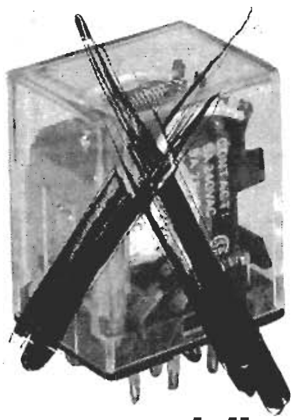
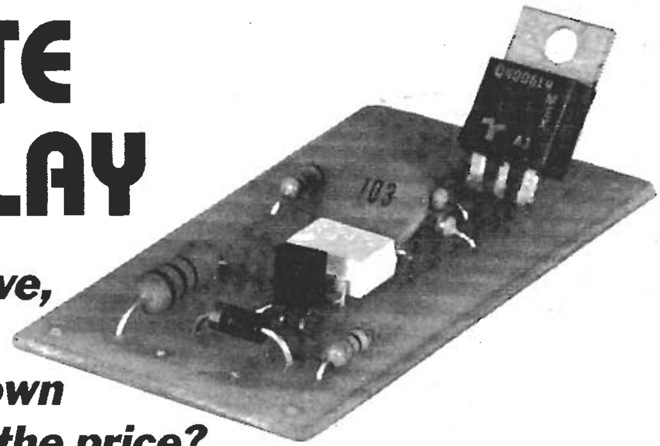


SOLID STATE RELAY



Why buy expensive, commercially made solid-state relays when you can make your own solid-state relays at a fraction of the price?

RODNEY A. KREUTER

SOLID-STATE RELAYS MAKE IT A cinch to connect digital logic to the nasty world of 115 volts (or more). These handy little devices make it possible for a battery-operated supply to turn on 100-watt light bulbs, 10-horse power motors, a lawn sprinkling system, or almost anything else you can imagine.

Solid-state relays, or SSR's, usually consist of an optoisolator and a Triac, which is used as an AC switch. There are many SSR variations such as those using reed relays in place of the optoisolator, and those using SCR's instead of Triacs, but most consist of less than a dozen parts.

Solid-state relays can provide isolation from 2 to 7.5 kilovolts and can drive tens of amps. They're usually offered in a plastic-filled cube with a heat sink on the bottom and screws for attaching the four wires—nothing could be simpler.

There are three common complaints with SSR's: First is the cost—twenty dollars apiece is about average. Second is the fact that they can't be repaired. When SSR's go bad, the fix could usually be a two-dollar Triac, but you can't get inside the plastic potting compound to repair it. Third is the fact that most SSR's made in large quantities are usually rated at about 10 amps. Who wants to pay for a ten-amp relay when all he needs is a two-amp relay? Besides, the larger the Triac, the larger the leakage currents.

There is hope for readers of **Radio-Electronics**, however. Using all new parts, the solid-state relay presented in this article can be built for less than eight dollars. An added bonus is that it can be repaired if anything goes wrong.

Operation

The basic operation of a solid-state relay is much like a switch that is controlled by an input voltage or current. That is illustrated in Fig. 1. Keep in mind that this switch can only be used for AC voltages because it will "latch up" on DC. (A Triac will turn off only when the current drops to zero.)

Our SSR circuit is shown in Fig. 2. Diode D1 provides protection in case you connect the input backward. Resistor R1 limits the input current. If you would like to use an SSR that requires a large input voltage (to increase the noise immunity) you can make R1 a large value. If you make R1 470 ohms, the relay will need about 12 volts to turn on. The power rating of R1 is a function of the maximum input voltage. For inputs up to 10 volts, a 1-watt resistor is needed.

The voltage across Q1's collector-emitter junction is almost constant (with a minimum input of three volts) at 1.75 volts (typical LED voltage) plus 0.7 volts (typical V_{BE}), or 2.45 volts. The voltage across R1 will therefore be the input voltage minus about 2.5 volts.

