APPENDIX A

THE TRW-330 DIGITAL CONTROL COMPUTER SYSTEM

THE TRW-330 DIGITAL CONTROL COMPUTER SYSTEM

1. GENERAL

TRW digital computers designated as the TRW-330 series are "second generation' computers. Their design is based upon the extensive experience of TRW Computers Company in the application of digital control computers to industrial processes.

The TRW-330 is a medium-speed, serial machine with extremely flexible digital and analog input/output facilities, and adaptable command structure and memory size. The rack-and-panel construction of the TRW-330 permits the computer to be assembled in a variety of forms, and the computer can be supplied in cabinets that will withstand rugged or hazardous industrial environments. Thus, each model of the TRW-330 series is designed to meet the requirements of a specific customer. Although the initial investment in a TRW-330 system can be limited to meet the immediate requirements of an installation, TRW-330 systems can be expanded later to accommodate an expanding plant or a more extensive control system.

The standard memory drum has a capacity of 8,000 28-bit words. However, this memory drum can be expanded to a total of 16,000 words by the addition of one 128-word track at a time. At slight additional cost, drums can be initially provided that are expandable to over 100,000 words. The prices for these modifications will vary depending upon whether they are done in our plant prior to shipment, or in the field after installation.

2. OPERATIONS AND SPEEDS

See Table I on the following page.

3. ADDITIONAL FEATURES

a. The contents of all computer registers used by the programmer can be displayed on the control panel during program execution. Under program control, the contents of any register or memory cell may be typed out on the Flexowriter, or displayed on the operator's console display in modified form.

b. Parity checking is made on operations involving memory access. Parity on inputs and outputs can be provided at extra cost.

Operation	Hardware or Program	Word Length	Execution Time	
Fixed pt. add or subtract	hardware	28 bits	260 µs	
Fixed pt. load and store	hardware	28 bits	260 µs	
Shift	hardware		(260 µs + 130 Nµs) where N = no. of places shifted	
Branch	hardware	28 bits	260 µs	
Fixed pt. multiply	hardware	(7 bits)x(28 bits) (14 bits)x(28 bits) (21 bits)x(28 bits) (28 bits)x(28 bits)	1.30 ms 2.21 ms 3.12 ms 3.90 ms	
Fixed pt. divide	hardware	(7 bits)/(28 bits) (14 bits)/(28 bits) (21 bits)/(28 bits) (28 bits)/(28 bits)	1.43 ms 2.34 ms 3.25 ms 4.03 ms	
Floating pt. add or subtract	program	28 bit mantissa 28 bit characteristic	66.4 ms	Instruction, interpretation, execution of operation and renormalization all included
Floating pt. multiply	program	28 bit mantissa 28 bit characteristic	49.8 ms	
Floating pt. divide	program	28 bit mantissa 28 bit characteristic	49.8 ms	
Normalize	hardware	28 bits	(260µs + 130Nµs) where N = no. of bit positions shifted	
Square root	hardware	28 bits	2.08 ms	

TABLE I

OPERATIONS AND SPEEDS

c. Automatic address modification and optimization is implemented by using the three modes of operation -- normal, delayed, and operand -- as described under "Command Structure".

d. One index register is standard in the TRW-330.

e. An automatic computer stop command is standard.

f. The capability to mark the current place in the program; branch to a subroutine; execute the subroutine; and subsequently return to the marked place, is standard on the TRW-330.

g. Hardware normalization is standard.

h. The block transfer feature is standard on the TRW-330; the block may be any length up to 128 words.

i. The standard scans -- analog input scan, digital input scan, and table search -- permit high-speed checking of analog and digital inputs and tabulated or reference values. Converted analog inputs are checked for upper and lower limits at the rate of 3840 per second; table searches are made at the rate of 3840 words per second; and digital inputs are checked against reference settings at the rate of 107,520 per second.

4. GUIDE LINES IN THE TRW-330 COMPUTER DESIGN

4.1 GENERAL

The TRW-330 computer represents an extensively developed and well-balanced over-all design. The choice of the many parameters in the final production design is based upon the cumulative experience of designing, installing, and checking out over two dozen different on-line computer systems, as well as on the design, construction, and checkout of a series of three prototype versions. The experience gained in system designing and programming two of these TRW-330 prototypes for customer installations resulted in final improvements in the command characteristics and other features; the design is now thoroughly developed and stabilized. The following paragraphs explain some of the reasoning behind this design.

In general, we have built extra performance into those areas of the TRW-330 which experience has shown can become limiting factors on the system design and usefulness. Special attention has been paid to the need for a protected and expandable memory; for special commands needed in on-line control problems; for input/output flexibility; and for features which would simplify and reduce the amount of manpower required to design, install, and check out a system.

4.2 MAGNETIC DRUM

The TRW-330 computer uses a magnetic drum only for memory (all registers are solid state). At a time when most manufacturers, including TRW Computers Company, are offering high-speed core-drum combination computers, this choice deserves some comment. In the use of the RW-300 computer for industrial control, we found that memory space was more often a limiting factor than speed. Measures of memory space and operating speed vary over an extremely wide range, depending on what problem is defined. However, in the work already performed on the TRW-330 systems, we are finding that for typical control applications the TRW-330 computer operates five times or more faster than the RW-300 and uses one-third as much memory. Nevertheless, it is available in a memory range extending to greater than 100,000 words. In summary, we believe that the speed and memory characteristics of this computer make it suitable for the great majority of process control applications. Exceptions might be complex, high-speed applications, such as nuclear power generation, or the integrated control of an entire process plant.

For those applications where a drum computer is adequate, we believe that the TRW-330 possesses definite, inherent advantages. Many applications involve substantial memory requirements, particularly when future expansion and growth is considered; and for these requirements the drum computer possesses definite cost advantages. A "homogeneous" memory, in which the entire contents of the memory are immediately and equally accessible to the program, allows a simpler over-all organization of the program than is possible when block transfers between moderate-speed and high-speed memory must be planned. The necessity for these transfers in both directions complicates the programmer's analysis and reduces the effective speed of the system, particularly in on-line applications which involve a mixture of scheduled operations, randomly timed or even emergency operations, and sometimes low priority off-line work. A magnetic drum memory provides the type of protection needed for a permanent, on-line program and also lends itself to providing a flexible memory guard system in which the operator or the program can control the writing access to selected portions of the memory. All or part of the drum memory can be placed in the "read-only" mode. In this mode, the memory may be read from, but may not be written into. This is accomplished by actuating manual switches or computer controlled relays which produces a physical disconnection of the recording heads from their associated write circuits. This guarded storage feature of the drum system provides memory protection to a degree that is unattainable in core memory. The information in the guarded portions of this memory are protected not only against power failures, but also against program errors, runaway program, and operator errors.

