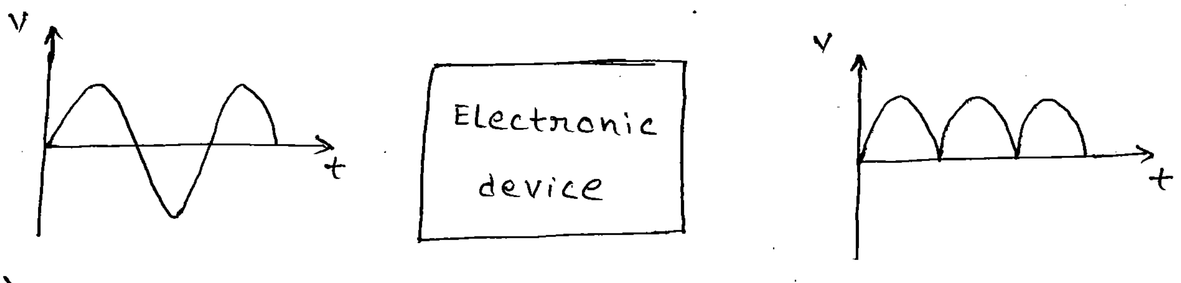
Electronics : The branch of Engineering which deals with current conduction through a vaccum or gas or semi conductor is known as Electronics.

Electronic Device : An electronic device is that in which current flows through a vaccum or gas or semi conductor.

Applications of Electronics :-

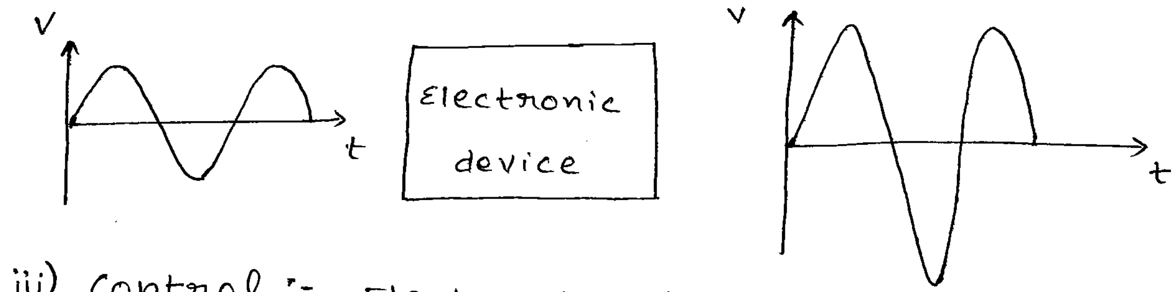
The Electronic devices are capable of performing the following functions

i) Rectification : The conversion of a.c in to d.c is called rectification. Electronic devices can convert a.c power in to d.c power with very high efficiency. This d.c supply can be used for charging storage batteries, field supply of d.c generators etc.



(ii) Amplification :- The process of raising the strength of a weak signal is known as Amplification.

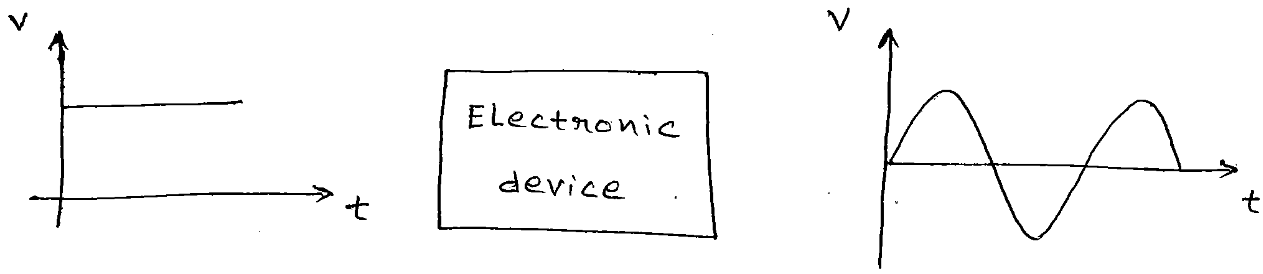
Ex. Radio's, Televisions



iii) Control :- Electronic devices find wide applications in automatic control.

Ex speed of a motor, voltage across a refrigirator etc

iv) Generation :- Electronic devices can convert d.c power in to a.c power of any frequency. when performing this function, they are known as oscillators.



v) conversion of Light in to Electricity :- Electronic devices can convert Light in to Electricity. This conversion of light in to electricity is known as photo Electricity. Ex Burglar alarms etc

vi) conversion of Electricity in to Light :- Electronic devices can convert electricity in to Light. This valuable property is utilised in television and radar.

Generally materials are classified in to 3 types

i) Insulators

ii) Metals

iii) Semiconductors

i) Insulators :- A very poor conductor of Electricity is called an Insulator

Ex wood, glass, Diamond, Mica etc

ii) Metals :- An Excellent conductor is a metal. Ex : copper, Alluminium etc

iii) Semi Conductor :- A material whose conductivity lies between that of conductors and insulators is called semi Conductors.

Ex: silicon and Germanium.

Structure of an Atom :-

→ All the protons and neutrons are bound together at the centre of an atom, which is called nucleus, while all the electrons are moving around the nucleus

→ the electrons are arranged in the different orbits at fixed distances from the nucleus

→ In general, an orbit or a shell can contain a maximum number of $2n^2$ electrons, where 'n' is the number of the shell.

→ Each shell has energy level associated

→ Closer the shell to the nucleus, more tightly it is bound to the nucleus and posesses Lower energy level.

→ The outermost shell is called valence shell and the electrons in this shell are called valence electrons.

→ The valence electrons revolving in the outer most shell are said to be having highest energy level

→ The amount of energy required to extract the valence electron from the outer shell is very less

→ An electron which is not subjected to the force of attraction of the nucleus is called a free electron. Such free electrons are basically responsible to the flow of current.

→ more the number of free electrons better is the conductivity of the metal.

<u>Energy band theory</u> :-

A material can be placed into insulators, conductors and semiconductors depending upon its energy band structure.

The energy band diagram consists of three bands

(1) valence band (2) conduction band (3) Forbidden band

(1) Valence band :- The valence electrons possess highest energy level. when such electrons form the covalent bonds due to the coupling between valence electrons of adjacent atom, the energy band formed due to merging of energy levels associated with the valence electrons. ie. electrons in the last shell is called the valence band

(2) conduction band :- valence electrons form the covalent bond and are not free, but when certain energy is imparted to them they become free.

The energy band formed due to merging of energy levels associated with the free electrons is called conduction band.

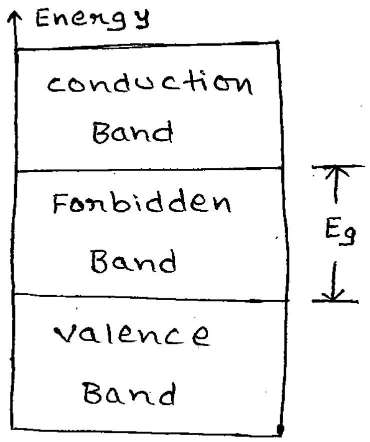
under normal conditions, the conduction band is empty and once energy is imparted the valence electrons jump from valence band to conduction band and become free.

(3) Forbidden band :-

while jumping from valence band to conduction band the electrons have to cross an energy gap

The energy gap which is present separating the conduction band and the valence band is called forbidden band or forbidden energy gap.

Insulators :- The energy band diagram of a insulator is shown in figure below.



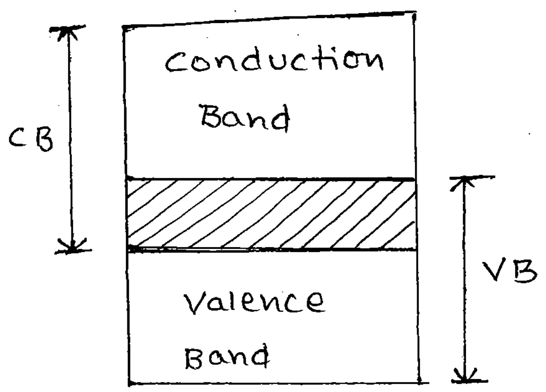
The valence band is fully filled and conduction band is almost empty and forbidden gap is more approximately of about 7ev

For a diamond, the forbidden gap is about 6ev.

conduction is impossible in insulators even by applying additional energy.

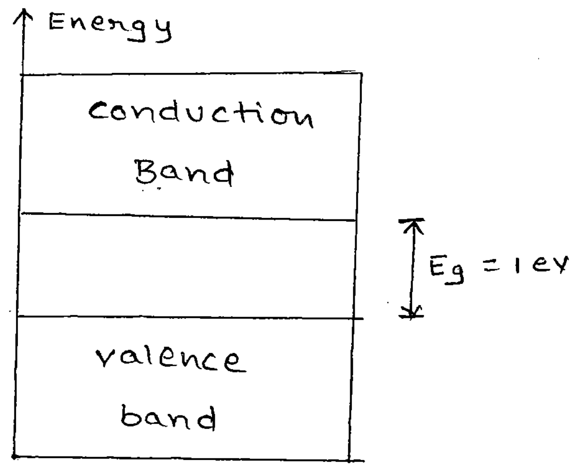
The resistivity of insulators is of the order of 10^7 ohm-meter.

Conductors : The energy band diagram of conductors is shown in figure below.



Here the valence band and conduction band overlap each other as shown in figure. As a result the electrons in the valence band can easily move in to the conduction band to make conduction easily. The resistivity is of the order of $10^{-8}\,\Omega$-m.

(3) <u>Semi Conductors</u> :- The energy band diagram of semi Conductors is shown in figure below.



Here the valence band is almost filled and conduction band is almost empty. The energy gap between valence band and conduction band is very small and is about 1 eV.

The resistivity of semi Conductor is of the order of $10^{-4}\,\Omega$-m.

Hence smaller electric field is required to push the electrons from the valence band to the conduction band.

At low temperature, the valance band is completely full and conduction band is completely empty. Therefore at low temperatures the

However even at room temperature, some of the valence electrons acquire thermal energy greater than Eg to overcome forbidden energy gap and jump in to the conduction band to make the conduction possible.

Hence as the temperature increases, the conductivity of semiconductor increases ie. resistance decreases. Therefore semi conductors have negative resistance temperature coefficient.

At 0°K, the forbidden gap for Germanium is

$$\boxed{E_g = 0.785\ eV}$$

and for Silicon (Si) is $\boxed{E_g = 1.21\ eV}$

The forbidden energy gap depends on temperature.

At Room temp ie 300° K

For Ge $E_g = 0.72\ eV$

For Si $E_g = 1.1\ eV$

Commonly used Semi Conductors :

There are many semi conductors available, but very few of them have a practical application in electronics. The two most frequently used materials are Germanium and Silicon. It is because the energy required to break their covalent bond (ie the energy required to release an electron from their valence bonds) is very small being 0.72 eV for Ge and 1.1 eV for Si

1) <u>Germanium (Ge) :</u>

The atomic number of Ge is 32. Therefore it has 32 protons and 32 electrons. Two electrons are in the first orbit; eight electrons in the second, 18 electrons in the third and 4 electrons in the outer (or) valence orbit.

It is clear that Ge atom has 4 valence electrons ie it is a tetravalent element. It is shown in fig (a)

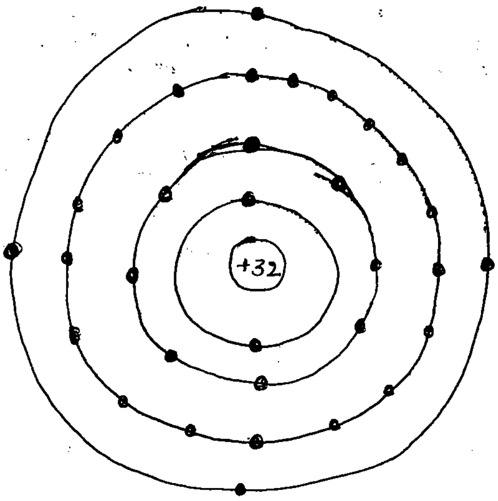


fig (a).

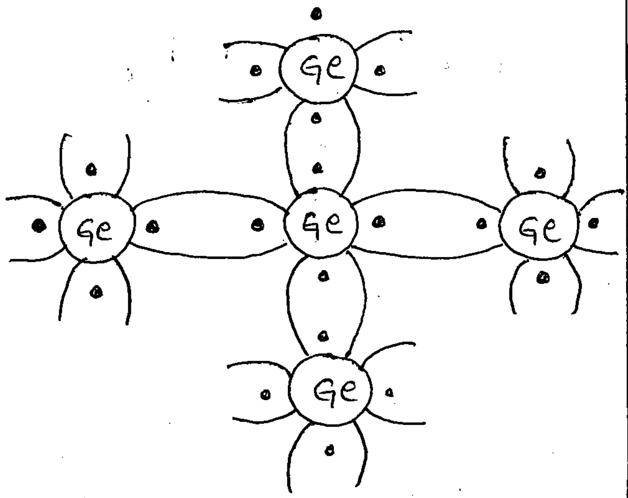


fig (b).

fig (b) shows how the various Germanium atoms are held through co-valent bonds. As the atoms are arranged in an orderly pattern, Ge has crystalline structure.

2) <u>Silicon (Si)</u> :- Silicon is an element ~~of~~ in most of the common rocks. Actually sand is silicon di oxide. And this is chemically reduced to silicon which is 100% pure for use as a semiconductor.

The atomic number of silicon is 14. Therefore it has 14 protons and 14 electrons. Two electrons are in the first orbit, eight electrons in the second orbit and four electrons in the ~~second~~ third orbit. This is shown in fig(a) below. It is clear that silicon atom has four valence electrons. ie. it is a tetravalent element.

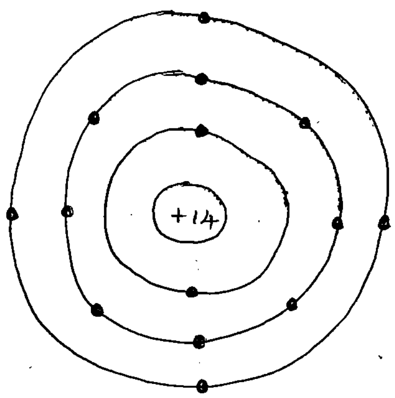


fig (a).

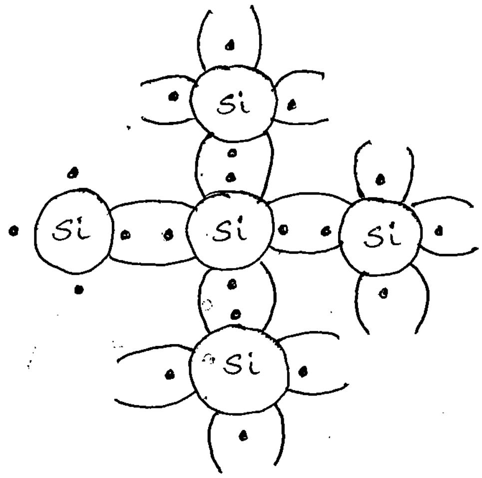


fig (b)

fig(b) shows how various silicon atoms are held through co-valent bonds. Like germanium, silicon atoms are also arranged in an orderly manner. Therefore silicon has crystalline structure.

Classification of Semi Conductor materials :-

Semi conductor materials are classified in to two types
1. Intrinsic Semi Conductors
2. Extrinsic Semi Conductors.

1) **Intrinsic Semi Conductor :-** A pure form of semi-conductor material is known as intrinsic semi conductor material.

when there are four electrons in the outermost orbit, the semi Conductor material is refered to as pure or intrinsic Semi Conductor.

In pure Semi Conductor, the number of holes is equal to the number of free electrons.

Even at room temperature, some of valence electrons may acquire sufficient energy to enter the conduction band to form free electrons under the influence of electric field, these electrons constitutes the electric current.

The current due to the movement of free electrons in the conduction band is an electron current.

A missing electron in the valance band leaves a vacant space there, which is known as a hole.

under the influence of electric field, the current due to the movement of holes in the valance band is a hole current.

Therefore the electron as well as hole current together constitutes the total current in an intrinsic Semi Conductor.

<u>Extrinsic Semi Conductor</u> :- The intrinsic semi conductor has little current conduction capability at room temperature. To be useful in

electronic devices, the pure semi conductor must be altered so as to significantly increase its conducting properties. This is achieved by adding a small amount of suitable impurity to a semi conductor. It is then called impurity or Extrinsic semiconductor. so

Doped semiconductor material is called Extrinsic (impure) Semi Conductor.

The process of adding small amount of impurities to the pure form of semi Conductor in order to increase the conductivity of semi Conductor is Known as doping.

Depending upon type of impurities, there are two types of extrinsic semi Conductors

(1) N- type (2) P- type.

(1) N - type Semi Conductor :-

When a small amount of pentavalent impurity such as Arsenic (As), Antimony (Sb), Phosphorous, Bismuth etc is added to pure form of Semi Conductor, it is Known as n-type semi Conductor. These pentavalent impurities are also called 'donar imprity atoms', because they donate or provide free electrons to the semi Conductor crystal.

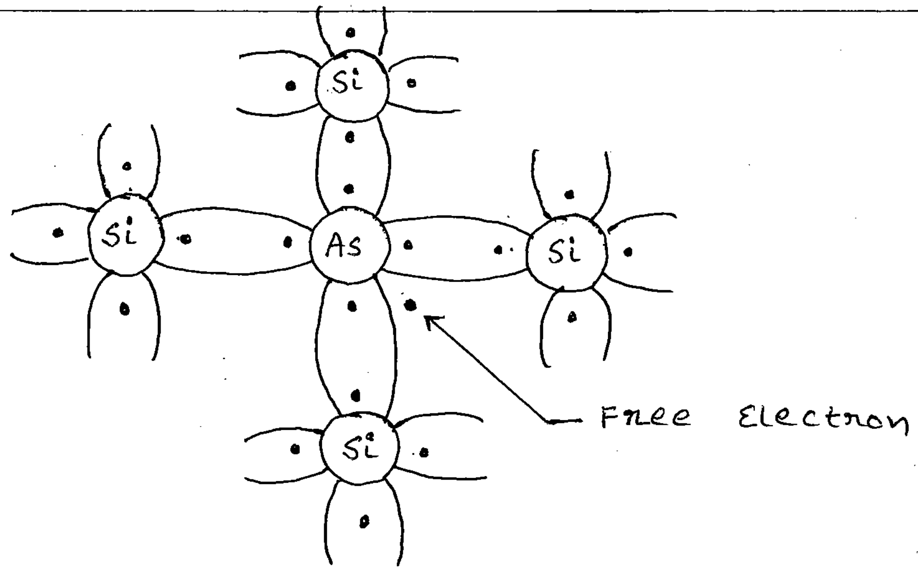


fig: Formation of covalent bonds in N-type semiconductor.

one donar impurity atom donates one free electron in N-type material. therefore free electrons are majority charge carriers in N-type semi conductors.

the following points may be noted carefully

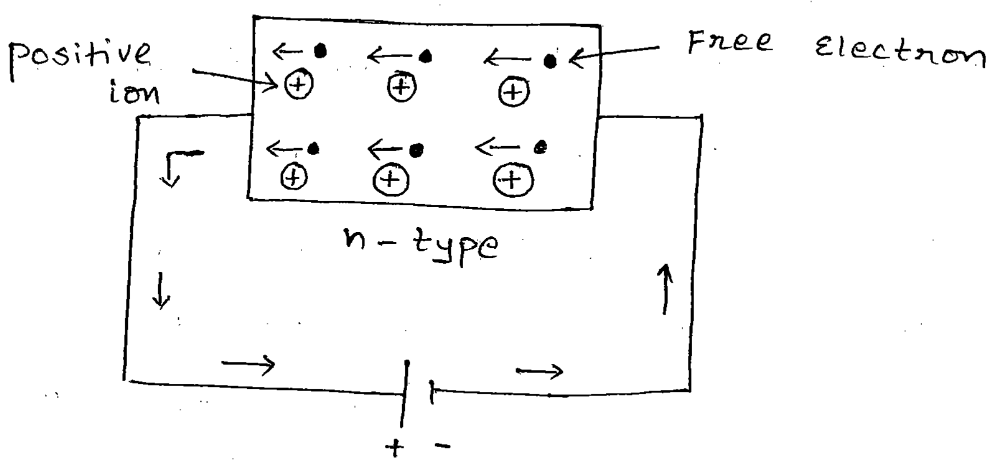
1) Many new free electrons are produced by the addition of pentavalent impurity.

2) Thermal energy at room temperature still generates a few electron-hole pairs. However the number of free electrons provided by the pentavalent impurity far exceeds the number of holes. It is due to this predominance of electrons over holes that it is called n-type semiconductor (n stands for negative). Here holes are the minority carriers.

n-type Conductivity :- The current conduction in an n-type semi Conductor is predominantly by free electrons. when potential difference is applied across n-type semi Conductor, the free electrons (donated by impurity) in the crystal will be directed towards the positive terminal, constituting electric current. so this type of conductivity is called n-type conductivity.

** The donor impurity atom donates one electron to the crystal and becomes "positive ion"

therefore n-type semi Conductor cosists of free electrons and 'positive ion'



P-type semi Conductor :-

when a small amount of trivalent impurity such as Boron, Aluminium, Indium, Gallium is added to a pure semi Conductor, It is called P-type semi Conductor. These trivalent impurities are also called "Acceptor impurities".

one Acceptor impurity creates one hole in a P-type material, therefore the holes are majority charge carriers.

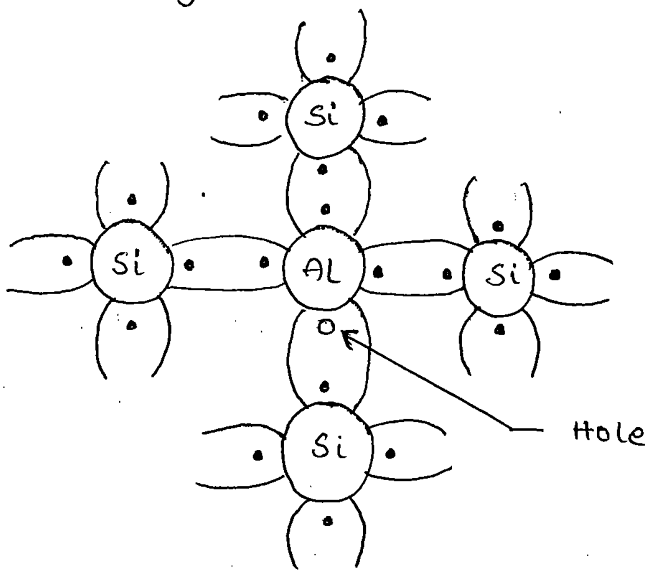
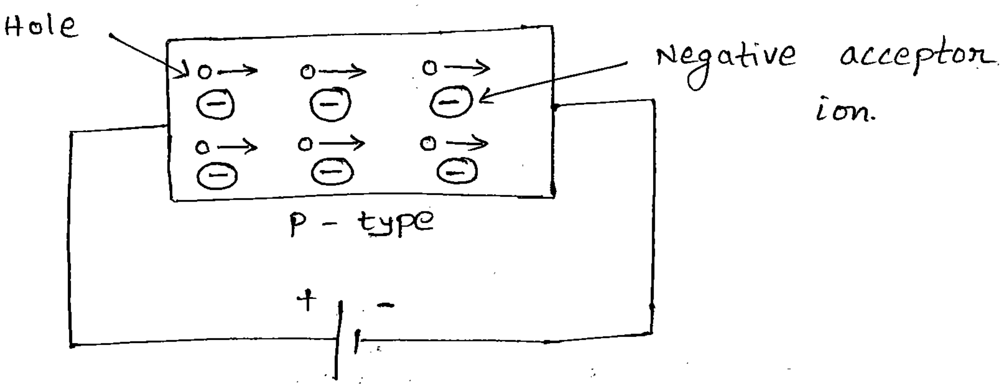


Fig: Formation of covalent bonds in P-type semi conductors.

Here fourth bond is incomplete, being short of one electron. This missing electron is called a hole. Therefore for each ~~gallium~~ AL atom added, one hole is created. A small amount of gallium provides millions of holes.

However, there are a few conduction band electrons due to thermal energy associated with room temperature. but the holes are far exceeds the number of electrons. because of this predominance of holes over free electrons, this type of semiconductor is called P-type semiconductor. (P stands for positive)

P-type conductivity :-



The current conduction in P-type Semi Conductor is predominantly by holes. when potential difference is applied to the P-type Semi Conductor, the holes are shifted from one covalent bond to another. As the holes are positively charged, they are directed towards the negative terminal, constituting hole current. so this type of conductivity is called P-type conductivity.

** The acceptor impurity atom is short of one electron, and becomes a negative ion.

Therefore P-type Semi Conductor consists of holes and negative ions.

Majority and minority carriers :-

In N- type Semi Conductor the majority Carriers are Electrons and the Minority carriers are the holes.

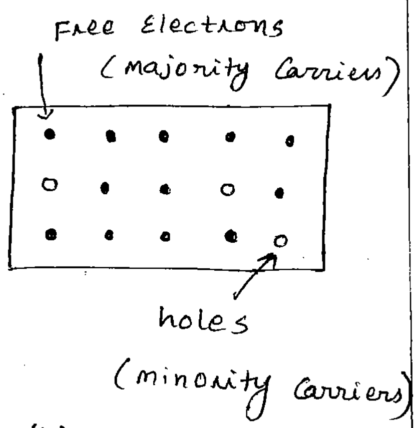
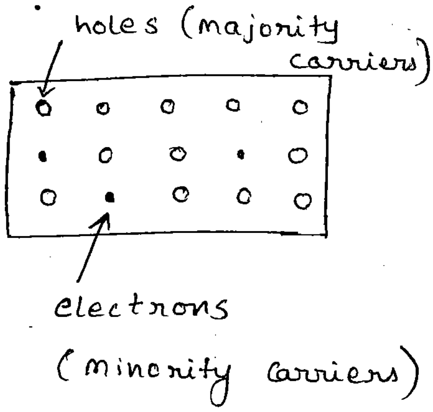


fig (i) N - type

In P- type Semi Conductor the majority carriers are holes and the minority Carriers are the electrons.

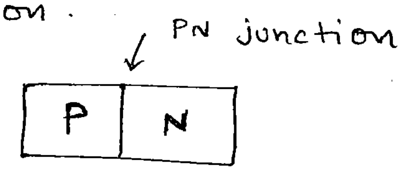


fig(ii) P- type

Qualitative theory of PN Junction (Formation of PN junction)

→ In a piece of semi conductor material, if one half is doped by P-type impurity and the other half is doped by N - type impurity, a PN junction is formed.

→ The plane dividing the two halves or zones is called PN junction.



→ P-type semi conductor consists of both holes and Negative acceptor ions (the acceptor impurity atom is short of one electron and becomes a negative ion)

→ The N- type semi conductor consists of both electrons and positive donor ion (The donor impurity atom donates one electron and becomes a positive ion)

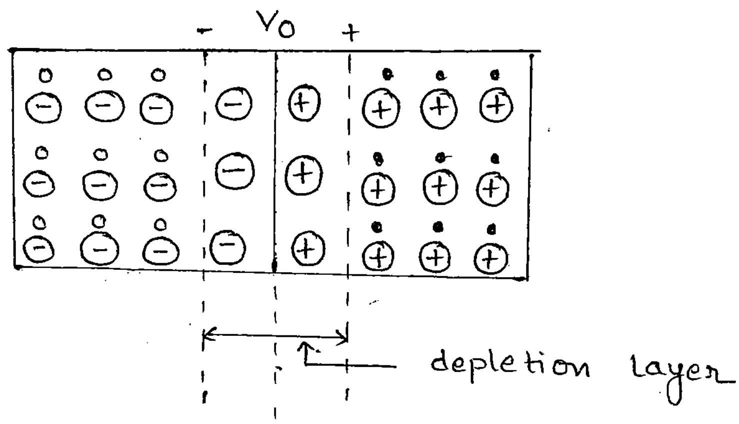
→ Here n - type material has a high concentration of free electrons while P-type material has high concentration of holes.

→ Therefore at the junction, there is a tendency for the free electrons to diffuse over to the P- side and holes to the N - side. This process is called diffusion.

→ As the free electrons move across the junction from n-type to P-type, Positive donor ions are uncovered. Hence a positive charge is built on the n- side of the junction.

→ At the same time, the free electrons cross the junction and uncover the negative acceptor ions by filling in the holes. Hence a net negative charge is established on P-side of the junction

→ Now positive charge on N-side repels holes to cross from P-type to n- type, and negative charge on P-side repels free electrons to enter from n-type to P-type. Thus barrier is set up against further movement of charge carriers. This is called potential barrier or barrier potential or junction barrier (V_0).



→ Barrier potential indicates the amount of voltage to be applied across the PN junction to restart the flow of electrons and holes across the junction

→ the barrior potential is expressed in volts. Its value is called the height of the barrior.

→ the Magnitude of the barrior potential varies with doping levels and temperature.

→ The potential barrior can be increased or decreased by applying an external voltage.

→ The potential barrior is approximately 0.7V for Si and 0.3 V for Ge at 25°C.

→ Inside the potential barrior, there is a positive charge on n-side and negative charge on P-side. This region is called depletion region or space charge region.

→ The thickness of this region is of the order of 10^{-4} cm (10^{-6} m = 1 micron)

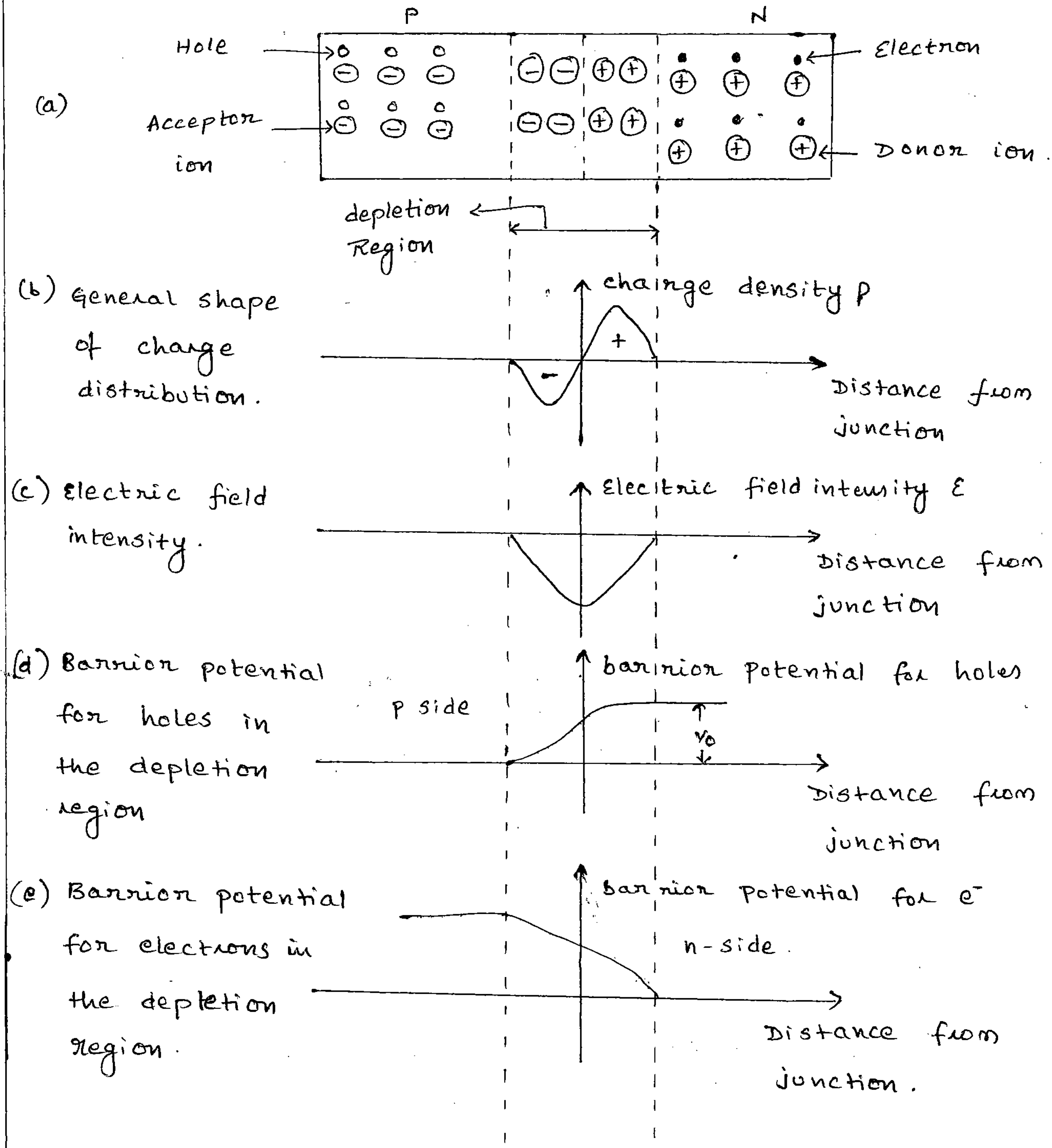
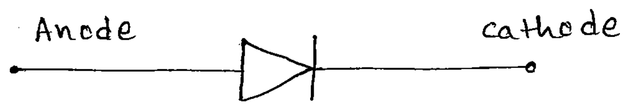


Figure: Formation of PN junction.

PN Junction as a Diode :-

The essential electrical characteristic of a PN junction is that it constitutes a diode which permits the easy flow of current in one direction and restricts the flow of current in opposite direction.

Diode Symbol : Diode symbol is shown in figure below.



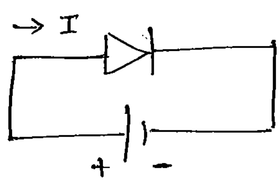
The P-type and n-type regions are referred to as Anode and Cathode respectively.
The Arrow in the symbol indicates the direction of easier conventional current flow.

Operation of PN junction Diode :

(1) **Forward Bias** :

→ when the positive terminal of the battery is connected to the P-type and the negative terminal of the battery is connected to n-type of PN junction diode, then the bias is said to be Forward bias.

→ A PN junction with forward bias is shown in figure below.



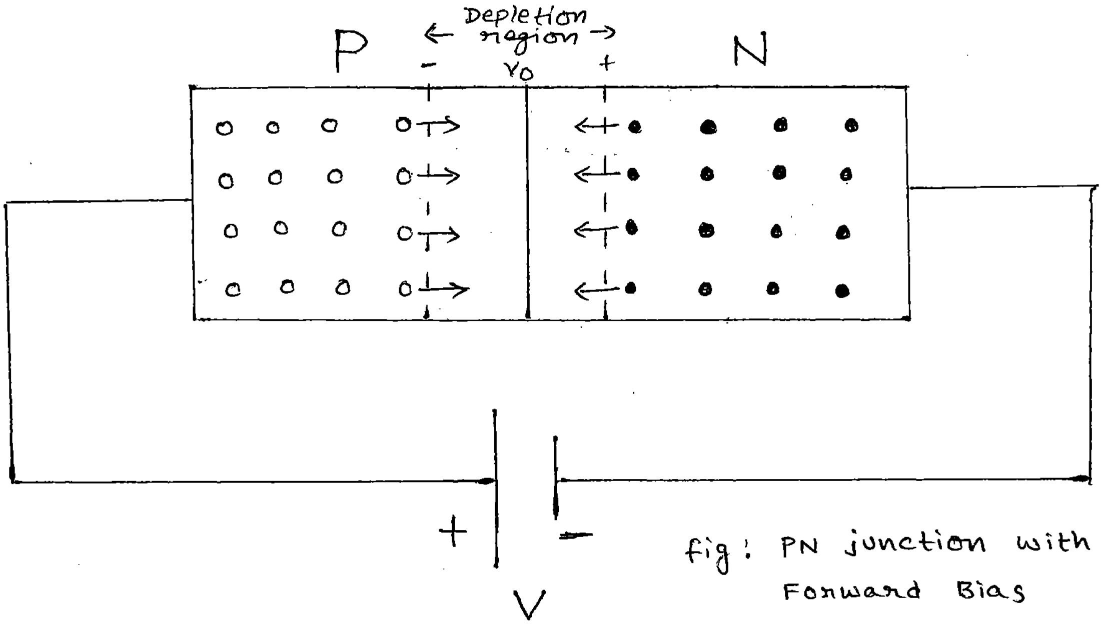


fig: PN junction with Forward Bias

→ when the PN junction is forward biased, as long as the applied voltage is less than the barrior potential there cannot be any conduction.

→ when the applied voltage becomes more than the barrior potential, the negative terminal of battery pushes the free electrons against barrior potential from n to p region. similarly positive terminal pushes the holes from p to n region. Thus holes get repelled by the positive terminal and cross the junction against the barrior potential, Electrons gets repelled by the negative terminal and cross the junction against the barrior potential. Thus the applied voltage overcomes the barrior potential. This reduces the width of the depletion region.

→ As forward voltage is increased, at a particular value the depletion region becomes very much narrow such that large number of majority charge carriers can cross the junction and these majority carriers can travel around the closed circuit and constitute a current called forward current.

→ The forward potential at which the potential barrior across the junction is completely eliminated and allows the current to flow through the junction is called cut-in voltage (or) threshold voltage of PN junction diode.

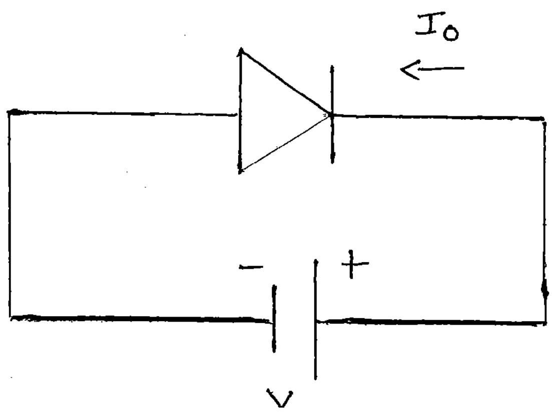
→ The cutin voltage for Ge is 0.3 V

→ The cut in voltage for Si is 0.7 V

(2) <u>Reverse Bias</u> :-

when the positive terminal of the battery is connected to the N type and the negative terminal of the battery is connected to the P type of the PN junction Diode, then bias is said to be 'Reverse Bias'.

A PN junction with reverse Bias is shown in figure below.



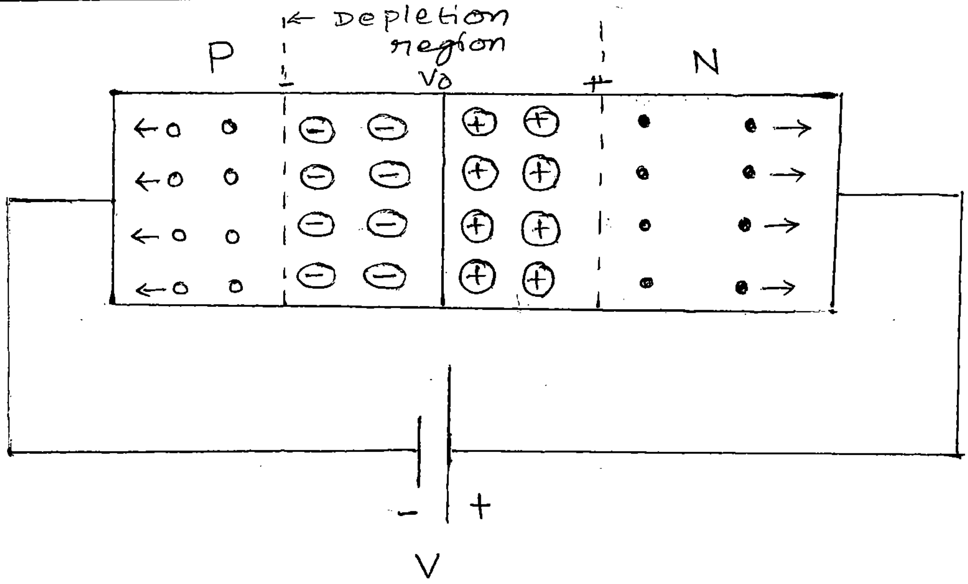


Fig: PN junction with Reverse Bias.

→ When the PN junction is reverse biased the negative terminal attracts the holes in the P-region, away from the junction, the positive terminal attracts the free electrons in the n-region away from the junction.

→ No charge carrier is able to cross the junction.

→ As electrons and holes both move away from the junction, the depletion region widens. Hence the resultant potential barrior is increased which prevents the flow of majority carriers in both directions.

→ therefore, theoretically no current should flow in the external circuit. But in practice, a very small current of the order of a few micro Amperes flows under reverse biased condition.

→ Electrons forming covalent bonds of the semiconductor atoms in the P and N type regions may absorb sufficient energy from heat and light to cause breaking of some covalent bonds. Hence electron-hole pairs are continually produced in both the P regions.

→ under the reverse bias condition, the thermally generated holes in the P-region are attracted towards the negative terminal of the battery and the electrons in the N-region are attracted towards the positive terminal of the battery

→ consequently the minority carriers ie. electrons in the P-region, and holes in the n-region, wander over to the junction and flow towards their majority carrier side, giving rise to a small reverse current. this current is known as reverse saturation current I_0.

→ the Magnitude of reverse saturation current mainly depends upon junction temperature. because the major source of minority carriers is thermally broken co-valent bonds.

→ As Already majority free Electrons from N-side are flowing towards ~~negative~~ positive terminal of battery, the newly Liberated electrons will also join with these majority electrons. thus a large number of free electrons are formed which is commonly called as an avalanche of free electrons. This leads to the breakdown of the junction leading to very large reverse current. The reverse voltage at which the junction break down occurs is known as Avalanche break down.

Diode current Equation :-

If we consider the generation and recombination of carriers in the depletion region, the general equation of the diode current is approximately given by

$$I = I_0 \left[e^{V/\eta V_T} - 1 \right] \longrightarrow (8)$$

where I = diode current

I_0 = diode reverse saturation current at room temp

V = External voltage applied to the diode.

η = a constant [1 for Ge and 2 for Si]

$V_T = \frac{kT}{q} = \frac{T}{11600}$, volt equivalent of temp ie thermal voltage

where k = Boltzman's constant (1.38×10^{-23} J/K)

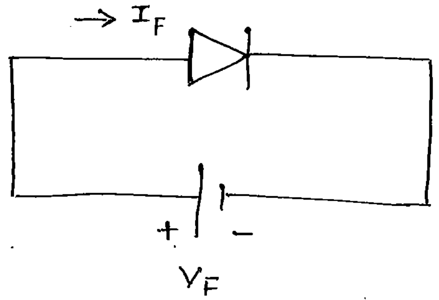
q = charge of the electron = 1.602×10^{-19} C

T = temperature of the diode junction (°K)

Volt - Ampere characteristics of a diode :-

(V-I characteristics)

(1) V-I characteristics in Forward bias condition:



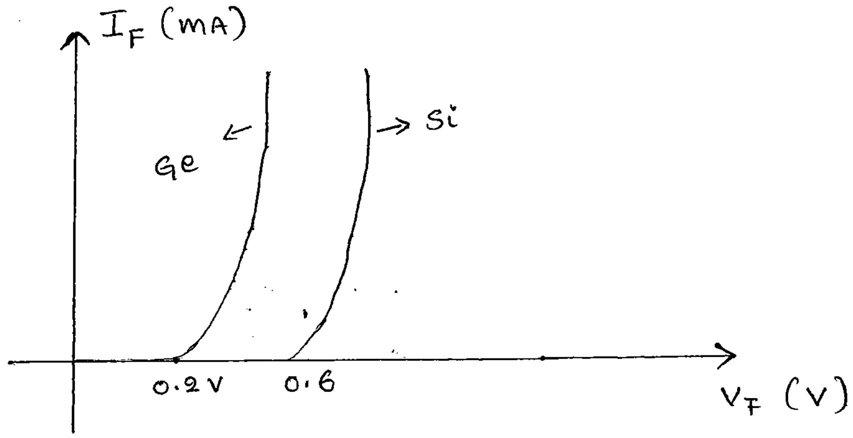
→ when a forward bias voltage V_F is applied to a PN junction diode, below the cut-in voltage V_γ, the diode will not conduct and the current flowing is very small. practically this current is assumed to be zero

→ The diodes will have a cut-in voltage or threshold voltage V_γ, below which current is very small, Beyond V_γ, the current rises very rapidly

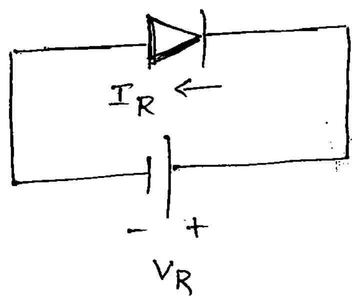
→ V_γ is approximately 0.2 V for Ge and 0.6 V for Si

→ As the forward biased voltage V_F is greater than the cut-in voltage V_γ, the potential barrior across the junction is completely eliminated and the current rises very rapidly.

