.*
Attenuator Readout	*Permits the readout of actual potentiometer problem voltages plus all computing components selectable by the Extended Readout System. The mode may be programmed by the ADIOS, and readouts recorded by the Typewriter and/or paper tape punch.*
Rate Test	*Initiates a dynamic test to determine the relative accuracy of integrator time scales. All integrators are fed with a common input from a Rate Test Potentiometer.*
Initial Condition	*Places all integrators at their static starting points. Summing inputs are removed, and integrators will only accept initial condition inputs.*
Static Test	*Prepares a problem for static check solutions by automatically switching arbitrary initial condition voltages to integrators whose problem initial conditions are zero. A special static-test reference is available at the patch panel.*
Operate	*Places all computing units and recording and plotting equipment in a dynamically active state. Integrators now accept inputs.*
Hold	*Enables a problem to be stopped at any time during its solution. Here, inputs to integrators are disconnected, integration stops and all variables are held to present values for examination.*
Slave	*Permits commands from another console to determine a computer's mode. The computer mode and problem check controls and reference are slaved to another console as selected by the Remote Master switch.*
Tape	*Slaves the computer mode controls to an ADIOS. Commands from the ADIOS desk determine the computer mode.*

tor system facilitates the rapid change of these time constants.

The Memory and Logic Control Unit (Figure 15) includes a central patching facility for controlling logical switching functions, integrator modes, time-scales, repetitive and iterative operation of the computer with maximum flexibility. The use of an auxiliary pre-patch panel allows the mode control program to be pre-patched and stored in the same manner as the analog computer program.

The Mode Logic Patching System includes a 600-contact

TABLE IV. 231R-V INTEGRATOR TIME SCALE PROGRAMMING

PATCHING CONFIGURATION	TIME CONSTANTS SEC BUTTON DEPRESSED			TIME CONSTANTS MS BUTTON DEPRESSED		
	PP(TOP ROW) DEPRESSED	N DEPRESSED	F DEPRESSED	PP(TOP ROW) DEPRESSED	N DEPRESSED	F DEPRESSED
1 	10 SEC	10 SEC	1 SEC	10 SEC	10 SEC	1 SEC
2 	10 SEC	1 SEC	0.1 SEC	10 SEC	1 SEC	0.1 SEC
3  AN IC INPUT IS REQUIRED WHEN F PUSHBUTTON IS DEPRESSED	10 SEC	0.1 SEC	0.01 SEC	10 SEC	0.1 SEC	0.01 SEC
4  AN IC INPUT IS REQUIRED WHEN MS PUSHBUTTON IS DEPRESSED	10 SEC	10 SEC	1 SEC	0.01 SEC	0.01 SEC	0.001 SEC
5  AN IC INPUT IS REQUIRED WHEN MS PUSHBUTTON IS DEPRESSED	10 SEC	1 SEC	0.1 SEC	0.01 SEC	0.001 SEC	0.0001 SEC

patch-bay with latching mechanism. As in the case of the Program Patching System, this latching mechanism also provides contact wiping action to maximize positive electrical connections. The Mode Logic Pre-Patch Panel is lettered and color-coded for ease in programming. Patching terminations are arranged in a modular layout with provisions for simple inter-connection of integrator groups for multi-speed operation. Available patching accessories include bottle plugs, and normal and fan-out patch cords in a variety of lengths.

REAL-TIME (RELAY) MODE CONTROL

Inputs to the Initial Condition and Hold Relays for each individual integrator are terminated in the integrator patching area of the Program Patch Panel. Control of these relays may be accomplished in several ways.

The main Computer Mode Control System makes use of output busses which terminate on the Program Patch Panel. These busses provide the necessary control voltage wave-forms to energize the relays. Whereas

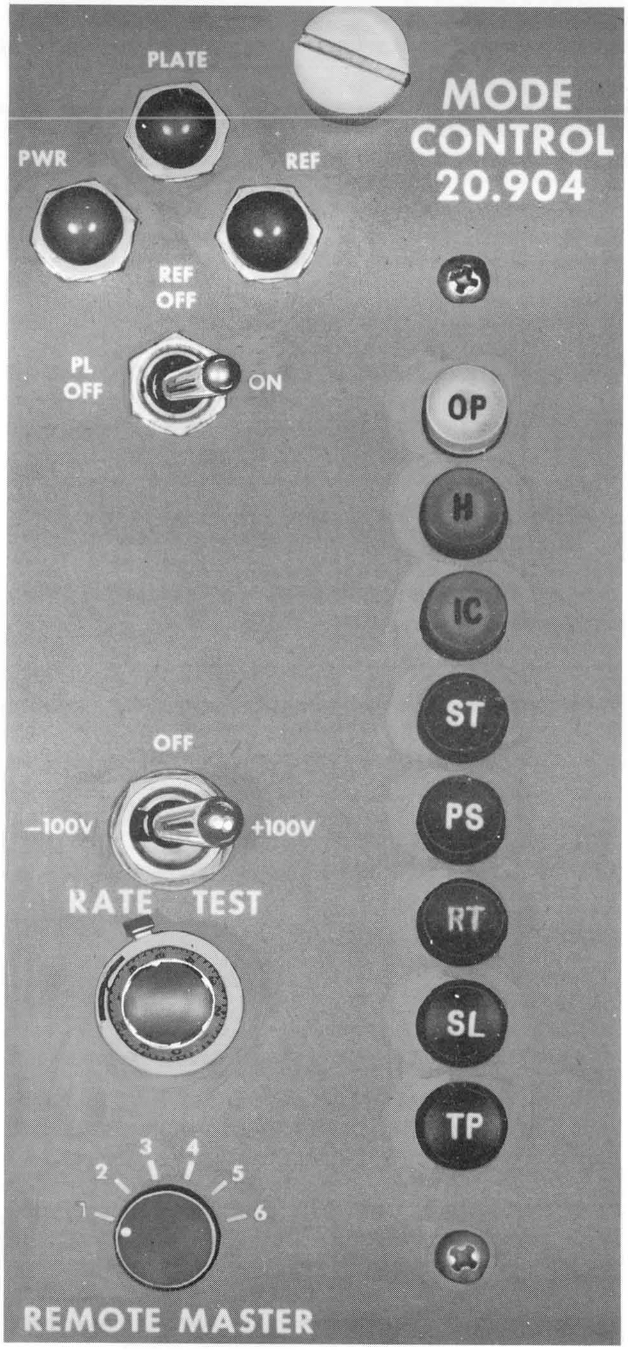


Figure 16. Mode Control Panel

the coils of the mode control relays are connected to these busses by patching, it is possible, by programming, to cause integrator groups to enter different modes on energizing the same busses. The mode busses are energized manually by means of pushbuttons on the Mode Control Panel (Figure 16) or automatically with a logic level input from the Mode Logic Patch Panel. Lights containted in the mode pushbuttons provide visual indication of the state of the mode busses. This state is also communicated to the program by means of Mode State Lines which yield level outputs at their Mode Logic Patch Panel terminations. Slaving provisions permit relinquishing control of the mode busses to another 231R Console, a HYDAC Digital Operations System, or an Automatic Digital Input-Output System (ADIOS).

Mode relays may be controlled individually from the Mode Logic Patch Panel with Mode Relay Drivers. Each Mode Relay Driver accepts a logic level input and provides an output waveform capable of driving up to four mode control relays. Similar Mode Relay Drivers are also available with the HYDAC Digital Operations System.

HIGH-SPEED (ELECTRONIC) MODE CONTROL

The solid-state switches (Mode Control Gates) for both the normal integrators and Analog Memory Units are controlled by logic level inputs from the Mode Logic Patch Panel. These inputs are terminated in the same patching area (Figure 17) as the mode switch and time-scale selection controls for each integrator. A unique "reset" circuit permits maximum repetitive rates with the Mode Control Gates.

A number of summing amplifiers contained in the computer may also be used as storage units. Conversion of these amplifiers to Analog Memory Units, as well as control of the associated solid-state mode switches, is obtained through the Mode Logic Patch Panel. Although an integrator with only an Initial Condition input may be used for storage, the storage summer adds the ability to store a voltage sum without the use of additional amplifiers. Individual Track-Hold networks with inputs terminated on the Mode Logic Panel are also available for use with either summer or summer-integrator amplifiers.

MODE LOGIC PROGRAMMING

The auxiliary patch panel of the Mode Logic Programming System provides control flexibility for high-speed repetitive and iterative solution techniques. Control inputs and outputs are represented by binary ZERO and ONE logic levels which may be inter-connected to establish the Mode Control Program. All components with logic level outputs provide complementary outputs for additional flexibility, while each output may be patched to several points in the program with "fan-out" patch cords. These logic levels may also be used for controlling external equipment by means of trunk lines – or conversely, external logic levels, (e.g. from the HYDAC Digital Operations System) may be trunked to the Mode Logic Pre-Patch Panel. Communication between the Mode Logic and Program Pre-Patch Panels is provided by inter-panel trunks and logic conversion devices.

One of the primary purposes of Mode Control Logic Programming is to offer the flexibility necessary for high-speed repetitive operation of the computer. The Analog

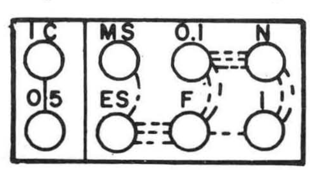
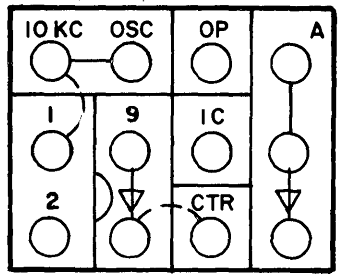


Figure 17. Integrator Patching Termination (MLPP)

Memory and Logic System includes several repetitive drives for multi-speed repetitive operation. The basic timing reference, or "clock", for the system is a 10KC square-wave generator synchronized with a crystal oscillator. In slaving the Mode Control System of a 231R-V Control Console to that of another console, the 10KC Master Oscillators are synchronized. When the Series 1905 Display Unit is used in conjunction with the Analog Memory and Logic System, the Master Oscillator is synchronized to the timing oscillator in the Display Unit with the addition of the Display Unit to a system, supplemental repetitive drive frequencies of 2500, 500 and 250 cycles per second are available.

Repetitive operation with adjustable Initial Condition and Operate periods is obtained through the use of interval timers which are, in effect, event counters. The Mode Logic Patch Panel includes provisions for terminating two interval timers – referred to as the Master Timer (Figure 18) and Slave Timer (Figure 19). These three-decade counters count up to preset values for each of two intervals. At the end of one interval the counter



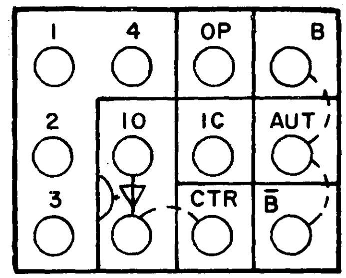


Figure 18 (left). Master Timer Patching Termination (MLPP)
Figure 19 (right). Slave Timer Patching Termination (MLPP)

is preset to the beginning of the second interval and again proceeds to count. At the end of each counting interval, the logic level output of the interval timer changes state –– the preset value or number of counts in each interval being determined by three-decade thumbwheel switches on the Memory and Logic Control Unit. The counters may be reset to the beginning of either interval by means of pushbuttons on the control panel, or logic level inputs from the Mode Logic Patch Panel.

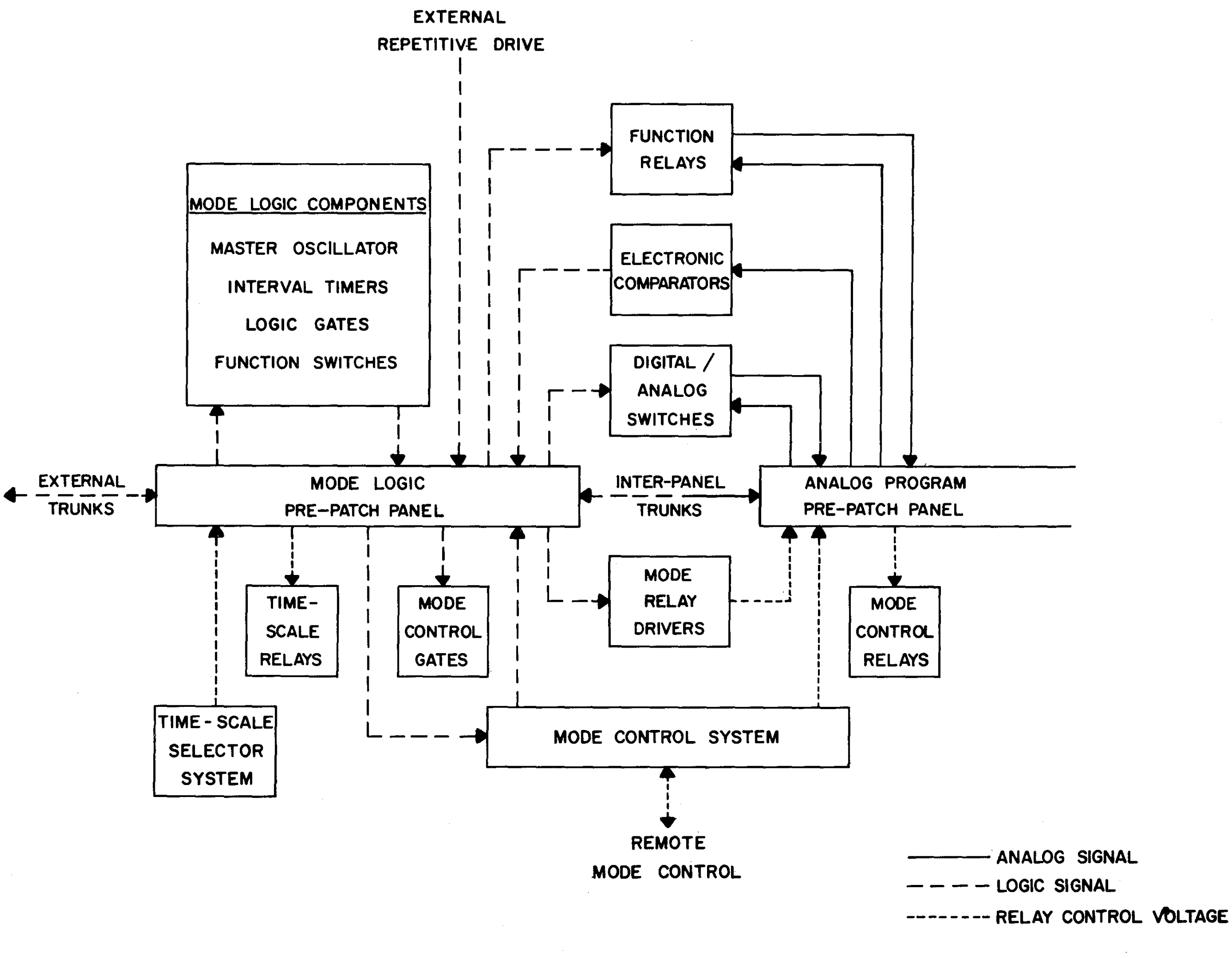


Figure 20. Analog Memory and Logic System Block Diagram

Inputs may be supplied to the interval timers by the 10KC Master Oscillator – or any other repetitive drive or logic level available at the Mode Logic Patch Panel. When an interval timer is driven by the Master Oscillator, each count is equal to one-tenth of a millisecond. The two counting intervals may, therefore, be adjusted from 0.1 to 99.9 milliseconds. In repetitive operation the two intervals are used to adjust the duration of the Initial Condition and Operate periods of the integrators. Slower repetitive rates may be obtained by cascading the interval timers. Events or conditions in the analog program detected by Electronic Comparators may also drive the timers.

To permit a greater degree of flexibility in mode control programming, the Analog Memory and Logic System includes a number of General Purpose Logic Gates which may be used to enable or inhibit the operation of interval timers, comparators, mode control switches, etc. Since both the normal and complementary logic level outputs of these gates as well as other components in the system are available, the gates may be programmed to perform logical AND, NAND, OR, or NOR functions, or combined in pairs to function as flip-flops.

Complex Mode Control Programs may require the facility for normal operation of individual elements in the program for check-out, or to facilitate varying the configuration of the logic program. For this purpose, single-pole, double-throw function switches are included with the Memory and Logic Control Unit –– terminating at the Mode Logic Patch Panel. Write-on areas adjacent to the switches permit identification of their functions.

LOGIC CONVERSION

The success with which mode control programming may be used for the solution of complicated problems depends to a large extent on the ease with which the analog computer and mode control programs are able to communicate with each other. The inter-face between the Mode Logic and Program Panels, in effect, divides analog voltage signals from binary logic levels. To permit communication between two such dissimilar systems, logic-to-voltage and voltage-to-logic conversion must be possible. The Analog Memory and Logic System provides this communication in a number of ways. (Figure 20)

The occurrence of an event or existence of a particular condition in the analog program may be communicated to the mode control program by means of Electronic Comparators, which compare two voltage inputs from the analog program and generate proportionate logic level outputs. Latching inputs to the comparators from the Mode Logic Patch Panel establishes a capability to over-ride the voltage outputs with a logic level. Lights which indicate the state of the comparator output also contain pushbuttons with which the operator may manually establish the comparator output during program check-out.

Logic levels may in turn act on the analog program when controlled by solid-state mode switches of the integrators or Analog Memory Units. Integrator mode relays are controlled from the logic program either by means of the mode busses and Mode Bus Driver or with individual Mode Relay Drivers as described above.

Signal switching in the analog program may be accomplished by either Digital-to-Analog Switches or Function Relays. The Digital-to-Analog Switch consists of a solid-state switch whose logic level control input terminates at the Mode Logic Patch Panel. These switches include precision input resistors and are used to switch voltages to the summing junction of an operational amplifier. When used in conjunction with an Electronic Comparator, they form the electronic equivalent of a Relay Comparator for high-speed or repetitive operation use. The double-pole, double-throw Function Relays of the 231R-V embody transistor relay drivers which accept logic level inputs. Relay Comparators are programmed by patching the output of an Electronic Comparator to these relay drivers.

Besides the logic conversion devices described above, an additional communication facility is supplied by inter-panel trunk lines –– which are limited to logic voltage levels. An analog voltage input to these trunks may thus be used to drive elements of the mode control program; or conversely logic voltage levels may be introduced into the analog computer program. External trunks may be used to control external equipment or introduce external logic signals. In this manner, complex logic programs on the HYDAC Digital Operations System may supply inputs to the analog computer mode control program.

TIME-SCALE PROGRAMMING

Precise computation by multi-speed techniques is readily accomplished using the 231R-V computer. With the Analog Memory and Logic System, any one of six different time constants may be individually selected for each integrator by patch-panel programming or switch selection. The six corresponding time-scales range from 100 microseconds to 10 seconds; the 10 second time scale being available as an option. Time scales are grouped into high-speed and real time sets, each with SLOW, NORMAL and FAST modes of operation, and are selected with proper patching of the Mode Logic Patch Panel. Capacitance is added or subtracted in parallel across the integrators––decreasing or increasing the speed of integration respectively.

