Unit -I

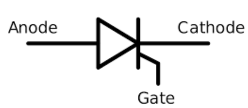
Power Electronic Devices

1. List the different types of Thyristor Family Devices.

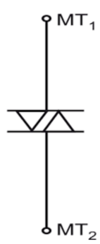
- SCR (Silicon Controlled Rectifier)
- DIAC (Bidirectional diode Thyristor)
- TRIAC (Bidirectional triode Thyristor)
- GTO SCR (Gate turn-OFF SCR)
- SUS (Silicon Unidirectional Switch)
- SBS (Silicon Bidirectional Switch)
- SCS (Silicon Controlled Switch)
- ASCR (Asymmetrical SCR)
- LASCR (Light Activated SCR)
- RCT (Reverse Conducting Thyristor)
- SITH (Static Induction Thyristor)
- MCT (MOS - Controlled Thyristor)
- FET-CTH (FET - Controlled Thyristor)
- PUT (Programmable Unijunction Thyristor)
- Shockley diode.

2. Draw the ISI Symbols for following devices.

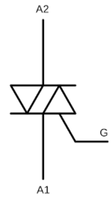
(a) SCR -



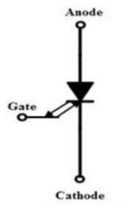
(b) DIAC -



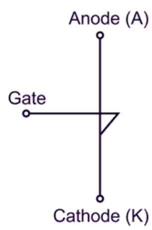
(c) TRIAC -



(d) GTO SCR -

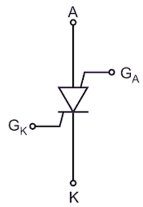


(e) SUS-



(f) SBS-

(g) SCS-



3. Explain the Construction Details of SCR.

SCR is a unidirectional device.

It blocks the low value of current from **Anode** to **Cathode** until it is triggered by the **Gate**. SCR is a four layer, three p-n junctions and three terminal (Anode, Cathode and Gate) device.

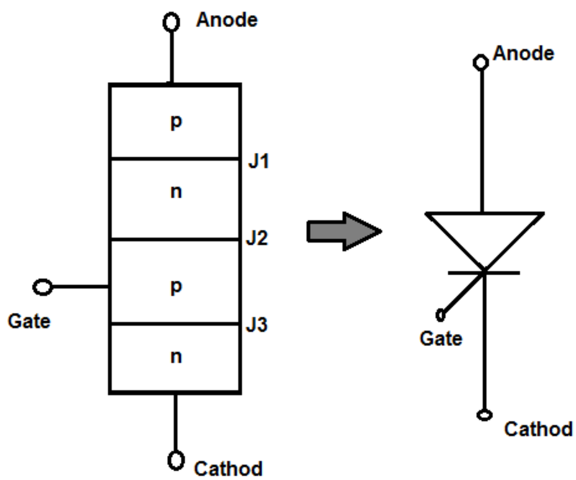


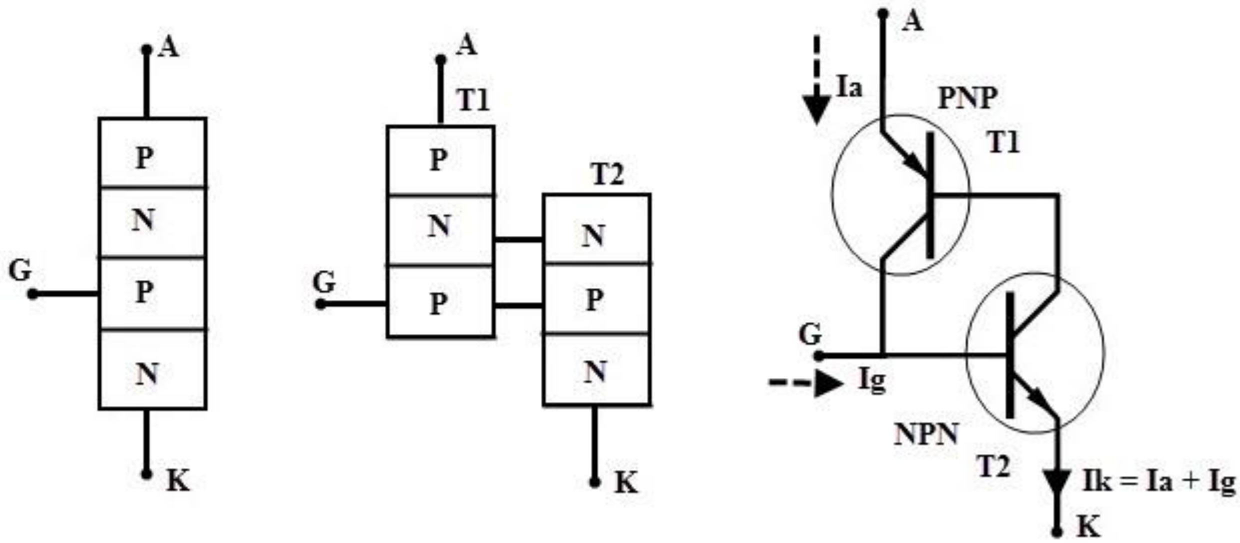
Figure-1 Figure-2

1. The three junctions J1, J2 and J3 are formed from the four layers of alternate p-type and n-type silicon semiconductors.
2. It has 3 terminals Anode, Cathode and Gate.
3. The threaded portion is provided for the purpose of tightening the thyristor to the frame or heat sink with the help of a nut.
4. Gate terminal is kept near the cathode terminal.
5. The terminal connected to outer p-region is called anode (A), the terminal connected to outer n-region is cathode (K) and terminal connected to inner p-region called the gate(G).

