delay lines such as the mercury tanks described in the previous article, because the purpose of the short delay line is not storage but computation. Short delay lines are important because pulses sent into the various parts of an electronic computer must arrive at the various points just when they are needed. For example, in the Bureau of delay times are figured to hundredths Standards Eastern automatic computer,

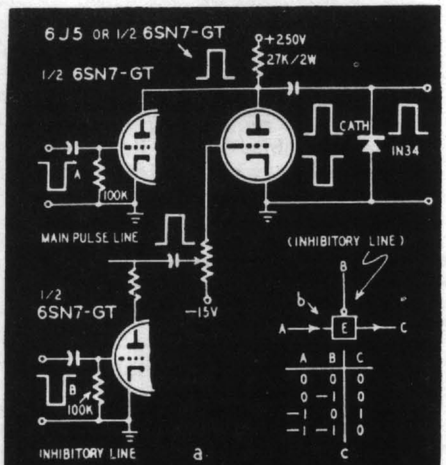

Fig. 5—A logical EXCEPT circuit. The pulse input at A appears at output C except if there is a pulse at input B.

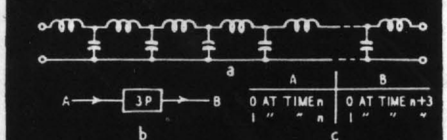

Fig. 6—Electrical delay line as used in computers. The 3 in the block symbol denotes a delay of three pulse times.

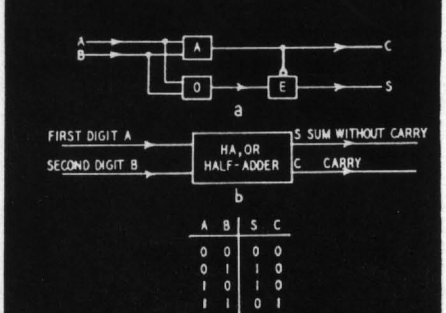

Fig. 7—This half-adder circuit gives the result of adding two binary digits.

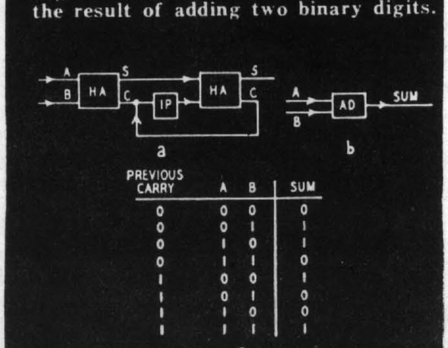

Fig. 8—An adder circuit is made up of two half-adders and a one-pulse delay.

of microseconds and pulses are timed to be safely within the planned intervals.

Half-adder

Now how do we take these various computing elements and begin to do computing with them?

The first thing is to assemble these elements so that we can add two binary digits. Suppose there are two input lines A and B, and either one may bring in a binary digit that may be 1 or 0. Suppose that we have two output lines, one of them S, that will give us the sum without carry, and the other C, that will give us the carry. The function that we want to express is the result of adding two binary digits: $A + B = C, S$, where $0 + 0 = 00$, $0 + 1 = 01$, $1 + 0 = 01$, and $1 + 1 = 10$. See Fig. 7.

To make a half-adder circuit, one logical AND circuit, one logical OR circuit, and one logical EXCEPT circuit, combined as shown in Fig. 7-a, are sufficient.

Adder

But we are not finished, because a previous addition may have given a carry that has to be taken into account. The circuit which will perform complete binary addition is called an *adder*. See Fig. 8.

Now let us trace through the adder circuit with some numbers and see what actually happens in the sequences of pulses on the several lines in the circuit.

The digit 1 will represent a pulse (assumed to be positive or negative as the circuit requires), and the digit 0 will mean absence of a pulse at the proper time. At the same time the digits 1 and 0 will represent information that we desire to compute with.

Suppose we write a binary number (or more generally any set of binary digits) in the ordinary way (with the smallest ranking digit at the right) on any circuit line where the pulses are traveling from left to right. Then the binary number will be attended to as a pattern of pulses by the circuit in just the sequence from right to left that we ordinarily deal with in arithmetic. At the same time the number will show the sequence of pulses in the order that they are handled in the circuit.

As an example of using the adder, let us add 101 (one 4, no 2 and one 1 in binary, or 5 in decimal) and 1011 (one 8, no 4, one 2, and one 1 in binary, or 11 in decimal). We write the two numbers on the input lines A and B (See Fig. 9) and now we set out to see what happens.

At the first pulse-time, the pulse (the 1) on the A line and the 1 (another pulse) on the B line go into half-adder No. 1, and give rise to no pulse on the S line (sum without carry) and a pulse on the C line (carry). The 0 on the S1 line goes into the second half-adder without delay; but the 1 on the C1 line goes into the one-pulse delay and so it is held back one pulse-time. As a result, at the first pulse-time, 0 and 0 go into the second half-adder; and so its output is 0 for the first digit of the true sum, and 0 for the carry. The 0 for the carry circles round the loop and comes up to the entrance of the one-pulse delay.

At the second pulse-time, 0 and 1 go into the first half-adder, and give rise to a 1 on the S1 line and a 0 on the C1 line. The 1 on the S1 line goes into the second half-adder without delay. Now the delayed previous carry (with no conflict from the absence of pulse that came around the loop) now issues from the one-pulse delay. So 1 and 1 now enter half-adder No. 2, and from it issues a 0 on the sum line S2 and a 1 on the carry line C2 which circulates around the loop, and enters the one-pulse delay so it will be ready for the next pulse time.

At the third, fourth, and fifth pulse-times, each of the proper operations takes place similarly, and so we get out of the second half-adder exactly the sum that we desire.

Subtracter

Now how do we manage to subtract? A circuit that will subtract is shown in Fig 10, using the constituents of an adder, and a logical EXCEPT circuit. The word "minuend" means "the number to be diminished." The word "subtrahend" means "the number to be subtracted."

Let us test this circuit by subtracting five from eleven, or in binary subtracting 101 from 1011. The pulses appear in succession on each of the lines in the diagram, as shown. By following through the circuit, remembering what each stage does, we see that exactly the right answer, 0110 or six, appears on the output line marked "difference."

Acknowledgement is made to Henry W. Schrimpf for a number of the circuits and ideas in this article.

In the next article we shall take up the multiplication and division of binary numbers using electronic circuits and begin the discussion of the control of an electronic computer.

(continued next month)

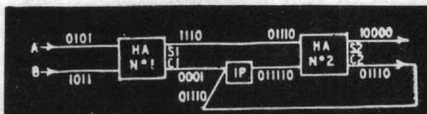

Fig. 9—The numbers on this adder show how 0101 is added to 1011 to get 10000.

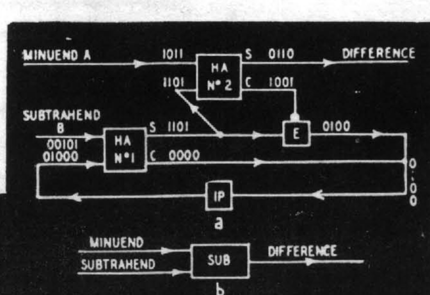

Fig. 10—Diagram of a subtracter. This one is taking 101 from 1011 to get 110.