NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
EDMONTON ALBERTA

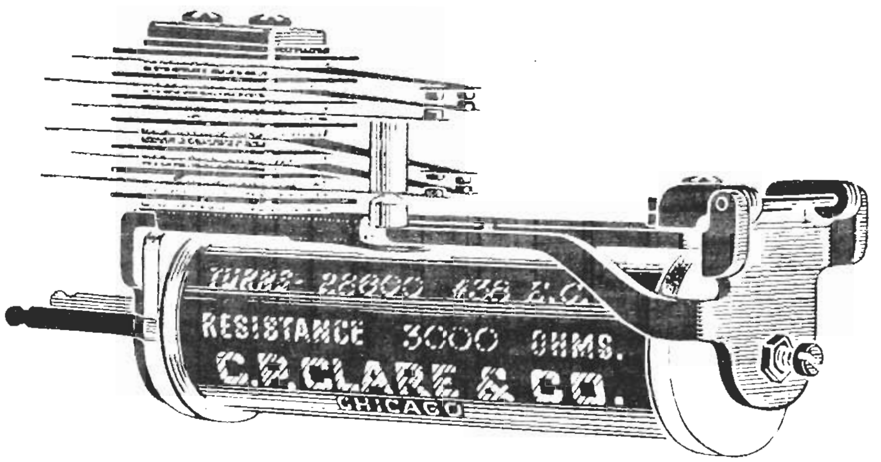
ELECTRONICS DEPARTMENT

RELAYS

A relay is an electro-mechanical device which is used to control electrical energy and applies the principles of magnetism in its basic operation.

In its simplest form a relay consists of a coil of wire mounted on a frame. Also on this frame, and directly over one end of the coil, is a piece of magnetic material suspended on a pivot or bearing. When the coil is energized the resulting magnetic effect causes the magnetic material to be attracted to the coil. The magnetic material is called the armature. Connected to, or an integrated part of the armature, is a moving arm. This moving arm is so placed as to actuate switch contacts. Depending on how the contacts are arranged, the movement of the armature towards the coil will either open or close the contacts.

The configuration of the mechanical portion of these relays takes many forms but they all operate on the same principle. A typical relay is shown below.



RELAY PARAMETERS

1. COIL

The magnetizing force required from the electromagnet (coil) depends upon the inertia of the armature, the switch arrangement and the tension of the coil spring. The coil spring is necessary to restore the armature to its original position when the electromagnetic field is removed. This coil spring is attached between the armature and the frame and its tension is adjusted so that the armature will return to its rest position when the coil is de-energized. This method is satisfactory where speed of operation is not an important factor. Where speed is a factor, the switch contacts are mounted on a spring steel alloy arm. The arm is then adjusted to return the armature to the rest position when the coil is de-energized. In either case, the magnetizing force must overcome the spring action and the inertia of the mass in order to move the armature and operate the contacts.

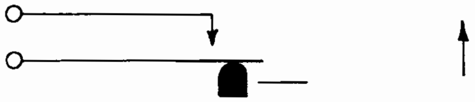
The magnetizing force is a function of the magnetic flux which in turn is a function of the ampere-turns of the coil. Since power consumption is an important factor, the driving current is usually kept to a minimum. Because the current through the coil in D-C operation is a function of the applied voltage and the coil resistance, in order to maintain the ampere-turns necessary, typical coil specifications for a telephone type relay would be:

6 VDC 30 ohms 2160 turns of #29 wire
120 VDC 3000 ohms 19,200 turns of #39 wire

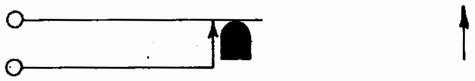
If a relay is to be operated from an A-C rather than a D-C driving source, it is necessary to modify the coil in order to prevent armature chatter. This is accomplished by placing a copper ring near the top end of the coil. This ring acts as a shorted secondary of a transformer and the current induced in it is approximately 90 degrees out of phase with the current in the coil. When the magnetic field of the coil falls in strength, the magnetic field set up by the current in the ring holds the armature in place against the force of the spring that is trying to pull it away.

2. CONTACT ARRANGEMENTS

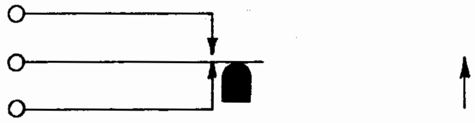
Type A
Open when the coil is de-energized.
Referred to as NORMALLY-OPEN



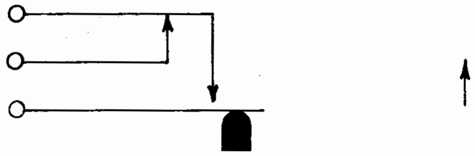
Type B
Closed when the coil is de-energized.
Referred to as NORMALLY-CLOSED



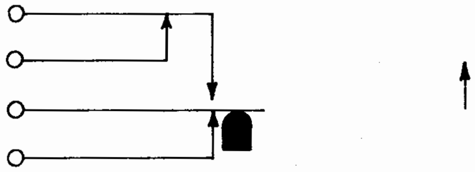
Type C
One type A and one type B



Type D
One type A and one type B in a
MAKE-BEFORE-BREAK arrangement.



Type E
Two type A and one type B in a
MAKE-BEFORE-BREAK arrangement.



3. CONTACT CONSTRUCTION AND CARE

Whether the relay is to be used in high speed switching operations involving low power circuits, or low speed operations involving higher power, the power capabilities of the switching contacts is an important parameter of the relay.

Various types of materials used in forming the contacts are:

Silver, palladium, platinum-iridium, gold alloy, tungsten

Typical contact specification would be as follows:

Silver 1 amp 50 watts	.075'' base dia; .025'' high
Tungsten 4 amps. 500 watt	.187'' dia .035'' high

The contacts are so arranged so that during the closing operation a wiping action takes place. This is to help reduce build-up of carbon and other foreign materials.

Contacts are cleaned by using soft paper, a burnishing tool, or some type of methyl-hydrate cleaner. Files or other abrasive materials should never be used.

4. CAPACITANCE

In addition to coil and contact ratings, there is another characteristic of relays that must be taken into consideration when a relay is to be used in a high frequency circuit. This characteristic is the inter-spring and spring-to-frame capacitance. Typical values would be as follows:

Interspring

0.5 mmf at 3 meg/c
0.5 mmf at 10 meg/c
0.55 mmf at 20 meg/c

Spring-to-frame

1.4 mmf at 3 meg/c
1.45 mmf at 10 meg/c
1.8 mmf at 20 meg/c

5. PICKUP AND DROPOUT CURRENT

Pickup current is the coil current necessary to energize the electromagnetic coil enough to attract the armature.

Dropout current is the coil current which causes the armature to drop back to its normal position.

In a standard relay, the pickup current is usually 10% higher than the dropout current.

TYPES OF RELAYS

1. CLAPPER TYPE RELAY - Forementioned

2. SOLENOID TYPE RELAY

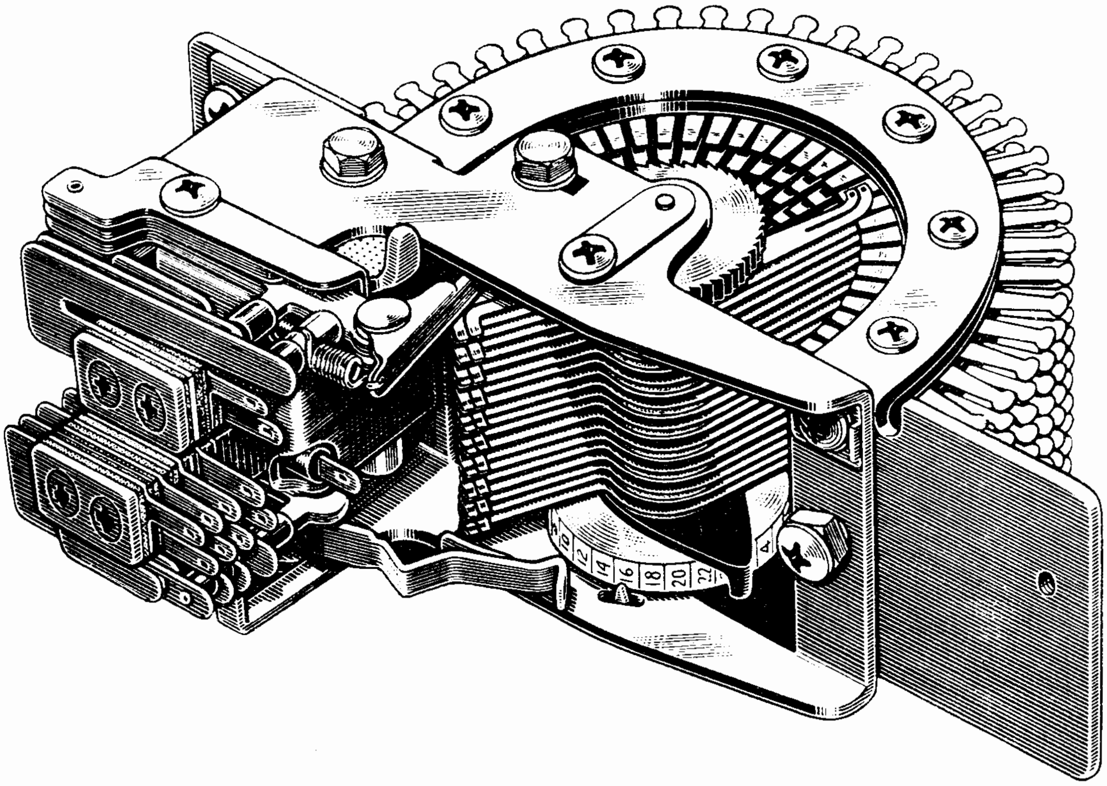
It is similar to construction to the clapper type, except the core is not securely fixed within the coil, but is moveable and attached to the armature. When current is passed through the coil, the core, or plunger, is pulled into the solenoid by the magnetic field. This type permits a greater distance of operation or travel of the moving parts. This type is used where larger currents are switched.

3. THERMAL RELAY

A thermal relay operates by the bending action of a bimetal strip due to heating. The best example of this type of relay is the thermostat used in electrical appliances and room temperature controls.

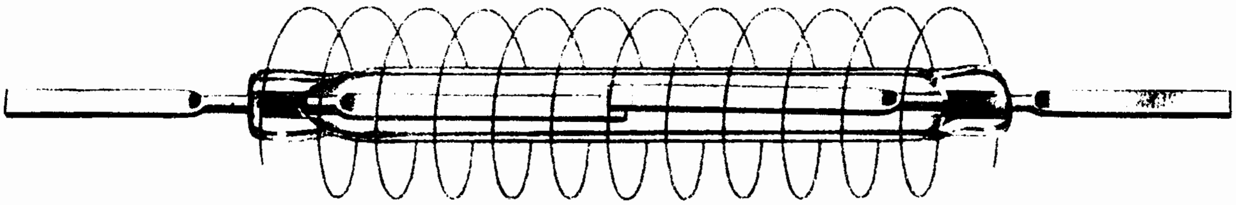
4. SPRING-DRIVEN STEPPING SWITCH (OR RELAY)

Ratchet or stepping relays are special developments of the clapper type. Through a pawl-and-ratchet arrangement, the shaft and contact arm are advanced one notch each time the relay armature is actuated. Thus, the arm advances to each contact in sequence. These type of relays are used in telephone step-by-step dial switching. Each number dialed produces a certain number of pulses which step the relay a certain number of steps. The line connection is made according to the numbers dialed.



5. DRY REED RELAY

The dry reed relay is very suitable for industrial control switching systems. A typical reed relay shown below consists of the reed switch and the operating coil. This complete unit is usually enclosed in a metal container for mounting purposes.

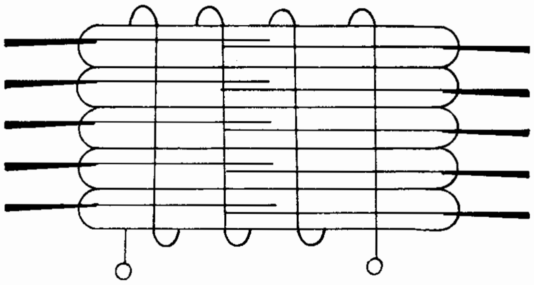


The basic reed switch consists of two identical flattened ferromagnetic reeds, sealed in a dry inert-gas atmosphere within a glass capsule. The reeds are sealed in the capsule in cantilever form so that their free ends overlap and are separated by a small air gap. When a magnetic force is generated parallel to the reed switch, the reeds become flux carriers in the magnetic circuit. The overlapping ends of the reeds become opposite magnetic poles, which attract each other. If the magnetic force between the poles is strong enough to overcome the restoring force of the reeds, the reeds will be drawn together. Minimum force - expressed in ampere-turns (NI) - which will cause the reeds to close is called the ''just-operate'' force.

Since the force between the poles increases as the gap decreases, a force of approximately half the ''just-operate'' force will maintain the operated state.

Speed of operation of the reed switch is determined by the excess of operating force over the just-operate force. The shortest possible operate time is that required to physically move the reeds together, typically 0.8 millisec. Contact bounce is usually 0.2 millisec, but increases with operating power. For maximum speed without extended contact bounce, the operating power should not be more than three times the "just-operate" power.

A number of capsules can be enclosed in one package to provide various contact arrangements.

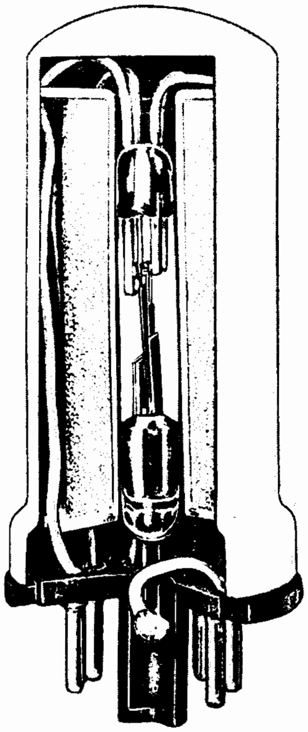


A 12 capsule relay may require only 1.75 watts input and will operate in 2.0 millisec. Due to their construction and type of operation, these relays are capable of in excess of one billion operations where little or no current is being carried by the contacts. In a typical application this means about 25 years of continuous operation.

6. MERCURY-WETTED CONTACT RELAY

The mercury wetted contact relay is similar to the reed relay. In the mercury wetted contact relay a pool of mercury has been added which supplies a continuous film of mercury to the contacts by capillary action.

The addition of the mercury eliminates contact bounce and increases the power handling capabilities over billions of operations. Contact bounce is eliminated by the bridging action of the mercury as the contacts open.



ASSEMBLY DETAILS

Glass capsule hermetically seals mercury-wetted contacts under high pressure hydrogen atmosphere.

Moving contacts consist of armature, supported by spring. Holds platinum contacts in normally closed position.

Two pairs of lead wires support four platinum fixed contacts.

Small pool of mercury coats all metal parts inside capsule with mercury. Mercury-wetting by capilliary action.

Extremely rapid breaking action is the result when filament of mercury between contacts is ruptured as coil, or spring action, causes contact movement.

Another feature of the mercury wetted contact is the retention of the contact resistance within 2 milliohms throughout the life of the device. This relay can be driven by a nominal 40 ma and is capable of handling up to 250 VA.

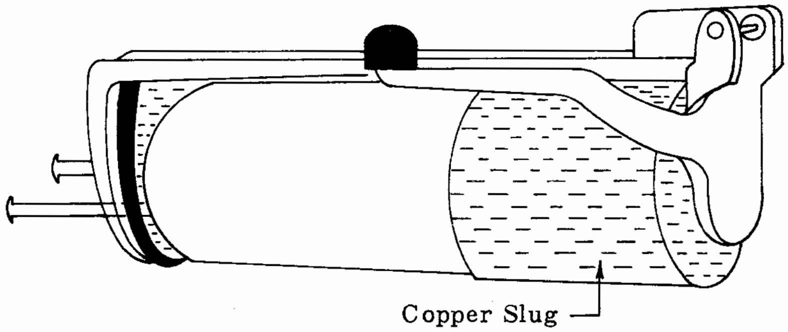
7. TIME DELAY RELAYS

These are relays that have a specific time delay between the time that the voltage is applied to the coil, and the time the contacts close or open, depending on the type of relay.

One such type of relay is the Amperite. A filament slowly heats a bimetal strip which bends, and makes the contact. These are often found in circuits employing vacuum or vapour tubes where they delay the application of plate voltage until the filaments or cathodes are heated.

Another type of delay relay uses a cylinder of compressed air or special liquid. When the coil is energized, pressure is put on a piston or diaphram, but it cannot move and close the contacts until a specific amount of air or liquid has moved through the opening. The opening or orifice can be adjusted to obtain specific time delays.

The operating time of the ordinary relay is in the order of 50 milliseconds, either on opening or closing. In some telephone circuits, it is desirable to control relay operating time in such a way that it can be longer than the nominal time. This can be effected within limits by adding a very low resistance path around the magnetic core of the relay in the form of either a short-circuited winding, or a solid metal sleeve. Then, when the current in the regular relay is broken, the decaying flux in the core will induce a circulating current in the sleeve. This, in turn, tends to produce flux in the core additional to and in the same direction as the original flux. The time required for the total flux to decay is thus increased, which causes a proportinate delay in the relay release time. Thus, by varying the resistance of the sleeve, or the short-circuited winding, it is possible to obtain a range of delay times extending from a minimum of 50 ms to as much as 500 ms.

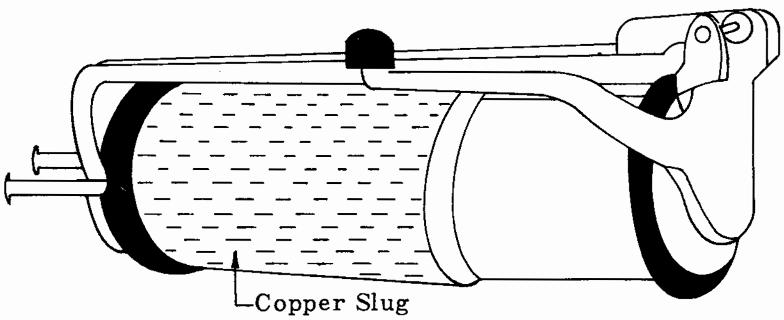


SLOW OPERATE RELAY

When the coil circuit is closed, the flux being built up in the magnetic cct links the low resistance copper ring. This change in flux sets up a current in the ring, which builds up an opposing flux. This opposing flux introduces a time delay into the operation of the relay.

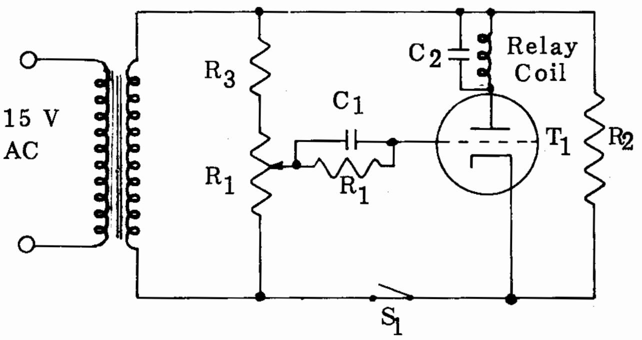
SLOW RELEASE RELAY

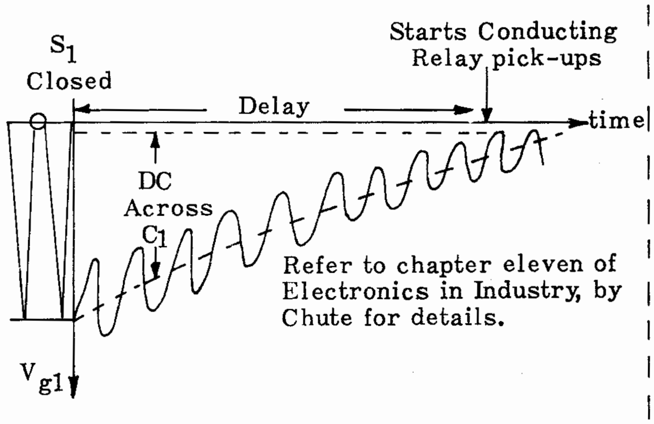
When the coil circuit is closed, the operation of the relay is not appreciably delayed because the flux, which doesn't link the slug, operates the armature. When the coil circuit is opened, the change in flux sets up a current which produces a flux which aids the main flux and therefore delays the release of the relay.



