Discussion

B. J. Carr (Applied Physics Lab., JHU): Is this interrupt scheme now incorporated in a computer in existence?

Mr. Brooks: This system is being designed for a very powerful new computer and is not incorporated in a computer in existence. The computer is in part described in "Design Objectives for the IBM Stretch Computer," by S. W. Dunwell, in the 1956 *Proceedings of the EJCC.*

F. M. Verzuh (M.I.T., Cambridge, Mass.): Does IBM plan to make this program interruption device available on 704-709 on RPQ basis? If so, what is the rental price?

Mr. Brooks: I know of no such plans.

H. Siegal (Remington Rand Univac): If one bit in the indicator and mask registers is indicative of an overflow interruption, for example, how would you distinguish between a programmed overflow and a nonprogrammed one, within a sequence of operations?

Mr. Brooks: You can distinguish by masking out interruptions from overflow when intentional overflows occur. For several reasons, intentional overflows will be quite rare in this system. If you did permit interruptions to occur anywhere, you can, in the fix-up routine, decide whether the overflow was intentional by the instruction location at which the overflow occurred.

Mr. Hirmes (Curtiss Wright): Is the particular type of error indicated by each digit of the indicator register built into the machine or can it be varied? Second, wouldn't the second instructions of a two or more instruction fix-up routine be the first instruction of the fix-up routine of the indicator digit following the one under consideration?

Mr. Brooks: First, the particular condition for each indicator is built into the machine. Second, because the system only inserts one instruction into the program, the condition you describe would not occur. Since the counter is not changed from 49, for example, it can't step on to 50. Therefore, if you want a fix-up routine with several instructions, you must write it as a subroutine and enter it as a subroutine. The single instruction inserted into the program is the store instruction counter and branch.

F. B. Banan (General Electric Co., Evansdale, Ohio): Could you please say a few words about the application of interrupt in cases where it is desired to save the contents of the console and memory, read in a completely different program to process data for which immediate answers are desired, and then restore the original programs and proceed from point of interruption.

When will this interrupt system be available? What will be its cost?

Mr. Brooks: First, the interruption system permits operation in the mode you describe. This demands a different approach to console philosophy, but otherwise the procedure is straightforward. One must have the dumping routine in memory, at least enough of it to dump part of memory and load a more powerful routine. The console and memory can be dumped on tape or into slow memory, and the pressing problem handled. At its conclusion, the console and memory contents are restored with fairly simple programming, and one proceeds as usual. The interruption system permits the high-priority program itself to be interrupted by anything of higher priority (errors, at least) as defined by the programmer.

Second, the first machine with such an interruption system is scheduled for delivery in early 1960. The interruption system is integrated into the machine, and it is not possible to separately identify its cost.

A Transistor-Circuit Chassis for High Reliability in Missile-Guidance Systems

G. A. RAYMOND†

Organization

In recognition of the special needs of the situation, a unique team was organized to develop this computer. Early in the development program, the usual project organization was augmented with engineers trained in quality control, specifications, production engineering and mechanical design, plus mathematicians and statisticians skilled in the use of computers. Organizational lines were bypassed, and a closely-knit working group was established. As development progressed, a special manufacturing department was organized to work directly with the design group so that manufacturing processes would be consistent with the reliability requirements. Much of the success of the program resulted from the close working relationships between the design and manufacturing groups.

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Circuit Reliability

The desire to use mechanized-design techniques[1] as an aid to the logical design, plus a requirement for simplified maintenance, dictated the use of a small, relatively simple building block. The standard circuit (Fig. 1) uses diode logic with a transistor amplifier. The input diodes function as an OR circuit, the surface-barrier transistor as an inverter, or NOT circuit, and the output diodes as AND circuits. Direct coupling is used with -2 vdc representing binary zero and ground potential representing binary one. Up to six inputs may be provided. A *p-n-p* alloy-junction transistor connected as an emitter follower provides the power amplification necessary to drive the eight possible outputs. Over three thousand of these basic circuits are used in the computer, some as the basic inverter circuit,

[1] S. R. Cray and R. N. Kisch, "A progress report on computer application design," *Proc. Western Joint Comp. Conf.;* 1956.

