# A Solid-State Electric-Blanket Controller*

## *Eliminates problems usually encountered with electromechanical controllers and provides greater efficiency and better heating comfort*

By Joseph O'Connell

Standard electromechanical controllers vary the average heat output of an electric blanket by repeatedly cycling on and off the embedded heating elements in a more or less "digital" manner in response to changing ambient temperatures. The solid-state replacement controller to be described continuously controls the blanket's temperature in an *analog* manner by varying the amount of power delivered to the heating elements, rather than switching between only full-off and full-on. This eliminates temperature fluctuations and provides more comfortable heating.

Our electronic controller also eliminates the bright dial light and contact clicking common to electromechanical controllers. Instead of a dial light, the electronic controller employs a multi-color light-emitting diode whose color gives an indication of the amount of power being delivered to the blanket's heating elements at any given moment. With this arrangement, you do not even have to read the numbers off a dial. Though bright, the LED is a small point source that will not be annoying—yet it can be "read" in the dark even from across a room. All "switching" is done in complete silence by electronic means.


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## About the Circuit

The major distinction of our electronic blanket controller is that it controls the power supplied to the heating elements with a triac that interrupts the ac line voltage at different points on its waveform by a process called "phase control." (See the "How Phase Control Works" box for a detailed description of the circuit.)

Outputs from typical electromechanical and electronic controllers are compared in Fig. 1. You can readily see that although both controllers produce the same average temperature, the electronic phase-controlled version exhibits none of the long-term fluctuations exhibited by the electromechanical version.

The amount of power supplied by the solid-state controller depends on the ratio of the on time to the off time. To simplify setting the controller—especially in the dark—light-emitting diode *LED1* in Fig. 2 indicates this ratio. When the output of the controller is zero (no power delivered to the blanket), *LED1* glows green. As the heat control is turned up, *LED1*'s color goes to yellowish-green and then to fully yellow at the half-power setting. Further power increases to the blanket cause *LED1* to go through shades of orange until it becomes fully red at full power. Hence, a single multi-color light-emitting diode gives at-a-glance indication of the heat setting. For convenience, during construction, *LED1* is placed at the index of HEAT control *R2* so that the latter can be easily located in the dark.

Note also in Fig. 2 that this controller also has a special FAST WARM switch, *S2*, that makes it easy to

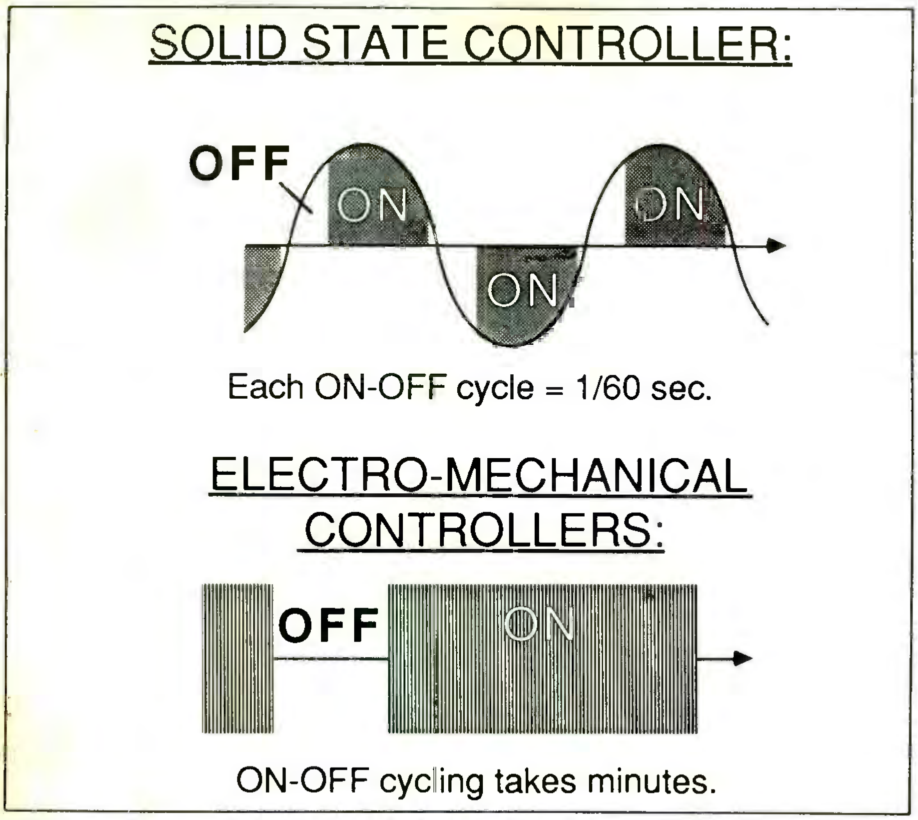


*Fig. 1. Solid-state controllers have none of the long-term output variations that characterize electromechanical controllers.*