Time delay can also be obtained by using RC constants with vacuum tubes and semi-conductors, or just a simple RC circuit.

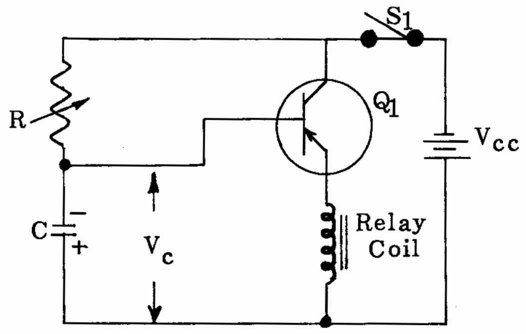
AC TIME DELAY RELAY

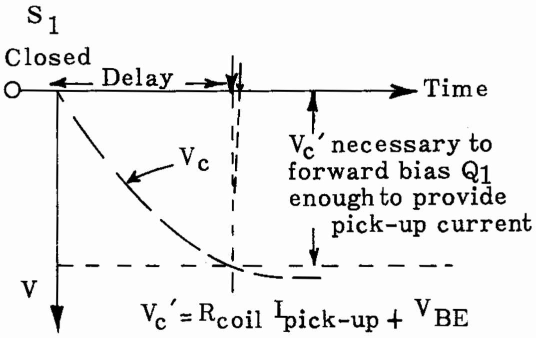




Refer to chapter eleven of Electronics in Industry, by Chute for details.

TRANSISTOR TIME-DELAY RELAY





USE OF RELAYS

1. POWER CONTROL

When large currents must be switched, magnetic switches are used. These would be of the solenoid type because the contacts must move a relatively greater distance apart to extinguish the arc that is produced on breaking of the circuit. The remotely switched room lights in this building use a clapper type relay that operates with 24 VAC.

2. SIGNAL CONTROL

Relays are used when it is desired to have a small current change switch a larger current. Such an application would be a photoelectric cell. The small increase of current through a photocell is certainly not enough to control power to other electrical devices, so a relay may be used. Also, some circuits require that several connections be made simultaneously. Multicontact relays can be used for this. Logic signal switching is usually done with reed relays. These are presently being replaced with solid state switches.

3. LIMITING RELAYS

Some applications require a relay to operate when an over-voltage or an under-voltage occurs. This is done by using relays with a higher coil resistance. Thus, when the coil current reaches a certain value the relay will operate. If it is used for under-voltage protection, a certain minimum current will allow the relay to "fall out" and the circuit will be broken. Such a relay circuit may be used on a large radio transmitter to disconnect the power if the line voltages rises too much above normal. Also, some circuits may be damaged if voltages drop too low. This may be necessary to ensure sufficient grid bias on a power tube. In this application, the relay would have normally closed contacts which would "fall out" when grid bias voltage dropped to a certain value.

PROBLEMS WITH RELAYS

The contacting points of relays must have a very low resistance to allow unhindered current flow. Thus contacts are usually made of precious metals such as gold, silver or platinum, or alloys. Palladium silver is one type in wide use. Platinum-ruthenium is another alloy type which gives a much longer life. One main fault of contacts is that some high resistance material gets between the contacts. This may be due to tarnishing of the contact surface or oxidation due to burning. This may cause a small arc to occur when the contacts are opened and further burning may result. Pitting occurs when the points arc and the melted metal actually is attracted from one contact to the other. This is why the points in a car must be replaced every 10,000 miles. Also, when there is excessive inductance or capacitance in the circuit, the current tends to flow after the contacts have opened. This is why the capacitor is used in the ignition system of a car.

If a relay fails to operate, the following may have happened:

1. Coil has shorted and overheated.
2. Coil is open.
3. Contacts are oxidated and will not close.
4. Points are welded together.
5. Points are pitted and are eratic in operation.

If the contacts are pitted they can be filed down and shaped again, but it is usually best to replace them. Also the circuit should be checked to see what is causing the arcing and pitting.

Some relay contacts are sealed in glass to prevent oxidation and dust from degrading the contacts. The reed relay and the Amperite relay are of this type.

Some of the disadvantages of relays are being overcome by the use of solid state switching, especially in the telephone industry. Also the glass reed relay is a great improvement in many applications.

ADAPTING RELAYS to Special Uses

The author solves relay problems by adapting standard units. So can you. He tells you how.

By LOUIS E. GARNER, JR.

SERVICE technicians, audio and TV installation specialists, amateurs, and experimenters, needing a relay for a special remote control or switching setup, must make a selection from comparatively few "stock" items offered to the general public. When a desirable item is listed in a manufacturer's catalog, you may find that local distributors and retailers, catering primarily to the service trade, do not carry the item in stock.

On the other hand, a factory design engineer does not hesitate to specify a special relay for a new piece of equipment because he can be sure of getting it. Many manufacturers make only a few stock relays, with the major portion of their business represented by relays designed for special applications and supplied in quantity on special order. These special relays are usually made by modifying the number of contacts, coil resistance, contact arrangement, and other characteristics of a standard model.

If you have a relay problem, you may find the solution in this description of the more common techniques which many laboratory technicians use to adapt a common relay for specific applications.

Increasing sensitivity

Relay sensitivity is determined by a number of factors, including weight of the armature, spring tension, spacing between the armature and core, and coil characteristics. Many of these factors are beyond the control of the experimenter unless he is willing to actually rebuild the relay. However, the sensitivity of small relays, of the types used for control purposes in phototube circuits, capacitance alarms, and similar electronic circuits, may be increased by either of two methods.

The first is to reduce the spring tension. Do this by stretching the spring slightly or by bending either of the hooks holding the spring. In some relays, one end of the spring is attached to an adjusting screw, and spring tension may be changed easily . . . either by adjusting a nut or turning a screw. *If it is necessary to stretch the spring, it should be done very carefully. Take special pains not to overstretch the spring or to deform its shape.*

The other method of increasing sensitivity is to move the armature closer to the coil core. The best way to do this in the type of relay shown in Fig. 1 is by adjusting the back contact to move the armature down toward the core so the contacts are brought closer together. Therefore this technique is limited by the current and voltage at which the contacts make or break. Where only low currents and voltages are involved, contact spacing can be made quite close.

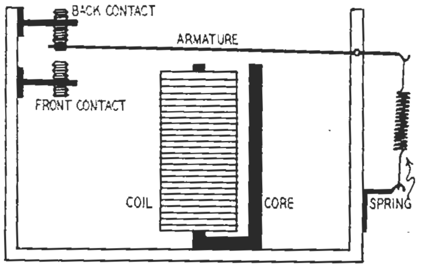


Fig. 1—A drawing showing the construction of a typical double-throw type relay. A single armature may carry several independent moving contacts.

Reducing relay sensitivity

Reverse the techniques described above to reduce relay sensitivity. That is, increase the spacing between armature and core or increase spring tension, or both.

In addition, resistors may be used either in shunt or series with the relay to change the sensitivity. Where the relay is operated by a current change, a shunt resistor is employed. Where control depends on a voltage change, a series resistor is used. Both methods are illustrated in Fig. 2.

Since the resistor size is determined by the control voltage (or current), the change in sensitivity desired, and the coil characteristics, it is generally difficult to specify the size beforehand. In most cases the resistor size is determined experimentally. For variable sensitivity, use a variable resistor.

Self-latching relay

More power is required to close a relay than is necessary to hold the relay in, once closed. This fact may be used to advantage in designing a self-latching relay circuit. The circuits for both current-controlled and voltage-controlled relays are given in Figs. 3-a and 3-b respectively. In Fig. 3-a, the resistor is adjusted to bypass sufficient circuit current so that the relay is held closed, but so that there is not sufficient current through the coil to pull the relay in, once opened. When the control current is stopped (or reduced sufficiently), the relay opens, and will re-

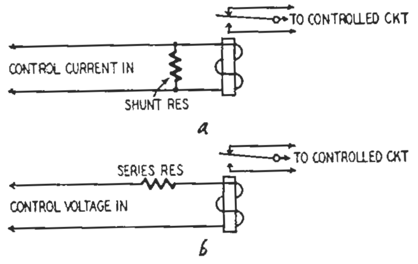


Fig. 2-a—The shunt resistor reduces sensitivity and adapts a low-current relay to a high-current control circuit. Fig. 2-b—The series resistor reduces the sensitivity and prevents voltage breakdown in the coil of the relay.

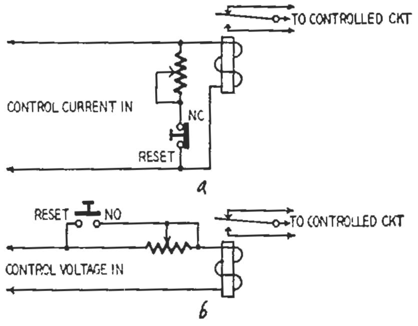


Fig. 3—Self-latching relays. The circuit at *a* is controlled by a change in current; circuit at *b* is controlled by a variation in the applied voltage.

main opened even though the control current is restored to its normal value, until the RESET switch is pressed to open the shunt circuit and permit the relay to pull in again.

The circuit in Fig. 3-b operates in a similar fashion, except that a series resistor rather than a shunt resistor is used. This circuit is suitable for voltage-controlled relays. In this circuit, the variable resistor is adjusted so the current through the relay is too weak to close the relay but it is strong enough to hold it closed if the armature is depressed manually. Interrupting or reducing the voltage will cause the relay to open. It will not close—even though the normal voltage is reapplied—until the RESET switch is closed momentarily to short out the variable resistor.

Sensitive a.c. relays

Extremely sensitive a.c. relays are not generally available except on special order. The circuit shown in Fig. 4

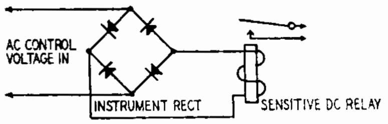


Fig. 4—Instrument rectifier adapts the sensitive d.c. relay to an a.c. circuit.

will give satisfactory results as a substitute for an a.c. unit. A small instrument rectifier (such as used in multitesters) and a sensitive d.c. relay make up the circuit. These small rectifiers cannot deliver more than a milliampere or two (depending on the type employed) and are limited as to maximum voltages. However, sensitive d.c. relays requiring only a milliampere or two are easily obtained at reasonable prices.

Time-delay relays

Three different time-delay circuits are shown in Fig. 5. Each is designed for a different application, and all may be used to give a wide range of time

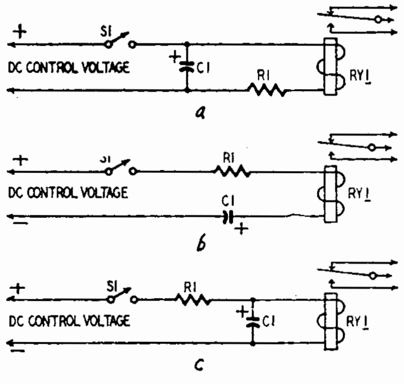


Fig. 5-a—RY1 remains closed for a short interval after opening S1. Fig. 5-b—Relay closes with S1 and then opens automatically after a timed interval when capacitor C1 is charged. Fig. 5-c—Operation of RY1 is delayed on opening or closing control switch S1.

delay. In each case, C1 is generally an electrolytic, with the values of both C1 and R1 chosen experimentally to give the desired time delay. The exact values depend on the resistance of the relay coil, the control voltage, and the delay time. The relay is generally a high-resistance (5,000-ohm to 10,000-ohm coil) unit.

The circuit in Fig. 5-a is designed to hold the relay closed for a given time after the control voltage is removed. In operation, closing S1 charges C1 and pulls in relay RY1. After S1 is opened, the capacitor C1 discharges slowly through R1 and RY1. RY1 stays closed until the discharge current drops below the hold-in current for the relay. In this circuit C1 may be either a paper or an electrolytic capacitor.

When the circuit shown in Fig. 5-b is used, the relay closes immediately when S1 is closed, but opens automatically shortly after, even though S1 remains closed. In operation, closing the switch permits C1 to charge from the control voltage. As long as C1 is charging, current flows through the circuit to pull in RY1 and hold it closed. When C1 approaches maximum charge, the charging current drops, permitting the relay to drop out. If it is desired to open the relay at any time before the end of the delay period, it is necessary only to open S1, in which case RY1 opens immediately.

An electrolytic capacitor is preferred for C1 (in Fig. 5-b) because its internal leakage will permit it to discharge completely between operating cycles. However, a paper capacitor may be used if shunted by a high resistance to provide the necessary leakage.

The circuit given in Fig. 5-c closes the relay at a predetermined time *after* the control voltage is applied. In operation, when S1 is closed, C1 charges slowly from a voltage divider consisting of R1 and the relay coil resistance in series. The current through R1 is the sum of the capacitor-charging current and the current through RY1. The current through RY1 does not reach a level high enough to pull in the armature until C1 is nearly charged.

This circuit also has a slow-opening time-delay characteristic. When S1 is opened, C1 discharges through the relay coil. The relay stays open until after the discharge current has dropped below the relay hold-in value. However, proper choice of components will keep the drop-out time down to a fraction of the pull-in time. Either a paper or electrolytic capacitor may be used for C1 in Fig. 5-C.

Increasing contact current

Very often the problem of controlling an extremely heavy current with a small control current arises in design work. Unfortunately, the most easily obtainable sensitive relays cannot handle large currents because the contact must be small to keep the armature weight as low as possible. In such cases, the usual technique is to use one relay to control another. See Fig. 6. The sensitive relay, RY1, is operated by the weak control current, and, in turn, controls the heavier current required to operate the heavy-duty relay, RY2.

The number of contacts and the contact arrangement may be modified easily in some types of commercially available relays. In others, especially the more sensitive types, changing the number of contacts is difficult. In addition, it may prove next to impossible to obtain a stock relay with the desired contact arrangement. In such cases, two or more relays may be connected in series or in parallel to give the desired circuit arrangement.

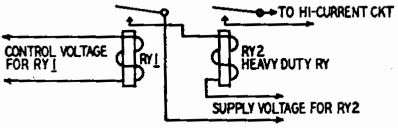


Fig. 6—Sensitive relay RY1 controls coil circuit of heavy-duty relay RY2.

Two s.p.s.t. relays are shown connected in parallel in Fig. 7-a to provide the equivalent of a d.p.s.t. relay. In Fig. 7-b a single-pole, normally open and a single-pole, normally closed relay are used together to provide s.p.d.t. action. Although the relay coils have been shown connected in parallel in both cases, they could just as well have been connected in series. The method of connection depends on the control voltage (or current) available. When using two or more relays together as outlined above, it is important that the relays have similar characteristics (coil resistance, armature tension, and size), regardless of individual contact arrangement. This is necessary if the relays are all to operate simultaneously. There is always a slight variation in pull-in and drop-out time for different types of relays.

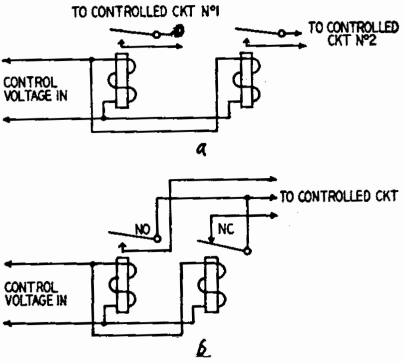


Fig. 7-a—A common method of adapting two s.p.s.t. relays for d.p.s.t. use. Fig. 7-b—Two s.p.s.t. relays (one normally closed) in a s.p.d.t. application.

Conclusion

While the methods outlined above represent the more basic techniques of adapting existing relays to specialized applications, they by no means represent all possibilities. It is perfectly feasible to combine two or more of the techniques described for special jobs. For example, one of the time-delay relay circuits might be used not only to operate equipment, but also to switch on, in turn, a different type of time-delay relay which is used to control still another piece of equipment. END

Rfi generation is a factor when selecting ac-switching relays

by Allan Q. Mowatt, *Theta-J Relays Inc., Reading, Mass*

☐ Relays are commonly used in alternating-current circuits to switch loads such as motors, tungsten lamps, and power supplies. An inevitable consequence of the selection of the tried-and-true electromechanical relay is the problem of radio-frequency interference, and so solid-state relays have come into prominence.

As a rule, electromechanical relays are the cheapest type. However, because of their inherent bounce during contact closure and opening, they can generate large switching transients, which manifest themselves as rfi. As a result, solid-state relays, which have no moving parts and so are free of bounce, are often chosen for those applications where rfi must be held down to a minimum.

For even more rfi reduction, many solid-state relays contain zero-crossover circuitry that delays their turn-on until the sinusoidal voltage applied to the load reaches 0. This delay could be as long as the entire first half-cycle of the driving waveform. Zero-crossover (also called zero-switching) relays are generally at least 30% more expensive than standard solid-state versions. In applications involving relatively low load currents, they do not improve performance appreciably more. However, they do have a place in high-ampere, high-speed switching.

Rfi and electromechanical relays

One cause of electromagnetic radiation at radio frequency is contact arcing during switching. Another source of interference-causing radiation is transient-induced voltage created by the relay coil when its energizing circuit is interrupted.

Characteristically, this interference is impulsive in nature and extends through a wide spectrum of frequencies. Hence, it is often referred to as broadband impulse interference. Figure 1 shows the considerable rfi typically generated by an electromechanical relay controlling an ac induction motor.

The closing of a set of relay contacts is invariably accompanied by contact bounce, which occurs when the interfaces separate as a result of the closing impact of the spring structures. When the contacts are carrying a current of greater than several hundred milliamperes at above 100 volts, abrupt signal changes occur in the contact leads, creating interference that is both conducted along these leads and radiated from them. Although these changes can be illustrated as a series of solid pulses, each pulse is actually a burst of rf oscillations across the contact gap.

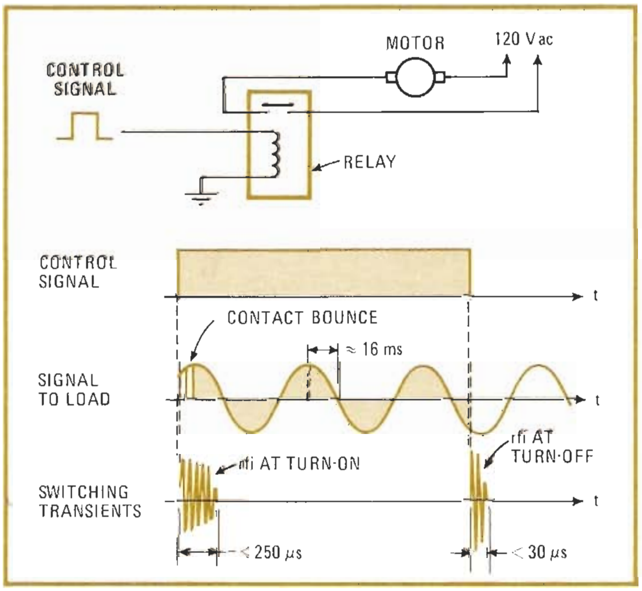
Conducted interference can be regarded as a noise signal that is coupled directly or capacitively to another location in the system. The conductor over which the noise impulse is carried can act like an antenna wire, thereby creating radiated interference.

The magnitude of the low-frequency components of this interference depends on overall pulse duration, while the high-frequency magnitude is related to the rise and fall times of the pulses. For a typical electromechanical relay, the average pulse width is about 30 microseconds. However, because contact bounce during switching usually involves a train of pulses, rfi can occur for 250 μs or longer. The slopes of the rise and fall portions of the rfi pulses are generally determined by the RLC transient behavior of the relay and load circuit.

