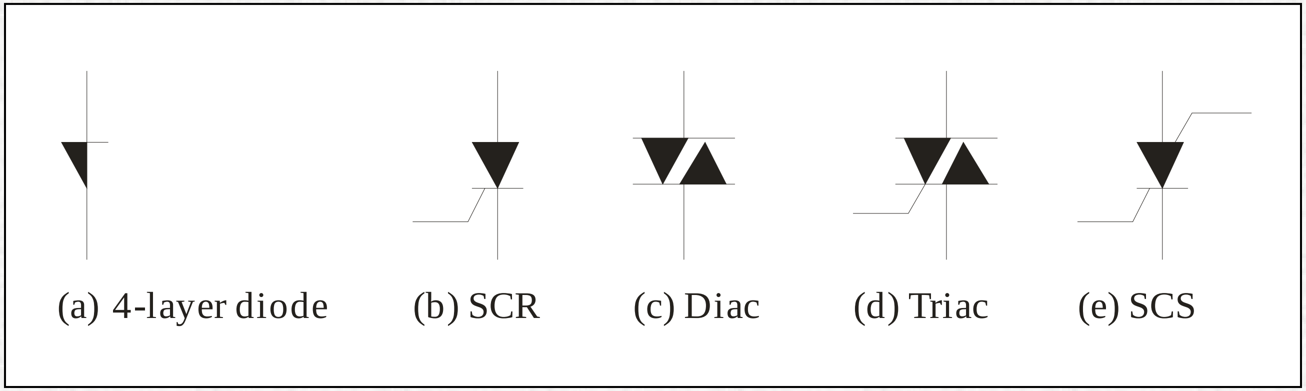
THYRISTORS

Thyristors

Thyristors are a class of semiconductor devices characterized by 4-layers of alternating *p* and *n* material. Four-layer devices act as either open or closed switches; for this reason, they are most frequently used in control applications.

Some thyristors and their symbols are



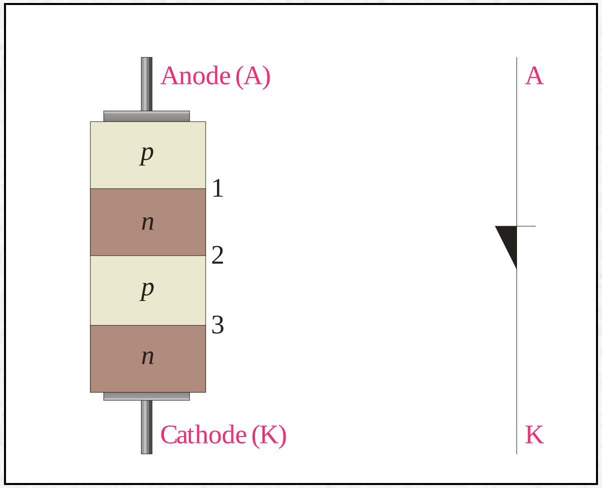
The Four-Layer Diode

The **4-layer diode** (or Shockley diode) is a type of thyristor that acts something like an ordinary diode but conducts in the forward direction only after a certain anode to cathode voltage called the forward-breakover voltage is reached.

The basic construction of a 4-layer diode and its schematic symbol are shown

The 4-layer diode has two leads, labeled the anode (A) and the cathode (K).

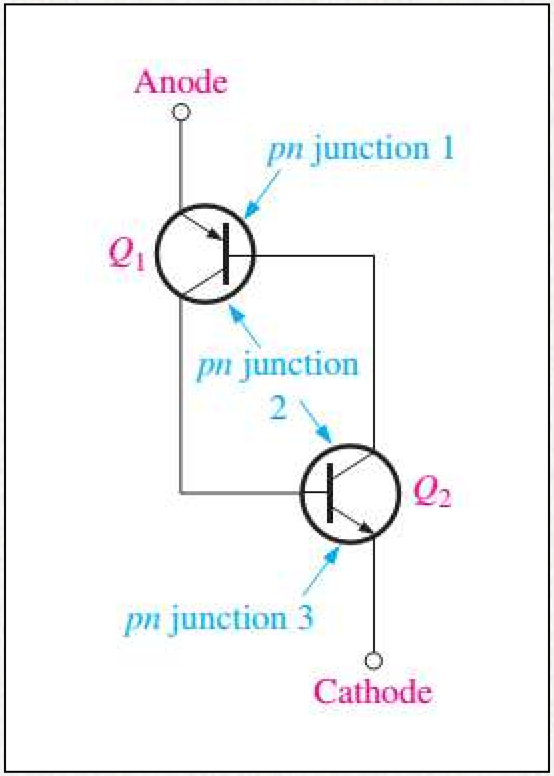
The symbol reminds you that it acts like a diode. It does not conduct when it is reverse-biased.



The Four-Layer Diode

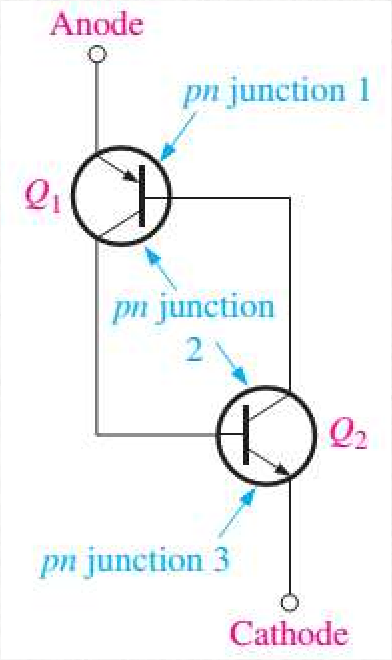
The concept of 4-layer devices is usually shown as an equivalent circuit of a *pnp* and an *npn* transistor.

Ideally, these devices would not conduct, but when forward biased, if there is sufficient leakage current in the upper *pnp* device, it can act as base current to the lower *npn* device causing it to conduct and bringing both transistors into saturation.



The Four-Layer Diode

The unusual connection shown uses positive feedback. Any change in the base current of Q_2 is amplified and fed back through Q_1 to magnify the original change. This positive feedback continues changing the base current of Q_2 until both transistors go into either saturation or cutoff.

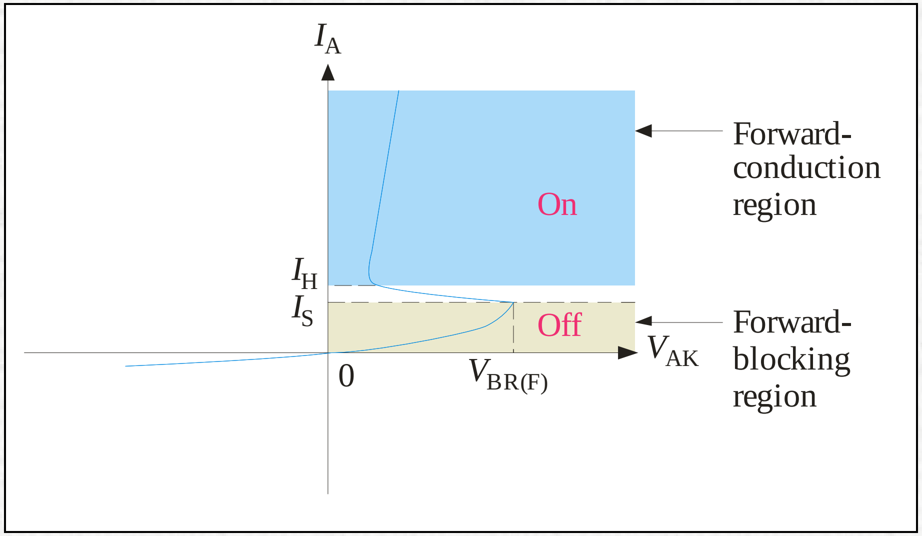


The only way to turn on the device is by breakover. This means using a large enough supply voltage to break down the Q_1 collector diode. Since the collector current of Q_1 increases the base current of Q_2, the positive feedback will start.

The Four-Layer Diode

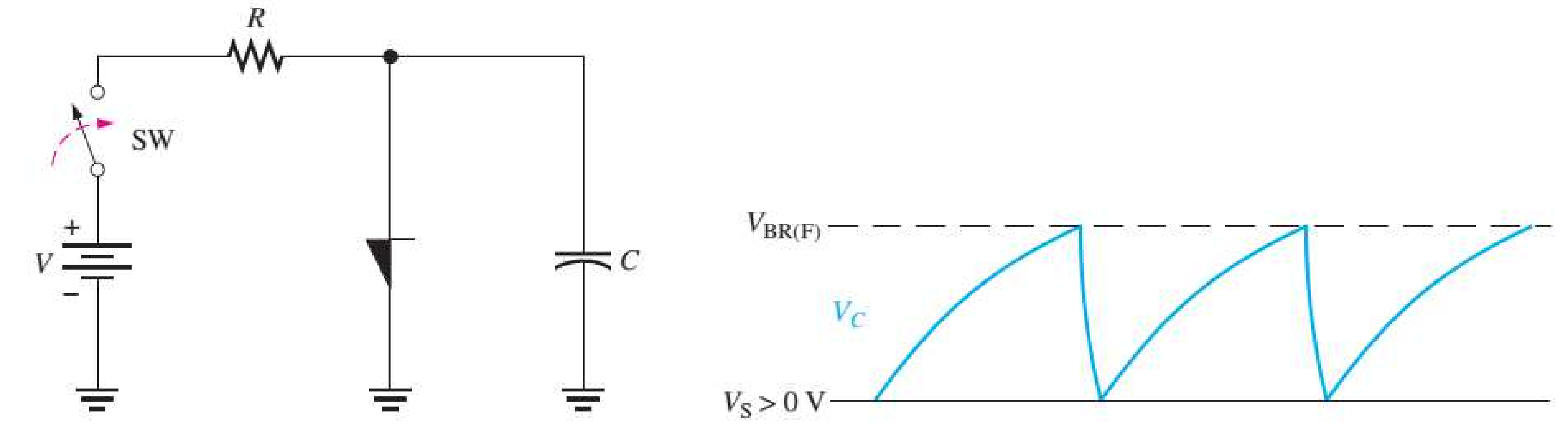
The characteristic curve for a 4-layer diode shows the forward blocking region. When the anode-to-cathode voltage exceeds V_{BR}, conduction occurs. The **switching current** at this point is I_S.

Once conduction begins, it will continue until anode current is reduced to less than the **holding current** (I_H). This is the only way to stop conduction.



