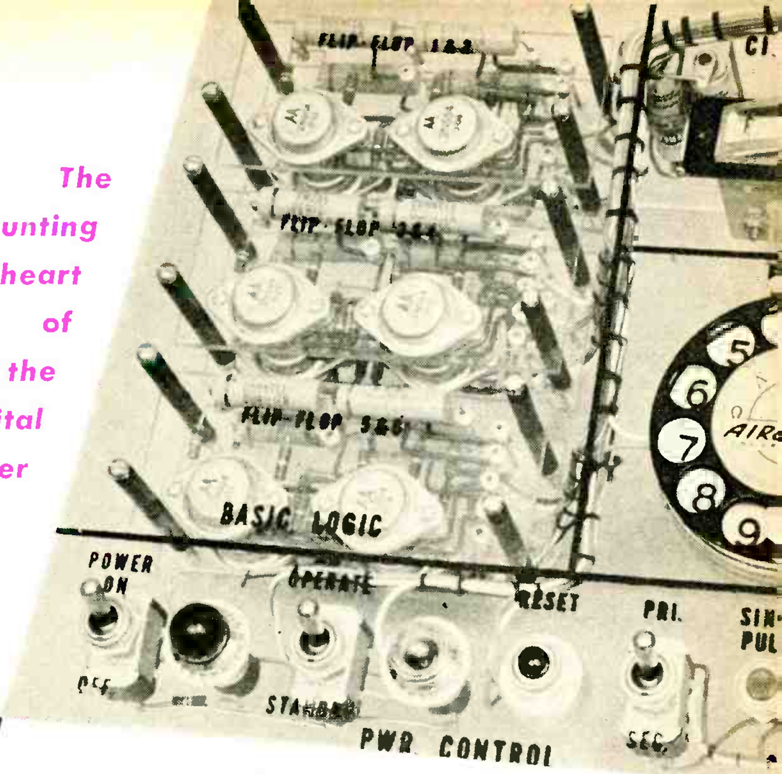
The counting heart of the digital computer



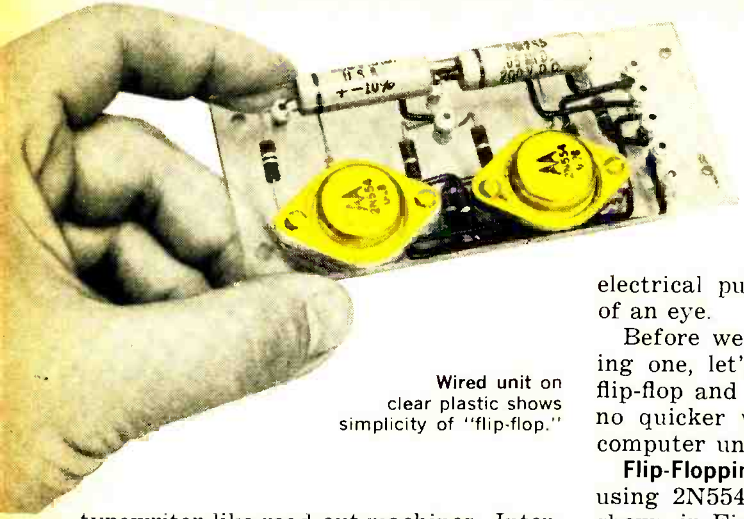
FLIP-FLOP CIRCUITS

By **JULIAN M. SIENKIEWICZ**
Managing Editor

This article discusses the transistor circuits used in the Digital Computer Demonstrator shown above and on this month's cover. Manufactured by Aironics, Inc., 1035 E. 26th St., Hialeah, Florida, the unit is an educational aid for demonstrating how simple transistor circuits can perform basic computations.

THE digital computer, the electronic brain so widely used in industry and science, is an awesome giant. It's true that some computers—those housed in office-sized desks, for instance—are relatively small physically. But to the untrained eye, their internal workings are a veritable electronic nightmare. Of even more gargantuan concept are the mammoth versions which actually occupy the whole of specially designed, air-conditioned buildings.