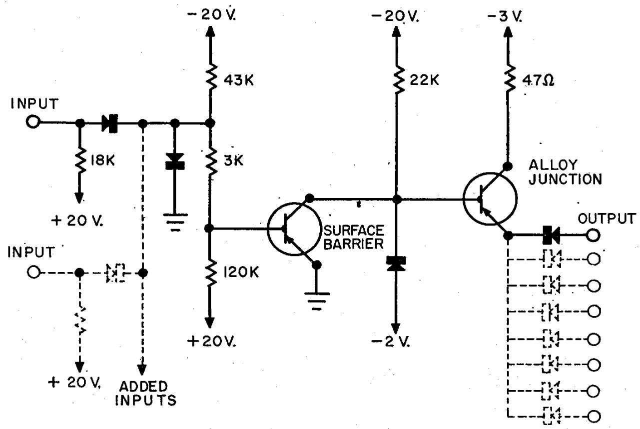

Fig. 1—Standard circuit for computer building block.

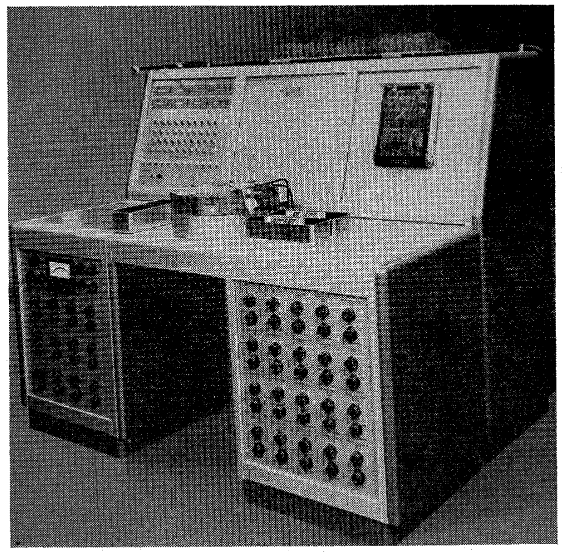

Fig. 2—Automatic transistor tester.

and others interconnected to form flip-flops. Altogether, 75 per cent of the computer is composed of this one basic circuit.

Since so many identical basic circuits are used, it became obvious that added circuit reliability could pay large dividends in computer reliability, and thus a major reliability effort was applied. Having established the circuit configuration and made the usual laboratory experiments, a program for the Univac Scientific was prepared using the circuit-design equations to compute optimum-circuit parameters.[2] After establishing criteria for expected parameter variation with life, the values of all parameters were calculated to give the maximum circuit stability. The results are impressive. Even after the beta gain of both transistors has dropped to two thirds of the purchase value, the diode reverse currents have increased from 50 to 400 μa, and all of the resistors have drifted 10 per cent in the worst direction, the circuit will still suffer a 10 per cent voltage variation without failure. Thus, it has been demonstrated that careful, detailed engineering will produce reliable circuits that remain reliable as the components age.

Component Reliability

The selection of components likely to contribute most to the reliability of the computer also required a comprehensive program. The decision to use transistors rather than vacuum tubes or magnetic-core switches resulted from an extensive investigation during which several small self-checking computers were built and operated. Substantial quantities of all types of components were subjected to heat, humidity, shock, vibration, low temperatures, and other destructive environments that might contribute information on comparative component reliability.

Particular care to detect a tendency toward catastrophic types of failure was necessary in this investigation. Components that deteriorate gradually with time would be detected and removed before failure occurred, while catastrophic failures would mean circuit failure every time. The final decisions on component choice had to be based on reliability and not electrical characteristics. Every engineer had to put reliability ahead of all other design requirements, and circuits had to be redesigned to use less efficient components where these proved to be more reliable.

Having established those components that were to be used, it became necessary to establish controls to assure that only these components would be used in manufacture of the equipment. Specifications were written covering every critical component with quality-level requirements exceeding the most rigid military specifications. Large samples drawn from every lot of components had to be subjected to rigid acceptance tests at the manufacturer's plant and again at Remington Rand Univac. To insure compliance with the specifications, Univac quality control representatives are stationed at each manufacturer's plant during the production and testing of the components.

The final assurance that only reliable components are used is the complete test of every component prior to introduction into the computer. In most cases this test is performed on specially designed automatic machines such as the transistor tester shown in Fig. 2. This unit, with a turntable arrangement, moves the transistor through a number of test stations. The test circuitry and parameters to be measured at each station are programmed on the plugboard at the upper right. Counters at the upper left record the rejects on each separate test while the components are being sorted into "accept" and "reject" categories. Extreme precaution had to be taken in the design of the test machines so that transients or equipment failures would not cause damage to the components being tested. This is extremely important in the case of surface-barrier transistors where even small transients may cause complete failure.

Continuous improvement of final screening tests is an important area where much can be done toward eliminating

[2] J. Alman, P. Phipps and D. Wilson, "Design of a basic computer building block," *Proc. Western Joint Comp. Conf.*; 1957.

