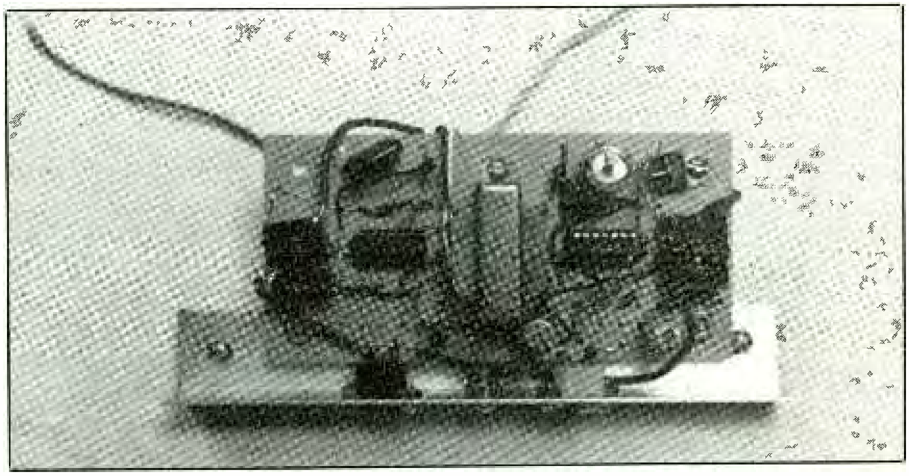
Switch Multiplier

Digital switching arrangement multiplies the number of ac-operated devices that can be controlled by a single wall switch without requiring house wiring modification

By Robert E. Samuelson



Installation of a new ceiling fan with light assembly in the center of our master bedroom presented some knotty problems. We wanted to control *both* fan and light from the existing wall switch located just inside the entry to the room—not by having to enter the room at night and groping for a pull chain. The single wiring circuit between the existing light fixture in the ceiling and wall switch could not be augmented without breaching the flat roof of our home, and dangling swags and surface wiring were ruled out for aesthetic reasons. Though I could have used commercial wireless control modules, I did not want a device that sits there continuously sucking up power just waiting for the occasional command.

The Switch Multiplier described here provided me with a solution to my dilemma. Though designed specifically to solve my fan/light problem, the Multiplier can be useful in other remote-switching applications in a household. The compact Switch Multiplier was small enough to fit into the metal ceiling box formerly occupied by a flush lighting fixture and now supporting my fan/light assembly—with a bit of bracing, of course.

Operation of the Switch Multiplier is very simple. Flipping the wall switch to ON turns on the light below the fan. A quick flip of the switch to OFF and then back ON turns off the light and on the fan. Another OFF/ON operation turns on both fan and light. Finally, setting the wall switch to OFF and leaving it there disables both fan and light.

About the Circuit

Figure 1 is a simplified representation of the circuitry contained in the Switch Multiplier. It shows how 117-volt ac line power is routed by relays *K1* and *K2* to the light or/and fan when wall switch *S1* is ON. The relays are controlled by a simple sequence-and-hold circuit that is activated by an impulse each time *S1* is switched to ON. The advantages of this system are that it draws no power when it is not in use (*S1* OFF) and no change in your house wiring is required to implement it.

Shown in Fig. 2 is the complete schematic diagram of the Switch Multiplier. The circuit consists of three major sections:

(1) A dc power supply that delivers 12 volts to the relay circuitry, together with a time-delay branch to trigger *IC1*, and a timed holding branch to power *IC1* and *IC2* to keep them alive when *S1* is OFF during an OFF/ON sequence;

(2) Integrated circuits *IC1* and *IC2*, which respond to the commands from wall switch *S1* and provide the proper sequencing and control to the relays;

(3) Relays *K1* and *K2*, which route ac line power to either or both loads, as directed by *IC2*.