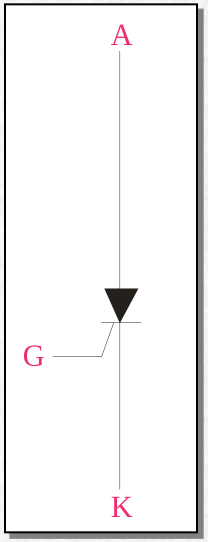
Four-Layer Diode Application

The circuit shown is a relaxation oscillator. When the switch is closed, the capacitor charges through R until its voltage reaches the forward breakover voltage of the 4-layer diode. At this point the diode switches into conduction, and the capacitor rapidly discharges through the diode. Discharging continues until the current through the diode falls below the holding value. At this point, the diode switches back to the off state, and the capacitor begins to charge again.



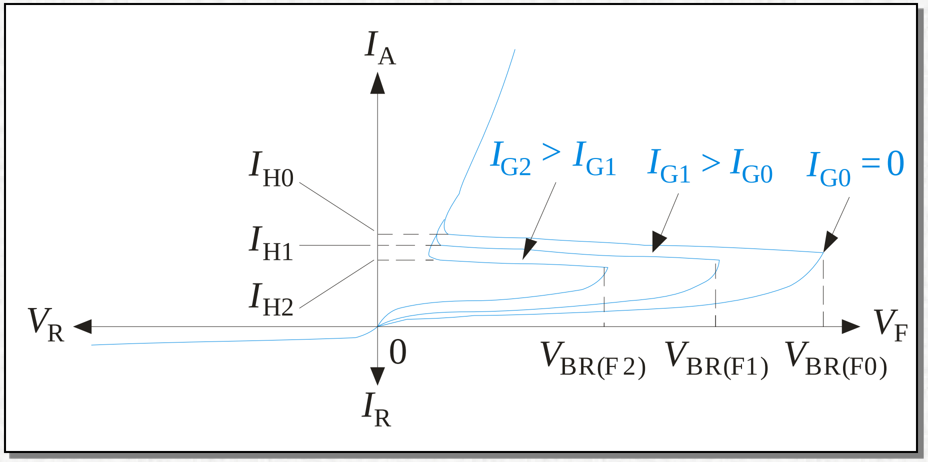
Silicon-Controlled Rectifier (SCR)

The **SCR** had its roots in the 4-layer diode. By adding a gate connection, the SCR could be triggered into conduction. The SCR is the most widely used thyristor. It can switch very large currents on and off.



The SCR can be turned on by exceeding the forward breakover voltage or by gate current. The gate current controls the amount of forward breakover voltage required for turning it on.

The SCR is far more useful than a four-layer diode because the gate triggering is easier than breakover triggering



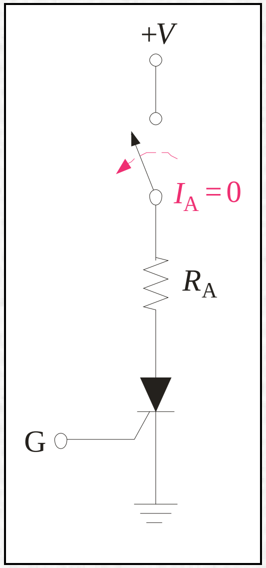
Electronic Devices, 9th edition
Thomas L. Floyd

Silicon-Controlled Rectifier (SCR)

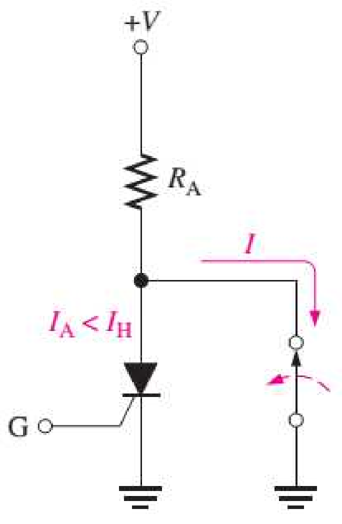
Like the 4-layer diode, the SCR will conduct as long as forward current exceeds I_H. There are two ways to drop the SCR out of conduction:

1) **Anode current interruption**

2) **Forced commutation**.



Anode current can be interrupted by breaking the anode current path, providing a path around the SCR, or dropping the anode voltage to the point that $I_A < I_H$.

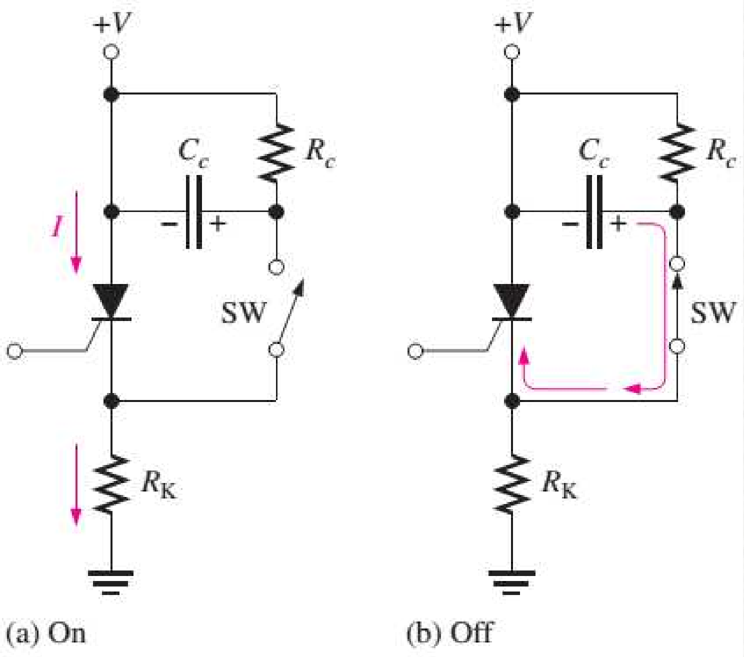


Silicon-Controlled Rectifier (SCR)

Force commutation uses an external circuit to momentarily force current in the opposite direction to forward conduction

The basic circuit consists of a switch and a capacitor. While the SCR is conducting, the switch is open and C_c is charged to the supply voltage through R_c .

To turn off the SCR, the switch is closed, placing the capacitor across the SCR and forcing current through it opposite to the forward current.



SCRs are commonly used in ac circuits, which forces the SCR out of conduction when the ac reverses.

SCR Specifications

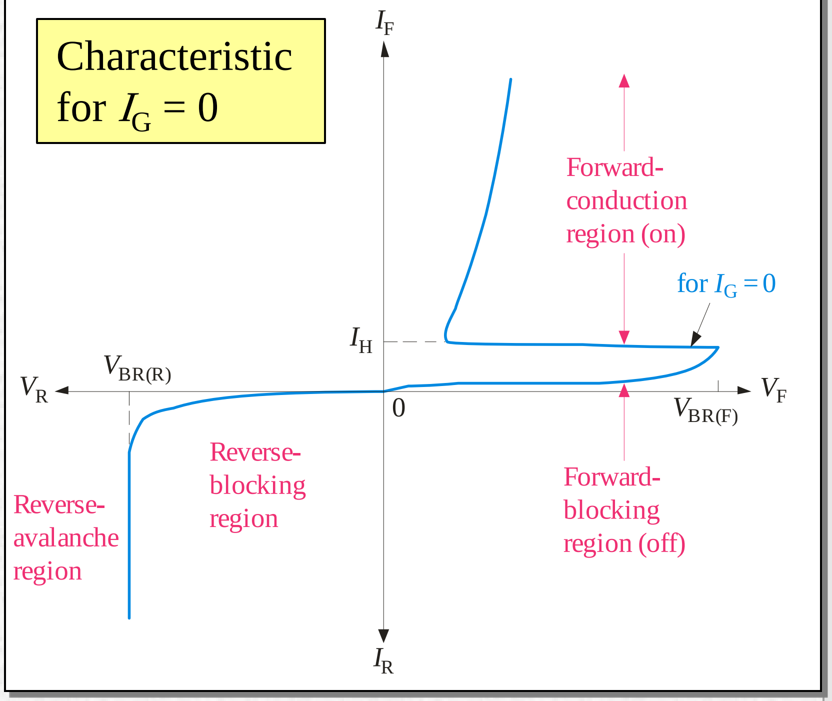
Three important SCR specifications are:

Forward-breakover voltage, $V_{BR(F)}$: This is the voltage at which the SCR enters the forward-conduction region.

Holding current, I_H: This is the value of anode current below which the SCR switches from the forward-conduction region to the forward-blocking region.

Gate trigger current, I_{GT}: This is the value of gate current necessary to switch the SCR from the forward-blocking region to the forward-conduction region under specified conditions.

Characteristic for $I_G = 0$

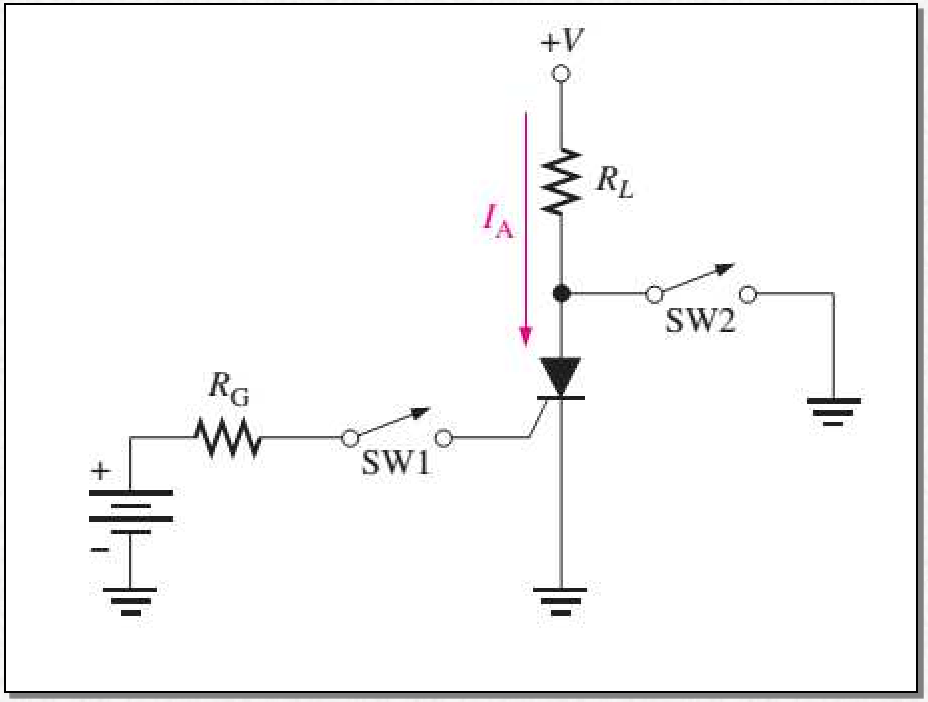


SCR Applications

On-Off Control of Current

The figure shows an SCR circuit that permits current to be switched to a load by the momentary closure of switch SW1 and removed from the load by the momentary closure of switch SW2.

