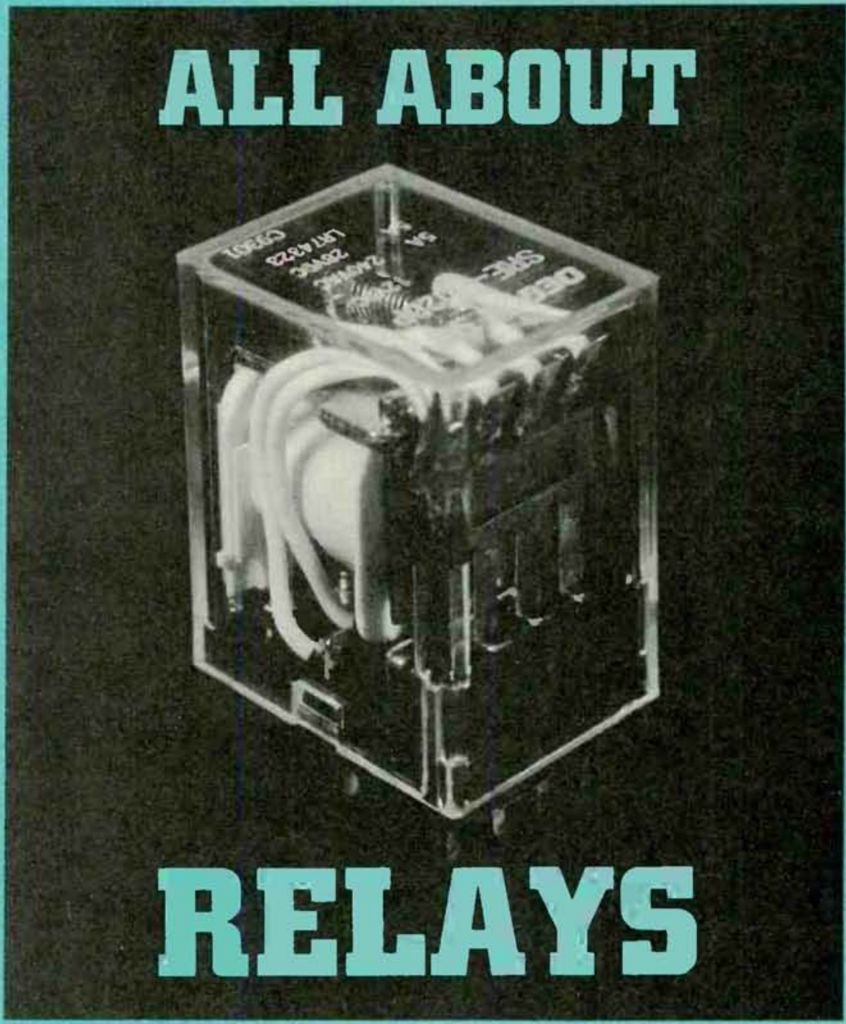
**RAY MARSTON**

# ALL ABOUT RELAYS



## *Learn about different kinds of relays, remote switches and CMOS bilateral IC switches and how to apply them.*

A RELAY IS A DEVICE THAT PERMITS power or signals to be switched remotely by an electrically isolated input circuit. Relays today are broadly classed as either electromechanical (EM) *coil and contact* and solid-state (SS) with virtual coils and contacts.

There are ongoing requirements for both small-signal and power relays in electronics. While electromechanical power relays have changed very little over the past 25 years, small-signal EM relays have shrunk to the size of sugar cubes. Solid-state relays can switch power, but miniature versions are adept at switching small signals. Various switch functions can now be created by wiring special switching ICs.

The classic electromechanical relay can be traced back to the last century when it was invented for extending the range of telegraph circuits. Although the concept of closing contacts remotely with an electrically isolated circuit has not changed, the possible variations in size, shape, function, and operating principle are astronomical.

Figure 1 shows a classical general purpose EM relay adapted for use in electronic circuits. A miniature assembly, it includes a coil with an iron core in the input circuit and silver or silver-alloy contacts that open and close in its output circuits. The moving contacts are mounted on a spring-loaded, insulated armature.

### EM relay basics

When the coil (input circuit) is energized, the armature "pulls in" against the tension of the spring. This closure switches the moving contacts on the ends of metal strips (called *poles*), from one set of fixed contacts to an alternative set. Armature pull-in can either energize or de-energize the relay's external circuits, depending on how they are wired.

The relay illustrated is a double-pole, double-throw (DPDT) unit. The transparent plastic dust cover that protects the assembly is not shown. Relays of this kind are available for circuit-board or socket mounting.

These factory-manufactured products are offered in a wide range of sizes and electrical ratings for AC or DC operation. UL recognition and CSA certification assures that the relay has met safety requirements for applications where potentially lethal AC and DC voltages might be encountered.

Figure 2 illustrates two common graphic symbols for relays that are likely to appear on schematic diagrams. Figure 2-*a* is the symbol for a single-pole, double-throw relay; the rectangle represents the iron core and the dotted line represents the control of the coil on the contacts. In Fig. 2-*b*, the coil of the same relay is shown as a transformer primary.

### EM Characteristics

The principal characteristics of a relay are given in its coil (input) and contact (output) specifications. Coil characteristics include input ratings in AC or DC volts, power consumption in volt-amperes (VA), and input impedance. The DC value will differ from the AC value because of coil impedance.

