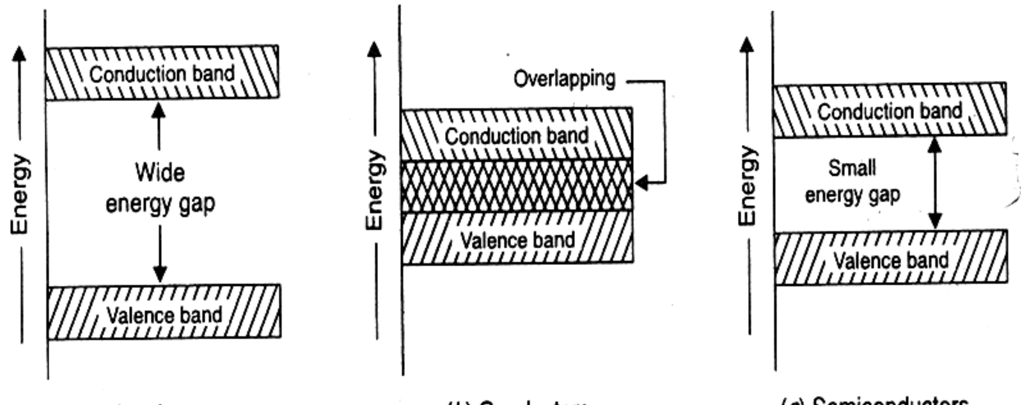
Insulators :
The materials in which the condition band and valence bands are seperated by a wide energy gap (≈ 15 eV) as shown in figure.
A wide energy gap means that a large amount of energy is required, to free the electrons, by moving them from the valence band into the condition band ;
Since at room temperature, the valence electrons of an insulator do not have enough energy to jump in to the condition, therefore insulator do not have an ability to conduct current. Thus insulators have very high resistively (or extremely low conductivity) at room temperatures.
However if the temperature is raised, some of the valence electrons may acquire energy and jump in to the conduction band. It causes the resistively of insulators to decrease.Therefore an insulator have negative temperature co-efficient of resistance.



(*a*) Insulators (*b*) Conductors (*c*) Semiconductors

Conductors :-
The materials in which conduction and valence bands overlap as shown in figure are called conductors. The overlapping indicates a large number of electrons available for conduction.Hence the application of a small amount of voltage results a large amount of current.

Semiconductors :-
The materials, in which the conduction and valence bands are separeated by a small energy gap (1eV) as shown in figure are called semiconductors.
Silicon and germanium are the commonly used semiconductors.
A small energy gap means that a small amount of energy is required to free the elctrons by moving them from the valence band in to the conduction band.
The semiconductors behave4 like insulators at 0K, because no electrons are available in the conduction band.
If the temperature is further increased, more valence elctrons will acquire energy to jump into the conduction band.Thus like insulators, semiconductors also have negative temperature co-efficient of resistance. It means that conductivity of semiconductors increases with the increases tempertature.

2. Explain the classification of semi-conducteurs.
Classification of semi-conducteurs :-
Semiconductors are classified in to two types
- Intrinsic Semiconductors
- Exterinsic semi-conducteurs
  - n-type semi-conductor
  - p-type semi-conductor

- **Intrinsic seiconductor**

A semiconductor in an extremely pure form is known as an intrinic semiconductor. An Intrinsic semiconductor, even at room temperature, hole-electron pairs all created. When electric field is applied across an semiconductor intrinisic semiconductor, the current conduction takes place by two process, namely by free electrons and holes.

Free electrons are produced due to the breeding up of fome co-valent bonds by thermal energy. At the same time holes are created in the co-valent bond itself.When electric field is applied across the semi-conducteurs material electrons will move towards the positive terminal of supply, holes will move towards negative terminal of the supply.

Thus current conduction inside this intrinisic semiconductor material is due to movement of holes & electrons.

But the current in the external wire is only because of electrons. Since while applying electric field, holes are attracted towards negative terminal. There one new electron is introduced. This electron will combine with the hole, thus cancelling them.

At the same time electrons are moving towards positive terminal, while leacing from this intrinisic material it leaves a hole. Again this holes are attracted towards negative terminal.