For many control and/or monitoring applications it is necessary to debug programs on-line without interfering with analog and digital scanning and certain other periodic functions. Since the period for performing these on-line operations is only a few seconds, and since there are many such operations, a large memory is required. Also since the on-line programs must be protected at all times, a guarded memory is required.

Finally, with the same relative effort and design excellence, a drum memory will be more reliable when used alone than in a combination that adds the complications of a second memory system.

4.3 WORD LENGTH

A word length of 28 bits, including sign, has been selected for the TRW-330 computer. For a core-drum computer, the cost of cores justifies a shorter word length. However, experience with the RW-300 has shown that when data is subjected to large linear program or other complex manipulations, operating speed must sometimes be sacrificed to ensure adequate precision of the calculations. In contrast, all the problems we have encountered so far can be comfortably handled with the 28-bit word. This is one example of a means of reducing the amount of engineering involved in the design and installation of a computer control system.

The long word length provides certain other advantages: It allows direct addressing of a fully expanded memory system; using the "operand mode" of instructions, a 16-bit constant may be contained within an instruction, reducing memory storage and eliminating the access problem. In TRW-330 programs written to date, over 60 percent of the constants are contained within their associated instructions. The longer word also allows the more rapid manipulation of messages and coded data.

4.4 REGISTERS AND COMMANDS

Several registers, numerous command options, and a number of very special commands have been included in the TRW-330 computer to aid programming, increase the effective speed of the machine, and to solve certain particular problems frequently encountered in industrial control. The standard computer (i.e. with no optional equipment) has five registers (in addition to the main accumulator) that are under the control of the programmer. All of these registers are switchable with the main accumulator. Three of these registers are addressable, so that their contents can be used as operands. Two of these registers besides the accumulator are directly storable in the main memory. Some of the registers have special features: one is an index register that can be incremented or decremented by any amount up to $2^{17}-1$. The X register functions in a float, or shift and count, command and in scan commands. The digital scan, analog scan, and table search commands and the variable-length block transfer are powerful additions to the computer.

The analog and digital input scan commands -- described in later sections -- and the table search command provide capabilities that are unusual in a drum computer; they represent an upgrading of performance where experience has shown it will be most useful. The analog scan, specially designed for industrial control, allows the program to compare 128 converted analog inputs against upper and lower limits in 33 milliseconds. Digital inputs can be scanned to detect a change from a previously stored image at the rate of one line every ten microseconds.

The table search command permits words recorded on the sectors of one track (comparison track) to be compared with the contents of corresponding sectors of a specified reference track. The search can be made for equality between the comparison word and the reference word, for inequality, for less than, and for greater than. The search is masked by a word loaded into one of the working registers; thus any single bit position, or any combination of bit positions, or entire words may be compared.

During execution of the table search command, the computer sequentially compares each comparison word (results of calculations, inputs, etc.) with its corresponding reference word. When the condition sought for is found, the computer identifies the word, and its location, that satisfies the condition.

A powerful repeat command permits a single word to be recorded in all the sectors of either the comparison or the reference track.

For systems entailing heavy logging or tape punching duties, a 512-character output buffer is available as optional equipment to drive logging typewriters, Flexowriters, and/or paper tape punches.

4.5 PROGRAM INTERRUPT CAPABILITIES

Program interrupt is an extremely important capability of a digital control computer. The capability permits the computer to perform normal on-line functions such as instrument scanning, logging, and control, as well as to respond to emergency conditions that can arise in the unit or plant where the computer is used. For maximum efficiency, the program interrupt capability must be able to evaluate interrupts in terms of their importance or priority.

A TRW-330 program can be interrupted from as many as 112 sources, with the priority of each source determined automatically (not by the program) with respect to all other interrupt sources, and with respect to the program in progress. Programmed instructions are not required to identify or examine an interrupt to determine its relative priority; however, programmed instructions can be used to change the priority relationship between the program in progress and interrupt sources. Thus, a minimum of computer time and memory is involved in handling interrupts. This extremely versatile interrupt capability provides the TRW-330 with a highly efficient means for handling emergencies, for accepting data intermittently, and for performing and interleaving diversified on-line and off-line tasks.

TRW-330 program interruption occurs only between programmed instructions. At these times, the computer recognizes that an interrupt condition exists, and begins to take action. (If two or more interrupts have occurred, the interrupt of highest priority is acted upon first.) The TRW-330 automatically stores the address of the next instruction of the program currently in progress, and then reacts to the interrupt by going to an "interrupt response" address. There are 112 possible interrupt response addresses -- one for each of the 112 possible interrupt sources. Thus, 112 different response routines can be entered automatically.

Computer operation can be repeatedly interrupted by events of higher priority, with no loss of re-entry addresses. Furthermore, the computer "remembers" interrupts of lower priority, and processes them in the order of their importance. Each time an interrupt response routine is completed, the computer automatically checks for "remaining interrupts" -- those interrupts that were remembered, but not acted upon by the computer -- plus any interrupt response routines that were not completed because an interrupt of higher priority occurred. The computer always resumes the main program or a response routine at the place where the interrupt occurred -- calculations do not have to begin at the beginning, so computing work is not lost by the interruptions.

4.5.1 Interrupt Sources

The interrupt sources are lines that are activated by switches, or by electrical sources. Switches can be controlled by sensor devices such as flow-limit switches, over-temperature switches, etc.; and switches can be controlled by an operator requesting a typeout, or some special computer action. The switches can be of the momentary type, or can be on-off toggles (where the signal for interrupt is: (1) the opening of switch contacts, (2) the closing of switch contacts, or (3) a change of state of contacts from closed-to-open or open-to-closed).

The interrupt lines can also be activated by electrical signals. The signals may originate within the computer or its subsystems, or can come from sources outside the computer. In addition to interrupts that can be originated by programmed instructions, other typical internal interrupts include:

(a) Elapsed time interrupts: these are program controlled timing devices that provide interrupts after an elapsed time of from 17 milliseconds to 500 hours. (This aids in time sharing the computer between on-line control calculations, on-line program debugging, and off-line calculations.)

(b) Interrupts that signal the completion of analog-to-digital conversion operations.

(c) Interrupts to tell the status of input-output buffers associated with printing or reading devices.

(d) An interrupt that occurs after every instruction can be used to provide a simple but powerful program tracing feature.

4.5.2 Interrupt Priority

Even after a TRW-330 program has been interrupted and the computer enters an interrupt response routine, the interrupt capability is still under program control. Several courses of action are possible.

The occurrence of an interrupt automatically inhibits additional interrupts until a programmed instruction restores the interrupt capability. For interrupts demanding immediate program action (e.g., if the loss of lube-oil pressure at a turbine bearing trips a pressure-limit switch), the interrupt response routine would not restore the interrupt capability until after the computer completes a program segment that warns the operator, turns on a spare lube pump, etc. After the appropriate emergency action has been taken by the computer, the interrupt capability would be restored.

