WORKING WITH TRIACS AND SCR's

Twenty-eight practical SCR and Triac circuits.
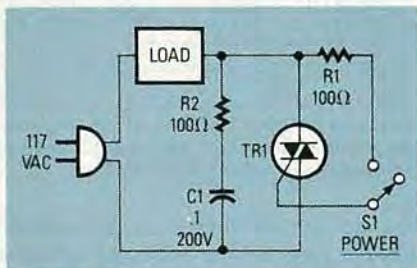
RAY MARSTON
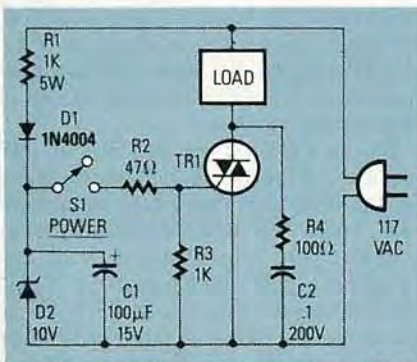

FIG 1—AC POWER SWITCH, AC triggered.

FIG 2—AC POWER SWITCH, DC triggered.

LAST TIME WE DISCUSSED BASIC SCR AND Triac theory, paying particular attention to the principles of synchronous and asynchronous triggering. (See **Radio-Electronics**, September 1987.) This time we'll present a number of practical circuits for which the user need only select an SCR or Triac having suitable voltage and current ratings. Let's start off by looking at several Triac circuits that can be used to control some line-voltage-powered devices.

Asynchronous designs

As explained last time, a Triac may be triggered (turned on) either synchronously or asynchronously. A synchronous circuit always turns on at the same point in each half-cycle, usually just after the zero-crossing point, in order to minimize RFI. An asynchronous circuit does not turn on at a fixed point, and the

initial current surge generated during turn-on at a non-zero point of the AC cycle can generate significant RFI. Triac turn-off is automatically synchronized to the zero-crossing point, because the device's main-terminal current falls below the minimum-holding value at the end of each half-cycle.

Figures 1–8 show a variety of asynchronous Triac power-switching circuits. In Fig. 1, the Triac is gated on (whenever S1 is closed) via the load and R1 shortly after the start of each half-cycle; the Triac remains off when S1 is open. Note that the trigger point is not line-synchronized when S1 is closed initially; however, synchronization is maintained on all subsequent half-cycles.

Figure 2 shows how the Triac can be triggered via a line-derived DC supply. Capacitor C1 is charged to +10-volts DC (via R1 and D1) on each positive half-cycle of the line. The charge on C1 is what triggers the Triac when S1 is closed. Note that all parts of the circuit are "live," and that makes it difficult to interface to external control circuitry.

Figure 3 shows how to modify the previous circuit so that it can interface with external control circuitry. Switch S1 is simply replaced by transistor Q2, which in turn is driven from the photo-transistor portion of an inexpensive optocoupler. The LED portion of the optocoupler is driven from a 5-volt DC source via R4. Opto-couplers have typical insulation potentials of several thousand volts, so the external circuit is always fully isolated from the line.

Figure 4 shows an interesting variation of the previous circuit. Here the Triac is AC-triggered on each half-cycle via C1, R1, and back-to-back Zeners D5 and D6. Note that C1's impedance determines the magnitude of the Triac's gate current.

The bridge rectifier composed of D1–D4 is wired across the D5/D6/R2 network and is loaded by Q1. When Q1 is off, the bridge is effectively open, so the Triac turns on shortly after the start of each half-cycle. However, when Q2 is on, a near-short appears across D5/D6/R2, thereby
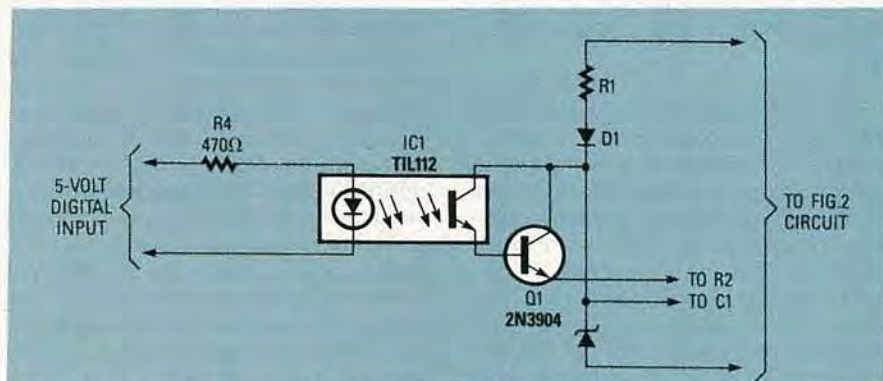

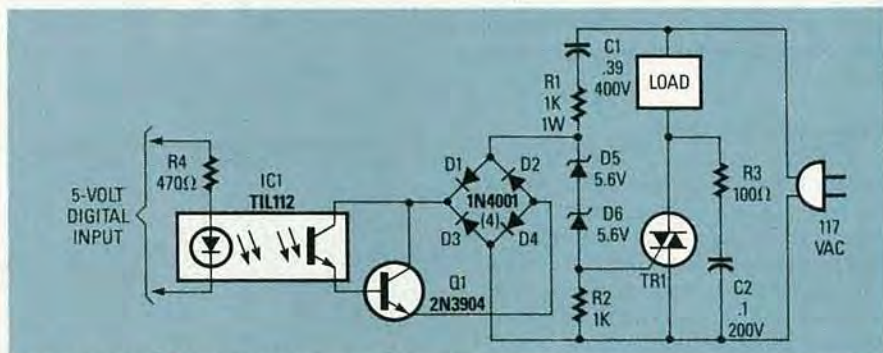**FIG 3—OPTICALLY ISOLATED AC power switch, DC triggered.**