warm up a cold bed quickly. Setting this switch to "on" bypasses the control circuitry and sends the full 117 volts of the ac line to the blanket. Although the HEAT control set to MAXIMUM does the same thing, a separate switch eliminates the need to frequently reset *R2*. Red light-emitting diode *LED2* flashes to let you know when the FAST WARM function has been selected.

Electromechanical controllers that the Fig. 2 circuit replaces have a rudimentary form of temperature compensation. The power they send to the blanket's heating elements varies in response to ambient room temperature and the dial setting. By building in temperature compensation, these controllers allow you to go to bed when the ambient temperature is still comfortable but drops to an uncomfortable level later on. It automatically increases power to the blanket as the room becomes colder.

In most cases, temperature compensation is not needed. Located inside the controller's housing, the temperature sensor cannot monitor the temperature of the sleeper. Thus, it cannot take into account the amount of insulation the bed provides or the amount of heat produced by the body. So even at best, this type of temperature compensation will be inaccurate.

Another reason why temperature compensation is not necessary in most cases is that changes in room temperature throughout a sleep period are usually slight in most homes. But the most important reason is the body itself. During sleep, the body regulates its own temperature throughout a wide range of ambient temperatures. Hence, the human body is remarkably tolerant of temperature variations.

The solid-state controller circuit shown in Fig. 2 is built around triac *Q1*, resistors *R1* and *R3*, potentiometer *R2* and capacitors *C2* and *C3*. Operation of this circuit is similar to that of a conventional lamp dimmer. Setting of the desired heating level is accomplished with HEAT control *R2*.

Three leads are provided on dual light-emitting diode *LED1*, one for the cathodes that are internally tied together and one each for the anodes of the red and green LEDs inside the device's molded plastic case.

At minimum setting of *R2*, *Q1* does not conduct, but current does flow through *S1*, *D1*, *R4* and the electric blanket's heating element to light the green LED element inside *LED1*. At this time, the red LED element remains off due to the triac's high resistance. However, when the setting of *R2* is turned up slightly, *Q1* begins to conduct for a brief period of time at the beginning of each half-cycle. For this short time, the green LED is shorted by *Q1* and power is switched to the red LED. Both LED elements inside *LED1* are never on simultaneously. The eye's image persistence combines a comparatively long interval of green and a short interval of red to resolve a yellowish-green color.

As the setting of the HEAT control is turned up, the red LED element remains on for longer portions of the ac waveform, the green LED element for shorter periods. This yields first a yellow, then an orange and, finally, a red perception of colors.

With *S2* set to FAST WARM, full ac line power bypasses *Q1* and is delivered directly to the blanket's heating element. When *S2* is in this position, *LED1* is switched out of the circuit and only *LED2* is switched in. Built into *LED2* is a CMOS chip that operates from a 3- to 7-volt power-supply potential. The dc supply for *LED2* is provided by *R6*, *D3* and *C7*.

Bypass capacitors *C1*, *C4*, *C5* and *C6* suppress arcing and radio-frequency emission in the circuit. Though the controller circuit will operate without these capacitors, the switches

