puter, in Washington, D. C.) is of this kind, and has a one-line bus along which all pulses travel in a series. It works with numbers of 45 binary digits, and its speed of operation is 1,100 additions or subtractions per second, or 330 multiplications or divisions per second.

But there is one electronic computer (Whirlwind I, built by the Servomechanism Laboratory at Massachusetts Institute of Technology) which uses a 16-line bus along which pulses travel in parallel. It works with numbers of 15 binary digits and an algebraic sign, plus or minus. Because of the parallel bus, this machine is able to reach the speed of 30,000 multiplications per second.

Flip-flop

As we have already seen, the first thing we have to do with a pulse of information is to store it—hold it in such a way that we can use it later. For example, in Simon, we would feed a number into a set of relays and hold it there till we had fed another number into another set. Then we could add the two numbers together, or compare their size, or do something else with them. Without this *memory*—this ability to store a number until it is needed—a computer would be so limited that it would be almost useless.

Large computers may use relays to store information till needed, or they may use electron tubes. One type of computer (such as the International Business Machines Electronic Selective Sequence Calculator, located at 57th Street and Madison Avenue, New York City), uses tubes for very short storage periods and relays for information that has to be stored for longer periods. Information that must be remembered indefinitely is placed on long punched rolls of paper.

If we can make the counter count up to 1,001 (9 in the decimal system) and then reset when the next pulse is received, we have a *decade* counter, or one that counts in tens. (The pulse that resets the first decade is fed to a second as an integer, so that two decades can count to 99.)

One of the standard ways of storing a pulse of information electronically is the *flip-flop* circuit (see Fig. 2). It consists of two triodes (in one envelope, a 6SN7-GT, for example; or in two envelopes, two 6J5's for example), and it has two stable states: (1) triode V1 conducting and triode V2 not conducting; (2) triode V1 not conducting and triode V2 conducting.

Now let us take a look at the operation of the flip-flop. Suppose we put a negative pulse (or voltage drop) on the input lead L1. Capacitor C1 transmits this pulse, and it goes to grid G1. The negative pulse reduces the current through triode V1, and so produces a rise in the plate voltage on plate P1. This positive pulse is at once transmitted through capacitor C2 to grid G2, and starts triode V2 conducting. As it starts to conduct, the current flow lowers the plate voltage on plate P2. This voltage drop is at once transmitted as a negative pulse through capacitor C3 to grid G1, and makes grid G1 even more negative, tending to cut off triode V1. This process continues and rushes to conclusion in less than a few microseconds. Triode V2 is then conducting (at saturation) and triode V1 is cut off. As long as the power supply is on, the flip-flop records and stores the fact that a negative pulse came along on lead L1. The neon lamp lights when triode V2 is conducting, and indicates a "1" stored in the flip-flop. The lamp is off when a "0" is stored.

Another consecutive negative pulse on L1 will now have no effect, but a positive pulse on lead L1 or a negative pulse on lead L2 will cause the flip-flop to change back to its original state. In regard to lead L2, we can see that a similar description applies symmetrically.

Now let us consider lead L3, which runs through capacitor C5 to the cathodes of both triodes. A negative pulse on this lead will cause a change of state in the flip-flop, no matter which of the two triodes is conducting. So the flip-flop will actually count, 0, 1, 0, 1, 0, 1, 0, 1, 0 ......, depending on the number of negative pulses that come in on this lead. A positive pulse will have no

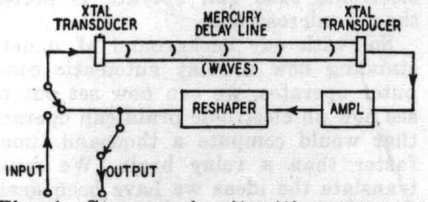

Fig. 4—Storage circuit with a mercury delay line and two crystal transducers.

effect. However, the shaping of these pulses may require additional components, while the shapes of the pulses used on leads L1 and L2 are not too critical.

This flip-flop is very similar to one actually used in the ENIAC, the first big automatic electronic computer. ENIAC was finished in 1946 at the Moore School of Electrical Engineering, and is now operating at the Ballistic Research Laboratories, Aberdeen, Maryland. (The ENIAC flip-flop is described further in a paper "High-Speed N-Scale Counters," by T. K. Sharpless, in *Electronics*, March 1948.)

Now suppose we hitch three more flip-flops in succession to this first flip-flop (see Fig. 3). We impulse FF1 by lead L3, so that (1) it changes state on every pulse, and (2) it puts out on output lead L4 alternately a positive pulse and a negative pulse. We connect lead L4 on flip-flop 1 to lead L1 on FF2; then only negative pulses on L4 cause flip-flop 2 to change state. We make similar connections, between FF2 and FF3, and between FF3 and FF4. Then we have a binary counter that will count 0000, 0001, 0010, 0011, 0100, etc., up to 1111. Capacitors C1 and C2 are used to trip the counter back to 0000 after holding 1001. This is the principle used in the 4-tube counter decade described by John T. Potter in *Electronics* of June, 1944.

For storing one binary digit of information, a 1 or a 0, a flip-flop is decidedly expensive. Consequently it is used only in those parts of an automatic computer where a great deal of traffic with information requires the convenience and justifies the expense.

Delay line

Another scheme for storing information in an electronic computer is the *sonic delay line* (see Fig. 4). A sonic delay line consists of material which will transmit pulses as a series of molecular vibrations, more slowly than the usual wire conductor. It may be made of a solid, or of liquid in a tube, or air, in the case of an echo.

For example, think of a long rope, one end in your hand, the other end tied, and the whole rope pulled fairly taut. You shake your hand quickly, and a wave (or pulse) will travel down the rope. As soon as one wave (or pulse) has been started down the rope (or delay line), another can be started almost immediately after it, and the second will follow the first one without interfering with it. Thus what is basically needed for a sonic delay line is any medium down which a pulse may travel. As long as the medium is built suitably, the pulse will not die out until it is needed.

Now in the case of the rope, when the wave or pulse reaches the end of the rope that is tied, the pulse is reflected, and a wave of reversed phase travels back. Of course, reflected waves are not wanted, and a sonic delay line, contrary to the rope, is designed so that reflections are eliminated or rendered unimportant.

We therefore can see that information is stored in a sonic delay line as a series of pulses and absences of pulses, a pattern of 1's (the presence of pulses) and 0's (the absence of pulses).

The pattern is retained by sending it around and around a loop. How do we "write" information in a sonic delay line? We feed a series of pulses and absences of pulses into it. How do we "read" information from the line? We send it along two channels, one the channel back to the front end of the delay line, so that the information will circulate and be remembered, and the other the channel into the part of the computer where we want to use the information, say, into a bank of flip-flops. How do we "erase" information in the delay line? We interrupt the circulating loop long enough so that all the pulses are eliminated.

A type of sonic delay line that has been used quite widely in electronic computers is the *mercury delay line* or *mercury tank* (see Fig. 4). At each end of a long tube filled with mercury is a quartz crystal in contact with the mercury. When a voltage pulse is applied to the quartz, its shape changes (piezoelectric effect). The quartz agitates the mercury, and sends a ripple down the tank. The ripple is picked up at the far end by another quartz crystal and there converted back into an electric pulse. It is somewhat smeared, and so