# RELAYS MAKE LOGIC CIRCUITS

*With tubes, transistors, assorted diodes, and magnetic devices to choose from, relays still hold their own. Here's how they work.*

By **KENNETH BRAMHAM**

WHEN SOMEONE mentions computer logic elements, we tend to respond by thinking of such "glamorous" components, developed in recent years, as semiconductors or magnetic devices. Magnetic cores, rods, and tape; transistors and Esaki diodes; MAD (multi-aperture devices); paramatrons; delay lines—these capture the imagination so much that they make one forget about vacuum or gas tubes and completely overshadow such a commonplace as the electro-mechanical relay.

Yet the relay, which was used before the mentioned devices came into prominence, is still the workhorse of the data-processing and control industries. The service technician is wrong to write it off as an antique because of the trend toward newer devices in large computers and telephone installations. In fact, he is more likely to encounter relays than any other devices. Relays are actually being used more than ever before in remote controls, machine-tool operation, office equipment, and computer input equipment. Consider even the modern, giant, "electronic brains," made possible by the latest advances, used in banking and accounting processes. It is a safe bet that several relays will have to operate before an input is received by the first transistor. What relays can do and how they are used are therefore important concerns.

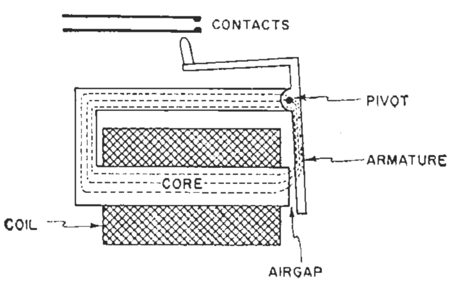



**Fig. 1. Electromagnetic energy pulls in relay armature, which switches contacts.**

The principle of relay operation is simple. Current is made to flow in a coil when a voltage is applied. This current produces a magnetic field in an iron core (Fig. 1) around which the coil is wound and in a movable armature. The only gap in the magnetic circuit, as shown, occurs between the core and the armature. Most of the energy in the field (magnetic flux is indicated by the broken lines) is concentrated at the air gap, so that the light armature is attracted to the heavy core. If the armature is mechanically coupled to a contact or switch assembly, its motion will make the switch contacts transfer. In the case of Fig. 1, armature motion will close the normally open switch contacts.

## Advantages & Disadvantages

At first thought, relays would seem to have a serious handicap when compared to other devices as logic elements. Others can amplify, or provide us with gain. It is not immediately obvious that a relay can do as much. We are familiar with the gain of a tube circuit as being the ratio between a change of input voltage and a greater change of output voltage. However, a relay may be operated by a small current in its coil. It can then control a much larger current through its contacts. This may be said to provide current gain. (Like the transistor, the relay is a current-sensitive rather than a voltage-sensitive component.)

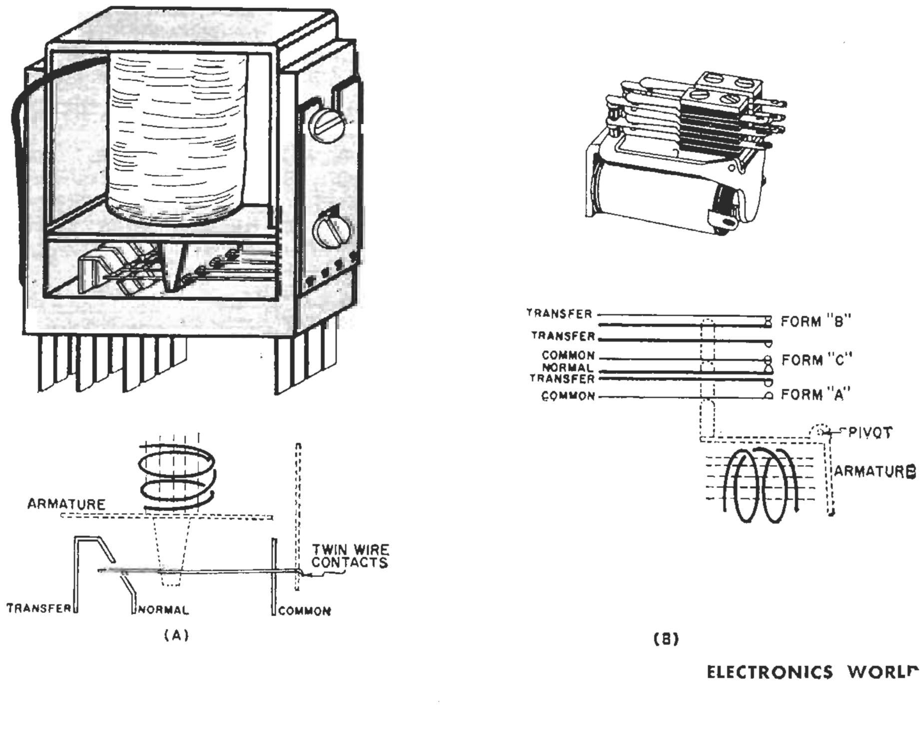
The relays dealt with here are also "two-state" devices; that is, they are either "on" or "off," with no degrees of operation in between. They do not have leakage current in the "off" state (as do transistors) nor resistance in the "on" state (as do tubes). Every relay requires a given, minimum current in its coil (input current) to attract the armature and transfer the contacts, just as a tube needs an input pulse of minimum amplitude to be triggered into conduction.