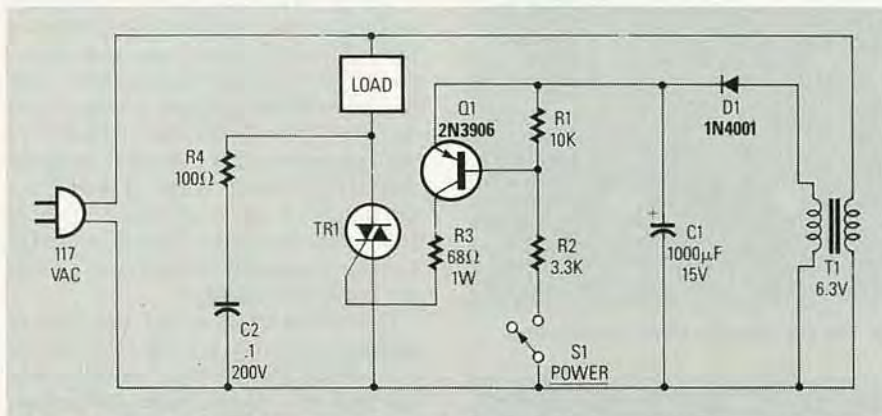**FIG 4—OPTICALLY ISOLATED AC power switch, AC triggered.**

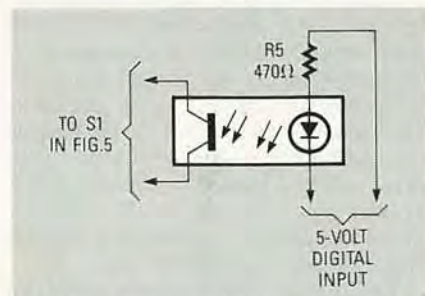FIG 5—AC POWER SWITCH with transistor- aided DC triggering.

FIG 6—TRIGGER THE PREVIOUS CIRCUIT with an optocoupler.

inhibiting the Triac's gate circuit, so it remains off.

Figures 5 and 6 show several ways of triggering the Triac via a transformer-derived DC supply and a transistor-aided switch. In the Fig. 5 circuit, Q1 and the Triac are both turned on when S1 is closed, and off when it is open. In practice, of course, S1 could be replaced by an electronic switch, enabling the Triac to be operated by heat, light, sound, time, etc. Note, however, that the whole of the Fig. 5 circuit is "live." Figure 6 shows how to modify the circuit so that is is suitable for use with an optocoupler.

To complete this section, Figures 7 and 8 show several ways of triggering a Triac from a fully isolated external circuit. In both circuits, triggering is obtained from an oscillator built around unijunction transistor Q1. The UJT operates at a frequency of several kHz and feeds its output pulses to the Triac's gate via pulse transformer T1, which provides the desired isolation. Also in both circuits, S1 can easily be replaced by an electronic switch.

In the Fig. 7 circuit, Q2 is wired in series with the UJT's main timing resistor, so the UJT and the Triac will turn on only when S1 is *closed*. In the Fig. 8 circuit, Q2 is wired in parallel with the UJT's main timing capacitor, so the UJT and the Triac turn on only when S1 is *open*.

Synchronous designs

Figures 9–18 show a number of power-switching circuits that use synchronous triggering.

Figure 9 shows the circuit of a synchronous line switch that is triggered near the zero-voltage crossover points. The Triac's gate-trigger current is obtained from a 10-volt DC supply that is derived from the network composed of R1, D1, D2, and C1. That supply is delivered to the gate via Q1, which in turn is controlled by S1 and the zero-crossing detector composed of Q2, Q3, and Q4.

Transistor Q5 can only conduct gate

current when S1 is closed and Q4 is off. The action of the zero-crossing detector is such that either Q2 or Q3 turns on whenever the instantaneous line voltage is positive or negative by more than a few volts, depending on the setting of R8. In either case, Q4 turns on via R3 and thereby inhibits Q5. The circuit thus produces minimal RFI.

Figure 10 shows how to modify the previous circuit so that the Triac can only turn on when S1 is open. In both circuits note that, because only a narrow pulse of gate current is sent to the Triac, average consumption of DC current is very low (one milliampere or so). Also note that S1 can be replaced by an electronic switch, to give automatic operation via heat, light, time, etc., or by an optocoupler, to provide full isolation.

A number of special-purpose synchronous zero-crossover Triac-gating IC's are available, the best-know examples being the CA3059 and the TDA1024. Both devices incorporate line-derived DC power-supply circuitry, a zero-crossing detector, Triac gate-drive circuitry, and a high-gain differential amplifier/gating network.

