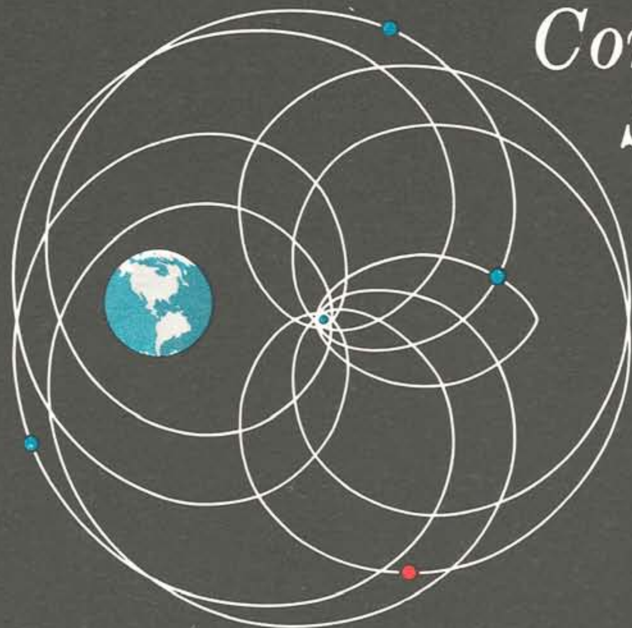
The HYCOMP® Hybrid Analog/Digital Computing System



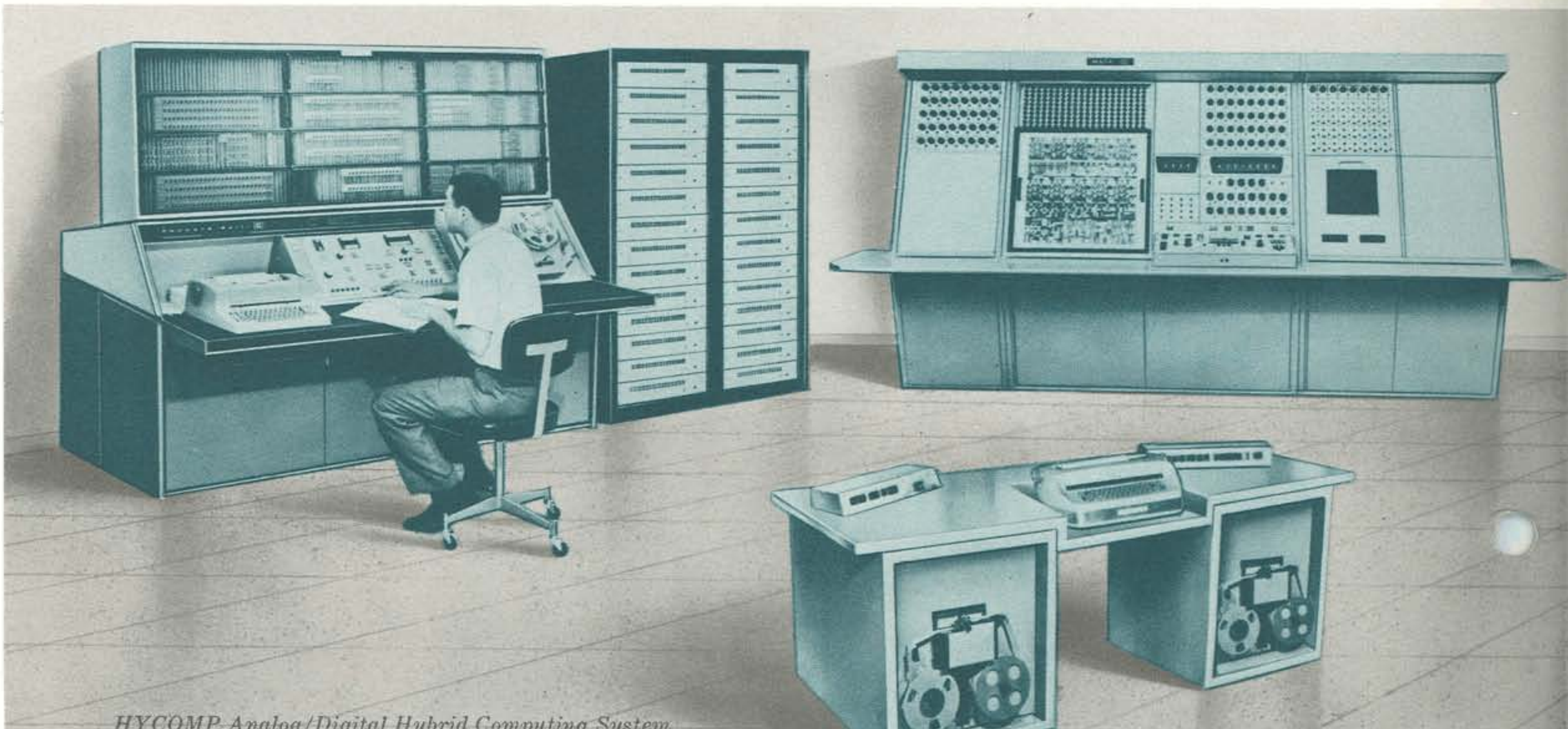
AEROSPACE SIMULATION

SAMPLED DATA SYSTEMS

MAN MACHINE SYSTEMS

Packard Bell Computer

Contents



HYCOMP Analog/Digital Hybrid Computing System

The **HYCOMP®** *Analog/Digital*
Hybrid Computing System

The HYCOMP Hybrid Analog-Digital Computing System offered jointly by Packard Bell Computer and Computer Products, Inc., represents a significant technological advance in the relatively new increasingly useful hybrid computing field and, at the same time, offers the scientific and engineering computer user substantial, easily documented benefits in regard to initial and operating cost, system integration, vendor responsibility, maintenance and other factors.

Major components in the HYCOMP* Hybrid Computing System are the Mark III Analog Computer designed and manufactured by Computer Products, Inc., and the PB440 Digital Computer, developed by Packard Bell. Among the Mark III's unique features are Solid State Electronic Mode Control of Reset Hold and Operate making it capable of faster operation than any other real-time general purpose analog computer available today.

The PB440, a console-size, solid-state computer, incorporates a unique dual memory stored logic concept which allows storage of command list in addition to program. No compromise is necessary in the command list to suit varied applications. The command list for hybrid computation is tailored specifically for hybrid applications and may be further modified by the programmer as desired.

Another major element in the HYCOMP Hybrid Computer is the analog-to-digital linkage system. This portion of the system is supplied by Packard Bell Computer. Packard Bell has more than five years experience in this field and has provided more successful linkage systems than any other manufacturer. These include systems linking analog-to-digital computers ranging in size from the Bendix G15 to the IBM 7090. A recently-installed system links an IBM 7090 digital computer to an analog computer over a distance of more than 2500 feet. Included in this system are remote inputs and displays in an Apollo simulator.

In addition to general purpose digital computers, Packard Bell produces an incremental computer known as the TRICE DDA (digital differential analyzer) System. Many TRICE-analog computer hybrid systems are in use for real-time simulation. These systems also include the Packard Bell PB250 Digital Computer so that the user has three-way hybrid computations — Analog, DDA, and GP Digital. Data conversion capabilities in these systems include analog-to-TRICE and analog-to-PB250 plus digital communication between TRICE and the Digital Computer and the Analog-TRICE mode, with sensing or control by the PB250.

Because the TRICE DDA is an exclusive Packard Bell Computer product, it is the only hybrid system manufacturer that can offer this three-way computing capability.

Packard Bell Computer's reputation in linkage systems is firmly established. One customer has installed four Packard Bell linkage systems. The third and fourth systems for another customer are now being built.

In addition many customers utilize Packard Bell converters in computer linkage systems of their own design. Packard Bell's linkage system capability is based, in part, on experience in developing a widely-accepted line of analog-to-digital and digital-to-analog converters. This experience began with development of the first solid state analog-to-digital converter in 1958. This was the M2 Multiverter which has since become an industry standard. An improved M2 is still being manufactured and even today exceeds the specifications of most units offered by other manufacturers.

