Power electronics devices

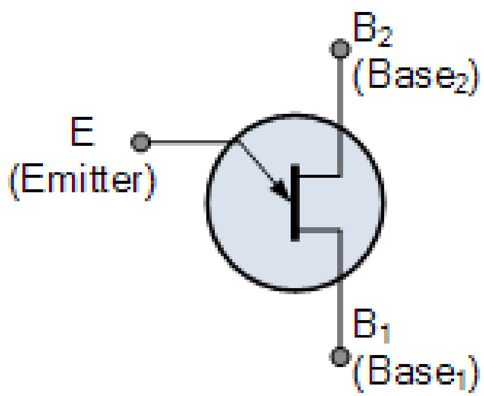
Presented by
Saloni Sharma
Department of Physics

Contents

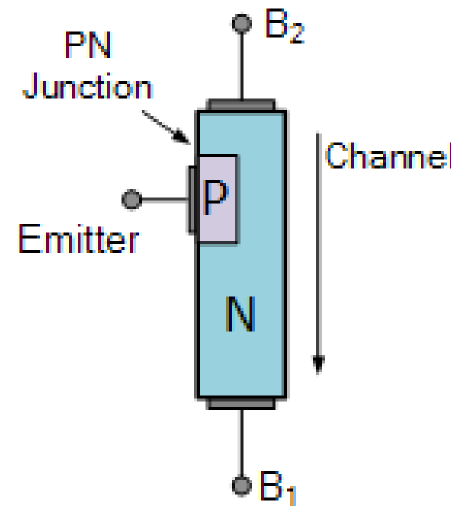
- Construction, Principle, Working and applications of:
- UJT
- SCR
- DIAC
- TRIAC
- SCS

Unijunction Transistor (UJT)

- UJT is another solid state three terminal device that can be used in gate pulse, timing circuits and trigger generator applications to switch and control thyristors and triacs for AC power control applications.



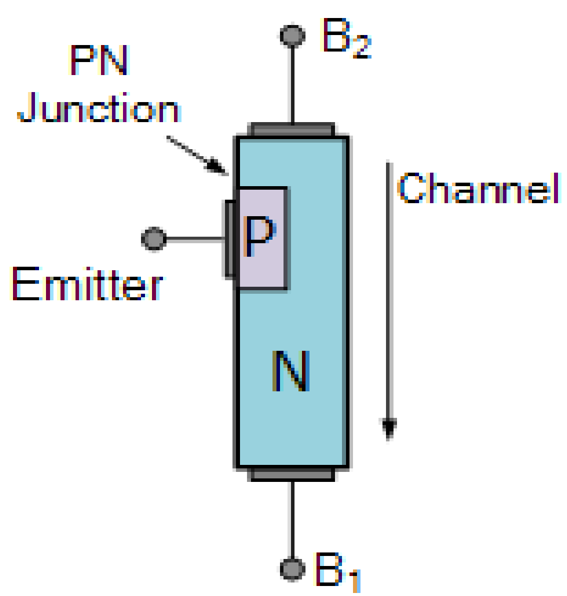
UJT Symbol



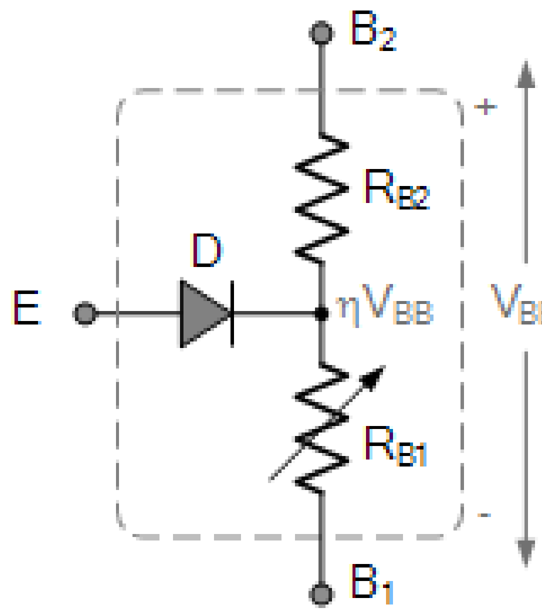
Construction

Unijunction Transistor (UJT)

- Equivalent Circuit: UJT's have unidirectional conductivity and negative impedance characteristics acting more like a variable voltage divider during breakdown



Construction

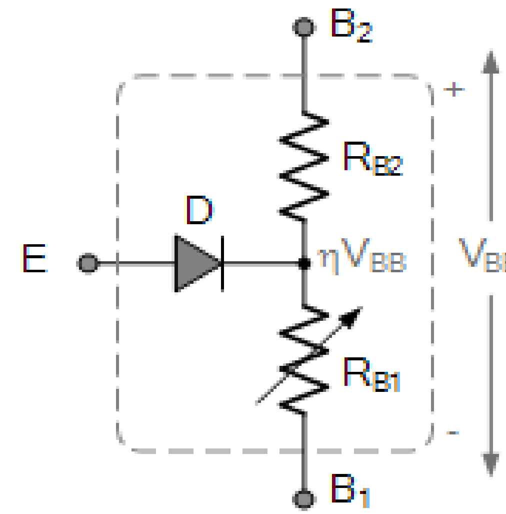


Simplified
Equivalent Circuit

Unijunction Transistor (UJT)

- As the physical position of the p-n junction is closer to terminal B_2 than B_1 the resistive value of R_{B2} will be less than R_{B1}.

- These two series resistances produce a voltage divider network between the two base terminals of the Unijunction transistor



Simplified Equivalent Circuit

- Since this channel stretches from B_2 to B_1, when a voltage is applied across the device, the potential at any point along the channel will be in proportion to its position between terminals B_2 and B_1.

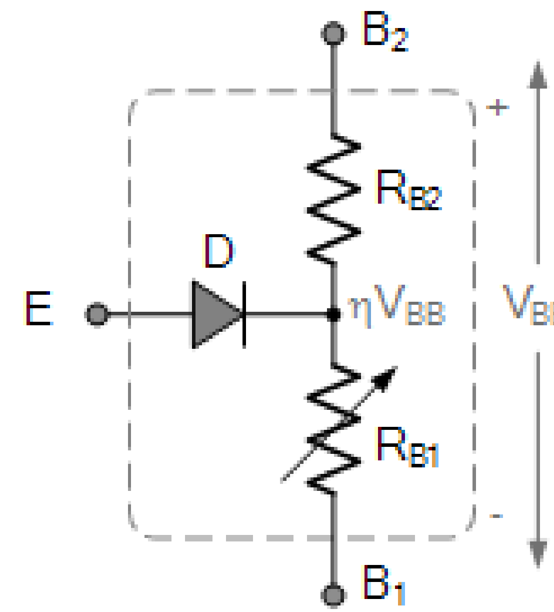
- The level of the voltage gradient therefore depends upon the amount of supply voltage.

Unijunction Transistor (UJT)

- When used in a circuit, terminal B_1 is connected to ground and the Emitter serves as the input to the device.

- Suppose a voltage V_{BB} is applied across the UJT between B_2 and B_1 so that B_2 is biased positive relative to B_1.

- With zero Emitter input applied, the voltage developed across R_{B1} (the lower resistance) of the resistive voltage divider can be calculated as:



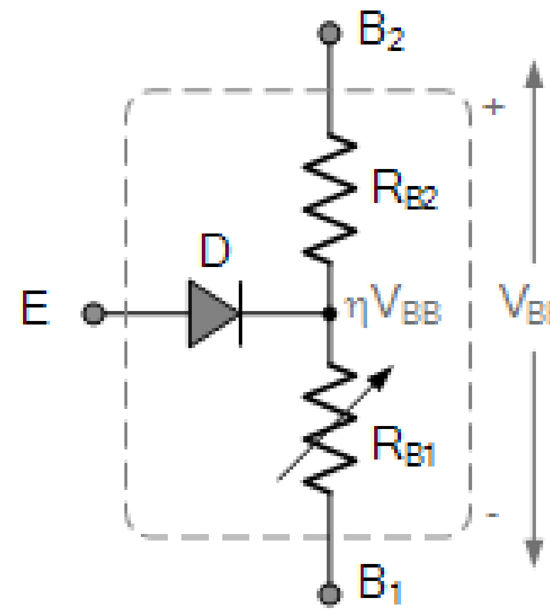
$$V_{RB1} = \frac{R_{B1}}{R_{B1} + R_{B2}} V_{BB}$$

Unijunction Transistor (UJT)

- For a Unijunction transistor, the resistive ratio of R_{B1} to R_{BB} is called the **intrinsic stand-off ratio (**η).

$$\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

- Typical standard values of η range from 0.5 to 0.8 for most common UJT's.



Simplified Equivalent Circuit

Unijunction Transistor (UJT)

- If a small positive input voltage (less than the voltage developed across resistance R_{B1} is now applied to the Emitter input terminal, the diode p-n junction is reverse biased, thus offering a very high impedance and the device does not conduct.