Figure 11 shows the internal circuitry of the CA3059, together with its minimal external connections. AC line power is applied to pin 5 via a limiting resistor
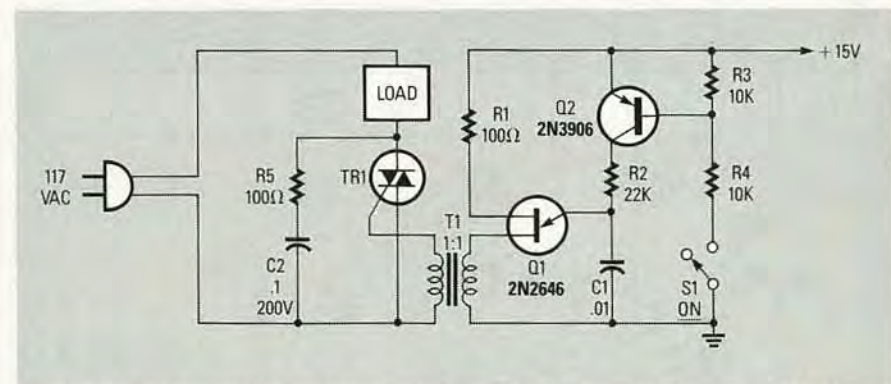

FIG 7—TRANSFORMER-COUPLED AC power switch. The Triac turns on when S1 is closed.
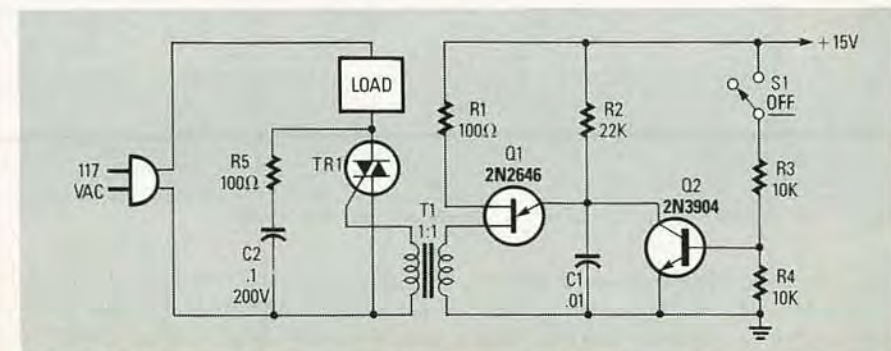

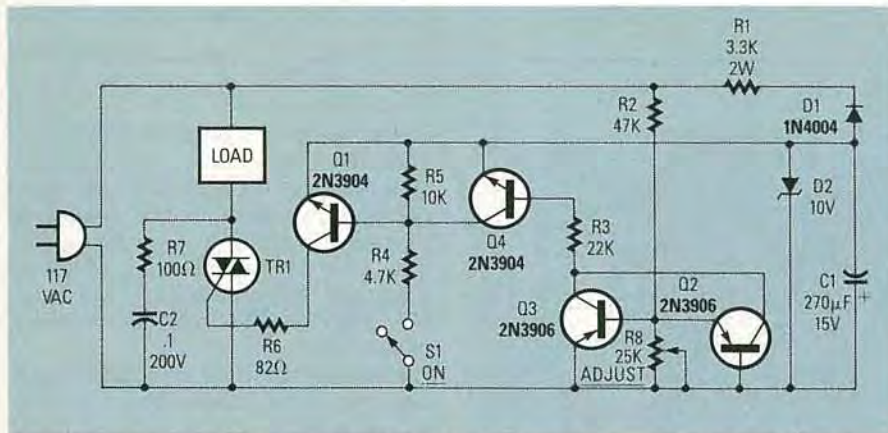FIG 8—ISOLATED-INPUT AC power switch. The Triac turns on when S1 is open.

FIG 9—ZERO-CROSSING synchronous line switch. The Triac turns on when S1 is closed.
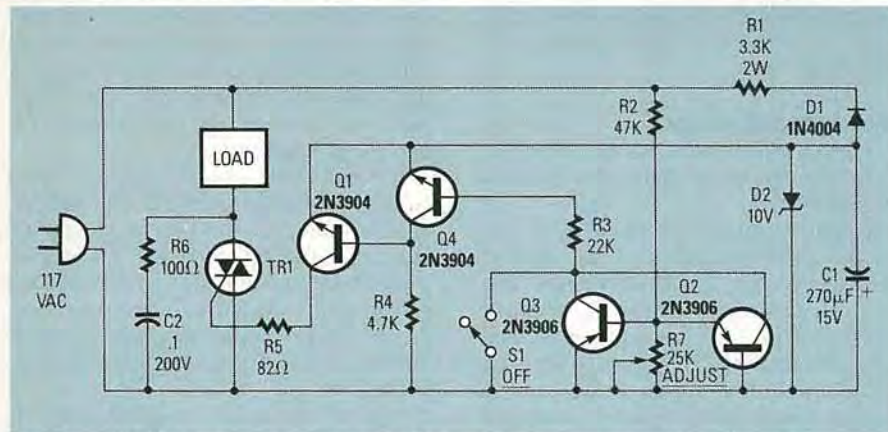

