

Experiment #10—Using SCRs

Thyristors—what a strange word! What do they do? Thyristors are common components found around the ham shack in power supplies and ac control circuits. They are solid-state replacements for *thyatron*s—tubes that act as current switches. Like transistors, a small current can switch a much larger current. In this experiment, we'll use the most common thyristor—a silicon-controlled rectifier or *SCR*—to control both ac and dc.

Terms to Learn

- **Breakover and breakdown voltage**—the voltages at which an SCR begins to conduct current without gate drive from anode-to-cathode (forward) and cathode-to-anode (reverse), respectively.
- **Conduction angle**—the number of degrees of an ac cycle during which the SCR is conducting forward current.
- **Holding current (I_H)**—the amount of forward current required to keep an SCR conducting.
- **Latch**—to change state and remain in that state.

How the SCR Works

The SCR has an NPN transistor's layered structure of N and P-type material but adds one additional P-type layer as shown in Figure 1. Starting at the cathode and moving left, you see what looks like the three layers of a regular NPN transistor. The extra P-type layer then creates a PN-diode at the anode. The SCR "looks like" a rectifier attached to an NPN transistor.

The SCR operates in just two states: ON and OFF. When OFF, the SCR acts like an open-circuit to voltages between the anode and cathode as long as the value is less than either the breakover or breakdown voltages. The SCR will remain OFF until gate-to-cathode current reaches the *gate trigger current*, I_{GT} , or *gate turn-on voltage*, V_{GTO} , at which point forward current flows from the anode to cathode and the SCR is ON.

It's important to understand that while the SCR is turned ON by gate current, it can't be turned OFF the same way. Once ON, the SCR is *latched* ON until forward current falls below the *holding current*, I_{HO} , when it resets to the OFF state. Forward current will fall below I_{HO} when the power source stops supplying or the load stops drawing current. In an ac circuit, the reversal of voltage across the SCR stops current flow.

Demonstrating SCR Functions

This is unfamiliar territory for many electronic designers, so

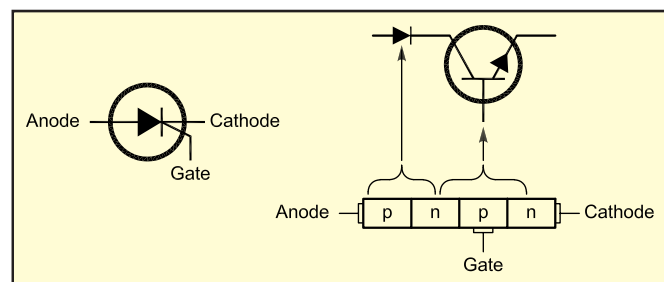


Figure 1—The internal construction shows that the SCR may be thought of as a rectifier in series with an NPN transistor.

let's start with a simple experiment that demonstrates the basic SCR functions to discharge a capacitor into a load.

- Construct the circuit of Figure 2. Don't use your prototype board; either solder the components together or use a terminal or barrier strip. A clip lead or jumper wire can be used for the switches.
- Open S2 then close S1. Connect the 12 V power supply. Monitor voltage across the capacitor to be sure it charges to 12 V. No voltage should appear across the 100 Ω load resistor.
- Open S1, leaving the charged capacitor connected to the SCR. Monitor voltage across the load resistor while *momentarily* closing S2. (If you leave S2 closed, gate current will continue to flow, overheating the 47 Ω resistor.) You will see a pulse of voltage across the load resistor as the capacitor discharges through it. The duration of the pulse will be approximately $R \times C = 100 \times 9400 \mu F = 0.94$ seconds.
- Observe the trailing edge of the pulse as the capacitor discharges. You will see load voltage abruptly drop to zero as current through the SCR falls below I_{HO} . This will happen with capacitor voltage around 2.2 V due to the 1.8 V forward voltage drop of the SCR, which leaves only 30-40 mA flowing in the load resistor. (This is clearest if you are able to monitor both capacitor and load voltage.)
- As soon as load voltage drops to zero, indicating that the SCR is reset, you can close S1 again to repeat the cycle.
- Experiment with the circuit by increasing the value of the gate resistor until the SCR no longer triggers. Similarly, if the load resistance is increased, maximum current will fall below I_{HO} and the capacitor will no longer discharge through the SCR.