Contact characteristics include their arrangement (e.g., single-pole, single-throw, normally open (SPST-NO)), composition (e.g., silver or silver-palladium), and AC or DC rat-

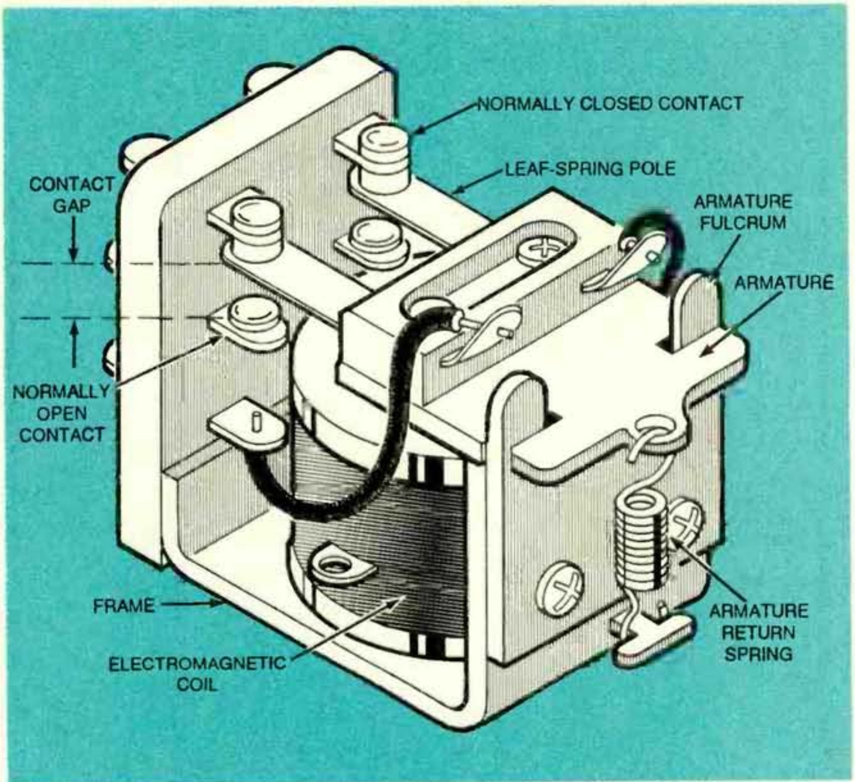


**FIG. 1—GENERAL PURPOSE ELECTROMECHANICAL RELAY** has DPDT contacts. It is usually protected with a clear plastic dust cover.

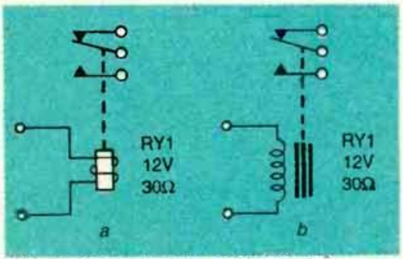


**FIG. 2—SCHEMATIC SYMBOLS** for a relay: Coil is represented as a winding on a core (*a*), and coil is represented as an iron-core inductor (*b*).

ings (e.g., current at a specified AC or DC voltage).

Figure 3 shows the graphic symbols for five common contact arrangements, identified by Forms A through E. In this figure, NO means normally open, NC means normally closed, and *make* and *break* refer to the opening and closing sequence of the contacts.

Most EM relays have more than one set of contacts and poles and they are usually *ganged*. *Single pole* (SP) means that the relay has only one pole, *double-pole* (DP) means two, and 3P and 4P mean three and four poles, respectively. Contacts for EM relays are rated lower for switching DC than AC, and these values can differ significantly. (DC current at a lower value than AC current can weld the contacts closed.)

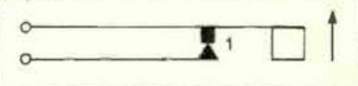
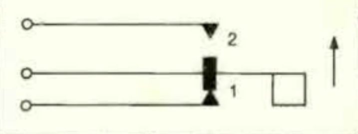
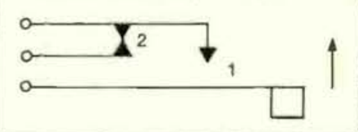
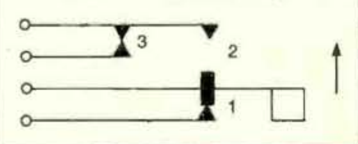
| DESIGN | SEQUENCE | SYMBOL | FORM |
|---|---|---|---|
| SPST-NO | MAKE (1) |  | A |
| SPST-NC | BREAK (1) |  | B |
| SPDT | BREAK (1) - - MAKE (2) |  | C |
| SPDT | MAKE (1) - - BEFORE BREAK (2) |  | D |
| SPDT<br>(B-M-B) | BREAK (1) - - MAKE (2)<br>BEFORE BREAK (3) |  | E |

**FIG. 3—RELAY CONTACT SYMBOLS** showing five different contact arrangements, sequence, and form.

**EM relay circuits**

Figures 4 to 9 show practical EM relay circuits. Figure 4 shows a relay with SPDT contacts connected so that it will not latch. Switch S1 is in series with the relay's coil and its power supply so that the relay will be actuated only when S1 is closed.

Figure 5 shows how a non-latching two-pole relay can be made self-latching by wiring switch S1 between one set of contacts. The NO contacts of one pole are wired in parallel with energizing switch S1. Thus both sets of contacts are normally off, but as switch S1 is closed, it causes the contacts of both poles to close and lock the output set of contacts in the ON state, even if S1 is subsequently re-opened. Once the relay is latched on, it can be turned off again only by opening the connection between the supply and the relay coil.

Figure 6 shows how a relay can be organized to perform AND logic. The relay will be actuated only when all of the series-connected switches S1, S2, and S3

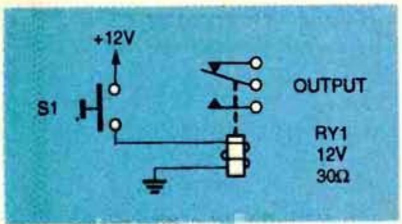


**FIG. 4—NON-LATCHING RELAY** schematic. Switch S1 is in the coil circuit of this relay.

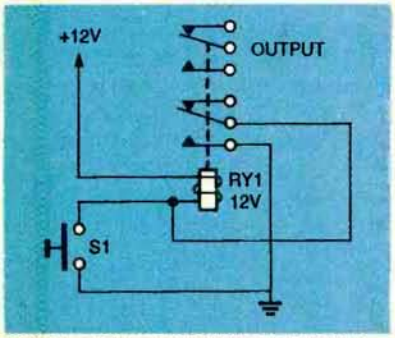


**FIG. 5—SELF-LATCHING RELAY** is a two-pole relay with a switch wired in parallel with one set of contacts.

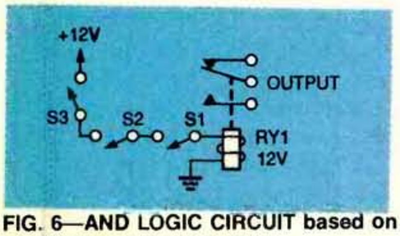


**FIG. 6—AND LOGIC CIRCUIT** based on an electromechanical relay.

are closed. Figure 7 shows how a relay can be organized to perform OR logic. The relay is actuated when at least one of the parallel-connected switches S1, S2 or S3 are closed.

