This paper is a scan of an 1101 Computer description by Frank C. Mullaney; the engineering supervisor who oversaw the 1101 shipment and installation. The paper was presented at an AIEE-IRE conference in December 1951, shortly after ERA became a division of Remington Rand.

The paper was found in the documents donated to the VIP Club by the estate of Curt Christensen who passed away in September 2016. This paper is now archived at the Charles Babbage Institute at the University of Minnesota.

Design Features of the ERA 1101 Computer

BY

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Eleven oh one in binary is thirteen in decimal. When ERA received government permission to market the classified ATLAS computer, Jack Hill said that it should be called 1101 because it had been developed on the CSAW Task 13. The shipment of the ATLAS computer from St. Paul to Washington DC in October 1950 was historical! This computer was operational doing code breaking in December 1950! America and the world's first stored program computer delivered and operating in a customer's facility.

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Design Features of the ERA 1101 Computer

F. C. MULLANEY

THE ERA 1101 computer is a single-address binary-system parallel computer using magnetic drum memory. The word length is 24 binary digits, equivalent to seven decimal digits plus sign. The logic is quite conventional.

A machine instruction consists of an operation code plus one execution address. The execution address usually specifies the location of an operand or the place where a result is to be stored. There are a total of 38 different operations which may be grouped as follows:

Ten arithmetic operations, including regular and special additions and subtractions, divide, and multiply.

Thirteen "insert" or transmissive operations.

Four "jump" or transfer operations to allow interruption of the instruction sequence in progress.

Four manipulative aids such as logical multiplication.

Two shifting operations, each shifting left one of two registers.

Two output operations; print and print punch.

Three stops; optional, intermediate, and final.

The memory element is a magnetic drum with a capacity of 16,384 words, each 24 binary digits long. The drum, which is $8^1/_2$ inches in diameter, rotates at 3,500 rpm. The resulting surface speed of 1,600 inches per second, together with a peripheral spot density of 80 per inch, produces a basic pulse rate of 125 kc for the memory section of the machine.

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Although the random average access time is 8 milliseconds, an average access time of less than 1 millisecond can be obtained by placing the orders and operands in locations on the drum which will permit a number of references in the same drum revolution.

The arithmetic section consists of the "X" and "Q" Registers and the Accumulator. The "X" Register, 24 bits long, functions as the repository for multiplicand, divisor, augend, and subtrahend. The "Q" Register, also 24 binary digits in length, possesses shifting properties. This register contains the multiplier during multiplication and the quotient after a division. It also may be used as a rapid-access 1 word storage. The principal arithmetic register, and the place where the actual arithmetic is performed, is the 48-place Accumulator. It possesses subtracting and shifting properties.

The number representation is in a one's complement system in which the highest order binary digit designates the sign of the number. Negative numbers are represented as complements on 2^n-1, where n is 24 or 48 depending on which register contains it and on whether single or double precision operation is being used.

The basic clock rate at which the control and arithmetic systems function is 400 kc. The time necessary for addition or subtraction is 96 microseconds. This time includes procurement of both operands and the next instruction from the magnetic drum memory and assumes that the drum addresses are placed to obtain minimum access time. The corresponding time for division is 415 microseconds and for multiplication, 352 microseconds.

The computation and control sections operate asynchronously with respect to the memory. Once a storage reference has been initiated by main control, further action in this section is suspended until a "resume" is signalled by the control circuitry of the memory system.

The main sequence control receives the operation code and issues the necessary operation pulses to perform the main steps involved in the particular instruction being processed. To control the more complex arithmetic operations, such as shift, multiply, and divide, an auxiliary control system is employed. It is known as the arithmetic sequence control.

The machine may be manually controlled from two locations. The operator's control panel contains a minimum number of controls and indicators for operating the machine. The maintenance control panel contains a complete display of indicators and a sufficient number of switches for complete control of the equipment for test and trouble diagnosis.

The input medium is a photoelectric paper tape reader. Standard 7-channel perforated paper tape is used, six channels of which are used for information. Four lines, therefore, contain a 24-bit word. The seventh channel contains the coded loading instructions. This code is used to direct the operations necessary to assemble the 6-bit word pieces into the standard 24-bit size, and store them in the proper location on the magnetic drum. The loading rate is 35 words per second. At this rate, the entire drum could be loaded in less than eight minutes if desired.