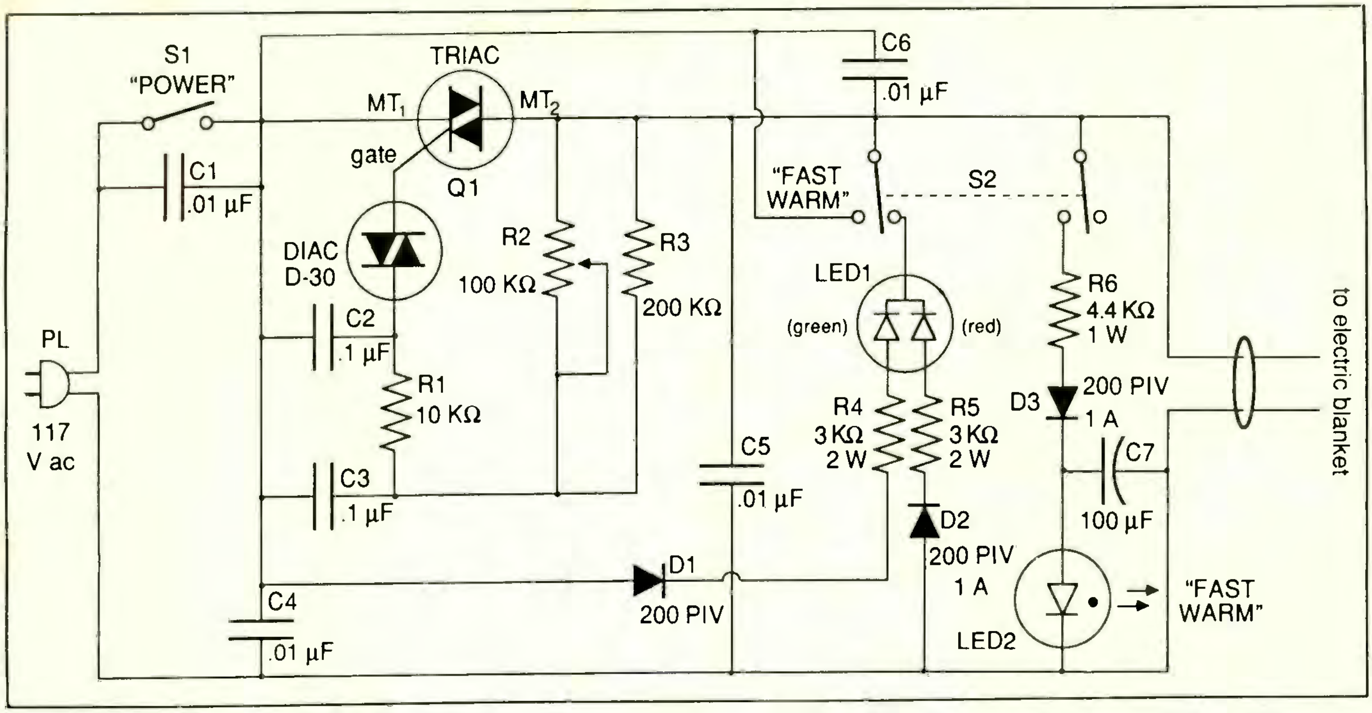


*Fig. 2. The complete schematic diagram of all-electronic solid-state electric-blanket controller.*

will soon wear out and nearby radios may pick up noise generated by the switching action of the triac.

## *Construction*

A suitable enclosure for this project is one of the plastic project boxes that come with an aluminum faceplate. If you use such a box, mount the control, switches and LEDs in holes drilled through the box's plastic bottom and use the aluminum plate as the base of the box and the heat sink on which you mount the triac. When the project is fully assembled, affix four small anti-skid plastic feet to the metal plate.

Almost half of the components that make up this project mount on the plastic portion of the box and the aluminum faceplate. Those that do not mount directly to the box can be supported by terminal strips to which whatever wiring is needed is made. This being the case, the project is more suited to point-to-point wiring than it is to printed-circuit or perforated board wiring.

Components that mount directly to the plastic portion and aluminum faceplate of the box, include the LEDs, switches, potentiometer and triac. The point-to-point wiring arrangement is illustrated in Fig. 3. Solid black dots identify connections that are made without the aid of terminal-strip lugs. Circles with Xs in them indicate points where terminal-

### PARTS LIST

**Semiconductors**

D1 thru D3—200-PIV, 1-ampere rectifier diode

D4—D-30 or equivalent (available from Active Electronics, P.O. Box 9100, Westborough, MA 01581; tel.: 1-800-343-0847)

LED1—Two-color light-emitting diode with three leads

LED2—Flashing red light-emitting diode (Radio Shack Cat. No. 276-036 or equivalent)

Q1—200-volt, 2-ampere triac

**Capacitors**

C1,C4,C5,C6—0.01-µF, 200-volt or better disc (value not critical)

