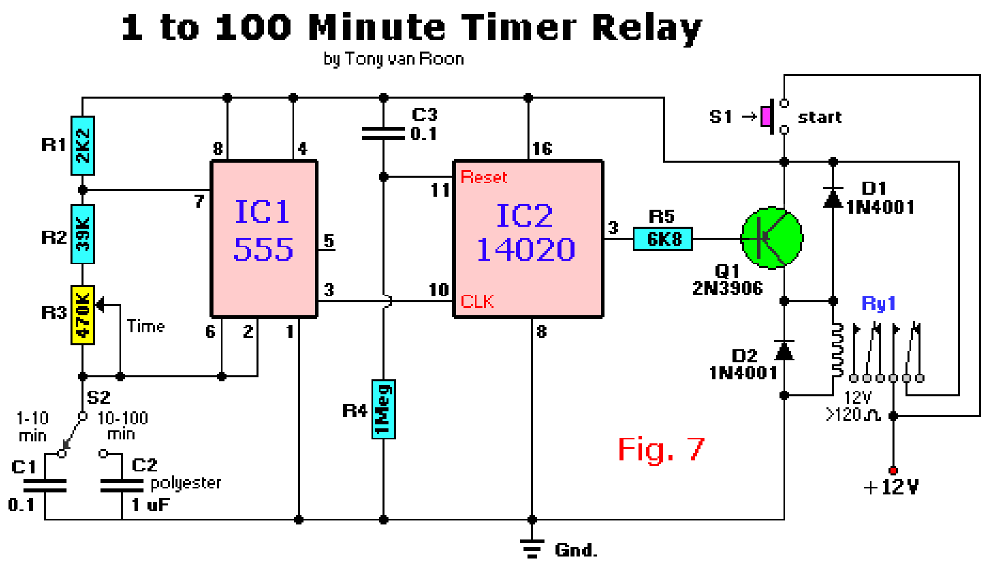


Fig. 7 This is an accurate **long-duration** time delay driver, switchable between 1 and 10 minutes or 10 to 100 minutes and whose function does not depend on electrolytic capacitors. Film dielectric caps have been selected. IC1 is configured as a free-running astable multivibrator which frequency is divided down by IC2, a 14020 (or 4020) CMOS 14-stage, ripple-carry binary divider. Consequently relay RY1 turns on as soon as switch S1 is closed, and it turns off again when the 8192nd astable pulse arrives. This method provides time periods ranging from 1 to 100 minutes, depending on the switch setting of S2.

Solid State Relays:

"Solid-State-Relay" (referred to as 'SSR' for short) means switching without any mechanical means. A solid-state **relay** is nothing more than a electronic switch, which can be a Triac, SCR, HexFet, or a High Speed MosFet, and an opto-isolator. Some are application dependent. Control-to-load isolation is provided either by opto-isolators or transformers. Solid-state relays are available in AC and DC versions; **Fig. 8** shows typical block diagrams. All approaches shoe use an opto-isolator to separate the control and drive segments. Figures x-c and x-d need a rectifier and filter for AC input. Figures x-a and x-c use a drive circuit, and NPN transistor, Zener transient suppression, and reverse-biased inductive load diode for DC output. Figure x-d use a zero voltage switch, an RC snubber filter, and a Triac for AC output.

Virtually all solid-state relays are **S**ingle-**P**ole **S**ingle-**T**hrow, **N**ormally **O**pen (SPST-NO) devices, where the outputs turn on in response to a control voltage. The majority take operating power from the control I/O, although some require separate DC logic power. The simplest DC input circuits use an LED optoisolator and series current-limiting resistor.

The resistor is usually sized for a 5-volt logic input, and results in a specified "ON" range of 3-6 volts DC. For wider operating ranges (typically 4-32 volts DC), the resistor is replaced by a constant-current diode. Then, AC input circuits rectify and filter the control input before applying it to the LED. Typical AC/DC LED currents can vary from 5 to 22mA.