Closure of SW1 provides a pulse of current into the gate, thus triggering the SCR on. When SW2 is momentarily closed, current is shunted around the SCR, thus reducing its anode current below the holding value. This turns the SCR off.

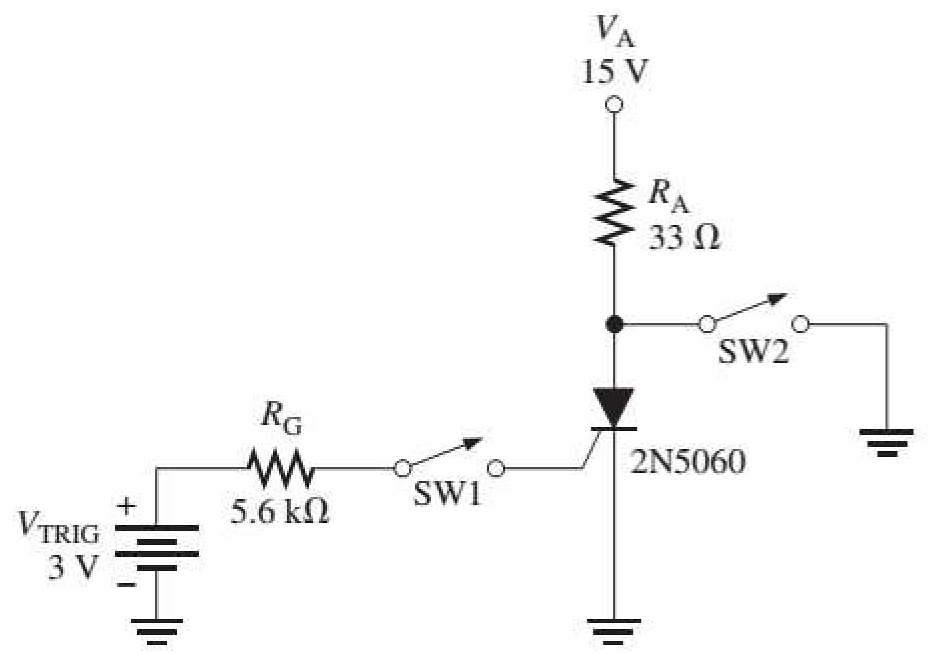


Example

Determine the gate trigger current and the anode current when the switch, SW1, is momentarily closed in Figure 11–16. Assume $V_{AK} = 0.2\text{ V}$, $V_{GK} = 0.7\text{ V}$, and $I_H = 5\text{ mA}$.

$$I_G = \frac{V_{TRIG} - V_{GK}}{R_G} = \frac{3\text{ V} - 0.7\text{ V}}{5.6\text{ k}\Omega} = \mathbf{410\ \mu A}$$

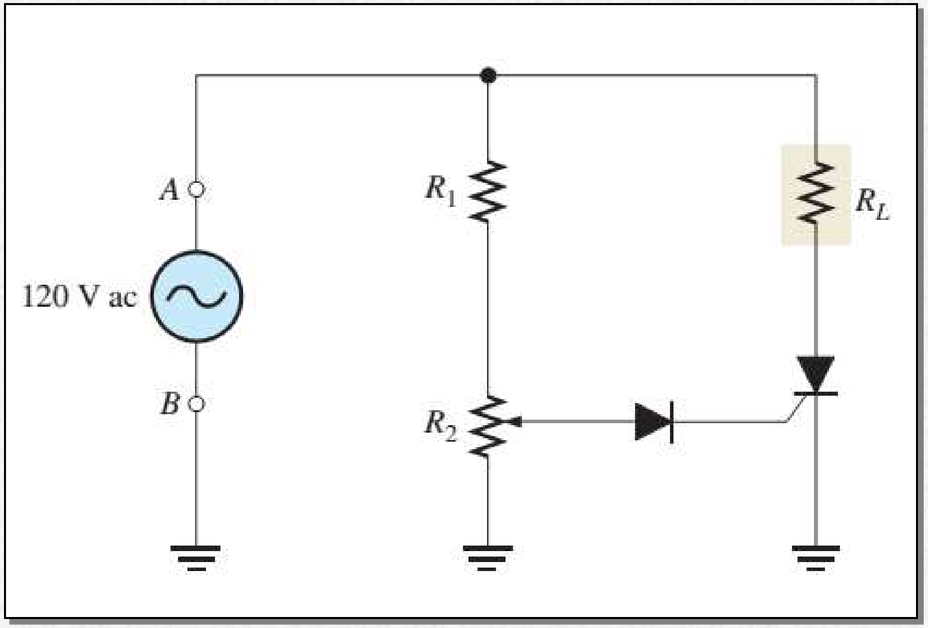
$$I_A = \frac{V_A - V_{AK}}{R_A} = \frac{15\text{ V} - 0.2\text{ V}}{33\ \Omega} = \mathbf{448\text{ mA}}$$



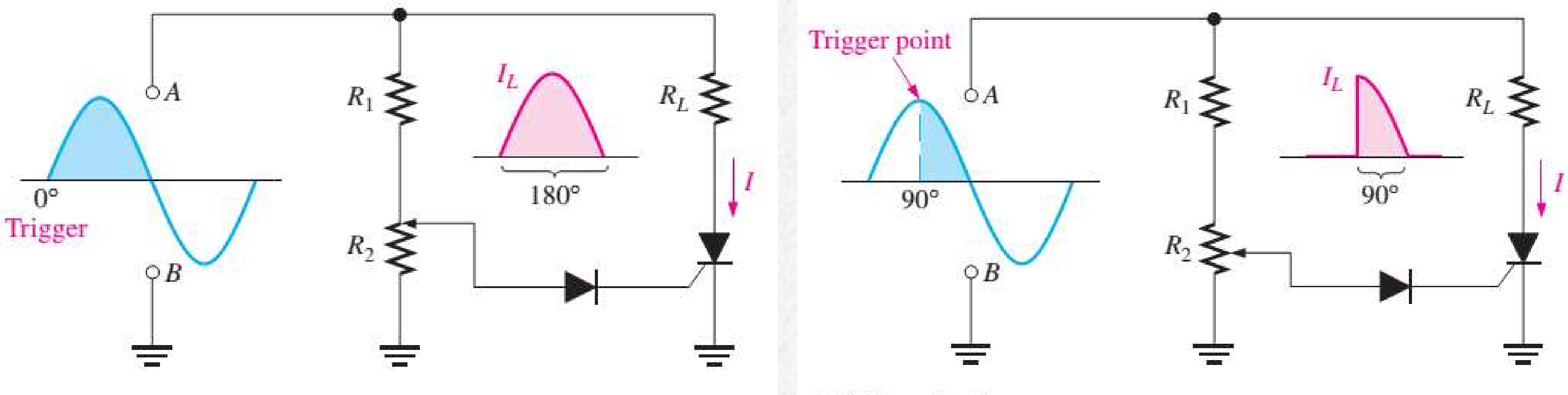
Half-Wave Power Control

A common application of SCRs is in the control of ac power for lamp dimmers, electric heaters, and electric motors. A half-wave, variable-resistance, phase-control circuit is shown. R_L represents the resistance of the load, R_1 limits the current, and potentiometer R_2 sets the trigger level for the SCR.

By adjusting R_2, the SCR can be made to trigger at any point on the positive half-cycle of the ac waveform between 0° and 90°, as shown in figure



Half-Wave Power Control



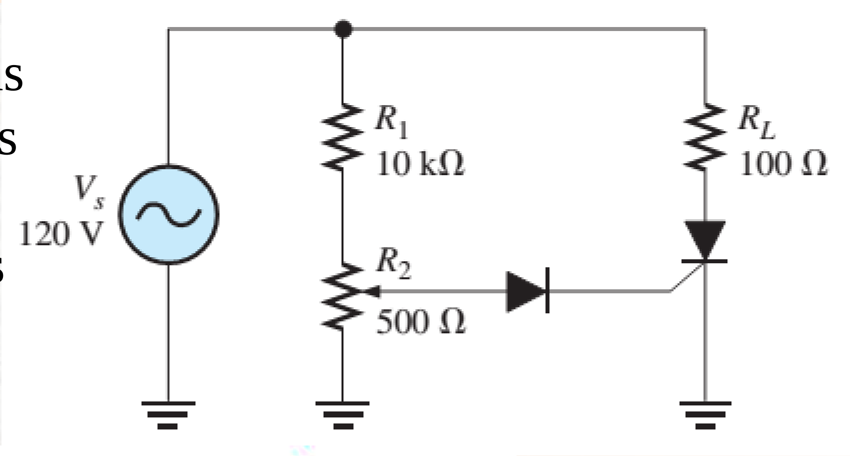
(a) 180° conduction

(b) 90° conduction

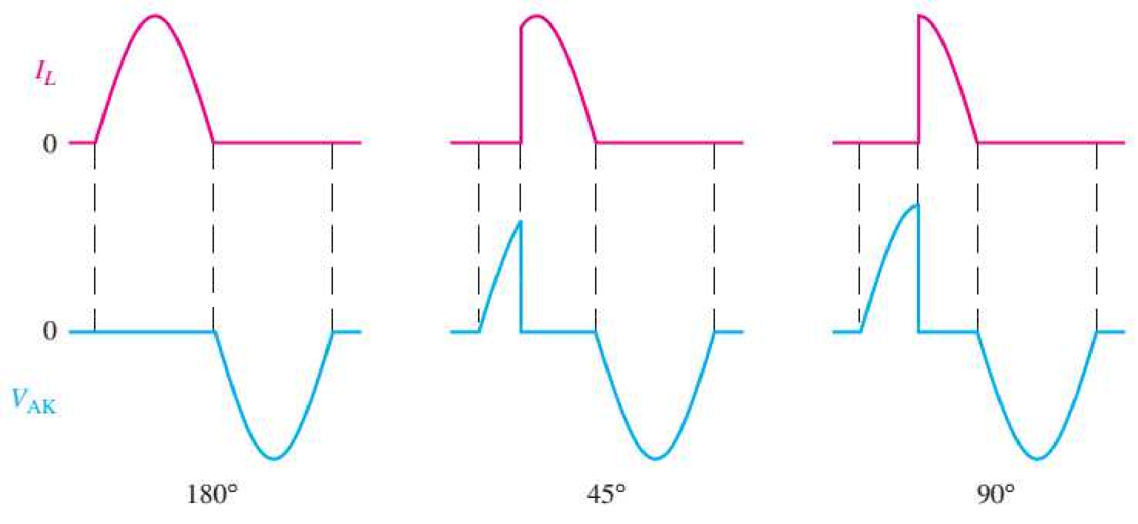
(c) 135° conduction

Example

Show the voltage waveform across the SCR in Figure 11–19 from anode to cathode (ground) in relation to the load current for 180°, 45°, and 90° conduction. Assume an ideal SCR.