- **Extrinisic semiconductor :**

The current conduction capability of intrinisic semiconductor is very low at rom temperature. So we can not use it in electric devices.

Hence the current conduction capability must be increased. This can be achieved by adding impurities to the intrinisic semiconductor. So that it become impurity semiconductor (or) Extrinisic semiconductor.The process of adding impurity is known as doping.

The amount & type of impurities have to be closely controlled during the preparation of extrinisic semiconductor. Generally, for 10^8 atoms of semiconductor, one impurity atom is added.

The purpose of adding impurity is to increase either the number of free electrons or holes in the semiconductor crystal. If the pentavalent impurity is adding to the semiconductor, a large number of free electrons are produced in the semiconductor.

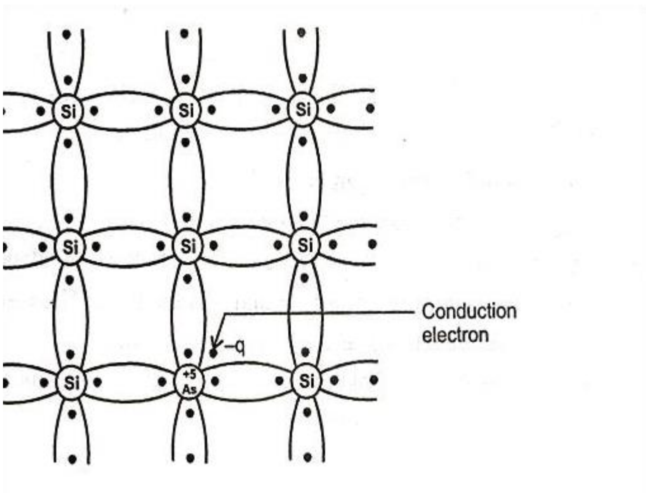
On the other hand if the trivalent impurtiy is added it introdued large number of holes. Depending upon the type of impurity added, extrisic semiconductors are classified into

- n – type Semiconductor
- p – type Semiconductor

n – type Semiconductor :

The number of free electrons in an instrinsic silicon can be increased by adding a pentavalent atom to it. These are atoms with five valence electrons. Typical example for pentavalent atoms are Arsenic, Phosphorous, Bismuth and Antimony.

Four of the pentavalent atoms valence electrons form covalent bond with the valence electrons of Silicon atom, leaving an extra electron. Since valence orbit cannot hold no more than eight electrons the extra electron becomes a conduction electron.



Crystal lattice of a Si atom displaced by arsenic atom

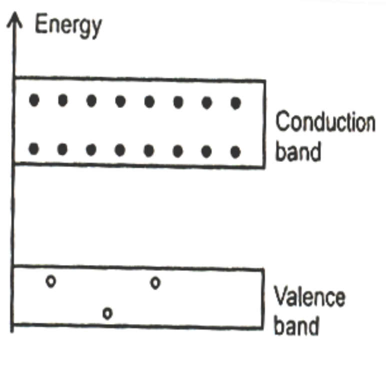
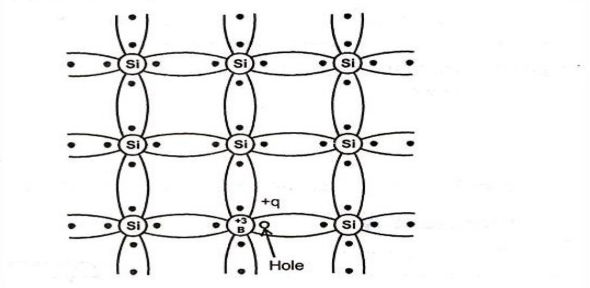


Fig. 1.12 Energy band diagram of a n-type semiconductor

Since the pentavalent atom donnates this extra conduction electron it is often called as a donor atom. For each pentavalent atom added, one free electron exists in a silicon crystal. A small amount of pentavalent impurity is enough to get more number of free electrons is greater than the nuumber of holes this extrinsic semiconductor is known as an n type semiconductor.