SCRs are almost universally employed for all high power controlled devices. By proper triggering the gate terminal (i.e ., by proper gate signal between gate and cathode terminal) the SCR will conduct the current from anode to cathode. Hence, the SCR is used as a **"controlled switch"** to perform various functions such as rectification, inversion and regulation

4. Explain the Working of SCR Using Two-Transistor Analogy.

The operation of thyristor can be explained with the use of two-transistor model. The two-transistor model is obtained by bisecting the two middle layers, shown in Fig. as a doted line and it is separated in two halves as shown in Fig.



Basic Structure of SCR   Two Transistor Model   Two Transistor Equivalent Circuit

From the Fig. the junctions J1 - J2 and J2 - J3 can be considered as PNP and NPN transistor respectively.The circuit representation of thyristor using PNP and NPN transistor is as shown in Fig.During the off state of a transistor, the collector current $\mathbf{I_c}$ and emitter current $\mathbf{I_e}$ is representedas

$$I_C = \alpha I_e + I_{cbo}$$

Where **α** is the common base current gain

$\mathbf{I_{cbo}}$ is the common base leakage current of collector base junction

Similarly,

- For transistor $\mathbf{Q_1}$,

The Emitter current,

$\mathbf{I_e}$=anode current $\mathbf{I_a}$

$$\mathbf{I_C = I_{c1}}$$

Therefore, $\mathbf{I_{c1}=\alpha_1 I_a + I_{cbo1}}$

Where **α** is the common base current gain of $\mathbf{Q_1}$

$\mathbf{I_{cbo1}}$ is the common base leakage current of $\mathbf{Q_1}$

- For transistor $\mathbf{Q_2}$

$$\mathbf{I_{c2}=\alpha_2 I_k+I_{cbo2}}$$

Where **α** is the common base current gain of $\mathbf{Q_2}$

$\mathbf{I_{cbo2}}$ is the common base leakage current of $\mathbf{Q_2}$

$\mathbf{I_k}$ is the Emitter current of $\mathbf{Q_2}$.

Therefore,

The total current $\mathbf{I_a}$ at $\mathbf{Q_1}$ is equal to the sum of two collector currents of two transistors .

$$\mathbf{I_a=I_{c1}+I_{c2}}$$

$$=\alpha_1 I_a+\mathbf{I_{cbo1}}+\alpha_2 I_k+\mathbf{I_{cbo2}}$$

When Gate is triggered

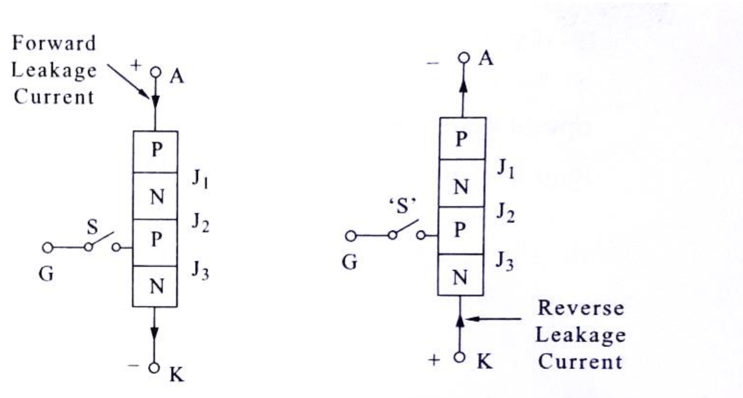
$$I_k=I_a+I_g$$

$$I_a=\alpha_1 I_a+\mathbf{I_{cbo1}}+\alpha_2(I_a+I_g)+\mathbf{I_{cbo2}}$$

$$I_a=(\alpha_2 I_g+\mathbf{I_{cbo1}}+\mathbf{I_{cbo2}})/1-(\alpha_1+\alpha_2)$$

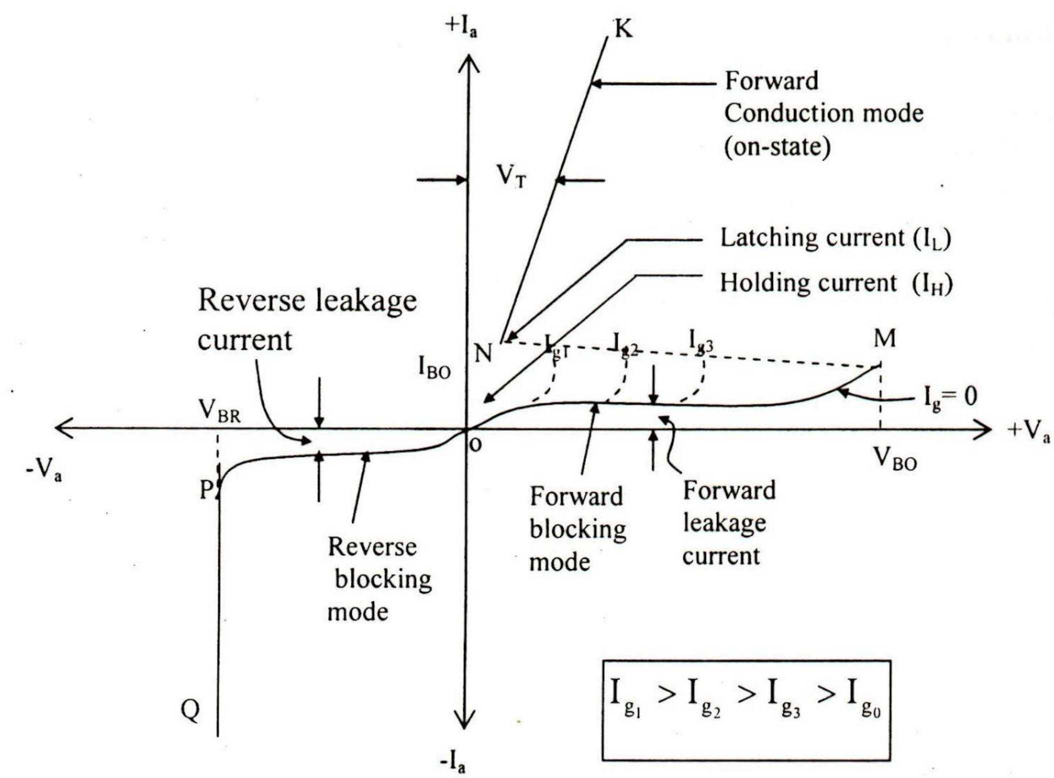
- In silicon transistors Emitter current $\mathbf{I_e}$ is proportional to current gain **α .**
- At $\mathbf{I_g=0}$ the $\mathbf{\alpha_1+\alpha_2}$ is very low. If we increase the Emitter current of two transistors then $\mathbf{\alpha_1+\alpha_2}$ becomes unity (1).
- Hence the Anode current $\mathbf{I_a}$ becomes infinity, then thyristor will get **turn ON**.