Latest additions to the Packard Bell Computer line of analog-to-digital converters are the ADC20, ADC21, ADC22, ADC23 and ADC24 modular units which range from 10 to 15-bits, 0.025% to 0.01% accuracy, and 4 to 1.2 microsec. per bit conversion speeds.

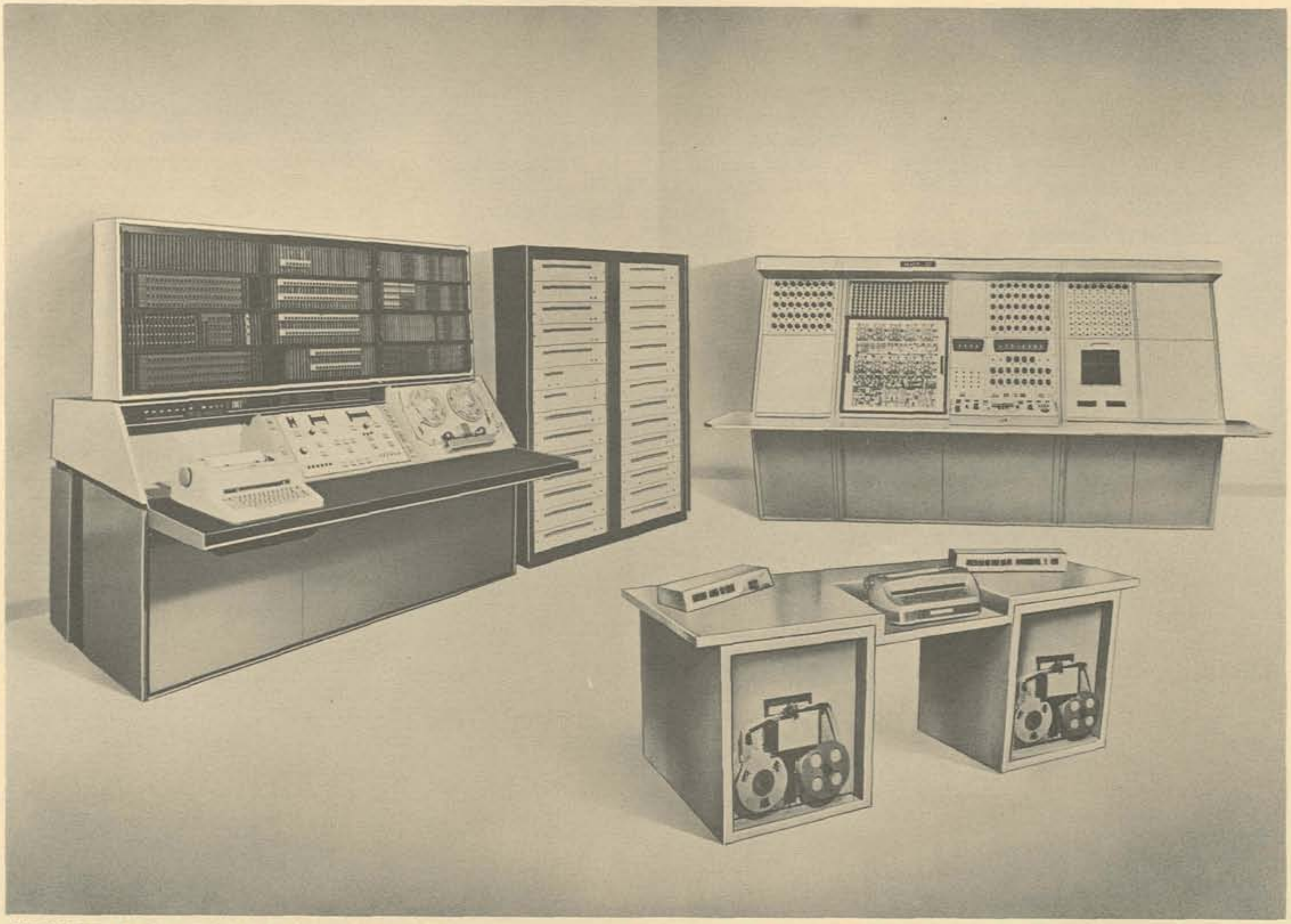
Fully expanded TRICE Digital Differential Analyzer.

The Customer Buys Just One System

Under a working agreement between Packard Bell Computer and Computer Products, Inc., complete Hybrid Computing System responsibility including installation and demonstration of performance is offered for the HYCOMP system under one contract with either company.

Specific advantages to the buyer include:

1. Only one contract for complete system responsibility.
2. A superior computing system because of the advanced features of the major system components, and because of joint design effort providing optimum interface of the two computers.
3. System checkout and proof of performance including both computers *at the manufacturer's plant* before delivery to the customer's computation site.
4. One procurement and one contract for an operational system *instead of* three separate procurements for analog computer, digital computer, and linkage system, with responsibility for an operating system left to the buyer.
5. Lower cost because (1) joint integrated design eliminates usual need to increase system price by contingency factor when large buy-outs are involved; (2) neither Computer Products, Inc., nor Packard Bell Computer must purchase the other's computer to offer a complete system, therefore overhead profits are not added and (3) a single buyer does not pay for custom engineering since a standard system design means engineering costs are spread over many systems.



HYCOMP Analog/Digital Hybrid Computing System

FEATURES AND APPLICATIONS
HYCOMP® Computing System

FEATURES

1. Three mode electronic control of Mark III Integrators individually or in any combination under program control from the PB440.

2. High speed, high accuracy, analog-to-digital conversion with a new model of the famous Packard Bell Multiverter. The ADC20 provides 15-bit conversion accuracy at a 30 KC conversion rate. Conversion rates to 120 KC optionally available.

3. Communications link, through the solid-state selection and readout system (DIDAC) of the Mark III, provides readout of all analog addresses to the PB440, setting of servoset pots and control of Mark III computing modes from the PB440.

4. Logic patching system, integral to the Mark III, with inputs from solid-state analog comparators and PB440 control lines and outputs to solid-state analog switches, integrator mode control, and PB440 interrupt and sense lines.

5. The PB440 is a dual memory stored logic digital computer which allows storage of command list and command format in addition to program. Special commands are provided for operation of the combined computing system. Transcendental functions such as sine, cosine, arctan, etc., appear as commands with extremely fast execution times.

   Simulation of proposed or existing control computers can be done on a command and format basis with the controlled system simulated on the Mark III.

6. Software — FORTRAN II with additional statements for operating the hybrid system simplifies the programming task for engineering personnel whose prime interest is *not* in the field of digital computer programming.

   Diagnostic routines for digital computer, linkage system and Mark III. Input/Output program which performs all analog scaling computations and automatic static check.

APPLICATIONS

The present state of development and use of hybrid computing began in 1955 when designers of the Atlas Missile wanted to study the effect of the short-period dynamics of the missile on trajectory and applied an analog computer to the dynamics while simultaneously computing the trajectory on a digital computer. Subsequently, a hybrid system linking a Bendix G15 digital computer to an analog computer with Packard Bell Computer data conversion equipment was installed at North American Aviation to help predict operation of a projected missile control computer, with the missile itself simulated on the analog computer.

Since that time many new and useful applications for hybrid computing systems have been developed. One of the most active areas is aerospace simulation, but others include design of sampled data systems; optimization of multiparameter systems; man-machine systems; and biomedical engineering.

Aerospace Simulation

In aerospace, two of the most useful and significant applications of hybrid computing are in studies of space vehicle guidance control and trajectories. In the design of space vehicles, the two types of problems most effectively solved by computers are (1) computations which require either considerable logic or a great deal of precision, and (2) differential equations in which high frequencies and non-linearities are present and only an imprecise knowledge of the parameters is available. Because these two types of problems are so closely interrelated in many steps of space vehicle design and the solution to one may be the conditions of the other, hybrid computing is clearly indicated. The computations of (1) above can be handled on the digital computer, and the computation of (2) by means of the analog computer.