Figure 8 shows how the basic circuits of Figs. 5 to 7 can be combined to make a simple but useful self-latching intrusion alarm that can be activated with any one of the contact or microswitches S1 to S3. (There is no theoretical limit to the number of switches that can be wired in parallel in these positions.) The alarm can either be enabled or turned off with switch S4.

When the alarm is enabled, it can be turned on by briefly closing any one of switches S1 to S3. These can be special, unobtrusive miniature switches which are activated by opening a window or door or treading on a mat. When any one of these switches is closed, the relay self-latches one set of contacts and activates the alarm bell with the second set.

Figure 9 shows how a relay and a capacitor form a low-frequency oscillator or lamp flasher. The operation of this circuit depends on the inherent (and substantial) difference between the relay coil's *pull-in* voltage (the minimum value for contact closure) and its *drop-out* voltage (when the contacts re-open).

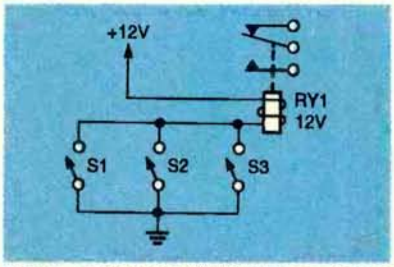


**FIG. 7—OR LOGIC CIRCUIT** based on an electromechanical relay.

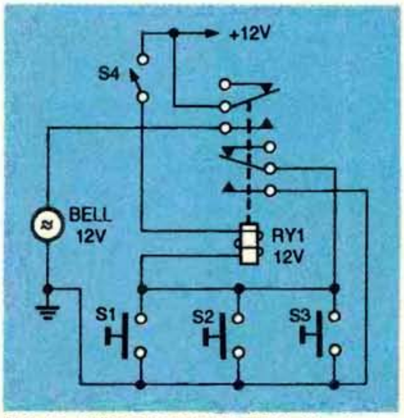


**FIG. 8—BURGLAR ALARM** that includes a self-latching relay.

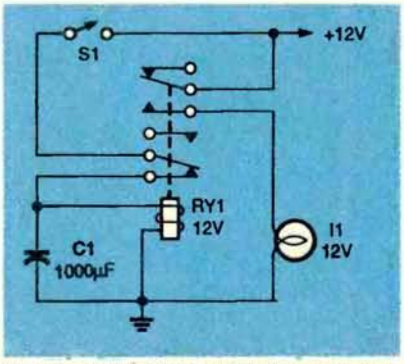


**FIG. 9—LOW-FREQUENCY** oscillator-flasher includes a self-latching relay.

A general purpose 12-volt relay might pull-in at about 10 volts and drop-out at about 5 volts. Under these conditions the circuit in Fig. 9 operates as follows:

When S1 is closed, C1 charges rapidly through the first (normally closed) set of contacts on relay RY1 until the relay's coil voltage reaches its pull-in value, causing the relay's second set of (normally open) contacts to close, turning on incandescent lamp I1. At that time, C1 discharges into the relay coil, holding the contacts open until C1's voltage falls to the drop-out value of the coil. When that value is reached, the normally closed contacts close again, causing C1 to recharge, starting the whole timing sequence again.

The relay contacts repeatedly open and close (oscillate) at a rate determined by the values of C1, the resistance of the coil, and the threshold voltage levels of coil pull-in and drop-out.