Designing with SCRs

The circuit you just tested is similar to over-voltage protection circuits found in dc power supplies, called *crowbars*. A heavy-duty SCR is connected directly across the power supply output and triggered to act as a short circuit if the output voltage gets too high. SCRs can handle a large surge current, so this either trips the supply's current limit circuit or blows a fuse. Either way, equipment connected to the supply is not subjected to excessive voltage.

Another popular use of SCRs is in ac circuits that control power to a load such as a light bulb dimmer or motor speed control. The circuit of Figure 3A shows a simple dimmer cir-

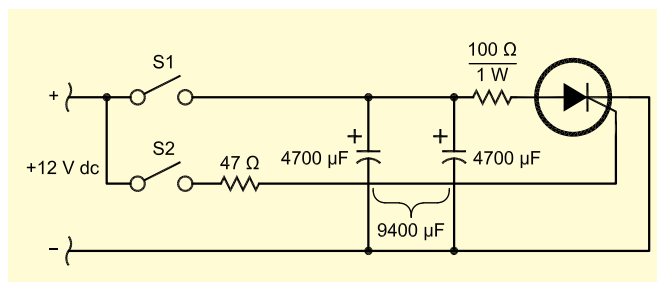


Figure 2—A simple charge-dumping circuit. The capacitor discharges through the load resistor and the SCR when a current pulse through the gate turns the SCR ON.

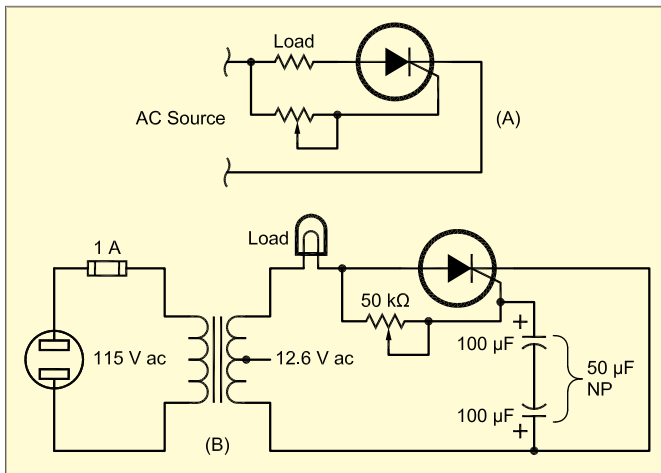


Figure 3—An RC-controlled dimmer circuit. To run this circuit at 115 V ac, the capacitor value can be reduced by a factor of 10 or more.

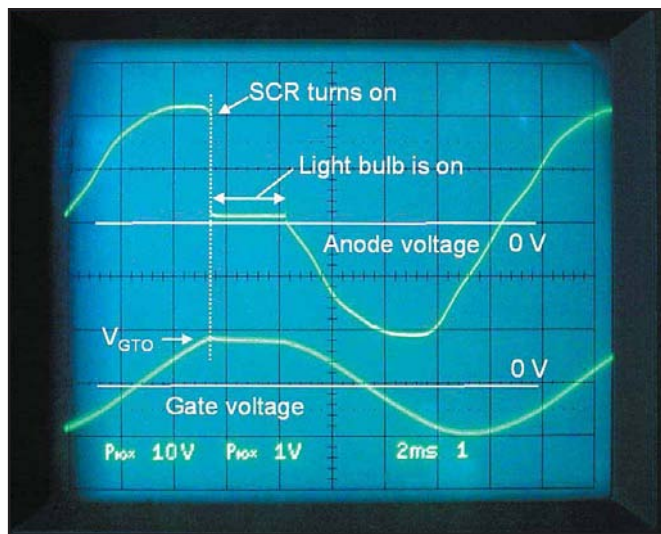


Figure 4—The SCR anode and gate voltages show a conduction angle of about 65°.

cuit. Starting with the gate control potentiometer set to a high value, the SCR remains OFF over the entire ac cycle. As the control resistance is reduced, eventually enough current enters the SCR gate at the very peak of the ac cycle, turning it ON for the duration of the positive half-cycle. As the control's resistance is reduced further, the SCR turns ON at lower and lower voltages, conducting over more of the positive half-cycle and delivering more power to the load.