In general, equations of a space vehicle are divided so that the dynamics are studied on the analog computer, while the kinematics and guidance equations are studied on the digital computer. The digital computer may also generate the aerodynamic functions and solve the force and moment equations.

If an airborne control computer is also part of the system, it can be simulated with the PB440 on a *command* and *format* basis.

Much work has been done in the hybrid simulation of space vehicles and has been reported in the literature.

One area which requires a parallel logical decision capability not found in either the analog or digital computer is the simulation of the reaction controls of a space vehicle attitude control system. Here the translation of attitude commands to jet pulses is most aptly done by a system of parallel logic. This is provided in HYCOMP as an integral part of the Mark III Analog Computer.

In general, in any system where a large number of discontinuities occur, the handling of these discontinuities by relay logic on an analog computer becomes cumbersome because of problems in switching time of the relay logic. This type of simulation can be handled more efficiently and economically by solid-state digital circuit elements.

When the operation becomes sequential in nature, that is, where memory is required to store past conditions, it is advantageous to handle the simulation of digital computers directly. Memory, arithmetic, and logical operations are readily available and the problem can be solved by digital computer programming, making use of a flow chart which is itself sequential in nature. This method is preferable to logical design of a special purpose computer using patched logical elements, a fact borne out by the present state of general purpose digital computers.

Sampled Data Systems

A valuable application of Hybrid Computation is in the design of sampled data systems. These are systems in which the data signals can change or are available for manipulation only at discrete intervals of time. Usually both discrete and continuous signals are involved. Examples of sampled data systems are the digital guidance computer of a space vehicle, chemical process digital control computers, machine tool control and many other control applications involving fluids or solids such as pipeline control, steel rolling mills, etc.

The space vehicle guidance computer application is typical. Here, either the continuous values of errors in parameters such as attitude are sampled and digitized, or the commanded and actual values are sampled and digitized (the commanded value may already be in digital form). The digital control computer solves a set of control equations to generate signals which control vehicle thrust jet power, duration, direction or some combination of the three. The control elements may require a continuous signal, necessitating desampling of the control computer outputs.

Use of a hybrid computer system is obvious. The system consists of analog elements, digital elements and sampling elements, and each of the three is simulated by its counterpart in the hybrid computing system. However, the simulation is not as straightforward as it might appear. The average digital computer will not have the same characteristics as the airborne computer. Speed, word, length, commands, command and data format, are characteristics in which the two may differ. The analog-to-digital and digital-to-analog conversion systems may also be significantly different from the system to be simulated.

The PB440 stored logic computer, however, eliminates difficulties in the simulation because of computer differences. The command list, command and data format, word length and execution times of a control computer may be duplicated so precisely that even the programming for the actual system may be done on the HYCOMP hybrid computer.

The stored logic concept provides commands for control of conversion system components for greatest flexibility in digitizing for simulation. High quantization accuracy (.03% overall) in a multiplexed sample and hold system can be provided using Computer Products, Inc. amplifiers, operated in sample and hold fashion via electronic mode control, plus Packard Bell Computer's EMX-01-01 Multiplexer and an ADC20, 15-bit, 30 KC, analog-to-digital converter. With a flexible, accurate digitizing system, studies requiring lower accuracies are easily simulated by using less than the maximum converter word length, per channel conversion time, channel switching time, etc. under program control of the PB440.

Man Machine Systems

An important area of application in simulation methods is the study of systems in which a human being participates as an element of the system. Since mathematical models for human performance are not available except for simple tasks, it is necessary to run such simulations in real-time. It is the requirement for real-time simulation of sophisticated and complex man-machine systems which has been responsible in large part for the growth of interest in hybrid computer techniques.

Where a human pilot performs control or guidance functions in the operation of a system, some form of simulation is essential, both during the design phase and for purposes of training and evaluation. The simulation may be entirely an analog simulation or it may be partially or entirely digital simulation in which case some form of analog-to-digital and digital-to analog conversion may be required.

In the design of flight control systems, the simulation generally becomes some form of physical simulation in which there is an interrelationship between a human pilot, an actual or simulated portion of a vehicle control system, and a general purpose computer (analog, digital, or hybrid) which provides inputs to the cockpit and operator. These inputs represent the variation of environmental characteristics as well as vehicle dynamics during a particular flight mission.

In connection with orbital and space missions, hybrid computation becomes imperative because:

1. Real-time operation is essential when there are human pilots. This presents no problem to the analog computer or to the TRICE DDA; however, only the largest, fastest digital computers, programmed in machine language, can even be considered if the simulation is to be done all digitally.

2. Inherent variability of human performance as well as random or stochastic elements in the pilot's responses requires each experiment to be repeated with a number of different operators. This means that long periods of computing time will be required—prohibitively expensive for large scale digital computers.

3. Duration of even sub-orbital missions will be in the order of hours and simulations requiring hours or days of real-time operation may become necessary. This requires full time use of the computer system — again prohibitively expensive for a large-scale digital computer.

   Use of large-scale digital computers in hybrid systems on an interrupt basis has been proposed. In this case, the digital computer is limited to such operations as described (4.) below. Interrupt operation has to be considered in the light of the amount of memory required and therefore the amount of time that may be spent loading and unloading the main memory to auxiliary memory.

4. Digital computers are present "on-board" space vehicles in order to perform guidance computations which would be extremely difficult or excessively time-consuming for the pilots themselves. For example, in the Apollo mission the pilot must obtain sightings with respect to certain stars at particular times during the flight. These sightings are then used as inputs to the on-board digital computer which must determine the precise trajectory the vehicle is following as well as compute the necessary corrections to insure arrival of the spacecraft at the desired location. Thus, the pilot has available a keyboard or similar device for direct entry to the digital computer and he receives information back from the digital computer. Such a facility must be available in connection with the simulation. This requirement precludes the use of an all-analog simulation. A stored logic digital computer such as the PB-440 is ideal for this application.

5. Display generation for simulated flights requires the availability of a digital computer. The displays seen by the pilot of a complex spacecraft can no longer be represented by means of simple dial movements but will in general include cathode ray tubes and other visual presentations which give the pilot a complete indication of his position in space, predicted position, necessary corrections and a great deal of additional information. The generation of the signals for driving the displays requires a multitude of logical operations and computations which can be carried out most conveniently by means of a digital computer.

6. Vehicle dynamics, simulation of attitude control systems, and similar problems can be handled conveniently by means of an analog computer.

7. Some aerospace vehicle simulators must also have the capability of representing the boost phase of the flight and re-entry into the earth's atmosphere. Consequently, the division of computational tasks between portions requiring drift-free high accuracy computation and portions requiring simulation of non-linear systems with high frequency signals will apply to the analog and digital computers respectively.

It seems clear that hybrid computation is ideally suited to the simulation of manned space vehicles.

Optimization of Multiparameter Systems

Optimization of system parameters is one of the most important phases of system engineering. It is the process of adjusting parameters so the system performs as close to optimum as possible, optimum performance having been determined by some preselected criterion.

In analog simulation this process has advanced from the manual adjustment of a few parameters between runs on a "one shot" analog computer, through the repetitive operation machine with continuous adjustment of parameters as runs are repeated at high speed. When it is necessary to adjust more than just a few parameters, the task becomes impossible for a human operator because of his limited capacity for remembering past adjustments and their effects. Moreover, an intuitive approach to deciding the next adjustment to be made will not suffice for a complicated system.

It also becomes evident that even if all parameters were limited to some finite number of values, the time required to investigate all of the possibilities under manual control would be prohibitive. For all but the simplest problems then, the memory and logical decision capability of the general purpose digital computer can be used to good advantage.

In order to use the digital computer to optimize the system parameters, we must have a mathematical statement of the performance criteria, a group of parameters on which adjustment is permitted, and an organized method of adjusting the parameters. The statement of performance criteria is called the criterion function. It is frequently stated in terms of the square of the error between the value of a pertinent system variable and the optimum value of this variable. For dynamic systems quite often the criterion function is the definite integral of the error squared, over the interval of interest. Both the criterion function and the list of parameters which may be adjusted are determined from a knowledge of the system.

