Discussion

D. J. Theobold (U.S.N.E.L.): What type of core material was used?

Mr. Best: The cores for all our memories are made at M.I.T. so we do not have direct counterparts. Two larger memories use the materials which are quite similar to General Ceramics' S-1. It switches in one microsecond. The core material used in the index memory is a very low-gravity, coarse material that is not square enough to be used in the two-to-one selection. It switches with a driving current of 110 milliamp-turns.

E. E. Jungclas, Jr. (Hughes Aircraft): What are the operational temperature limits?

Mr. Best: The relatively high-speed core is used in the two larger core memories, with a high enough Curie temperature for most land base applications. The index memory that is used has a core that has quite a bit of zinc in it, in order to get the cores to force down. The Curie temperature of that is relatively low.

Jan Rajchman (RCA Laboratories): What is the inside diameter of the 0.047-inch cores?

Mr. Best: The inside diameter is 27 mills.

David Zeheb (General Electric): Would you amplify on the manner in which you use two cores per bit in the index memory?

Mr. Best: The two cores used in this particular bit are A and B (Fig. 10). The reason for using two cores is so that during "read" one can overdrive the cores very heavily, and switch them quickly, and therefore get short access time. You can only use two cores per bit when you have external selection, that is, some external active element for each word. The read current only goes through these cores, and it does not disturb any portion in the whole range. The main reason for going into the two cores per bit is to get a short read time.

When you have two cores there are actually four possible states of those cores; you can have both clear, or both set, right after you have read you have both cores cleared. But you never have both cores set, at least never on purpose. The primary reason for going into two cores was to get a fast read time (indicating on slide). A current of $\frac{2}{3}$ is set in the word line and a current of $\frac{1}{3}$ in the digit winding. These two windings are wound so that they add in one core and subtract in another. So, depending upon the polarity of the current in the digit winding, only one of the two cores would be set.

R. L. Compton (Librascope, Inc.): Do you mean to imply that the magnetic core memory system was operative to temperatures of the same order as the Curie temperature of the cores?

Mr. Best: No. The room is air-conditioned.

Transistor Circuitry in the Lincoln TX-2*

KENNETH H. OLSEN†

Circuit Configurations

ONLY TWO BASIC circuits are needed to perform most of the logical operations in the TX-2 computer; a saturated transistor inverter and a saturated emitter follower. To the logical designer who works with them, these circuits can be considered as simple switches which are either open or closed.

The schematic diagram of an emitter follower and the symbol used by the logical designers is shown in Fig. 1.

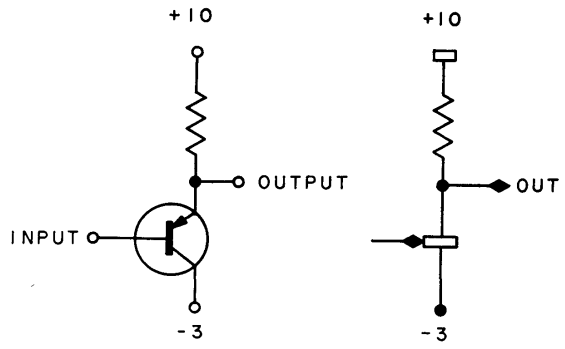

Fig. 1—Emitter follower.

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† Lincoln Lab., M.I.T., Lexington, Mass.

With a negative input, the output is "shorted" to the −3-volt supply as through a switch. When several of these emitter followers are combined in parallel, as in Fig. 2, any one of them will clamp the output to −3 v.

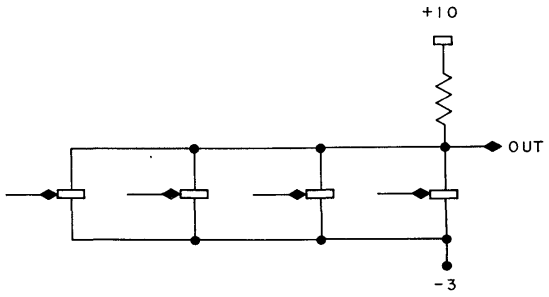

Fig. 2—Parallel emitter follower.

We have then an OR circuit for negative signals and an AND circuit for positive signals. The transistor inverter is shown in Fig. 3 (next page) with its logic symbol. Basic AND, OR circuits result from the connection of these simple switches in series or parallel (Figs. 4 and 5). More complex networks like the TX-2 carry circuit use these elements arranged in series-parallel (Fig. 6).