The output section consists of an electric typewriter and paper tape punch. The maximum output rate is about seven characters per second.

The machine logic, while not basically novel, has certain distinctive features which are worthy of mention. Two

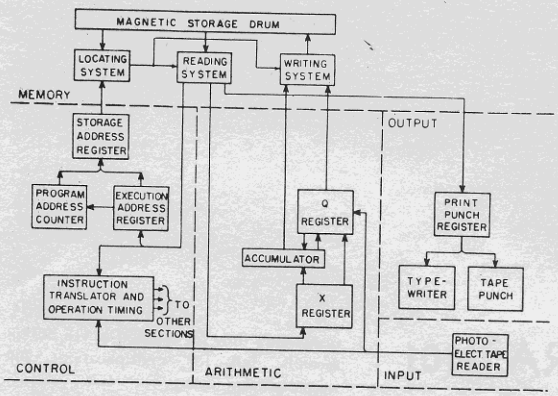


Figure 1. Principal elements ERA 1101 computer

types of multiplication are provided: clear multiply and hold multiply. In the former, the factors are held in the "X" and "Q" Registers and the product is assembled in the initially cleared Accumulator. In the hold multiply, however, the Accumulator is not precleared and the product is added to the initial Accumulator contents. This feature provides rapid performance on routines requiring the accumulation of sums of products, for example, operations on double precision numbers. Another important aspect of the machine multiplication is that the multiplier remains unchanged in the "Q" Register after the completion of the operation.

The unusually large memory capacity of 16,384 memory boxes permits long-time storage of subroutines. There is no restriction on the assignment of memory boxes to order words or operands. Either type of word is permitted in any of the locations.

Four branch operations offer unusual flexibility in programming. These operations are an unconditional jump, sign-recognition jumps, (sensing either "Q" Register or Accumulator) and a zero-sensing jump.

The output section is a potential bottleneck in most electronic computers; the ERA 1101 is no exception in this respect. However, this bottleneck can be greatly relieved if print instructions can be spaced by computational instructions. Computation proceeds immediately after the print signal is issued by the control system; the machine is not held up by output unless another print or punch is called for before the completion of a previous print operation.

The ERA 1101, with its long list of operations, provides the programmer not only with the essential tools but also many of the refinements which save programming time, reduce the lengths of programs, and result in more efficient use of machine time.

Because of the "nonvolatile" character of magnetic storage, test problems, subroutines, and function tables may be stored for as long a time as desired.

In the usual machine operation, orders are taken from consecutively numbered memory boxes as directed by a Program Address Counter. However, these consecutively numbered positions need not be physically adjacent on the drum. In fact, they may be spaced at the option of the programmer so that an operation may be completed just before the next order enters under the reading head. The operand used with an order may be so located on the drum that it is available just after the order has been read out of storage. In this way, it is possible to reduce greatly the access time which would be required on a purely random basis. Improvements in operating time of ten to one over a random arrangement are realized in practice.

Figure 1 shows the relationship among the various elements of the machine. The storage drum is shown at the top with its locating system, writing and reading circuits.

To read out an instruction, the address is transmitted from the Program Address Counter to the Storage Address Register. The locating system finds the proper address and the instruction is sent from the reading system to the control registers—the operation code to the Instruction Translator and the single address to the Execution Address Register.

To read out a number, the execution address is sent to the Storage Address Register; the number is read into the "X" Register.

For multiplication, the multiplier is placed in the "Q" register, the multiplicand in the "X" register. The product is assembled in the Accumulator. After the multiplication, the multiplier remains intact in the "Q" register. In division, the dividend is placed in the Accumulator, the divisor in the "X" register. The quotient is assembled in the "Q" register, leaving a positive remainder in the Accumulator.

Additions and subtractions are made from the "X" register into the Accumulator. Note also that 2-way communication exists between Accumulator and "Q" register so that "Q" may be used as a rapid access one word storage.

A third path from the reading system is to the Print Punch Register. The typewriter (or typewriter and punch) is energized by the output of this register.

The drum is initially loaded from the photoelectric tape reader via the "Q" Register where the word is assembled.

