

This article, written by Elwood Gilliland, was first published in the June, 1982 Issue of *Electrical Contractor Magazine*.
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Definition

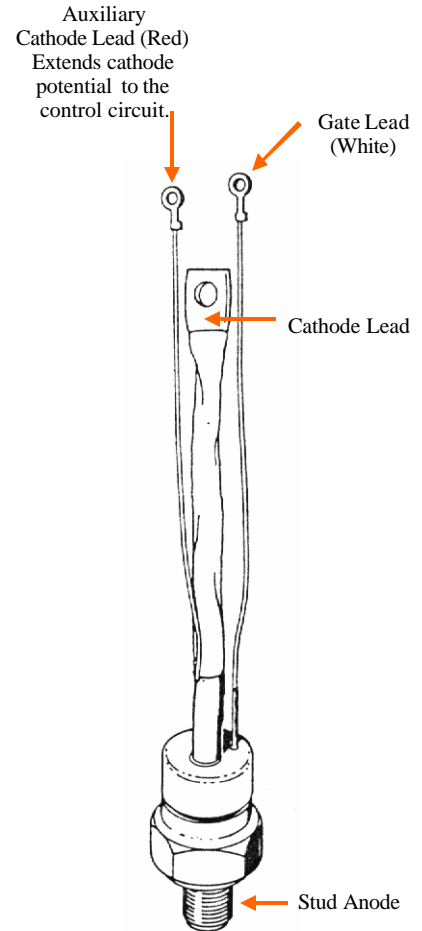
The Silicon Controlled Rectifier (SCR) is a semiconductor device that is a member of a family of control devices known as Thyristors. The SCR has become the workhorse of the industrial control industry. Its evolution over the years has yielded a device that is less expensive, more reliable, and smaller in size than ever before. Typical applications include : DC motor control, generator field regulation, Variable Frequency Drive (VFD) DC Bus voltage control, Solid State Relays and lighting system control.

- The SCR is a three-lead device with an anode and a cathode (as with a standard diode) plus a third control lead or *gate*. As the name implies, it is a rectifier which can be controlled - or more correctly - one that can be triggered to the "ON" state by applying a small positive voltage (V_{TM}) to the gate lead.
- Once gated ON, the trigger signal may be removed and the SCR will remain conducting as long as current flows through the device.
- The load to be controlled by the SCR is normally placed in the anode circuit. See drawing below.

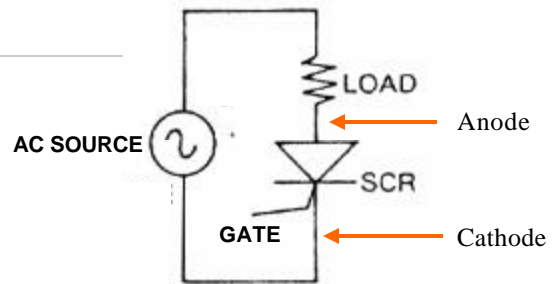
Commutation

For the SCR to turn OFF the current flow through the device must be interrupted, or drop below the *Minimum Holding Current* (I_H), for a short period of time (typically 10 -20 microseconds) which is known as the *Commutated-Turn-Off-Time* (t_q).

- When applied to Alternating Current circuits or pulsating DC systems, the device will self-commutate at the end of every half -cycle when the current goes through zero.
- When applied to pure DC circuits, in applications such as alarm or trip circuit latching, the SCR can be reset manually by interrupting the current with a push button. When used in VFD's or inverters, SCRs are electronically forced OFF using additional commutating circuitry, such as smaller SCRs and capacitors, which momentarily apply an opposing reverse-bias voltage across the SCR. (This is complicated - everything has to be exactly right.)



Stud- Mounted SCR
110 Amp RMS Rating



SCR Connection Diagram
Showing load placement in the anode circuit.

This arrangement would provide control of one-half of the sine wave. For full-wave control, the SCRs would be arranged in a bridge configuration.

The GTO

Another member of the Thyristor Family is the GTO, or *Gate-Turn-Off Device*. While this component has been around for many years, it has just recently evolved to the point where it is capable of carrying the high currents required for motor control circuitry.

Unlike the SCR, the GTO can be turned ON *and* OFF with a signal applied to the gate. The turn-on signal is a small positive voltage; the turn-off signal is a negative current pulse. The GTO is now finding applications in the output stage of medium-voltage, high horsepower, Variable Frequency Drives.

Thyristors

Volt-Ampere Characteristics

Figure One below illustrates the volt-ampere characteristics curve of an SCR. The vertical axis $\pm I$ represents the device current, and the horizontal axis $\pm V$ is the voltage applied across the device anode to cathode. The parameter I_F defines the RMS forward current that the SCR can carry in the ON state, while V_R defines the amount of voltage the unit can block in the OFF state.