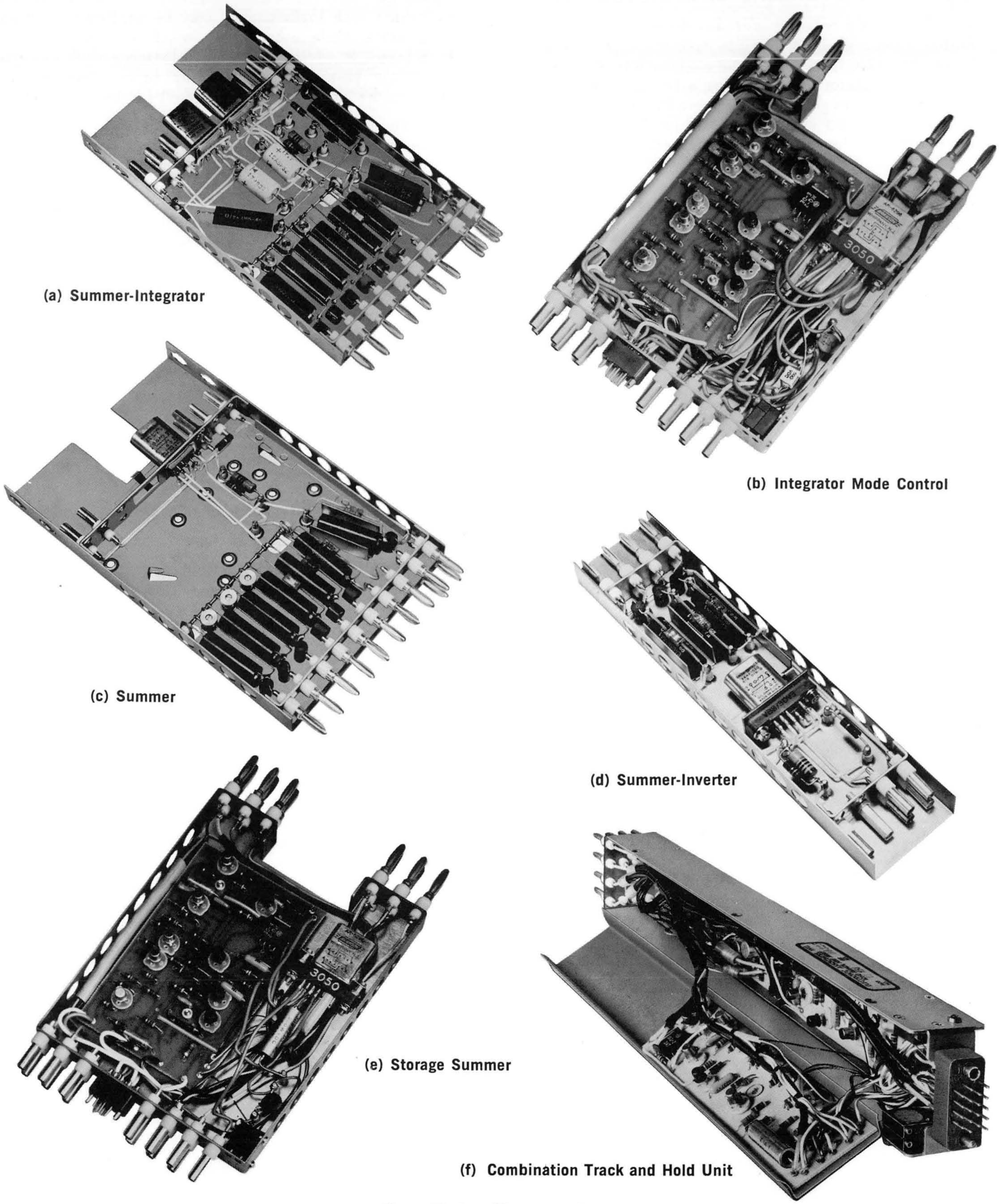
Integrator programming on the program pre-patch panel of the 231R-V computer is independent of, and not effected by, connections made on the Mode Logic Patch Panel. The patching configurations used to select the different integrator time constants are indicated by dotted lines (Figure 17) between patching terminations. Independent of the patching, time-scales can be changed by a factor of 10 in either direction by switching between the NORMAL, and the FAST or SLOW modes––thus increasing operating flexibility. In addition, time-scales can be changed by a factor of 1000 by switching between the high-speed and real time sets. Changes in time scale for one or more integrators can be made individually or simultaneously with the use of a function switch or with the Time

Scale Selector of the Analog Memory and Logic System.

The Time-Scale Selector includes three groups of push-button switches which serve to activate control relays. These relays in turn select the mode and time constant for each integrator by completing all required electrical connections through the Mode Logic Patch Panel. Each push-button group consists of two independently operated rows of four buttons each. One set of push-buttons in each group is used to select either relay or electronic mode-switching for an associated group of integrators; another set is used to select the integrator time constants.

Through appropriate combinations of selector and patching arrangements, it is possible to operate one group of integrators in a program with one time-scale while another group of integrators is operated with a different time-scale. Moreover, with special patching, operating functions may be interchanged. Electronic mode-switching with logic control may be applied to certain integrators while others are switched simultaneously by relays. In addition, one push-button switch in each integrator group will remote the functioning of that group to the Mode Logic Patch Panel for program control.

A summary of time-scale programming and selection is given in Table IV. This table indicates the various combinations of integrator time constants and their associated patching configurations and push-button settings. The MS, N and F (Millisecond, Normal, and Fast) terminals shown in the patching diagrams are each connected to a control relay bus which is energized when the corresponding push-button is depressed. Patching between the control relay terminals ES (Electronic Switch), 1, 0.1 and the busses completes the electrical connections required for time-scale and mode switch selection.



(a) Summer-Integrator

(b) Integrator Mode Control

(c) Summer

(d) Summer-Inverter

(e) Storage Summer

(f) Combination Track and Hold Unit

Figure 22. Amplifier Networks

COMPUTING COMPONENTS

The computational section of a General-Purpose Analog Computing system is made up of a number of individual building blocks or components which perform the mathematical operations of addition, subtraction, multiplication, division, integration, function generation, etc. Results are expressed in voltage form. These computing components may be divided into five general categories: operational amplifiers, coefficient attenuators, multipliers, function generators, and switching devices. Within each of these categories are many possible variations in terms of speed, accuracy, and flexibility.

Since these variations are reflected in the cost of the individual components, and ultimately in the cost of the computing system, a computer which satisfies the needs of both small and large-scale simulation laboratories must accommodate a wide variety of components. In addition to this, if the computer is to cope with increasing work load and problem complexity, it must include provisions for expansion of both the quantity and type of computing components.

The EAI 231R-V employs a modular expansion philosophy which makes it possible for each computer to be tailored to the immediate problem solving requirements of a particular customer, and yet permit future expansion to satisfy the broadest range of user requirements. A complete selection of electro-mechanical as well as all-electronic components makes it possible for the 231R-V to function both as a high-speed repetitive or iterative computer, and to satisfy requirements for real-time simulation.

Interchangeability of components, not only between computers—but interchangeability of different types of components as well, further extends the flexibility of the 231R-V. It permits the configuration of the computer to be changed, or its capacity increased, depending on the requirements of individual programs.

EAI's constant emphasis on progressive engineering includes a continuing program for the development of new computing components to either supplement or replace existing components. As a result, it is possible for a customer to up-date the 231R computer by adding or substituting new components as advancing technology permits—made possible by improvements in performance characteristics as well as in design and manufacturing techniques. This philosophy has made it possible for EAI computers to keep pace with the state-of-the-art—avoiding the need for replacement or addition of new equipments with minor programming and performance improvements.

OPERATIONAL AMPLIFIERS

By far, the most important component in an analog computing system is the High-Gain DC (Direct-Coupled) Operational Amplifier. Nearly all linear and non-linear operations occurring in the computer are accomplished by networks used in conjunction with the amplifier. The utility of this device permits integration, summation, inversion, multiplication, function generation, coordinate transformation, plus many other computing functions. In fact, in defining computing capability, present-day owners of analog equipment cite the quantity of amplifiers in their installations or applications as a figure of merit. Hence, "a two-hundred amplifier system" expresses the problem-solving capability for that amount of equipment.

In almost all situations it is the amplifier's characteristics that determine the computer program accuracy and dependability of performance. Specifications such as high output current, low output impedance, high-gain, wide bandwidth, high velocity limit, low-drift, low noise and high stability are essential requirements for good computational results. Just as important is the variation of these characteristics with time and environmental conditions. Continuous operation of the amplifiers in a computer installation necessarily demands long-term reliability with a minimum down-time for maintenance considerations.

To fulfill all of these criteria, EAI provides the Model 6.217 Dual DC Operational Amplifier (Figure 21) in the 231R-V Analog Computer. Years of experience in the development and manufacture of analog computing equipment has fostered improvements over many successive generations of operational amplifiers to yield the advanced field-proven design of the Model 6.217. This amplifier's output current capability eliminates the need for using multiple-amplifier circuits to drive large loads. A low drift feature, when performing integration, allows long-term open loop computation. The design for high natural cut-off frequencies within the amplifier permits stable operation over a wide range of feedback impedances, assuring proper performance in special function generating circuits. Low hum, noise and cross talk, coupled with the amplifier's excellent dynamic characteristics, enable the computer to perform the many repetitive and iterative calculations required by modern computing technology.

Consistent employment of the Model 6.217 Amplifier with all 231R-V equipment assures uniform computing quality throughout the system, and provides complete interchangeability among amplifier chassis. Each Model 6.217, containing two amplifiers mounted on teflon printed-circuit cards, is a plug-in unit which is installed and removed from the front of all computing

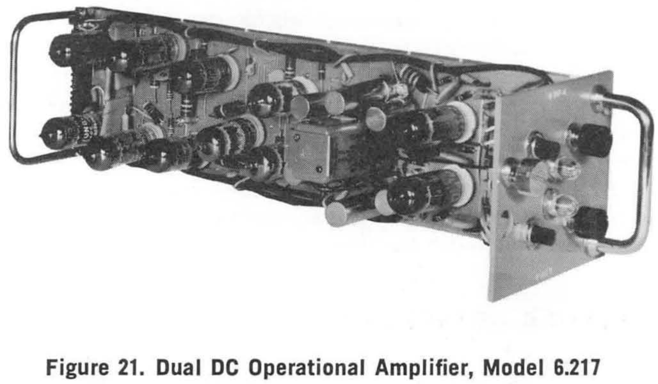


Figure 21. Dual DC Operational Amplifier, Model 6.217

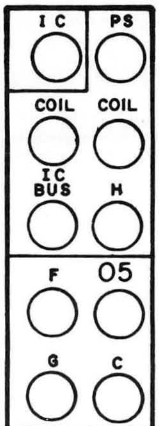


Figure 23. Summer-Integrator Patching Termination (Program Patch Panel)

cabinets offering easy accessibility for servicing. Located on the front panel of each chassis are the individual balancing controls. Overload indication is at the Control Console.

The amplifier design incorporates a dynamic balancing circuit to minimize inherent drift of the direct-coupled amplifier stages. This balancing is accomplished with an A.C. stabilizer section, which pre-amplifies the D.C. and low-frequency components of an input signal before they reach the D.C. amplifier. As a result of the additional gain of the stabilizer, the amplifier summing junction is maintained at essentially zero, thereby compensating for any drift in the amplifier. Other design features include an EAI-patented circuit for rapid recovery from overload conditions, and special decoupling networks to eliminate power source cross talk.

AMPLIFIER NETWORKS

Amplifier performance characteristics are a major consideration in the achievement of proper computing accuracies. Equally as important, however, are the various input and feedback networks used in conjunction with the amplifiers to perform linear and non-linear operations; e.g., sign inversion, summation, integration, function generation, etc. It follows that these networks must be of such a design as to maintain the high standard of operation established by the computing amplifiers.

To meet these requirements, all critical network elements of the 231R-V are housed in the temperature-stabilized oven of the Control Console. Precision resistors, capacitors, diodes and switching circuits are packaged in fully-shielded metal enclosures which plug directly into banana pin receptacles mounted on the rear of the patch bay. These network cans physically mate with corresponding shields also mounted on the patch bay, offering complete protection against network cross-coupling effects. In addition, shielded output wiring and coaxial cable inputs to amplifier grids assure low noise operation with minimum interaction. For similar reasons, integrating capacitors are located in a separately enclosed section of the oven to maintain a restricted-temperature environment. This location also permits easy accessibility for maintenance adjustments.

Of major concern in the various types of oven networks is the quality of the precision input and feedback resistors. To meet the stringent computing requirements of problem applications, these elements are specially manufactured for EAI to yield essential low tolerance and long-term stability characteristics. Non-inductive, wire-wound resistors, thermally aged and stabilized before EAI receives them, are used throughout. Once mounted in a network can, frequency-compensating capacitors are added to each resistor and adjusted to produce the best dynamic performance possible.

The amplifier networks (Figure 22) may be grouped into three main categories, depending on their function. They are the Summer-Integrator, the Summer and the Analog Memory Unit. Each of these includes precision network components and switching circuitry necessary to permit their use with an operational amplifier as a high-accuracy computing component having maximum programming flexibility.

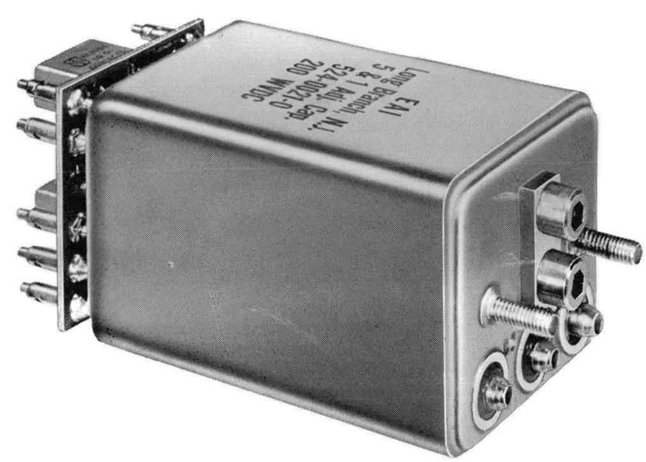


Figure 24. Integrator Capacitor Assembly

Summer - Integrators

The Summer-Integrator Amplifier is one of the most versatile components in the 231R-V computer system. By simple patching changes it may be programmed for voltage summation, sign inversion, integration, or as a high-gain amplifier which is disassociated from the input and feedback elements of the network but not from its control circuitry. The network contains the compensated precision input and feedback resistors, plus relays and control circuitry for use in either Summers or real-time Integrators.

Each Summer-Integrator patching area (Figure 23) on the Program Pre-Patch Panel provides signal terminations for amplifier outputs, three gain-of-one inputs, three gain-of-ten inputs, and a summing junction for the addition of supplementary inputs or other networks. In the upper portion of the patching area are additional terminals for the amplifier's grid and output, feedback resistor and capacitor, mode relay coils, mode control busses, and an initial condition input for integrator operation. These terminations are used to control the amplifier functions and are arranged such that a six-prong patching plug can be conveniently connected to select the standard functions.

Up to six different time-constants are associated with each Summer-Integrator to permit both real-time and high-speed integrator operations. Employed in the feedback of the Operational Amplifier, precision adjustable capacitors (Figure 24) employ a polystyrene dielectric to obtain the high accuracy, long-term stability and low leakage characteristics necessary for proper operation.

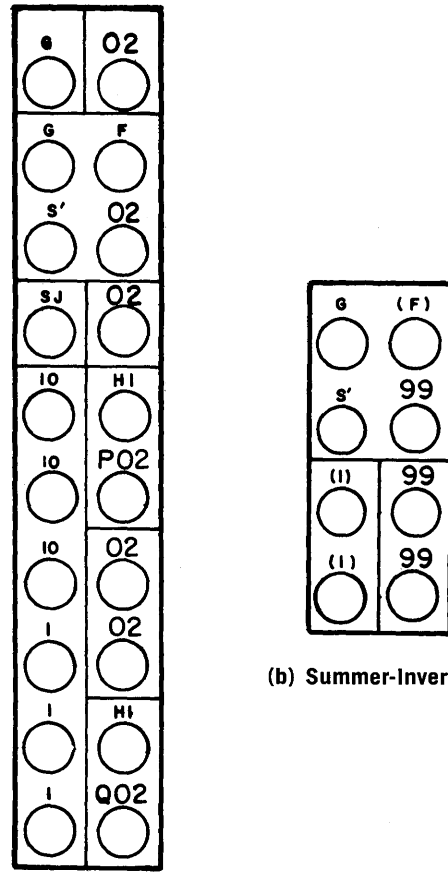
Reliability of the capacitors is maximized by such strict Quality Control measures as infra-red-spectrum analysis of dielectric material at stages of production, and by the utilization of controlled environmental conditions during fabrication and test.

To perform high-speed mode control of an integrator, each Summer-Intergrator network has associated with it a Mode Control Gate Network. This solid-state mode switch is contained in a separate network can which mates with the Summer-Integrator network. The transistor-driven diode gate operates from logic level control inputs on the Mode Logic Patch Panel and offers microsecond propagation times coupled with low offset and excellent dynamic performance for all repetitive and iterative applications.

Summers

In an analog computer program the Summing Amplifier is used for a number of purposes – linking computing components, performing summation and sign inversions, and combining with non-linear components for many different operations. As in the case of the Summer-Integrators, the Summer networks contain precision input and feedback resistors, plus the relays and control circuitry for mode control.

Summers terminate at the Program Pre-Patch Panel in two types of patching configurations (Figure 25) either as complete Summers or Summer-Inverters. The greater percentage of the units are complete summers which provides terminations for amplifier outputs, three-gain-of-one inputs, three-gain-of-ten inputs, and a summing junction. Terminations for the amplifier grid and output, the feedback resistor and the switched side of the summing junction are in the upper portion of the patching area. This permits insertion of a four-prong patch plug to affect Summer operation. Conversion to a high-gain amplifier requires the removal of this plug, replacing it by a two-prong vertical connection between S' and G.



(a) Summer

(b) Summer-Inverter

Figure 25. Summer Patching Terminations (Program Patch Panel).

The second patching configuration is used with two-gain-of-one Summer-Inverters. Its upper patching area offers the same patch plug control as the Summer with fewer input and output terminations. The Summer-Inverters are conveniently located adjacent to the Combination Track and Hold patching areas on the Program Pre-Patch Panel, for reduced patching when combined for storage operations.

Analog Memory Units

The parallel solution of partial differential equations that represent physical systems often requires excessive quantities of both linear and non-linear computing equipment. To avoid this problem, serial solution techniques may be used where the repetition of circuitry is replaced by a single basic circuit together with interpolation and storage circuits. Such analog storage permits problem solving in a sequential manner, with accompanying benefits from the time-sharing of computer components. Similar requirements also frequently occur for storing the results of a previous solution when iterative techniques are employed.

Naturally, storage of information from an analog program could be accomplished with a digital memory; however, it is more convenient and certainly less costly to store information in an analog voltage form. In the 231R-V, the necessary voltage storage is accomplished with capacitor networks similar to those used with an integrating amplifier. In addition to the standard Summer-Integrator storage capability, EAI also offers both Storage Summers and the Combination Track and Hold Unit.

Although Summer-Integrators are frequently used as storage devices, the necessity for tying up complete Integrator networks is economically impractical. To avoid this, the Analog Memory and Logic System includes a quantity of separate Analog Memory Units specifically intended for point storage. These devices are associated with Summer amplifiers, and have the capability of storing voltage sums and individual voltages without the use of additional amplifiers. Conversion of Summers to Analog Memory Units is accomplished by patching on the Mode Logic Patch Panel (Figure 26). Here, a patch plug connection converts the Summer amplifier to a Storage Summer. Appropriate logic levels may then be applied to the control input terminals, while the voltage or voltage sum to be stored is patched to the analog inputs on the Program

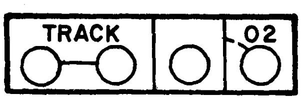
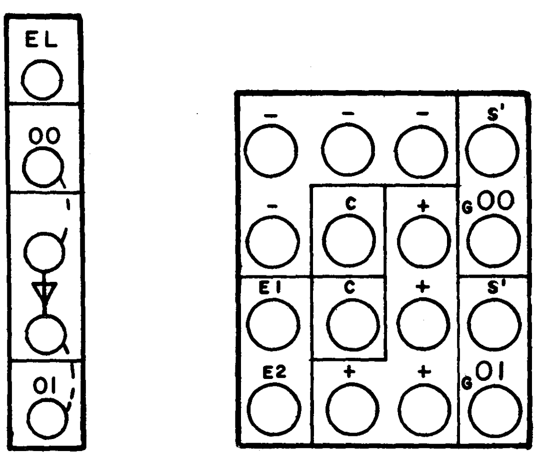


Figure 26. Storage Summer Patching Termination (MLPP)



(a) Mode Logic Patch Panel **(b) Program Patch Panel**

Figure 27. Combination Track and Hold Unit Patching Terminations.

Pre-Patch Panel. In this manner, individual mode control of each Storage Summer may be synchronized with the repetitive operation timers, or may be controlled by Electronic Comparators or other devices with logic level outputs.

High-speed control of the Track and Hold modes of Storage Summers is achieved through the use of solid-state switches similar to the Summer-Integrator Mode Control Gates. Just as with the Mode Control Gates, the Storage Summer's control circuitry is also located in the network oven and physically mounted with its related Summer network.

In addition to the Storage Summers, the 231R-V includes Combination Track and Hold Units which provide even greater programming conveniences. Each Combination Track and Hold Unit consists of two storage networks containing solid-state switching circuitry and a high-speed Electronic Comparator. The comparator's logic level output and its binary complement, together with a latching input and the inputs to the storage networks, terminate at the Mode Logic Patch Panel (Figure 27a). By using patching plugs, complementary or comparator-controlled operation of the storage networks is conveniently obtained. The comparator and storage networks may also be operated together to produce the electronic equivalent of a SPDT relay, or the networks may be operated individually for logic-controlled signal switching.

Located in the network oven of the 231R-V, the Combination Track and Hold Unit mounts directly behind its patching area on the Program Pre-Patch Panel, (Figure 27b). Each unit may be patched for use with any summer or high-gain amplifier — in some cases sharing this amplifier with other computing components. Individual comparator manual overrides for each state of the comparator, plus an output state indicating light, are included to facilitate program checkout.

Passive Elements

To provide additional inputs to the computing networks described above, and for use in special networks, the 231R-V includes provisions for a quantity of precision resistors and capacitors which are not associated with any specific computing component. These Passive Elements are contained in the network oven and are of the same high quality as those used in the computing networks. Both terminals of each element are available at the Program Patching System, and are conveniently arranged to permit interconnection without the use of additional tie points or multiples. Passive Element Patch Cords are available to supplement those elements contained in the computer. These patch cords include either a resistor, capacitor, or diode. Other patch cords containing special networks may be supplied to satisfy specific customer requirements.

COEFFICIENT ATTENUATORS

The Coefficient-Setting Attenuator is used to introduce constant coefficients into equations programmed on a General-Purpose Analog Computer. It also enables the scaling of problem voltages for optimum performance of the computing components and permits the introduction of initial conditions into the program. In general, the Coefficient Attenuator is a variable voltage-divider or potentiometer which the programmer adjusts to the value required in the program. There are a number of types of Coefficient Attenuator available, depending on the particular computer configuration and its intended applications.