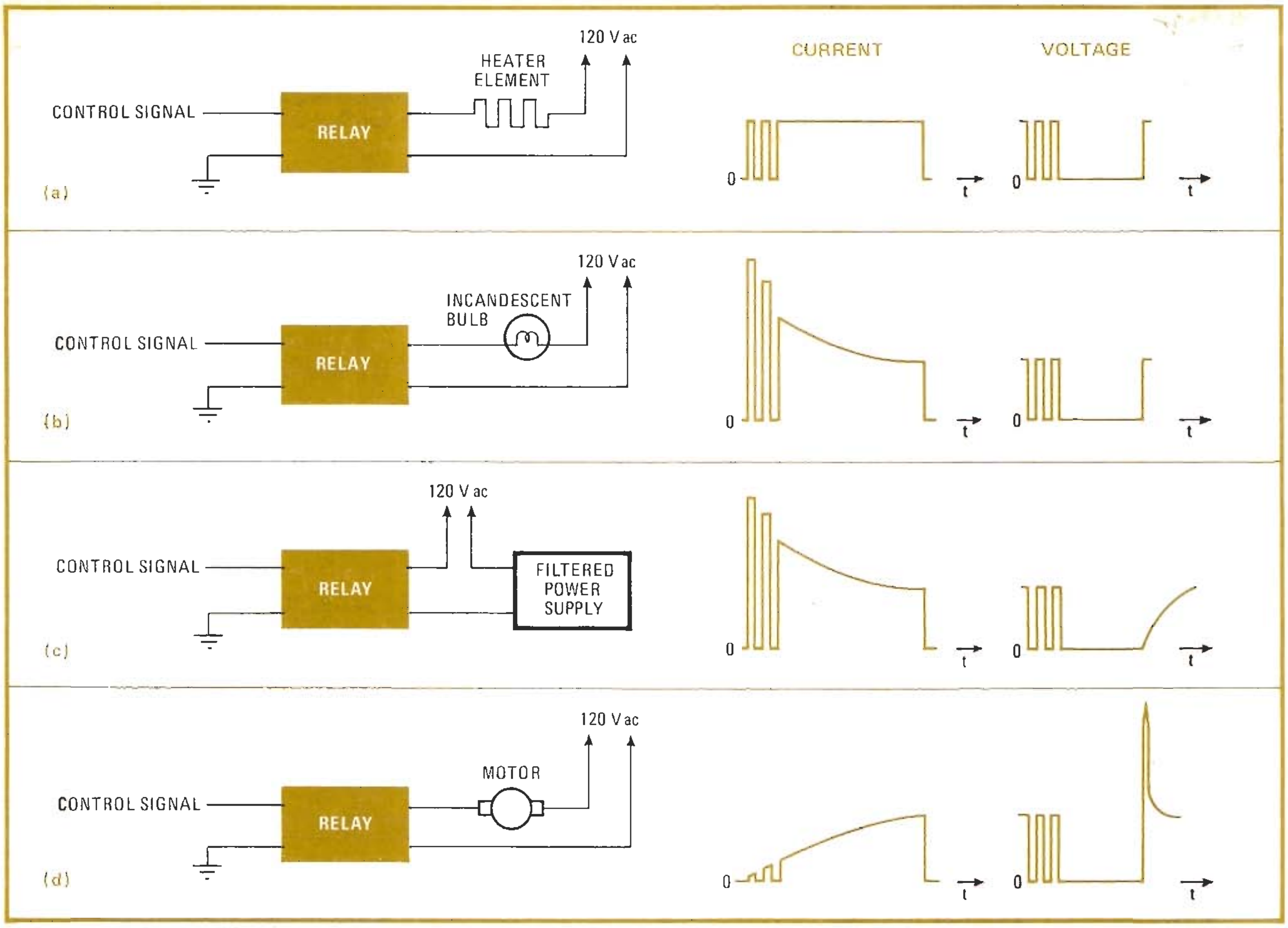
Figure 2 shows the contact bounce that occurs during closure of an electromechanical relay for various types of loads. Current and voltage waveforms are given for a purely resistive load (a), a tungsten-lamp load (b), a primarily capacitive load (c), and a primarily inductive load (d). In the last case, the largest voltage spike occurs, not upon closure because of contact bounce, but upon opening when load current is interrupted.

Consequences of contact opening

Needless to say, rf oscillations can be particularly severe during interruption of current to an inductive load. Figure 3a depicts the shape of the contact discharge-voltage waveform when steady-state current is less than the minimum required to produce arcing, while Fig. 3b



1. Severe rfi. When an electromechanical relay is used to control an ac induction motor, considerable rfi is generated when the load is switched on, as well as when it is switched off. The tinted areas of the timing waveforms indicate the on portions of these signals.



2. Contact bounce vs load. In an electromechanical relay, contact bounce occurs when the load is switched on. The extent to which bounce disrupts load current and load voltage depends on the load itself, whether it is a heater element (a), an incandescent bulb (b), a power supply (c), or a motor (d). In the latter case, the largest switching spike is produced upon contact opening, not contact closure.

shows this voltage when the current is greater than the minimum for arcing. Moreover, similar oscillations, caused by bounce and brief separation, can occur at contact closure.

The high-frequency oscillations—or "showering" effect—are produced when the inductive load current charges the contact capacitance to a level sufficient for arcing. The arc discharges the capacitance; the inductive current reverses, and so the cycle continues until all of the inductive energy is dissipated.

The radiated element for contact opening of this interference is broadband, with peaks and nulls occurring all the way from 10 to 1,000 megahertz, as indicated in Fig. 4a. The amplitude of the radiation and its location in the frequency spectrum depend on the load current and such layout factors as wiring, shielding, and the capacitance to ground.

The spectrum of conducted interference for contact closure typically resembles the plot of Fig. 4b. This conducted rfi has the frequency distribution of a step function—that is, a continuous spectrum of noise with an amplitude that decreases with frequency at the rate of 20 decibels per octave.

Like an electromechanical relay, a solid-state relay containing a thyristor output switch (whether a triac or back-to-back silicon controlled rectifiers) generates a transient at turn-on. This transient occurs when power is first switched on to an ac load at a point where the driving sine wave is well above 0.

The spectrum of conducted interference for a solid-state relay is generally the same as that shown in Fig. 4b for an electromechanical relay. But there the similarity ends.

No contact bounce

In a solid-state relay, there is no contact bounce, no arcing, and consequently no lengthy showering period during which broadband rf oscillations are produced. Since the relay's thyristor output usually switches on in less than 1 μs, the resultant rf oscillatory period is only about 5% of the time of a single contact bounce of an electromechanical relay.

Standard solid-state relays are available in several versions (Fig.5). They can be transformer-isolated (a) or optically isolated with either a photo-transistor (b) or a string of photo-SCRs (c) when very high blocking voltage is needed. Zero-crossover models, like the one shown in Fig. 6, contain additional control circuitry and usually employ a phototransistor optical coupler for isolation.

Zero-crossover solid-state relays can perform a function not possible with electromechanical relays—

through special circuit configurations, they guarantee that relay turn-on for resistive loads occurs only near the zero crossing of the voltage sine wave. Even if the relay is signaled to fire when the voltage sine wave is at or near its peak value, turn-on is delayed until the next zero crossing.

The operation of a zero-crossover circuit is relatively simple. In the relay of Fig. 6, the state of transistor Q_1 is governed by the control signal applied to the optical coupler, while the state of transistor Q_2 is essentially determined by the level of the driving voltage. If either of these transistors is saturated, the SCR cannot fire because its gate is clamped to ground.

The entire circuit is always off at the zero crossing of the driving sine wave. With no control signal present, transistor Q_1 goes into saturation once the voltage at the anode of the SCR exceeds 1 volt. Transistor Q_2 saturates a little later, when this voltage reaches approximately 5 V. The SCR, therefore, never fires without a control signal being applied.

If the control signal is present at the next zero crossing, transistor Q_1 remains off, no matter the level of the driving voltage. However, transistor Q_2 stays off only until the SCR's anode voltage reaches 5 V. This means that both Q_1 and Q_2 are off for a brief time, permitting the SCR to fire and trigger the triac, so that the load switches on.

In essence, then, transistors Q_1 and Q_2 create a brief firing window at the beginning of each half-cycle, between about 1 and 5 V. If the relay is signalled to turn on at a later point in the cycle, it must wait until the next window occurs—when both Q_1 and Q_2 are off.

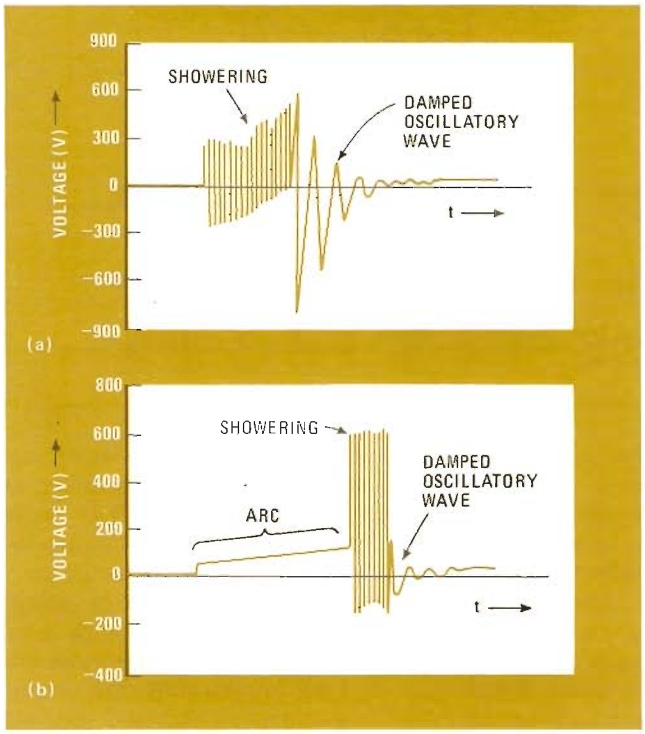
However, it should be noted that zero-switching relays trigger at the voltage zero crossing, not the current zero crossing. Because of the phase shift caused by highly inductive loads, the two crossovers don't coincide. Therefore, zero-switching relays are best suited to resistive loads in applications where their performance is not degraded by a leading or lagging power factor.

These relays were originally intended for variable-power ac applications as a noise-free substitute for phase control. Consequently, it is often assumed that a standard solid-state relay must generate rfi similar to that of variable-power phase control. To the contrary, a phase-controlled thyristor circuit turns on late in the cycle, producing an rfi pulse each half-cycle (see "Phase control and rfi").

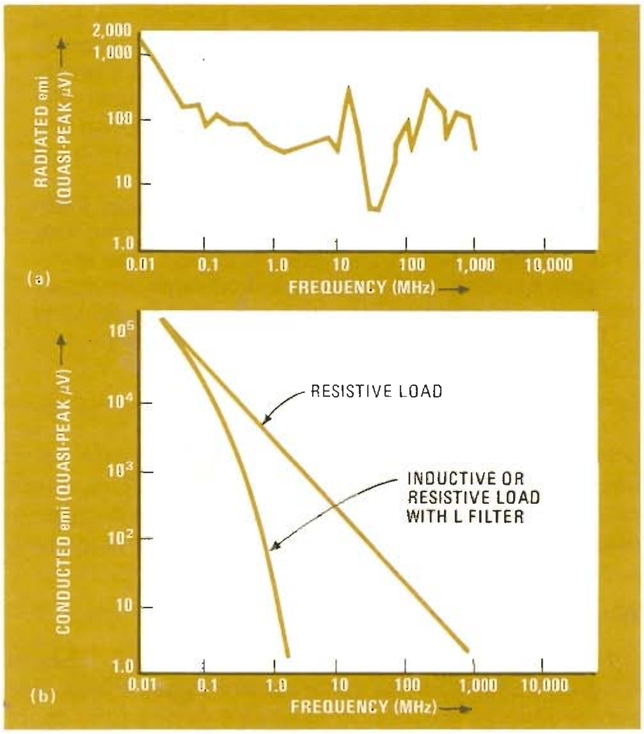
The small amount of rfi generated in a standard solid-state relay occurs only upon initial closure, during the first half-cycle of conduction. For all subsequent half-cycles, turn-on takes place near voltage 0, so that essentially no rfi is produced.

But what about turn-off, the equivalent of contact opening for an electromechanical relay? It is during contact break that an electromechanical relay generates the most significant levels of rfi, especially when interrupting current to an inductive load.

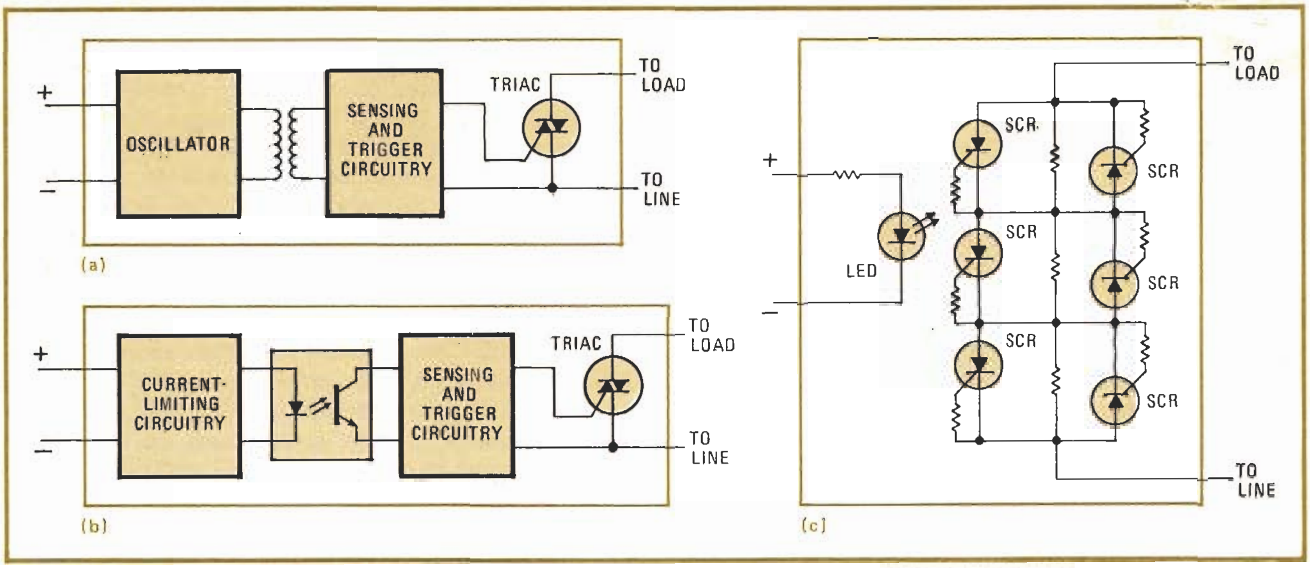
However, the thyristor-output solid-state relay could not be better in terms of turn-off rfi—the amount generated is immeasurably small. A thyristor is inherently a



3. Rfi and contact break. Unwanted switching spikes are particularly severe when an electromechanical relay switches off an inductive load. The contact voltage breaks up into a series of sharp spikes that eventually damp out. This high-frequency showering takes place even if there is no arcing (a). When arcing does occur, (b), the amplitude of the spikes becomes substantially higher.



4. Jagged spectrum. With electromechanical relays, both contact opening and closure create interference that is radiated directly, as well as being conducted along lead wires, which then act like antennas and also radiate rfi. Radiated interference (a) is highly erratic, especially from 10 to 1,000 MHz. In contrast, conducted interference (b) exhibits a continuous spectrum of noise.



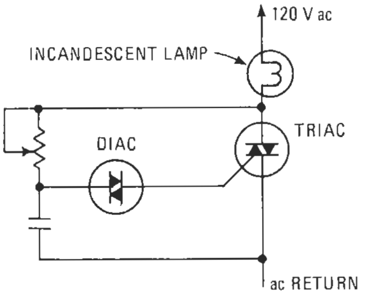
5. Standard solid state. Because they don't include optional zero-crossover circuitry, standard solid-state relays are generally about 30% less expensive than their zero-switching counterparts. Here, three versions are shown: transformer-isolated (a) and optically isolated with either a phototransistor (b) or a chain of photo-SCRs (c). The latter configuration is used to obtain very high blocking voltage.

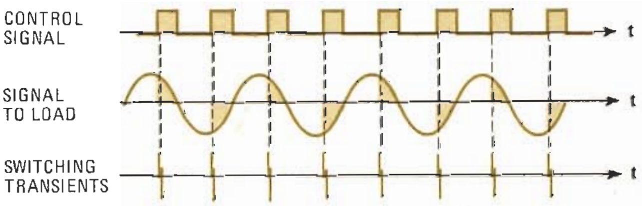
Phase control and rfi

Phase control is a widely used circuit technique for varying the root-mean-square power to an ac load. The approach is simple, but noisy, with a transient generated every time the load receives power—approximately 120 times a second.

In the circuit here, the diac and the triac are controlling the power to a tungsten-lamp load. During each half-cycle of the ac line, the capacitor charges towards the peak line voltage until the diac's breakdown voltage is reached. The capacitor then discharges through the diac, creating a trigger pulse that fires the triac. The resistor sets the point at which the triac conducts in each half-cycle.

Every time the triac turns on, radio-frequency interference occurs, as shown in the timing diagram. This rfi manifests itself as an audible 120-hertz buzz at virtually all points in the amplitude-modulated broadcast range. An unfiltered 600-watt lamp dimmer adjusted for low brilliance is a good example of the a-m hum induced by phase control.





zero-crossover device for turn-off: after the gate signal has been removed, it will not turn off until its anode current has decreased to about 0. From the standpoint of turn-off, there is no difference between a zero-crossover solid-state relay and a standard one.

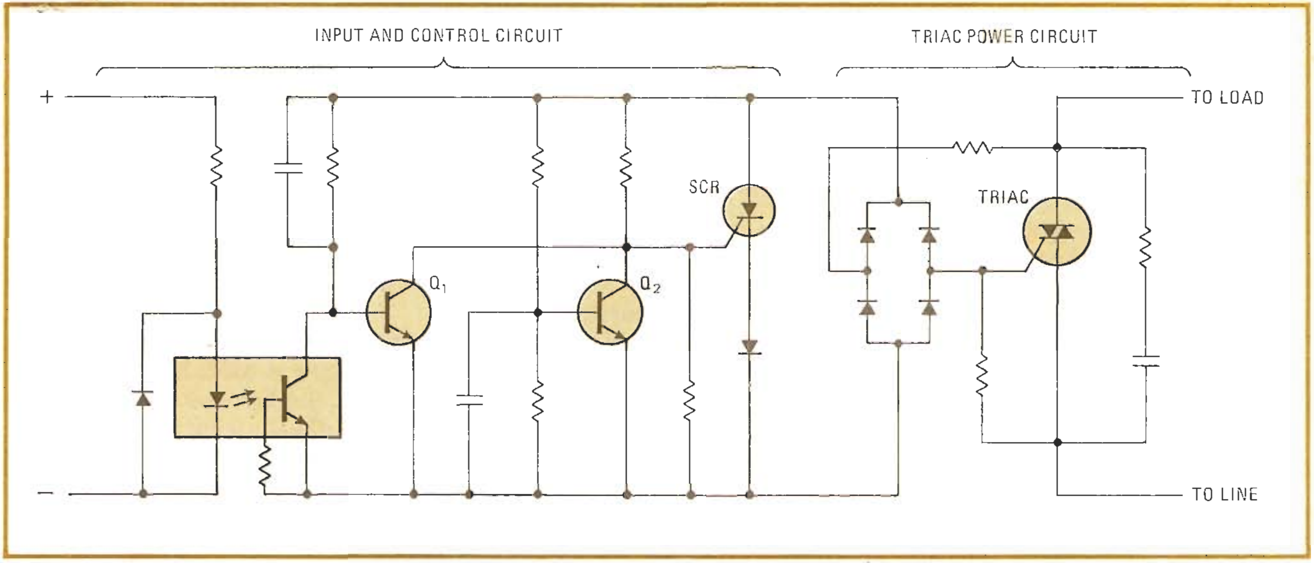
When to use zero crossover

Figure 7 compares the rfi created by both types of solid-state relays for the same control signal. Either type greatly reduces the total rfi produced during turn-on. In a zero-crossover relay, additional circuits are employed to delay turn-on in the first half-cycle of operation until the zero crossing of the voltage sine wave. For all subsequent half-cycles, operation is identical to a standard solid-state relay.