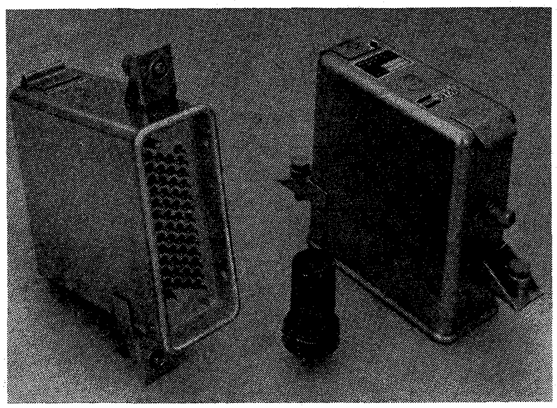

Fig. 3—Standard circuit packaging with vacuum tube for size comparison.

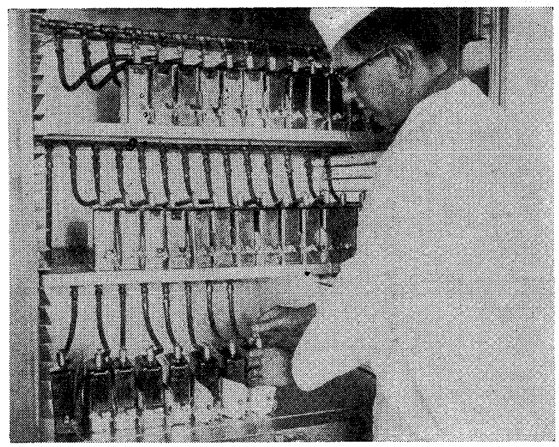

Fig. 4—Chassis are baked under high vacuum prior to sealing.

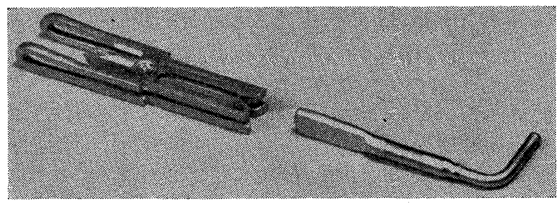

Fig. 5—Male- and female-contact assemblies used in special reliable connectors.

the "weak sisters" from component lots. Improvement of these tests is continuing as results from a large-scale component-testing program are received.[3] This program is being conducted by Inland Testing Laboratories in Chicago, Ill., and Battelle Memorial Institute in Columbus, Ohio, and will give life characteristics and data for screening tests on transistors, diodes, and resistors used in the computer. Approximately 60,000 components are on test in this program.

Reliable Packaging

Many of the components tested during the development program showed tendencies toward deterioration under certain environmental conditions. High humidity proved to be the worst offender, and complete protection of the components from humid atmosphere showed prospects of improving reliability. The results of this phase of the design effort are perhaps the most unique of all the work done to achieve greater reliability.

A specially designed connector, mounting two etched-circuit boards, is the standard package for all electronic circuitry in the computer, and all circuits are mounted in this fashion. The package design, shown in Fig. 3, provides positive hermetic sealing. Connector pins are brought out through glass to metal seals in the base, and a pressure valve is provided for pressurizing the chassis with dry gas. The seal around the base is made by induction soldering and may be unsoldered for repair of the circuitry. The manufacturing process includes a complete bake out of the chassis under high vacuum (see Fig. 4) to reduce the relative humidity below 1 per cent after sealing. The relative humidity may be checked by means of a humidity-sensing element inside each chassis.

The highly reliable contact arrangement is shown in Fig. 5. The arrangement is reminiscent of the knife switch used in power circuits with a flattened male pin and tuning fork shaped female contacts. Two completely independent pairs of contacts in the female connector give redundancy for added reliability. Of the 100,000 contacts in connectors used to date, not one single case of poor contact has occurred.

The etched-wiring boards mounted on the connector are fiberglass-epoxy laminate with rolled copper foil on one side. Extreme care is observed in selecting and processing this material so that the finished boards are completely free of scratches, pinholes, or other defects such as warpage or contamination. Assembly of the entire chassis is a "clean-room" operation with temperature and humidity control, white smocks and gloves for all operators, and strict process control. Policy prohibits touching any component with the bare hands. Any component that is dropped, even in a container, is rejected. Rework is carefully controlled and strictly limited. Complete records are kept of each operation on each unit including the time, date, and operator number so that assembly reference can be made during the routine failure analysis which follows every failure.