C2,C3—0.1-µF, 200-volt or better disc

C7—100-µF, 10-volt electrolytic

**Resistors** (10% tolerance)

R1—10,000 ohms, ¼ watt

R3—200,000 ohms, ¼ watt (or whatever value gives smoothest control response over entire range of R2 when project is tested with incandescent light)

R4,R5—3,000 ohms, 2 watts (3,300-ohm, 2-watt resistor in parallel with a 33,000-ohm, ¼-watt resistor)

R6—4,400 ohms, 2 watts

R2—100,000-ohm linear-taper potentiometer

**Miscellaneous**

PL1—Ac line cord with plug

S1—5-ampere spst miniature toggle switch

S2—5-ampere dpdt miniature toggle switch

Suitable enclosure (see text); terminal strip (see text); rubber grommets (2); small-diameter heat-shrinkable or plastic tubing; mica washer and shoulder fiber washer for Q1 (see text); fast-set clear epoxy cement or hot-melt glue; lettering kit; machine hardware; hookup wire; solder; etc.

strip solder lugs are needed. Any terminal strip used should be mounted on the aluminum faceplate of the box with machine hardware.

As shown in Fig. 3, you need at least three terminal-strip solder lugs to wire the circuit. Keep in mind that not every connection indicated by an X in a circle requires a separate solder-lug tie point. For example, no separate tie point is needed between *R5* and *D2*. You simply connect and solder together one lead of *R4* and the cathode lead of *D2* and then connect the anode lead of *D2* to the solder lug to which *PL1*, *C4*, cathode lead of *LED2* and one output conductor tie together.

When you connect to the lugs on the terminal strip, be sure not to use any that are electrically connected to the strip's mounting tab(s).

As you install each component and solder it into place, it is a good idea to use a red pen to indicate what you did on the Fig. 3 illustration or a photocopy of it. This reduces the possibility of wiring errors and shows you your progress. To make wiring even simpler, you might consider numbering the tie points on both the schematic diagram and the solder lugs.

Machining of the enclosure is quite simple. You need a separate ¹³⁄₆₄-inch hole for each LED and suitably sized holes for mounting the switches and potentiometer on the plastic portion of the box. You also need an entry hole for the ac line cord entry and blanket cord exit. Arrange the holes for the potentiometer and switches in a pattern that you will readily recognize in the dark (see lead photo).

Mount the LEDs, potentiometer and switches in their respective holes. Secure the LEDs in place with clear fast-set epoxy cement or hot-melt glue. Then line the hole for the ac line cord and electric blanket cord with a rubber grommet.

Cut the blanket cable from the electromechanical controller that was originally supplied with the electric blanket. Separate the conductors at the cut end a distance of about 1½ inches and trim from each about ¼ inch of insulation. Tightly twist together the fine wires in each conductor and sparingly tin with solder. Prepare the free end of the ac line cord in the same manner.

Pass the free ends of both cords through the rubber grommet into the box and tie a knot in both about 4 to 5 inches from the ends inside the box to serve as a strain relief. Referring to Fig. 3, crimp but do not solder one ac line cord conductor to one lug of *S1* and repeat for the other conductor and the tie point identified with the X in the circle at the bottom of the illustration. Then crimp but do not solder the output cable to one lug of *S2* and the same tie point to which you crimped the second ac line cord conductor.