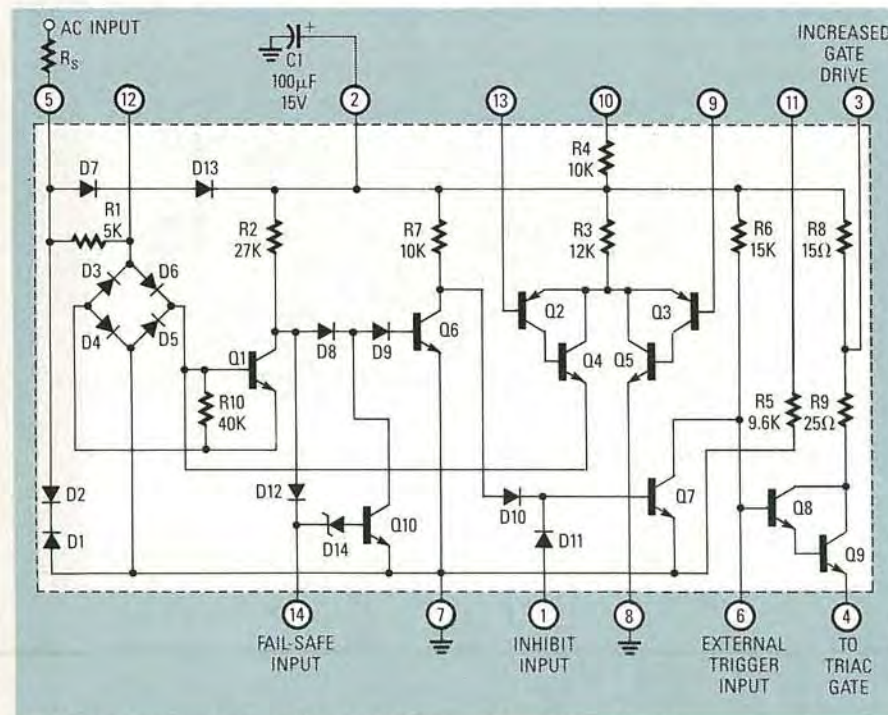FIG 10—ALTERNATE synchronous line switch. The Triac turns on when S1 is open.

FIG 11—THE CA3059'S internal circuit and necessary external components.

circuitry. It also provides adequate drive to the gate of the Triac, and a few mA of current are available for powering external circuitry.

Bridge rectifier D3–D6 and transistor Q1 function as a zero-crossing detector, with Q1 being driven to saturation whenever the pin-5 voltage exceeds –3V. Gate drive to an external Triac can be provided (via pin 4) from the emitter of the Q8/Q9 Darlington pair; that current is available only when Q7 is off. When Q1 is on (i. e., the voltage at pin 5 exceeds –3V), Q6 turns off through lack of base drive, so Q7 is driven to saturation via R7, so no current is available at pin 4.

The overall effect is that gate drive is available only when pin 5 is close to zero volts. When gate drive is available, it is delivered as a narrow pulse centered on the crossover point; the gate-drive current is supplied via C1.

The CA3059 incorporates several transistors (Q2–Q5) that may be configured as a differential amplifier or a voltage comparator. Resistors R4 and R5 are externally available for biasing the amplifier. Q4's emitter current flows via the base of Q1; the configuration is such that gate drive can be disabled by making pin 9 positive relative to pin 13. The drive can also be disabled by connecting external signals to pin 1, pin 14, or both.

Figures 12 and 13 show how the CA3059 can provide manually-controlled zero-voltage on/off Triac switching. Each circuit uses a switch (S1) to enable and disable the Triac's gate drive via the IC's differential amplifier. In the Fig. 12 circuit, pin 9 is biased at $V_{CC}/2$ and pin 13 is biased via R2, R3, and S1. The Triac turns on only when S1 is closed.

In Fig. 13, pin 13 is biased at $V_{CC}/2$ and pin 9 is biased via R2, R3, and S1. Again, the Triac turns on only when S1 is closed. In both circuits, S1 handles maximums of 6 volts and 1 mA. In both circuits C2 is used to apply a slight phase delay to pin 5 (the zero-voltage detecting terminal); that delay causes gate pulses to be delivered after the zero-voltage point, rather than straddling it.

Note that, in the Fig. 13 circuit, the Triac can be turned on by pulling R3 low, and that it can be turned off by letting that resistor float. The circuits shown in Fig. 14 and Fig. 15 illustrate how that ability can increase the versatility of the basic circuit. In Fig. 14, the Triac can be turned on and off by transistor Q1, which in turn can be activated by any low-voltage circuit, even CMOS devices. And Fig. 15 shows how to use the circuit with an optocoupler.

Figure 16 shows how the Signetics TDA1024 can be used in a similar circuit to provide optically coupled zero-voltage Triac control.

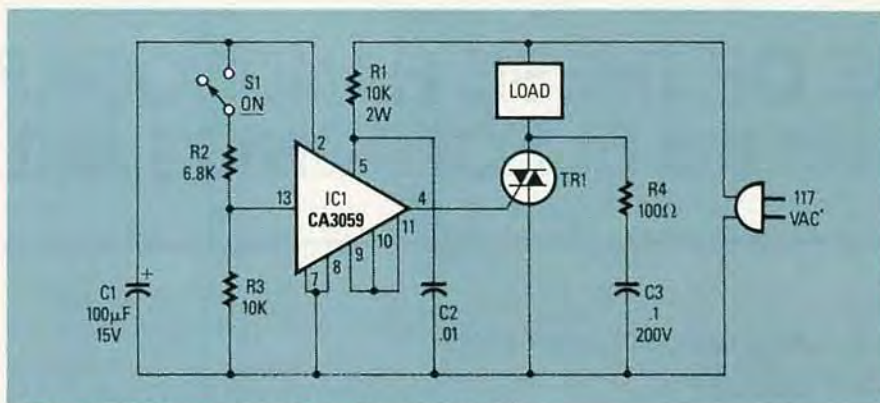To complete this section, Fig. 17 and Fig. 18 show several ways of using the

(R_S), which should have a value of 12K at 5W for 117-volt use. Diodes D1 and D2 function as back-to-back zeners that limit the potential on pin 5 to ±8 volts. On positive half-cycles, D7 and D13 rectify that voltage and generate 6.5 volts across external capacitor C1. That capacitor stores enough energy to drive all internal

FIG 12—ZERO-VOLTAGE line switch built from the CA3059.
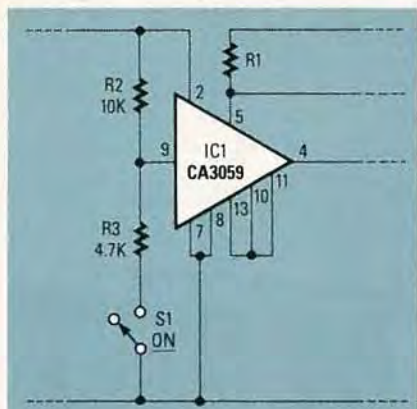
FIG 13—ALTERNATE CA3059 zero-voltage switch.