AC and DC Outputs:

The optoisolator photocurrent is amplified and used to drive whatever output device the relay is connected to, whether a transistor for DC outputs, a thyristor for AC, or a power MOSFET for either. The power for the drive circuitry is taken either from the output load or is supplied separately. In some MOSFET designs, the photocurrent is sufficient to drive the output device. **Table 1** summarizes typical specifications.

Normally, DC output devices like those in Figs. x-a and x-b use an NPN transistor and may include a Zener diode across the output for transient suppression. The transistor will drop some voltage in the "ON" state, and the drive circuit will need some current to operate. Typical output drop is 1-2 volts at the full rated load current, while the "OFF"-state leakage may range from approximately 10μA-1mA.
Most AC output devices include zero-voltage-switching circuitry. Logic detects when the AC load voltage crosses zero (changes polarity) and delays the triac turn-on pulse until then. The triac turns on a the next zero crossing after the input goes high. Once triggered, it remains on until its current goes to zero. Zero-voltage and zero-current switching minimize transients and **E**lectro**M**agnetic**I**nterference (EMI). The RC snubber in Figs. 1-b and 1-d suppresses rapid voltage changes that can inadvertently turn on the thyristor.
In some applications, having the output turn on instantly is desirable. Relays referred to as "random turn-on" are designed without zero-voltage switching. Turn-off still occurs at zero-current, due to the inherent latching effect of thyristors. As with DC output relays, the thyristor drops voltage while conducting, while the drive circuitry requires power to operate. In addition, th snubber passes AC leakage in the "OFF" state. Typical "ON"-state voltage 1.6 volts, while "OFF"-state leakage is 2-20mA for 60Hz power.
With recent advantages in power MOSFET's, solid-state relays can be designed with lower "ON"-state voltage drops, and greatly reduce "OFF"-stage leakage. These MOSFET's (and HexFets) offer bidirectional current flow, near-zero gate-drive current, no inherent source-to-drain offset

voltage, and low "ON"-state (rDS) resistance and "OFF"-state leakage.
Due to near-zero gate current, power MosFet's can be driven directly from a series stack of photodiode junctions, as in Fig. 2. The "photovoltaic-generator" stack from International Rectifier shown in

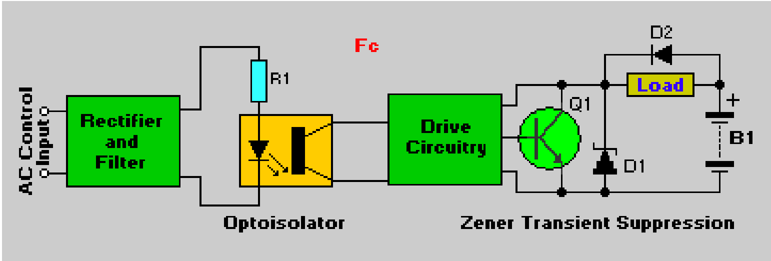
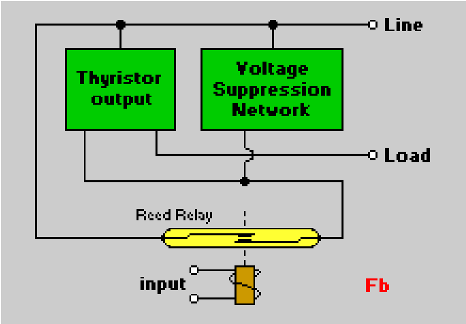


Fig. 3 is constructed using IC fabrication techniques, and exposes a series of photo diodes to LED illumination. No operating power is required from the load.
Most FET-output relays are housed in Dual-Inline-Packages (DIP's). Their main use is as a replacement for reed relays, where low offset and low leakage are important, and for control of low-power AC/DC loads. High power AC loads are best controlled by thyristors, which are easily controlled for zero-voltage turn-on; they also offer inherent zero-current turn-off, and produce lower output-voltage drop at high currents. However, FET design involves tradeoffs in voltage, current and resistance specs. In particular, high-voltage FET's have higher "ON" resistances, making them unsuitable for switching high-current line-voltage loads. Typical DIP relays have 70-500mA current ratings, "OFF"-state leakage resistances of 100 MegaOhms or more, and "ON" resistances from about one ohm for a 60-100 volt rating, to 25-50 ohms for a 300-400 volt rating. Switching times range from 10-100µSec.