Let us consider what these characteristics mean in terms of "gain" and efficiency. Take a typical relay that may require an input of 50 ma. (50 volts across a 1000-ohm coil) and that has eight sets of contacts. These contacts will have infinite resistance when open and negligible resistance when closed. Each set can handle two amperes—a current gain of 40 (2/.05). If all eight sets of contacts are used, there is a total gain of 320!

Comparison with that other current-sensitive device, the transistor, is interesting. For comparable operation, eight transistor circuits would be required, each capable of handling two amperes with an input current of 6.25 ma. (.05/8 =.00625). Normally each of the eight circuits would require at least two stages of amplification. This makes a total of 16 transistors, plus associated resistors and capacitors in the external circuits, instead of one relay.

Furthermore, we have been considering a simple case, in which we only want to switch the output circuits on (or only switch them off). This function parallels the action of a single-throw switch. Suppose we wanted to choose between two current-handling outputs in each section. We would need 32 transistors along with associated circuit components. A single relay with eight sets of

**Fig. 2. High-speed wire contact relays (A) are used in office equipment and computers. "Telephone" types (B) offer a wide choice of combinations of contacts.**



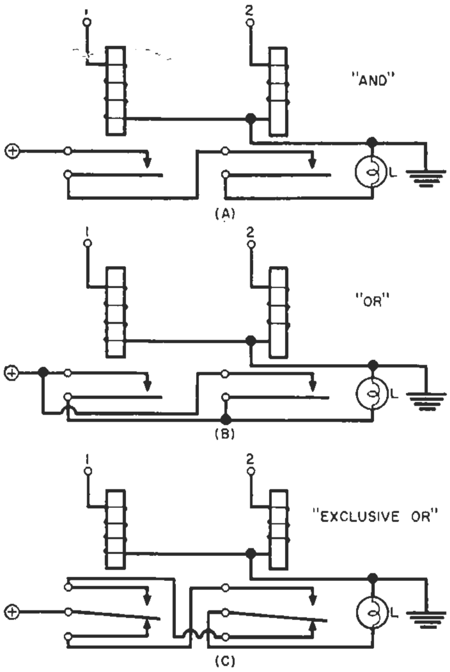



Fig. 3. Basic logic elements with relays.

contacts will still do the job, if the contacts are of the *C* type. In these, one contact, which moves with the armature, may swing to either of two other fixed contacts between which it is located. This duplicates the action of a double-throw switch.

Relays also have drawbacks when compared with other devices. Operating speed is a disadvantage that rules out the use of relays in high-speed computing; but, in applications where 5 to 10 milliseconds of switching time can be tolerated, relay logic circuits can be used to advantage. Other problems result from the inductance of the coils. The inductive kick produced when the coil current is interrupted must be suppressed, if damage to contacts is to be avoided. Adequate suppression often results in greatly increased switching time and adds to the design problems. Without suppression, if it is required to break a relay coil circuit with the contacts of another relay, much heavier contacts must be used than would be the case with full suppression. In any case, relay contacts rated to carry a given current will be rated to make or break at a much lower current.