When a pentavalent atom is added a number of conduction band electrons are produced. Only a few holes exist in the valence band, created by thermal energy. Therefore in an n-type semiconductor, electrons are majority carriers and holes are minority carriers.

p-type semiconductor



Crystal lattice with a Si atom displaced by Boron atom

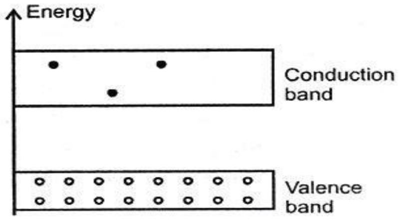


Fig. 1.14 Energy band diagram of a p-type semiconductor

A p-type semiconductor (p for Positive) is obtained by carrying out a process of doping by adding a certain type of atoms (acceptors) to the semiconductor in order to increase the number of free charge carriers (in this case positive holes).

When the doping material is added, it takes away (accepts) weakly bound outer electrons from the semiconductor atoms. This type of doping agent is also known as an acceptor material and the vacancy left behind by the electron is known as a hole.

The purpose of p-type doping is to create an abundance of holes. In the case of silicon, a trivalent atom (typically from Group 13 of the periodic table, such as boron or aluminium) is substituted into the crystal lattice. The result is that one electron is missing from one of the four covalent bonds normal for the silicon lattice. Thus the dopant atom can accept an electron from a neighboring atom's covalent bond to complete the fourth bond. This is why such dopants are called acceptors.

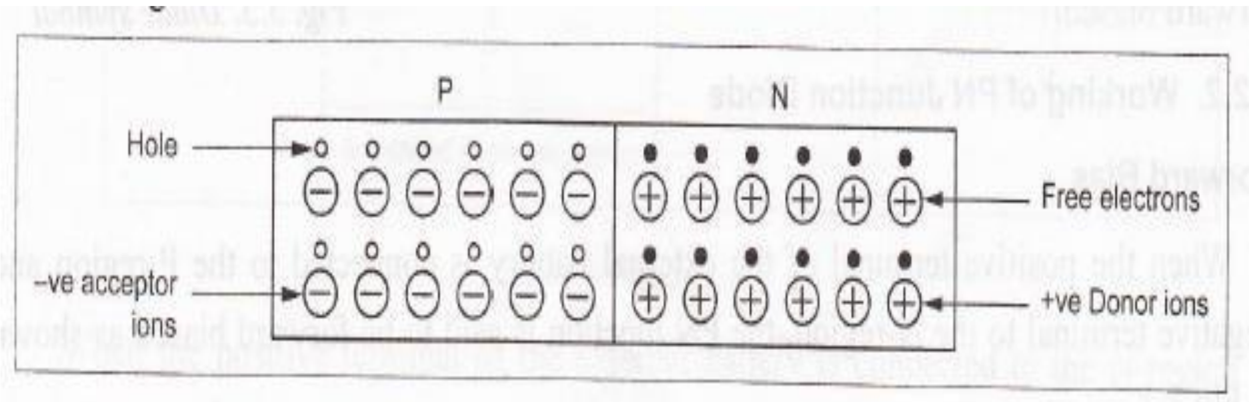
The dopant atom accepts an electron, causing the loss of half of one bond from the neighboring atom and resulting in the formation of a "hole". Each hole is associated with a nearby negatively charged dopant ion, and the semiconductor remains electrically neutral as a whole. However, once each hole has wandered away into the lattice, one proton in the atom at the hole's location will be "exposed" and no longer cancelled by an electron.

This atom will have 3 electrons and 1 hole surrounding a particular nucleus with 4 protons. For this reason a hole behaves as a positive charge. When a sufficiently large number of acceptor atoms are added, the holes greatly outnumber thermal excited electrons. Thus, holes are the majority carriers, while electrons become minority carriers in p-type materials.