FIG 14—TRANSISTOR-CONTROLLED CA3059 switch.

13 voltage exceeds that at pin 9, and the Triac is enabled. The circuit's switching point is set with R3.

Figure 18 shows how a degree of hysteresis or "backlash" can be added to the previous circuit. Doing so prevents the Triac from switching in response to small changes (passing shadows, etc.) in ambient light level.

FIG 15—OPTICALLY COUPLED CA3059 switch.

FIG 16—OPTICALLY COUPLED TDA1024-based zero-voltage switch.

Electric-heater controllers.

A Triac can easily be used to provide automatic room-temperature control by using an electric heater as the Triac's load, and either thermostats or thermistors as the thermal feedback elements. Two
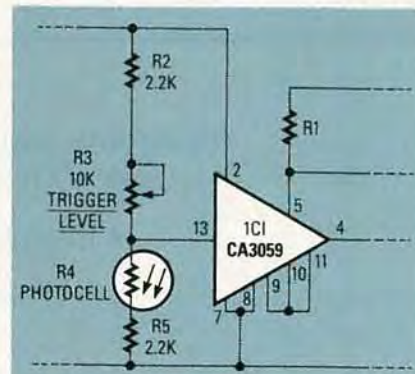
FIG 17—DARK-ACTIVATED zero-voltage switch.
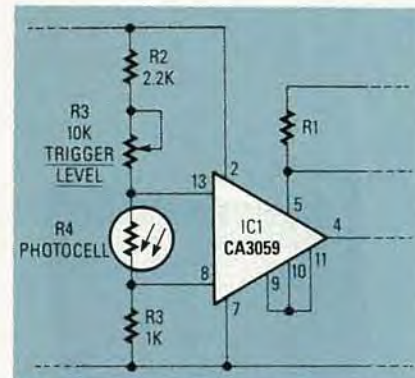
FIG 18—DARK-ACTIVATED zero-voltage switch with hysteresis.

methods of heater control can be used: automatic on/off power switching, or fully automatic proportional power control. In the former case, the heater turns fully on when room temperature falls below a preset level, and it turns fully off when the temperature rises above that level.

In proportional power control, the average power delivered to the heater is automatically adjusted so that, when room temperature is at the preset level, the heater's output power self-adjusts to precisely balance the thermal losses of the room.
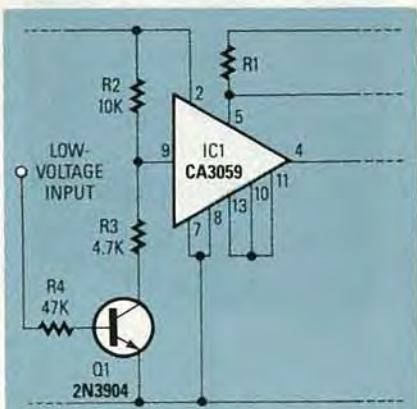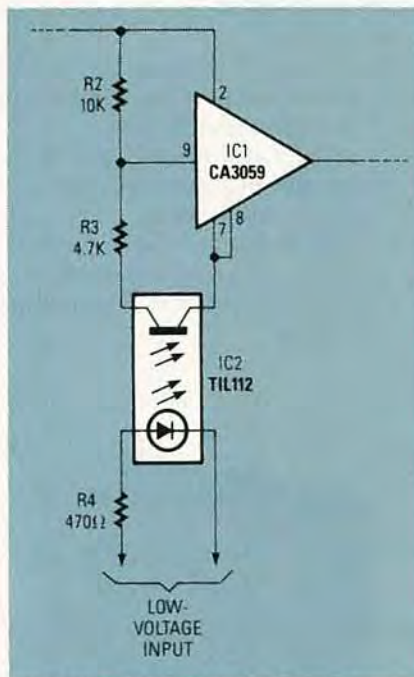
CA3059 so that the Triac operates as a light-sensitive dark-operated power switch. In both designs the IC's built-in differential amplifier is used as a precision voltage comparator that turns the Triac on or off when one of the comparator input voltages goes above or below the other comparator input voltage.