Constructional Features

Figure 2 is an over-all view of the computer. The cabinets to the right contain the electronic equipment associated with the magnetic drum memory. The cabinets to the left contain the arithmetic and control sections. In the center and behind the front row of cabinets is the maintenance control cabinet which con-

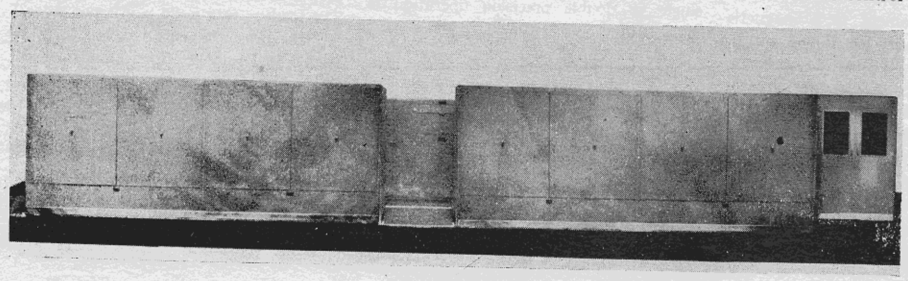


Figure 2. ERA 1101 digital computer

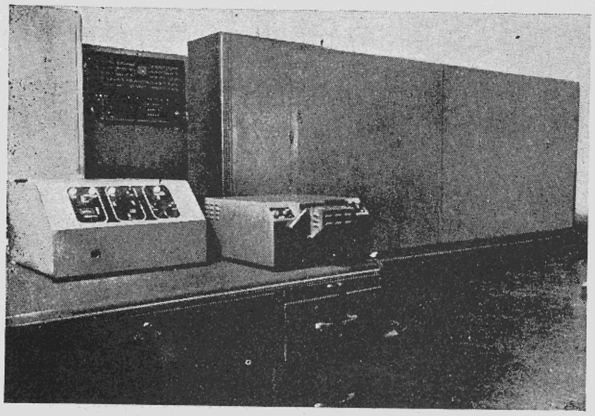


Figure 3. Portion of ERA 1101 computer

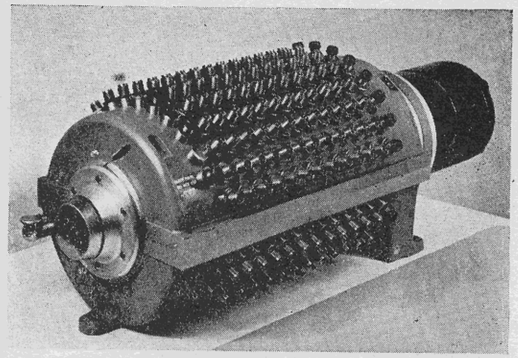


Figure 5. 400,000-bit magnetic storage drum

tains the controls and indicators used in test and maintenance of the machine. The power supply is located immediately behind the arithmetic and control cabinets. The magnetic drum is behind the cabinets to the right. At the extreme right is the fan cabinet which provides water cooled air to the other units of the equipment.

Figure 3 is a view from the operator's desk. The operator's control unit and the photoelectric tape reader may be seen in the foreground.

The magnetic drum is shown in Figure 4 with the heads in place and the cables attached. A 1/3-horsepower motor is directly coupled to the drum shaft. This drum accommodates over 200 heads and will store more than 400,000 binary digits.

Figure 5 is another view of the drum. The staggering of the heads to allow a center-to-center track spacing of 1/16 inch is shown. An integral part of the head is a 5-pin connector.

A view of one of the electronic cabinets with the door open is shown in Figure 6. The arrangement of the plug-in unit chassis may be seen. The indicators at the top are for the 100-degree Fahrenheit thermostats located in each channel. The formica spacers channel the air flow through the units and also provide protection against accidental short circuits when replacing units.

Next is the same cabinet with the chassis removed, Figure 7. The chassis engaging mechanism is shown and also the plate which contains complete identification of the unit mounted in that place.

The standard plug-in unit, Figure 8, accommodates a maximum of 16 tubes. The design allows short lead lengths from components to connector. The component boards are placed to allow effective cooling. The pan at the bottom of the unit mounts up to five dual section capacitors which are used for power supply decoupling. On this same bracket are mounted up to eight ERA molded pulse transformers. This unit size has proved to be convenient for quick isolation of a defective unit. The connectors are easily disengaged and the unit removed by means of a lever operated mechanism.

Figure 9 is a view of the rear of the Arithmetic Cabinet with doors opened. It shows the back of the channels which mount the unit chassis. The filament transformers are at the top. The heater busses and the d-c service lines run vertically. The flip-flop indicator lines and the manual control lines are laced in cables. The signal wiring within the cabinet is carried on the spaced transmission lines. Pulses leaving a cabinet are sent into coaxial cables.

