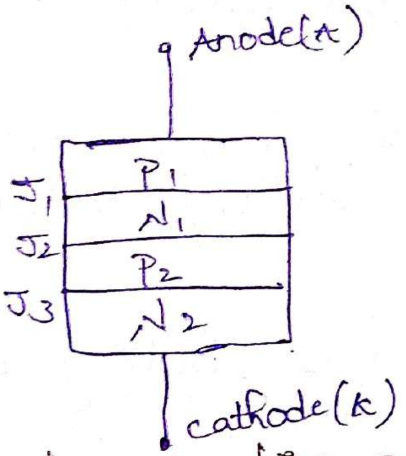
UNIT-5

Thyristors and other Devices

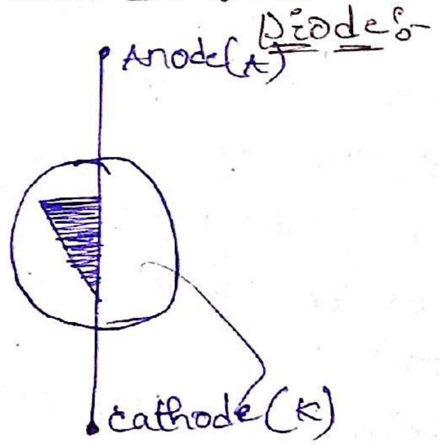
* The family of Thyristors are
1) PNPN (Shockley Diode)
2) SCR (Silicon control Rectifier)
3) LASCR (Light Activated Silicon control Rectifier)
4) TRIAC (Triode as AC switch)
5) DIAC (Diode as AC switch)
6) UJT (unipolar junction transistor)
7) IGBT (Insulate Gate Bi-Polar Transistor).

1) PNPN (Shockley Diode):-

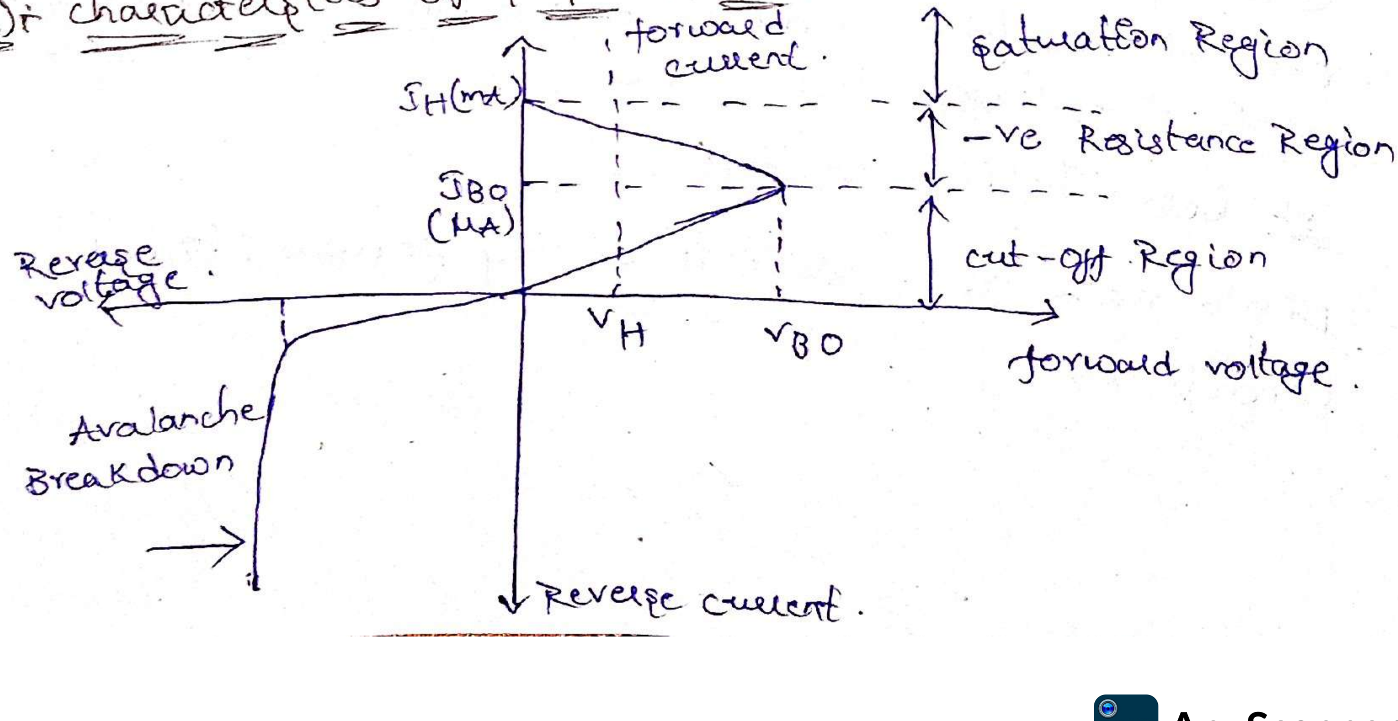
fig(a):- PNPN - Basic structure:-



fig(b):- circuit symbol of PNPN Diode:-



fig(c):- characteristics of PNPN Diode:-



- Thyristor in general is a semi conductor device having three or more junctions
- such a device acts as a switch without any bias & voltage Ratings of several hundred volts & current ratings several hundred volts and current ratings of almost thousand Amperes
- family of thyristors consists of pnpn diode (shockley diode) SCR, LASCR, TRIAC, DIAC, UJT etc.
- As shown in fig, it is four layers pnpn silicon device with two terminals.
- when an external voltage is applied to the device from anode to cathode junctions J_1 & J_3 are forward biased & J_2 is reverse biased.
- current flowing is only reverse saturation current.
- As applied voltage is ↑ed, current also ↑es slowly until so called firing or breakover voltage (V_{BO}) is reached.
- Once firing takes place current ↑es whereas voltage ↓es in which diode switches from "off" to "on" state.
- minimum amount of current known as ~~H~~holding current (I_H) is flown to keep in 'on' state.
- current has to be reduced below I_H by reducing applied voltage close to zero,
ie below holding voltage, V_H.
- Diode acts as a switch during forward bias condition.

Thyristor Ratings:

1) Latching current (I_L): The minimum current is required to latch (or) trigger the device from its off-state to on-state.