Figure 17 is the circuit of a simple dark-activated power switch. Here, pin 9 is tied to $V_{CC}/2$ and pin 13 is controlled via the R2–R5 resistive string. In bright light, photocell R4 has low resistance, so the voltage at pin 9 exceeds that at pin 13, and the Triac is disabled. In darkness, the photocell has a high resistance, so the pin
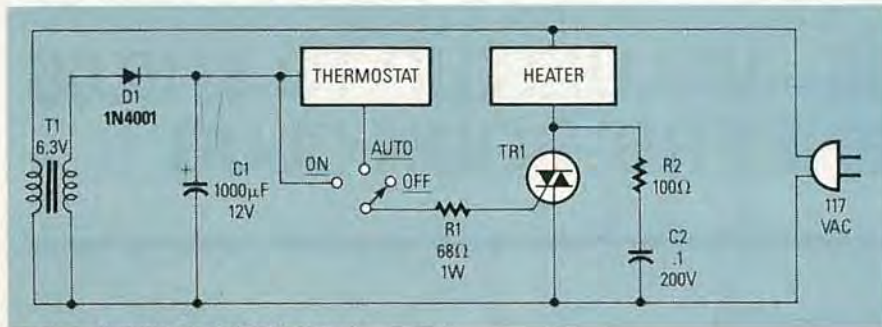
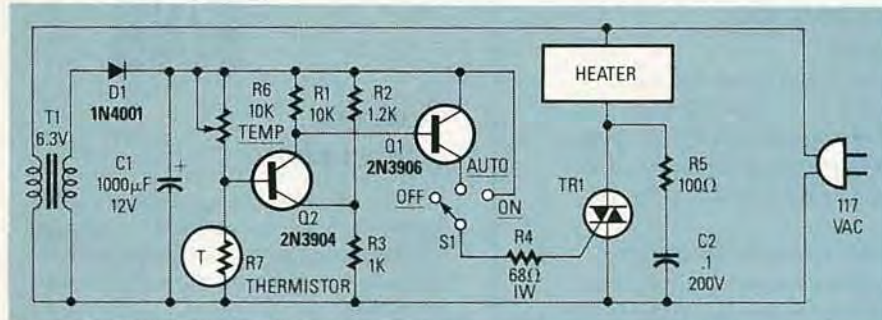FIG 19—THERMOSTAT-SWITCHED heater controller.

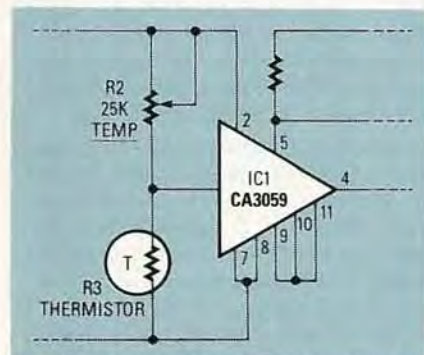FIG 20—THERMISTOR-SWITCHED heater controller.

FIG 21—HEATER CONTROLLER with thermistor-regulated zero-voltage switching.

Because of the high power requirements of an electric heater, the circuit must be carefully designed to minimize RFI generation. The designer's two main options are to use either continuous DC gating or synchronous pulsed gating. The advantage of DC gating is that, in basic on/off switching applications, the Triac generates zero RFI under normal running conditions; the disadvantage is that the Triac may generate very powerful RFI as it is turned on. The advantage of synchronous gating is that no high-level RFI is generated as the Triac turns on; the disadvantage is that the Triac generates continuous low-level RFI under normal running conditions.

Figures 19 and 20 show several DC-gated heater-controller circuits. In both cases the DC supply is derived via T1, D1, and C1, and the heater can be controlled either manually or automatically via S1. The Fig. 19 circuit is turned on and off by the thermostat, depending on its temperature.

The Fig. 20 circuit, on the other hand, is controlled by Negative Temperature Coefficeint (NTC) thermistor R7 and transistors Q1 and Q2. The network composed of R2, R3, R6, and R7 is used as a thermal bridge, and Q2 acts as the bridge-balance detector. Potentiometer R6 is adjusted so that Q2 just starts to turn on as the temperature falls to the desired level. Below that level, Q2, Q3, and the Triac are all fully on; above that level all three components are cut off.
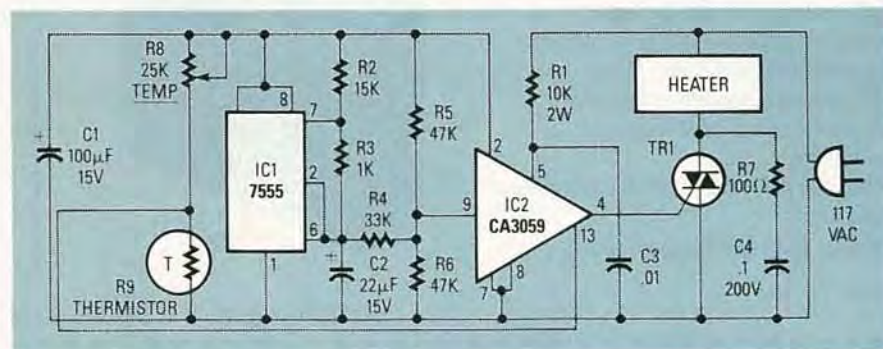
Because the gate-drive polarity is always positive, but the Triac's main-terminal current alternates, the Triac is gated alternately in the +I and +III quadrants, and gate sensitivity varies tremendously between them. (See our discussion of gate sensitivity in the September issue.) Consequently, when the temperature is well below the preset level, Q1 is driven fully on. Therefore, the Triac is gated on in both quadrants, so it provides full power to the heater. However, when the temperature is very close to the preset value, Q1 is driven on "gently," so the Triac is

gated in the +I mode only, and the heater operates at half maximum power drive. The circuit thus provides fine temperature control.

Synchronous circuits

Figure 21 shows how a CA3059 can be used to build a synchronous thermistor-regulated electric-heater controller. The circuit is similar to that of the dark-activated power switch of Fig. 17, except that the thermistor (R3) is used as the sensing element. The circuit is capable of maintaining room temperature within a degree or so of the value set by R2.