In Figure 3B, the load—a light bulb—has been moved to the supply side of the potentiometer and a gate capacitor has been added. This allows smoother control of the *conduction angle*. Starting once again with the SCR in the OFF state, all of the applied voltage appears across the SCR and the gate capacitor charges through the potentiometer. When the capacitor has charged to the SCR's gate turn-on voltage, V_{GTO} , the SCR turns ON. The SCR stays ON until the voltage reverses.

By choosing the right values for the potentiometer and capacitor, the SCR's conduction angle can be varied from about 30°, turning on near the end of the positive half-cycle, to almost 180°, conducting over the entire positive half-cycle. Ready to try it for real?

Testing a Dimmer Circuit

- Construct the circuit of Figure 3B taking special care with the ac supply. All 115 V_{rms} line circuits must be insulated and fused. Use a ground-fault interrupter (GFI) circuit, if possible. The gate capacitor must be nonpolarized and is constructed from two electrolytic caps connected back to back with opposing polarities.
- Set the potentiometer to its maximum value. Monitor SCR anode voltage and gate capacitor voltage with an oscilloscope. Connect a voltmeter across the light bulb set to measure ac voltage. Power up the circuit. The light bulb should be OFF. You will observe a small ac voltage across the gate capacitor.
- Slowly reduce the potentiometer value until voltage across the light bulb begins to increase. You will see the gate capacitor voltage increasing to V_{GTO} (about 1 V) at which point the SCR turns ON. Continue decreasing the potentiometer resistance. The gate capacitor will charge to V_{GTO} faster and the SCR will conduct over more of the ac cycle, increasing bulb brightness and the voltage across it. Figure 4 shows one ac cycle of the SCR gate and anode voltage.
- Try to maximize the range of the SCR's conduction angle by changing the gate capacitor or control pot values. A 25 kΩ pot and 100 μF capacitors worked best for the SCR I used.

Suggested Reading

The amateur literature is sparse in the area of thyristors, but manufacturers offer detailed design and application information. The Teccor Electronics Web site has an excellent series of downloadable application notes on thyristors at: http://www.littelfuse.com/cgi-bin/r.cgi/know_file_detail.html?LFSESSION=FXeUIzu4L7&FilebaseID=903. The classic, but old data book by RCA—the *Transistor, Thyristor and Diode Manual*—also has an excellent tutorial section on thyristor basics.

Shopping List

- SCR—RadioShack 276-1067, 267-1020 or similar.
- 115 V_{rms} to 12.6 V_{rms} power transformer—RadioShack 273-1365 or similar.
- Two 4700 μF @ 16 V or greater, two 100 μF @ 16 V or greater capacitors.
- 100 Ω -1 W, 47 Ω -1/4 W resistors.
- 50 kΩ potentiometer—RadioShack 271-1716.
- 12 V incandescent lamp—RadioShack 900-2665 or similar.

Next Month

Next month we'll jump back to one of my favorite op-amp circuits—the comparator. These handy circuits are used for all sorts of detection and sensing duties, so get the prototype board and 741s dusted off!

Remember the Hands-On Radio Web site: www.arrrl.org/hands-on-radio/.

STRAYS

QST congratulates . . .

◇ Amateur Radio on the International Space Station (ARISS) Chairman Frank Bauer, KA3HDO, who has been promoted to the highest technical rank accorded a NASA scientist or engineer. Bauer, who works at NASA Goddard Space Flight Center in Maryland, now is a Special Technical—or ST—in recognition of his record of exceptional technical achievement in the field of guidance, navigation and control.