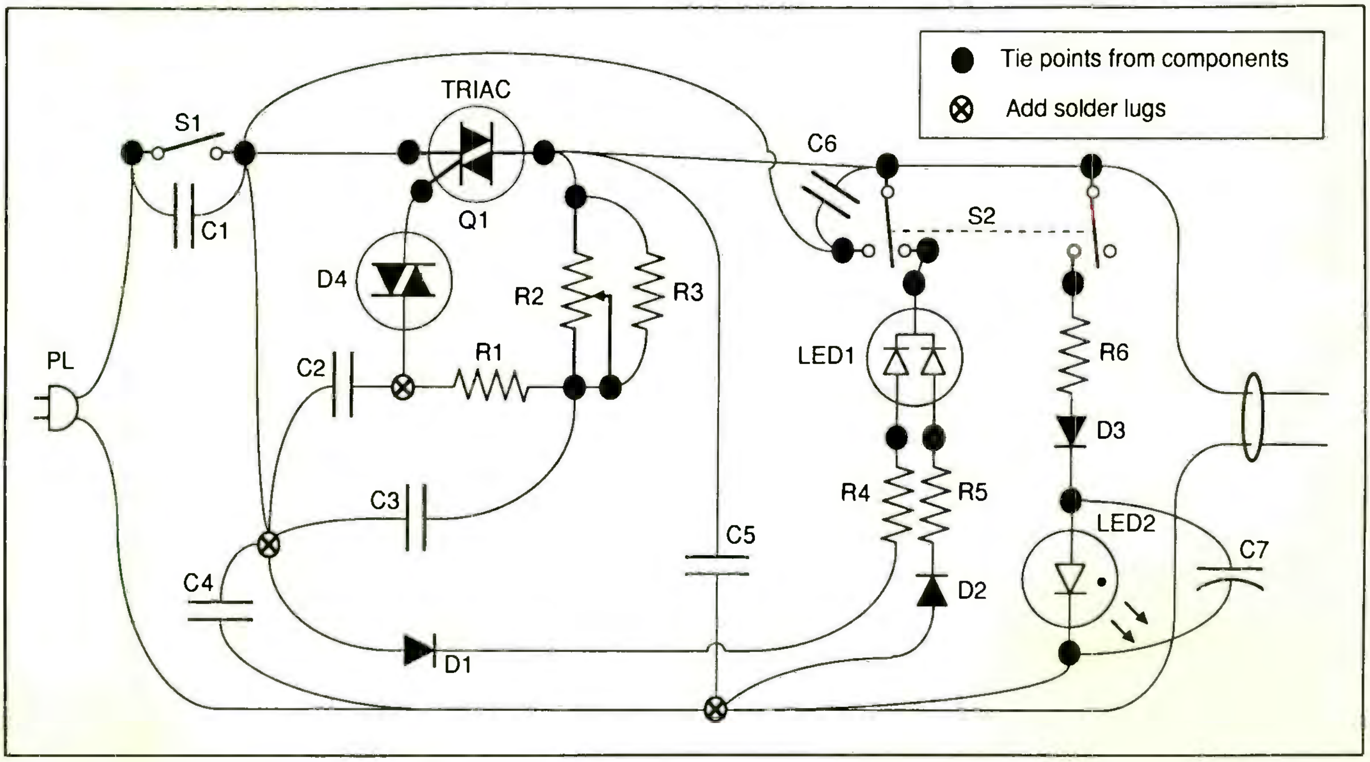


*Fig. 3. The wiring guide for controller. Components are wired between each other's lugs/leads and a few added tie points, the latter indicated by Xs in circles.*

# How Phase Control Works

**When controlling** a large electrical device, it is more efficient to have it turned all they way on or all the way off, rather than in between. For the load to receive less than full power, the controlling circuit would have to dissipate the excess as heat. That would be inefficient. This is why high-power loads are controlled by rapidly switching them on and off. The average power the load receives can be any fraction of its full power, but at every instant it is either fully on or fully off.

A common and efficient way of controlling large ac loads is by means of phase control. Most phase-control circuits make use of the fact that ac already switches on and off twice in each cycle. To vary power, the circuits interrupt a selected part of each waveform and keep it from reaching the load. A typical output would show the ac waveform chopped into sections that are either fully on or fully off, as shown in Fig. 1 of the main article.

Switching is usually performed electronically, rather than electromechanically, with a triac whose gate pulse is derived in some way from the ac waveform itself. This assures that the control pulses are automatically synchronized with the power that is being switched on and off.

Shown in Fig. A is a phase-control circuit of the type commonly used in lamp dimmers and some motor speed controllers. There are two series RC phase-shift networks in this circuit: one made up of *R1* and *C1* and the other made up of *R2* and *C2*.

When ac is applied to a series-connected resistor and capacitor, as in the two cases in this circuit, an ac voltage appears at the top of the capacitor. This ac voltage lags the applied voltage by a phase difference of from 0 to 90 degrees, depending on the setting of the potentiometer in the first RC network. If you could see both the applied ac voltage and the voltage across *C1* on an oscilloscope, you would see the ac line voltage and, following it, a second delayed voltage.

With a 100,000-ohm potentiometer, the phase shift is variable from 0 at minimum setting (where the output is electrically connected to the input) to a maximum of about 75 degrees. The *R2/C2* network extends the total phase shift range from 0 to 180 degrees at point *T* in Fig. B by varying the setting of the potentiometer. The phase-shifted signal at point *T* is used to trigger the triac that controls power to the load.

