Performance of TRADIC Transistor Digital Computer

J. H. Felker

At the Joint Computer Conference in February 1952, I presented a paper on the transistor as a digital computer component. My talk at that time was based upon some early experience with transistors which led to the TRADIC program. This paper will present a progress report on what has come out of those early experiences. In 1951 we had a high-speed point-contact transistor. We also had an amplifier using that transistor which could regenerate digital data at a pulse rate of 1 mc. At the request of the Air Force, a program was started to lead to a transistor digital computer for an air-borne application. The application can probably best be characterized by saying that it required a series of extensive computations to be performed periodically upon less than 20 input numbers. The number of outputs required from the machine is even less than its inputs. The computer was to become a part of a military machine; that is, its inputs were not numbers from an electric typewriter or a punched tape but rather were from shafts and special dials. Its outputs similarly were not printed sheets of paper but were shaft positions and operational signals to other machinery. Thus, a large number of problems which we faced had to do with conversions from analogue data to digital data and conversely.†

In January 1954, we completed a breadboard computer which is known as the TRADIC phase-one computer. This machine multiplies or divides in less than 300 microseconds (μsec) and adds or subtracts in 16 μsec. It is a serial machine and employs a 16-digit word length. It runs on less than 100 watts of power. The main supply voltage is 8 volts. Auxiliary bias voltages of 2 and 6 volts are also required. The machine uses a group of electric delay lines for its internal memory. It has 18 such electric delay lines each of 1-word capacity. It has provision for 13 16-digit constants which are stored in toggle switches. The program is stored in a plug board.

Although the machine was finished in January of 1954, it was not apparent for several months who had finished whom. The central computer was developed by a group under J. C. Tryon of H. W. Bode’s Mathematical Research Department. These problems were solved in a group led by J. C. Lozier. The work of both groups was substantially aided by S. Darlington and J. G. Lozier of H. W. Bode’s Mathematical Research Department.

The TRADIC phase-one computer is a complex machine. It has 700 point-contact germanium transistors and 11,000 point-contact germanium diodes. There are 6,000 resistors and 4,000 capacitors and more than 1,000 transformers. During the first month of operation, the machine suffered from the equivalent of the usual diseases of childhood and as soon as the measles were past, the mumps set in. Although the symptoms of many diseases were present, it turned out that there was only one ailment, loose and improper connections. On May 1, the machine was put on a life test which is still continuing. During this test, the machine operates 24 hours a day, usually on error-detecting programs. Since we are proud of the machine, we frequently interrupt it to run special programs and sometimes use it to produce useful output results. We find that it will run over periods of several days without errors of any kind. Since the machine is being operated in a building which is under continuous expansion and remodeling, we have been unable to obtain error-free runs of more than 8 days. The most valuable output of the machine and indeed one of the reasons for its existence is the reliability of figures that are emerging for transistors and diodes. The TRADIC computer is the first large-scale application of transistors and for that reason we are watching it very closely to see if we can get any clues concerning the reliability of the new solid-state art.

In the 5,000 hours that the machine has been operating, we have replaced four of the 700 transistors. One of these was replaced because the machine made transient errors. Another was replaced as the result of a human failure as much understood as regretted. Two were replaced because the voltage margins of the machine were deteriorating. These transistors had not caused the machine to make errors but they were replaced because it had been decided that the machine should have a voltage margin on the 8-volt supply of greater than ±0.7 volt. The four replacements have established a replacement rate of approximately 1/10 of 1 per cent per 1,000 hours. This means that a computer with 1,000 transistors in TRADIC circuits could be expected to require a transistor replacement about
once every 1,000 hours, or less frequently than once a month. We are frequently tempted to compute a half-life for transistors based upon this experience. Whenever we think of doing this we see how foolish it would be to make a prediction based upon what has happened to only four out of 700 transistors; yet consider how long we may have to wait before we have enough replacements to make a prediction of half-life with any certainty. It is questionable that the half-life is of practical interest since it appears to be comparable to the life of a human being.

