Turning off the silicon controlled rectifier requires that the current between the anode and cathode be reduced below the small level designated as the *holding current*. Control begins when a controlled rectifier is *triggered* or made to conduct in the forward direction. It will remain conducting even after the trigger signal is removed. To shut it off requires reducing the forward current to a level below the specified holding current or reversing the potential across the terminals. The rectifier then returns quickly to its nonconducting state until it is triggered again.

Turn-Off Methods

The SCR resembles a latching switch in that its basic function is to turn on current or power to a load when a signal is applied, and then to maintain the closed circuit when the signal is removed. Turning off the power must be accomplished through separate circuitry.

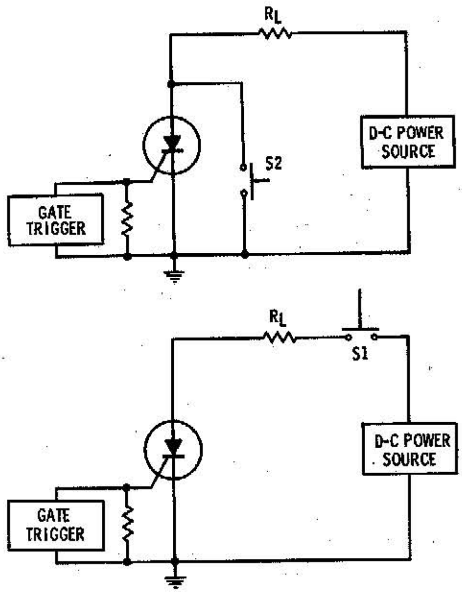
To stop an SCR from conducting, the cathode-to-anode current (which is also the load current) must be reduced to a value lower than the holding current. For most SCR's the latter is 5 to 20 milliamperes. Since normal load current is in the ampere region, this is almost the same as saying that the current must be reduced to a value of zero.

Where the source voltage is alternating current, turn off is automatic. The a-c voltage and current at the anode of the SCR drop to zero (and below) every cycle (Fig. 1-6), effectively causing the SCR to stop conduction. This feature makes the SCR extremely useful in circuits involving alternating current. Complete turn-on and turn-off control is possible by working with the gate signals only. SCR's are available that will handle a-c frequencies up to 25 kHz. Where d-c power is being switched, turn-off arrangements vary from simple switches to self-timing circuitry.

Switch Turn-Off—Probably the most obvious way to accomplish turn-off is with a switch, and this can be very practical in some SCR circuits. Fig. 1-9 shows two possible variations.

A normally open push-button switch is used in Fig. 1-9A. When the switch is closed, the anode and cathode of the SCR are shorted together, reducing the voltage (and current) across them to zero. Power will still flow to the load, however, since there is a complete circuit from source to load. Releasing the switch puts the SCR (which has been cut off) back in the circuit. Power through the load is now interrupted since the SCR is nonconducting.

In Fig. 1-9B a normally closed push button accomplishes the same objective. Depressing the switch opens the load circuit, thus reducing the SCR current to zero. When the push button is released the circuit is reset; the next time the SCR is triggered, power will be applied to the load.



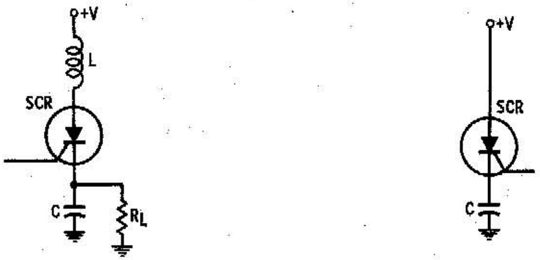
(A) Parallel switch.

(B) Series switch.

Fig. 1-9. Turn-off using a switch.

Capacitor Turn-off—In controlling d-c power one can use circuit components for the turn-off instead of depending on a manual switch. Either a series capacitor or a shunt capacitor may be employed. As one method, Fig. 1-10A shows a series-capacitor or hammer circuit. When the SCR is triggered, capacitor C charges to approximately twice the d-c supply voltage by the inductive action of L. The discharging capacitor reverse biases the SCR turning it off. In this circuit, current is delivered to the load in pulses, one pulse for each trigger signal. The length of the pulses is determined by the value of capacitance and inductance.

Fig. 1-10B shows a simple circuit with a capacitor in series with a controlled rectifier. This circuit can be used as a final stage in turn-



(A) Capacitor and inductor.

(B) Capacitor only.

Fig. 1-10. Series capacitor turn-off.

off circuitry since it turns itself off. When capacitor C approaches full charge, the current is reduced below the holding current value, and the SCR is turned off.

The circuit in Fig. 1-11 combines a capacitor and a manual switch to provide turn-off action. This has the advantage over the simple switch of Fig. 1-9 in that the full load current does not pass through the switch. With the SCR in its conducting state, capacitor C charges up to the d-c source minus the voltage drop across the SCR. The time required to charge capacitor C is determined by R2. When the switch is closed, capacitor C will produce a back bias for the SCR, allowing the SCR to regain its forward blocking feature. Capacitor C also supplies the load current for a short interval. The RL network in series with capacitor is used to limit the reverse recovery current.