If an interrupt is of lesser priority (e.g., when an operator closes a switch to request a printed summary of operating conditions), one of the first programmed actions when the computer enters the interrupt response routine would be the restoration of the interrupt capability -- so that the response routine can be interrupted by an event of higher priority. Another programmed action would inhibit interrupts of lower priority.

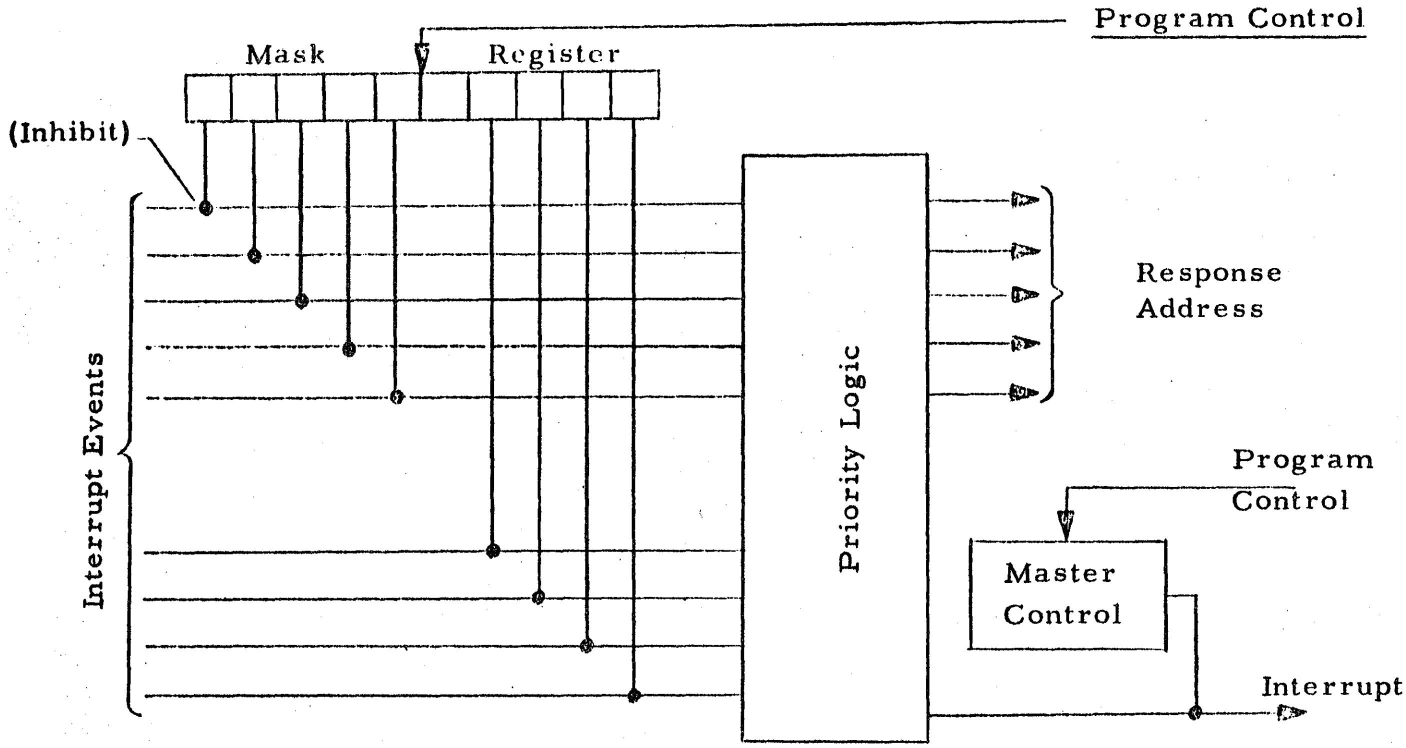
However, the inhibition of interrupts is not restricted to the suppression of low-priority interrupts while responding to a high-priority interrupt; all interrupts can be inhibited by the main program if desired (e.g., when it is important to monitor closely the effect of a setpoint adjustment).

In industrial control applications, different modes of plant operation often require different responses to the same interrupt condition. Interrupt response addresses can be changed under program control.

For example, an operator-initiated interrupt requesting printout of important operating variables may require different printouts for startup, shutdown, and normal modes of plant operation. The printout can be changed simply through program modifications that are made when plant operation proceeds from one mode to another.

The flexibility of the TRW-330 interrupt system also permits a main program structure that is based upon a simple service routine -- with control calculations, logging, scanning, etc., performed in response to periodic interrupts from a digital clock; but with high-priority, emergency functions performed at any time. Service routines that could constitute the main program might be: a self-checking routine, an on-line program debugging routine, etc. This mode of program operation is possible in the TRW-330 because of its unique program interrupt capability -- a capability that minimizes the need for the main program to maintain counters, to test flags, and to check time of day.

The following is a simplified schematic of the interrupt system.



A master interrupt control is provided which is under program control. Individual interrupt mask registers enable program priority control over each interrupt as desired.

4.6 BUFFERED INPUT

The TRW-330 buffered analog input system with its program-control options provides several types of important flexibility. All analog signals are automatically digitized and stored in the computer's memory without requiring any program attention. All signals, both high- and low-level, are isolated from the converter by a solid-state amplifier. The system operates under the control of a track of memory that contains 128 control words. These control words determine the sequence in which variables are selected, as well as the range of amplification to be employed for each signal. The control words can also cause program interrupts to indicate that the sampling has reached a certain point in the sequence. This allows most changes in the instrumentation of a system to be accomplished without wiring changes to the analog input system.

A more important aspect for the performance of the program is that the input selection system determines where each piece of data is first deposited on the drum. This allows the reading of a flow meter, for instance, to be brought in, and "packed" in a group of flows for integration purposes at one time. Later in the program, this same flow meter data may be brought to the drum arranged in the sequence of data as it is to appear in a trend log or in a demand log. This flexibility is an important advantage in the subsequent handling of all data within the program. Although it is under program control, this system does not burden the program since it will cycle continuously under the control of the control track. Any part or all of this cycle can be changed simply by the program through the use of the block transfer command, or individual one-word store commands. In summary, this system not only improves the performance of the program, but also simplifies the engineering and analysis which must be performed by the user to obtain this performance.

4.7 TRW-330 COMPUTER RELIABILITY

The design of the TRW-330 computer incorporates the experience gained in several hundred thousand hours of field operation of the RW-300 computer. These computer systems, including their peripheral equipment, have provided an average availability of greater than 99 percent in around-the-clock operation. Our objective in developing the TRW-330 computer and associated equipment has been to cut the failure rate and the associated downtime by a factor of two or more. Preliminary evidence indicates that we have been successful. At the time of this writing, the prototype TRW-330 computer in a television switching application has been running continuously for over six months without a component failure.