5. Draw and explain the V-I Characteristics of Thyristor



(a) J_2 Reverse biased & J_1, J_3 Forward biased

(b) J_2 Forward biased & J_1, J_3 Reverse biased



A thyristor is having four layers, three terminal with three PN junctions. The circuit diagram for obtaining static V-I Characteristics of a thyristor is as shown in Fig.

Forward leakage current

1. When the anode voltage is made positive with respect to the cathode with switch 'S' open the junctions J1 and J3 are forward biased as shown in Fig. (a).
2. The junction J2 is reverse biased and only a small leakage current few milli amperes will flows from anode to cathode. At this position the thyristor will behave like "forward blocking (or) OFF-state condition".
3. If the anode to cathode voltage is increased to a sufficiently large voltage, the reverse biased junction J2 will breakdown. This is known as "Avalanche breakdown".
4. The voltage at which the junction J2 will break down that voltage is known as "Forward break-over voltage" and it is represented in the graph as VBO in Fig.
5. Hence all the three junctions will allow the electrons from anode to cathode, consequently a large current will flow this is known as "Forward anode current".
6. In order to maintain the thyristor ON-state this anode current must be more than the value of "Latching current (I_L)", otherwise the thyristor will return to the blocking state.
7. Latching current is the minimum value of anode current required to maintain the thyristor in ON-state.
8. Holding current is the minimum value of anode current below which it must fall for turning -off the thyristor. Latching current is higher than the holding current, latching current is associated with turn – on process and Holding current with turn off process.

Reverse leakage current

1. When cathode is made positive with respect to the anode with "s" open the thyristor is reverse biased. The junctions Ji and J3 are reverse biased and J2 is forward biased as shown in Fig. (b).
2. A small leakage current of the order of few milli ampere (or) few micro-ampere will flow. This is known as "Reverse blocking (or) OFF-state" of thyristor.
3. If the reverse voltage is increased, then at a critical breakdown level, called "reverse break down voltage" an avalanche occurs at J1 & J3 and the reverse current increases rapidly.

- Due to this large reverse current and the losses will be increased hence it may lead to damagethe thyristor.
- Hence when the thyristor is operating in reverse bias the supply voltage must be less than V_{BR} otherwise the thyristor may lead to damage.

6. Mention the Ratings of SCR.

SCR's are generally represented with following ratings namely.

- Anode voltage ratings
- Current rating
- Power rating
- dv/dt rating
- di/dt rating
- Turn-ON and Turn-OFF times
- Latching and Holding currents

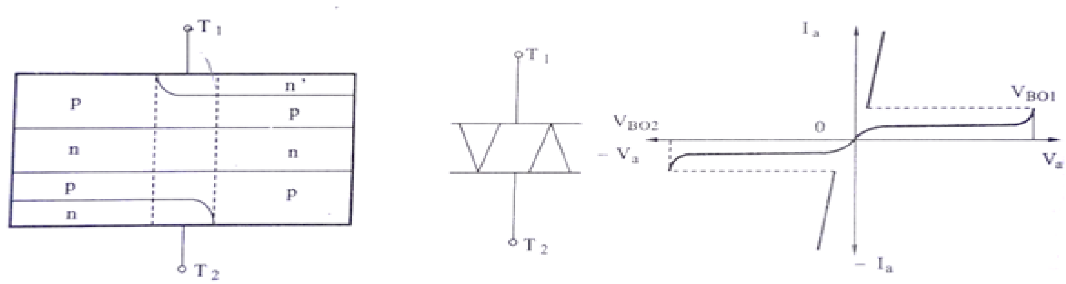
7. Write the applications of SCR.

Applications of SCR's

- Battery charging circuits.
- Emergency lamp circuits
- Uninterrupted power supplies (UPS)
- Air conditioning units (A/c)
- Personal computers
- Television sets
- Washing machines
- Electric door openers

8. Explain the operation of DIAC with its characteristics.

DIAC: The word 'DIAC' is obtained from Capital letters, Diode that can work on AC (Alternating Current).It is a two terminal device which can conduct in either direction.Hence, it is called Bidirectional device.