Circuit operation is as follows. Power transformer *T1* steps down the 117 volts ac delivered to it from the ac line to 12.6 volts ac. This reduced ac voltage is then converted to pulsating dc by rectifier diode *D1* and is filtered to pure dc by capacitor *C1*. The dc voltage is then regulated to +12 volts by regulator *IC3* and is then distributed throughout the low-voltage circuitry as needed.

Triggering impulses are generated

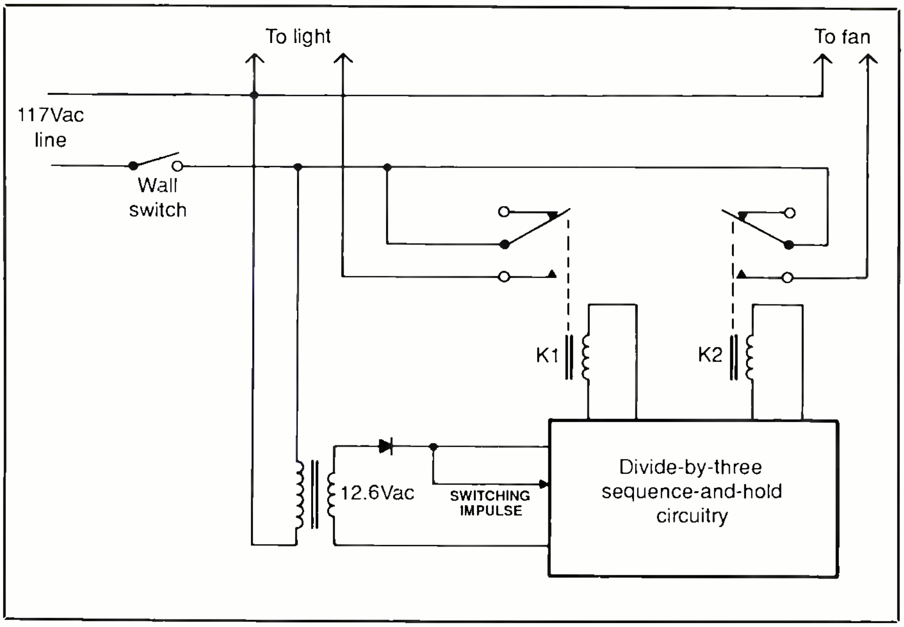


Fig. 1. Simplified diagram of the elements that make up a device that controls two ac-operated electrical devices with a single ac line.

every time *S1* is switched to ON. These impulses are picked off at the junction of *D1*, positive lead of *C1* and INPUT terminal of *IC3* and are sent to the input of *IC1*. To arrive at *IC1*'s input, the trigger pulses must negotiate the time-delay network made up of resistors *R2*, *R3* and *R4* and capacitor *C4*, which imposes a delay of about 0.06 second (60 milliseconds) that holds off triggering *IC1* and *IC2* until these devices are powered up. Discharge time of the network is short enough so that the input to *IC1* goes low while *S1* is being operated; so *IC1* will remain ready for the next trigger pulse.

While flipping *S1* to OFF and then back to ON, power must be maintained on *IC1* and *IC2* to preserve the existing state of *IC2* until the cycle is stepped ahead. To accomplish this, a timed holding branch circuit is employed. This branch is made up of rectifier diode *D2*, 100-microfarad capacitor *C3* and 100,000-ohm resistor *R2*.

When *S1* is closed (ON), *C3* quickly charges to approximately 12 volts, taking about 10 milliseconds to do so. But when *S1* is opened (OFF), the time constant of the *C3R3* network, which is about 10 seconds, maintains sufficient voltage on *IC1* and *IC2* to preserve their status until the wall switch is again closed.

CMOS 4023 triple 3-input NOR gate *IC1* is wired in this circuit to form a Schmitt trigger that provides a clean, sharp input to *IC2*. CMOS 4027 JK flip-flop *IC2* is configured as a divide-by-three circuit here. Three successive closures of *S1* step *IC2* through three sequential states. Connecting the proper outputs of *IC2* through *R6* and *R7* to the relay circuits as shown will then provide the desired sequence of LIGHT/FAN/BOTH/OFF. See Fig. 3 for the internal connections of the logic circuitry.