Biasing

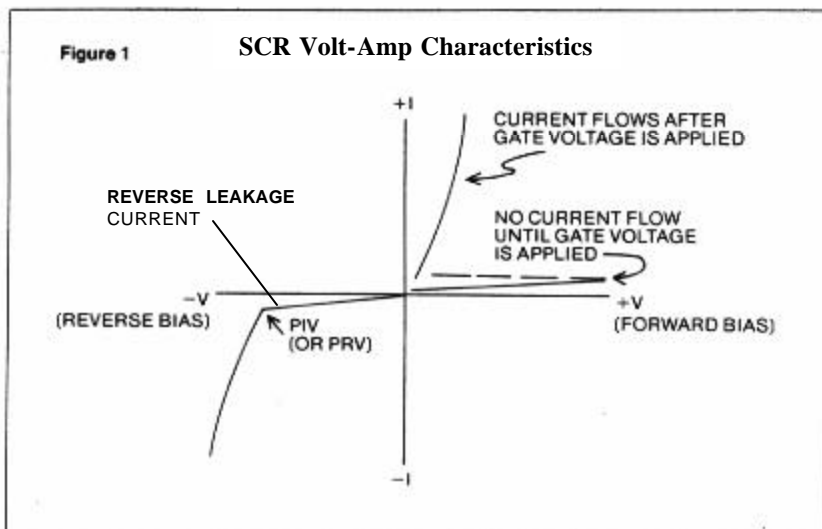
The application of an external voltage to a semiconductor is referred to as a *bias*.

Forward Bias Operation

- A forward bias, shown below as $+V$, will result when a positive potential is applied to the anode and negative to the cathode.
- Even after the application of a forward bias, the device remains non-conducting until the positive gate trigger voltage is applied.
- After the device is triggered ON it reverts to a low impedance state and current flows through the unit. The unit will remain conducting after the gate voltage has been removed. In the ON state (represented by $+I$), the current must be limited by the load, or damage to the SCR will result.

Reverse Bias Operation

- The reverse bias condition is represented by $-V$. A reverse bias exists when the potential applied across the SCR results in the cathode being more positive than the anode.
- In this condition the SCR is non-conducting and the application of a trigger voltage will have no effect on the device. In the reverse bias mode, the *knee* of the curve is known as the Peak Inverse Voltage PIV (or Peak Reverse Voltage - PRV) and this value cannot be exceeded or the device will break-down and be destroyed. A good Rule-of-Thumb is to select a device with a PIV of at least three times the RMS value of the applied voltage.



NOTE: In the drawing that a small amount of leakage current through the device exists even when it is in the OFF state.

CAUTION: When working on solid-state equipment, the equipment must be disconnected with a separate disconnecting means to insure that the equipment is de-energized; simply stopping the equipment may still result in the existence of a hazardous potential.

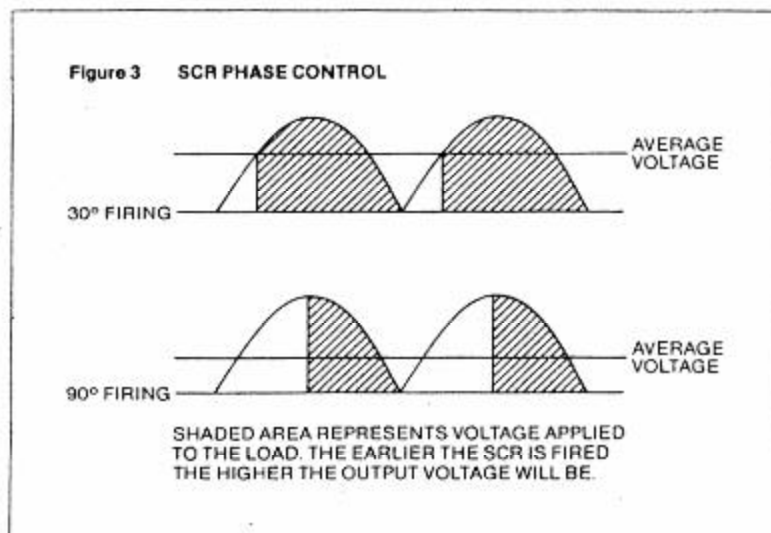
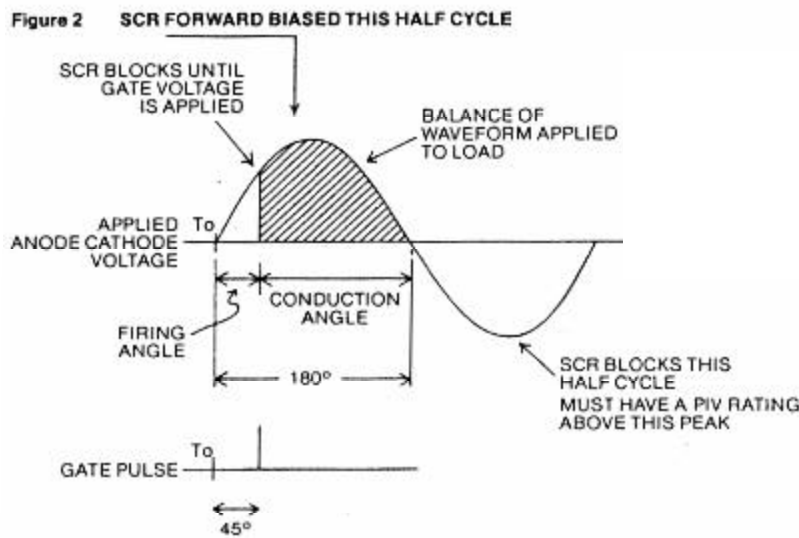
SCR Phase Control