What about the diodes? At the time we started the TRADIC program, we thought that we might use ten times as many diodes as transistors. We have used approximately 15 times as many diodes. We do not regret the use of the diodes. The aid that they give the transistor in performing its functions is no doubt an important contribution to the low replacement rate of the transistor. In the 5,000 hours of life we have had to replace six of our 11,000 diodes. Of these six replacements, two were the results of the same kind of human failure mentioned earlier and four replacements were required in order to keep the machine with good voltage margins. These four diodes were all used in the same spot in our regenerative amplifier circuit. This application makes a very stringent demand upon the reverse recovery time of the diode. Of course, in any future work with these circuits, we will obtain a diode better suited to the application. The diodes are hermetically sealed and the transistors are not. The replacement rate for the diodes is approximately 1/100 of 1 per cent per 1,000 hours.

Based upon newer devices we have seen, it is quite likely that device failure rates much lower than these will be observed. It is comforting and perhaps necessary to the ego of the circuit designer to blame the device when he explains failures. When quality transistors are available in large quantities, the weakest link in the reliability chain is likely to be the lack of thoroughness of the circuit designers. If failure rates of 1/10th of 1 per cent per 1,000 hours are to become common, the time constants of design and testing must be prolonged. A constant failure rate of 1/10th of 1 per cent, as indicated earlier, would predict a half-life of approximately 70 years. This means that years of testing and observation may be required to indicate the effects on reliability of design changes in devices and circuits. In one way we were fortunate when we worked with unreliable elements. We did not have to wait too many weeks before we found out whether or not a change had improved reliability or decreased it. Nature did not evolve the brain in a few million years. If we want to increase the complexity of the machines which we undertake, we should contemplate long programs of research and development.

**TRADIC Phase-One Computer**

The TRADIC phase-one computer is based upon a high-speed point-contact switching transistor which has been given many numbers in different mechanical versions. The cartridge version is known as the 1734, the bead version is known as the 1760, and the hermetically sealed version was known informally as the 1894 but is now officially referred to as the 2N67. The 2N67 is now in production at the Western Electric Company. The phase-one computer, which used the 1734, is not a small machine as can be seen from Fig. 1. There just was not time to investigate miniaturization.

Every transistor is used in the same fashion. That is, it is used as a regenerative amplifier. However, we associate the amplifier with a variety of logic and memory circuits. The machine is made out of the eight packages whose functions are listed in the following:

- **Basic TRADIC Packages**
  - AND—4 terminal
  - OR—4 terminal
  - INHIBIT
  - MEMORY
  - Passive Delay
  - Active Short Delay
  - Integrating AND
  - Clock Filter

We have a physical embodiment of each of these functions, which can be recognized as conventional logic, memory, and delay functions. Fig. 2 shows the packages. Note the point-contact transistor at the top of the package, a great profusion of diodes, and three transformers. All of these parts are commercially available except the transformers which are a special design based upon miniature ferrite cup cores. However, transformers of the same performance in somewhat larger size could be procured commercially. We associated these packages with one another in strips as is seen on Fig. 3. These strips plug into the frames which make up the computer. To give an example of what size might be realized through miniaturization, Fig. 4 shows an experimental TRADIC package. One can put 400 of these packages and their connecting circuits in a cubic foot.

**Fig. 3. Packages and mounting strip**

**Fig. 4. An experimental package**

*From the collection of the Computer History Museum (www.computerhistory.org)*
Three years ago, I made certain predictions which I have reviewed before undertaking any new ones. At that time, I felt that 400 or 500 transistors might be put in a cubic foot, and this density has been achieved. Within the next 3 years it should become possible to put five times that many transistors and associated circuits in a cubic foot. This advance will come about not from using smaller transistors, but by realizing equivalent performance with fewer associated components. The TRADIC phase-one packages are complex circuits. There are approximately 40 parts per transistor. The package density will also be increased, of course, as we improve understanding of what we have sometimes called the microconnection problem. That is, the problem of making, say, 1,000,000 connections in a cubic foot. To do this we must surrender the convenience of 2-dimensional mounting of parts and make full use of all three dimensions. We must do this, of course, in the interconnecting wiring as well as within the packages. A real obstacle is that we do not have a 3-dimensional equivalent of the 2-dimensional printed circuit board.

In so far as operating power is concerned, things have gone about as predicted. Flip-flops have been built with junction devices which operate on less than 100 microwatts of power. Repetition rates have been increased substantially over the past few years. The TRADIC machine running at 1 mc is competitive with the majority of the vacuum-tube computers. Another group at Bell Telephone Laboratories has succeeded in building computer circuits with point contact transistors which run at 3 mc. These circuits have been described in the literature by J. H. Vogelsong. The tetrod1 as made by R. L. Wallace of the Laboratories has proved to be capable of regenerating digital data at even higher rates. Both Wallace's tetrode and Early's p-n-a-p transistor2 make operation at 10 mc appear realizable in the next few years.