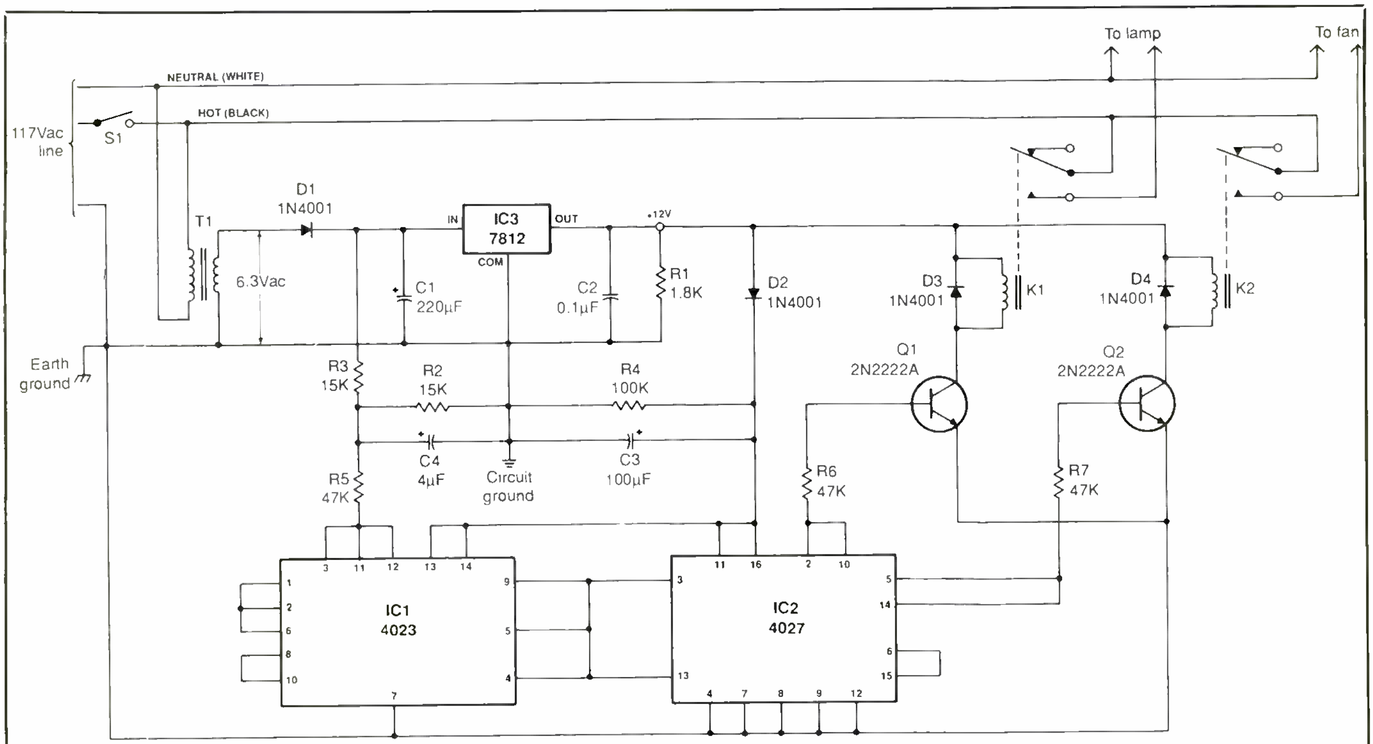
Relays *K1* and *K2* in this project are Radio Shack Cat. No. 275-248 units that have 320-ohm, 12-volt dc coils and contacts rated at 10 amperes. The contact rating is adequate for light-to-moderate loads, such as the fan and light for which the project was designed. The driving circuits for the relays are conventional. They are made up of transistors *Q1* and *Q2* for *K1* and *K2*, respectively. Diodes *D3* and *D4* are surge suppressers, and resistors *R6* and *R7* isolate the transistors from the outputs of *IC2*.