(a) Cross sectional view (b) Circuit symbol (c) V-I Characteristics of a diac

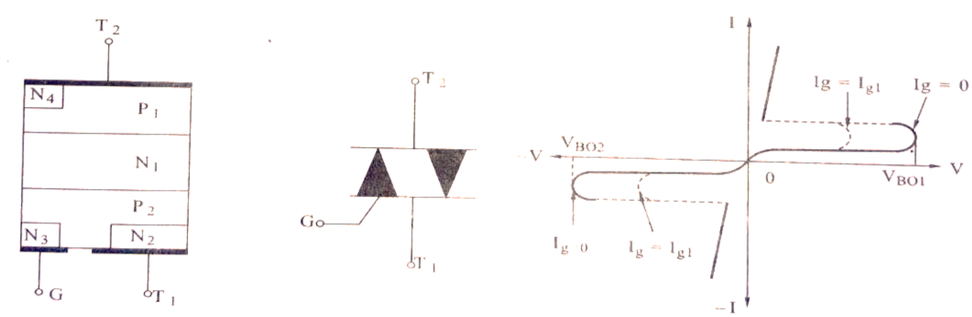
1. It consists of four layers (PNPN and PNPN’), and has two terminals T_1 and T_2.
2. These terminals (T_1&T_2) are connected to P-regions of silicon separated by N-region. The symbol of diac is shown in Fig. 1.13 (b).
3. When the terminal T_1 is positive with respect to T_2, the layers P-N-P-N start conducting. when the voltage of T_1 is more than break over voltage V_{BO1} .
4. Once the conduction starts, the current through the diac becomes very large and is limited by the external resistance in the circuit.
5. When the terminal T_2 is positive with respect to T_1, the layers P-N-P-N’ starts conducting when the voltage of T_2 is more than break over voltage V_{BO2},
6. In both cases the currents during blocking regions are very small and are called as leakage currents. The behaviour in both directions are similar because doping level is same in all the layers in two directions and is shown in Fig. (c)
7. Generally the breakover voltage of DIAC is about 30 - 50 volt and voltage drop is across the device is about 3 - 5 volt.
8. As compared to TRIAC the operating characteristics of DIAC is similar but it has no gate terminal. Hence, it is also called as GATE LESS TRIAC.

Applications :

1. As a triggering device for TRIAC.
2. Light dimming.
3. Heat control.
4. Universal Motor Speed Control.

9. Explain the operation of TRIAC with its characteristics.

The major drawback of an SCR is that, it can conduct current in one direction only. Hence, SCR can control D.C. power (or) forward biased half cycles of AC. However, in

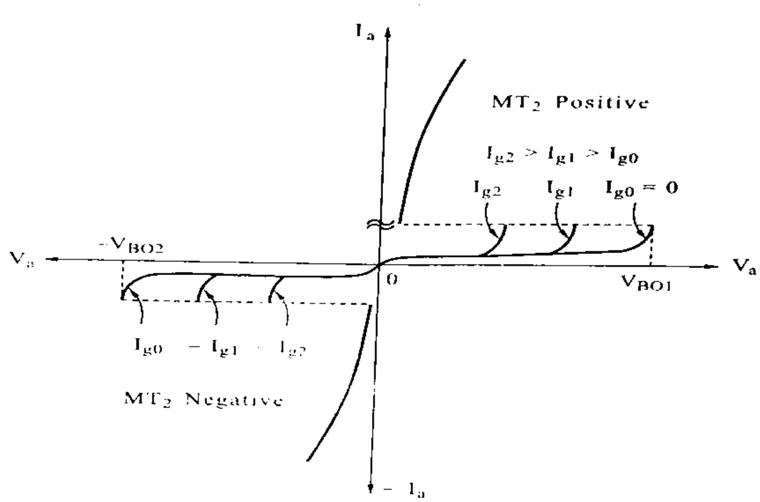


(a) Construction view of TRIAC (b) Symbol (c) V-I Characteristics of Triac an A.C. system it is very necessary to control over both positive and Negative half cycles. For this purpose, a semiconductor device called TRIAC is used. It is a combination of two SCR's connected in anti-parallel. The word "TRIAC" is obtained from capital letters Triode that can work on AC. It is a three terminal device which can conduct in both the directions. Hence, it is called "Bidirectional device" and its symbol shown in Fig. (b). Fig(a) shows the construction view of a Triac. It consists of four layers, three terminals (T_1, T_2 and Gate G). The Gate terminal (G) is near the T_1 terminal. From the 1.14(a), the terminal T_1 makes contact with layers N_2 and P_2. Terminal T_2 makes contact with layers P_1 and N_4 and Gate (G) terminal makes contacts with layers N_3 and P_2.This configuration is necessary for conducting the TRIAC in both directions and also for giving triggering pulse to the Gate terminal which is either positive (or) Negative with respect to terminal T_1.Since, triac is a bidirectional device the operating characteristics are similar in the first and third quadrants. If gate signal is not applied the triac break over voltages are V_{BO1} and V_{BO2} and if the gate current is increased, the break over voltage is reduces and are shown Fig. (c).

Applications: The triac is mainly used in

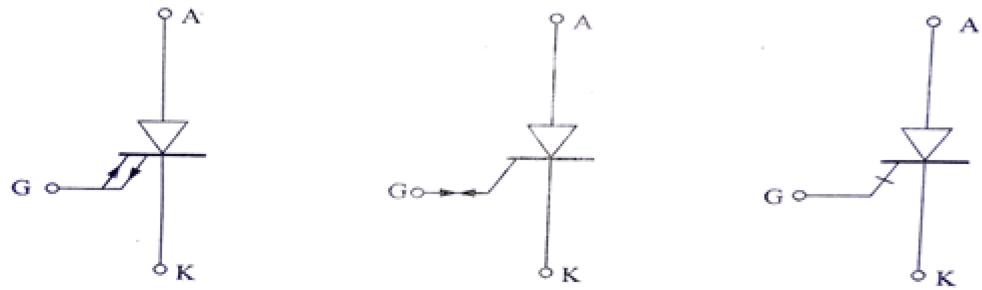
1. Speed control of single phase Induction Motors as well as Series motors.
2. Temperature Control.
3. Phase Control Circuits.
4. Illumination level control
5. Light dimmer circuits (Industrial & domestic fields)

