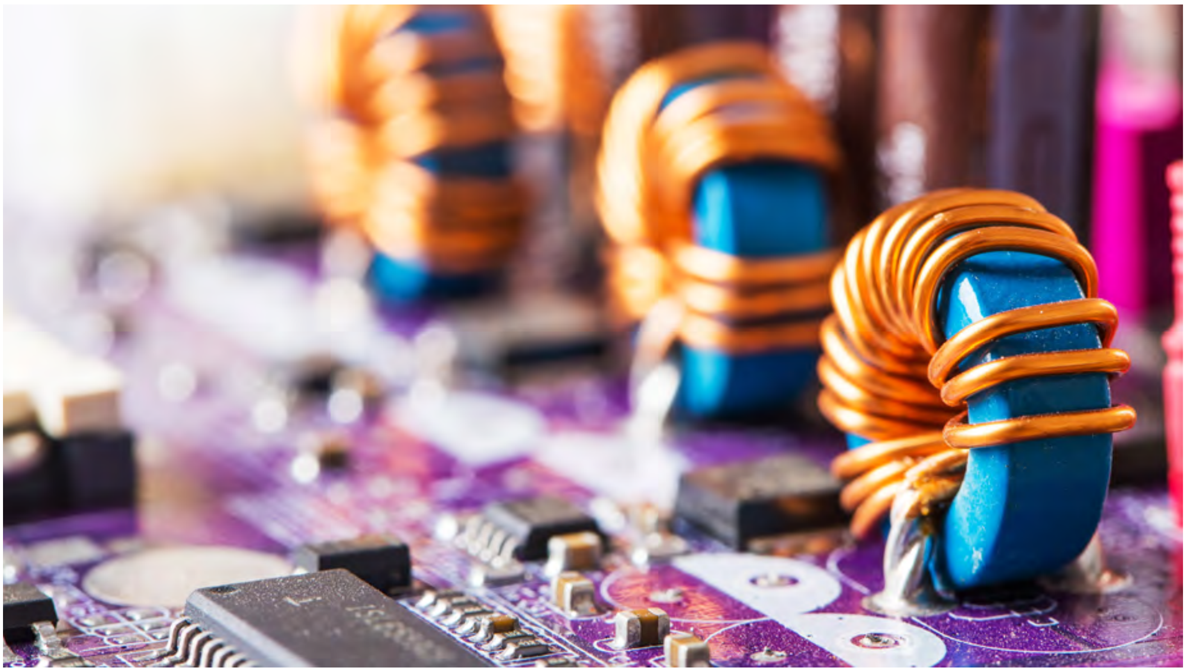

Power Electronics

Thyristors

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Thyristors

Thyristors are the class of devices that mainly work on the principle of internal regeneration. Before the invention of high power transistors, thyristors were mainly used for power conversion.

There is a big family of thyristors. Some of the commonly used members of the thyristor family are listed below :

- Silicon controlled rectifiers (SCR)
- Gate turn-off thyristor (GTO)
- Reverse conducting thyristor (RCT)
- Static induction thyristor (SITH)
- Gale assisted turn-off thyristor (GATT)
- Light activated silicon controlled rectifier (LASCR)
- MOS-controlled thyristor (MCT)
- TRIAC

Silicon Controlled Rectifier (SCR) is most commonly used thyristor. It is used in almost all of the power converters. It is an attractive device for controlled rectifiers (AC-DC converters) as mentioned in its name as well.

Thyristors mainly lack in switching speeds compared to power transistors. But their power handling capabilities are very high.

The drive requirements of thyristors are also simple compared to power transistors.

CONSTRUCTION OF SCR

We know that SCR is a four layer device. Fig. (a) shows the symbol of the SCR. It has three terminals : Anode (A), Cathode (K) and Gate (G). A small positive voltage between gate and cathode turns on the SCR.

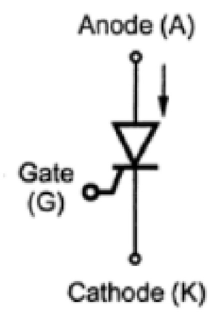
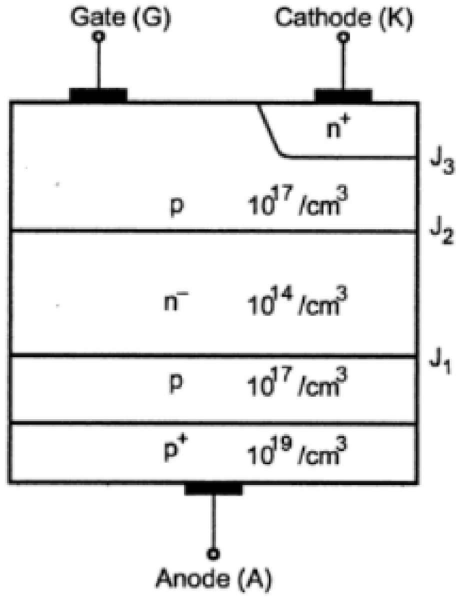


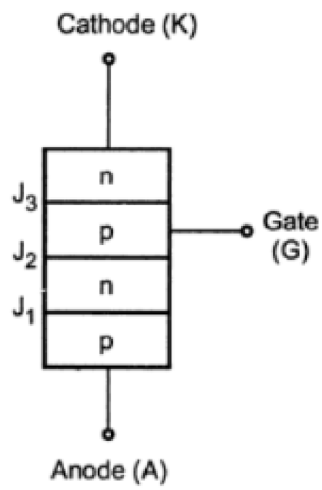
Fig. (b) shows the detailed structure.



The p^+ layer is doped at 10^{19}/cm . The player is doped at $10^{17}/cm^3$. The p and p^+ layers from anode (A) of the SCR. The thickness of the p^- layer is 30 to 50 μm. The n^- layer is lightly doped. The doping level of this layer is $10^{14}/cm^3$. The width of n^- layer is 50 to 1000 μm. This layer absorbs depletion layer of the junction J_2.

When SCR is forward biased (V_{AK} positive), junction J_2 is reverse biased. And J_1 and J_3 are forward biased. The depletion layer of J_2 is absorbed by n^- layer when SCR is forward biased. The width of n^- layer decides forward blocking capability of the SCR. The next p^- layer, having doping level of $10^{17}/cm^3$ forms the gate of SCR. The width of this layer is 30 to 100 μm. The next, i.e. n^+ layer (doping level of $10^{19}/cm^3$) forms the cathode of SCR.

Fig. (c) shows the simplified structure of SCR.



The gate - cathode junction is J_3 When this junction is forward biased, (i.e. gate signal applied) SCR can be turn-on. Due to gate signal, current starts flowing across J_3. Some carriers flow across J_2 also. Hence, internal regeneration starts and SCR turns on.

MERITS OF SCR

- Very small amount of gate drive is required since SCR is a regenerative device,
- SCRs with high voltage and current ratings are available,
- On-state losses in SCRs are reduced.

DEMERITS OF SCR

- Gate has no control, once the SCR is turned on.
- External circuits are required to turn-off the SCR.
- Operating frequencies are very low.
- Snubbers (RC circuits) are required for dv/dt protection.

APPLICATIONS OF SCR

- SCRs are best suitable for controlled rectifiers.
- AC regulators, lighting and heating applications.
- DC motor drives, large power supplies and electronic circuit breakers.

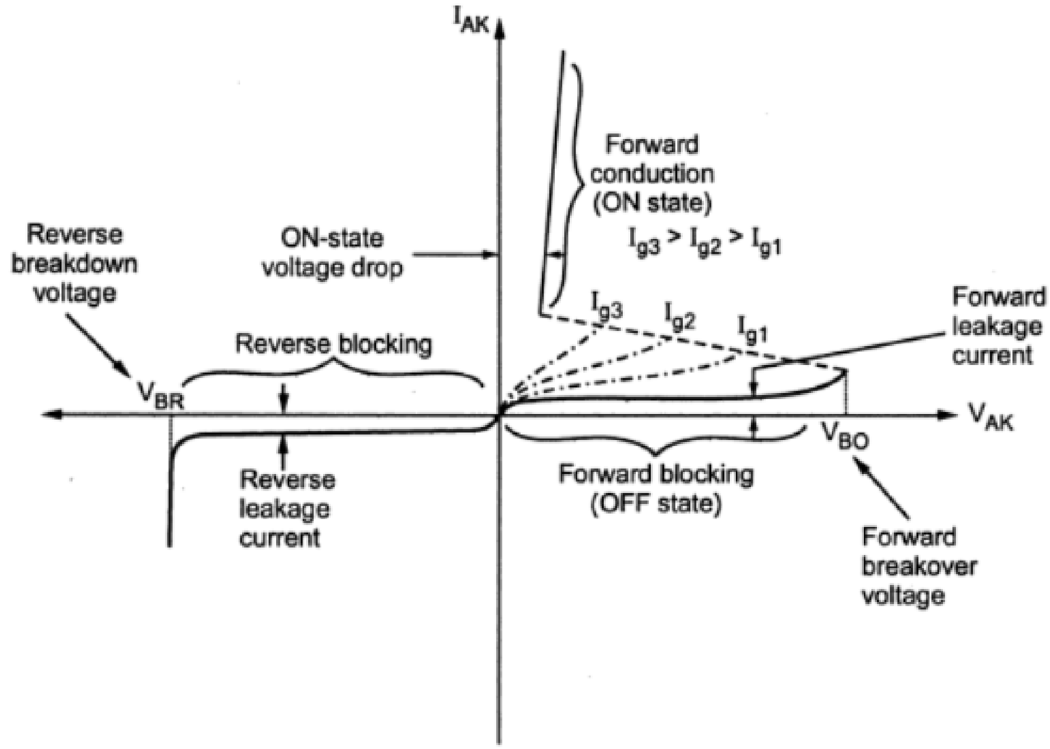
COMPARISON BETWEEN POWER DIODES AND THYRISTORS

Power Diodes	Thyristors
These devices are not controlled.	These devices are controlled by gate.
These devices normally have one junction.	These devices have more than one junction
These are used for rectification. freewheeling and feedback.	These are used for controlled rectification AC regulation, inversion and DC-DC conversion.
These are used as protection for thyristors.	Thyristors are main power conversion devices.
The diodes of this type are fast recovery diodes, Schottky diodes, etc.	SCR, TRIAC. GTO are the devices of thyristor family.

SCR CHARACTERISTICS AND MODES OF OPERATION

The working of the SCR can be discussed into three modes : Reverse blocking mode, forward blocking mode and forward conduction mode. Fig. shows the V-I characteristics of the SCR.

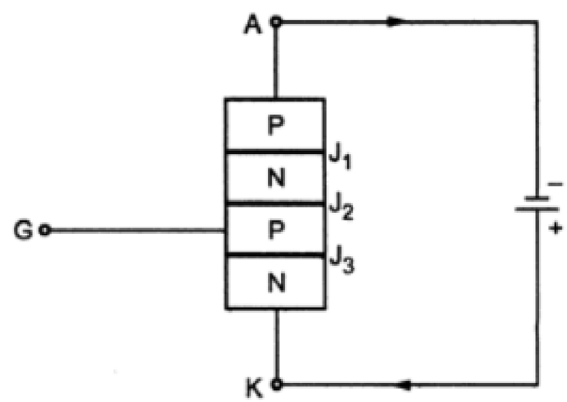
The characteristics shown in this are called static characteristics. The anode to cathode current I_{AK} is plotted with respect to anode to cathode voltage V_{AK}. The voltage V_{BO} is the forward break over voltage. V_{BR} is the reverse break-down voltage. And I_{g1}, I_{g2}, I_{g3} are the gate currents applied to the SCR.



Static V-I characteristics of a SCR

Reverse Blocking Mode

Following figure shows the situation when the thyristor will be in reverse blocking mode.



In this figure, observe that the anode (A) is made negative with respect to cathode (K). The gate is kept open. There are three PN junctions in the SCR : J_1, J_2 and J_3. Due to this reverse bias, junctions J_1 and J_3 are also reverse biased. And junction J_2 is forward biased. The SCR does not conduct due to this reverse bias. A very small current flows from cathode to anode. This current is called *reverse leakage current* of the SCR. This mode is called *reverse blocking mode*.