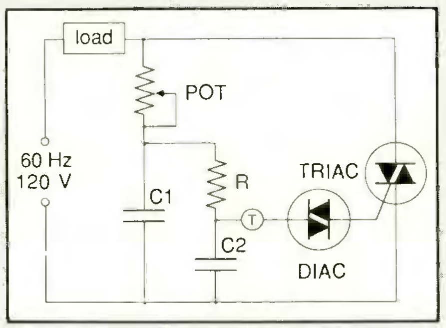


*Fig. A. A full-wave phase-control circuit typically used in light dimmers and motor speed controllers.*

The diac in Fig. A is a two-way voltage threshold switch that is needed here because the gate sensitivity of a triac is not symmetrical. A diac's triggering voltage is the same in both directions and is well in excess of the triggering voltage of the triac. Use of a diac makes the triac equally sensitive in both polarities of gate signals since the triac must wait for the diac to conduct before it fires. The diac used in the project described in the main article will conduct when 30 volts appears across its terminals in either direction.

In Fig. B, the point at which the voltage at *T* reaches ±30 volts determines the point at which the triac begins to conduct power to the load. However, bear in mind that the voltage present at point *T* is the delayed sine wave. Relative to the main ac waveform, the time at which point *T* reaches 30 volts can be varied by the potentiometer in Fig. A. Consequently, the point where the triac begins to conduct can be varied to take place over a 0-to-180-degree range in the ac waveform.Once the triac triggers into conduction, it remains conducting until the zero-crossing point in each half-cycle is reached. Therefore, what the potentiometer is actually controlling is the *interval* during which the triac remains on. This interval is the amount of on time to off time and is responsible for the amount of power the load receives.

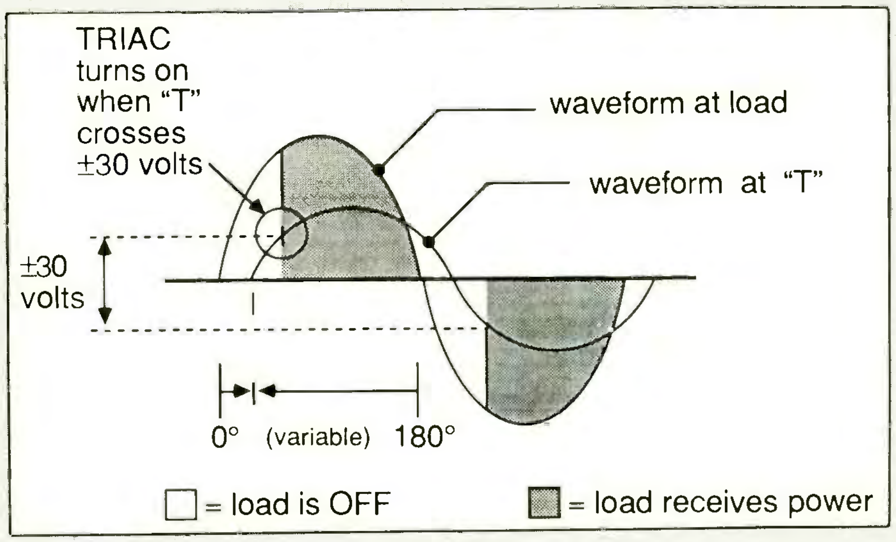


*Fig. B. Large-excursion ac waveform is output to load; smaller-excursion waveform that appears at point T in Fig. A can be "moved" left or right by the potentiometer.*

In the following procedure, hookup-wire lengths are given for a small enclosure box. If you use a larger box, adjust the lengths as needed. Also, always trim all component lead lengths so that, when mounted, the components cannot sag and possibly cause unwanted short circuits. Wherever possible, use small-diameter heat-shrinkable tubing or plastic tubing to insulate bare wire leads and connections. In any case where a component's lead length is insufficient to bridge two points, you can lengthen the lead with insulated hookup wire. The best way to do this is to cut the component's lead to ½ inch long and crimp and solder it to the hookup wire. Then insulate the connection with tubing.