V–I Characteristics of TRIAC



10. Explain the operation of GTO-SCR with its characteristics.

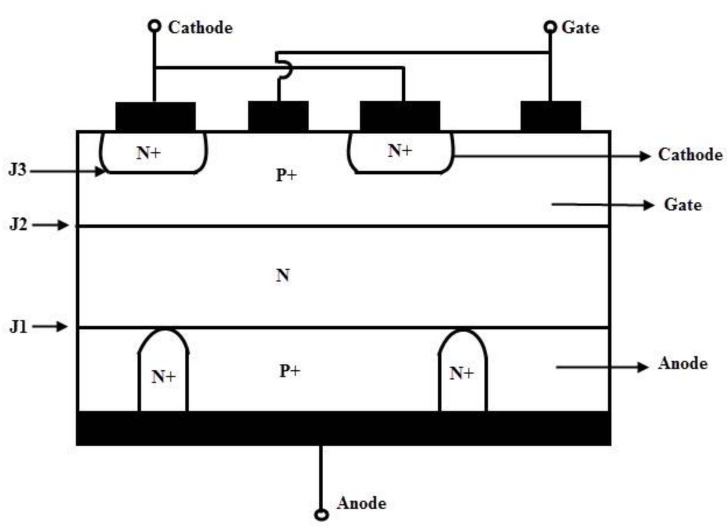
Gate Turn-OFF SCR (GTO SCR): A gate turn-OFF SCR (GTO) is a member of the thyristor family. It is a three terminal [anode (A), Cathode (K) and Gate (G)], four layer PNPN device. It



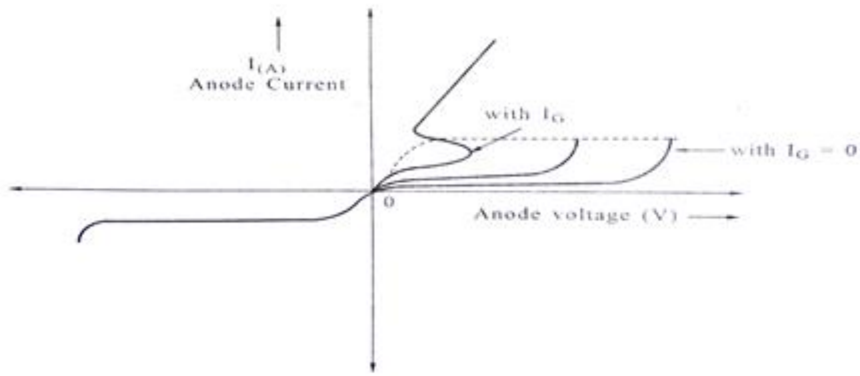
Symbols of G.T.O SCR

can be turned ON by a positive gate pulse (like in SCR) and turned-OFF by a high amplitude negative gate pulse.

Turn-OFF Action : When a positive signal is applied, a GTO switches into conduction state like an ordinary SCR (thyristor). In ordinary thyristor, the current gains of two transistors (npn and pnp) are very high. So that the gate sensitivity for turn on the thyristor is high and hence the ON-state voltagedrop is low. But in case of GTO SCR. The current gain of PNP transistor is low so that turn-OFF is possible. Reduction in gain of the PNP transistor may be obtained by introduction of anode to N-base short circuiting as shown in Fig.



V–I Characteristics of GTO SCR



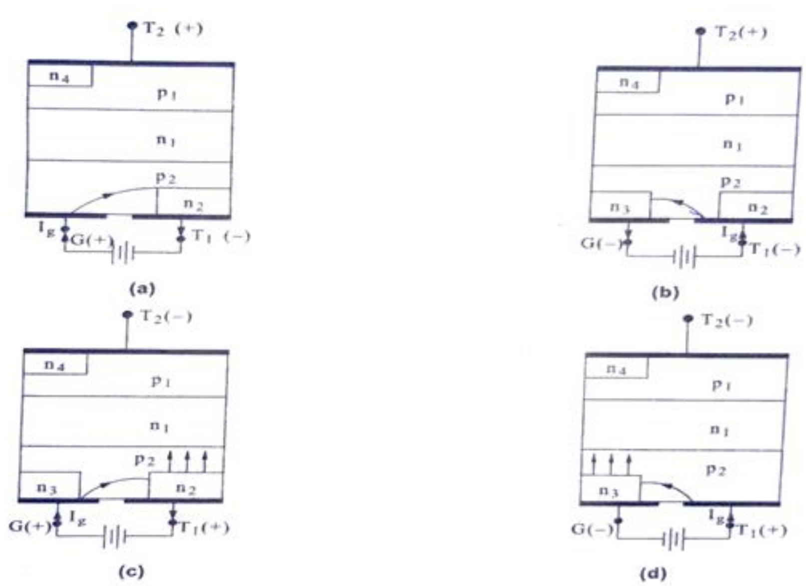
V-I Characteristics of GTO

Applications of GTO SCR:

1. Used in Electric traction (railways) because of lesser weight.
2. Used in adjustable frequency inverter drives
3. Used in robotics etc.

11. Explain the TRAIC triggering modes.

Triggering Modes of TRIAC: If the voltage applied is less than break over voltage and gate signal is not applied, the Triac is in blocking state for both the directions. Depending on polarity of terminal T_1 or T_2 is positive and whether gate signal is positive or negative, the triggering methods of triac are classified into four modes.