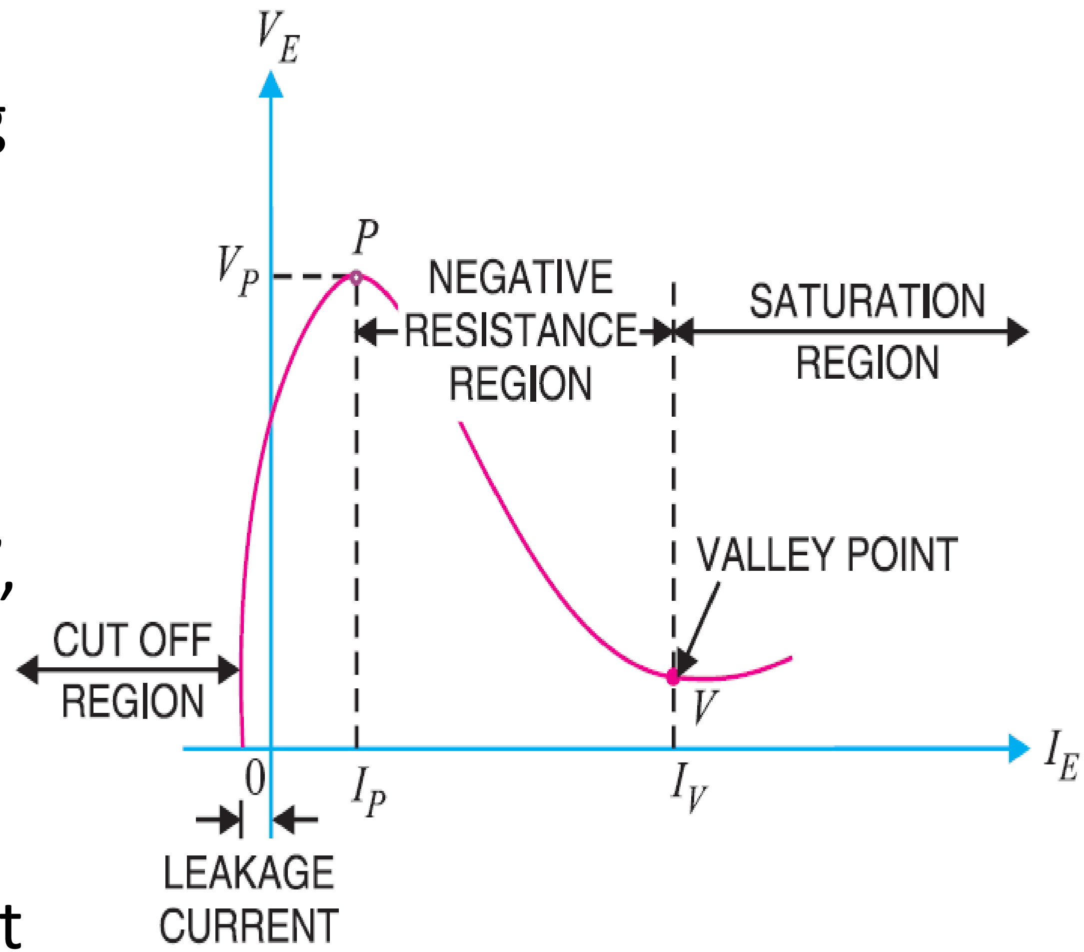
- The UJT is switched “OFF” and zero current flows.

- However, when the Emitter input voltage is increased and becomes greater than V_{RB1} (or ηV_{BB} + 0.7V, where 0.7V equals the p-n junction diode volt drop) the p-n junction becomes forward biased and the Unijunction transistor begins to conduct.

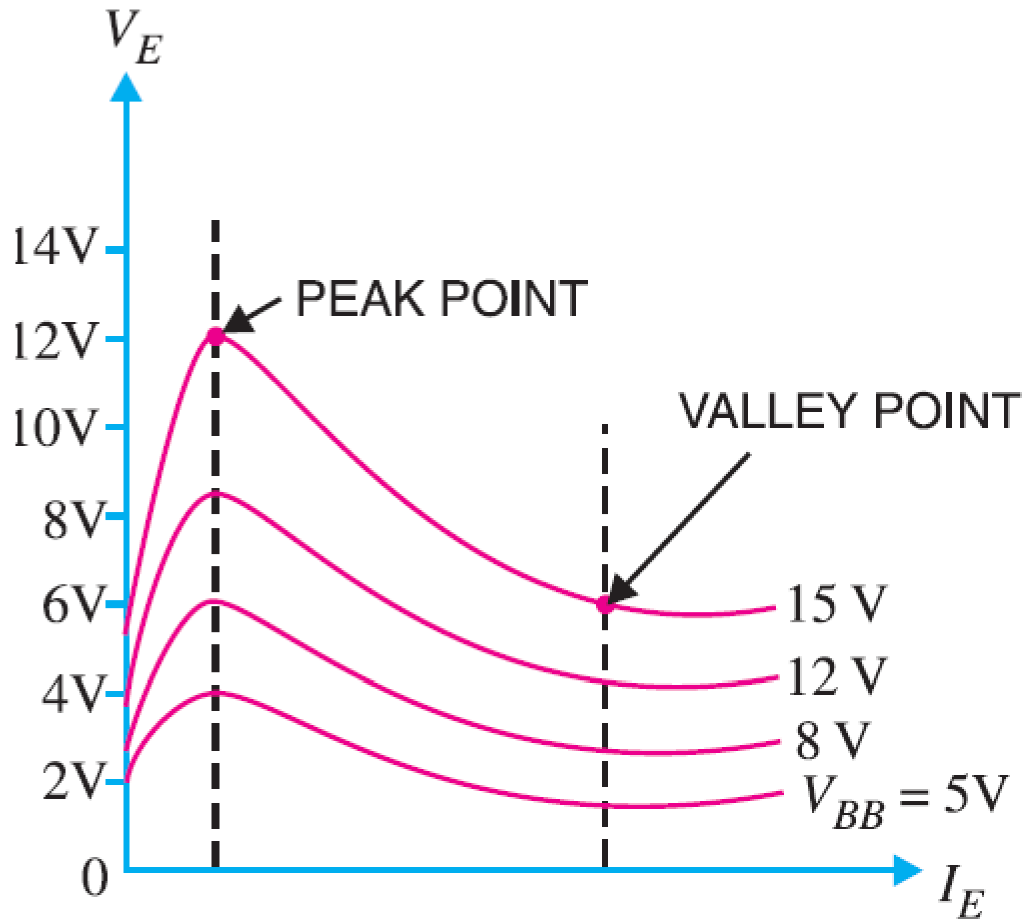
- The result is that Emitter current, ηI_E now flows from the Emitter into the Base region.

UJT Characteristics

The UJT is a switching device; it is not an amplifier. When the emitter voltage reaches V_P (the peak point), the UJT "fires", going through the unstable negative resistance region to produce a fast current pulse.



UJT Characteristics



UJT Applications

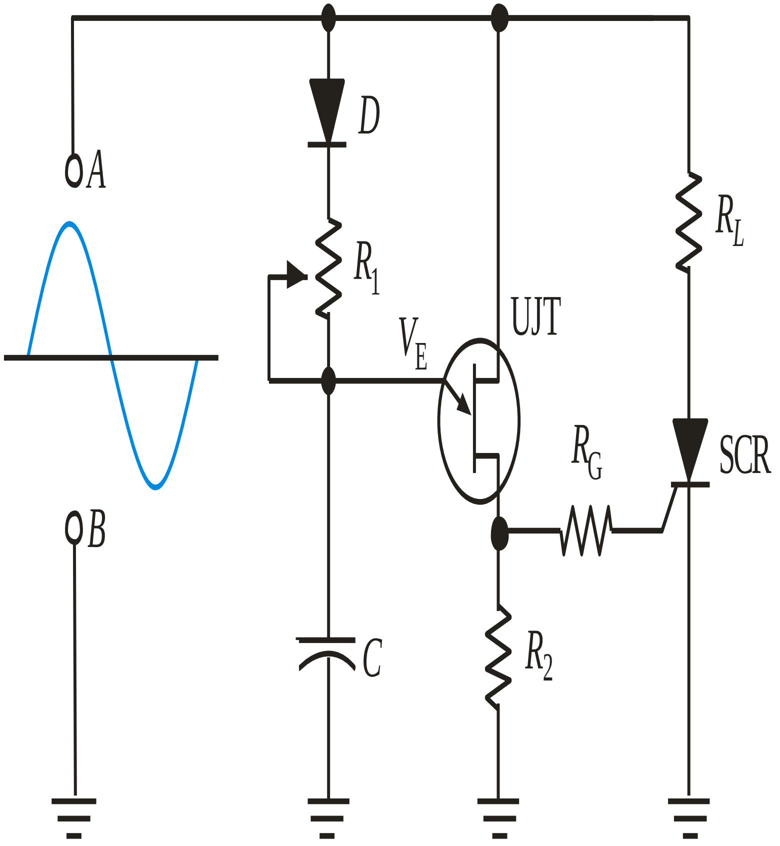
- The most common application of a Unijunction transistor is as a triggering device for SCR's and Triacs

- Other UJT applications include sawtoothed generators, simple oscillators, phase control, and timing circuits.

- The simplest of all UJT circuits is the Relaxation Oscillator producing non-sinusoidal waveforms.