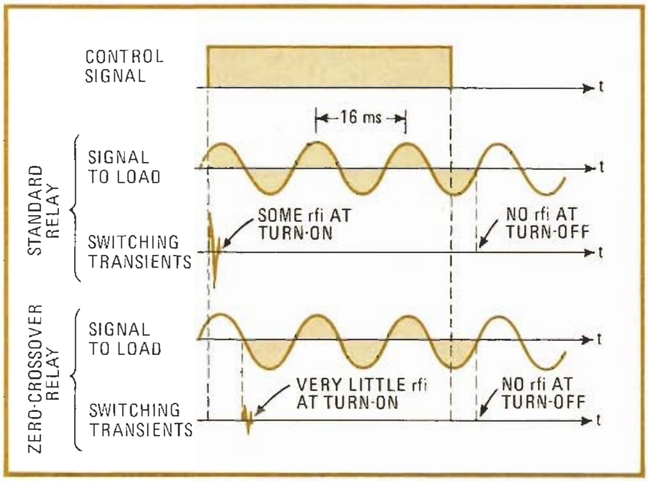
Such rfi-suppression similarities between the two relay types raises the question of the value of zero-crossover switching. However, it definitely has its place in applications where even the slightest random rfi pulse cannot be tolerated or for constant, 10-to-20-closures-a-minute switching of loads of more than a few amperes.

Zero-crossover turn-on can also be of value in certain applications where relatively high currents of 25 A or more and fairly high voltages of 440 V ac or greater are switched repetitively. In such applications, the output thyristor can be forced to dissipate an excessive amount of power at turn-on. If the thyristor is fired when the voltage sine wave is at its maximum amplitude, the voltage across the device drops from the peak line value down to approximately 1 V. At the same time, device current abruptly rises from 0 up to its peak load value.

As the voltage and current are changing levels, there



6. Zero-voltage switch. Special circuitry in zero-switching solid-state relays delays device turn-on until the driving-voltage sine wave crosses 0. In this Motorola circuit, there is a brief turn-on window between 0 and 5 V when transistor Q_1 is off, permitting the SCR to fire and trigger the triac. As long as Q_1 is on, the gate of the SCR is held at ground potential, thereby preventing it from conducting.



7. Solid-state comparison. With or without zero-crossover, solid-state relays generate only a fraction of the rfi produced by electromechanical units. Although zero-crossover versions create less rfi at turn-on than standard models, both types essentially eliminate rfi at turn-off. This is because each employs a thyristor output, and a thyristor is inherently a zero-crossover device for turnoff.

is a point at which device dissipation (the product of voltage and current) reaches a maximum. Depending on thyristor design, excessive turn-on dissipation can cause failure under long-term use.

Minimizing dissipation

To minimize the peak turn-on dissipation, conduction should occur as close as possible to the zero-crossover point. This can be achieved with zero-crossover switching, which ensures that turn-on occurs at the point of minimum power dissipation. As with rfi, turn-on dissipation becomes a factor in applications involving constant high-speed switching of high-current loads.

Zero switching is often regarded as a good technique for extending the life of incandescent (tungsten-filament) lamps, particularly in applications where they flash on and off. It is commonly believed that, if lamp turn-on is at the zero voltage point, the filament is subjected to a reduced initial surge current, thereby lowering the thermal stress to which it is subjected. However, thermal fatigue is not really the cause of lamp failure. With today's lamps, fatigue usually occurs long after the lamp has met its specified life requirements.

The two principal factors that do contribute to lamp failure are filament evaporation and mechanical shock, in which the filament is actually broken. Reducing the root-mean-square voltage driving the lamp will slow the evaporative process. The problem of mechanical shock can be dealt with through the use of filament support structures or mechanically stronger filament materials, like tungsten-rhenium.

Although repetitive on/off switching does degrade the life of fluorescent lamps, it has no measurable effect on the life of incandescent lamps. So, longer incandescent-lamp life does not result from zero-switching.

Since ac switching circuits encompass a broad variety of tasks, there's plenty of room for all three relay technologies—electromechanical, standard solid-state, and zero-crossover solid-state. Electromechanical relays will remain the choice when inexpensive multipole switching is needed or if heat-sinking limitations exist. Standard solid-state relays will eventually be cost-competitive with electromechanical types. Right now they can offer the advantages of logic compatibility, as well as improved reliability. And, of course, zero-crossover relays will continue to address the really tough switching problems. ☐

BIBLIOGRAPHY

Kay, David C. ed., "Transient Voltage Suppression Manual," General Electric Co., Syracuse, N.Y., 1976

Malarkey, Terry, "Solid-State Relays for ac Power Control," Motorola Semiconductor Products Inc., Phoenix, Ariz., 1975

Grafham, D.R. and Hey, J.C. eds., "SCR Manual," 5th edition, General Electric Co., Auburn, N.Y., 1972

Oliver, Frank J., "Practical Relay Circuits," Hayden Book Co., Rochelle Park, N.J. 1971

Machine Design, Reference issue on electric controls, March, 1969

Murray, Robert J. ed., "SCR Designer's Handbook," Westinghouse Electric Corp., 1964

NORTHERN ALBERTA INSTITUTE OF TECHNOLOGY
EDMONTON ALBERTA

ELECTRONICS DEPARTMENT

AC AND DC RELAY DRIVERS

Though semiconductor devices are replacing electro-mechanical relays in many uses, some applications require the switching of a signal which is isolated from power and other sources. This can be done only with a relay. This application note describes three different circuits that can be used for electronic control of these relays.

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INTRODUCTION

There is no universal solid-state replacement for the electro-mechanical relay. Some requirements can only be satisfied by a relay, which can be controlled either manually or electronically. The many ways to implement electronic control result from different power sources and types of relays. For example, either an ac or dc source can be used and the voltage can be of any value. The implementation of the proper circuit must also consider protective devices for voltage spikes generated by the inductance of the relay coil. Careful consideration of these facts are necessary for the driving circuit to be properly designed for reliable operation.

RELAY DRIVERS

Electronic control of either ac or dc relays is possible through the use of a transistor placed in series with the coil of the relay. This must be done through a bridge when an ac relay is used. Figure 1 is the schematic of a dc relay that can be controlled by an electronic signal which can supply a current of 1/2 mA. The relay coil is the load for transistor Q1. When a positive control voltage is applied to R1, Q1 receives base drive and saturates, thus connecting the relay coil to the supply voltage. R1 must allow enough base current to saturate Q1. For the components shown the 1/2 mA of base current will assure this since the relay requires 5 mA and the transistor has a minimum gain of 50. When the control voltage drops to zero the transistor turns off, de-energizing the relay. Since the relay coil is inductive, a voltage spike could occur at the collector of Q1; a protective circuit for the transistor should be included. The diode (D1) across the relay coil clamps the collector voltage to the supply voltage by providing a path for the current in the relay coil when the transistor turns off.

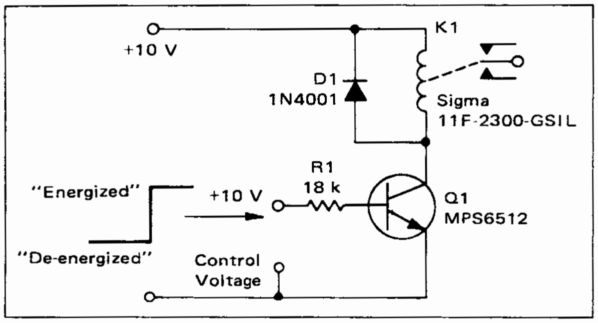

FIGURE 1 — Electronic Control of a DC Relay

A modification of this relay circuit is shown in Figure 2. In this case, the control of the relay is provided by light. When sufficient light is directed at Q1, it turns on. This drives Q2 which energizes the relay coil as in the previous circuit. A light magnitude of 220 foot-candles was enough to drive relay driver Q2 to saturation. When light is removed from Q1, base drive is removed from Q2 and Q2 turns off. In this circuit, Q2 turns off slightly slower than in the previous circuit, therefore a small capacitor (C1) across the relay is adequate to limit the maximum voltage spike to below the breakdown level of Q2.

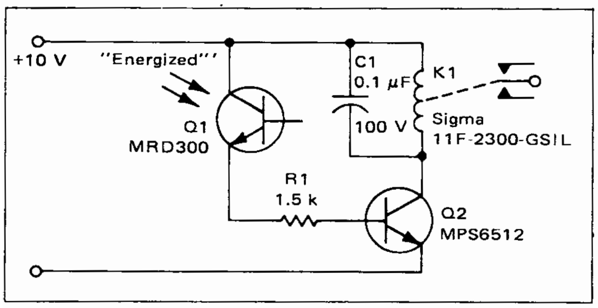

FIGURE 2 — Light-Operated Relay

The circuit shown in Figure 3 can be used to control an ac operated relay. The bridge consisting of D1, D2, D3 and D4 provides dc to the transistor while the relay sees an ac voltage. When a dc control voltage is applied to R1, Q1 saturates and energizes the relay coil. As before, adequate base current must be provided to saturate Q1. A disadvantage of this circuit is that the control signal must be isolated from the power line. The prime advantage is, of course, that an ac relay can be controlled by a single transistor. A forced gain of 10 guarantees that Q1 will be saturated, therefore the base current of 1.6 mA will drive a relay coil requiring 16 mA. In this circuit, protection against voltage spikes must also be provided for the transistor when it is turned off. The capacitor C1 across the relay coil provides such protection.

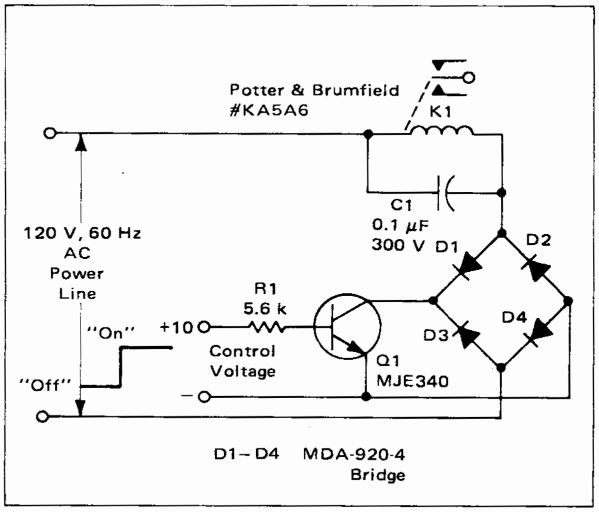

FIGURE 3 — Electronic Control of an AC Relay

Simple pulse shaper or relay driver

To obtain pulses of a required duration and constant amplitude, one would normally use a monostable circuit. In most cases a simpler circuit can be made using the economical Signetics 555 integrated circuit. This device can provide output pulse currents of up to 200mA and can drive a relay directly from input pulses which may have a duration of less than a microsecond.

The circuit shown uses the 8-pin dual-in-line NE555V or the equivalent TO-99 type NE555T. It provides output pulses of a duration equal to $1.1R_3C_2$; this can range from microseconds to many minutes, but R_3 should not exceed 20MΩ. Output pulse amplitude is a little less than V_{CC}, the exact value depending on output current. Rise and fall times are about 0.1μs.

In the circuit, the input pulse amplitude must cause the voltage at pin 2 to fall to $V_{CC}/3$ or less. Inclusion of R_2 reduces the required amplitude of the pulse considerably. The value of C_1 should be chosen so that the input time constant is appreciably greater than the fall time of the leading edge of the input pulses to minimize pulse attenuation. The 555 can be triggered by a current of 0.5μA from pin

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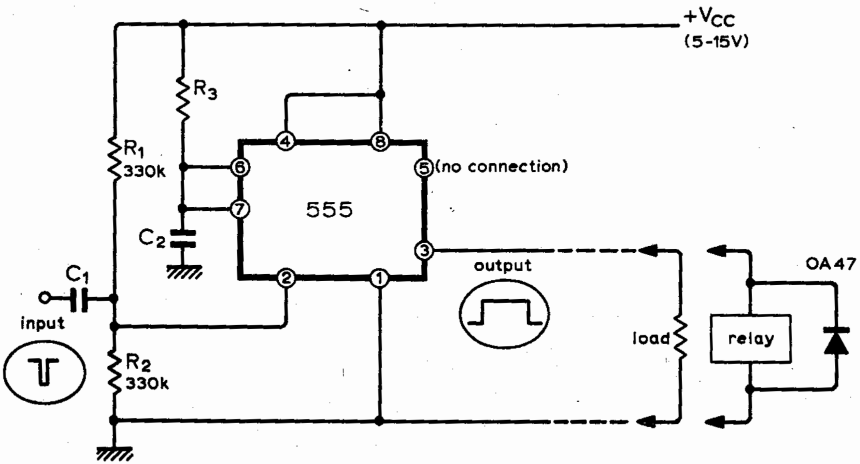


The 555 operates with negative-going trigger pulses. If positive-going pulses with a steep trailing edge are available, the 555 can be triggered on the negative-going trailing edge. However, the use of positive-going pulses results in the output being delayed until the trailing edge of the input pulse occurs; with wide input pulses this may be unacceptable.

To operate a relay directly, the relay coil may be connected in place of the load, in which case an input pulse causes the relay to close for a time $1.1R_3C_2$. A diode must be connected across the relay coil to suppress transient voltages developed across the inductive load when the current in the coil is switched off. Such transients may damage the 555 and they have been found to cause automatic re-triggering of the circuit as a result of pick-up. If re-triggering occurs, the relay fails to open. Not all types of diode give adequate suppression to prevent re-triggering; I found the gold-bonded types (such as the OA47) suitable.

If the relay and diode are connected between pin 3 and $+V_{CC}$, the coil will normally be energized, but the relay will open for the pre-determined time when the input pulse triggers the circuit.

The relay should be rated to operate from a potential approximately equal to that used for V_{CC} at a current of not more than 200mA. A small electromagnetic counter could be used instead of a relay.

J. B. Dance,
Alcester,
Warwickshire.

How to trigger power relays

SOUP-UP YOUR RELAYS

By LYMAN E. GREENLEE

ARE YOU AT YOUR WIT'S END TRYING to find a sensitive relay with husky contacts to complete a pet project? If so, you've probably found that relay sensitivity (rated in milliwatts input per single-pole contact) drops sharply as contact current rating increases. Really sensitive relays with heavy contacts are generally very expensive or not readily available. If this is your problem, don't despair, I may have a simple solution.

You can use an ordinary power relay and multiply its sensitivity many times by using an SCR to drive it. Typically, a relay handling up to 30 amps at 600 volts can be triggered by only 200 μA at 0.8 volt on the SCR gate. The basic SCR/relay circuits in Figs. 1 and 2 work well, but must be modified to make them immune to power-line transients that are produced when oil burners, air conditioners and similar devices are turned on or off.

In Fig. 1 resistors R1 and R2 form a voltage divider to limit gate current to a safe value. The SCR, one of G-E's low-cost C106 series, will carry up to 2 amps. This is adequate to handle power relays that switch 30 amps at up to 600 volts. When S1 is closed, the gate is biased on; the SCR conducts on positive half-cycles of the ac input voltage and keeps the relays energized. The SCR stops conducting on the next half-cycle following the opening of S1.

If we add a diode and capacitor as in Fig. 2, we have a self-locking circuit. When S1 is closed momentarily, the SCR fires and keeps the relay energized until released by opening S2. S1 and S2 may be momentary-contact switches with S1 normally open and S2 normally closed.

A locking circuit such as this is useful in alarms and similar devices. Reset (by opening S2) may be either manual or automatic. The value of R3 is selected to clamp the voltage across C1 at about 120 volts dc. R4 is the surge-limiting resistor for D1—a 200-piV, 500-mA silicon diode.

The circuits in Figs. 1 and 2 are okay for experimenting, but are not practical because they are subject to random triggering by transients. So let's see how we develop a practical, reliable circuit.

Noise-immune circuits

First, in Fig. 3 we add transformer T1 to isolate the relay coil and SCR from the power line. This, in itself, does not eliminate all random triggering, so a filter (R5–C4–C5) is connected in the primary circuit. The drop across R5 is about 20 volts when the relay is energized. Idling or "relay off" current will produce a drop of about 10 volts across R5.

Resistor R4 and capacitor C3 provide additional filtering across the secondary of T1. A NE-2 neon lamp isolates the SCR gate from the triggering circuit. The advantage of using the neon lamp is that the gate cannot be triggered until the lamp is conducting. Thus random pulses below the firing voltage of the lamp cannot trigger the SCR.

Resistor R3 and C2 eliminate any secondary or electrostatic discharge

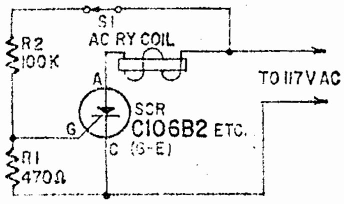


Fig. 1—Basic SCR relay driver. Switch S1 carries only the SCR gate current.

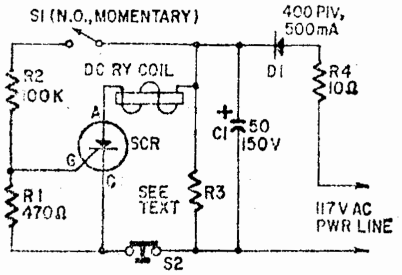
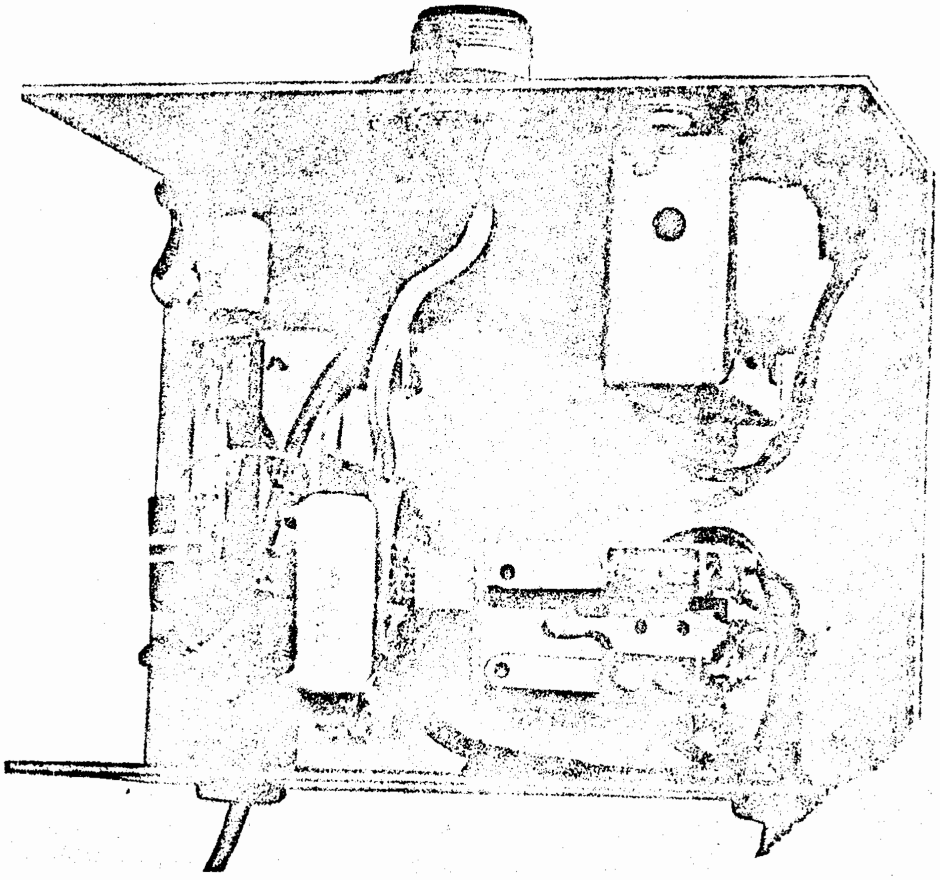


Fig. 2—A locking-type circuit. Closing S1 triggers the SCR and locks-in the relay. Opening S2 releases the relay.



A typical SCR/relay combination as in Figs. 3 and 4 fits neatly in a small metal box. The trigger leads run to the switch or LDR through the connector.

with a 200-microampere, 0.8-volt signal

WITH SCR DRIVERS

across the NE-2. An electrostatic charge will lead to false triggering. The optimum value of R3 is around 3.3 megohms, but it may be reduced to as low as 1 megohm, if necessary, to eliminate secondary glow in the lamp.