Contact bounce is another disadvantage of many relay types. This is caused by the mechanical characteristics of the contact springs and will often cause a series of short pulses in the output circuit before a static condition is reached. This is seldom a problem when the output is taken to another relay coil, as the short pulses will not affect the switching time of a relatively slow-operating relay. If this pulsing output is taken to a high-speed transistor circuit, however, some special circuitry may be needed to give a clean signal.

## Using the Relays

Those who are familiar with basic logic elements, such as those described in recent articles in this publication, will be interested to see how these may be built from simple relays. Actually, there are dozens of relay types to choose from. Only two are shown in Fig. 2, the wire-contact type (A) and the "telephone" type (B). The top illustrations are for physical appearance, the lower ones give an idea how they work.

Only *C* type contacts are available on the wire-contact relay, but as many as 12 sets may be found. When the coil is not energized, one circuit is closed through the "Normal" contact. With coil current, the other circuit is made through the "Transfer" contact as the wire is attracted upward.

Just a few of the many types of combinations are shown for the telephone relay. The movement of the single armature in Fig. 2B will close a pair of contacts (single-throw) on form *A*, transfer from one circuit contact to another on form *C* (double-throw), and open another circuit on form *B* (single-throw). Because of the restrictions imposed by wire-contact and other types of relays, we will show only logic circuits that can be made with *C* contacts, although all contacts will not always be in use.

Three basic logic elements, the *and*, *or*, and *exclusive or* configurations, are shown in Fig. 3 as they would be developed with relays. These are the simplest cases. The actual number of relays used can be many more than the two shown in each case. In each example, output is indicated by the lighting of lamp *L*.

In Fig. 3A, the contacts of one relay

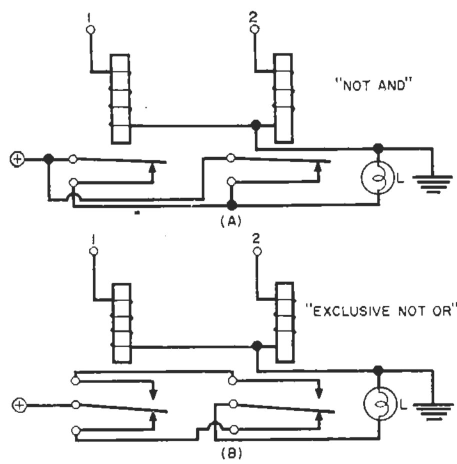
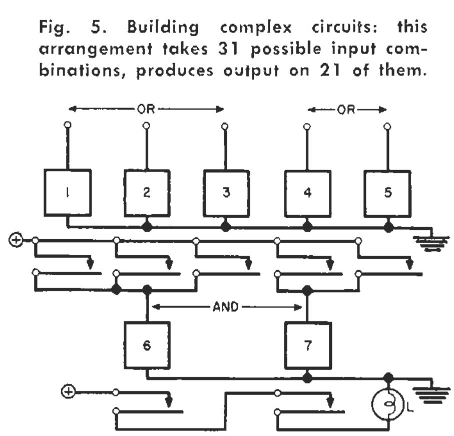



Fig. 4. The complimentary circuits for two elements in Fig. 3 are also possible.

Fig. 5. Building complex circuits: this arrangement takes 31 possible input combinations, produces output on 21 of them.



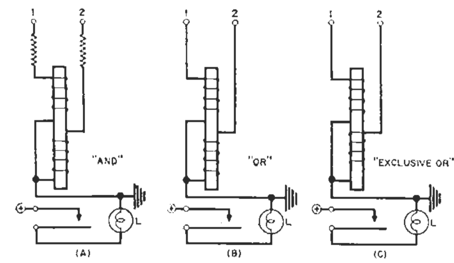




Fig. 6. One relay having two coils can simplify any of the circuits in Fig. 3.

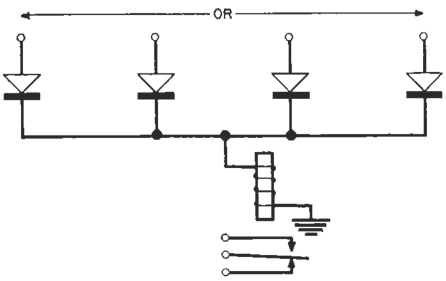



Fig. 7. If diodes are used, several inputs can be fed to a single-coil relay.

are in series with the contacts of the other. For output to be produced (for voltage to be applied to the lamp through a completed path), both relays must be energized. In Fig. 3B, relay 1 contacts parallel relay 2 contacts. Energizing either one (or both) will light the lamp. The *exclusive or* circuit of Fig. 3C has an interesting arrangement: the normally open contacts of one relay are in series with the normally closed contacts of the other, and *vice versa*. The path from the applied voltage to the lamp is complete only when either relay, but not both, is energized.