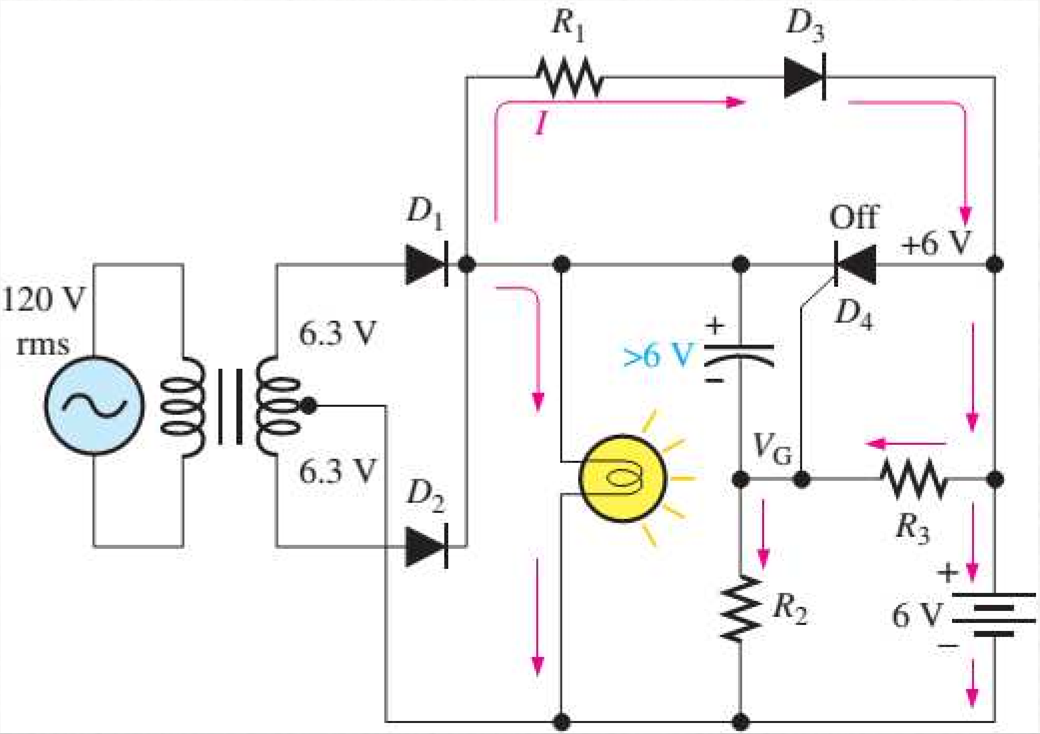


When there is load current, the SCR is conducting and the voltage across it is ideally zero. When there is no load current, the voltage across the SCR is the same as the applied voltage. The waveforms are shown.



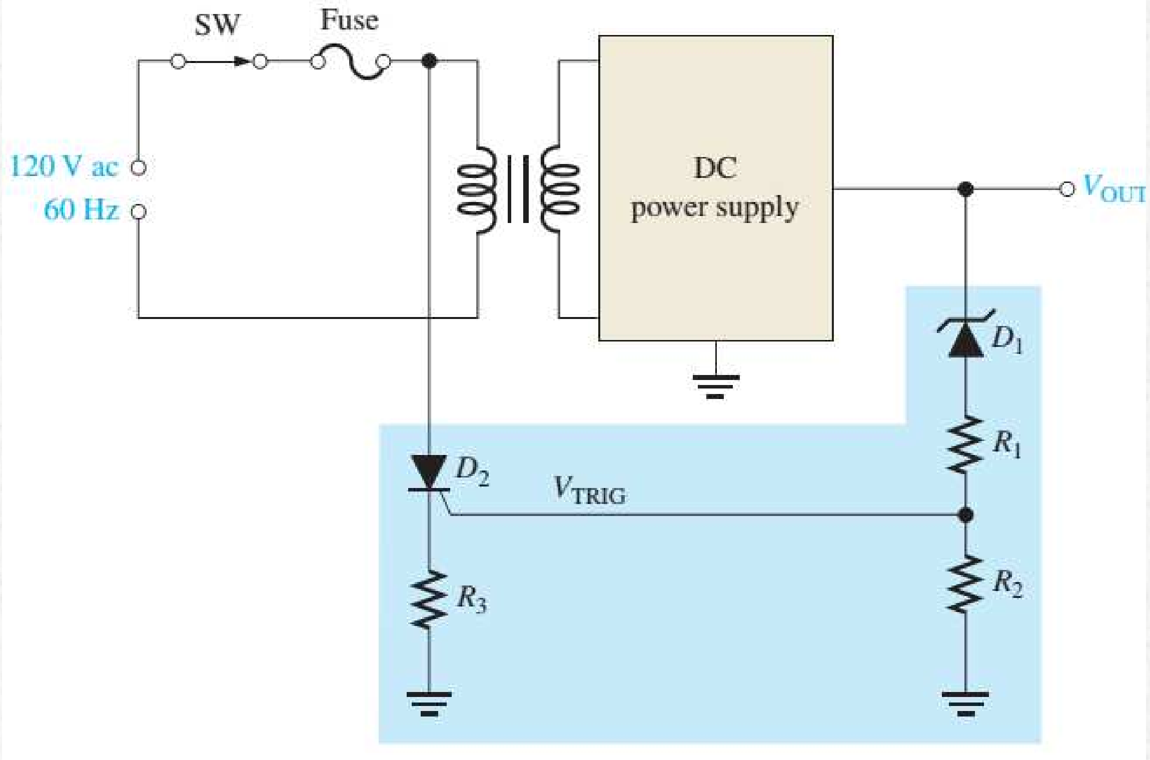
Backup Lighting for Power Interruptions

The circuit shown will maintain lighting by using a backup battery when there is an ac power failure. As long as the ac power is available, the battery charges through diode D3 and R1. When there is an interruption of ac power, the SCR conducts and current from the battery keeps illumination



An Over-Voltage Protection Circuit

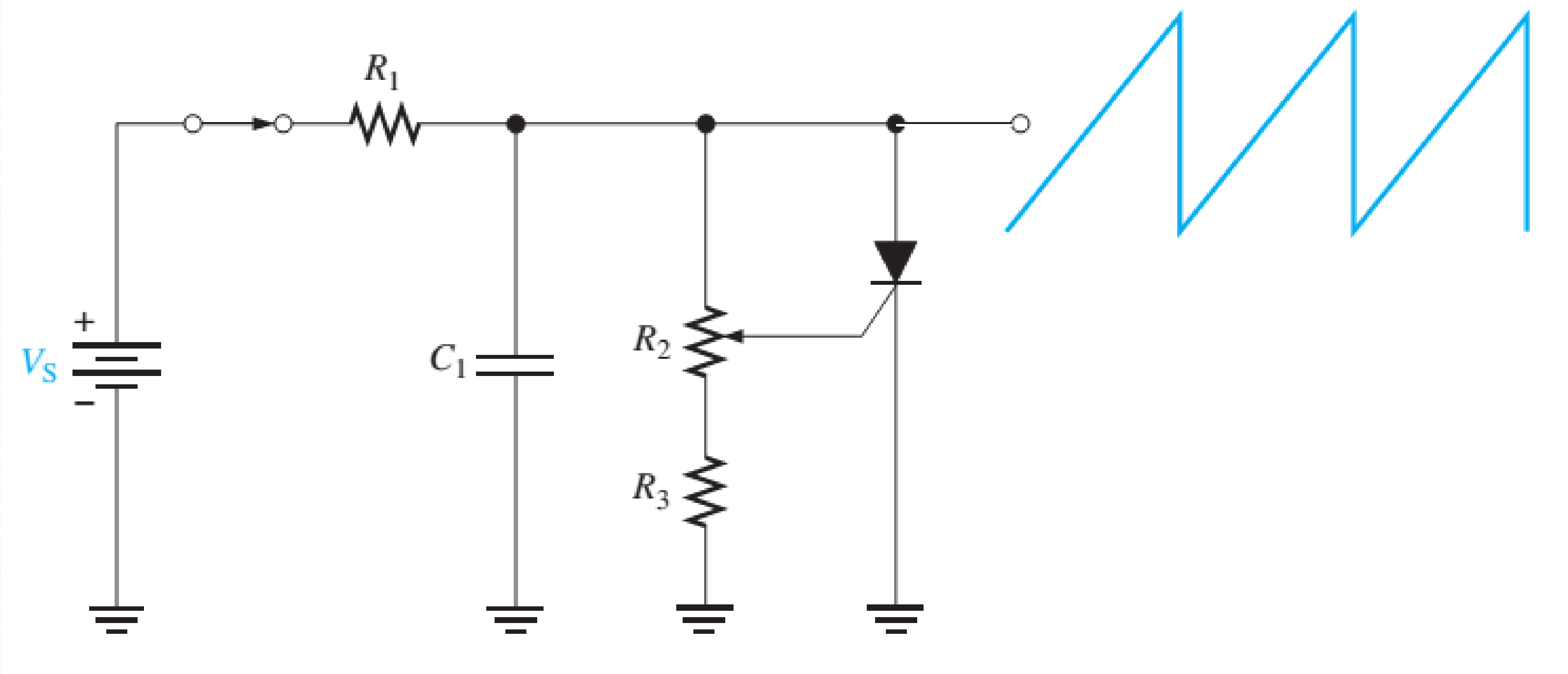
An over-voltage protection (crowbar) circuit is shown. If the dc output voltage is exceeds the zener voltage, the zener conducts and the voltage divider produces an SCR trigger voltage. The trigger voltage turns on the SCR, causing the fuse to blow.



Sawtooth Generator

- The SCR can be used in conjunction with an RC circuit to produce a repetitive sawtooth waveform.
- The time constant is set by R_1 and C_1, and the voltage at which the SCR triggers on is determined by the variable voltage-divider formed by R_2 and R_3 .
- When the switch is closed, the capacitor begins charging and turns on the SCR. When the SCR turns on, the capacitor quickly discharges through it; the anode current then decreases below the holding value, causing the SCR to turn off.
- As soon as the SCR is off, the capacitor starts charging again and the cycle is repeated.