The two basic types may be referred to as two and three-terminal units, depending on whether only two or all three of the points in the divider network are available to the programmer. The two-terminal, or grounded Attenuator, has one leg of its resistance and the wiper or arm terminated at the patch panel of the computer and is used for introducing constants into the program. The three-terminal, or ungrounded Attenuator, has all three points terminated and finds application in special networks and circuits where voltage is applied to both ends of the resistance. The most common application for three-terminal Attenuators is in special diode circuits, or for bias adjustments where it is desirable to vary a voltage from positive to negative values without reprogramming.

There are also variations in the manner in which Coefficient Attenuators are adjusted. In the past, most computers were equipped with manually-adjusted units ——where the programmer enters the value by manually positioning the shaft of the potentiometer. With the requirements for reduced programming times and more efficient operation of the computer, however, there has been increased emphasis on automatic or servo-set Coefficient Attenuators. The potentiometer itself is generally similar to that of a manual unit, in that it consists of a resistance winding and wiper contact, positioned by a shaft input; however, it makes use of a motor and and servo system to position the shaft——based on inputs from a precision voltage source. The output of the precision voltage source may be determined either manually with a keyboard, or automatically from punched tape——or both. The servo-setting system makes it possible to adjust a large number of Coefficient Attenuators automatically, in considerably less time than that required for manual adjustment.

Signal frequencies encountered in high-speed or iterative operation of a General-Purpose Analog Computer demand additional considerations in the area of Coefficient Attenuators. Since the potentiometer makes use of a resistance, which takes the form of a toroid, there are inductance effects which result in undesirable phase-shift characteristics for high-speed signals. To avoid these effects, the potentiometers may be equipped with compensating networks which reduce the phase-shift at high frequencies. Although it is not generally necessary for an iterative or repetitive Analog Computer to be equipped entirely with such phase-compensated potentiometers, it is desirable that a quantity be included for critical applications—— in high-speed loops and other computer circuits which are subject to phase-shift errors.

Manual Attenuators

The standard 231R-V Analog Computing System is equipped with twenty manually-adjusted Coefficient Attenuators——located on the sloping control panel of the Console. These units are conveniently available to the operator for introducing parameter variations during the course of a series of solutions. The remainder of the potentiometer complement is available as either manual, or servo-set units.

There are two types of manually-adjusted Coefficient Attenuators (Figure 28) available for use with the 231R-V. The more common version makes use of ten-turn helical potentiometers mounted on the front panel of the computer. A turns-counting dial, with locking device, allows the programmer to readily adjust the potentiometer and to visually check its approximate setting. Since such dials cannot take into account all of the current loading effects brought about by connecting the potentiometer to the input of an operational amplifier or other computing components, the normal adjustment procedure makes use of the Electronic Digital Voltmeter (EDVM). A lever-action switch, adjacent to each dial, connects the output of the Attenuator to the voltmeter and its input either to the computer reference voltage or to the Program Pre-Patch Panel. This makes it possible to monitor not only the setting of the Attenuator, but its voltage output from the program as well——by means of the Electronic Digital Voltmeter. This same switch also displays the address of the potentiometer on the EDVM address readout for identification.

For high-speed applications, a manually-adjusted Attenuator with phase-compensating network is also available. This unit consists of a decade selector switch and single-turn vernier potentiometer, together with compensating network. Adjustment is accomplished in much the same way as the helical potentiometer; however, the first digit of the Attenuator setting is determined by the ten position switch. The basic twenty manual Attenuators in a 231R-V, equipped with

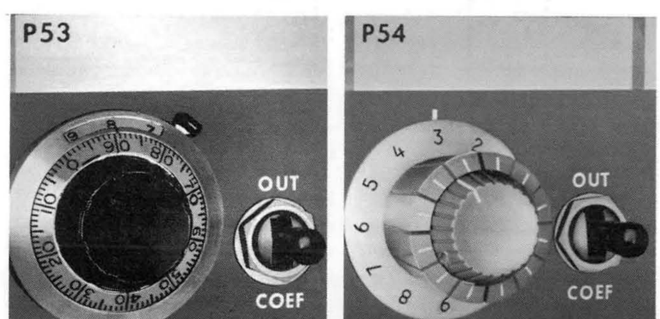


Figure 28. Manual Coefficient Attenuators

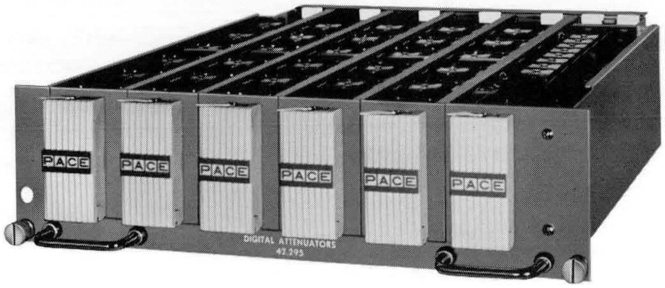


Figure 29. Servo-Set Attenuator Chassis

the Analog Memory and Logic System are of this type. Other manual or servo-set Attenuators in the computer may be of either the compensated or uncompensated variety.

Servo-Set Attenuators

Expansion of the 231R-V beyond the basic twenty manual Coefficient Attenuators may be accomplished with either manual or Servo-Set units. The Servo-Set Attenuator offers the distinct advantage of automatic selection and adjustment from keyboard or punched-tape input. The potentiometers used are ten-turn helical units mounted in a chassis (Figure 29) which includes the servo motor as well as provisions for mechanically engaging the shaft of the potentiometer. Each potentiometer is provided with an individual selection solenoid, for connecting its shaft to the drive motor, and relays, for making electrical connections to the Digital Attenuator System and the Automatic Extended Read Out (AERO) System. For high-speed applications, tapped potentiometers with compensating networks may be substituted for the uncompensated units.

SERVO MULTIPLIERS AND RESOLVERS

Although repetitive or iterative operation of the General-Purpose Analog Computer dictates the need for speeds possible only with all-electronic computing components, there are many real-time applications where electro-mechanical devices offer a degree of flexibility and economy not possible with electronic equipment. Among these are applications which require the generation of powers or roots, several functions or products of one variable, or the resolution of a number of vectors with a common angle. Such requirements are particularly suited to the use of Servo Multipliers and Resolvers which make possible high-accuracy multiplication and angular resolution without the electrical noise, temperature sensitivity, or discontinuous operation inherent in other devices.

The principle of the Servo is similar to that of the coefficient attenuator in that the positioning of a potentiometer wiper or arm is used to multiply a voltage applied to the winding by a value proportional to the shaft position. In the Servo this principle is extended to permit automatic adjustment from problem voltages by means of motor-driven potentiometers. A servomechanism makes it possible to continuously position the arm of the potentiometer in accordance with an input variable and thereby produce the product of two variables.

The Servo Multiplier or Resolver generally includes a number of potentiometers whose wipers are fixed to a single shaft positioned by a servo mechanism consisting of an amplifier, motor, and gear train. One of the driven potentiometers is employed as a feedback element in the servo system to convert shaft position into a voltage for comparison with the input signal in the servo amplifier. The difference between the input and feedback voltages is then amplified and applied to the control winding of the motor until the servo is nulled. Special effects may be achieved through the use of potentiometers with non-linear resistance windings. Sine/cosine potentiometers make it possible for the servo to perform vector resolution or coordinate transformation while multi-tapped potentiometers with voltages applied to the taps are used to generate functions of the input variable. Since in all cases the output of the potentiometer is multiplied by the voltage applied to its resistance winding, the servo may provide a combination of multiplication and function generation in one computing component. Servos are also frequently used for driving simulator displays and in other applications where voltage to shaft conversion is required.

The accuracy of a servo multiplier or resolver is dependent not only on the resolution of its potentiometers but also on the speed with which the wiper is required to traverse these windings. Speed, on the other hand, is determined largely by the power of the servo motor and the number of shaft revolutions necessary to move the arm from one end of the potentiometer winding to the other. Since increasing the number of windings requires the use of multi-turn potentiometers there is an obvious conflict between speed and accuracy performance of a Servo. In order to satisfy varying requirements for speed and accuracy, both single-turn and multi-turn units are necessary—the multi-turn units offering greater accuracy but less speed than the single-turn units.

In order to fulfill these needs, EAI offers a complete selection of both Servo Multipliers and Resolver-Multipliers for use with the 231R-V Analog Computing System. Four basic designs with more than a dozen variations in potentiometer configuration, as shown in Table V, are available to satisfy individual problem requirements. Each model includes a servo amplifier, motor, gear train, and potentiometer assembly mounted in a standard EAI chassis. Units may be supplied with up to six potentiometers of any type.

Servo Multipliers

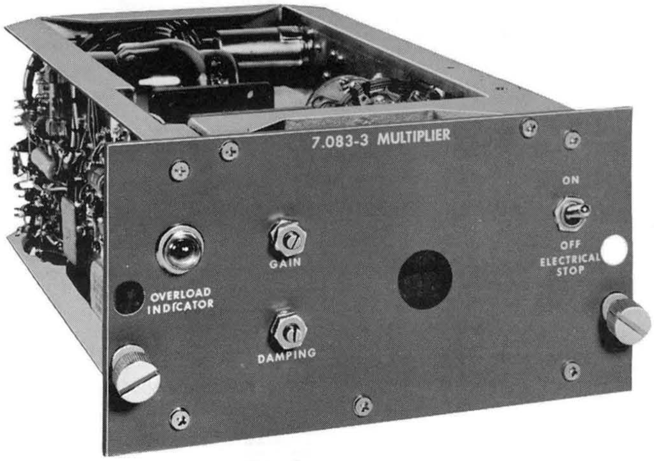
Servo multipliers for use with the 231R-V Computing System fall into three model classifications (Figure 30) which cover a wide range of speed and accuracy performance. All three units are interchangeable and include patching terminations (Figure 31) at the Program Patch Panel for the input to the servo amplifier

TABLE V. SERVO MULTIPLIER AND RESOLVER POTENTIOMETER CONFIGURATIONS

Model	Description	Center-Tapped Multiplying Potentiometers (includes feedback cup)	Multi-Tapped Potentiometers for Function Generation	Sine-Cosine Potentiometers	Total
7.017-1	*400 cycle servos with single turn potentiometers*	6	0	0	6
7.017-2		2	4	0	6
7.017-3		4	2	0	6
7.017-5		4	0	0	4
7.017-6		1	5	0	6
7.017-9		0	6*	0	6
7.083-0	*60 cycle servos with ten turn potentiometers*	0	6*	0	6
7.083-1		6	0	0	6
7.083-2		2	4	0	6
7.083-3		4	2	0	6
7.083-5		4	0	0	4
7.083-6		1	5	0	6
7.083-7		0	4*	0	4
7.084-0	*60 cycle servos with single turn potentiometers*	0	6*	0	6
7.084-1		6	0	0	6
7.084-2		2	4	0	6
7.084-3		4	2	0	6
7.084-4		2	4*	0	6
7.084-5		4	0	0	4
7.084-6		1	5	0	6
7.084-8		1	0	4	5
16-8B	*60 cycle servos with ten turn potentiometers; will accept angular position inputs*	4	0	2	6
16-8E		4	0	2	6
26-8H-11	*400 cycle servos with single turn potentiometers; will accept angular position inputs*	3	0	2	5
26-8H-20		4	0	2	6
8.010-1	*60 cycle servos with single turn potentiometers; will accept angular position inputs*	3	0	2	5
8.010-2		1	2 (100KΩ)	2	5
8.010-3		1	2 (30KΩ)	2	5
8.010-8		2	0	3	5
8.020-1	*60 cycle servos with single turn potentiometers; will accept angular position or rate inputs*	3	0	2	5
8.020-3		1	2	2	5
8.020-5		1	0	6	7
8.020-6		1	3	3	7
8.020-7		4	0	3	7
8.020-8		2	0	3	5
8.020-9		1	0	4	5

* *Indicates feedback potentiometer is multi-tapped rather than just center tapped.*

(a) Model 7.084



(b) Model 7.083

(c) Model 7.017

Figure 30. Servo Multiplier Chassis

and both ends of the winding, the center tap, and the arm of each potentiometer. Either uni-polar or bi-polar operation may be achieved with appropriate patching of reference voltage to the feedback potentiometer.

The Servo Multiplier, Model 7.084 is an accepted standard in the 60-cycle servo-multiplying field. Ideally

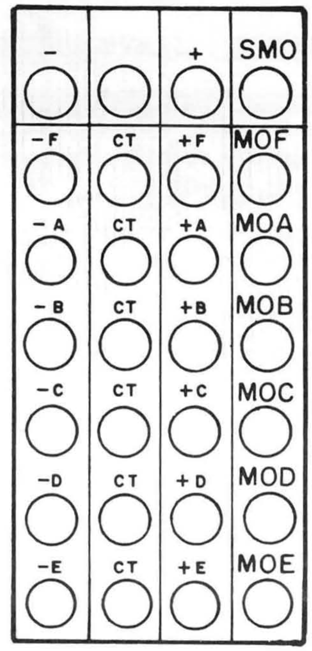
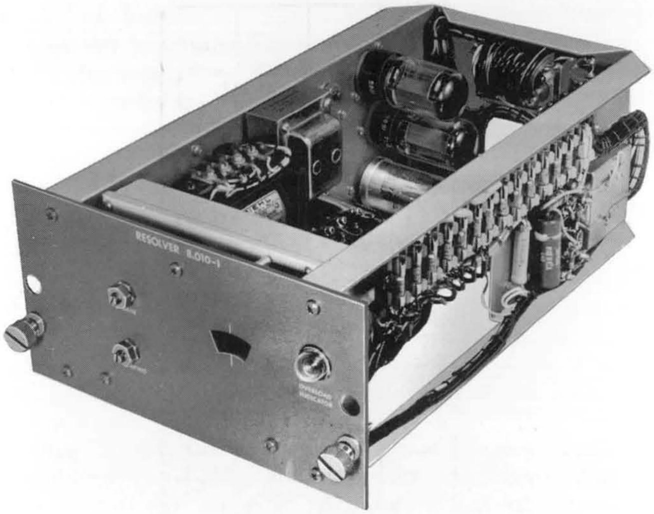


Figure 31. Servo Multiplier Patching Termination

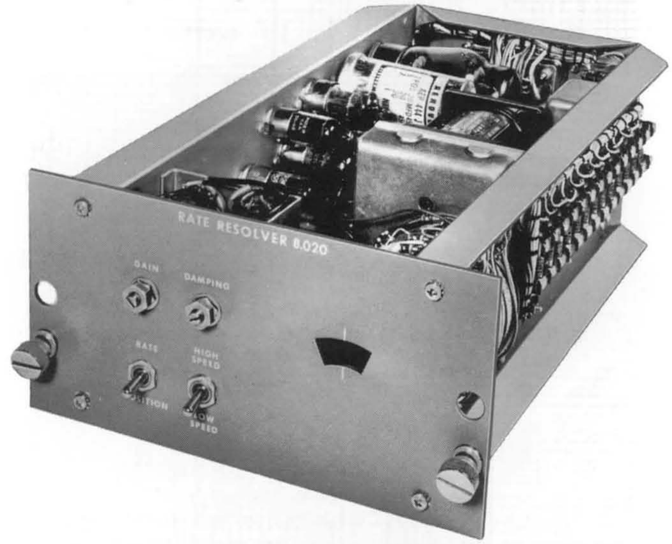
suited to the solution of all basic non-linear computations, these units may be used for all phases of multiplication, division and function generation. Featuring both electronic and mechanical stops and fully protected potentiometer wiper arms, maximum reliability has been assured in a unit proven during thousands of successful operational hours. Each Multiplier uses a single-turn ganged potentiometer assembled from standard potentiometer sections (cups). A maximum of six cups may be mounted on the servo-driven multiplying shaft.

Servo Multiplier, Model 7.083, is intended to satisfy the Computer Engineer's requirement for a highly accurate, medium speed Servo Multiplier. Precision, multi-turn wirewound potentiometers, manufactured to maximum linearity specifications, are used as the basic multiplying unit. The instrument gear box, driven by a ten-watt servo system, has been designed to fully utilize this superior accuracy in a multiplication system featuring extremely low static nulling error and gear backlash. Both electronic and mechanical stops are provided. Each potentiometer wiper arm is individually phased. U-shaped chassis facilitate cooling and maintain the stability and reliability inherent in the basic design. Each multiplier uses from one to three dual, multi-turn potentiometers selected from standard assemblies. Tapped sections are available, providing for the high accuracy generation of arbitrary functions.

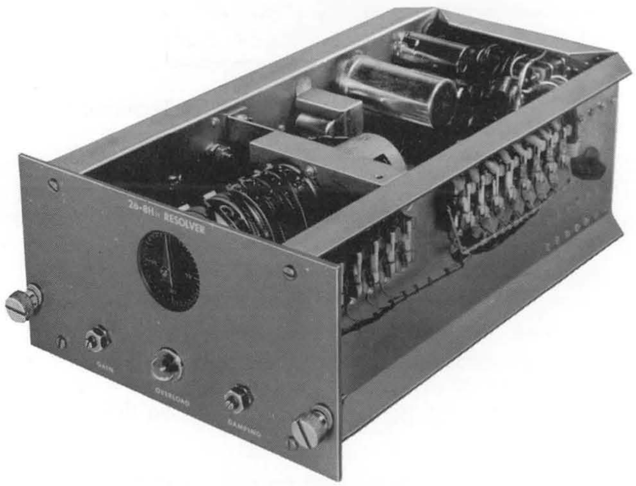
The Model 7.017 Servo Multiplier provides performance for the most demanding applications. This multiplier features dynamic operation far exceeding the characteristics of any previously available servo-driven computing unit. Newly developed design techniques were employed to create a unique innovation in multiplying components with operational characteristics suited to a



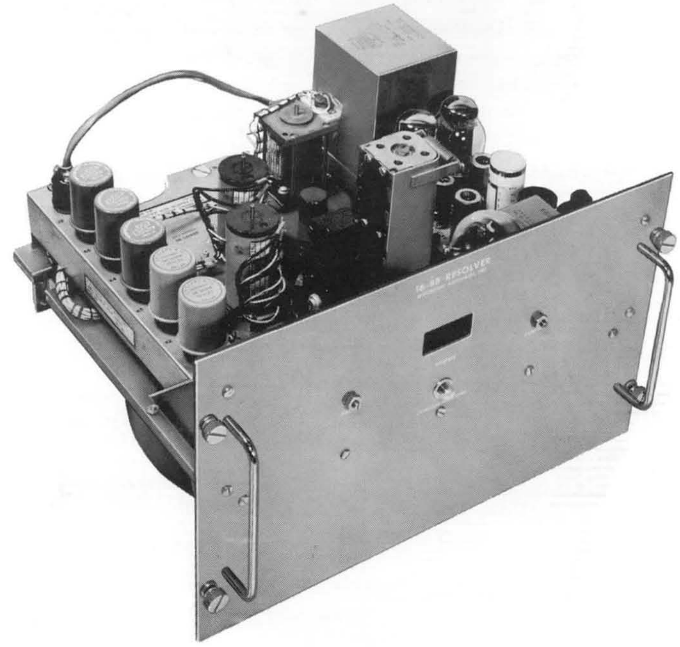
(a) Model 8.010



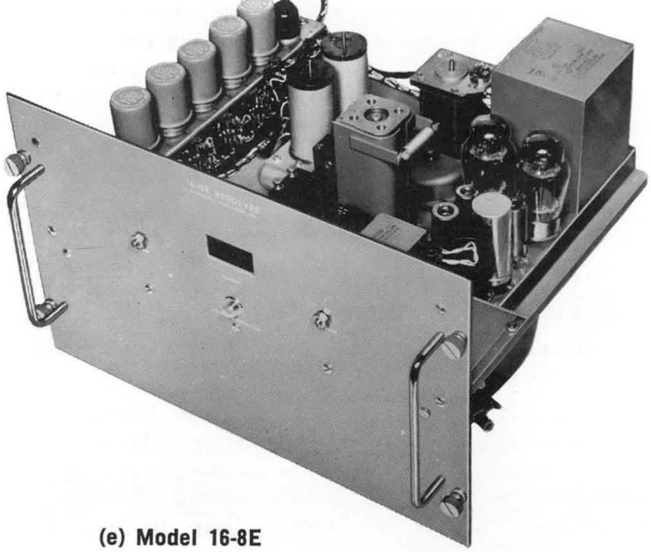
(b) Model 8.020



(c) Model 26-8H



(d) Model 16-8B



(e) Model 16-8E

Figure 32. Servo Resolver-Multiplier Chassis

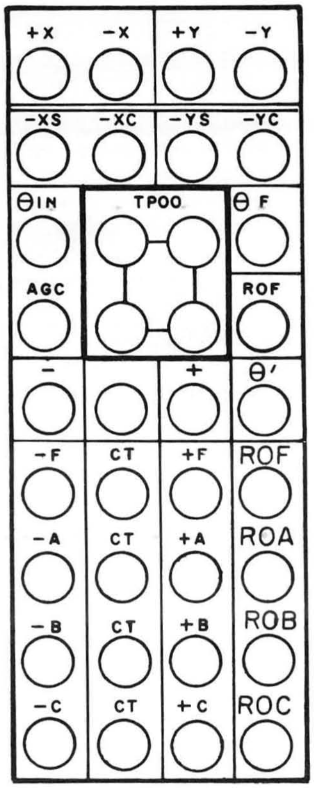


Figure 33. Servo Resolver Multiplier Patching Termination

wide range of applications. High static nulling accuracy permits its use in all of the standard operational circuits with outstanding dynamic performance. Many standard models are available, each assembled from standard wirewound potentiometer sections (cups). Multi-tapped sections may be used to further extend the application of these units to arbitrary function generation.