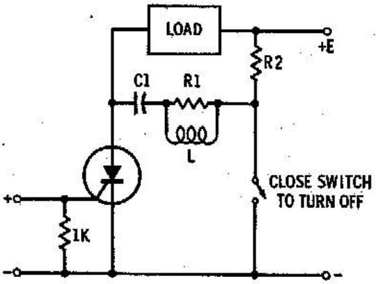


Fig. 1-11. Shunt switch turn-off.

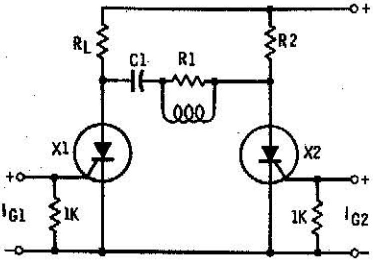


Fig. 1-12. Two-SCR turn-off.

The value of C depends on the load impedance and the recovery time of the controlled rectifier. C is also dependent on the amount of peak reverse current allowed to flow through the device during the time that it is reverse biased. These will vary with the individual circuits and the SCR that are used.

Capacitor-SCR Turn-Off—The switch in Fig. 1-11 used to turn off the SCR can be replaced with another controlled rectifier in some applications. This circuit (Fig. 1-12) is quite similar to a latching relay with two inputs, one to latch the relay and one to unlatch it. X1 can be turned off by turning X2 on; X2 can be turned off by turning X1 on. The resulting current in the load is a series of pulses as the two gates are alternately triggered. In this circuit one must be sure that both inputs are never energized at the same time. The first SCR is chosen to carry the required current for the load, while the second SCR may be one with a much lower rating. This circuit can be made with two equal SCR's for applications where two separate loads are to be handled.

Turn-off of the SCR's is accomplished by the discharging of capacitor C1. When X1 is fired, capacitor C1 charges up through resistor R to the positive supply (less the drop across X1) with the polarity shown. When X2 is fired, the capacitor discharges, placing a negative voltage on the anode of X1 and thus turning it off. Capacitor C1 then charges up through R_L and X2 to a polarity opposite that shown. When X1 is again fired, X2 is turned off by the same process as above. The proper value for capacitor C1 is determined by the load current, the applied d-c voltage, and the turn-off time of the SCR.

The gate signal is *current*, not voltage, for an SCR. Application for any controlled rectifier includes modulation of power, as is needed to control the speed of motors or vary the intensity of electric lights.

An a-c supply is commonly used, and power is modulated by turning the rectifier on for only a portion of each cycle, with devices such as magnetic triggers, so that power is being transmitted only part of the time. The average power transmitted depends on the ratio of on time to off time.

Warm-up is eliminated with an SCR because conduction starts at once; since there are no start-up voltage requirements, power can be applied to the gate (triggering terminal) and the anode at the same time. The device usually functions as a solid-state circuit breaker and requires no external contactors.

General Definitions

PNPN-Type Switch—A PNPN-type switch as shown in Fig. 1-13 is a bistable-semiconductor device comprising three or more junctions, at least one of which can switch between reverse- and forward-voltage polarity within a single quadrant of the anode-to-cathode voltage-current characteristic.

Triode PNPN-Type Switch—A triode PNPN-type switch is a PNPN-type switch having one anode terminal, one cathode terminal, and one gate terminal.

Reverse Blocking PNPN-Type Switch—A reverse blocking PNPN-type switch, which for negative anode-to-cathode voltage does not

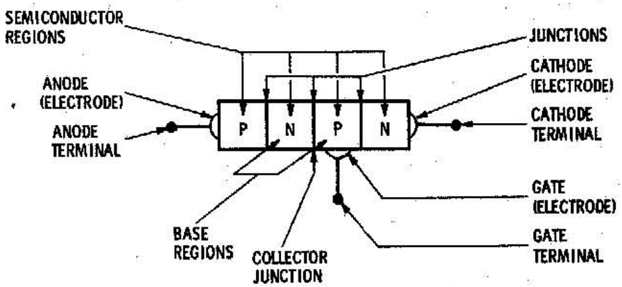


Fig. 1-13. A PNPN-type switch.

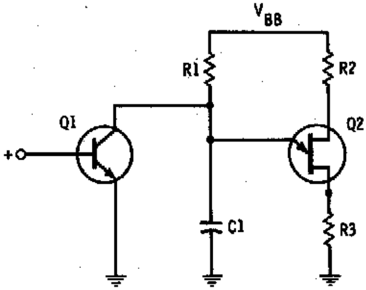


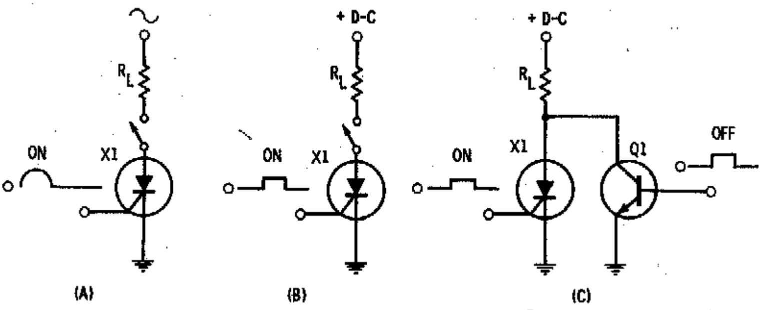
Fig. 2-9. Parallel transistor control of unijunction-trigger circuit.