Construction

This is a simple, straightforward project that requires no special component layout or routing of conductors. The only admonition to bear firmly in mind is that you must take care to place conductors and connections that carry 117-volt ac line power as far as possible from the low-voltage portions of the circuit.

You can build the project using any wiring technique that suits you. For this project, perforated-board construction is perhaps the simplest way to go. If you do go this route, use perforated board that has holes on 0.1-inch centers and suitable Wire Wrap or soldering hardware. If you prefer printed-circuit wiring, feel free to design and fabricate your own pc board. Should you wish to use prototyping board instead, choose the type that accepts DIP integrated circuits and has extra connecting points for each IC pin. In any case, whatever wiring technique you decide to use, it is a good idea to use sockets for *IC1* and *IC2*.

The miniature Radio Shack relays specified for *K1* and *K2* in the Parts List will fit standard perforated boards, but remember to observe full precautions for the terminals that will be at 117 volts ac line potential when the project is operating. Be certain to allow adequate clearance between these high-voltage points and the low-voltage points in the circuit layout. Also, if you are using printed-circuit or prototyping board, check the copper traces to which the 117-volt-level connections will be made. If the traces appear to be skimpy or fragile, augment them by carefully soldering in parallel lengths of 18- or 16-gauge solid wire to carry the moderate current that will be drawn by the loads.



PARTS LIST

Semiconductors

D1 thru D4—1N4001 silicon rectifier diode

IC1—4023 CMOS triple 3-input NAND gate

IC2—4027 CMOS dual JK flip-flop

IC3—7812 + 12-volt regulator

Q1,Q2—2N2222A or similar general-purpose silicon npn transistor

Capacitors

C1—220-µF, 25-volt electrolytic

C2—0.01-µF ceramic disc

C3—100-µF, 35-volt electrolytic

C4—4-µF, 35-volt electrolytic

Resistors (¼-watt, 10% tolerance)

R1—1,800 ohms (½-watt)

R2—100,000 ohms

R3,R4—15,000 ohms

R5,R6,R7—47,000 ohms

Miscellaneous

K1,K2—Miniature 12-volt, 100-mA or less relay with 10-ampere spdt contacts (Shack Cat. No. 275-248 or similar; other applications may require relays with different coil ratings and contact ratings/arrangements—see text)

S1—Existing ac lighting wall switch

T1—Miniature 12.6-volt, 300-mA power transformer (Radio Shack Cat. No. 273-1385 or similar)

Circuit board (perforated board with holes on 0.1″ centers and suitable Wire Wrap or soldering hardware or pc board of your own design (see text); suitable enclosure; sockets for DIP ICs; terminal strips and connectors as needed; 18-gauge or heavier stranded wire; wire nuts; machine hardware; hookup wire; solder; etc.

Fig. 2. Complete schematic diagram of the Switch Multiplier designed to handle two moderate-power loads, such as a ceiling fan and its lighting fixture.

You can avoid some possible difficulties later on if you mount the relays on the circuit-board assembly with their connection pins pointing upward *away from* the board. Secure the relays to the top surface of the board with silicone adhesive or even a simple U clamp made from short lengths of insulated hookup wire routed through holes in the board and soldered securely into place.

Using Fig. 2 as a guide, wire together the project's circuit. However, do *not* make the connections between the relay contacts and 117-volt ac line. These will be made later, after suitable voltage and operational checks have been completed.

In the lead photo is shown a photo of the original version of the Switch Multiplier, which was built to control my ceiling fan and its accessory lighting fixture. This version was built on a Radio Shack Cat. No. 276-151 Dual IC Experimenters PC Board and has been faithfully turning on and off my bedroom fan and light for more than four years. Notice here that the relays (shown as the black squares at opposite ends of the board) are mounted with their connection pins pointing upward, away from the board.