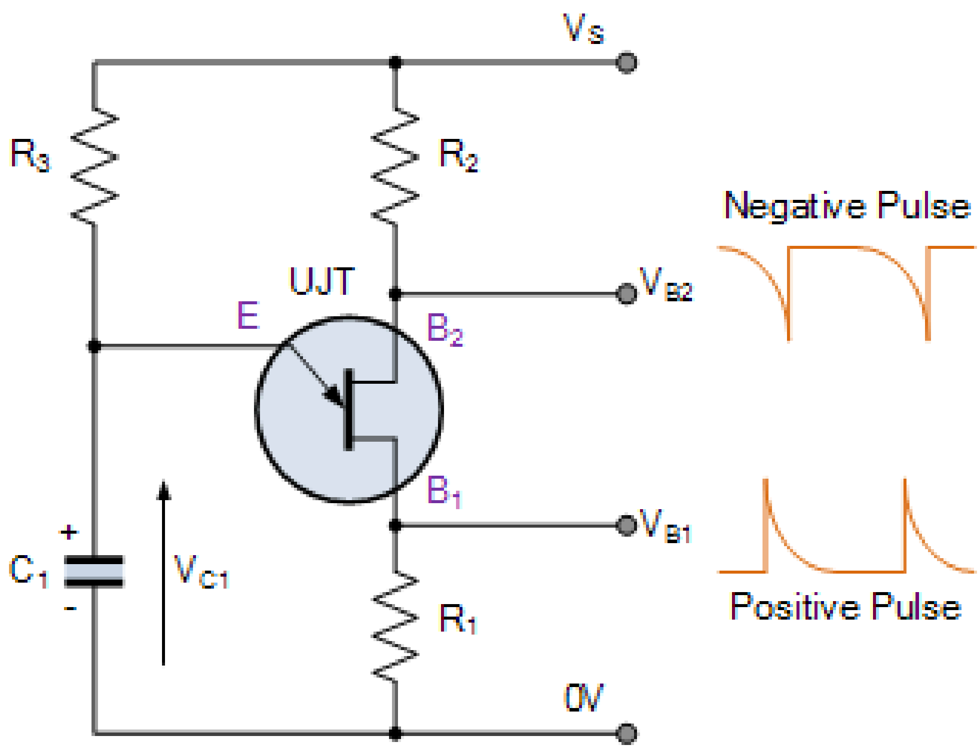
UJT as triggering device

- 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.



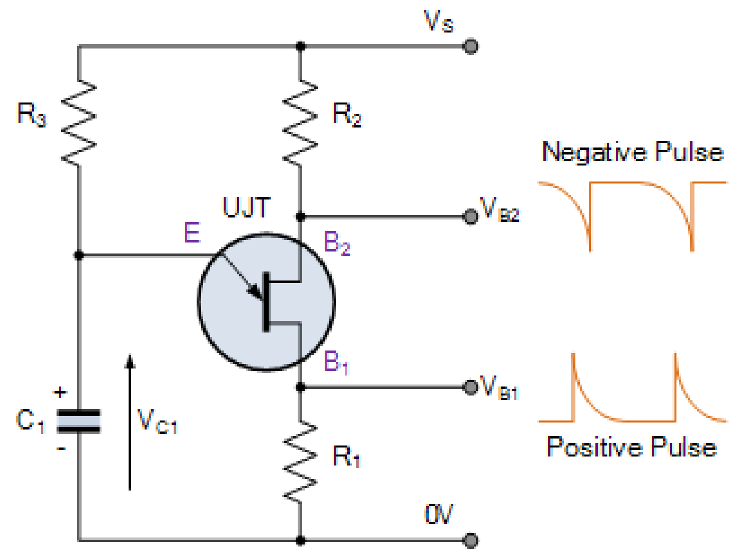
UJT Relaxation Oscillator

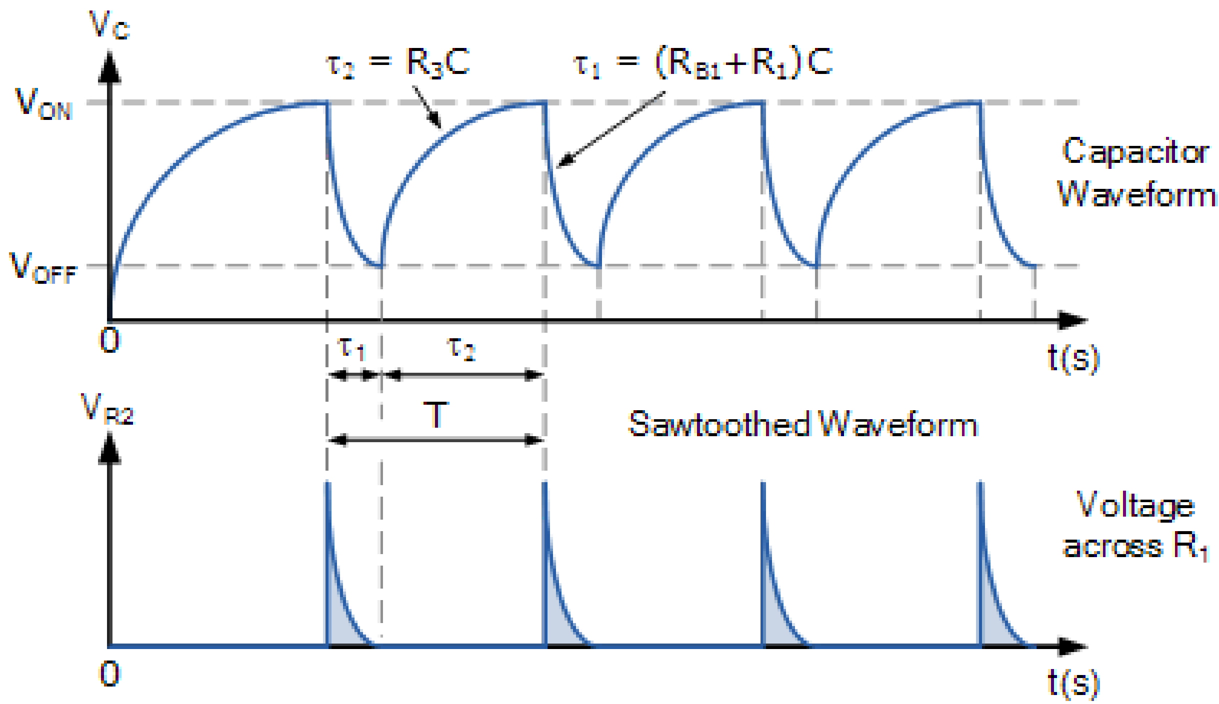
- In a basic and typical UJT relaxation oscillator circuit, the Emitter terminal of the Unijunction transistor is connected to the junction of a series connected resistor and capacitor.



UJT Relaxation Oscillator

$$V_C = V_{BB}(1 - e^{-t/R_3C})$$





UJT Relaxation Oscillator

$$V_C = V_{BB}(1 - e^{-t/R_3C})$$

- Discharge of the capacitor occurs when $V_C = V_p$.

$$V_P = V_{BB}(1 - e^{-t/R_3C})$$

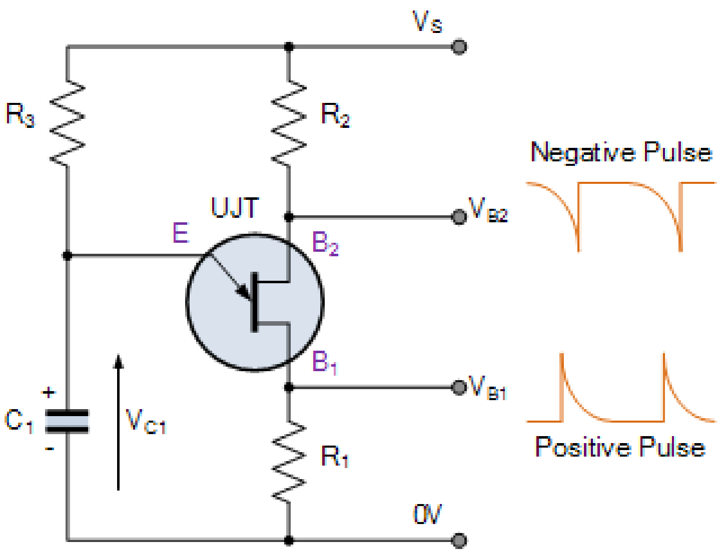
$$\eta V_{BB} = V_{BB}(1 - e^{-t/R_3C})$$

- Note: V_D is ignored in above equation

$$1 - \eta = e^{-t/R_3C}$$

$$\ln(1 - \eta) = -\frac{t}{R_3C}$$

$$R_3C \ln\left(\frac{1}{1 - \eta}\right) = t$$

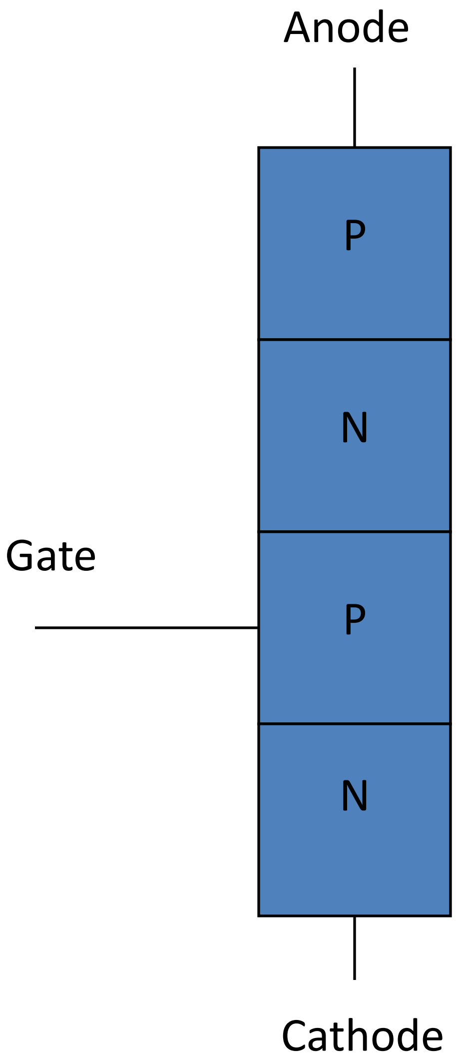


SCR/ Thyristor

- An SCR (Thyristor) is a “Silicon Controlled Rectifier ” (diode)
- Control the conduction under forward bias by applying a current into the Gate terminal
- Under reverse bias, looks like conventional pn junction diode

