of the scale of notation. We obtain the *ones complement* of a binary number by taking each of its digits away from 1. The *twos complement* is then equal to the ones complement plus 1.

So to subtract in binary:

1. find the *ones complement* of the number, by taking each digit away from 1;
2. obtain the *twos complement* by adding 1 to the ones complement;
3. add the *twos complement*, and discard the extreme digit on the left.

Suppose we do this arithmetically first, and then examine a series of circuits which will produce the same result. Let us return to the example of subtracting 101 from 1110. Let us assume that we have a five-column binary calculator. The *ones complement* of 101, then, is 11010; adding 1, we get the twos complement, 11011. We add:

$$\begin{array}{r} 1110 \\ +\ 11011 \\ \hline 101001 \end{array}$$

The extreme left-hand digit 1 vanishes ("goes off the keyboard") and the result is 1001, the same result as before, as would be expected.

Subtraction circuits

A series of circuits for subtraction is shown in Fig. 1. First (see part 1), the number to be subtracted is stored in the C register in relays C5 to C1. The example shows 101 stored (or 00101) where the first 0 tells us the number is positive. The C3 and C1 relays only are energized as shown in red. At Time 1, terminal T1 holds these relays energized through their hold contacts.

At Time 2 (see part 2), the ones complement of the C number is obtained, by reading out from terminal T2 through normally closed contacts of the C relays, into the D relays. Hence, the number stored in the D relays is 11010, precisely the ones complement of 00101.

All the rest of the calculation is "reduced to the previous case," as the mathematicians say: reduced to transfers and additions, which have been described in earlier articles but are as follows:

The D number—the ones complement —(see part 2) is transferred via the transfer circuits of part 4 into the augend relays of the addition circuits (see part 5). A constant 1 stored in the relay E1 (see part 3) is transferred (see part 4) into the addend relays of the addition circuits (see part 5). The sum obtained in the sum register, the S relays (see part 5), is routed back via the transfer circuits of part 4 (and perhaps via an extra temporary storage register) into the addend relays of the addition circuits. So at this point we have the twos complement of the number to be subtracted, stored in the addend of the addition circuit.

Next, the number to be diminished is transferred from whatever register it is stored in via the transfer circuits of part 4, into the augend relays (see part 5) of the addition circuit.

Then finally we pulse the addition circuit a second time, and the result of the subtraction is produced in the sum register of the addition circuit.

Note that the transfer circuits of part 4 are here assumed to transfer a five-digit binary number from a five-relay register via a five-line bus into another five-relay register. The transfer circuits of Article I of this series show only two-relay registers and a two-line bus; but the extension should give no difficulty.

Plus and minus numbers

At this point we start thinking again and say to ourselves, "It is foolish to have a calculator that can only handle positive numbers. Our calculator should handle both positive and negative numbers. How shall we arrange that?"

A good answer, though not the only one, is to agree that the extreme left-hand digit of the number will tell the

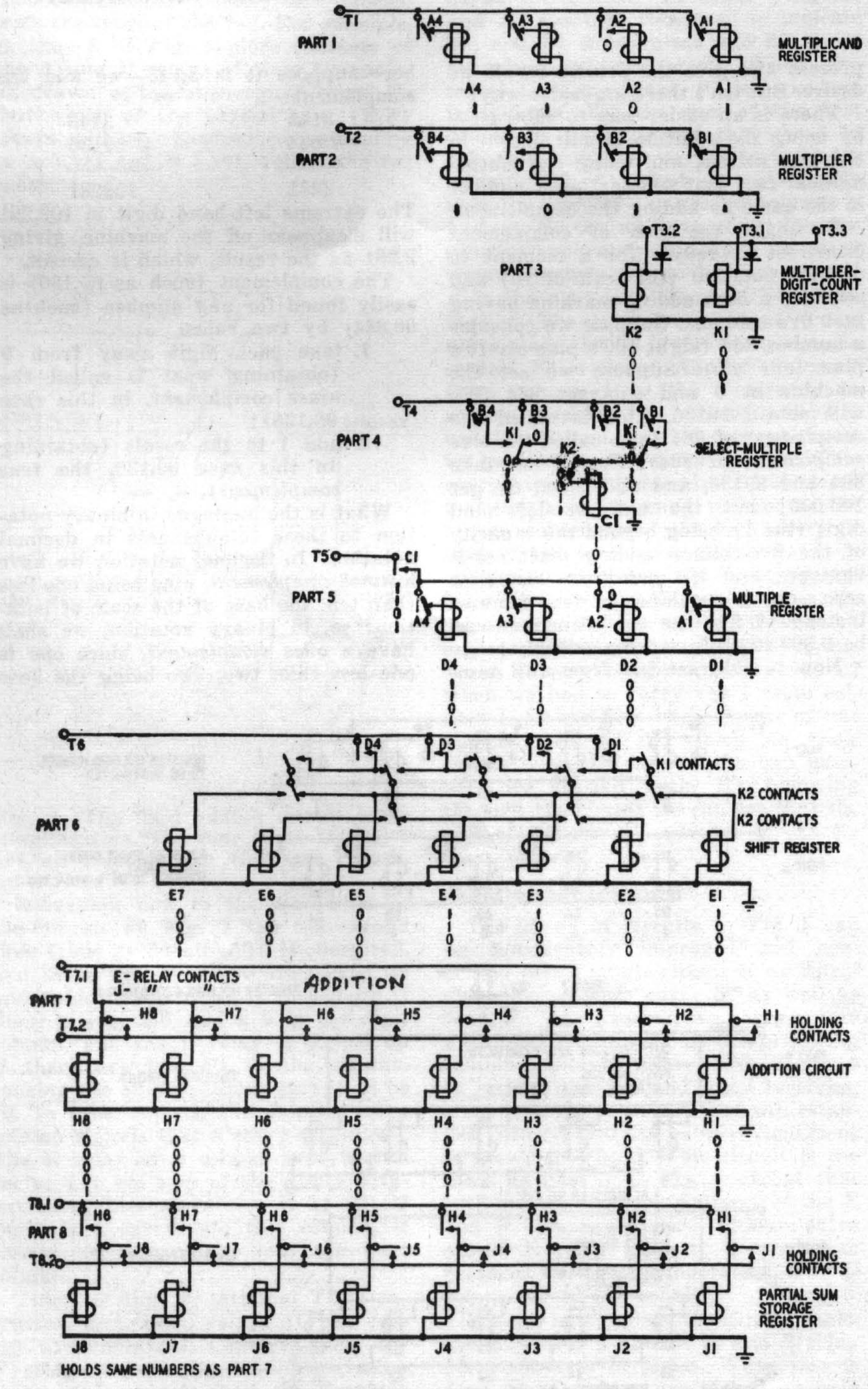

Fig. 2—A relay multiplication circuit. It is really an adding circuit which shifts successive multiples of the multiplicand to the left and adds them.