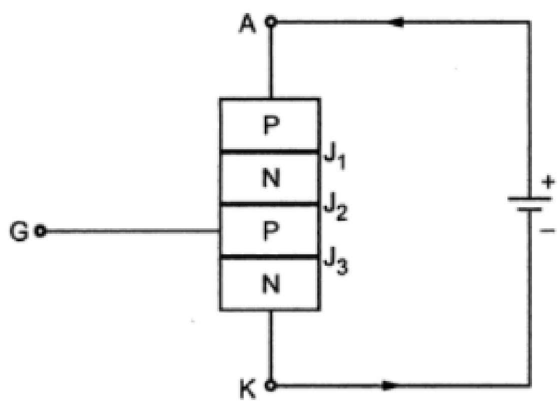
Previous figure of V-I characteristics of SCR shows the characteristic of SCR in reverse blocking mode.

Observe that reverse voltage increases but very small current flows. At reverse break down voltage (VBR), the reverse current increases rapidly. At the time of reverse breakdown, the high voltage is present across the SCR and heavy current flows through it. Hence large power dissipation takes place in the thyristor. Due to this dissipation, the junction temperature exceeds the permissible value and the SCR is damaged. Hence a reverse voltage across the SCR should never exceed VBR.

During the reverse blocking mode, the positive gate signal should not be applied. If the positive signal is applied between gate and cathode, junction J_3 is forward biased. Hence current starts flowing through it. This current adds to reverse leakage current of the SCR. Hence dissipation is also increased.

Forward Blocking Mode

The SCR is said to be forward biased when anode is made positive with respect to cathode as shown in following figure.



Due to this forward bias the junction J_1 and J_3 is forward biased and J_2 is reverse biased. Hence the forward voltage is to be hold by junction J_2. A very small current flows from anode to cathode. This current is called *forward leakage current*. This current is of the order of few milli amperes. In the forward blocking mode, the thyristor is forward biased but it does not turn-on. In the forward blocking mode a very small forward leakage current flows. In the forward blocking mode the voltage (V_{AK}) can be increased till V_{BO} This situation is shown in previous figure of VI characteristics of SCR. When the forward voltage reaches V_{BO}, the SCR turns on. The SCR goes from forward blocking mode to forward conduction mode. Normally gate drive is applied for this purpose. The highest voltage to be sustained in forward blocking mode is forward break-over voltage, V_{BO}.

When the voltage increases above V_{BO}, the SCR goes into forward conduction mode (i.e. turns-on) even if gate drive is not applied. Thus SCR is not damaged if voltage $V_{AK} > V_{BO}$, rather it is turned-on.

The forward breakover voltage is obtained due to blocking capability of junction J_2. The reverse breakover voltage is obtained due to blocking capabilities of junctions J_1 and J_3 The blocking capability of ($J_1 + J_3$) combined is higher than that of J_2. Therefore reverse blocking voltage is higher than forward blocking voltage of SCR.

Forward Conduction Mode (Thyristor Turn On/Triggering Methods)

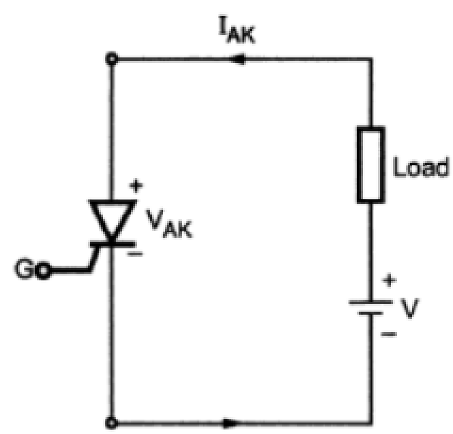
When the SCR is forward biased, then thyristor can be turned on (triggered) by using any of following methods:

- When $V_{AK} > V_{BO}$ (Forward voltage triggering)
- When gate drive is applied (Gate triggering)
- When dv/dt exceeds permissible value (dv/dt triggering)
- When gate cathode junction is exposed to light (light triggering)

Here note that the SCR can go in the forward conduction mode only if it is in the forward blocking mode earlier.

When $V_{AK} > V_{BO}$

The SCR is driven into forward conduction mode when anode to cathode voltage (V_{AK}) exceeds the forward break-over voltage (V_{BO}). The SCR is said to have turned-on when it operates in forward conduction mode. When $V_{AK} > V_{BO}$, the SCR is driven in forward conduction even if gate is open. From following figure, it is clear that junction J_2 is reverse biased during forward blocking mode ($V_{AK} < V_{BO}$) When V_{AK} exceeds V_{BO}, the avalanche break-down of junction J_2 takes place even if gate drive is not applied.



Hence heavy current starts flowing through the SCR and anode to cathode voltage falls to very small value. This is shown in V-I characteristics of SCR. The dotted line (...........) indicates switching of SCR from forward blocking state (i.e. OFF) to forward conduction state (i.e. ON). The anode to cathode current of the SCR is only limited by the load. Given figure shows such situation.

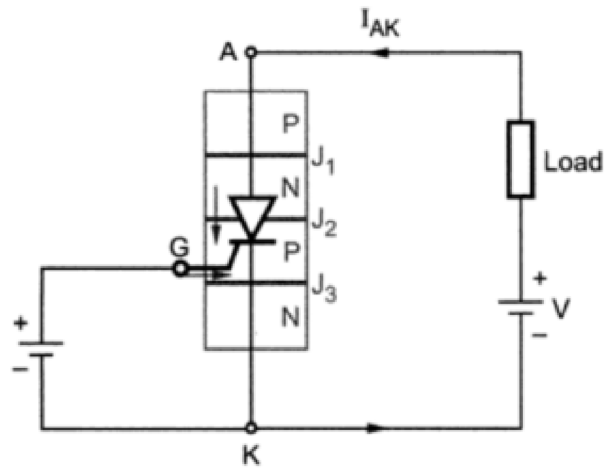
When the SCR conducts in the forward conduction mode, it is said to have turned 'ON'. The anode to cathode voltage is less than 2 volts. This voltage is normally neglected in calculations. Then the current through the load and SCR will be.

$$I_{AK} = V/load$$

Thus the SCR current is only limited by the load, once the SCR turns 'on'.

When gate drive is applied

A positive gate to cathode signal is applied whenever the SCR is to be driven into forward conduction mode (ON state). This is also called gate triggering of the SCR. Such situation is shown by the typical circuit of given figure.



The SCR is in forward blocking mode when gate drive is not applied. When the positive gate to cathode voltage is applied, current flows from gate to cathode. This current adds to the forward leakage current. Hence avalanche break-down of junction J_2 takes place at lower anode to cathode voltage also. Thus SCR is driven into forward conduction mode (ON state) even if $V_{AK} < V_{BO}$. VI characteristics of SCR shows the characteristic by centre (-.-.-.-.) lines.

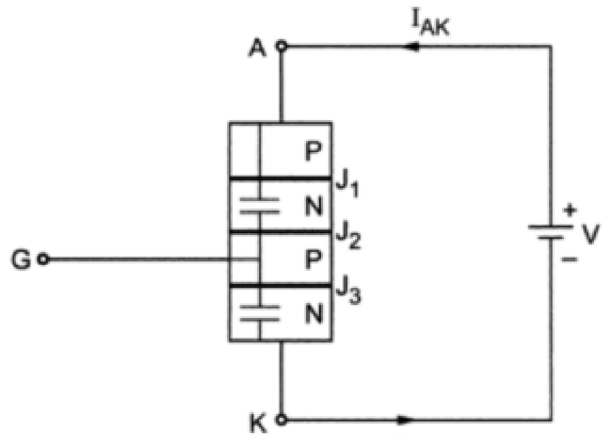
when gate drive is applied. Observe that, as the gate current is increased, the SCR turns-on at lower and lower values of anode to cathode voltages. All these anode to cathode voltages are less than V_{BO}. Thus gate triggering is the most convenient way of triggering the SCR.

Once the thyristor goes into forward conduction mode, the gate has no control over the conduction of thyristor. The current V_{AK} is only limited by the load, i.e.,

$$I_{AK} = V/load$$

When dv/dt exceeds permissible value

Here dv/dt is the rate of change of anode to cathode voltage with respect to time. Whenever the SCR is in forward blocking state, only forward leakage current flows through the SCR. In such state an equivalent internal capacitor is formed inside the SCR from anode to gate and gate to cathode. Following figure shows such internal circuit.



Whenever the voltage applied across the SCR changes rapidly, a transient current flows through the SCR. This transient current flows due to rapid voltage variations (dv/dt) and internal capacitance. This current adds to the forward leakage current. And hence the SCR turns on even if $V_{AK} < V_{BO}$ or gate drive is not applied.

The dv/dt turn-on makes false triggering (unwanted) of the SCR. It is never used for triggering. Every SCR has dv/dt rating. It is expressed in volts per microseconds (V/μs). The voltage variations across the SCR must be kept less than permissible value of dv/dt to avoid false triggering. Normally a small resistance is connected between gate and cathode to avoid false triggering of SCR due to dv/dt. This resistance acts as a external path for leakage current generated by the internal capacitor.

When a gate cathode junction is exposed to light

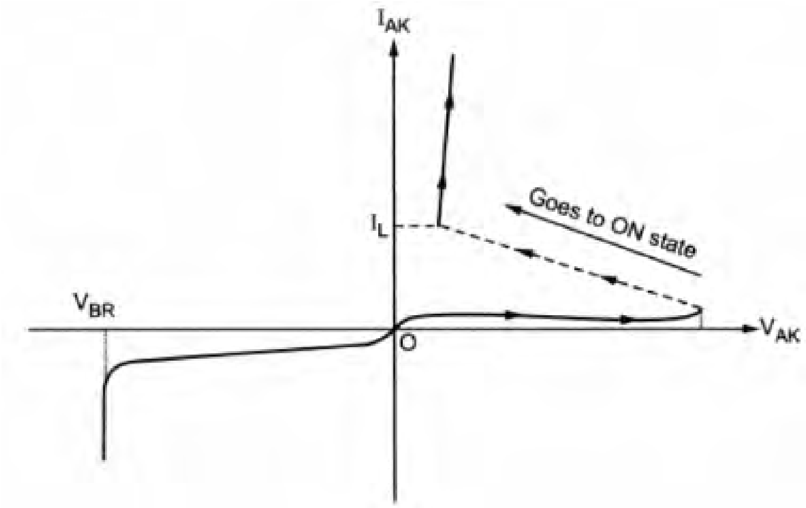
When the gate cathode junction is exposed to a beam of light, the current flows in the junction due to photons of light. This current acts as a gate drive to the SCR and it is driven into conduction. This type of triggering is normally used in light activated SCRs (LASCR).

Latching Current (I_L)

Consider that the SCR is in forward blocking state. Then the SCR can be turned-on by applying a gate drive. Then the SCR goes into forward conduction mode (ON state). For the SCR to remain in the 'ON' state, the anode to cathode current (I_{AK}) must be greater than latching current, i.e.,

$I_{AK} \geq I_L$; to remain in ON state after triggering.

Following figure shows the V-I characteristics of the SCR showing latching current.



V-l characteristics of the SCR showing latching current

Observe that latching current is the lowest current which flows through the SCR to remain in forward conduction (ON state) after triggering. If the current through the SCR is less than latching current, then the SCR goes back into forward blocking state as soon as gate drive is removed. This is said to be SCR is not latched (i.e. not turned-on). From the above discussion, the latching current can be defined as follows:

Latching current is the minimum forward current that flows through the SCR to keep it in forward conduction mode (i.e. ON state) at the time of triggering. If forward current is less than latching current, SCR does not turn-on.

HOLDING CURRENT (I_H)

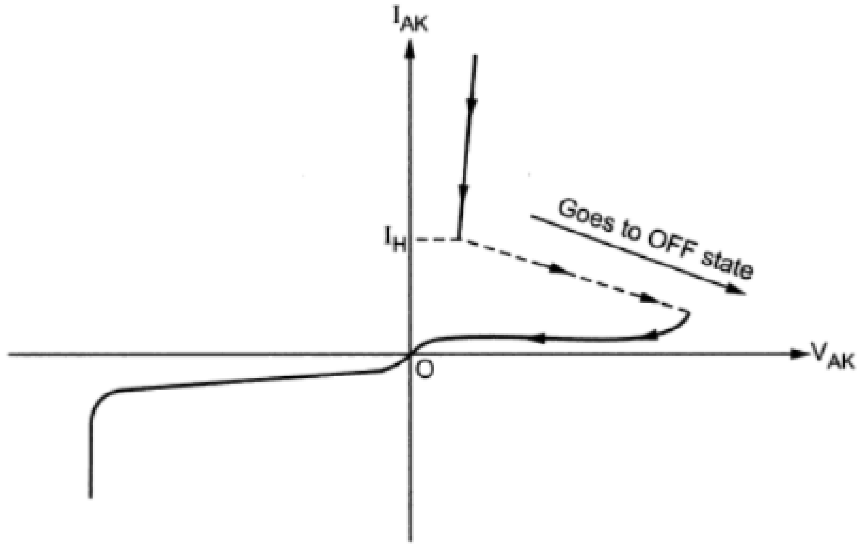
Consider that the SCR is in forward conduction state (i.e. ON state). The SCR goes into forward blocking state when current through it falls below holding current I_H Y i.e., $I_{AK} < I_H$; SCR turns-off.