2) Holding current (I_H):- minimum value of current to hold the device in on-state. for turning off, anode current should be lowered below I_H by ↑ing external circuit resistance

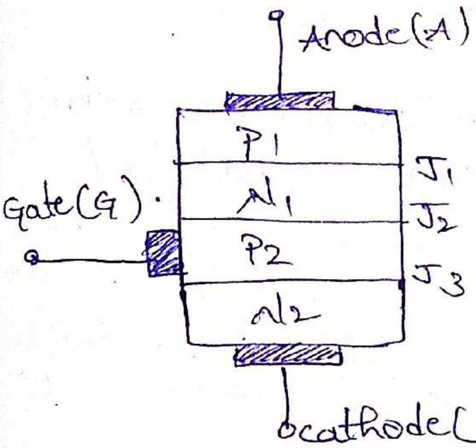
3) Gate current (I_g):- current applied to the gate of device for control purposes.

4) voltage safety factor (V_f):- value of V_f normally lies b/w 2 and 2.7

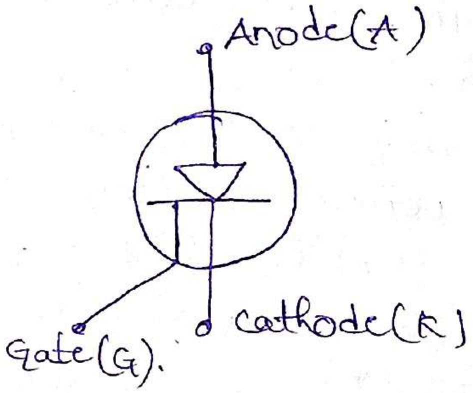
$$\boxed{V_f = \frac{PIV}{\sqrt{2} \times \text{Rms value of operating voltage}}}$$

2) SCR (Silicon Controlled Rectifier)

fig(a):- Basic structure of SCR:



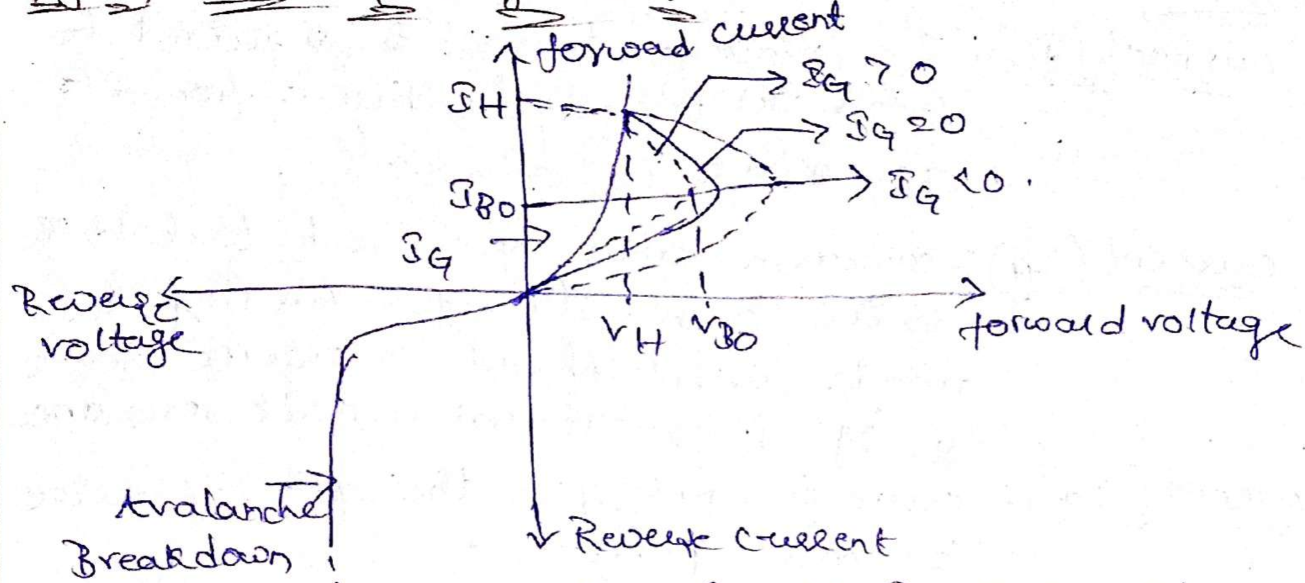
fig(b):- circuit symbol of SCR



* It is a four layer, three terminals in which end p-layer acts as anode, end N-layer acts as cathode and P-layer nearer to cathode acts as gate.

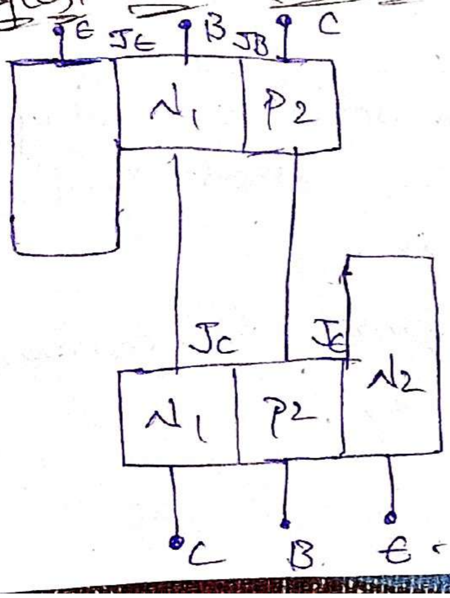
* As leakage current in Si is very small when compared to Ge, SCR's are made of Si & not Ge.

fig(c): characteristics of SCR:

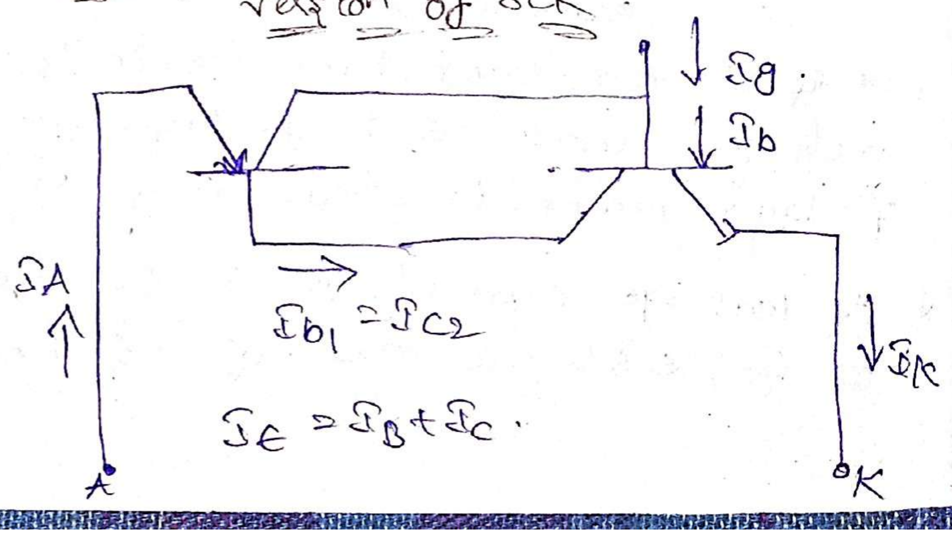


* SCR acts as a switch when it is forward Bias
* when gate is kept open with large i.e: gate current $I_G = 0$, operation of SCR is similar to pnpn diode
* when $I_G < 0$, amount of Reverse bias is applied to J_2 is ↑ed there by ↑ing breakover voltage.
* As voltage at which SCR is switched 'on' can be controlled by varying Gate current I_G, commonly known as controlled switch.
* SCR is used in Relay control, motor control, phase control, heater control, battery charges, inventors regulated power supplies & static switches.

fig(d): Two transistors version of SCR:



fig(e): Equivalent circuit of two transistor version of SCR



* operation of SCR is a simple way in terms of two transistors called as two transistor version of SCR.
* As shown in fig-(d), an SCR can be split into two parts and displaced from one another but connected electrically.
* Device may be considered by two transistors T_1 (PNP) & T_2 (NPN) connected back to back.
* Assuming leakage current of T_1 to be negligibly small, we get

$$I_{b_1} = I_A - I_{e_1} = I_A - \alpha I_A = (1-\alpha_1) I_A \rightarrow (1)$$

from eq's $I_{b_1} = I_{C_2} \rightarrow (2)$

$$I_{C_2} = \alpha_2 I_K \rightarrow (3)$$

By substituting equ's → (1) & (3) in eq (2), we get

$$(1-\alpha_1) I_A = \alpha_2 I_K \rightarrow (4)$$

w.k.T $I_K = I_A + I_B \rightarrow (5)$

By substituting eq (5) in eq (4) we get

$$(1-\alpha_1) I_A = \alpha_2 (I_A + I_B)$$

$$\boxed{I_A = \left[\frac{\alpha_2 I_g}{1-(\alpha_1+\alpha_2}\right]} \rightarrow (6)$$

* This characteristics of device is known as regenerative action.

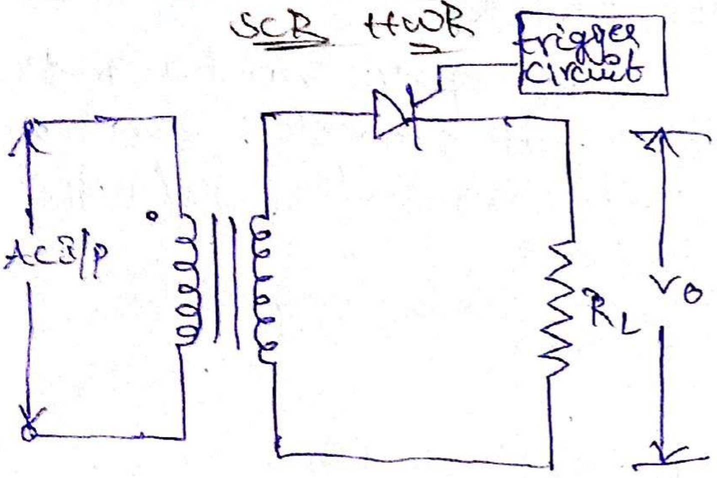
SCR Applications:

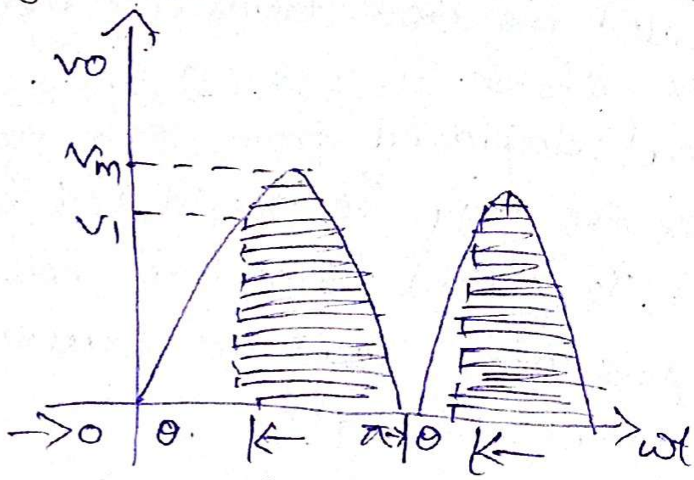
1) SCR ~~Half~~ wave Rectifier:

* Though SCR is basically a switch can be used in linear applications like rectification.
* During -ve half-cycle, SCR does not conduct irrespective of gate current.
* As anode is -ve with respect to cathode & also PIV is less than reverse breakdown voltage.

fig(a): circuit diagram of SCR HWR

fig(b): o/p waveform of SCR HWR





* During +ve half cycle, SCR conducts which provides proper gate current to flow.
* Greater the gate current, lesser the supply at which SCR is triggered on
* SCR will be conducting till applied voltage becomes zero
* Angle at which SCR starts conducting during +ve half cycle is called as firing angle θ.
* Conduction angle is $(180° - \theta)$
* If angle θ is zero, this will be an ordinary half wave rectification.

$$V_{avg} = \frac{1}{2\pi}\int_{\theta}^{\pi} V_m \sin \omega t \, d(\omega t)$$

$$= \frac{1}{2\pi}\left[-V_m \cos \omega t\right]_{\theta}^{\pi} = \frac{V_m}{2\pi}\left(1+\cos\theta\right)_{\theta}^{\pi}.$$

for $\theta = 0°$ $\boxed{V_{avg} = \frac{V_m}{\pi}}$ for $\theta = 90°$ $\boxed{V_{avg} = \frac{V_m}{2\pi}}$

2) SCR full wave Rectifier:
* Exactly similar to that of ordinary FWR except that two diodes have been replaced by two SCR's.
* Angle of conduction can be changed by adjusting gate current.
* During +ve half cycle of i/p signal, anode of SCR_1 becomes +ve & at same time anode of SCR_2 becomes -ve.
* SCR_1 starts conducting & only shaded portion of +ve half cycle will pass through load.