To complete our discussion of heater controllers, Fig. 22 shows the circuit of a proportional heater controller that is capable of maintaining room temperature within 0.5°C. In that circuit a thermistor-controlled voltage is applied to the pin-13 side of the CA3059's comparator, and a repetitive 300-mS ramp signal, centered on $V_{CC}/2$, is applied to the pin-9 side of the comparator from astable multivibrator IC1.

The action of the circuit is such that the Triac is synchronously turned fully on if the ambient temperature is more than a couple of degrees below the preset level, or is cut fully off if the temperature is more than a couple of degrees above the preset level. When the temperature is within a couple of degrees of the preset value, however, the ramp waveform comes into effect and synchronously turns the Triac on and off once every 300 mS, with a Mark/Space (M/S) ratio that is proportional to the temperature differential.

For example, if the M/S ratio is 1:1, the heater generates only half of maximum
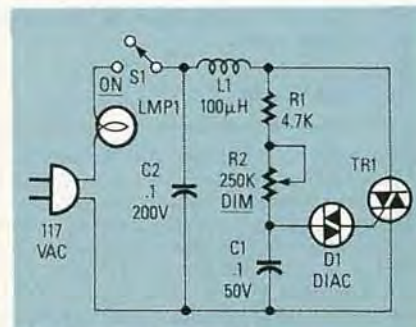

FIG 22—HEATER CONTROLLER with precision temperature regulation.
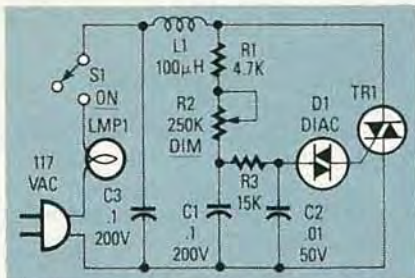

FIG 23—SIMPLE LAMP DIMMER.

FIG 24—IMPROVED LAMP DIMMER with gate slaving.

Lamp-dimmer circuits

A Triac can be used to make a lamp dimmer by using the phase-triggered power-control principles discussed last time. In that type of circuit, the Triac is turned on and off once in each line half-cycle, its M/S ratio controlling the mean power fed to the lamp. All circuits of that type require the use of a simple LC filter in the lamp's feed line to eliminate RFI.

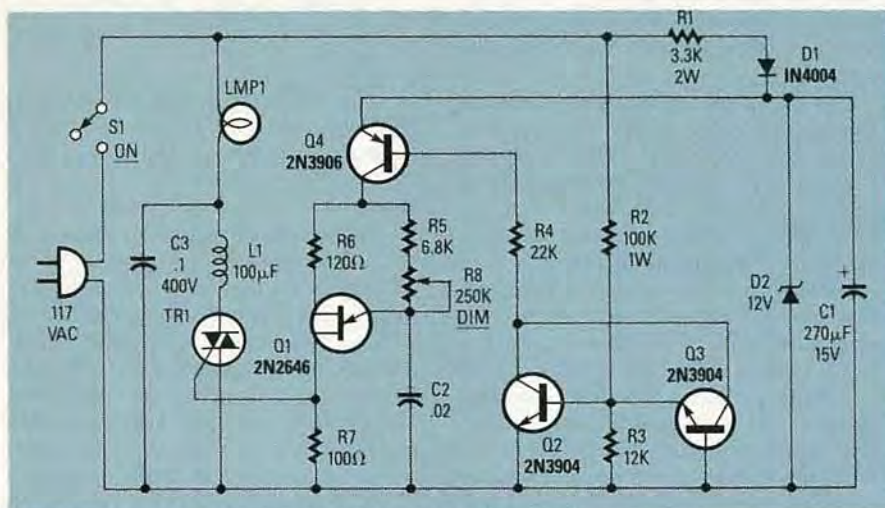The three most popular methods of obtaining variable phase-delay triggering

FIG 27—UNIVERSAL-MOTOR light-duty speed controller.

FIG 25—UJT-TRIGGERED zero-backlash lamp dimmer.

FIG 28—SELF-REGULATING UNIVERSAL-MOTOR heavy-duty speed controller.

If the lamp is dimmed by increasing the R2's value almost to maximum, the lamp will not go on again until R2 is reduced to about 80% of the former, at which it burns at a fairly high brightness level. Backlash is caused because the Diac partially discharges C1 each time the Triac fires.

Backlash can be reduced by wiring a 47-ohm resistor in series with the Diac, to reduce its effect on C1. An even better solution is to use the gate-slaving circuit shown in Fig. 24, in which the Diac is triggered from C2, which "copies" C1's phase-delay voltage, but provides discharge isolation through R3.

If backlash must be eliminated altogether, the UJT-triggered circuit shown in Fig. 25 can be used. The UJT (Q1) is powered from a 12-volt DC supply built around Zener diode D2. The UJT is line-synchronized by the Q2-Q3-Q4 zero-crossing detector network, in which Q4 is turned on (thereby applying power to the UJT) at all times *other* than when line voltage is close to zero.

So, shortly after the start of each half-cycle, power is applied to the UJT circuit via Q4, and some later time (which is determined by R5, R8, and C2), a trigger pulse is applied to the Triac's gate via the UJT.