The stray capacitance of long leads to the tripping contacts (S1) will tend to drive the NE-2 and make necessary the use of lower values for R3. Use the shortest possible length of low-capacitance, low-leakage cable to connect S1 to the circuit. If R3 has to be less than 1 megohm, you will have to move the control circuit closer to S1 or use leads with lower capacitance.

The circuit in Fig. 3 is useful for many relay applications in which the actuator is an on–off switch capable of handling 200 μA. This includes such low-current devices as meter relays where contact current is limited. Easy to construct, it can be fitted into a 5″ x 4″ x 3″ utility box with room to spare. The relay may be almost any 117-volt ac type with contact combinations handling up to 10 amps. Its contacts may range up to 6-pole double-throw for polarity reversing, line transfer and other complex switching. Heavier relays may require a larger box.

The C106 SCR will handle up to 2 amps but should be used on an adequate heat sink when used to drive a relay whose coil draws more than about 300 mW.

Parts layout is not critical except for R4 and R5. They get quite hot and must be kept away from the other components, particularly the SCR. The SCR, C2, C3, R2, R4 and the NE-2 are all mounted on a 1¾″ x 2″ piece of linen Bakelite board. Use a heat sink when soldering the SCR into the circuit. A fuse is desirable but can be eliminated if space is needed for a larger relay.

Note that no part of the circuit is grounded or connected to the metal case. If grounded duplex ac receptacles are available, use a three-wire ac cord and ground the case through the third wire in the cord.

If you use a different relay or transformer, adjust the value of R5 for about a 10-volt drop when the SCR is cut off and not more than 20 volts when it is conducting and the relay is energized. Adjust R4 to balance the load and allow about 100 volts across the coil of the relay when the SCR is conducting.

Using temperature or light control

Figure 4 shows how the circuit can be modified so the relay can be triggered at any predetermined level of light or temperature. Here, the resistance of R2-a, R2-b and the LDR or thermistor in series is equal to 100,000 ohms, the value of R2 in Fig. 3. R2-a is adjusted to compensate for the resistance added by the LDR or thermistor. Potentiometer R2-b is selected to limit SCR trigger current to a safe value at the minimum resistance of the LDR and R2-a in series. R6 controls the sensitivity.

The circuit can be adjusted to provide 200 μA at 0.8 volt to trigger the SCR at any desired light or temperature level. The 5AJ/NE-86 (G-E) neon lamp has been doped with a radioactive material so it has low firing-voltage characteristics that are independent of light intensity. **R-E**

Parts List (Fig. 3)

R1—470-ohm, ¼-watt resistor
R2—100,000-ohm, ½-watt resistor
R3—3.3 meg, ½-watt resistor
R4—10,000-ohm 2-watt resistor
R5—500-ohm, 5-watt resistor
C2—56-pF 500-volt mica capacitor
C3, C4, C5—.047-μF, 600-volt Mylar capacitor
NE1–NE-2 neon lamp
F1—¼-ampere, slow-blow fuse
T1—Isolation transformer, 117-volt primary, 110-volt 30-mA secondary (Olson Electronics No. T-173 or equal)
RY1—General-purpose ac relay, 115-volt coil, 10 amp or heavier contacts as needed.
SCR1—C106-B2 silicon controlled rectifier (G-E)

Additional parts for Fig. 4

NE1–5AJ/NE-86 (G-E)
R2-a, R2-b—100,000-ohm miniature pot or as required to match the LDR or thermistor resistance. Be sure that the SCR gate is not overloaded at the minimum setting of R2-a. Select R2-b to keep the minimum circuit resistance at 100,000 ohms.

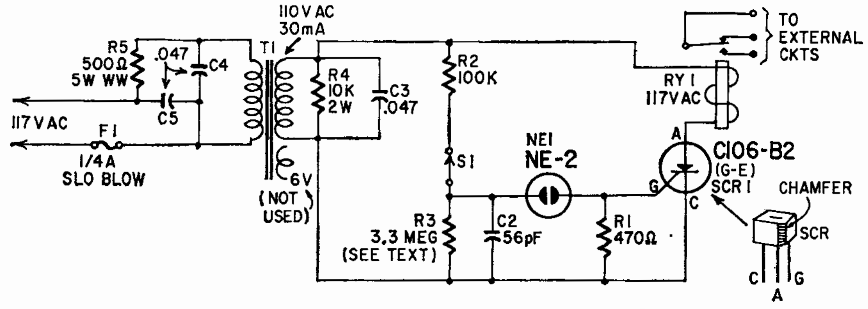


Fig. 3—This improved SCR/relay circuit is extremely sensitive but is immune to noise and transients on the power line. The neon lamp isolates the SCR from the trigger.

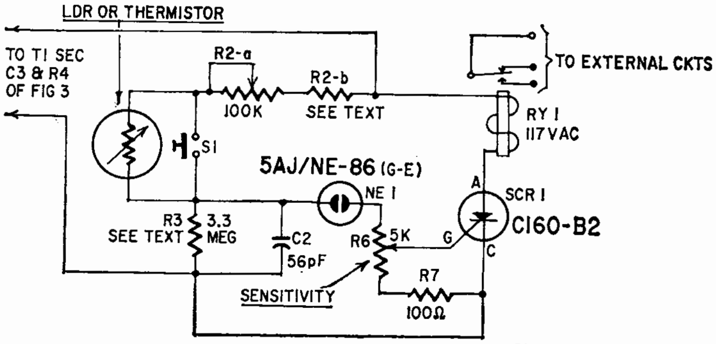


Fig. 4—How Fig. 3 is modified so relay can be controlled by a desired level of light falling on a photocell or by temperature change sensed by a thermistor.

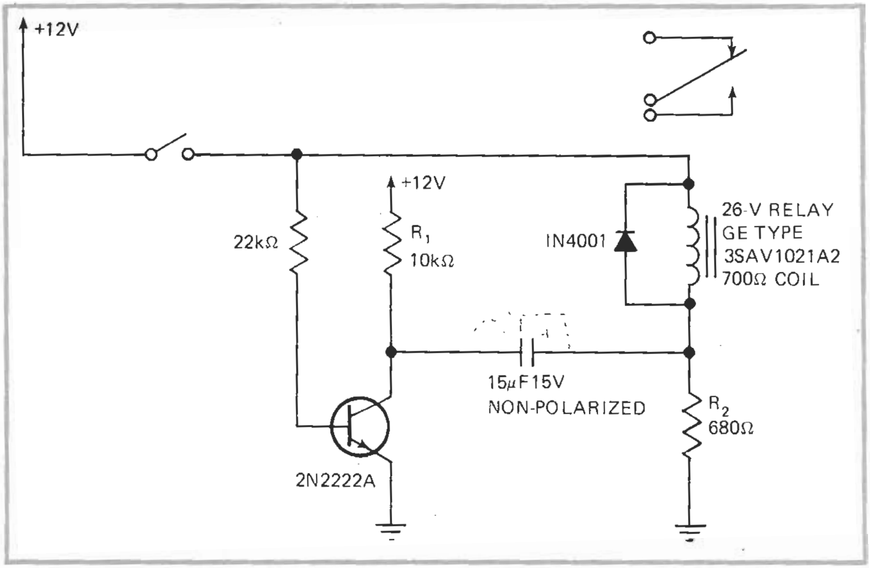
Charged capacitor reduces relay actuating power

by John R. Nelson
Motorola Inc., Government Electronics Division, Scottsdale, Ariz.

Operating a relay at its nominally rated voltage wastes power. Usually half that voltage or even less is enough to keep the device energized after actuation, and the same voltage can also actuate the relay if first given a boost by a simple circuit.

By using a transistor to add the voltage across a charged capacitor to the source voltage, the actuator circuit energizes a 26-volt relay with only 12 v. The comparison in the table indicates the substantial saving in power that results.

The capacitor is initially charged to 12 v through R_1 and R_2 in the figure. Closing the switch applies 12 v to the relay coil, and at the same time, turns on the transistor, which drops the positive side of the capacitor to ground. This effectively forces −12 v on the other side of the capacitor, and the relay pulls in with 24 volts across its coil. Once the capacitor has discharged through R_2 and the coil, the approximately 7 v across the relay coil is sufficient to keep it energized, as evident in



Energizer. In driving a 26-volt relay with only 12 V, this circuit makes use of the fact that the device's holding current is very much less than its pull-in current.

RELAY POWER REQUIREMENTS

Parameter	Alone			With Actuator Circuit*		
	Voltage	Current	Power	Voltage	Current	Power
Nominal	26V	35mA	910mW	12V	10.3mA	124mW
Threshold of pull–in	12.9V	18mA	232mW	9.1V	7.8mA	71mW
Threshold of drop–out	3.5V	4.9mA	17mW	6.9V	5.9mA	41mW

*Current and power measurements include transistor circuit requirements the table that is shown on page 113.

The circuit works well with 26-v relays having coil resistances in the region of 1,000 ohms. However, the value of R_2 may have to be changed to suit the requirements of different relays.

The capacitor should be a nonpolarized unit, because there will be a reverse voltage across it whenever the relay is energized. If power to the circuit is interrupted, the switch must be opened and closed to reactuate the relay. The diode across the relay coil protects the transistor from transients. □

Engineer's notebook is a regular feature in *Electronics*. We invite readers to submit original design shortcuts, calculation aids, measurement and test techniques, and other ideas for saving engineering time or cost. We'll pay $50 for each item published.

Relays and logic ICs can be working partners

Direct interface of mechanical relays and standard logic families provides economy and power-handling capability for many applications

by Patrick M. Craney, *Potter and Brumfield Division, AMF Inc., Princeton, Ind.*

☐ It's time to dispel the long-standing myth that electromechanical relays are not directly compatible with logic integrated circuits. Standard logic ICs that are capable of driving relays directly have been around for years.

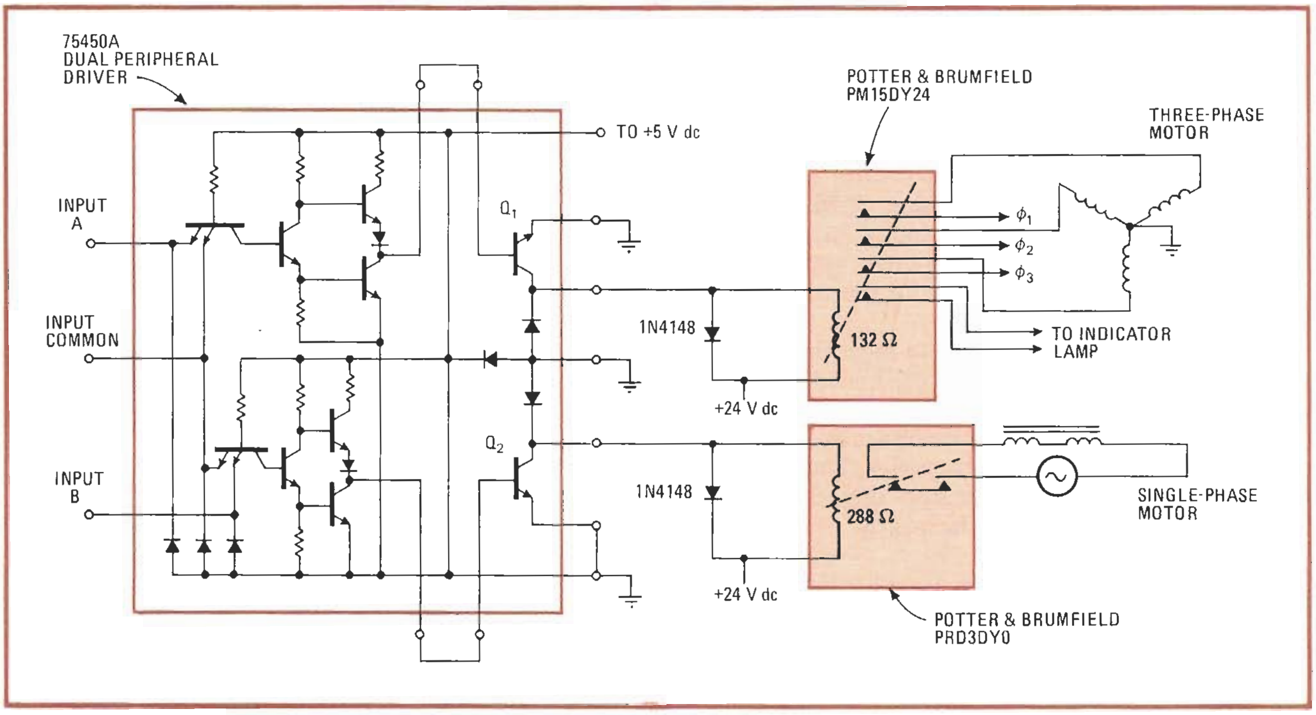
Besides direct compatibility with ICs, electromechanical relays offer designers several other advantages. They are not falsely activated by surges or transients, nor do their contacts require protection from such intermittent conditions. Furthermore, the contacts need not be derated for increasing operating temperature, and heat sinks are unnecessary. But perhaps the best reason logic designers should consider electromechanical relays is the ease with which these devices can be incorporated into logic systems.

Electromechanical vs solid-state

There is a tendency among designers to believe that a TTL or C-MOS gate cannot handle an inductive load without being damaged. On the contrary, logic systems can be terminated with IC drivers capable of switching in excess of 300 milliamperes at up to 60 volts dc—more than enough to drive a relay that will handle a 30-ampere load or a 1-horsepower motor. Even standard TTL or C-MOS buffers can be used with high-sensitivity relays for switching sizable loads of up to 10 A.

Many designers are unaware of these facts and tend almost automatically to think of a solid-state device, like a thyristor or a solid-state relay, to control the load. The approach seems simple, but it can sometimes prove more complex or costly.

In many systems, the load characteristics may require a dv/dt network to protect the solid-state device from false turn-on by line voltage transients. Also, a space-consuming heat sink may be needed, or isolation may be required between logic and load. What's more, for reliable trouble-free operation, the solid-state device must be carefully matched to the system and the load.



1. TTL drives power relays. Conventional TTL interface circuit, a dual peripheral driver, controls a pair of electromechanical power relays, which together can switch up to 125 A. Total power dissipation required of IC package is only 176 mW, well below the 800 mW allowed.

Though all of this can add up to a good deal of time and expense, the designer may end up with what amounts to only a single-pole switch. Yet often he could take advantage of a relay's economy, inherent isolation, power-handling capability, and multi-pole switching.

Furthermore, a designer sometimes opts for the solid-state route only to find that he must turn to electromechanical relays in the long run. Even with dv/dt protection, his solid-state device may not be 100% failsafe, or perhaps the heat-sinking required would consume space that is just not available, or switching multiple loads may far exceed the allotted budget.

Even after realizing that he is forced to use an electromechanical relay, the designer may think he needs a transistor or thyristor to interface between his logic and the relay. Or, he may try to salvage his switch design for driving the relay. However, more often than not, an electromechanical relay simply does not require such an interface. Chances are that the logic gate, buffer, or driver terminating his logic system can do the job quite well. A couple of examples will help to illustrate how it can be done.

Interfacing with TTL

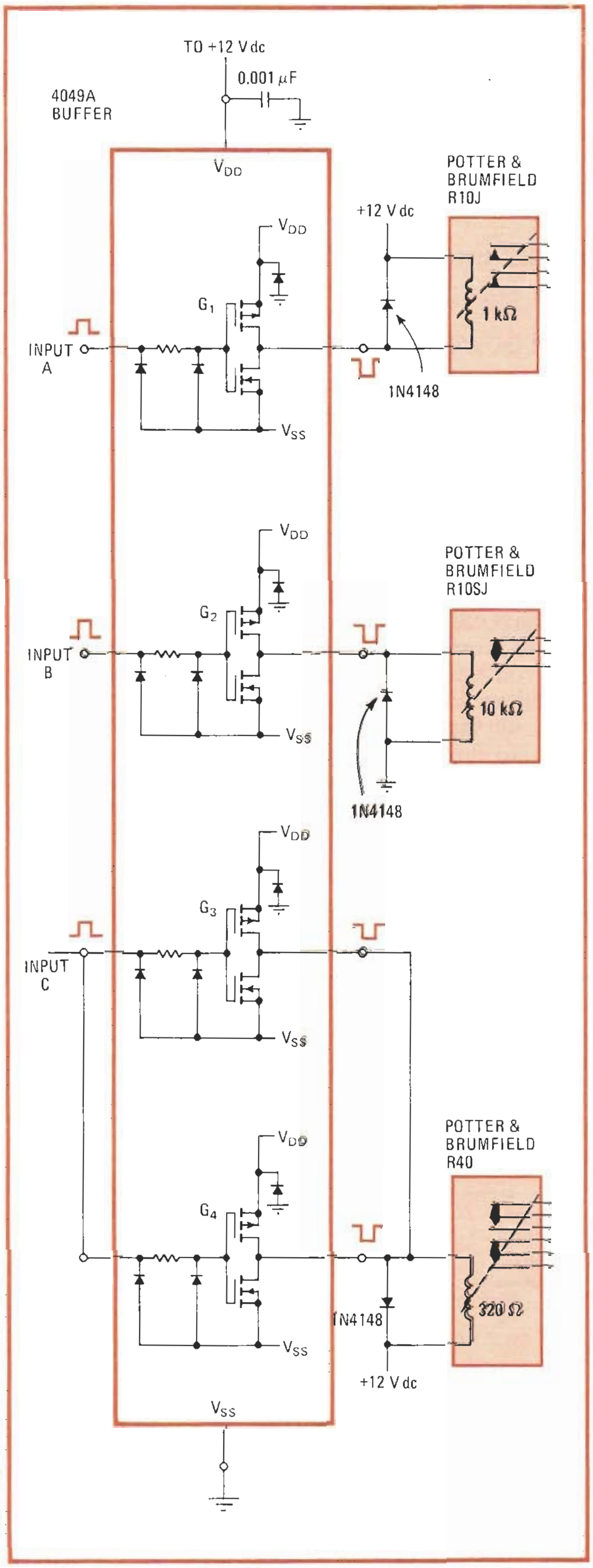
Standard TTL peripheral drivers used to terminate logic boards can deliver sizable outputs of up to several hundred milliamperes. Such IC drivers make ideal circuits for controlling relays. For instance, the 75450A-type interface circuit is a dual peripheral driver made up of a pair of 7400-type TTL NAND gates and two uncommitted npn transistors, each rated at 35 V dc and 300 mA. The circuit is housed in a 14-pin dual in-line package capable of dissipating up to 800 milliwatts continuously.

In Fig. 1, the 75450A is driving a pair of electromechanical power relays. The upper relay has four sets of single-pole single-throw contacts, each rated for up to 25 A at 250 V ac or 1 hp at 120/240 V ac. The lower relay has a single contact set, also rated at 25 A or 1 hp. This means that the total relay load switching capability here is 125 A or five 1-hp motors.

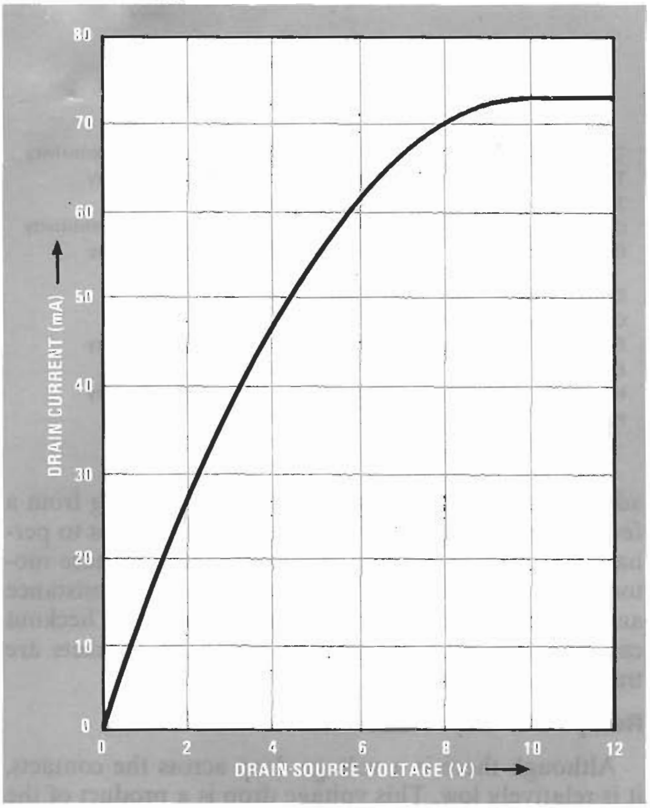
The upper relay is being used to control a three-phase wye-connected motor and to close a circuit containing an indicator lamp that signals motor actuation. The lower relay is controlling a single-phase motor. The relay coil voltages are set at 24 V dc for the sake of convenience.