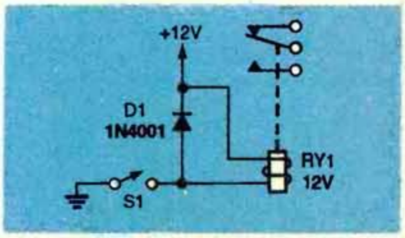


**FIG. 10—SINGLE-DIODE RELAY** coil damper is a diode across the relay's coil windings.

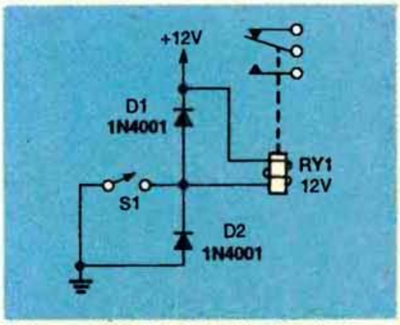


**FIG. 11—TWO-DIODE RELAY** coil damper has one diode across the coil and the other across the switch

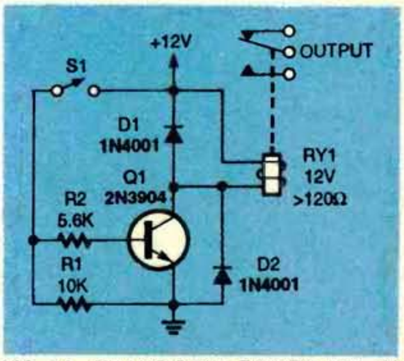


**FIG. 12—TRANSISTOR-DRIVEN RELAY** with a coil damper.

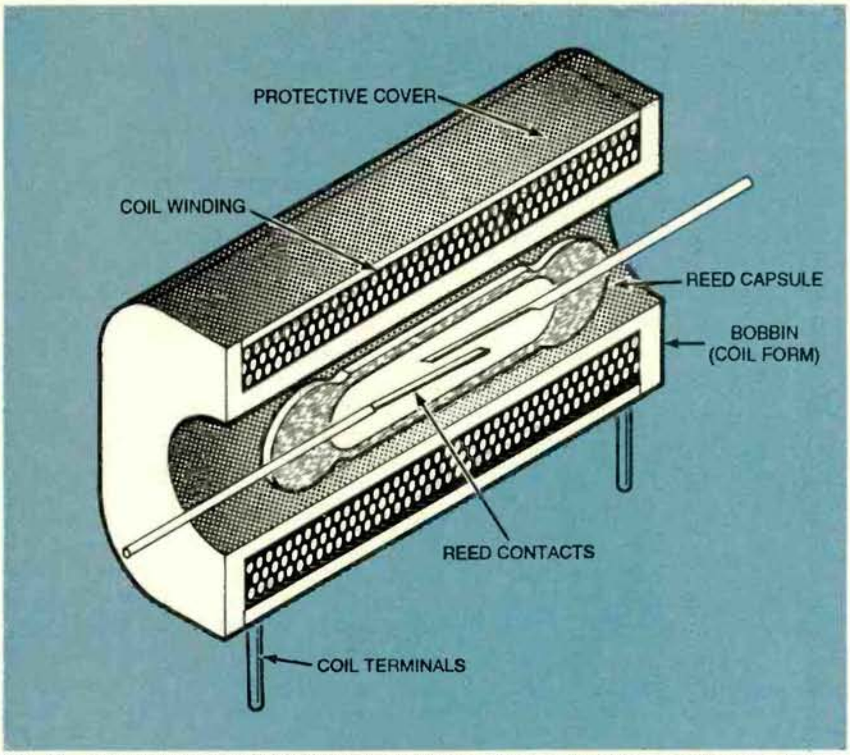


**FIG. 13—CUTAWAY VIEW OF A REED RELAY** showing section views of the energizing coil and reed-switch capsule.

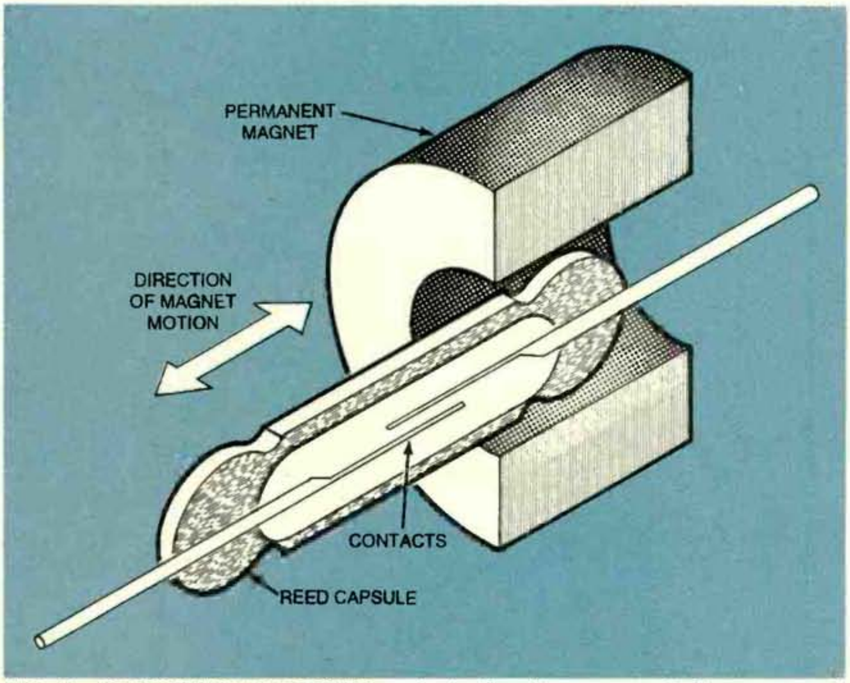


**FIG. 14—REED-SWITCH CAPSULE** is actuated by the movement of a permanent magnet with respect to the reeds.

### Coil damping

Because relay coils are inherently inductive, they can generate large back electromotive forces (EMFs) or voltages if their coil-current conductors are suddenly opened. A typical 12-volt coil can produce a peak back EMF of about 200 volts. These high unwanted voltages can easily damage switch contacts or electronic components connected in the coil circuit.

To prevent damage from back EMF, it is advisable to *damp* relay coils with protective diodes. In Fig. 10 this damping is provided by reverse-connected diode D1, often called a *snubber* diode. It prevents back EMF caused by coil switch-off from driving the junction between the RY1 coil and switch S1 more than 600 millivolts above the positive supply value. This protection is adequate for most relay circuits.

In situations where extra damping would prove beneficial, a pair of protective diodes can be installed. Diodes D1 and D2 in Fig. 11 ensure that the junction between the RY1 coil and switch S1 cannot swing more than 600 millivolts above the positive supply or below ground level. A diode pair is recommended in circuits where switch S1 has been replaced by a transistor or other solid-state switch.

The transistor in Fig. 12 increases the *sensitivity* of relay RY1's coil. If the coil were controlled directly by the switch, S1 would have to conduct a switching current of at least 100 milliamperes. With transistor Q1 functioning as a current amplifier between the S1 and the RY1 coil, the switching current can be reduced to less than 4 milliamperes.

### Reed relays and switches

Reed relays are a second major class of electromechanical relays. Unlike the general purpose EM relay, reed relays are almost exclusively found in electronic circuits for signal-level switching in medical instruments, telecommunications equipment, and automated test equipment (ATE). The reed relay is based on a reed capsule that includes the contacts.

Figure 13 is a cutaway view of a reed relay. It consists of a reed capsule mounted within a coil wound on a bobbin. The reed capsule is an hermetically sealed, inert gas-filled glass tube with a pair of thin iron-alloy strips or reeds sealed inside. The cantilevered ends of the reeds overlap but they do not touch.

The Form A or SPST-NO contact arrangement shown in Fig. 13 is a popular form of reed capsule. When the capsule is not in a magnetic field, a small gap exists between the reed ends. However, if the reed capsule is mounted within a coil that is energized, the resulting magnetic field causes the reed ends to close, completing or *making* an external circuit.