I/O Isolation:
The majority of solid-state relays use optoisolators. All off at least 1.5 kilo-volt RMS I/O breakdown, and 2.5 or 4 kilo-volt ratings are common. Most of them have been rated, listed, or approved by safety agencies like UL, CSA, and VDE. Transformer coupling is also used to isolate solid-state relays.

Figure Fc shows a transformer-coupled AC-output relay; DC and AC/DC FET relays are also available with transformer coupling. The control



input powers an oscillator, the output which is coupled through a small pulse transformer to trigger the output thyristor. Circuitry of the type shown produces random turn-on operation; transformer-coupled relays generally don't include zero-voltage switching circuitry. Transformer coupling allows faster switching. The oscillator frequency is typically 1-3MHz, resulting in switching times as low as 1µSec. Opto-isolators exhibit slower response, with times for DC versions typically 10 to 100µSec. They can be designed for slightly higher temperatures, being free of LED limitations. However, achieving breakdown voltages above 1.5 kilovolts is easier using optical techniques.

Hybrid Relays:

Hybrid relays marry reed relays with a solid-state power output. **Figure Fb** shows a thyristor version; DC outputs are also offered. The hermetically sealed reed contacts switch only low power, and last 10 million operations or even longer. The turn-on time is that of the reed relay, about 1 mSec. Other hybrid relays are the reverse, using a solid-state input amplifier driving a reed-relay output, the obvious advantage being high input sensitivity. The term "hybrid" sometimes describes construction technique, rather than method of operation. In some catalogs you'll find hybrid solid-state relays with no mechanical components at all.

Self-Powered and Buffered Relays:

So far, all the relays that have been discussed until now have been "self-powered," in that they take operating power from the applied signals. All models, whether optoisolated, transformer coupled, of hybrid, require approximately 5-50mA at their inputs. Some, notably thyristor-output

relays with zero-voltage switching, also take operating power from output loads, although none require separate power connections.
Buffered relays offer improved input sensitivity at the expense of needing separate DC power, and are usually used in systems that already include DC power supplies (not as stand-alone devices). **Fig. XX** shows a buffered DC-output relay. The input circuitry and the LED are powered from a separate logic supply, allowing the logic input current to be typically 25-250µA.

Package Styles:

Solid-State relays are generally grouped into DIP's, power relays, and I/O modules. DIP relays are available with transistor (DC), thyristor (AC), or MOSFET (AC/DC) outputs, and with optoisolator or transformer coupling. Most power relays are used to switch AC power, and use thyristor switching with optoisolator coupling. Transistor (DC) outputs and transformer coupling are also available. I/O modules are always opto-coupled, and don't offer MOSFET outputs;

Safety Issues:

Building an SSR requires putting 115/220 volts on a printed circuit board. From an electrical point of view, that can be perfectly safe. However, it is good practice to cover all printed circuit tracks on the 115/220VAC side with a silicon sealer, varnish, lacquer, or even nail polish. Couple layers will do fine. 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 (earth ground, or green wire).