→ The V-I characteristics under forward biased condition is shown in figure below.



(2) V-I characteristics in Reverse biased condition:-



When a PN junction diode is reverse biased, the negative terminal attracts the holes in the P-region away from the junction. The positive terminal attracts the free electrons in n-region away from the junction. No change carrier is able to cross the junction.

As electrons and holes both move away from the junction, the depletion region widens.

As depletion region widens, barrior potential across the junction also increases. The polarities of barrier potential are same as that of the applied voltage.

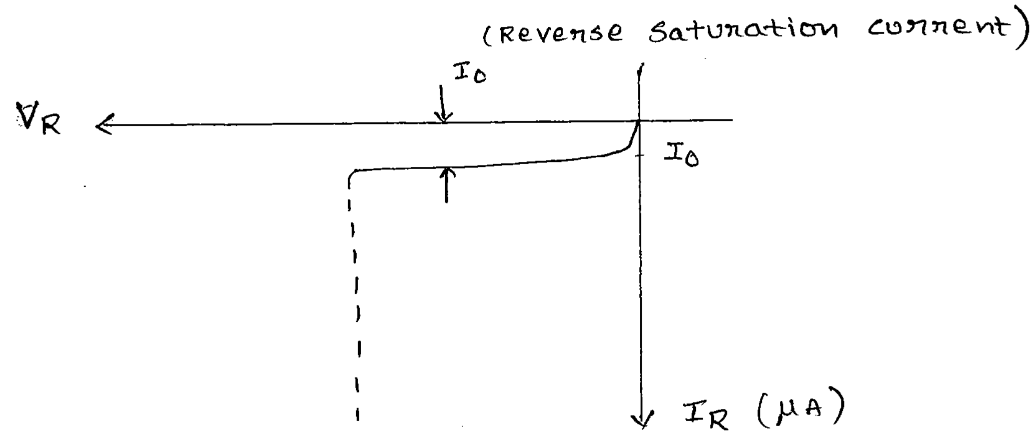
However a small reverse current called reverse saturation current I_0 flows across the junction due to the movement of minority charge carriers across the junction.

Reverse saturation current is very small of the order of few microamperes for Ge and few nanoamperes for Si Pn junction diode.

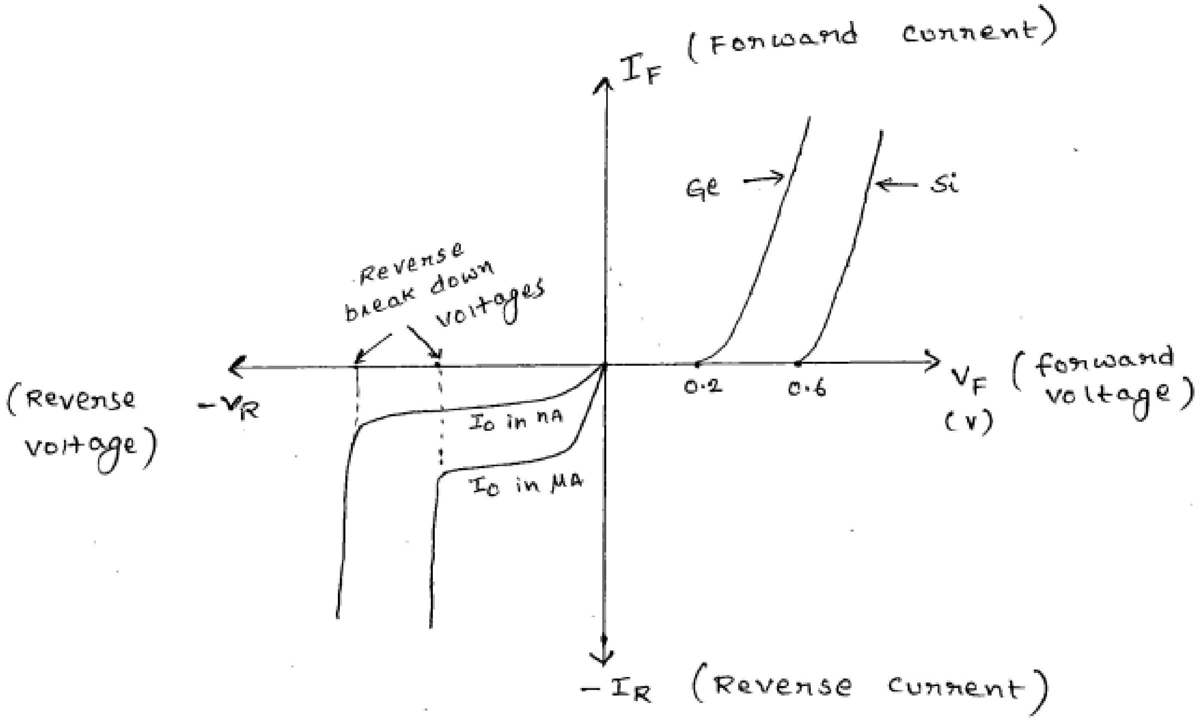
The generation of minority charge carriers depends on the temperature and not on the applied reverse bias voltage.

If the reverse bias voltage is increased beyond certain limit the junction breaks down and a very large reverse current flows.

The V-I characteristics under reverse biased condition for a Pn junction diode is shown in figure below.



The complete VI characteristics of a PN diode (Forward bias and Reverse bias) for both Ge and Si are shown in figure below.



Problem :

A Silicon diode has a reverse saturation current of 7.12 nA at room temperature of 27°c. calculate its forward current if it is forward biased with a voltage of 0.7 V

Solution : Given data

$I_0 = 7.12 \times 10^{-9}$ A , $V = 0.7$ V

$T = 27°c = 300° K$, $\eta = 2$ for Si

$$V_T = \frac{KT}{q} = \frac{T}{11600} = \frac{300}{11600} \simeq 26 \text{ mV}$$

According to diode current equation

$$I = I_0 \left(e^{V/\eta V_T} - 1 \right)$$

$$I = 7.12 \times 10^{-9} \left(e^{0.7/(2 \times 0.026)} - 1 \right)$$

$$I \simeq 5 \text{ mA}.$$

PROBLEM :

A Ge diode has a saturation current of 1 nA at 20°c. Find its current when it is forward biased by 0.4 V. Find the current in the same diode when the temperature rises to 110°c.

Solution : Given data

For Ge diode $\eta = 1$

$I_{01} = 1$ nA $= 10^{-9}$ A

$T_1 = 20°C = 20 + 273 = 293° K$

$$V_T = \frac{T_1}{11600} = \frac{293}{11600} = 0.0252 \text{ V}$$

$V = 0.4\,V \quad , \quad I = ?$

$$I = I_0 \left(e^{V/\eta V_T} - 1 \right)$$

$$I = 10^{-9} \left(e^{0.4/(1 \times 0.0252)} - 1 \right)$$

$$I = 4.8\ mA.$$

If $T_2 = 110^\circ c$ then $I = ?$

$$I_{02} = \left[2^{(T_2 - T_1)/10} \right] I_{01}$$

$$I_{02} = 2^9 \times 10^{-9} = 512 \times 10^{-9}\ A.$$

At $T_2 = 110^\circ c = 110 + 273 = 383^\circ K$

$$V_T = \frac{383}{11600} = 0.033\,V$$

$$I = I_{02} \left(e^{V/\eta V_T} - 1 \right)$$

$$I = 512 \times 10^{-9} \left(e^{0.4/(1 \times 0.033)} - 1 \right)$$

$$I =$$

Problem:

The diode current is 0.6 mA, when the applied voltage is 400 mv and 20 mA when the applied voltage is 500 mv. Determine η. Assume

$$\frac{KT}{q} = 25\,mV$$

Solution: The diode current $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

$$0.6 \times 10^{-3} = I_0 \left(e^{\frac{400}{25\eta}} \right)$$

($\because$ neglecting 1)

Similarly $20 \times 10^{-3} = I_o \left(e^{\frac{500}{25\eta}} \right)$

After simplifying $\eta = 1.14$.

Diode Resistance :-

(1) **Forward resistance of a diode :**

The resistance offered by the diode in forward biased condition is called forward resistance. The forward resistance is defined in two ways.

(i) Static or DC forward resistance (R_F)

(ii) Dynamic or AC forward resistance (r_f)

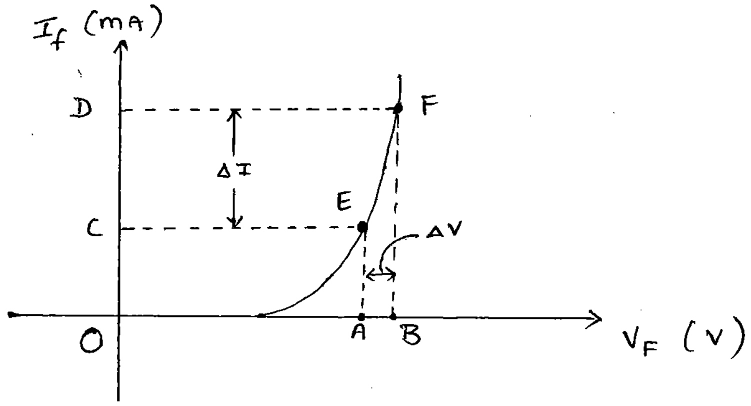


Fig: Forward characteristics of a diode.

(i) **Static or DC forward resistance :-**

The static or DC forward resistance R_F is defined as the ratio of the DC voltage applied across the PN junction to the DC current flowing through the PN junction.

$$R_F = \frac{\text{Forward dc voltage}}{\text{Forward dc current}} = \frac{OA}{OC} \text{ at point E}$$

ii) Dynamic or AC forward resistance :-

The resistance offered by the Pn junction under AC conditions is called dynamic or ac forward resistance and is denoted by r_f

→ The dynamic resistance is defined as the reciprocal of the slope of the V-I characteristics.

ie $$r_f = \frac{dV}{dI}$$

The dynamic resistance is not a constant but depends upon the operating voltage.

From the diode current equation, we have

$$I = I_0 \left(e^{V/\eta V_T} - 1 \right)$$

Differentiating the above equation w.r.t V, we get

$$\Rightarrow \frac{dI}{dV} = I_0 \left(e^{V/\eta V_T} \cdot \frac{1}{\eta V_T} - 0 \right)$$

$$\Rightarrow \frac{dI}{dV} = \frac{I_0 \, e^{V/\eta V_T}}{\eta V_T}$$

$$\Rightarrow \frac{dI}{dV} = \frac{I_0 + I}{\eta V_T}$$

For a forward bias, $I >> I_0$ and r_f is given approximately by

$$r_f = \frac{dV}{dI} \simeq \frac{\eta V_T}{I}$$

$$\therefore \boxed{r_f = \frac{\eta V_T}{I}}$$

→ The dynamic resistance varies inversely with current.

→ At room temperature and for $\eta = 1$

$$r_f = \frac{1 \times 26\,mV}{I}$$, where I is in mA. then

r_f will be in ohms (Ω)

For a forward current of 26 mA, the dynamic resistance is 1Ω.

From the above figure

$$r_f = \frac{\Delta V}{\Delta I} = \frac{1}{\Delta I / \Delta V} = \frac{1}{\text{slope of forward characteristics}}$$

→ Generally the value of r_f is very small of the order of few ohms in the operating region.

(2) <u>Reverse Resistance of a diode</u> :-

→ The resistance offered by the diode in reverse biased condition is called "<u>Reverse resistance</u>"

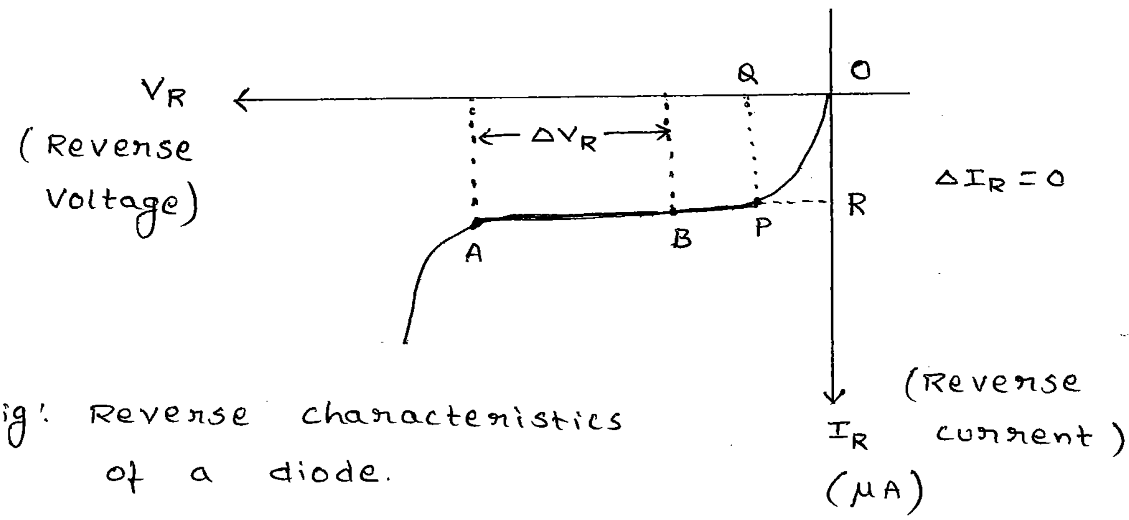


fig: Reverse characteristics of a diode.

The reverse resistance is defined in two ways

(i) static or DC reverse resistance (R_R)

(ii) dynamic or AC reverse resistance (r_r)

(i) Static reverse resistance (R_R) :-

The static reverse resistance R_R is defined as the ratio of applied reverse DC voltage to the reverse saturation current (I_o) flowing through the PN junction.

$$R_R = \frac{\text{Applied Reverse DC voltage}}{\text{Reverse Saturation current}} = \frac{OQ}{OR}$$

(at point P)

(ii) Dynamic reverse resistance (r_r) :

The reverse dynamic resistance r_r is defined as the ratio of incremental change in the reverse voltage applied to the corresponding change in the reverse current.

$$r_r = \frac{\Delta V_R}{\Delta I_R} = \frac{\text{change in reverse voltage}}{\text{change in reverse current}}$$

Problem :

A PN junction diode has a reverse saturation current of 30 μA at a temperature of 125°C. At the same temperature find the dynamic resistance for 0.2 V bias in forward and reverse direction.

Solution : Given data

$$I_0 = 30\,\mu A = 30 \times 10^{-6}\,A$$

$$T = 125^\circ C = 125 + 273 = 398^\circ K$$

$$V = 0.2\,V$$

For Ge, $\eta = 1$, $V_T = \frac{T}{11600} = \frac{398}{11600} = 0.0343\,V$

we have $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

neglecting '1' we get

$$I = I_0 \, e^{V/\eta V_T}$$

differentiating w.r.t voltage (V)

$$\frac{dI}{dV} = \frac{I_0 \, e^{V/\eta V_T}}{\eta V_T}$$

$$\frac{dI}{dV} = \frac{I_0}{V_T} e^{V/V_T} \quad \left[\because \eta = 1 \right]$$

$$\frac{1}{r_f} = \frac{dI}{dV} = \frac{I_0}{V_T} e^{V/V_T} \quad \left[\text{sub all the values} \right]$$

we get $\therefore r_f = 3.36 \, \Omega$

Illy $\frac{1}{r_r} = \frac{dI}{dV} = \frac{I_0}{V_T} e^{-V/V_T}$

$\therefore r_r =$

Problem:

calculate the dynamic forward and reverse resistance of PN junction silicon diode when the applied voltage is 0.25 V at $T = 300^\circ K$ with given $I_0 = 2 \mu A$.

Solution: Given data

$I_0 = 2 \mu A$

$V = 0.25 \, V$

For Si, $\eta = 2$

At $T = 300^\circ K$

$V_T = 26 \, mV$

we have $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

Neglecting '1' we get $I = I_0 \, e^{V/\eta V_T}$

$$\frac{dI}{dV} = \frac{I_0}{\eta V_T} e^{V/\eta V_T}$$

Forward resistance $r_f = \dfrac{dV}{dI} = \dfrac{\eta V_T}{I_0} e^{V/\eta V_T}$

$$r_f = \frac{2 \times 26 \times 10^{-3}}{2 \times 10^{-6}} e^{0.25/(2 \times 26 \times 10^{-3})}$$

$$r_f = 212.3 \, \Omega$$

For reverse resistance r_r use $V = -0.25\,V$

$$r_r = \frac{\eta V_T}{I_0} e^{-V/\eta V_T}$$ (After substituting all values)

$$r_r = 3.18 \, M\Omega$$

Problem:

The voltage across a silicon diode at room temp of $300^\circ K$ is $0.7V$, when $2mA$ current flows through it. If the voltage increases to $0.75V$, calculate the diode current assuming $V_T = 26\,mV$.

Solution: Given data $V = 0.7\,V$, $\eta = 2$ for Si, $V_T = 26\,mV$, $I = 2mA$.

Now $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$ After substituting all values

we get $I_0 = 2.84 \times 10^{-9}\,A$.

Now New voltage $V' = 0.75\,V$

$\therefore \; I' = I_0 \left(e^{V'/\eta V_T} - 1 \right) \Rightarrow I' = 5.23\,mA$ [After substituting all values]

Ideal versus practical diode :

Ideal diode :

1) The cut-in voltage is zero. Since for an ideal diode there is no barrior potential, thus any small forward bias voltage causes conduction through the device

2) The forward resistance is zero

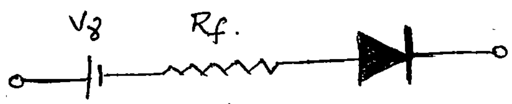
3) The reverse resistance is infinite

4) The diode readily conducts when forward biased and it blocks conduction when reverse biased.

5) The reverse saturation current I_0 is zero

6) The ideal diode acts as a fast acting electronic switch.

Practical Diode :-



1) There is a potential barrior across the junction, and this must be over come before the diode can conduct.

2) The cut-in voltage or threshold voltage is approximately 0.2 V for Ge and 0.6 V for Si.

3) The forward resistance is in the range of few tens of ohms.

4) The reverse resistance is in the range of Mega ohms.

5) In forward bias condition, when the bias voltage is more than the cut-in voltage, the diode conducts.

6) The diode doesn't conduct when reverse biased. However a small reverse saturation current flows across the junction in the range of nano Amps for si diode and micro Amps for Ge diode.

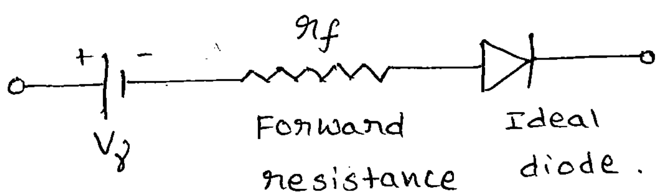
7) The diode also acts as a fast acting Electronic Switch.

<u>Diode Equivalent circuits</u> :-

An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device in a particular operating region.

→ A diode is replaced by a model with a battery equivalent to cut-in voltage of a diode, the forward resistance of a diode in series with an ideal diode.

→ the piece wise Linear equivalent circuit of a diode is shown in figure below.



Assuming $r_f = 0$, since for most applications, it is small to be ignored compared with resistance of other elements of the network.

→ Therefore the simplified equivalent circuit is as shown in figure below.

V_γ Ideal diode.

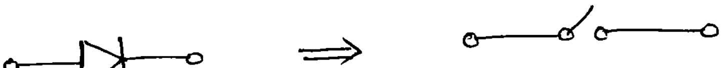
→ Asuming $V_\gamma = 0$ and $r_f = 0$, the equivalent circuit becomes the circuit model for an ideal diode.

Ideal diode

→ In forward biased condition the ideal diode acts as short circuit

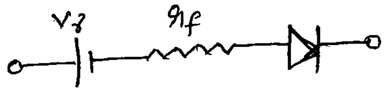
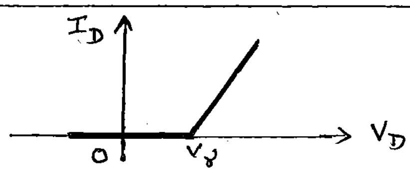
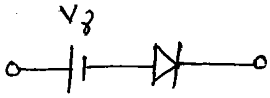
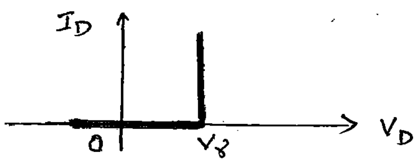
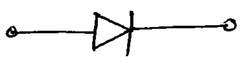
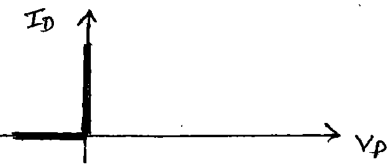
short ckt under forward bias

→ In Reverse bias condition the ideal diode acts as open ckt.



open ckt under Reverse bias.

Diode Equivalent circuits / models / V-I characteristics :-

S.NO	Type	Model	characteristics
1.	Piece wise Linear model	 $V_\gamma \neq 0,\ r_f \neq 0,\ r_r = \infty$	
2.	Simplified Model	 $V_\gamma \neq 0,\ r_f = 0,\ r_r = \infty$	
3.	Ideal Model	 $V_\gamma = 0,\ r_f = 0,\ r_r = \infty$	

PN diode Applications :-

An ideal PN junction diode is a two terminal Polarity sensitive device that has zero resistance when it is forward biased and infinite resistance when reverse biased. Due to this characteristic the diode finds a number of applications as follows.

1) Rectifiers in dc power supplies
2) Switch in digital logic circuits used in Computers.
3) clamping networks used as dc restorer in TV receivers and voltage multipliers.
4) clipping circuits used as wave shaping circuits used in computers, radars, radio and TV receivers
5) Demodulation (detector) circuits.

→ The same PN junction with different doping Concentration finds special applications as follows

1) Detectors (PIN photo diode) in optical Communication circuits.
2) Zener diodes in Voltage Regulators
3) Varactor diodes in tuning sections of radio and TV receivers
4) LED's in digital displays
5) LASER diodes in optical Communication.
6) Tunnel diodes as a relaxation oscillator at Microwave frequencies.

Half wave rectifier converts an a.c voltage in to a pulsating d.c voltage using only one half of the applied a.c voltage. The rectifying diode conducts during one half of the a.c cycle only. fig(a) and fig(b) shows the basic circuit and wave forms of a half wave rectifier.

Operation :

Let V_i be the voltage to the primary of the transformer and given by the equation

$$V_i = V_m \sin \omega t \quad ; \quad V_m >> V_\gamma$$

where V_γ is the cut-in voltage of the diode.

→ During the positive half cycle of the input signal, the anode of the diode becomes more positive with respect to the cathode and hence diode D conducts (Forward bias). For an ideal diode the forward voltage drop is zero. So the whole input voltage will appear across the load resistance (R_L).

→ During negative half cycle of the input signal, the anode of the diode becomes negative with respect to the cathode and hence diode D doesn't conduct. (Reverse bias) For an ideal diode, the impedance offered by the diode is infinity. Hence the diode conducts no current. Hence the voltage drop across R_L is zero.

Harmonic Components of a Half wave Rectifier.

The input sinusoidal voltage ~~of~~ applied at the input of the transformer is given by

$$V_i = V_m \sin wt \longrightarrow (1)$$

The diode current or load current is given by

$$i(t) = \begin{cases} I_m \sin wt & \text{for } 0 < wt < \pi \\ 0 & \text{for } \pi < wt < 2\pi \end{cases} \longrightarrow (2)$$

Maximum or peak current through the circuit

$$I_m = \frac{V_m}{R_f + R_L} \longrightarrow (3)$$

where R_f = Forward resistance of the diode

R_L = Load resistance.

1) Average current (or) DC current :-

$$I_{avg} = I_{d.c} = \frac{1}{T} \int_0^T i(t)\, dt$$

$$= \frac{1}{2\pi} \int_0^{2\pi} i(t)\, dt \qquad [\because T = 2\pi]$$

$$\Rightarrow I_{dc} = \frac{1}{2\pi} \left\{ \int_0^{\pi} I_m \sin wt \, d(wt) + \int_{\pi}^{2\pi} 0 \cdot d(wt) \right\}$$

$$I_{dc} = \frac{I_m}{2\pi} \left[-\cos wt \right]_0^{\pi}$$

$$I_{dc} = \frac{I_m}{2\pi} \left\{ -[(-1) - 1] \right\} = \frac{I_m}{\pi} = \frac{V_m}{\pi(R_f + R_L)}$$

Similarly the DC output voltage or Average voltage is given by

$$V_{d.c} = I_{d.c} \cdot R_L = \frac{I_m}{\pi} R_L = \frac{V_m}{\pi(R_f + R_L)} \cdot R_L$$

$$\therefore \boxed{V_{dc} = \frac{V_m}{\pi\left(1 + \frac{R_f}{R_L}\right)}}$$

(2) <u>RMS</u> <u>Current</u> :

$$I_{rms} = \sqrt{\frac{1}{T} \int_0^T i^2(t)\, d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i^2(t)\, d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \cdot d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi} \int_0^{\pi} \left(\frac{1 - \cos 2\omega t}{2} \right) d\omega t}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{4\pi} \int_0^{\pi} d(\omega t) - \frac{I_m^2}{4\pi} \int_0^{\pi} \cancel{\frac{\cos 2\omega t}{2\omega}}^{\,0} d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{4\pi} \times \pi} = \frac{I_m}{2} = \frac{V_m}{2(R_f + R_L)}$$

Similarly Rms voltage across the load is given by

$$V_{rms} = I_{rms} \cdot R_L = \frac{I_m}{2} R_L = \frac{V_m}{2(R_f + R_L)} \cdot R_L$$

$$\boxed{V_{rms} = \frac{V_m}{2\left(1 + \frac{R_f}{R_L}\right)}} \Rightarrow \text{If } R_f << R_L \text{ then } \boxed{V_{rms} = \frac{V_m}{2}}$$

(3) Rectifier efficiency (η)

Rectifier efficiency is defined as ratio of dc output power (P_{dc}) to A.c input power (P_{ac}).

Here $P_{dc} = I_{d.c}^2 R_L = \dfrac{I_m^2 R_L}{\pi^2}$

$$P_{ac} = P_d + P_L$$

P_d = Power dissipated across diode

P_L = power dissipated across load

$$P_d = I_{rms}^2 R_f = \frac{I_m^2}{4} R_f$$

$$P_L = I_{rms}^2 R_L = \frac{I_m^2}{4} R_L$$

$$\therefore \quad P_{ac} = \frac{I_m^2}{4}(R_f + R_L)$$

$$\therefore \quad \eta = \frac{P_{dc}}{P_{ac}} = \frac{\dfrac{I_m^2}{\pi^2} R_L}{\dfrac{I_m^2}{4}(R_f + R_L)}$$

$$\eta = \frac{0.406}{\left(1 + \dfrac{R_f}{R_L}\right)}$$

$$\% \eta = \frac{0.406}{1 + \dfrac{R_f}{R_L}} \times 100 = \frac{40.6}{1 + \dfrac{R_f}{R_L}}$$

If $R_f << R_L$ then $\% \eta = 40.6\%$

The maximum efficiency of a half wave rectifier is 40.6 %

4) Ripple factor (Γ) :-

The ratio of rms value of a.c component to the dc component in the output is known as ripple factor (Γ).

$$\text{Ripple factor} = \frac{\text{rms value of a.c component}}{\text{d.c value of component}}$$

$$\Gamma = \frac{V_{r,rms}}{V_{dc}}$$

$$V_{r,rms} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\therefore \Gamma = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}} = \sqrt{\frac{V_{rms}^2 - V_{dc}^2}{V_{dc}^2}}$$

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

$$\Gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\Gamma = \sqrt{\frac{\left(\frac{I_m}{2}\right)^2}{\left(\frac{I_m}{\pi}\right)^2} - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

5) Transformer utilisation factor :-

In the design of any power supply, the rating of the transformer should be determined. This can be done with a knowledge of the d.c power delivered to the load and the type of rectifying circuit used

$$TUF = \frac{\text{dc power delivered to the load}}{\text{ac rating of the transformer secondary}}$$

$$TUF = \frac{P_{dc}}{P_{ac\ rated}}$$

$$P_{dc} = I_{dc}^2 R_L \Rightarrow \left(\frac{I_m}{\pi}\right)^2 \times R_L .$$

$$P_{ac\ rated} = \text{rated voltage of transformer secondary} \times I_{rms}$$

$$P_{ac\ rated} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{I_m^2 (R_f + R_L)}{2\sqrt{2}}$$

$$\therefore \quad TUF = \frac{\frac{I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2\sqrt{2}} (R_f + R_L)} = \frac{0.287\ R_L}{(R_f + R_L)}$$

$$\therefore \quad TUF = \frac{0.287}{\left(1 + \frac{R_f}{R_L}\right)}$$

As $R_f << R_L$, $TUF = 0.287$.

⑥ **Regulation :-**

It is defined as the variation in dc voltage with change in dc load current.

It is also defined as

$$\text{Percentage Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

Here V_{NL} = No load voltage

V_{FL} = Full load voltage.

Ideally Full load voltage is equal to No load voltage and hence the percentage regulation of an ideal device is zero.

(7) ~~It is defined as the~~ Peak inverse voltage (PIV):-

It is defined as a maximum reverse voltage that a diode can withstand without destroying the junction.

The Peak inverse voltage across a diode is the peak of the Negative half cycle

For half wave rectifier PIV is V_m.

Form factor :-

$$\text{Form Factor} = \frac{\text{Rms value}}{\text{Average value}} = \frac{\frac{I_m}{2}}{\frac{I_m}{\pi}} = \frac{\pi}{2} = 1.57$$

Peak Factor :-

$$\text{Peak Factor} = \frac{\text{Peak Value}}{\text{rms Value}} = \frac{I_m}{\frac{I_m}{2}} = 2$$

Problem :

A Half wave rectifier, having a resistive load of 1000Ω, rectifies an alternating voltage of 325 V peak value and the diode has forward resistance of 100Ω. calculate a) peak, average and rms value of current

b) d.c power output

c) a.c input power and

d) Efficiency of the rectifier

Solution : Given data

$R_L = 1000\Omega$, $V_m = 325$ V, $r_f = 100\Omega$

a) Peak value of current $= I_m = \dfrac{V_m}{r_f + R_L}$

$$\therefore I_m = \frac{325}{100 + 1000} = 295.45 \text{ mA}$$

Average current $I_{d.c} = \dfrac{I_m}{\pi} = \dfrac{295.45 \text{ mA}}{3.14}$

$$\therefore I_{dc} = 94.046 \text{ mA}$$

RMS value of current $I_{rms} = \dfrac{I_m}{2} = \dfrac{295.45 \text{ m}}{2}$

$$\therefore I_{r.m.s} = 147.725 \text{ mA}$$

b) d.c power output, $P_{d.c} = I_{d.c}^2 \times R_L$

$$P_{d.c} = (94.046)^2 \times 1000 = 8.845 \text{ W}$$

c) A.c input power $P_{a.c} = (I_{r.m.s})^2 \times (r_f + R_L) = 24$ W

d) Efficiency of rectification $\eta = \dfrac{P_{d.c}}{P_{a.c}} = \dfrac{8.845}{24} = 36.85\%$

Problem : A half wave rectifier is used to supply 24 V dc to a resistive load of 500 Ω and a diode has forward resistance of 50 Ω. calculate the maximum value of the a.c voltage required at the input.

Solution : Given data

$V_{d.c} = 24\ V$, $R_L = 50\ \Omega$.

Average value of load current

$$I_{d.c} = \frac{V_{d.c}}{R_L} = \frac{24}{500} = 48\ mA$$

$$I_{d.c} = \frac{I_m}{\pi} \Rightarrow I_m = I_{d.c} \times \pi$$

Maximum value of load cuuent $I_m = I_{d.c} \times \pi$

$$I_m = 48 \times 10^{-3} \times 3.14 = 150.8\ mA$$

Therefore maximum a.c voltage required at the input $V_m = I_m (r_f + R_L) = 82.94\ V$

Problem :- An a.c supply of 230 V is applied to a half wave rectifier circuit through transformer of turns ratio 5:1. Assume the diode is an ideal one. The load resistance is 300 Ω. Find

a) d.c output voltage b) PIV c) maximum and d) average values of power delivered to the load.

Solution : Given data

$V_1 = 230\ V$, $N_1 : N_2 = 5:1$, $R_L = 300\ \Omega$

a) Transformer secondary voltage

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$V_2 = V_1 \times \frac{N_2}{N_1} = \frac{230 \times 1}{5} = 46\ V$$

$$V_2 = V_{r.m.s} = 46\ V$$

maximum value of secondary voltage is V_m

$$V_{r.m.s} = \frac{V_m}{\sqrt{2}} \Rightarrow V_m = 46 \times \sqrt{2} = 65\ V$$

$\therefore$ d.c output voltage $V_{d.c} = \frac{V_m}{\pi} = 20.7\ V$

b) PIV of a diode is $V_m \Rightarrow V_m = 65\ V$

c) maximum value of load current

$$I_m = \frac{V_m}{R_L} = \frac{65}{300} = 0.217\ A$$

maximum value of power delivered to the load

$$P_m = I_m^2 \times R_L = (0.217)^2 \times 300 = 14.1\ W$$

d) The average value of load current

$$I_{d.c} = \frac{V_{d.c}}{R_L} = \frac{20.7}{300} = 0.069\ A$$

average value of power delivered to the Load

$$P_{d.c} = I_{d.c}^2 \times R_L = (0.069)^2 \times 300$$

$$P_{d.c} = 1.43\ W.$$

Full wave rectifier :

It converts an a.c voltage into a pulsating d.c voltage using both half cycles of the applied a.c voltage. It uses two diodes of which one conducts during one half cycle while the other diode conducts during the other half cycle of the applied a.c voltage. Figure shows the basic circuit and waveforms of full-wave rectifier.

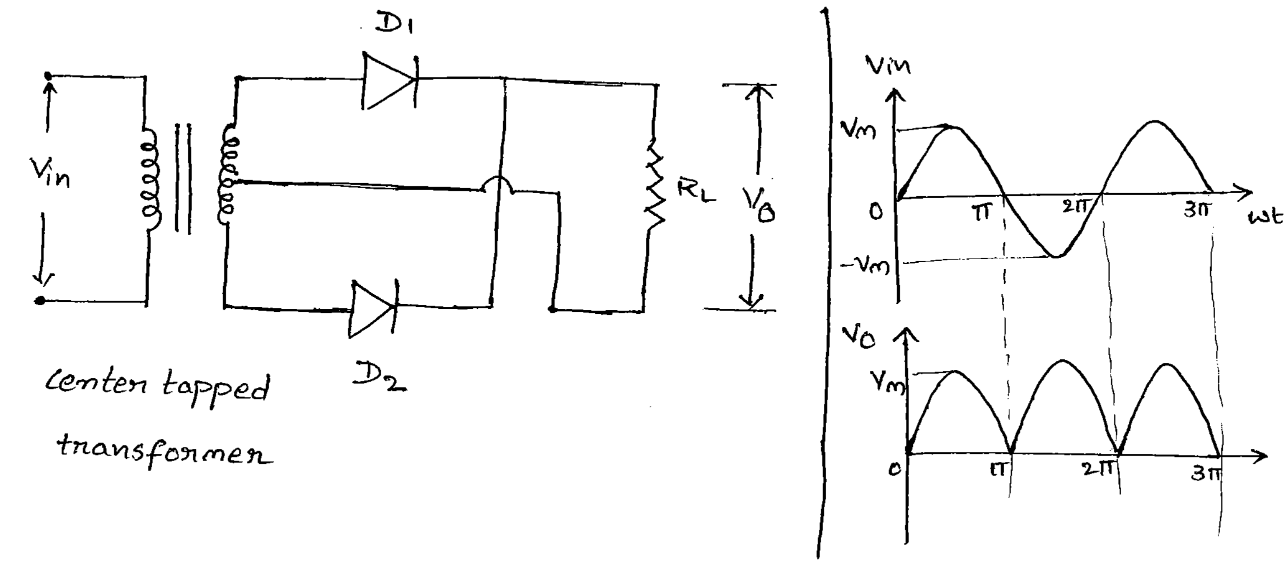
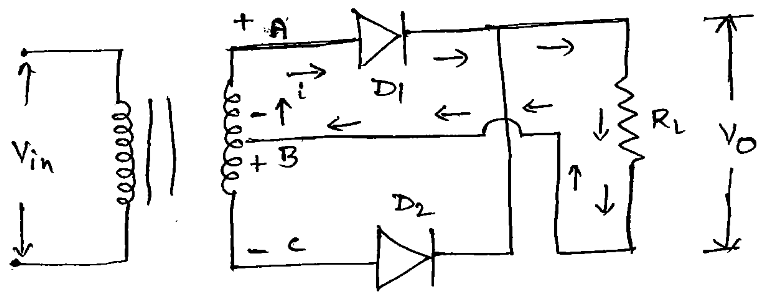


fig: Full wave rectifier

operation :

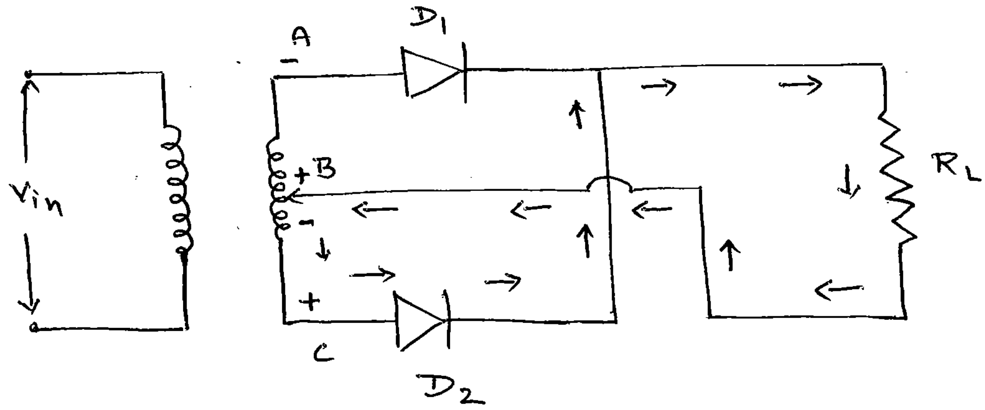
During positive half cycle



During the positive half cycle of ac input the terminal A is more positive than terminal C so diode D_1 becomes forward biased and D_2 becomes reverse biased. Therefore diode D_1 conducts while diode D_2 doesn't conduct. The conventional current flow is shown by the path below.

$$A \rightarrow D_1 \rightarrow R_L \rightarrow B \rightarrow A.$$

During Negative Half cycle :-



During the Negative half cycle, ~~of~~ the input terminal C is more positive than A. So diode D_1 becomes reverse biased and D_2 becomes forward biased. Therefore diode D_2 conducts while D_1 doesn't conduct. The path shown below gives the conventional current flow during Negative half cycle.

$$C \rightarrow D_2 \rightarrow R_L \rightarrow B \rightarrow C$$

Harmonic components in a fullwave rectifier circuit:

1) Average current (or) dc current :-

$$I_{dc} = \frac{1}{T}\int_0^T i(t)\,dt$$

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\omega t \; d(\omega t)$$

$$I_{dc} = \frac{I_m}{\pi}\Big[-\cos\omega t\Big]_0^{\pi} = -\frac{I_m}{\pi}\left[-1-1\right]$$

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2V_m}{\pi(R_f+R_L)} \quad \left[\because I_m = \frac{V_m}{R_f+R_L}\right]$$

Similarly $V_{dc} = I_{dc} \times R_L = \frac{2V_m}{\pi(R_f+R_L)} \cdot R_L$

$$\therefore V_{dc} = \frac{2V_m}{\pi\left(1+\frac{R_f}{R_L}\right)}$$

As $R_f << R_L \Rightarrow V_{dc} = \frac{2V_m}{\pi}$.

2) RMS current :

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt}$$

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \; d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{\pi}\int_0^{\pi}\left[\frac{1-\cos 2\omega t}{2}\right] d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi}\times\pi} = \frac{I_m}{\sqrt{2}} = \frac{V_m}{\sqrt{2}\,(R_f+R_L)}$$

Similarly ~~Average~~ voltage

$$V_{rms} = I_{rms} \times R_L$$

$$V_{rms} = \frac{I_m}{\sqrt{2}} R_L = \frac{V_m \; R_L}{\sqrt{2}\,(R_f + R_L)}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}\left(1 + \frac{R_f}{R_L}\right)}$$

As $R_f << R_L \Rightarrow V_{rms} = \frac{V_m}{\sqrt{2}}$

3) <u>Rectifier</u> <u>Efficiency</u> (η) :-

$$\eta = \frac{\text{dc output power}}{\text{AC input power}} = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L$$

$$P_{ac} = I_{rms}^2 (R_f + R_L)$$

$$P_{dc} = I_{dc}^2 \cdot R_L$$

$$P_{dc} = \left(\frac{2 I_m}{\pi}\right)^2 \times R_L = \frac{4 I_m^2}{\pi^2} \times R_L$$

$$P_{ac} = I_{rms}^2 (R_f + R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L)$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4 I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2} \times (R_f + R_L)}$$

$$\eta = \frac{8}{\pi^2} \times \frac{R_L}{R_f + R_L} = \frac{0.812}{\left(1 + \frac{R_f}{R_L}\right)}$$

As $R_f << R_L$, $\eta = 0.812$

% Efficiency = % η = 81.2 %

$81.2\% = 2 \times (40.6\%)$

Full wave rectifier Efficiency = 2 × (Half wave rectifier Efficiency)

∴ The maximum efficiency of a full wave rectifier is twice the maximum efficiency of a Half wave rectifier.

4) Ripple factor (Γ) :-

$$\Gamma = \frac{\text{rms value of a.c component}}{\text{dc value of component}}$$

$$\Gamma = \frac{V_{r,rms}}{V_{dc}}$$

$$\Gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$\Gamma = \sqrt{\frac{\left(\frac{I_m}{\sqrt{2}}\right)^2}{\left(\frac{2 I_m}{\pi}\right)^2} - 1}$$

$$\Gamma = 0.48.$$

5) Transformer utilisation factor (TUF) :-

In a full wave rectifier, the secondary current flows through each half separately in every half cycle. while the primary of transformer carries current continuosly. Hence TUF is calculated for primary and secondary windings separately and the average TUF is determined.

$$\therefore \quad TUF = \frac{(TUF)_{primary} + (TUF)_{secondary}}{2}$$

$(TUF)_{primary}$:-

The primary of the transformer is feeding two half wave rectifiers separately. These two half wave rectifiers work independently of each other but feed a common load.

$$(TUF)_{primary} = 2 \times TUF \text{ of } HWR = 2 \times 0.287$$

$$\therefore \quad (TUF)_{primary} = 0.574$$

$(TUF)_{secondary}$:-

$$(TUF)_{secondary} = \frac{\text{dc power delivered to the load}}{\text{a.c rating of Transformer secondary}}$$

$$(TUF)_{secondary} = \frac{P_{dc}}{P_{ac\,rated}}$$

$$P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2 I_m}{\pi}\right)^2 \times R_L = \frac{4 I_m^2}{\pi^2} R_L$$

$$P_{ac\,rated} = \frac{\text{rated voltage of}}{\text{transformer secondary}} \times I_{rms}$$

$$P_{ac\,rated} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} = \frac{I_m (R_f + R_L)}{\sqrt{2}\,(\cancel{R_f + R_L})} \times \frac{I_m}{\sqrt{2}}$$

$$P_{ac\,rated} = \frac{I_m^2}{2(\cancel{R_f + R_L})} \times (R_f + R_L)$$

$$(TUF)_{secondary} = \frac{\frac{4 I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2(\cancel{R_f + R_L})} (R_f + R_L)} = \frac{8}{\pi^2 \left(1 + \frac{R_f}{R_L}\right)}$$

As $R_f << R_L$, $(TUF)_{secondary} = 0.812$

$$\therefore \quad TUF = \frac{(TUF)_p + (TUF)_s}{2} = \frac{0.574 + 0.812}{2}$$

$$\boxed{TUF = 0.693}$$

6) <u>Peak inverse voltage (PIV)</u> :-

Peak inverse voltage can be defined as the maximum voltage that a diode can withstand under reverse biased condition.