The availability of a computer system is a function both of the mean time between failures, and of the average time required to detect, analyze, and repair a failure. Both aspects have been improved in the TRW-330 design.

The first approach to reducing the number of failures has been to simplify the design physically and electrically as much as possible. New circuit techniques have provided a large increase in the number, sophistication, and speed of operation of the commands with only a slight increase in the number of diodes and transistors required. At the same time, as Figures A-1 and A-2 illustrate, an integrated wiring design, and the elimination of connectors where not needed, has reduced the number of

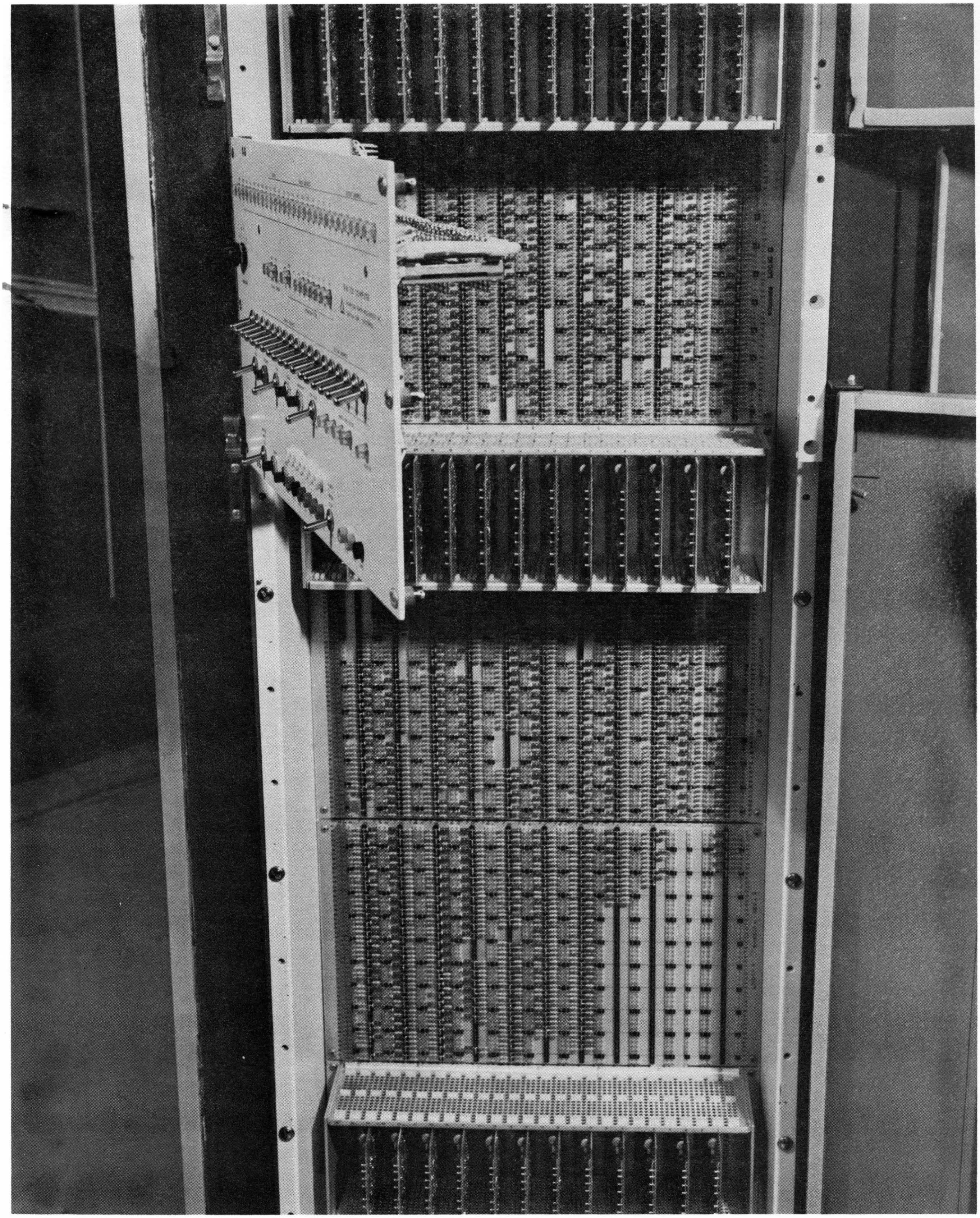


FIGURE A-1. FRONT VIEW - TRW-340 ARITHMETIC AND CONTROL UNIT

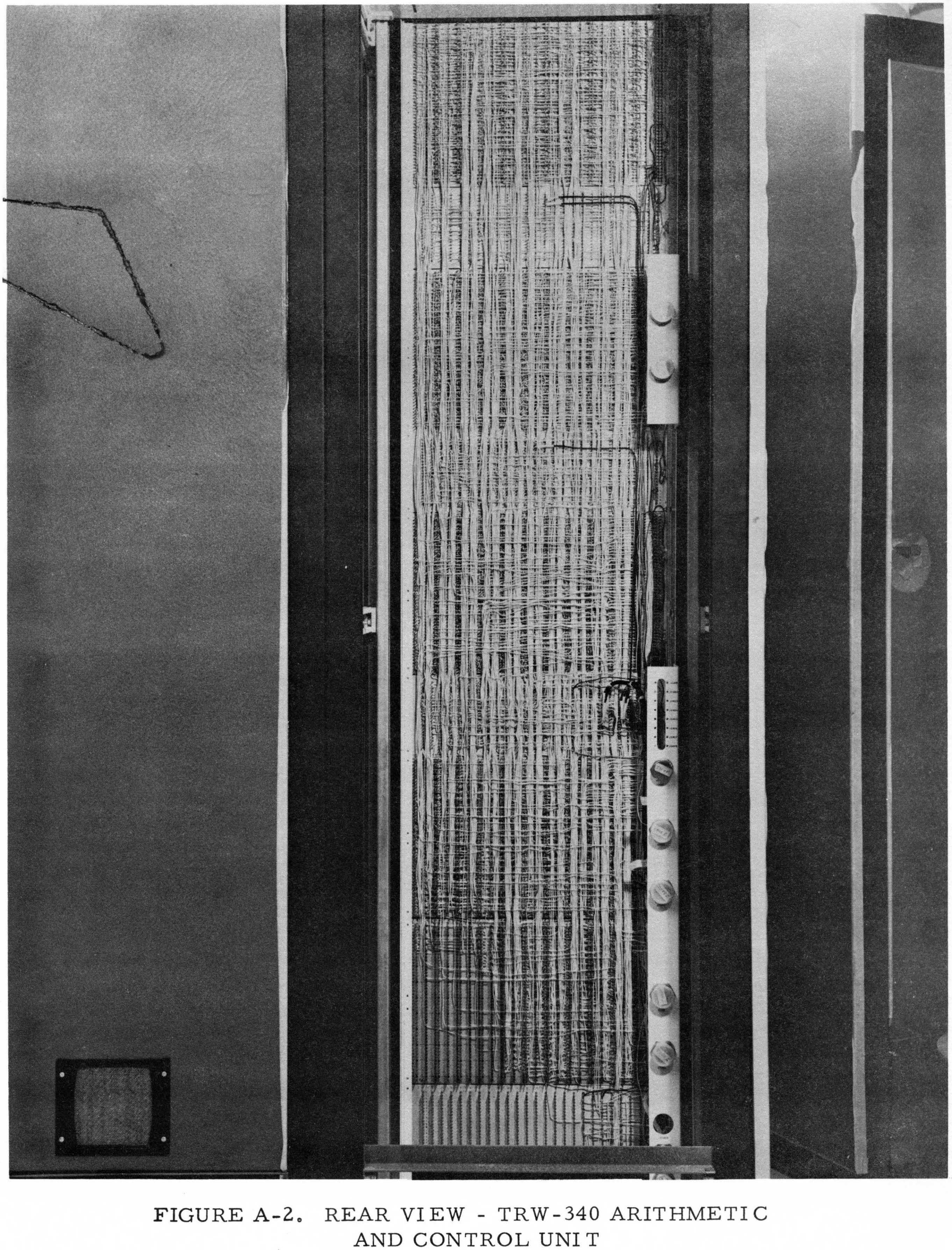


FIGURE A-2. REAR VIEW - TRW-340 ARITHMETIC AND CONTROL UNIT plugs, connectors, cables, and wiring connections in the TRW-330 by more than one-half. Many individual features have been improved, each of minor significance alone; but taken together, these contribute significantly towards improved reliability. Some examples will illustrate this.

The circulating registers are completely solid state. All vacuum tubes have been eliminated; the synchronous magnetic drum motor has been changed to an induction motor, having superior starting characteristics and not susceptible to "drop out" during line fluctuations. The time-of-day clock uses mercury-wetted-contact relays rather than stepping switches. The different sections of the memory are guarded by toggle switches and/or mercury-wetted relays when program control of the guard feature is required. The design of our analog input system, including the conservative use of noise filters, permits one amplifier to sample sixty points per