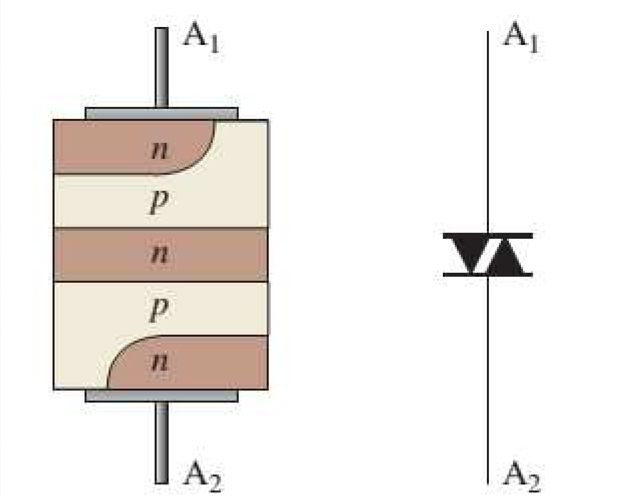
Sawtooth Generator



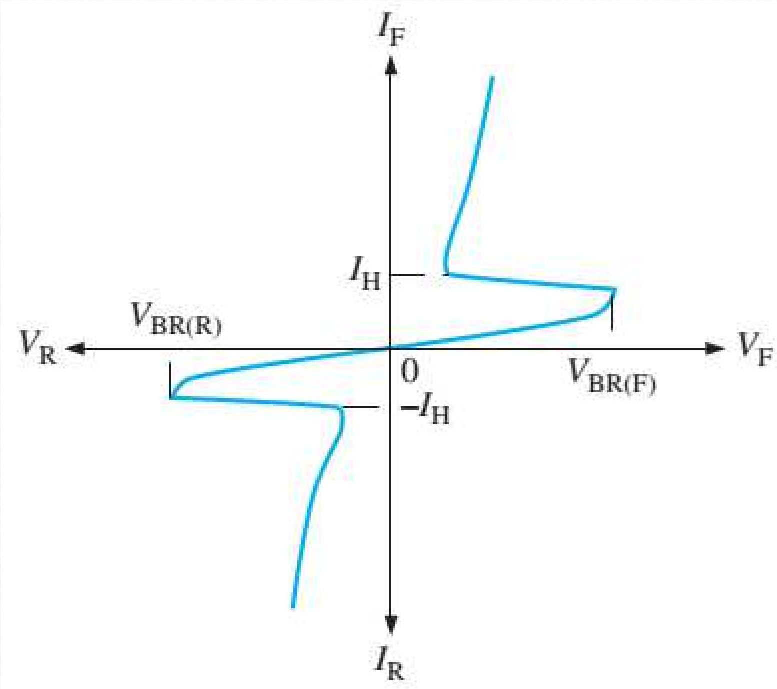
By adjusting the potentiometer, the frequency of the sawtooth waveform can be changed.

The Diac

The **diac** is a thyristor that acts like two back-to-back 4-layer diodes. It can conduct current in either direction. Because it is bidirectional, the terminals are equivalent and labeled A_1 and A_2.



(a) Basic construction (b) Symbol

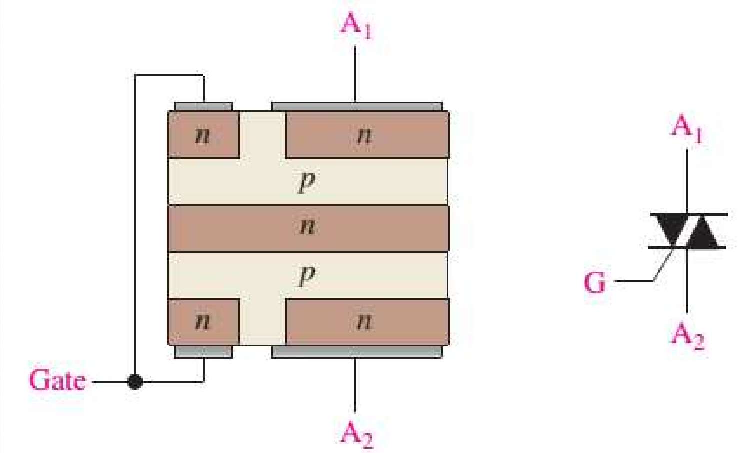


The Diac

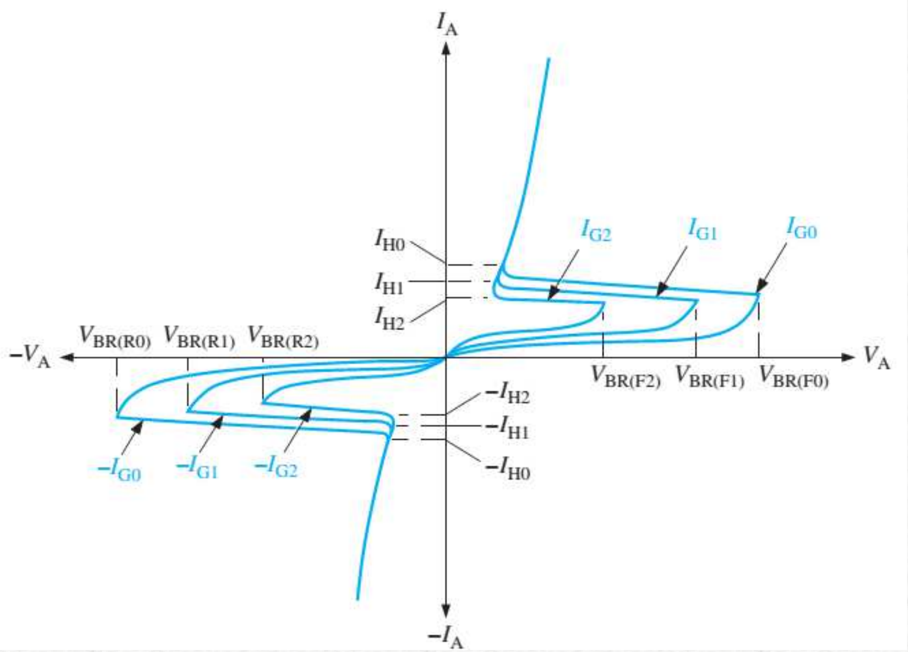
- The top and bottom layers contain both n and p materials.
- The right side of the stack can be regarded as a pnpn structure with the same characteristics as a four-layer diode, while the left side is an inverted four-layer diode having an npnp structure.
- Conduction occurs in a diac when the breakover voltage is reached with either polarity across the two terminals.
- Once breakover occurs, current is in a direction depending on the polarity of the voltage acrossthe terminals.
- The diac remains in conduction as long as the current is above the holding current, I_H.

The Triac

Basically, a triac can be thought as two SCRs connected in parallel and in opposite directions with a common gate terminal. Unlike the SCR, the triac can conduct current in either direction when it is triggered on, depending on the polarity of the voltage across its A_1 and A_2 terminals.



(a) Basic construction (b) Symbol



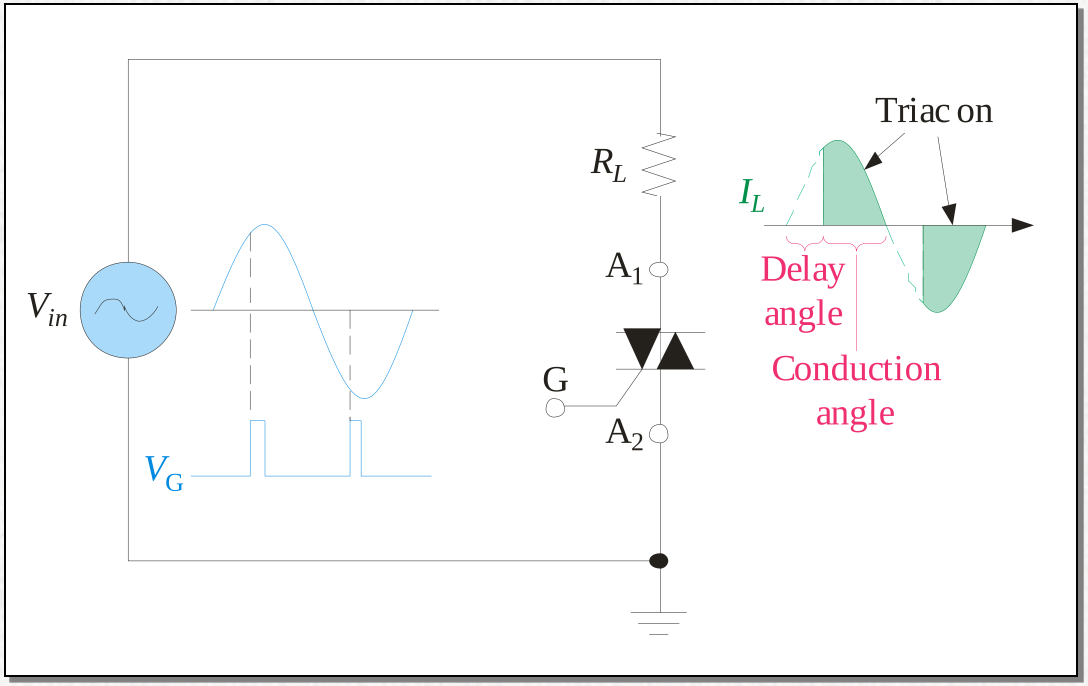
TheTriac

- The characteristic curve shows that the breakover potential decreases as the gate current increases, just as with the SCR.
- When the voltage on the A_1 terminal is positive with respect to A_2, a gate current pulse will cause the left SCR to conduct. When the anode voltages are reversed, the gate current pulse will cause the right SCR to conduct.
- As with other thyristors, the triac ceases to conduct when the anode current drops below the specified value of the holding current I_H.
- The only way to turn off the triac is to reduce the current to a sufficiently low level.