Following figure shows the V-I characteristics of the SCR showing holding current.

Observe that the holding current is the lowest current below which SCR turns-off. In other words we can say that, for the SCR to remain in ON-state, its forward current should not reduce below holding current. From the above discussion, the holding current can be defined as follows :

Holding current is the minimum forward current that flows through the SCR to keep it in forward conduction mode. When forward current reduces below holding current, SCR turns-off.

The holding current of the SCRs is of the order of 8 to 10 milli amperes.



Latching current is always greater than holding current since it is the current that is required at the time of turning on the thyristor. But holding current is the current that is required to keep the thyristor in 'on' condition. Unless the SCR is turned on (latched) it cannot be turned-off. Hence latching current must be higher than holding current.

Comparison (Difference) between Holding and Latching Currents

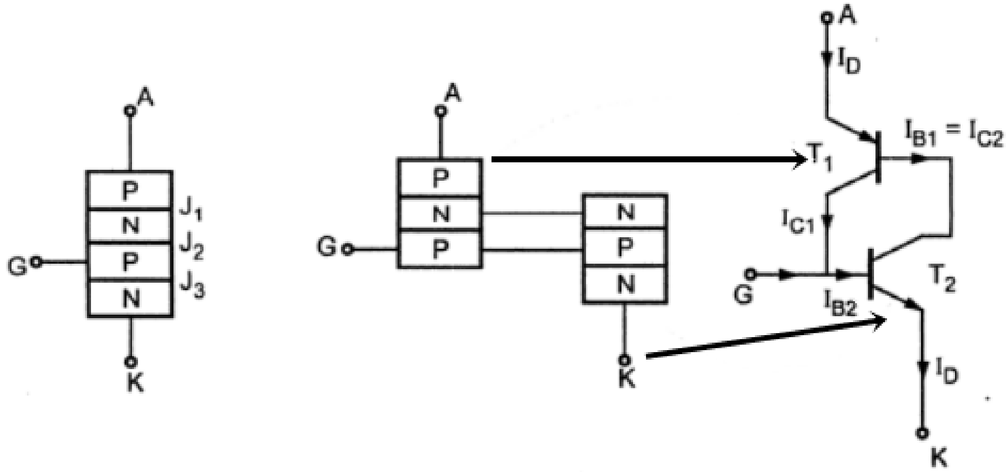
The definitions of holding current and latching current appear similar but they are totally different. The differences are mentioned below :

- Latching current is effective at the time of turning-ON, whereas holding current is effective at the time of turning-OFF the SCR.
- Latching current is the minimum current that should flow at the time of triggering to turn-ON the SCR. Whereas once the SCR is already in ON-state, its current should not reduce below holding current otherwise it turns-OFF.
- Latching current is greater than holding current even though their magnitudes are much related.

TWO TRANSISTOR MODEL OF SCR

The operation of the SCR can be explained with the help of two transistor model. Following figure shows how the two transistor model of the SCR is formed.

As shown in Fig. (b), the middle two layers are split into two separate parts. Because of this, the two transistors are formed. These transistors are shown in Fig. (c). The transistor T_1 is pnp, whereas T_2 is npn. The base of T_1 is connected to collector of T_2. Similarly base of T_2 is connected to collector of T_1. These transistors are in common base configuration. When the SCR is forward biased and gate is open, various currents flow as shown in Fig. (c).



(a) Four layer structure of SCR (b) Middle two layers split into two separate parts

(c) Two transistor mode of the SCR from Fig. (b)

As shown in this figure, the anode to cathode current is I_D. The collector current, emitter current and leakage currents of T_1 are related as

$$I_{C1} = \alpha_1 I_D + I_{CO1}$$

$$I_{C2} = \alpha_2 I_D + I_{CO2}$$

$$I_D = I_{C1} + I_{C2}$$

$$\therefore \quad I_D = \frac{I_{CO}}{1-(\alpha_1-\alpha_2)} \qquad (1)$$

Here I_{CO} is the reverse leakage current of the reverse biased junction J_2. And α_1 is the common base current gain of T_1, and α_2 is common base current gain of T_2. Initially when forward voltage is small, $(\alpha_1 + \alpha_2)$ is very small and less than 1. Hence forward blocking current as given by equation (1) is also small. As forward voltage applied across the SCR increases, the values of α_1 and α_2 also increase. When $(\alpha_1 + \alpha_2)$ tends unity, then I_D approaches infinity as given by equation (1) At this instant, internal regeneration starts and the SCR goes into forward conduction (ON-state) mode. The current through the SCR is only limited by the external load.

Once the SCR goes into conduction, the two transistor model is no more applicable. Here note that the internal regeneration takes place in the SCR due to avalanche breakdown of reverse biased junction J_2. It does not take place when SCR is reverse biased. When the current through the SCR falls below holding current, the forward blocking state is regained. Then α_1 and α_2 of transistors are also reduced to small values.

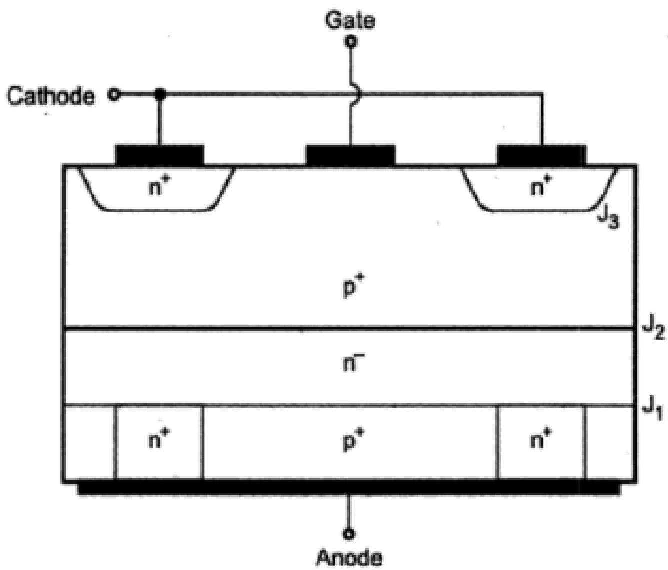
When the gate current I_g is applied, then equation (1) will be written as

$$I_D = \frac{I_{CO}+I_g}{1-(\alpha_1-\alpha_2)} \qquad (2)$$

Thus the forward leakage current (I_D) is increased due to gate drive (I_g). This leakage current flows through junction J_2 and its avalanche break-down occurs at lower forward voltage. Thus with the gate drive, the SCR is turned on at voltages less than V_{BO}. Hence gate becomes convenient way of triggering the SCR. Once the SCR is turned-on, the gate has no control over its conduction.

GATE TURN-OFF THYRISTOR (GTO)

At the beginning of the chapter we discussed structure and working of SCR. The SCR is most commonly used member of thyristor family. But SCR needs external circuits for turn-off. Now we present another thyristor, called GTO. The GTO can be turned-off by gate drive. Thus gate has full control over the operation of GTO. Following figure shows the structure of GTO.

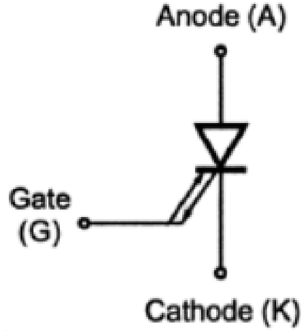


Structure of GTO

Observe that the structure of GTO is almost similar to SCR. But there are significant differences that make GTO different than SCR- These differences are:

- Gate and cathodes are highly interdigited with various geometric forms. This maximizes periphery of the cathode and minimize gate-cathode distance.
- There are n+ regions at regular intervals in the p^+ anode layer. This n^+ layer makes direct contact with n^- layer. This is called *anode short*. This speeds up the turn-off mechanism of GTO.
- The operation of GTO can be explained with the help of two transistor analogy. The gain of p-n-p transistor is reduced. This reduces the regenerative action. Hence turn-off of GTO can be achieved by negative current from gate.

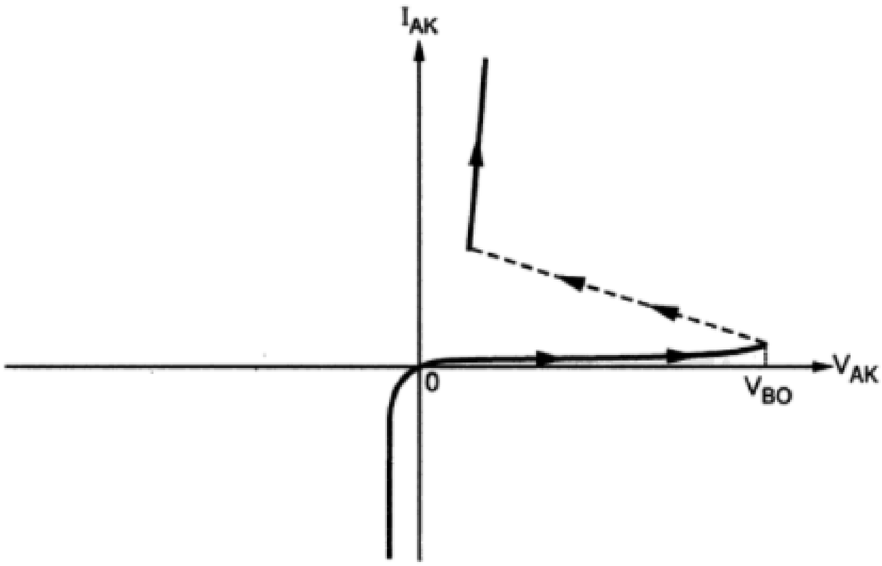
Following figure shows the symbol of GTO.



Observe that there is double arrow on the gate. This indicates that bidirectional current flows through the gate. The rest of the symbol is similar to SCR.

Characteristics of GTO

Following figure shows the V-I characteristics of GTO.



In the figure of structure of GTO observe that the V-I characteristics of GTO in forward direction are similar to that of SCR. But in reverse direction GTO has virtually no blocking capability. Observe that GTO starts conducting in reverse direction after very small reverse (20 to 30 V) voltage. This is because of the anode short structure.

In following figure observe that junction J_3 blocks reverse voltages. But J_3 has very small reverse breakdown voltage. Thus GTO has asymmetric voltage blocking capability.

Advantages of GTO

- Higher voltage blocking capability
- Gate has full control over the operation of GTO.
- Low on-state loss. iv. High ratio of peak surge current to average current.
- High on-state gain.

Limitations of GTO

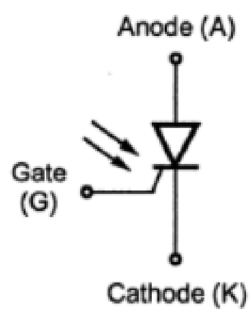
- GTOs require large negative gate currents for turn-off. Hence they are suitable for low power applications.
- Very small reverse voltage blocking capability.
- Switching frequencies are very small.

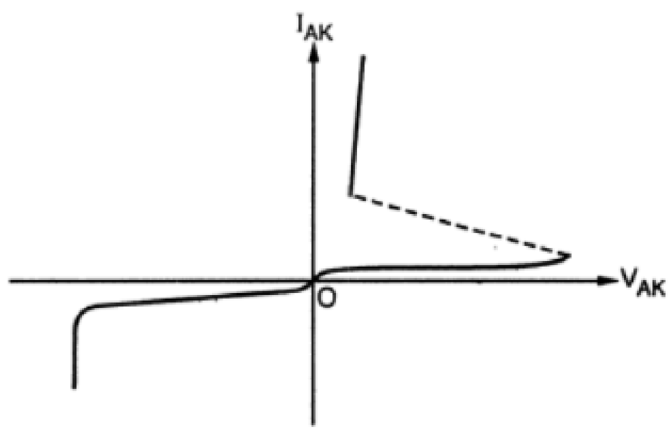
Applications

- GTOs are suitable mainly for low power applications.
- Induction heating and motor drives.