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 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 time more. Keep that in mind when you design your own.
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. Just in case it is not sufficient for your design, you can use a transistor as a current-sink.
Although not really a strict requirement, an isolated Triac is good practice and a good safety precaution. Isolated Triacs (usually listed in catalogs as iso-tab) provide electrical isolation from the electrical connections to the case. Early Triacs were not normally isolated. That meant

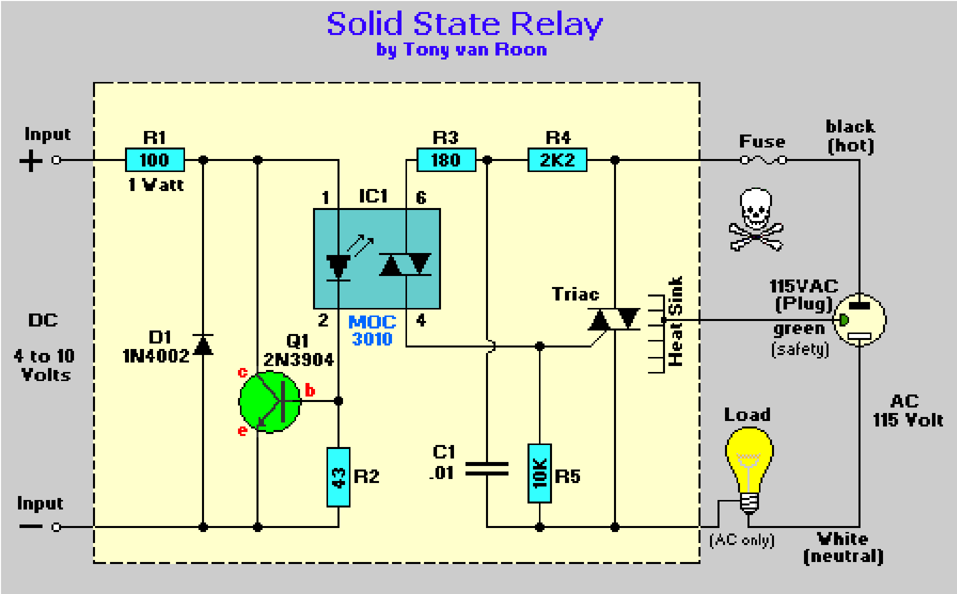
that you had to use mica washers and thermal grease. Thermal grease is still a good idea, but the mica washer isn't required for isolated Triacs. If you don't know whether or not your Triac is isolated, simply measure the resistance from each lead to the case. An isolated Triac will measure open on all three leads.
Warning: The Radio Shack 400-volt, 6-amp Triac (part number 276-1000) will work well but is NOT isolated. You *must* use a TO-220 mica washer and thermal grease if you plan to use that device.

Zero-Voltage Switching:

I can hear you mumbling already... "what the heck is zero-voltage 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 sine wave. If the trigger occurs near a peak (90 or 270 degrees), al 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 filatmnet of ordinary light bulbs. In order tho 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 zeo volts. Now you know. I personally don't use any other type.

Construction of a SSR:

Below is good working Solid State Relay using an opto-isolator and a Triac. Use of the shown printed circuit board is highly recommended but not required. **Remember to isolate the AC tracks when you're all done!**



For a simple SSR, an optoisolator such as the Motorola MOC3010 or the NTE3047 will be sufficient. For a zero-crossing SSR, a MOC3031 or NTE3049 will do. May companies make optoisolators. Make sure yours has a "Triac output" and that the pinouts are compatible with your design. Table 2 shows some typical Triac output optoisolator specifications. The models shown are already a decade old but still widely used and available.

Again, although the SSR can certainly be build without using the PCB, using one makes assembly using the layout in Fig.xxx a snap.

The only precaution, other than the one about working with 115/220/220 AC volts, is to heatsink the Triac. If you leave the leads on the Triac long, it should be simple matter to find some heat sink to attach to the Triac. Just remember to connect the heat sink to earth-ground. Even if you're using an isolated tab Triac, the earth ground is still necessary. Otherwise you should buy your solid-state relays from a reliable company--don't build them yourself.

Remember that SSR's can only switch an AC line. Trying to switch a DC line will result in a relay that closes but never opens... Have fun!