On closer inspection, however, the biggest digital computer proves to be only slightly more complex than a brick building. Made up of hundreds, sometimes thousands, of tiny printed-circuit boards—its "bricks," the digital computer also contains such rather unspectacular items as plug-in control panels, tape decks, and



Wired unit on clear plastic shows simplicity of "flip-flop."

typewriter-like read-out machines. Interconnecting its multitude of components are precisely what you might think—miles and miles of wire!

One of the building "bricks" which make up the counting heart of the digital computer is the "flip-flop" circuit, usually tucked away within the computer on a printed-circuit board about the size of a postcard. One such "flip-flop" is the Eccles-Jordan bistable multivibrator. An easy way to visualize its operation is to think of it as an on-off toggle switch. Like the switch, a flip-flop must settle in one of two stable states. But unlike the switch, the "flipping" or "flopping" of the Eccles-Jordan is accomplished by electrical pulses quicker than the blink of an eye.

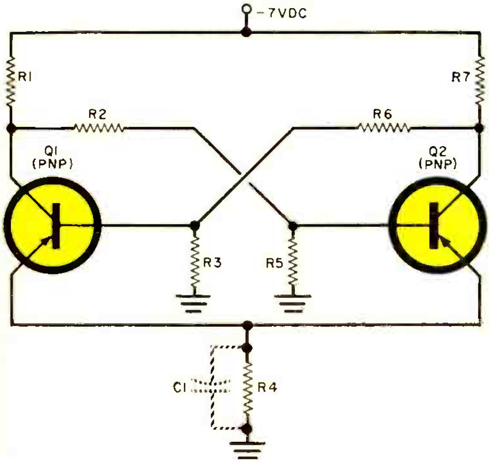


Fig. 1. Typical flip-flop circuit using power transistors. C1 is optional—see text.

Before we actually set to work building one, let's take a closer look at the flip-flop and see how it is used. There's no quicker way to get on the road to computer understanding.

Flip-Flopping. A typical flip-flop circuit using 2N554 *p-n-p* power transistors is shown in Fig. 1. Whenever power is applied to the circuit, one of the transistors will conduct and the other will be cut off. To understand how this happens, let's assume that transistor *Q1* is conducting ("on") and transistor *Q2* is cut off ("off"). The voltage at *Q1*'s collector is low—less than one volt—due to the large collector current through *R1*.

The current through *Q1* also passes through the common-emitter resistor, *R4*, developing a voltage drop which makes the top end of *R4* more negative than its grounded end. The value of *R4* is such that this would ordinarily make the base of *Q1* more positive than the emitter (reverse bias), preventing *Q1* from conducting. However, the base of *Q1* receives enough negative voltage from the collector of *Q2* to overcome this negative emitter voltage, keeping the base-emitter bias negative and transistor *Q1* conducting.

The voltage at the collector of *Q2* is approximately −7 volts (the same as the power supply voltage), since *Q2* is not conducting and the voltage drop across *R7* is almost zero. There is, however, a small current drain through *R7* due to *R6* and *R3* and collector-emitter leakage in *Q2*.

Transistor *Q2* is held at cutoff because the negative voltage at its emitter—due to the voltage drop across *R4*—is greater than the negative voltage reaching its base from the collector of *Q1*. In other words, the base of *Q2* is positive compared to its emitter (reverse bias) and *Q2* cannot conduct.