LIGHT ACTIVATED SCR (LASCR)

The light activated SCRs can be triggered using a beam of light. Their gate region is photosensitive. Following figure shows the symbol and V-I characteristics of LASCR.





(a) Symbol of LASCR **(b) V-I characteristics of LASCR**

The photons of light induce electrons in the gate-cathode junction. Because of these electrons, current starts flowing across J_3 and SCR turns-on. Once the SCR is turned on, gate has no control over its operation.

Advantages

- It can be turned-on by a beam of light. Hence isolation is provided between control circuit and SCR.
- Because of optical triggering, effects of noise are reduced.

Applications

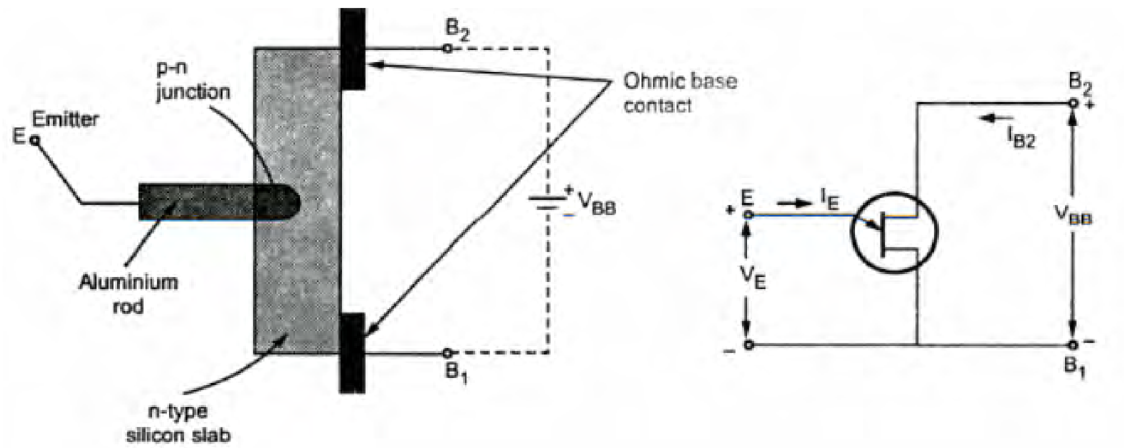
- Used in high power applications like HVDC transmission, VAR compensation etc.
- Used in noise environments for better triggering control.

UJT (UNIJUNCTION TRANSISTOR)

A unijunction transistor (UJT) is a device which does not belong to thyristor family but is used to turn ON SCRs.

Construction

It is a three terminal device, having two layers. It consists of a slab of lightly doped n-type silicon material. The two base contacts are attached to both the ends of this n-type surface. These are denoted as B_1 and B_2 respectively. A p-type material is used to form a p-n junction at the boundary of the aluminium rod and n-type silicon slab. The third terminal called emitter (E) is taken out from this p-type material. The n-type is lightly doped while p-type is heavily doped. The basic construction is shown in following figure (a).



(a) Construction of UJT (b) Symbol of UJT

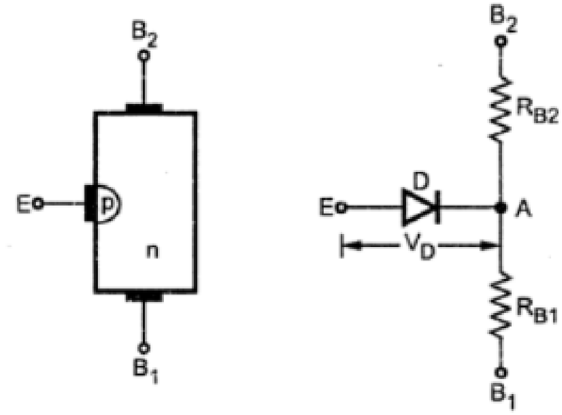
As n-type is lightly doped, it provides high resistivity and p-type as heavily doped, provides low resistivity.

The symbolic representation of UJT is shown in the Fig. (b). The emitter is shown by an arrow which is at an angle to the vertical line representing n-type material. This arrow indicates the direction of flow of conventional current when the UJT is forward biased.

Equivalent Circuit of UJT

The Fig. (a) shows the basic structure of UJT while the Fig. (b) shows the equivalent circuit of UJT.

The internal resistances of the two bases are represented as R_{B1} and RB_2. In the actual construction, the terminal E is closer to B_2 as compared to B_1. Hence resistance RB_1 is more than the resistance Rm. The p-n junction is represented by a normal diode with V_D as the drop across it.



(a) Structure (b) Equivalent circuit

When the emitter diode is not conducting then the resistance between the two bases B_1 and B_2 is called interbase resistance denoted as R_{BB}.

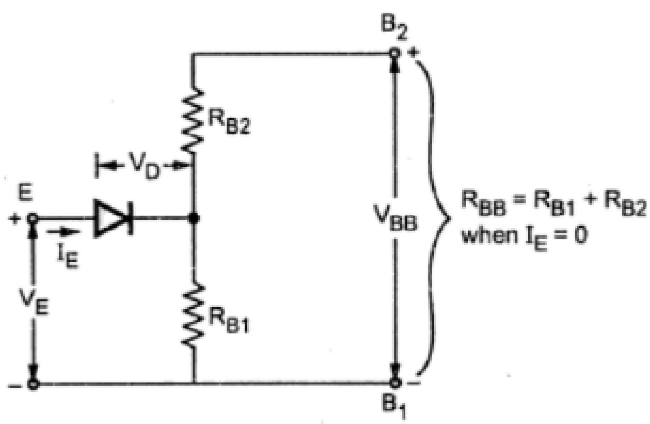
$$R_{BB} = R_{B1} + R_{B2}$$

Its value ranges between 4 kΩ and 12 kΩ.

Intrinsic Stand Off Ratio (η)

Consider UJT as shown in figure to which supply V_{BB} is connected. With I_E =0 i.e. emitter diode is not conducting.

$$R_{BB} = R_{B1} + R_{B2}$$



Then the voltage drop across R_{B1} can be obtained by using potential divider rule.

$$V_{RB1} = \frac{R_{B1} V_{BB}}{R_{B1} + R_{B2}} = \eta V_{BB} \qquad \text{when } I_E = 0$$

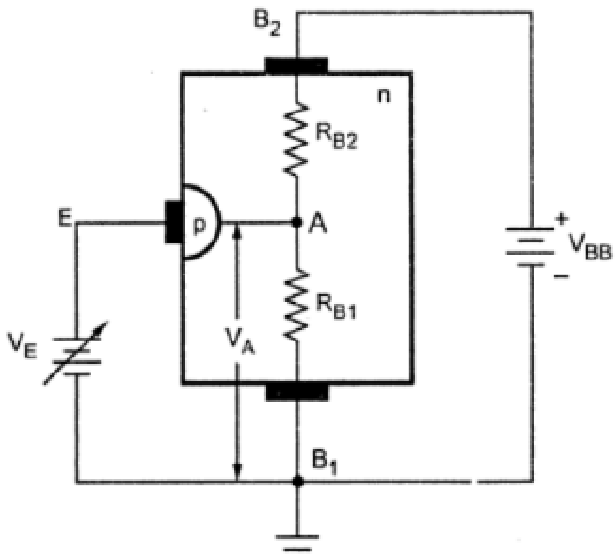
Then $$\eta = Intrinsic\ strand\ off\ ratio = \left.\frac{R_{B1}}{R_{B1} + R_{B2}}\right|_{I_E = 0}$$

$$\eta = \left.\frac{R_{B1}}{R_{BB}}\right|_{I_E = 0}$$

The typical range of η is from 0.5 to 0.8. The voltage V_{RB1} is called *intrinsic stand off voltage* because it keeps the emitter diode reversed biased for all the emitter voltages less than V_{RB1}.

Principle of Operation

While operating an UJT, the supply V_{BB} is applied between B_2. and B_1 while the variable emitter voltage V_E is applied across the emitter terminals. This arrangement is shown in the following figure.



Let us see the effect of change in V_A. The potential of A is decided by η and is equal to ηV_{BB}.

Case 1 : $V_E < V_A$

As long as V_E is less than V_A, the p-n junction is reverse biased. Hence emitter current It will not flow. Thus UJT is said to be OFF.

Case 2 : $V_E > V_P$

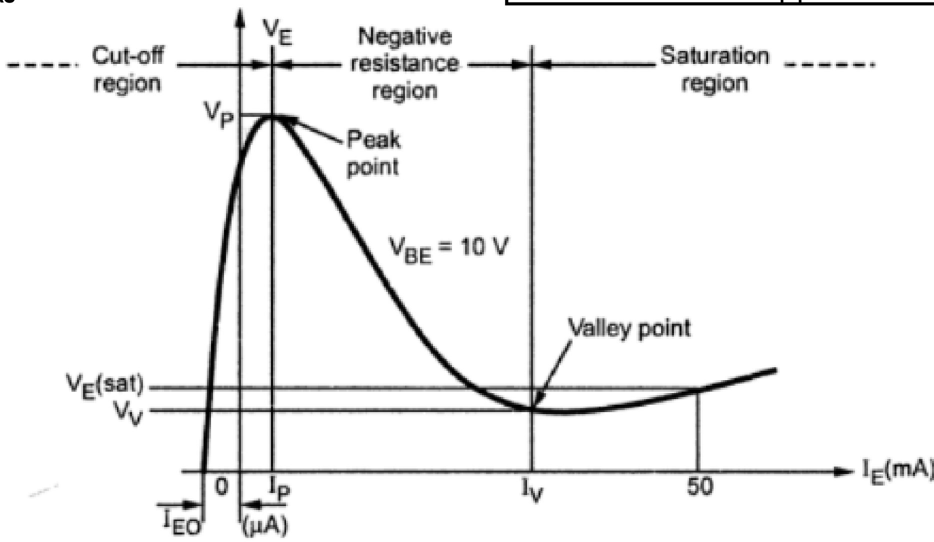
The diode drop V_D is generally between 0.3 to 0.7 V. Hence we can write,

$$V_D = V_A + V_D = \eta V_{BB} + V_D$$

When V_E becomes equal to or greater than V_P the p-n junction becomes forward biased and current I_E flows. The UJT is said to be ON.

UJT Characteristics

The graph of emitter current against emitter voltage plotted for a particular value of V_{BB} is called the *characteristics of UJT*. For a particular fixed value of V_{BB} such characteristics is shown in following figure.



The characteristics can be divided into three main regions which are,

1. **Cut-off region:** The emitter voltage V_E is less than V_P and the p-n junction is reverse biased. A small amount of reverse saturation current I_{E0} flows through the device, which is negligibly small of the order of μA. This condition remains till the peak point.

2. **Negative resistance region:** When the emitter voltage V_E becomes equal to V_P the p-n junction becomes forward biased and I_E starts flowing. The voltage across the device decreases in this region, though the current through the device increases. Hence the region is called negative resistance region. This decreases the resistance R_{B1}. This region is stable and used in many applications. This region continues rill valley point.

3. **Saturation region:** Increase in I_E further valley point current Iv drives the device in the saturation region. The voltage corresponding to valley point is called *valley point voltage* denoted as V_V. In this region, further decrease in voltage does not take place. The characteristic is similar to that of a semiconductor diode, in this region.

The active region i.e. negative resistance region, the holes which are large in number on p-side, get injected into n-side. This causes increase in free electrons in the n-type slab. This increases the conductivity i.e. decreases the resistivity. Hence the resistance R_{B1} decreases in this region.

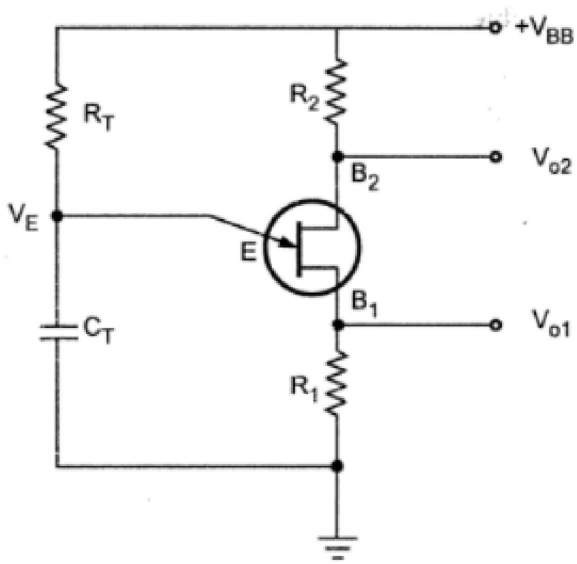
As the V_{BB} increases, the potential V_P corresponding to peak point will increase.