Triac Applications

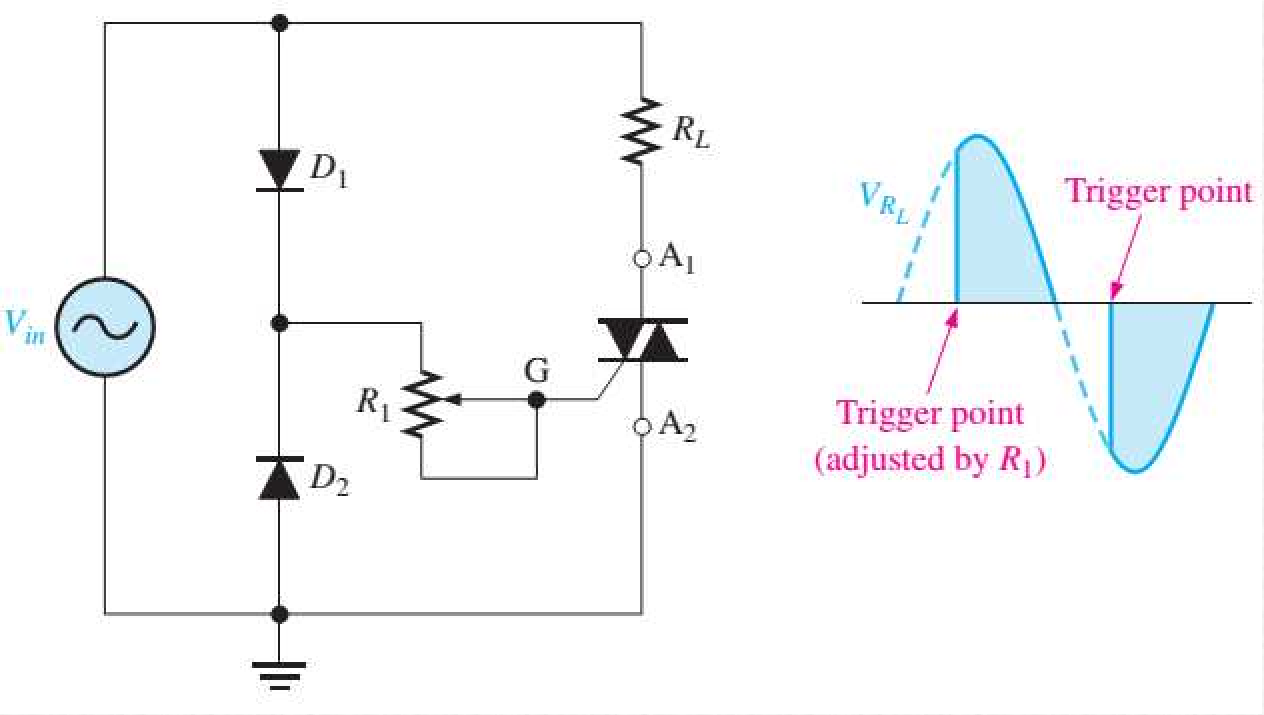
Like the SCR, triacs are also used to control average power to a load by the method of phase control. The triac can be triggered such that the ac power is supplied to the load for a controlled portion of each half-cycle.

During +ve half-cycle, the triac is off for a certain interval, called the delay angle, and then it is on for the remaining portion, called the conduction angle. Similar action occurs on the negative half-cycle.



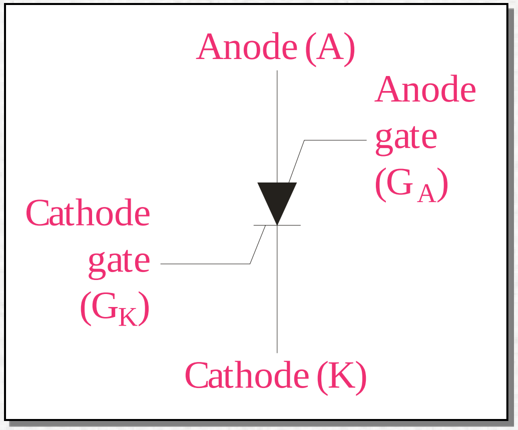
Triac Applications

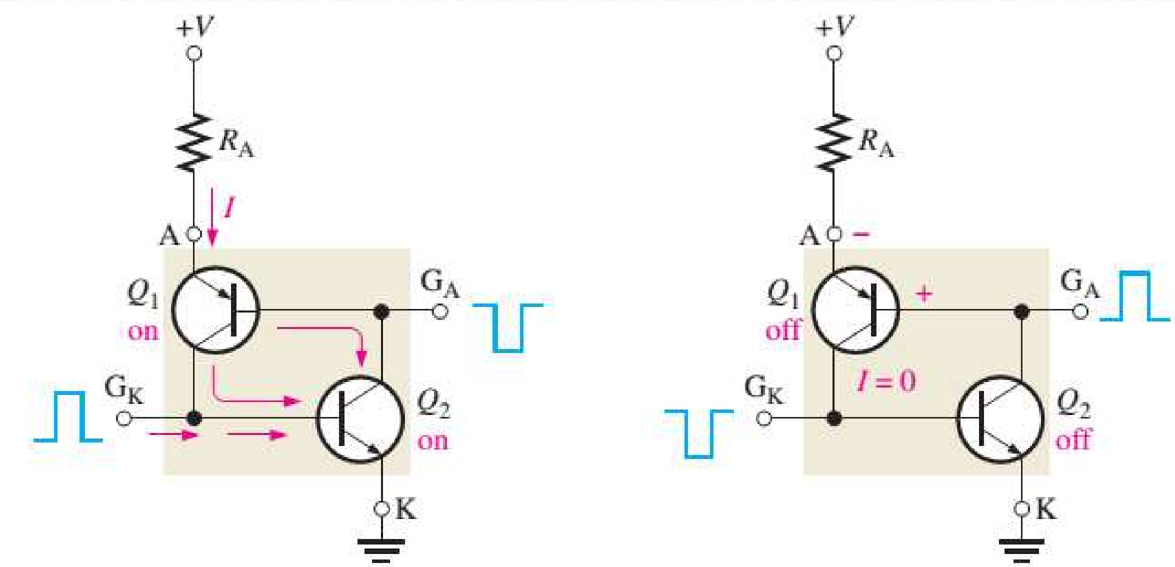
One example of phase control using a triac is shown. Diodes are used to provide trigger pulses to the gate of the triac. Diode D_1 conducts during the positive half-cycle and Diode D_2 conducts during the negative half-cycle. The value of R_1 sets the point at which the triac triggers.



The Silicon-Controlled Switch (SCS)

The silicon-controlled switch (SCS) is similar in construction to the SCR. The SCS, however, has two gate terminals, the cathode gate and the anode gate. The SCS can be turned on and off using either gate terminal.





(a) *Turn-on*: Positive pulse on G_K *or* negative pulse on G_A

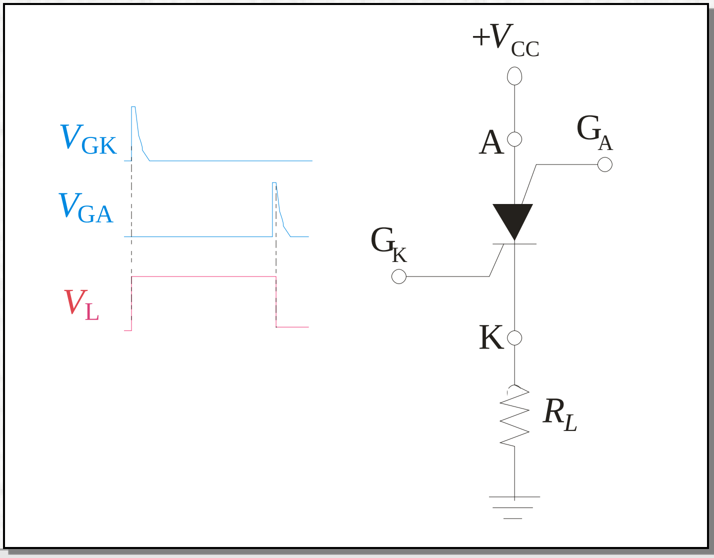
(b) *Turn-off*: Positive pulse on G_A *or* negative pulse on G_K

The Silicon-Controlled Switch (SCS)

The SCS can also be turned on by applying a positive pulse on the cathode gate or a negative pulse on the anode gate. To turn the SCS off, a negative pulse is applied to the cathode gate or a positive pulse is applied to the anode gate.

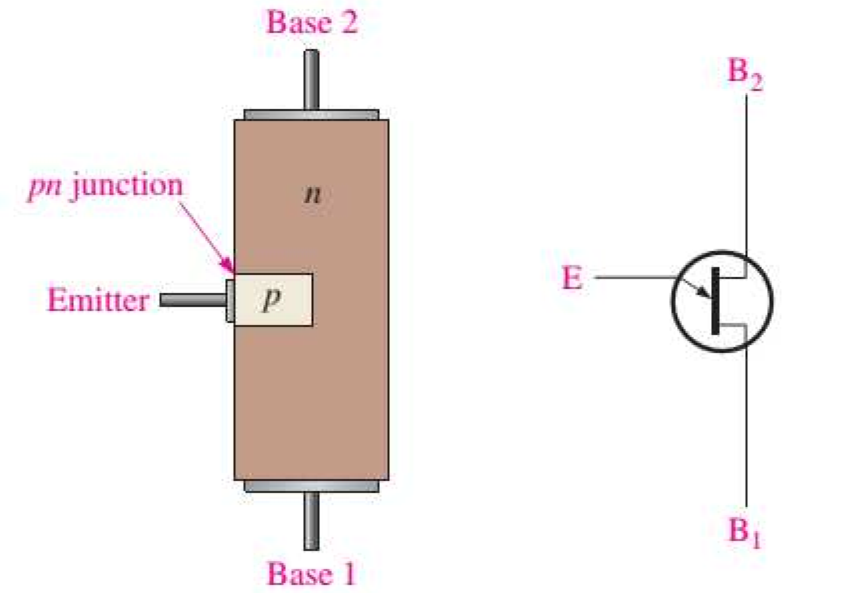
The SCS and SCR are used in similar applications. The SCS has the advantage of faster turn-off with pulses on either gate terminal.

In this example, the SCS is controlling a dc source. The load is in the cathode circuit, which has the advantage of one side of the load being on circuit ground.



The Unijunction Transistor (UJT)

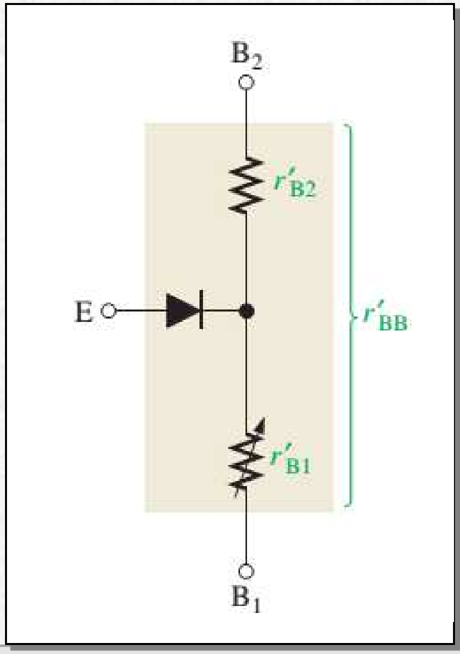
The UJT (unijunction transistor) is a three-terminal device. It is composed of a bar of N-type silicon with a P-type connection in the middle. The connections at the ends of the bar are known as bases B_1 and B_2; the P-type mid-point is the emitter.