The general purpose computer must search for either a maxima or minima of the criterion function depending on how the function is formulated. It should be pointed out that the criterion function may have more than one maxima or minima, so that only a relative maximum or minimum may be found.

There are two general types of systems in which optimization problems occur, static and dynamic. Static systems have no energy storage and can be represented by algebraic equations rather than differential equations. Profit optimization, scheduling, and transportation problems belong to this group. Mathematical problems including the solution of linear algebraic equations and the finding roots of polynominals can also be handled by the optimization approach. The method of steepest descents can be employed to solve these problems in a continuous manner on the analog computer.

Optimization by the continuous steepest descent method is not possible in dynamic systems which include energy storage and are represented by differential equations. Iterative techniques consisting alternately of a time solution of the dynamic system and a computation of the parameter adjustments must be used. These techniques may be implemented accurately and efficiently with a hybrid analog-digital computer system.

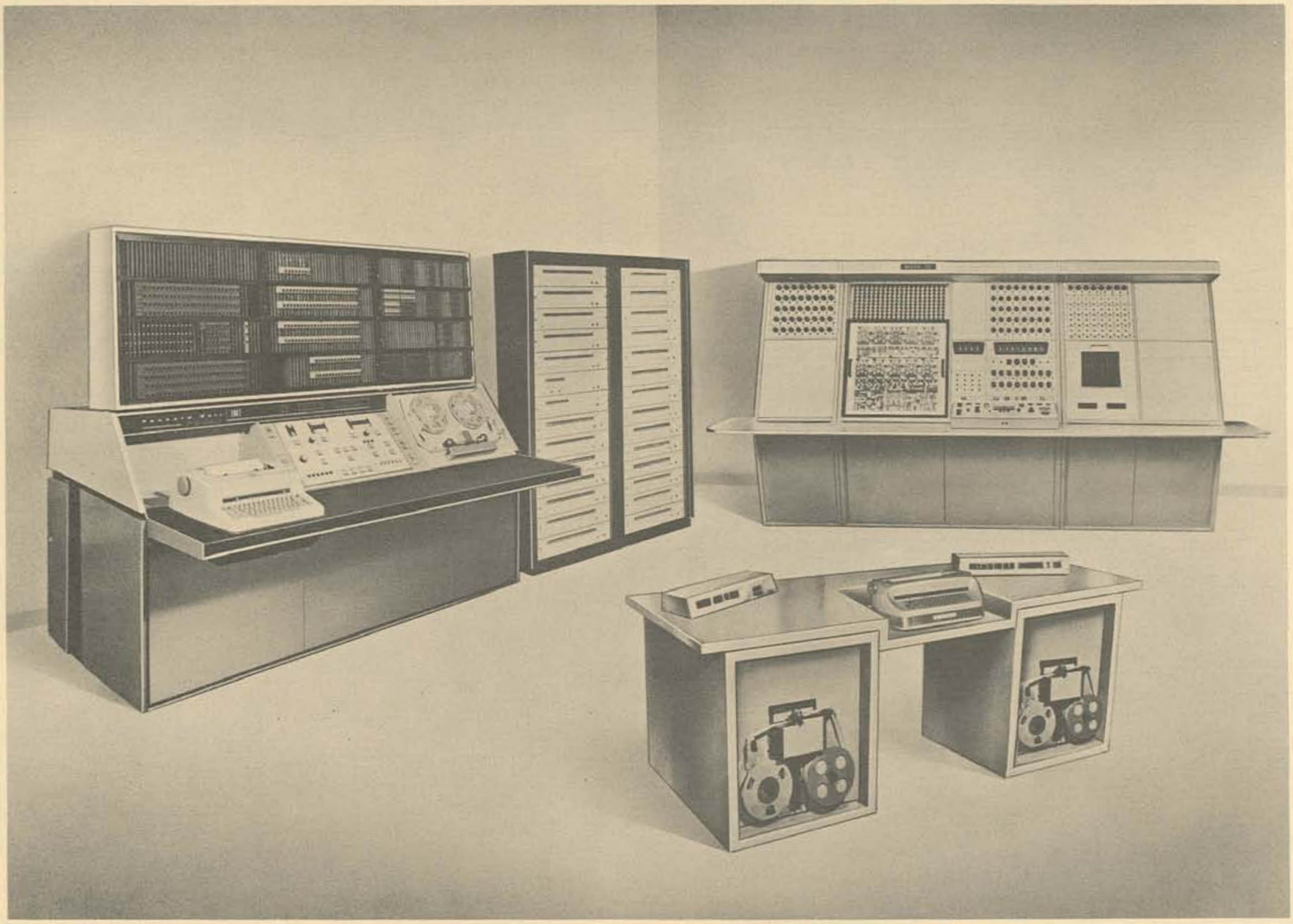
The Hycomp system has several features designed specifically for optimization.

The digital-to-analog converters may be used to multiply analog variables directly, thus obviating the need for an analog multiplier to provide high speed parameter adjustment.

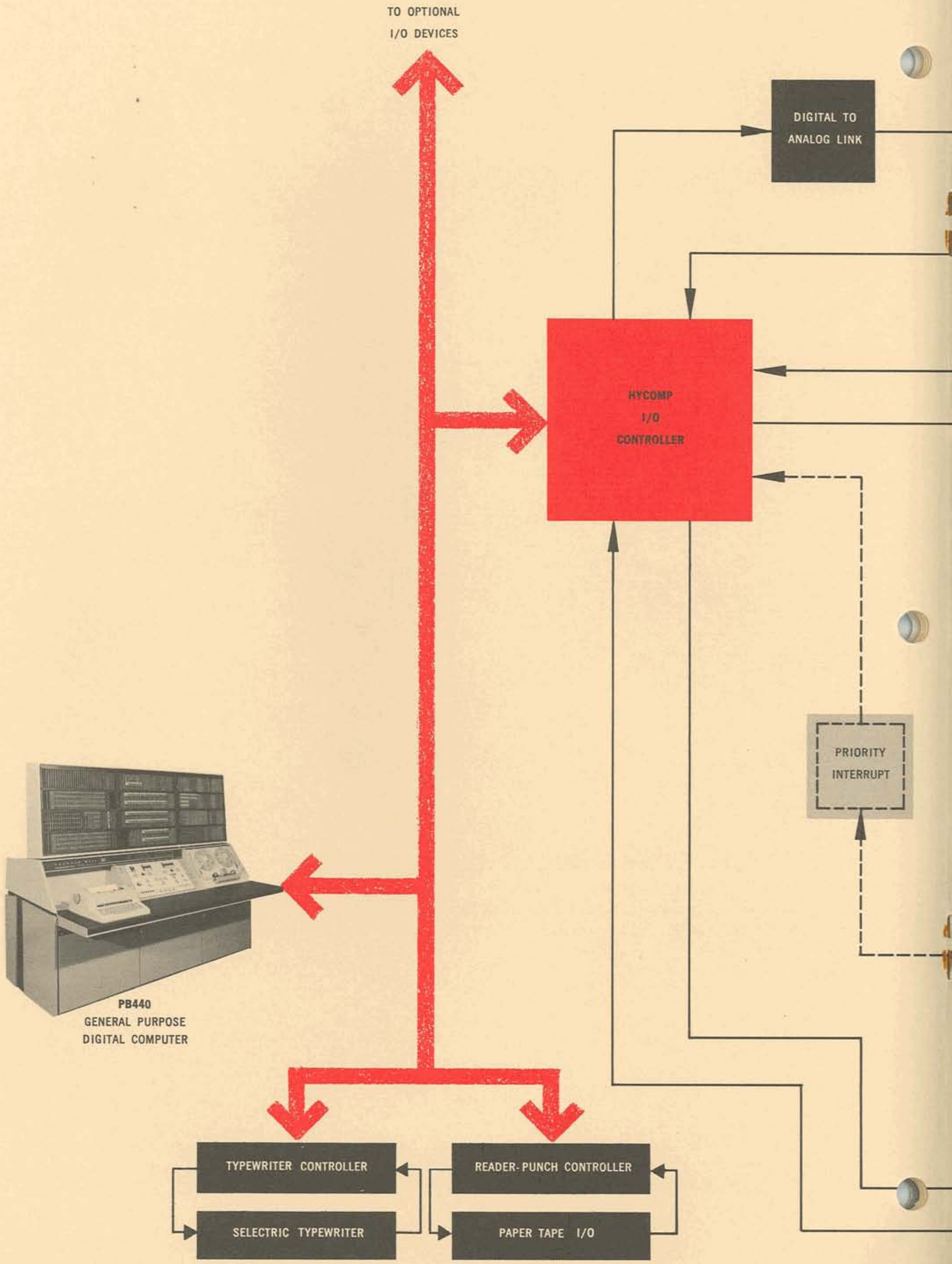
The servo-set pots may be set under control of the PB440 and used for parameter adjustments.