Modes of Operation of TRIAC

1) T_2 is positive and gate G is positive (with respect to terminal T_1). The junctions P1-n1 and p2-n2 are forward biased but the junction n1-p2 is reverse biased. The gate current flows through p2-n2 junction as shown in Fig (a).
2) When gate current is able to inject sufficient number of charge carriers in p2 layer, the junction n1-p2 breaks down and triac starts conducting leading to an increase in current and V-I characteristic similar to that of thyristor. Triac operates in first-quadrant in this mode of operation.
3) T_2 is positive but gate G is negative (with respect to terminal T_1). The junctions p1 _ n1 and p2 – n2 are forward biased but the junction n1 – p2 is reverse biased. The gate current flows through p2 – n3 junction as shown in Fig(b). Initially, the triac conduction current flows through the layers p1-n1-p2-n3. Due to this the potential of the left part of layer p2 in contact with n3 increases.
4) This potential gradient across the p2 layer causes flow of current from left to right through layer p2. This current is similar to conventional gate current of thyristor.

Therefore, the right hand portion p1-n1-p2-n2 starts conducting. The device operates in the first quadrant. In this mode of operation a higher gate current is required for triggering.

5) T_2 is negative and gate G is positive (with respect to T_1). The four layers used in this mode of operation are p2-01-P1-n4. The junction of n1-p1 layers is reverse biased. Since the gate terminal is positive, the gate current forward biases p2-n2junction.
6) Layer n2 injects electrons into p2 layer (as shown by arrows) and the reverse biased junction n1-p1 breaks down. Finally, the layers p2-n1-p1-n4 start conducting and the current increases. As in a thyristor the current is limited only by the external resistance in the circuit. The device operates in the third quadrant. In this mode also triac is less sensitive and a higher gate current is required for turning ON. Operation is shown in Fig. ©.
7) T_2 is negative and gate G is negative (with respect to T1). Fig(d) shows the operation. The gate current flows from p2 to n3 and electrons are injected as shown by arrows. The reverse biased junction n1-p1 breaks down. The current flows through layers p2-n1-P1-n4. The device is more sensitive in this mode of operation and the gate current required is less. It operates in the third quadrant.
8) From the above, it is observed that triac can be operated with T_1 or T_2 positive and

with positive or negative gate current. However, when it operates in first-quadrant (i.e ., with T_2 positive) the gate current required for triggering is less if triggering is through positive gate current.

Similarly the gate current required is less when operated in third-quadrant and triggered bynegative gate current. Therefore, these two are the preferred modes of operation.It is seen that conducting paths from T_1 or T_2 and vice versa interact with each other. Due tothis voltage, current and frequency ratings of triacs are lower than those for thyristors.

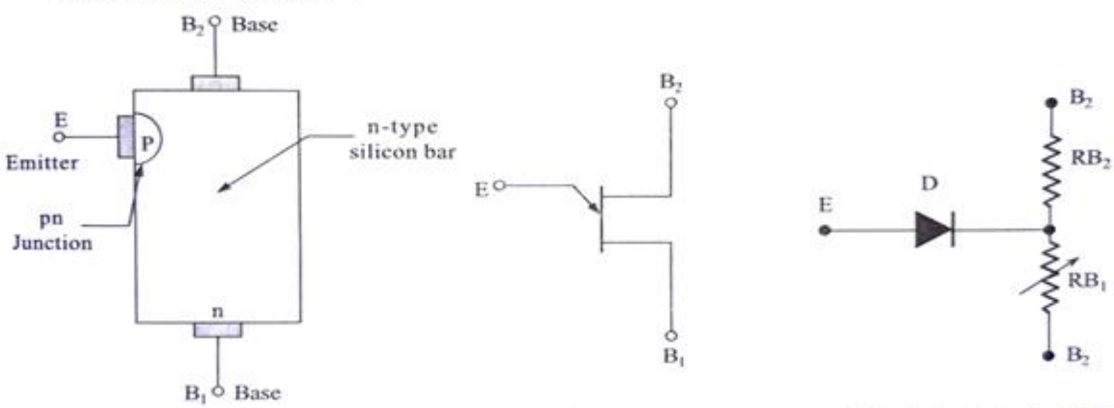
12. Compare between SUS, SBS,SCS & LASCR

S.NO.	SUS	SBS	SCS	LASCR
1.	It is available in ICs	It is available in ICs	It is a four layer device	It is a four layer device
2.	It is a three terminal device.	It is a three terminal device.	It is a four terminal device.	It is a three terminal device.
3.	It is a unidirectional switch.	It is a bidirectional switch.	It is a undirectional switch.	It is a undirectional device.
4.	High switching stability.	High switching stability.	Low switching stability.	Low switching stability
5.	Its cost is tow.	Its cost is tow.	Its cost is high.	Its cost is high.
6.	It has +ve turn ON Characteristic.	It has +ve turn ON Characteristic.	It has +ve turn OFF Characteristics.	It has +ve turn ON Characteristics.
7.	Used in high speed switching circuits.	Used in D.C. power supply.	Used in low power digitalcircuits.	Used in HVDC electricalpower transmission.