The complement of an *and* circuit is *not and;* the circuit for this is shown in Fig. 4A, where the light is seen to be normally on and is disconnected only when relay coils 1 and 2 are energized simultaneously. Similarly, the complement of *exclusive or* is shown in Fig. 4B; the light being disconnected when either relay, but not both, is operated.

In all the circuits shown, a light bulb has been used to indicate an output. In practice, this output may be used to operate almost any electrical device. Quite often the output of one logic circuit is used as an input to another logic circuit. The diagram of Fig. 5 shows the output from two *or* circuits (one with two inputs, the other with three) used as an input to an *and* circuit. (To simplify the diagram all relay coils are shown as rectangles containing an identifying number. This is common practice in relay logic diagrams.) Out of a possible 31 combinations of two or more inputs, 21 will give an output to the light.

Only simple relays have been discussed to this point; however, there is a variation of these relays that is widely used and often reduces the number of relays needed for a logic element. This is the double-coil relay. Construction is identical with the simple, single-coil version except for an additional wind-

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## Relays in Logic Circuits

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ing on the core. If both windings are identical and wound in the same direction, the result is a two-input *or* circuit in a single relay (Fig. 6B). If either coil is energized, the relay contacts will transfer.

A dual-coil *and* circuit is shown in Fig. 6A. In this circuit, a resistor is added in series with each coil to reduce the current in each below the point where the relay will transfer. However, the fields produced by the coils are additive. Thus, when coil 1 and coil 2 are both energized through the resistors, the total flux will be sufficient to transfer the relay.

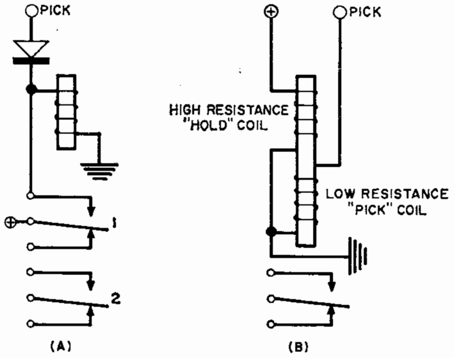
In the *exclusive or* circuit of Fig. 6C, the two coils are connected so that the resulting fields are in opposition. Consequently, if either coil is energized, the relay will transfer; if both coils are energized, their fields will cancel and the relay will not transfer. Other double-coil relay types using non-identical coils will be discussed later.

Diode *or* circuits, perhaps the most familiar of all logic elements, are often the most economical to use. Fig. 7 shows a four-input *or* circuit that uses only one relay and four diodes. A positive voltage applied to any of the four diodes will transfer the relay and produce an output. The diodes serve to isolate the input connections, so that a positive voltage applied to one will not appear at the others. While the example shown uses only four inputs and therefore only four diodes, 10 or 20 diode inputs are not uncommon in practice.

### Holding Circuits

A logic circuit is often required to operate with only a short input pulse, but remain active after the pulse disappears. This is accomplished with a "holding circuit." Figs. 8A and 8B show two widely used holding circuits. In the first, a pulse applied to the "pick" connection energizes the coil and transfers the contacts. A voltage is now applied to the coil through contacts 1 and the relay remains transferred. The other pair of contacts (2) operates the output circuit. A diode is included in the pick circuit to prevent the positive holding voltage from appearing on the pick connection while the relay is held. As only a fraction of the current needed to transfer a relay will hold the relay once it is transferred, a resistor may be included in the holding circuit. This has the advantage of reducing the energy that must be dissipated by the coil during the holding period. The result is cooler operation and faster drop-out when the hold voltage is removed.