Applications

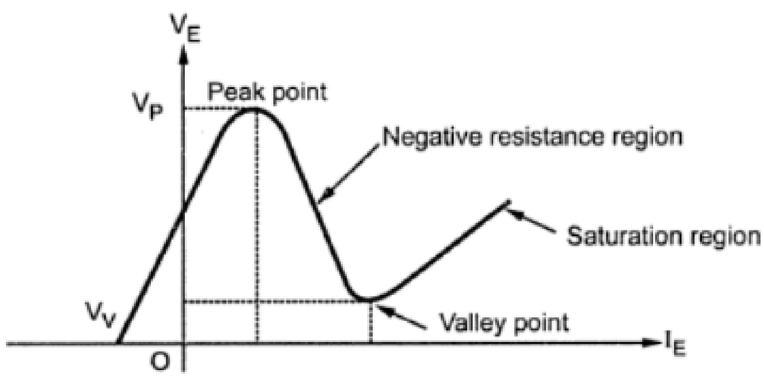
The UJT is mainly used in the triggering of other devices such as SCR. It is also used in the sawtooth wave generators and some timing circuits. The most popular application of UJT is as a **relaxation oscillator** to obtain short pulses for triggering of SCRs.

UJT RELAXATION OSCILLATOR

The pulse signal required to drive the digital circuits can be obtained from a single stage oscillator circuits using a particular device like unijunction transistor. Such a oscillator which uses UJT is called UJT relaxation oscillator. The basic circuit of UJT relaxation oscillator is shown in following figure.



The R_1 and R_2 are biasing resistances which are selected such that they are lower than interbase resistances R_{B1} and R_{B2}. The resistance R_T and the capacitance C_T decide the oscillating rate. The value of R_T is so selected that the operating point of UJT remains in the negative resistance region. The UJT characteristics and the negative resistance region of the characteristics are shown in the following figure.



The characteristics of UJT shows the variation between V_E and I_E, where V_E is emitter voltage and I_E is emitter current.

Operation

Capacitor C_T gets charged through the resistance R_T towards supply voltage V_{BB}. As long as the capacitor voltage is less than peak voltage V_P, the emitter appears as an open circuit.

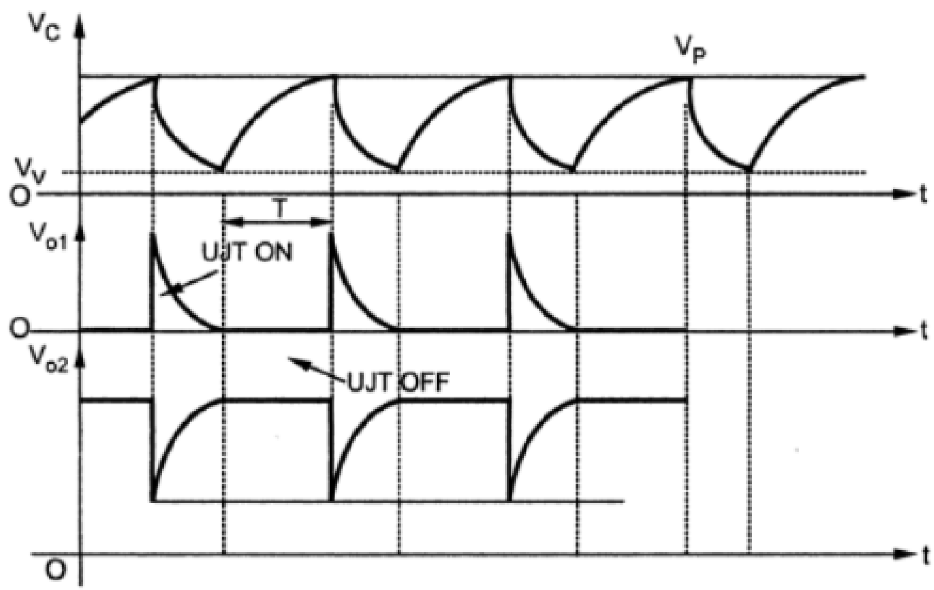
$$V_P = \eta V_{BB} + V_D \qquad (1)$$

where η is stand off ratio of UJT and V_D is cut in voltage of diode.

When the capacitor voltage V_C exceeds the voltage V_P, the UJT fires. The capacitor starts discharging through $R_1 + R_{B1}$ where R_{B1} internal base resistance. As R_{B1} is assumed negligible and hence capacitor discharges through R_1.

Due to the design of R_1, this discharge is very fast, and it produces a pulse across R_1 When the capacitor voltage falls below V_V i.e. $V_C = V_E = V_V$, the UJT gets turned OFF. The capacitor starts charging again.

The discharge time of the pulse is controlled by the time constant C_TR_1 while the charging time constant by R_TC_T. The waveforms are shown in the following figure.



There is voltage drop across R_2 and voltage rise across R_1 when UJT fires. The charging equation of the capacitor is given by

$$V_{C(t)} = V_V + V_{BB}[1 - e^{-t/R_TC_T}] \quad (2)$$

$$V_{C(t)} = V_P \quad \text{at } t = T$$

$$V_P = V_V + V_{BB}[1 - e^{-1/R_TC_T}] \quad (3)$$

Using the equation (1)

$$\therefore \quad \eta V_{BB} + V_D = V_V + V_{BB}[1 - e^{-T/R_TC_T}] \quad (4)$$

Neglecting V_D and V_V to get approximate relation for T.

$$\therefore \quad \eta = 1 - e^{-T/R_TC_T}$$

$$\therefore \quad T = R_TC_T \ln\left[\frac{1}{1-\eta}\right] \quad (5)$$

$$f_0 = \frac{1}{T} = \frac{1}{R_T C_T \ln\left[\frac{1}{1-\eta}\right]} \qquad (6)$$

where f_0 is oscillating frequency.

Example

In a UJT relaxation oscillator, R_T = 5 kΩ, C_T = 0.1 μF and η = 0.58. Find the frequency of the oscillations.

Answer: 2.305 kHz

Example

For a certain UJT relaxation oscillator, the resistance is 10 kΩ while the capacitance is 0.1 μF. The valley potential is 1.5 V when V_{BB} = 20 V. Assuming diode cut-in voltage of 0.7 V and stand off ratio as 0.6, calculate the frequency of oscillations.

Solution

In this problem all values are given i.e. V_V, V_D etc. So instead of using approximate relation, we have to use equation (1).

$$V_P = \eta V_{BB} + V_D = 0.6 \text{ x } 20 + 0.7 = 12.7 \text{ V}$$

Now $V_P = V_V = V_{BB}[1 - e^{-t/R_T C_T}]$

Here $V_V = 1.5$ V, $R_T = 10 \text{ x } 10^3$ Ω, $C_T = 0.1$ μF

Putting these values in above equation

$$e^{-T/0.001} = 0.44$$

$$-\frac{T}{0.001} = \ln(0.44) = -0.8209$$

∴ $T = 8.209 \text{ x } 10^{-4}$ sec

∴ $$f_0 = \frac{1}{T} = \frac{1}{8.209 x 10^{-4}} = 1.218\, kHz$$

Example

Determine the range of R_T for the UJT relaxation oscillator that will ensure proper turn ON and OFF of the UJT used. The various UJT parameters are η = 0.33, V_V = 0.8 V, I_V = 15 mA, I_P = 35 μA and V_P = 18 V. Assume V_{BB} = 30 V.

Solution

For turn ON

$$R_T < \frac{V_{BB} - V_P}{I_P} < \frac{30 - 18}{35x10^{-6}} < 342.85\,k\Omega$$

For turn OFF

$$R_T > \frac{V_{BB} - V_V}{I_V} > \frac{30 - 0.8}{15x10^{-3}} < 1.94\,k\Omega$$

So, range of R_T is

$$1.94\ k\Omega < R_T < 342.85\ k\Omega$$

THYRISTOR PROTECTION

Reliable operation of a thyristor demands that its specified ratings are not exceeded. In practice, a thyristor may be subjected to over voltages or over currents. During SCR turn-on, **di/dt** may be prohibitively large. There may be false triggering of SCR by high value of **dv/dt**. A spurious signal across gate-cathode terminals may lead to unwanted turn-on. A thyristor must be protected against all such abnormal conditions for satisfactory and reliable operation-of SCR circuit and the equipment. SCRs are very delicate devices, their protection against abnormal operating conditions is, therefore, essential.

di/dt protection

When a thyristor is forward biased and is turned on by a gate pulse, conduction of anode current begins in the immediate neighbourhood of the gate-cathode junction. Thereafter, the current spreads across the whole area of junction. The thyristor design permits the spread of conduction to the whole junction area as rapidly as possible. However, if the rate of rise of anode current, i.e. di/dt, is large as compared to the spread velocity of carriers, local hot spots will be formed near the gate connection on account of high current density. This localised heating may destroy the thyristor. Therefore, the rate of rise of anode current at the time of turn-on must be kept below the specified limiting value. The value of di/dt can be maintained below acceptable limit by using a small inductor, called di/dt inductor, in series with the anode circuit. Typical di/dt limit values of SCRs are 20-500 A/μsec.

Local spot heating can also be avoided by ensuring that the conduction spreads to the whole area as rapidly as possible. This can be achieved by applying a gate current nearer to (but never greater than) the maximum specified gate current.

dv/dt protection

With forward voltage across the anode and cathode of a thyristor, the two outer junctions are forward biased but the inner junction is reverse biased. This reverse biased junction J2 has the characteristics of a capacitor due to charges existing across the junction. In other words, space-charges exist in the depletion region around junction Jo and therefore junction J_2 behaves like a capacitance. If the entire anode to cathode forward voltage V_a appears across J_2 junction and the charge is denoted by Q, then a charging current i given by

$$i = \frac{dQ}{dt} = \frac{d}{dt}(C_j.V_a) = C_j\frac{dV_a}{dt} + V_a\frac{dC_j}{dt} \qquad (1)$$

As C_j, the capacitance of junction J_2 is almost constant, the current is given by

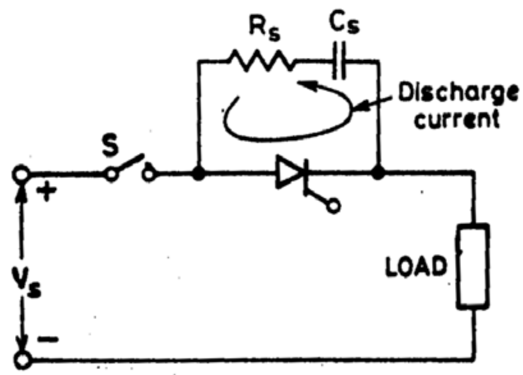
$$i = C_j\frac{dV_a}{dt} \qquad (2)$$

If the rate of rise of forward voltage dV_a/dt is high, the charging current i will be more.

This charging current plays the role of gate current and turns on the SCR even when gate signal is zero. Such phenomena of turning-on a thyristor, called dv/dt turn-on must be avoided as it leads to false operation of the thyristor circuit. For controllable operation of the thyristor, the rate of rise of forward anode to cathode voltage dV_a/dt must be kept below the specified rated limit. Typical values of dv/dt are 20 - 500 V/μsec. False turn-on of a thyristor by large dv/dt can be prevented by using a snubber circuit in parallel with the device.

Design of Snubber Circuit

A snubber circuit consists of a series combination of resistance R_s and capacitance C_s in parallel with the thyristor as shown in following figure.



Strictly speaking, a capacitor C_s in parallel with the device is sufficient to prevent unwanted dv/dt triggering of the SCR. When switch S is closed, a sudden voltage appears across the circuit. Capacitor C_s behaves like a short circuit, therefore voltage across SCR is zero. With the passage of time, voltage across Cs builds up at a slow rate such that dv/dt across Cs and therefore across SCR is less than the specified maximum dv/dt rating of the device. Here the question arises that if C_s is enough to prevent accidental turn-on of the device by dv/dt, what is the need of putting R_s in series with C_s.