To determine if the IC driver can meet the power demands of the relays, the power dissipated in the npn transistors must be computed. This power is the product of coil current times the forward voltage drop across the collector and emitter of each transistor. The power that must be dissipated by the transistors should not be confused with relay coil power, which is the product of coil current times coil voltage.

Since the relay coil voltages are 24 V dc, the coil of the upper relay draws about 182 mA, while the coil of the lower relay requires around 83 mA. This sort of data can be obtained from the relays' specification sheets, and the data for the npn transistors can be obtained from the 75450A's published specifications. At 182 mA, $V_{CE(SAT)}$ is approximately 0.5 V dc for transistor Q_1 and



2. Operating relays from C-MOS. Standard C-MOS buffer gates can directly control high-sensitivity relays (gates G_1 and G_2) or share the coil current of general-purpose relay (gates G_3 and G_4). Allowable dissipation is 200 mW, but only 68 mW are consumed here.



3. C-MOS at 12-V supply. Output voltage of C-MOS device driving electromechanical relay can be determined from drain characteristic. This curve from RCA Corp. is for a 4049A-type buffer gate operating from supply voltage of 12 V dc at 25°C ambient temperature.

about 0.3 V for transistor Q_2 at 83 mA. The transistor power dissipation can be calculated as:

$$P_D = V_{CE(SAT)} \times (\mathit{coil\ current})$$

For transistor Q_1, the dissipation is:

$$(P_D)_{Q1} = (0.5\ V) \times (182\ mA) = 91\ mW$$

And for transistor Q_2, the dissipation is:

$$(P_D)_{Q2} = (0.3\ V) \times (83\ mA) = 25\ mW$$

The two transistors, therefore, dissipate a total of 116 mW. The dissipation of the two NAND gates—about 60 mW total—must be added to this figure, so that the total package dissipation comes to just 176 mW, which is less than a quarter of the maximum allowable continuous package dissipation.

Each relay coil is shunted by a signal diode whose cathode faces the positive coil supply voltage. This diode permits back emf generated during coil de-energization to recirculate through the coil, rather than through the device driving the relay. Although the diode lengthens the dropout time of the relay, its presence is absolutely essential for proper circuit protection. The turn-on time of the diode should be at least as fast as that of the device driving the relay.

Operating temperature should also be considered when a designer is "matching" a relay and a TTL device. Relay current requirements are usually specified at 25°C, whereas TTL current-sinking capability is generally given at either -55°C or 0°C, even though the TTL data sheet may not call out this fact specifically.

At 25°C, TTL can sink more current than it can a -55°C—perhaps two to three times as much—withou exceeding its maximum dissipation rating. For example suppose a TTL gate is rated to sink 20 mA at a worst-case condition of -55°C. It is probably capable of safely sinking 60 mA at 25°C, which is more than sufficient to drive a reed relay pulling 25 mA at 5 V dc and 25°C.

Relays work with C-MOS, too

Standard C-MOS circuits, like the 4049A-type hex buffer, can also be used for driving electromechanical relays directly. The 4049A, which consists of six inverting buffer gates, is normally intended for logic-level conversions between C-MOS and TTL devices. Each buffer gate offers a maximum dissipation rating of 100 mW, but the maximum total dissipation of the 16-lead package cannot exceed 200 mW.

Figure 2 shows four of the buffer gates driving three general-purpose relays. The other two gates of the 4049A are not used simply because they are not needed for this application. Of course, the inputs of any unused gate in a C-MOS package must be connected to ground

The upper relay contains a pair of normally open spst contacts, each rated at 10 A maximum. The middle relay has one single-pole double-throw contact set rated at 3 A maximum. The bottom relay contains two spdt contacts having ratings of 7.5 A maximum. Since the coil current of the bottom relay is too much for a single gate, two of the buffers are wired to share this relay's coil current. The other two relays are high-sensitivity devices; therefore, their coil currents are moderate, and a single gate is sufficient in each case.

With C-MOS, current must be shared by gates diffused on the same substrate. If current sharing is attempted between gates of separate packages—even though the ICs seem identical—the small difference in gate turn-on times may result in a brief, but excessive, current in the first gate that turns on.

Although C-MOS works quite well at supply voltages from 3 to 15 V, designers often prefer to operate in the range from 12 to 15 V, where noise immunity is better than down around 5 or 6 V. Moreover, at the higher supply levels, relay coils require less current. Here, both the C-MOS gates and the relays are operating from the same 12-V supply. A decoupling capacitor may be added at the positive supply lead, as done here, to help guard against any coil back emf that might interfere with proper gate operation.

For each gate, a positive input (logic high) results in a negative output (logic low). In other words, a positive input turns off a gate's p-channel device and turns on the n-channel device. Conversely, a negative input turns the p-channel device on and the n-channel device off.

Since the upper relay is connected across the p channel of gate G_1, it will draw current through G_1's n channel when this device is on, so that G_1 will be operating in the current-sinking mode. On the other hand, the middle and lower relays parallel the n channels of their respective gates, so that these gates operate in the current-sourcing mode.

Such current-sourcing operation, though possible with MOS devices, is not possible with TTL devices having totem-pole outputs. The TTL devices, unlike their MOS counterparts, contain a current-limiting pullup resistance in their positive supply lead. If a relay coil current is passed through this resistance, the TTL gate will be destroyed. Consequently, when operated from TTL, a relay can be driven in the sink mode only.

To compute the total power dissipation of the C-MOS package, the drain characteristic of an individual gate operating from the appropriate supply voltage is needed. Such a curve can be obtained from the C-MOS data sheet. The one shown here in Fig. 3 is the minimum n-channel drain characteristic for the 4049A at 25°C and a drain supply voltage of 12 V. As before, the coil currents of the relays can be determined from their respective data sheets.

At 12 V dc, the upper relay draws 12 mA, the middle relay 1.2 mA, and the bottom relay 38 mA. From the curve in Fig. 3, the output voltages of the gates can be determined. The 12-mA current requirement of the upper relay will cause an output voltage of about 0.9 V across the n channel of gate G_1. For the 1.2-mA coil current of the middle relay, output voltage will be approximately 0.2 V across the p channel of gate G_2. And the 38 mA required by the bottom relay will be shared as 19 mA through the n channels of gates G_3 and G_4, so that the output voltage will be 1.5 V across each n channel. Therefore, for gate G_1:

$$(P_D)_{G1} = (0.9\ V) \times (12\ mA) = 10.8\ mW$$

For gate G_2:

$$(P_D)_{G2} = (0.2\ V) \times (1.2\ mA) = 0.24\ mW$$

For gate G_3:

$$(P_D)_{G3} = (1.5\ V) \times (19\ mA) = 28.5\ mW$$

And for gate G_4:

$$(P_D)_{G4} = (1.5\ V) \times (19\ mA) = 28.5\ mW$$

Total package dissipation is found by simply adding up the dissipations of the individual gates, bringing the sum to slightly less than 68 mW—well below the 200 mW allowed.

These two examples have demonstrated that a variety of electromechanical relays can be driven directly from standard TTL or C-MOS ICs. In addition to the pair of ICs suggested here, there are several other readily available drivers, buffers, and gates suitable for controlling relays, as indicated in the table.

Standard 7400-series TTL buffers and drivers can be used to drive conventional general-purpose relays that require coil currents as low as 36 mA, yet provide multi-pole 10-A contacts. Other popular general-purpose relays are also capable of switching from low-level conditions to 10-A loads and can be operated from the gates and buffers of high-threshold logic at 15 V dc or emitter-coupled logic at 5.2 V dc. Additionally, high-sensitivity multi-pole printed-circuit-board relays, which require as little as 1.2 mA of coil current at 12 V dc, may be driven directly from many standard C-MOS logic gates.

LOGIC ICs FOR DRIVING ELECTROMECHANICAL RELAYS

Logic device	Type of relay
TTL peripheral driver	power, general-purpose, reed, high-sensitivity
TTL buffer gate	general-purpose, reed, high-sensitivity
TTL gate	reed, high-sensitivity
C-MOS peripheral driver	power, general-purpose, reed, high-sensitivity
C-MOS buffer gates (current sharing)	general-purpose, reed, high-sensitivity
C-MOS buffer gate	reed, high-sensitivity
C-MOS gate	high-sensitivity
ECL buffer gate	general-purpose, reed, high-sensitivity
ECL gate	reed, high-sensitivity
HTL buffer gate	general-purpose, reed, high-sensitivity
HTL gate	reed, high-sensitivity

In addition to its direct compatibility with ICs, an electromechanical relay affords considerable economic advantages. It is fairly inexpensive itself, costing from a few dollars for a general-purpose multi-pole unit to perhaps $15 for one capable of switching a polyphase motor. And troubleshooting it is easy because no resistance and/or voltage measurements must be made. Checkout can be done visually—one can see if the contacts are transferring properly.

Relays are easy to use

Although there is a voltage drop across the contacts, it is relatively low. This voltage drop is a product of the contact-to-contact resistance, which is often under 50 milliohms. Also, an electromechanical relay has an inherently high isolation between its coil (input) and contacts (output)—generally on the order of 100 megohms or greater. Moreover, its dielectric strength usually exceeds 1,000 V at 60 hertz.

What's more, electromechanical relays can provide long operating life under a variety of load conditions, since their contacts can be made from a number of different metals and alloys. If a set of contacts has a life expectancy of 100,000 operations at maximum rated conditions, this means that the contacts will switch the rated load at least 100,000 times. When the load requires somewhat less current than the maximum rating of the contacts, life expectancy may well be five to 10 times longer than what is specified at full load conditions.

Then, too, mechanical life expectancy, which is always much greater than the life at full rated load, can be as high as 10 million operations. However, this does not mean that a set of 20-A contacts will provide millions of operations at, say, 10 mA. Many contacts require a specific minimum current to prevent buildup of surface contamination—the current keeps the contamination burned away. But 20-A contacts are often used to switch a 5-A load to achieve a long life of several hundred thousand operations, which may even exceed the life of the load.

Best of all, electromechanical relays are easy to design with—once the specifications of a relay and a logic IC are known, it takes only a few moments to determine whether the two are compatible. Furthermore, since both relays and ICs come in a multitude of models, styles, and ratings, quite often what the designer needs is already in stock at his local distributor. □

Ordinary relays can flip, flop, switch, oscillate, pull in or drop out slower or faster than normal with the help of a few extra parts. Find out how to do these . . .

Special Tricks with Relays

By **RONALD L. IVES**

MOST ELECTRONIC WORKERS REGARD A relay as a primitive form of remote-controlled switch, with which a load of several hundred watts can be turned on and off at a considerable distance, with only a few watts. That (in very general terms) is the most common function of a relay, and most relays are made for that kind of job.

But a look at a telephony or computer manual immediately shows that relays are used for many other purposes. At slow speeds (roughly above .05 sec), relays can do many jobs that vacuum tubes and transistors do at higher speeds and frequencies. *In a surprising number of cases, complicated and costly electronic circuits are used to do things that actually can be done better and cheaper by relays!*

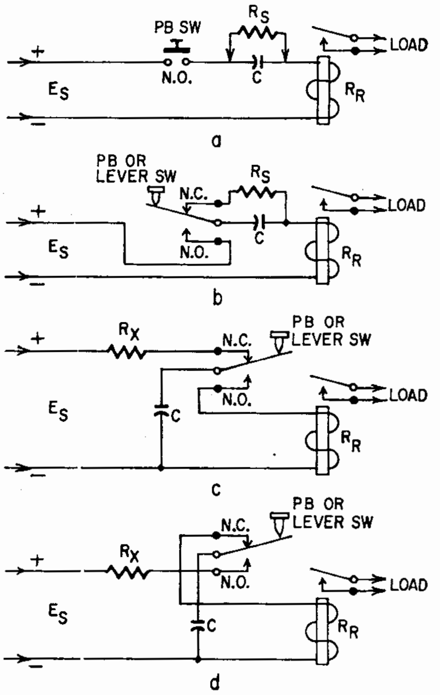


Fig. 1—Four "momentary" circuits: relay holds in only for a certain time, regardless of how long circuit is closed.

All the circuits here (and these are just a few of the thousands possible) have been used extensively in the industry. All, within their limits, are consistent performers and often need no servicing other than routine cleaning.

Momentary operation

In a wide variety of control circuits, the controlled circuit should be closed (or open) for a short fixed time no matter how much longer the control switch is closed. For this purpose, the *relay limiter* is ideal. Four conventional limiter circuits are shown in Fig. 1. All depend for their operation on the rate of charge of a capacitor through a resistance (the relay coil).

When the switch is closed in Fig. 1-a, current flowing into the empty capacitor energizes the relay coil and magnetic circuit, pulling down the armature. As the charge on the capacitor gradually increases, the voltage across the coil decreases. When the voltage across the coil falls to the dropout value of the relay, the armature releases, and nothing more happens, no matter how long the circuit remains closed.

The time the armature is pulled in is closely approximated by:

$$(1) \qquad T = 2.303\ R_rC \times \log_{10} \frac{E_s}{E_d}$$

in which: T = time in seconds, R_r = relay resistance in megohms, C = capacitance in microfarads, E_s = supply voltage and E_d = dropout voltage of the relay.

Since the ratio of E_s/E_d for many low-power commercial relays is approximately 3, and the common log of 3 is approximately 0.478, we may simplify our computations, in many instances, by using the formula

$$(2) \qquad T = R_rC$$

with the symbols the same as before.

With the circuit in Fig. 1-a, the time lapse between operations must be very long, so that the charge on the capacitor can leak away. This could be several days with high-grade capacitors. We can speed up by shunting the capacitor with a resistor, R_s, of a relatively high value (10 or more times R_r). This still introduces a considerable delay between operations—usually 10 or more times the duration of the contact closure. For more rapid recycling, use the circuit shown in Fig. 1-b.

Here, the control switch is single-pole double-throw. When it is depressed, the action is as just described. When the switch is released, resistor R_s is shunted across the capacitor, discharging it and readying the system for the next operation. Charge-dumping resistor R_s can be small (an ohm or two), and is used only to limit the discharge current through the switch.

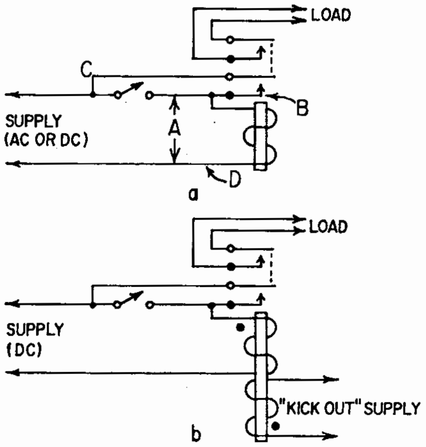


Fig. 2—Two latching, or self-holding, circuits. Circuit b requires a special relay.

Equally useful is the *shunt limiter,* one form of which is shown in Fig. 1-c. Here, the capacitor charges from the line through a small resistor, R_x, which limits inflow current. When the switch is pressed, the charged capacitor is shunted across the relay coil, and the stored charge operates the relay until the voltage across the capacitor falls to the dropout value of the relay. As this point, the relay contacts open, and no further relay action takes place no matter how long the switch remains depressed. Time of contact closure is shown by formulas (1) and (2).

A similar circuit, which actuates the relay only when the switch has been depressed and released, is shown in Fig. 1-d. This circuit is particularly useful in systems incorporating indirect-action stepping switches, where the contacting arm is not stopped until the driving circuit is interrupted.

Self-holding circuit

The circuit of a relay which closes and remains closed when the actuating switch is closed only momentarily is shown in Fig. 2-a. Here, when the relay armature pulls down, one set of contacts shorts the actuating switch, maintaining the relay current indefinitely.

The armature can be released by shorting the coil at point A (not recommended) or by opening the circuit at point B, C or D. An elegant release method, with a dual-winding relay, is diagrammed in Fig. 2-b. Here, an auxiliary coil produces a field in the magnetic circuit of the relay which exactly counteracts that produced by the main coil. When this "kickout" coil is energized, there is no magnetic field to hold the armature down, and it releases.

The same coil configuration can be used to produce an "either but not both" logic circuit, minus the self-holding feature.

Relay oscillator

When connected so that it alternately charges and discharges a capacitor, a dc relay can be made to oscillate, from about 20 cycles per second to 1 cycle every 5 minutes. Circuit of a series relay oscillator is shown in Fig. 3-a. Here, when the switch is closed, the charging current of the capacitor energizes the relay coil, pulling the armature down. As the capacitor charges, the charging current decreases, eventually falling to such a value that the voltage across the relay coil reaches the drop-out point. The armature then releases, the capacitor discharges rapidly through resistor R_z, and another cycle starts.

Time for a single cycle is closely approximated by formula (1). R_z prevents welding of the relay contacts during the discharge phase of the cycle, which is very short. Its value should be as low as the contact rating permits—if the contacts are rated at 5 amperes, R_z should be $\frac{1}{5}$ ohm per supply volt.

The circuit of a shunt relay oscillator is shown in Fig. 3-b. When the switch is closed, capacitor C (shunted by the relay resistance) charges up to the pull-in voltage of the relay. The relay armature then pulls down, and the capacitor discharges through the relay until the voltage across the coil falls to the drop out value. Then the relay armature releases, and another cycle starts.

Time for a single cycle is closely approximated by

$$(3) \qquad T = 2.303\, R_z C \times \log_{10} \frac{E_p}{E_d}$$

in which E_p is the pull-in voltage of the relay, and all other symbols have been defined before. Note that the shunt oscillator operates through the range E_p–E_d, whereas the series oscillator uses the voltage range E_s–E_d. So, for a given set of components, the series oscillator will give a slightly longer period. It is, however, quite sensitive to changes in the value of R_z. Numerous long-continued experiments show that, while both oscillators work well, the shunt relay oscillator is very slightly more dependable, and more consistent, than the series oscillator.

Relay accelerators

We often need a relay that will respond somewhat faster than its rating in a conventional circuit. Numerous people have discovered in the last three-quarters of a century that a relay can be speeded up by overvolting it. And most of these same people later discovered—to their dismay—an overvolted relay doesn't last long.

To secure the advantages of overvolting without most of its disadvantages, a system of time-limited overvolting of relays was worked out during WW II. The basic circuit is shown in Fig. 4-a. The supply voltage is somewhat higher than the rated operating voltage of the relay. When the switch is open, the capacitor charges to full supply voltage. Closing the switch applies this high voltage to the relay, which operates rapidly. As the charge on the capacitor is reduced, the voltage across the relay terminals falls, due to the drop across R_m, to a value sometimes called the "holding voltage," somewhere between the pull-in voltage (E_p) and the drop-out voltage (E_d).

A relay will operate without immediate damage, using this method, with supply voltages of up to 10 times the relay rating. This shortens the response time of the relay by a factor of about 6, and the life of the relay by about the same factor.

Even higher voltages, producing even higher response speeds, are possible, but at the risk of dished relay armatures, peened-over pole pieces and burned coils.

Another relay accelerator, which requires only a resistor and a higher-than-rated supply voltage, takes advantage of the fundamental properties of an electromagnet for its operation. The time of operation of any relay can be indicated by the simplified relation

$$(4) \qquad T \sim \frac{L}{R} + M,$$

in which L is an inductive term, R is a resistive term and M is a mechanical term.

All other factors remaining the same, the operating time can be reduced if we reduce L, increase R or reduce M. Because L and M are commonly built into the relay and variable only with great difficulty, we can accelerate the relay most simply by working with R. The circuit of this relay accelerator is shown in Fig. 4-b.

As used, the supply voltage is above the relay rating, and the series resistor is so chosen that the steady-state current through the coil is the rated current. Between turn-on and armature pull-down, current flow through the relay coil is less than normal, due to the inductance of the coil. With the accelerator circuit, voltage across the relay coil is then higher than normal when current through the coil (and therefore the drop across the series resistor) is less than normal. This produces a self-limiting overvolting during the turn-on lag only, and thereby shortens this lag.