The reed capsule offers very high isolation ($10^{12}$ ohms) when off and a very low resistance (0.75 ohm) when on. Because the reeds are hermetically sealed, the contact area (usually precious-metal plated) remains clean and free of oxidation. The reeds will open and close reliably for millions of operations.

A reed relay capsule with a single pair of reeds is a single pole unit. Multipole reed relays can be made by inserting two, three, or more capsules in a single coil. The capsules are also available with Class C SPDT contacts.

Reed relays are now packaged in flatpacks and dual-in-line and single-in-line packages (DIPs and SIPs) for PC board mounting. Standard coil voltages are 5, 6, 12 and 24 volts DC. Mercury is added to some reed relay capsules to damp out contact bounce or chatter.

**Reed switch**

The reed capsule can also be switched by moving the capsule with respect to a permanent magnet, as shown in Fig. 14. Contact switching is accomplished either by moving the capsule close to a magnet or moving a magnet close to the capsule. Assemblies that include both of these parts are actually reed switches rather than relays, but they perform remote switching. The reed keyswitch was widely used in military-style keyboards because the contacts were protected from hostile environments.

Figure 15 illustrates an application for reed switching with a permanent magnet. The magnet can be concealed in the edge of the door or window, and a reed capsule can be recessed in the door or window frame. An alarm can be set off if an intruder or unauthorized person opens a closed door or window.

A reed relay can be substituted for a general purpose

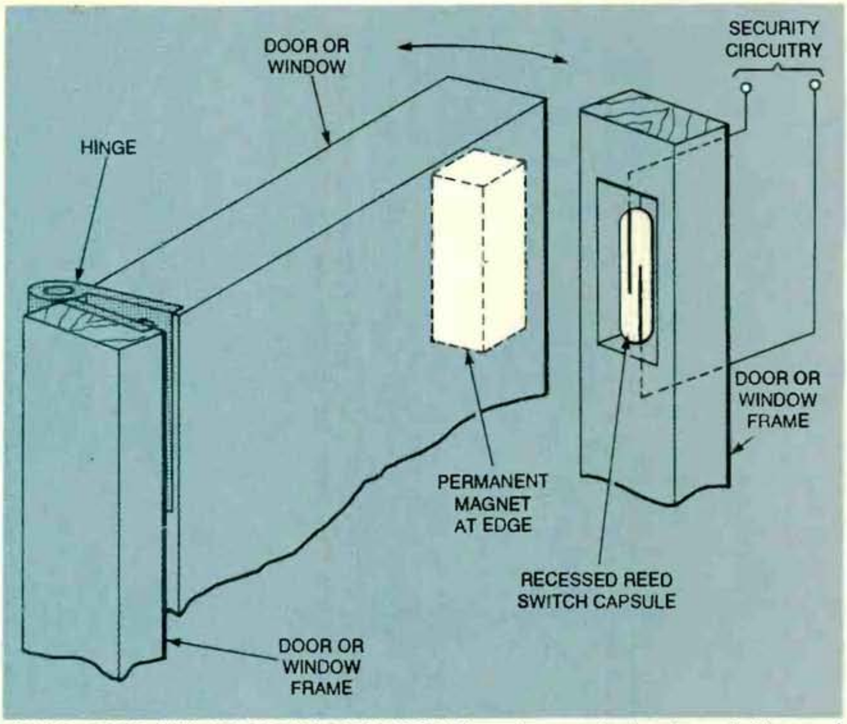


**FIG. 15—REED-SWITCH CAPSULE RECESSED in a door or window frame is triggered by a permanent magnet recessed in the door or window edge. Together they function as an input switch in an intrusion detection system.**

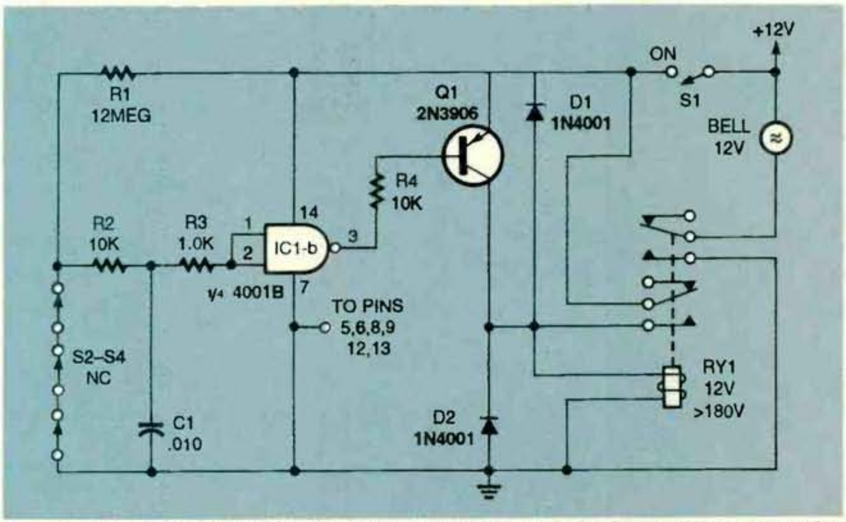


**FIG. 16—INTRUSION DETECTION ALARM CIRCUIT, energized by closing switch S1, can be triggered by opening any of the normally closed reed switches S2 to S4.**

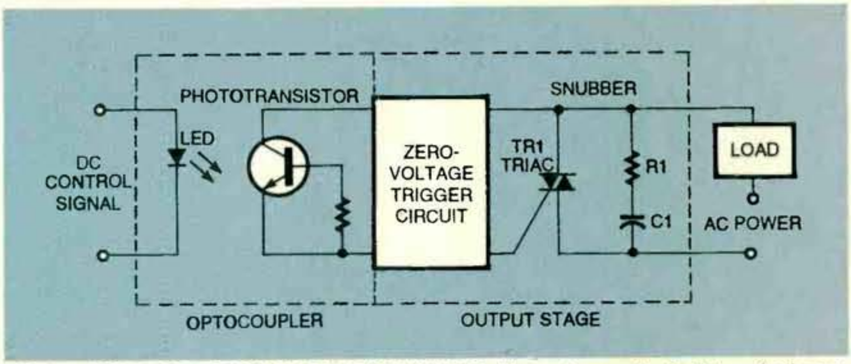


**FIG. 17—SOLID-STATE RELAY BLOCK DIAGRAM. The optocoupler isolates the input circuit (coil) from the triac (contacts). The zero-voltage circuit protects the triac.**