In Fig. 3 the resistor R_1 is chosen so that under the worst combinations of stated component and power

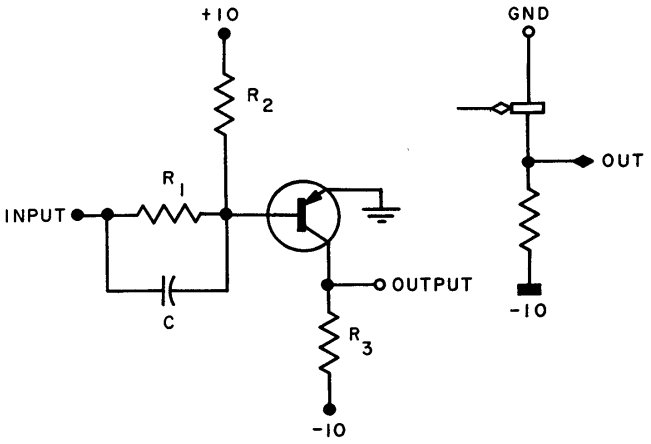

Fig. 3—Inverter.

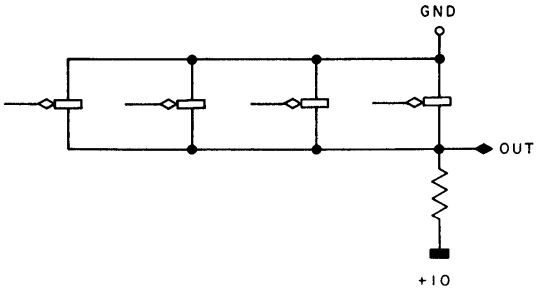

Fig. 4—Parallel inverters.

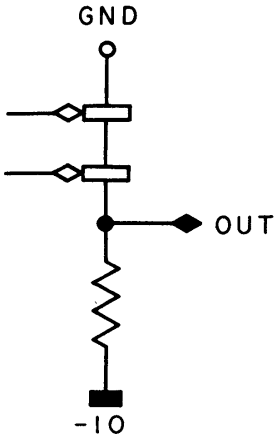

Fig. 5—Series inverters.

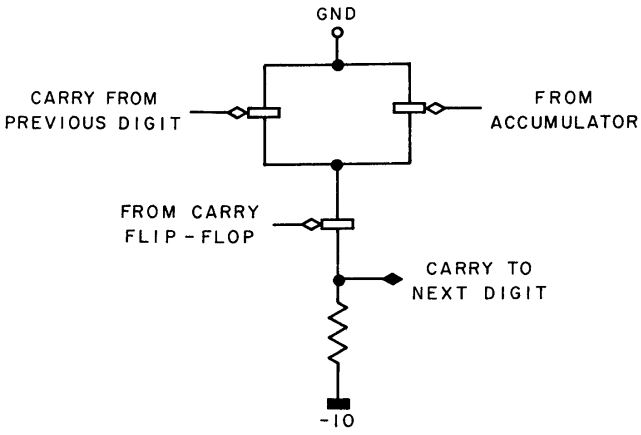

Fig. 6—TX-2 carry circuits.

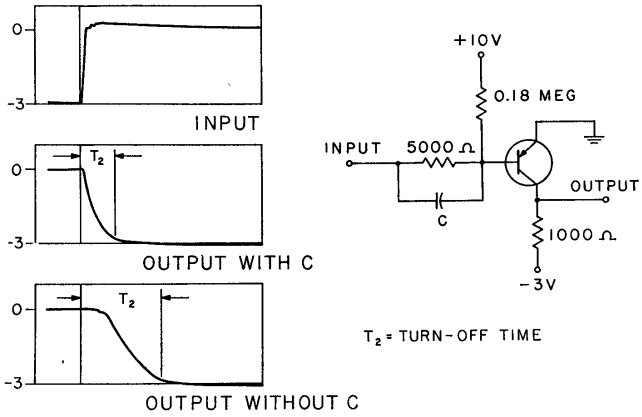

Fig. 7—Turn-off time.

supply variations, the drop across the transistor will be less than 200 millivolts during the "on-condition." R_2 biases the transistor base positive during the off condition to provide greater tolerance to noise, I_{co}, and signal variations. Capacitance C was selected to remove all of the minority carriers from the base when the transistor is being turned off. The effect of C on a test circuit driven by a fast step is shown in Fig. 7. Note that the delay due to hole storage is only a few millimicroseconds.