With small industrial relays, quadrupling the supply voltage, in this circuit, roughly triples the response speed of the relay. Still higher voltages can further increase speed, but most of these relays have an upper limit of about 80 cycles per second, due to mechanical factors, which cannot be exceeded by any ordinary electrical means.

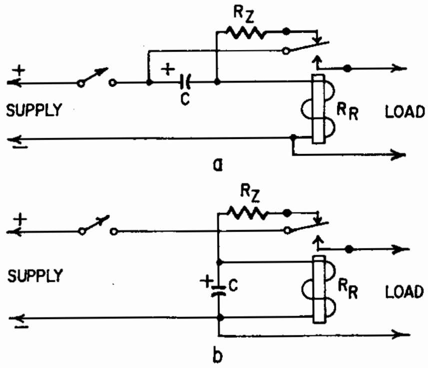


Fig. 3—Two relay oscillators: series capacitor, a, and shunt capacitor, b.

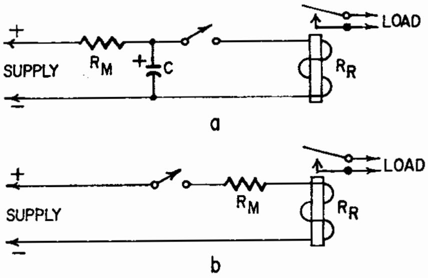


Fig. 4—Relay accelerators speed pull-in. Circuit a applies short-time overvoltage to coil from capacitor C. Circuit b uses inductance of coil to give initial higher-than-normal voltage.

Relay retarder

Slow-acting relays are commercially available in a wide variety. They are retarded by using copper slugs on the pole pieces for lags of up to about 1 second, and by dashpot mechanisms for longer delays. Thermal time-delay relays, with lags of from a few seconds to a few minutes, are made commercially by Amperite and Edison.

A very satisfactory slow-response relay can also be made with a standard relay and a resistance-capacitance circuit. An elementary form is shown in Fig. 5-a. Note the similarity to the relay accelerator of Fig. 4-a.

Supply voltage is normally above the relay rating, and series resistor R_m is so chosen that the steady-state voltage across the coil is the rated voltage.

When the switch is closed, current is applied to the relay and capacitor in shunt, through series resistor R_m. Intially, the charging current of capacitor C is high, producing a voltage drop in R_m, so that voltage across the relay is below the pull-in value. As the capacitor charges, its inflow current falls, and the voltage drop across R_m also falls. After a time determined by the capacitance of C, the resistance of R_m and the relay coil resistance, voltage across the capacitor rises to the value at which the armature pulls in. Delays of more than 1 minute can be secured by proper choice of relay, capacitor and series resistor.

In it simplest form (Fig. 5-a), the relay retarder is both a slow-operate and a slow-release device. When the switch is opened, the charge on capacitor C leaks away through relay resistance R_r keeping the relay armature down for a time indicated by formula (1).

The basic relay retarder can be converted into a slow-operate, quick-release device by an auxiliary relay contact, as in Fig. 5-b. Here, during the delay, when the switch is on and before the relay armature pulls down, the capacitor is connected by the normally closed contacts. This produces the delay. When the relay armature pulls down, the capacitor is disconnected and discharged through "dumper" resistor, R_n, whose value is small compared to R_r. When the switch is opened, the relay armature releases immediately, and the capacitor, discharged, is restored to the circuit and ready for the next operation.

With inexpensive and dependable silicon and germanium rectifiers, we can eliminate the auxiliary relay contact and construct a slow-operate, quick-release relay circuit as in Fig. 5-c. Resistors R_o and R_p are chosen so that the voltage between point K and ground (system negative) equals the steady-state voltage across the relay coil. With this arrangement, current cannot flow through D1 and D2 to ground when the switch is closed, for there is no potential difference across the rectifiers when the switch is closed.

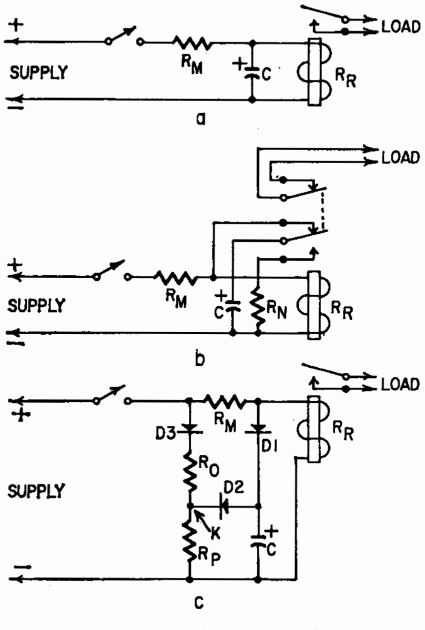


Fig. 5—Relay retarders. In a, slow operate, slow release; b and c, slow operate, quick release.

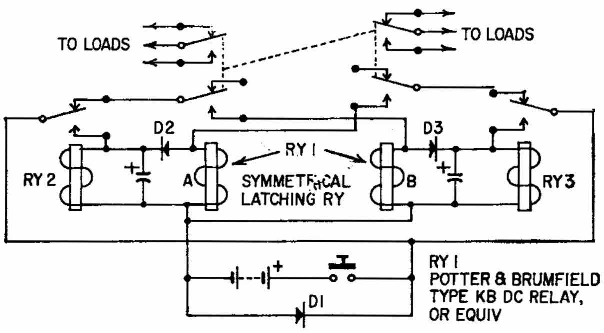


Fig. 6—A relay flip-flop, for very slow counting, from one count per day to one per minute.

With this circuit, when the switch is closed, current flows through R_m and D1 to capacitor C. This charges slowly until its voltage equals the pull-in voltage of the relay, which then operates. When the switch is opened, the relay armature is released immediately. Point K is no longer held above ground by current through D3 and R_o, so D2 conducts, and C discharges through D2 and R_p, readying the circuit for the next operation. D3 is necessary to block a sneak circuit to the relay coil through D2, R. and R_m.

Relay scale-of-2

For very slow operations, such as in many types of meteorological and climatological instruments, and for handling relatively large powers at medium speeds, vacuum-tube and solid-state flip-flop scales of 2 leave much to be desired, particularly when power economy is important.

For such applications, a relay flip-flop has been developed, admirably suited for operating speeds from 1 per day to 1 per minute. Circuit of one form of the relay flip-flop is shown in Fig. 6.

Assume that the A armature of the electro-mechanical symmetrical latching relay (RY1) is down and locked in position, and that the switch is open. Closing the switch energizes coil B of RY1 and the coil RY3, and charges the capacitor shunted across RY3's coil. (The circuit from the switch is through the upper contact of RY2 and the lower contact of RY1, A.) The armature of coil B (RY1) pulls down, releasing the armature of coil A. This latches armature B in its down position mechanically, and removes the voltage feed to coil B. At the same time, the armature of RY3 has pulled down, connecting it in a self-maintaining mode, with slow release provided by the shunt capacitor. This assures that, after armature B of RY1 has pulled down, no further switching action will take place until the switch has been opened and again closed. When the switch has been released, and a very short time allowed for discharging the capacitor shunted across the active auxiliary relay (here RY3), armature B is locked in down position, and all other armatures are up. A second closing of the switch repeats the process in mirror-reversed order, restoring the circuit to the initial conditions.

Rectifier D1 is a spark absorber, which reduces flyback voltages to a negligible value, preventing much contact sparking and radio interference. Rectifiers D2 and D3 isolate the capacitors across the auxiliary relays from the main relay (RY1) coils, so that much smaller capacitors can be used. As the main relay coils are rather low-resistance, whereas the auxiliary relay coils are comparatively high, this leads to a great saving in capacitor bulk. These same rectifiers also lead to a considerable power saving, as the active coil of the main relay (RY1) draws current only during the instant of switching, no matter how long the switch remains closed.

By omitting the normally open (lower) contact of each auxiliary relay, this circuit becomes an astable multivibrator, whose half-cycle period is indicated by formula (1). With high-resistance auxiliary relays and large electrolytic capacitors across them, cycle durations of more than 5 minutes are possible.

Relays can also be used for a number of logic functions. One of the first large computers was a relay integrator developed by Bell Telephone Laboratories more than a generation ago. END

Relay Electronics

By RUSSELL D. SHATTUCK

The variety of useful "circuits" you can design with relays is endless. The many shown here only scratch the surface.

AS A RULE, the electronics technician or the experimenter doesn't expect a relay to be anything more than an electrically operated switch. Most users never get beyond this basic application because they don't give the component credit for much sense. Actually a relay can be the active element in practically any circuit a tube or transistor can handle. The former can't compete when it comes to response, being confined to operation at rather low frequencies, but very fast rise times can be achieved.

A number of circuits built around these mundane devices are shown here. In each, the *Potter & Brumfield* RS5D relay with 10,000-ohm winding has been employed. This is a basic s.p.d.t. type. With suitable changes, practically any other relay could be substituted. To accommodate different needs, there is a wide variety of current- and voltage-sensitive types of different sensitivities available.

The basic feature important to each illustrated application is that the device actuates on a certain pull-in current or voltage and releases at a certain drop-out current or voltage. Drop-out value is ordinarily about one-third of pull-in value.

There are two common uses of a relay that are widely known. One is the control of a large amount of power by a small amount of power. The other is remote operation of a circuit either for isolation or convenience. The circuit of Fig. 1 illustrates both of these functions. Manual closing of the switch in the low-voltage supply to the relay causes the latter to pull in, applying the higher voltage to load R_L. The latter may be some distance from the relay switch.

Note that the input voltage and current to the relay are considerably lower than the voltage and current (to the load) being controlled. This is analogous to a conventional tube circuit in which a small input voltage produces a much greater output at the plate. Fig. 1 may thus be considered an amplifier. In this case, voltage gain is 4.6, current gain 800, and power gain 3680.

Measuring with Relays

The common denominator of the four configurations in Fig. 3 is that they all belong to the general class of voltmeters, despite application differences. The general circuit (Fig. 3A) relies on the repeatability of the pull-in current or voltage of the relay. The unknown voltage is connected with *R* set at its maximum value. *R* is then reduced until the relay closes and operates the indicator (light, bell, or other). A dial on the potentiometer shaft can be calibrated in volts.

The switch is an added convenience for opening the relay without having to disconnect test leads or change the setting of *R* to reduce the test voltage. With the relay mentioned earlier and the value shown for the potentiometer, the useful measuring range would be from about 25 to 250 volts. By choosing a relay with different characteristics and a pot of another value, either or both ends of the usable range could be shifted in either direction. Battery voltage and the indicator are simply chosen to suit each other.

The precision voltmeter (Fig. 3B) depends on the fact that a VR tube (a zener diode may be used instead) does not conduct until a certain, critical voltage is applied across its terminals. Then it conducts with a fixed voltage drop. Control *R* is used to set the range of measurement.

With a VR105 tube, the latter will fire with about 118 volts across it but won't conduct enough current to operate the relay. After firing, the voltage drop across the tube goes to 105 volts and remains there. If *R* is set to zero resistance and the unknown voltage is at least 105 volts plus the value needed to pull in the relay (totalling 140 volts with the relay specified), the latter closes, operating the indicator. If *R* is set to equal the relay's resistance, indication will begin at 155 volts.

Precision results because an accurately known, fixed voltage is subtracted from the unknown voltage before measurement is made. With the reading range thus limited, close calibration is possible (*i.e.*, a relatively narrow range of voltage variation is spread out over the rotation of the potentiometer dial). The larger the fixed voltage subtracted in relation to the total voltage applied, the more accurate is the final measurement. The principle is the same one used in conventional suppressed-zero, expanded-scale voltmeters designed

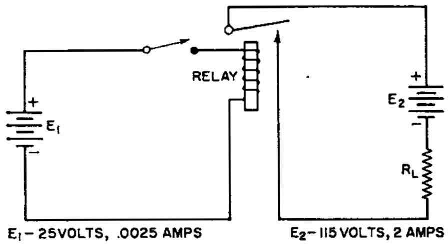


Fig. 1. The relay used as an "amplifier."

Fig. 2. A light flasher—which is really a simple, low-frequency, pulse generator.

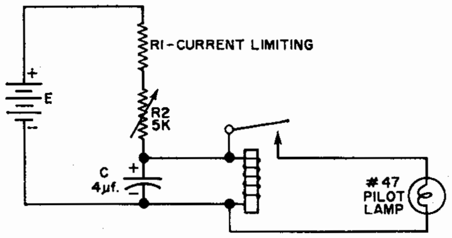
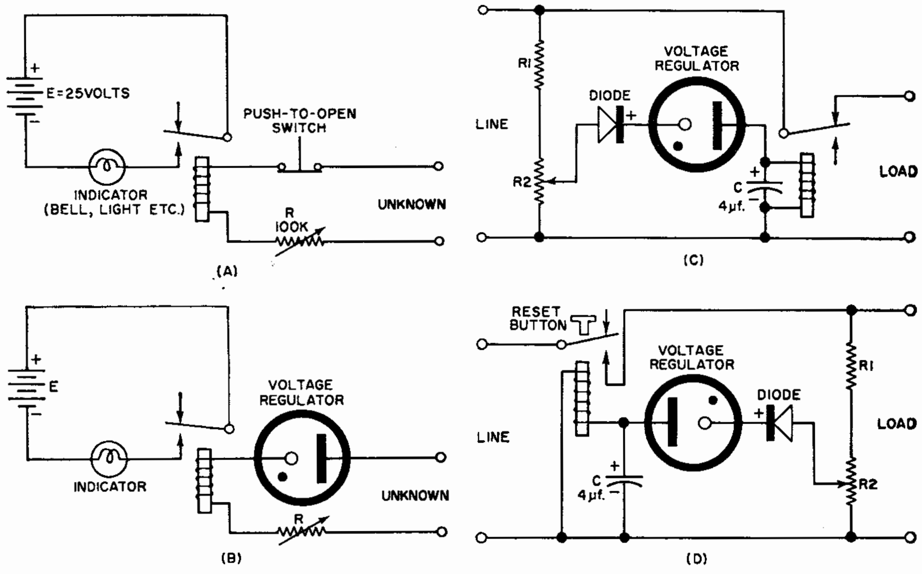


Fig. 3. These are only four of many possible general and special voltmeter circuits.



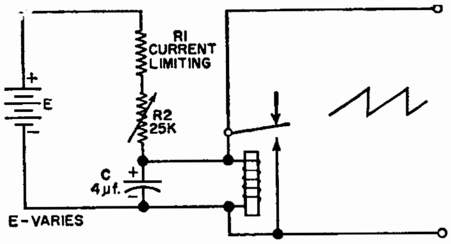


Fig. 4. Generating a saw-tooth output.

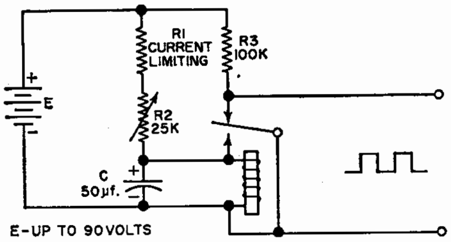


Fig. 5. Perhaps you prefer square waves.

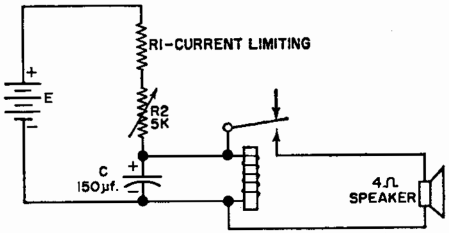


Fig. 6. The metronome. It is actually a special case of the timer or counter.

to be highly accurate over a limited range of interest—a category in which the circuit of Fig. 3B may be included.

The arrangement is obviously useless at levels lower than the sum of the voltage drops across the VR tube or other regulating element, the relay, and any fixed series resistance. The lower limit can be changed by choosing relays of various sensitivity and VR tubes or zener diodes of appropriate characteristics. The upper voltage limit can be shifted by changing the value of *R*.

Circuit Protection

The over-voltage relay (Fig. 3C) is also, in effect, a voltmeter, but its application is different. The purpose is to disconnect a load from a power source if the applied voltage becomes too high. The relay contacts are thus used to accomplish this at the desired level instead of operating an indicator. The added diode and capacitor are necessary only if the unit is to be operated on a.c. With a d.c. supply, however, the diode would also be useful in blocking voltage if the applied polarity is incorrect. The VR tube or zener diode is optional, depending on the specific case.

Part of the source voltage is tapped off through R_1 and R_2 and applied to the relay. R_2 sets the pull-in voltage at the desired level. When it is reached, the contacts open to disconnect the load, which remains disconnected as long as line voltage remains too high. Use of the regulating element, as described in the preceding circuit, reduces the range over which the relay operates and thus improves accuracy. It also provides another advantage. Without it, line voltage would have to be reduced to about one third its normal value to drop out the relay and re-connect the load. With it, drop-out can be made to occur in the normal voltage range. A re-set switch would, of course, accomplish a similar purpose.

The values of R_1 and R_2 are chosen to provide the desired adjustment range. Capacitor *C* permits control of the time response of the circuit, even from a d.c. supply. A larger value prevents pulses or short transients from triggering the relay. A smaller value permits more rapid response to changes. Excessive reduction, however, will cause the relay to chatter if the circuit is used on a.c.

The under-voltage relay (Fig. 3D) is similar in operation but different in function. Certain devices, like some motors, can be damaged when supplied with insufficient voltage. They draw more current from the source and overheat.

Line voltage in this circuit is connected to the load as long as the relay remains pulled in, but power is removed at drop-out. In the preceding circuit, the contacts are wired to produce the opposite effect. To establish the drop-out point, the re-set button is depressed (or the armature is pushed in) with the line voltage kept low. The latter is then increased until the voltage across the load is at least the required minimum. R_2 is adjusted so that the relay will be held by this load voltage. Relay voltage is then reduced by careful re-adjustment of R_2 to the point where any further reduction would release relay contacts. As for the functions and values of components shown, the same considerations apply that were discussed in connection with the over-voltage relay.

Generating Pulses

The light flasher of Fig. 2 operates by charging capacitor *C* through its series resistance until the pull-in voltage of the relay is reached. On closing, the relay applies voltage to the bulb, lighting it, and also permits the capacitor to discharge through it to open the relay. This cycle repeats itself. The flash frequency depends on the time-constant of the circuit, which is established by the values of *E*, R_1, R_2, *C*, and the characteristics of the relay.

The value of R_1, which is important, is selected so that, even when R_2 is set to minimum position, maximum voltage and current applied to the bulb will not exceed its ratings. It saves lamps when some enthusiast tries to speed up the flashing rate too much. Addition of a rectifier diode and experimentation with component values would enable operation with larger bulbs from an a.c. source.

The sweep or saw-tooth generator (Fig. 4) differs from the light flasher mainly in the way output is taken from the capacitor. This output may be used to provide low-frequency sweep on an oscilloscope, with application to the horizontal plates of the CR tube feasible. Here the current-limiting resistor is used to prevent short-circuiting the power supply, which would occur at the same time the capacitor is shorted by closing of the relay contacts, if R_2 is set to zero.

Values shown, used with a relay like the one specified earlier, would produce a sweep-frequency range between about 1 and 20 cps, extending the usable range of the average scope downward for special applications. *E* need simply be greater than the triggering voltage required, and its level will determine the value of R_1. Sweep linearity could be improved considerably by doubling the value of *C*, but the range of operating frequencies would also be lowered.

This circuit has another use with an oscilloscope. Since the amplitude of the saw-tooth pulse is always the firing voltage of the relay, it could be used as a scope calibrator that would not be affected by variations in the supply voltage.

With another resistor and a slight change in wiring of the relay contacts, we have the low-frequency, square-wave generator of Fig. 5. Amplitude of the output is nearly that of the battery voltage, with the relay armature alternately sampling the battery voltage and shorting the output. R_3 prevents a short across the battery when the positive electrode is sampled and also helps to equalize pulse width of the positive and negative half-cycles. Trimming of values can adjust such inequality. If you want to lock in the output on your scope, you can take off a sync signal from across capacitor *C*.