Figure 4 shows the same circuit built more recently for a different application. This version was assem-

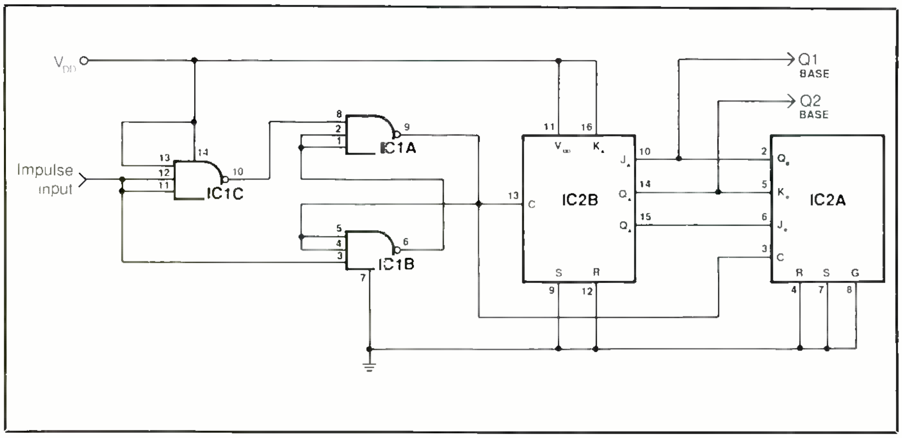


Fig. 3. Details of internal logic-circuit wiring.

bled on a Radio Shack Cat. No. 276-170 Experimenters PC Board. This particular board has copper traces with multiple pads for each IC pin on the bottom of the board. In this version of the project, the pins of the miniature relays (the two squares to the right of the ICs) are plugged into the holes in the board, rather that pointing upward away from the board's surface.

The boards used in both versions of the project have provisions for mounting and connecting DIP IC sockets. This greatly reduced the amount of time and effort needed to drill holes and make connections.

When you assemble your project, mount the IC sockets—*not* the ICs themselves—into place first. Mounting of the circuit-board assembly, power transformer *T1* and voltage regulator *IC3* require machine screws, nuts and lockwashers. Also, make sure to provide a good, solid electrical ground during installation.

Your choice of housing for your Switch Multiplier depends on the application for which the project is built. If you build it for the fan/light application for which I originally designed the project, the circuit-board assembly must be mounted inside a protective enclosure that has provisions for making the necessary 117-volt ac input and output connections. As you can see in Fig. 4, a pair of chassis-mount ac receptacles mounted on the metal L bracket at the bottom of the photo provide the means for connecting the fan and lamp to the project. If you go this route, you must equip the fan and light power conductors with their own separate ac plugs. Alternatively, these conductors can be wired directly into the circuit.

In the case of the original application for the Switch Multiplier to control a fan and a lamp, removal of the glass and reflector of the existing flush-mount lighting fixture left a metal box measuring 9 × 9 × 4 inches. This was set into the ceiling. If you plan on using the project for this same type of application in a location where the fixture is not set into the ceiling but is designed to accommodate a hanging light fixture, you may have to remove the existing box, enlarge the hole and use a box that is large enough to accommodate the circuitry. In either case, you will need a length of 1 × 1-inch angle iron to provide a reinforcing support for the weight of the fan and light. The angle iron also provides a convenient mounting bracket for the circuit-board assembly.

Ac-line input conductors to the Switch multiplier should be stranded wires not less than 16 gauge in size. Make all hookups with ordinary wire nuts. Outputs to the fan and lamp (or other medium-duty loads) should also be made with stranded wires, these not less than 18 gauge in size.

If you are building the project for any purpose other than to control a fan and lighting fixture, house the circuitry in any enclosure that will suit your needs. Then make connections according to the demands of the items being controlled.