We run the circuits under saturated conditions to achieve stability and a wide tolerance to parameters without the need for clamp diodes. Unlike vacuum tubes which always need an appreciable voltage across them for operation, a transistor requires practically no voltage across it. In spite of the delay in turning off saturated transistors, these circuits are faster than most vacuum tube circuits. Faster circuit speed is not due to the fact that the transistors are faster than vacuum tubes, but because they operate at much lower voltage levels. A vacuum tube takes a signal of several volts to turn it from fully "on" to fully "off;" a transistor takes less than one volt.

Flip-Flop

On the basis of previous experience, we decided that the advantages of having one standard flip-flop were worth some complication in TX-2 circuitry. The circuit diagram of the flip-flop package in Fig. 8 is basically an Eccles-Jordan trigger circuit with a three-transistor amplifier on each output. The input amplifiers isolate the pulse input circuits and give high input impedance. The amplifiers give enough delay to allow the flip-flop to be set at the same time that it is being sensed. Fig. 9 shows the waveforms of this flip-flop package when complemented at a 10-megapulse rate. The rise and fall

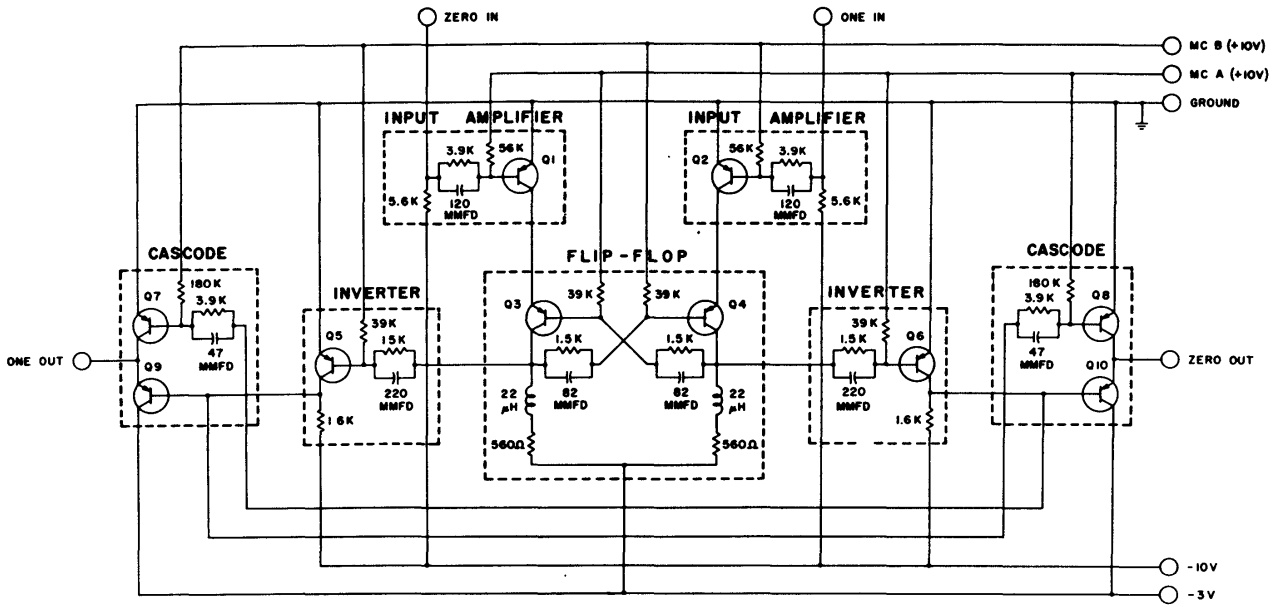

Fig. 8—TX-2 flip-flop.