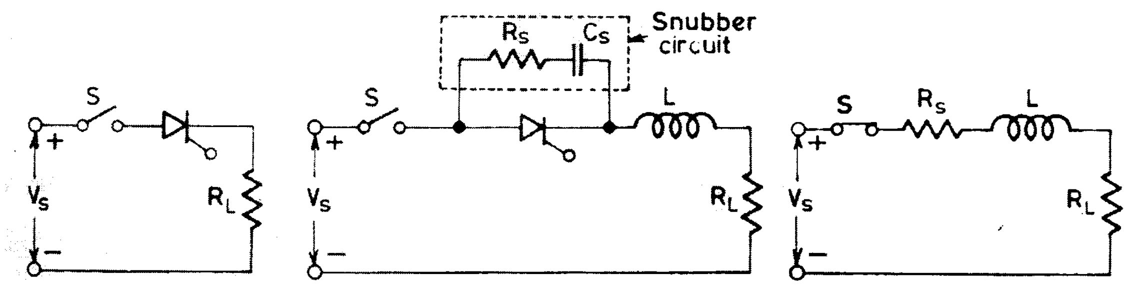
The answer to this is as under.

Before SCR is fired by gate pulse, C_s charges to full voltage V_s. When the SCR is turned on, capacitor discharges through the SCR and sends a current equal to V_s/(resistance of local path formed by C_s and SCR). As this resistance is quite low, the turn-on di/dt will tend to be excessive and as a result, SCR may be destroyed. In order to limit the magnitude of discharge current, a resistance R_s is inserted in series with C_s as shown in figure. Now when SCR is turned on, initial discharge current V_s/R_s is relatively small and turn-on di/dt is reduced.

In actual practice ; R_s, C_s and the load circuit parameters should be such that dv/dt across C_s during its charging is less than the specified du/dt rating of the SCR and discharge current at the turn-on of SCR is within reasonable limits. Normally, R_s, C_s and load circuit parameters form an underdamped circuit so that dv/dt is limited to acceptable values.

Example

Figure (a) shows a thyristor controlling the power in a load resistance R_L. The supply voltage is 240 V dc and the specified limits for di/dt and dv/dt for the SCR are 50A/μsec and 300 V/μsec respectively. Determine the values of the di/dt inductance and the snubber circuit parameters R_s and C_s.



(a) (6) m

(a) Thyristor in series with R_L (b) Thyristor protection with L and R_s, C_s (c) Equivalent circuit fig (b) at the instant switch S is closed.

Solution

Snubber circuit parameters R_s and C_s are connected across SCR and di/dt inductor L in series with anode circuit as shown in Fig. (b). When switch S is closed, the capacitor behaves like a short circuit and SCR in the forward blocking state offers a very high resistance. Therefore, the equivalent circuit soon after the instant of closing the switch S is as shown in Fig. (c). For this circuit, the voltage equation is

$$V_s = (R_s + R_L)i + L\frac{di}{dt} \qquad (1)$$

Its solution is $i = I(1 - e^{-t/r})$

where $$I = \frac{V_s}{R_s + R_L}$$

and $$\tau = \frac{L}{R_s + R_L}$$

In eq (1), t is the time in seconds measured from the instant of closing the switch.

From this equation

$$\frac{di}{dt} = I.e^{-t/\tau}.\frac{1}{\tau} = \frac{V_s}{R_s + R_L}.\frac{R_s + R_L}{L}e^{-t/\tau} = \frac{V_s}{L}e^{-t/\tau}$$

The value of di/dt is maximum when t = 0

$$\therefore \qquad \left(\frac{di}{dt}\right)_{max} = \frac{V_s}{L} \qquad (2)$$

$$\therefore \qquad L = \frac{V_s}{(di/dt)_{max}} = \frac{240x10^{-6}}{50} = 4.8\,\mu H$$

The voltage across SCR is given by, $v_a = R_s.i$

$$\text{or} \qquad \left(\frac{dv_a}{dt}\right)_{max} = R_s.\left(\frac{di}{dt}\right)_{max} \qquad (3)$$

From (2) and (3)

$$\left(\frac{dv_a}{dt}\right)_{max} = \frac{R_s.V_s}{L}$$

$$\text{or} \qquad R_s = \frac{L}{V_s}\left(\frac{dv_a}{dt}\right)_{max} = \frac{4.8}{240}x300 = 6\Omega$$

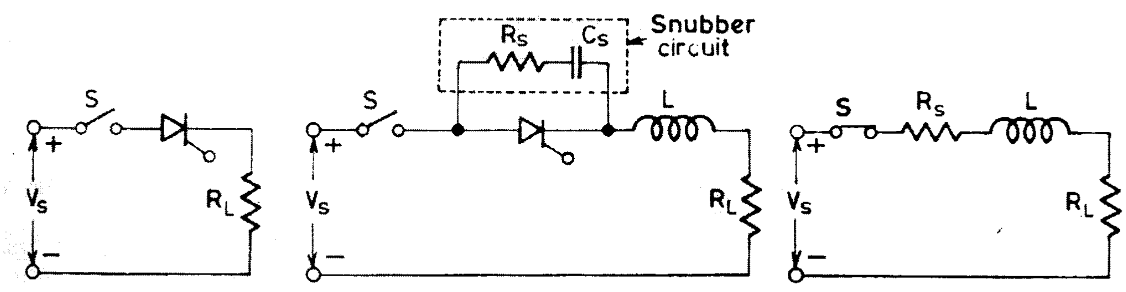
$$\text{Now} \qquad C_s = \left(\frac{2\xi^2}{R_s}\right)^2 L$$

Take $\xi = 0.65$

$$C_s = \left(\frac{2x0.65}{6}\right)^2 x4.8x10^{-6} = 0.2253\,\mu F$$

Problem

Figure (a) shows a thyristor controlling the power in a load resistance R_L. The supply voltage is 400 V dc and the specified limits for di/dt and dv/dt for the SCR are 50A/μsec and 300 V/μsec respectively. Determine the values of the di/dt inductance and the snubber circuit parameters R_s and C_s.



Answer: L = 8 μH, R_s = 6 Ω, C_s = 0.222 μF

OVERVOLTAGE PROTECTION

Thyristors are very sensitive to over voltages just as other semi-conductor devices are. Overvoltage transients are perhaps the main cause of thyristor failure. Transient over voltages cause either maloperation of the circuit by unwanted turn-on of a thyristor or permanent damage to the device due to reverse breakdown. A thyristor may be subjected to internal or external overvoltages; the former is caused by the thyristor operation whereas the latter comes from the supply lines or the load circuit.

Internal overvoltages

Large voltages may be generated internally during the commutation of a thyristor. After thyristor anode current reduces to zero, anode current reverses due to stored charges. This reverse recovery current rises to a peak value at which time the SCR begins to block. After this peak, reverse recovery current decays abruptly with large di/dt. Because of the series inductance L of the SCR circuit, large transient voltage L(di/dt) is produced. As this internal overvoltage may be several times the breakover voltage of the device, the thyristor may be destroyed permanently.

External overvoltages

External overvoltages are caused due to the interruption of current flow in an inductive circuit and also due to lightning strokes on the lines feeding the thyristor systems. When a thyristor converter is fed through a transformer, voltage transients are likely to occur when the transformer primary is energised or de-energised. Such overvoltages may cause random turn on of a thyristor. As a result, the overvoltages may appear across the load causing the flow of large fault currents. Overvoltages may also damage the thyristor by an inverse breakdown. For reliable operation, the overvoltages must be suppressed by adopting suitable techniques.

Suppression of Overvoltages

In order to keep the protective components to a minimum, thyristors are chosen with their peak voltage ratings of 2.5 to 3 times their normal peak working voltage. The effect of overvoltages is usually minimised by using RC circuits and non-linear resistors called **voltage clamping devices**.

The RC circuit, called snubber circuit, is connected across the device to be protected. It provides a local path for internal overvoltages caused by reverse recovery current. Snubber circuit is also helpful in damping overvoltage transient spikes and for limiting dv/dt across the thyristor. The capacitor charges at a slow rate and thus the rate of rise of forward voltage (dv/dt) across SCR is also reduced. The resistance R_s damps out the ringing oscillations between the snubber circuit and the stray circuit inductance. Snubber circuits are also connected across transformer secondary terminals to suppress overvoltage transients caused by switching on or switching off of the primary winding. As snubber circuits provide only partial protection to SCR against transient overvoltages, thyristor protection against such overvoltages must be upgraded. This is done with the help of voltage-clamping devices.

Overcurrent Protection

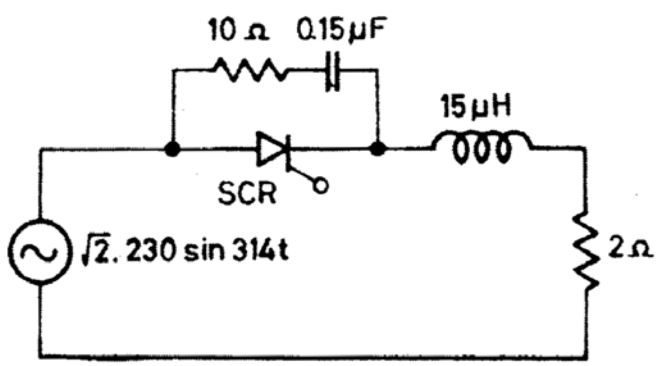
Thyristors have small thermal time constants. Therefore, if a thyristor is subjected to overcurrent due to faults, short circuits or surge currents ; its junction temperature may exceed the rated value and the device may be damaged. There is thus a need for the overcurrent protection of SCRs. As in other electrical systems, overcurrent protection in thyristor circuits is achieved through the use of **circuit breakers and fast-acting fuses**.

The type of protection used against overcurrent depends upon whether the supply system is weak or stiff. In a weak supply network, fault current is limited by the source impedance below the multi-cycle surge current rating of the thyristor. In machine tool and excavator drives, if the motor stalls due to overloads, the current is limited by the source and motor impedances. The filter inductance commonly employed in dc and ac drives may limit the rate of rise of fault current below the multicycle surge current rating of the thyristor. For all such systems, overcurrent can be interrupted by conventional fuses and circuit breakers. However, proper co-ordination is essential to guarantee that (i) fault current is interrupted before the thyristor is damaged and (ii) only faulty branches of the network are isolated.

Conventional protective methods are, however, inadequate in electrical stiff supply networks. In such systems, magnitude and rate of rise of current is not limited because source has negligible impedance. As such, fault current and therefore junction temperature rise within a few milliseconds. Special fast-acting current-limiting fuses are, therefore, required for the protection of thyristors in these stiff supply networks.

Example

For the circuit shown in figure,



Calculate the maximum values of di/dt and dv/dt for the SCR.

Solution

$$\left(\frac{di}{dt}\right)_{max} = \left(\frac{V_s}{L}\right) = \frac{\sqrt{2}x230}{15x10^{-6}} = 21.685\,A/\mu\sec$$

$$\left(\frac{dv}{dt}\right)_{max} = R_s\left(\frac{di}{dt}\right)_{max} = 10x21.685 = 216.85V/\mu\sec$$

HEATING, COOLING AND MOUNTING OF THYRISTORS

Some power loss occurs in a thyristor during its working. The various components of this power loss in the junction region of a thyristor are as under :

- Forward conduction loss
- Loss due to leakage current during forward and reverse blocking
- Switching losses at turn-on and turn-off
- Gate triggering loss

At industrial power frequencies between zero and 400 Hz, the forward conduction loss, or on-state conduction loss, is usually the major component. But switching losses become dominant at high operating frequencies. These electrical losses produce thermal heat which must be removed from the junction region. The thermal losses and hence the temperature rise of the device increase with the thyristor rating. The cooling of thyristors, therefore, becomes more difficult as the SCR rating increases.

The heat produced in a thyristor by electrical loss is dissipated to ambient fluid (air or water) by mounting the device on a heat sink. When heat due to losses is equal to that dissipated by the heat sink, steady junction temperature is reached. Thyristor heating and hence its junction temperature rise is dependent primarily on current handled by the device during its working. As such, current rating of thyristors is often based on thermal considerations.