Figure 26 shows how a dedicated IC, the Siemens S566B "Touch Dimmer,"can be used to build a smart lamp dimmer that can be controlled by several devices simultaneously: a touch pad, a pushbutton switch, or an infrared link.
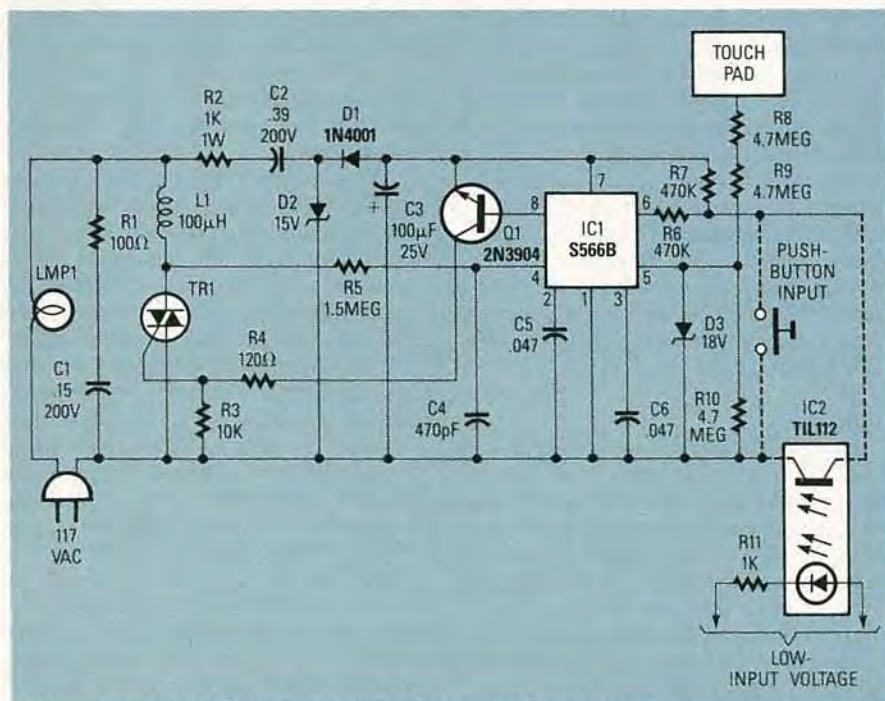

FIG 26—SMART LAMP DIMMER controlled by a Siemens S566B.

power, and if the mark/space ratio is 1:3 it generates only one quarter of maximum power. The net effect is that the heater does not switch fully off, but generates just enough output power to match the thermal losses of the room precisely. As a result, the circuit provides very precise temperature control.

are: (1) Diac plus RC phase-delay network; (2) line-synchronized variable-delay UJT trigger; (3) special-purpose IC as the Triac trigger.

Figure 23 shows the circuit of a Diac-triggered lamp dimmer. A defect of that type of design is that it suffers from considerable control hysteresis or backlash.
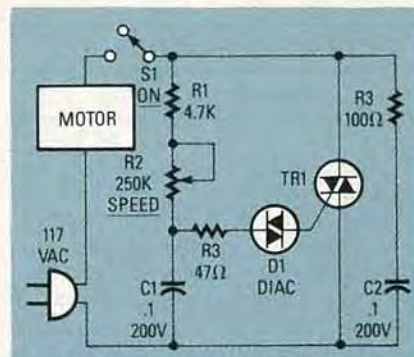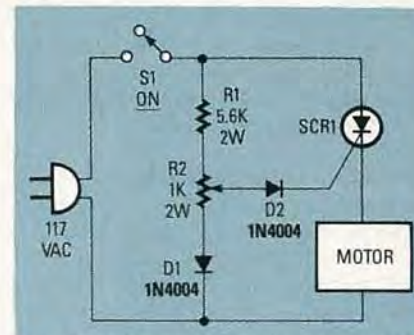
The IC, which provides a phase-delayed trigger output to the Triac, provides both on/off and proportional output control.

To do so, the S566B incorporates conditioning circuitry that recognizes a brief input as a "change stage" command. In addition, a sustained input causes the IC to go into the ramp mode, in which lamp power slowly increases from 3% to 97% of maximum. After reaching maximum, it ramps downward to a minimum of 3%, and then again reverses.

The touch pad used with the circuit may be simple strips of conductive material; the operator is safely insulated from the line voltage via R8 and R9.

Universal motor controllers

Domestic appliances are usually powered by a series-wound universal electric motor, so-called because they can operate from either AC or DC power. In operation, that type of motor produces a back EMF that is proportional to the motor's speed. The effective voltage applied to that type of motor is equal to the applied voltage minus the back EMF. That results in some self-regulation of motor speed, because an increase in motor loading tends to reduce speed and back EMF, thereby increasing the effective applied voltage and causing motor speed to try to increase to its original value.

Most universal motors are designed to provide single-speed operation. A Triac-based phase-control circuit can easily be used to provide that type of motor with fully-variable speed control. A suitable circuit is shown in Fig 27.

That circuit is useful for controlling lightly-loaded appliances (food mixers, sewing machines, etc.). However, heavy-duty tools (electric drills and sanders, for example) are subject to heavy load variations, and therefore require a circuit like the one in Fig. 28.

An SCR is used in that circuit as the control element; it feeds half-wave power to the motor, which results in a 20% or so reduction in available speed and power. However, during the half-cycles when the motor is off, its back EMF is sensed by the SCR and is used to adjust the next gating pulse automatically.

The network composed of R1, R2, and D1 provides only 90° of phase adjustment, so all motor power pulses have a minimum duration of 90° and provide very high torque. At low speeds the circuit goes into a "skip-cycling" mode, in which power pulses are provided intermittently, to suit motor-loading conditions. The result is that the circuit provides particularly high torque under low-speed conditions. **R-E**