**Fig. 8. Two ways in which a relay can be picked by a short pulse and then held by (A) its own contacts or (B) an extra coil.**




The circuit in Fig. 8B uses a double-coil relay. The relay is transferred by a pulse applied to the pick coil and held by the current in the hold coil. If identical coils were used, as in the double-coil relays discussed previously, the hold coil could also pick the relay. However, a much higher resistance coil is used for holding and the current in this coil is not sufficient to transfer the contacts, but only to hold them once they have been picked by the heavier current in the pick coil. A diode is not required in the pick circuit, as no voltage appears across the pick coil while the relay is being held. This circuit gives a fast pick, because the magnetic field in the hold coil aids that in the pick coil, and a fast drop-out because minimum energy must be dissipated when the holding voltage is removed. It also dispenses with the extra set of contacts.

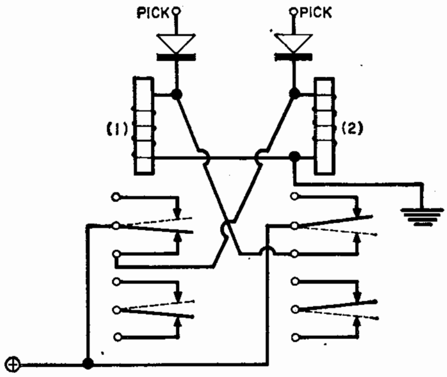



**Fig. 9. The familiar flip-flop circuit, widely used in binary counting and other functions, can be made up of two relays.**

Holding circuits make possible another relay logic element, the flip-flop, or bi-stable element. This one has two possible states and will remain in one state until a pulse is applied to switch it to the other. The relay flip-flop circuit in Fig. 9 uses two relays, each with a holding circuit wired through the contacts of the other. When relay 1 is picked (broken lines), relay 2 drops and its contacts hold relay 1. When relay 2 is picked (solid-line position), relay 1 drops and its contacts hold relay 2. These are the two states of a bi-stable flip-flop.

Capacitors are often added to relay circuits to introduce a time delay. Two such circuits are shown in Fig. 10. The circuit in Fig. 10A uses a relay, a resistor, and a capacitor to make a free-running (astable) element. The output is a square wave with a frequency determined by the combined *CLR* values. In this circuit, the supply voltage is applied, through the resistor and relay contacts, to the coil and large-value capacitor in parallel.

Since the uncharged capacitor across the coil initially acts as a short circuit, most of the voltage first applied through the upper set of contacts is dropped across the resistor, and the relay is not energized. However, full positive voltage appears at the output.

As the capacitor charges, voltage across the relay coil increases. When it reaches a given level, sufficient current flows through the coil to make the contacts transfer. This disconnects supply voltage from the output, through the lower set of contacts.

With this second condition achieved, the capacitor begins to discharge through the coil. This keeps the relay energized until the capacitor can no longer supply enough current through the coil for this purpose. The holding time is thus determined by the characteristics of coil and capacitor. Contacts are then switched back to the original condition, and the cycle of operation continues as described. The output waveform is shown below.

The delay provided by a capacitor is also used in the circuit of Fig. 10B. In this case, input of brief duration (such as an unwanted transient) cannot pick the relay. When input is first applied, the capacitor, as in Fig. 10A, first acts as a short circuit across the coil, preventing the latter from pulling in the relay at once. After a period of delay (determined by the *CLR* values), the relay will be energized, if an input is

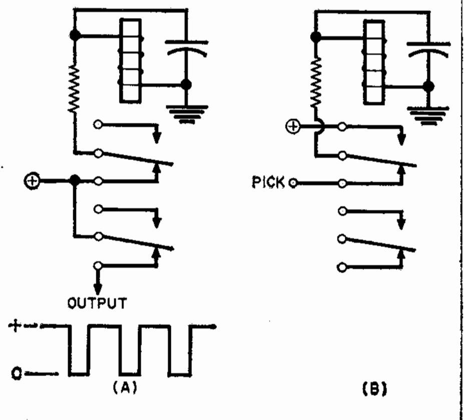



**Fig. 10. Delay provided by added capacitor makes more circuits possible. One (A) is a free-running square-wave generator.**

still being supplied. Once the relay is pulled in, the holding circuit (voltage applied through the upper contact) keeps it in this condition. This makes it possible to pick a relay reliably through its own contacts. Such capacitor-delayed relay circuits are useful in overcoming timing problems.

Although only the basic relay circuits have been discussed here, they provide the basis for understanding the more complicated ones that may be encountered, which are generally built up from the simple ones. Many electro-mechanical control devices are in use today, and many more will be built in the future before more "glamorous" components approach the economy of relays. –30–