The view of the front of the control cabinet, Figure 10, is of interest because its arrangement differs from that of the other cabinets. The electronic portion of the control system is shown to the left. The relays associated with the manual controls are shown here. The remainder of the space is occupied by a relay power supply and miscellaneous terminal strips.

One of the control units which contains some of the subcommand circuits is pictured in Figure 11. Note the concentration of mixing diodes on the component board.

Figure 4. Magnetic drum memory.

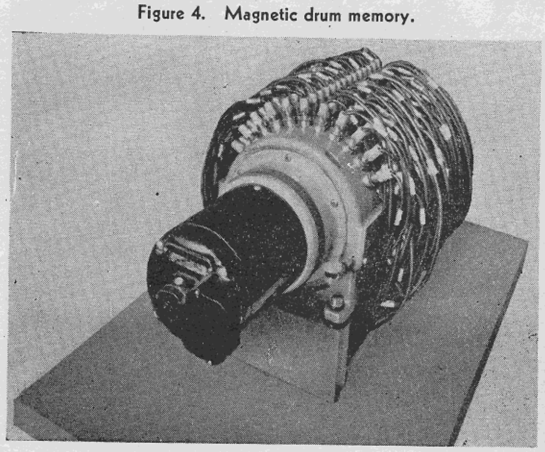
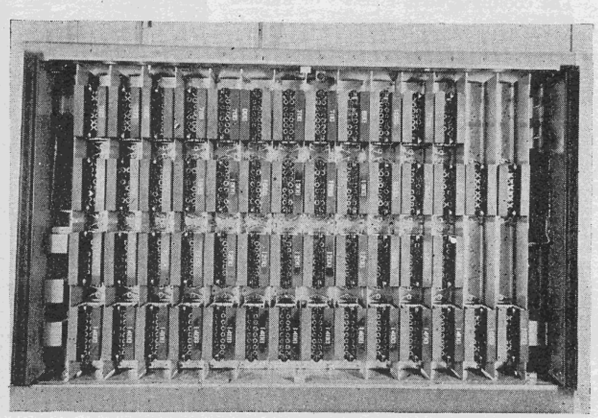
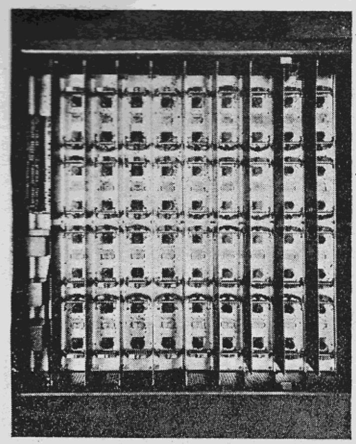


Figure 6. Electronic section of storage system





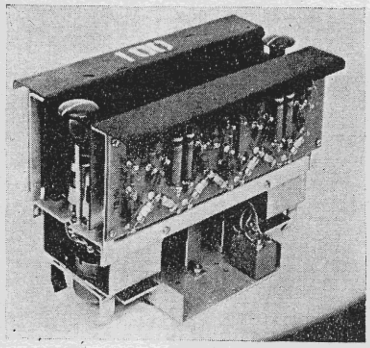


Figure 7 (left). Electronic cabinet, chassis removed

Figure 8 (above). Typical 16-tube unit chassis

In one case, for reasons of circuit design, a unit of the type shown in Figure 12 was built. It occupies on the channel the space taken by two of the smaller units. Note the pulse transformers—there are 37 in this unit.

The main control translator is shown in Figure 13. Here again, it was desirable to depart from the small size chassis. This unit receives information in the form of a 6-digit binary operation code. The information is received on flip-flops; from there on to the output, the circuits are direct coupled. There are 48 outputs built in this unit, of which 38 are used. Failure to establish an output on one of these lines at the proper time stops the machine and indicates a failure. The output, from cathode followers, is at an impedance level of about 100 ohms. The chassis contains 44 tubes and almost 200 crystal diodes.

The power control panel is shown in Figure 14, left side. It contains metering facilities, off-voltage indicators, operating and emergency controls. The section to the right contains the electronic regulators.