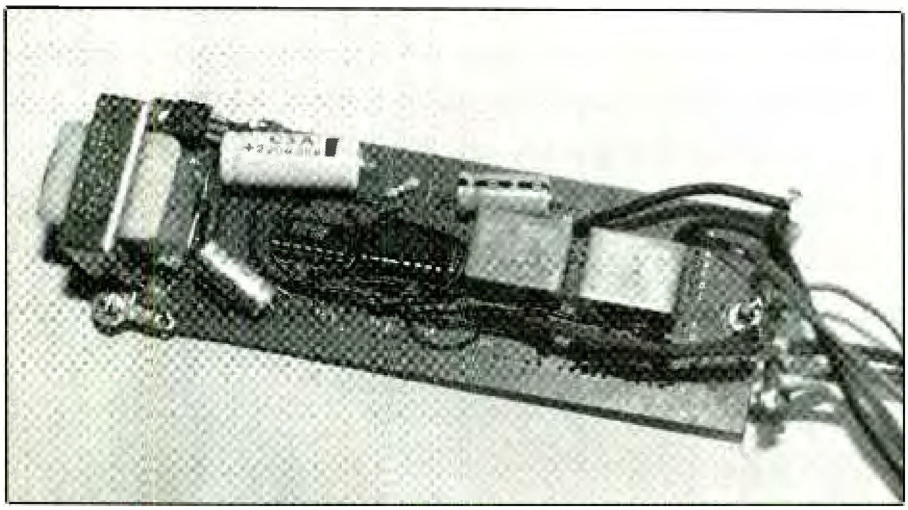


Fig. 4. A later version of the project (the original is shown in the lead photo) wired on a DIP style prototyping board that has copper traces that interconnect several pads for each IC-pin hole and with relay pins plugged into the hole matrix.

With DIP integrated circuits still not installed in their sockets and no ac-line-level connections made to the contact lugs of the relays, carefully check all wiring and soldered connections. It is a good idea to use a magnifying glass for this inspection. Check especially between closely spaced pads and conductors for solder bridges.

If you locate any suspicious connections, reflow the solder around it. Clear any solder bridges with desoldering wick or a vacuum-type desoldering tool. Then use an ohmmeter set to a high range to make a "tour" of the circuit, checking all points that are and are not supposed to be at ground level. Then set the ohmmeter to a low range and check the polarities of all four rectifier diodes. Be careful here because some meters reverse the polarity of the test voltage delivered to their probes. If you consistently get a wrong-polarity indication, suspect the polarity of the test voltage.

Do not proceed to powering up the project until you are absolutely certain that all wiring is correct and that all components are in their correct locations and are installed in proper orientation. Once everything checks out okay, proceed to a live check of the 12-volt dc portion of the project. Before you do this, however, keep firmly in mind that you will be working around potentially lethal ac line potentials. Exercise extreme caution at all times when working on the powered-up circuit!

Connect a temporary ac line cord —switched, if possible, to simplify operational checks—to the primary leads of the power transformer, using wire nuts. Make sure that these connections are solidly made and that no part of the line-potential wiring is exposed. At this point, there should be no other points in the circuit that will be at 117 volts ac when the circuit is powered.

Use a dc voltmeter or multimeter set to dc volts to make the following voltage checks. The meter should have at least a 1-megohm input resistance. Connect the meter's common probe to a convenient circuit-ground point and plug the line cord into a convenient ac outlet. Switch on power if you are using a switched line cord.