Three mode electronic code control including "Hold" is a feature of the Mark III which permits sampling other variables than those connected to the high speed conversion system for evaluation by the digital computer. Readout to the PB440 is accomplished through the DIDAC link using the DIDAC desk.

HYCOMP® *System Description*



Major components of the Hycomp Hybrid Analog/Digital Computing System are the Packard Bell PB440 Digital Computer (left); the Mark III Analog Computer, manufactured by Computer Products, Inc., (right); the DIDAC automatic remote input/output control system (foreground); and associated analog-to-digital and digital-to-analog conversion and control linkage (rear center).



TO OPTIONAL
I/O DEVICES
DIGITAL TO
ANALOG LINK
HYCOMP
I/O
CONTROLLER
PRIORITY
INTERRUPT
PB440
GENERAL PURPOSE
DIGITAL COMPUTER
TYPEWRITER CONTROLLER
SELECTRIC TYPEWRITER
READER-PUNCH CONTROLLER
PAPER TAPE I/O

HYCOMP® *System Description*

A general block diagram of the Hycomp hybrid computation system is shown in figure 1. (diagram here).

The major components of the Hycomp system include the following:

- PB-440 DIGITAL COMPUTER with Selectric typewriter and paper tape reader and punch.
- MARK III Analog Computer with DIDAC automatic remote input-output control system.
- HYCOMP — Input-Output Controller.
- CONTROL AND SENSE LINES (per figure).
- HIGH SPEED, High Accuracy A-D and D-A Linkage.
- Parallel Logic Expansion Group (for special application). Optional where more than the normal logic complement of the Mark III is desired.
- Priority Interrupt System Optional (for special application).

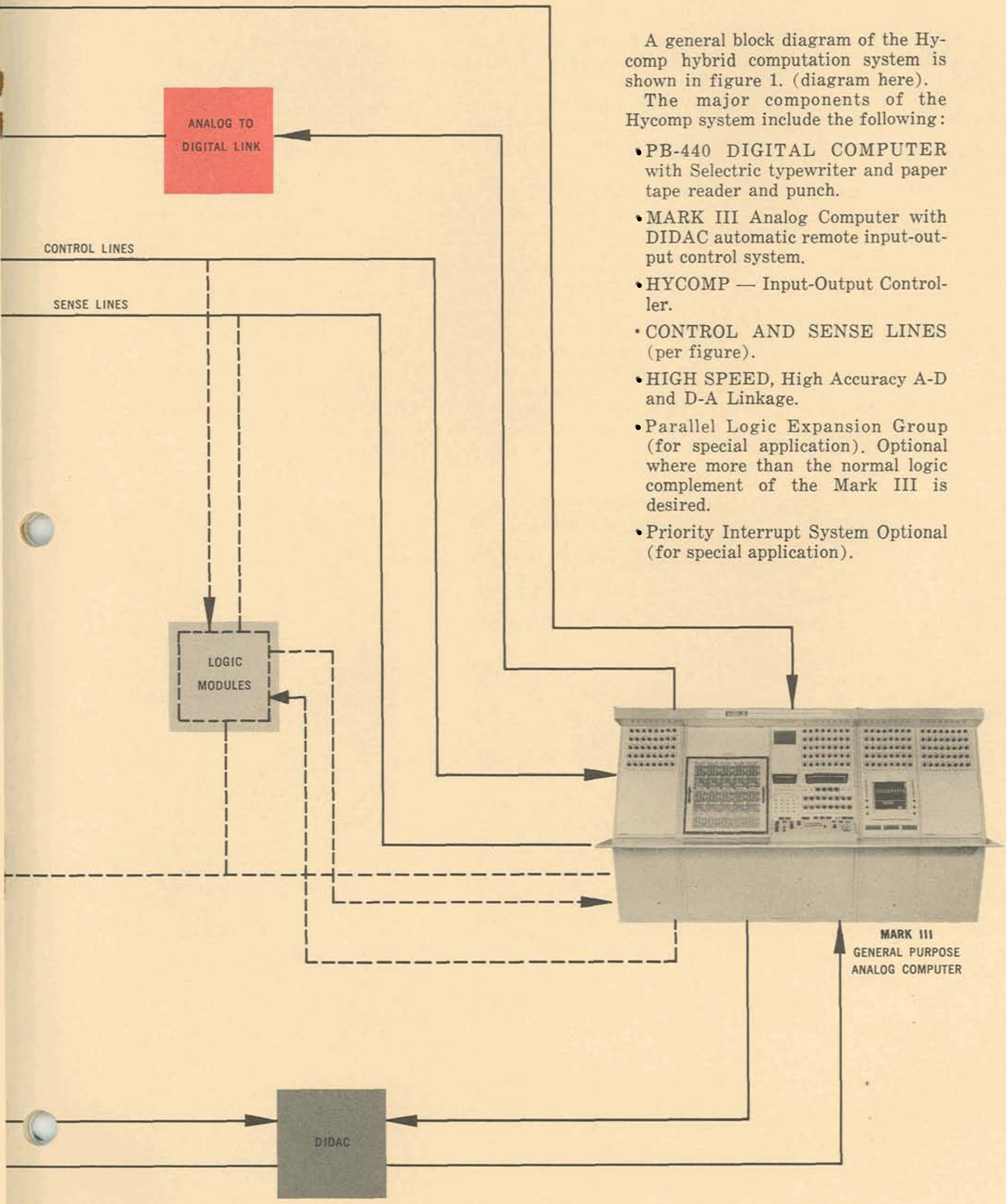


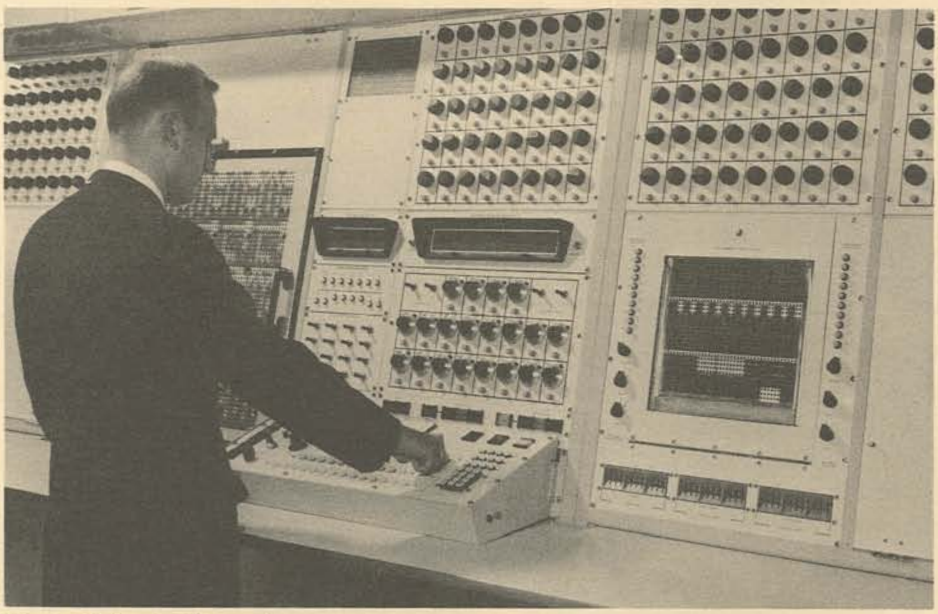
Figure 1: Hycomp Block Diagram

Features of the PB440 Digital Computer for Hybrid Computation

The PB440 is ideally suited to hybrid computation because of its stored logic capability. With stored logic the machine has a variable command list which facilitates meeting requirements for diverse applications. The command list of the PB440 may be designed especially for hybrid computation so the machine has exactly the desired characteristics for combined analog-digital problem solution.