* During −ve half cycle of I/P signal, anode of SCR_1 becomes −ve & anode of SCR_2 becomes +ve.
* Main advantage of this circuit over ordinary FWR is that any voltage can be made available at O/P by simply changing firing angle of SCR's

$$V_{avg} = \frac{1}{\pi}\int_{\theta}^{\pi} V_m \sin\omega t \, d(\omega t)$$

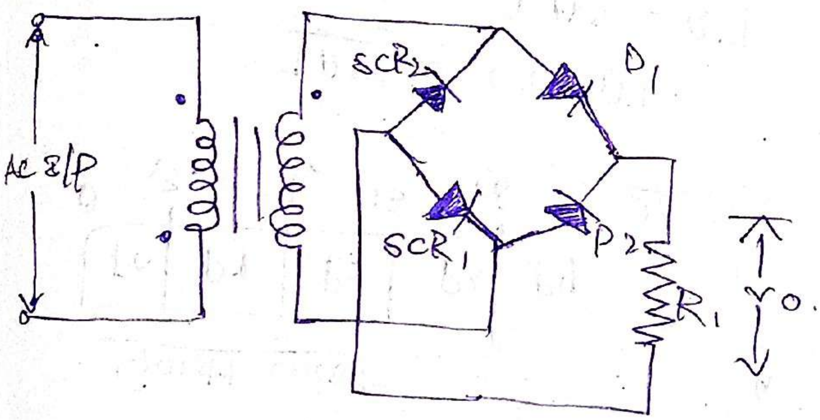
$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_{\theta}^{\pi} = \frac{V_m}{\pi}\left(1+\cos\theta\right)$$

$$\boxed{V_{avg} = \frac{V_m}{\pi}\left(1+\cos\theta\right)}$$

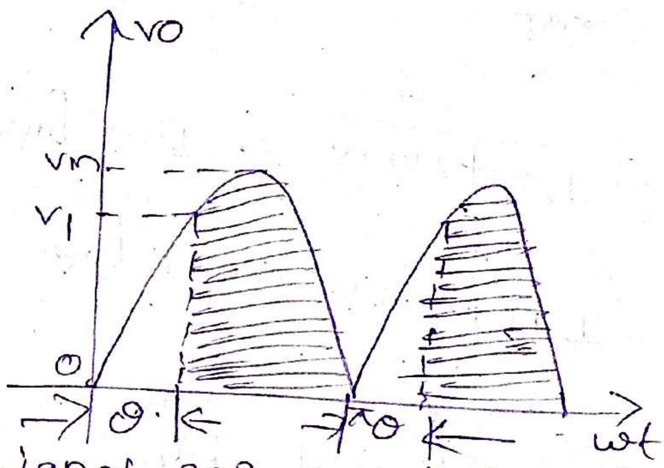
* It is double that of HWR, as −ve half cycle is also rectified.

3) SCR Bridge Rectifier:-

fig(a): Circuit diagram of SCR Bridge Rectifier



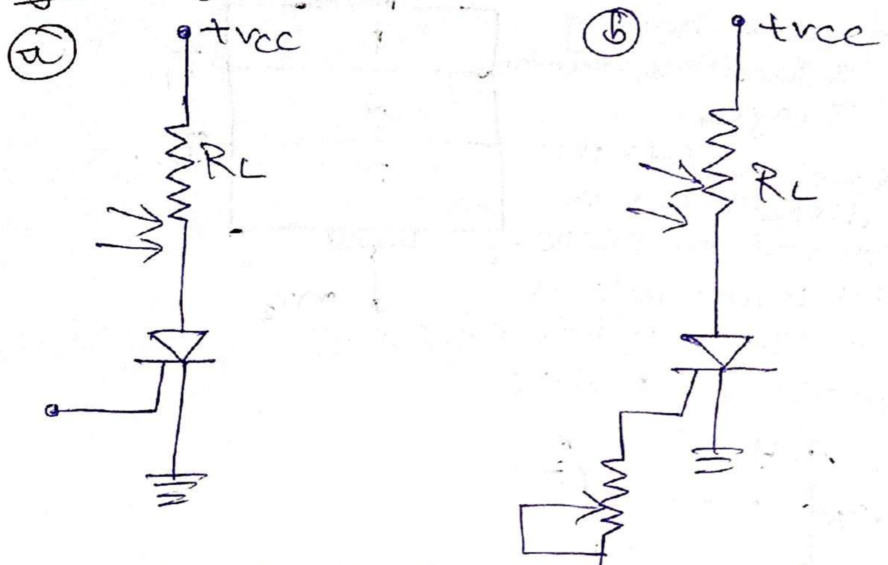
fig(b): O/P waveform of SCR Bridge Rectifier



* During +ve half cycle of I/P signal, SCR_1 & Diode D_1 conducts where SCR_2 & Diode D_2 does not conducts
* During −ve half cycle of I/P signal, SCR_2 & Diode D_2 conducts where SCR_1 & Diode D_1 does not conducts.
* Conduction angle and hence O/P voltage can be changed by adjusting gate currents of SCR_1 & SCR_2.
* D.C O/P voltage (a) $\boxed{V_{avg} = \frac{V_m}{\pi}(1+\cos\theta)}$ which is equal to that of SCR FWR
* If current is lowered below I_H by ↑ing external circuit resistance, then SCR will switch OFF.

3) LASCR (Light Activated Silicon Controlled Rectifier)

fig(a):- Light Activated SCR.



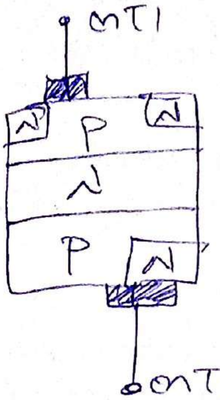
* As show in the figure LASCR is triggered by irradiating with light.
* Arrow represents incoming light that passes through window & falls on depletion layer closer to middle junction J_2 of SCR.
* Incident light generates electron hole (e-h) pairs in the device thus increasing number of charge carriers
* This leads to instantaneous flow of current within the device & it turns ON.
* for light triggering to occur, device must have high value of rate of change of voltage with time, dv/dt.

