Introduction to Thyristors

How to use diacs, SCRs and triacs to switch and control ac voltages to resistive and reactive loads

By Dan Becker

Thyristors provide an efficient, low-cost method of controlling power to a load. For many applications, small size and high current capacity—as much as 4,000 amperes—make them more attractive than mechanical relays. The three most common types of thyristors are the diac, the silicon controlled rectifier (SCR) and the triac. Although these devices are primarily used with ac line voltages, the SCR is also extensively used in dc pulse applications. All are bistable semiconductor devices that can be switched from a high-impedance off state to a low-impedance on state.

Once triggered, a thyristor remains on until its forward current drops below the level necessary to maintain the on condition, which is called holding current I_h. Because ac line voltage falls to zero at the end of each half-cycle, thyristor current drops below the I_h level and reverts to the off state every half-cycle.

Thyristor Basics

•*Diac.* A diac, shown schematically in Fig. 1(A), has two terminals. When off, it is equivalent to an open circuit. It stays in the off state until a positive or negative voltage of sufficient amplitude—called the breakover voltage V_{BO} (or switching voltage V_s)—is placed across the terminals. The diac then turns on and the current through it is limited only by load resistance.

Figures 1(B) and 1(C) illustrate the single-pole, single-throw switch-like action of a diac. A typical diac has a breakover potential of 24 to 32 volts.

Diacs are primarily used with triacs in power control circuits, such as light-dimmers. We will go into more applications detail and the effect they have on circuit performance later.

•*SCR.* Similar to the diac, the SCR has two stable states, defined as on and off. The schematic symbol is shown in Fig. 2(A). Unlike the diac, however, current can flow in only one direction. In addition, the voltage at which breakover (switching) occurs is adjustable and is controlled by the third, gate, terminal.

Breakover voltage of an SCR is specified by the manufacturer for zero gate current. When designing a circuit, you must select a thyristor that is rated higher than the maximum voltage anticipated. For example, for ac-line operation, you would select an SCR with a 600-volt V_{DRM} rating. This ensures that the reverse-blocking voltage rating will also be adequate. Typically, it is 100 volts greater than the V_{BO} rating and is equivalent to the peak reverse voltage rating of a rectifier diode.

Cathode-to-anode action of an SCR is similar to that of a diode in series with a single-pole, single-throw switch. The "switch" closes under gate control. That is, to switch on an SCR, a small current must be passed to the gate terminal. Figures

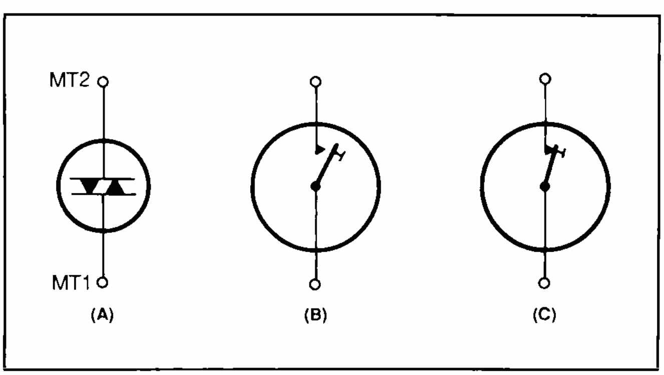

Fig. 1. Schematic symbol of diac (A) and simplified models of on (B) and off (C) states.

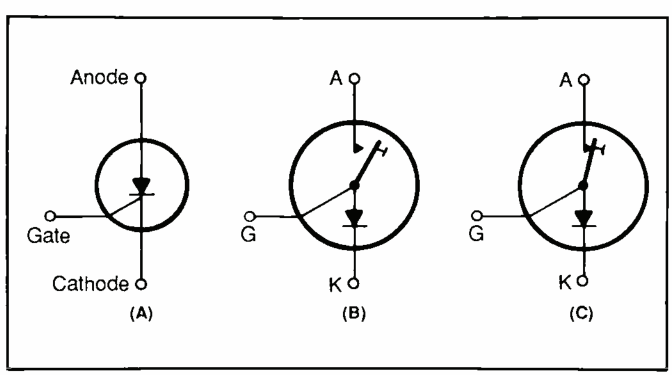

Fig. 2. Schematic symbol of SCR (A) and simplifed models of on (B) and off (C) states.