In this case peak inverse voltage is calculated as follows. during positive half cycle, D_1 is conducting and D_2 is off. The maximum voltage at the lower part of the transformer is V_m and the voltage drop across the R_L due to diode D_1 conducting is V_m. Hence the total voltage across diode D_2 is ($\cancel{V_m + V_m}$) $2V_m$ $(V_m + V_m)$

Therefore $PIV = 2V_m$

7) <u>Voltage Regulation</u> :- It is defined as variation in dc voltage with change in dc load current.

$$\text{Percentage Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100.$$

where V_{NL} = No load voltage

V_{FL} = Full load voltage.

8) Form factor $= \dfrac{\text{Rms value}}{\text{Average value}} = \dfrac{I_{rms}}{I_{dc}} = \dfrac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}} = 1.11$

9) Peak factor $= \dfrac{\text{Peak value}}{\text{Rms value}} = \dfrac{I_m}{I_{rms}} = \dfrac{I_m}{I_m/\sqrt{2}} = \sqrt{2}$

Problem:

A 230 V, 60 Hz voltage is applied to the primary of a 5:1 step down, center tap transformer used in a full wave rectifier having a load of 900Ω. If the diode resistance and the secondary coil resistance together has a resistance of 100Ω. determine

a) dc voltage across the load b) dc current flowing through the load c) dc power delivered to the load d) PIV across each diode and e) ripple voltage and its frequency.

Solution: Given data

Primary voltage $V_1 = 230V$, $N_1 : N_2 = 5:1$

$R_L = 900\Omega$, $r_s + r_f = 100\Omega$.

secondary voltage V_2

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow \frac{230}{V_2} = \frac{5}{1} \Rightarrow V_2 = 46\ V$$

Voltage from Center tapping to one end $= 23\ V$

$$V_m = \sqrt{2} \times 23\ V.$$

$$V_m = 23\sqrt{2}\ V$$

a) d.c voltage across the load $V_{d.c} = \frac{2V_m}{\pi}$

$$V_{d.c} = \frac{2 \times 23 \times \sqrt{2}}{\pi} = 20.7\ V$$

b) dc current flowing through the load

$$I_{dc} = \frac{V_{d.c}}{r_s + r_f + R_L}$$

$$I_{d.c} = \frac{20.7}{100+900} = 20.7 \text{ mA}.$$

c) d.c power delivered to the load

$$P_{d.c} = (I_{d.c})^2 \times R_L = (20.7 \times 10^{-3})^2 \times 900 = 0.386 \text{ W}$$

d) PIV across each diode $= 2V_m = 2 \times 23 \times \sqrt{2} = 65 \text{ V}$

e) ripple voltage $V_{r,rms} = \sqrt{(V_{rms})^2 - (V_{d.c})^2}$

$$V_{r.m.s} = \frac{V_m}{\sqrt{2}} = \frac{23\sqrt{2}}{\sqrt{2}} = 23$$

$$\text{Ripple voltage} = \sqrt{(23)^2 - (20.7)^2} = 10.05 \text{ V}$$

frequency of ripple voltage $2f_m = 2 \times 60 = 120 \text{ Hz}$.

Problem:

A full wave rectifier delivers 50 W to a load of 200 Ω. If the ripple factor is 1%. calculate the a.c ripple voltage across the load.

Solution: Given data $P_{d.c} = 50 \text{ W}$, $R_L = 200\,\Omega$

Ripple factor $(\Gamma) = 1\% = \frac{1}{100} = 0.01$

we know that $P_{d.c} = \frac{V_{d.c}^2}{R_L} \Rightarrow V_{d.c}^2 = P_{d.c} \times R_L$

therefore $V_{dc} = \sqrt{P_{d.c} \times R_L} = \sqrt{50 \times 200} = 100 \text{ V}$

$$\text{Ripple factor } \Gamma = \frac{V_{r,rms}}{V_{d.c}} = \frac{V_{ac}}{V_{d.c}}$$

$$\Rightarrow 0.01 = \frac{V_{a.c}}{100} \Rightarrow V_{ac} = 1 \text{ V}$$

a.c ripple voltage across the load $= 1\text{ V}$.

Full wave Bridge Rectifier :-

The need for a center tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D_1, D_2, D_3 and D_4 connected to form bridge as shown in figure below.

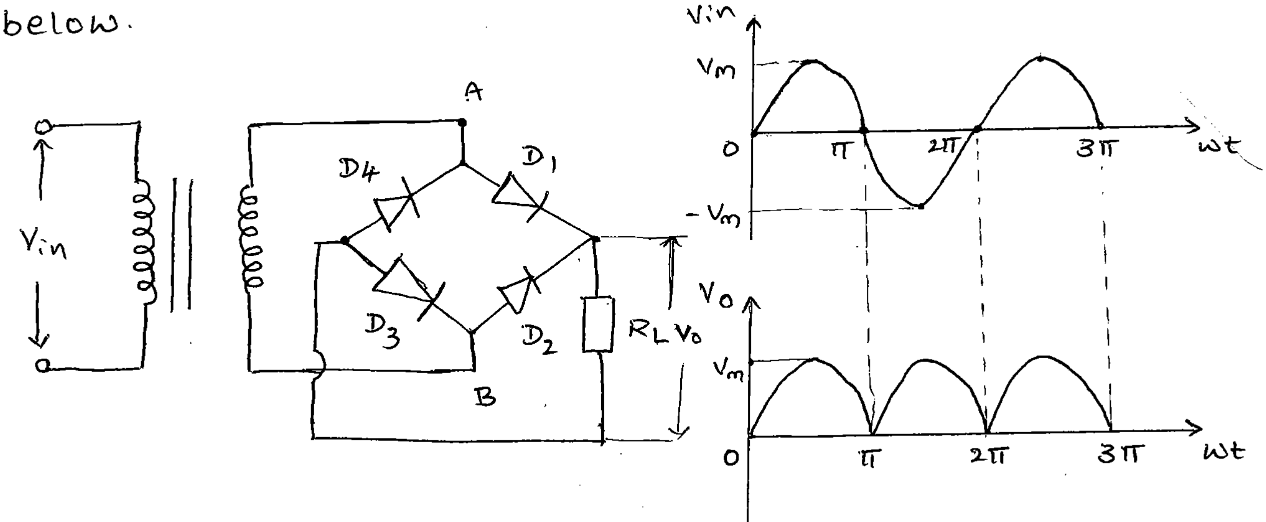


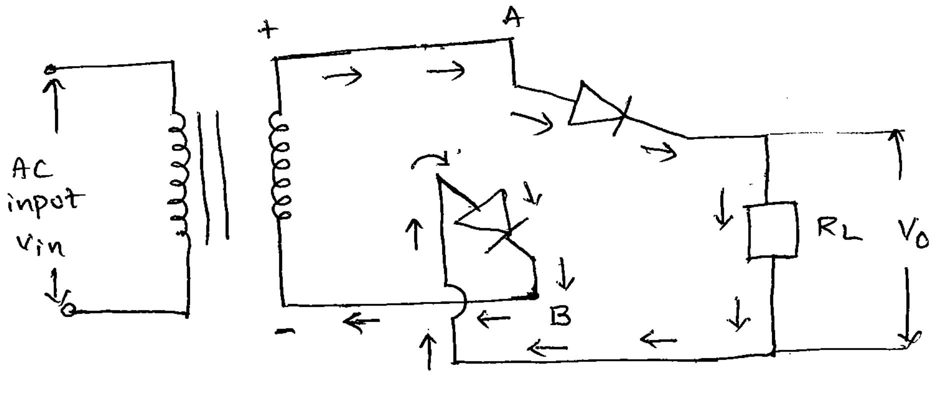
fig: Full wave bridge rectifier and wave forms

operation :-

During positive half cycle :

During positive half cycle the point A of the secondary winding becomes positive and point B becomes negative.

This makes diodes D_1 and D_3 forward biased while D_2 and D_4 are reverse biased.

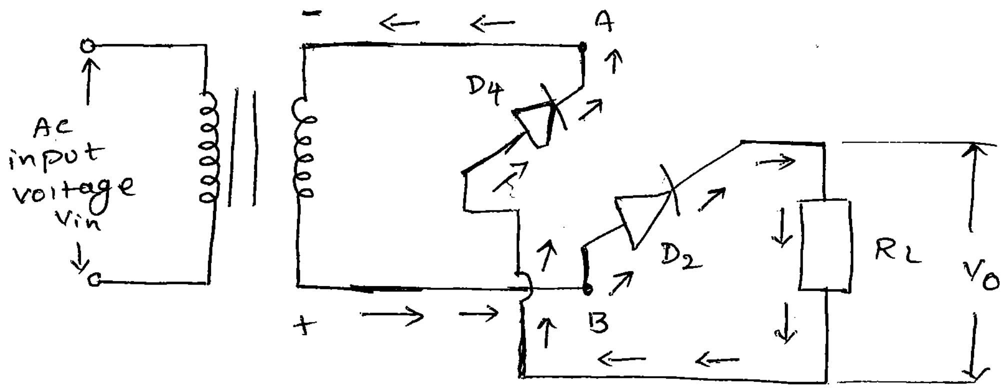


Therefore only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L as shown in figure above.

The conventional current flow path ~~is~~ of full wave bridge rectifier is shown below

$A \rightarrow D_1 \rightarrow R_L \rightarrow D_3 \rightarrow B$

During Negative half cycle :-



During the Negative half cycle of Secondary voltage, the point A becomes Negative and point B becomes positive.

This makes diodes D_2 and D_4 becomes forward biased while diodes D_1 and D_3 becomes reverse biased. Therefore only diodes D_2 and D_4 conduct. These two diodes will be in series through the Load R_L as shown in figure above.

The conventional current flow of full wave bridge rectifier during Negative half cycle is shown below. $B \rightarrow D_2 \rightarrow R_L \rightarrow D_4 \rightarrow A$.

→ In both the case the current flowing through the resistor R_L is in same direction, thus it is called uni directional current.

→ The wave form of the load current is essentially the same as in the case of full wave rectifier. The ripple frequency of the output is twice that of the fundamental frequency.

Harmonic components of bridge rectifier :-

The average values of output voltage and load current for bridge rectifier are the same as for a center tapped full wave rectifier. Hence

$$V_{d.c} = \frac{2V_m}{\pi} \qquad V_{rms} = \frac{V_m}{\sqrt{2}}$$

$$I_{dc} = \frac{2I_m}{\pi} \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\text{Ripple factor}(\Gamma) = 0.48$$

$$\text{Rectifier Efficiency} = 81.2\%$$

$$\text{PIV across each diode} = V_m$$

$$\text{Ripple frequency} = f_m$$

Note : The derivations for bridge rectifiers are same as that of centre tapped FWR, except transformer utilisation factor (TUF)

In this case centre tapped transformer is not required hence the secondary utilisation factor itself defines the TUF

$$TUF = \frac{P_{dc}}{P_{ac\ rated}}$$

$$P_{dc} = (I_{d.c})^2 \times R_L = \left(\frac{2 I_m}{\pi}\right)^2 \times R_L$$

$$P_{ac\ rated} = \text{rated voltage of a transformer} \times I_{rms} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}$$

$$P_{ac\ rated} = \frac{V_m I_m}{2} = \frac{I_m^2}{2R_L} \quad \left[\because V_m = \frac{I_m}{R_L}\right]$$

$$\therefore \boxed{TUF = 0.812}$$

→ Form factor and peak factor are same as that of Full wave rectifier.

Form factor = 1.11

Peak factor = $\sqrt{2}$

<u>Problem</u>: A 230V, 50 Hz voltage is applied to the primary of a 4:1 step down transformer used in a bridge rectifier having a load resistance of 600 Ω. Assuming the diodes to be ideal, determine (a) dc output voltage (b) dc power delivered to the load (c) PIV (d) output frequency.

<u>Solution</u>: Given data primary voltage $V_1 = 230V$

$N_1 : N_2 = 4:1$, $R_L = 600\Omega$

Secondary voltage V_2 ?

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} \Rightarrow V_2 = V_1 \times \frac{N_2}{N_1} = 230 \times \frac{1}{4}$$

Secondary Voltage $V_2 = 57.5\ V$

$$V_m = \sqrt{2} \times \text{secondary voltage} = 81.3\ V$$

a) $V_{d.c} = \frac{2V_m}{\pi} = 52\ V$

b) $P_{d.c} = \frac{V_{d.c}^2}{R_L} = \frac{52^2}{1000} = 2.704\ W$

c) PIV across each diode $V_m = 81.3\ V$

d) output frequency $= 2f_m = 2 \times 50 = 100\ Hz$

Comparison of Rectifiers :-

S.NO	Parameter	Half wave	Full wave	Bridge
1	NO of diodes	1	2	4
2.	Maximum efficiency	40.6 %	81.2 %	81.2 %
3.	$V_{d.c}$ (no load)	V_m/π	$2V_m/\pi$	$2V_m/\pi$
4.	Average current $I_{d.c}$	I_m/π	$2I_m/\pi$	$2I_m/\pi$
5.	Ripple factor	1.21	0.48	0.48
6.	Peak inverse voltage	V_m	$2V_m$	$2V_m$
7.	output frequency	f_m	$2f_m$	$2f_m$
8	TUF	0.287	0.693	0.812
9	Form factor	1.57	1.11	1.11
10	Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

Introduction to Filters :

The output of the rectifier circuit is a pulsating dc, it contains both ac and dc components. The presence of ac components is undesirable feature, hence it has to be removed from the rectified output by using a suitable circuit. Such a circuit is known as a filter.

A filter may be defined as the circuit which removes the unwanted ac components of the rectifier output and allows only dc components to reach the load.

A filter circuit consists of a passive circuit elements, such as inductors, capacitors and their combinations.

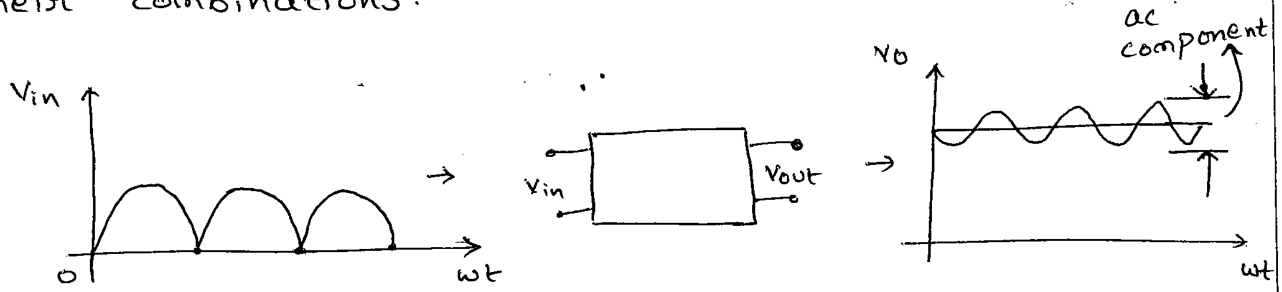


figure shows the concept of a filter, where the full wave rectified output voltage is applied at its input. The output of a filter is not exactly a constant d.c. level. But it also contains a small amount of a.c component. Some important filters are

1) Induction filter 2) capacitor filter
3) LC or L-section filter 4) CLC or π-type filter

Inductor Filter

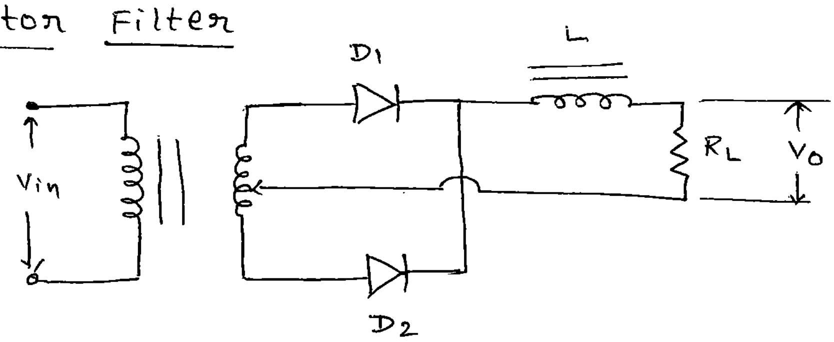


fig: Full wave rectifier with Inductor filter.

Figure shows the fullwave rectifier with inductor filter. when the output of the FWR passes through an inductor, it blocks the ac component and allows only the dc component to reach the load.

The ripple factor of the inductor filter is given by

$$\Gamma = \frac{R_L}{3\sqrt{2}\,\omega L}$$

It shows that the ripple factor will decrease when L is increased. and R_L is decreased. The inductor filter is more effective only when the load current is high (small R_L). The larger value of the inductor can reduce the ripple and at the same time the output d.c voltage will be lowered as a inductor has a higher d.c. resistance.

The operation of the inductor filter depends on its well known fundamental property to oppose any change of current passing through it.

Analysis of Inductor filter :

To analyse this filter for a full-wave, the fourier series can be written as

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{\pi}\left[\frac{1}{3}\cos 2\omega t + \frac{1}{15}\cos 4\omega t + \frac{1}{35}\cos 6\omega t + \text{------}\right] \longrightarrow (1)$$

Assuming the third and higher terms contribute little output, the output voltage is

$$V_o = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t. \longrightarrow (2)$$

The diode, choke (L) and transformer resistances can be neglected since they are very small as compared with R_L. Therefore

The d.c component of current $I_m = \frac{V_m}{R_L}$

The impedance of series combination of L and R_L at 2ω is (for second harmonic)

$$Z = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2}.$$

Therefore ~~for~~ the a.c component of current

$$I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}} \qquad \left(\because I_m = \frac{V_m}{Z}\right)$$

Therefore the resulting current is given by from Eq (2)

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi} \frac{\cos(2\omega t - \phi)}{\sqrt{R_L^2 + 4\omega^2 L^2}} \longrightarrow (3)$$

where $\phi = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)$

where ϕ is the angle by which the load current lags behind the voltage, From eq (3)

$$I_{dc} = \frac{2V_m}{\pi R_L}, \quad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$I_{rms} = \frac{4V_m}{3\pi\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}}$$

The ripple factor which can be defined as the ratio of rms value of the ripple to the d.c value of the wave.

$$\text{Ripple factor } \Gamma = \frac{I_{rms}}{I_{dc}} = \frac{\frac{4V_m}{3\pi\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}}}{\frac{2V_m}{\pi R_L}}$$

$$\Gamma = \frac{2}{3\sqrt{2}} \frac{1}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

If $\frac{4\omega^2 L^2}{R_L^2} >> 1$, then a simplified expression for Γ is

$$\Gamma = \frac{2}{3\sqrt{2}} \frac{1}{\sqrt{\frac{4\omega^2 L^2}{R_L^2}}} = \frac{2}{3\sqrt{2}} \times \frac{R_L}{2\omega L}$$

$$\boxed{\Gamma = \frac{R_L}{3\sqrt{2}\,\omega L}}$$

This expression clearly shows that reduced ripple will occur for larger values of L. But it also shows that the ripple will increase as the load increased to Infinite value

Hence this filter ~~is~~ ~~suitable~~ ~~for~~ ~~only~~ should only be used where R_L is consistently small.

Problem: calculate the value of inductance to use in the inductor filter connected to a full-wave rectifier operating at 60Hz to provide a d.c output with 4% ripple for a 100Ω load.

Solution: Given data

$$f = 60\,Hz \quad , \quad R_L = 100\,\Omega$$

$$\text{Ripple factor } \Gamma = 4\% = 0.04$$

we know that ripple factor of inductor filter is

$$\Gamma = \frac{R_L}{3\sqrt{2}\,\omega L} \quad , \quad \omega = 2\pi f$$

$$0.04 = \frac{100}{3\sqrt{2} \times (2 \times \pi \times 60) \times L}$$

$$\Rightarrow \quad L = 1.5625\ Hz.$$

Capacitor filter :- An inexpensive filter for light loads is found in the capacitor filter which is connected directly across the load as shown in figure below.

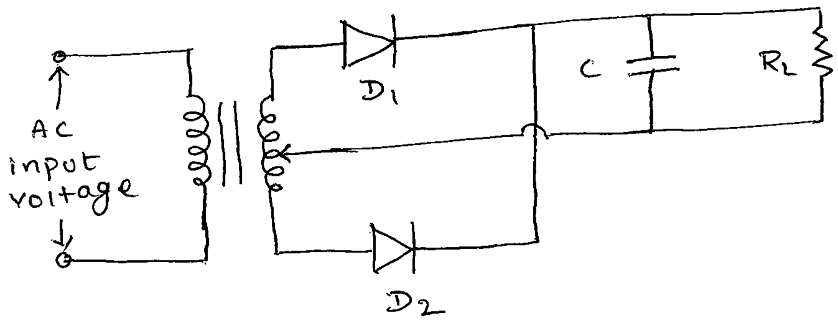
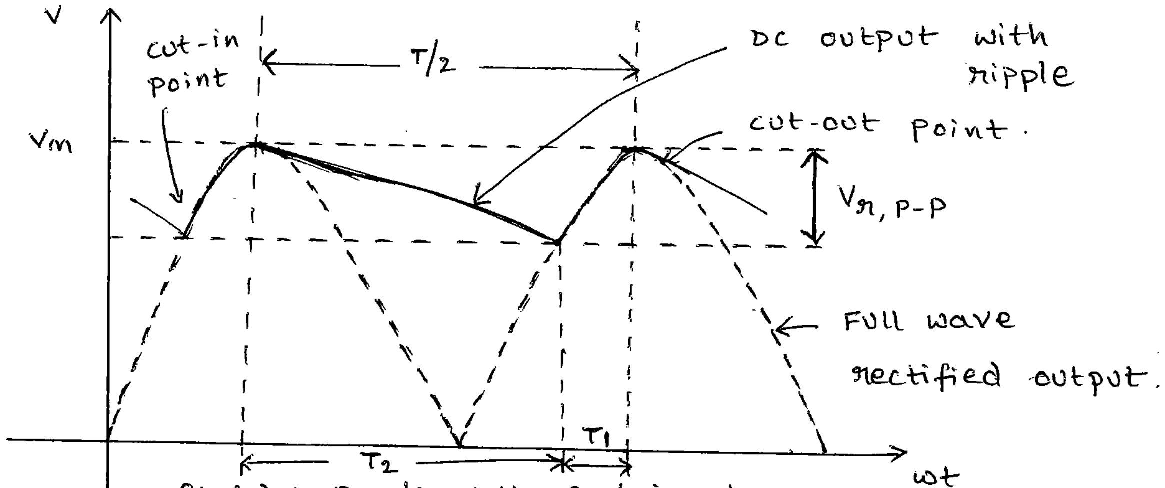


fig: Full wave rectifier with capacitor filter

The property of a capacitor is that it allows a.c component and blocks the dc component. The operation of a capacitor filter is to short the ripple to ground but leave the dc to appear at the output when it is connected across a pulsating d.c voltage.



fig(b) : Ripple voltage triangular waveform

During the positive half cycle, the capacitor charges upto the peak value of the transformer secondary voltage, Vm and will try to maintain this value as the full wave input drops to zero.

The capacitor will discharge through R_L slowly until the transformer secondary voltage again increases to a value greater than the capacitor voltage. The diode conducts for a period which depends on the capacitor voltage. The diode will conduct when the transformer secondary voltage becomes more than the diode voltage. This is called the cut-in voltage.

The diode stops conducting when the transformer voltage becomes less than the diode voltage. This is called cut-out voltage.

In figure (b) with slight approximation, the ripple voltage waveform can be assumed as triangular.

From the cut-in point to cut-out point, whatever ~~the~~ charge, the capacitor acquires, is equal to the charge, the capacitor has lost during the period of non-conduction. ie from cut out point to the next cut-in point.

The charge it has acquired $= V_{r,p-p} \times C \longrightarrow (1)$

The charge it has lost $= I_{d.c} \times T_2 \longrightarrow (2)$

Therefore $V_{r,p-p} \times C = I_{d.c} \times T_2 \longrightarrow (3)$

With the assumption made above, the ripple waveform will be triangular in nature and the rms value of the ripple is given by

$$V_{r,rms} = \frac{V_{r,p-p}}{2\sqrt{3}} \longrightarrow (4)$$

If the value of the capacitor is fairly large, or the value of the load resistance is very large, then it can be assumed that that the time T_2 is equal to the half the periodic time of the waveform

$$T_2 = \frac{T}{2} = \frac{1}{2f} \quad \text{then from eq (3)}$$

$$V_{r,p-p} = \frac{I_{d.c}}{2fC} \longrightarrow (5)$$

Substituting eq (5) in eq (4)

$$V_{r,rms} = \frac{I_{d.c}}{4\sqrt{3}\,fC}$$

$$V_{r,rms} = \frac{V_{d.c}}{4\sqrt{3}\,fCR_L} \qquad \left[\because I_{d.c} = \frac{V_{d.c}}{R_L}\right]$$

Therefore ripple $\Gamma = \frac{V_{r,rms}}{V_{d.c}} = \frac{1}{4\sqrt{3}\,fCR_L}$

The ripple may be decreased by increasing C (or) R_L (or both) with a resulting increase in d.c output voltage.

Problem :

Calculate the value of capacitance to use in a capacitor filter connected to a full-wave rectifier operating at a standard air craft power frequency of 400Hz, if the ripple factor is 10% for a Load of 500Ω.

Solution : Given data

ripple factor $= \frac{10}{100} = 0.1$

$f = 400\,Hz$, $R_L = 500\,\Omega$

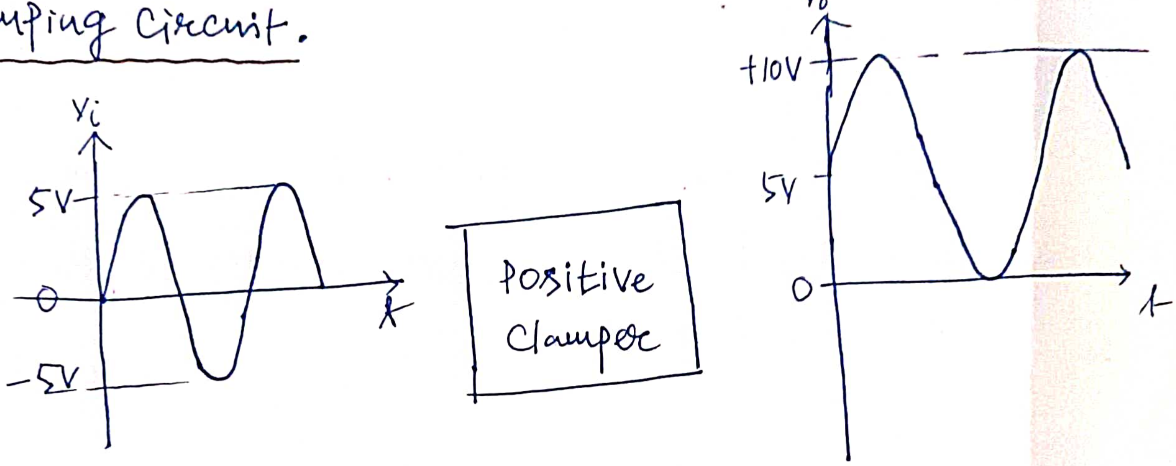
$$\Gamma = \frac{1}{4\sqrt{3}\,fCR_L}$$

$$0.1 = \frac{1}{4 \times \sqrt{3} \times 400 \times C \times 500}$$

$C = 72.2\ \mu F.$

CLAMPING CIRCUITS

A circuit that places either the positive or negative peak of a signal at desired dc level is known as Clamping circuit.



→ Clamper essentially adds a dc component to the signal.

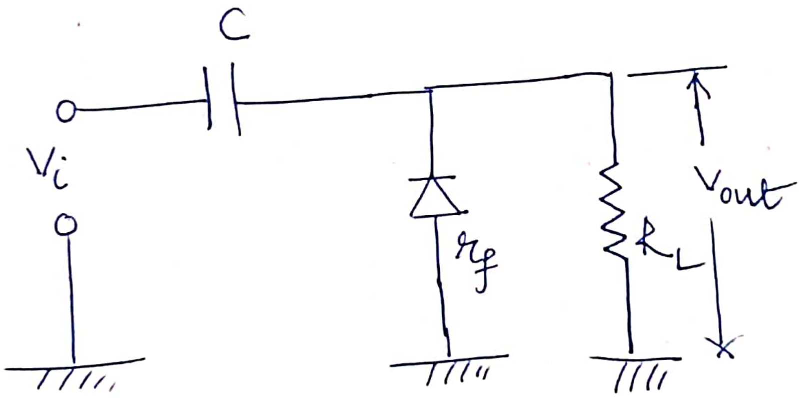
→ It may be seen that shape of original signal has not changed; only there is vertical shift in the signal. Such a clamper is called Positive Clamper.
Here negative peaks fall on zero level.

→ Negative Clamper pushes signal downwards so that positive peaks falls on zero level.

Basic Idea of Clamper

A clamper should not change peak-to-peak value of signal; it should only change dc level. To do so, clamper circuit uses a capacitor, together with diode and a load resistor R_L.

The operation of clamper is based on principle that charging time of capacitor is made very small as compared to discharging time.



→ Charging time constant $\tau_C = r_f \times C$ (few μs)

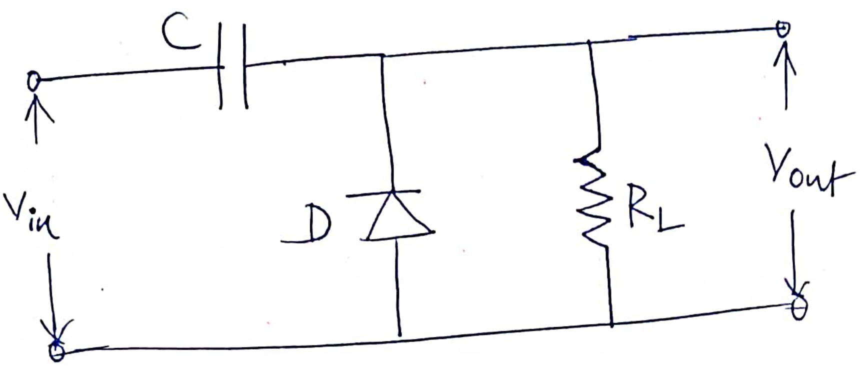
r_f = forward resistance of diode (few ohms)

→ Discharging time constant $\tau_D = R_L \times C$ (few ms)

($R_L >> r_f$)

$\tau_D >> \tau_C$ ✓

POSITIVE CLAMPER



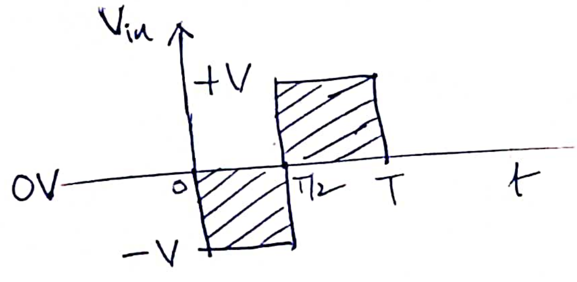
The input signal is assumed to be a square wave with time period T. Clamped output is obtained across R_L.

Two assumptions to be incorporated.

(i) values of C and R_L are so selected that time constant $\tau_D = CR_L$ is very large. This means voltage across capacitor will not discharge significantly during the interval the diode is non conducting.

(ii) $R_L C$ time constant is deliberately made much greater than the time period T of incoming signal (V_{in})

V_{in}



When $0 < t < T/2$

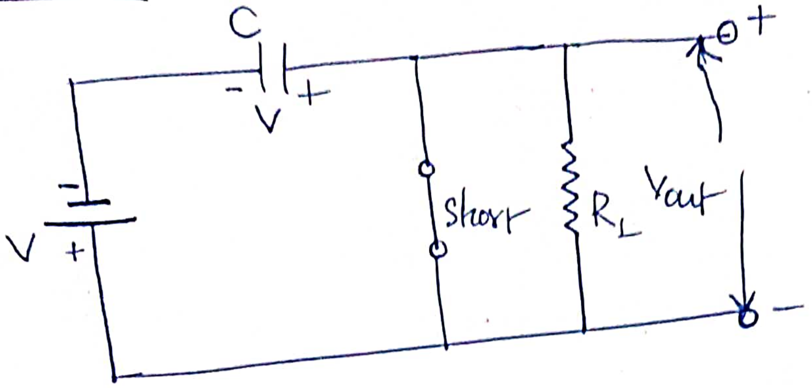
$V_{in} = -V$

When $\frac{T}{2} < t < T$

$V_{in} = +V$

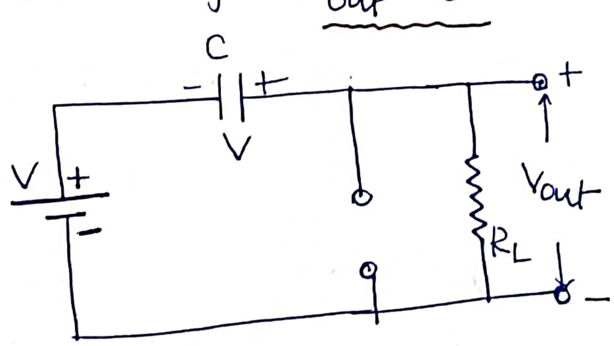
Operation

(i)



During negative half cycle of input signal, the diode is forward biased. Therefore, diode behaves as a short as shown in figure. The charging time constant $T_C = r_f \times C$ is very small so that capacitor will charge to V volts very quickly. It is easy to see that during this interval, the output voltage (V_{out}) is directly across short circuit. Therefore $V_{out} = 0$.

(ii) When the input switches to +V, (positive half cycle), the diode is reverse biased and behaves as an open as shown in figure.

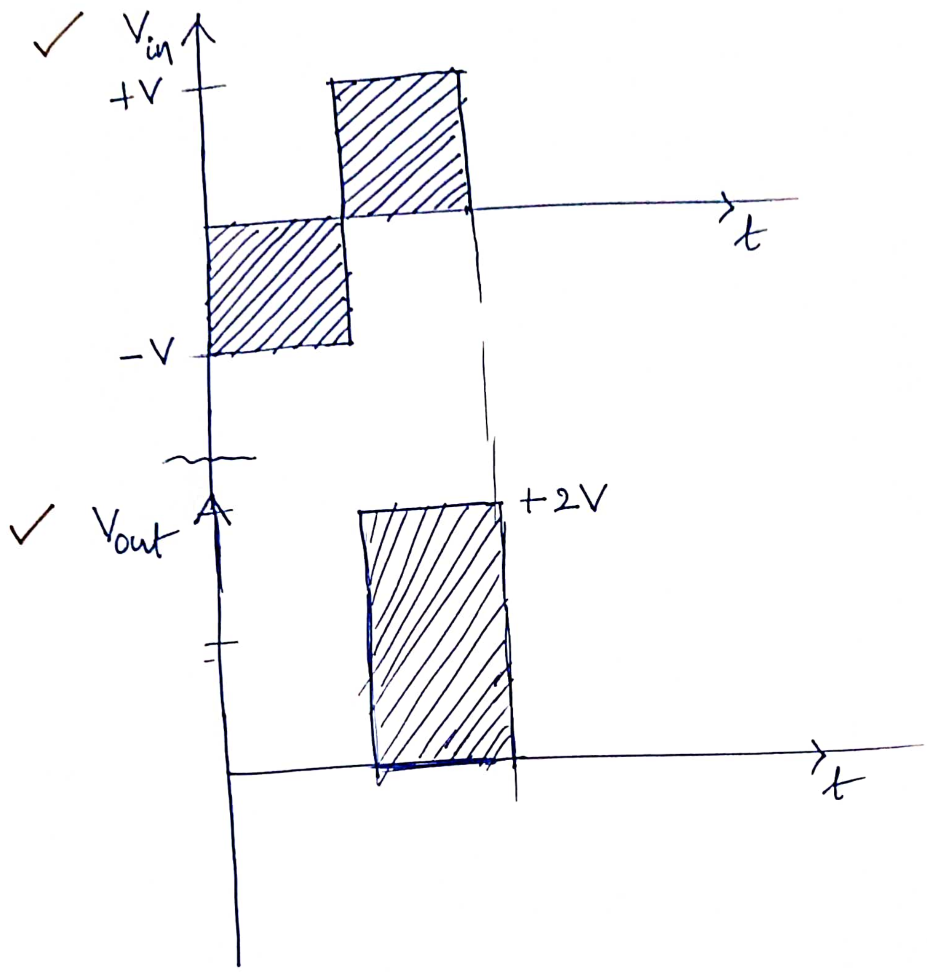


Since discharging time constant $T_D = R_L \times C$ is much greater than time period of input signal, the capacitor remains almost fully charged to V volts, during the off time of diode. Applying KVL to input loop, we have,

$$V + V - V_{out} = 0$$

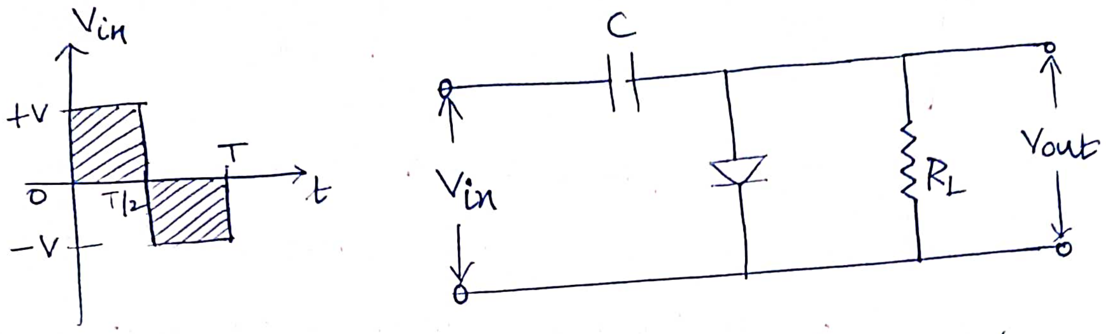
$$V_{out} = 2V$$

The resulting waveforms



(Positive clamper)

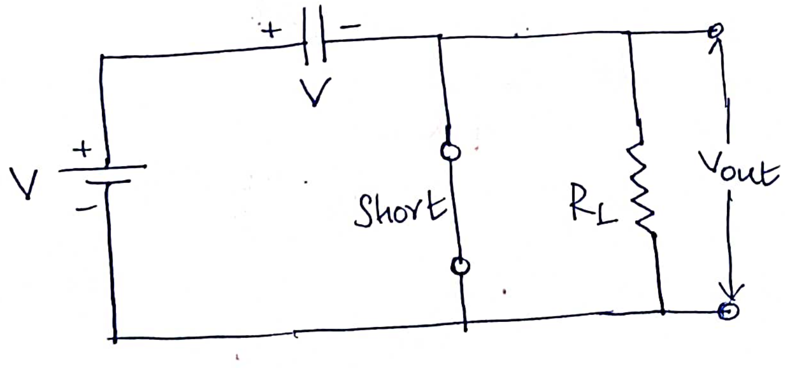
Negative clamper :

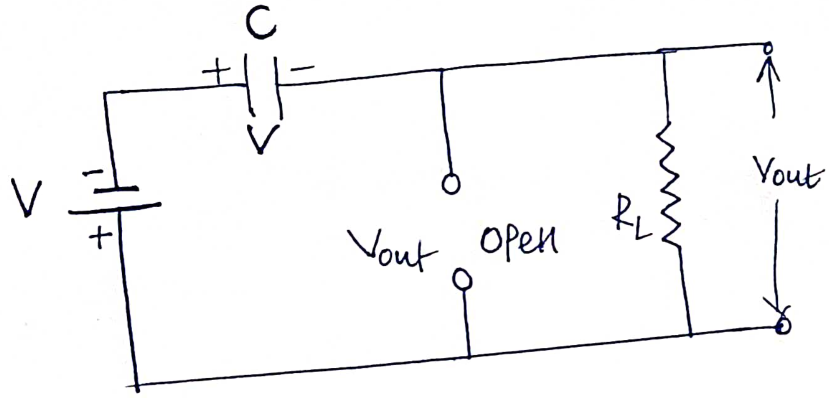


→ The clamped output is taken across R_L. Note that only change from positive clamper is that connections of diode are reversed.

(i) During the positive half-cycle of input signal, the diode is forward biased. Therefore, the diode behaves as a short as shown in below figure. The charging time constant $(\tau_c = C \times r_f)$ is very small so that capacitor will charge to V volts very quickly. It is easy to see that during this interval, the output voltage (Vout) is directly across the short circuit. Therefore $\boxed{V_{out} = 0}$ ✓

↓

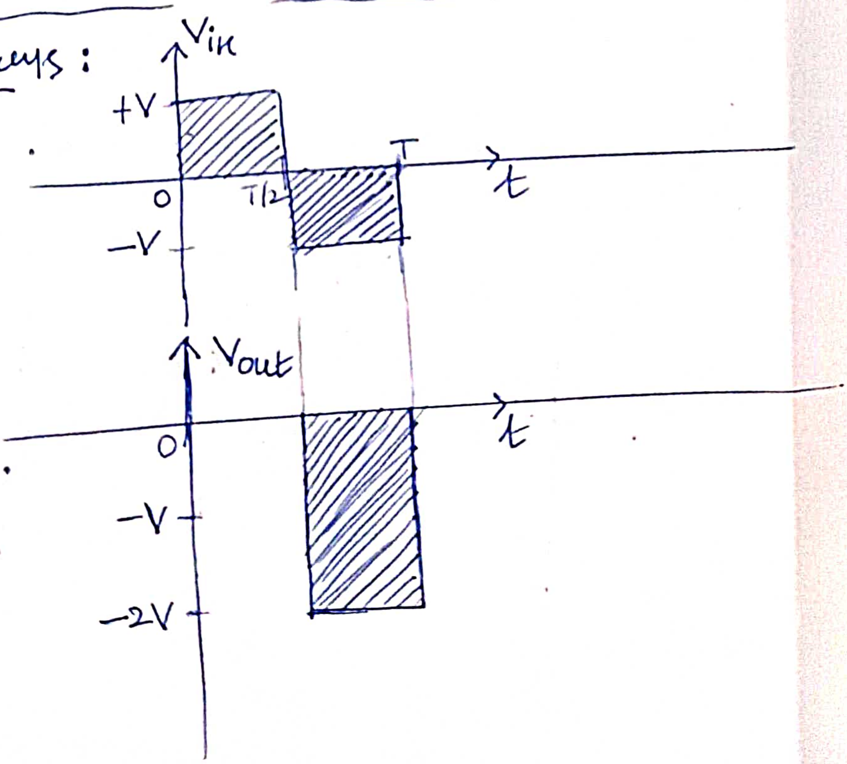




(ii) When the input switches to $-V$ state (i.e negative half cycle) the diode is reverse biased and behaves as an open as shown in figure. Since the discharge time constant $(= C \times R_L)$ is much greater than time period of input signal, the capacitor almost remains fully charged to V volts during the off time of the diode. Referring to figure, and applying KVL to input loop, we have,

$$-V - V - V_{out} = 0 \Rightarrow \boxed{V_{out} = -2V}$$

Resulting waveforms :

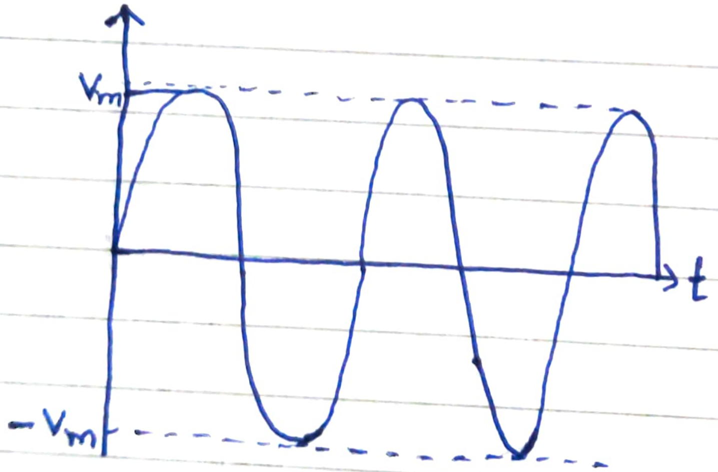


- To convert an AC to DC power, an rectifier ciruit comes for the rescue
- A simple p-n junction diode acts as a rectifier. The forward biasing and reverse biasing conditions of the diode makes the rectification

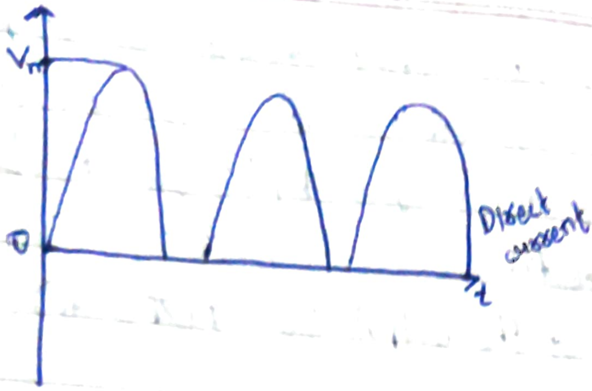
*** rectification:-**

An alternating current has the property to change its states continuously. These is understood by observing the sine wave by which an alternating current is indicated.