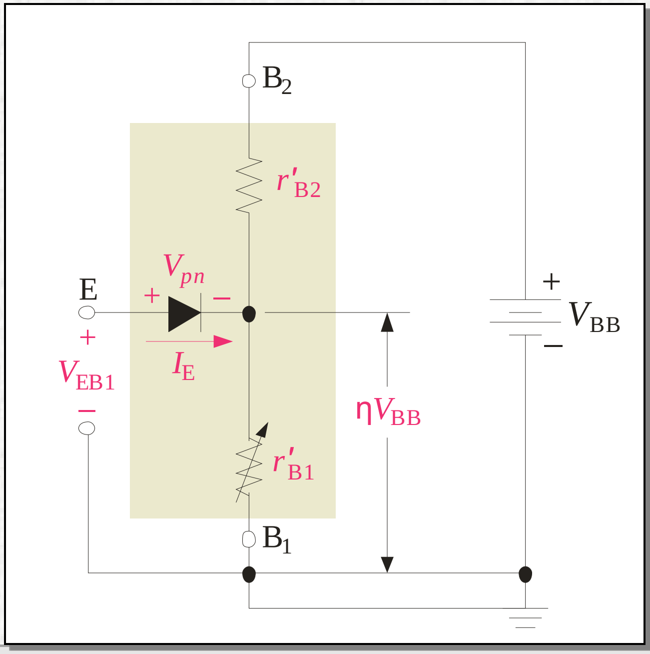


(a) Basic construction (b) Symbol

The Unijunction Transistor (UJT)

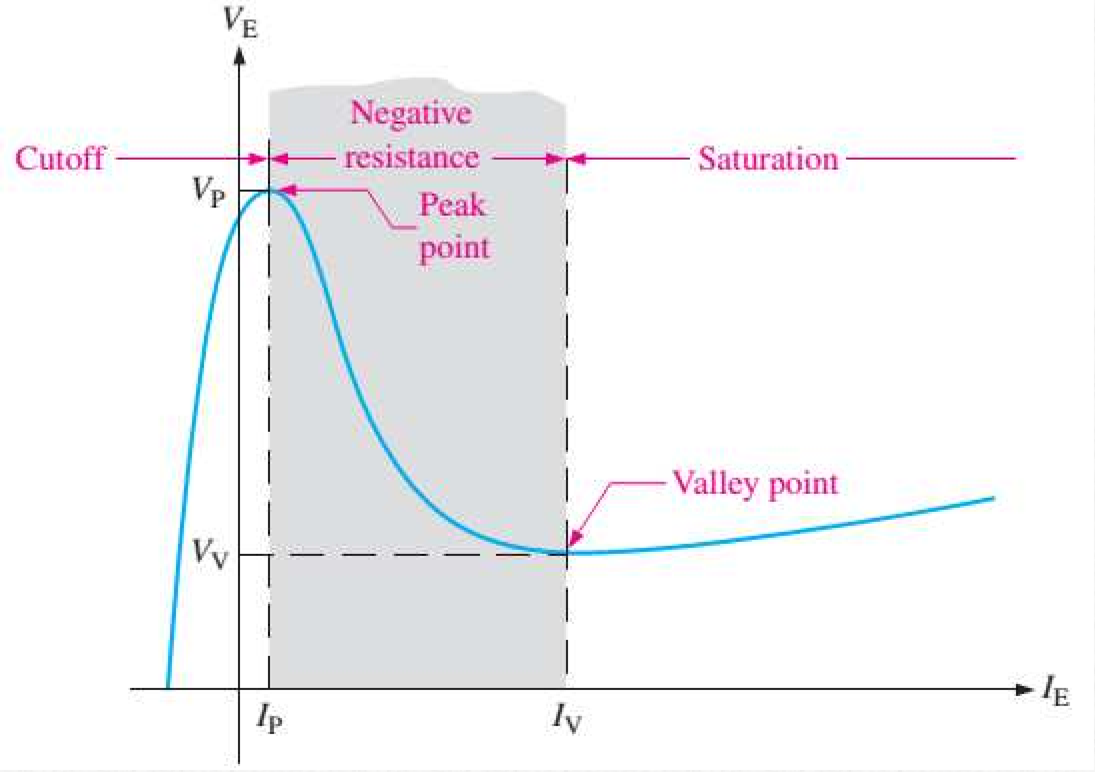
The equivalent circuit for the UJT is shown. The total resistance between the base terminals is the sum of the dynamic resistances r'_{B1} and r'_{B2} and is called the interbase resistance r'_{BB}. The ratio $\eta = r'_{B1}/r'_{BB}$ is called a UJT standoff ratio. When the emitter voltage reaches V_P (the peak point), the UJT "fires", where $V_P = \eta V_{BB} + V_{Pn}$





The Unijunction Transistor (UJT)

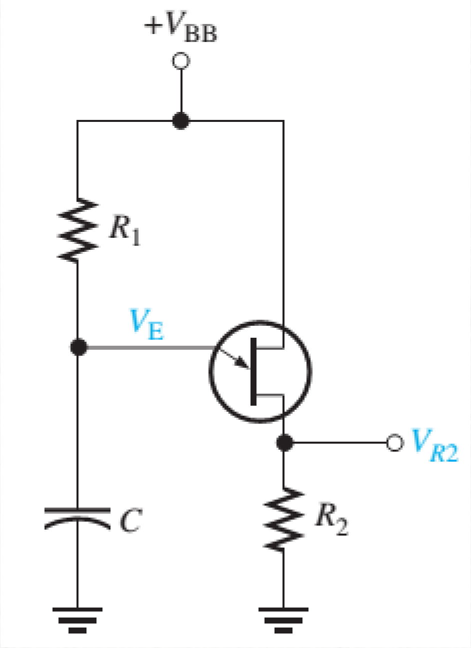
Where V_{Pn} is the barrier potential of the pn Junction. After turn-on, the UJT operates in a negative resistance region up to a certain value of I_E (valley point). Beyond the valley point, the device is in saturation, and V_E increases very little with an increasing I_E.



UJT Applications

The UJT can be used as a trigger device for SCRs and triacs. Other applications include nonsinusoidal oscillators, sawtooth generators, phase control, and timing circuits. The figure shows a UJT relaxation oscillator as an example of one application.

When dc power is applied, the capacitor C charges until it reaches the peak-point voltage. At this point, the pn junction becomes forward-biased, and the emitter characteristic goes into the negative resistance region. The capacitor quickly discharges through the forward-biased junction.

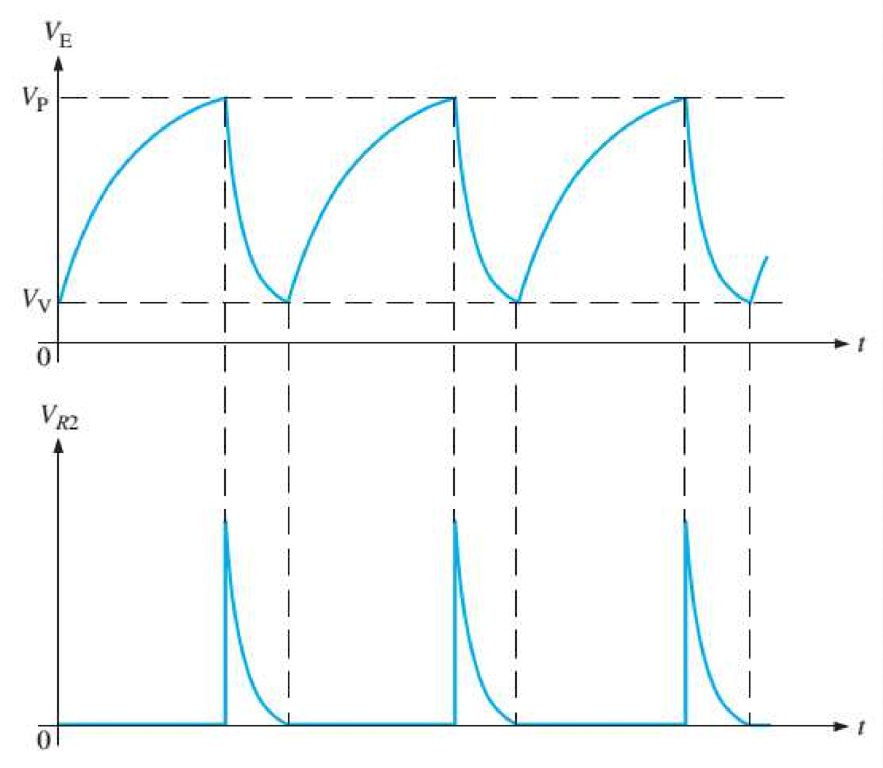


UJT Applications

When the capacitor voltage decreases to the valley-point voltage the UJT turns off, the capacitor begins to charge again, and the cycle is repeated. During the discharge time of the capacitor, the UJT is conducting.

to ensure that the UJT reliably turn on and turn off R_1 must be in the range

$$\frac{V_{BB} - V_P}{I_P} > R_1 > \frac{V_{BB} - V_V}{I_V}$$



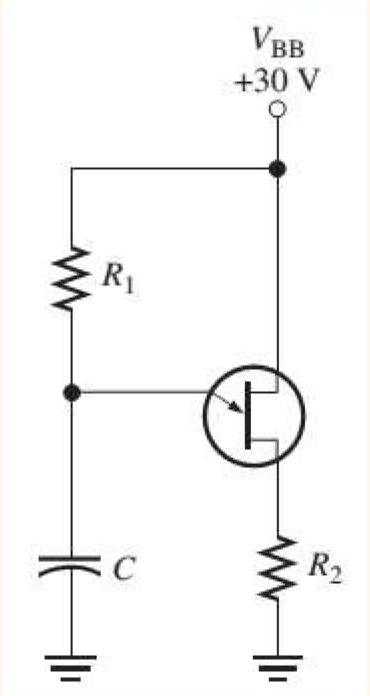
Example

Determine a value of R_1 in Figure 11–41 that will ensure proper turn-on and turn-off of the UJT. The characteristic of the UJT exhibits the following values: $\eta = 0.5$, $V_V = 1\text{ V}$, $I_V = 10\text{ mA}$, $I_P = 20\ \mu\text{A}$, and $V_P = 14\text{ V}$.