The cooling system consists of water-cooled air with a plenum chamber distribution system. Figure 15 shows the fan cabinet with its filters, cooling coil, and fan. The fan has a capacity of 3,500 cubic feet per minute. The water enters at 50 degrees Fahrenheit. The air is discharged into the plenum chamber at about 60 degrees Fahrenheit. The air flow in various sections of the equipment is adjusted initially by varying the size of perforations in plates depending upon the heat dissipation in a particular section. These adjustments have very little effect on the static pressure within the plenum chamber, hence any individual adjustment has a negligible effect on the rest of the system.

A closeup of a portion of the operator's desk is shown in Figure 16. On the left is the operator's control unit. It contains a minimum number of controls and indicators and allows machine operation by comparatively unskilled personnel. Having started the computation, the operator can stop the machine only at programmed stops. To the right is shown the photoelectric tape reader. The tape passes between the lamp housing and the light gate which consists of pulse shaping apertures. The light passing through those apertures which line up at any particular time with holes in the passing paper tape, impinges on the ends of lucite rods which transmit the light to miniature phototubes. A removable chassis contains amplifiers which bring the signals up to the level needed to enable the transmission gates located in one of the main cabinets.

The tape speed is 14 inches per second. The corresponding pulse rate is 140 cycles per second. If a tape snarl occurs during loading, a "tangle stop" immediately stops the drive before the tape can be snapped.

Testing and Maintenance

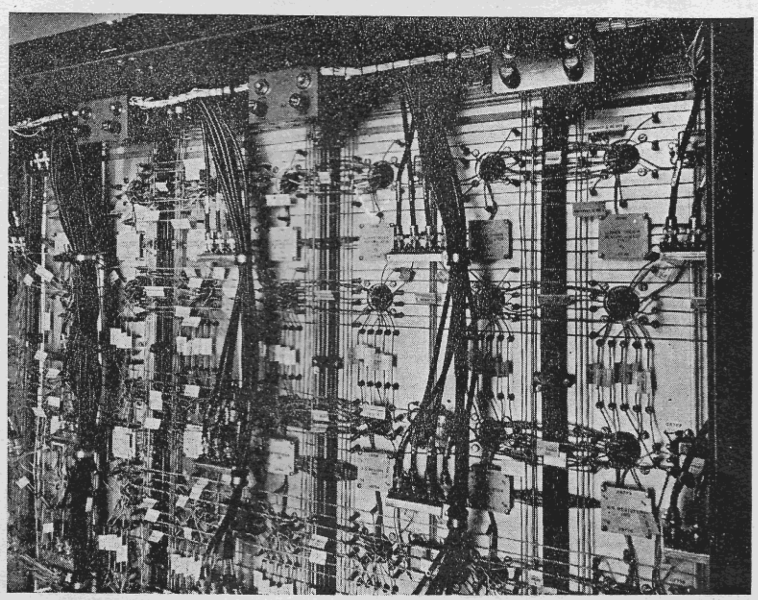
The control panel shown in Figure 17 contains the indicators and switches needed for complete control of the equipment. The machine is operated from here for program trouble shooting, testing and maintenance.

Every flip-flop has indicators on both sides. Each digit of a register has a push button for manual setting during test. One group of toggle switches allows certain control lines to be disconnected to permit cycling of normally nonrepetitive operations.

Another group of switches permits reduction of heater voltages by sections as a marginal checking aid. We do not feel that heater voltage reduction is the complete answer to marginal checking problems. It has, however, proved extremely valuable in providing a safe margin of operation. Failures rarely occur during operation.

A self-checking test problem is used in conjunction with the reduced heater voltage tests. This problem checks all of the operations used in the machine. If