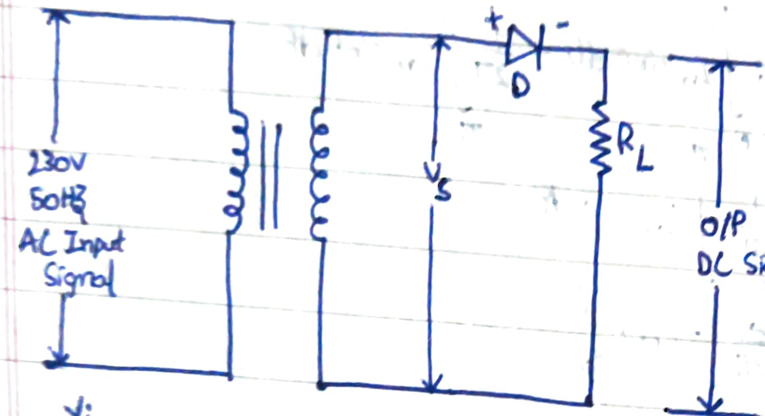
- It raises in its positive direction goes to a peak positive value, reduces from there to normal and again goes to negative portion and reaches to the negative peak and again get back to normal.

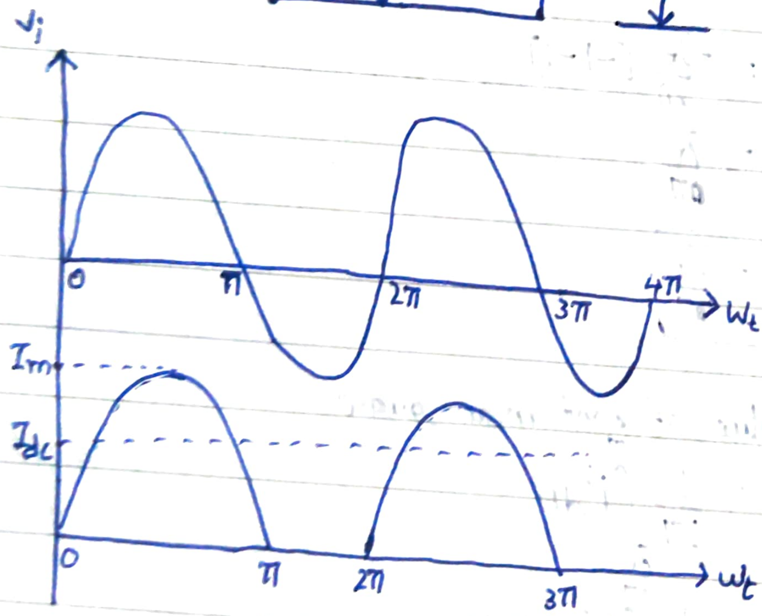


- In the formation of the wave we can observe that a wave goes in positive and negative directions actually it alters completely and hence the name alternative current.
- But during the process of rectifiation, this AC is changed to DC. The wave which flows in both positive and negative direction. Till then will get its direction, restricted only to the positive direction when converted to DC.
- Hence, the current is allowed to flow only in +ve direction and restricted in -ve direction



- Half-Wave Rectifier -





- The AC voltages to be rectified is applied at the primary of the transformer, the secondary is connected to a load Resistance R_L through a diode D. let the diode be ideal.
- During the positive half cycle of input the diode D is forward bias and conducts hence the current i flows through resistance R_L
- During the negative half cycle of input the diode D is reverse

bias and in the closed circuit current does not p
resistance R_L i.e., the current flows in only one d

- The Output current i is given by $i = I_m \sin\theta$ $\quad 0$ ... π

* parameters of rectifiers-

1. Average value of the output current (I_{dc})

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\,d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\,d\theta + \frac{1}{2\pi}\int_{\pi}^{2\pi} I_m \sin\theta\,d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\,d\theta$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= -\frac{I_m}{2\pi}\left[-1-1\right]$$

$$= \frac{I_m}{\pi}$$

$$\boxed{I_{dc} = \frac{I_m}{\pi}}$$

2. rms value of root mean square

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2\,d\theta$$

$$= \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta\,d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta\,d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right)d\theta$$

$$= \frac{I_m^2}{4\pi}\left[\left[\theta\right]_0^{\pi} - \left[\frac{\sin 2\theta}{2}\right]_0^{\pi}\right]$$

$$= \frac{I_m^2}{} \times \pi$$

$$I_{rms}^2 = \frac{I_m^2}{4}$$

$$\boxed{I_{rms} = \frac{I_m}{2}}$$

3. Efficiency - is defined as the ratio of dc power delivered to the load a.c input power from transformer secondary

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L$$

$$= \frac{I_m^2}{\pi^2} R_L$$

$$P_{ac} = I_{rms}^2 (R_L + R_f)$$

$$= \frac{I_m^2}{4} (R_L + R_f)$$

If $R_L >>> R_f$

$$\eta = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4}(R_L + R_f)}$$

$$\eta = \frac{4}{\pi^2} = 0.406 \approx 40.6\%$$

4. Voltage ~~Ven~~ Regulation - The variation of dc output voltage as a function of dc output current is known as regulation.

- For an ideal power supply ~~VDL~~ V_{dc} is independent of I_{dc} i.e., the percentage regulation is zero

$$\% \text{ Regulation} = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100$$

~~$V_{NL} \rightarrow$~~

$\cancel{V} = \cancel{\sqrt{I_{rms}}}$

PIV → Peak Inverse voltage

→ It is defined as maximum reverse voltage that a diode can withstand, if the reverse bias voltage exceeds this value, the reverse current increase rapidly and the junction breakdown the maximum peak inverse [illegible] of rectifier is V_m

- Ripple Factor (γ) - The fluctuating of AC components present along with dc current component of a rectif[illegible]

the ripple factor (γ) = $\frac{\text{ripple voltage}}{\text{dc voltage}}$

$$\gamma = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1}$$

$$= \sqrt{(1.57)^2 - 1}$$

$$= 1.21$$

Transformer Utilisation Factor (TUF):-

It is defined as the ratio of dc power output to VA rating of transformer

$$TUF = \frac{\frac{V_m I_m}{\pi}}{\frac{V_m I_m}{2\sqrt{2}}} = \frac{2\sqrt{2}}{\pi}$$

$$TUF = 0.2865$$

⇒ Summary of Half Wave Rectifier.

$$I_{dc} = \frac{I_m}{2\pi}$$

$$I_{rms} = \frac{I_m}{2}$$

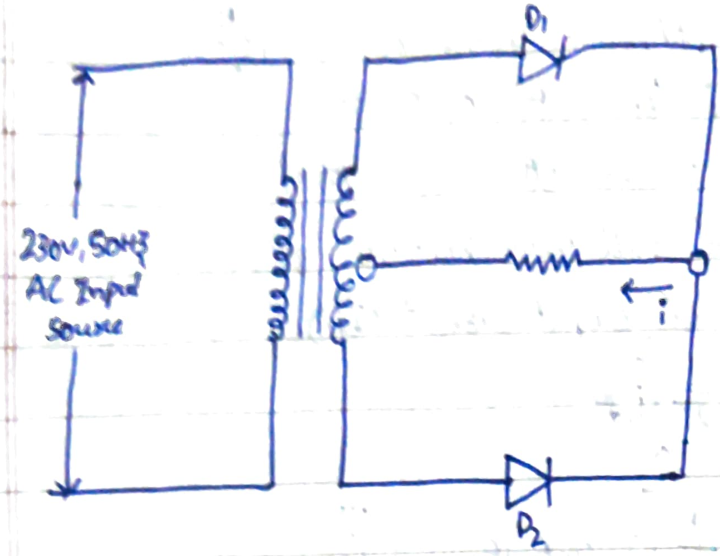
$$\eta = 40.6\%$$

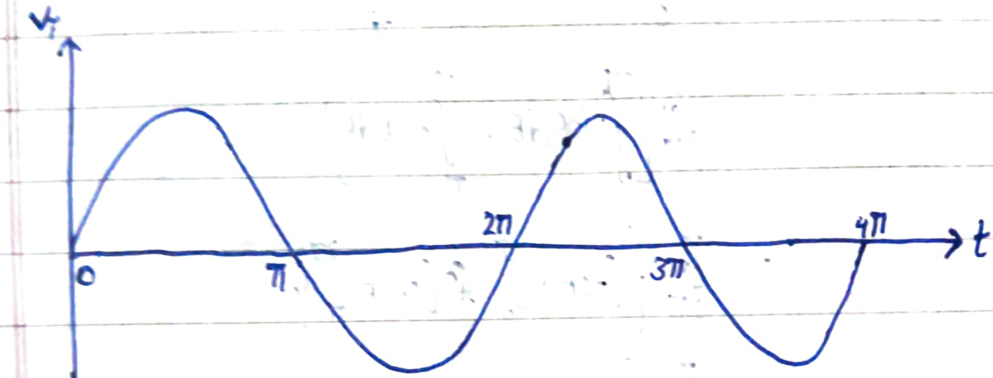
$$\%\text{ regulation} = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100$$

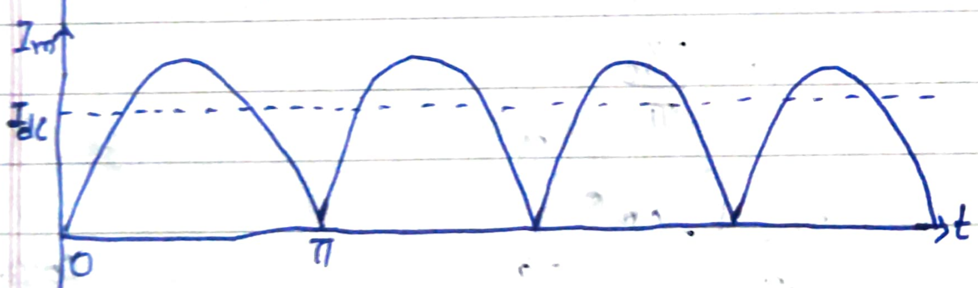
Ripple factor (γ) = $\frac{\text{ripple voltage}}{\text{d.c voltage}} = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1} = 1.21$

TUF = $\frac{\text{dc power output}}{\text{VA rating ...}}$ = 0.2865

Full Wave Rectifier -







- It consists two diodes D_1 and D_2 and a centre taped transformer. The AC voltage to be rectified is applied to the primary of a transformer. let us assume the diode D_1 & D_2 are ideal.
- during the positive half cycle the diode D_1 is forward biased and D_2 is reverse biased so D_1 acts as short circuit and D_2 acts as open circuit hence current flows through Diode D_1.
- during the negative half cycle the diode D_1 is reverse biased and D_2 is forward biased so D_1 acts as an open circuit and D_2 acts

as short circuit. Hence current flows through Diode D_2

- The current through load resistor R_L is

$$i = I_m \sin\theta \quad 0 \le \theta \le \pi$$

$$= -I_m \sin\theta \quad \pi \le \theta \le 2\pi$$

- parameters of full wave rectifier

1. average value of output current (I_{dc})

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\, d\theta$$

$$\frac{I_m}{2\pi}\int_0^{\pi} \sin\theta d\theta - \int_{\pi}^{2\pi} \sin\theta d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\, d\theta + \frac{1}{2\pi}\int_{\pi}^{2\pi} I_m \sin\theta\, d\theta$$

$$= \frac{I_m}{2\pi}\left[\int_0^{\pi} \sin\theta d\theta - \int_{\pi}^{2\pi} \sin\theta d\theta\right]$$

$$= \frac{I_m}{2\pi}\left\{[-\cos\theta]_0^{\pi} + [\cos\theta]_{\pi}^{2\pi}\right\}$$

$$= \frac{I_m}{2\pi}\left[-\cos\pi + \cos 0 + \cos 2\pi - \cos\pi\right]$$

$$= \frac{2I_m}{\pi}$$

$$\frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$\frac{I_m}{2\pi}\left[-(\cos\pi - \cos 0)\right]$$

$$-(-1-1)$$

$$-(\cos 2\pi - \cos\pi)$$

$$\frac{I_m}{2\pi}\left[-2\right.$$

cos 360°

cos(4×90+0)

+cos 0°

=1

2. rms value of (root mean square)

$$I_{rms}^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta$$

$$= \frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta \, d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{2\pi} \frac{1-\cos 2\theta}{2} d\theta$$

$$= \frac{I_m^2}{4\pi}\left[[\theta]_0^{2\pi} - \left[\frac{\sin 2\theta}{2}\right]_0^{2\pi} \right]$$

$$I_{rms}^2 = \frac{I_m^2}{4\pi} \times 2\pi$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

3. Voltage Regulation

$$I_{dc} = \frac{2I_m}{\pi}$$

But $I_m = \dfrac{V_m}{R_s + R_f + R_L}$

$$I_{dc} = \frac{2V_m}{\pi(R_s + R_f + R_L)}$$

$$I_{dc}(R_s + R_f) + I_{dc} R_L = \frac{2V_m}{\pi}$$

$$I_{dc} R_L = \frac{2V_m}{\pi} - I_{dc}(R_s + R_f)$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}}$$

4. Ripple factor

$$\gamma = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1} = 0.48$$

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$P_{dc} = I_{dc}^2 R_L$$
$$= \left(\frac{2I_m}{\pi}\right)^2 R_L$$
$$= \frac{4I_m^2}{\pi^2} R_L$$

$$P_{ac} = I_{rms}^2 (R_L + R_f)$$
$$= \left[\frac{I_m}{\sqrt{2}}\right]^2 (R_L + R_f)$$
$$= \frac{I_m^2}{2} (R_L + R_f)$$

$$\eta = \frac{\frac{4I_m^2}{\pi^2} R_L}{\frac{I_m^2}{2}(R_L + R_f)} = \frac{8}{\pi^2} \times \frac{R_L}{R_L + R_f}$$

$$\eta = 0.812 = 81.2\%$$

Peak Inverse Voltage of full wave rectifier:-

The maximum reverse voltage that can be applied across the di

For a full wave rectifier the PIV across each diode is twice the maximum transformer voltage

- The PIV of full wave rectifier is $2V_m$

Summary of full wave rectifier

$$I_{dc} = \frac{2I_m}{\pi}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

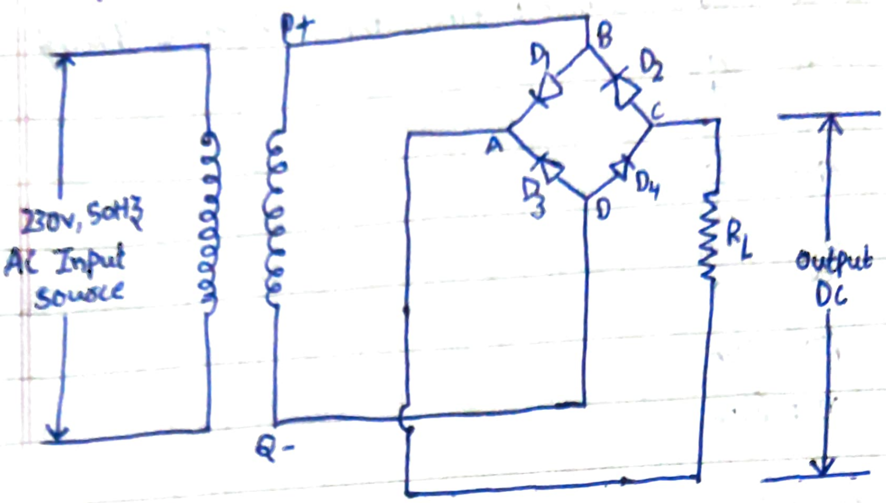
$$V_{dc} = \frac{2V_m}{\pi}$$

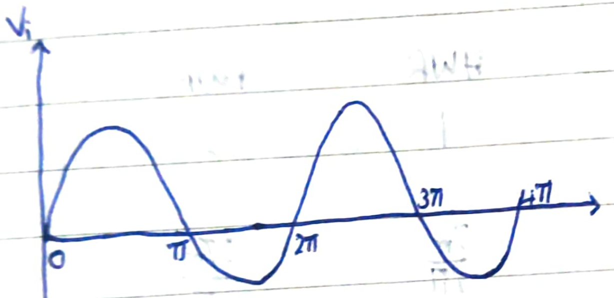
$$\gamma = \sqrt{\left[\frac{I_{rms}}{I_{dc}}\right]^2 - 1} = 0.48$$

$$\eta = 81.2\%$$

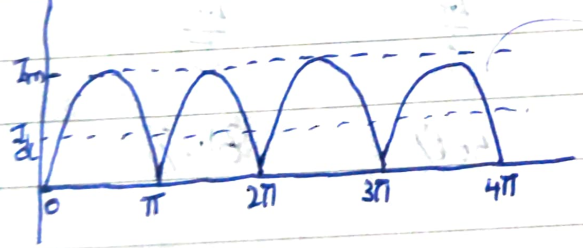
PIV of full wave $= 2V_m$

Bridge Rectifier-





I/P AC Signal



- It's basically a full wave rectifier but it does not need a centre taped transformer it has 4 diodes D_1, D_2, D_3, D_4 connected as a bridge. The AC voltage to be rectified is applied to the primary of the transformer
- During positive half cycle the Diode D_1 & D_4 are positive biased and D_2 and D_4 will conduct and the path for current is PBACDQ
- During negative half cycle the Diode D_1 & D_4 are reverse biased and

D_2 and D_4 will conduct and path for current ... A to C through R

- In both cycles current flows from A to C through R

$I_{dc} = \frac{2I_m}{\pi}$

$I_{rms} = \frac{I_m}{\sqrt{2}}$

$V_{dc} = \frac{2V_m}{\pi}$

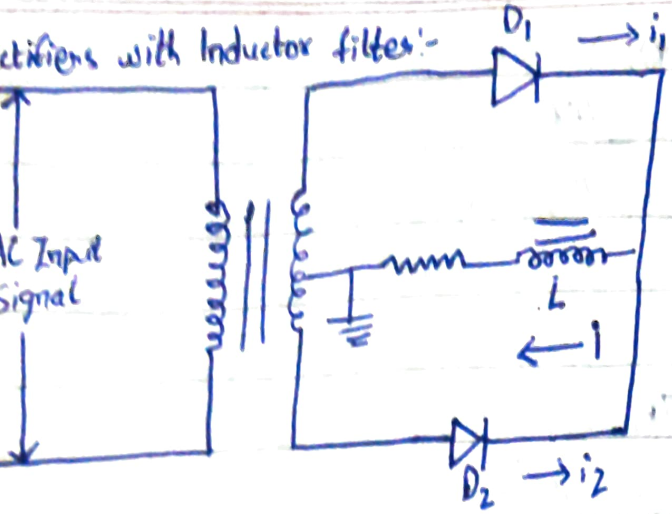
$PIV = V_m$

$\eta = 81.2$

⇒ Comparison b/wn Half wave rectifier, full wave rectifier, Bridge wave rectifier

parameter	HWR	FWR	BR
No. of diodes	1	2	4
I_{dc}	$\frac{I_m}{2\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
η	40.6%	81.2%	81.2%
γ	1.21	0.48	0.48
PIV	V_m	$2V_m$	V_m
V_{dc}	$\frac{V_m}{2\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
TUF	0.287	0.693	0.812

ctifiers with Inductor filter:-



An inductor opposes any changes of current in the circuit. So any sudden change that might occur in a circuit without an inductor are smooth out with the presence of inductor in the case of AC there is change in the magnitude of current with time. Inductor is a short circuit for DC and offers some impedance with for AC. It can be used as a filter. AC voltages are dropped across the inductors whereas DC passes through it. Therefore the AC is minimised in the output.

$$I_m = \frac{V_m}{R_L}$$

Impedence due to L & R_L in series

$$|Z| = \sqrt{R_L^2 + (2\omega L)^2}$$

$$I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}}$$

substituting this expression for current

$$I = \frac{2I_m}{\pi} - \frac{4I_m}{3\pi}\cos 2\omega t + \text{--------}$$

By Inductor to higher frequencies like $4\omega t$,

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\sqrt{2}\pi\sqrt{R_L^2 + 4\omega^2 L^2}}$$

$$\theta = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)$$

Ripple factor (γ):-

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{4V_m}{3\sqrt{2}\pi\sqrt{R_L^2+4L^2\omega^2}}$$

$$I_{dc} = \frac{2V_m}{\pi R_L}$$

$$\gamma = \frac{4V_m \times \pi R_L}{3\sqrt{2}\pi\sqrt{R^2+4\omega^2 L^2} \cdot 2V_m}$$

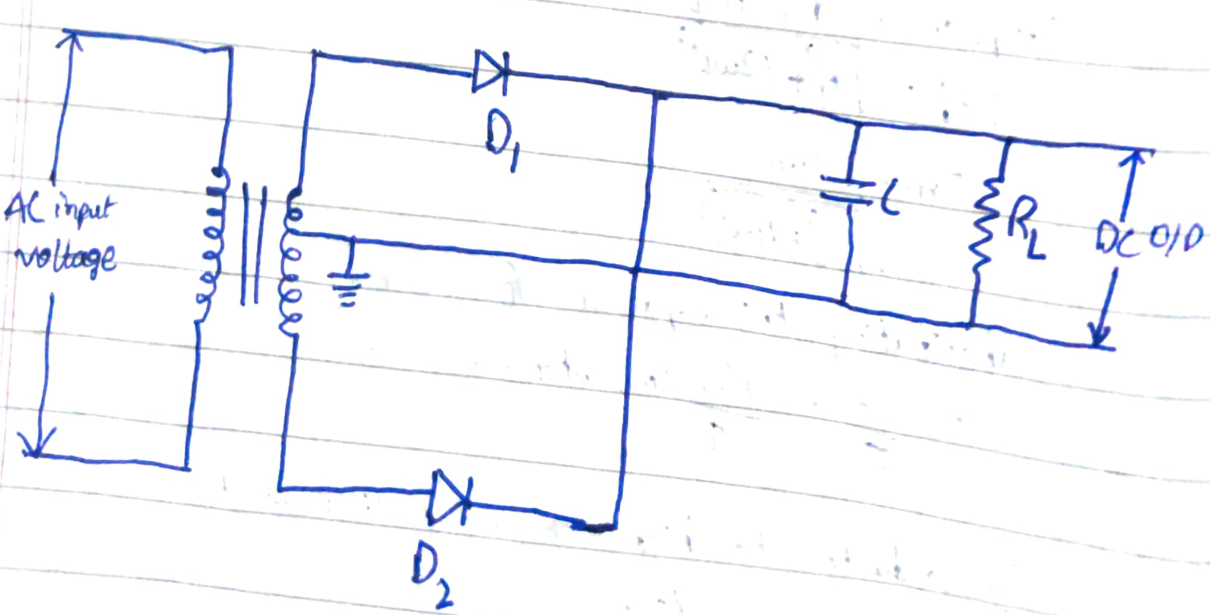
$$= \frac{2}{3\sqrt{2}} \times \frac{1}{\sqrt{1+\frac{4\omega^2 L^2}{R_L^2}}}$$

If $\frac{4\omega^2 L^2}{R_L^2} >> 1$

$$\gamma = \frac{R_L \times 2}{3\sqrt{2} \times 2\omega L} = \frac{R_L}{3\sqrt{2}\omega L}$$

$$\boxed{\gamma = \frac{R_L}{3\sqrt{2}\omega L}}$$

→ Capacitor filter-



The X_c should be smaller than R_L because the current should pass through capacitor C and get charged. If C value is very small, X_c will be large and the current flows through resistor R and no filter action takes place.

During a positive half cycle of a rectifier of a rectifier with a 'C' filter, C gets charged when the diode is conducting and gets discharged through load resistor R_L when the input voltage $e = E_m \sin \omega t$ is greater than the capacitor voltage, C gets charged

when the input voltage is less than capacitor voltage C will discharged through load resistor R_L.

The stored energy in the capacitor maintaining the load voltage ~~for~~ at a high value for a long period. The diode conducts only for a short interval of high current. The capacitor opposes sudden fluctuations in voltages across it. So the ripple voltage is minimised

$$\boxed{\gamma = \frac{1}{4\sqrt{3}fCR_L}}$$

Clippers & clampers:-

- If the signal applied has an amplitude value greater than that of the range described this results in distortion.
- There is another problem related to signals that are their levels the circuit level always maintained on the positive side but the sine wave consist of both positive and negative then in such cases the levels of the signals must be then operated on the electronic circuitary.
- for this processing of comparing the signals to define ranges and signal levels. clipper and clampers are used.

→ Clippers:

The clippers which are used to protect the electronic circuit by applying the AC input signal to the described voltage range. It will remove either positive half and negative half of the AC by considering requirement and defined voltage.

* Working of clipper circuit-

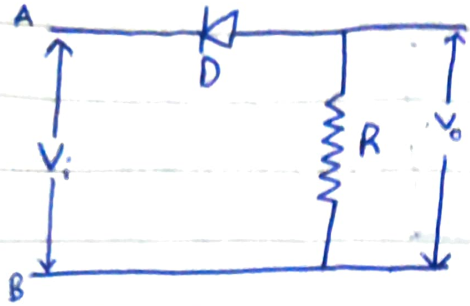
- A clipper circuit consists of linear elements known as resistors and non linear elements such as diodes but does not contain any energy storage device such as capacitor.
- These clippers are often limiting the voltage and current amplitudes. These are commonly refered to as slicers.

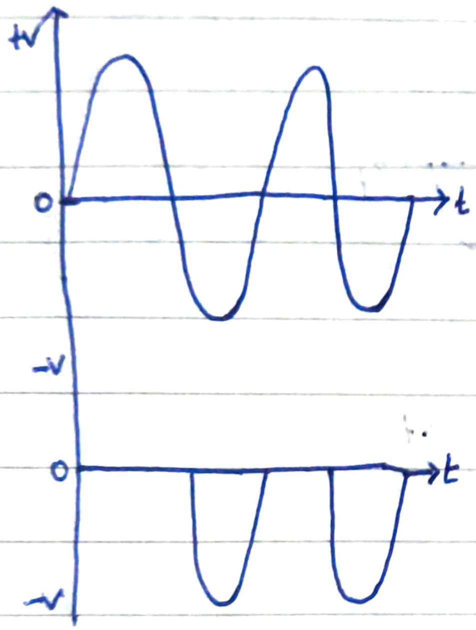
→ Types of clippers:-

1. Series clipper
2. Shunt clipper
3. dual clipper

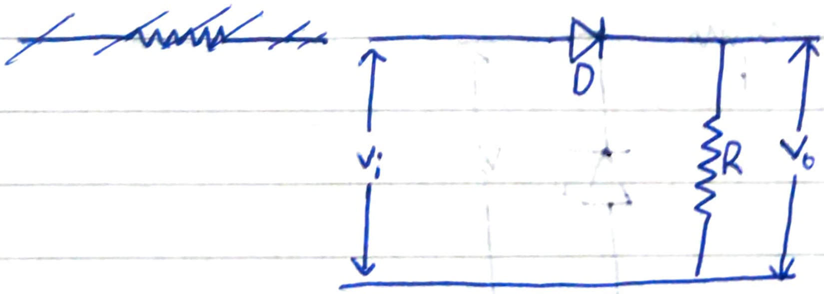
1. Series clipper:-

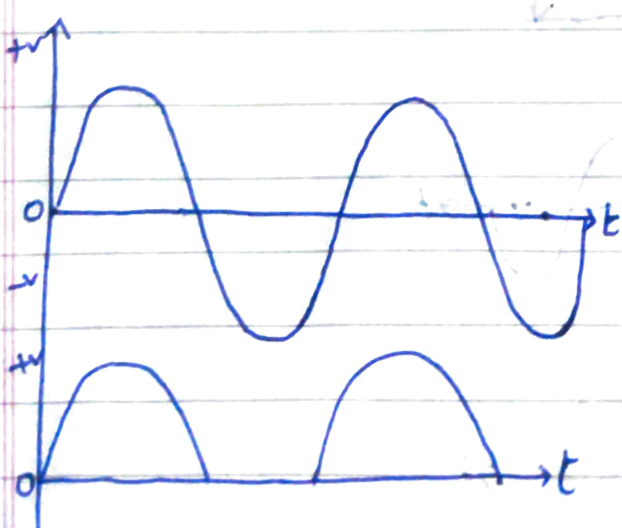
(i) Series positive clipper





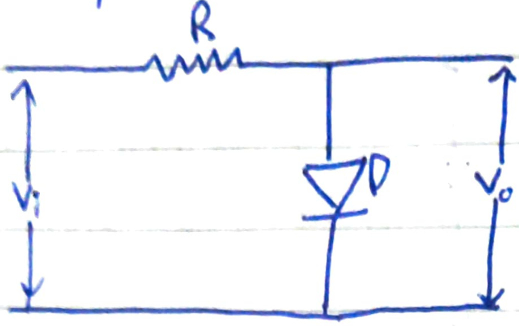
(ii) Series Negative clipper

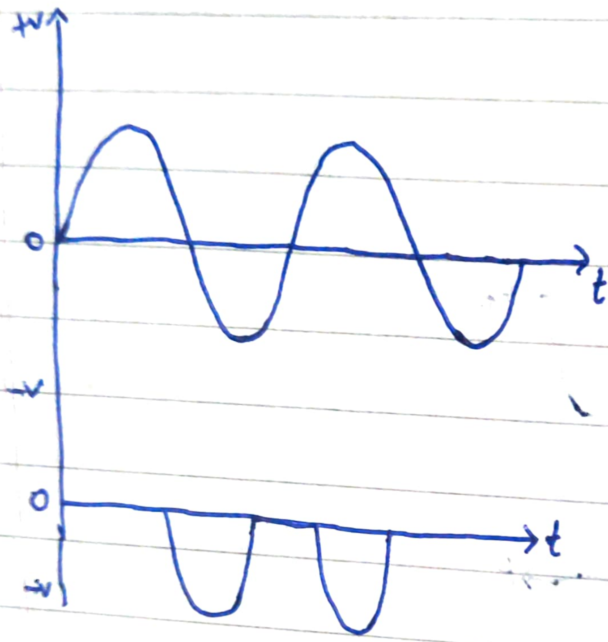




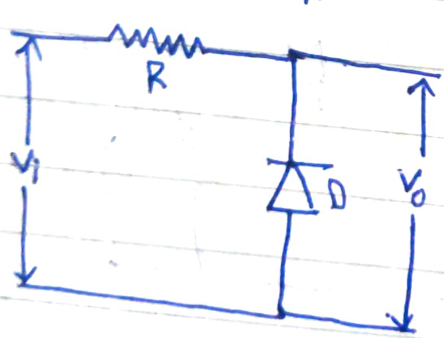
2. Shunt clipper

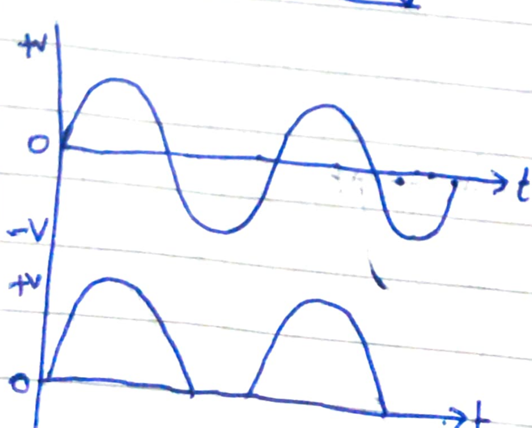
i) shunt positive clipper:





ii) Shunt negative clipper





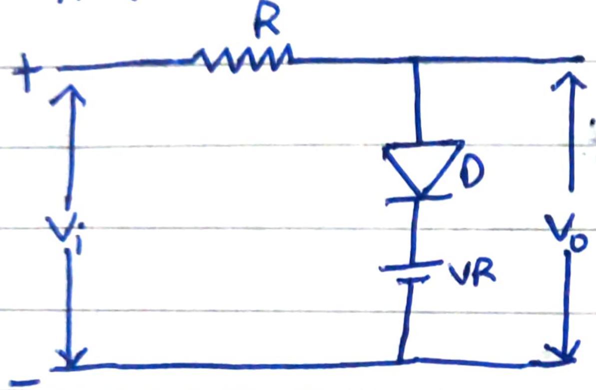
→ Series positive Clipper -

The positive cycle of the signal is clipped in this type of clippers these circuits consists of a diode connected in such a way that arrow is pointing towards input. It is connected along with series to the output load. The resistance is considered as load.

In exam

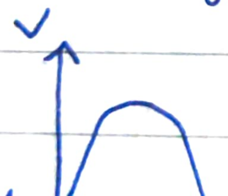
① shunt clippers

a. clipping above the ref. voltage (VR)

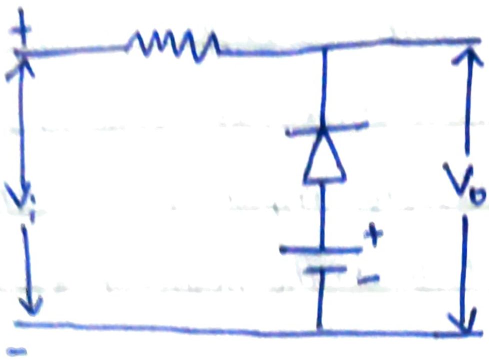


$V_0 = V_i$ & $V_0 < VR$

$V_0 = V_R$

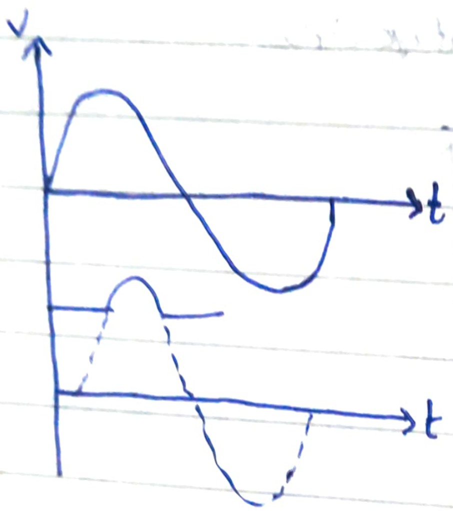


b. Clipping below the ref. voltage (VR)



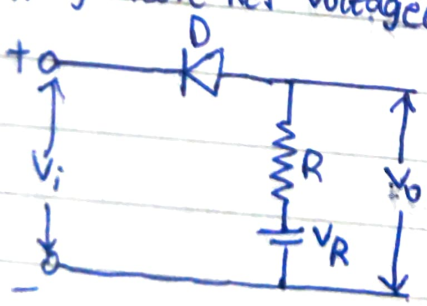
$V_i < V_R$ $\quad V_o = V_R$

$V_i > V_R$ $\quad V_i = V_o$



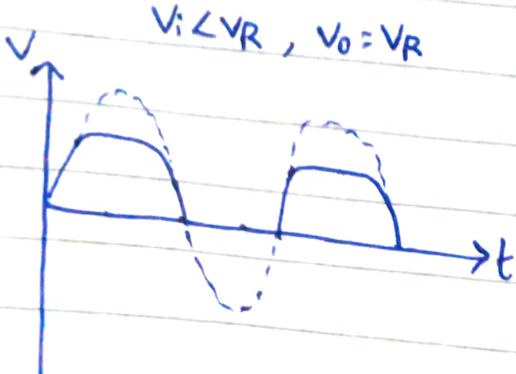
(2) Series clipping

(a) clipping above Ref voltage (VR)

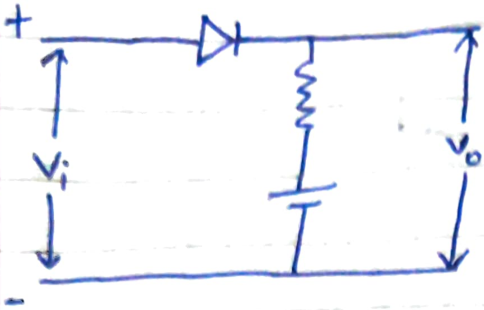


$V_i < V_R$; $V_o = V_i$

$V_i < V_R$, $V_o = V_R$

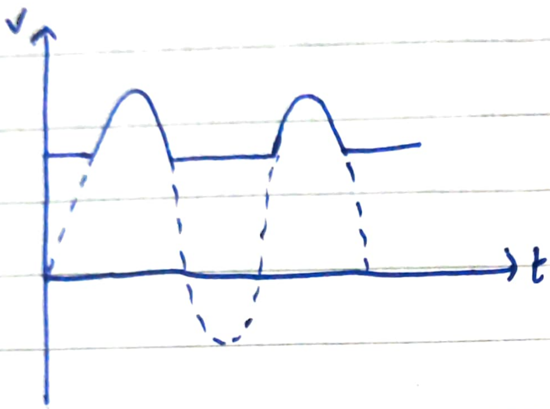


ⓑ clipping below the ref. voltage (V_R)

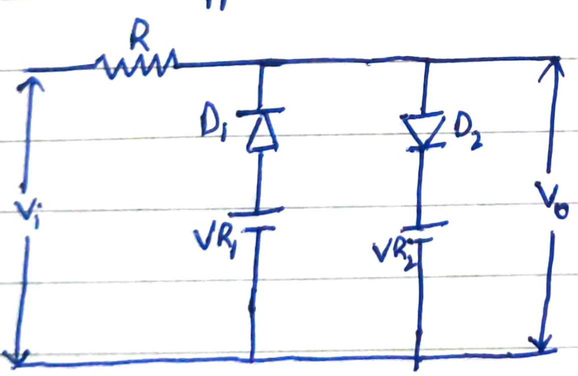


$V_i < V_R$; $V_0 = V_R$

$V_i > V_R$; $V_0 = V_i$



Two-Level clipper-



case ①:-

ⓐ $V_i < VR_1$

$\Rightarrow D_1 = F \cdot B \Rightarrow ON$

$D_2 = R \cdot B \Rightarrow OFF$

ⓑ $VR_2 > V_i > VR_1$

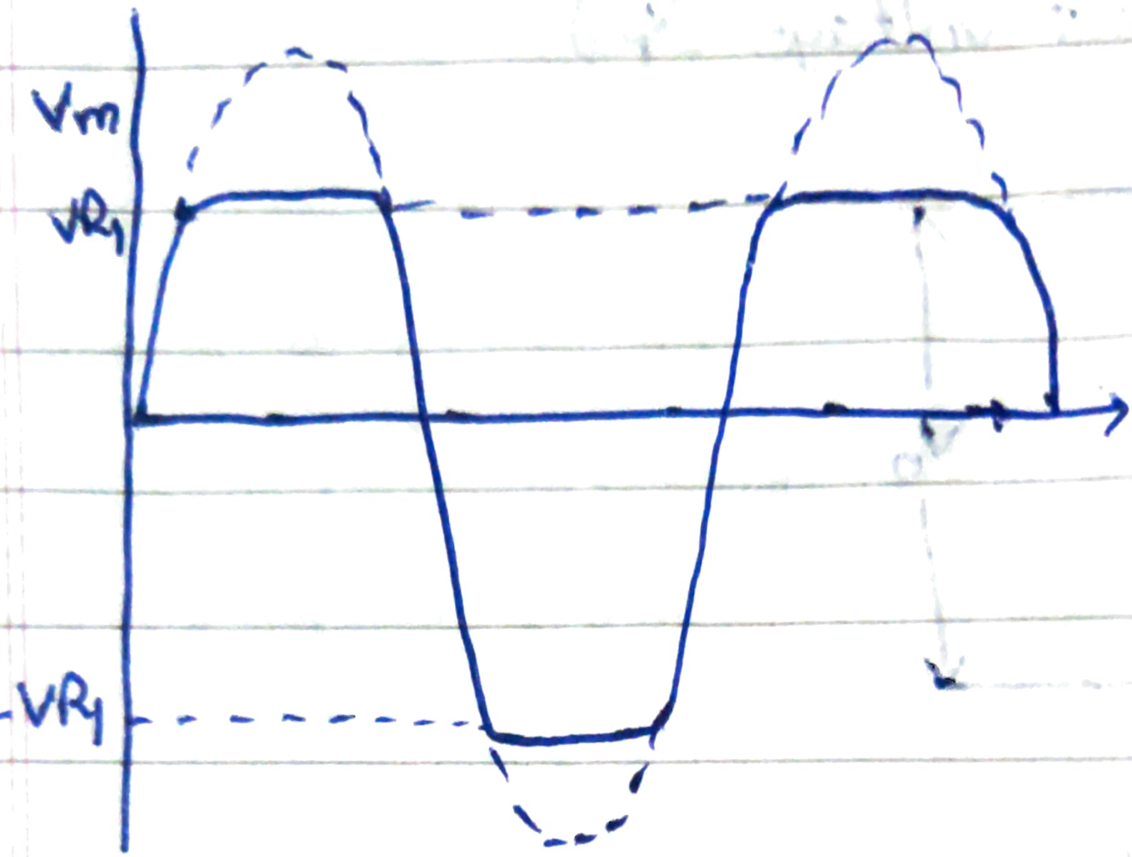
D_1 & D_2 : $R \cdot B \Rightarrow OFF$

Then $V_0 = V_i$

ⓒ $V_i > VR_2$

$D_2 = F \cdot B \Rightarrow ON$

$D_1 = R \cdot B \Rightarrow OFF$



Vm
VR1
-VR1

BIPOLAR JUNCTION TRANSISTOR

BJT construction

BJT symbol

BJT operation

Transistor current components

Input & Output characteristics of a transistor in CB configuration

Input & Output characteristics of a transistor in CE configuration

Input & Output characteristics of a transistor in CC configuration

Comparison of a transistor in CB, CE and CC configurations

BJT specifications

Bipolar junction Transistor (BJT) :-

Introduction :

* A Bipolar junction transistor is a three terminal semi conductor device in which the operation depends on the interaction of majority and minority carriers. hence it is named as Bipolar device.

* Transistor means 'Transfer Resistor' ie signals are transfered from low resistance circuit (input) into high resistance (output circuit).

* Basically a third doped element is added to a crystal diode in such a way that two PN junctions are formed. These two junctions give three regions called emitter, base and collector.

* The BJT is analogous to a vaccum triode and is comparatively smaller in size.