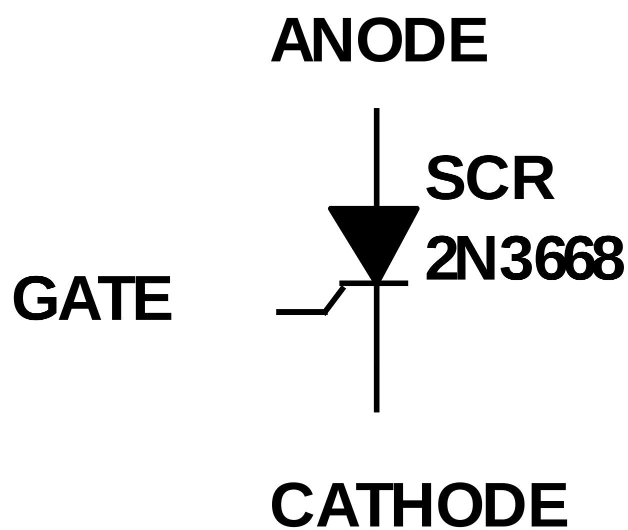
SCR / Thyristor

- 4-layer (pnpn) device
- Anode, Cathode as for a conventional pn junction diode
- Cathode Gate brought out for controlling input

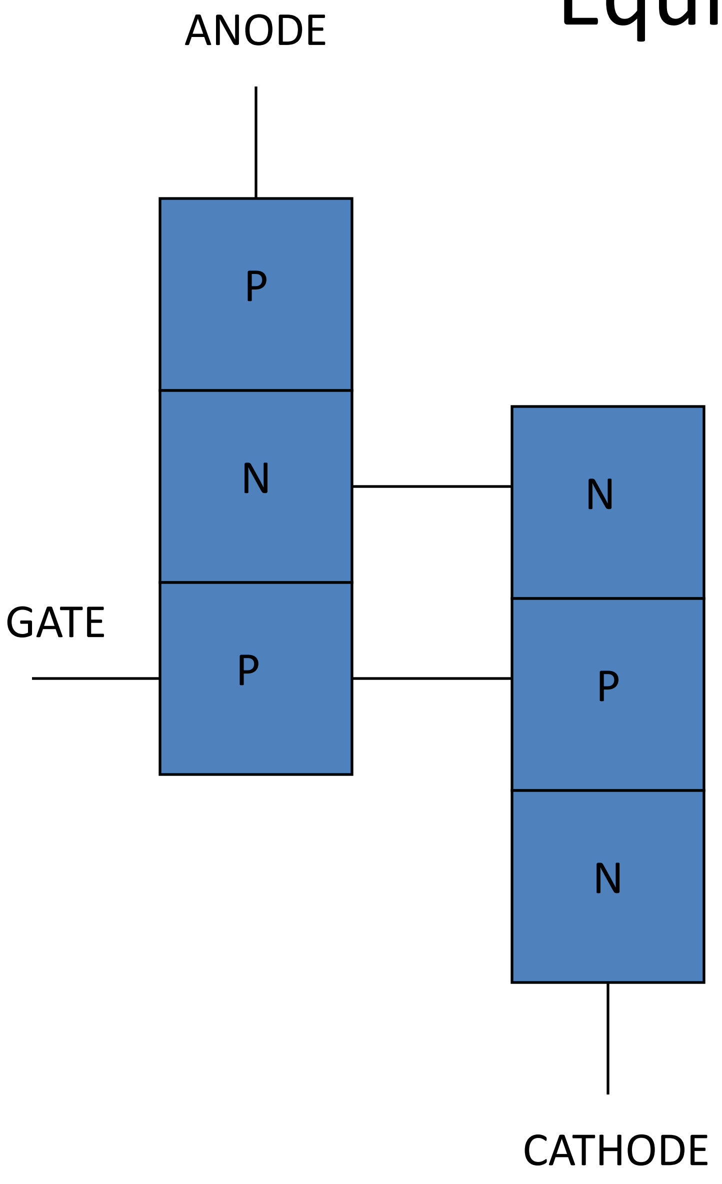


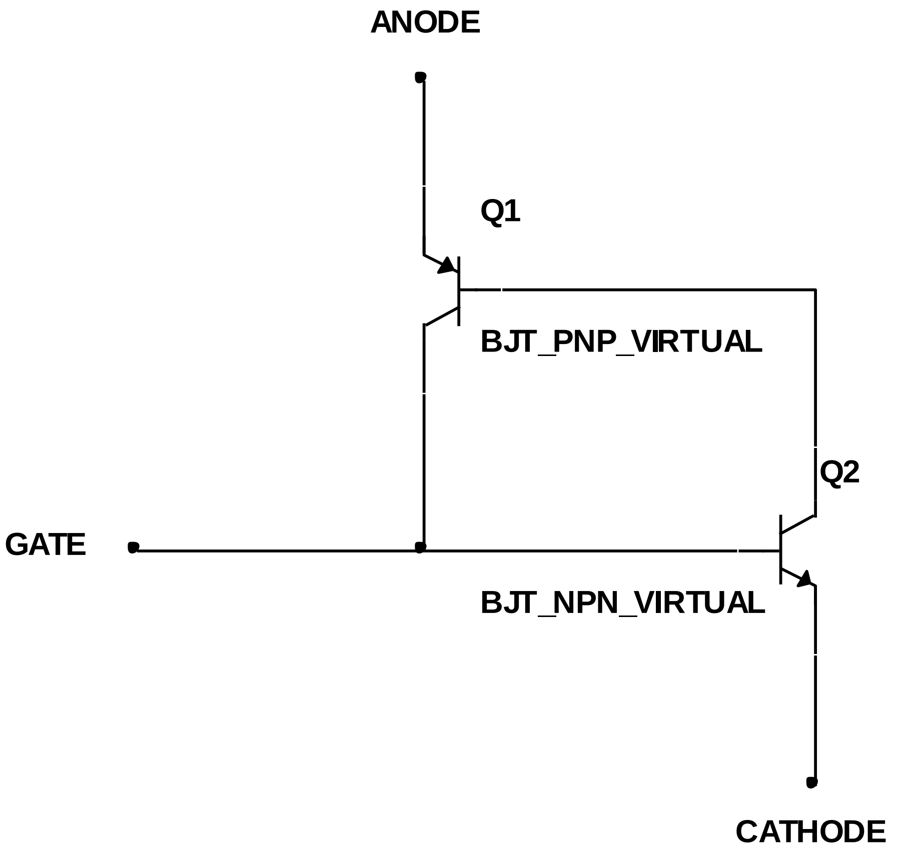
SCR / Thyristor
Circuit Symbol and Terminal Identification

- Anode and Cathode terminals as conventional pn junction diode
- Gate terminal for a controlling input signal