In SCR Phase Control, the firing angle, or point during the half-cycle at which the SCR is triggered, determines the amount of current which flows through the device. It acts as a high-speed switch which is open for the first part of the cycle, and then closes to allow power flow after the trigger pulse is applied.

Figure Two below shows an AC waveform being applied with a gating pulse at 45 degrees. There are 360 electrical degrees in a cycle; 180 degrees in a half-cycle. The number of degrees from the beginning of the cycle until the SCR is gated ON is referred to as the *firing angle*, and the number of degrees that the SCR remains conducting is known as the *conduction angle*.

The earlier in the cycle the SCR is gated ON, the greater will be the voltage applied to the load. Figure Three shows a comparison between the average output voltage for an SCR being gated on at 30 degrees as compared with one which has a firing angle of 90 degrees. Note that the *earlier* the SCR is fired, the *higher* the output voltage applied to the load.

The voltage actually applied to the load is no longer sinusoidal, rather it is pulsating DC having a steep wavefront which is high in harmonics. This waveform does not usually cause any problems on the driven equipment itself; in the case of motor loads, the waveform is smoothed by the circuit inductance. However, radio or television interference can occur. Often times the manufacturer of the SCR equipment will include an Electro-Magnetic-Interference (EMI) filter network in the control to eliminate such problems.



SCR

Protection / Firing Circuits / Testing

SCR Protection

The SCR, like a conventional diode, has a very high one-cycle surge rating. Typically, the device will carry from eight to ten times its continuous current rating for a period of one electrical cycle. It is extremely important that the proper high-speed, current-limiting, rectifier fuses recommended by the manufacturer be employed - *never substitute with another type fuse*. Current limiting fuses are designed to sense a fault in a quarter-cycle and clear the fault in one-half of a cycle, thereby protecting the SCR from damage due to short circuits.

Switching spikes and transients, which may exceed the device PIV rating, are also an enemy of any semiconductor. Surge suppressors, such as the GE Metal-Oxide-Varistor (MOV), are extremely effective in absorbing these short-term transients. High voltage capacitors are also often employed as a means of absorbing these destructive spikes and provide a degree of electrical noise suppression as well.

Computing the Required Firing Angle

For accurate SCR gating, the *Firing Circuit* must be synchronized with the AC line voltage being applied anode-to-cathode across the device. Without synchronization, the SCR firing would be random in nature and the system response erratic.

In closed-loop systems, such as motor control, an *Error Detector Circuit* computes the required firing angle based on the system setpoint and the actual system output.

The firing circuit is able to sense the start of the cycle, and, based on an input from the Error Detector, delay the firing pulse until the proper time in the cycle to provide the desired output voltage. An analogy of a firing circuit would be an automobile distributor which advances or retards the spark plug firing based on the action of the vacuum advance mechanism.

In analog control systems the error detector circuit is usually an integrated circuit operational amplifier which takes reference and system feedback inputs and computes the amount of *error* (difference) between the actual output voltage and the desired setpoint value.

Even though the SCR is an analog device, many new control systems now use a microprocessor based, digital, firing circuit to sense the AC line zero-crossing, measure feedback and compare it with the setpoint, and generate the required firing angle to hold the system in-balance.

Testing the SCR

Shorted SCRs can usually be detected with an ohmmeter check (SCRs usually fail shorted rather than open). Measure the anode-to-cathode resistance in both the forward and reverse direction; a good SCR should measure near infinity in both directions.

Small and medium-size SCRs can also be gated ON with an ohmmeter (on a digital meter use the Diode Check Function). Forward bias the SCR with the ohmmeter by connecting the red (+) lead to the anode and the black (-) lead to the cathode. Momentarily touch the gate lead to the anode; this will provide a small positive turn-on voltage to the gate and the cathode-to-anode resistance reading will drop to a low value. Even after removing the gate voltage, the SCR will stay conducting. Disconnecting the meter leads from the anode or cathode will cause the SCR to revert to its non-conducting state.

When conducting the above test, the meter impedance acts as the SCR load. On larger SCRs, the unit may not latch ON because the test current is not above the SCR holding current. Special testers are required for larger SCRs in order to provide an adequate value of gate voltage and load the SCR sufficiently to latch ON.

Hockey puck SCRs must be compressed in a heat sink (to make-up the internal connections to the semiconductor) before they can be tested or operated.

Some equipment manufacturers provide tabulated ohmmeter check-data for testing SCR assemblies.