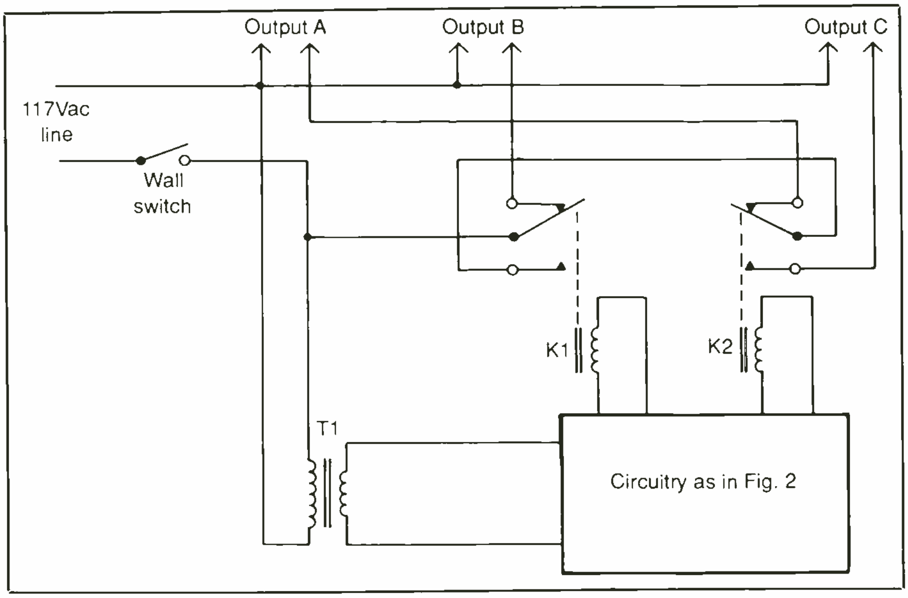


Fig. 5. Wiring for controlling three loads with a single ac line.

Measure the potential at the junction formed by *C1* and *R3*; you should obtain a meter reading of about +14 volts. At the junction formed by *R2* and *R3*, the reading should be about +7 volts. Then the potential measured at the top of *R1*, *C2*, *D2*, *K1* and *K2* should be +12 volts, as should be the reading at the junction formed by *D2*, *C3* and *R2*. If you pull the plug (or switch off the line cord), the reading at the *D2/C3/R2* junction should very slowly decrease as the charge on the capacitor in this timing circuit bleeds off.

If you do not obtain the proper reading at any point, remove ac power from the circuit and rectify the problem. Do *not* proceed until you have corrected the problem.

Allow the charges to leak off all capacitors. Then, exercising the normal precautions for handling MOS devices, install *IC1* and *IC2* in their respective sockets. Make sure that each is properly oriented before inserting it and that no pins overhang the sockets or fold under between ICs and sockets. With a continuity checker or an ohmmeter set to a low range, check operation of the contacts of *K1* and *K2* as follows.

First, connect the checker's or ohmmeter's leads to the normally-open contacts of *K1* and then *K2* and note the indications obtained. In both cases, there should be no sound from the checker or low resistance or short circuit from the meter. Move the tester's or meter's probes to the normally-closed contacts of first one and then the other relay. In both cases, there should be continuity on the order of zero ohm.

Leave the checker's or ohmmeter's probes connected to the normally-open contacts of *K1* and power up the circuit. You should now obtain an indication of continuity. Checking the normally-open contacts of *K2* should yield an infinity reading.

Turn off and then on the ac power to the project. Now the indication across the normally-open contacts of *K2* should be continuity and across the normally-open contacts of *K1* should be open. Once again turn off and then on ac power. Now the indications across the normally-open contacts of both relays should be continuity. Finally, turn off power altogether and check all combinations of relay contacts; normally-open contacts should show infinite resistance and normally-closed contacts should show continuity.

If you do not obtain the appropriate indications in all cases, remove ac power from the project and troubleshoot it. Rectify the problem before proceeding.

Once all indications are correct, finish wiring the 117-volt ac input and output connections to the relays. Always use at least 18-gauge—and preferably 16-gauge—stranded wire for all conductors that carry line-level voltages from the ac line and to the loads. Then perform an actual in-circuit operational check of the project as detailed above.

When working on the connections in the ceiling electrical box, make sure that you kill ac power to this branch circuit by removing the appropriate fuse from the fuse box or flipping the appropriate circuit breaker's toggle to OFF. If you are not sure which fuse to remove or circuit breaker to flip, kill power at the main fuse or breaker. If you are not sure about what you are doing with regard to the ac line, have someone who does help you or have a licensed electrician do the installation.