Figure 9. Typical wiring in electronic sections



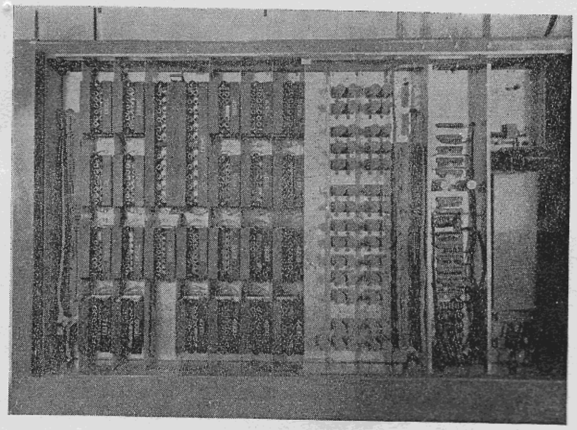


Figure 10. Control section

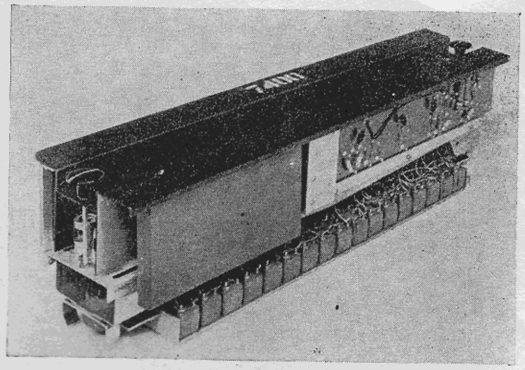


Figure 12. Unit chassis, dual size

there is a failure in any individual test, operation is halted. The address held in the execution address register at the time of the stop indicates in which test the failure occurred. Slow speed and step-by-step operation are used to pin-point the cause of the trouble.

This problem also may be used during regular operation to provide assurance that the machine is functioning properly. It is inserted automatically at intervals during the course of a computation. The time needed to execute the test problem once is about 0.1 second.

Points of circuit design which we feel contribute to reliability are: decoupling capacitors on every d-c supply line inside each chassis; cathode followers to couple flip-flops to gates; intercabinet pulses transmitted at an impedance level of about 100 ohms; pulse transformers liberally used for impedance transformation and pulse polarity inversion.

All components are operated well within manufacturers' ratings. Maximum tube dissipation is limited to 50 per cent of rating. Resistor dissipation is limited to less than 35 per cent of rating. Crystal diodes, with few exceptions, are not subjected to inverse voltages greater than half of the manufacturer's rating, nor are they required to conduct direct currents greater than 50 per cent of the ratings.

The protective features of the equipment include cabinet interlocks, airstream monitor, and two levels of thermostatic protection in each cabinet. Each column of unit chassis contains a 100-degree Fahrenheit thermostat. If this temperature is exceeded in any of these locations, the operation is halted, but the power remains on. If the condition is corrected, the start button may be pushed and the computation will proceed. In the warmest region of each cabinet is a 120-degree Fahrenheit thermostat. If this temperature is exceeded, the machine is halted and the power is removed. Also in the category of protective features are abnormal voltage and current detectors and a drum-speed detector.

Operational Record

The computer was delivered in December 1950. It was unpacked, installed, tested, and ready for operation in only eight days. The maintenance personnel assigned to the machine are not employed by ERA nor are they under its supervision. Only two of them had seen the equipment before its delivery. The operating record being achieved is without doubt a tribute to the abilities of the maintenance group. We also believe that it speaks well for the design of the machine. For the first 4,500 hours of "heater on" time, the equipment was available operationally 86 per cent of the time. Of the remaining 14 per cent, 10 per cent was used in scheduled preventive maintenance and marginal checking. Only 4 per cent of the total time was spent in unscheduled maintenance.

A detailed tube life analysis is not available at this time. The tube replacement data which is available does not indicate outstanding life. For all of the 2,700 tubes in the machine, the survival rate at 4,500 hours is greater than 57 per

Figure 11. Unit chassis, side view

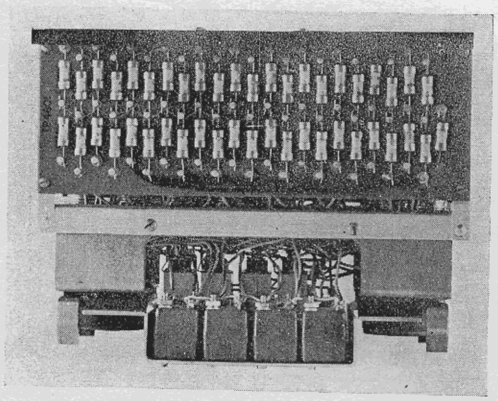
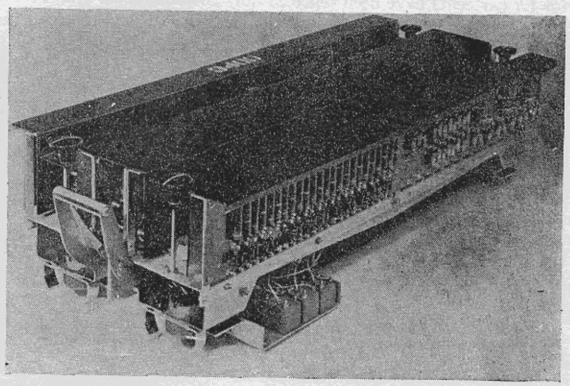