second; this reduces the number of amplifiers required to one per system. The amplifier used is a Redcor, which is completely solid state, including the choppers. Susceptibility to malfunction because of noise generated both within and external to the system has been reduced through numerous changes in circuitry. These and similar changes, continued investigations to determine the most reliable components, and a program of closer integration of our engineering and production facilities have combined to provide an improved failure rate in the TRW-330 computers produced to date.

Recognizing that failures will not be eliminated entirely, we have also developed the TRW-330 design to minimize the time required to locate and correct a trouble. As mentioned above, we have simplified the circuitry compared to the RW-300, reducing the number of different types of circuits and standardizing on DC flip-flops and logic only. All the resistor diode logic of the computer has been laid out in a single plane on five "logic boards" (see Figure A-3). Color coding of the nylon feed-through insulators on these boards makes it possible to quickly locate any individual point. The nomenclature of the computer organization and logical equations uses these coordinate designations. As a consequence of this system, the number of drawings the maintenance engineer must work with is sharply reduced, as well as his need to refer to them. His thoughts can be concentrated on the trouble itself rather than on the work of interpreting drawings. Initial experience has shown that it is substantially easier to learn to maintain the TRW-330 than the RW-300.

Because of their conservative use, the failure rate of logical diodes and resistors is extremely low (less than one per year per computer in the RW-300). Furthermore, when one does fail, it can be identified with an