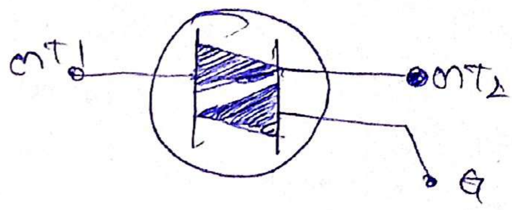
4) TRIAC (Triode As a AC switch):-

* Triac is a three terminal semiconductor switching device which can control alternating current in a load
* It's three terminal's are MT_1, MT_2 & gate(G)
* Basic structure & circuit symbol of Triac are show in fig a & fig b
* Triac is equivalent two SCR's connected in parallel but in reverse direction as shown in figure.

fig(a): Basic structure

fig(b): Circuit symbol

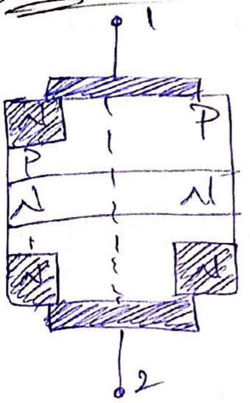


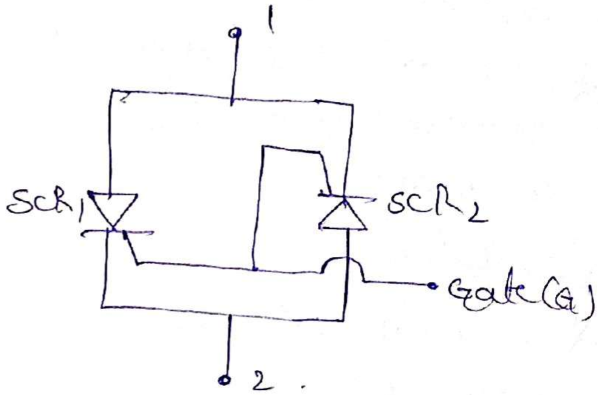


* So Triac will act as a switch for both directions.

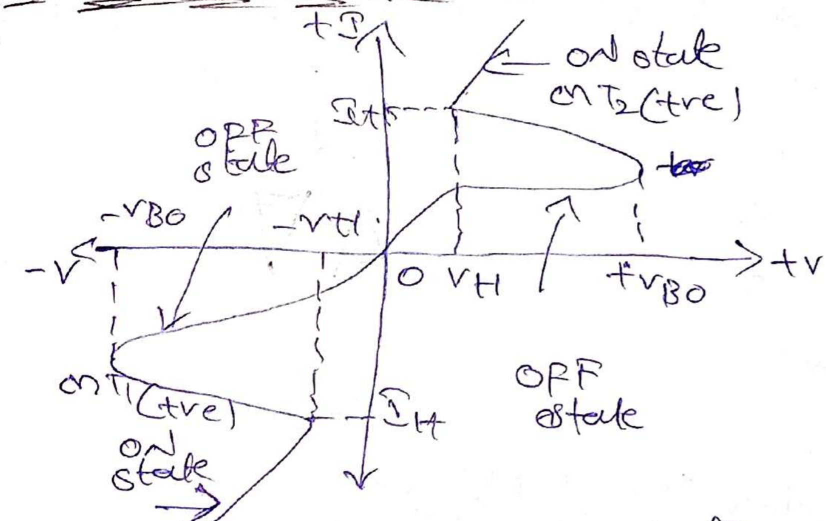
fig(c): Two SCR version TRIAC Basic structure

fig(d): Equivalent circuit





fig(e): characteristics of TRIAC:



* Like SCR Triac also starts conducting only when break over voltage is reached.
* Device when starts conducting allows very heavy amount of current to flow through it.
* High current must be produced using external resistance otherwise device will be damaged.

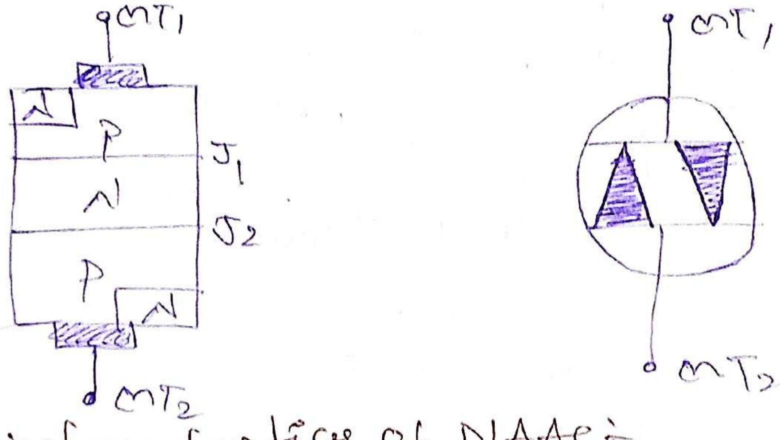
* During +ve half cycle MT_1 is +ve w.r.t MT_2 whereas MT_2 is +ve w.r.t MT_1 during -ve half cycle.
* Triac is bi-directional device & can be triggered either by +ve or by -ve gate signal.
* By applying proper signal at gate breakover voltage can be changed this phase control process can be achieved.
* used for illumination control, temperature control, liquid level control, motor speed control & as static switch to turn power ON & OFF
* Now-a-days, dia & triac pairs are Ted to be replaced by a single component units known as quadrac.