Servo Resolver-Multipliers

The major difference between the Servo Multiplier and Servo Resolver-Multiplier is in the use of sine-cosine potentiometers for angular resolution. Each of these potentiometers has two wipers separated by a 90^{0} angle to permit both the sine and cosine of the angular shaft position to be generated simultaneously. All units provide both polar-to-rectangular and rectangular-to-polar coordinate transformation and include a number of linear potentiometers for multiplication. Three of the five Servo Resolver-Multiplier models (Figure 32) are derived from the Servo Multipliers previously described and are interchangeable with these units.

The Model 8.010 is a single-turn position Servo Resolver utilizing a 60-cycle servo system. Recommended for applications requiring medium speed and accuracy, this unit features improved automatic gain control circuits for more accurate rectangular-to-polar conversion. The Model 8.020 is similar to the 8.010 but offers the additional capability of continuous resolution with an angular rate input. A switch on the front of the chassis converts the unit's operation from position to rate mode and substitutes DC tachometer feedback for the linear feedback potentiometer. A second front panel switch allows the selection of two rate sensitivities. The Model 26-8H is designed for those applications requiring high-speed with moderate accuracy, and uses high resolution, low torque potentiometers, together with a 400-cycle servo system.

The Model 16-8B and 16-8E Servo Resolvers are intended to satisfy requirements for high precision angular resolution. The sine/cosine potentiometers employed are specially wound by EAI to the most critical accuracy specifications. In order to minimize temperature effects on the sine/cosine sections, each is encased in a special oil bath. The 16-8B and 16-8E differ only in the range of their angular input variable. The Model 16-8B covers a plus or minus 180^{0} range, while the 16-8E includes gearing to provide ten-turn operation for an angular input range of plus or minus 1800^{0}. Both units also include four linear, ten-turn potentiometers, one of which is used in the feedback circuit. The linear potentiometers of all Servo Resolvers permit their use in simultaneous multiplication and resolution. Patching terminations (Figure 33), similarly to the Servo Multiplier, include terminations for both ends of

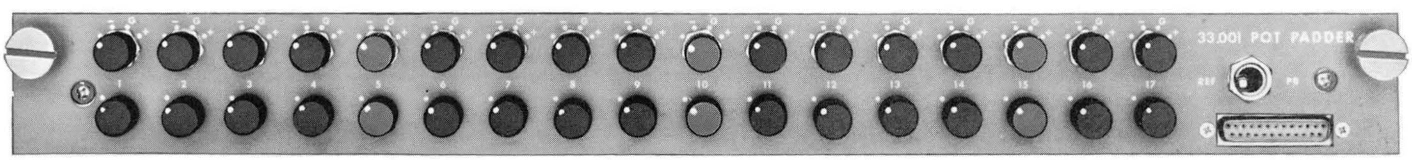


Figure 34. Potentiometer Padding Unit, Model 33.001

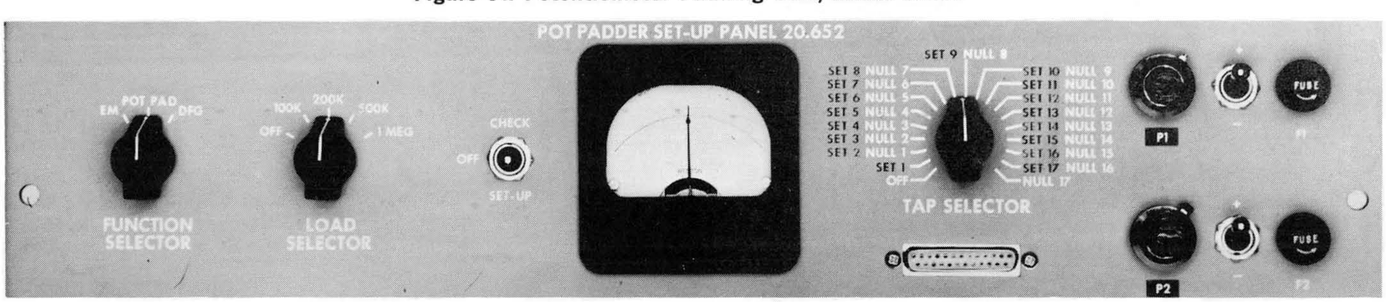


Figure 35. Pot-Padder Set-Up Panel

the windings, the center tap, and wiper or wipers (sine and cosine) of each potentiometer, as well as the necessary automatic gain control connections and the input to the servo amplifier.

Potentiometer Padding Units

Servo Multipliers or Resolver-Multipliers equipped with multi-tapped potentiometers may be used for arbitrary function generation with the addition of the Model 33.001 Potentiometer Padding Unit (Figure 34). By means of the potentiometer padding unit individually adjustable voltages are applied to the taps of the potentiometer to produce a straight line segment approximation of the function described by these voltage values.

Each Potentiometer Padding Unit includes seventeen variable resistors or potentiometers which are connected to the taps of the servo potentiometer. A three-position switch associated with each of these loading potentiometers determines the polarity of the voltage applied to the tap. In this manner either plus or minus reference voltage or a variable voltage from the program may be conveniently selected. When program voltages are used, it is possible to generate the product of this voltage and a function of the input to the servo. Individual cables associated with each potentiometer padding unit allow the programmer to select the servo potentiometer to be used with each Padding Unit.

To efficiently set up the potentiometer padding unit for a particular function, a Potentiometer Padder Set-Up Panel (Figure 35) is available. This panel includes a switch for selecting the tap to be adjusted, and a nulling system for rapidly adjusting the voltage applied to each tap of the potentiometer.

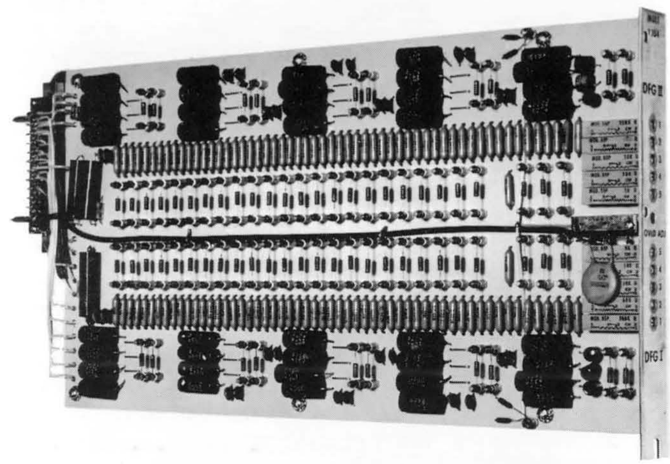
ELECTRONIC MULTIPLIERS AND RESOLVERS

The increased need for high-speed operation of the General-Purpose Analog Computer has placed particular emphasis on the design of computing components which provide both high accuracy and extended usable frequency response. Since non-linear components have traditionally been the speed-limiting elements of the computer the need has been most acute in this area. To meet this need EAI has developed techniques for the design of precision oven-mounting non-linear computing components with extremely wide bandwidth characteristics. Presently EAI offers two versions of Electronic Multiplier and a precision Sine/Cosine Generator which make use of these techniques. An Electronic Resolver combining the Multipliers and Sine/Cosine Generators into a complete system for co-ordinate transformation is also available.

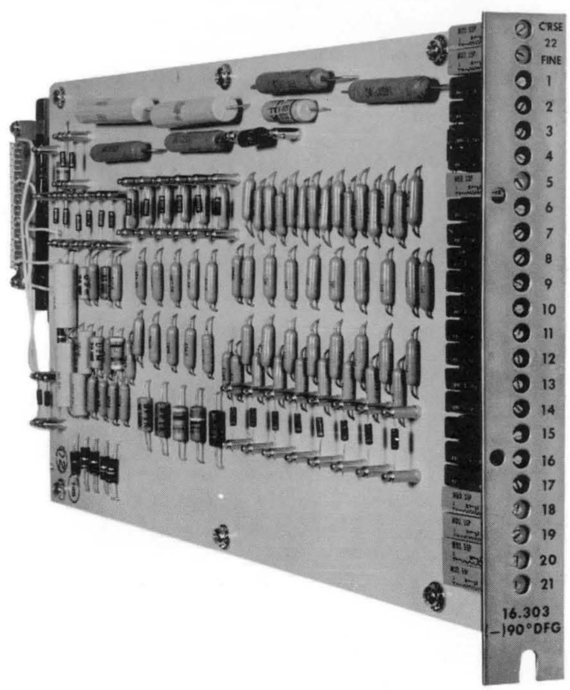
Both the Multipliers and Sine/Cosine Generators make use of printed-circuit cards (Figure 36) housed in temperature-controlled ovens (Figure 37) to insure maximum operating stability. Precision resistors and silicon diodes are used for function generation and the networks are frequency-compensated to achieve the optimum balance of wide-bandwidth operation and minimum dynamic error. Calibration adjustments are included to compensate for long-term changes in components and are available to maintenance personnel without removing the units from the oven. Associated amplifiers are identical to all other computing amplifiers in the 231R-V system to insure uniform performance and extend component interchangeability.

Electronic Multipliers

The EAI Model 7.104 and 7.109 Quarter-Square Electronic Multipliers are solid-state computing components designed specifically for high-speed repetitive and iterative computation. The two models are interchange-



(a) Quarter-Square Electronic Multiplier



(b) Sine-Cosine Function Generator

Figure 36. Precision Non-Linear Computing Components

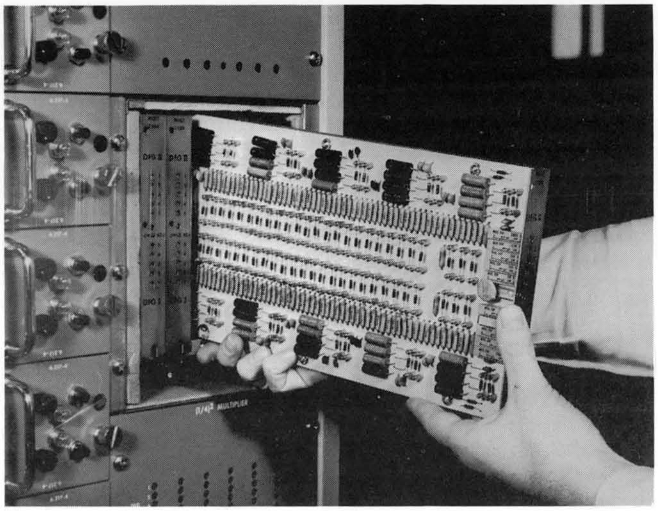


Figure 37. Non-Linear Component Oven

able and differ only in their static accuracy characteristics. Each consists of a printed circuit card containing the precision resistors and diodes which form the squaring function generators required for square law multiplication. An absolute value input circuit eliminates the need for both positive and negative function generators, thereby significantly reducing the number of components and calibration adjustments necessary. All such adjustments (Figure 38) are accessible without removing the Multiplier from its mounting oven to permit calibration under actual operating conditions.

Both Electronic Multipliers may be supplied either by themselves with their inputs and outputs terminated at the patch bay of the computer console or with two as-

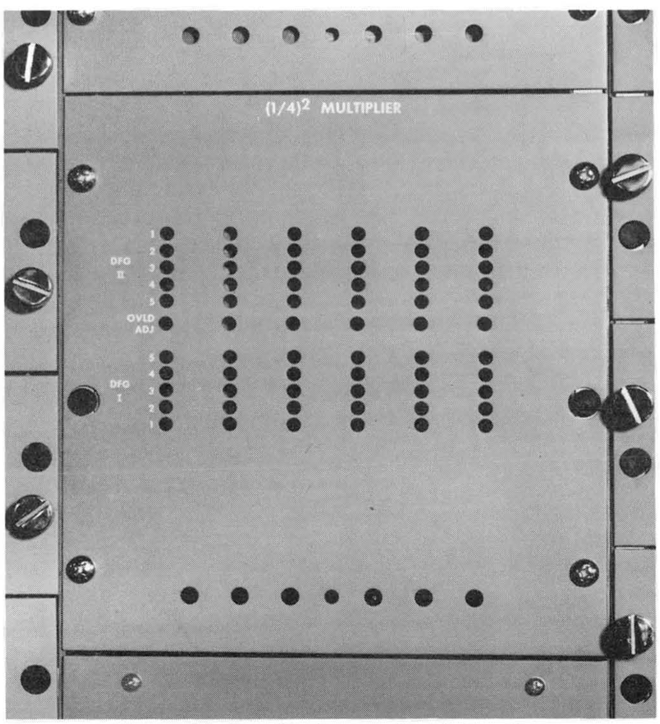


Figure 38. Quarter-Square Multiplier Oven

sociated operational amplifiers. One of these amplifiers is employed as an output amplifier, while the other provides a sign inversion for one of the two inputs to the multiplier. Overload indication includes not only the associated operational amplifiers but also the squaring function generators to indicate non-linear operation when either input exceeds the maximum operating voltage level. Individual adjustments on each Multiplier card permit adjustment of its input overload voltage. In the event that a particular multiplier is not in use its input amplifier may be used as a high-gain amplifier for other computation circuits. Alternately, when this amplifier is associated with the multiplier, it may also be used for summing since its summing junction is terminated at the patch bay. Similarly, the input inverter amplifier may be used for other purposes since both its input and output are terminated.

In addition to the availability of the associated input and output amplifiers for use either by themselves or with the Multiplier, the flexibility of the Electronic Multiplier is further extended by patch-panel selection of operating mode. Each multiplier has its own assigned patching area (Figure 39) which allows patching plug selection of either multiply/divide or square/square-root operation. In the squaring mode each multiplier accepts two input variables and may produce either two separate squaring functions or one square and one square-root function simultaneously.

In recognizing the importance of Electronic Multiplier performance for high-speed analog computer operation, special consideration has been given to the operating characteristics of the Model 7.104 and 7.109 Multipliers. In addition to their extremely wide computing bandwidth, the Multipliers in combination with their operational amplifiers have an essentially flat noise spectrum whose amplitude is only slightly more than that of the amplifier alone. Of even greater significance is the fact that besides being designed for maximum overall accuracy of operation with very low zero error, both multipliers employ squaring function generators whose segments are arranged for improved accuracy at low input levels. Careful design consideration enables the multipliers to have reduced error when the absolute value of the sum of the inputs is less than 100 volts, eliminating the need to re-scale problems for variables with a wide dynamic range.

Electronic Resolvers

The EAI Electronic Resolver system combines the high-accuracy Quarter-Square Electronic Multipliers and precision Sine/Cosine Generators to form an integrated all-electronic system for angular resolution, coordinate rotation, or complete coordinate transformation. Its design provides the convenience of a complete electronic resolver with the flexibility offered by individual multipliers and sine/cosine generators. Particular emphasis has been placed on high-accuracy performance without sacrificing the speed required for repetitive and iterative operation of the computer.

Each fully-expanded Electronic Resolver provides nine

TABLE VI. ELECTRONIC RESOLVER OPERATING MODES

RESOLVER MODE	FUNCTIONS
Free Component Mode	*The sine/cosine function generator and all multipliers are completely independent of each other. Two multipliers will be capable of performing multiplication or division.*
PR-1 Mode	*Polar to rectangular conversion of one vector. Two multipliers are free for either multiplication or division.*
PR-2 Mode	*Polar to rectangular conversion of two vectors with a common angle.*
Rotation of Axes Mode	*The X and Y axes are rotated over an angle Θ to give U and V coordinates which are a function of the X and Y coordinates and Θ.*
RP Mode	*Rectangular to polar conversion of one vector.*
CPR-1 Mode	*Continuous resolution, from polar to rectangular coordinates, of one vector. Two multipliers may be patched to external amplifiers, and operated independently of the resolver.*
CPR-2 Mode	*Continuous resolution, from polar to rectangular coordinates, of two vectors with a common angle.*
Continuous Rotation of Axes Mode	*The axes are continuously rotated from the X and Y to the U and V coordinate system.*
CRP Mode	*Continuous resolution, from rectangular to polar coordinates, of one vector.*

computing component suited to the most demanding high-speed and real-time analog computer applications.

DIODE FUNCTION GENERATORS

The General Purpose Analog Computer components described previously make it possible to perform the routine mathematical operations of addition, subtraction, multiplication, division and integration with a high degree of accuracy. There are, however, many quantities which cannot conveniently be expressed with simple mathematical relationships. Among these are powers and roots, empirical relationships, discontinuities (friction, hysterisis, backlash, limits, etc.), and functions expressed mathematically by a series expansion (sines, cosines, logarithms, etc.). To efficiently cope with problems involving such quantities, the analog computer must be equipped with a function generating capability that is compatible in speed and accuracy with its other computing components.

Although many different techniques have been developed for performing analog function generation, most of them have inherent speed limitations which prevent their use in high-speed repetitive or iterative operation. To overcome these limitations, and to provide static and dynamic performance comparable to the linear computing components, it is necessary to apply linear computing techniques to the generation of non-linear functions. This is accomplished through the use of straight-line segment approximations of the desired functions. Switching at the breakpoints, or intersections, of the linear segments is performed by biased-diode circuits used in conjunction with an operational amplifier. These circuits employ high-quality diodes whose conducting points are preset to limit voltage at specific values.

The simplest version of a function generator is the diode limiter, which makes possible the simulation of discontinuities in an analog computer program. Two types of limiters are frequently used. The first of these, the feedback limiter, is employed in the feedback of an operational amplifier to restrict its output voltage range to pre-determined positive or negative values. The other type is the input limiter which limits only one of the inputs to an amplifier. By superimposing a quantity of input limiting circuits, it is possible to generate functions consisting of several straight-line segments. This technique finds extensive use in the Diode Function Generator, which is used for generating both fixed (sine, cosine, square, square root, logarithm, etc.), and variable or arbitrary functions in the General Purpose Analog Computer.

EAI offers a complete line of both arbitrary and fixed Diode Function Generators for use with the 231R-V Analog Computing System. All function generators are designed for use with the Model 6.217 Dual DC Amplifier, and are frequency-compensated to achieve the optimum balance of wide-bandwidth operation and minimum dynamic error. Fixed function generators produce commonly used functions without the need for time consuming set-up.

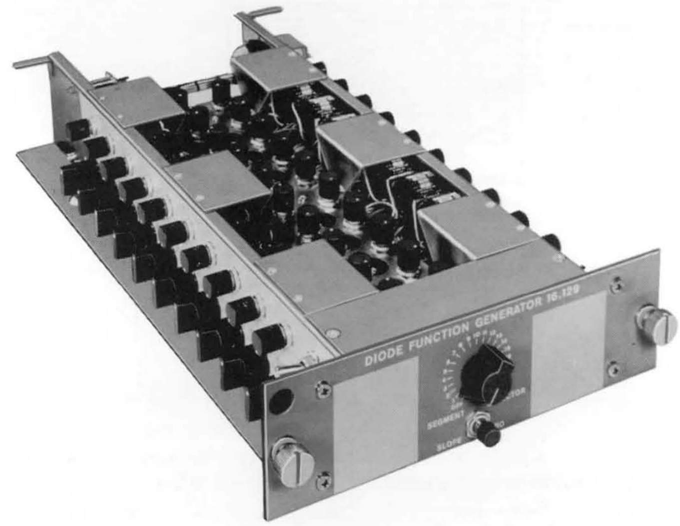


Figure 42. Arbitrary Diode Function Generator, Model 16.129

Arbitrary Diode Function Generators

The Model 16.129 Arbitrary Diode Function Generator (Figure 42) is a compactly-designed unit containing two ten-segment function generators. Each function generator chassis may be used to generate two independent ten-segment functions, or the two functions may be combined to provide a twenty-segment representation. Each segment is variable in breakpoint and slope, and segments may be superimposed for increased slope. Each ten-segment function generator has a separate parallax adjustment to allow biasing in either the positive or negative direction, plus one segment which may be converted to a central slope adjustment for functions which start at, or pass through, the origin.

Function generation is accomplished by changing the gain ratio of an operational amplifier as the input variable changes in value. Silicon diodes are employed in the parallel diode limiting circuits, which are used as input networks to the amplifier. Each segment is produceable in any of the four quadrants, depending on the polarity of the input voltage and the position of a quadrant switch.

The diodes are biased to conduct at adjustable 'breakpoints' — or values of the input voltage as it changes from minimum to maximum values. When each diode conducts it adds a current input to the amplifier that is proportional to the input voltage. The constant of proportionaity for each current differs by the circuit parameters and the setting of a 'slope' potentiometer associated with each segment. Thus, the output voltage of the amplifier varies as a function of its input—along a sequence of straight-line segments which closely approximates the desired function.