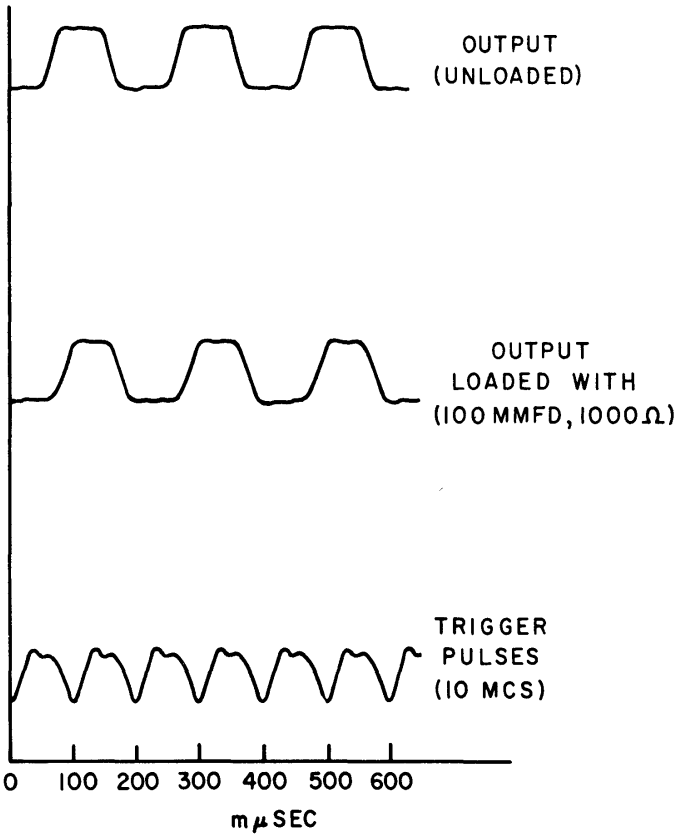

Fig. 9—Flip-flop waveforms.

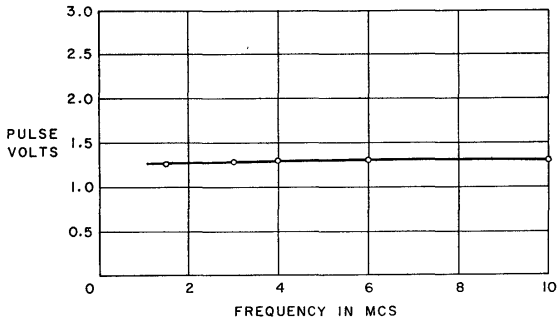

Fig. 10—Trigger sensitivity.

times, about 25 millimicroseconds, are faster than one normally sees in a single inverter, or an emitter follower because on each output there is an inverter that pulls to ground and an emitter follower that pulls to −3 v.

Fig. 10 is a plot of the pulse amplitude necessary to complement the flip-flop at various frequencies. Note the independence of trigger sensitivity to pulse repetition rate. This circuit will operate at a 10-megapulse rate, twice the maximum rate at which it will be used in TX-2.

The TX-2 circuits reproduced most often were designed with a minimum number of components to achieve economies in manufacture and maintenance. The design of less frequently reproduced circuits made liberal use of components—even redundancy to achieve long life and broad tolerance to component variations. The goal was system simplicity and high performance with a lower total number of components than might otherwise be possible. For example, the number of flip-flops in the TX-2 is small compared to the gates which transfer information from one group of flip-flops to another; so the flip-flops were allowed to be relatively complicated but the TX-2 transfer gates were made very simple. A transfer gate is only a single inverter. The emitter is connected to the output of the flip-flop be-

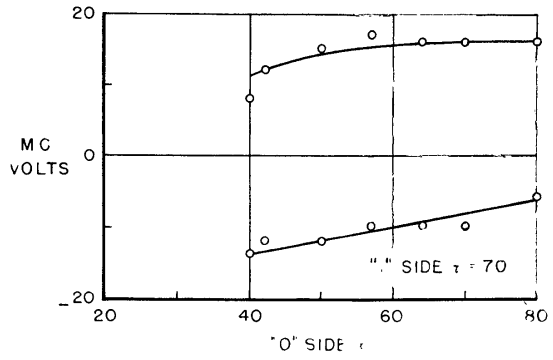

Fig. 11—Tau margins.

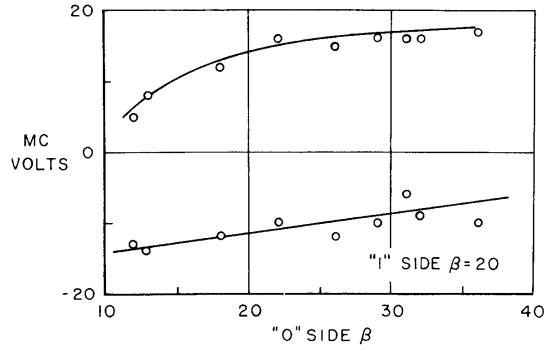

Fig. 12—Beta margins.