A major result which will soon be achieved is the combination of transistors and magnetic cores. About a year ago we were able to drive a 64-stage shift register with junction transistors at a 621/2-ka rate. The germanium alloy transistors used developed 200-milliampere pulses.

Since that time we have been using transistors to drive small matrices of cores and we expect to use transistors to drive large arrays of cores in the near future. Regarding predictions about the reliability which will be obtained it can be said that replacement rates as low as 1/100th of 1 per cent per 1,000 hours can be achieved with hermetically sealed junction transistors running at rates of about 100 kc. However, when such rates are claimed, it will take many years to establish them.

Discussion

E. S. McCollister (ElectroData Corporation): In view of the high component reliability figures you have given, do you think there will be a trend toward more or less checking units in the machine?

J. H. Felker: It is my personal opinion that we will not see a trend toward more checking in a machine; the kind of checking I am speaking of is the checking of the performance of the electronic components. Some of my most intimate associates disagree violently with me on this subject and there is room for difference of opinion, but I think we can build machines reliable enough that they just won't need the checking. If we increase the complexity of our machines by the factor of 100, and talk about 500,000 transistors, I think we will have to build in checking, not to obtain reliability figures you have given, but margin but as a rule, when this is done, some aspect of performance is sacrificed. You give a little and you take a little there.

We all look forward to having silicon transistors when we won't have this temperature limitation, but it is a very real limitation today. However, I have not seen a computer in many years which didn't have an air-conditioning unit attached to it.

H. Freeman (Sperry Gyroscope Company): D. F. Albanese (Federal Telecommunication Laboratories): Does the heat of the encapsulation process affect the transistors and diodes?

J. H. Felker: Well, one thing about temperature is that we were not quite as naive as I may have indicated. Before we put this machine on the air we took all the packages out and cycled them over a temperature range. We wanted to find out if we had any weaknesses here and I suppose we eliminated about 5 per cent that way. It was not a very severe temperature cycle, but it did last for 24 hours.

Does the heat of encapsulation process affect the transistors and diodes? It certainly affects some of the transistors. You know the old story about the Indians who threw their babies into the water to teach them to swim, and those who could swim survived. I think the heat of encapsulation has a beneficial aspect like that, too, as long as you don't have any humanitarian ideas about transistors.

It does kill off some of them, but I think it fortunate to be rid of those before you place a machine on the air.

E. Kinnen (Westinghouse Electric Corporation); R. J. Pfaff (International Business Machines Corporation); E. Sard (Airborne Instruments Laboratory); R. T. Prince (Armour Research Foundation): Please compare the junction transistors and point contact transistors.

J. H. Felker: The point contact transistor has been the fastest transistor we have had to work with. It also has been the transistor we had in quantity and has been reliable. The first junction transistors were not very reliable. That situation has improved enormously in the last year.

Junction transistors that are available are not as fast as point contact transistors, but I think it became clear to us about a year ago that the future is with junction transistors rather than point contacts. There were two things that convinced us of this. One was that physicists aren't interested in the point contact. They don't understand and won't work on the point contact so it will never be improved.

The junction device obeys the mathematics that they understand, and this is a real thing. If the best effort goes on a particular device, that device will get better.

The other thing which is equally significant is that the junction transistor is now becoming faster than the point contact. 10-megacycle regeneration of pulses

References


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can be achieved with a few of Wallace's better tetrodes, and we haven't been able to do that with point contacts. The p-n-i-p transistors will operate at higher frequencies.

There are only two things wrong with the tetrode and p-n-i-p: We haven't any, or rather we don't have enough to build a computer. We have small samples.

J. L. Hill (Remington Rand Inc.): Will you identify the 200-milliampere transistor and state your estimate of the date of its availability outside military channels?

J. H. Felker: We have had some internal codes which I would not like to identify since they would cause hard feelings back home; people would be asking for them and not getting them. We get them in small quantities—10, 15, 20—and as soon as we can get 100 or so we will build a core memory with them. But I believe that people haven't really done a good job of looking around at other suppliers. There has been a tendency to wait for the big companies to come out with good transistors. There are a number of small places making germanium-alloy transistors and I think if someone were willing to put four or five engineers to the task of surveying the output of these people they would find available transistors that would switch 200 mgs. Maybe the designers don't know it yet, but I think we are within the capability of a number of alloy transistors which they are putting out now.