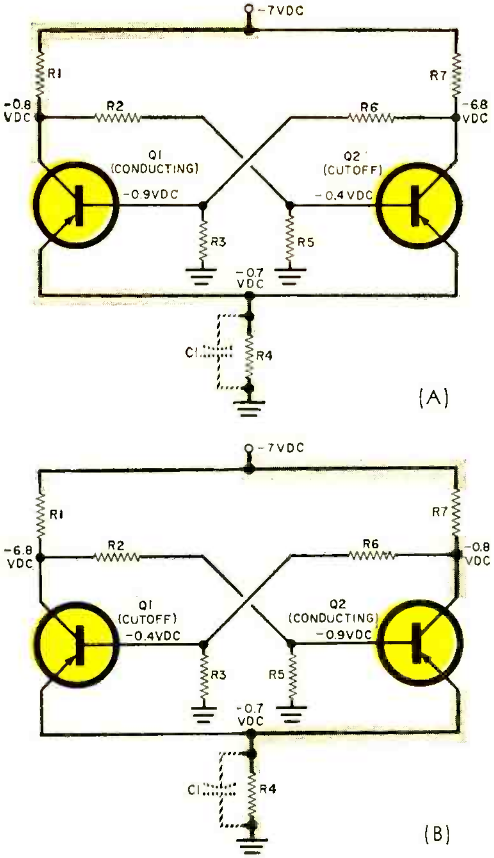


Fig. 2. Shaded lines indicate current path through flip-flop multivibrator when Q1 conducts (A) and when Q2 conducts (B).

Figure 2 (A) shows the current path through the flip-flop multivibrator and d.c. voltages measured to ground when *Q1* is conducting. The heavy lines show the current path from the —7 volt power supply, through *Q1*, to ground.

This state of affairs—*Q1* "on" and *Q2* "off"—will continue indefinitely because the flip-flop circuit is in a stable state. To reverse the transistor conditions—that is, to make the circuit "flip"—let's assume that we momentarily decrease the negative voltage on *Q1*'s base so that the transistor stops conducting. The flip-flop now goes through a transition period of very short duration.

As *Q1* cuts off, its collector voltage increases to —7 volts. The base of *Q2*, which was positive compared to its emitter, now becomes more negative, because the negative voltage at *Q1*'s collector is passed on to *Q2*'s base through a voltage divider, *R2-R5*. Transistor *Q2* now conducts heavily and *R7* drops the voltage at *Q2*'s collector to less than a volt. This low negative voltage is transmitted through *R6* and *R3* to the base of *Q1*, permitting *Q1* to remain in a cut-off state.

The circuit has now "flipped" and the transition period has ended. As before, the flip-flop is in a stable state, but *Q2* is "on" and *Q1* is "off." The multivibrator will remain in either stable state until a pulse from an external triggering circuit causes it to flip or flop. Figure 2 (B) shows the current path and circuit voltages when *Q2* is conducting.

During the transition period, incidentally, when one transistor cuts off and the other is turned on, the voltage drop across *R4* remains practically unchanged.

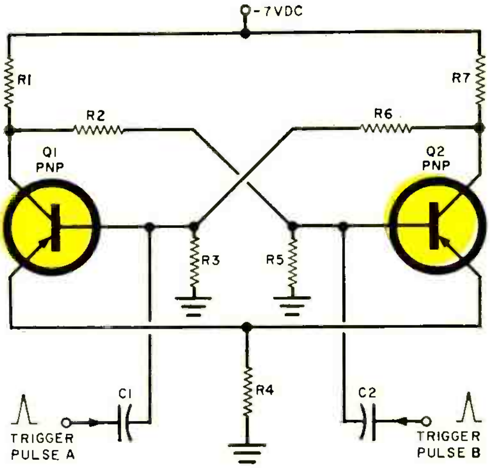


Fig. 3. The circuit of Fig. 1 with two trigger inputs added.

In many flip-flop circuit applications, *R4* is bypassed by a high-value electrolytic capacitor, *C1*, to insure constant voltage on the emitters of *Q1* and *Q2* during the flip or flop of the multivibrator.

Triggering. Before we can put the flip-flop to work for us in a digital computer, some additions to the basic flip-flop circuit are necessary so that we can make either transistor conduct at will. The circuit shown in Fig. 3 is identical to that in Fig. 1 except that two input triggering signals can now be applied to the base of either transistor through capacitors *C1* and *C2*. By applying a positive pulse to the base of the "on" transistor or a negative trigger pulse to the base of the "off" transistor, the circuit will switch from one state to the other. Let's consider the positive trigger pulse because we will see later that it can be obtained with a simple circuit using only a push-button switch and a resistor.