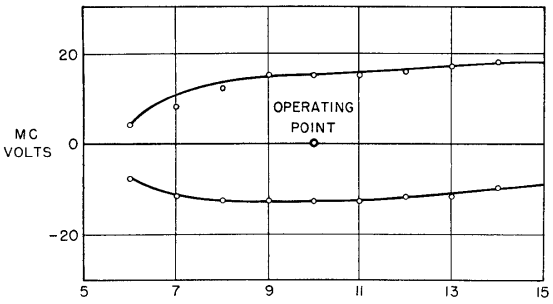

Fig. 13——10-volt supply margins.

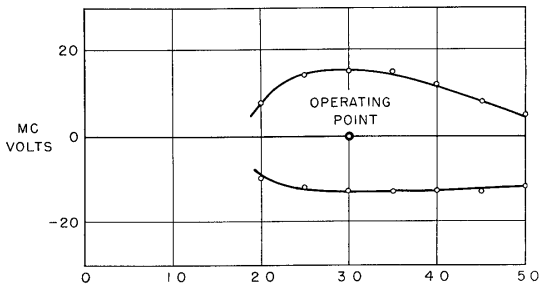

Fig. 14——3-volt supply margins.

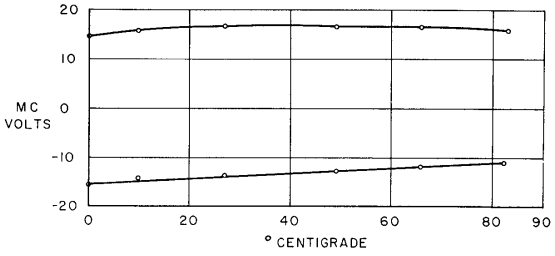

Fig. 15—Temperature margins.

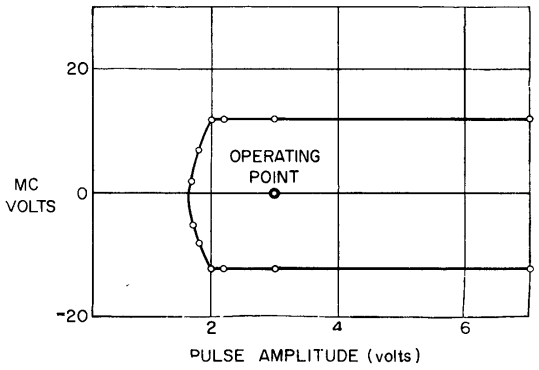

Fig. 16—Pulse margins.

ing read and the collector is connected to the input of the flip-flop being set. The output impedance of the flip-flop is so low that, when the output is at the ground level, a pulse on the base of the transfer gate shorts the input of the other flip-flop to ground and sets its condition.

Marginal Checking

We planned, of course, to incorporate marginal checking in the design of these circuits so that, under a program of regularly scheduled maintenance, deteriorating components could be located before they caused failure in the system. We also found it practical to use the technique during the design of the circuits to locate the design center of the various parameters and to indicate the tolerance of circuit performance to these parameters. A further application of marginal checking has been found in other systems during shakedown and initial operation to pin point noise and other system faults not serious enough to cause failure and therefore very difficult to isolate by other means.

The operating condition of the inverters is indicated by varying the +10-v bias. In the flip-flop schematic in Fig. 8, the inverters were divided into two groups for marginal checking, and the two leads labeled MCA and MCB were varied one at a time for most critical checking of the circuit. The following curves show the locus of failure points for various parameters as a function of the marginal checking voltage. Fig. 11 shows the tolerance to tau, a measure of hole storage and Fig. 12 shows the tolerance to beta, the current gain. Operating margins for supply voltages, temperature, and pulse amplitude are shown in Figs. 13 through 16.

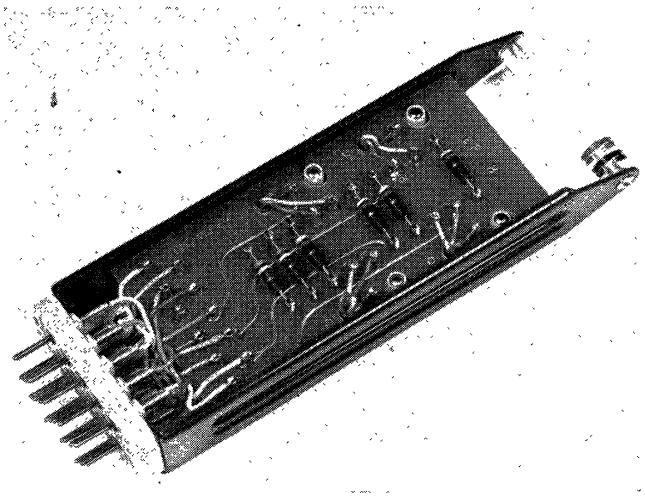

Fig. 17—TX-2 plug-in unit.