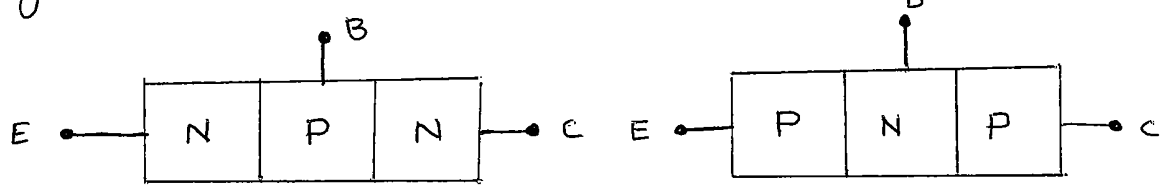
* BJT's are used in amplifier and oscillator circuits and as a switch in digital circuits

BJT construction :-

* The BJT consists of a silicon (Germanium) crystal in which a thin layer of N-type silicon is sandwiched between two layers of P-type silicon. This transistor is referred to as PNP

* similarly, a layer of P-type material is sandwiched between two layers of N-type material this transistor is referred to as NPN.

The two types of BJT are represented in figure below.



(a) NPN Transistor (b) PNP Transistor

* The symbolic representation of the two types of the BJT is shown in figure below.

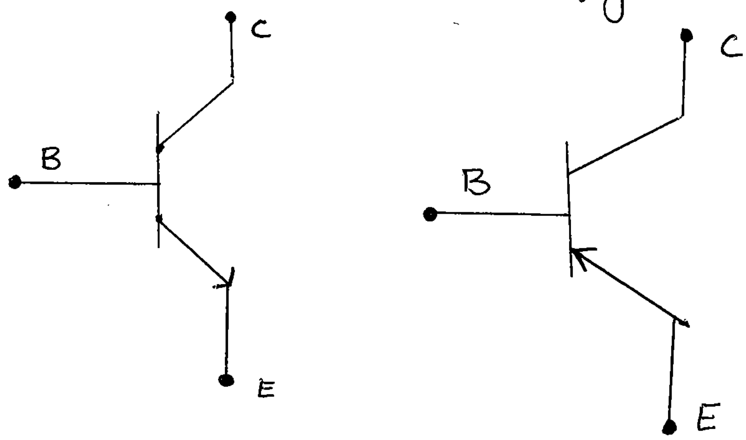


fig (a) Symbol for NPN Transistor fig(b) Symbol for PNP Transistor.

The three portions of the transistor are Emitter, Base and collector shown as E, B and C respectively. The arrow of the emitter specifies the direction of the current flow when the EB Junction is forward biased.

Two junctions are EB → Emitter-base junction
CB → collector-base junction

Emitter: It is more heavily doped than any of the other region because its main function is to supply majority charge carriers to the base.

Base: Base is lightly doped and very thin. It passes most of the injected charge carriers from the emitter in to the collector.

Collector: collector is moderately doped. Its main function is to collect the majority charge carriers coming from the emitter and passing through the base. In most transistors, collector region is made physically larger than the emitter region because it has to dissipate much greater power.

Transistor Biasing :-

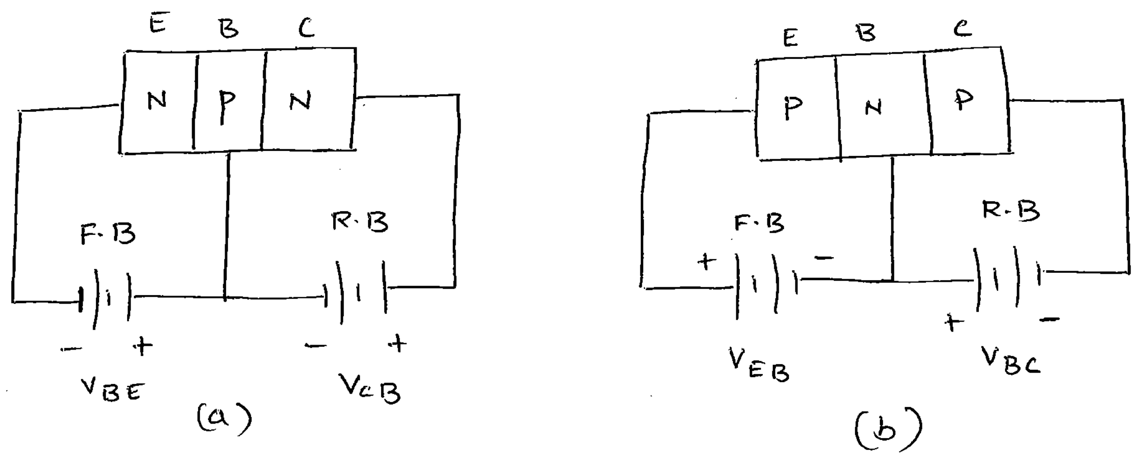
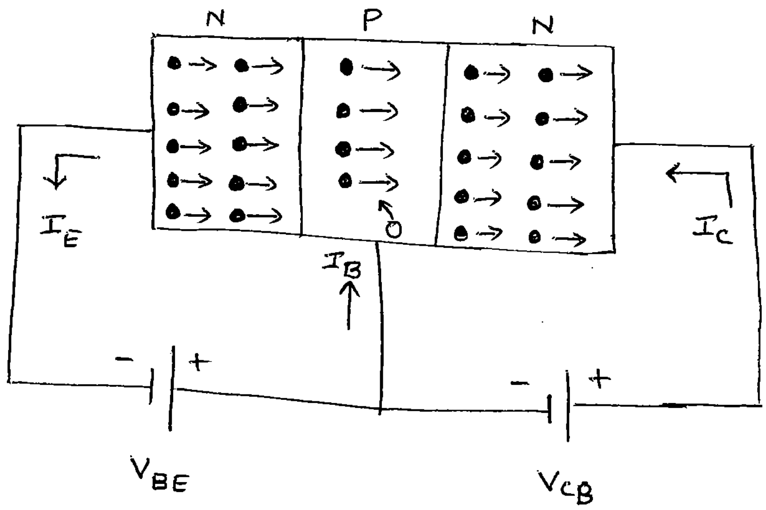


fig: Transistor biasing (a) NPN Transistor and (b) PNP Transistor.

As shown in figure, usually the emitter base junction is forward biased and collector base junction is reverse biased. Due to the forward bias on the emitter base junction, an emitter current flows through the base in to the collector. Though the collector - base junction is reverse biased almost the entire emitter current flows through the collector circuit.

Operation of NPN Transistor :-



As shown in figure, the forward bias is applied to the emitter base junction of an NPN transistor causes a lot of electrons from the emitter region to cross over to the base region.

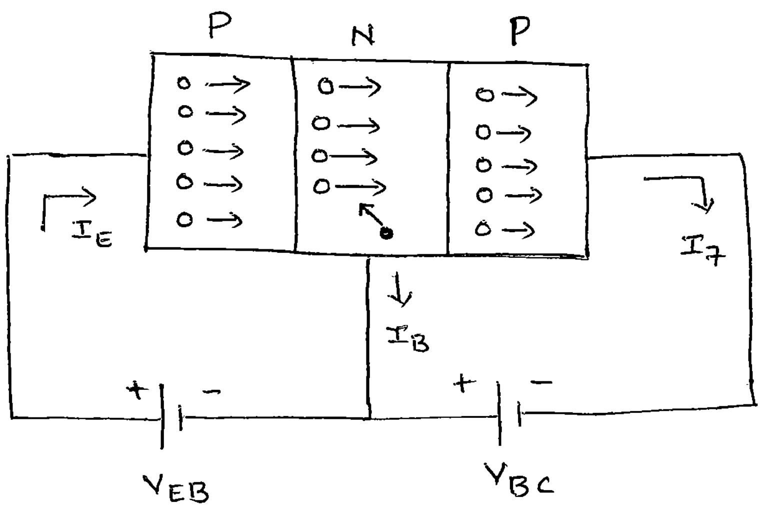
As the base is lightly doped with P-type impurity, the number of holes in the base region is very small and hence the number of electrons that combine with holes in the P-type base region is also very small. Hence a few electrons combine with holes to constitute a base current I_B. The remaining electrons (more than 95%) crossover into the collector region to constitute a collector current (I_C). Thus the base and collector current summed up gives the emitter current. ie

$$I_E = -(I_C + I_B) \quad \left[\because \text{As per KCL} \quad I_C + I_B + I_E = 0 \right]$$

In the external circuit of the NPN bipolar junction transistor, the magnitudes of emitter current I_E, the base current I_B and the collector current I_C are related by

$$\boxed{I_E = I_C + I_B}$$

Operation of PNP Transistor :-



As shown in figure above, the forward bias applied to the emitter base junction of a PNP transistor causes a lot of holes from the emitter region to crossover to the base region.

As the base is lightly doped with N-type impurity, the number of electrons in the base region are very small and hence the number of holes combined with electrons in the N-type region is also very small. Hence a few holes combined with electrons to constitute a base current I_B. The remaining holes (more than 95 %) cross over in to the collector region to constitute a collector current I_C. Thus the collector and base current when summed up gives the emitter current

$$\text{ie} \quad I_E = -(I_C + I_B)$$

In the external circuit of the PNP bipolar junction transistor, the magnitudes of the emitter current I_E, the base current I_B and the collector current I_C are related by

$$\boxed{I_E = I_C + I_B}$$

<u>current components in a transistor</u>:

The figure below shows the various current components which flow across the forward biased emitter junction and reverse biased collector junction in P.N.P Transistor.

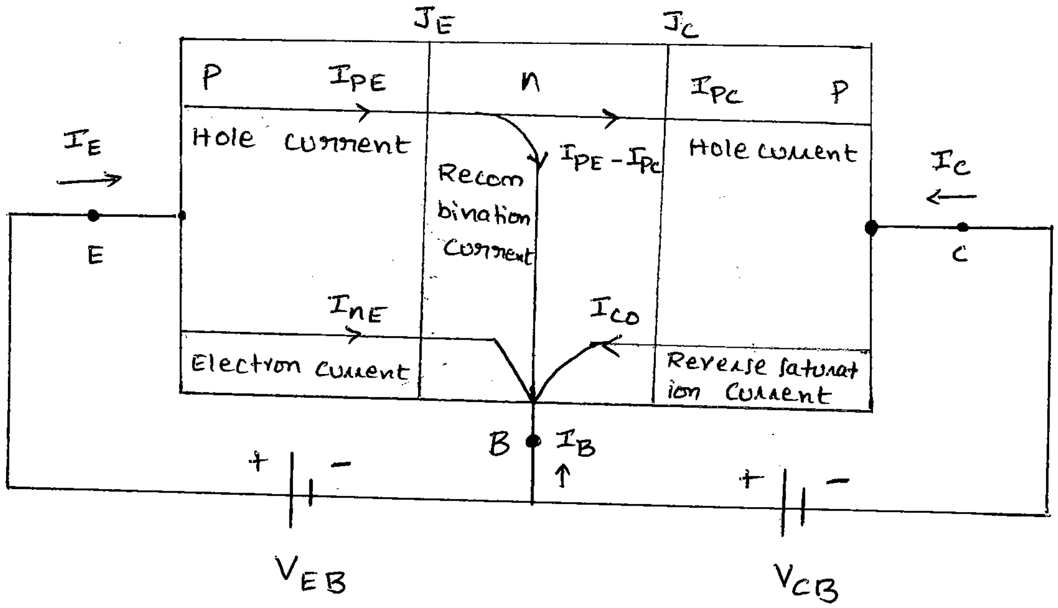


Figure: current components in a transistor with forward biased emitter and reverse biased collector junctions.

The emitter current consists of the following two parts.

1) Hole current I_{PE} constituted by holes (holes crossing from emitter in to base

2) Electron current I_{nE} constituted by electrons (electrons crossing from base in to the emitter)

Therefore total emitter current

$$I_E = I_{PE}\,(\text{majority}) + I_{nE}\,(\text{minority})$$

The holes crossing the emitter base junction J_E reaching the collector base junction J_C constitutes collector current I_{PC}.

Not all the holes crossing the emitter base junction reach collector base junction J_C

because some of them combine with the electrons in the n-type base

Since base width is very small, most of the holes cross the collector base junction J_C and very few recombine, constituting the base current $(I_{PE} - I_{PC})$

When the emitter is open circuited, $I_E = 0$ and hence $I_{PC} = 0$. Under this condition, the base and collector together current I_C equals the reverse saturation current I_{CO}, which consists of the following two parts.

1) I_{PCO} caused by the holes moving across I_C from N region to P region

2) I_{nCO} caused by electrons moving across I_C from P-region to N-region.

$$\therefore \quad I_{CO} = I_{nCO} + I_{PCO}$$

In general $\quad I_C = I_{nC} + I_{PC}$

thus for a PNP Transistor

$$\boxed{I_E = I_B + I_C}$$

Transistor circuit configurations:

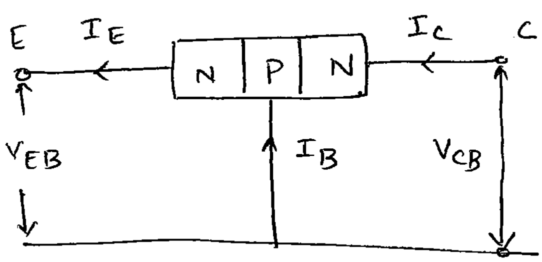
Basically there are three types of circuit connections for operating a transistor.

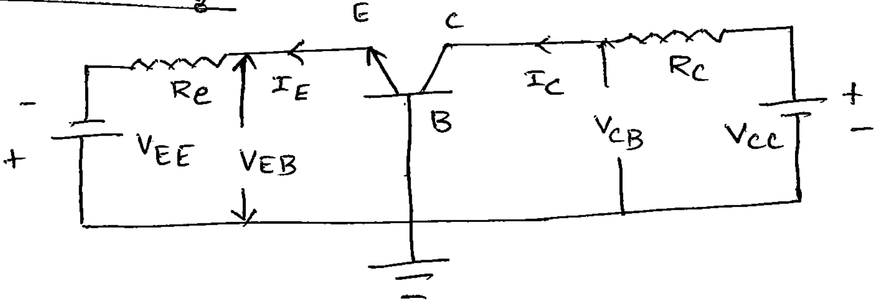
1. Common base configuration (CB)
2. common emitter configuration (CE)
3. common collector configuration (CC)

1. CB configuration:

This is also called grounded base configuration. In this configuration, emitter is the input terminal, collector is the output terminal and base is the common terminal.

The input signal is applied between the emitter and base where as output is taken out from the collector and base, thus emitter current is the input current and collector current is the output current.





The ratio of collector current to emitter current is called <u>dc current gain</u> (α_{dc} or α) of a transistor

$$\alpha = -\frac{I_c}{I_E} \Rightarrow \boxed{I_c = -\alpha I_E}$$

The negative sign indicates that emitter and collector currents flow in opposite direction (ie. the conventional emitter current flows out and collector current enters in to the transistor)

Thus α of a transistor is a measure of the quality of a transistor, higher the value of α, better the transistor in the sense that the collector current more closely equal to the emitter current. Its value ranges from 0.98 to ~~0.99~~. 0.985.

For simplicity $I_c = \alpha I_E$

we know that $I_E = I_c + I_B$

$$I_B = I_E - \alpha I_E$$

$$\boxed{I_B = (1-\alpha) I_E}$$

ac current gain $\alpha_{ac} = \frac{-\Delta I_c}{\Delta I_E}$

(It refers to the change in collector current to change in emitter current)

<u>Total collector current</u> :-

The whole emitter current does not reach the collector because a small percentage of electron hole combination occuring in the base area it gives rise to base current. Due to reverse biasing of collector base junction wide depletion region is formed across it, this depletion region helps the minority carriers of base (electrons) to cross the collector base junction, thus more collector current flows in addition to this leakage current (I_{CBO}) therefore total collector current is given by

$$I_C = \alpha I_E + I_{CBO}$$

where I_{CBO} = leakage current. Hence it is very small hence it is neglected in circuit calculation.

Characteristics of CB Configuration :-

The circuit diagram for determining the static characteristics of an NPN Transistor in the common base configuration is shown in figure below.

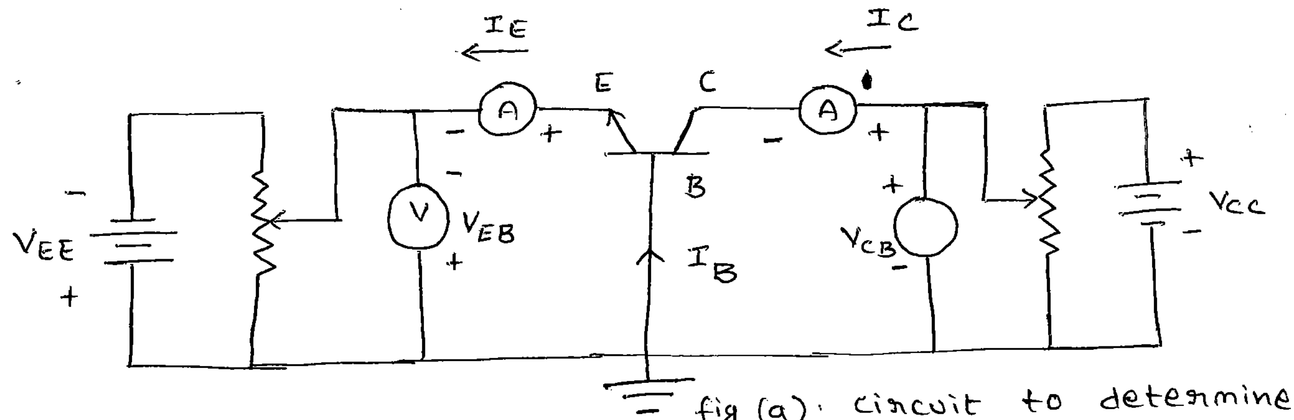


fig (a): circuit to determine CB static characteristics

Input characteristics :-

To determine the input characteristics the collector base voltage V_{CB} is kept constant at zero volt and the emitter current I_E is increased from zero in suitable equal steps by increasing V_{EB}

This is repeated for higher fixed values of V_{CB}. A curve is drawn between emitter current (I_E) and emitter base voltage (V_{EB}) at constant collector base voltage (V_{CB}). The input characteristics thus obtained are shown in figure below.

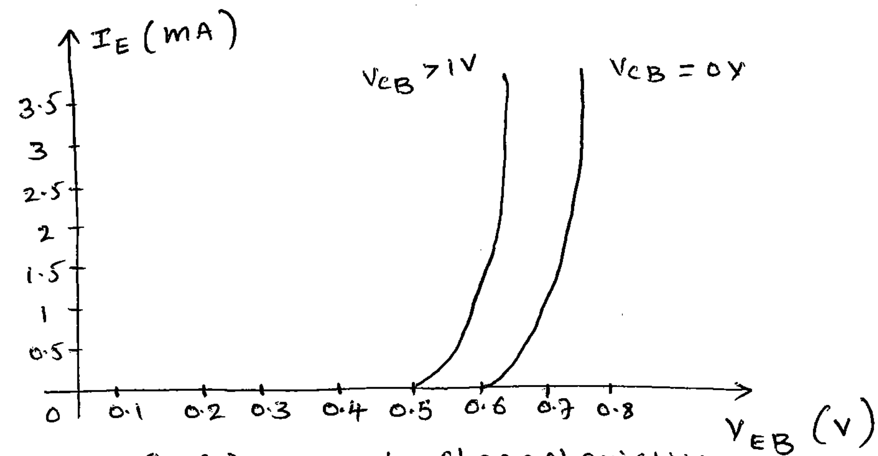


fig (b): Input Characteristics

When V_{CB} is equal to zero and the emitter base junction is forward biased as shown in the characteristics, the junction behaves as a forward biased diode so that emitter current (I_E) increases rapidly with small increase in emitter base voltage (V_{EB})

When V_{CB} is increased keeping V_{EB} constant, the width of the base region will decrease. This effect results in an increase of I_E. Therefore the curve shift ~~two~~ towards the left as V_{CB} is increased.

Output Characteristics :- To determine the output characteristics, the emitter current I_E is kept constant at a suitable value by adjusting the

the emitter - base voltage (V_{EB}). Then V_{CB} is increased in suitable equal steps and the collector current I_C is noted for each value of I_E. This is repeated for different fixed values of I_E. Now the curves of I_C versus V_{CB} are plotted for constant values of I_E and the output characteristics thus obtained is shown in figure below.

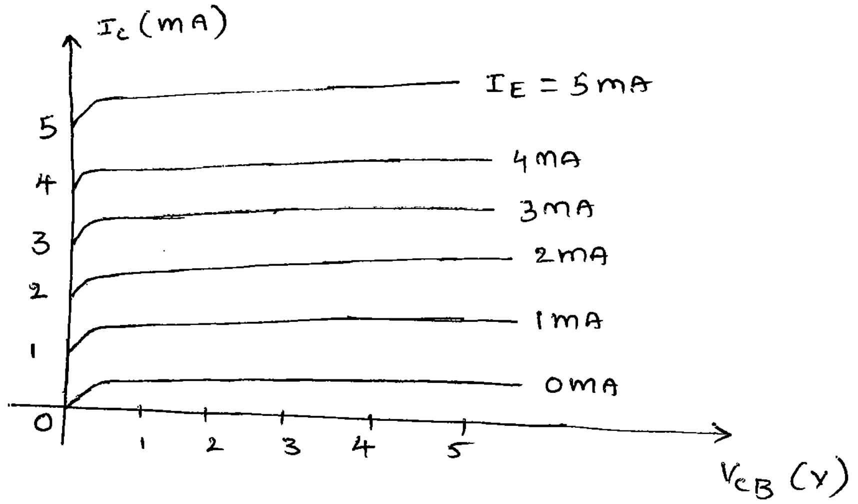


fig c:- CB output characteristics

From the characteristics, it is seen that for a constant value of I_E, I_C is independent of V_{CB} and the curves are parallel to the axis of V_{CB}.

I_C flows even when V_{CB} is equal to zero. As the emitter base junction is forward biased, the majority carriers ie electrons, from the emitter are injected in to the base region. Due to the action of the internal potential barrior at the reverse biased collector base junction, they flow to the collector region and gives rise to I_C even when V_{CB} is equal to zero.

Early effect or base-width modulation :-

As the collector voltage V_{cc} is made to increase the reverse bias, the depletion region width between collector and base tends to increase, with the result that the effective width of the base decreases. This dependency of base width on collector to emitter voltage is known as the 'Early Effect'. This decrease in effective base-width has three consequences.

(1) There is a less chance for recombination within the base region. Hence α increases with increasing $|V_{CB}|$

(2) The charge gradient is increased within the base, and consequently, the current of minority carriers injected across the emitter junction increases.

(3) For extremely large voltages, the effective base width may be reduced to zero, causing voltage break down in the transistor. This phenomenon is called the "punch through."

For higher values of V_{CB}, due to Early effect, the value of α increases. for example α changes from 0.98 to 0.985. Hence there is a very small positive slope in the CB output characteristics and hence the output resistance is not zero.

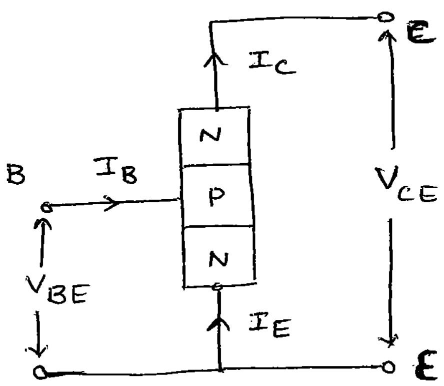
2) Common emitter configuration (CE):

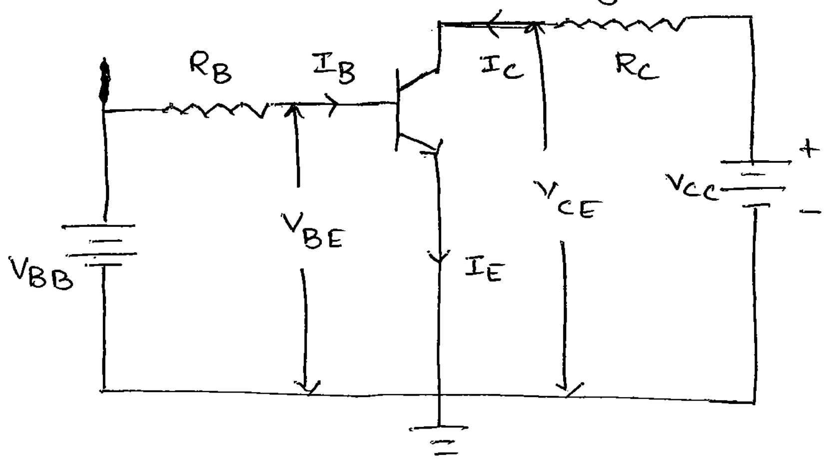
CE configuration means the emitter terminal is common to the input and output. In this case input signal is applied between the base and emitter and output signal is taken out from the collector and emitter terminals.

The ratio of dc collector current (output) to the dc base current (input) is called the dc current gain (β_{dc} or β).

$$\beta = \frac{I_C}{I_B}$$

The collector current of a transistor is much larger than the base current. Therefore the value of β is much greater than unity.





Relation between α and β :-

$$\beta = \frac{I_C}{I_B} \quad \text{and} \quad \alpha = \frac{I_C}{I_E} \Rightarrow \frac{\beta}{\alpha} = \frac{I_E}{I_B}$$

we know that $I_B = I_E - I_C$

$$\therefore \quad \beta = \frac{I_C}{I_E - I_C} = \frac{\frac{I_C}{I_E}}{1 - \frac{I_C}{I_E}} = \frac{\alpha}{1-\alpha}$$

so $\boxed{\beta = \frac{\alpha}{1-\alpha}}$ from this we can calculate for α

$$\therefore \quad \boxed{\alpha = \frac{\beta}{1+\beta}}$$

Total collector current :-

In CE configuration I_B is the input current and I_C is the output current.

we know that $I_E = I_C + I_B$

but $I_C = \alpha I_E + I_{CBO}$

$$I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$I_C (1-\alpha) = \alpha I_B + I_{CBO}$$

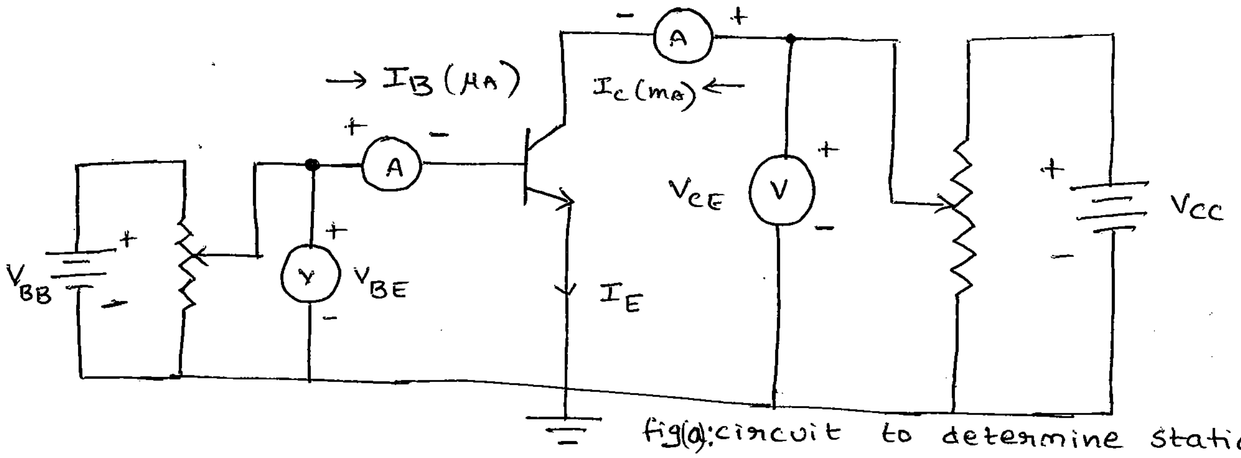
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$I_C = \beta I_B + I_{CEO}$$

where $\beta = \frac{\alpha}{1-\alpha}$, I_{CEO} = Leakage current in CE configuration

$$\therefore \quad \boxed{I_C = \beta I_B + I_{CEO}}$$

Common Emitter Configuration (CE) Characteristics :-

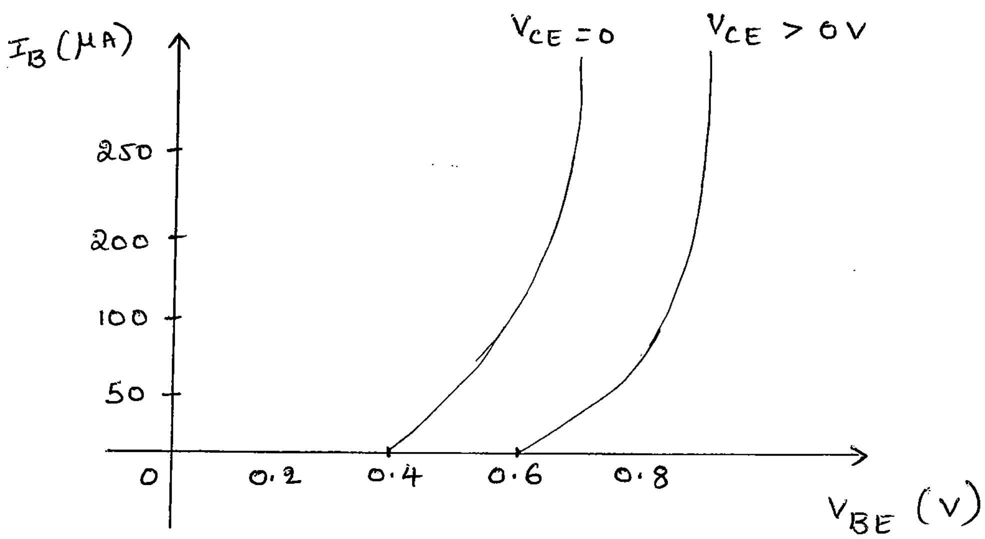


fig(a): circuit to determine static char's in CE configuration

The circuit diagram for determining the static characteristics curves of an NPN transistor in the common Emitter configuration is shown in figure above.

Input characteristics :-

To determine the input characteristics, the collector to emitter voltage is kept constant at zero volt and base current is increased from zero in equal steps by increasing V_{BE} in the circuit shown in fig(a).



fig(b): CE input characteristics.

The value of V_{BE} is noted for each setting of I_B. This procedure is repeated for higher fixed values of V_{CE}, and the curves of I_B Vs V_{BE} are drawn. The input characteristics thus obtained are shown in ~~above~~ fig (b).

When $V_{CE} = 0$, the emitter - base junction is forward biased and the junction behaves as a forward biased diode. Hence the input characteristic for $V_{CE} = 0$ is similar to that of a forward-biased diode.

When V_{CE} is increased, the width of the depletion region at the reverse biased collector - base junction will increase. Hence the effective width of the base will decrease. This effect causes a decrease in the base current (I_B). Hence to get the same value of I_B as that for $V_{CE} = 0$, V_{BE} should be increased. Therefore the curve shifts to the right as V_{CE} increases.

Output Characteristics :-

To determine the output characteristics, the base current I_B is kept constant at a suitable value by adjusting base - emitter voltage V_{BE}.

The magnitude of collector - emitter voltage (V_{CE}) is increased in suitable equal steps from zero and the collector current I_C is noted for each setting of V_{CE}. Now the curves of I_C versus V_{CE} are plotted for different constant values of I_B. The output characteristics thus obtained are shown in fig (c) below

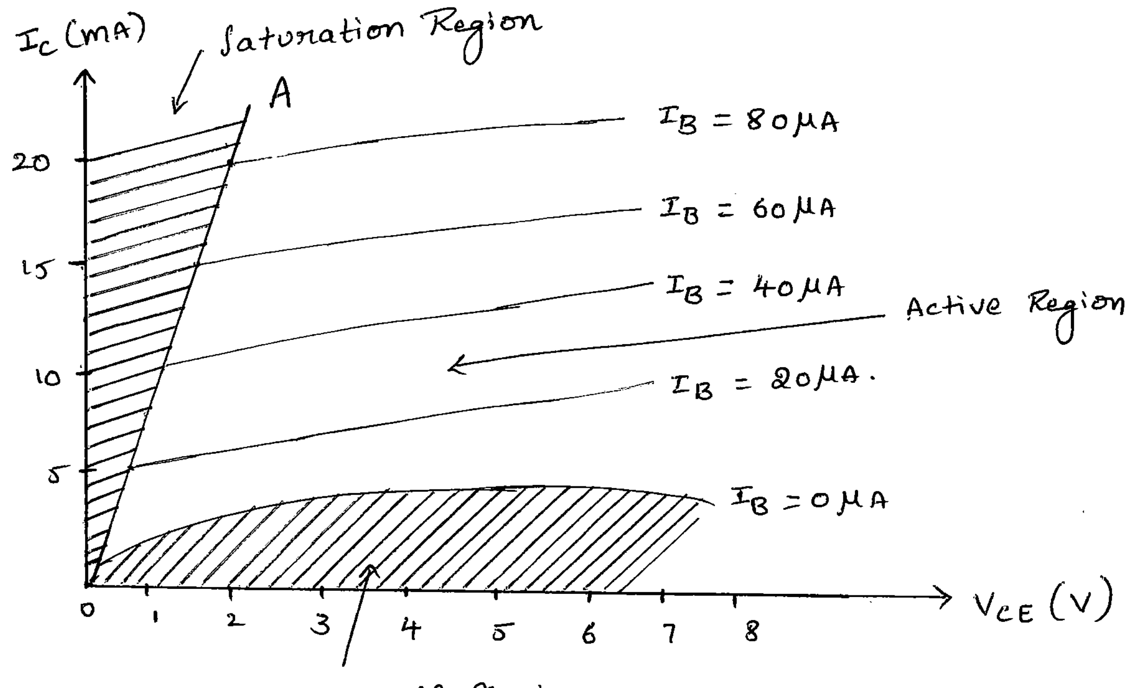


fig c: output characteristics.

we know that $\beta = \frac{\alpha}{1-\alpha}$

For larger values of V_{CE}, due to early effect, a very small change in α is reflected in a very large change in β.

For example $\alpha = 0.98$ then $\beta = \frac{0.98}{1-0.98} = 49$

If α increases to 0.985, then $\beta = \frac{0.985}{1-0.985} = 66$.

Here a slight increase in α by about 0.5% results in an increase in β by about 34%.

Hence the output characteristics of CE configuration show a larger slope when compared with CB configu-ration.

The output characteristics have three regions

1. Saturation region
2. cut off region
3. Active region.

① Saturation Region :-

The region of curves to the left of the line OA is called the saturation region (hatched) and the line OA is called the saturation line. In this region both junctions are forward biased and an increase in base current doesn't cause a corresponding large change in I_C. The ratio of $V_{CE(sat)}$ to I_C in this region is called Saturation resistance.

② cut-off region :-

The region below the curve for $I_B = 0$ is called the cut-off region (hatched) In this region both junctions are reverse biased. When the operating point for the transistors enter the cut-off region, the transistor is off. Hence the collector current becomes almost zero and the collector voltage almost equals V_{CC}. The transistor is virtually an open circuit between collector and emitter.

3) Active Region:-

The central region where the curves are uniform in spacing and slope is called the 'active region (un hatched). In this region emitter base junction is forward biased and the collector base junction is reverse biased. If the transistor is to be used ~~operated~~ as a linear amplifier, it should be operated in the active region.

→ If the base current is subsequently driven large and positive, the transistor switches in to the saturation region via the active region.

→ In this ON condition large collector current flows and collector voltage falls to a very low value called $V_{CE\,sat}$, typically around 0.2 V for a Si transistor. The transistor is virtually a short circuit in this state.

Transistor parameters:-

The slope of the CE characteristics will give the following four transistor parameters. Since these parameters have different dimensions they are commonly known as common emitter hybrid parameters or h parameters.

3) Common collector configuration (CC) :-

CC configuration means the collector terminal is common to the input and output. In this case input signal is applied between the base and collector and output signal is taken out from the emitter and collector terminals.

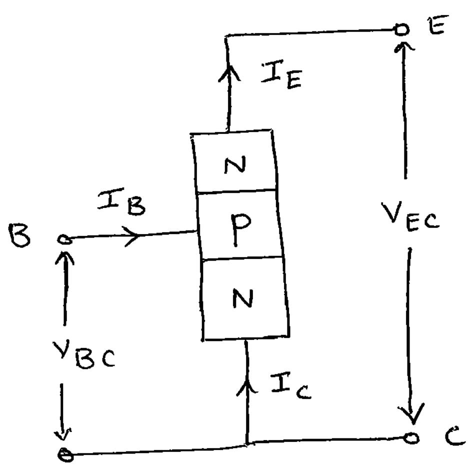
The ratio of emitter current (~~input~~ output) to the base current (~~output~~ input) is called the dc current gain (γ_{dc} or γ).

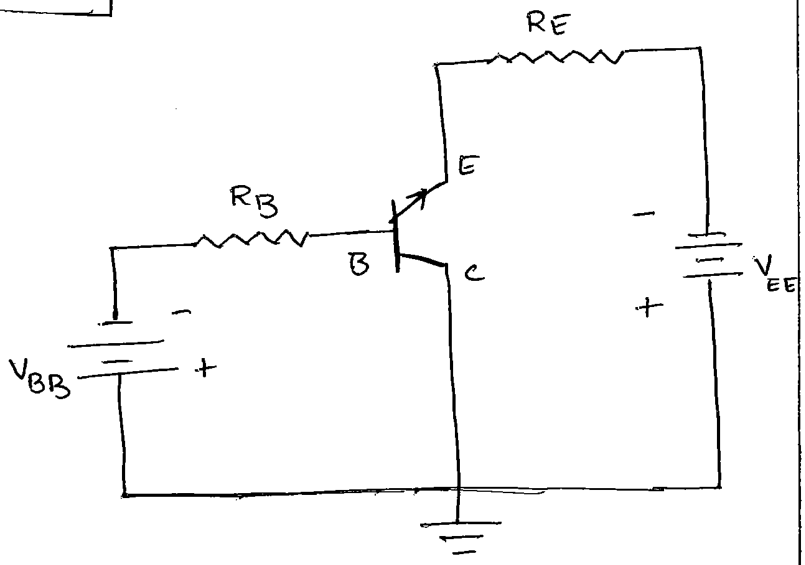
$$\therefore \quad \gamma = \frac{I_E}{I_B}$$

$$\gamma = \frac{I_E}{I_B} = \frac{I_E}{I_C}\,\frac{I_C}{I_B} = \frac{1}{\alpha}\cdot\beta = \frac{\beta}{\alpha}$$

$$\gamma = \frac{\beta}{\alpha} = \frac{\beta}{\beta/1+\beta} = 1+\beta$$

$$\therefore \quad \boxed{\gamma = \frac{1}{1-\alpha} = 1+\beta}$$





Total Emitter current :

we know that $I_C = \alpha I_E + I_{CBO}$

and $I_E = I_C + I_B$

$$I_E = I_B + \alpha I_E + I_{CBO}$$

$$I_E(1-\alpha) = I_B + I_{CBO}$$

$$I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$I_E = (\beta+1) I_B + (\beta+1) I_{CBO}$$

Characteristics of CC configuration :-

The circuit diagram for determining the static characteristics of an NPN transistor in the common collector configuration. is shown in figure below.

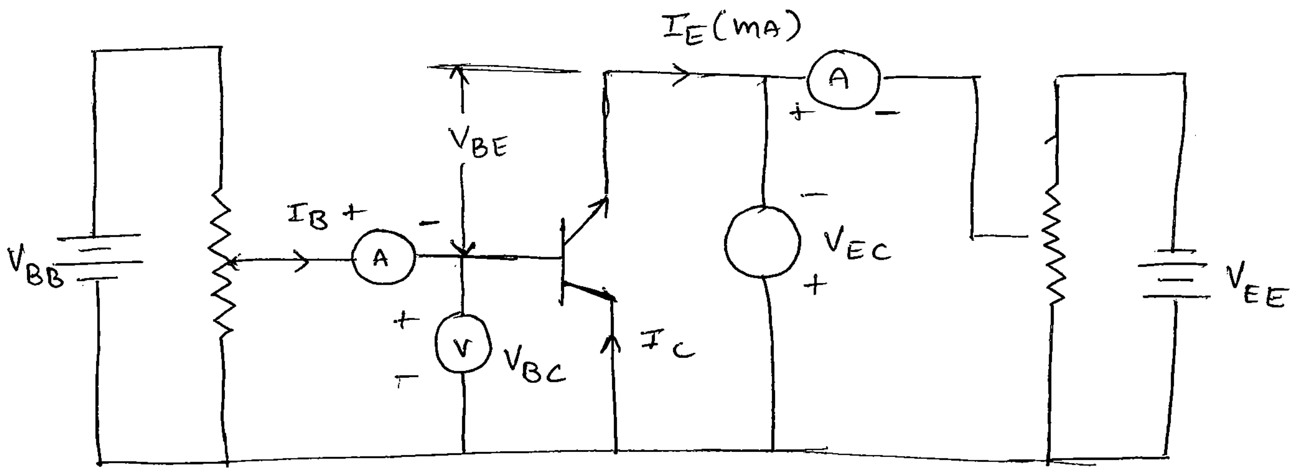
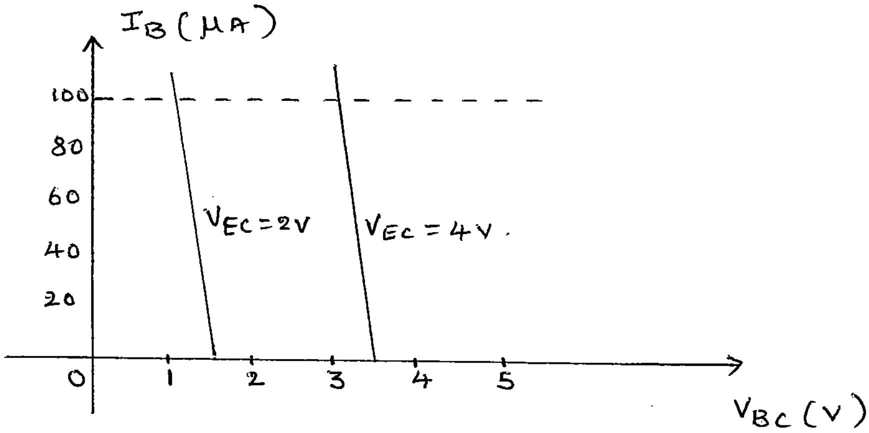


fig (a) circuit to determine CC static char's

Input Characteristics :-

To determine the input characteristics V_{EC} is kept at a suitable fixed value.

then V_{BC} is increased in equal steps and the corresponding increase in I_B is noted. This is repeated for different fixed values of V_{EC}. The input characteristics are plotted below.



fig(b) : CC input characteristics

The common collector input characteristics are different from CB and CE configurations. The difference is due to the fact that V_{BC} is determined by V_{EC}. This is because when the transistor is biased on, V_{BE} remains around 0.7 V, (for Si) and 0.3 for Ge and V_{EC} may be much larger than 0.7V

from fig(a) $V_{EC} = V_{BC} + V_{BE}$

$$V_{BE} = V_{EC} - V_{BC}$$

If $V_{EC} = 2V$ at $I_B = 100\mu A$ then

$$V_{BC} = V_{EC} - V_{BE} = 2 - 0.7 = 1.3V.$$

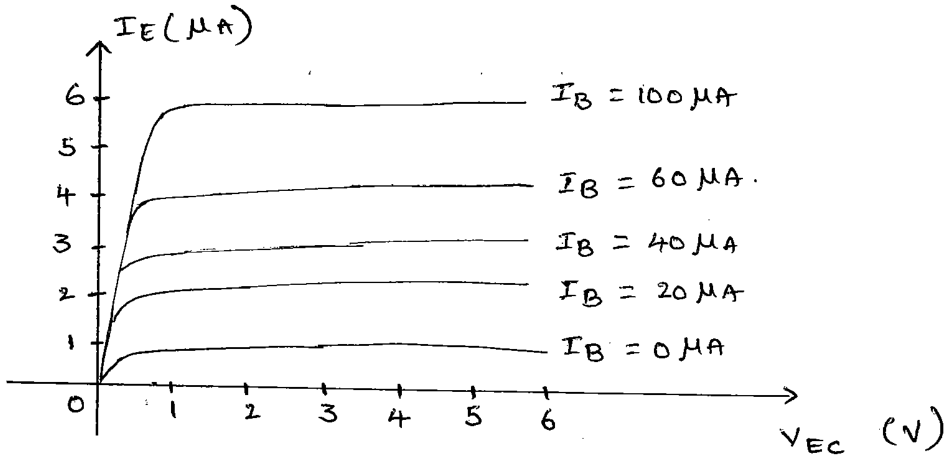
Suppose V_{EC} is maintained constant at 2V, while the input voltage V_{BC} is increased to 1.5V then V_{BE} is reduced to 0.5V. Because of V_{BE} is reduced,

I_B is reduced from 100μA to zero.