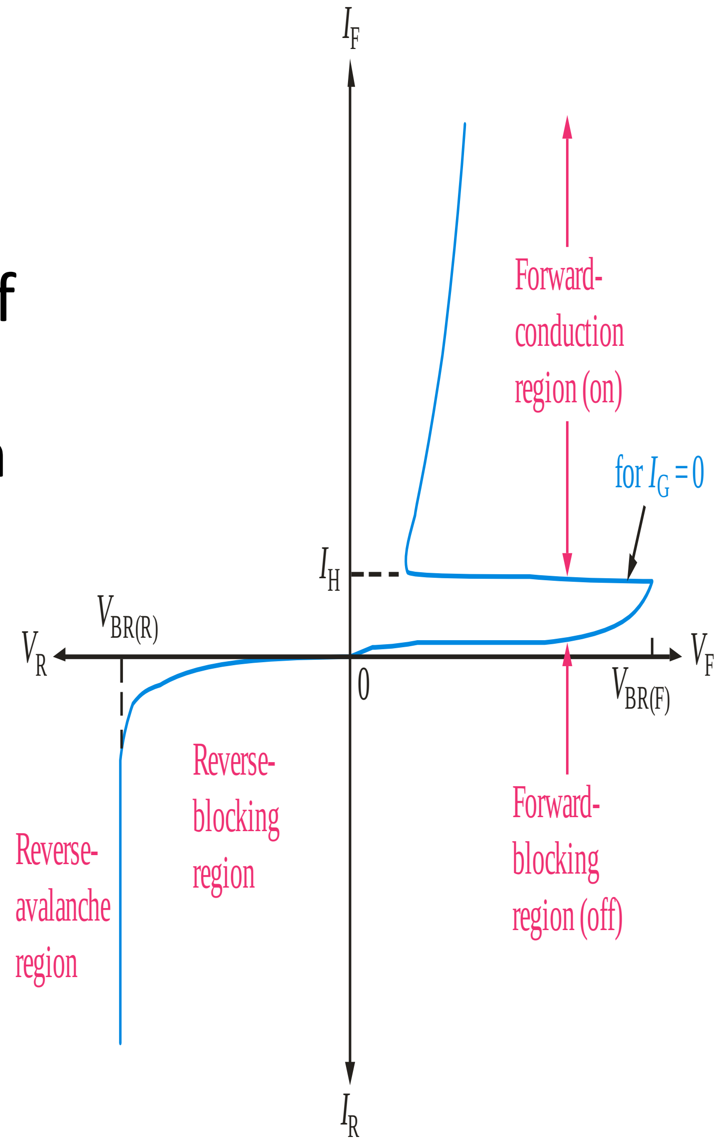
Equivalent Circuit





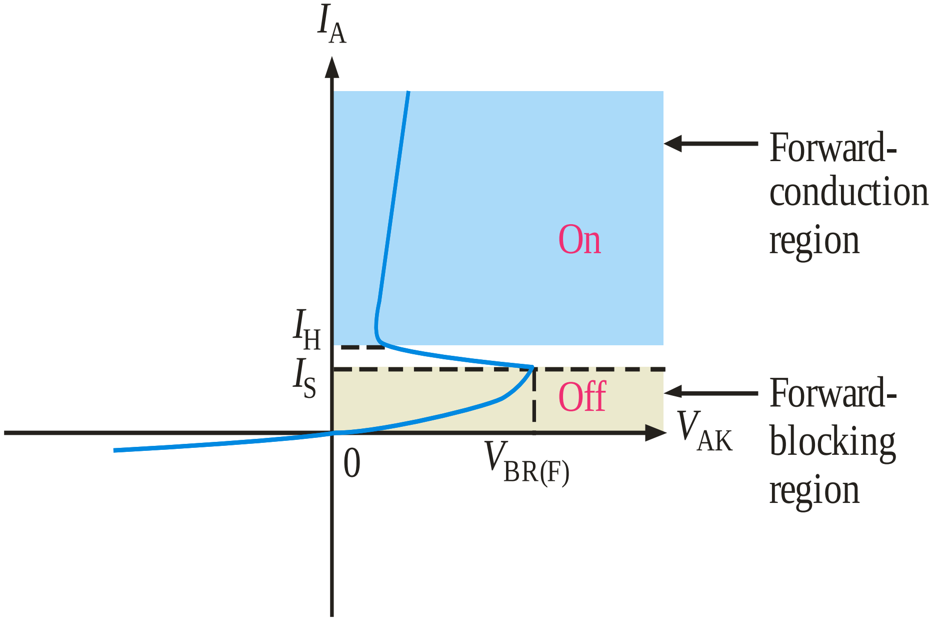
Three important SCR specifications are:

- **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.



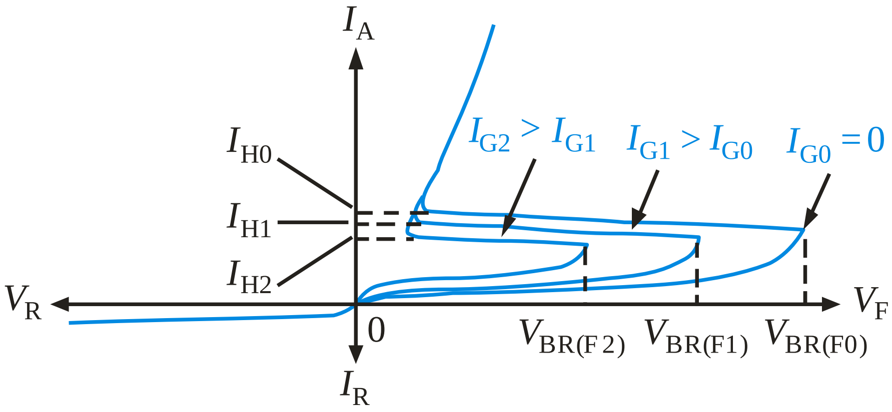
- The SCR can be turned on by exceeding the forward breakover voltage or by gate current.
- When the anode-to-cathode voltage exceeds breakover voltage V_{BR}, conduction occurs. The **switching current** at this point is I_S.

- The SCR could also be triggered into conduction by controlling the gate current.



The gate current controls the amount of forward breakover voltage required for turning it on. The **switching current** at this point is I_S.

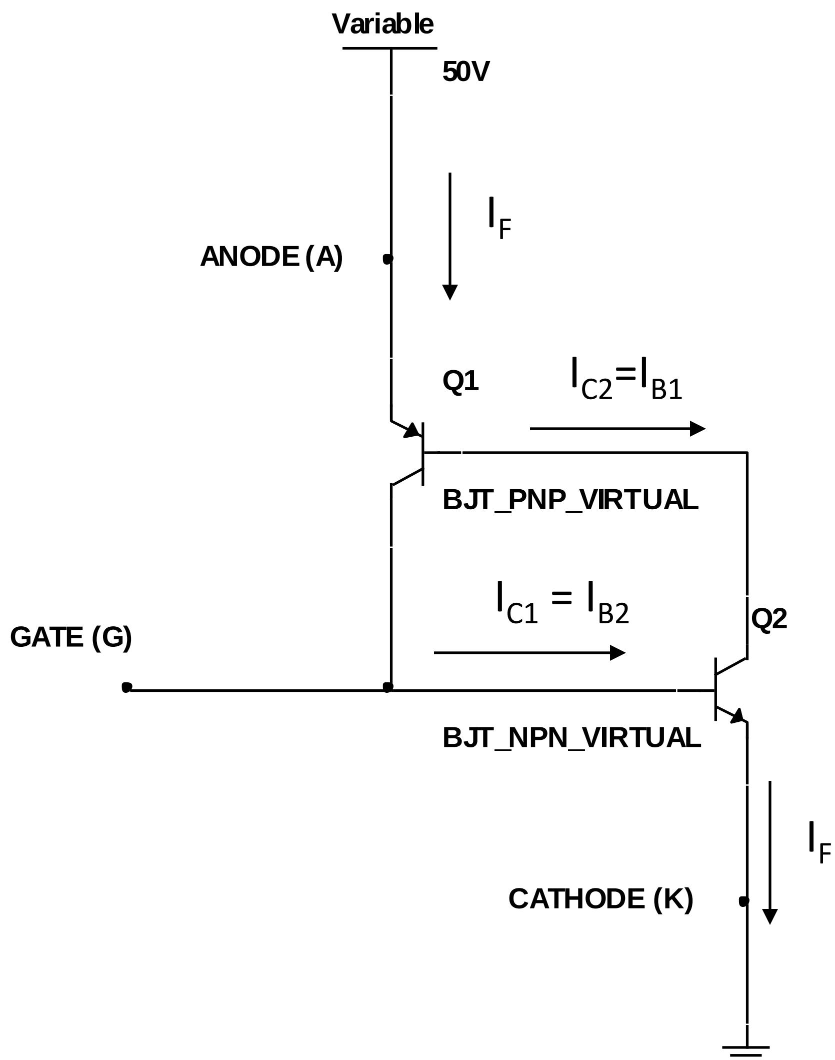
Once conduction begins, it will continue until anode current is reduced to less than the **holding current** (I_H). This is the only way to stop conduction.



Apply Biasing

With the Gate terminal OPEN, both transistors are OFF. As the applied voltage increases, there will be a “breakdown” that causes both transistors to conduct (saturate) making $I_F > 0$ and $V_{AK} = 0$.

$V_{Breakdown} = V_{BR(F)}$



Apply a Gate Current

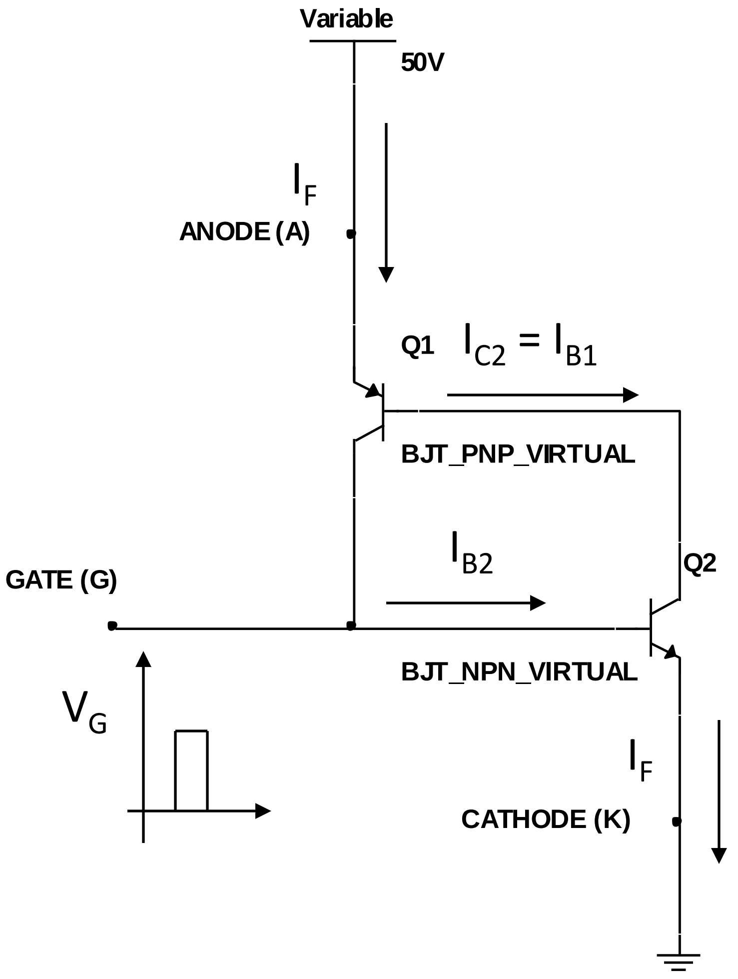
For $0 < V_{AK} < V_{BR(F)}$,

Turn Q_2 ON by applying a current into the Gate

This causes Q_1 to turn ON, and eventually both transistors SATURATE

$V_{AK} = V_{CEsat} + V_{BEsat}$

If the Gate pulse is removed, Q_1 and Q_2 still stay ON!



