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Memorandum M-1300



Digital Computer Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: TRIP TO BELL LABORATORIES, WHIPPANY

To: J. W. Forrester

From: D. R. Brown

Date: October 18, 1951

Abstract: The use of transistors in digital computers was discussed with Mr. Jean H. Felker who has designed and constructed a 16-digit serial multiplier using 44 transistors and no vacuum tubes. The basic prf is one megacycle. A regenerative pulse amplifier which takes advantage of the instability of the transistor is the basic active circuit. Good reliability has been obtained by providing adequate margins in the circuit design, and by selecting transistors by means of a dynamic test. The lower signal levels used are said to result in longer life for transistors and diodes.

On October 10, 1951, Messrs. Brown, Everett, and Taylor visited the Bell Telephone Laboratories, Whippany, N. J., to discuss the use of transistors in digital computers. Mr. Jean H. Felker of that laboratory has designed and constructed a 16-digit serial multiplier which uses 44 transistors and no vacuum tubes. The transistor computer occupies a portion of a relay rack and includes a frequency-divider, word generator, adder, and multiply control. All transistors are type M1734. The total power required is less than 5 watts. This power is nearly all signal power and therefore depends upon computer activity. A one-megacycle clock, which produces half-microsecond pulses, employs vacuum tubes and is placed in a different rack. One basic transistor circuit is used in all parts except in the frequency divider where 5 transistor blocking oscillators are employed. The blocking oscillator was the first circuit developed by Felker which would produce pulses with rise times of the order of 0.01 microsecond and durations of less than 0.5 microsecond. The blocking-oscillator frequency divider has been in operation since December of 1950 and two blocking oscillators have been in continuous operation since last June as part of a reliability test. No failures have been observed. The blocking oscillator was not used as the basic circuit for the rest of the computer because the pulse duration was found to vary too much from one transistor to another.

The circuit finally adopted was chosen after a number of tests on 100 type M1734 transistors. Felker found that if the circuit impedances were kept low enough to obtain the rise times desired, operation was unstable. The regenerative pulse amplifier finally adopted makes use of this instability. The transistor operates with base grounded through a 470-ohm resistor and a 470-ohm collector resistance. Operation is stable in the region of negative emitter currents and also, the input resistance is large. When the operating point is moved into the unstable positive-emitter-current region the circuit rapidly switches to a stable state where the impedance is very low, the order of 100 ohms, looking in from any point. The central clock is used to switch the circuit back to its initial state 0.5 microseconds later. The clock is directly connected to all regenerative pulse amplifiers, pulsing them at a one-megacycle rate.

Diode gates, "and" circuits and "or" circuits, can easily be appended to the input of the regenerative pulse amplifier. The d-c voltage levels at the emitter must be chosen with care. The quiescent operating point must not be too near the region of unstable operation. The situation is aggrevated by the fact that the edge of the unstable region, or peak point, not only varies from one transistor to another, but depends upon the temperature-sensitive collector current at negative emitter current. The variation in peak point determines the amplitude of pulse which must be used in the computer. Felker has selected transistors which give a peak point between zero and -0.5 v. The quiescent operating point is at -1.5 v and a positive 2-volt pulse is supplied to drive the emitter to +0.5 v.

The edge of the second stable region, or valley point, is also important; it must be more negative than the quiescent operating point of the emitter. Transistors having valley points between -2.5 v and -4 v are used. Felker has developed a dynamic test for determining the peak and valley points. The test is made in the circuit of the regenerative pulse amplifier with a particular pattern of input pulses and variable emitter bias. Static measurements are of little value.

The pulse at the collector of the regenerative pulse amplifier has a fast rise of a few hundredths of a microsecond, a flat top, and a not-so-fast fall. The fall may be delayed by hole storage.

The technique of using a single, basic amplifier circuit is very similar to that used in the SEAC. One advantage of the transistor is that the back voltage on diodes need not exceed a few volts. Lower back voltage on diodes is said to result in longer diode life.

An interesting sidelight was that of hole storage in germanium rectifiers. The degree of hole storage varies from one diode or transistor to another; in particular, from one production lot to another. In one Western Electric application in which a diode was placed in a relay circuit, the diode was required to withstand a sudden back voltage of 30 v when the relay opened. Operation was satisfactory until a particular batch of diodes was used, then failures became frequent. Trouble was traced to large back current immediately after switching. The back current was due to holes which had been produced while the diode was passing current in the forward direction.

Felker emphasized that reliability can be achieved with transistors, but that the circuit designer must provide the margins required by the transistor.

Some general aspects of our program were discussed with Mr. Alexis A. Lundstrom and magnetic-core storage was discussed with Mr. Walter H. MacWilliams, Jr.

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