2(B) and 2(C) show the on and off states of this simplified model.

How gate current can be applied to an SCR is illustrated in Fig. 3. Here, an external switch in series with a current-limiting resistor is used to open and close the gate current path. The series gate resistor assures that the gate current will decrease to a safe value after the SCR is triggered. In addition, a 1N4004 rectifier diode is installed in series with the gate. This prevents the negative half of the ac line-voltage cycle from damaging the cathode-gate semiconductor junction of the device.

With an open gate switch, the SCR remains off, due to the high breakover voltage rating. If the gate switch is closed, the breakover voltage point is lowered through the action of gate current. Thus, the SCR would switch on during the positive half of the line voltage.

When on, forward current through an SCR is limited only by the load resistance. The SCR will remain on until forward current drops below holding current I_h.

When the line voltage alternates to the negative half of the cycle, forward current drops below holding current, forcing the SCR into the off state. Thus, the SCR must be retriggered (switched on) once every cycle, while the polarity of the cathode to anode voltage is in the forward direction (cathode negative and anode positive).

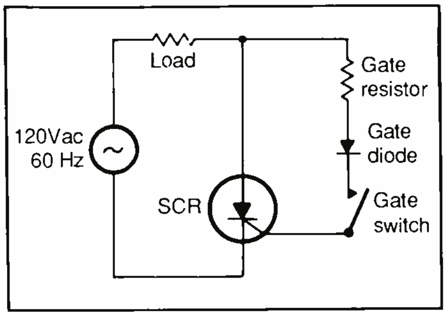

Fig. 3. An SCR test circuit.

By making the gate resistor variable, the breakover-voltage point can be controlled. As gate current increases, breakover voltage is lowered. This controls the point during the positive half-cycle at which the SCR fires, thereby controlling the amount of power fed to the load. At maximum gate current, this device operates like a half-wave rectifier in series with the load.

• *Triac.* To obtain control over both positive and negative halves of the line-voltage cycle, a more versatile device than the SCR is required. This brings us to the bidirectional triac.

Shown schematically in Fig. 4(A), the triac combines the bidirectional properties of the diac with the breakover-voltage gate-control mechanism of the SCR. The three terminals of the triac are identified as main terminal one (MT1), main terminal two (MT2) and gate (G).

A triac can be switched on during both positive and negative halves of the 360-degree ac cycle, making the complete voltage cycle available to the load, instead of only the 180 degrees afforded by the SCR.

Gate current in a triac is always referenced to MT1 and can flow in either direction. In addition, it can be applied continuously or in pulses. The manufacturer's data sheet specifies the value of gate current I_{GT} necessary to trigger on the device. Often, this refers to the dc current required to trigger the device with 12 volts ac applied between MT1 and MT2. As the temperature of the triac increases, the required amount of gate current decreases.

Continuous gate current is easily accomplished with a dc voltage (with a current-limiting series resistor) applied between the gate and MT1. This triggers the thyristor on for both halves of the ac line voltage. It permits the triac to function as an electronically controlled switch. Figures 4(B) and 4(C) illustrate the on and off circuit characteristics, respectively.

Unlike the SCR, gate current of a triac can flow in either direction. This is convenient because it allows the ac line voltage to be used to supply the gate control circuit. Typically, pulses of gate current are generated, one for each half of the ac cycle. The polarity of each pulse corresponds to the instantaneous polarity of the voltage across the main terminals. Pulsed gate current allows triggering of the device at nearly any convenient point in the line-voltage cycle. This method is used in the light-dimmer circuit to be described shortly.

Some of the symbols manufacturers use to specify the characteristics of a thyristor are detailed in the thyristor characteristics table.

Thyristors are available in a variety of case styles. Examples of the

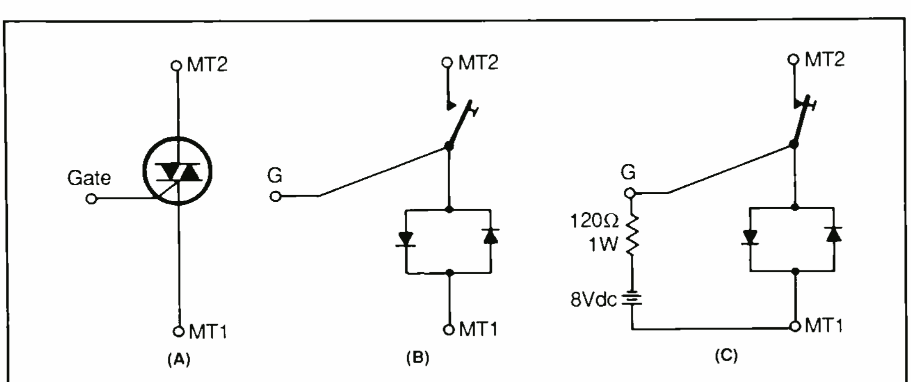

Fig. 4. Schematic symbol of triac (A) and simplified on (B) and off (C) models.

