energized and relay A3 is not energized. Suppose 1,101 is stored in the B or Addend register. Then relays B4, B3, B1 are energized, and relay B2 is not energized. In the diagram the relay contacts that will be closed for this particular state are shown in red. The energized coils are marked with a 1 and the unenergized coils with a 0.

Let us stop for a moment to explain the convention used in the figures. The coils of relays are *not* drawn next to their corresponding contacts, as is common in radio work, but follow a practice common in electrical diagrams: The contacts of a relay are labeled with the label of the coil. For example, in time 2 of Fig. 1 more contacts of the A and B relays of time 1 appear, all drawn in the unenergized state. To find which of the partial sum (E,F) relays will be energized corresponding to A 1,011 and B 1,101, follow the red contacts.

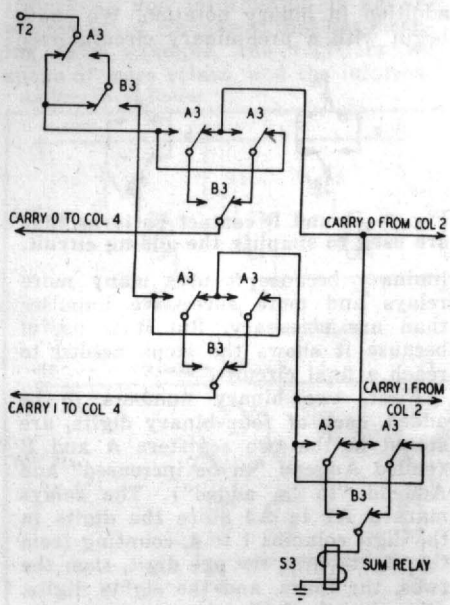

Fig. 4—The final adding circuit after simplification. The four parts of Fig. 1 are all combined in this one circuit.

Returning now to the discussion of the circuit of Fig. 1, at the second time (time 2) terminal T2 is energized, and the E and F relays are picked up and held. The E relay is picked up if there is just a 1 and a 0 in the digit column, and the F relay is picked up if there are two 1's in the column, causing the sum (without carry) to be 10. In other words, the F relay of a column signals that a carry originates. The E relay of a column reports two facts: (1) the sum of the digits without carry in that column is 1; (2) if there is a carry into this column, it should be transmitted into the next column.

Third, at time 3, terminal T3 is energized, and the C relays (C for carry) are energized. Contacts from the F relays report the originating of a carry, and contacts from the E relays do the transmitting of the carry.

Fourth, at time 4, terminal T4 is energized, and the binary sum is recorded in the S (S for sum) relays. Any sum relay will be energized under two conditions: (1) the sum without carry in a column is 0, and there is a carry of 1 arriving in that column; (2) the sum without carry in a column is 1, and there is no carry of 1 arriving in that column.

Some circuit tracing

To test the circuit of Fig. 1, let us follow through the addition of the first two columns of the two numbers we are adding (1,011 and 1,101). These two columns will have 11 as the augend and 01 as the addend. To begin with, A1 and A2 are both energized to indicate 11; and B1 is energized and B2 is not energized to indicate 01. When terminal T2 is energized, F1 is picked up to indicate that the sum of the first column is 1+1=10 and that the 1 in this sum must be carried to the next column. E2 is picked up to indicate that the sum of the second column is 1+0=1. So far we have added the two columns separately and have indicated where numbers are to be carried.

In the next step terminal T3 is energized. The carry from column 1 now takes place and C2 is picked up because contact F1 is closed. Adding the carry from column 1 to the 1 already in column 2 makes the sum of column 2 equal to 10 and the 1 of this sum must be carried to the third column. This carry takes place because E2 is closed to indicate a 1 already present in the second column, and the new carry is transferred to column 3.

In the final step T4 is energized. Now S1 is not picked up because E1 was not picked up when T2 was energized. S2 is also not picked up because E2 was energized, but so was C2 when we had to carry the 1 from column 1. So the first two columns of our addition will be 00, which we know checks with the sum of the two numbers we started with. By following through the circuit we can see that the rest of the circuit operates in exactly the same way.

A simplified circuit

The group of circuits in Fig. 1 can be considerably improved and condensed into a single circuit if we introduce the concept "carry 0" as well as "carry 1". In general, we carry 0 into a column if, and only if, the preceding column contains either both digits 0 or just a 1 and a 0 and is not receiving a carry itself. A circuit that will establish both carry-0 and carry-1 conditions is shown in Fig. 2. This circuit is the same as part 3 of Fig. 1 except that both make and break contacts of the E and F relays are used and an extra set of E relay contacts is needed to perform the carry-0 operation. The G relays record the condition of carry 0.

We can now replace the F relay make contacts with a pair of A and B relay make contacts in series. When this is done, the C relays are picked up only when both A and B relays are energized, which is the condition we need to indicate a carry.

We further simplify by replacing the E make contacts by the pattern of A and B contacts shown in Fig. 3-a and the E break contacts by the arrangement of Fig. 3-b. Now the G relay is energized through the A and B contacts only for the carry-0 condition and the C relays for the carry 1.

Instead of allowing the lines to lead down to the G and C relay coils we insert the E and C contacts of part 4 of Fig. 1, but immediately replace these with a pattern of A and B contacts. The circuit then looks like Fig. 4, which shows the relays only for column 3. (Note that the adjacent B contacts are combined in a single contact.)

There are four conditions when the S3 relay must be energized:

1. A3=0, B3=0, carry 1 in;
2. A3=1, B3=0, carry 0 in;
3. A3=0, B3=1, carry 0 in;
4. A3=1, B3=1, carry 1 in.

For condition 1, the S3 relay is picked up directly through the carry-1 line from column 2 and the carry 0 is appiled to column 4. For conditions 2 and 3, S3 is energized directly by the carry 0 from column 2 and carry 0 is also fed to column 4. For condition 4, S3 is operated by the carry 1 coming in, and a carry 1 is fed to column 4. Under these conditions, but no others, will the S3 relay be energized. By similar reasoning, we can list the condition for which we want S3 to remain unenergized and whether we want a carry 0 or carry 1 to go to the next column. Then with a little more tracing we will see that the circuit of Fig. 4 will meet all these conditions. Doubtless this circuit also can be improved and simplified