13. Explain the construction and working principle of UJT.

UJT (Uni Junction Transistor)

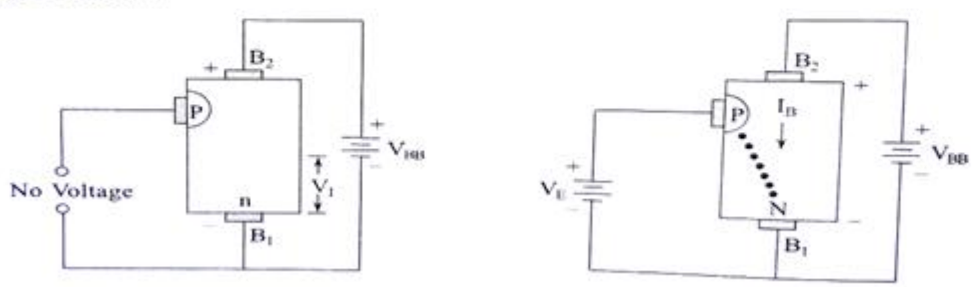
Construction of UJT :



(a) Construction of UJT (b) Symbol of UJT (c) Equivalent circuit of UJT

1. It is a three terminal [Base – 1, Base-2, and emitter] single P-N junction device. It is operated with emitter junction forward-biased mode and mainly used for controlling the large A.C power with a small signal.
2. Figure (a) shows the construction of UJT. It has lightly doped N-type silicon barwith connecting leads Base-1 and Base-2 at the bottom and top sides respectively.
3. A heavily doped P-type region is placed at one side of the N-type bar and a terminal isbrought to its outside called Emitter (E). Hence, the P-type and N-type material form aPN junction.
4. Emitter to Base-2 terminals offers less resistance because Emitter is placed very nearer to Base-2 simultaneously the Emitter to Base-1 terminals offers high resistance because of its longer distance between Emitter to Base-1.

Working of UJT :



If emitter is open (i.e ., $V_E = 0$) and V_{BB} is applied between base-1 and base-2.

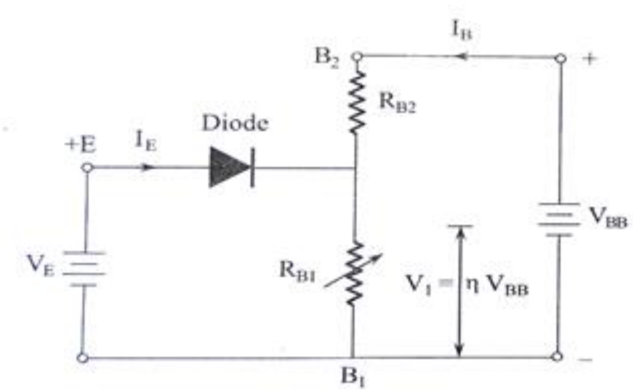
- If voltage VBB is applied between B1 and B2 and there is no input voltage is applied at emitter (i.e ., emitter open) at this condition, the voltage gradient is established along the N-type bar.
- Since the emitter is located nearer to Bo more than half of VBB appears between the emitter and B1. The voltage V1 between emitter and B1 as shown in figure establishes a reverse biason the pn junction and the emitter current is cutoff. i.e $I_E = 0$.

If a positive voltage is applied at the emitter (i.e ., V_E = + Ve) and V_{BB} isapplied between base-1 and base-2 :

- If a positive voltage is applied at the emitter, the pn-junction will remain reverse biased so long as the input voltage is less than V1 (i.e ., $V_E < V_1$). If the input voltage to the emitter exceeds V1, the pn-junction becomes forward biased.
- Under these conditions, holes are injected from p-type material into then-type bar. These holes are repelled by positive B2 terminal and they are attracted towards B1 region results inthe decrease of resistance in this section of the bar.
- The result is that internal voltage drop from emitter to B1 is decreased and hence the emitter current IE increases. As more holes are injected a condition of saturation is limited by emitterpower supply only. The device is now in the ON state.

1. If a negative voltage is applied to the emitter, the pn-junction is reverse biased and the emitter current is cut-off. The device is then said to be in the OFF state.

14. Define Intrinsic Stand-Off Ratio of UJT



Equivalent Circuit of UJT

The equivalent circuit of UJT consists of an PN-junction diode and two resistors R_{B1} and R_{B2}. The resistance between base-1 (B_1) and base-2 (B_2) of the silicon bar with emitter terminal openis called the inter base resistance (R_{BB}).

Inter base resistance, $R_{BB} = R_{B1} + R_{B2}$

When emitter terminal is open and voltage V_{BB} is applied silicon between bar. The voltage dropis voltage gradient (V_1) is establishes along the N-type across R_{B1} is given by,

$$V_1 = V_{BB}R_{B1}/R_{B1} + R_{B2}$$

$$V_1 = \eta V_{BB}$$

The ratio of V_1 to V_{BB} is know as "instrinsic stand off ratio".

$$\eta = V_1/V_{BB}$$

The resistance ratio between R_{B1} and R_{BB} is called the "instrinsic standoff Ratio

$\eta = R_{B1}/R_{B1}+R_{B2}$ where η-is the Instrinsic stand-off ratio.

15. Define Negative resistance region of UJT

Negative Resistance Region: The region between peak point to valley point is called "Negative resistance region". In this region the diode is forward bias, starts conducting and holes are injected into N-layer. Hence, the emitter current I_E increases with emitter voltage V_E decreases. The increase in emitter current due to the decrease in resistance R_{B1}. That's why this region is called "Negative resistance region".