The minimum input voltage needed to turn on the SSR is a function of the minimum LED current (the LED inside IC1) and R1. The minimum for the MOC3010 is 15 milliamps. That works out to an input voltage of about 4 volts using the components shown. You can reduce the minimum voltage needed by decreasing R1 or by using an optoisolator that requires less LED current. Since the LED needs about 1.75 volts across it before it begins to emit light, operation below three volts isn't practical. The maximum current through the LED is set by resistor R2.

When the voltage across R2 reaches about 0.65 volts, Q1 begins to conduct, shunting current from the LED. The result is that, although the current through R1 rises as the input voltage rises, the current through the LED stops increasing at about 15 milliamps. The minimum LED current, therefore, is not the minimum current you can pass through the LED; rather it is the minimum LED current that will operate the Triac.

Probably the most misunderstood aspect of solid-state re-

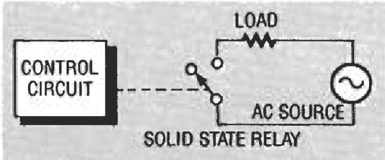


FIG. 1—A SOLID-STATE RELAY is much like a switch that is controlled by an input voltage or current.

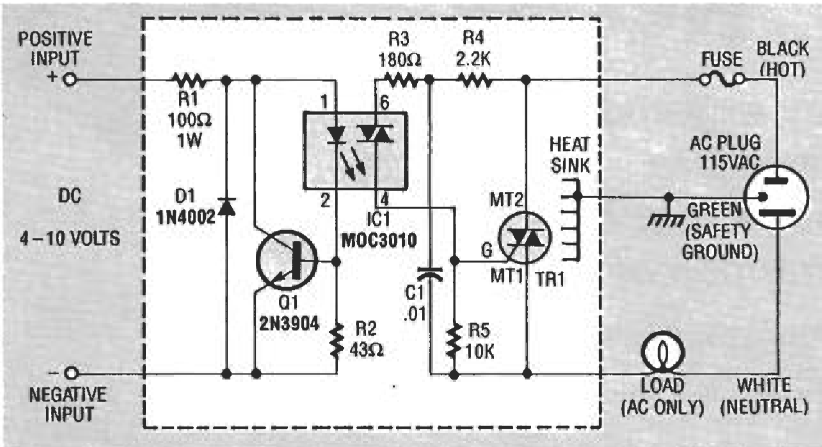


FIG. 2—SSR CIRCUIT. Diode D1 protects the unit if you connect the input backward, and R1 limits the input current.

lays is that the input requirement is really current, not voltage. That means that the driving circuit must be able to supply the current necessary to operate the LED in the SSR. In the example shown, the current is about 15 milliamps. The current can come from a current source as in Fig. 3 or a current sink as in Fig. 4. Most circuits can sink more current than they can source. For example, TTL can source only one milliamp or so, but it can sink 10 to 15 milliamps. If you must use a logic family that can't source or sink much current, such as the output of most computer ports, you can use a transistor to provide a current sink as shown in Fig. 5.

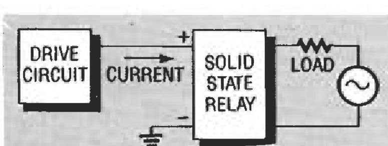


FIG. 3—THE INPUT REQUIREMENT of an SSR is current. Here the driving circuit is shown as a current source.

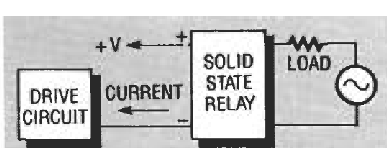


FIG. 4—THE DRIVING CIRCUIT is shown here as a current sink.

Zero-voltage switching

Some of the newer SSR's provide zero-voltage or zero-crossing switching. In normal operation the trigger side of the relay is totally asynchronous to the AC side. That means that a trigger could occur during any part of the AC sine wave. If the trigger occurs near a peak (90 or 270 degrees), a large current will flow into the load almost instantly. That creates a lot of RFI (radio frequency interference) and also is very hard on the filament of ordinary light bulbs. In order to prevent that, zero-crossing SSR's accept the trigger at any time but delay turning on the AC load until the next time the AC voltage passes through zero volts.