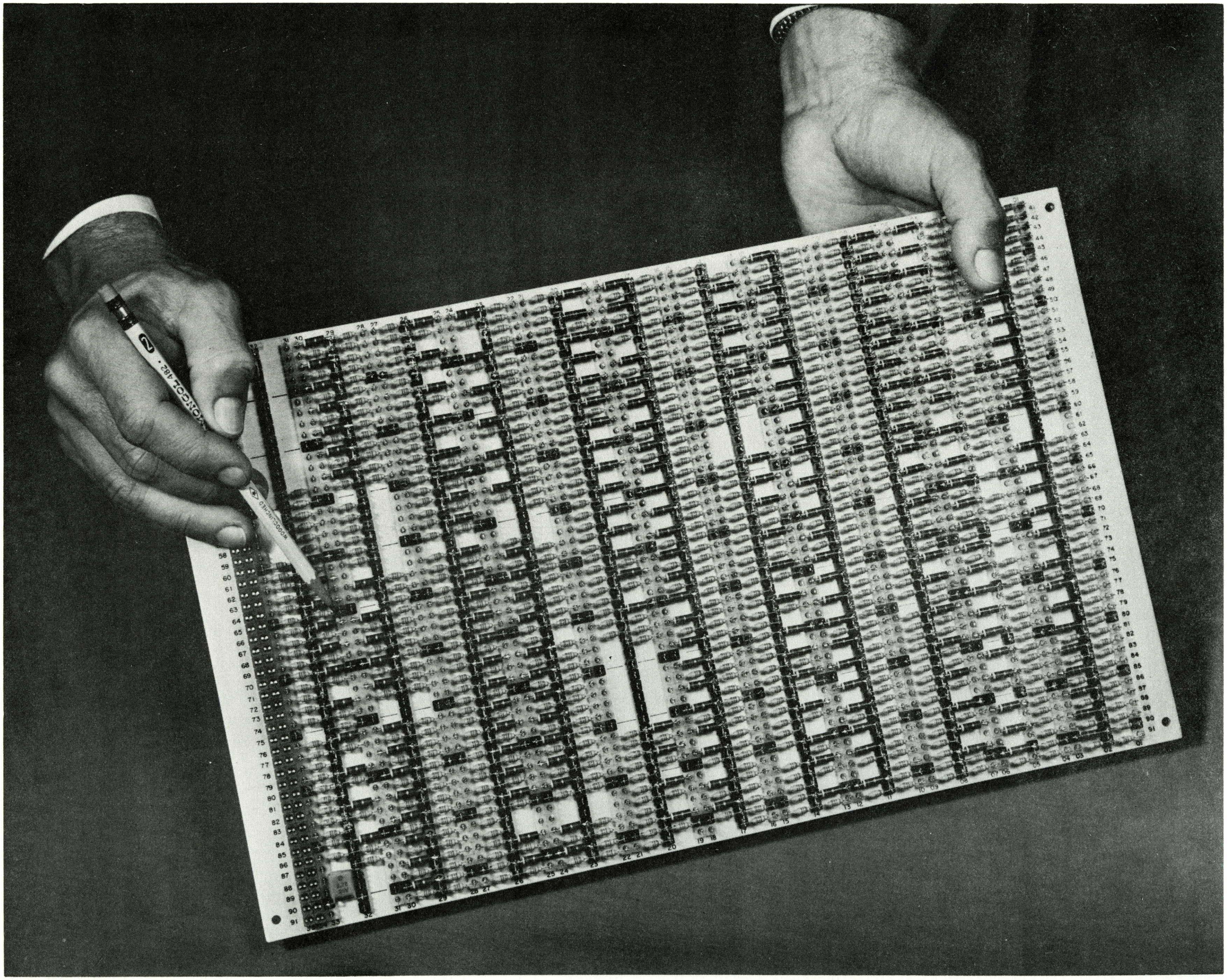


FIGURE A-3. TRW-340 LOGIC BOARD

ohmmeter. In the TRW-330, therefore, we have eliminated the use of any connectors in wiring these components into the computer. However, a weak transistor cannot always be reliably found without removing it from its circuit. Therefore, all of the active circuits containing transistors in the TRW-330 computer are mounted on insert cards contained in rugged aluminum modules (see Figure A-4). This permits a rapid substitution technique in trouble-shooting these circuits.

Generally speaking, anything that helps the programmer also assists the maintenance man. Numerous features built into the TRW-330 for the benefit of the programmer will aid speedy localization of failures. For instance, the block transfer command and the table comparison command (one mode of the scan command), coupled with the parity check, make it possible to quickly localize a memory fault. A toggle switch allows the maintenance engineer to cause the machine to stop at any point, rather than merely record a parity error.

The more powerful command structure and better utilization of memory makes it much easier to keep certain maintenance programs, such as the utility package, permanently stored in the machine.

Features that reduce human fatigue and assist in checking programs include: (a) the ability to remain seated while stepping through a program; (b) easily read neon bulb displays; (c) only one button need be depressed to step through an instruction; (d) the stop-on-jump switch makes it possible to stop at predetermined points in the program.

5. ANALOG INPUT AND OUTPUT FACILITIES

5.1 GENERAL

The TRW-330 analog input-output subsystem is designed to meet the requirements of each installation. The analog converter can accept 2048 analog input signals and can supply over 128 analog output signals to controllers. Conversion accuracies are within 0.1 percent.

The analog-to-digital converter accepts analog input signals in ranges of either zero to +10.23 volts, or -10.23 to +10.23 volts. Signals from thermocouples and other instruments with low-level outputs are filtered to attenuate noise, and are amplified before being applied to the analog converter. Through a relay-selection technique, a single variable-gain amplifier can accommodate both high- and low-level input signals.

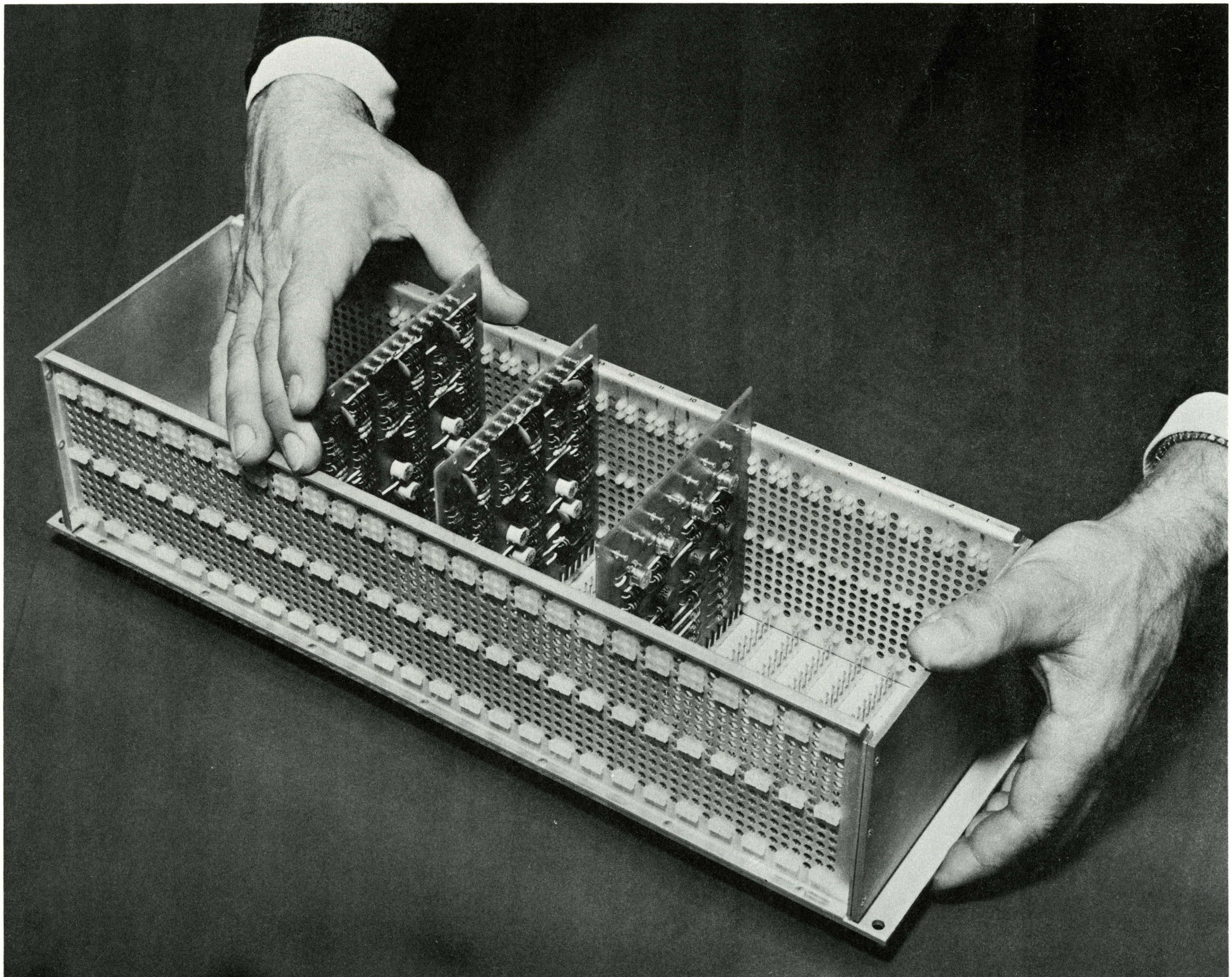


FIGURE A-4. TRW-340 INSERT CARD HOLDER

Amplifier gain is controlled by control bits in the variable selection address.

The converter may communicate directly with the computer -- through digital inputs -- or the converter may communicate directly with the drum memory. These two communication methods are under program control and are discussed in the following two paragraphs.