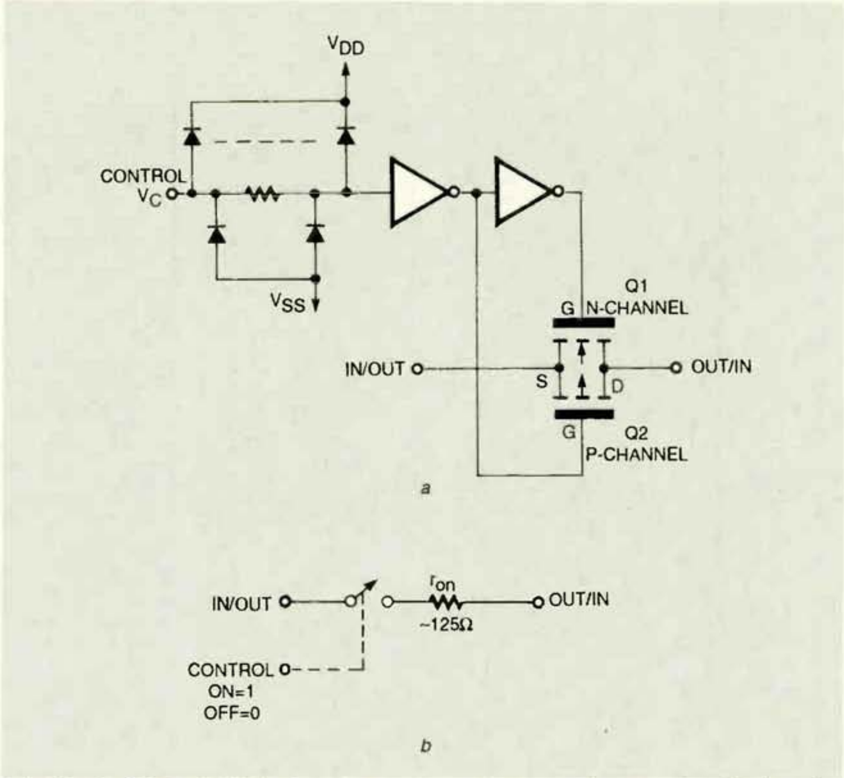


**FIG. 18—CMOS BILATERAL SWITCH functional diagram (*a*) and a simplified equivalent circuit (*b*).**

relay in the circuits from Figs. 4 to 9. and its coil can damped by the diodes as shown in Figs. 10 to 12. To compete with the reed relay in many applications, some manufacturers have introduced ultrasensitive, miniature PC-board mounted EM relays. Others have introduced miniature, solid-state, PC-board mounted relays billed as "reed relay replacements."

The intrusion detection alarm circuit of Fig. 16 draws a quiescent current of only 1 microampere when it is in the "standby" mode with control switch S1 and all of the series-connected sensor switches S2 to S4 closed.

When any of the S2 to S4 switches are open, a "high" voltage is applied to the input of the quad 2-input NOR gate, a CMOS CD4001B. It is wired as an inverting buffer to drive relay RY1 on through transistor Q1. When RY1 turns on, it self-latches with one set of contacts and sounds the alarm bell with its second set of contacts.

The network of resistors R2 and R3 and capacitor C1 acts as a transient-suppressing filter to protect the alarm against false activation from transients caused by man-made or natural electrical sources.

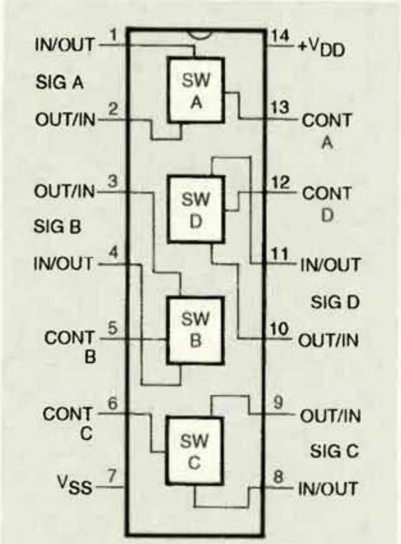


**FIG. 19—FUNCTIONAL DIAGRAM of a CMOS CD4066B quad bilateral switch.**

**Solid-state relay**

A solid-state relay (SSR) is an electronic circuit with no moving parts that consists of a signal-level trigger circuit coupled to a power semiconductor switch.

An SSR's classification is based on its input circuit and method of achieving isolation between the input and output circuits. True SSRs include optocouplers for isolation, but hybrid SSRs depend on reed capsules or transformers for isolation. The input circuit of an SSR acts as the coil of an EMR. It is electrically isolated from the power semiconductor that acts as the contacts.

SSRs for switching AC have either two inverse-parallel (back-to-back) silicon controlled rectifiers (SCRs) or an electrically equivalent triac as its contacts. However, if DC is switched, either a power bipolar transistor or MOSFET (metal-oxide semiconductor field-effect transistor) will function as the contacts.

Either AC or DC signals can be applied at the input circuit of an SSR with a block diagram as shown in Fig. 17. The first stage of this circuit is an optocoupler with an infrared-emitting diode matched to a photodetector. (See *Optocoupler Devices*, August 1992 *Electronics Now*, page 44.)

The signal output from the photodetector (phototransistor or phototriac) triggers the output triac so that it switches the load current. The zero-voltage detector assures that the triac will be triggered only when the AC voltage crosses the zero reference. This minimizes the effect of surge currents that occur when the triac is switched. Surge currents result from switching loads such as incandescent lamps or capacitors.