Limitations:-

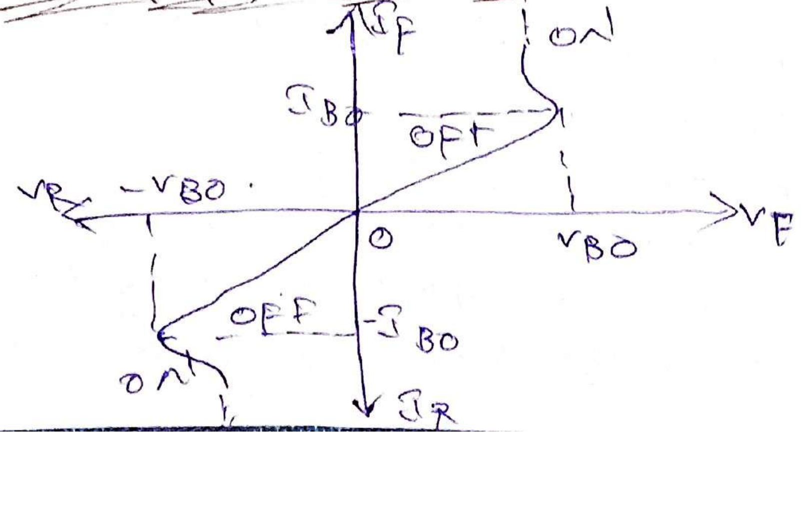
* In comparison to SCR is low power handling capacity.

5) DIAC (Diode as a Ac switch)

fig(a):- DIAC Basic structure:- fig(b):- circuit symbol:-



fig(c):- characteristics of DIAC:-



* construction & symbol of diac are shown in fig (a) & (b)
* It is a three layer, two terminal semiconductor device.
* MT_1 & MT_2 are two main Terminals which are interchangeable.
* Acts as bi-directional Avalanche diode
* Does not have any control terminal
* Does not have any control terminal
* Has two junctions J_1 & J_2
* Diac resemble a bipolar transistor but central layer is free from any connection with terminal
* from characteristics of Dia show in fig (c) acts as a switch in both directions
* As doping level at two ends of device is same, diac has identical chars for both +ve & -ve half of A.C cycle.
* During +ve half cycle, MT_1 is +ve w.r.t MT_2 where as MT_2 is +ve w.r.t MT_1 in -ve half cycle
* At voltage level reaches breakover voltage, device starts conducting & exhibits -ve resistance characteristics
ie current ↑es & voltage ↓es.
* DIAC is not a control device
* used as triggering device in triac, phase control circuits used for light dimming, motor speed control & heater control.

6) UJT (unijunction Transistor) :-

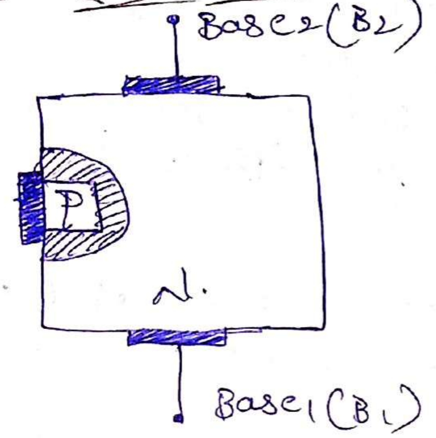
* UJT is a three terminal semi conductor switching device

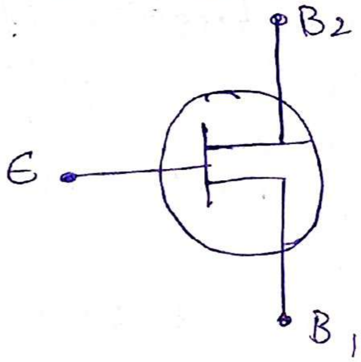
* It has only one P-N junction & three leads, so it is commonly called as uni-junction transistor

* It consists of a lightly doped N-type si with a heavily doped P-type si for producing single P-N junction

* circuit symbol of UJT is shown in fig (b).

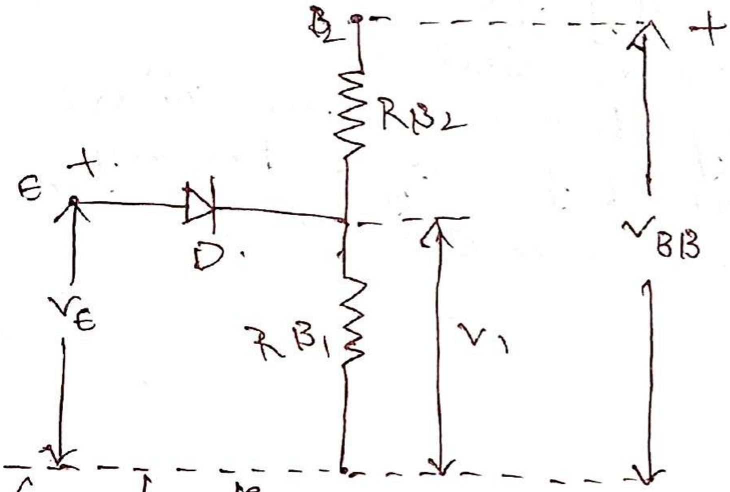
fig (a) :- UJT Basic structure: fig (b) :- circuit symbol





* Arrow in fig-(b) indicates direction of conventional.

fig (c) :- equivalent circuit :-



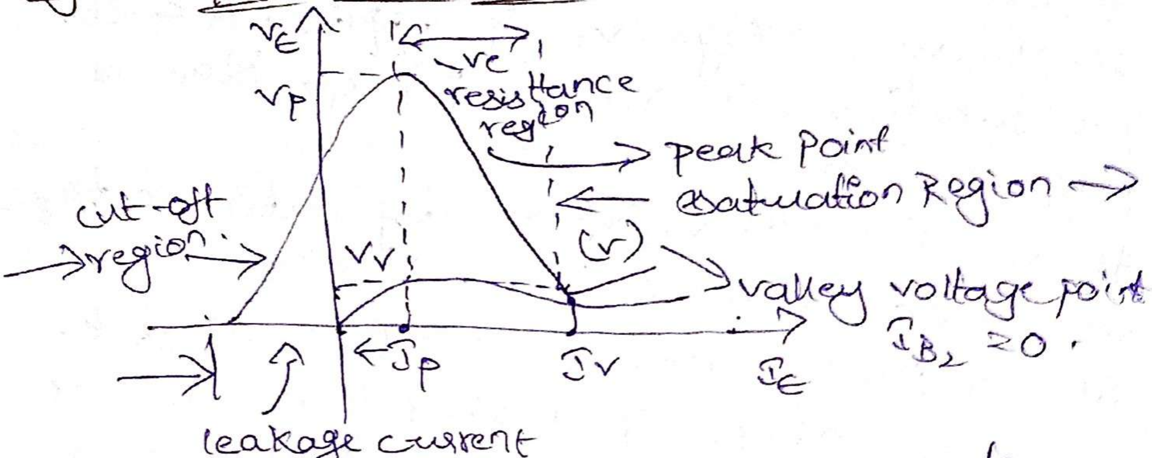
characteristics of UJT :-

* As shown in fig-(c) Interbase resistance b/w B_2 & B_1 of si is $\boxed{R_{BB} = R_{B_1} + R_{B_2}}$