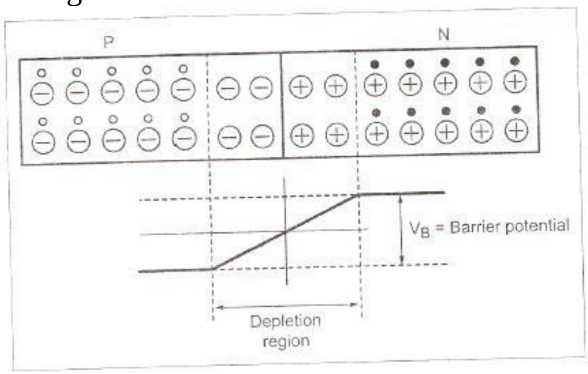
PN junction diode: structure, operation & V-I characteristics

A **PN junction** is formed from a piece of semiconductor (Ge or Si) by diffusing p-type material (Acceptor impurity Atoms) to one half side and N type material to (Donar Impurity Atoms) other half side. The plane dividing the two zones is known as 'Junction'.

The P-region of the semiconductor contains a large number of holes and N region, contains a large number of electrons. A PN junction just immediately formed is shown in Fig.

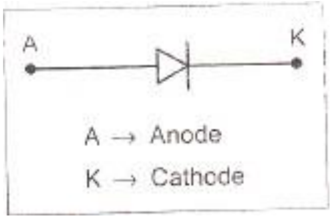


When PN junction is formed, there is a tendency for the electrons in the N-region to diffuse into the p-region, and holes from P-region to N-region. This process is called diffusion. While crossing the junction, the electrons and holes recombines with each other, leaving the immobile ions in the neighborhood of the junction neutralized as shown in Fig.



These immobile + ve and –ve ions, set up a potential across the junction. This potential is called potential barrier or junction barrier. Due to the potential barrier no further diffusion of electrons and holes takes place across the junction. Potential barrier is defined as a potential difference built up across the PN junction which restricts further movement of charge carriers across the junction. The potential barrier for a silicon PN junction is about 0.7 volt, whereas for Germanium PN junction is approximately 0.3 volt.

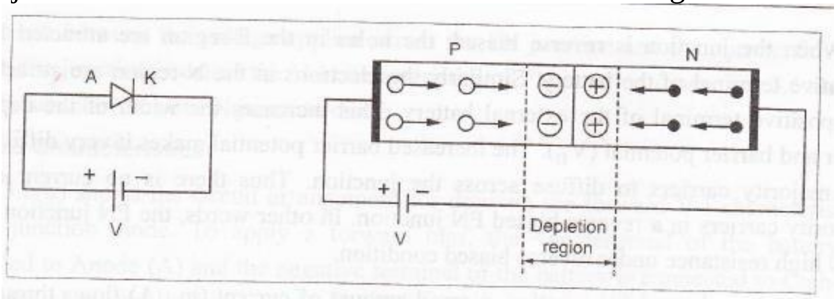
Symbol of Diode:
The symbol of PN junction diode is shown in Fig. The P-type and N-type regions are referred to as Anode and Cathode respectively. The arrowhead shows the conventional direction of current flow when the diode is forward biased.



Working of PN Junction Diode:

Forward Bias:

When the positive terminal of the external battery is connected to the P-region and negative terminal to the N-region, the PN junction is said to be forward biased as shown in Fig.