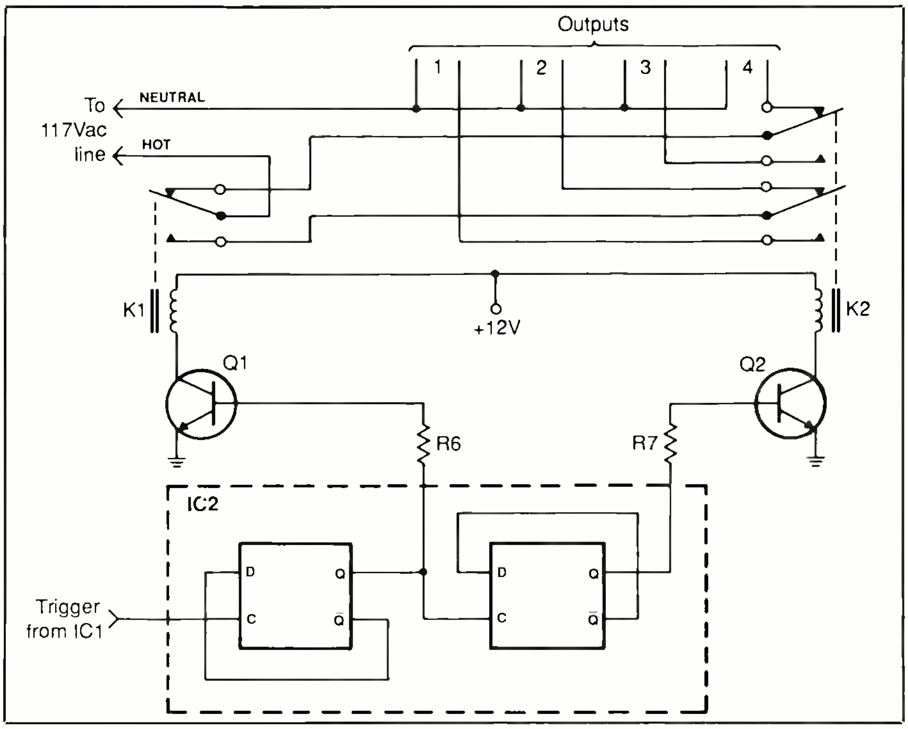


Fig. 6. A one-of-four selector wiring arrangement. This option requires that IC2 and K2 in the original circuit be replaced as detailed in the text.

Other Applications

As mentioned above, the Switch Multiplier is not limited to use as a fan/light controller. In one possible alternative application, the project can be used as a single circuit that controls, say, a patio light and, separately, a floodlight—from inside your home. Of course, control can be exercised over any combination of light options, such as strings of perimeter, path or driveway lights. Since these are all outside installations, be sure to house the circuitry inside a weatherproof box located under the eaves at a location convenient to normal 117-volt ac wiring.

Another possible application for the project is as a remote selector for three different loads. This can be accomplished with a simple change in wiring of the contacts of *K2*, as illustrated in Fig. 5.

Yet another application is to expand the project to serve as a one-of-four selector by replacing *IC2* with a CMOS 4013 dual D flip-flop and wiring it as a divide-by-four counter and replacing *K2* with a relay that has dpdt contacts (for example, Radio Shack's Cat. No. 275-218 relay). Connections for this arrangement are illustrated in Fig. 6.

Though the original circuit was designed to switch loads that require 117-volt ac line power, it can be wired to switch low-voltage loads as well. To accomplish this, you would change the wiring to the contacts of the relays to route the low voltage instead of the 117 volts from the ac power line.

To have the project's power supply deliver the necessary low dc voltage to such things as lighting, solenoid-operated water valves and the like, replace *T1* with a heftier power transformer. A good choice here is Radio Shack's Cat. No. 273-512 power transformer, which outputs 25 volts center-tapped at its secondary. Use the 25-volt tap connected through the relay contacts to power the loads being controlled by the project.

If you use the Switch Multiplier to control anything other than a ceiling fan and lighting fixture, do not exceed the contact rating of the relays. If the loads you expect to control draw more than about 7.5 amperes, upgrade the relays or have the project's relays control power relays. Also, upgrade the gauge of the ac-line input and output wiring to safely handle the amount of power that will be drawn by the loads. **ME**