Output characteristics :

The cc output characteristics are plotted, I_E versus V_{EC} for several fixed values of I_B.

we know that the CE output characteristics are plotted b/n I_C and V_{CE}. since I_C is approximately equal to I_E thus cc o/p characteristics is identical to CE output characteristics.



fig(c): cc output characteristics.

Current Amplification factor :-

In a transistor amplifier with a.c input signal, the ratio of change in output current to the change in input current is known as the current amplification factor.

In the CB configuration the current amplification factor $\alpha = \frac{\Delta I_C}{\Delta I_E}$ ⟶ ①

In the CE configuration the current amplification factor $\beta = \frac{\Delta I_C}{\Delta I_B}$ ⟶ ②

In the CC configuration the current amplification factor $\gamma = \frac{\Delta I_E}{\Delta I_B} \longrightarrow (3)$

Relationship between α and β

we know that $\Delta I_E = \Delta I_c + \Delta I_B \longrightarrow (4)$

By definition $\Delta I_C = \alpha \Delta I_E$ (from eq (1))

ie $\Delta I_E = \alpha \Delta I_E + \Delta I_B$

$$\Delta I_B = \Delta I_E (1-\alpha) \longrightarrow (5)$$

Dividing both sides by ΔI_c, we get

$$\frac{\Delta I_B}{\Delta I_c} = \frac{\Delta I_E}{\Delta I_c}(1-\alpha)$$

$$\Rightarrow \frac{1}{\beta} = \frac{1}{\alpha}(1-\alpha) \Longrightarrow \beta = \frac{\alpha}{1-\alpha}$$

Re arranging we also get $\alpha = \frac{\beta}{1+\beta}$ (or) $\frac{1}{\alpha} - \frac{1}{\beta} = 1$

From this relationship, it is clear that as α approaches unity, β approaches infinity. The CE configuration is used for almost all transistor applications because of its high current gain β.

<u>Relation among α, β and γ</u> :

In the CC transistor amplifier circuit, I_B is the input current and I_E is the output current.

from eq (3) $\gamma = \frac{\Delta I_E}{\Delta I_B}$

Substituting $\Delta I_B = \Delta I_E - \Delta I_c$, we get

$$\gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C} \longrightarrow (6)$$

~~Diving &~~ Dividing the numerator and denominator of eq (6) by ΔI_E, we get

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{1}{1-\alpha}$$

$$\therefore \quad \gamma = \frac{1}{1-\alpha} \longrightarrow (7)$$

$$\gamma = \frac{1}{1-\alpha} = \frac{1}{1 - \frac{\beta}{1+\beta}} = \frac{1+\beta}{1+\beta-\beta} = 1+\beta$$

$$\therefore \quad \boxed{\gamma = \frac{1}{1-\alpha} = 1+\beta}$$

Comparison of CB, CE and CC configurations

Property	CB	CE	CC
Input resistance	Low (about 100 Ω)	Moderate (about 750 Ω)	High (750)
Output resistance	High (450 KΩ)	Moderate (45 KΩ)	Low (25 Ω)
Current gain	1	High	High
Voltage gain	About 150	About 500.	Less than 1
phase shift b/n i/p and o/p voltages	0 (or) 360°	180°	0 (or) 360°
Applications	For high frequency circuits	for audio frequency ckts	For impedance matching

BJT specifications :-

In different conditions such as active, saturation and cut-off there are different junction voltages. The junction voltages for a typical npn transistor at 25°c are given in the table below.

Type	$V_{CE\,sat}$	$V_{BE\,sat}$	$V_{BE\,active}$	$V_{BE\,cut\,in}$	$V_{BE\,cutoff}$
Si	0.3	0.7	0.7	0.5	0.0
Ge	0.1	0.3	0.3	0.1	-0.1

The junction voltages in the above table are appropriate for an npn transistor. For pnp transistor the signs of all entries should be reversed.

TRANSISTOR AS AN AMPLIFIER

A load resistor R_L is connected in series with the collector supply voltage V_{CC} of CB transistor configuration as shown in Fig. 3.16.

A small change in the input voltage between emitter and base, say ΔV_i, causes a relatively larger change in emitter current, say ΔI_E. A fraction of this change in current is collected and passed through R_L and is denoted by symbol α'. Therefore the corresponding change in voltage across the load resistor R_L due to this current is $\Delta V_o = \alpha' R_L \, \Delta I_E$.

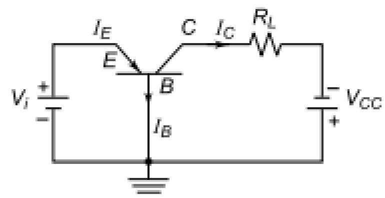


Fig. 3.16 Common Base Transistor Configuration

Here, the voltage amplification $A_v = \dfrac{\Delta V_o}{\Delta V_i}$ is greater than unity and thus the transistor acts as an amplifier.

NEED FOR BIASING

Biasing in amplifiers sets the static dc voltage and current levels on a transistor at a point (called quiescent point or Q-point) where they can be made to vary with an input signal without going into saturation or cut-off.

In order to produce distortion-free output in amplifier circuits, the supply voltages and resistances in the circuit must be suitably chosen. These voltages and resis-

tances establish a set of dc voltage V_{CEQ} and current I_{CQ} to operate the transistor in the active region. These voltages and currents are called *quiescent values* which determine the *operating point* or Q-point for the transistor. The process of giving proper supply voltages and resistances for obtaining the desired Q-point is called *biasing*. The circuits used for getting the desired and proper operating point are known as *biasing circuits*.

The collector current for common-emitter amplifier is expressed by

$$I_C = \beta I_B + I_{CEO} = (1 + \beta)I_{CO}$$

Here the three variables h_{FE} i.e. β, I_B and I_{CO} are found to increase with temperature. For every 10°C rise in temperature, I_{CO} doubles itself. When I_{CO} increases, I_C increases significantly. This causes power dissipation to increase and hence to make I_{CO} increase. This will cause I_C to increase further and the process becomes cumulative which will lead to thermal runaway that will destroy the transistor. In addition, the quiescent operating point can shift due to temperature changes and the transistor can be driven into the region of saturation. The effect of β on the Q-point is shown in Fig. 5.1. One more source of bias instability is to be considered due to the variation of V_{BE} with temperature. V_{BE} is about 0.6 V for a silicon transistor and 0.2 V for a germanium transistor at room temperature. As the temperature increases, $|V_{BE}|$ decreases at the rate of 2.5 mV/°C for both silicon and germanium transistors. The transfer characteristic curve shifts to the left at the rate of 2.5 mV/°C (at constant I_C) for increasing temperature and hence the operating point shifts accordingly. To establish the operating point in the active region, compensation techniques are needed.

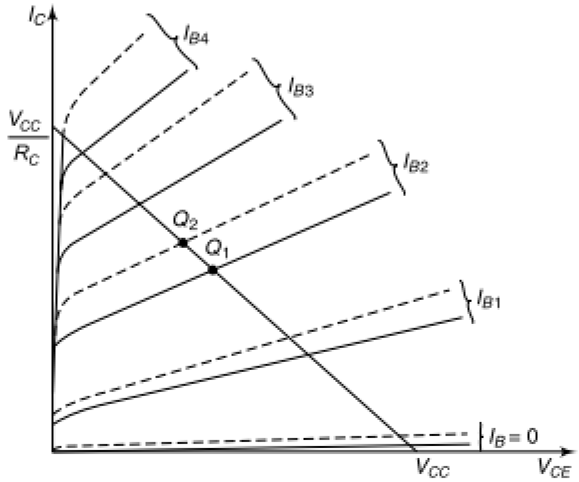


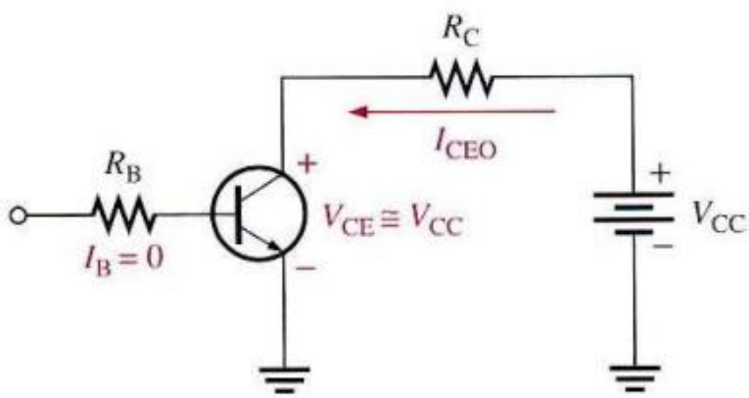
Fig. 5.1

EXPLAIN HOW TRANSISTOR ACTS AS A SWITCH

Cutoff

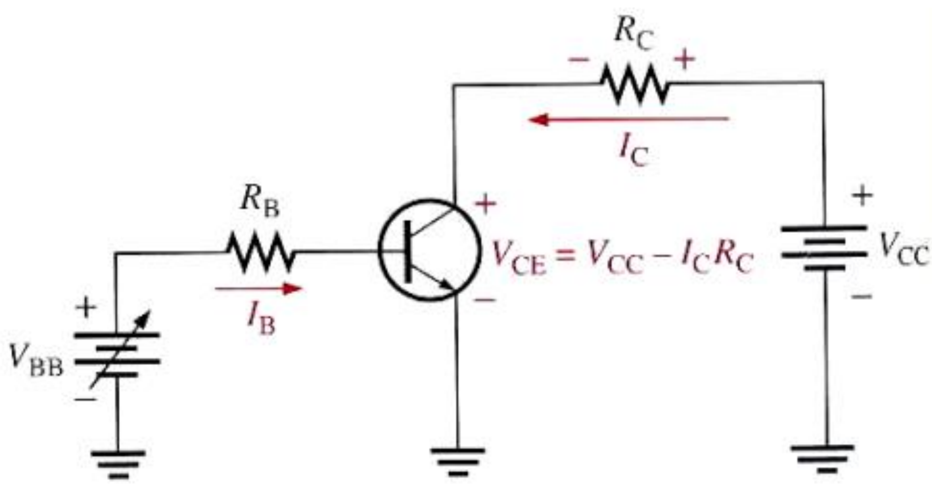
When $I_B = 0$, the transistor is in the cutoff region of its operation. This is shown in Figure with the base lead open, resulting in a base current of zero.

Under this condition, there is very small of collector leakage current, I_{CEO}, due mainly to thermally produced carriers. Because, I_{CEO} is extremely small, it will usually be neglected in circuit analysis so that $V_{CE} = V_{CC}$. Moreover, in cutoff mode, both the base-emitter and the base-collector junction are reverse-biased.

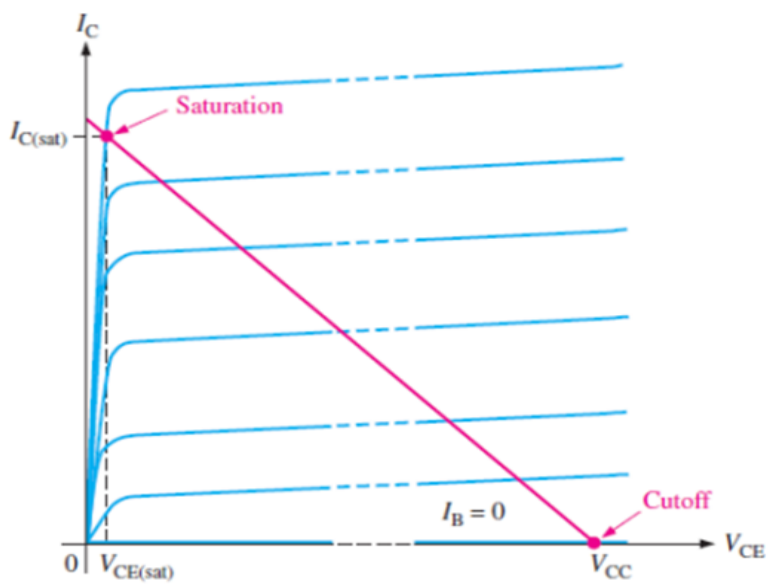


Saturation

When the base-emitter junction becomes forward-biased and the base-current is increased, the collector current also increases and V_{CE} decreases as a result of more drop across the collector resistor ($V_{CE} = V_{CC} - I_C R_C$). This is illustrated in Figure . When V_{CE} reaches its saturation value, $V_{CE(sat)}$, the base-collector junction becomes forward-biased and I_C can increase no further even with a continued increase in I_B. And $V_{CE(sat)}$ is usually only 0.2 – 0.3 V for silicon transistors.



R_C
I_C
R_B
$V_{CE} = V_{CC} - I_C R_C$
V_{CC}
I_B
V_{BB}



I_C
Saturation
$I_{C(sat)}$
$I_B = 0$
Cutoff
V_{CE}
0
$V_{CE(sat)}$
V_{CC}

The Transistor as a Switch

The basic operation as a switching device is illustrated in Figure 4.24. In part (a), the transistor is in the cutoff region because the base-emitter junction is not forward-biased. In this condition, there is, ideally, an open between collector and emitter, as indicated by the switch equivalent. In part (b), the transistor is in the saturation region because the base-emitter junction and the base-collector junction are forward-biased and the base current is made large enough to cause the collector to reach its saturation value.

In this condition, there is, ideally, a short between collector and emitter, as indicated by the switch equivalent. Actually, a voltage drop of up to a few tenths of a volt normally occurs, which is the saturation voltage, $V_{CE(sat)}$.

Conditions in Cutoff:

As mentioned before, a transistor is in the cutoff region when the base-emitter junction it not forward-biased. Neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}. Or $V_{CE(cutoff)} = V_{CC}$

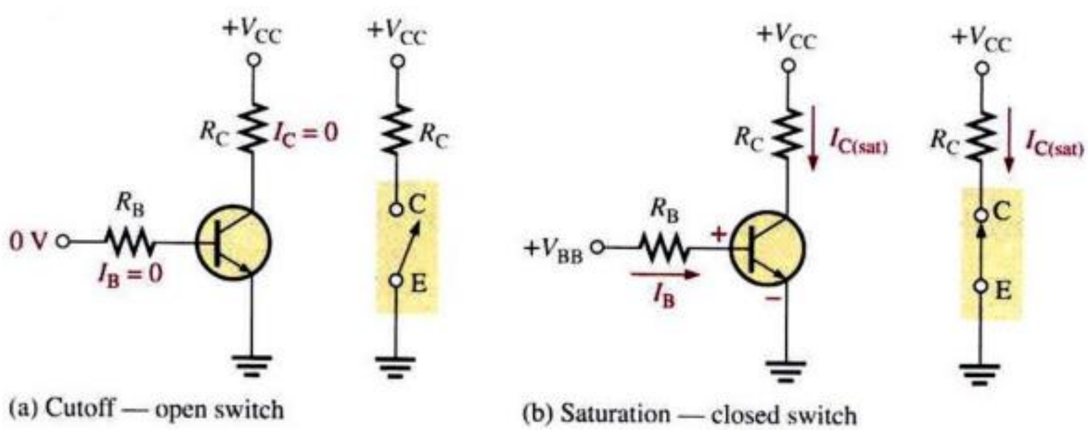


Figure 4.24 Switching action of an ideal transistor. [5]

Conditions in Saturation:

When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated. The formula for collector saturation current is

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C},$$

since $V_{CE(sat)}$ is very small and can usually be neglected

The minimum value of base current needed to produce saturation is

$$I_{B(\min)} = \frac{I_{C(\mathrm{sat})}}{\beta_{DC}}$$

I_B should be significantly greater than $I_{B(min)}$ to keep the transistor well into saturation.

Name of the Subject: Name of the Faculty: C. Ashok Kumar Topic:	Unit No: 4 Lecture No: Link to Session Planner (SP):S.No.... of SP Book Reference: Date Conducted: Page No: 1

CONSTRUCTION:

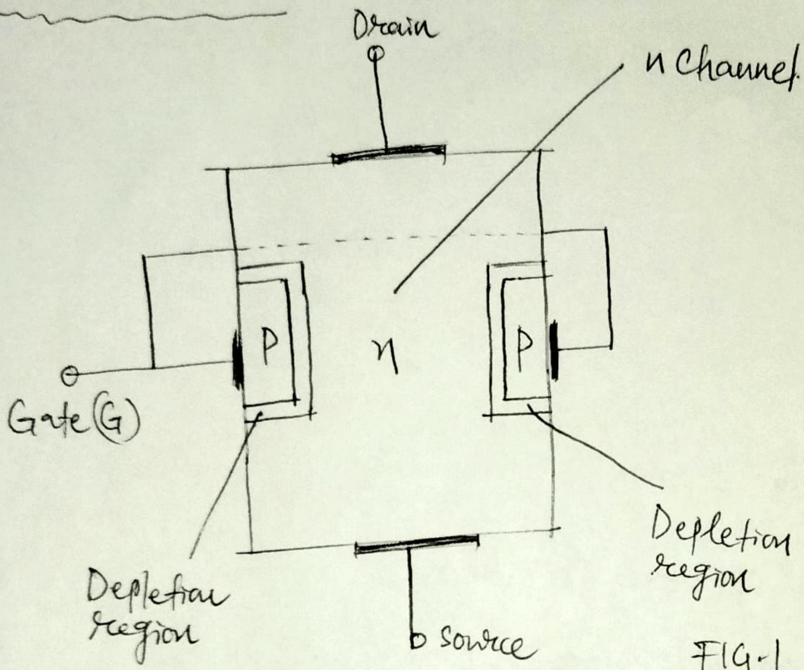


FIG-1

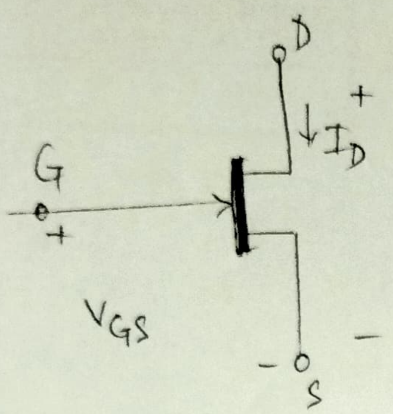
→ Major part of structure is the n-type material, which forms the channel between the embedded layers of p-type material.

→ Top of n-type channel is connected through an ohmic contact to a terminal refered as the drain (D), whereas lower end of same material is connected through an ohmic contact to a terminal refered to as the source (S).

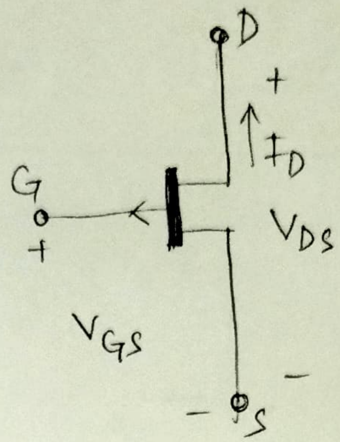
→ The two p-type materials are connected together and to the Gate (G) terminal.

→ In the absence of any applied potentials the JFET has two p-n junctions under no-bias condition. The result is depletion region at each junction as shown in figure.

JFET Symbols



n- Channel JFET



P- Channel JFET

JFET operating Characteristics

There are three basic operating conditions.

1. → $V_{GS} = 0$, V_{DS} increasing to some positive value
2. → $V_{GS} < 0$, V_{DS} at some positive value.
3. → voltage controlled resistor.

1 $V_{GS} = 0$, V_{DS} increasing to some positive value

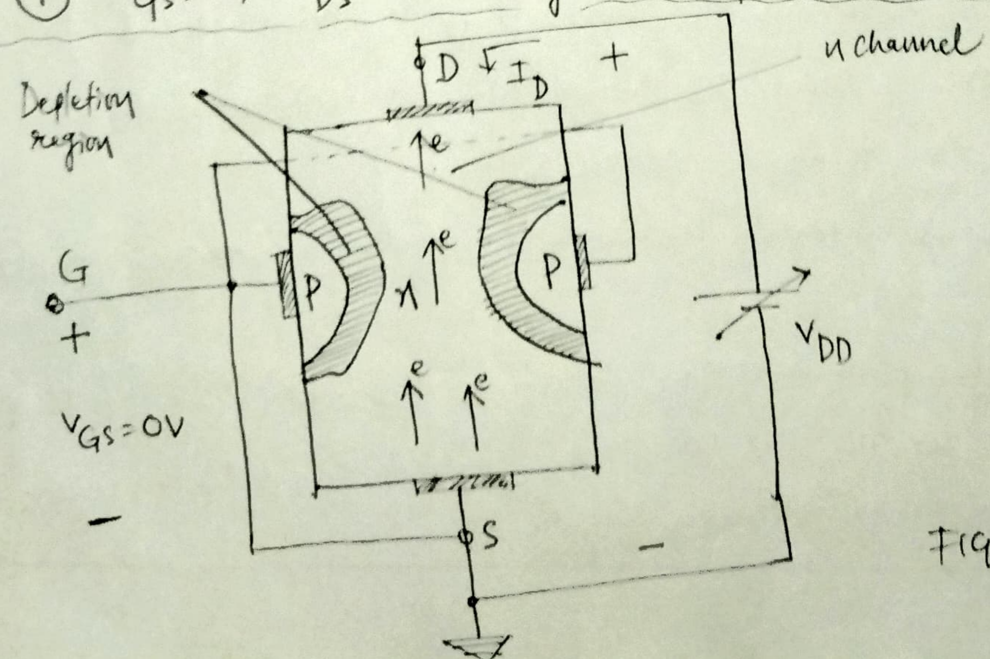


FIG. 2

As shown in Fig, a positive voltage V_{DS} is applied across the channel and gate is connected directly to the source to establish the condition $V_{GS} = 0V$. V_{DS} increased from 0V to few volts, Then,

→ The depletion region between p-gate and n-channel increases

→ Increasing the depletion region, decreases the size of n-channel which increases the resistance of n-channel.

→ Even though, n-channel resistance is increasing, the current (I_D) from source to drain through the n-channel is increasing. This is because V_{DS} is increasing

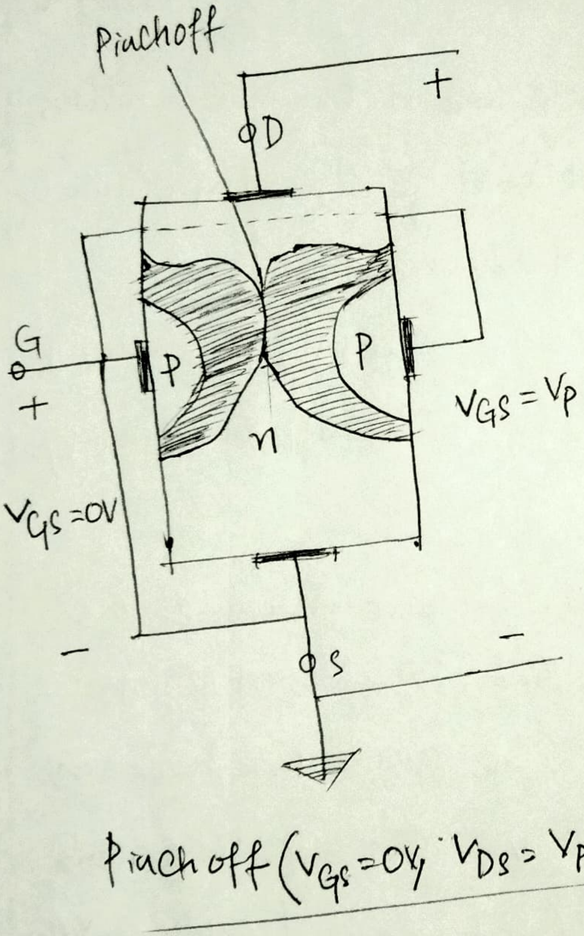
Pinchoff : If $V_{GS} = 0$ and V_{DS} is further increased to a more positive voltage, then it appears that two depletion regions would touch as shown in fig. 3, a condition refered to as Pinchoff will result. The level of V_{DS} that establishes this condition is refered to as pinch-off voltage and denoted by V_P. Depletion regions pinches off the n-channel. Here, I_D does not drop off to zero but instead it maintains the saturation level.

When $V_{DS} > V_P$, level of I_D remains constant (same).

As shown in Fig 4, current is fixed at $I_D = I_{DSS}$.

I_{DSS} = Drain to source current with short-circuit connection from gate to source.

I_{DSS} is maximum drain current for a JFET defined by conditions $V_{GS} = 0V$ and $V_{DS} > |V_P|$



Pinch off ($V_{GS} = 0V$, $V_{DS} = V_P$)

Fig.3

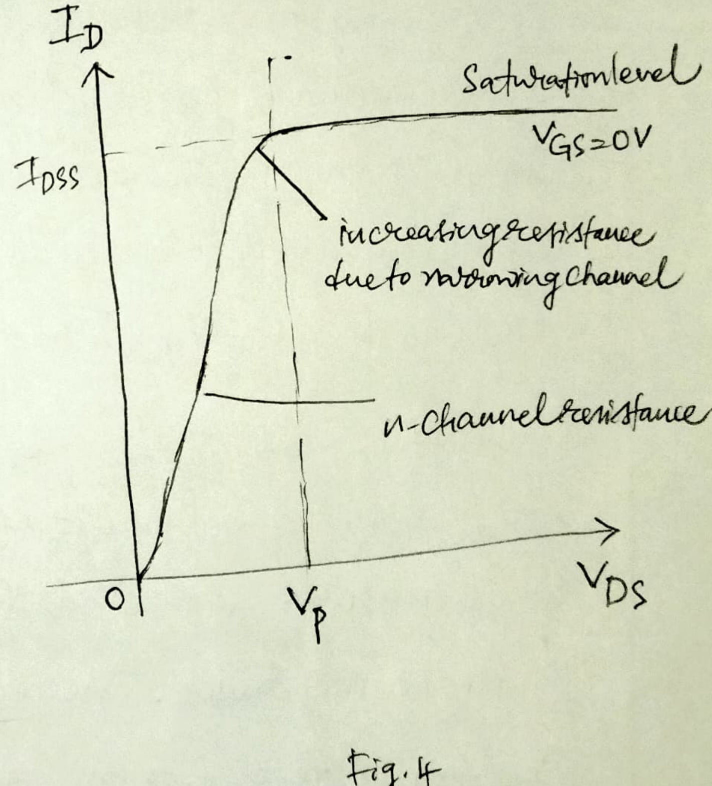


Fig.4

② $V_{GS} < 0$, V_{DS} at some positive value.

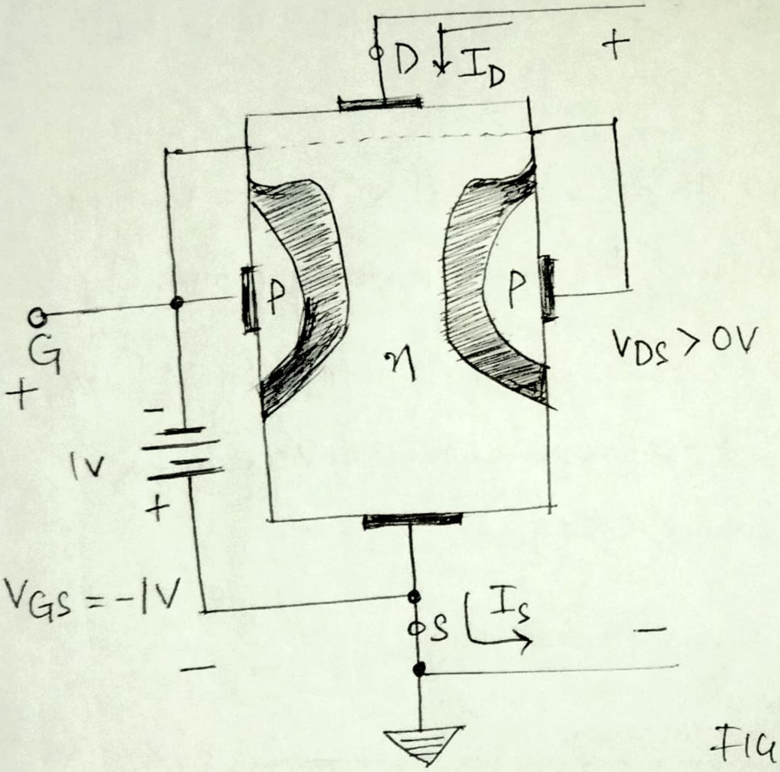


FIG. 5

A negative voltage of −1V is applied between gate and source terminals for a lower level of V_{DS}.

The effect of applied negative bias V_{GS} is to establish depletion regions similar to those obtained with $V_{GS} = 0V$ but at lower levels of V_{DS}.

The result of applying a negative bias to the gate is to reach the saturation level at a lower level of V_{DS} as shown in fig.

Example : If $V_P = 4V$, $V_{DS} = 4V$ when $V_{GS} = 0V$

$V_{DS} = 3V$ when $V_{GS} = -1V$

The resulting saturation level for I_D has been reduced and in fact will continue to decrease as V_{GS} is made more and more negative.

From the Fig. 6, we see that Pinch-off voltage continues to drop in a parabolic manner as V_{GS} becomes more and more negative.

Finally, when $V_{GS} = -V_P$, sufficient negative voltage enough to establish a saturation level that is essentially 0 mA. (I_d)

* The level of V_{GS} that results in $I_D = 0$ mA is defined by $V_{GS} = V_P$, with V_P being a negative voltage for n-channel devices and a positive voltage for P-channel JFETs.

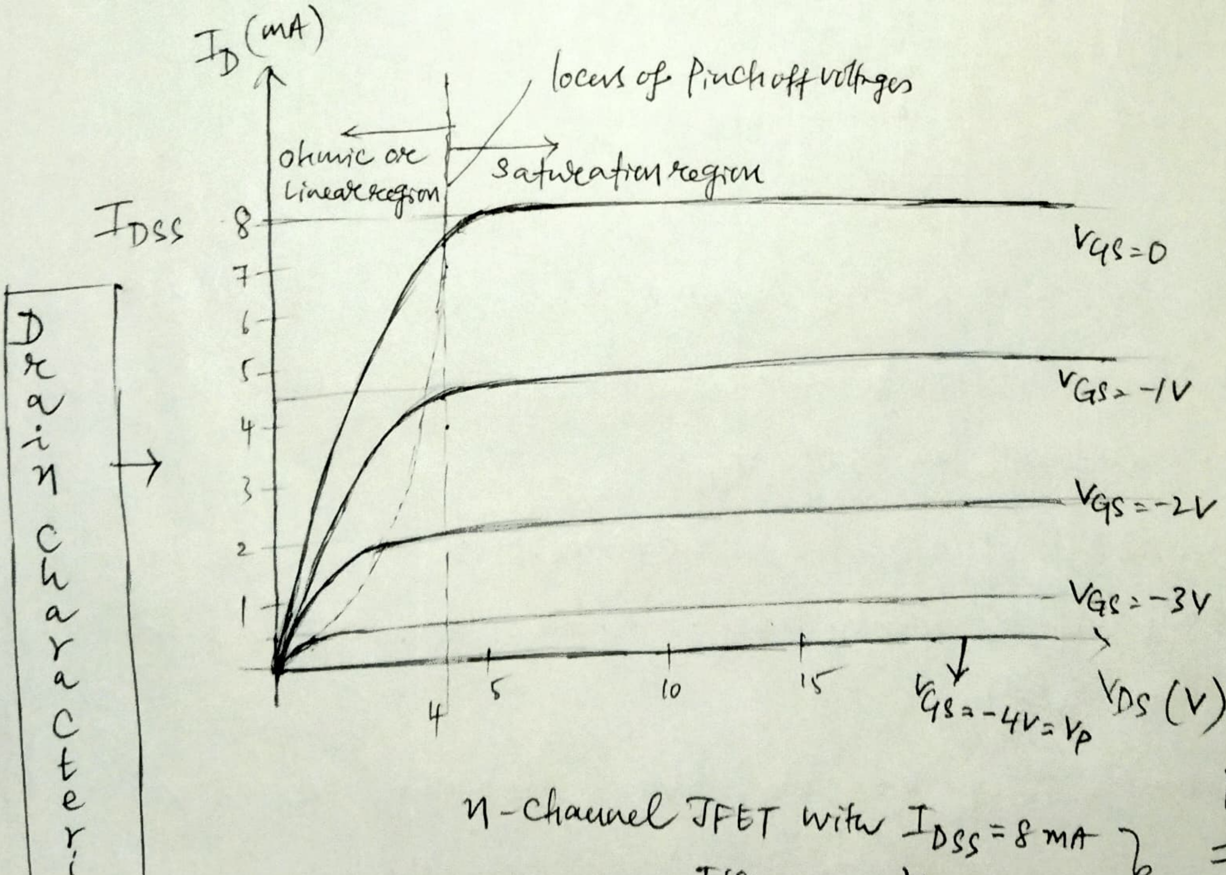


FIG. 6

n-channel JFET with $I_{DSS} = 8$ mA
FIG. $V_P = -4V$.

Name of the Subject: Name of the Faculty: Topic:	Unit No: Lecture No: Link to Session Planner (SP):S.No.... of SP Book Reference: Date Conducted: Page No: 4

Transfer characteristics

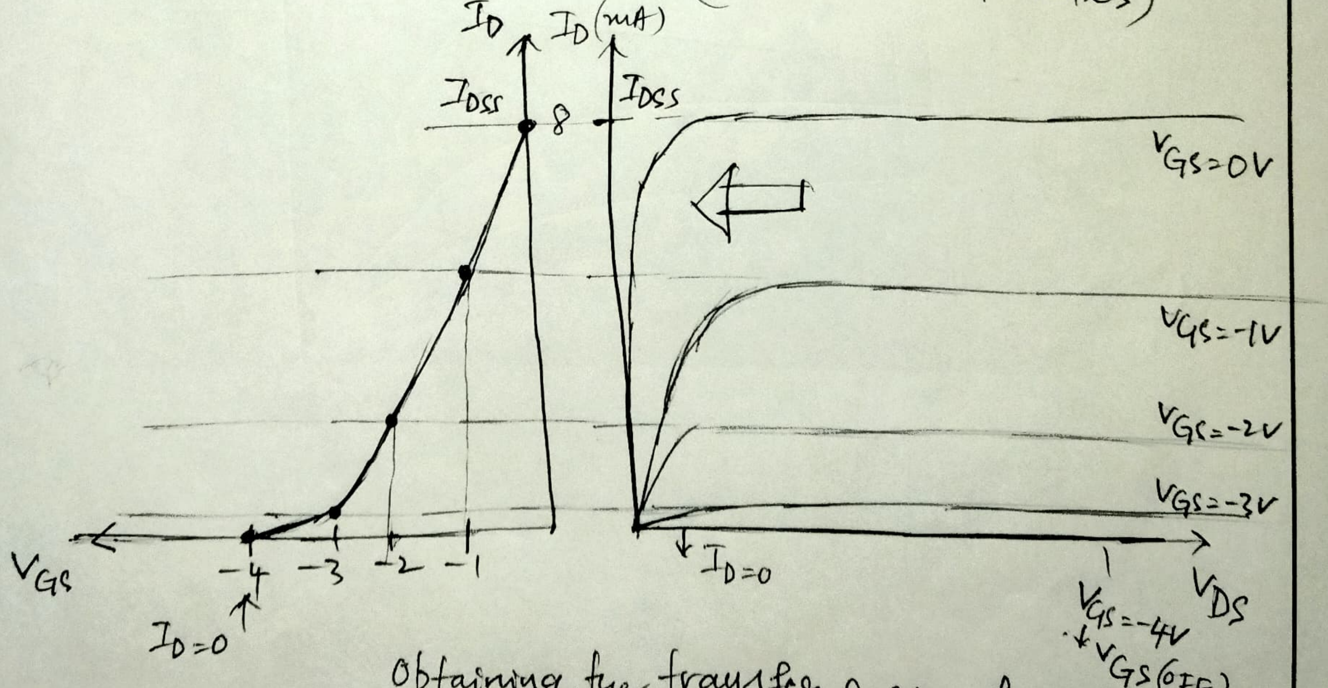
The relationship between I_D & V_{GS} is defined by Shockley's equation.

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

control variable.

constants

The transfer curve can be obtained using Schockley's equation or from output characteristics (Drain characteristics)



Obtaining the transfer curve from Drain characteristics.

P.T.O

When $V_{GS} = 0V$, $I_D = I_{DSS}$

When $V_{GS} = V_P = -4V$, $I_D = 0$ mA.

* Gate cut off voltage:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2$$

After a certain gate-to source voltage (V_{GS}), the drain current I_D becomes zero. This voltage is known as cutoff voltage $V_{GS(off)}$

Name of the Subject: Name of the Faculty: Topic:	Unit No: Lecture No: Link to Session Planner (SP):S.No.... of SP Book Reference: Date Conducted: Page No: 5

(3) Voltage-controlled resistor

→ The region to the left of pinch off locus of Fig. is refered as the ohmic or voltage controlled resistance region.

→ In this region, JFET can be employed as variable resistor, which whose resistance is controlled by applied gate-to-source voltage.

→ As V_{GS} becomes more and more negative, the slope of each curve becomes more and more horizontal, corresponding to an increasing resistance level.

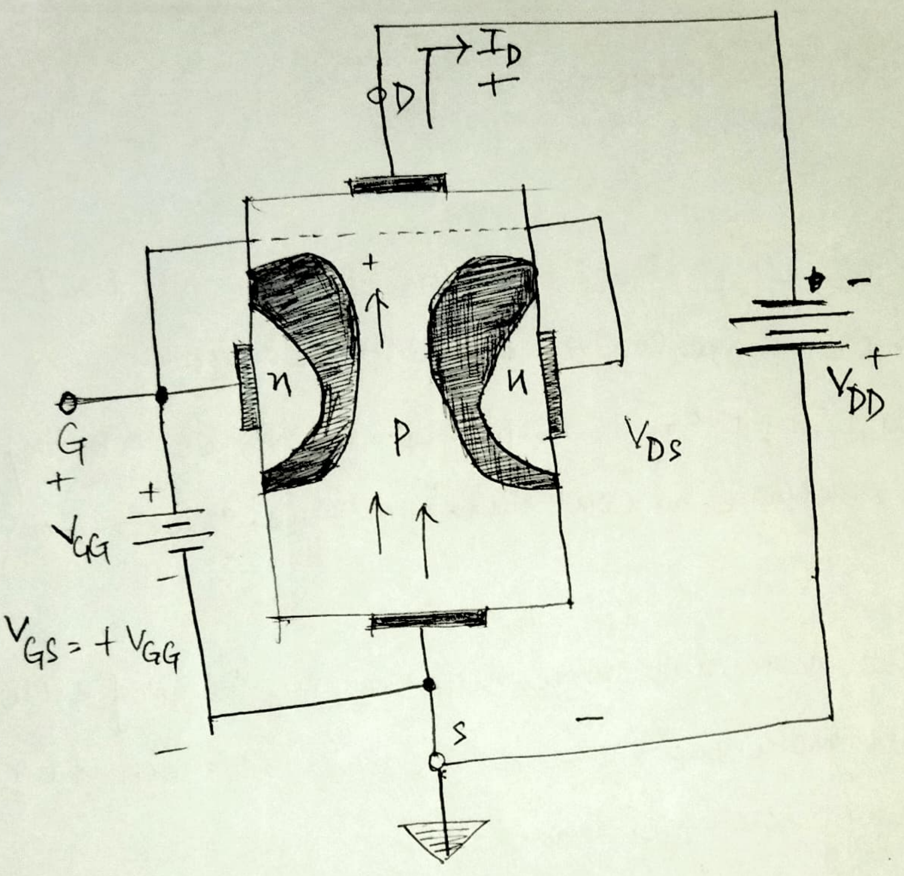
→ $$r_d = \frac{r_o}{\left(1 - \frac{V_{GS}}{V_p}\right)^2} \quad \text{——} \quad (1)$$

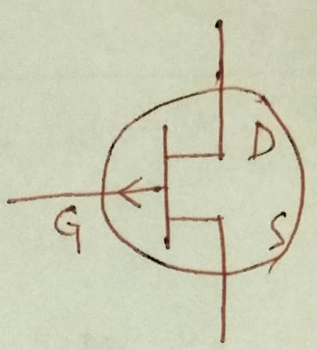
where r_o is the resistance with $V_{GS} = 0V$

& r_d is the resistance at particular level of V_{GS}

→ At $V_{GS} = V_p \Rightarrow r_d = \infty$, $I_d = 0$

P- Channel JFET:





→ It is constructed in exactly same manner as n-Channel JFET but with a reversal of P- and n- type materials as shown in fig.

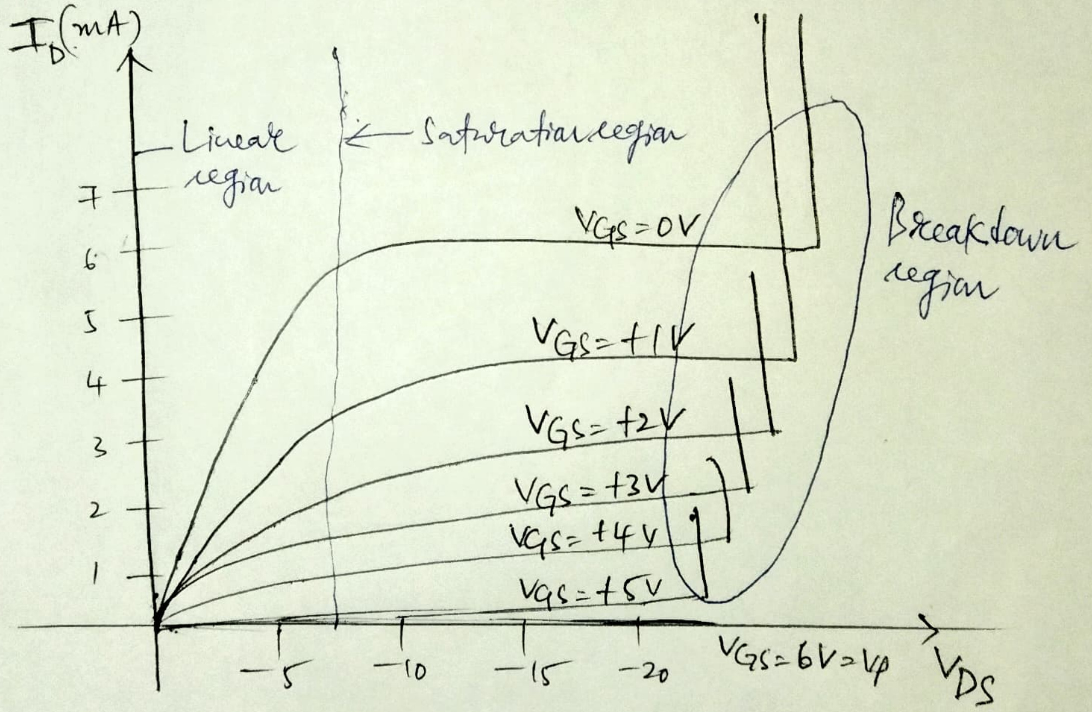
→ Polarities of voltages V_{GS} & V_{DS} are reversed, I_D direction reversed.

→ Channel will be reduced by increasing positive voltages from gate to source and negative voltages for V_{DS}.