When *Q1* is conducting (Fig. 3), a positive trigger pulse (*A*) is applied to the base of *Q1*. If this positive pulse is of sufficient amplitude, the base will be driven positive with respect to its collector and *Q1* cut off. The collector voltage of *Q1* will rise rapidly to —7 volts and a part of this voltage will be applied to the base of *Q2* through voltage divider *R2-R5*. Transistor *Q2* will now conduct, its collector voltage will drop to less than a volt, and this voltage will be applied to the base of *Q1* via *R6* and *R3* to hold *Q1* at cutoff when the positive trigger ends.

Obviously, we have just "flipped" the circuit. This same action takes place when a positive trigger pulse (*B*) is applied to *Q2* as this transistor is conducting, although nothing will happen in the event that a positive pulse is applied to either transistor when it is *not* conducting. This results from the fact that when the transistor is cut off, a positive pulse only helps to keep it in its cut-off state. Therefore, no change will take place.

The flip-flop shown in Fig. 3 requires two trigger signals to "switch" it from one state to the other and back again. With the modified triggering circuit shown in Fig. 4, only one signal source is necessary.

Let's see what happens in the circuit of Fig. 4 when *Q2* is conducting. From Fig. 2 (B) we know that *Q2*'s collector is more positive than its base. Diode *D2*, connected across the base and collector of *Q2* through *R9*, is biased so that it will conduct heavily the instant a positive trigger pulse passes through *C2*. Diode *D1* is wired in the same manner except that its anode is about six volts negative with respect to its cathode. Therefore, a positive trigger pulse must overcome this large negative bias before it can pass through *D1*.

Switch *S1* controls the positive pulse that flips the circuit; note that the junctions of *C1*, *C2*, and *S1* are connected to —7 volts through *R10*. When *S1* is depressed, the —7 volts at this junction are

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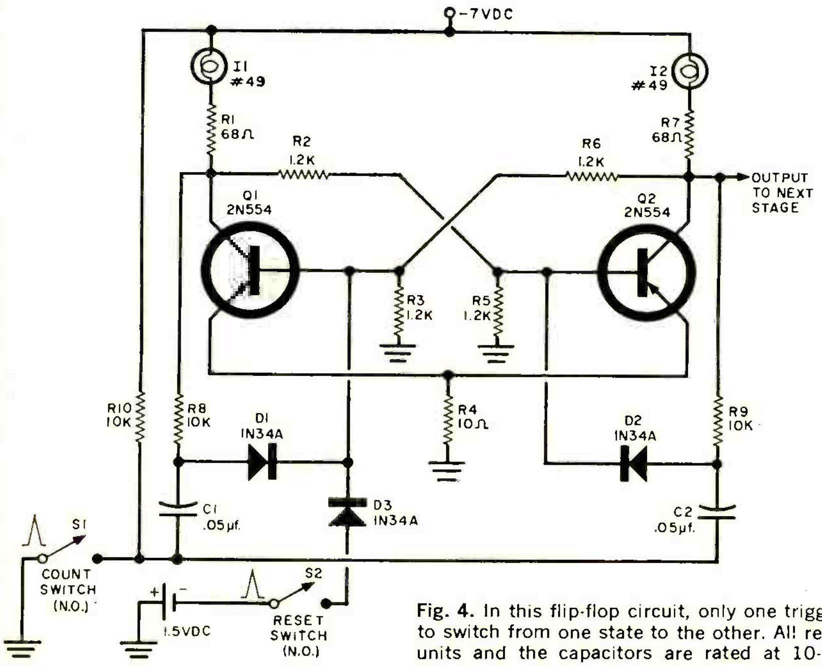

Fig. 4. In this flip-flop circuit, only one trigger input is needed to switch from one state to the other. All resistors are ½-watt units and the capacitors are rated at 10-w.v.d.c. minimum.