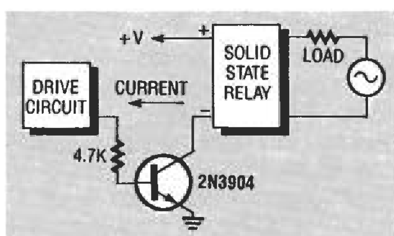


FIG. 5—IF YOUR CIRCUIT can't source or sink much current, use a transistor as a current sink.

Safety

Building an SSR requires putting 110 volts on a printed circuit board. From an electrical point of view, that can be perfectly safe. However, it's probably a good idea to cover all printed circuit runs on the 110-volt side of the PC board with silicone sealer. Also, try to use only isolated Triacs (where the case is electrically isolated from the Triac), and ground the heat sink to the AC safety wire (green, or earth ground).

Choosing a Triac

There are three basic requirements when choosing the output Triac. First is to make sure that it will handle the voltage required. The minimum for a 115-volt AC line requires a 200-volt Triac. A 220-volt line requires a 400-volt Triac. Remember that those are the minimum so, for a few cents more, it pays to use the next highest voltage rating.

The next requirement is current. A 6-amp Triac will handle 6 amps only if it is properly heat

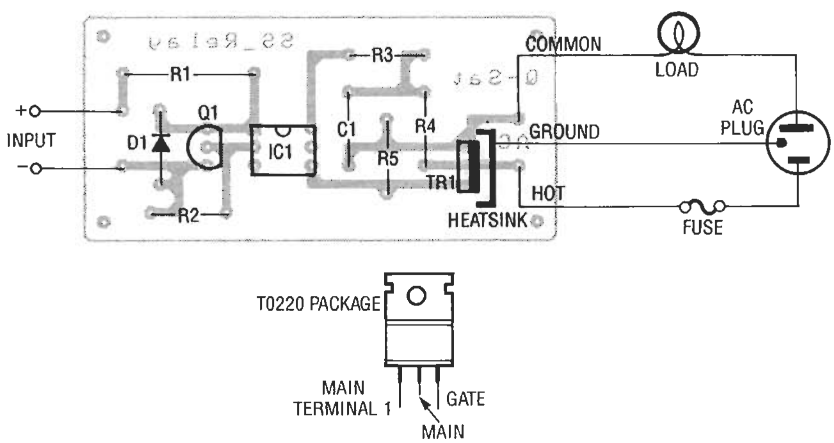


FIG. 6—PARTS-PLACEMENT DIAGRAM. You must heatsink the Triac and connect the heatsink to earth ground, even if you're using an isolated Triac.

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1—100 ohms, 1-watt (see text)
R2—43 ohms (see text)
R3—180 ohms
R4—2200 ohms
R5—10,000 ohms
Capacitors
C1—0.01 μF, 500 volts, ceramic
Semiconductors
IC1—Motorola MOC3010 Triac-output optoisolator (or MOC3011 for zero-crossing switching, see text)
D1—1N4002 diode (or any 1-amp, 100-volt or greater diode)
Q1—2N3904 NPN transistor
TR1—Teccor Q4006L4 Triac (or equivalent, see text)

Note: The following items are available from Q-Sat, PO Box 110, Boalsburg, PA 16827:
- **A printed circuit board for two solid-state relays, can be cut in two or left together (part number SSR-PCB)—$8.00 postpaid**
- **A complete kit minus heat sinks for two solid-state relays (sorry, sold in multiples of two only, part number SSR-KIT)—$18.00 postpaid**

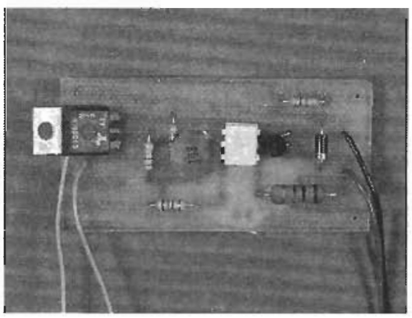
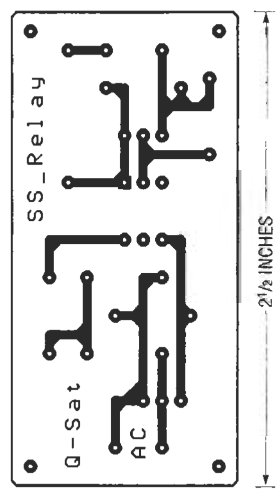


FIG. 7—THE AUTHOR'S PROTOTYPE. The board is shown here without a heatsink on the Triac, although one should definitely be used.