* with emitter terminal open, voltage V_{BB} is applied b/w two bases, a voltage gradient is established
* voltage drop across R_{B1} is given by $\boxed{V_1 = \eta V_{BB}}$ where intrinsic stand-off ration $\boxed{\eta = \frac{R_{B1}}{R_{B1}+R_{B2}}}$
* Typical value of η ranges from 0.56 to 0.75
* voltage V_1 reverse biases p-n junction & I_E is cut-off
* If a +ve voltage V_E is applied to emitter pn junction will remain reverse bias as long as $V_E < V_1$
* If V_E exceeds $V_1 (V_E > V_1)$ by cutin voltage V_γ, diode becomes forward bias
* ~~If V_γ~~ Device now is in the 'on' state.
* If a -ve voltage is applied to the emitter, p-n junction remains reverse bias & I_E is cut-off
* Device now is in the 'off' state.
* upto the peak point P, the diode is R.B & hence to the left of peak point is called as cut-off region.
* At P, peak voltage $\boxed{V_P = \eta V_{BB} + V_\gamma}$ diode starts conducting & holes are injected into n-layer.
* Hence, resistance ↓es there by ↓ing V_E for ↑ing I_E
* so, there is a -ve resistance region from peak point P to valley point V.
* Region to the right of valley point is called saturation region
* ~~so, there is a -ve resistance~~

* In the valley point, resistance changes from +ve to -ve
* Resistance remains +ve in the saturation region
* for very large I_E, characteristic asymptotically approches curve for $I_{B_2} = 0$.

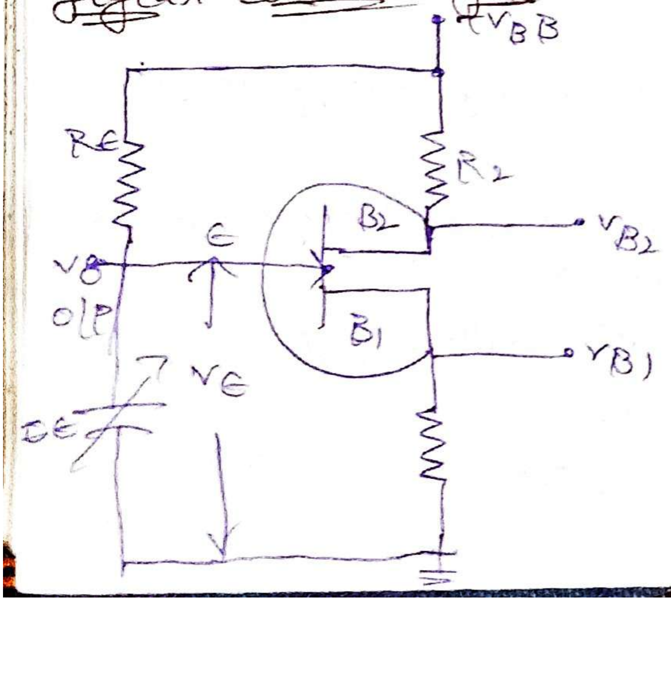
fig(d): I/p characteristics of UJT:



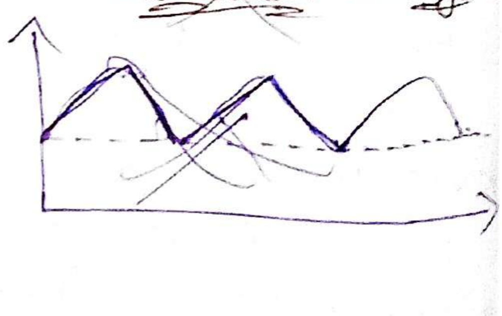
* when it is triggered, I_E ↑es regeneratively untill it is limited by emitter power supply
* Due to -ve resistance property, a UJT can be used for variety of applications such as sawtooth generator, pulse Generator, switching, timing & phase control circuits.

UJT Relaxation oscillator:

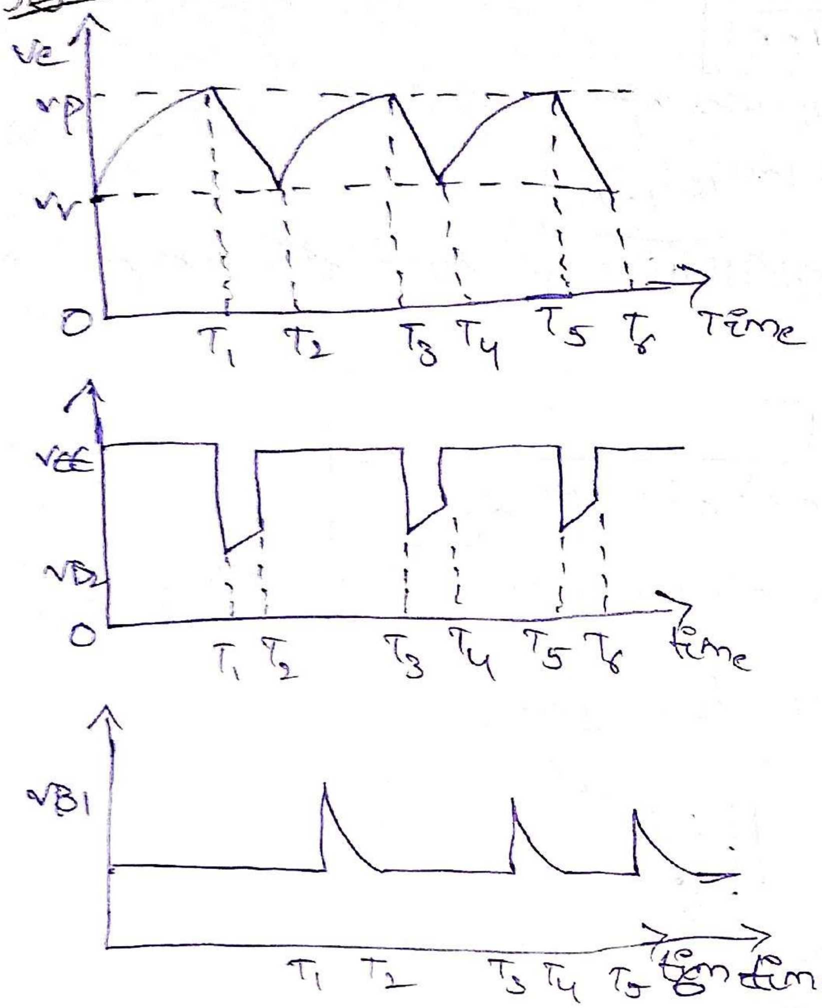
fig(a): circuit diagram:



fig(b): UJT Relaxation oscillator waveform



fig(b): UJT Relaxation oscillator waveform



* Relaxation oscillation using UJT for generating sawtooth waveform is show in fig (a).
* It consists of a UJT & a capacitor C_E charged through R_E as supply voltage V_{BB} is switched on.
* V_C across capacitor is given by $\boxed{V_C = V_{BB}(1 - e^{-t/R_E C_E})}$
  where $R_E C_E$ = charging time constant of resistor-capacitor ckt
  t = time of the waveform.
* Discharge of capacitor occurs where V_C = peak-pt voltage V_P : $V_C = V_P = \eta V_{BB}$

let $V_C = \eta V_{BB} = V_{BB}(1 - e^{-t/R_E C_E})$

$\eta = 1 - e^{-t/R_E C_E} \Rightarrow e^{-t/R_E C_E} = (1-\eta)$

General time period of UJT.

$$\therefore \boxed{t = R_E C_E \log_e \frac{1}{(1-n)}}$$

Time period when waveform occurs

$$\therefore \boxed{t = 2.303 R_E C_E \log_{10} \frac{1}{(1-n)}}$$

$\therefore$ frequency of oscillation of sawtooth wave is given by

$$\boxed{f = \frac{1}{T} = \frac{1}{2.303 R_E C_E \log_{10} \frac{1}{(1-n)}}}$$

7) IGBT (Insulated - Gate Bipolar Transistor)

fig(a) circuit Symbol for IGBT :

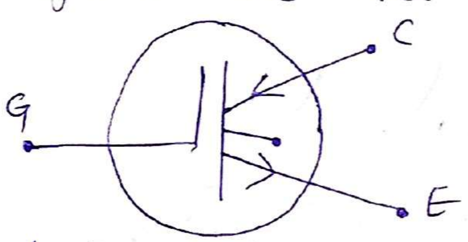
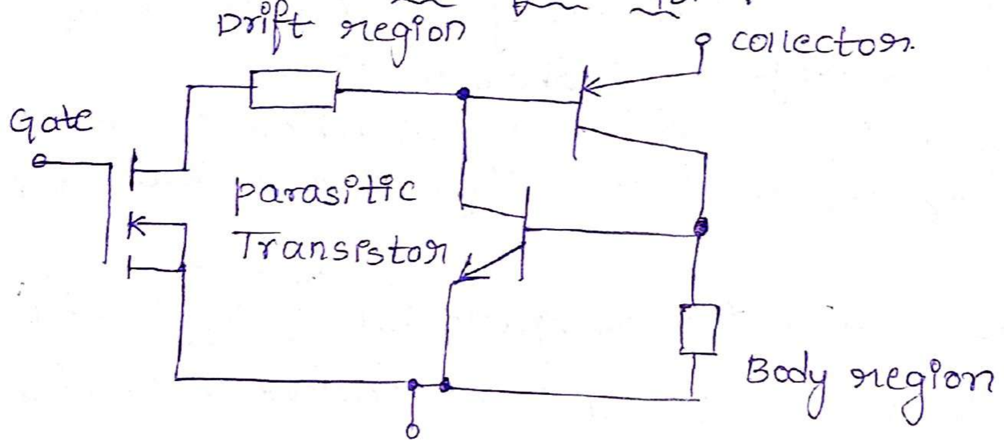


fig b:- Equivalent ckt for IGBT :

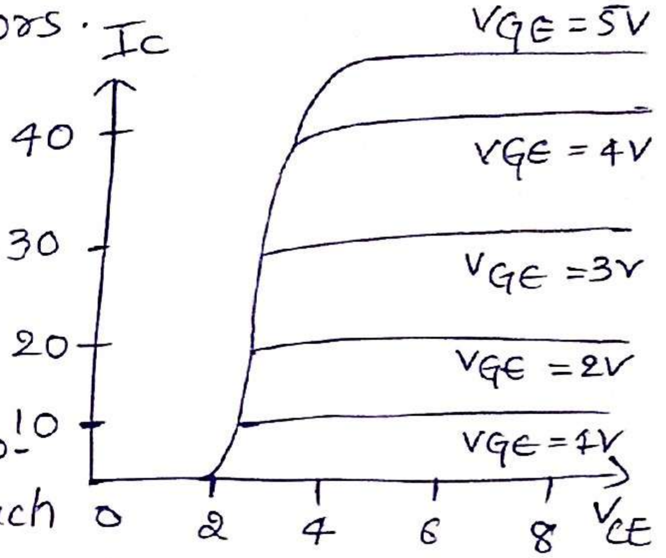


* IGBT is a three ~~dimen~~ terminal power semiconductor device mainly used as electronic switch.
* This switch is mainly developed to combine high efficiency and fast switching
* It switches electric power in many modern appliances such as variable frequency drives (VFD's)

electric cars, trains, variable speed refrigerators, lamp ballasts, air- conditioners & even stereo systems.

* In switching applications ultrasonic range frequencies are at least 10 times the highest audio frequency when used as an analog audio amplifier.

* IGBT combines simple gate drive characteristics of MOSFET's with high current and low-saturation voltage of bipolar transistors.



* IGBT combines an isolated gate FET for control input and bipolar power transistor as a switch in single device.

* IGBT is used in medium-to-high power applications such as switched mode power supplies, traction motor control & induction heating.

* Large IGBT modules typically consists of many devices in parallel and can have very high current in hundreds of amperes blocking voltages of 6000V and power is of kilowatts.

* IGBT's are important for electric vehicles and hybrid cars.