Courtesy Texas Instruments Inc.

Normal phase control of the triggering signal is accomplished with a potentiometer as shown in the earlier figure. However, very small error voltages and input signals can be utilized to control the capacitor charging rate with the addition of series or parallel transistors in the emitter charging path. Fig. 2-8 shows a series transistor-control circuit to vary the triggering-phase angle. The output change in the period of oscillation is almost linear with input transistor-base current. Fig. 2-9 shows a parallel transistor circuit which has very high power gain but poor linearity characteristics for the change in the period of oscillation.

ANODE TURN-OFF METHODS

Controlled rectifiers can trigger large anode currents with very small gate-current levels. However, the controlled rectifier loses gate control of the anode current after conduction begins. The controlled rectifier must be turned off by reducing the anode current below the device's holding current. For a-c circuit applications there is no problem because the device turns off at the end of each conduction half cycle when the anode voltage goes to zero. Fig. 2-10 shows three simple circuits for anode holding-current turn-off operation. All three

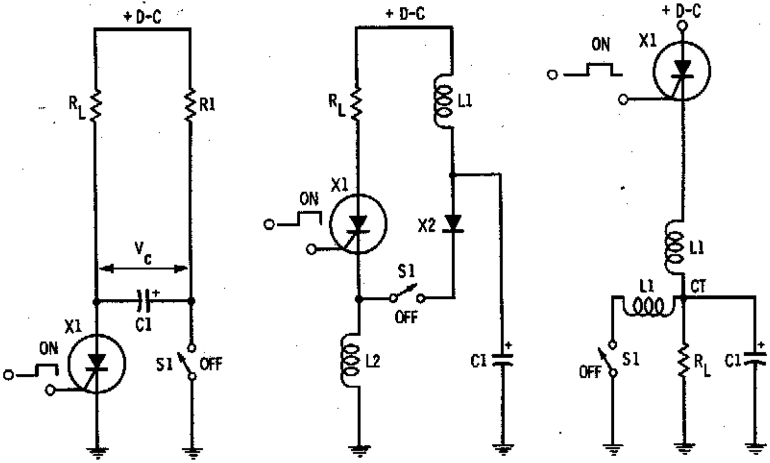


Courtesy Texas Instruments Inc.

Fig. 2-10. Anode holding-current turn-off methods.

methods depend on the reduction of the anode current below the device holding current to achieve turn-off. This method of turn-off is slow and generally not acceptable where high-frequency operation is desired.

Faster turn-off operation can be achieved by the use of a charged capacitor delivering energy into the SCR when allowed to reverse bias an SCR in the conduction state. The device will conduct high reverse current, discharging the capacitance until the device's emitter junctions recover; and then a finite additional time is required for carrier recombination to become complete in the N base of the SCR. Fig. 2-11 illustrates three circuits used to turn off an SCR employing a charged capacitor to deliver energy to the SCR. A switch is shown in Fig. 2-11A to activate the turn-off mechanism, but another SCR could be used in the circuits to achieve the same results. Load current is turned on with the gate signal of the SCR. The source voltage will appear across R1 and charge capacitor C1 as shown. When switch S1 is closed, the charged capacitor is connected across the SCR, reverse biasing the conducting device until the SCR recovers and turns off. The size of the capacitance necessary to achieve this turn-off method is dependent on the anode current being turned off and the source voltage charging the capacitor.



(A) Reverse biasing. (B) Cathode turn off. (C) Modified cathode turn off.

Courtesy Texas Instruments Inc.

Fig. 2-11. Capacitor discharge turn-off methods.

Fig. 2-11B shows a typical cathode turn-off circuit. The SCR is turned on, and load current passes through R_L and L2. The capacitor (C1) will charge up through L1 to twice the d-c source voltage.

When the switch is closed, capacitor C1 discharges through L2 and the cathode of the SCR will be driven positive with respect to the anode. This allows reverse recovery current to flow and the SCR will turn off. When another SCR is used in place of switch S1, the SCR in the capacitor-discharge circuit will turn off when inductor L2 tries to ring back into C1.

Fig. 2-11C is a modification of the previous cathode turn-off circuit employing a center-tapped inductor to provide autotransformer action. The SCR is turned on and load current passes into the load (R_L) through half of the inductor L1, charging capacitor C1 to the d-c source voltage. When the switch is closed, capacitor C1 discharges through the other half of the inductor (L1), and the cathode of the SCR is driven positive with respect to the anode by autotransformer action. The reverse bias on the SCR allows reverse recovery current to flow and the SCR turns off.