The triac, once triggered, will

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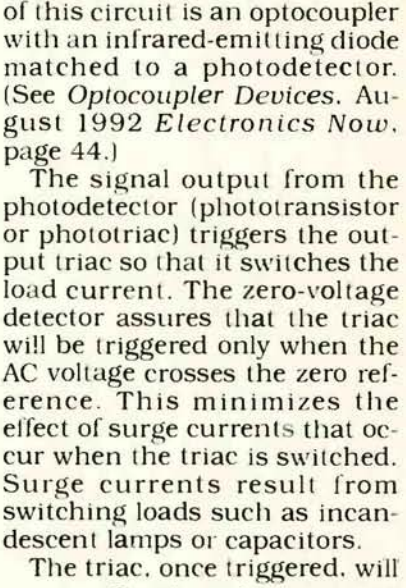

**FIG. 20—CD4066B BILATERAL SWITCH power connections for digital and analog signals.**

row in the side wall of the case for switches S1 to S8, as shown in Fig. 4. You can simplify the task of drilling an even row of holes in the case for the switches by applying a strip of drafting tape to the case and marking the locations of the hole centers. Note: The ganged bodies of the eight switches selected occupied the space between the cover mounting posts inside the case.

Drill the eight holes for the switches as well as the holes for plug PL1 and jacks J1 and J2. Mount all the switches and the plug and jacks with the ring nuts provided or nut and bolt sets, as required.

Mark the locations of the eight holes in a row across the cover to admit the lenses of the LEDs. (In the prototype they were sized for the diameter of T1¼ LED lenses.) Tape a section of perforated board on the top surface of the cover and use the 0.1-inch matrix as a guide for locating the centers of the holes to be drilled. The spacing should correspond to the spacing of the LEDs on the circuit board.

Drill the eight holes for the LEDs, drill the four countersunk holes in the case cover for mounting the circuit to the underside of the cover, and drill the three holes in the cover for switches S9, S10, and S11, as shown in Fig. 4. You might want to apply decals to the cover to identify the switch functions.

Fasten the circuit board to the cover with the four spacers and suitable self-tapping screws. It will not be necessary to drill additional holes in the circuit board because the screws will pick up on matching holes in the board.

After fastening the circuit board to the case, attach the miniature test clips to the ends of the ribbon cables and separate twin lead. The test clips were color coded in the prototype: eight green clips on the eight-wire ribbon cable, eight white clips and one black and white clip on the nine-wire cable, and black and red clips to terminate the twin wires. The Digilyzer is now complete. Ω

## RELAYS

*continued from page 74*

not stop conducting until the load current being conducted falls to zero. A resistor and capacitor in series, called a *snubber*, bypasses voltage transients that occur with inductive loads when current and voltage are out of phase. Triacs are the thyristors of choice for general-purpose AC SSRs with ratings up to 10 amperes at 120 to 240 volts.

Solid-state relays typically cost more than comparably rated EM relays, but their performance advantages over EM relays include:

- Longer-life and higher reliability
- Better compatibility with logic-level circuits
- Higher speed switching
- Higher resistance to shock and vibration
- Absence of moving mechanical contacts

Without moving mechanical contacts, the SSR is not a source of electromagnetic interference (EMI). Thus there is no contact bounce. The absence of

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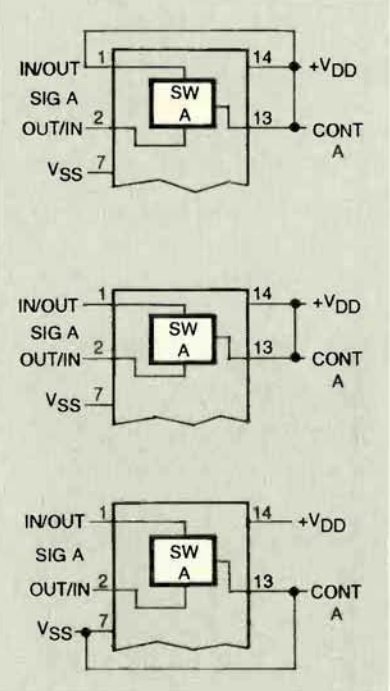

**FIG. 21—THREE METHODS for disabling the unused sections of a CD4066B quad bilateral switch by connecting the control terminal with the $V_{DD}$ or $V_{SS}$ terminals.**

## PC BENCHMARKS

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### Don't guess—test

The PC industry has struggled for years with the question of measuring computer performance effectively, but it looks as if resolution is in sight. User-level hybrid benchmarks are at the cutting edge of benchmark technology, and the next generation of hybrids should raise the level of PC testing by a quantum leap while simultaneously establishing sorely-needed benchmark standards.

It is unlikely that today's benchmarks are going to be obsolete any time soon. The Whetstone, Dhrystone, and MIPS are firmly entrenched in PC history. Ω