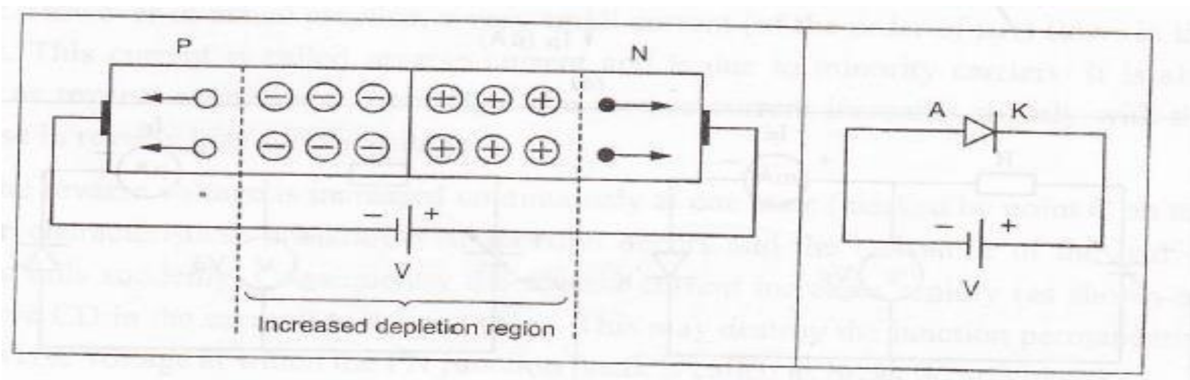


When the junction is forward biased, the holes in the p-region are repelled by the positive terminal of the battery and are forced to move towards the junction. similarly, the electrons in the N-region are repelled by the negative terminal of the battery and are forced to move towards the-junction.

This reduces the width of the depletion layer and barrier potential. If the applied voltage is greater than the potential barrier v_r, then the majority carriers namely holes in P-region and electrons in N-region, cross the barrier. During crossing some of the charges get neutralized the remaining charges after crossing, reach the other side and constitute current in the forward direction. The PN junction offers very low resistance under forward biased condition.

Since the barrier potential is very small (nearly 0.7 V for silicon and 0.3 V for Germanium junction), a small forward voltage is enough to completely eliminate the barrier. once the potential barrier is eliminated by the forward voltage, a large current start flowing through the PN junction.

Reverse Bias:

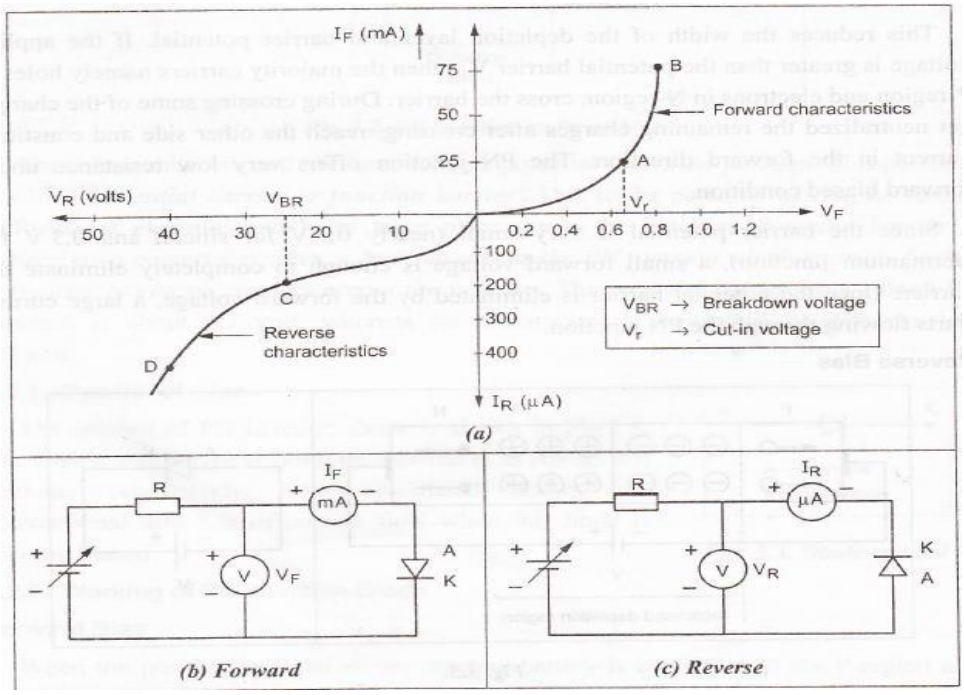


When the positive terminal of the external battery is connected to the N-region and negative terminal to the p-region, the PN junction is said to be reverse biased. When the junction is reverse biased, the holes in the P-region are attracted by the negative terminal of the battery. Similarly, the electrons in the N-region are attracted by the positive terminal of the external battery. This increases the width of the depletion layer and barrier potential (Vs).

The increased barrier potential makes it very difficult for the majority carriers to diffuse across the junction. Thus, there is no current due to majority carriers in a reverse biased PN junction. In other words, the PN junction offers very high resistance under reverse biased condition.