Flip-Flop Circuits

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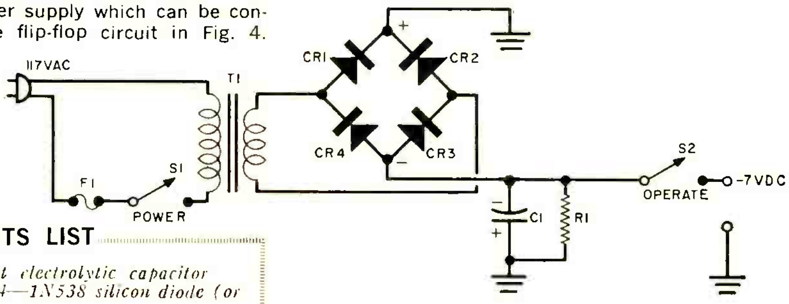
quickly dropped to ground potential because one side of the switch is grounded. The sudden rise in voltage from −7 volts to zero is actually a positive pulse which is coupled through *C2*, and through conducting diode *D2*, to the base of *Q2*.

Although the same positive pulse passes through *C1* to the anode of *D1,* it is not large enough to overcome the negative bias on the diode. When the positive pulse is applied to *Q2*'s base, the circuit switches its conducting state and is ready for the next pulse. Now, a positive pulse will pass through diode *D1* to the base of *Q1* because the voltages seen by the diodes are reversed—refer back to Fig. 2 (A). The circuit will continue to flip and flop depending upon the number of positive pulses supplied to it.

Fig. 5. Seven-volt power supply which can be constructed to power the flip-flop circuit in Fig. 4.



PARTS LIST

C1—1000-µf., 10-volt electrolytic capacitor
CR1, CR2, CR3, CR4—1N538 silicon diode (or equivalent)
F1—1-amp. fuse
R1—10,000-ohm, ½-watt resistor
S1, S2—S.p.s.t. toggle switch
T1—Filament transformer; 117-volt primary; 6.3-volt, 3-amp. secondary, CT not used (Knight 62G031 or equivalent)

Counting. The only things left unexplained about Fig. 4 are the two lamps and the reset circuit. The lamps indicate which transistor is conducting. When *Q1* conducts, the large current passed by it must pass through *I1*. At the same time, *I2* is not illuminated because *Q2* is cut off. These lamps are useful in determining how many positive pulses are supplied by the count switch, *S1*.

Let's assume the count switch is depressed only once. Although one bulb will go out and the other will come on, we as yet have no way of determining which bulb will light—this will depend solely on which transistor was conducting before the button was depressed.

The reset switch, *S2*, is the answer to our problem. By depressing it before any count is made, we enable *B1* to apply a positive voltage through *D3* to the base of *Q1*, cutting off the transistor. Now, *I1* is out and *I2* is on, indicating a count of "zero." Although *I2* should be in the circuit for balance, you can paint its glass so that it will show no light, since it is not used for counting.

With our flip-flop in operation, pressing *S1* will turn *I1* "on," indicating a count of "one." Pressing *S1* a second time will return the lamp to the "off" state, indicating zero again. Although a single flip-flop such as this one can only indicate counts of zero and one by itself, other flip-flops can be added to the circuit and higher counts obtained. How this is done will be explained in the next issue of POPULAR ELECTRONICS. Binary counting will also be covered.

Build a Flip-Flop. In the meantime, so that you will fully understand how flip-flop circuits work, we suggest that you build the circuit shown in Fig. 4.

Measure the voltages at the terminals of the transistors and see how they agree with the theory discussed in this article. There may be slight voltage variations between the circuit you build and the values given in Figs. 2 (A) and 2 (B), but this is to be expected due to variations in tolerances of the components. Breadboard your circuit, keeping in mind that you will want to reuse the parts in circuits which will appear next month.

Figure 5 is the schematic diagram of a seven-volt power supply for the flip-flop. If you build it, wire it neatly—you will be using it again. —30—