Figure 13. Unit chassis, quad size



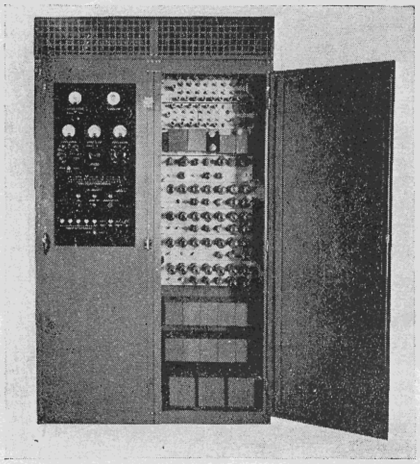


Figure 14 (left). Power supply and control

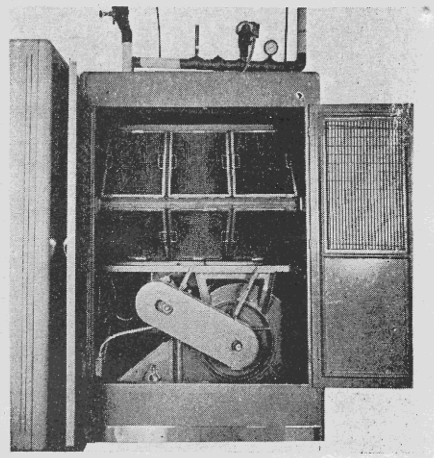


Figure 15 (right). Fan cabinet, interior view

cent. This figure does not take into account the fact that more than one tube may have been replaced in any particular socket. The actual survival figure would therefore be higher. Undoubtedly a large number of usable tubes have been replaced. The users of the machine place much more importance on the time the machine is available for use rather than on how long a tube stays in a socket. In attempting to locate some obscure fault in a chassis, all tubes may be tested. Those that look at all doubtful are replaced. It is likely that many of those replaced would have operated satisfactorily for a long time. Also, it is known that some tubes have been tested to rather exacting standards while the circuits in which they are used may be extremely tolerant as to tube characteristics. Although this type of tube replacement does not happen to agree with the procedures which we would recommend if tube life were the most important factor, the users apparently find that it produces for them the maximum amount of operating time.

Out of 2,385 crystal diodes used, 185 (or 7.7 per cent) have been replaced during the first ten months of operation. The diodes being used for replacement are of later design and manufacture than those installed originally. Their characteristics seem to be more stable than the earlier production. Therefore it is expected that the replacement rate should decrease as time goes on.

Up to this point, little has been said to indicate that there is anything undesirable in this machine. The characteristics and operational record of the 1101 make it equipment worthy of duplication. There are, of course, certain things which we would do differently in a new design.

1. A new machine would have a rapid access memory, retaining the drum for a large capacity storage.
2. More extensive use would be made of germanium diodes in order to reduce the tube count.
3. Tube count could also be reduced by making greater use of a central exchange register, thereby requiring fewer transmission gates.
4. A few circuits which have proved to be somewhat critical with regard to tube characteristics would be replaced. (For example, the ERA 1101 standard pulse is 0.1 microsecond wide. A wider pulse could have been used to advantage. The greater energy content obtained would allow circuit operation with smaller amplitude pulses. Thus, the tubes can deteriorate to a greater degree before affecting operation adversely.)

Some of the constructional features of the ERA 1101 which appear to deserve inclusion in new equipment are:

1. A plug-in chassis of about the same size.
2. A maintenance control panel. This panel could be a section of the operating console, but should be definitely separated from the strictly operational controls.
3. A magnetic drum for a large-capacity nonvolatile memory.
4. For cooling, an air-to-water heat exchanger with plenum chamber air distribution.
5. The same general scheme of protective devices as that used in the 1101: thermostats, air-flow detector, off-voltage, overcurrent protection, to name a few.
6. Conservative component deratings.
7. The general layout of the interchassis wiring.
8. Self-checking test problems plus adequate marginal checking provisions.

Figure 16 (below). Operator's control station and photoelectric tape reader

Figure 17 (right). Maintenance control panel