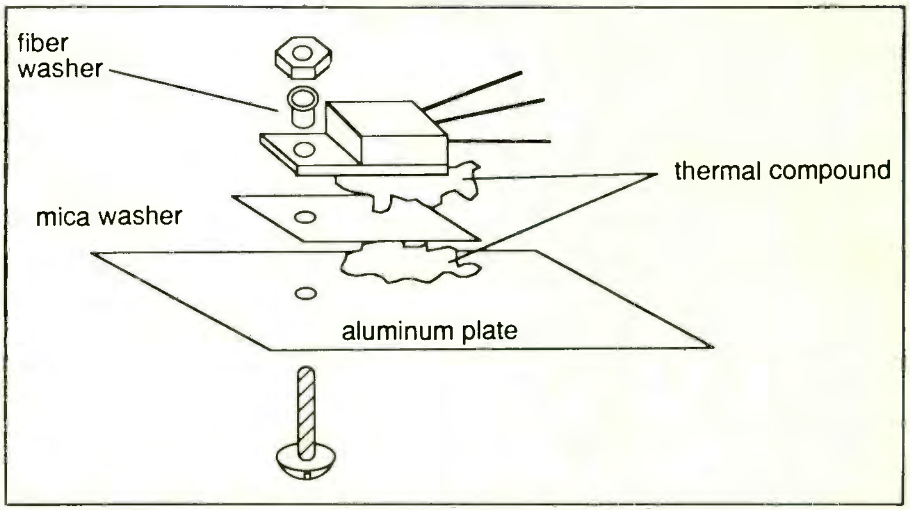


*Fig. 4. The proper way to isolate the triac from the project box's metal faceplate heat sink.*

Crimp the anode lead of *D2*, one lead of *C4* and *C5* and the cathode lead of *LED2* to the tie point to which you crimped the line cord and output cable conductors. Before soldering, heat sink *D2* and *LED2* and solder all six leads to the terminal strip solder lug.

Crimp the other lead of *C4*, a 3-inch insulated wire from which you have stripped ¼ inch of insulation from both ends, and one lead of *C2* and *C3* and the anode lead of *D1* to a second lug on the terminal strip. Heat sink the diodes and solder the four leads and one wire to the solder lug. Crimp the free end of the wire to the unoccupied lug of *S1*.

To the third and final lug on the terminal strip, crimp but do not solder the other lead of *C2* and one lead of *D4* and *R1*. Once again, heat sink the diac and solder all three leads to the lug.

After trimming them to appropriate length, if needed, crimp but do not solder the leads of *C1* to the lugs of *S1* and *C6* to the appropriate lugs of *S2*. Then interconnect the specified switch lugs by crimping an appropriate length of hookup wire as shown. Trim ¼ of insulation from both ends of a 3-inch hookup wire and crimp one end to the specified lug of *S1* and solder the capacitor lead and all three wires to the lug.

Now crimp but do not solder a hookup wire to the specified outer lug on *R2*. Crimp the leads of *R3* and the free leads of *C3* and *R1* to the other outer lug of *R2*. Pass a bare solid wire from the lug to which *C3*, *R1* and *R3* are crimped to the center lug on the potentiometer. Solder the center-lug connection and trim away any excess wire length that might possibly short to the third lug. Then solder the two outer lug connections of *R2*.

Crimp one end of a 4-inch hookup wire to the toggle lug of *S2* to which *C6* is crimped. Pass a bare solid wire through both toggle lugs of *S2* and solder the connections at both lugs of the switch.

Carefully twist the leads of *C7* around those of *LED2* (observe polarity). Solder both connections. Then solder the cathode lead of *D3* to the junction of *C7* and anode lead of *LED2*. Solder the anode lead of *D3* to one lead of *R6* and crimp and solder the other lead of *R6* to the appropriate lug on *S2*.

Identify the anode lead for the green LED element in *LED1* and connect and solder to it one lead of *R4*. Do the same for the red LED element and *R5*. Connect and solder the free leads of *R4* and *R5* to the cathode leads of *D1* and *D2*, respectively. Then crimp and solder the common cathode lead of *LED1* to the appropriate pole lug of *S2*.

Drill a hole for mounting triac *Q1* on the aluminum faceplate. When mounted, make sure that neither the triac nor its mounting hardware make electrical contact with the aluminum plate. To assure this, use thermal grease or paste and a mica washer between the triac and metal plate and an insulating shoulder fiber washer between the machine hardware and the triac's mounting tab, as illustrated in Fig. 4.