These desired characteristics are:

1. *Rapid input/output* to the analog portion of the system, easily programmed, flexible, and requiring a minimum of housekeeping functions. Uses commands designed for this purpose.
2. *Floating point* operation at speeds useful in the fastest real-time applications in order to minimize scaling.
3. A *varied list of arithmetic operations* plus logarithms, power, roots, and transcendental functions. All execute rapidly to supplant the analog computer where more accuracy is needed in real-time.
4. *FORTRAN* — Completely documented and IBM-compatible so that existing programs may be used directly, as in the case of check solutions. For example, it can be used in hybrid computation problems and is fast enough in execution speed to be used in a large portion of the real-time requirements. When not fast enough for a specific real-time application, it can be used to check out the mathematical model of the system at a reduced time scale with programmed inputs replacing inputs from actual hardware. After the model is developed to a satisfactory state, the FORTRAN program can be translated to machine language to gain the necessary speed for real-time operation. Statements for use with the hybrid system are included in the FORTRAN package so that the FORTRAN programmer need not know anything about machine language programming to use the hybrid system.



Mark III Analog Computer

PB440 Digital Computer

5. *Simulation of other computers* is easily facilitated so that the operation of existing or proposed computers in a control system can be studied. Capability of simulating other computers on an individual command, command format, and word length basis is highly valuable for this application. By means of such simulation, the validity of a proposed control computer design can be established before the computer is built. Similarly, the suitability of an existing computer for a particular control application can be determined before the computer is purchased.

6. *Direct memory access capability* is available as a standard option. This mode of operation is used where the amount of data transferred in and out of the digital computer under program control becomes large enough to require an appreciable part of the computation cycle time. Large-scale simulators are an example of this requirement. Here, large amounts of data must be up-dated and sent to numerous displays periodically, in addition to the transfer of dynamic and kinematic data to and from the analog computer and simulator. Some types or combined problems require the use of mass memory such as magnetic tape or disc file. Communication with these devices under program control may be impractical because of the amount of program cycle time required. In this case communication via direct memory access becomes extremely useful.

7. *Expandability* is an important requirement for a hybrid computer, because all potential uses for such a system cannot possibly be anticipated at the time of purchase. Expandability is provided by a sufficiently large addressing scheme in the PB440. Large-scale computers often provide 32,000 words or more of memory and problems which require that much memory are not uncommon. While this much memory will not normally be required initially in a hybrid facility, the capability for adding it later on should be specified. Real-time computation may also require an expansion of the program to the extent that the program cycle becomes excessive. In such cases, the capability for easily adding an additional main frame to the system so that the program may be divided between two or more simultaneous processors is important. This capability is built into the PB440. No additional engineering changes are required and the expansion can be accomplished in the field.

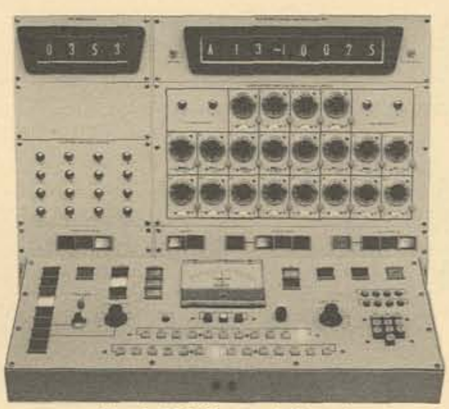
8. *The computer console* is another important consideration. Features which make the PB440 easier to use, especially for the engineer-programmer to whom programming is a means rather than an end, are:
   a. Console selection of registers and memory locations for entry or display of information.
   b. Display of register and memory contents in octal arabic character as well as binary format.
   c. Manual control of program advance one step or one clock cycle at a time.
   d. Built-in bootstrap loader.
   e. Indicator light display of the state of *all* arithmetic and control unit flip-flops.

The Mark III Analog Computer - - - Designed for Hybrid Computation

The Mark III Analog Computer, the only totally new analog machine in the past year, was designed from its inception to be directly employable in hybrid systems. The designers, free from any restraints which would arise from an inventory of older equipment, were remarkably successful in creating a computer which is simultaneously the finest analog computer available and one which can be used in hybrid systems with no interface difficulties.

Features of the Mark III which make it uniquely usable in a hybrid system include the following:

1. Digital Control —
   All computer control signals are of a binary logical type with signal levels directly compatible with PB440 computer control lines and sense lines.
2. Flexible Integrator Control —
   Individual control of every integrator available to permit multirate operation and the use of special logical and storage operations.
3. High-Speed Three-Mode Switching —
   Three-mode electronic switching of every integrator. "Operate," "Reset," and "Hold" functions with 500 nanosecond switching times.



Mark III Control Panel

Mark III Digital Voltmeter

4. Self-Contained Logic Capability— Electronic comparators and logic elements as part of the standard computer complement. The full complement of the Mark III provides for 20 high speed electronic comparators with digital level outputs. Provision is made for direct installation of other logical elements such as flip-flops, gates, registers, and memory units.
5. Electronic Input/Output System — All electronic input/output system. The Mark III's complete monitoring and setup, and readout system is controlled through solid-state circuitry designed for digital level signals. The circuitry provides for both random access and sequential addressing of components as desired.
6. Auxiliary Digital Control Patch Panel — Digital control signals are terminated on a separate patch panel to isolate analog signals from digital signals.

Switching of all summer-integrators to integrators, switching from relay to electronic mode control, and choice of rate and hold capacitors for each integrator are accomplished at the Electronic Mode Control (EMC) panel. Outputs of electronic comparators and timers; inputs to electronic switches; control, sense, and interrupt lines for connections to a digital computer; trunk lines for connections between consoles; drive lines for function relays; capacitor override controls; display start; oscilloscope sync; and digital logic elements also appear on the EMC panel.

HYCOMP I/O Controller

The Conversion, Binary Signal and DIDAC Links of the system are connected to the PB440 through an interface called the HYCOMP I/O Controller as shown in the Hycomp block diagram (Figure 1). The information is sent to this controller in the form of both data and address. The controller then decodes the address, generates the required control signals and transmits the data to the proper digital-to-analog channels. When the data is to be inputted, an address is sent to the controller, decoded, and requested data is then sent to the PB440. Again, the controller provides the required timing and control signals.

When fully buffered output is required for a specific application, the memory interchange feature can be supplied as an option. With this option data may be inputted or outputted directly into or from memory independently of the program. A somewhat more sophisticated controller than the HYCOMP Controller is required for such a system to provide the additional I/O control which is required.

Control and Data Links

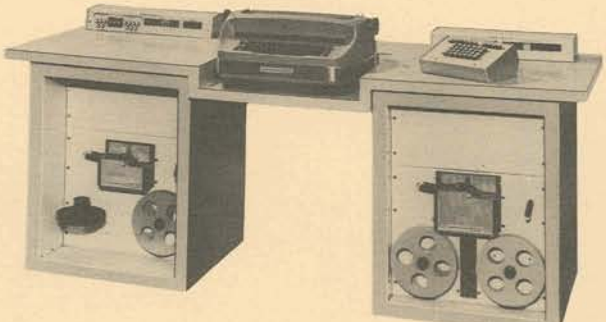
As is indicated in the block diagram, three different types of two-way links are supplied in the general system. They are:

1. *HIGH SPEED DATA LINK* The analog-digital and digital-analog link through which problem data is transferred between computers. This link is of high accuracy and high speed so that truly combined computations can be performed.
2. *DIDAC LINK* The DIDAC link which provides decimal numbers for potentiometer settings and control characters to the DIDAC addresses of analog computer modules. Similar data are transmitted to the PB440 by the DIDAC when requested. The DIDAC link is used for problem set-up and control as well as parameter, initial condition and final condition read-out.