Name of the Subject: Name of the Faculty: Topic:	Unit No: Lecture No: Link to Session Planner (SP):S.No.... of SP Book Reference: Date Conducted: Page No: 6

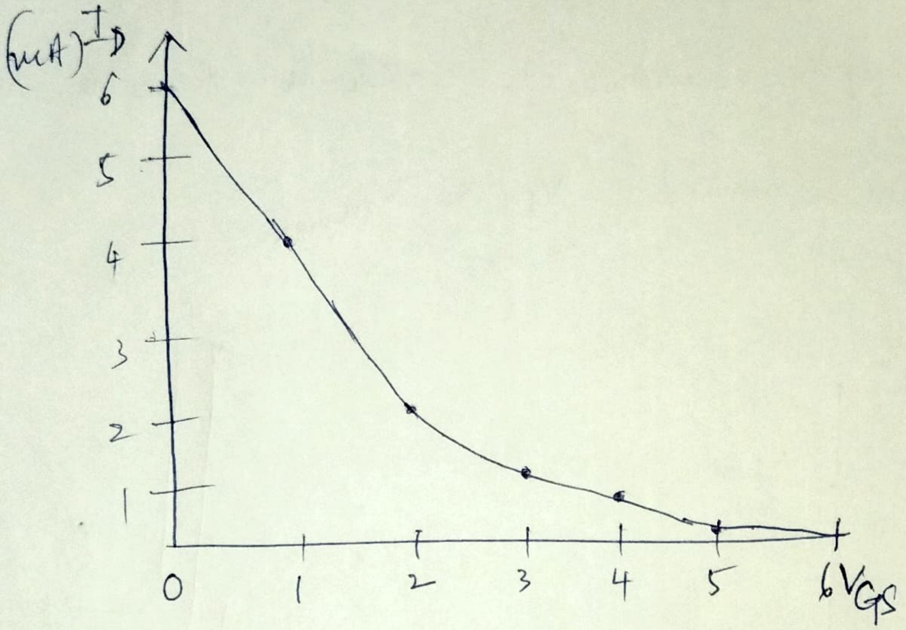
→ At high levels of V_{DS} the curves suddenly rise vertically indicating the occurrence of breakdown. (rise in current I_D).

→ This can be avoided if $V_{DS} < V_{DS\,max}$



P-channel JFET characteristic with $I_{DSS} = 6mA$ and $V_P = +6V$

Transfer Characteristics of P-Channel JFET



$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

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Lecture No:
Link to Session
Planner (SP):S.No.... of SP
Book Reference:
Date Conducted:

Characteristic parameters of JFET

① Transconductance

It is ratio of change in drain current ΔI_D to change in the gate to source voltage (ΔV_{GS}) at a constant drain to source voltage (V_{DS} = constant)

$$\boxed{g_m = \frac{\Delta I_D}{\Delta V_{GS}} \text{ at constant } V_{DS}} \quad \text{—— ①}$$

$$= \left.\frac{dI_D}{dV_{GS}}\right| \text{ at } V_{DS} = \text{constant}$$

we have $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

$$g_m = \frac{dI_D}{dV_{GS}} = \frac{-2I_{DSS}}{V_P}\left(1 - \frac{V_{GS}}{V_P}\right)$$

At $V_{GS} = 0$, g_m becomes max value as g_{mo}

$$\boxed{\therefore g_{mo} = \frac{-2I_{DSS}}{V_P}}$$

② Drain resistance (r_d): This is the ratio of change of drain to source voltage (ΔV_{DS}) to change of drain current (ΔI_D) V_{GS} = constant.

$$\boxed{r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ at constant } V_{GS}} \quad \text{— ②}$$

③ Amplification factor : (μ) :

It is defined as ratio of Change of drain voltage (ΔV_{DS}) to Change of gate voltage (ΔV_{GS}) at a constant drain current (I_D = constant)

$$\boxed{\mu = \left| \frac{\Delta V_{DS}}{\Delta V_{GS}} \right| \text{ at constant } I_D} \quad \text{——— ③}$$

Relation among μ, r_d, g_m :—

We know that

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$= r_d \times g_m$$

$$\left(\because r_d = \frac{\Delta V_{DS}}{\Delta I_D} , \quad g_m = \frac{\Delta I_D}{\Delta V_{GS}} \right)$$

so, $\boxed{\mu = g_m \times r_d}$ ✓

COMPARISION BETWEEN FET & BJT

FET	BJT
1. FET is an unipolar semi conductor device because its operation depends upon the flow of majority carriers i.e either holes or electrons as the case may be.	1. BJT is a bipolar semiconductor device because the current constituting elements are both majority carriers as well as minority carriers in this case.
2. The input impedance of FET is much larger (in the range of Megaohms) than BJT. The reason is that input terminal i.e gate to source of FET is reverse biased, which offer ideally infinite resistance.	2. The input impedence of BJT is very less in comparision to FET.
3. FET is voltage controlled device.	3. BJT is current controlled device.
4. FET is less noisy. Because there are no junctions.	4. BJT is much noisy than FET.
5. Higher frequency response	5. Frequency variation affects the performance.
6. Good thermal stability because of absence of minority carriers.	6. Temperature dependent, thermal runaway may cause.
7. Costlier than BJT.	7. Relatively Cheaper.

FET	BJT
8. Occupies less space (small size). So, it is used in ICs.	8. Comparatively bigger.
9. $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$	9. $I = I_0\left(e^{V/\eta V_T} - 1\right)$
10. No offset voltage, so it works better as a switch.	10. There is an always an offset voltage before switching.
11. Small gain bandwidth product.	11. Greater than FET

* FET applications *

1) Due to their high input impedance, FETs are commonly used as input amplifiers in devices i.e voltmeters, oscilloscopes, and other measuring devices.

2) FETs are also used in radio frequency amplifiers for FM devices.

3) FETs are used for mixer operation of FM and TV Receivers.

4) FET is a voltage controlled device due to this it is used in operational amplifier as voltage variable resistors.

5) FETs are used in large scale integration (LSI) and computer memories because of its small size.

FET Disadvantages

1) It has relatively lower gain bandwidth product compared to BJT.

2) FET performance degrades as frequency increases. This is due to the feed back by internal capacitance.

3) Transconductance is low, hence voltage gain is low.

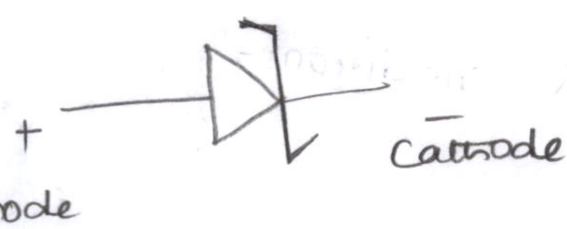
Special purpose Devices

Zener diode:-

A Zener diode is a type of PN junction diode that is designed to conduct in both forward and reverse directions. It has heavily doped regions and is mainly used to conduct current in the reverse direction. It starts conducting in the reverse direction when the reverse voltage exceeds a certain limit known as reverse breakdown (or) Zener breakdown voltage.

Symbol of Zener diode:

The symbol of zener diode resembles an ordinary diode except for the change in a little bend at the edges of the vertical line to make a shape that resembles Z as shown below.

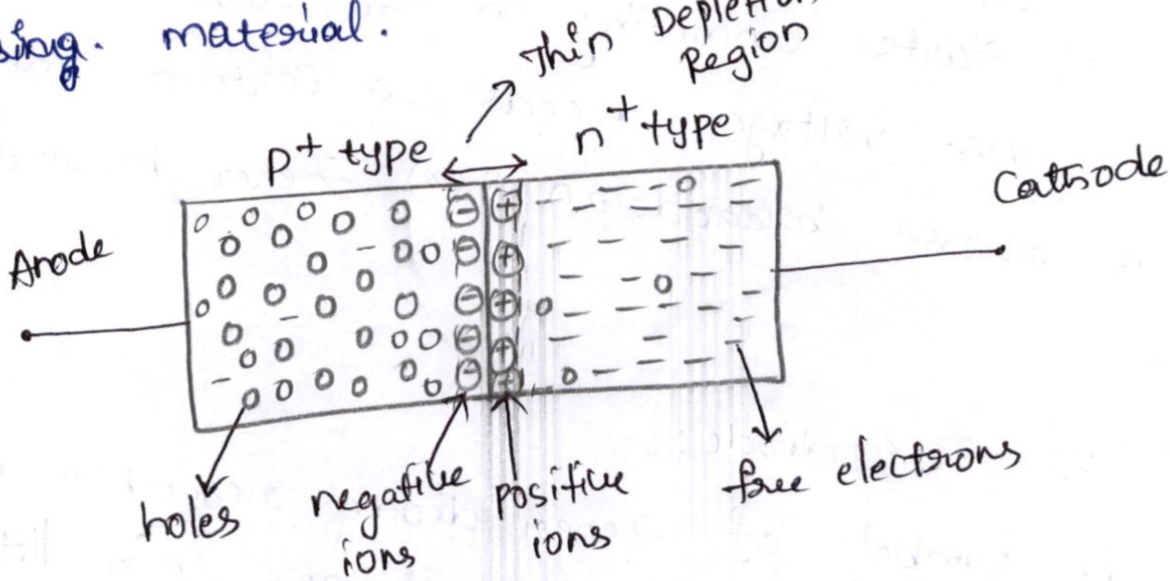


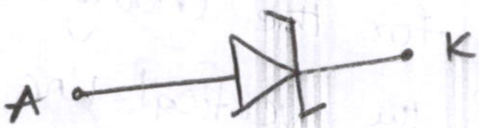
Construction of zener diode: (circuit diagram (or) layer structure of zener diode)

Zener diode is always connected in reverse direction because it is specifically designed to work in reverse direction.

The reverse biasing means the anode of the diode is connected to the positive terminal of the supply & the cathode is connected to the -ve terminal of the ~~diode~~ supply.

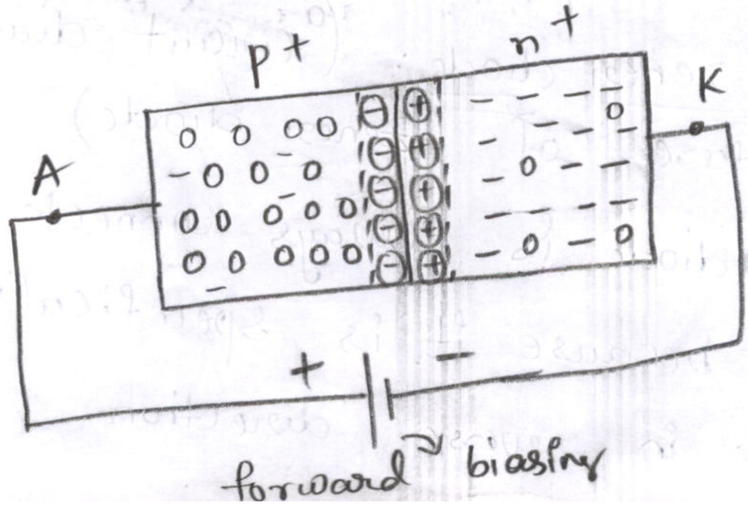
→ The depletion region is very thin because it is made of the heavily doped P & n type semiconductor ~~biasing~~. material.



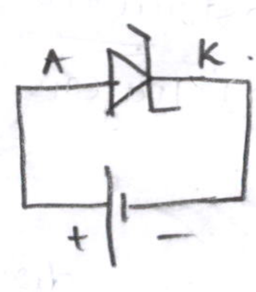


Working of zener diode and V-I characteristics of Zener diode :-

① under forward biased condition:-



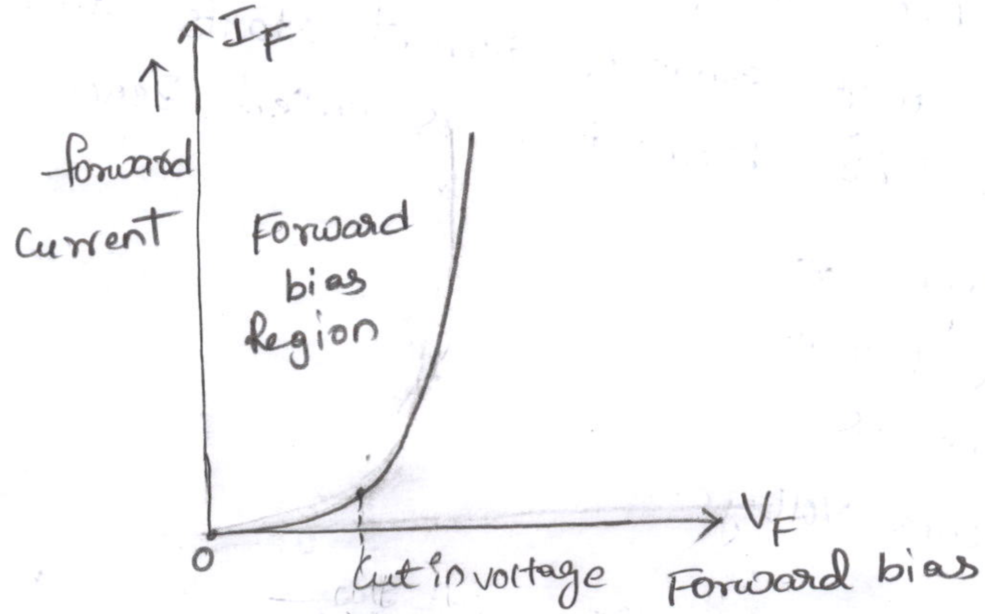
(or)



→ Zener diode is heavily doped than the normal pn junction diode. Hence it has very thin depletion region.

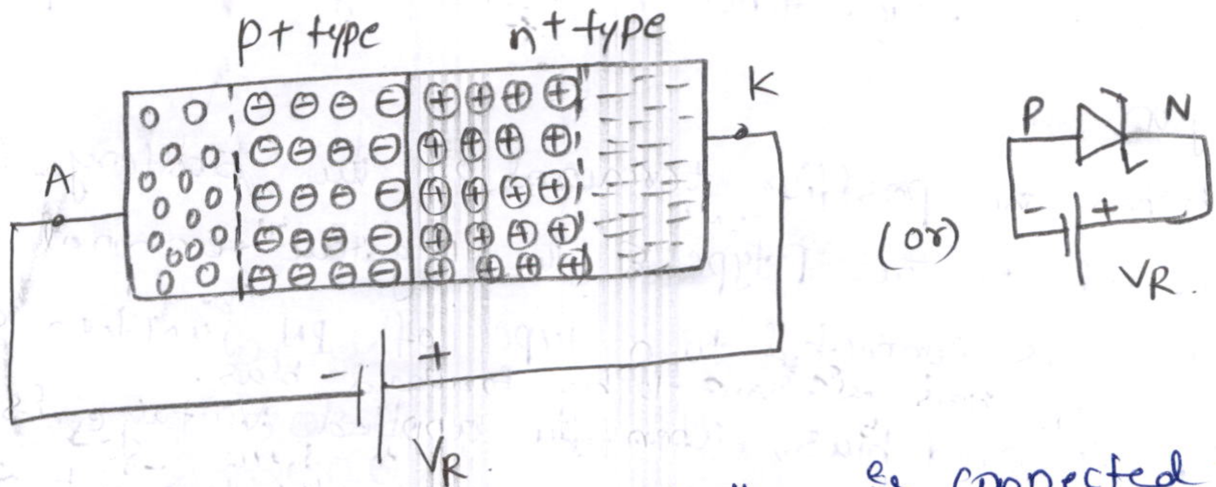
→ When the positive terminal of the battery is Connected to the P type & the negative terminal of the battery is connected to n type of PN junction diode. then the bias is said to be forward bias.

→ In forward bias, when the applied voltage is lower than the barrier potential, the diode does not allow current through it but only the small leakage current. Once the applied voltage crosses the barrier voltage the current increases suddenly while the voltage remains constant. The forward bias operation in the zener diode is the same as in any normal diode.



VI characteristics under forward bias.

(2) under reverse biased Condition:



→ when negative terminal of battery is connected to p type and +ve terminal is connected to n type then the bias is said to be reverse bias.

→ If this reverse biased voltage across the diode is increased, high electric field develop across the junction. This strong electric field break all the covalent near the junction and the junction breaksdown and a large reverse current starts flowing through the diode. This breakdown is called Zener breakdown.

→ The voltage at which this break down occurs is called Zener voltage.

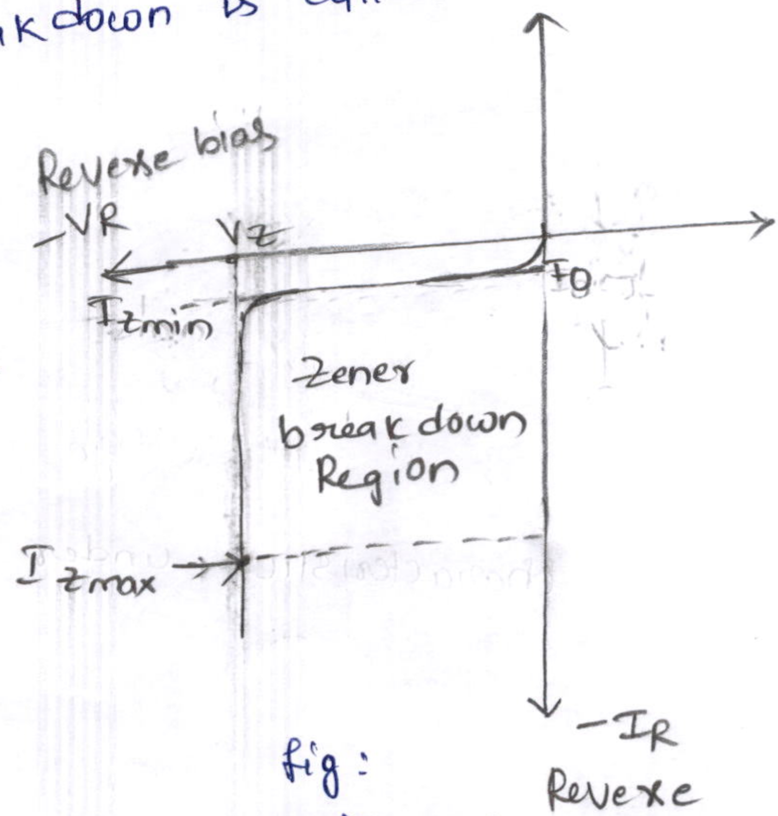
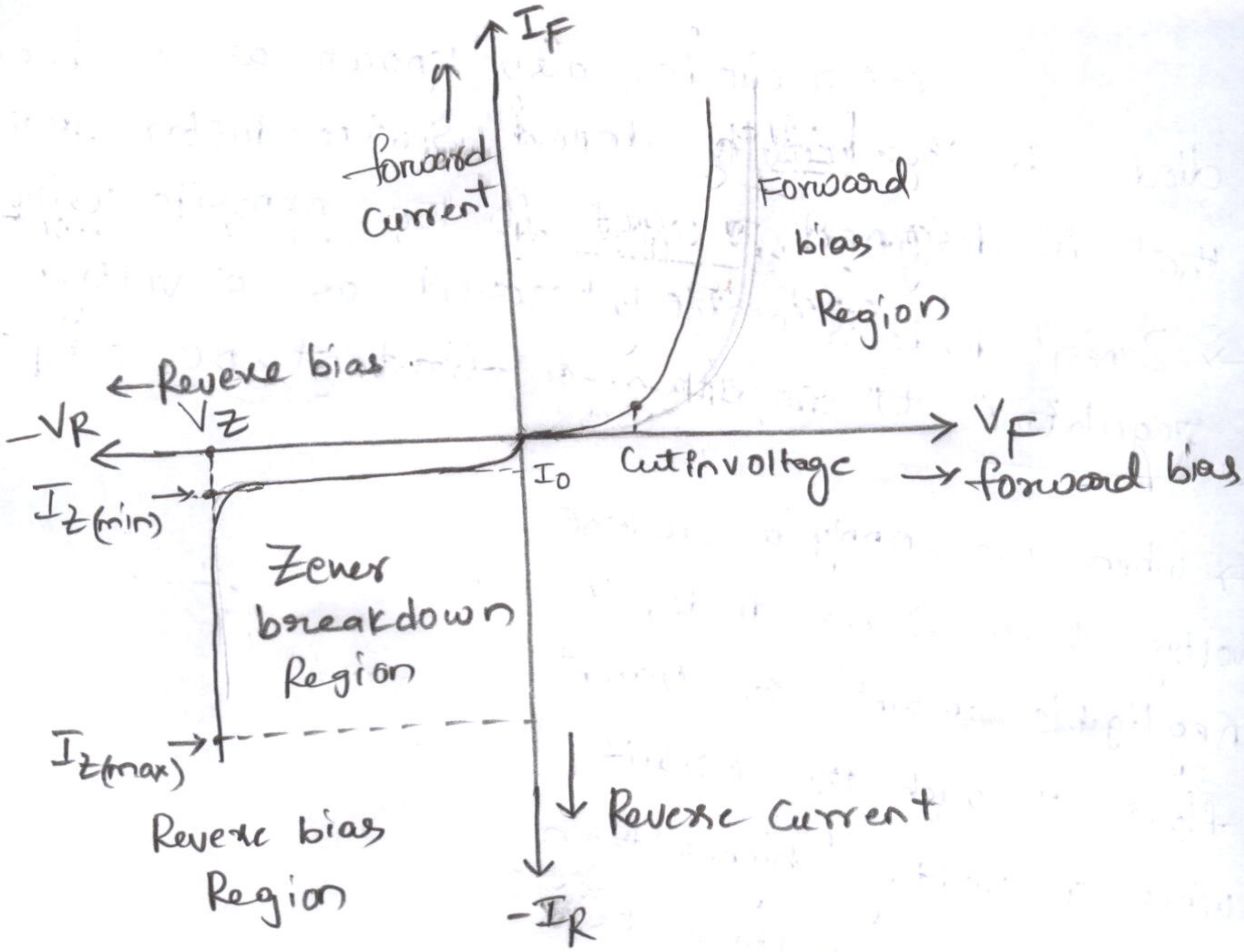


fig: VI characteristics under Reverse bias

Complete VI characteristics of Zener diode:



Equivalent circuit of Zener diode:-

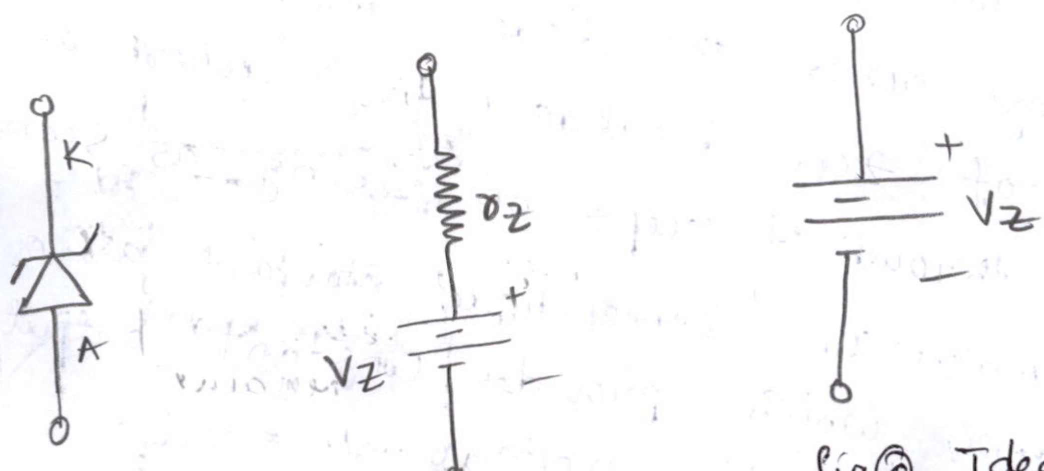


fig ⓐ: Zener diode

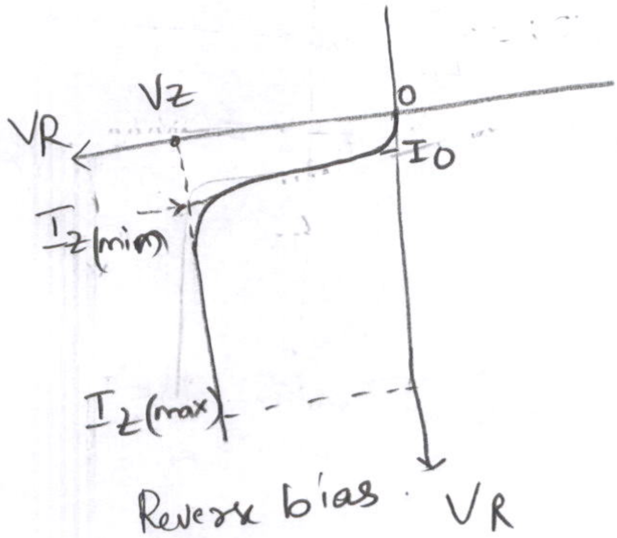
fig ⓑ practical diode

fig ⓒ Ideal Equivalent circuit.

Zener diode as Voltage Regulator:-

Zener diode, also known as a breakdown diode, is a heavily doped Semiconductor device that is designed to act in the opposite direction.

→ Zener diode is commonly used as a voltage regulator to maintain a Constant DC output voltage



→ when we apply a reverse voltage to a Zener diode, a negligible amount of current flows through the circuit.

→ when a voltage higher than Zenerbreakdown voltage is applied, Zener breakdown occurs.

→ when we increase the reverse voltage further, the voltage across the diode remains at the same value of Zener breakdown (Vz) where as the Current through it keeps on rising as seen in figure.

→ This makes the Zener diode to act as a voltage Regulator, which provides Constant output which is Zener breakdown voltage.

→ A Zener diode working in the breakdown region can serve as a voltage regulator. It maintains a Constant output voltage even when input voltage V_i (or) load current i_L varies.

→ The circuit diagram of a zener diode as a voltage regulator is as shown below:

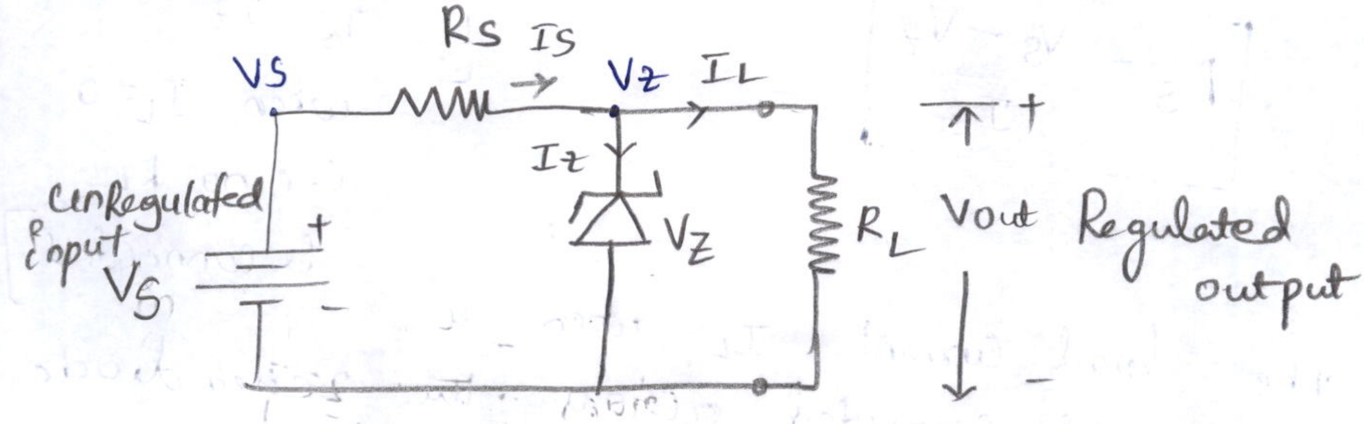


fig: voltage Regulator.

→ As shown in the above figure, by passing a small current through the diode from a voltage source Vs via a suitable current limiting resistor (Rs), the zener diode will conduct sufficient current to maintain a voltage drop of Vout.

→ Resistor Rs is connected in series with the zener diode to limit the current flow through the diode.

→ zener diode cathode is connected to the positive terminal of DC supply, so it is reverse biased & will be operating in its breakdown condition.

→ The load is connected in parallel with the zener diode, so the voltage across R_L is always the same as the zener diode,

$$\boxed{V_{R_L} = V_Z}$$

→ The minimum value of the series Resistor R_S to limit the flow of current through the diodes, when no load is connected across it is,

$$\boxed{R_S = \frac{V_S - V_Z}{I_Z}}$$

[∵ $I_S = I_Z$ when $I_L = 0$ i.e no R_L is connected]

→ The load current I_L when a load R_L is connected across the zener diode is $I_L = \frac{V_Z}{R_L}$

→ The zener current I_Z at full load is

$I_S = I_Z + I_L$

$\Rightarrow \boxed{I_Z = I_S - I_L}$

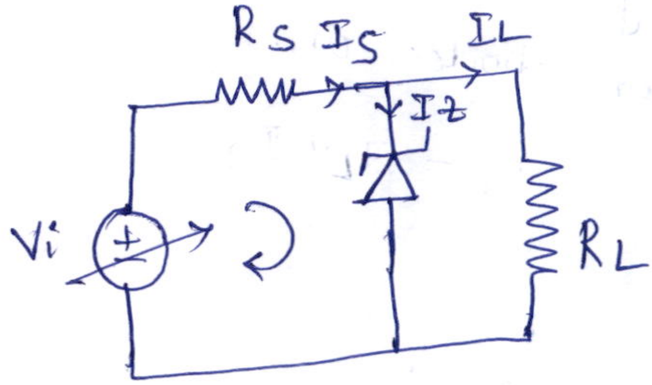
Basically there are two types of regulations such as

① Line Regulation: In this regulation, series resistance & load resistance are fixed, only i/p voltage is changing. output voltage Remains the same as as long as the i/p voltage is maintained above a minimum value.

Load Regulation:

In this type of regulation, input voltage is fixed and the load resistance is varying. output voltage remains same as long as the load Resistance is maintained above a minimum value.

Line Regulation:-



In line Regulation, load resistance is Constant and i/p voltage varies. V_i must be sufficiently large to turn the zener diode ON.

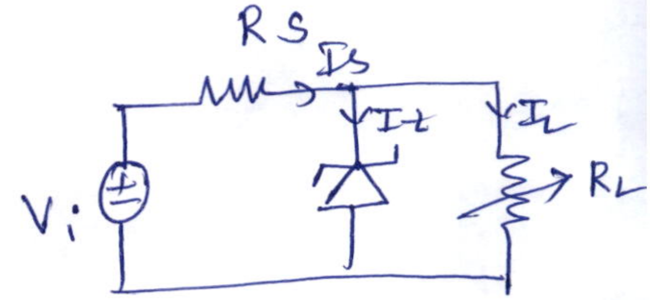
$$V_L = V_Z = \frac{V_{Imin} \times R_L}{(R_L + R_S)}$$

$$V_{Imin} = \frac{V_Z (R_L + R_s)}{R_L}$$

$$V_{Imax} = I_{Rmax} \times R + V_Z$$

$$V_0 = V_i - I_s \times R_s$$

Load Regulation:-



In load Regulation, i/p voltage is Constant & load resistance varies. Too small a load resistance R_L

$$V_L = V_Z = \frac{V_{Imin} \times R_L}{R_L + R_S}$$

so, the minimum load resistance R_L

$$R_{Lmin} = \frac{V_Z \times R_S}{V_I - V_Z}$$

Any load resistance > than R_{Lmin} will make Zener diode ON.

$$I_S = I_L + I_Z$$

Class Notes

Subject:
Faculty:
Topic:

Unit No:
Lecture No:
Link to Session
Planner (SP):S.No…. of SP
Book Reference:
Date Conducted:
Page No:

Silicon Controlled Rectifier (SCR):-

A silicon controlled Rectifier is a 3 terminal and 4 layer semiconductor current controlling device. It is ~~same~~ some times referred as SCR diode, 4 layer diode, 4 layer device (or) thyristor. It is made up of a silicon material which controls high power and converts high AC current into DC current. Hence it is named as silicon controlled rectifier.

Construction and Symbol of SCR:

A silicon controlled rectifier is made up of 4 semiconductor layers of alternating P and N type materials, which forms NPNP (or) PNPN structures.

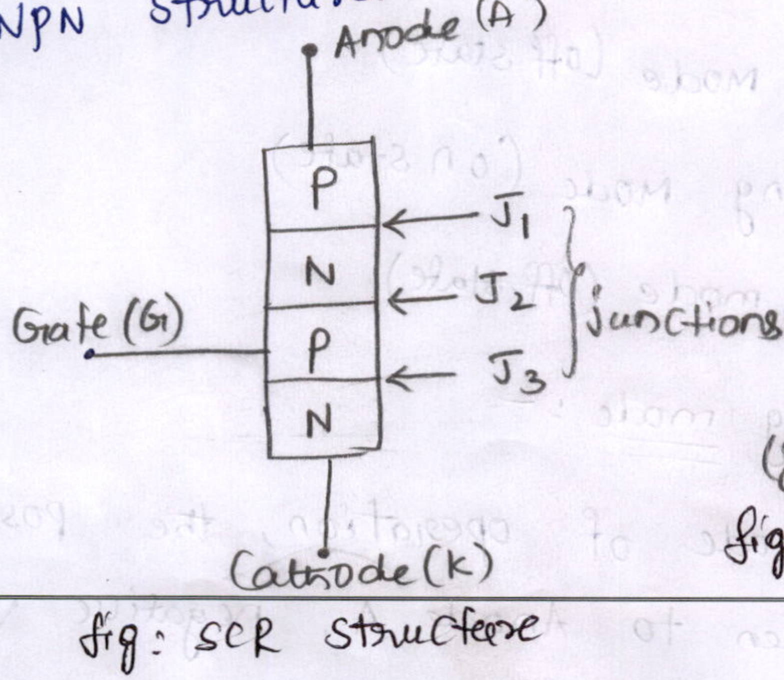


fig: SCR structure

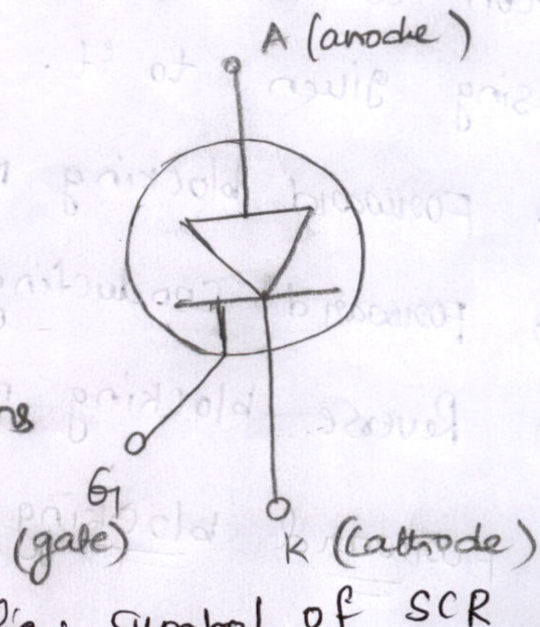


fig: Symbol of SCR

→ It has 3 PN junctions namely J_1, J_2, J_3 with 3 terminals attached to the semiconductors materials namely Anode (A), Cathode (K), and gate (G)

→ Anode, is a positively charged electrode through which the current enters into an electrical device,

→ Cathode, is a negatively charged electrode through which the conventional current leaves the electrical device

→ Gate, is a terminal that controls the flow of current between anode and cathode.

→ Junction J_1 is formed between the first P-N layer the junction J_2 is formed between the N-P layer and the junction J_3 is formed between the last P-N layer.

Modes of operation in SCR:-

There are 3 modes of operation for a silicon controlled rectifier (SCR), depending upon the biasing given to it.

1. Forward blocking Mode (off state)
2. Forward conducting Mode (on state)
3. Reverse blocking mode (~~off state~~)

1. Forward blocking mode:-

In this mode of operation, the positive voltage (+) is given to Anode A, negative voltage is given to cathode (K) and gate G is open circuited as shown in below figure.

→ In this case, the junction J_1 and J_3 are forward biased where as the junction J_2 becomes reverse biased.

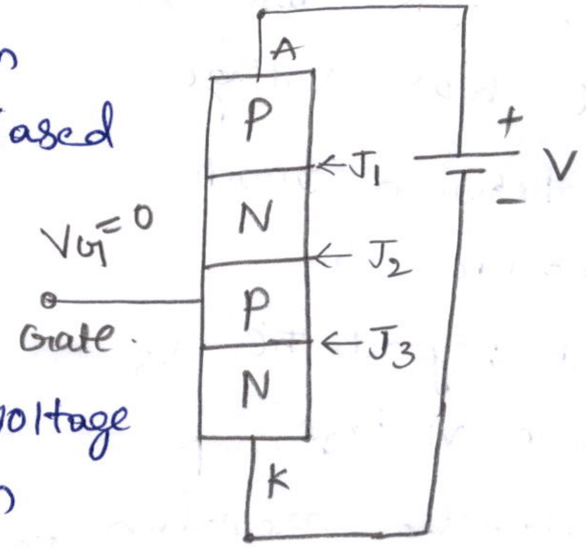


fig: Forward blocking mode of SCR

→ Due to the reverse bias voltage the width of depletion region increases at junction J_2.
It blocks the current flowing between junction J_1 & J_3.

→ However a small amount of leakage current flows between J_1 & J_3 junctions.

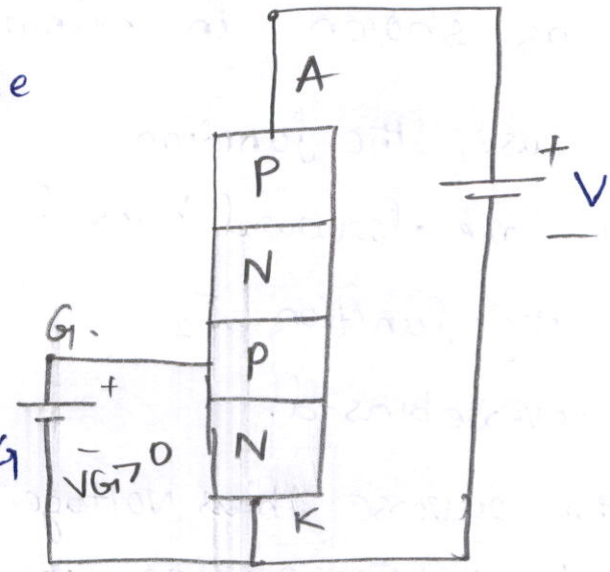
→ when the voltage applied to SCR reaches a breakdown value, the high energy minority carriers causes avalanche breakdown. At this breakdown voltage, current starts flowing through the SCR. But below this breakdown voltage, the SCR offers high resistance to current & so it will be in off state.

② Forward Conducting mode:-

The SCR can be made to conduct in two ways.

1. By increasing the forward bias voltage applied between anode and cathode beyond the breakdown voltage.

2) By applying positive voltage at gate terminal.



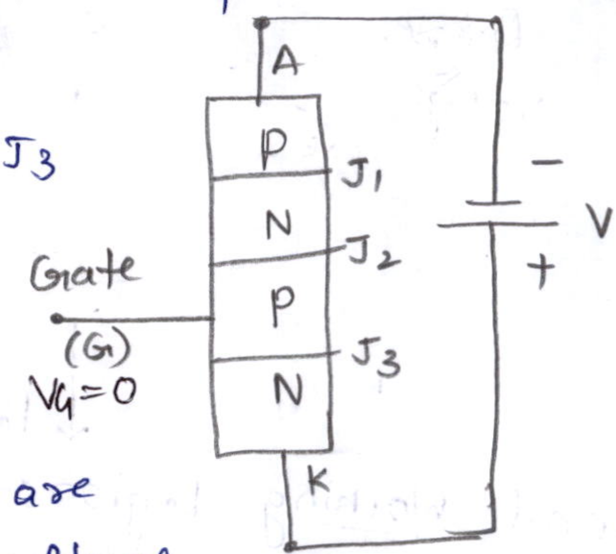
Forward conducting mode of SCR.

→ In the first case the forward bias voltage applied between anode and cathode is increased beyond the break down voltage, then avalanche breakdown occurs at junction J_2 and current starts flowing through the SCR. So the SCR will be in ON state.

→ In the Second case, a small positive voltage V_G is applied to the gate terminal, which makes junction J_2 forward bias. So the depletion region width at junction J_2 becomes very narrow. under this Condition applying a small forward bias voltage between anode and Cathode is enough for electric current to penetrate through this narrow depletion region. There fore electric Current starts flowing through the SCR circuit.

3 Reverse blocking mode :-

In this mode of operation, the negative voltage is given to anode and positive voltage is given to cathode and gate is open circuited as shown below, In this case the junction J_1 and junction J_3 are reverse biased where as the junction J_2 becomes forward biased.

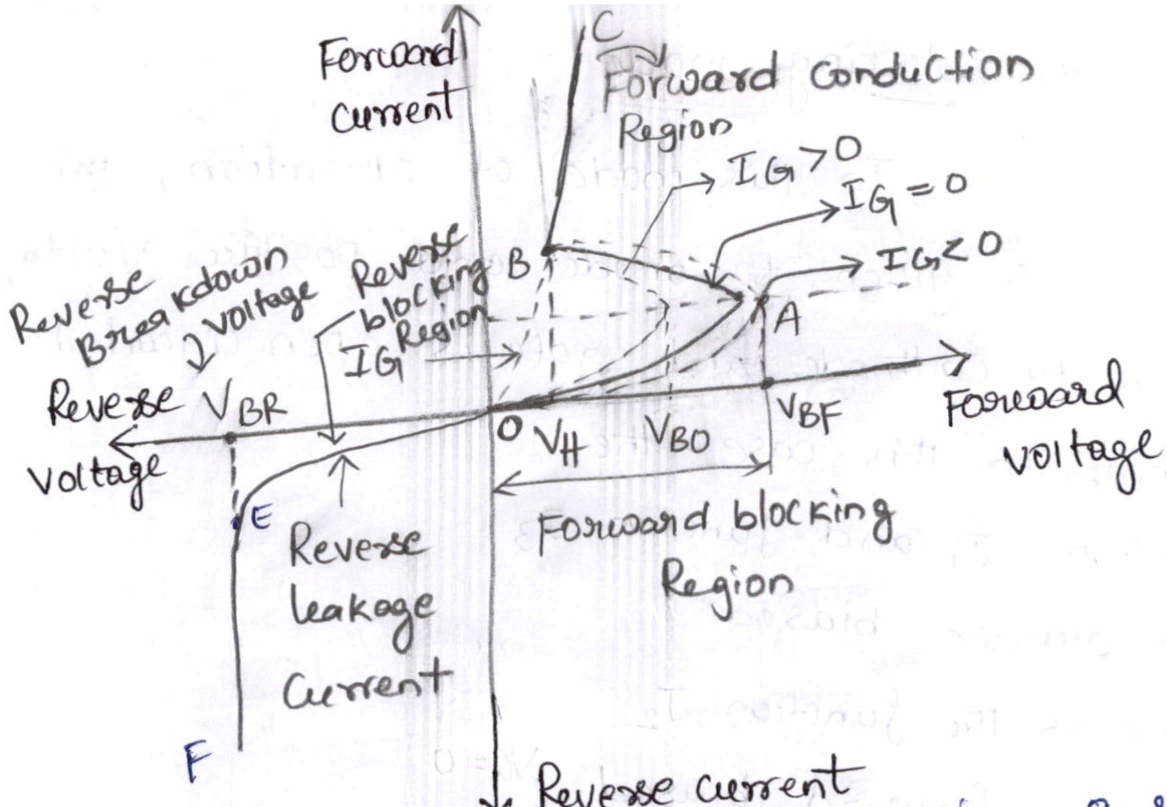


→ As junctions J_1 and J_3 are reverse biased no current flows through the SCR circuit. But a small leakage current flows due to drift of charge carriers in the forward biased junction J_2. This small leakage current is not enough to turn on SCR. So SCR will be in off state

VI characteristics of SCR :-

The V-I characteristics of SCR is divided into 3 Regions.

i) Forward blocking Region
ii) Forward conduction Region
iii) Reverse blocking Region.



i) <u>Forward blocking Region</u>:- In this region, a small leakage current flows from anode to cathode. This small leakage current is known as forward leakage current. The region OA is known as forward blocking region.

ii) <u>Forward Conduction Region</u>:- In this region the current flow in the SCR increases rapidly after junction breakdown occurs. The voltage at which the junction J_2 gets broken when the gate is open is called forward breakdown voltage V_{BF}.

→ The Region AB indicates that as soon as the device becomes on, the voltage across the SCR drops to some volts.