$$\frac{V_{BB} - V_P}{I_P} > R_1 > \frac{V_{BB} - V_V}{I_V}$$

$$\frac{30\text{ V} - 14\text{ V}}{20\ \mu\text{A}} > R_1 > \frac{30\text{ V} - 1\text{ V}}{10\text{ mA}}$$

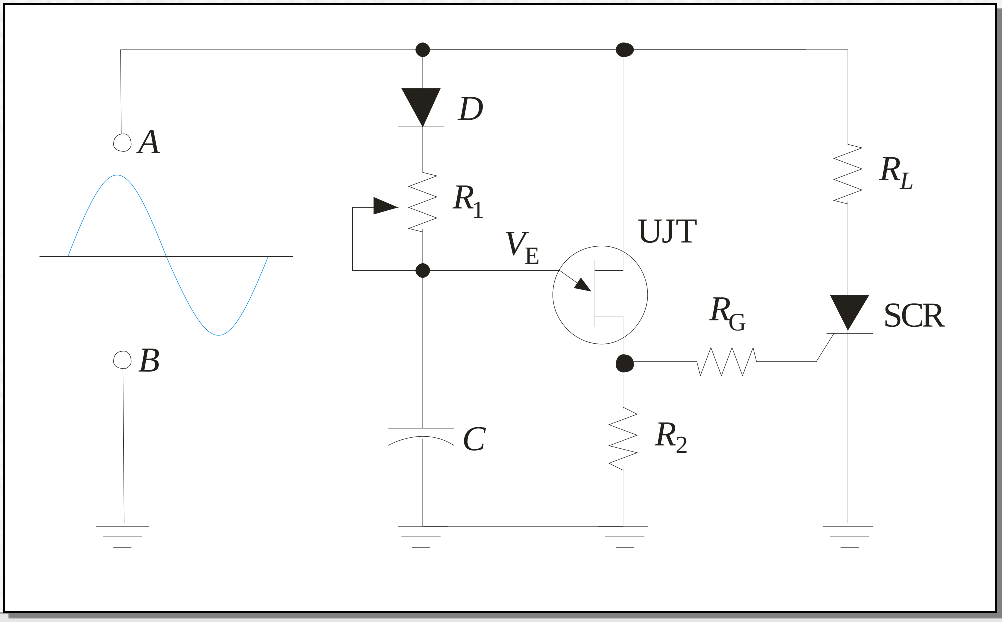
$$\mathbf{800\ k\Omega} > R_1 > \mathbf{2.9\ k\Omega}$$



UJT Applications

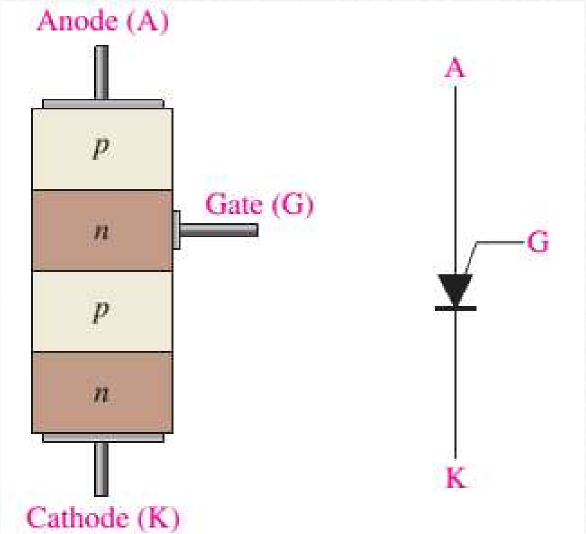
A circuit using a UJT to fire an SCR is shown. When the UJT fires, a pulse of current is delivered to the gate of the SCR. The setting of R_1 determines when the UJT fires. The diode isolates the UJT from the negative part of the ac.

The UJT produces a fast, reliable current pulse to the SCR, so that it tends to fire in the same place every cycle.

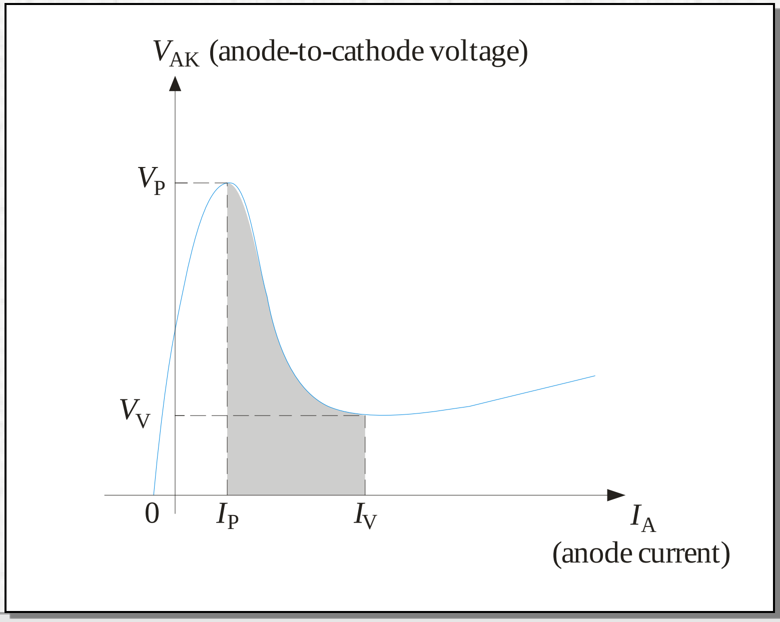


The Programmable Unijunction Transistor (PUT)

The PUT is a 4-layer thyristor with a gate. The gate pulse can trigger a sharp increase in current at the output. The cathode terminal is connected to a voltage lower than the gate. When the anode voltage becomes 0.7 V higher than the gate, the PUT turns on. The device will remain on until its anode current falls below a valley current.

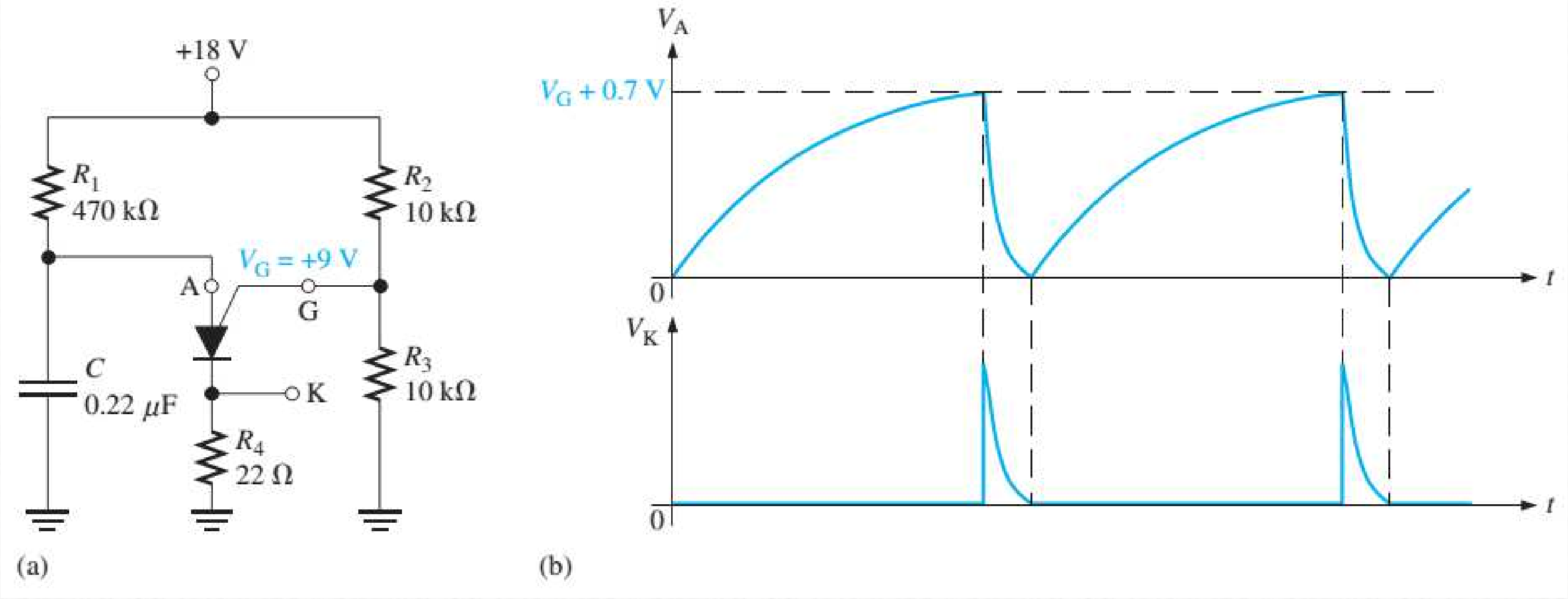


(a) Basic construction (b) Symbol



The Programmable Unijunction Transistor (PUT)

The principle application for a PUT is for driving SCRs and triacs, but, like the UJT, can be used in relaxation oscillators. The gate is biased at +9 V. When dc power is applied, the PUT is off and the capacitor charges toward +18 V. When the capacitor reaches V_G+0.7 V, the PUT turns on and the capacitor rapidly discharges through the low on resistance of the PUT



Selected Key Terms

4-layer diode The type of 2-terminal thyristor that conducts current when the anode-to-cathode voltage reaches a specified "breakover" value.

Thyristor A class of four-layer (*pnpn*) semiconductor devices.

SCR Silicon-controlled rectifier; a type of three terminal thyristor that conducts current when triggered by a voltage at the single gate terminal and remains on until anode current falls below a specified value.

Selected Key Terms

LASCR Light-activated silicon-controlled rectifier; a four layer semiconductor device (thyristor) that conducts current in one direction when activated by a sufficient amount of light and continues to conduct until the current falls below a specified value.

Diac A two-terminal four-layer semiconductor device (thyristor) that can conduct current in either direction when properly activated.

Triac A three-terminal thyristor that can conduct current in either direction when properly activated.

Selected Key Terms

SCS Silicon-controlled switch; a type of four-terminal thyristor that has two gate terminals that are used to trigger the device on and off.

UJT Unijunction transistor; a three terminal single *pn* junction device that exhibits a negative resistance characteristic.

PUT Programmable unijunction transistor; a type of three terminal thyristor (physically more like an SCR than a unijunction) that is triggered into conduction when the voltage at the anode exceeds the voltage at the gate.