Dip soldering is used to attach the component leads to the etched wiring and also to connect the etched wiring to the connector pins. These two separate operations are performed on a selective soldering machine which permits masking the entire circuit and exposing only the areas where solder is desired. This procedure reduces the heat transfer to components and permits attaching the components to the board in one operation and the board to the connector in a following operation. Results of selective soldering are shown in Fig. 6. Following the dip soldering and prior to an electrical test, the completed board is given a temperature shock from room temperature to +155°F and then to −50°F. The temperature-shock treatment is further insurance against marginal components or connections that might later show intermittent failure.

[3] D. R. Bair and P. Gottfried, "Reliability results from large-scale testing," *Elec. Equip.;* January, 1957.

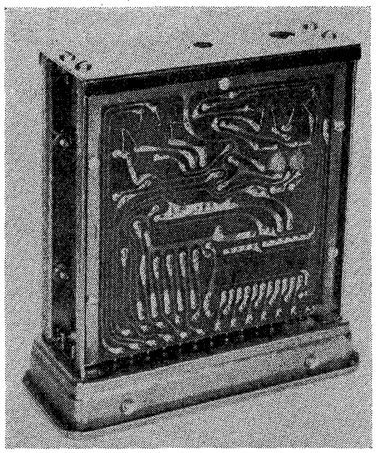

Fig. 6—Standard package without cover—showing results of selective soldering.

Final assembly of the sealed chassis includes pressurization with a mixture of nitrogen and helium thus allowing a standard helium-leak detector to be used for checking the final seal.

With the final seal complete and final electrical checkout satisfactorily performed, the chassis is installed in the computer panel as shown in Fig. 7. Insertion is performed with a special tool to prevent damage to the connector pins. The chassis is fastened in place with hold-down screws and is ready for operation.

Conclusion

The purpose of this paper is to present a broad picture of a reliability-design effort that achieved true reliability. The salient points may all be summarized in the one word—*attitude*. The desire for reliability must be present in the mind of each person from the chief engineer to the girl on the assembly line. The finest quality control cannot make a poor design reliable and the finest design will not be reliable if the person who builds it is careless. Careful attention to minor details in the selection of components, the design of the circuitry, the packaging of components, and the manufacturing process can pay off in a big way where reliability is the most important requirement.

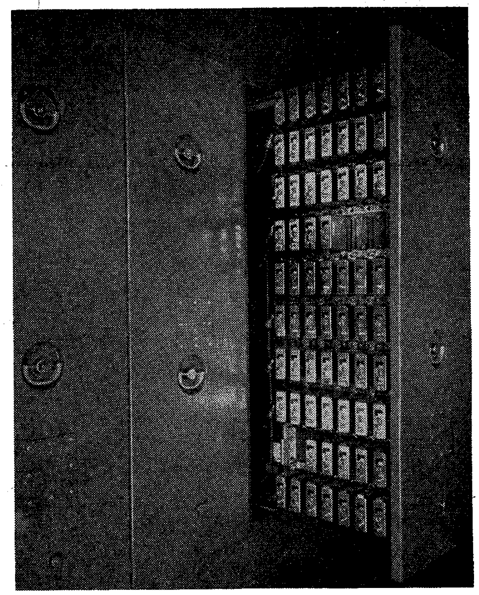

Fig. 7—Completed packages installed in computer rack.

Discussion

Since the discussion at the Conference dealt mostly with types and causes of failures, an updated summary from December, 1957, through February, 1958, follows.

From completion of the final checkout May 17, 1957, until March 1, 1958, the computer has operated 1613 hours. Failures considered in determining computer reliability were limited to those which, had they occurred during guidance missions, would have caused the mission to fail. They have been seven failures in this category. They are summarized below.

1) Intermittent chassis—the defect has not yet been located.
2) Intermittent chassis—defective solder connection inside pulse transformer.
3) Defective chassis—two shorted diodes, apparently damaged by externally applied voltage.
4) Defective chassis—collector-emitter short in transistor.
5) Defective chassis—collector-emitter short in transistor.
6) Possible intermittent chassis—has not been established as a definite failure, but is suspected.
7) Two rectifier stacks in the power supply—resulted from improper design in the switching circuitry.

Transients from the power supply are suspected as the cause in 4) and 5). No transistor failures have occurred since October when this defect was eliminated.

Two failures previously reported have been removed from this list after detailed study indicated that in one case there was no defect, and in the other case, that the defect would not have caused a computer failure.

There have been twelve chassis removed for reasons which would not have caused computer failure. Of these, four chassis were removed because of low gas pressure, six because of high humidity indication, and two because of defective indicator transistors. No other chassis have been removed for any reason.