How do you turn it OFF?

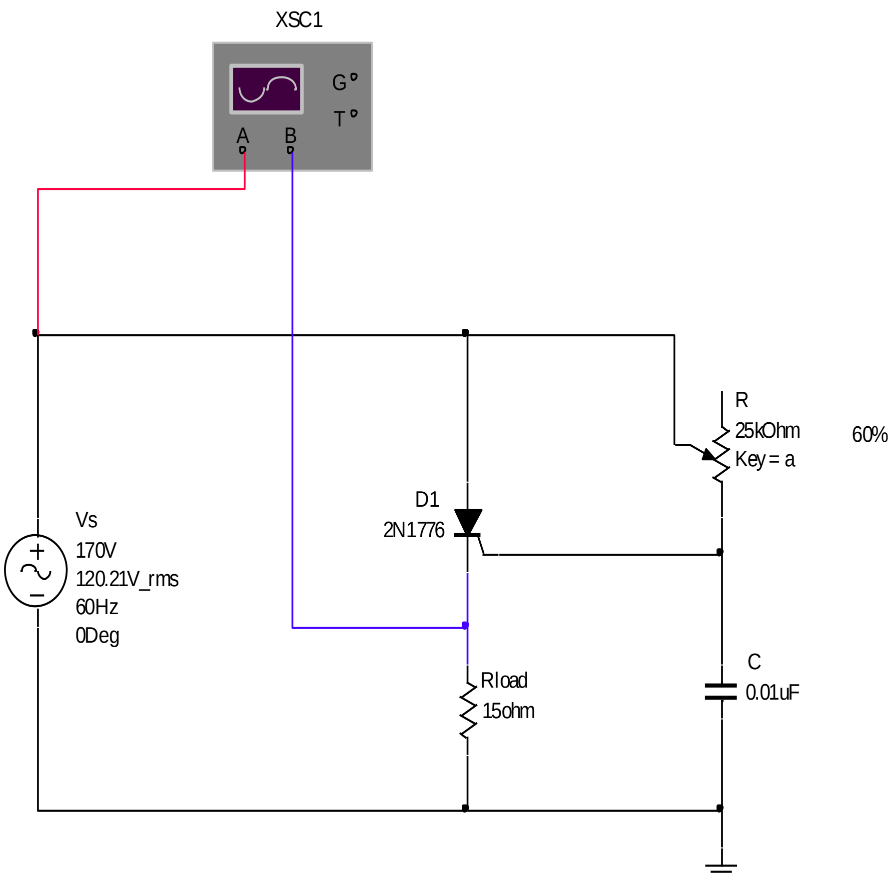
- Cause the forward current to fall below the value if the “holding” current, I_H

- Reverse bias the device

SCR Application – Power Control

- SCRs are used in a variety of power control applications. One of the most common applications is to use it in *ac* circuits to control a *dc motor* or appliance because the SCR can both rectify and control.
- The SCR is triggered on the positive cycle and turns off on the negative cycle. A circuit like this is useful for speed control for fans or power tools and other related applications

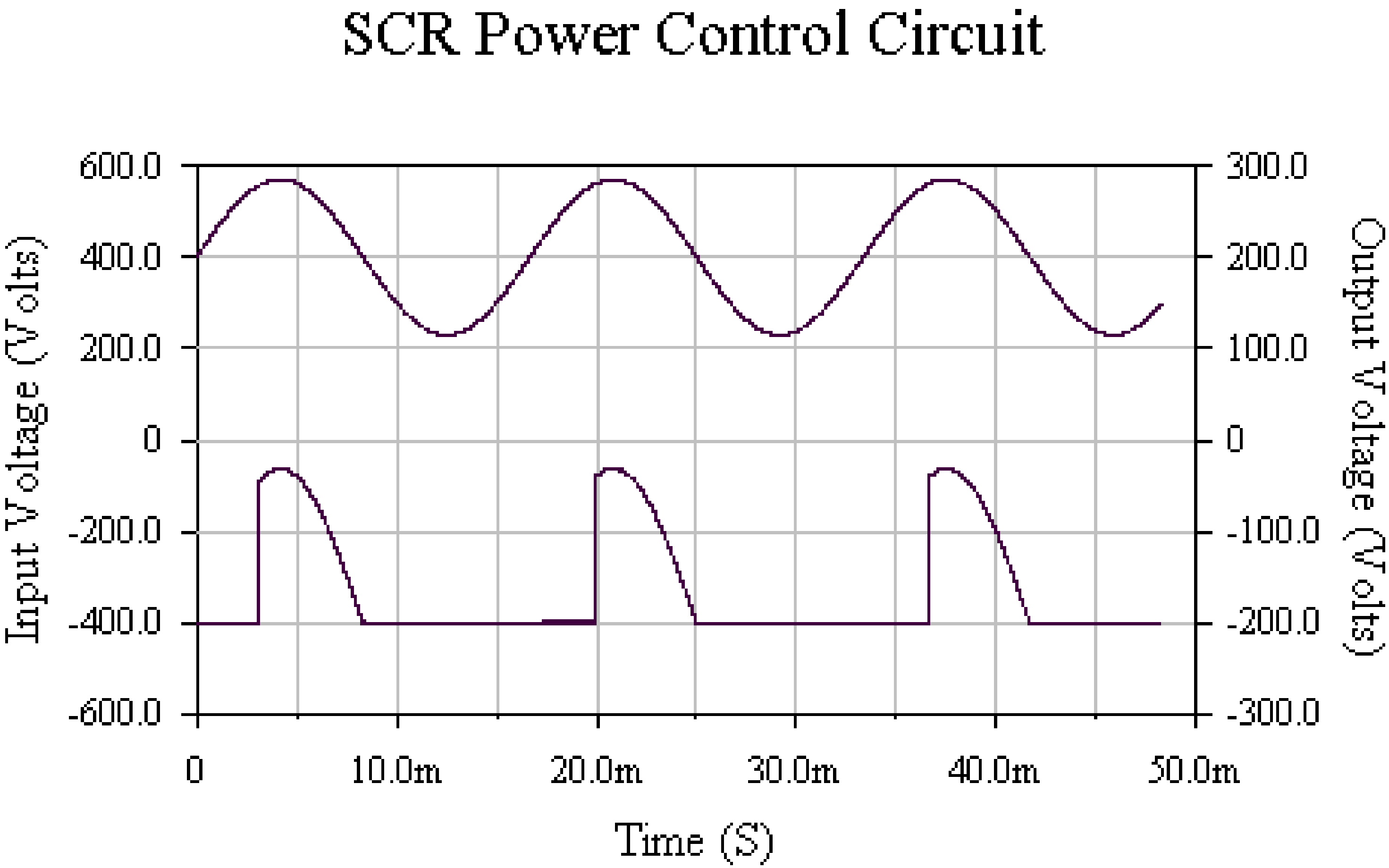
SCR Application – Power Control



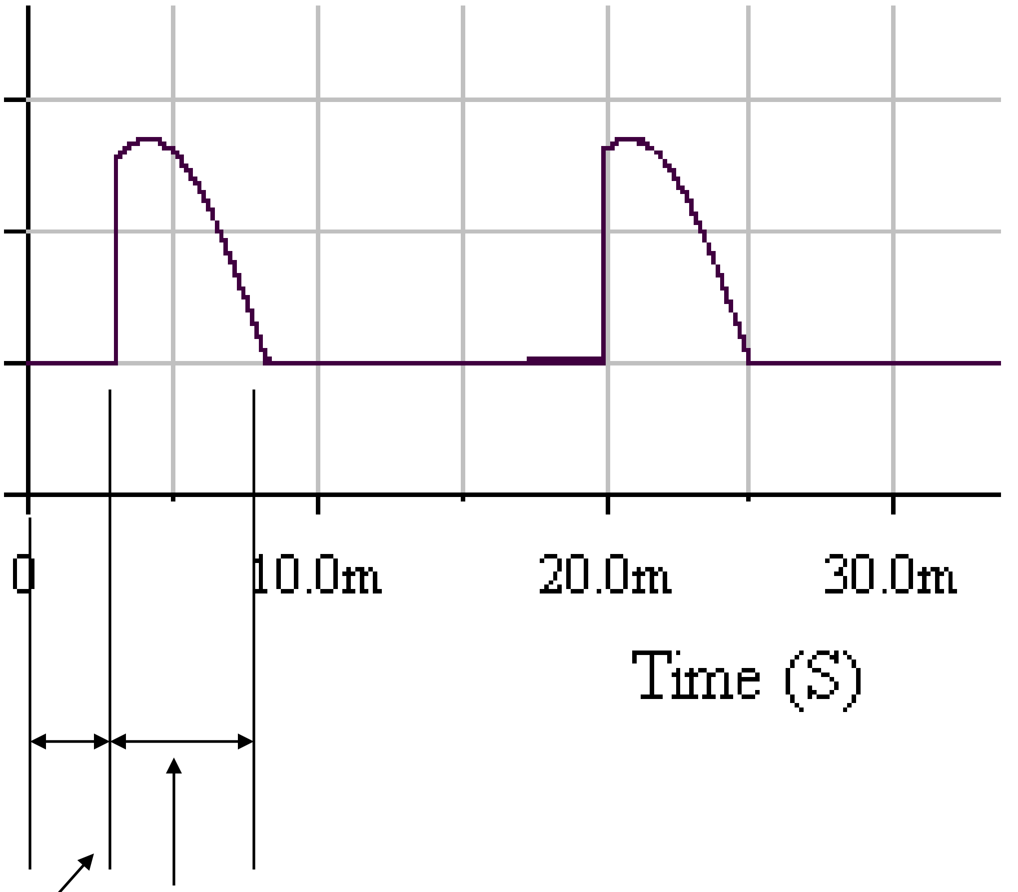
When the voltage across the capacitor reaches the "trigger-point" voltage of the device, the SCR turns ON, current flows in the Load for the remainder of the positive half-cycle.