Patch panel terminations (Figure 43) provide complete flexibility for the Model 16.129 Diode Function Generator. Input and output terminations for the function generators, and their associated operational amplifiers, are available. In addition, provisions are made for selecting either ten or twenty-segment modes of oper-

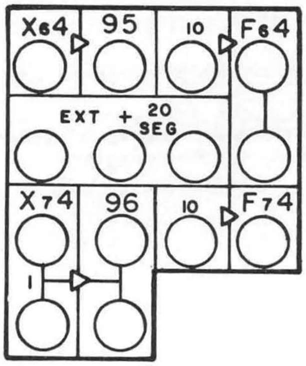


Figure 43. Diode Function Generator Patching Termination

ation with a patching plug. When the function generator is in the twenty-segment mode, two of its four associated amplifiers are available for use as inverters. If the function generator is not required in the program, all four amplifiers are made available to the Program Patching System. These amplifiers are identical to all other computing amplifiers in the 231R-V System, assuring uniform performance and providing component interchangeability.

The Model 16.129 Arbitrary Diode Function Generator is contained in a drawer type chassis. Quadrant switches, breakpoint slope and parallax adjustments are made accessible for set-up by withdrawing the unit from its rack position. After the function has been set up, all adjustments are protected from accidental changes by sliding the chassis back into the rack.

Set-up of the Model 16.129 is facilitated by the use of a set-up panel (Figure 44) which provides a unique set-up procedure. An automatic nulling circuit, used in conjunction with chopper-stabilized set-up amplifiers, makes it possible to set-up functions by reading out the X and Y values of the function directly on the Electronic Digital Voltmeter — without the use of normally time-consuming nulling procedures.

Fixed Diode Function Generators

In analog computing, certain analytic functions arise so frequently that an appreciable savings in equipment cost and programming time may be realized through the use of components specifically designed to generate such functions. Among these functions are sines, cosines, roots, powers, and logarithms. To take advantage of this, EAI offers a variety of diode function generators with fixed segments—located as closely as possible to the desired function for minimum approximation error. Each of these Fixed Diode Function Generators, designed for use with 231R-V operational amplifiers employs precision resistors and silicon diodes mounted on printed circuit cards. Standard functions available include X^2, X^4, log X, sine X, and cosine X. Special functions may be supplied to satisfy specific customer requirements.

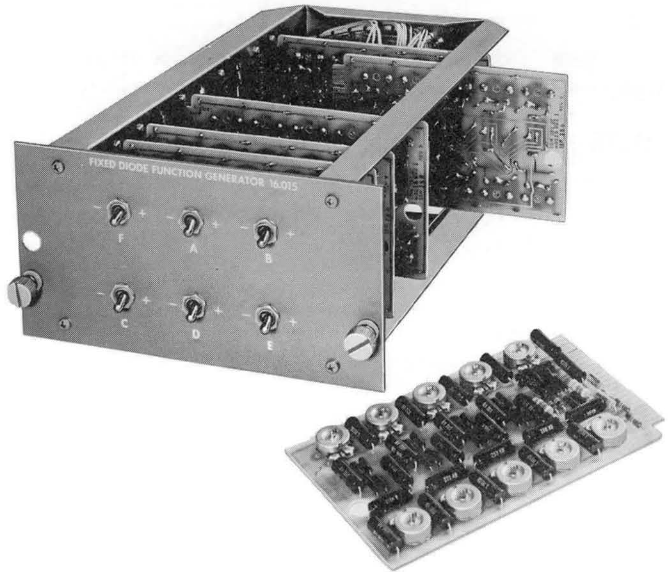


Figure 45. Fixed Diode Function Generator Chassis,

The Model 16.015 Fixed Diode Function Generator Chassis (Figure 45) is a general-purpose computing component with provisions for mounting up to six diode function generator cards. Each of these cards will accept input voltages of either polarity as determined by switches on the front panel of the chassis. The Model 16.015 chassis is interchangeable with the servo multipliers in the 231R-V system, and makes use of the standard servo multiplier patching terminations.

Square and square-root operations may be performed with the Model 16.022 Squaring Diode Function Generator Card, which mounts in the Model 16.015 chassis. As an input network to an operational amplifier, it produces an output voltage which varies as the square of the input to the card. When placed in the feedback circuit of an amplifier, the square-root of the input variable is obtained. In this manner multiple inputs may be applied to the amplifier to generate an output equal to the square root of their algebraic sum. The Model 16.043 Fourth-Power Diode Function Generator Card makes possible fourth-power and fourth-root operations, and is employed in a manner similar to that of the Model 16.022.

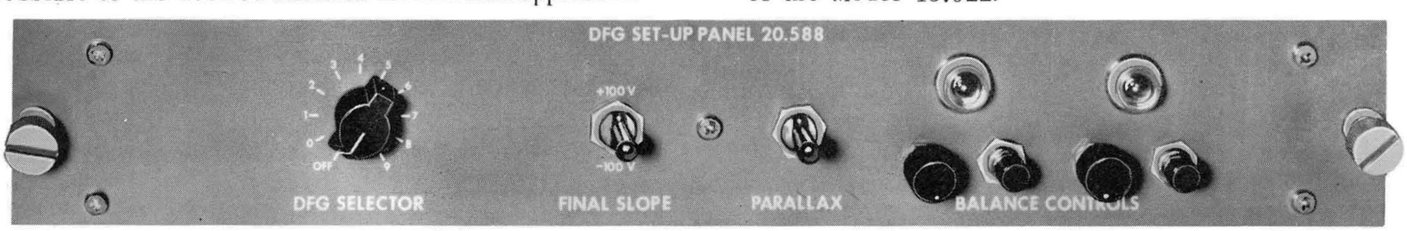
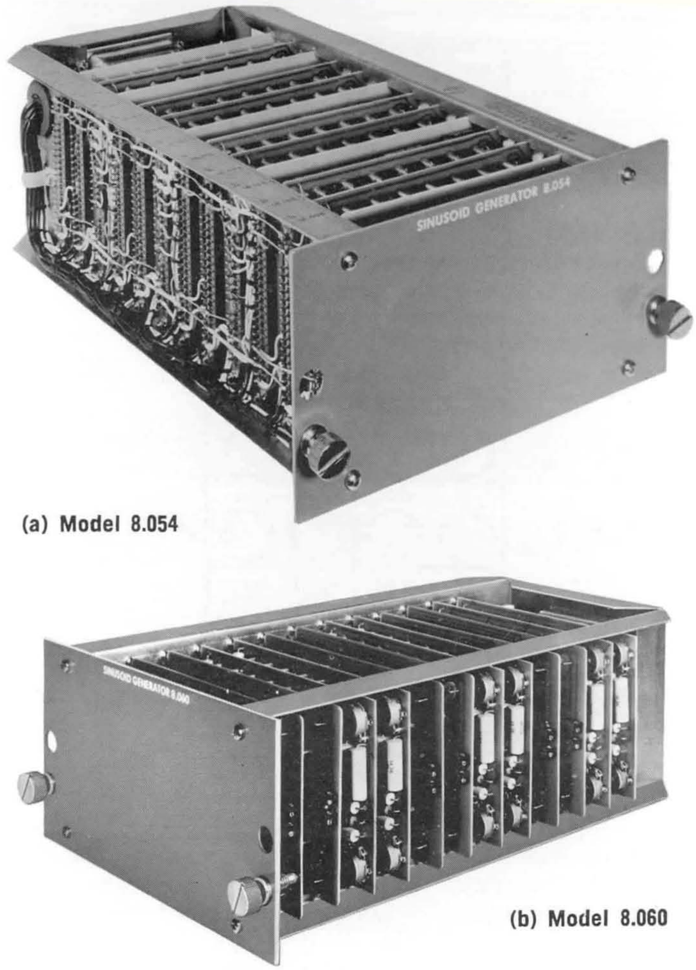


Figure 44. Manual DFG Set-Up Panel



(a) Model 8.054

(b) Model 8.060

Figure 46. Sinusoid Generators

Logarithms and exponentials are frequently encountered in the solution of certain classes of problems. Such functions may be conveniently generated on the 231R-V with the Model 16.032 Logarithmic Diode Function Generator Card – which is also designed for use with the Model 16.015 chassis. Logarithms and antilogarithms, either natural or base-ten, may be obtained with an operational amplifier by using basically the same techniques described above. Operations such as generating the negative exponential of a fixed or variable quantity, raising a variable to a fixed or changing power, and single quadrant multiplication of two variables may be performed by suitable combinations of operational amplifiers, logarithmic function generators, and multipliers.

Of the fixed functions which must be generated on the General Purpose Analog Computer, the sine and the cosine of a variable angle occur most frequently. These functions are usually required to resolve a vector quantity into its components or rectangular coordinates, or to convert rectangular coordinates into polar coordinates. In addition to the servo and electronic resolvers, described previously, EAI offers several versions of independent Sine and Cosine Function Generators for this purpose. Complete vector resolution or coordinate transformations may be performed by combining these sine-cosine generators with the Quarter-Square Electronic Multipliers.

To provide maximum accuracy with a minimum number of circuit components and adjustments, a unique function generating technique is used. Two precision Diode Function Generators, which are designed for use in the feedback circuit of an operational amplifier, are used to generate either the sine or cosine of an input angle. Each unit approximates a 90^{o} portion of the sine function. One function generator accepts input angles from zero to plus 90^{o}, and the other from zero to minus 90^{o}. Thus, when they are employed back-to-back as feedback elements of an operational amplifier, the sine function is approximated from minus 90^{o} to plus 90^{o}.

The third function generator, or "shaping network", is used to shift the sine function 90^{o} for generating the cosine, and to increase the range of either the sine or cosine function. This is done by applying the voltage that represents the angular input to a "dead-space" simulator circuit – whose output is a function of the input. This output is summed with the angular input voltage to produce a saw-tooth wave-form, which drives the sine function generator and an absolute value function to drive the cosine generator. The resultant voltage at the input of the function generator amplifiers effectively shifts their outputs by plus or minus 90^{o} to permit the desired function of the input angle to be generated. A function generator to generate both the sine and cosine of an input angle, therefore, requires two positive and two negative sine generators, plus the shaping networks.

Several versions of Sine-Cosine Diode Function Generator are available, differing in their static accuracy characteristics and range of input angles. All versions employ precision resistors and silicon diodes mounted on printed circuit cards. Calibration adjustments are included to compensate for long-term changes in circuit components.

The Model 8.054 Sinusoid Generator Chassis (Figure 46), which is interchangeable with the servo multipliers in the 231R-V system, contains provisions for mounting up to four independent function generators. These can be used to generate either the sine or cosine of an input angle within the range of plus or minus 180^{o}. Each function generator consists of the positive and negative sine function generator cards and a shaping network card. This shaping network not only extends the range of the function generators, but also includes provisions for controlling the mode of operation of the function generator. Patching terminations (Figure 47) at the Program Patch Panel make it possible to select either the sine or cosine function generating mode.

The Model 8.060 Sinusoid Generator is also interchangeable with servo-multipliers, and contains up to three solid-state function generators. These function generators are similar to those of the Model 8.054, except that their range is extended to plus or minus 360^{o} by a different shaping network. The same patching terminations apply.

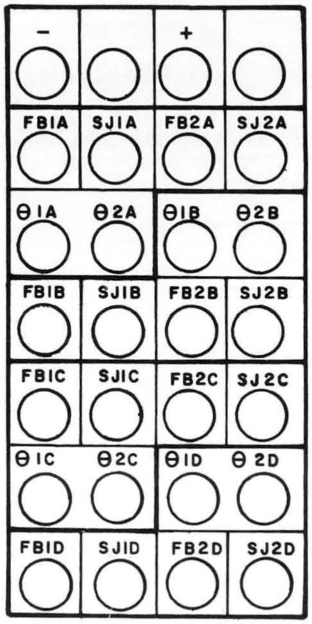


Fig 47. Sine-Cosine Function Generator Patching Termination

For programs requiring exceptionally high static accuracy, the oven-mounted Model 2.710 Sine-Cosine Diode Generator is available. This unit is similar to the sine-cosine generator employed with the electronic resolver, and is housed in a temperature-controlled oven to maintain the stability required for high accuracy performance. Each oven accommodates two function generators which may be patched to provide either the sine or cosine of their input angles. Patching terminations are similar to those of the Model 8.054 Sinusoid Generator.

Diode Limiters

It is frequently necessary, in an analog computing program, to represent mechanical stops or other limitations placed on the magnitude of a problem variable. Such discontinuities may be represented with diode limiters, used in conjunction with an operational amplifier. The diode limiter is, in effect, a two-segment diode function generator with one segment having zero slope, and the slope of the other determined by the gain of the amplifier. EAI offers two types of diode limiters for use with the 231R-V Analog Computing System.

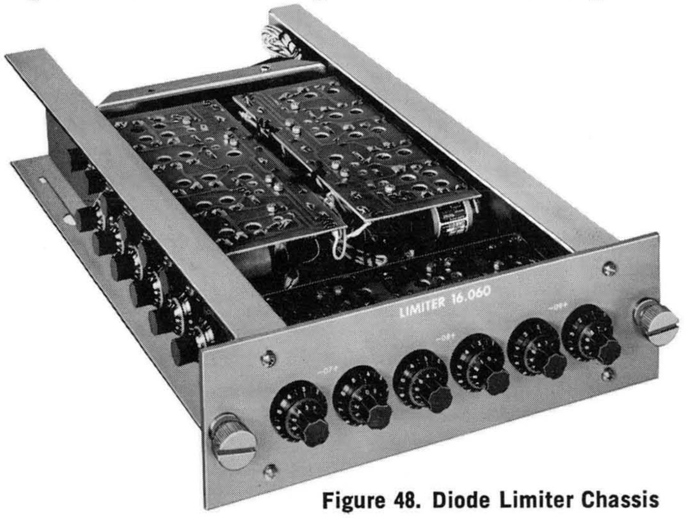


Figure 48. Diode Limiter Chassis

The first of these is the Feedback Limiter, which is placed in the feedback circuit of an operational amplifier to reduce its gain when the output reaches a predetermined level. The Bridge or Input Limiter, on the other hand, is placed in the input circuit of an operational amplifier and limits only one of its input voltages. In both cases provisions are included for independent adjustment of the positive and negative limiting values.

The Feedback and Input Limiters make use of printed circuit cards which contain three complete diode limiter networks. Each limiter makes use of silicon diodes and multi-turn wire-wound adjustment potentiometers, which may be equipped with optional dials. The limiter chassis (Figure 48) includes provisions for mounting up to five cards of either type.

SWITCHING DEVICES

Iterative operation of a General Purpose Analog Computer is a trial and error process for obtaining problem solutions which satisfy certain criteria. These criteria may define an optimum condition, or may be intended to minimize differences between the computer solution and experimental data. In either case, a series of solutions must be computed and compared with the desired solution. Decisions based on the results of each solution are used to effect changes in the computer program for subsequent solutions. These changes frequently involve the switching of voltages to introduce new initial conditions, add or subtract terms in the equations, vary parameters, etc.

If the criteria are relatively simple and few in number, the operator may himself make these decisions and manually introduce the necessary changes into the program. This is easily accomplished with function switches whose contacts terminate at the computer patch panel. More complex problems, however, involving a large number of decisions, require that the computer make decisions and perform switching functions automatically. In order to do this, the computer must be capable of automatically testing conditions related to the criteria and to make decisions based on these conditions. The results of such decisions must then be translated into control commands or changes in the computer program for the next solution.

Events or conditions in an analog computer program may generally be detected by a comparison between two problem variables, or between one variable and a fixed quantity. Such comparisons are made by electronic comparators, which detect conditions in the analog program and translate them into logic signals. The output state of a comparator is determined by the algebraic sum of its voltage inputs, and may be used to perform control and switching operations on the computer program. Automatic switching of signal voltages in the analog computer may be accomplished either with function relays or solid-state digital-to-analog switches.

The Analog Memory and Logic System adds the necessary capability for decision-making and automatic switching to the EAI 231R-V. Logic signals are used to indicate the existence of conditions in the analog computer and mode control programs. Decisions based on these conditions are transformed into program changes by function relays or digital-to-analog switches. The Mode Logic Patching System provides a convenient means of inter-connecting the logic level outputs of the comparators, and the inputs to the switches to form a completely automatic control program. Standard iterative routines may thus be developed and stored for use with a variety of analog programs.

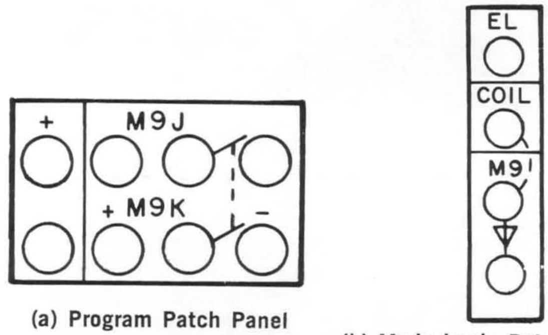
Electronic Comparators

To perform control and switching operations, using the results of decisions based on conditions existing in the analog computer program, the 231R-V includes provisions for a number of Electronic Comparators. Each Comparator consists of a high-gain, solid-state amplifier which accepts two analog voltage inputs and generates a logic level output. The output state of the comparator is determined by the algebraic sum of its inputs, and is referenced to the program by a logic signal which appears in both normal and complementary form at the Mode Logic Patching System. In addition to the comparator outputs, the patching terminations (Figure 49) at the Mode Logic Pre-Patch Panel also include a latching input—which makes it possible to inhibit the operation of the comparator. A light to indicate the state of the comparator, and pushbuttons to manually override its inputs, are available on the control panel of the Memory and Logic Unit.

Since the Electronic Comparators are most frequently used to perform signal switching operations or to control the sampling of problem variables, the comparators for use with the 231R-V are normally associated with either the function relays or Combination Track-and-Hold Units. The Model 12.956 Combination Track-and-Hold Unit, described previously, consists of an Electronic Comparator and two sample-and-hold networks. The Model 6.639 Relay Comparator (Figure 50) includes a high-speed solid-state Comparator, and a transistor-driven, double-pole, double-throw function relay—which may be used independent of the comparator. Both Comparators are identical electrically and provide the same patching terminations.

Function Relays

To permit the use of logic levels for signal switching operations, the 231R-V include provisions for a number of Function Relays. Because of their frequent association with electronic comparators, a Function Relay is included with each Model 6.639 Comparator. These Function Relays consist of a high-speed double-pole, double-throw relay and its transistor driven circuits. Patching terminations (Figure 49) at the Program Patching System include the arms and both sets of contacts for the relay. The input to the driver which determines the state of the relay appears at the Mode Logic Patching System.



(a) Program Patch Panel

(b) Mode Logic Patch Panel.

Figure 49. Relay Comparator Patching Terminations.

Digital-to-Analog Switches

Since the function relay is unsuitable for high-speed repetitive or iterative operation, the 231R-V may also be equipped with Digital-to-Analog switches. The Model 12.1143 Digital-to-Analog Switch Card (Figure 51) includes three high-speed solid-state signal switches, each of which consists of a precision input resistor and transistor-driven diode gate—which is used to switch voltages to the summing junction of an operational amplifier. Analog input and output terminations for the gate appear at the Program Patching System. The control input terminates at the Mode Logic Patching System and may be driven by an electronic comparator to provide the solid-state equivalent of a single-pole single-throw relay comparator.

Figure 50. Comparator Model 6.639

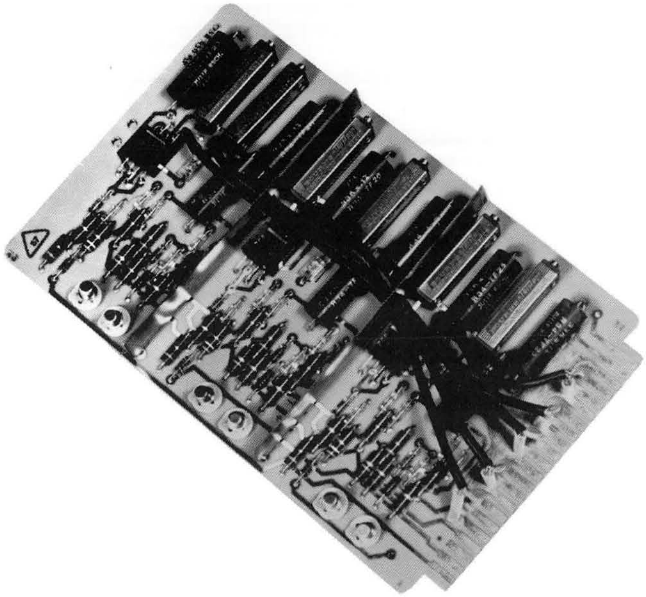


Figure 51. Digital-to-Analog Switch Card

Function Switches

The 231R-V Analog Computing System includes provisions for up to twenty single-pole, triple-throw manual function switches (Figure 52) located on the sloping panel of the control console. The arm and three contacts of each switch terminate at the Program Patching System.

NOISE GENERATORS

In many branches of engineering and science, the solution to a problem may be expressed only in statistical terms. This is particularly true in the analysis of the response characteristics of non-linear systems, examples of which are found in missile guidance and control equipment. Such systems are seldom designed to perform a single task which can be completely specified beforehand; rather, they are intended to perform tasks selected at random from a repertory of possible tasks. Primarily, their purpose is to completely analyze the behavior of systems over a wide range of operating conditions and inputs. This may best be accomplished by applying statistical methods of analysis to an output distribution in response to random inputs. The General-Purpose Analog Computer makes possible such analyses through the use of a random input device — a noise generator.