A Timing Circuit

The metronome of Fig. 6 goes back to the basic light flasher

(*Continued on page* 72)

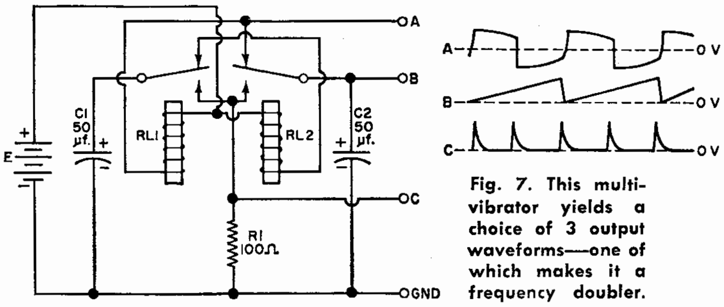


Fig. 7. This multivibrator yields a choice of 3 output waveforms—one of which makes it a frequency doubler.

Relay Electronics

(*Continued from page* 49)

(Fig. 2). Chief difference is use of a speaker as the output load, for audible indication, instead of a bulb. Although a 4-ohm speaker is shown, voice-coil impedance is of little consequence. Operating frequency with the values shown is adjustable from 15 to 300 pulses per minute, encompassing the full range of conventional metronomes with room to spare at either extreme.

The circuit has also been employed in a sports-car rally computer (a device used to gage average speed) by substituting a counter for the speaker. Accuracy was commendable. In such an application, stability of the voltage supply is important.

Especially interesting as a multiple-output, low-frequency generator, the multivibrator of Fig. 7 is also good for getting a laugh with its audible clip-clop. When power is applied, both relays try to close but, because of slight differences between the two sides of the circuit (as with tube multivibrators), one closes before the other can. The faster relay drops out when the capacitor in series with it is fully charged, and applies current to the other relay and its series capacitor. Pull-in of the second relay switches the first capacitor's connection so that the latter can discharge. This cycle of operation repeats as long as power is applied.

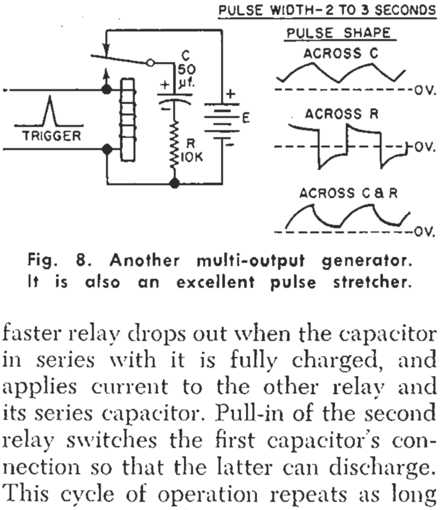


Fig. 8. Another multi-output generator. It is also an excellent pulse stretcher.

Specifically, assume RL_2 closes first. Its coil is in series with C_1 through the contacts of RL_1, so the capacitor charges. When C_1 is fully charged, current ceases to flow in the series circuit and there is no voltage drop across the coil of RL_2. The latter can no longer hold. When it switches, it puts C_2 in series with the supply through the winding of RL_1. The charging current through C_2 produces a sufficient drop across RL_1 to pull in the latter, which connects C_1 to ground through R_1 so that the capacitor can discharge. The purpose of the resistor is to limit discharge current.

Operating frequency can be set by varying *E*. With the values shown, a range from 28 to 46 volts will produce output from 52 to 27 cycles per minute. If output is taken between point *A* and ground, a fairly good square wave is obtained. Point *B* yields a good sawtooth. The voltage across the resistor (point *C*) is a series of spikes at twice the frequency of the other two waveforms. Some juggling of component values may be needed to get good waveform symmetry.

The one-shot circuit (Fig. 8) is extremely versatile. The width of the output pulse can be varied by manipulating the values of *R* and/or *C*. Thus the configuration can serve as a pulse stretcher: a pulse too narrow to operate a counter, power relay, or other device can be lengthened.

If a d.p.d.t. relay is used in place of the s.p.d.t. type shown, the circuit can be made an excellent square-wave generator or scope calibrator. A stable voltage source would be needed in the latter application, of course. The circuit can also act as a frequency divider if trigger amplitude, shape and width of the pulse, and frequency are kept nearly constant.

Adjustable Fusing

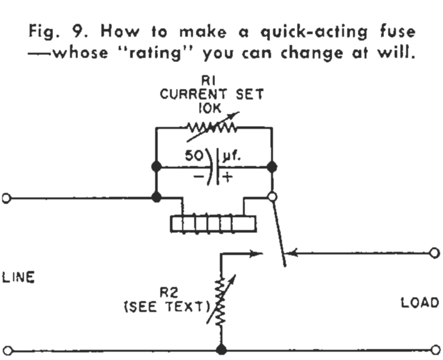
The over-current relay of Fig. 9 is an excellent, stable, and quick-acting cut-out. In many applications, such as when even a slight overload is not to be tolerated, it is preferable to a fuse. The relay "measures" load current in terms of the voltage drop across R_1, which is in series with the load. When this current becomes too high, the relay begins to pull in, removing power from the source.

However, in disconnecting power from the load, the relay cuts off its own driving power. Thus, without the capacitor, the relay would never complete its cycle. The charge on the capacitor across the relay coil is enough to carry the armature all the way to the pulled-in position. Once contact is made here, holding current is maintained through R_2. The value of the latter, not very critical, is simply selected or adjusted to limit coil current to a safe value.

Since the network serves as a versatile fuse whose rating can be changed at will, it can be very useful in variable-voltage supplies. Dial scales can be made for the shafts of R_1 and R_2 to permit convenient adjustment to various loads.

The value of the capacitor may also be determined by the use to which the supply is put. If the latter is employed

Fig. 9. How to make a quick-acting fuse —whose "rating" you can change at will.



with transistor circuits, the relay should open as quickly as possible and the capacitor should therefore be small. If power is being applied to a motor, however, the surge of starting current would open a fast-acting relay, so a large capacitor would be used to introduce time delay. Note that this circuit does not automatically re-connect the load when the overload has passed.

Only a fraction of the unusual and interesting possibilities are presented here, and even those have been presented in their simplest forms without elaborating the full list of applications and variations. With less simple relays (more contacts, two coils), possibilities become endless. Nevertheless, the examples chosen may open the door for many technicians. If you have a practical problem requiring an active element that consumes very little standby power, you should consider the possibility of adapting a relay. Just remember that it has more intelligence than it usually gets credit for. ▲

RELAY MULTIVIBRATOR

AMONG THE EARLIER MULTIVIBRATORS, one of the simpler models was a device using two relays and one or more capacitors and resistors to control the timing cycle and operating frequency. When it comes to small size and speed, all is in favor of the solid-state electronic multivibrator.

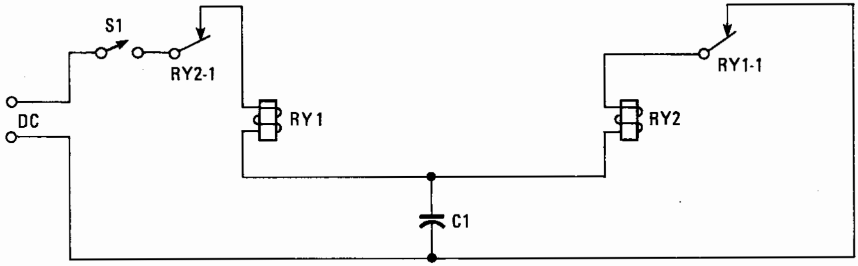


FIG. 1

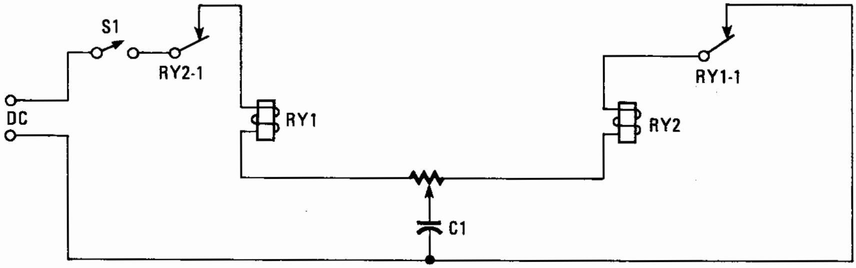


FIG. 2

However, from time to time we may need the simplicity of the relay multivibrator. Most circuits shown in literature use the charging of a capacitor to control the timing and one or more resistors to limit the discharge current so it won't damage the relay contacts. The circuit in Fig. 1 was developed around two relays and a single capacitor to perform the same tasks as the more elaborate circuits.

Circuit operation is as follows: When switch S1 is first closed, the C1 charging current activates relay RY1 and causes its normally closed contacts (RY1-1) to open. When the C1 charging current falls below the hold-in rating of RY1, the relay releases and closes contact RY1-1.

At that moment, the coil of RY2 is connected across C1. The capacitor starts to discharge and the discharge current energizes RY2 and causes contact RY2-1 to open. When the discharge current drops below RY2's hold-in current rating, contact RY2-1 closes to start the cycle anew. The multivibrator will switch back and forth between the relays at a frequency governed by the capacitance of C1, the resistance of the relay coils, the applied voltage, and the hold-in current of the relays. As the relays cycle, switching operations can be carried out as needed by auxiliary contacts on either or both relays.

A potentiometer can be inserted between the relays as in Fig. 2 so you can vary the cycling.—*J. Ofer*

General Information for selecting the proper P&B relay

Factors to consider

Four inter-related factors, the contact system, the magnetic system, the environment, and the physical requirements for installation are prime considerations in the selection of the proper relay for a specific job.

CONTACTS

The contacts in an electromagnetic relay make or break connections in electric circuits. The contacts carry the inrush as well as the nominal load current. How well they perform physically is dependent on their arrangement, mechanical construction and on the suitability of the contact materials. Electrically, two important factors influence contact performance: first, the magnitude of load current and open circuit voltage; second, the specific characteristics of the circuitry.

Potter & Brumfield offers a wide selection of relays to fit practically any type of physical and electrical contact requirement. Expert engineering assistance is yours for the asking.

COILS

The coil of the relay's magnetic system causes the contacts to open or close when power is applied to the coil. Except in special cases, the coil must be sufficiently energized by the voltage of the power source to operate the contact system at all times, and the power source should not drift to cause the coil to malfunction. While coil function is inter-related with the functions of other relay components, the coil design has a major effect on relay sensitivity, operating speed and power consumption.

COIL POWER CODES:

A—AC 50/60 Hz.
D—DC

TERMINALS

The choice of terminals is almost infinite; screw-type, threaded stud, quick-connect, pierced or wire solder lug, taper tab, octal base and other plug-in types meet every connection requirement. Terminals can also be supplied for printed or dip solder circuitry.

ENCLOSURES

Certain environments require dust-proof or hermetically sealed enclosures.

Contact Code and NARM Designator

1—1A SPST-NO
2—1B SPST-NC
3—1A-DM—SPST-NO-DM
4—1B-DB—SPST-NC-DB
5—1C—SPDT
6—1Z—SPDT-NC-NO (DM-DB)
7—2A—DPST-NO
8—2B—DPST-NC
9—2A-DM DPST-NO-DM
10—2B-DB DPST-NC-DB
11—2C DPDT
12—3A 3PST-NO
13—3B 3PST-NC
14—3C 3PDT
15—4A 4PST-NO
16—4B 4PST-NC
17—4C 4PDT

circuit shown in Fig. 5A is increased in the negative direction, no base current flows through *Q1* until V_{IN} exceeds the 10-volt breakdown potential of the zener diode plus the base-emitter forward voltage drop required for *Q1* to conduct (about 0.3 to 0.5 volt). When V_{IN} reaches about 11 volts, *Q1* saturates and collector current energizes the relay.

The silicon diode across the base-emitter junction of *Q1* prevents it from being overdriven. With up to 0.6 volt on the transistor's base, the diode does not conduct. Beyond this point, it conducts and shunts excess current away from the transistor's base. Because of the sharp breakdown characteristics of the zener diode, drop-out signal potential of this circuit is within a few hundred millivolts of relay energizing voltage.

Use of a p-channel MOSFET with a threshold potential of about 5 volts to yield close differential relay operation is shown in Fig. 5B. When V_{IN} is greater than 6 volts, the zener diode conducts through *R1*, but as long as the input is less than 11 volts, the drop across *R1* is less than 5 volts and *Q1* is off.

As long as *Q1* is cut off, *Q2* is also cut off and the relay is deenergized. When the input exceeds 11 volts, *Q1* conducts and current through *R2* to *Q2*'s base causes the relay to energize. When V_{IN} is less than 11 volts, the relay is deenergized, while it energizes with positive action when V_{IN} exceeds 12 volts. By cascading a second FET after the first, it is possible to reduce the difference between energizing and deenergizing potentials to 0.1 volt.

AC Drive Circuits. Any dc relay can be adapted to work from an ac source by combining it with rectifiers. In Fig. 6A, *D1* permits only positive current to pass through the relay and should have a current-carrying capacity several times the operating current of the relay. Clamping diode *D2* is optional and is used for surge suppression. It not only protects the relay contacts, but prevents high reverse voltage on *D1*.

Another diode arrangement is shown in Fig. 6B. Here, four diodes are used in a full-wave bridge circuit. Note that the bridge circuit inherently provides protection from inductive spikes.

The circuit in Fig. 6C allows a true ac relay to be operated electronically through an SCR. When *S1* is open, the SCR has no potential applied to its gate and does not conduct. Meanwhile, current from *T1* is rectified by *D1* and generates a dc voltage that is stored in *C1*. When *S1* is closed, the positive voltage across *C1* is applied to the gate, causing the SCR to conduct and remain on as long as *S1* is closed. Opening *S1* causes the SCR to cut off when the ac cycle passes through zero, causing the relay to be deenergized.

Op Amp Relay Drivers. Contingent on the type and level of the input signal, relay amplifiers can be built up with op amps whose extremely high (open-loop) gain is sufficient to allow operation with minute input levels. The op amp also allows for differential operation where an input signal can be compared with a known reference so that the relay pulls in (or drops out) only when the desired voltage differential exists.

In addition, the op amp, with its very high gain, can be used with reactive feedback to form filters that produce relay operation only at certain input frequencies (assuming an ac input). A phase-locked-loop (PLL) using a 567 for instance, can also be a frequency-sensitive driver for a relay amplifier. Since many op amps do not have sufficient output current to drive a relay directly, a transistor power stage will often be required between the op amp and the relay. ◇

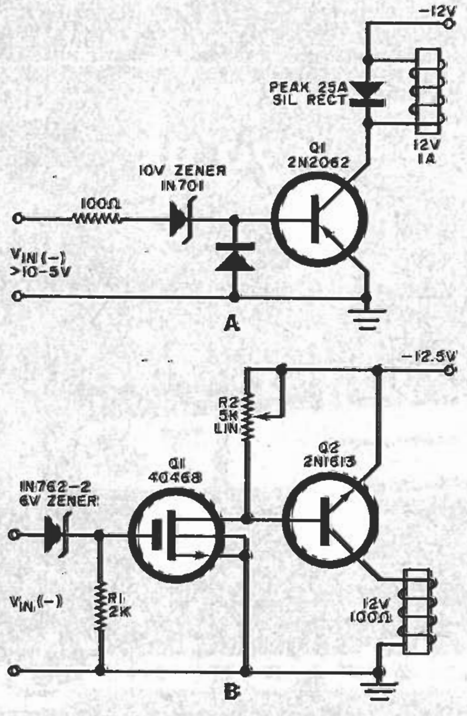


Fig. 5. Driver circuits with close differential operation:
(A) single-stage transistor with zener;
(B) two-stage FET and bipolar transistor.

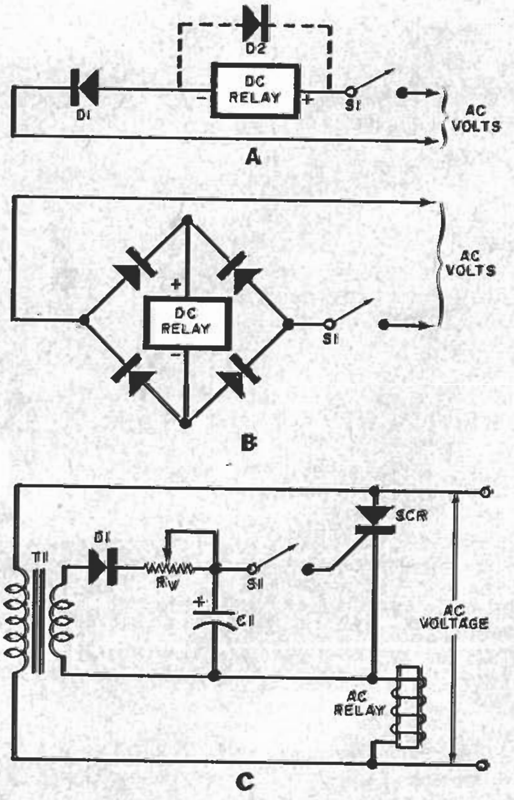


Fig. 6. Ac drive circuits: (A) single diode; (B) diode bridge; (C) thyristor.

Relay Soldering Manual

This manual provides the precautions for soldering Takamisawa miniature relays.

1. MOUNTING

1-1 Care should be taken not to bend the relay terminals when the relay is mounted on the P.C. board. Relay malfunction may be caused by damaged terminals.

1-2 The mounted P.C. board must be handled carefully. The enclosure of the relay should not be removed after the relay has been mounted to keep the relay performance in good condition.

1-3 The performance of any relay dropped to the ground should be checked prior to mounting.

2. SOLDERING

2-1 The precautions for hand soldering are given below:

(1) The capacity of the bit must be smaller than 30W.

(2) Any bit with a bigger capacity may cause damage to the copper of P.C. board or the relay mold.

(3) Avoid applying the bit for a long time, otherwise the copper of P.C. board or the relay mold may be damaged.

2-2 The precautions for the dip or automatic soldering are mentioned below:

(1) Only resin flux with non-corrosive residue should be used.

(2) The soldering flux must be applied equally with a foam-fluxing unit, etc. The foam should be fine enough to allow the precise level control in the fluxing unit.

(3) In case the soldering flux is applied with the impregnated sponge, take care not to pour the soldering flux on the surface of the P.C. board to prevent the flux from entering the relay. For the same reason, avoid putting the mounted P.C. board directly in the soldering tub.

(4) Heating is required after applying the soldering flux. The best condition is a heating temperature of 70°C to 90°C. Since the heating improves the solderability, the soldering flux dries quickly, and can be prevented from intruding into the relay.

(5) The best temperature for the soldering tub 250°C ± 5°C.

(6) Material oxidized in the soldering tub should be periodically removed by hand or by an automatic device.

(7) The soldering dip time must be shorter than five (5) seconds. The traveling speed of the P.C. board must be adjusted to the above condition.

(8) The composition of the bar solder to be used is to be 60% tin/40% lead or 63% tin/37% lead.

3. CLEANING

The following precautions must be observed to maintain good relay performance (some solvents may cause erosion or breakage of the plastic parts):

3-1 Solvent

(1) Recommendable: Freon Family and Alcohol Family

(2) Unrecommendable: Chlorine Family

(3) Organic solvents such as trichloro-ethlene, Chlorothene, etc. may damage the polycarbonate parts such as the enclosure, etc.

3-2 Cleaning method

(1) Standard Type
Only the soldered side of the board should be cleaned. Take care not to pour the solvent on the surface of the board.

The printed board must be laid with its soldered side downwards on a detergent-impregnated sponge to dissolve the flux. The board must lie for approximately 1 minute on the sponge. Subsequently, the remains of soldering flux can be removed by slight rubbing.

(2) Washable Type
The typical cleaning procedures are given below:

- Vapor washing with recommendable solvent: 5 minute maximum
- Shower with 70°C hot water for 5 to 10 minutes
- Drying approximately at 80°C 2 minutes.

(3) Ultrasonic cleaning should be avoided whenever possible, since certain components are apt to be damaged. If it is unavoidable, a series of tests should be carried out on odd components of the same type, using various cleaning times and solvents. In addition, cleaning time should be shorter than 60 seconds.

4. VARNISHING

If no cleaning has been performed, no varnishing is necessary. However, if special requirements are made, E.G. in case of bare copper conductors which need varnishing, only the soldered side of the board should be treated.