Thermal Resistance

Thermal energy, or heat, flows from a region of higher temperature to a region of lower temperature. This is similar to the flow of current from higher to lower potential in an electric circuit. There is thus an analogy between thermal-power flow and current flow as given in tabular form below:

It is seen from above that thermal resistance, analogous to electrical resistance, is the resistance offered to thermal power flow. Thermal resistance is denoted by θ. If power loss, P_{av} in watts, causes the temperature of two points to be at $T_1\ ^0C$ and $T_2\ ^0C$ where $T_1 > T_2$, then thermal resistance is given by

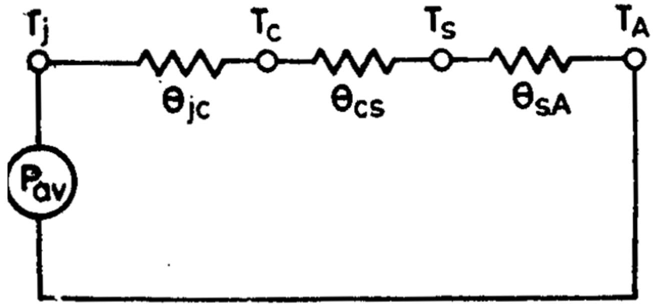
$$\theta_{12} = \frac{T_1 - T_2}{P_{av}}\ ^0C/W$$

The heat generated in a thyristor due to internal losses is taken to be developed at a junction within the semiconductor material. The heat flow in a thyristor is then as under:

- from the junction to thyristor case ;
- from the thyristor case to heat sink and
- from the heat sink to the surrounding ambient fluid (air or water).

There is thus thermal resistance θ_{jc} between junction temperature T_j and case temperature T_c. Similarly, there is thermal resistance θ_{cs} between T_c and sink temperature T_s and θ_{sa} between

T_s and ambient temperature T_A. Using the electrical analogy, a thermal equivalent circuit depicting the flow of heat from junction to ambient fluid can be drawn as shown



Here $$P_{av} = \frac{T_j - T_c}{\theta_{jc}} = \frac{T_c - T_s}{\theta_{cs}} = \frac{T_s - T_A}{\theta_{sA}} = \frac{T_j - T_A}{\theta_{jA}} \quad (1)$$

where $$\theta_{jA} = \theta_{jc} + \theta_{cs} + \theta_{sA}$$

is the total thermal resistance between junction and ambient.

The difference in temperature between junction and ambient can be written as

$$T_j - T_A = P_{av}(\theta_{jc} + \theta_{cs} + \theta_{sA}) \quad (2)$$

Heat Sink Specifications

The thyristor data sheet specifies maximum junction temperature T_j thermal resistances θ_{jc} and θ_{cs} The manufacturers of heat sinks provide catalogue in which sufficient data on heat sink is available.

Heat sinks are made from metal with high thermal conductivity. Aluminium is the most commonly used metal. Copper, being a costly metal, is seldom used as a heat sink material. Heat dissipation from heat sink takes place primarily by convection. As such, thyristor cooling by convection can be made more effective by enlarging the cooling surface area by providing the heat sink with peripheral fins. Heat dissipation also takes place by radiation. Heat sinks are usually provided with black anodized finish to enhance the heat dissipation by radiation.

Sometimes the size of naturally-cooled finned heat sink may become large. In such a case, size of the heat sink can be reduced by using forced air cooling which involves a fan blowing air over the fins. With forced air cooling, heat-removing capability of the finned heat sink increases by a factor of two to three. For dissipating large losses in high-power thyristors, water-cooling is usually employed to get a compact size of the heat sink.

FIRING CIRCUITS FOR THYRISTORS

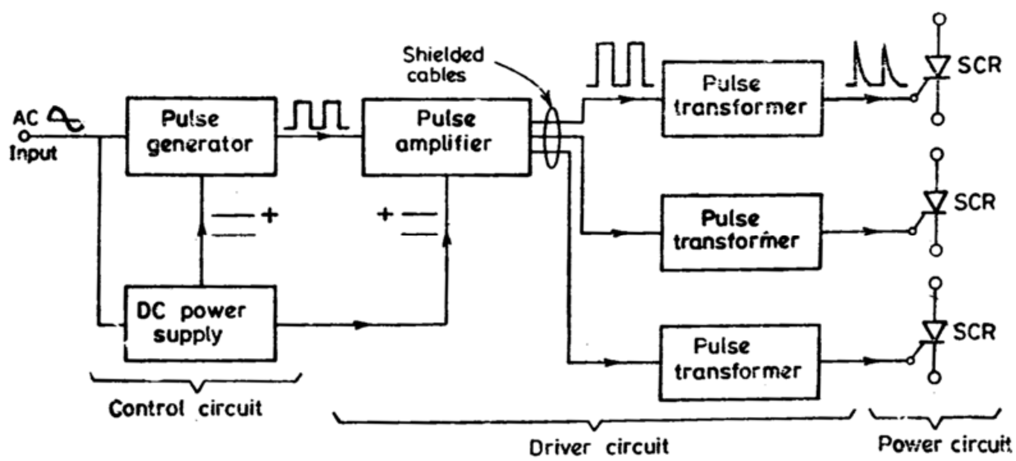
An SCR can be switched from off-state to on-state in several ways ; these are forward-voltage triggering, dv/dt triggering, temperature triggering, light triggering and gate triggering. The instant of turning on the SCR cannot be controlled by the first three methods listed above. Light triggering is used in some applications, particularly in a series-connected string. *Gate triggering is, however, the most common method of turning on the SCRs*, because this method lends itself accurately for turning on the SCR at the desired instant of time. In addition, gate triggering is an efficient and reliable method.

Main Features of Firing Circuits

As stated above, the most common method for controlling the onset of conduction in an SCR is by means of gate voltage control. The **gate control circuit** is also called *firing*, or *triggering*, circuit. These gating circuits are usually low-power electronic circuits. A firing circuit should fulfil the following two functions.

1. If power circuit has more than one SCR, the firing circuit should produce gating pulses for each SCR at the desired instant for proper operation of the power circuit. These pulses must be periodic in nature and the sequence of firing must correspond with the type of thyristorised power controller. For example, in a single-phase semiconductor using two SCRs, the triggering circuit must produce one firing pulse in each half cycle; in a 3-phase full converter using six SCRs, gating circuit must produce one trigger pulse after every 60^0 interval.
2. The control signal generated by a firing circuit may not be able to turn-on an SCR. It is therefore common to feed the voltage pulses to a driver circuit and then to gate-cathode circuit. A driver circuit consists of a pulse amplifier and a pulse transformer.

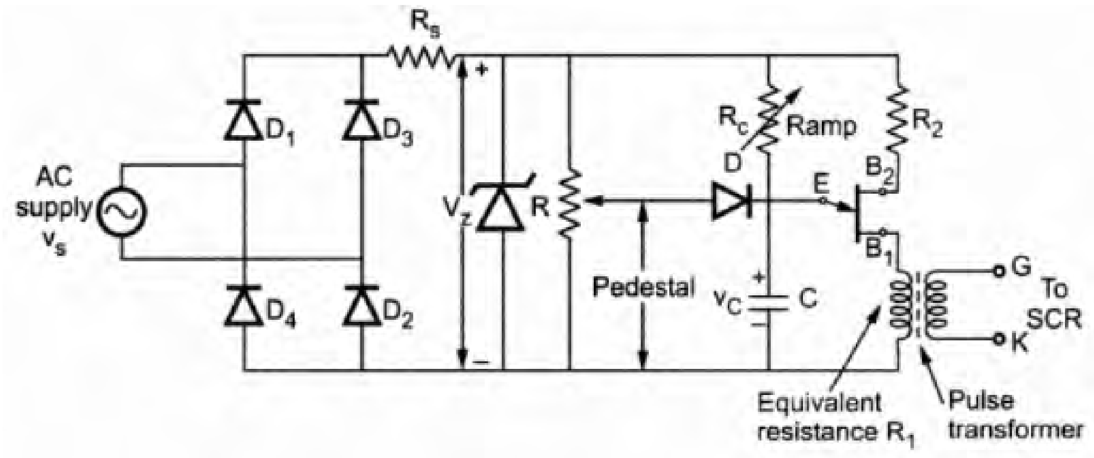
A firing circuit scheme, in general, consists of the components shown below.



A regulated dc power supply is obtained from an alternating voltage source. Pulse generator, supplied from both ac and dc sources, gives out voltage pulses which are then fed to pulse amplifier for their amplification. Shielded cables transmit the amplified pulses to pulse transformers. The function of pulse transformer is to isolate the low-voltage gate-cathode circuit from the high-voltage anode-cathode circuit. Some firing circuit schemes are described in this section.

UJT TRIGGERING CIRCUIT

The Unijunction transistor (UJT) triggering circuit is used in most of the applications. Following figure shows the circuit diagram of UJT triggering circuit.



Operation

The supply voltage is rectified and given to the zener regulator. The voltage of zener diode is V_z. The zener diode clamps the rectified voltage to V_z. Hence voltage V_z is applied to the UJT circuit.

The pedestal control indicates initial voltage level in the capacitor. It can be adjusted through resistance R. The ramp control indicates charging of capacitor from pedestal level.

- The capacitor charges through resistance R_c. When the capacitor voltage becomes equal to $_p$, the peak voltage of the UJT, it turns-on. The capacitor discharges through emitter (E), base (B.) and primary of pulse transformer. The UJT is turned-on when the capacitor discharges. Since current flows through the primary of pulse transformer, a pulse is generated.
- When the capacitor discharges to a voltage called valley voltage (V_v), the UJT turns-off and capacitor again starts charging from pedestal level. This mode of working of UJT is called *relaxation oscillator*.
- The delay angle 'α' is the angle when first triggering pulse is generated in the half cycle. The charging of the capacitor can be varied by resistance R_C. Hence delay angle can also be varied. The UJT trigger circuit has the firing angle range from 0 to 180^0.

The zener voltage acts as a supply voltage for UJT relaxation oscillator. This voltage becomes zero at 0, π, 2π, 3π, ...etc. The capacitor voltage also becomes zero at these instants. Thus synchronization with zero crossings is achieved. The UJT trigger circuit can be used to trigger SCRs in 1ϕ converters, 1ϕ AC regulators etc.

Advantages of UJT Triggering

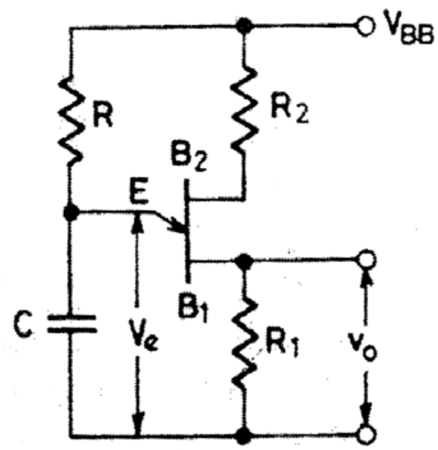
UJT triggering provides high frequency pulses to the gate for triggering. Theses high frequency pulses are generated basically due to UJT as a relaxation oscillator. It has all the advantages of pulsed gate drive.

- SCR can be turned on at the first pulse only.
- Since drive is in the form of pulses, power dissipation in gate is reduced.
- High frequency gate drive signal can be easily coupled through pulse transformer that also provides isolation between gate circuit and SCR.
- The frequency of pulses can be easily changed by R and C values in UJT trigger circuit.
- Since SCR turns on normally in first or second pulse, the rest of the pulses are redundant. Thus there is no need of continuous signal for gate drive.

Example

A relaxation oscillator using an UJT, Fig. (a), is to be designed for triggering an SCR. The UJT has the following data:

$\eta = 0.72, I_p = 0.6\ mA, V_p = 18.0, V_v = 1.0\ V, I_v = 2.5\ mA, R_{BB} = 5\ k\Omega$



Normal leakage current with emitter open = 4.2 mA

The firing frequency is 2 kHz. For C = 0.04 μF, computer the values of R, R_1 and R_2.