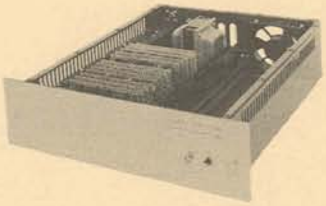
The DIDAC link automates analog computer operations, since through the DIDAC the PB440 can perform all operator functions. In addition, the PB440 can calculate and set initial conditions, process and store final or intermediate results, perform problem checks and similar functions which in an all-analog installation would be done by the analog computer operator. The DIDAC link also provides capability for computer operation in applications such as parameter optimization, boundary value problems, trajectory studies, statistical studies, etc.

Normal inputs to the DIDAC are from its Selectric typewriter and paper tape reader. DIDAC output is sent to the typewriter or a paper tape punch.

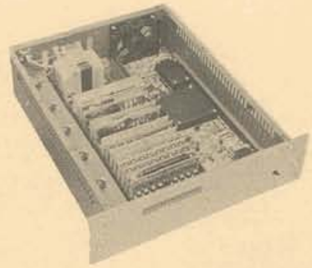
Linking of the PB440 and the DIDAC is accomplished by circuitry which makes the PB440 appear to the DIDAC as another Selectric typewriter and vice-versa. The DIDAC channel is



The DIDAC Desk



DAC20 Digital-to-Analog Converter



ADC20 Analog-to-Digital Converter

assigned one of the addresses of the HYCOMP Controller. To communicate with the DIDAC, the DIDAC address and a seven-bit character is sent to the HYCOMP Controller, which relays the character to the DIDAC. The character is accepted by the DIDAC as if it had come from the Selectric typewriter, and appropriate action is taken; i.e., the DIDAC performs its normal decoding function on the character. If the character sent to DIDAC requests an output, the requested data is returned to the HYCOMP Controller in serial character format as if it were being sent to the Selectric typewriter.

3. *BINARY DATA AND CONTROL LINK* This is a binary signal link with sense lines and control lines through which the PB440 sends control signals to activate individual electronic mode control switches, sense the state of analog comparators and provide control signals to or sense the state of patched logic elements. A single program interrupt line is provided with this system. A priority interrupt system for up to 32 priority interrupts is an optional feature.

With the addition of Binary Signal and DIDAC links to the hybrid system, participation of the PB440 computer in the overall problem solution is as broad as the programmer wishes to make it.

Conversion Link

The Analog-to-Digital Channels

The analog to digital link is shown in figure 2. In this link n±100 volt analog signals are converted to ±10 volt signals which are the inputs to the Multiplexer. The signal from the designated channel is connected to the ADC-20-15 bit converter through a buffer amplifier. The analog-to-digital converter and the multiplexer are controlled by the PB440 program.

The analog-digital channels may be supplied or used with or without parallel sample-and-hold depending upon the problem or system requirements. When sample and hold is not supplied, level converters replace the sample-and-hold amplifiers. Control of the sample-and-hold function is accomplished by patching the appropriate control signals to the individual amplifier electronic mode control switches, allowing great flexibility of control. Simultaneous sample and hold may then be accomplished on any number of the channels individually or by groups of channels. When sample-and-hold is not required the sample-and-hold amplifiers are left in the sample mode. The control signals, when provided by the PB440, come through the binary signal link.

The addressing schemes of the HYCOMP Controller can accommodate up to 128 channels. The EMP-05-01 multiplexer and the ADC-20-15 converter with power supplies are contained in a single case.

Accuracy of the analog-to-digital link with the sample and hold is within 0.03% of full scale on a 3σ basis. The relationship of the voltage input to the level converter and the digital number transferred from the ADC is such that an input of +100V yields positive full scale output. The output number is in two's complement form for negative voltages. When level converters are used in place of the sample and hold units the relationship is the same except for opposite signs.

The Digital-to-Analog Channels

After computation in the digital computer, the discrete data must be returned to continuous form by desampling. The simplest and most often used method is the "zero order hold." By this method the discrete data is returned in the form of a series of contiguous amplitude modulated pulses resembling a staircase. The most often used and preferred technique is the use of a separate digital-to-analog converter with a storage register for each channel. This technique allows the most accurate conversion and an infinite holding time without drift since storage is digital.

Alternately, a single digital-to-analog converter may be used with a demultiplexer and sample and hold amplifiers. This technique is less expensive, but it has these disadvantages: Skew (the difference in time between the conversion of adjacent channels or between the first and the last channel) is much greater than with parallel converters and cannot be eliminated, and loss of accuracy occurs in the sample and hold amplifiers, because of drift over the sample interval.

The use of a sample-hold multiplex system for data sampling and desampling may be compared. Simultaneous sampling can be obtained with the parallel sample-hold amplifiers by switching all units to hold at the same instant. Conversely skew occurs in desampling from the digital-to-analog conversion time, multiplexer switching time and sample-hold time constant.

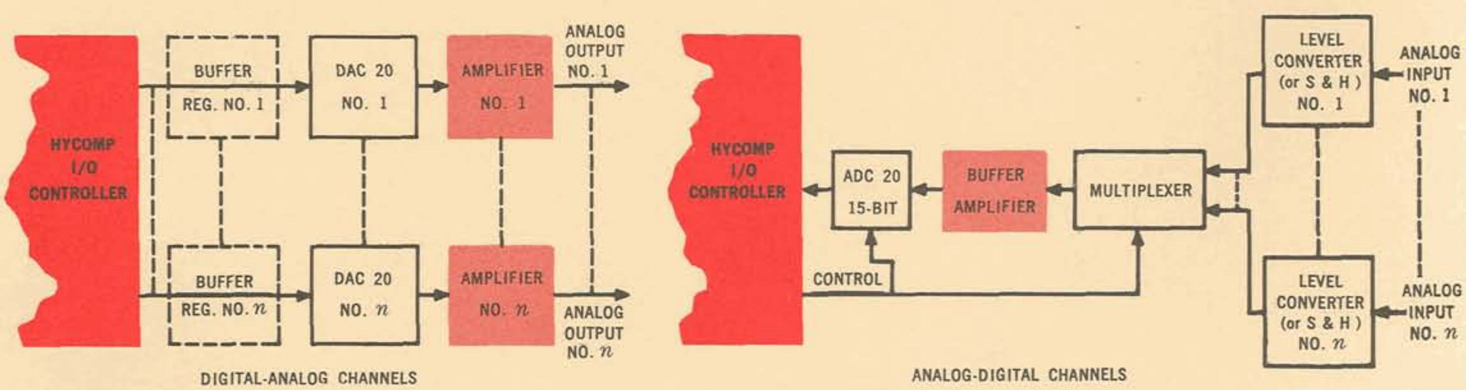


Figure 2: Block Diagrams of Conversion Channels

Drift of the sample-hold amplifiers is far less in the sampling mode since they need only hold in the worst case for the conversion time of all analog-to-digital channels. In demultiplexing the sample-hold must hold over the computation interval, which is typically in the order of 50 times as long as the conversion cycle. The cost difference between parallel analog-to-digital converters and a multiplexing system is much greater than the cost difference between parallel digital-to-analog converters and a demultiplexing system.

The digital-to-analog link, which transfers the data from the PB440 to the proper converter, is depicted in more detail in Figure 2. This link consists of DAC-20 14-bit converters whose outputs are coupled to the summing junctions of analog computer amplifiers which provide the desired voltage swing and degree of isolation. The voltage swing at the output of the analog amplifier is ±100 volts. Since the DAC is unipolar, an offset voltage is introduced at the summing junction to yield 0 volts from the amplifier for half scale in the DAC. The input to the DAC is logically arranged to provide the correct polarity voltage from 2's complement binary numbers. The overall accuracy of each channel is determined by the resolution of the DAC which is better than ±.015% of full scale.