Current flow stops when the applied voltage goes negative.

Input / Output Voltages



Look at the LOAD Current

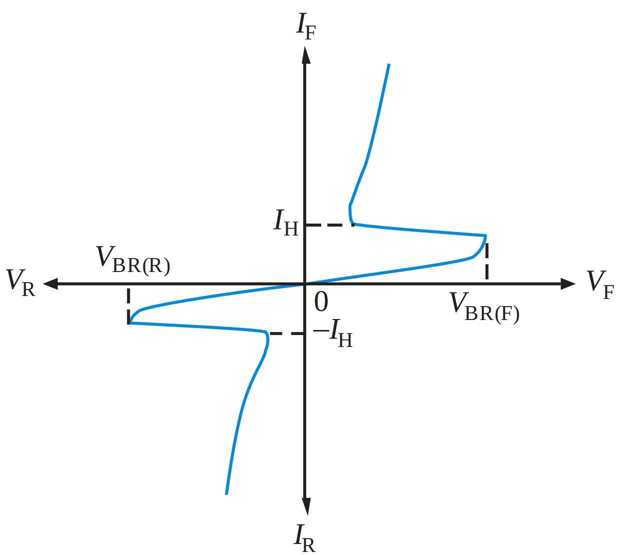


Conduction time → Conduction Angle = 180° - α

"Firing" time → Firing Angle (α)

DIAC: Diode for Alternating Current"

- The **diac** is a thyristor that acts like two back-to-back 4-layer diodes with two equivalent terminals labeled A_1 and A_2; it has no gate electrode. It can conduct current in either direction, because it is bidirectional.
- The diac conducts current after the breakdown voltage is reached. At that point, the diac goes into avalanche conduction, creating a current pulse sufficient to trigger another thyristor (an SCR or triac). The diac remains in conduction as long as the current is above the holding current, I_H.

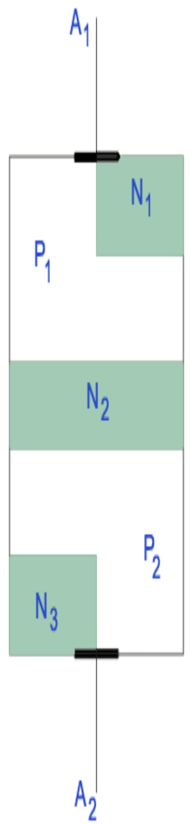


- DIAC can be either turned on or off for both polarities of voltage (i.e. positive or negative voltage). They also still works when avalanche breakdown occurs.

- DIAC has two p-type material and three n-type materials. Also, it does not have any gate terminal in it.

- The DIAC can be turned on for both the polarity of voltages. When A_2 is more positive with respect to A_1 then the current does not flows through the corresponding N-layer but flows from P_2-N_2-P_1-N_1. When A_1 is more positive A_2 then the current flows through P_1-N_2-P_2-N_3.
  The construction resembles the diode connected in series.

- It gives symmetrical switching characteristics for either polarity of voltages



Construction of Diac

Electrical 4 U

- When the applied voltage is small in either polarity, a very small current flows which is known as leakage current because of the drift of electrons and holes in the depletion region. Although a small current flows, it is not sufficient to produce avalanche breakdown, hence the device remains in the non-conducting state.
- When the applied voltage in either polarity exceeds the breakdown voltage, DIAC current rises and the device conducts in accordance with its V-I characteristics.
- The V-I characteristics resemble English letter Z. The DIAC acts as an open circuit when the voltage is less than its avalanche breakdown voltage. When the device has to be turned off, the voltage must be reduced below its avalanche breakdown voltage.

The main advantage of using this device is-

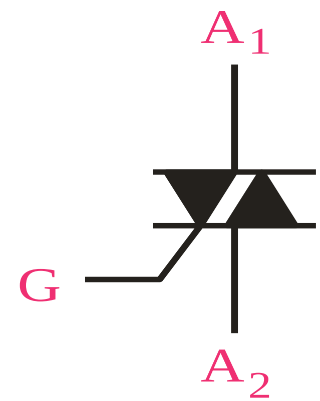
1.It does not switch sharply to a low voltage condition at a low current level as done by SCR or TRIAC.

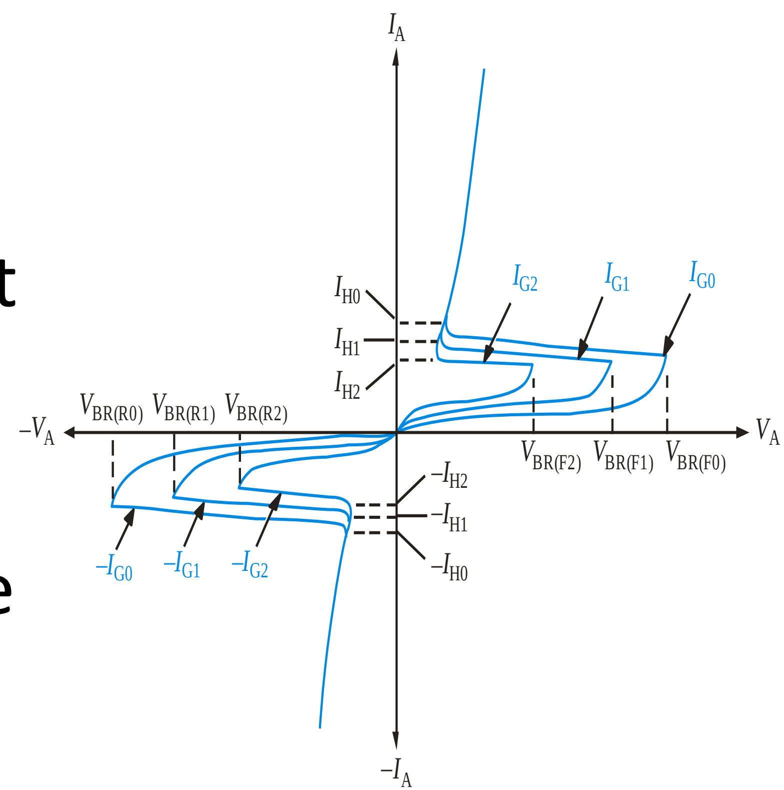
2.It has low on state voltage drop until its current falls below the holding current level.

3.Voltage drop decreases with the increase in current.

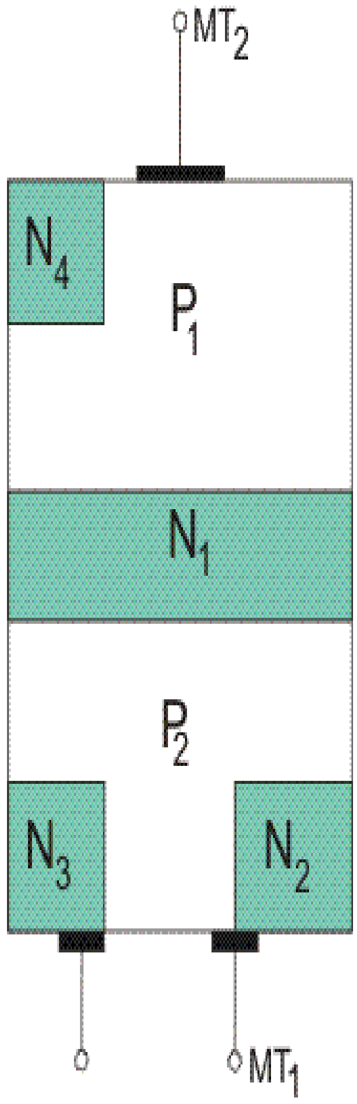
TRIAC

- The **triac** is essentially a bidirectional SCR but the anodes are *not* interchangeable. Triggering is done by applying a current pulse to the gate; breakover triggering is not normally used.
- 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.





It consists of three terminals namely, main terminal 1(MT_1), main terminal 2(MT_2), and gate terminal G.



The triac can be turned on by applying the gate voltage higher than break over voltage. However, without making the voltage high, it can be turned on by applying the gate pulse of 35 micro seconds to turn it on.

When the voltage applied is less than the break over voltage, we use gate triggering method to turn it on.