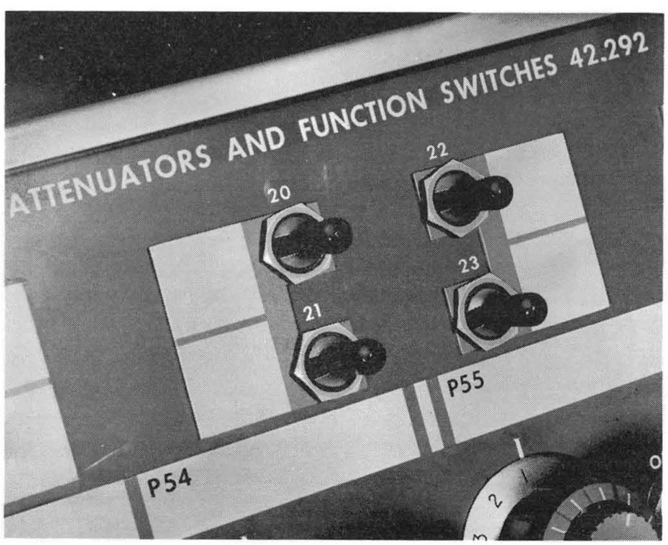
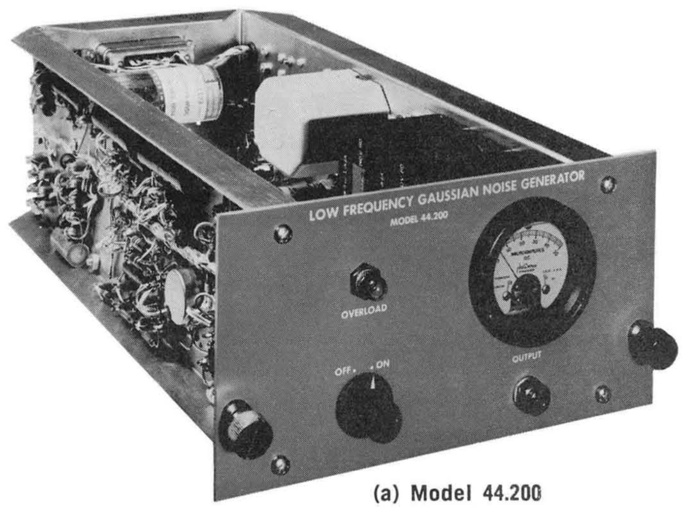


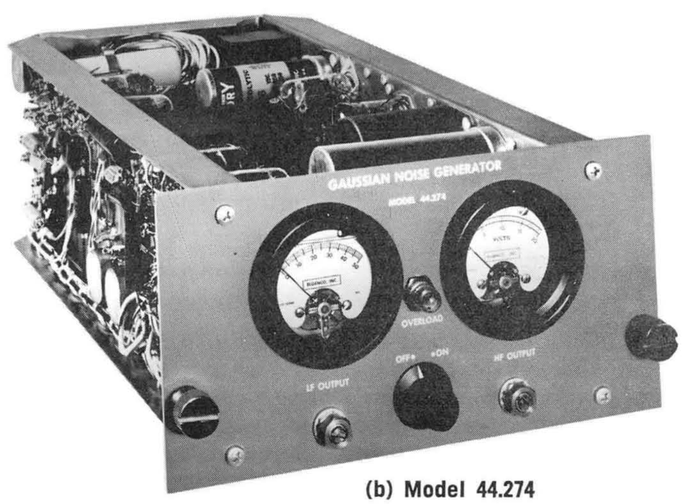
Figure 52. Function Switches

EAI offers two interchangeable noise generator models (Figure 53) for use with the 231R-V Analog Computing System. The Model 44.200 Gaussian Noise Generator produces a voltage output with gaussian amplitude distribution over the low-frequency range of 0 to 35 cycles per second, for use in real-time simulation applications. For both high-speed and real-time operation, the Model 44.274 Noise Generator supplies two noise outputs which cover the range of 0 to 35 and 10 to 20,000 cycles per second.

Both noise generators provide voltage outputs with gaussian amplitude distribution and precisely-controlled power frequency spectrum. The primary source of noise in each unit is a grid-controlled gas thyratron,



(a) Model 44.200



(b) Model 44.274

Figure 53. Noise Generators

operating in a transverse magnetic field. The output of the thyratron is passed through a regulator circuit which continuously stabilizes its output against a reference voltage. The resulting noise voltage passes through an attenuator and amplifier, providing a constant noise spectrum for high-frequency outputs, and a precision-network filtered, low-frequency output.

Output monitoring is provided by panel-mounted meters which are filled with a silicon fluid for an extremely long and uniform time constant. Individual level adjustments make it possible to set the voltage amplitude of the noise outputs. Output terminations for both the low and high-frequency signals are provided at the 231R-V Program Patching System.

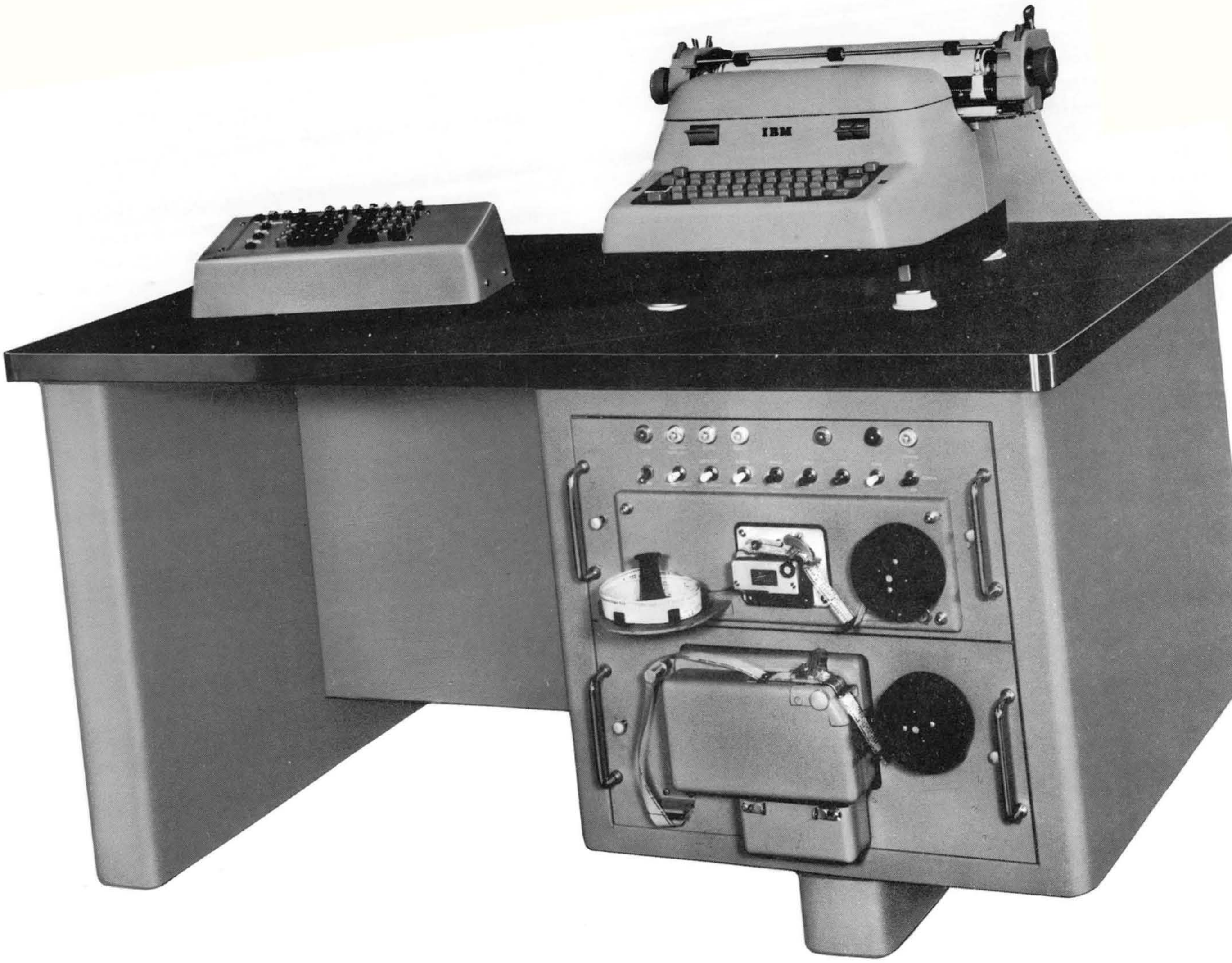


Figure 54. Series 330 Automatic Digital Input-Output System (ADIOS)

Figure 55. ADIOS Input Keyboard

PERIPHERAL EQUIPMENT

The performance of an electronic computer is of prime importance – but equally as important is its ability to communicate with the operator or programmer. Since much of this communication takes place through peripheral devices, a major consideration in the selection of a computer is the availability of suitable peripheral equipment. The quality and performance of these devices, and the manner in which they are integrated into the overall computing system, must also be considered if the computer is to function as an efficient problem-solving tool.

To realize the full potential of the 231R-V, EAI offers a complete line of analog computer peripheral equipment. This equipment includes both time-base and XY recorders, cathode ray tube displays, digital input and output devices. Each is designed to function not merely as an addition to the computer but as an integral part of the computing system. Each has special control and interface circuitry associated with it to adapt it for efficient use with the 231R-V system.

Although EAI manufactures most of its own peripheral equipment, certain items are produced for EAI by other manufacturers in order to take advantage of their extensive experience in specific fields. In all such cases, the suppliers of this equipment are leaders in their particular field and the equipment is manufactured to EAI specifications —— assuring quality and performance equivalent to that of the computer.

AUTOMATIC DIGITAL INPUT-OUTPUT SYSTEM (ADIOS)

While automatic computer programming has greatly profited from the data processing capability of digital computers through the use of assemblers, compilers and debugging programs, a large number of the operations required to program a General Purpose Analog Computer are still performed manually. Certain of the more tedious operations, however, have been eliminated through the use of servo-set coefficient attenuators and automatic readout facilities. To take full advantage of this, in the 231R-V Analog Computing System, EAI has developed the Series 330 Automatic Digital Input-Output System (ADIOS) which makes possible automatic programming of coefficient attenuator settings, readout of attenuator settings and component outputs, and computer mode control from punched-tape inputs. This system provides the capability for semi-automatic programming and checkout of the 231R-V – significantly reducing non-productive computer time, and facilitating the use of data processing equipment in calculating attenuator settings, static check values, etc.

The ADIOS (Figure 54) consists of a desk-style console, an IBM electric typewriter, input keyboard (Figure 55), punched-tape reader, and a tape punch plus the necessary information-decoding and distribution circuitry to permit communication between these devices and the Analog Computer Console. The ADIOS may be used as the input/output unit for computing systems of up to seven EAI 231R computers.

The interface equipment makes it possible to supply inputs to the Mode Control, Automatic Extended Readout (AERO), and Digital Attenuator Systems, and to read the Electronic Digital Voltmeter of an EAI Series 231R Analog Computer. This interface consists of an input-output decoder, relay-controlled voltage divider, component address register, EDVM output buffer, and the necessary input and output distributors to route information to the appropriate devices. The flexibility of the system allows the ADIOS to perform a variety of functions as a control unit for the analog computer. It makes provisions for selecting computer operating modes, changing parameter settings, reading-out steady-state values, etc., for automatic tape-programmed operation of the computer.

The decoding circuitry of the ADIOS includes provisions for performing the following input-output and control operations.

1) Select up to seven analog computer consoles in any one system for control and entry or readout of information.
2) Select the operating and checkout modes (OPERATE, HOLD, INITIAL CONDITION, POT SET, RATE TEST, and STATIC TEST), and the Digital Attenuator System modes (ATTENUATOR SET, ATTENUATOR CHECK, and READOUT) of the analog computer console.
3) Address the analog computer Automatic Extended Readout (AERO) System to adjust servo-set attenuators or for readout of component outputs with the Electronic Digital Voltmeter.
4) Set up the relay-controlled voltage divider to adjust servo-set attenuators in the analog computer, or for comparison of input information with actual problem voltages.
5) Control and read the output register of the Electronic Digital Voltmeter.
6) Switch the input of the DAS servo-amplifier to the patch bay of the analog computer to permit adjusting servo-set potentiometers with program voltage inputs.

Input information to the ADIOS takes the form of component addresses, attenuator settings or predicted component output values, mode control commands, etc., which may be entered either manually through the keyboard or automatically from punched tape. Outputs include voltage values measured by the Electronic Digital Voltmeter, and the results of comparisons between predicted and measured values of component outputs. Coded inputs to the ADIOS and outputs from the computer may be recorded by the typewriter, tape-punch or both. The typewriter may also be used to manually enter alpha/numeric characters for record identification.

As an input-output system, the ADIOS makes it possible to automatically select and adjust servo-set coefficient attenuators from punched tape, and simultaneously perform a comparison between the desired and actual settings. Similarly, predicted or calculated component output values may be entered into the ADIOS for comparison with outputs measured by the Electronic Digital Voltmeter. In both cases the typewriter prints an error indication when the difference exceeds a pre-determined amount. In the ERRORS ONLY mode, only those comparisons resulting in an error indication will be printed out on the typewriter. This facility makes it possible for the computer to perform a complete static check by automatically checking the settings of coefficient attenuators and comparing the actual and calculated values of component outputs.

The typewriter is the primary output device for the ADIOS. Its format includes, at the operator's option, columns for direct readout of computer instructions and run information from the tape, address of computer components being adjusted or monitored – and their desired or predicted settings or output values, and the actual values as measured by the EDVM. An error column indicates the result of an automatic comparison of predicted and measured values. The same information, with a similar format, may also be recorded on punched tape.

The ADIOS operator may choose, at his discretion, one of three output format variations for the Typewriter and/or Paper Tape Punch. A convenient three-position lever-switch (the RECORD switch) determines the selection. In the position labeled COMPLETE, all data is recorded during the input cycle as well as during the output cycle. NORMAL operation only records data on the output cycle. For the ERRORS ONLY position, no data is recorded *unless* an error exists. When ERRORS ONLY is employed, the ADIOS "interrogates" the computer. If the error between the RCVD and the EDVM is greater than a pre-determined amount, then data is recorded as in the NORMAL mode — with an additional print-out of an "e" indicating the error. The ERRORS ONLY mode punches or types an output only when its analog error detector indicates a discrepancy between the component's predicted or desired value and actual value.

A complete sequential record of computer operation may be automatically obtained for each problem run when controlled by ADIOS. Alternately, the ADIOS enables a series of computer runs involving problem parameter changes, to be programmed such that the entire group of solutions can be obtained automatically.

With the ADIOS Reprogram mode, a tape which has been used to set a number of coefficient potentiometers before a computer run can be used to make a new tape. The original tape containing the potentiometer addresses and desired values -- is placed in the tape reader, and as the tape passes through the reader a new tape is prepared – the readings from the EDVM being punched on the tape in place of the original value readings. This tape can then be used for future problem runs. Optionally, a universal tape may be prepared with addresses only, to read out all coefficients and outputs, and thereby prepare a Reprogram tape which will set-up and re-check any problem.

REPETITIVE OPERATION DISPLAY UNIT

The General-Purpose Analog Computer is frequently used in the development of mathematical models to describe the behavior of physical systems. An integral part of this process is a "performance" comparison between a theoretical model and experimental data obtained from the actual system. By varying the parameters of the model, its performance may be matched to the data for a more accurate representation of the system. For a complex system, with a large number of parameters, an excessive amount of time is required for trial and error procedures using real-time computing techniques. The time may be significantly reduced, however, through the use of high-speed repetitive operation – where the computer solves the problem repetitively while the operator observes the effect of various parameter changes. In order to do this efficiently, it is necessary that the computer operator be able to rapidly observe the effect of parameter changes on the problem solution, and simultaneously compare the theoretical solution with test data.

The need for simultaneous presentation of several variables, at computing speeds encountered in repetitive operation, makes it impractical to consider the use of direct-writing recorders for display. For this reason, considerable emphasis has been placed on the development of high-speed cathode-ray tube display units for use with the General-Purpose Analog Computer.

To provide a Repetitive Operation Display suitable in accuracy and performance to the 231R-V Analog Computing System, EAI offers the Series 1905 Repetitive Operation Display Unit (Figure 56). This system allows simultaneous viewing of up to eight problem variables on a 17" magnetic-deflection cathode-ray tube. Provisions are included to permit the display of either eight input variables as functions of time or seven variables as functions of an eighth independent variable. An electronically-generated voltage and time grid eliminates parallax and errors due to non-linearities in the display system. Significantly, the voltage calibration lines of this grid are slaved to the reference voltage supply of the computer for accurate measurement of signal levels.

Timing for the display is derived from a crystal-stabilized oscillator employing frequency dividers to establish different display times. Switching is provided to select display times of 10, 20, 40, and 80 milliseconds. When used in conjunction with the Analog Memory and Logic System the Display Unit provides the 10KC timing reference or clock to synchronize the integrator mode control gates with the display. Additional drive frequencies from the display unit are also made available at the Mode Logic Patching System. Any of the Display Unit outputs may be

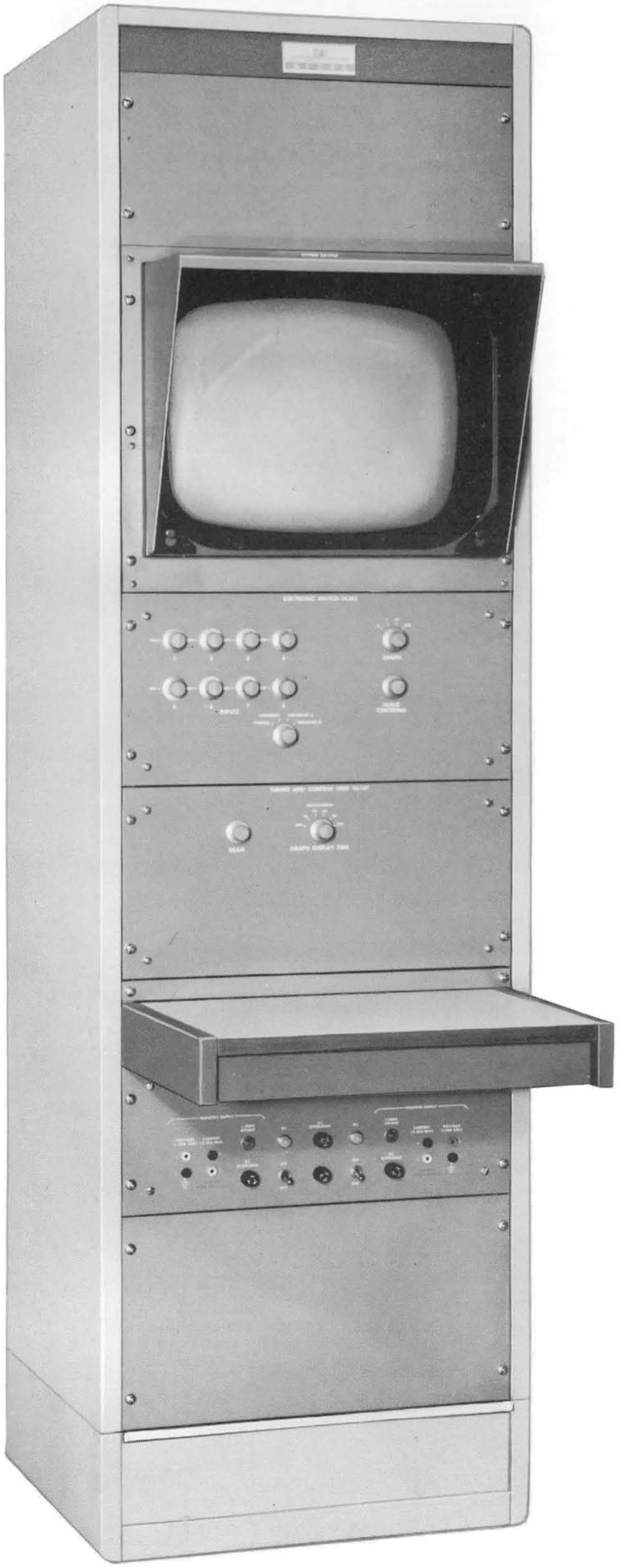


Figure 56. Series 1905 Repetitive Operation Display

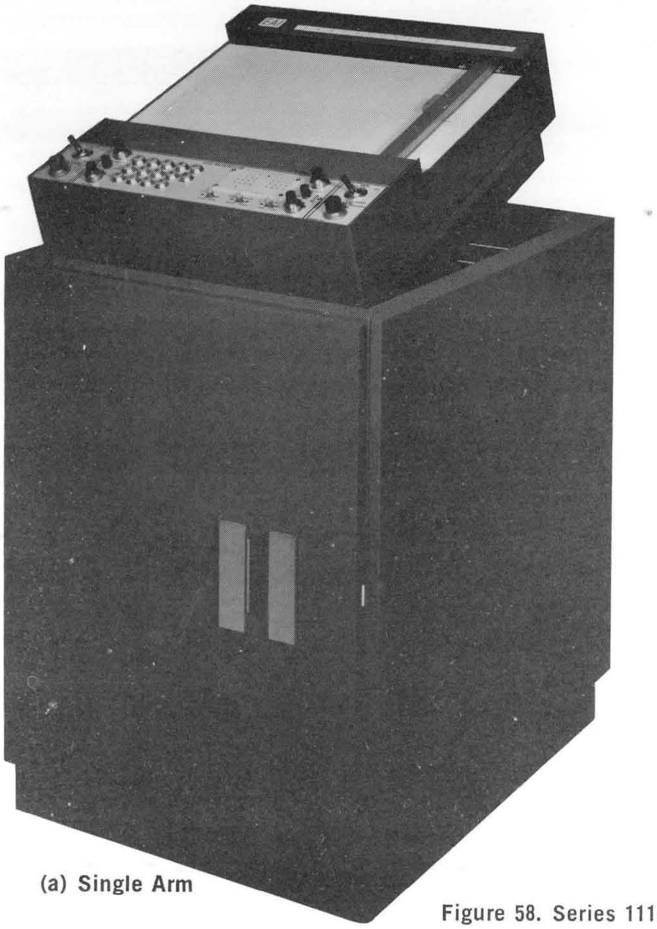
Figure 57. Series 1910 Eight-Channel Recorder

patched to the interval timers of the Analog Memory and Logic System – offering a wide variety of repetitive rates.