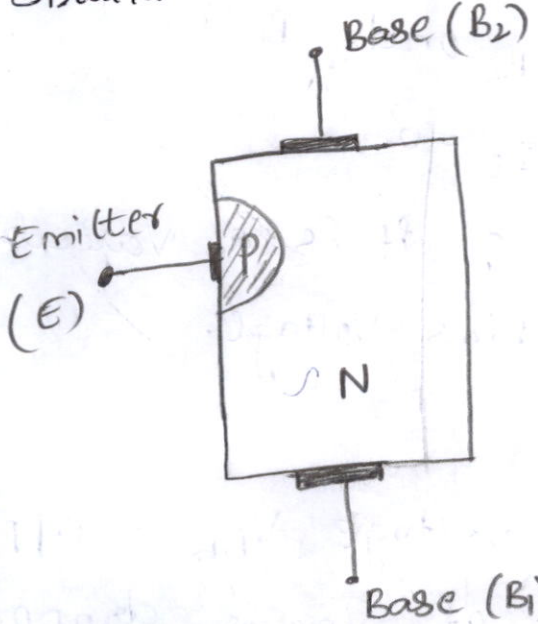
→ The Region BC is called Conduction Region.

iii) <u>Reverse Blocking Region</u>:- In this region as J_1 and J_3 are reverse biased, no current flows through the SCR circuit. But a small leakage current flows due to drift of charge carriers in the forward biased junction J_2. If the reverse bias voltage applied between anode and cathode is increased beyond the reverse breakdown voltage an avalanche breakdown occurs. As a result the current increases rapidly. The region EF shows the avalanche region. This current may damage the SCR.

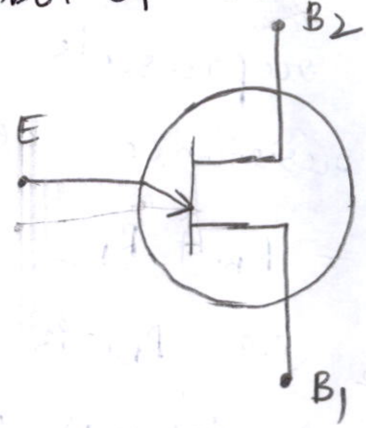
UJT (uni junction transistor):-

UJT is a three terminal semiconductor switching device. As it has only one PN junction and three leads Emitter, Base 1 and Base 2. It is commonly called as unijunction transistor.

Structure of UJT:



Symbol of UJT:-

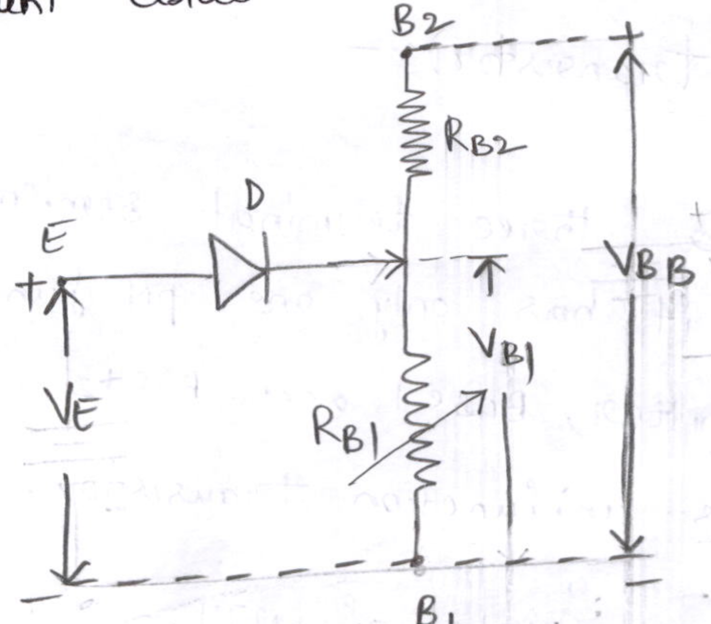


→ UJT Consists of a lightly doped N type Si bar into which heavily doped P type material is diffused closer to base 2.

→ It forms a single PN junction.

→ The arrow in the emitter represents the direction of the Conventional current.

Equivalent circuit:-



→ Diode D represents PN junction

→ Internal resistance between B_2 and B_1 is

$$R_{BB} = R_{B1} + R_{B2} \quad \text{when } I_E = 0$$

→ $R_{B1} > R_{B2}$ i.e R_{B1} is greater & it is a variable resistor which depends on the bias Voltage.

Intrinsic stand off ratio:

→ with emitter open, if Voltage V_{BB} is applied between B_2 and B_1 then part of V_{BB} is dropped over R_{B1} and R_{B2}

The voltage drop across R_{B1} is V_{B1}

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

$$V_{B1} = V_{BB}\left(\frac{R_{B1}}{R_{B1} + R_{B2}}\right)$$

$$\Rightarrow V_{B1} = V_{BB}\,\eta$$

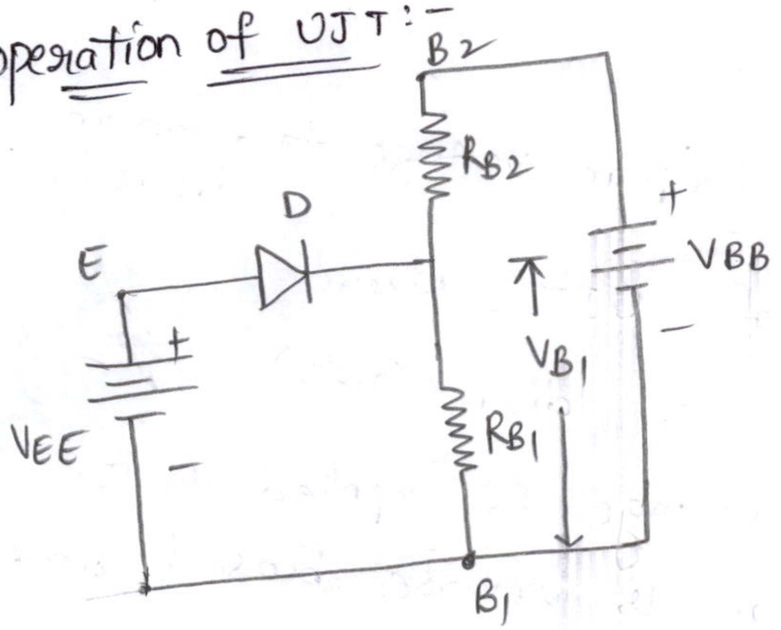
where $\boxed{\eta = \frac{R_{B1}}{R_{B1} + R_{B2}}}$ ⇒ Intrinsic stand off ratio

η ranges from 0.5 to 0.75

→ η will define the reverse bias condition for diode.

→ V_{B1} reverse biases the PN junction & I_E is in cutoff Codition.

<u>Operation of UJT</u>:–



(i) with Emitter terminal open: when $V_E = 0$ and only V_{BB} is applied between B_1 & B_2.
I_E is cutoff

→ V_{B1} reverse biases the PN junction, I_E is cutoff

→ Due to the minority carriers there is a small leakage Current flowing from B_2 to E.

(ii) when a positive voltage V_E is applied to Emitter:

→ If V_E exceeds V_{B1} by atleast 0.7V then the diode becomes forward biased.

→ Holes are injected from heavily doped p type material into N type bar.

→ These holes are repelled by B_2 and attracted by B_1 because B_2 is connected to '+' terminal & B_1 is connected to '−' terminal.

→ So more current I_E will flow into R_{B1} which reduces the value of R_{B1}

→ V_E increases the I_E which inturn reduces the R_{B1}. This causes further increase in I_E regeneratively. It is limited by V_E.

$$\boxed{V_P = \eta V_{BB} + V_D}$$ [⇒ peak voltage to turn on diode.]

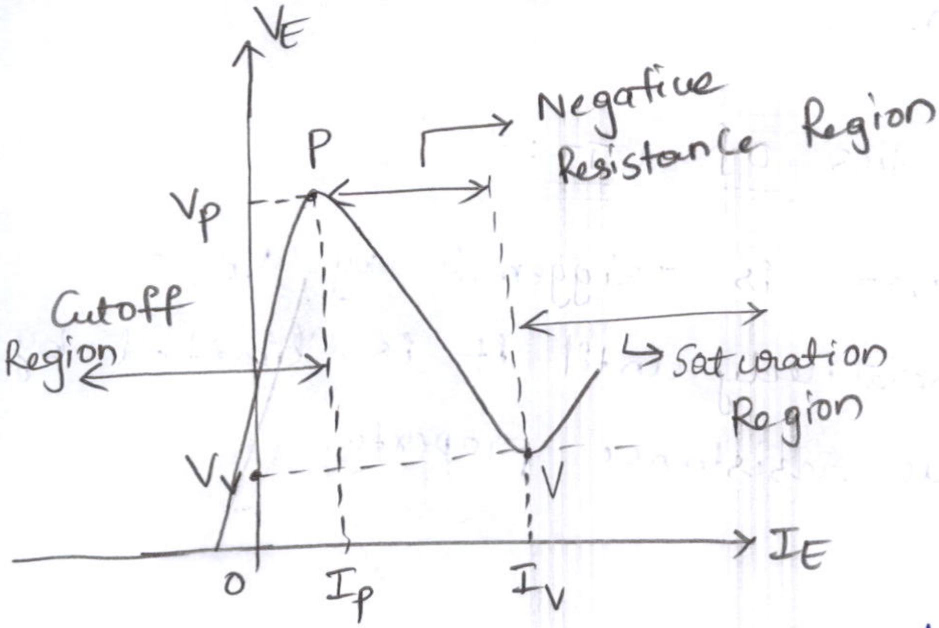
where

V_P → peak voltage of UJT,

V_D is cutin voltage of diode (0.7V)

(iii) when a negative voltage is applied to the Emitter:- PN junction is reverse biased and I_E is cutoff. UJT is in OFF condition.

VI characteristics of UJT :-



→ VI characteristics of UJT can be Explained by

i) cutoff Region

ii) Negative Resistance Region

iii) Saturation region.

→ If $V_E < V_p$ (Emitter voltage < peak voltage) the Emitter is reverse biased there is a small leakage current.

UJT is in OFF condition, the region left of the peak point is <u>Cutoff region</u>.

→ If $V_E > V_p$, the diode is forward biased.

→ It increases the I_E and decreases R_{B1} there by decreasing V_E ⇒ $I_E \propto \frac{1}{R_{B1}}$ ⇒ Negative Resistance.

→ I_E increases until it reaches the valley point.

→ The region between P and V is the negative resistance region.

→ After the Valley point, the device is driven into saturation region.

Unique characteristics of UJT:-

When UJT is triggered by V_E, I_E increases regeneratively until it is limited by V_E. i.e negative resistance property.

Applications:-

- → Switching circuits
- → UJT Relaxation oscillator
- → Sawtooth generator
- → pulse generator
- → timing and trigger Control/circuits.

Class Notes

Subject:
Faculty:
Topic:

Unit No:
Lecture No:
Link to Session Planner (SP):S.No…. of SP
Book Reference:
Date Conducted:
Page No:

Photo diode:-

A photo diode is a PN junction diode that consumes light energy to produce an electric current. It is also called as a photo detector, a light detector and photo sensor.

→ The photo diode is a semiconductor pn junction device whose region of operation is limited to the reverse biased region. The below figure shows the symbol of photo diode.

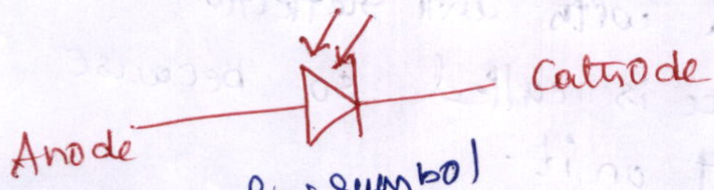
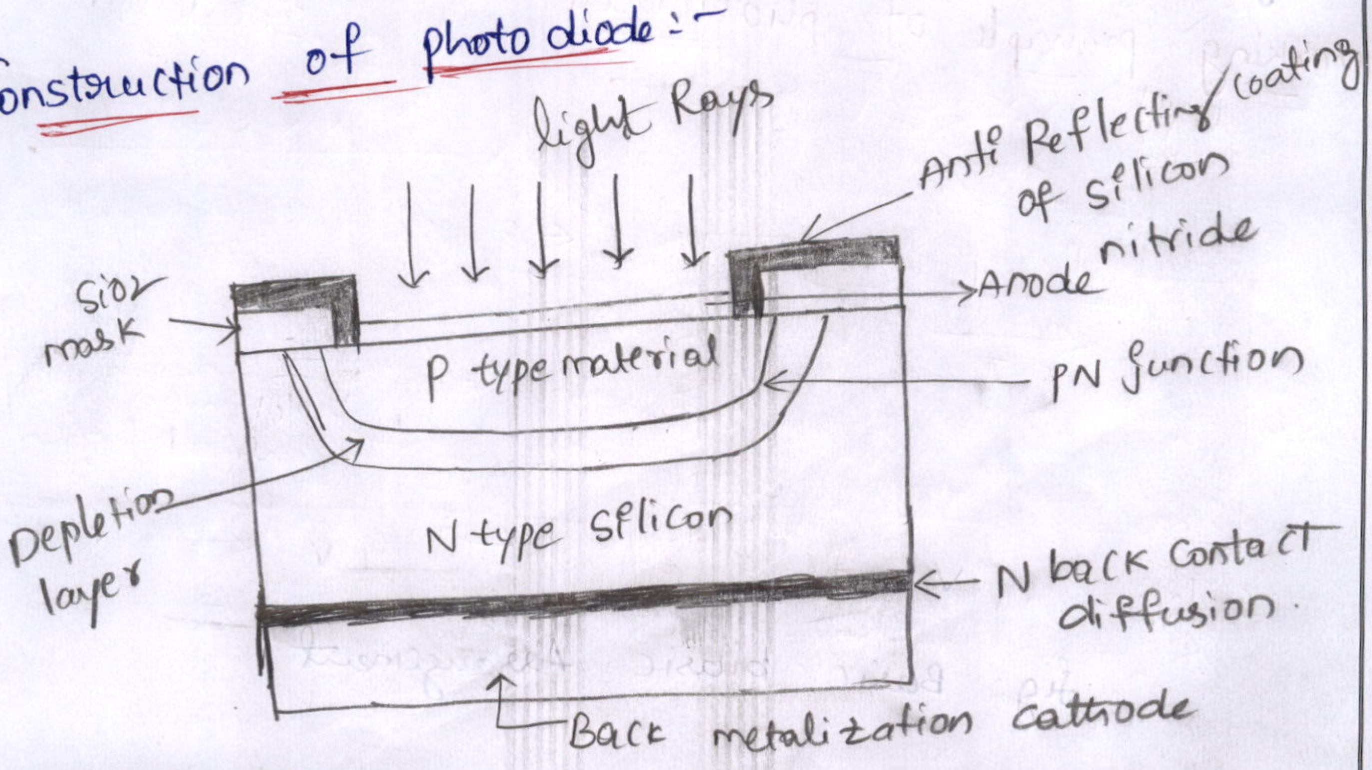


fig: symbol

Construction of photo diode:-



The photodiode is made up of two layers of p type and N type semiconductor. In this the p type material is formed from diffusion of the lightly doped ptype substrate. Thus the layer of p+ ions is formed due to the diffusion process.

→ The p+ diffusion layer is developed on N type heavily doped epitaxial layer.

→ The contacts are made up of metals to form two terminal cathode and anode.

→ The front area of the diode is divided into two types that are active and non active surface.

→ The non active is made up of SiO_2 and active surface is coated with anti reflection material.

→ The active surface is called so because the light rays are incident on it.

Working principle of photodiode :-

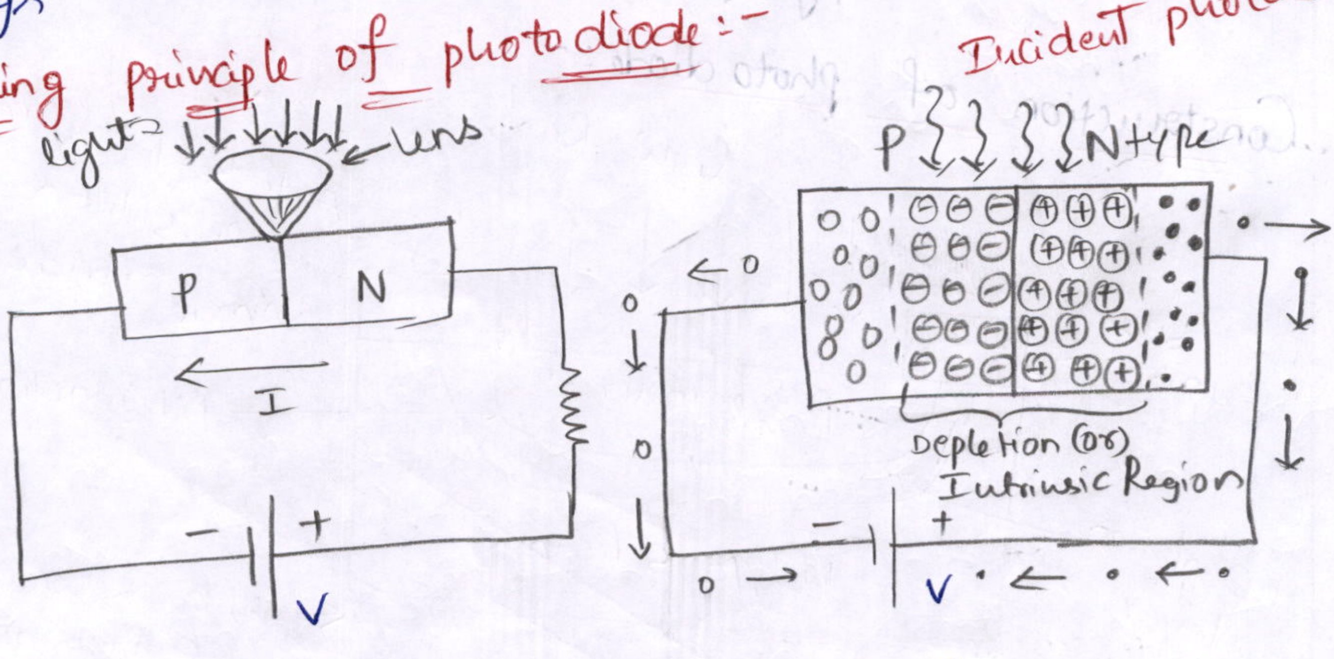


fig: Basic biasic Arrangement

Class Notes

Subject:
Faculty:
Topic:

Unit No:
Lecture No:
Link to Session
Planner (SP):S.No…. of SP
Book Reference:
Date Conducted:
Page No:

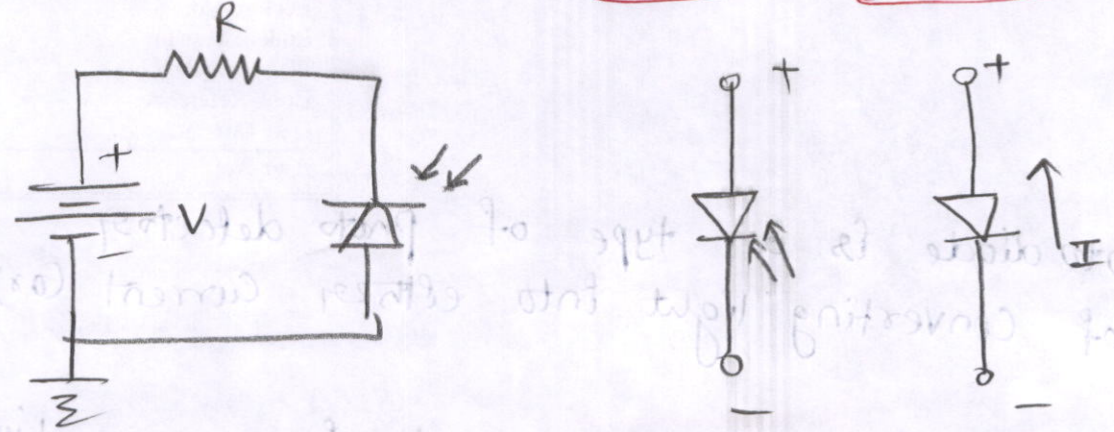
→ A photodiode is a type of photo detector capable of converting light into either current (or) voltage.

→ A photodiode is designed to operate in reverse bias. The depletion region width is large. under normal conditions it carries small reverse current due to minority charge carriers.

→ When light is incident through glass window on the PN junction, photons in the light hits the pn junction and some energy is imparted to the valance electons. so valance Electrons break covalent bonds and become free electrons. That means electrons from valance band get the energy to jump into the conduction band and contribute to current. In this way, the photodiode converts light energy into electrical energy.

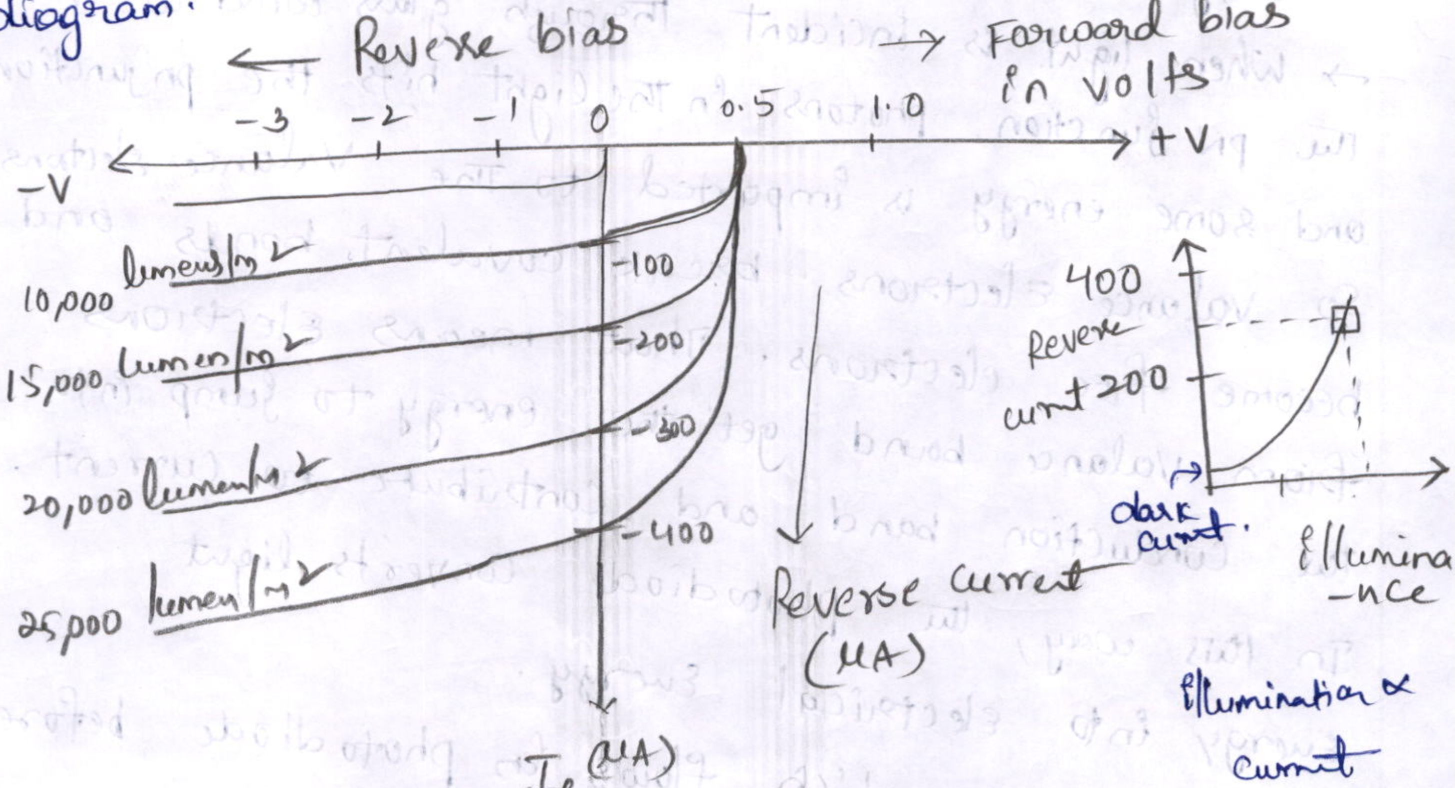
→ The current which flows in photodiode before light rays are incident on it is called dark current.

Equivalent circuit & symbol of photodiode



VI characteristics of photodiode :-

The characteristics curve of the photodiode can be understood with the help of the below diagram.



→ The characteristics are shown in the negative region because the photodiode can be operated in reverse mode only.

→ The reverse saturation current in the photodiode is denoted by I_0.

It varies linearly with the intensity of photons striking the diode surface.

→ The Reverse saturation current,

$$I = I_{sc} + I_0 \left(1 - e^{V/\eta V_t}\right)$$

→ I_{sc} → short circuit current

→ V is +ve for forward voltage & negative for reverse bias.

→ V_t → volt equivalent

→ $\eta = 1$ for Ge $\eta = 2$ for Si

Advantages: The advantages of photo diode are

→ It can be used as variable resistance device

→ Highly sensitive to light

→ The speed of operation is very high.

→ light weight & compact size

→ wide spectral response

→ Relatively low cost

Disadvantages:-

→ Rapid increase in dark current and it depends on temperature.

→ Require amplification at low illumination level

→ photodiode characteristics are temperature dependent & have poor temperature stability.

Applications of photodiode:

→ photo diodes are used in safety Electronics such as fire and smoke detectors.

→ used in numerous medical applications. They are used in ~~numerous~~ instruments that analyze samples, detectors for Computed tomography and also used in blood gas monitors.

→ photo diodes are used in solar cell panels.

→ used in logic circuits.

→ used in detection circuits

→ used in character recognition circuits.

→ These are used for the exact measurement of the intensity of light in science & industry.

→ photo diodes are faster and more complex than normal PN junction diodes & hence are frequently used for lightning regulation & optical Communication.

Class Notes

Subject:
Faculty:
Topic:

Unit No:
Lecture No:
Link to Session
Planner (SP):S.No…. of SP
Book Reference:
Date Conducted:
Page No:

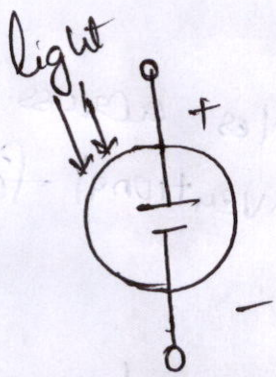
Solar Cell:-

A solar cell is also known as a photovoltaic cell (PV cell) is defined as an Electrical device that converts light energy into Electrical Energy through photovoltaic ~~effect~~ effect.

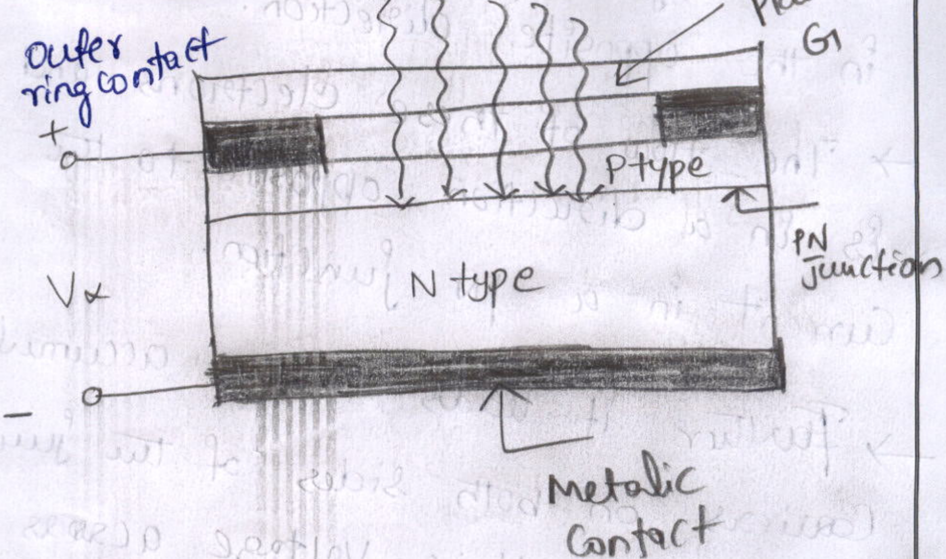
→ A solar cell is basically a pn junction diode.

→ solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics such as current, voltage (or) resistance vary when exposed to light.

Symbol of solar cell



Construction of a PN junction Solar cell



Construction and working of solar cell:

When sunlight is incident on a photovoltaic cell it is converted into electrical Energy. solar cell is used in satellites to provide the electrical power.

→ Solar cell consists of a single semiconductor crystal which has been doped with both P and N type impurities, thereby forming a PN junction. The basic construction of a PN junction solar cell is as shown in above figure.

→ Sunlight incident on the glass plate G passes through it and reaches the junction. An incident light photon at the junction may colide with a valance electron and impart sufficient energy to make a transition to conduction band.

→ As a result, an electron hole pair is formed.

→ The newly formed electrons are minority carriers in the P region. They move freely across the junction.

→ Similarly holes formed in the N region cross the junction in the opposite direction.

→ The flow of these electrons and holes across the junction is in a direction opposite to the conventional forward current in a PN junction.

→ Further it leads to the accumulation of a majority carriers on both sides of the junction. This gives rise to a photovoltaic voltage across the junction in the open circuit condition.

Class Notes

Subject:
Faculty:
Topic:

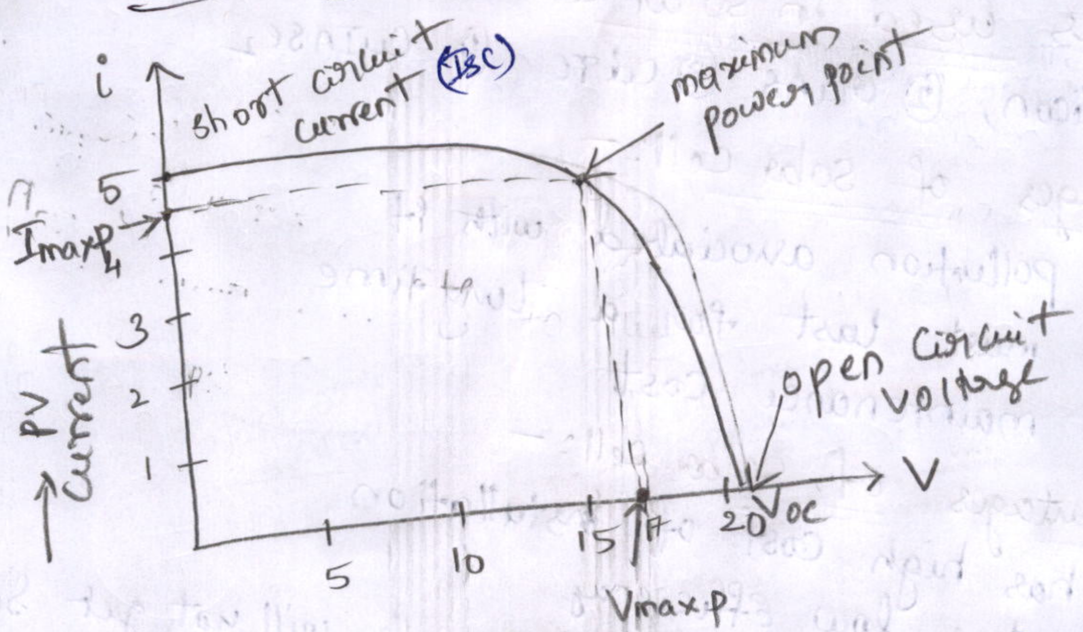
Unit No:
Lecture No:
Link to Session
Planner (SP):S.No…. of SP
Book Reference:
Date Conducted:
Page No:

In bright sunlight, about 0.6V is developed by a single solar cell.

→ The efficiency of the solar cell is measured by the ratio of electrical energy o/p to the light energy input.

→ At present an efficiency in the range of 10 to 40% is obtained.

VI characteristics of Solar cell:



Short circuit current: It is the maximum current that a solar cell can deliver without harming its own construction. It is measured by short circuiting the terminals of the cell..

Open circuit voltage of solar cell:- (V_{oc}) It is measured by measuring voltage across the terminals of the cell when no load is connected to the cell.

Maximum power point of solar cell:- (P_m) The maximum electrical power one solar cell can deliver at its standard test condition. If we draw the VI characteristics maximum power will occur at the bend point of the characteristic curve denoted by P_m.

→ Current & voltage at maximum power point is denoted by I_m & V_m

→ Efficiency = $\eta = \frac{P_m}{P_{in}}$

Materials used in solar cell:-

1. Silicon, ② GaAs ③ CdTe ④ $CuInSe_2$

Advantages of solar cell:-

→ No pollution associated with it
→ It must last for a long time
→ No maintenance cost

Disadvantages of solar cell:-

→ It has high cost of installation
→ It has low efficiency
→ During cloudy day & night we will not get solar energy

Uses of solar generation systems:

→ It may be used to charge batteries
→ used in light meters
→ used to power calculators & wrist watches
→ It is used in space craft to provide electrical
→ It can be used in space craft to provide electrical energy.

Class Notes

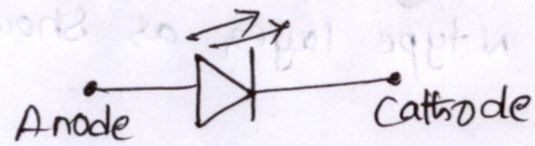
Subject:
Faculty:
Topic:

Unit No:	
Lecture No:	
Link to Session Planner (SP):S.No…. of SP	
Book Reference:	
Date Conducted:	
Page No:	

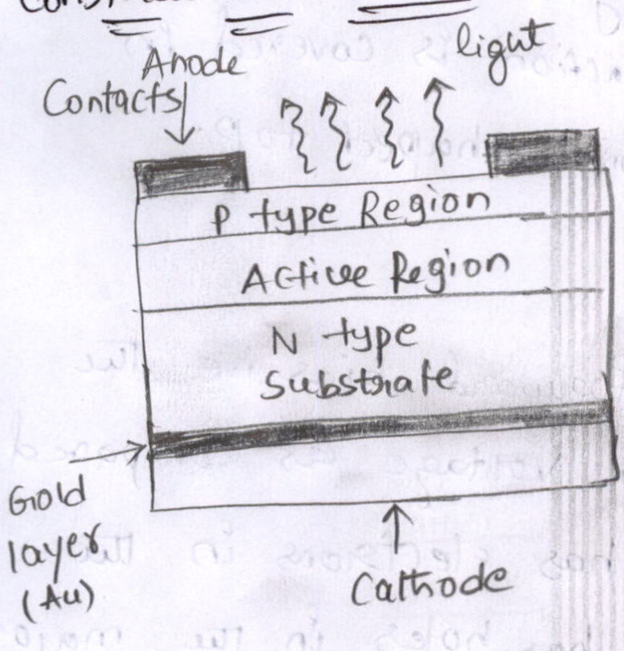
Light Emitting Diode:-

LED is a special type of diode that converts electrical energy into light energy. It is a simple PN junction diode that radiates light in forward bias.

Symbol of LED:- The symbol of LED resembles any conventional PN junction diode except it has arrows pointing outward representing the emission of light as shown in below figure



Construction of LED:-



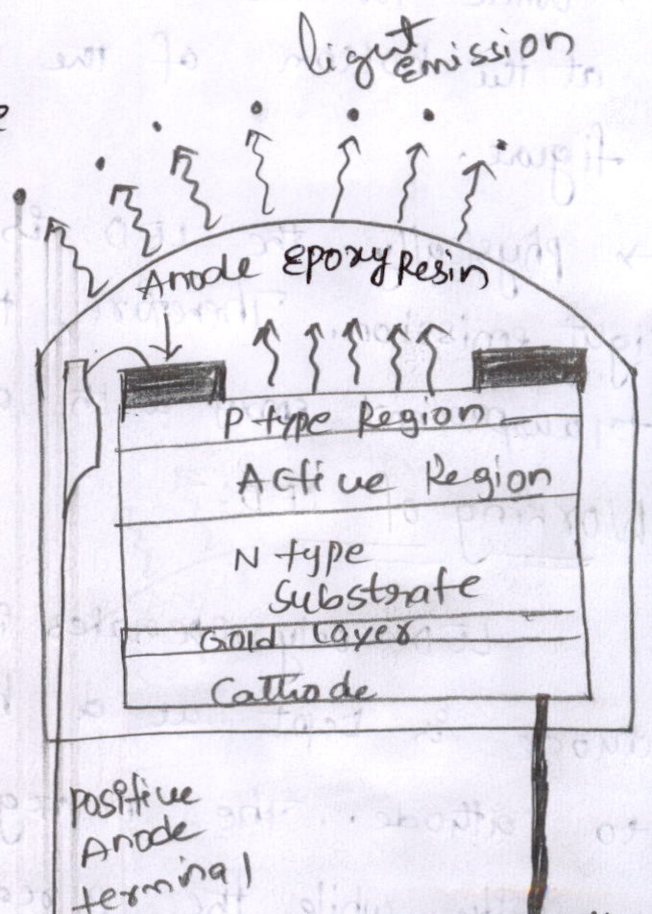


fig: Structure of LED

LED is made of 3 layers p type Semiconductor layer, ~~and~~ N type Semiconductor layer and active region.

→ The N layer had the majority of Electrons & ~~hole~~ the p layer has a majority of holes. The active Region has Equal no of holes & electrons in active Region.

→ The layer of p type material and N type material is combined together on top of each other with an active region between them. As the Electron hole recombination occurs in p region, the p layer is kept at the top & the anode is deposited at the edge of the p layer to have maximum light emission.

→ While for the cathode, a gold film is deposited at the bottom of the N type layer as shown in the figure.

→ physically the LED is designed to have maximum light emission. Therefore, the junction is covered in transparent epoxy with a dome shaped top.

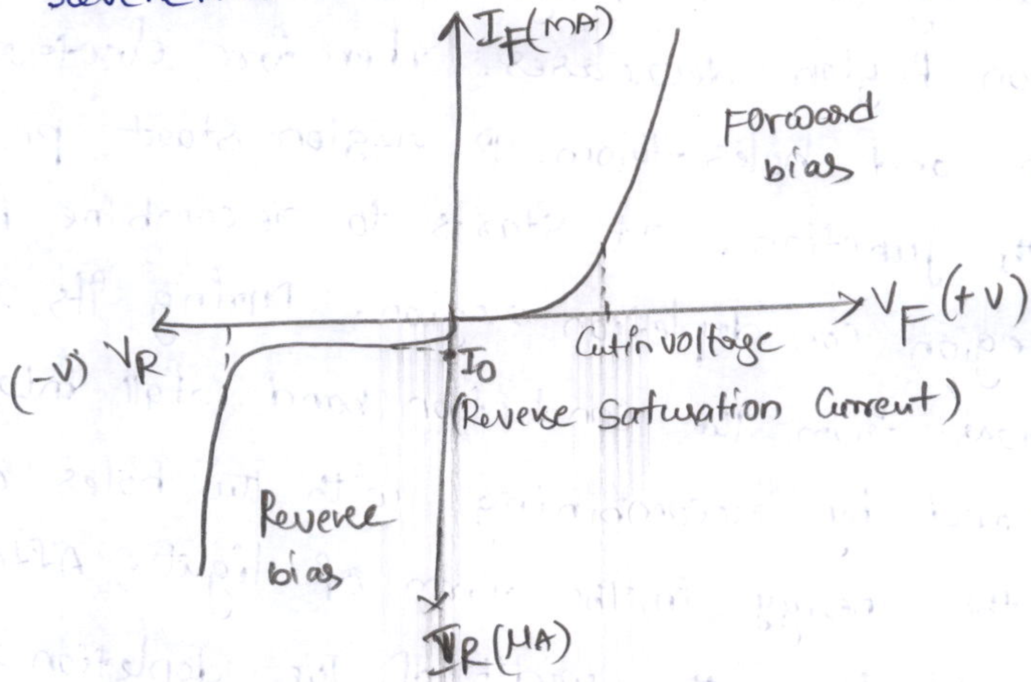
Working of LED:-

LED only operates in forward bias i.e the anode is kept at a higher voltage as compared to cathode. The n region has electrons in the majority while the p region has holes in the majority. Apart from that n type layer is heavily doped as compared to p type.

VI characteristics of LED:-

The VI characteristics of LED are same as VI characteristics of PN diode. i-e It allows current in forward direction. when the applied voltage is less than the cutin voltage LED does not pass current and does not produce light until the forward voltage exceeds the knee voltage

→ Under reverse bias LED acts as a normal diode.



Advantages of LED:-

→ The operating temperature of LED ranges from 0° to 70°C

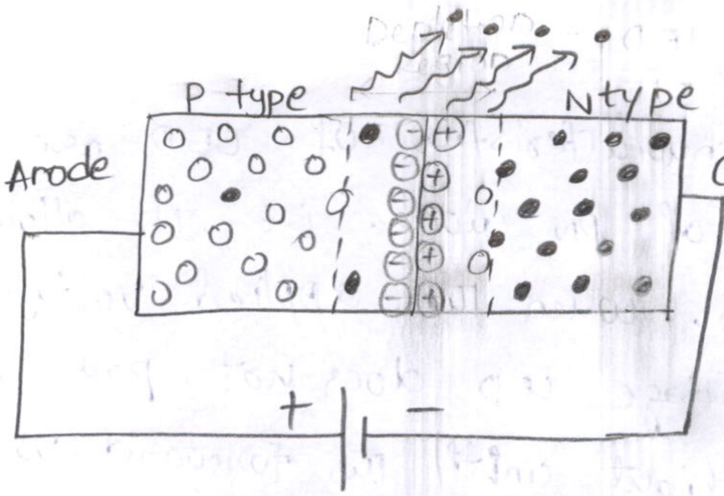
→ LED can withstand mechanical shock & vibrations.

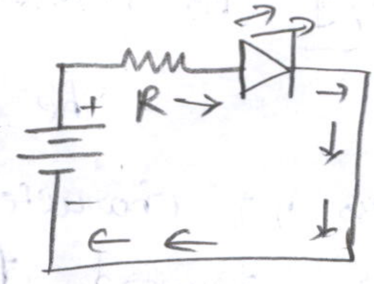
→ It has longer life span.

→ It requires very small voltage & consumes very low power.

→ LEDs are cheaper & very reliable

→ The switching time of LED is very fast in the range of 1ns.



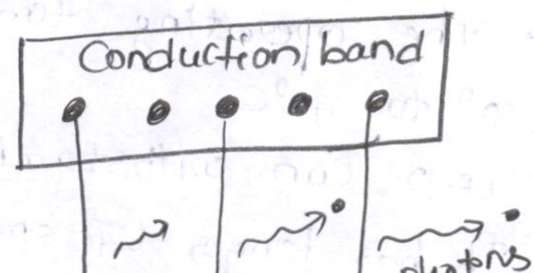


Equivalent circuit of LED

Working of LED

when LED is forward biased, the applied potential
starts pushing on the P layer & the N layer. As a result
the depletion Region decreases. Therefore electrons from
n region and holes from p region start passing
through the junction. It starts to recombine in the
active region (or) depletion region. During its recombination
the electrons from the conduction band fall into the
valance band by recombining with the holes and
release the energy in the form of light. After a
few recombination, the width of the depletion region
further decreases & the intensity of light is increased.

→ The convertion of electricity
into light energy is called
Electro Luminance. The semi
conductors exhibit such property
are GaAs, GaAsp, GaP.



→ Intensity of LED is can be controlled by varying the current flowing through it.

Disadvantages:

→ LEDs are not as energy efficient as LCDs Therefore it cannot be made into a large display.
→ It is expensive as compared to a large LCD.
→ High initial price
→ Temperature dependence
→ It is liable to get damaged by over voltage (or) over current.

Applications of LEDs:—

→ LED's are used in traffic signs & signal lights at every intersection & in the street lights.
→ used as a display in digital clocks, calculators and digital multimeters, etc.,
→ Colourful LEDs are used for decorations & in toys
→ In automobiles, they are used for lighting as well as indicators.
→ Laser LED's of a single wavelength are used in optical communication.
→ It is indeed in digital camera flashes & torch lights.
→ LED's are used in medical equipment.