5.2 UNBUFFERED INPUT

When the unbuffered subsystem is used, analog inputs and outputs are controlled directly by programmed instructions. In this case, the computer program can order an input. After ordering the conversions, the computer can continue with its program during the time that relays are being set and the analog values are being digitized. When the digitized values are ready for storage in the computer memory, the analog subsystem generates an interrupt signal, causing the computer to accept the input values. The total time elapsed for this operation is less than 17 ms. The use of the interrupt to determine that a converted input is ready is not mandatory, i.e., the generation of interrupt signals by the analog subsystem is a programmed-controlled option. Thus, the program can inhibit the interrupt signal and accept the converted input at any convenient time after 17 ms. Furthermore, as the computer receives each input for storage, it can perform alarm scanning. That is, it can check each value against prestored high and low limits, and can give an alarm and/or take corrective action when a variable is out-of-limits.

5.3 BUFFERED INPUT

When the buffered (direct-to-drum) subsystem is used, two tracks -- a buffer track and a control track -- are used for input control and storage. The digital equivalents of analog values are stored in the analog buffer track, automatically, at the rate of 60 per second. The sequence in which values are recorded in the buffer track is controlled from the analog control track. For each sector in the buffer track, there is a corresponding sector in the control track from which the analog input is addressed.

Each sector of the control track contains the following information:

(a) Relay address -- the analog input to be converted.

(b) Gain control -- the amplifier gain appropriate for that input.

(c) RTD control -- on-off selection of RTD bridge compensation, on for thermocouple inputs.

(d) Order code -- for restarting the analog sequence and/or generating a computer interrupt.

The order code restart makes it possible to sample any given number of analog inputs repeatedly, without waiting for the sampling of the entire 128 that would normally take place. When the restart bit appears in one of the control track sectors, the sampling begins again at the start sector rather than continuing with the normal sector order.

The order code interrupt may be used to alert the program that a certain group of analog inputs has been sampled, so that the program may use the data. Or the interrupt may be used to indicate that a complete set of inputs has been recorded, so that the computer may limit-scan these inputs and reload the control track for a new set of inputs.

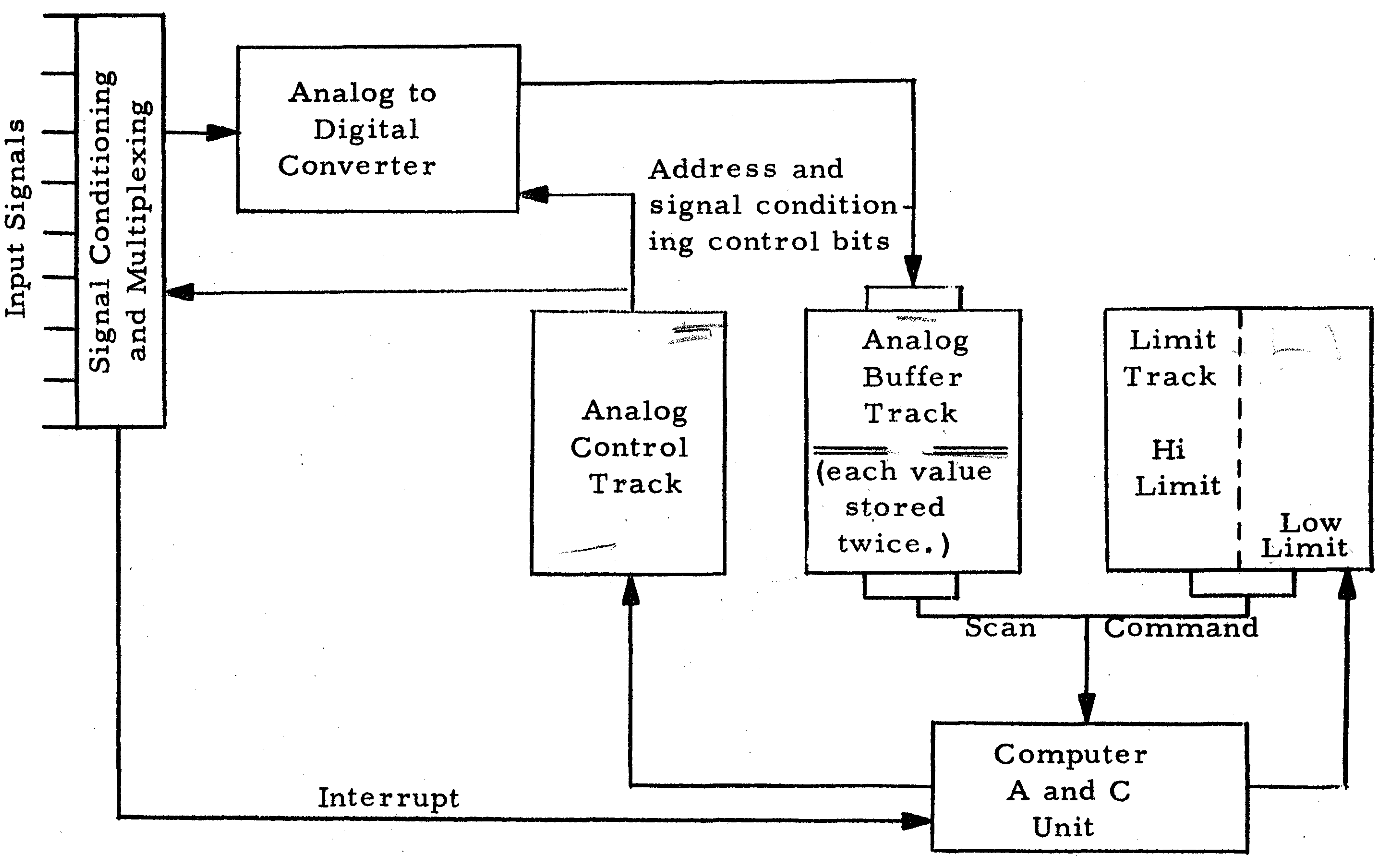
Limit-scanning of the analog buffer track is performed in connection with an analog limit track. For each sector in the buffer track there is a corresponding sector in the limit track. The entire buffer track -- 128 analog inputs -- can be scanned for high and low limits in 33 milliseconds with a single analog scan command.

So that both high and low limit scanning can be performed at once, each sector in the limit track contains both the high and low limits for the associated analog value in the buffer track. When the analog scan detects that a high or low limit has been exceeded, the computer, besides taking appropriate action, can suppress that limit, for as long as necessary, so that it will not give repeated alarms.

The speed and efficiency of the analog input and scanning system is shown in the following table.

OPERATION	TIME (ms)	MEMORY SPACE REQUIRED
Select 128 new analog inputs for conversion; i.e., load the control track.	33	2 instruction words plus 128 selection code words
Scan 128 analog inputs for both high and low limits.	33	2 instruction words plus 128 high/low limit words

Additional control and buffer tracks can be supplied with the TRW-330 computer, but the versatility of the basic system makes such added circuitry unnecessary for most applications. The basic system, using a single buffer track, can handle up to 2048 analog inputs, with any 128 of these being monitored at a time. (There are few installations, if any, in which simultaneous monitoring of more than 128 analog inputs is necessary.)