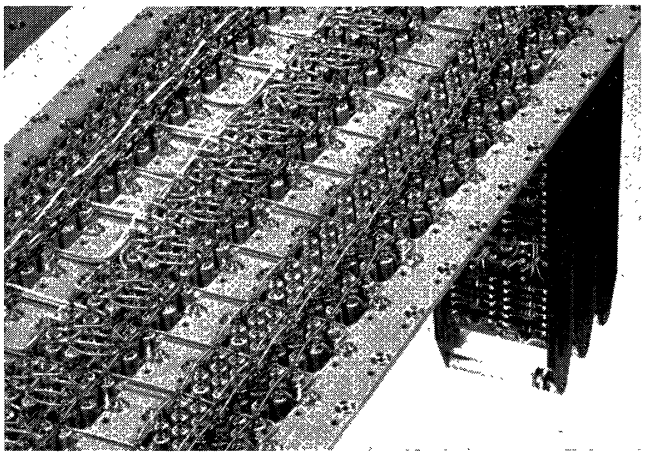

Fig. 18—TX-2 back panel.

Packaging

The number of types of plug-in units was kept small for ease of production and to keep the number of spares to a minimum. The circuits are built on dip soldered etched boards and the components are hand soldered to solid turret lugs. The boards are mounted in steel shells shown in Fig. 17 to keep the boards from flexing. The male and female contacts are machined and gold plated. The sockets are hand wired and soldered in panels as in Fig. 18.

Conclusion

The result of these design considerations is a 5-megapulse control and arithmetic element which will take less than 40 square feet of space and dissipate less than 800 watts of power. The simplicity of the circuits has encouraged a degree of logical sophistication which would not have been chanced before.

Acknowledgment

A number of people took part in the work reported here. Major contributions were made by B. M. Gurley, J. R. Fadiman, R. A. Hughes, K. H. Konkle, and M. E. Petersen.

Discussion

R. D. Gloor (Ramo-Wooldridge Corp.): What is the estimate of the expected mean-free-time between component failures for TX-2?

Mr. Olsen: The TX-0 Computer, which has been running eight hours a day since last April, has lost no transistors. So our experience with the TX-0 is that we expect the transistor portion of the machine to go for weeks without an error.

John Hayes (U.S.N.E.L.): What type of transistors are used in the flip-flops?

Mr. Olsen: The Philco Service Barrier Transistor was a key part of this development. It is tested to computer specifications.

We also use two or three thousand Micro-alloy transistors. We would like to use 100 per cent Micro-alloy transistors, but there were only two or three thousand available at the time we needed them. They have higher gains, particularly higher current, and appear to be much better transistors.

L. P. Retzinger (Litton): What is the propagation time per carry digit?

Mr. Olsen: About 40 millmicroseconds per digit. We made no effort to speed this up. This is a straightforward cascaded inverter, and it was the simplest type carrier we felt we could make. Even though it is slow compared to the rest of the circuits, in the over-all system it contributes very little to it in time or calculations.

Win Soule (Digital Techniques): How do you obtain visual indication of flip-flop position?

Mr. Olsen: We drive incandescent bulbs with a jumping transistor—a hardly satisfactory way of doing it: 400 transistors drive 400 incandescent bulbs. This is probably the best system as a whole, because it is not too expensive. We have been looking for less expensive ways for getting information.

L. H. Crandon (Autonetics): Are there any other sensitive parameters, different from voltage, which are used in marginal checking?

Mr. Olsen: One of course, can spend a lifetime comparing every parameter with every other parameter. Marginal checking gives you very good measure of most sensitive areas, and this is the one we concentrated on, and we feel that this is a reasonable approach to it, when one is limited by a limited length of time.

R. O. Barnes (Boeing): How much circuitry is represented in one plug-in unit (as shown in the figure) *i.e.*, how many flip-flops per unit?

Mr. Olsen: The figure shows that it contained one of the ten transistor flip-flops, plus three volume transistors. Three is in one package of cross section of one by two inches, one flip-flop plus a little logic; eight to twelve converters, or eight to twelve interfollowers.