more common types are given in Fig. 5. Case style and size are related to the power-handling capacity of the device. Because of the high efficiency associated with thyristors, even small packages like the TO-92 can handle rms currents in excess of 1 ampere and peak (nonrepetitive) currents of 15 amperes. Larger case styles, like the TO-48 stud mount, typically feature a current ratings of 40 amperes.

Because a thyristor is less than an ideal switch, 1 to 2 volts is dropped whenever current flows. This generates heat that must be dissipated by a heat sink. In an application like the light dimmer shown in Fig. 6, where the thyristor controls a 60-watt load, power dissipation is about 1 watt and requires only a small heat sink.

When a control circuit operates directly from the ac line, mounting a thyristor to a heat sink should be given careful consideration. The reason for this is that the metal tab on the case of the device is usually not electrically insulated from MT2. Therefore, you should install a Teflon or mica washer between the thyristor and the heat sink before fastening them together. This keeps the "hot" side of the ac line isolated from the heat sink and the enclosure and maintains good transfer of heat.

Some thyristors feature an isolated mounting stud. This lets you forget about the washer, since MT2 (or the anode of an SCR) is internally insulated from the case of the device.

Phase-Control Circuit

Illustrated in Fig. 6 is a typical application for thyristors—a light-dimmer control. Potentiometer *R1* lets you adjust the brightness of the lamp over a range from a weak flicker up to full on. Three different settings, shown as A, B and C, are indicated for *R1*, corresponding to the three pairs of points indicated on the ac line-voltage curve in Fig. 7.

Thyristor Characteristics.

V_{ORM}	Peak Off Voltage—exceeding this value switches on the device.
V_{BO} or V_S	Breakover or Switching Voltage—must exist across terminals before device switches on.
V_{TM}	On Voltage—voltage dropped across device by forward current.
V_{GT}	Gate Trigger Voltage—forward biases the gate terminal.
I_{GT}	Gate Trigger Current—value to use to ensure positive device triggering.
I_h	Holding Current—minimum current required to maintain the on state; often specified in milliamperes (mA).
$I_{T(RMS)}$	Rms Current—maximum rms on-state current without device failure.
$I_{T(AV)}$	Average Current—maximum average on current without device failure.
I_{TSM}	Surge Current—maximum peak on current (nonrepetitive) without device failure.

With *R1* set near maximum resistance (A), the triac switches on at point A on the time/voltage curve. This corresponds to minimum light brightness. At the opposite extreme, if *R1* is set toward minimum resistance (C), the triac fires at the beginning of each half-cycle, delivering maximum power to the lamp.

Following Fig. 6, potentiometer *R1* and capacitor *C1* form a voltage divider with a time constant of up to 5 milliseconds. Therefore, the voltage across *C1* lags the voltage across the main terminals of the triac. A second RC circuit consisting of *R2* and *C2* is connected in parallel with *C1*. The voltage across *C2* lags still further behind the terminal voltage of the triac. In addition, the voltage is now reduced to a fraction of the ac line voltage.

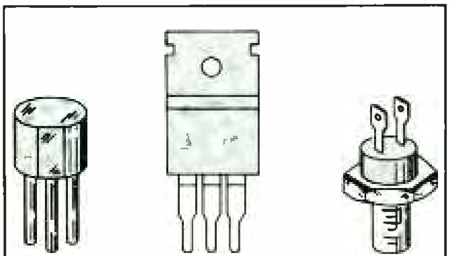

Fig. 5. Typical thyristor package configurations.