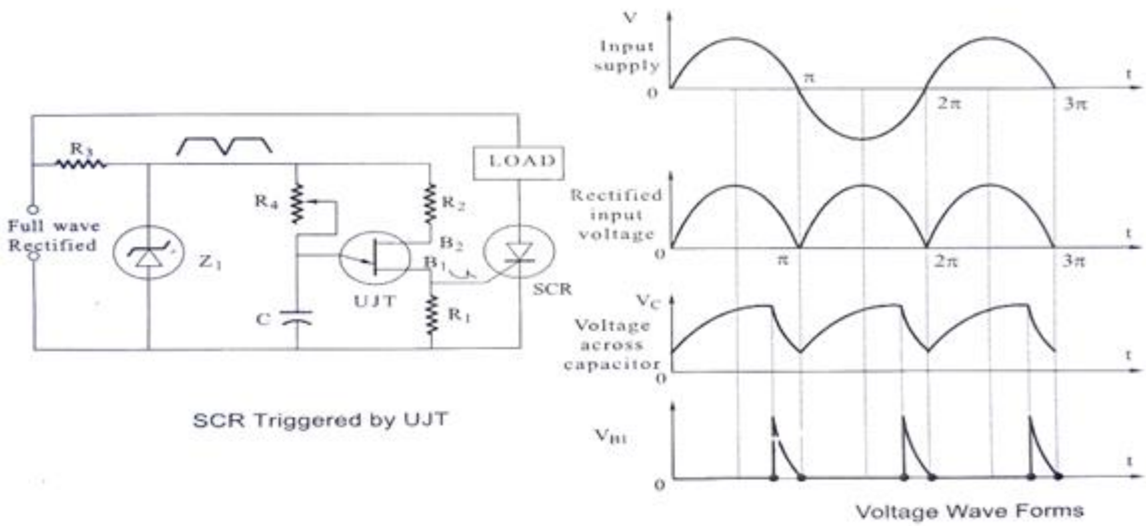
16. Explain the triggering of SCR using UJT.

An UJT is a 3 terminal, 2 layer PN device. When it is used as an oscillator provides constant frequency, sharp pulses with small rise time. Hence, these are alsoused for triggering the SCR's.

- Fig. 1.26 shows the SCR triggered by UJT. The pulses developed across R_1, in the base1 of the UJT are used to trigger the SCR. The UJT is connected to work as a relaxation oscillator.
- The frequency of the sawtooth voltage developed across C is determined by the value of R_4 and C.
- By varying the values of R_4 and C, the timing of the trigger pulses developed across R_1, can be adjusted to control the firing of the SCR at different points on the input anode wave.
- Full wave rectified ac (pulsating) is employed as a power source to the SCR instead of

using direct ac supply.

- Therefore, it increases the load current capability by 2 times and also it eliminates the negative half cycle, so that it avoids SCR turn OFF.



SCR Triggered by UJT

Voltage Wave Forms

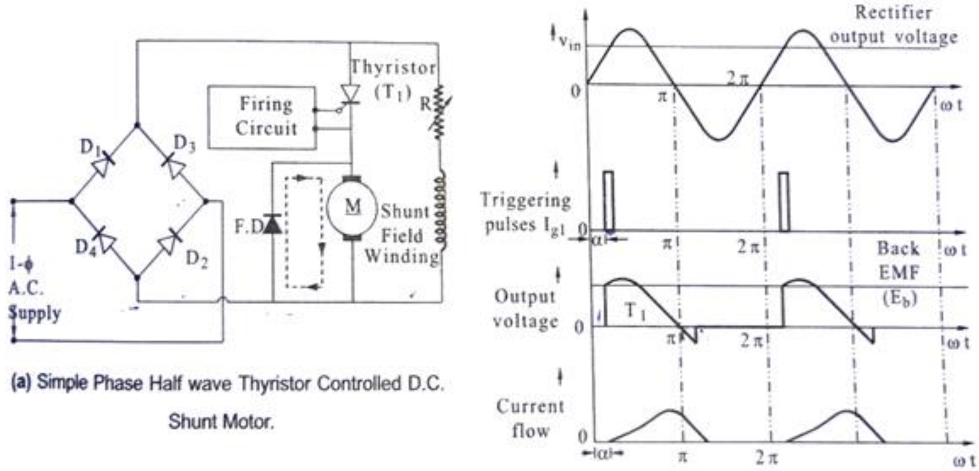
However, it permits the SCR to turn off when the anode voltage is reduced below theholding current.

- The zener Z_1 clips the tops of the positive alternations and provides stable voltage level to which capacitor C can charge through R_4.
- In this a pure dc cannot be used for charging the capacitor, because the frequency of the output pulses of UJT will not synchronise to the frequency of pulsating dc applied to the SCR.

17. Explain the speed control of DC motor using SCR.

Speed Control of D.C. Shunt Motor Using Single-Phase Half-Wave Thyristor Drive :

1. It consists of a diode bridge circuit which converts AC Voltage into D.C. Voltage. The shunt field winding is directly fed from the bridge rectifier.
2. But the armature of the D.C motor is fed from the bridge rectifier through the Thyristor. The D.C.Voltage applied to the armature is controlled by varying the firing angle **α**



(a) Simple Phase Half wave Thyristor Controlled D.C. Shunt Motor.

(b) Wave Forms of Input Voltage, Triggering Pulses, Back Emf and Current.

The free-wheeling diode [FD] is connected across the motor armature winding to provide a circulating path [shown dotted] for the energy stored in the inductance of the armature winding during the period of thyristor turns-off.

3. At **ω**t = **α**, the thyristor is triggered, the output voltage of bridge rectifier is appeared across the motor armature terminals as well as field winding. The current wave form will go to zero beyond π radians due to the presence of Inductance in the armature winding.

Speed Control of D.C. Shunt Motor Using Single-Phase Full-Wave rectifier

1. It consists of a diode bridge circuit which converts A.C. Voltage into D.C. Voltage to supply the voltage to the field winding of the motor.
2. During the positive half cycles of input a.c. Supply thyristor T_1 conducts and supplies d.c voltage to the armature winding.
3. During the Negative half cycles, thyristor T_2 is made to conduct and supply the armature winding. The d.c voltage applied across the armature winding is varied by varying the firing angle **α**.

We know that, the speed of the D.C. Motor.

$$N \propto V - I_a R_a$$

Hence, from the above if the voltage (v) applied across the armature is varied then thespeed of the motor is also varied.