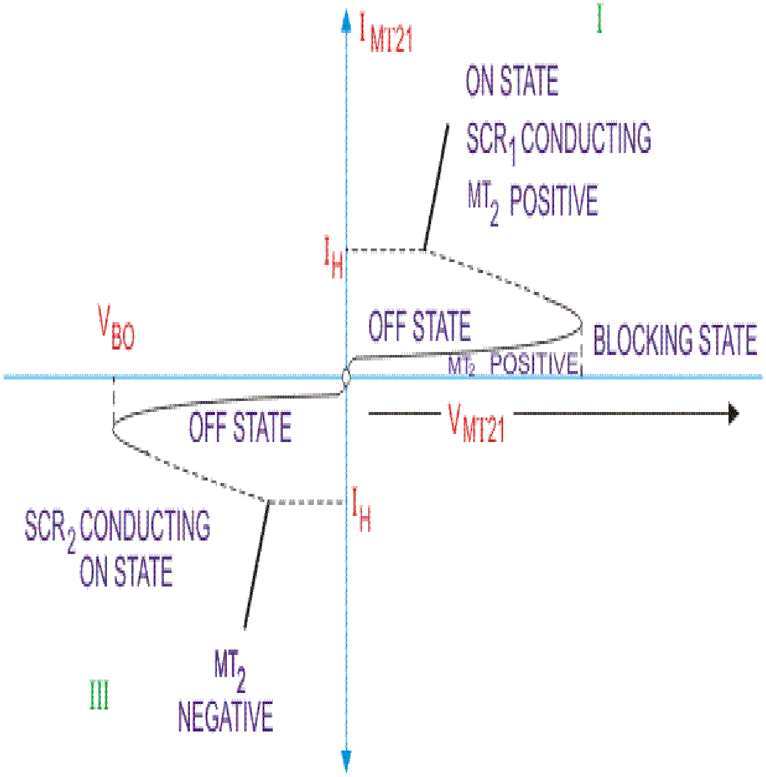
- **Triac** is a three terminal AC switch which is different from the other silicon controlled rectifiers in the sense that it can conduct in both the directions that is whether the applied gate signal is positive or negative, it will conduct. Thus, this device can be used for AC systems as a switch.
-

- **There are four different modes of operations, they are-**
- When MT_2 and Gate being Positive with Respect to MT_1
When this happens, current flows through the path P_1-N_1-P_2-N_2. Here, P_1-N_1 and P_2-N_2 are forward biased but N_1-P_2 is reverse biased. The triac is said to be operated in positively biased region. Positive gate with respect to MT_1 forward biases P_2-N_2 and breakdown occurs.
- When MT_2 is Positive but Gate is Negative with Respect to MT_1
The current flows through the path P_1-N_1-P_2-N_2. But P_2-N_3 is forward biased and current carriers injected into P_2 on the triac.

- When MT_2 and Gate are Negative with Respect to MT_1 Current flows through the path P_2-N_1-P_1-N_4. Two junctions P_2-N_1 and P_1-N_4 are forward biased but the junction N1-P1 is reverse biased. The triac is said to be in the negatively biased region.
- When MT_2 is Negative but Gate is Positive with Respect to MT_1
  P_2-N_2 is forward biased at that condition. Current carriers are injected so the triac turns on. This mode of operation has a disadvantage that it should not be used for high (di/dt) circuits. Sensitivity of triggering in mode 2 and 3 is high and if marginal triggering capability is required, negative gate pulses should be used. Triggering in mode 1 is more sensitive than mode 2 and mode 3.

Characteristics of TRIAC

- The **triac** characteristics is similar to SCR but it is applicable to both positive and negative triac voltages. The operation can be summarized as follows-
- **First Quadrant Operation of Triac**
- Voltage at terminal MT_2 is positive with respect to terminal MT_1 and gate voltage is also positive with respect to first terminal.
- **Second Quadrant Operation of Triac**
- Voltage at terminal 2 is positive with respect to terminal 1 and gate voltage is negative with respect to terminal 1.
- **Third Quadrant Operation of Triac**
- Voltage of terminal 1 is positive with respect to terminal 2 and the gate voltage is negative.
- **Fourth Quadrant Operation of Triac**
- Voltage of terminal 2 is negative with respect to terminal 1 and gate voltage is positive.

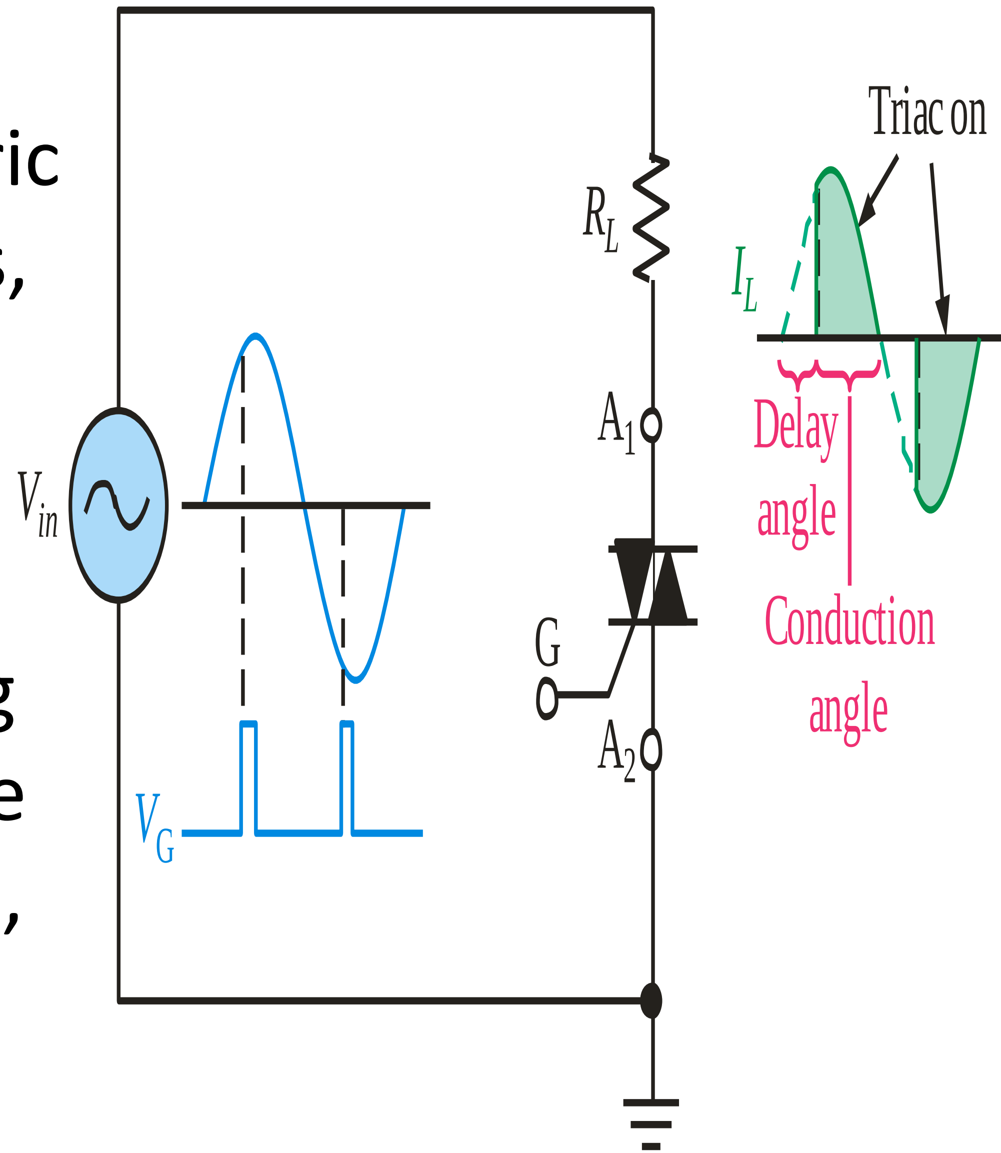


V-I Characteristic of a Triac

- When the device gets turned on, a heavy current flows through it which may damage the device, hence in order to limit the current a current limiting resistor should be connected externally to it.
- By applying proper gate signal, firing angle of the device may be controlled.

- The gate triggering circuits should be used for proper gate triggering. We can use diac for triggering the gate pulse

- Triacs are used for control of ac in applications like electric range heating controls, light dimmers, and small motors.
- Like the SCR, the triac latches after triggering and turns off when the current is below the I_H, which happens at the end of each alteration



Advantages of TRIAC

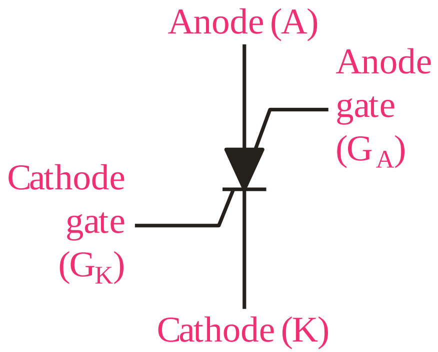
- It can be triggered with positive or negative polarity of gate pulses.
- It requires only a single heat sink of slightly larger size, whereas for SCR, two heat sinks should be required of smaller size.
- It requires single fuse for protection.
- A safe breakdown in either direction is possible but for SCR protection should be given with parallel diode.

USES OF TRIAC

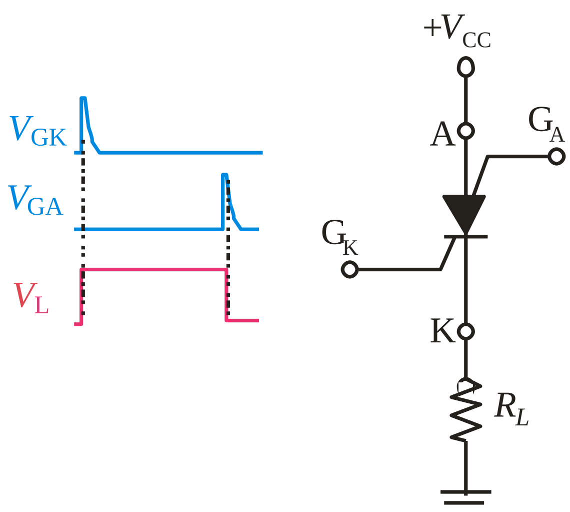
- They are used in control circuits.
- It is used in High power lamp switching.
- It is used in AC power control.

Silicon controlled switch

- The **SCS** is similar to an SCR but with two gates. It can be triggered on with a positive pulse on the cathode gate, and can be triggered off with a positive pulse on the anode gate.



- 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.



THANKS