Solution

The value of charging resistor R will be

$$R = \frac{T}{C \ln \frac{1}{1-\eta}} = \frac{1}{fC \ln \frac{1}{1-\eta}} = \frac{10^6}{2000 x 0.04 \ln \frac{1}{0.28}} = 9.82\,k\Omega$$

As V_D is not given, $V_p = \eta V_{BB}$

$$\therefore \qquad V_{BB} = \frac{V_p}{\eta} = \frac{18.00}{0.72} = 25V$$

$$R_2 = \frac{10^4}{\eta V_{BB}} = \frac{10^4}{0.72x25} = 555.55\Omega$$

With emitter open

V_{BB} = Leakage current ($R_1 + R_2 + R_{BB}$)

$$R_1 = \frac{25}{4.2x10^{-3}} - 5000 - 555.55\Omega = 396.83\Omega$$

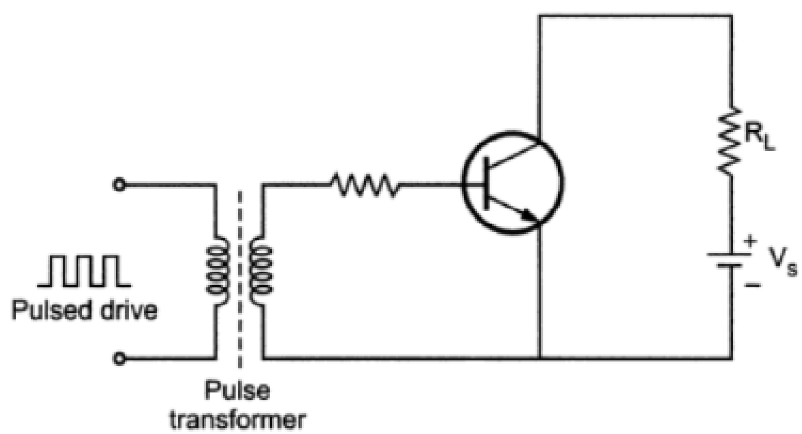
PULSE TRANSFORMER

Pulse transformers are used quite often in firing circuits for SCRs and GTOs. This transformer has usually two secondaries. The turn ratio from primary to two secondaries is 2:1:1 or 1:1 :1. These transformers are designed to have low winding resistance, low leakage reactance and low inter-winding capacitance. The advantages of using pulse transformers in triggering semiconductor devices are :

- the isolation of low-voltage gate circuit from high-voltage anode circuit and
- the triggering of two or more devices from the same trigger source.

A square pulse at the primary terminals of a pulse transformer may be transmitted at its secondary terminals faithfully as a square wave or it may be transmitted as a derivative of the input waveform.

Pulse transformer has one primary and one or more secondary windings. It is normally used for pulsed mode of triggering. Following figure shows the isolation using pulse transformer.



In the above circuit, observe that triggering circuit is electrically isolated from BJT. Hence if there is any electric damage to BJT, there will be no effect on triggering circuit.

Advantages

- Pulse transformer does not need external power for its operation,

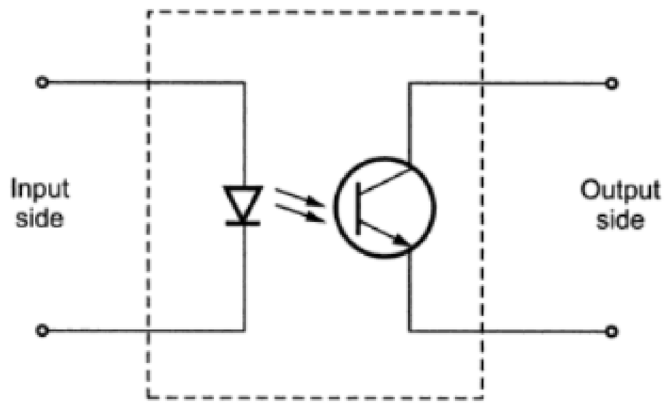
- It is very simple to use.

Disadvantages

- Pulse transformer saturates at low frequencies hence it can be used only for high frequencies.
- Due to magnetic coupling, the signal is distorted.

ISOLATION USING OPTOCOUPLERS

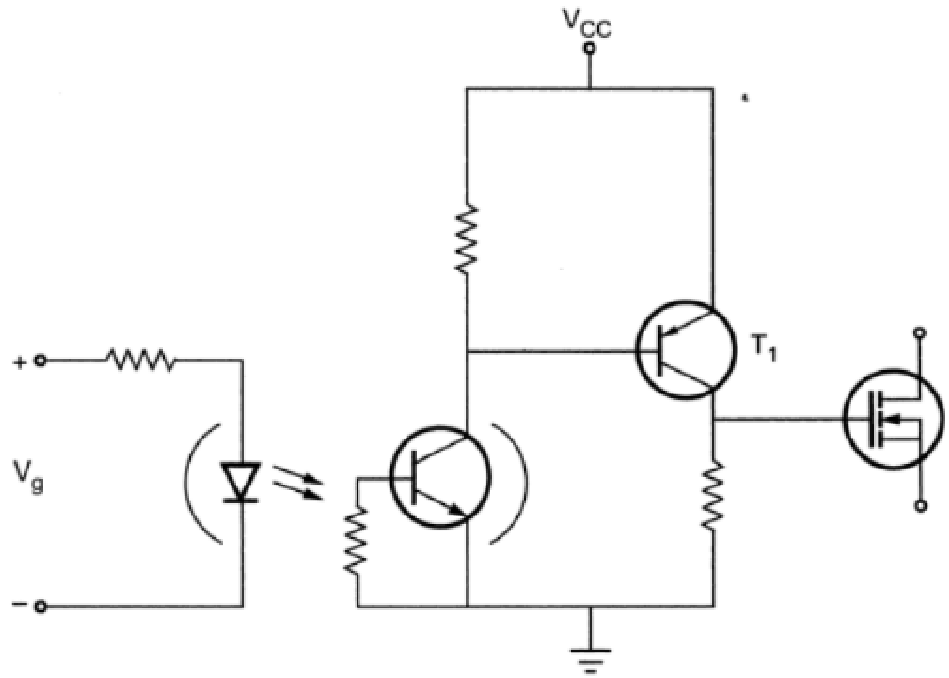
Optocoupler consists of a pair of infrared LED and phototransistor. Following figure shows the symbol of Optocoupler.



When the signal is applied to the infrared LED, it turns-on. It's light falls on phototransistor. Therefore phototransistor also starts conducting. There is no electric connection between LED and phototransistor.

Following figure shows the triggering circuit that uses optocoupler.

In this circuit the triggering pulses are given to the input (LED) of optocoupler. When V_g is positive, LED turns-on. It's light falls on phototransistor. Hence it turns-on. Therefore base of T_1 is connected to zero volts through phototransistor. Due to this, T_1 turns-on. Therefore the voltage V_{cc} is applied to gate of the MOSFET. Hence MOSFET turns-on. When $V_g = 0$, the LED turns-off, therefore phototransistor also turn-off. Therefore base drive of T_1 goes to V_{cc} and it turn-off. When T_1 turns-off, MOSFET gate voltage becomes zero. Therefore MOSFET turns-off. Thus gate drive circuit using optocoupler works.



MOSFET triggering circuit using optocoupler

Advantages

- Very good response at low frequencies.
- Compact and cheaper optocoupler devices are available.

Disadvantages

- Optocoupler need, external biasing voltage for their operation.
- High frequency response is poor.

Applications

Inverters, SMPS, Choppers, AC motor drives use optocouplers.

ASSIGNMENT

Q.1. (AMIE W13, 5 marks): Explain the turn-off and turn-on processes of a GTO with the help of two transistor analogy.

Q.2. (AMIE S11, 5 marks): Write short note on GTO.

Q.3. (AMIE W13, 5 marks): Discus briefly the voltage commutation and current commutation techniques used for the commutation of thyristors.

Q.4. (AMIE S15, 8 marks): Briefly explain the operation of a class-D commutation.

Q.5. (AMIE W15, 10 marks): (i) Explain the need of commutation in thyristor circuits. (ii) Discuss, with relevant waveforms, class B (resonant-pulse commutation) commutation employed for thyristor circuits.

Q.6. (AMIE W13, 5 marks): Comment on the statement: When subjected to standby increasing over voltages, the thyristor needs over-current protection but not overvoltage protection.

Q.7. (AMIE W13, 6 marks): Explain the following thermal ratings of thyristors : (i) Junction temperature, and (ii) transient thermal resistance.

Q.8. (AMIE W13, 4 marks): With the help of a structure diagram and equivalent circuit, explain the behaviour of a MOS-controlled SCR.

Q.9. (AMIE W13, 4 marks): Explain the principle of operation of emitter-turn-off thyristor (ETO).

Q.10. (AMIE S14, 15, 5 marks): Explain the working of thyristor using two transistor analogy.

Q.11. (AMIE S14, 5 marks): Compare SCR with GTO.

Q.12. (AMIE W14, 5 marks): Enumerate various mechanisms by which thyristors can be triggered into conduction.

Q.13. (AMIE W14, 5 marks): Discuss various abnormal conditions against which thyristors must be protected.

Q.14. (AMIE W14, 4 marks): Discuss briefly different components of power loss that occur in a thyristor during its working.

Q.15. (AMIE W14, 4 marks): Which of the power loss component/components is/are dominant at power frequencies and which at high frequencies?

Q.16. (AMIE S15, 4 marks): Suggest a driver circuit for SCRs used in HVDC system.

Q.17. (AMIE S14, 5 marks): Briefly describe the operation of an a.c. mains synchronizer UJT oscillator.

Q.18. (AMIE S15, 6 marks): Define intrinsic stand-off ratio of a UJT. Derive the expression for frequency of oscillation of a UJT oscillator.

Q.19. (AMIE W15, 10 marks): (i) Draw and explain the working of an UJT oscillator. (ii) Discuss how the amplitude of output voltage pulse can be estimated in this oscillator.

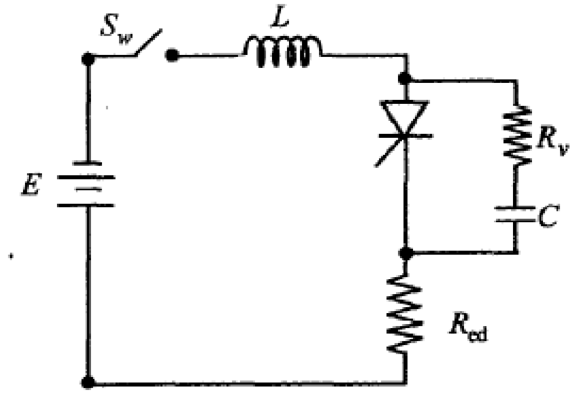
Q.20. (AMIE S14, 5 marks): What is a UJT relaxation oscillator? Derive an expression for frequency of oscillations.

Q.21. (AMIE W14, 8 marks): Write the merits and demerits of "pulse transformer" and "opto coupler" while using in a driver circuit.

Q.22. (AMIE W15, 5 marks): For an SCR, the gate-cathode characteristic has a straight line slope of 130. Find the gate-source resistance for trigger source voltage of 15 V and allowable gate power dissipation of 0.5 W.

Q.23. (AMIE W13, 6 marks): Design various elements, of an UJT relaxation oscillator, given the following data for the UJT: V_f = 24 V, I_P = 48 μA, V_v = 0.75, I_V = 5.1 mA, η = 0.72, R_{BB} = 6.5 kΩ and R_B = 60 Ω. Also, compute pulse height obtained as per the design and maximum frequency range.

Q.24. (AMIE W13, 6 marks): The circuit shown below is used to determine $(di/dt)_{max}$ and $(dv/dt)_{max}$ ratings of the thyristor. Resistance R_v is increased in steps and the switch S_w, is closed to trigger the thyristor.



In this process, at a value of $R_v = 1.2\ \Omega$, the thyristor gets triggered. Determine the value of $(di/dt)_{max}$ and $(dv/dt)_{max}$. Given: E = 120 V, L = 10μH, $V_{c(o)} = 0$ V and $R_{ed} = 18\ \Omega$.

Answer: 12 A/μs; 144 V/μs

Q.25. (AMIE S15, 4 marks): Define di/dt and dv/dt ratings of a switching device, A thyristor is feeding to a resistive load from a 400 V d.c. supply. If it is desired to limit the di/dt to 100A/μs, then find the value of series inductance.

Answer: L = 4 μH

Q.26. (AMIE W14, 5 marks): A 150 A SCR is to be connected in parallel with a 200 A SCR. The on state voltage drops of the SCR is given as 2.0 V an 1.9 V, respectively. Calculate the series resistance that should be connected with each SCR. if two SCRs have to share that current 350 A in proportion to their ratings.

Answer: 0.002 Ω

Q.27. (AMIE W10, S15, 4 marks): A thyristor assembly can dissipate 500 W power with junction temperature limited to 105^0C at 40^0C ambient temperature. Find the required thermal-resistance of heat-sink to be used. Assume junction to heat-sink thermal resistance of 0.1^0C/W.

Answer: 0.03^0C/W

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