### RESOURCES

**PC Tools**
Central Point Software
15220 Green Brier N.W. Pkwy.
Beaverton, OR 97006
800-964-6896

**DisplayMate**
Sonera Technologies
PO Box 565
Rumson, NJ 07760
908-747-6886

**Lotus 1-2-3**
Lotus Development Corp.
55 Cambridge Pkwy.
Cambridge, MA 02142
800-343-5414

**MathCad**
MathSoft Corp.
101 Main St.
Cambridge, MA 02142
800-628-4223
617-577-1017

**Norton Utilities**
Symantec Corp.
10201 Torre Ave.
Cupertino, CA 95014
800-526-4787

**QAPlus**
DiagSoft, Inc.
5615 Scotts Valley Dr. #140
Scotts Valley, CA 95066
408-438-8247

**Quattro Pro**
Borland International Inc.
100 Borland Way
Scotts Valley, CA 95067
800-336-6464

**WordPerfect**
WordPerfect Corp.
1555 North Technology Way
Orem, UT 84057
800-526-4787

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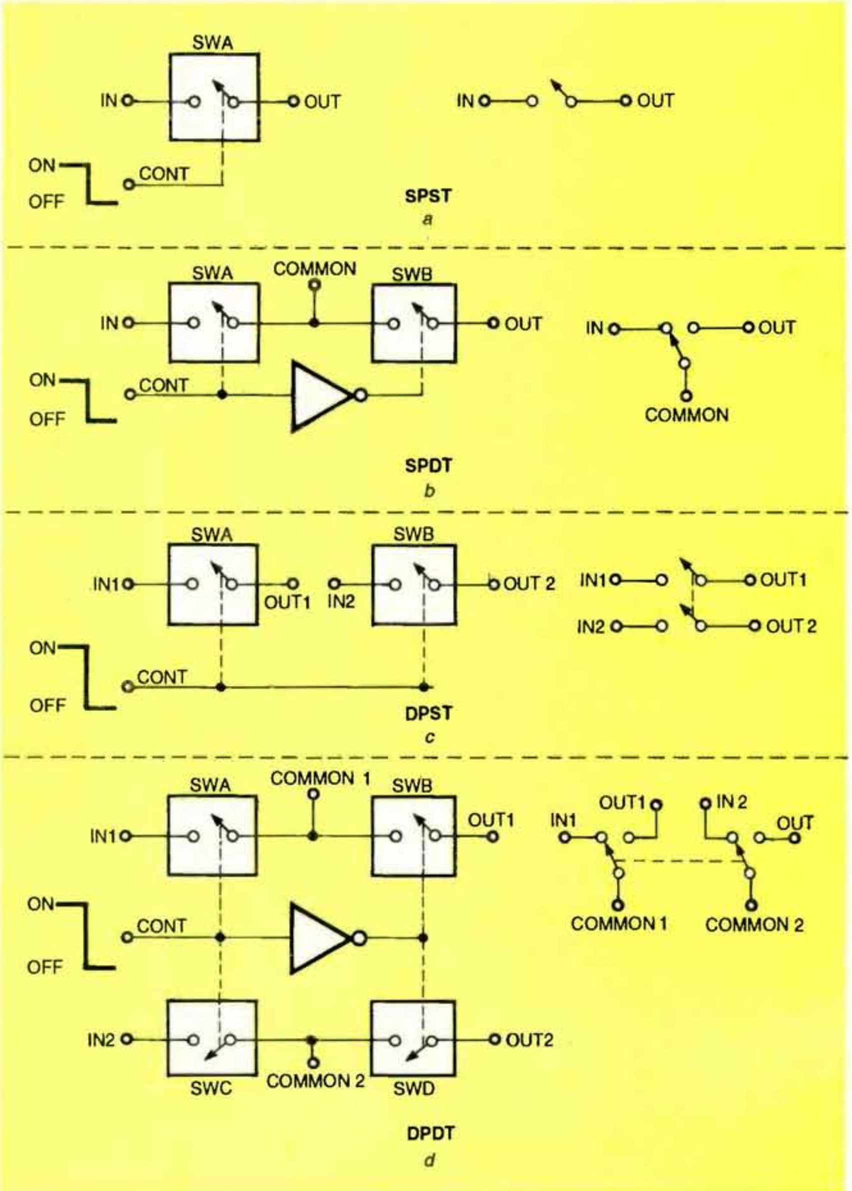

FIG. 22—FOUR BASIC SWITCHING functions organized on a CD4066: SPST (*a*), SPDT(*a*), DPST(*a*), and DPDT(*a*).

arcing caused by contact opening eliminates the hazard of switching EM relays in the presence of explosive gas mixtures.

The term solid-state relay is usually a reference to a factory-made and tested product. However, identical functions can be performed by connecting discrete components on a circuit board. (Readers who want to build their own SSRs should refer to *Solid-State Relay* in the May 1992 *Radio-Electronics*.)

Some manufacturers build low-voltage SSRs on circuit boards in their electronic products, but most are likely to purchase factory-made relays for switching power circuits.

**CMOS Bilateral switch**

The CMOS *bilateral switch* shown schematically in Fig. 18-*a* acts like a low-power, voltage-activated SSR (or remote-operated SPST switch) with a near-infinite input impedance.

The output stage of the circuit consists of Q1, an N-channel, enhancement-mode MOSFET and Q2, a P-channel enhancement-mode MOSFET connected in inverse parallel (drain-to-source and source-to-drain). Their gates are driven in opposing phase with a pair of internal inverters.

The control input can be either a logic 0 or logic 1 signal. MOSFETs Q1 and Q2 are both fully cut off and an effective open circuit "switch" exists between the IN and OUT terminals when a logic 0 signal is applied to the CONTROL terminal. However, Q1 and Q2 are both driven fully on, and an effective "closed switch" exists between IN and OUT with a logic 1 control input.

When Q1 and Q2 are saturated, signal currents can flow in either direction between the IN and OUT terminals. However, the signal voltages must not exceed the $V_{SS}$-to-$V_{DD}$ limits.

MOSFETs Q1 and Q2 have finite on-state resistance values ($r_{on}$) of about 125 ohms for 15-volt operation. Figure 18-*b* is a simplified bilateral switch equivalent circuit.

The bilateral switch is useful in analog-to-digital and digital-to-analog conversion and the digital control of frequency, impedance, phase and analog signal gain. Four of these switches have been integrated on the CD4066B as shown in Fig. 19.

Figure 20 shows a simplified equivalent circuit for the power supply and control connections for switching digital and analog signals. When working with the CD4066B, be sure that all unused sections are disabled either by connecting its control terminal to $V_{DD}$ and one of its switch terminals, connecting $V_{DD}$ to the control terminal or connecting $V_{SS}$ to the control terminal, as shown in Fig. 21.

Figure 22 shows how the CD4066B can perform the four basic SPST, SPDT, DPST and DPDT switching functions. The SPST function is shown in Fig. 22-*a*. The SPDT function, shown in Fig. 22-*b*, is formed by connecting an inverter stage between the SWA and SWB control terminals. The DPST switch in Fig. 22-*c* is just two SPST switches sharing a common control terminal. The DPDT switch in Fig. 22-*d*, is two SPDT switches sharing an inverter stage in the control line. Ω