As the value of *R1* is reduced, the voltage across *C2* increases. A point is reached at which the peak voltage across *C2* exceeds the breakover voltage of the diac. At this point, the diac switches on and capacitor *C2*

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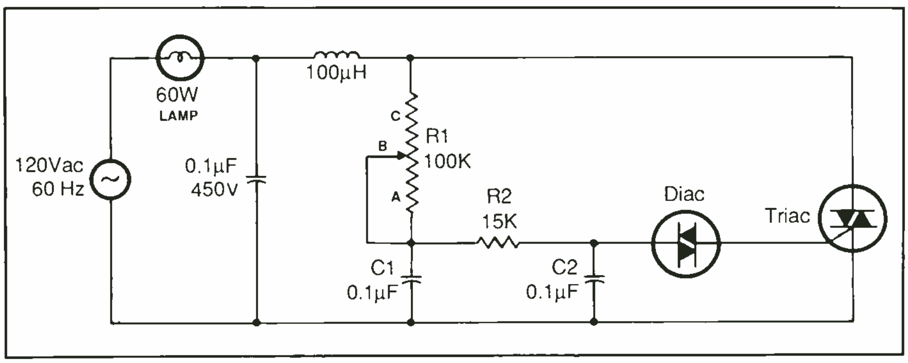

Fig. 6. A diac/SCR light-dimmer circuit with rfi suppression.

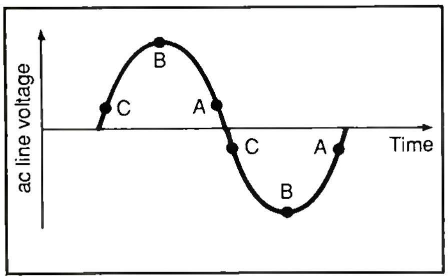

Fig. 7. A, B and C indicate voltage trigger points for Fig. 6. circuit.

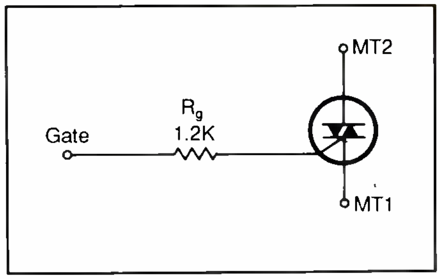

Fig. 8. Series gate resistor R_g is added to stretch gate-trigger pulse.

discharges through it and the triac's gate. When this happens, the thyristor triggers on and remains that way for the remainder of that half-cycle of line voltage.

If a diac were not used, the Triac's gate would act as a diode in parallel with *C2*. Therefore, *C2* would charge enough to forward bias only this diode (MT1 to gate) before triggering the triac and discharging. You could substitute a neon lamp for the diac, though this would cause the minimum trigger point to be closer to point B than to point A.

In addition to giving *C2* more time to charge, the diac serves another purpose. By letting *C2* store a large charge, it allows triggering current to be a high-magnitude pulse instead of a gradually increasing ramp. Manufacturers recommend this type of triggering because it reduces the switching time, which minimizes the power dissipated in the triac.

Loose Ends

When a thyristor is triggered on, it immediately connects the ac line voltage to the load connected in series with it. If the load happens to be inductive, such as an electric motor, current will lag behind by as much as 4 milliseconds. Without an initial flow of current, called the "latching" current, a thyristor will immediately shut off. The latching current is usually less than twice the holding current. Therefore, when the load is inductive, a longer-duration gate trigger pulse is required to keep the thyristor on until a latching current is reached. This is generally accomplished by increasing the time constant of the gate circuit. In Fig. 8, a series 1,200-ohm resistor stretches the pulse of gate current discharged from the gate capacitor.

When a thyristor is constantly switching on and off, it generates radio frequency interference (rfi). This electrical noise travels along the ac power line, radiating undesirable interference. By using a 100-microhenry r-f choke and a 0.1-microfarad capacitor in the circuit, as shown in Fig. 6, rfi is reduced. If a thyristor is used as a full-on/full-off switch (not as a variable power control), an rfi filter is seldom required.

Now that you know how thyristors operate and how they can be used, it is time to think up applications of your own. Keep in mind that thyristor applications are not limited to high-voltage switching and control. You could just as easily build a circuit to control power delivery to a load from a 12-volt transformer. **ME**

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Conclusion

This reworking of the basic ZX81/TS1000 gives new life to these computers. With just a few dollars and a few hours of your time, you'll restore an idle computer to useful service and more than recoup whatever monetary investment you made for it in the first place. **ME**

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