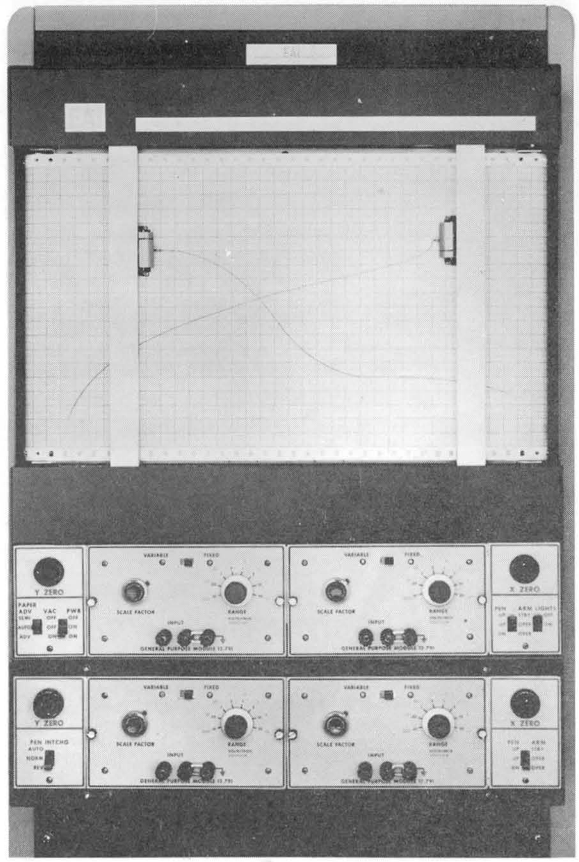
The Series 1905 Repetitive Operation Display Unit is contained in a single-bay console which may be equipped with an optional base for mobile operation. The cathode-ray tube is mounted behind a protective safety glass plate and includes a shield to minimize glare. Separate controls make it possible to vary the intensity level of each channel, or to display only those channels of particular interest at any time. Controls are also available to regulate the intensity of the grid and to select either the timing or voltage reference lines, or both.

STRIP-CHART RECORDER

The Series 1910 Recording System (Figure 57) is manufactured for EAI by the Brush Instruments, division of the Clevite Corporation, and is a version of their Mark 200 Recorder modified for use with the EAI Series 231R Analog Computing System. This recorder includes an eight-channel direct-writing oscillograph with a forced-fluid writing system, and provides simultaneous rectilinear display of eight analog (voltage) input channels and two timing or event channels.

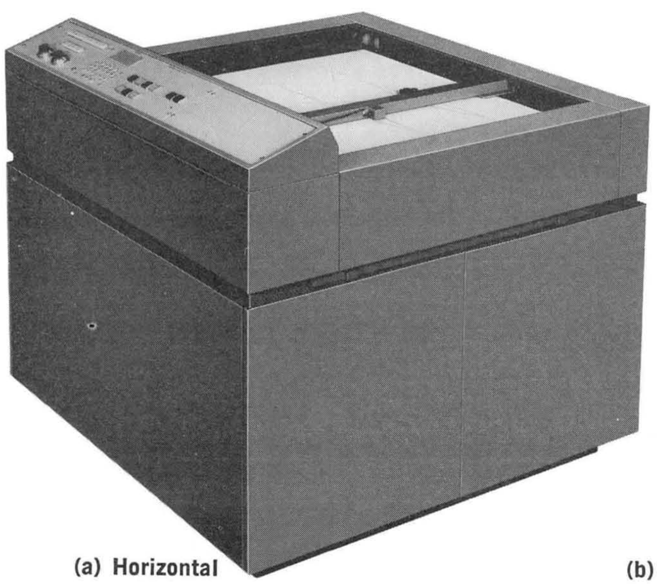


(a) Single Arm

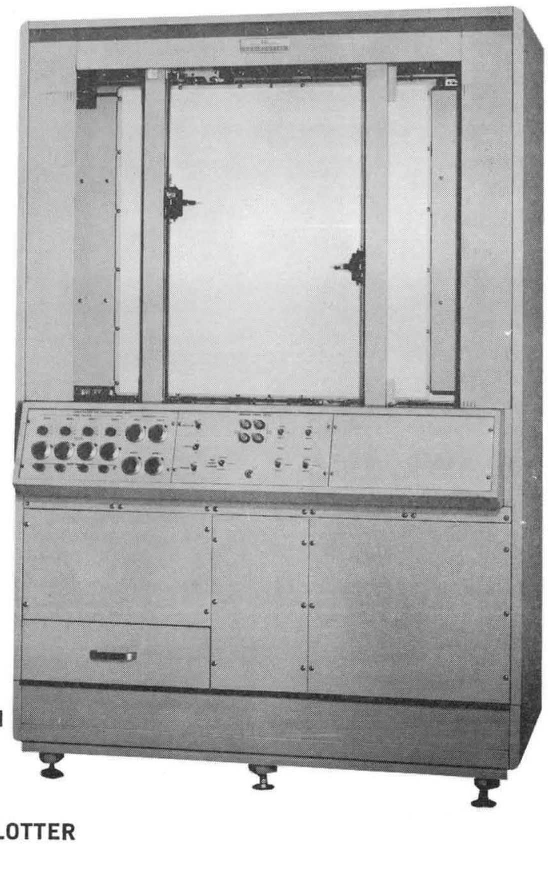


(b) Dual Arm

Figure 58. Series 1110 VARIPLOTTER



(a) Horizontal



(b) Vertical

Figure 59. Series 205 VARIPLOTTER

Inputs from the analog computer system drive the penmotors, through specially designed drive amplifiers, with pushbutton selection of nine attenuator steps for each channel. Overload lights for each channel indicate when pens are not accurately following the input signals. Eight pen positioning controls permit each pen to be located anywhere within the channel, and allow either edge of the channel, or any point between, to be used as a base line (zero signal position). In addition, a polarity reversal switch for each channel permits either a positive or negative display of unipolar signals, or reversal of bipolar signals without the use of additional analog computer components.

Maximum recording accuracy is achieved with penmotors, which utilize the proprietary Brush Metrisite transducer for position feedback control to eliminate the mechanical restraint of the conventional torsion rod for zero return. The penmotor coil, supported by precision ball bearings, rotates freely in a constant magnetic field. Pen position is continuously sensed by the Metrisite, contained within the penmotor housing, to produce a signal proportional to displacement. This feedback signal is converted to d-c and compared against the input signal to the drive amplifier. Any difference between the Metrisite output and the input command produces an "error" signal, which is amplified and applied to the penmotor.

A closed inking system supplies the ten writing pens with a permanent writing fluid. The fluid is held under pressure in a replaceable cartridge to eliminate pen clogging and to avoid the need for priming. Pen pressure against the chart paper seals the pressure system. A special chart paper, designed to match the pressurized inking system by absorbing the correct amount of ink, provides sharp, uniform, high-contrast traces without sacrificing the economy of ink-type papers over comparable heat or electric writing papers. A solenoid-driven valve shuts off the ink supply when the instrument is turned off.

The chart drive is contained in a separate chassis which may be pulled out on slides from the front of the recorder for use as a horizontal writing shelf. Provisions are included for pushbutton selection of twelve chart speeds which range from 0.05 to 200 millimeters per second. Control of the chart drive motor may be slaved to the 231R-V Mode Control System to conserve paper. Conversely, RESET, HOLD, and OPERATE pushbuttons on the recorder make it possible to select the analog computer operating modes from the recorder.

In addition to the operating modes, the Series 1910 recorder also includes three calibrate modes for adjusting the zero signal voltage position, adjusting amplifier gain, and for recording the attenuator setting for each channel. Pen deflections are used to provide a permanent record of the attenuator setting for each channel. Timing calibration provided by an internal pulse generator may be switched to either or both event marker pens.

X-Y RECORDING EQUIPMENT

The General-Purpose Analog Computer is frequently used to investigate the effect of parameter variations on the behavior of a physical system. This requires the comparison of a series of solutions to the same basic problem over a range of variations in parameters or initial conditions. The X-Y Recorder or plotting board is an ideal output device for this purpose since a number of curves may be plotted on the same set of axes to greatly simplify analysis. In addition, it provides an accurate means of recording computer output information and avoids the necessity for tedious and often inaccurate manual plotting of data.

The EAI Variplotter X-Y Recorders provide fast, accurate, and convenient plotting of information available in analog form. Particular emphasis has been placed on flexibility in the design of these recorders to satisfy the requirements of both special-purpose and general-purpose laboratory applications. The Variplotter is available with plotting board sizes to accommodate a variety of paper size requirements. The two most popular versions, the Series 1110 (Figure 58) and Series 205 (Figure 59) accept 11″ x 17″ and 30″ x 30″ maximum paper sizes respectively. A unit with a 45″ x 60″ plotting surface is available on special order. Since all Variplotters employ vacuum paper hold-down systems, the large plotting boards may also be used with smaller paper sizes.

Both the Series 1110 and Series 205 Variplotters may be supplied either in a single-arm version – which permits plotting one variable as a function of another, or in a two-arm version for plotting two independent curves. All two-arm Variplotters are equipped with an automatic pen-interchange circuit which exchanges the functions of the pens to permit the use of the entire plotting surface for both curves.

The Series 1110 and Series 205 Variplotters are designed for either horizontal or vertical mounting. The Series 1110 may be mounted vertically in an equipment rack, or supplied with a table-top stand – with provisions for adjusting the angular position of the plotting surface from horizontal to nearly vertical. The Series 205 may also be supplied for horizontal table-top use or for vertical mounting on a wall or bulkhead. Optional base cabinets for either horizontal or vertical mounting are also available.

Input circuitry for all Variplotters includes provisions for fixed and variable scale factor adjustment – facilitating rapid enlargement or reduction of plots according to the dynamic range of the variables under consideration. Continuous parallax or origin adjustment, with provisions for zero suppression of up to one full board length in any direction, makes it possible to enlarge sections of a curve for investigation of specific interest areas.

EAI Variplotter X-Y Recorders are readily integrated with the 231R-V Analog Computing System. Receptacles for plotter cables with terminations at the Program

Patching System are supplied with every 231R Control Console. An interlock is also designed into the plotter which allows the pen-lift to be controlled by the computer Mode Control System. In this manner, the pen is prohibited from writing in all modes except OPERATE or HOLD to avoid excessive inking.

The Variplotter may also be used as an input device to the 231R-V Analog Computing System with the addition of a curve-follower function generator accessary. The curve-follower produces a trace of an output voltage that is related to an input variable by an arbitrary function — drawn on standard graph paper with conducting ink. A high-frequency voltage applied to the inked line is sensed by a miniature inductive probe which replaces the pen. The function generator converts this signal to a DC voltage which is nulled in the input amplifier, causing the probe to follow the line.

In addition to the Variplotter X-Y Recorders EAI offers the Dataplotter, which accepts both analog and digital inputs. Dataplotters may be supplied with 11"x 17", 30"x 30", or 45"x 60"plotting surfaces with provisions for accepting keyboard, punched card, punched tape, or magnetic tape inputs. Versions of the Dataplotter are also available to operate directly on-line with digital computers or data processing equipment.

OSCILLOSCOPES

During the check-out of high-speed programs on the General Purpose Analog Computer, it is frequently necessary to make use of a general-purpose oscilloscope for monitoring the control and problem signals. Since there are a number of excellent laboratory oscilloscopes available, the choice is frequently determined by a desire for standardization in the laboratory. As a convenience to 231R-V customers, EAI makes available oscilloscopes of different manufacturers, in a variety of models, for use with the 231R-V. Such oscilloscopes may be selected for either rack-mounting or table-top operation, and may include provisions for single or multiple trace displays. When mounted in the computer, the inputs to the instrument terminate at the Program Patching System to facilitate monitoring the outputs of individual computing components.

COMPUTER TEST EQUIPMENT

The 231R-V Analog Computing System provides a degree of reliability previously unknown in the analog computer field. As with all quality electronic equipment, however, optimum performance may be obtained only with routine preventive maintenance. In order to facilitate this maintenance, special care has been exercised in the design of the computer. Examples of this are found in the use of bus bar power distribution, interchangeable components and power supplies, and the accessibility of operating controls and monitoring provisions. To supplement this, EAI also offers test equipment specifically designed for use with the 231R-V to enable more efficient maintenance, thus minimizing computer downtime. These equipments are offshoots of production test equipment used by EAI in the manufacture and in-house checkout of computer components and systems.

All computing systems are supplied with service shelves, test cables, schematic and wiring diagrams, component location charts and complete parts lists to aid maintenance personnel in the trouble-shooting and repair of individual computer components. These accessories provide complete access to all components and electrical connections so that the unit may be tested in operation. More complete tests, i.e., those required for a thorough maintenance program, are made possible by patch panels permanently wired for standard test programs.

MAINTENANCE TEST CONSOLE

To avoid interruption of computer operation for component maintenance, most large analog computer laboratories include a separate maintenance facility equipped with appropriate test equipment. In many cases this equipment includes specially-constructed test jigs which make it possible to service computer components under power. Since proper servicing of an analog computer component may be obtained only under the same environmental conditions as those of the analog computer itself, these test jigs frequently fail to indicate mal-functions which effect the operation of the computer.

To permit servicing of computer components under actual operating conditions, EAI has developed the Series 231X Maintenance Test Console (Figure 60) which provides the necessary facilities for performing off-line test and maintenance of EAI Analog Computing System components. The 231X has been designed to include a temperature-controlled oven, patch bay, mode control system, read-out system, etc., with characteristics similar to those of the 231R-V Control Console. In addition, provisions are included in the console for a number of linear computing components (i.e. summers, summer-integrators, coefficient attenuators, and function switches), which may be used to simulate program operating conditions for components under test. The Maintenance Test Console is, therefore, a small analog computer itself, and as such serves not only as a test stand for computing components but as an expansion to the main analog computer as well – or as a small training computer.

The 231X Console consists of a two-and-one-half bay cabinet with patch-bay, network oven, and maintenance work shelf. A recessed test cable well (Figure 61) conveniently located above this shelf provides extension cables for each of the components contained in the associated analog computing system. These cables are internally connected to appropriate component patch-bay positions and power supply bus terminations to permit the programming of components in actual computing circuits. Similarly to the 231R-V, integral patch-bay terminations and receptacles are also provided for the acceptance of recording equipment, enabling component performance monitoring.

The electrical and mechanical design features of the 231R-V Program Patching System have also been incorporated into the 231X Console. This patching system makes use of a 2,070 contact patch-bay with removable aluminum pre-patch panel, employing the standard component terminations of the 231R-V. Computing networks are contained in a temperature-stabilized oven directly behind the patch bay. All critical wiring in the console and test cables is shielded for low-noise operation.

Operating controls for the Series 231X Maintenance Test Console (Figure 62) include provisions for selection of component outputs, control of the operating modes, and selection of special test conditions. Monitoring equipment includes an electronic digital voltmeter, vacuum tube voltmeter, and plotting and recording equipment, as required. Provisions may also be included for a digital printer. Spare computing components and monitoring equipment may be used with the 231X to minimize the investment in test equipment.

The Series 231X Maintenance Test Console has been modularly designed so that it can easily be tailored to the specific requirements of each 231R-V Analog Computing System installation. Facilities may be included for testing not only computing components for the 231R-V, but for other versions of the 231R and earlier EAI computers as well. The 231X may easily be expanded to accommodate new computing components as they are added to the Analog Computing System.

PREVENTIVE MAINTENANCE CHECK (PMC) PANELS

Although preventive maintenance routines may be easily programmed on the 231R-V Program Patching System, the time required for patching and the possibility of patching errors makes it desirable to use permanently-wired pre-patch panels for this purpose. For this reason EAI has developed the Preventive Maintenance Check (PMC) Panels which provide a means of rapidly and accurately checking the performance of components in the 231R-V Analog Computing System.

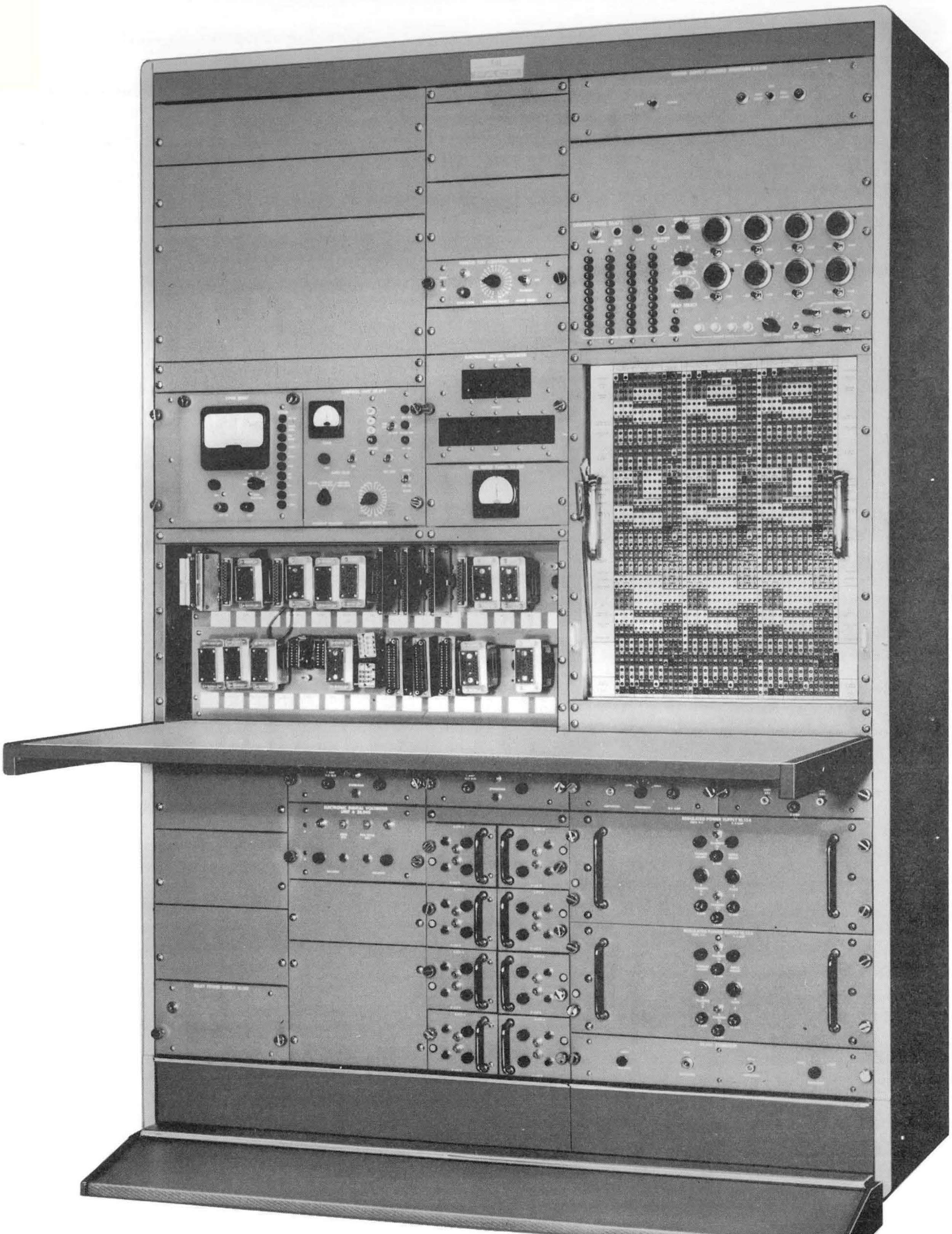


Figure 60. Series 231X Maintenance Test Console

Each PMC Panel consists of a metal patch-board, similar to the standard pre-patch panel used for programming the computer, with a control assembly containing the necessary circuitry and switching provisions to perform both static and dynamic tests on each component in the computer. Standard test programs are permanently-wired into each panel to connect the computer control circuits and appropriate components for the desired tests. These connections are made by pins inserted into the holes in the patch panel. When the PMC Panel is installed in the patch-bay these pins engage the spring contacts of the patch-bay in the same manner as the patch cord tips.