The addressing scheme of the HYCOMP Controller can conveniently accommodate up to 128 DAC channels. Eight DAC units with power supplies are contained in a standard case and the analog amplifiers are grouped 10 to a case, of identical size including power supplies.

Binary Signal Link

The addressing scheme of the HYCOMP controller accommodates up to 120 sense lines and 120 control signals, all of which are of binary (on or off) nature. Thirty-two of each are terminated on the Mark III. The HYCOMP Controller contains one program interrupt line which is independent of the sense lines. If additional interrupt lines are required, an optional priority interrupt system — also terminated on the EMC panel — can be provided.

Parallel Digital Logic

In many types of problems utilizing the electronic switching capability of the Mark III computer there is a need for a small number of uncommitted digital "building block" elements for performing "housekeeping" in the analog computer. In the Mark III, this parallel digital logic is controlled through the Electronic Mode Control panel.

Flip-flops are needed for latching comparators and remembering the scale factor in "on-the-fly" scaling applications, and gates are useful in building logic nets for simulating simple on-off controllers. One-shot multivibrators can introduce delays and momentarily switch an integrator to initial condition for tracking and storing an input variable. Momentary and alternate action switches are useful for changing conditions on the EMC panel and indicator lights are useful for indicating states of flip-flops and gates.

The logic elements of the Mark III consist of:

225 Electronic Switches associated with 45 Integrator-Summers

20 Solid State Analog Comparators

7 Flip Flops

1 Ring Counter

12 And Gates

1 Master Timer, 100 KC Oscillator

2 Auxiliary Timers (Count Down)

1 Single Shot Multivibrator

All logic levels are represented: True (0 volts - 0.2 volts) and False (−10 volts - −2 volts). These levels are compatible with the output levels of electronic comparators and timers and the required input levels of the electronic switches. Rise times are compatible with those required for operating electronic switches.

The Control Lines

The control lines are used as inputs to logic elements and for control of the electronic mode switches of individual analog components. Channeling of the control signals to the desired point in the analog computer system is accomplished at the Mark III Electronic Mode Control Panel (the outputs are capable of withstanding shorts to ground or reference supplies). The signals are levels rather than pulses. The setting and resetting (i.e., the establishing of the level) of the control lines is under program control, and each line may be addressed individually.

The control lines are supplied in groups of eight up to the maximum of 120. Thirty-two are connected to the EMC panel. The remainder other than those used for control of the conversion system may be connected to the parallel Logic Expansion Group.

Sense Lines

The sense lines allow the PB440 digital computer to determine the states of switches and decision devices such as analog comparators or gates and flip-flops of the logic elements which may be supplied. The origin of these lines is the control patchboard and/or the patchboard for the logic elements. The sense lines are tested individually in the program by sending the address of the sense line to the HYCOMP Controller which returns a one-bit character indicating the state of the addressed line to the digital computer.

The sense lines are available in groups of eight up to a maximum of 120. Thirty-two are connected to the EMC panel; the remainder may be connected to the Parallel Logic Expansion Group.

Mark PL3

Parallel Logic Expansion Group—Certain limited classes of problems involve extensive logical operations in the part of the problem ordinarily solved on the analog portion of the system. In such cases, it may be economical to expand the basic logical capability of the analog machine by the addition of elements to perform decision and control functions. This grouping of logical elements forms an optional system unit which has the capability of performing logical elements and communication via binary signals with either the Mark III or the PB440. These elements are interconnected through a removable 3600-hole patch punch which also terminates the control lines of both computers.

The Mark PL3 utilizes digital logic elements manufactured by Packard Bell Computer. The 3 megacycle elements are modular units and permit ease of expansion at low cost. The PL3 uses a 3600-hole patch panel designed to provide complete programming flexibility by permitting maximum use of bottle plugs. A nonshorting patching feature is achieved by an exclusive CPI design that utilizes female patchcords and coaxial type patch panel.

Priority Interrupt—The linkage has a single interrupt line by which the computer program may be interrupted by an external signal. For many applications this is sufficient since frequently there is either only one signal which is urgent enough to require interrupt or there are only a few such signals which may be "OR'd" into the one interrupt line as well as connected individually to sense lines, allowing the priority decision to be made by the digital computer program. However, for those applications where many and conflicting interrupt signals may exist, an optional priority interrupt system can be provided. This system provides an interrupt signal to the computer directly if only one such signal exists, but in the event of multiple interrupt signals submits them to the computer sequentially on the basis of a predetermined priority.

The priority interrupt system is available in increments of 4 lines up to a maximum of 64. The inputs to the priority interrupt come from the EMC panels. Up to 32 inputs may be terminated at that point.

HYCOMP Specifications

1. Analog-to-Digital Channels
   Number of Channels......128 maximum

   Overall conversion accuracy, voltage input to sample and hold units to digital number, less than ......0.03% of Full Scale

   Word Size ....14 bits + sign

   Maximum conversion rate (Channels) ....25 Kcps.

2. Digital-to-Analog Channels
   Number of Channels.............8/case, 128 maximum

   Overall conversion accuracy, digital number to ± 100V. analog signal, less than ....0.013% of Full Scale

   Word Size ....13 bits + sign

   Maximum conversion ....100 Kcps. rate (Channels) ....200 Kcps. with direct memory access

3. Binary Signal Link
   Control lines..........32 lines standard, expandable to 120 in groups of 8.

   Sense lines............32 lines standard, expandable to 120 in groups of 8.

   Single interrupt standard; priority interrupt up to 64 channels in units of 4 optional.

SOFTWARE

MACRO COMMANDS FOR SYSTEM OPERATION To facilitate programming for systems operation macro instructions specifically designed for hybrid computation are provided. These macros may be divided into three categories: 1. Those for communication with DIDAC, 2. those for controlling and communicating with the conversion system and 3. those required to set control lines and interrogate sense lines. A few of the available macro commands are described here.

1. Communication with DIDAC.
   ADDRESS..Send address to DIDAC. The designated address is indexable.
   READ ADDRESS........The designated analog address is read and the value put into a PB440 register. The designated address is indexable.
   SET POT......Set the potentiometer to value contained in the designated storage location. The address of the storage location is indexable. If the pot is not set to the proper accuracy, the desired setting and actual setting are typed out.
   I. C. ....The analog computer is put into I. C. mode.
   POT SET................The analog computer is put into Pot Set mode.
   HOLD ....The analog computer is put into Hold mode.
   OPERATE ....The analog computer is put into Operate mode.
   RATE TEST..........The analog computer is put into Rate Test mode.
   STATIC TEST..............The analog computer is put into Static mode.
   SELECT CONSOLE..........Any one of seven analog computer consoles is designated as the recipient of all subsequent communications.

2. Conversion System
   SELECT MPX CHANNEL......Address portion of instruction becomes multiplexer address. This address is indexable.
   CONVERT & STORE A/D CHANNEL........ADC conversion cycle is initiated and result of conversion stored in designated memory location. The memory location is indexable.
   FILL DAC......Send contents of designated location to D/A converter. Address is indexable.

3. Binary Signal
   SET CONTROL LINE....Set the control line designated by the address portion of the command.
   RESET CONTROL LINE........Reset the control line designated by the address portion of the word.
   INTERROGATE SENSE LINE........Set a program flag to coincide with state of designated sense line.

4. Input/Output Program
   This is a special program which provides table storage in the PB440 for Mark III Problem Readout Values, Pot Settings and Scale Factors. It may be used to input or read out values to and from the Mark III in engineering units. All scaling computations are performed automatically.
   The program may be used as a diagnostic for the Mark III in conjunction with a diagnostic patch panel. This panel is patched to use all of the servo set pots and amplifier inputs; the pots are set and the outputs of the amplifiers which are the sum of pot settings times amplifier gains are read out and compared with expected values stored in the PB440 Problem Value table. Pots failing to set and read out values or failing to check are logged on the Selectric typewriter.
   In a similar manner the program may be used to set up a problem and establish a static check.

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