ANALOG INPUT SUBSYSTEM

The analog input system provides a great deal of flexibility, since the sampling sequence can be changed at any time by changing the contents of the control track. Thus, instrument values can be read in any desired sequence and frequency. For instance, certain values could be sampled every second (or more frequently); some every five seconds; some every minute; and so on. Where desirable, certain input points could be held as backups, to be monitored only when a limit is exceeded for primary measurements. The extreme range of the system extends from repeated sampling of a single variable to the monitoring of a full 2048 inputs in order

5.4 SIGNAL CONDITIONING AND MULTIPLEXING

The signal conditioning and multiplexing scheme is illustrated on the following page.

6. DIGITAL INPUT AND OUTPUT FACILITIES

6.1 OUTPUT

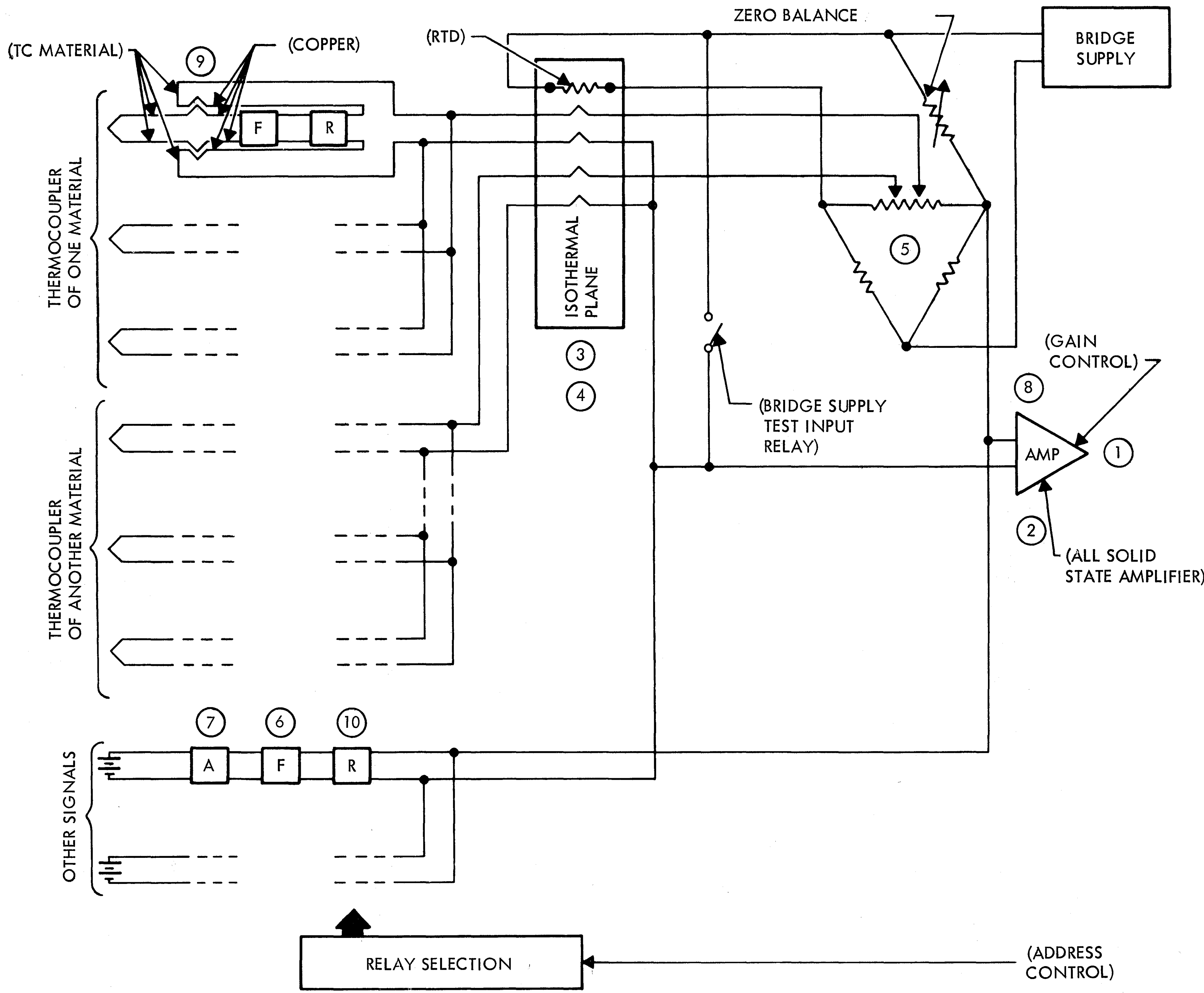
The TRW-330 uses high quality mercury-wetted relays in digital output circuits. They are mounted on insert cards which are easily accessible from the front of the cabinet

6.2 INPUT

The TRW-330's word length is 28 bits, therefore digital inputs are accepted in groups of 28 lines. The TRW-330 has a powerful digital input handling ability. This is due in part to the input group size of 28 bits, however the greatest feature is the scan command.

The digital input scan command permits digital input groups to be compared for inequality with the contents of sectors of a specified track. For each 28-bit (or less) input group, there is a corresponding "reference word" stored in the computer's memory. During execution of the scan command, the computer sequentially compares each 28-bit input group with its corresponding "reference word". When inequality is detected, the computer, by identifying the group and the unequal bits, identifies the input line, or lines, on which the inequality was detected.

If the previous states of the digital input lines are stored in the "reference word" sectors, inequality will exist only in those groups that contain at



LEGEND

A — ATTENUATOR (AS REQUIRED)

F — FILTER (AS REQUIRED)

R — RELAY (MERCURY WETTED)

Circled numbers on the drawing refer to the following explanations:

1. Only one amplifier is required.
2. The amplifier is solid state, including the choppers.
3. There are no heating or temperature regulating circuits for the thermocouple reference plane.
4. The isothermal plane contains only one pair of junctions for each type thermocouple material (i.e., one to four); the small plane makes it possible to maintain a temperature uniformity of ±1/10° F.
5. The compensating bridge not only compensates for reference plane temperature variations, but also provides a bias, where necessary, to simplify range and scaling problems.
6. Filters are supplied to suit each line.
7. Attenuators are supplied, as required, simplifying scaling problems.
8. Because the gain is switched by control bits in the control track, a given variable may be sampled at more than one gain.
9. The thermocouple signals are introduced on thermocouple material, transferred to copper wire, routed through the filters and multiplexing relays, and then transferred back to thermocouple material; the signals from the two opposing thermocouple junctions cancel each other.
10. The mercury-wetted relays are mounted on insert cards.

SIGNAL CONDITIONING AND MULTIPLEXING SCHEMATIC