In a reverse biased PN junction, a small amount of current (in µA) flows through the junction because of minority carriers. (i.e., electrons in the P-region and holes in the N region).The reverse current is small because the number of majority carrier in both regions is small.

V-l characteristics of PN-Junction Diode:



A graph between the voltage applied across the PN junction and the current flowing through the junction is called the V-I characteristics of PN junction diode. Fig. shows the V-I characteristics of PN junction diode.

Forward Characteristics:

Fig. (a) shows the circuit arrangement for drawing the forward V-I characteristics of PN junction diode. To apply a forward bias, the +ve terminal of the battery is connected to Anode (A) and the negative terminal of the battery is connected to Cathode (K). Now, when supply voltage is increased the circuit current increases very slowly and the curve is nonlinear (region-OA).

The slow rise in current in this region is because the external applied voltage is used to overcome the barrier potential (0.7 V for Si; 0.3V for Ge) of the PN junction' However once the potential barrier is eliminated and the external supply voltage is increased further, the current flowing through the PN junction diode increases rapidly (region AB). This region of the curve is almost linear. The applied voltage should not be increased beyond a certain safe limit, otherwise the diode will burnout.

The forward voltage at which the current through the PN junction starts increasing rapidly is called by **knee voltage**. It is denoted by the letter V_B.

Reverse Characteristics:

Fig (b) shows the circuit arrangement for drawing the reverse V-I characteristics of PN junction diode. To apply a reverse bias, the +ve terminal of the battery is connected to cathode (K) and - ve terminal of the battery is connected to anode (A).

Under this condition the potential buried at the junction is increased. Therefore, the junction resistance becomes very high and practically no. current flows through the circuit. However, in actual practice, a very small current (of the order of µA) flows in the circuit. This current is called reverse current and is due to minority carriers. It is also called as reverse saturation current (I). The reverse current increases slightly with the increase in reverse bias supply voltage.

If the reverse voltage is increased continuously at one state (marked by point C on the reverse characteristics) breakdown of junction occurs and the resistance of the barrier regions falls suddenly. Consequently, the reverse current increases rapidly (as shown by the curve CD in the current) to a large value. This may destroy the junction permanently. The reverse voltage at which the PN junction breaks is called as break down voltage.

Temperature effects

The cut in voltage decreases as the temperature increases. The reverse saturation current increases.

$I_{02} = 2^{(\Delta T/10)} I_{01}$

I_{01},I_{02} are the reverse current at T_1°C, T_2°C

$\Delta T = T_2 - T_1$.

The voltage equivalent of temperature V_T also increases. The reverse breakdown voltage increases.

2. **Derive the PN diode current equation.**

The applied voltage and current though diode are related by the equation

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

Where,

Io = Reverse saturation current
V = Applied voltage
I = Diode current
VT = Volt equivalent temperature

$$V_T = \frac{\bar{k}T}{q}$$

$\bar{k}$= 1.38*10^{-23} J/K
T = temperature of the diode junction
I = diode current
Q = change of electron 1.602*10^{-19} C
At any temperature

$$V_T = \frac{\bar{k}T}{q} = \frac{1.38 \times 10^{-23}}{1.602 \times 10^{-19}} = \frac{T}{11600}$$

At room temperature

$$V_T = \frac{300}{11600} = 26mV$$

The value of η=1 for germanium and 2 for silicon.