SSR FOIL PATTERN shown actual size.

sinked. As a word of warning, motors draw a lot more current on start-up than they do during normal operation, sometimes as much as ten times more.

The third requirement is the gate current. The Motorola MOC3010 optoisolator will provide about 100 milliamps of drive current for the output Triac. That should be adequate for any Triac you can find in a TO-220 package.

Although not a strict requirement, an isolated Triac is a good safety precaution. Isolated Triacs provide electrical isolation from the electrical connections to the case. Early Triacs were not normally isolated. That meant that you had to use mica washers and thermal grease. Thermal grease is still a good idea, but the mica washer isn't required for isolated Triacs. If you don't know whether or not your Triac is isolated, simply measure the resistance from each lead to the case. An isolated Triac will measure open on all three leads.

Warning: The Radio Shack 400-volt, 6-amp Triac (part number 276-1000) will work well in this circuit, but it is *not* isolated. You *must* use a TO-220 mica washer and thermal grease if you plan to use that device.

Construction

For a simple SSR, an optoisolator such as the Motorola MOC3010 will be sufficient. For a zero-crossing SSR, an MOC3031 will do. Many companies make optoisolators. Make sure yours has a Triac output and that the pinouts are compatible with your design. Table 1 shows some typical Triac-output optoisolator specifications.

Although the SSR can certainly be built without a printed circuit board, using the foil pattern we've provided will make building it a simple task. You can also buy a pre-made PC board from the source mentioned in the parts list. Figure 6 shows the parts-placement diagram. The only precaution, other than the one about working with 110 volts, is to heatsink the Triac. If you leave the leads on the Triac long, it should be a simple matter to find some heat sink to attach to the Triac. Just remember to connect the heatsink to an earth ground. Even if you're using an isolated Triac, the earth ground is still necessary. Otherwise you should buy your solid-state relays from a reliable company—don't build them yourself. Figure 7 shows the author's completed prototype.

Remember that SSR's can switch only an AC line. Trying to switch a DC line will result in a relay that closes but never opens. **R-E**

TABLE 1—TYPICAL TRIAC-OUTPUT OPTOISOLATORS

Motorola Type	Blocking Voltage	LED Current (mA)	Maximum R2 (ohms)	Zero Crossing Switching	AC Line Voltage
MOC3009	250	30	22	No	115
MOC3010	250	15	43	No	115
MOC3011	250	10	68	No	115
MOC3012	250	5	130	No	115
MOC3020	400	30	22	No	220
MOC3021	400	15	43	No	220
MOC3022	400	10	68	No	220
MOC3023	400	5	130	No	220
MOC3030	250	30	22	Yes	115
MOC3031	250	15	43	Yes	115
MOC3032	250	10	68	Yes	115
MOC3040	400	30	22	Yes	220
MOC3041	400	15	43	Yes	220

SOLID-STATE RELAY UPDATE

Regarding the article, "Solid-State Relay" (**Radio-Electronics**, May 1992), a very important feature is the zero-current switch-off characteristic inherent in the triac.

The interruption of the circuit at the instant the current is zero avoids voltage spikes that could be produced by the stored energy (E) in the distributed inductance of the power line and leakage inductance of the mains (line) transformer (L) if the current is suddenly interrupted at a non-zero value, as occurs with mechanical contact breakers. As we know, $E = \frac{1}{2} Li^2$. At the instant the current crosses zero, the stored energy is also zero.

These voltage transients, which are caused by switching heavy currents, are often the reason for failure of electronic equipment connected to the same line. The solid-state relay prevents such damage.

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