Once the triac is mounted into place, carefully connect and solder the free ends of wire coming from *S1* to *Q1*'s MT1 terminal. Use a 1-inch length of tubing to insulate the connection. Connect the free end of the wire coming from the potentiometer and the free lead of *C5* to the triac's MT2 terminal. Finally, connect and solder the free lead of *D4* to the GATE terminal of the triac, again using tubing to insulate the connection. This completes wiring the circuit. Place a control knob on the potentiometer.

Shown in Fig. 5 is a photo of the fully wired project inside a small plastic project box that has an aluminum faceplate.

## *Checkout & Use*

With the project completely wired and double checked for poor soldering and incorrectly connected or oriented components, particularly with regard to the triac, test it before putting it into service. To do this, you need an incandescent lamp to use as the load instead of the blanket itself. Using a lamp gives an immediate visual indication of circuit operation.

A convenient way to connect the lamp to the output of the project is to temporarily solder a zip cord terminated in an ac receptacle to one tog-

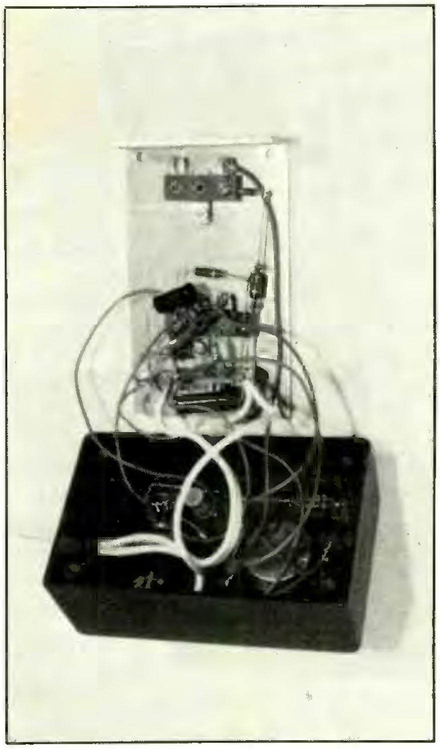

*Fig. 5. Interior view of completed project.*

gle lug of *S2* and the terminal strip lug to which one conductor of the ac line cord is connected. Plug the lamp's cord into the ac receptacle. Then turn on the lamp and make sure *S1* and *S2* are set to "off" and *R2* is set for minimum output. Plug the project's line cord into an ac outlet; neither LED should be on.

Setting POWER switch *S1* to "on" should cause *LED1* to glow green. If this occurs, setting FAST WARM switch *S2* to "on" should cause *LED2* to light and flash and the lamp to turn on at full brilliance. If you do not obtain these results, power down the project and recheck all wiring. Do not proceed until you have corrected the problem.

With *S1* on and *S2* off and *R2* set for minimum output, *LED1* should be glowing green and the incandescent lamp should be off. Slowly adjusting the setting of *R2* toward full output should cause *LED1* to change color to first yellow, then orange and finally, at full power, to all red. Simultaneously, the lamp should begin to glow and become brighter as the control is turned up. At full output power *LED1* should be glowing red and the lamp should be at full brightness.

Once you obtain the above results, the circuit is working properly. Unplug the project from the ac outlet and desolder the test cable from *S2* and the terminal strip lug. Finally, mount the aluminum faceplate on the box and fix to it four small anti-skid rubber feet. Label the switches, LEDs and control, as shown in the lead photo.

As mentioned previously, this controller is a direct replacement for the electromechanical controller originally supplied with your electric blanket. Once you have made the substitution, use your blanket as you normally would, controlling it with this project instead of its original unit. Lack of temperature cycling and silent operation will not be noticed, except by their absence, but other features can be appreciated more readily.

The FAST WARM function is useful on those cold days when you want to quickly warm your bed before getting into it. Set both switches to "on" about 5 minutes before you plan to retire to use this function.

Take care not to leave *S2* on too long, especially if your electric blanket is covered or folded. Even though all electric blankets come with built-in thermal cutoffs; and no fire hazard exists, too much heat is not good for the blanket's fabric.

Once your bed is warmed sufficiently in the FAST WARM mode, set *S2* to "off" and adjust the setting of HEAT control *R2* for a comfortable heat setting. Use two-color *LED1* as a guide to temperature setting. With a little experience, you will quickly come to know what setting is best for you simply by observing the color of the LED as you adjust the control setting. **ME**