Richard Walding (Remington Rand, Inc.): How do you find the bad components when they do not cause errors? Do you have a marginal check?

J. H. Felker: We have very extensive marginal checking. In Fig. 3 of the paper I showed the strips into which we plug packages, about 20 packages to a strip. We have each one of those strips plugged into a plug in the frame, and associated with the wiring for each strip is a group of switches which permit us to switch that strip from the regulated power supply, which, incidentally, is a transistor-regulated power supply, to unregulated power supplies. We can perform marginal checking on a frame basis on the whole computer, or on individual strips, and we do this frequently. We would not build this many switches into another computer, but this is a research model and we wanted to get as much data as possible.

We are a firm believer in marginal checking. As a matter of fact, I think people ought to marginal check their machines continuously instead of having regulated power supplies. We should have a power supply with a sine-wave variation of the voltage on it, perhaps not so bad if it is not more than a volt the machine is going wrong. When I have wished I had this was when I have known that in 3 hours I was going to have to demonstrate the machine. It would be very nice if I had had this a week before this machine had been working continuously with a 20-per-cent or 30-per-cent variation in the power supplies.

Marshall Middleton, Jr. (Westinghouse Electric Company): Is the failure rate of transistors and diodes a function of the number of times the circuit is turned on and off?

Franz Wagner (North American Aviation Corporation): Why do life tests take so long? How about designing some accelerated service tests?

J. H. Felker: Our computer is on all the time. We are trying to pile up hours of operation and we never turn it off deliberately, although nature sometimes does that for us. We lose power supply with hurricanes and construction, etc., but we have no evidence that a 200 microsecond should hurt the transistors. I think the low power we have used is significant in reliability.

Why do life tests take so long? I think if you have good devices life tests have to take a long time. It is very good to give accelerated life tests, but I don't know what they prove except that the devices stand the accelerated life test. Nobody has written a theory yet that I know of which relates the degradation features to the kind of life in which we are really interested. Our transformer people perform accelerated life tests and it is extremely important that they do so, but it isn't a complete substitute for having the machine run. To me there is no substitute for that.

K. Enslin (University of Rochester): What type of diodes did you use? Who are the manufacturers and what are the type numbers?

J. H. Felker: These diodes were obtained from the Hughes organization. They are excellent diodes, needless to say. We were delighted when they came out. Western Electric does not make a diode that would do our job.

There must be five or six different types used, and I think one reason we have the reliability we have is that the Hughes people were willing and anxious to make diodes to our specifications. I don't know if any of these diodes have Army-Navy designations yet or have commercial numbers, but when we were building the machine we certainly got them in large quantities and I would suspect that someone else could.

Incidentally, we have put out reports which are available through military channels; our Air Force contract is AF 33(600)-2153.

D. J. Niehaus (Bendix Aviation Corporation): What voltage tolerances were needed on the diodes?

J. H. Felker: We always tried to use the diode that had the highest back-voltage rating possible and then use it with as low a voltage as possible. Most of our diodes don't stand back voltages of more than a volt or two, except the diode in the clock circuit, which has to withstand 8 volts peak. This is the way we use diodes. There is one exception however. We had the four diodes that failed. They were all in one place. We made an error of judgment there. We needed a diode that would recover very rapidly after a forward transient and we wanted to recover to a back current of less than 100 microamperes in 1/10 microsecond. Hughes did a good job in supplying us with a diode to do it. There must be 700 or 800 of them in the machine, but the four, out of a total of 11,000, that went wrong were all of that same type. The back voltage at which that diode is tested is only 3 volts, so it was rather a marginal thing to do, even though in our circuit it receives a back voltage of only a volt. We might have been smarter to have let the diode have a poor recovery time in order to get a greater back-voltage margin and take a loss in margin elsewhere in the machine. But those are the things that are difficult to know in advance.

L. M. Schmidt (International Business Machines Corporation): Was an attempt made to utilize unsoldered wrapped connections in TRADIC?