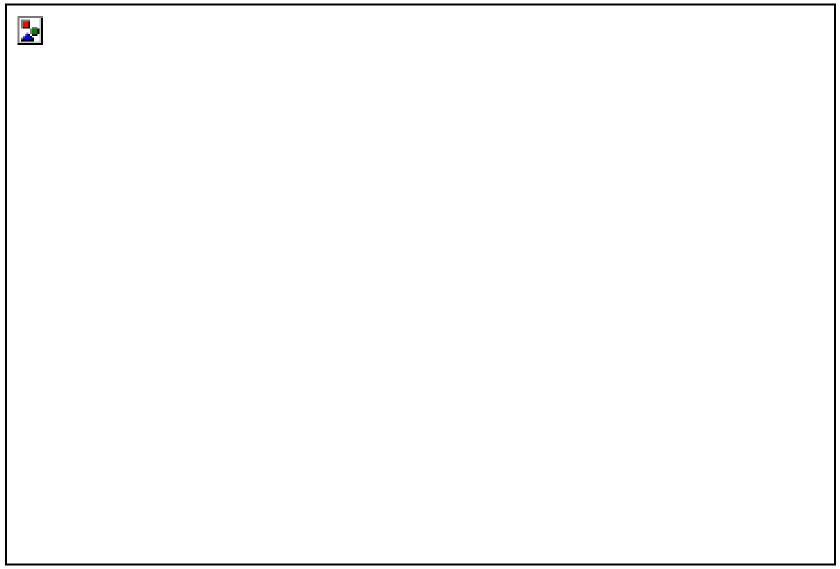


Table 1

Part	Description	Radio Shack	Digi Key	Newark	Notes
IC1	LM741 Op-Amp	276-007	LM741CN-ND	LM741CN	NE741,µA741, etc.
Q1	2N2222A transistor	276-2009	2N2222A-ND	2N3904	See text
D1	1N4148 Diode	276-1122	1N4148GICT-ND	1N4001	1N4001, or others
Th1	10K Thermistor	271-110	KC003T-ND	96F3309	KC003T in prototype
Re1	12V Relay	275-249	Z753-ND	83F8057	RS is 1A (min)
R1	47K, 5% resistor				yellow-purple-orange
R2	5%, Resistor				see text

R3	1K8, 5% resistor		Optional		brown-gray-red
R4,R5	2K2, 5% resistor				red-red-red
P1	50K Trimmer Pot				Multi-turn

Couple Notes:

The Thermistor, or NTC (Negative Temperature Coefficient) of 10K, is a standard type. Most types will work. The one in the diagram is a 10K model made by Fenwal (#197-103LAG-A01).

The resistance lowers as the surrounding temperature increases which affects the output (pin 6) and energizes the small relay and Led1(optional, just cosmetic and can be left out).

P1 is a regular Bourns trimmer potentiometer and adjusts a certain range of temperatures. I used a 50K, 10-turn type for a bit finer adjustment but any type will work.

R1 is there to protect the Thermistor (NTC) from a full 12V just in case trimmer pot P1 is adjusted all the way down to '0' ohms. In which case it gets very hot and probably burn.
R2 is optional in case your relays tends to 'chatter' a bit. It provides a bit of hysteresis when the set temperature of the thermistor reaches its threshold point. This value may need to be adjusted anywhere between 120K and 470K (although I indicated different values on the schematic).

Transistor Q1 can be a 2N2222(A), 2N3904, NTE123A, ECG123A, etc. Not critical at all. It acts only as a switch for the relay so almost any type will work, as long as it can provide the current needed to activate the relay's coil.

D1, the 1N4148, acts as a spark arrestor when the contacts of the relay open and eliminates false triggering. Feel free to use any other type, like a 1N4001 or something. Solder directly onto the '+' and '-' relay terminals.

If you need a 'Frost' sensor, just swap positions of the R1 and Th1 positions.