Two PMC Panels (Figure 63) are necessary for a complete test of the 231R-V Analog Computing System — one model to check all linear computing elements and another to check all non-linear components. Since no patching alterations or potentiometer coefficient changes are necessary to perform tests with the PMC's, a problem may be interrupted at any time to verify component performance. Switches located on the PMC Panel select the tests, and make the proper connections to the components under test.

When using the PMC Panels, the console monitoring facilities operate in a normal manner — enabling the test results to be observed on the computer Electronic Digital Voltmeter. Furthermore, by employing the Automatic Extended Read-Out (AERO) System with the associated digital printer, results may be automatically recorded. Multi-channel recorders and X-Y plotters are also used with certain test procedures.

Figure 61. Test Cable Well

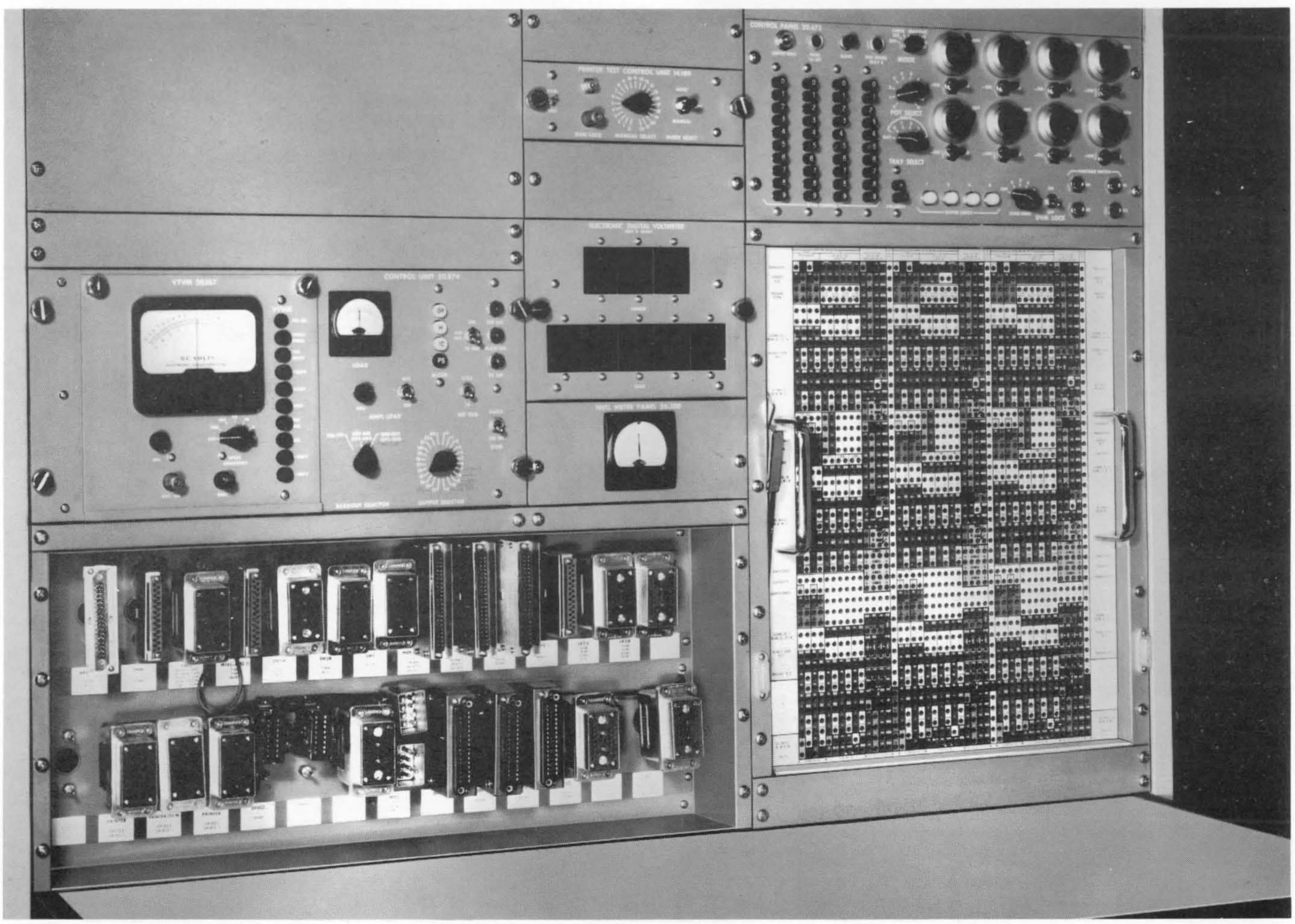
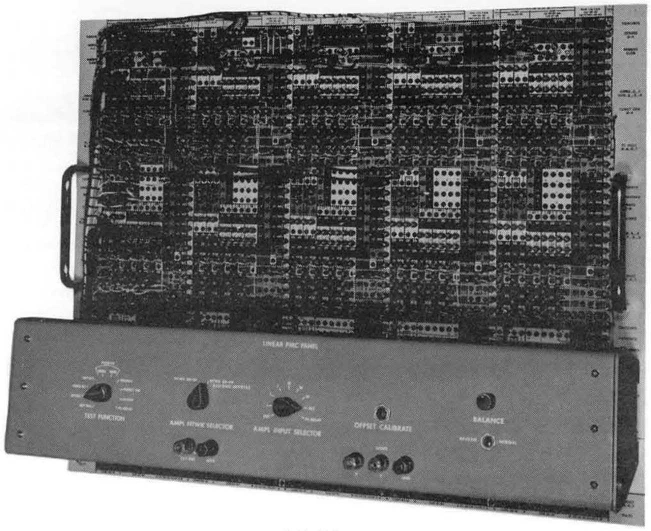
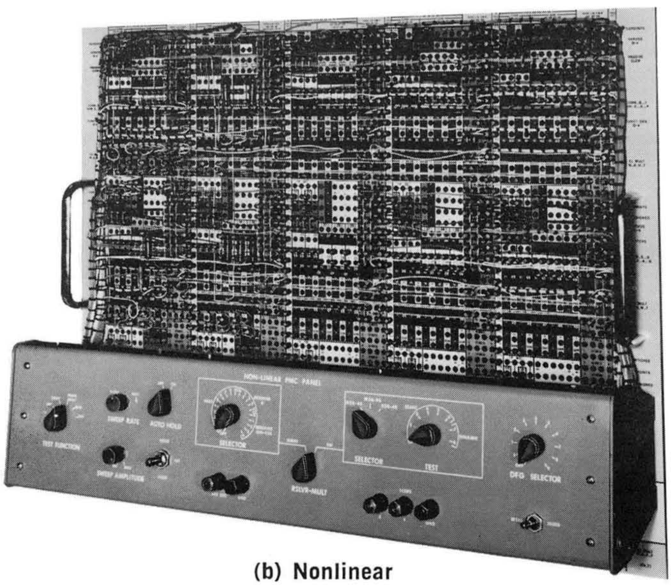


Figure 62. Control Panel



(a) Linear



(b) Nonlinear

Figure 63. Preventive Maintenance Check (PMC) Panels

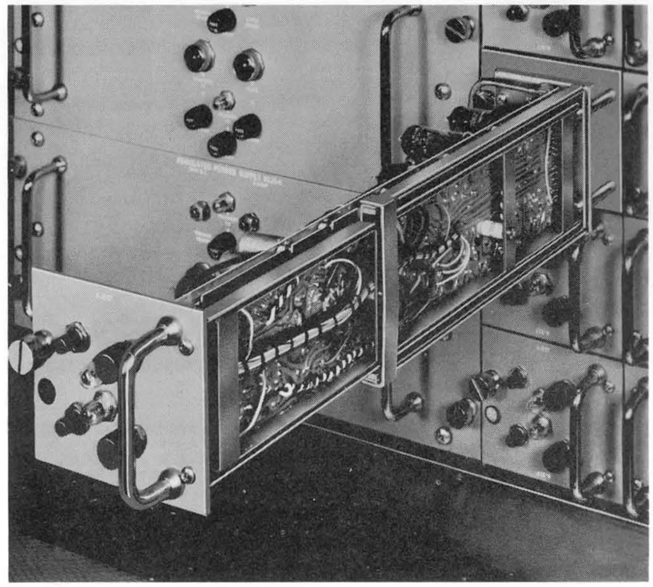


Figure 64. Component Service Shelf

MISCELLANEOUS TEST EQUIPMENT

An assortment of special tools, test equipment, spare parts, etc., are provided as standard equipment with each EAI 231R-V Analog Computing System to aid in the service and maintenance of the computing components. Test equipment supplied includes service shelves, test cables, and printed circuit card extenders for the components contained in the computer. The service shelves and test cables make possible the general trouble-shooting and repair of individual component chassis. When installed in the computer, the service shelf (Figure 64) performs the function of a test jig which may be substituted for the component. The associated test cable then may be used to provide complete electrical connections for the component. In this manner the circuitry is made available to maintenance personnel while the component remains electrically connected to the computer. In the case of components which contain printed circuit cards, printed circuit card extenders are supplied to permit access to circuit components.

COMPUTATION SERVICES

The availability of support services from the manufacturer is essential to the successful operation of a large-scale computing laboratory. Such support should not only assure the satisfactory operation of the computer, but provide for its full utilization as an effective problem-solving tool as well. EAI has incorporated this basic philosophy into a complete program of customer support activities to assist the user in maintaining equipment, in training personnel, and in applying new computing techniques to the solution of scientific and engineering problems. Continued support of this type has been largely responsibile for the high degree of customer acceptance of the 231R Analog Computing System.

Available services fall into two general categories: those associated with training, applications assistance, and computer time rental, and those associated with maintenance, repair service, and availability of replacement parts. Each of these functions is assigned to a specific department in the EAI organization to assure the customer of immediate response to requests.

For those services requiring an extensive knowledge of the programming and application of computing equipment, EAI maintains and operates a number of Computation Centers in the United States and Europe that offer equipment rental, applications assistance, training, and systems analysis. A complete staff of experienced engineering and scientific personnel is available at each location to analyze technical problems, interpret scientific data, and provide complete engineering assistance to customers. These personnel are also available to conduct training programs at customer installations and to assist in the programming and operation of EAI computing equipment.

EAI has established a large network of regional service engineering offices and parts depots throughout the world. Each of the regional locations is equipped to provide rapid and efficient service to guarantee maximum utilization of EAI computing equipment. Trained service engineering personnel are available at each office to supply emergency service when needed. EAI also offers a variety of maintenance programs under which EAI personnel will assume complete responsibility for the maintenance of customer equipment, or will serve to supplement the customer's own maintenance staff.

Inter-related operations in research, engineering, manufacturing and marketing activities makes it possible for EAI to provide this extensive back-up support – support that is available only from a major manufacturer of electronic equipment. This complete technical capability and EAI's exceptionally high standards of quality stand behind every EAI computing system – assuring the customer of complete and professional support in the operation of his computation facility.

TRAINING

General-Purpose Analog Computers, like other complex equipment, are only as effective as the personnel who use them. Proper maintenance and operation, as well as the programming, of any computer requires specialized training – with appropriate emphasis placed on the use of the techniques which permit more effective utilization of the equipment.

Since 1957 EAI has offered a complete curriculum of introductory and advanced courses in analog computation, including general computer training as well as courses related to specific EAI computing equipment. Advanced courses are also given on hybrid and analog computation which cover specific fields of application such as chemical process, aerospace, and bio-medical simulation. Although these programs are offered periodically at the EAI Computation Centers, general and specialized courses, tailored to individual requirements, may also be presented at customer facilities. To supplement the training available at its Computation Centers, EAI will work closely with colleges and universities to establish 'on-campus' courses in computation for industry, government, and university personnel.

All EAI training programs are conducted by experienced engineer-instructors, who also prepare the written and visual training material. Since the instructors, when not actually engaged in classroom work, are assigned to simulation and analysis projects for the many organizations served by the EAI Computation Centers, the most recent developments in computing applications are integrated into the training programs.

Operation and Maintenance Courses

With each 231R-V Analog Computing System, a complete training program is provided for the operation and maintenance of the computer and its peripheral equipment. This program, given periodically at the EAI Computation Centers, is divided into two courses. The first of these describes the programming and operation of the computer, while the second familiarizes customer maintenance personnel with standard servicing techniques and procedures. Each course consists of a week or more of lectures, homework assignments and laboratory sessions – which make use of the 231R computing equipment installed at the Computation Centers.

The Operators Course for the 231R begins with an introduction to general-purpose analog computers, and is followed by coverage of the programming procedures and techniques for each computing component. In the area of programming, the complete process from problem preparation to the actual solution on the computer is presented. Teams of three to five students are assigned to each of the computers to program problems, practice program checkout procedures and to produce solutions. This gives the student opportunity to make use of the lecture material and to gain operating experience on the 231R computer.

The Maintenance Course includes a description of 231R-V computing components, control console and peripheral equipment, and details the proper preventive maintenance and servicing techniques for this equipment. Functional performance of each element, its block diagram and circuit functions are presented to familiarize the student with component failure characteristics. Preventive maintenance routines, test and alignment procedures and program patching are also taught. Laboratory sessions allow the student to put the test and maintenance procedures into practice, and to develop a proficiency through trouble-shooting malfunctions intentionally introduced into equipment by the instructor.

Applications Courses

In addition to courses in the operation and maintenance of EAI computing equipment, tuition courses are available which cover the application of general-purpose analog and hybrid computing equipment to industrial problems. These courses are general in nature, and are not specifically related to EAI computing equipment. A variety of courses on advanced computing techniques used in general and in specific industries are also offered.

Each course develops the mathematical approach, and provides the basic analytical methods to be applied to a number of different problems. Lectures, homework, and laboratory assignments make it possible for the student to apply his engineering and mathematical training to the effective use of simulation in the analysis of physical systems. In addition to providing the fundamentals of analog computation, courses include advanced techniques in partial differential equations, iterative computation, repetitive operation, and the use of such mathematical tools as vector analysis, method of steepest descents, and the adjoint technique. These methods, which have been proven successful in practice, are illustrated by examples drawn from EAI's experience in applying computers to modern scientific and engineering problems.

The Applications Courses are designed to give scientists and engineers a working knowledge of the analog computer and its applications. Their object is to train qualified people to plan and direct the use of computers in their industries for activities which are presently undertaken by manual calculation, direct experimentation, or prototype testing. Upon completion, the engineer is conversant with many areas of mathematical model building, and the use of modern computing techniques to expedite this process.

MAINTENANCE

The efficient operation of a large-scale computing laboratory is dependent, to a large extent, on the availability of trained maintenance personnel — able to perform routine preventive maintenance checks as well as to trouble shoot and service the computer. Since the development of a staff with this level of experience takes considerable time, it is particularly important to the customer that the manufacturer of the computing equipment be in a position to supply this service in the degree necessary for each installation.

EAI offers this through a world-wide organization of experienced service engineers. Distributed among more than 13 field service offices, these men are on call to provide assistance to the customer whenever and wherever it is needed. Comprehensive and effective programs for preventive, corrective, and emergency maintenance of EAI computing equipment — tailored to individual requirements — are readily available.

Years of experience in maintaining analog and hybrid computing equipment, analog and digital plotters, simulators and checkout systems, industrial and laboratory instruments and industrial control systems has resulted in a diversified and thorough knowledge of electronic equipment and systems. The decentralization of personnel, repair facilities and parts depots has made possible the complete maintenance of any sized installation, containing electronic equipment of all types of manufacture. This capability, coupled with the philosophy of controlling system performance instead of being controlled by equipment failure, has established EAI's record for qualified, dependable, timely service to industrial, university, commercial, military, and government installations.

Service engineering is responsible for the installation, checkout and warranty maintenance of all EAI systems. Pre-installation planning and layout, installation, system operation and specification tests, customer familiarization and training assures maximum satisfaction from EAI computing equipment.

As a further service, EAI field engineers maintain close customer liaison through courtesy calls for technical assistance to engineering and maintenance personnel. Information on the latest engineering modifications and product improvements are automatically provided as continued support in maintaining an up-to-date facility.

Installation

During the installation of each 231R Analog Computing System, the EAI service engineer carries out a series of on-site tests to verify that the equipment meets its operational and performance specifications. These tests include the repetition of tests conducted during the final system checkout at the EAI manufacturing facility, and a comparison of results to assure that no damage has come to the equipment through handling and shipping. Shortly after installation the service engineer returns to the customer installation to correct any subsequent malfunctions. Thereafter he will make courtesy visits whenever possible to assist customer personnel in the maintenance of the facility.

When emergency service is required, every effort is made to accomplish repairs as rapidly and economically as possible. Not only are the most frequently needed spares available at the regional service engineering offices, but a close liaison with the EAI parts sales departments guarantees rapid delivery of necessary replacement parts.

The customer is supplied regularly with bulletins that describe new modifications and improvements to keep existing 231R equipment up-to-date. As design improvements are made, or new maintenance techniques develop, these bulletins are prepared and distributed to all 231R users.

Maintenance Contracts

To assure high quality maintenance service on a regular basis — to supplement existing staffs or to serve as the maintenance staff — EAI offers a variety of service engineering programs on a contract basis. These programs range from complete resident field service to periodic service programs. Weekly or monthly visits can be arranged, as well as longer periods, to assist the customer with major expansion or modification programs.

EAI resident field engineers are responsible for the execution of maintenance programs, inventory control, availability of replacement parts and the proper operation of equipment at all times. This service not only assures maximum availability of computing equipment, but also provides an opportunity to train customer personnel in the service and maintenance of EAI computers. When the training of customer personnel has advanced to an appropriate level, the resident contract may be converted to a periodic service program. As an optional part of the field service program, the customer may also contract to have the EAI field engineer stock and supply necessary replacement parts and provide major factory repairs for a fixed annual fee. This frees the customer from the burden of handling the purchase of small parts, and avoids a substantial investment in stocking replacement parts.

Equipment Repair

For those repairs which are impractical or inconvenient for the customer to perform, EAI offers an equipment repair service at several of their field service offices. Each repair center is fully-equipped for testing or recalibration of computing equipment.

In order to provide rapid response to customer requests for replacement parts, EAI maintains a separate parts sales department. Qualified technical personnel assist the user in determining the proper replacement parts and in expediting the delivery of these parts. In cases where equivalent parts may be obtained locally from an electronic supplier, EAI provides the customer with all necessary information. Over 50,000 separate items which are manufactured by EAI, or supplied by other manufacturers to EAI specifications, are indexed and programmed for rapid location, quick delivery, and automatic inventory control — thus guaranteeing maximum service for the life of the computer.

COMPUTATION

Frequently, organizations with problems which require the use of electronic computing equipment do not have a sufficient volume of work to justify establishing their own computing facility. In order to make available to these organizations the needed computation service, EAI maintains and operates a number of Computation Centers in the United States and Europe. These Centers are strategically located to serve industry, research, and government organizations and include the most up-to-date EAI computing equipment together with a staff of trained engineering and scientific personnel thoroughly familiar with both analog and digital computing equipment. Facilities are designed for maximum convenience and security and are staffed by personnel experienced not only in the computing sciences, but also in a variety of industrial fields. Each staff member is both a skilled scientist and an experienced engineer.

Almost a decade of successful teamwork with scientific, industrial and research organizations stands behind the accomplishments of the EAI Computation Center staff. This experience has provided many organizations with the broad insight necessary to overcome communications barriers for effective exploitation of modern computing techniques. Organizations with tasks in such fields as physical science, engineering, management control, and data processing who have found the cost of duplicating EAI facilities and capabilities to be prohibitive, employ the Computation Center services on a regular basis. This has frequently proven to be the best way to obtain the benefits of modern computing science without extensive capital investment. The ability and experience to design and implement programs for all computer systems, both large and small, brings to these customers the most advanced techniques for tasks ranging from operations research to the solution of partial differential equations.

Large-scale computing equipment available at the Computation Centers includes fully-expanded 231R Analog, and HYDAC Hybrid Digital-Analog Computing Systems. Portable computers are also available for off-site use. Because modern computing science constantly creates better methods and equipment to meet new demands, a program of updating on a continuing basis brings these benefits to Computation Center users. As a result of systematic updating, average age of computing equipment never exceed 1.5 years.

Security-cleared facilities and personnel are available, and all requirements for receipt, storage and transmission of classified information are rigidly fulfilled.

Methodical procedures have been initiated to safeguard proprietary information received from private industry and research organizations employing these services. Classified files for both Government and private industry are maintained and no information may be released without appropriate approval or clearance.

Centers are housed in modern, air-conditioned buildings designed for maximum efficiency, both as computation laboratories and engineering centers. EAI brings the most advanced economical, efficient methods and machines of computing science within financial reach of every industrial, government, or research organization.

Because the needs of organizations vary from computer-time rental to analytical design tasks, preliminary discussions with Computation Center representatives to define individual requirements are encouraged.

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