J. H. Felker: There was no attempt to do so. I think that the wrapped connection described in the Bell System Technical Journal and probably in Western Electric advertisements is better than the soldered connection, but it was not a technique available for us. We are all interested in printed circuit cables, and I explained about the 2-dimensional limitation. It may be the wrapped wire connector that will give us the microconnection that we are looking for, because wires are remarkably efficient. You can pack them in three dimensions.
Application of the Burroughs E101 Computer

ALEX ORDEN

THE Burroughs E101 digital computer is designed to fill the gap between standard desk calculators and large-scale digital computers. The machine combines flexibility of operator access and judgment, as in use of desk calculators, with automaticity on repetitive routines, which is the great virtue of the large-scale digital computers. Use of the machine is expected to be generally on a decentralized basis, in individual offices and laboratories, rather than in a centralized computing machine installation. In many situations decentralizations of computations to the source of the data should more than compensate for the greater internal speed characteristic of large-scale computers.

The E101 can be used effectively on problems of moderate size in the same automatic fashion as a large-scale digital computer. On the other hand, it can be used as a "super desk calculator," that is, in a manner similar to a desk calculator, but with extension of the operations which can be carried out by the machine, from the basic arithmetic operations, to such operations as square root, trigonometric functions, standard deviation, etc. Finally, the combined approach, the handling of computations in a manner which involves a mixture of manual intervention and automatic sequencing, will be presented in this paper as an approach to computation which warrants a great deal of attention.

The sections which follow present:
1. A brief description of the computer in order to highlight its relation to other machines and provide a basis for the discussion of methods of application. (Literature available from the Burroughs Corporation provides detailed information on characteristics, programming, and operation.)
2. Methods of application of the E101, primarily with reference to engineering and scientific computation. The paper is not intended as a review of the general scope of applications, but specific topics are discussed to illustrate the general approach.
4. Accessories to the basic machine.

Description of the E101

A prototype of the E101 is shown in Fig. 1. Seen externally, it is the size of an office desk, has a numeric columnar keyboard input like a standard desk calculator, prints up to 12 digits at a time, at a rate of two words per second (that is, a maximum printing rate of 24 digits per second), and has the computation program stored in pinboards, which are located on the desk top to the right of the keyboard. Internally, the machine contains a magnetic drum of 100 registers, a 3-kw tubeless power supply, and electronic circuitry that involves the use of 163 vacuum tubes and 1,500 diodes.

The most novel construction feature is the pinboard programming unit. This involves, as distinct from most large-scale computers, storage of instructions separately from data. Instructions are, however, expressed in a single-address form of the type which is familiar in the large-scale digital computers, where instructions and data are stored in a single internal memory. For example, the instruction to add the contents of magnetic drum register 29 to the contents of the accumulator is written in the form, +29.

Such instructions are entered in the pinboard in the manner shown in Fig. 2. The pinboard has 16 lines, each of which holds one single address instruction. The three characters in +29 require the entry of three pins into a line, and these three pins are indicated by black dots in the top line of the illustration. One pin has been entered in the + column, as shown at the top of the pinboard, one pin in the 2-column in the set of columns that are used for the 10's digit, and one pin in the 9-column in the set of columns that are used for the units digit of the address. Eight such pinboards, each of 16-step capacity, can be mounted in the pinboard panel, giving 128 single-address steps. Transfers to subroutines are handled by instructions such as U 4 12, meaning unconditional transfer to pinboard 4 step 12, as illustrated on a lower line in Fig. 2.

Each of the eight pinboards can be removed and reinserted or replaced easily. The traditional block diagram for digital computers showing boxes for input, output, memory, arithmetic, and control is familiar to anyone who has dealt with large-scale digital computers; it is shown in Fig. 3 for subsequent comparison with the E101. The dashed-line block at the top of Fig. 3, "keyboard input for supervisory control," is usually omitted or considered to be covered by the main input block, but is pertinent here in relation to the E101.

This diagram serves well as a functional representation of most general-purpose digital computers. If desired, the input, output, and memory blocks can be shown as several blocks in those machines that contain more than one type of input-output or memory, but the basic character of the schematic remains the same.

By comparison, a functional block diagram for the E101 is as shown in Fig. 4. The keyboard is the main data input and the printer alone is the output. Coded input-output, shown in dashed lines, will be accessories to the basic machine. The instructions, in the form of pinboards, are indicated as an input because of their removability and interchangeability.

Finally, with regard to the general rela-

Fig. 1. The E101 digital computer

 Orden—Application of the Burroughs E101 Computer

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