For forward bias voltage the current equation reduces to

$$I = I_0\,(e^{V/yV_T})$$

At room temperature for germanium transistor

$$I = I_0(e^{40})$$

When the diode is reverse biased

$$I = I_0\,(e^{V/yV_T} - 1)$$

$$I \cong I_0$$

Rectifiers – Half Wave and Full Wave

Half Wave

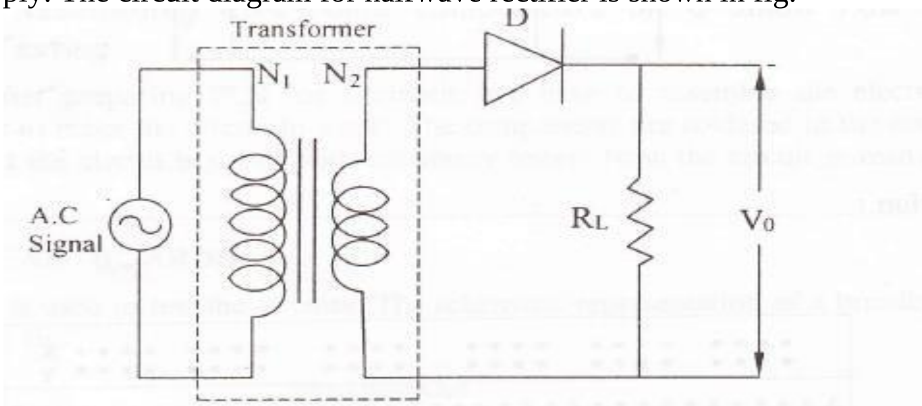
Rectifiers *are a class of circuits whose purpose is to convert ac waveforms (usually sinusoidal and with zero average value) into a waveform that has a significant non-zero average value (dc component)*. Simply stated, rectifiers are ac-to-dc energy converter circuits. Most rectifier circuits employ diodes as the principal elements in the energy conversion process; thus, the almost inseparable notions of diodes and rectifiers.

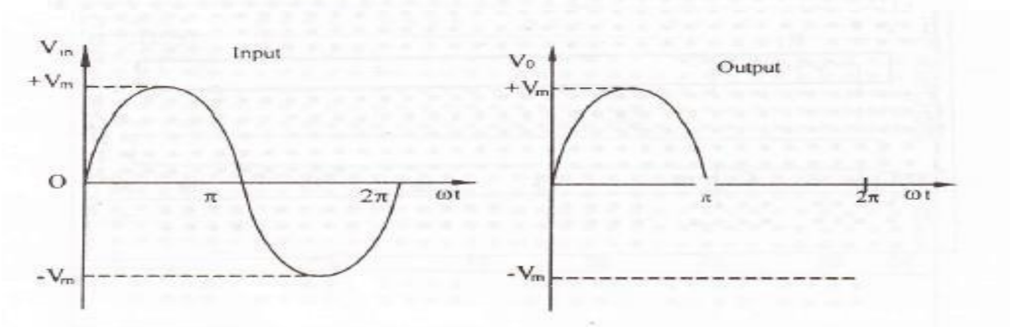
Uncontrolled rectifier: *uncontrolled* refers to the absence of any control signal necessary to operate the primary switching elements (diodes) in the rectifier circuit. (The discussion of controlled rectifier circuits, and the controlled switches themselves, is more appropriate in the context of power electronics applications). Rectifiers are the fundamental building block in dc power supplies of all types and in dc power transmission used by some electric utilities.

There are two types of rectifiers:

(a) Half Wave (HW) rectifier (b) Full Wave (FW) rectifier

Half -wave Rectifier:
It consists of a single diode in series with a load resistor. The input to half wave rectifier is supplied from the 50 Hz a.c supply. The circuit diagram for halfwave rectifier is shown in fig.





Positive half cycle:
During the positive half cycle of the input signal the *anode of the diode becomes positive with respect to the cathode* and hence the diode D conducts. For an ideal to the cathode and hence the diode D conducts. For an ideal diode, the forward voltage drop is zero. So the whole-input voltage will appear across load resistance R_L.

Negative half cycle:

During negative half cycle of the input signal, the *anode of the diode becomes negative with respective to the cathode* and hence the diode D does not contact. For an ideal diode the impedance by the diode is infinity. So the whole input voltage appears across the diode D. hence the voltage drop across R, is zero.

Analysis of Half wave rectifier:

Let Vi be the input voltage to the rectifier

$$V_i = V_m sin\omega t$$

Where,

V_m = Maximum value of the input voltage.

Let I be the current flowing though the circuit when the diode is conducting.

$$i = \left\{ \begin{array}{ll} I_m sin\omega t & For\ 0 \le \omega t \le \pi \\ 0 & For\ \pi \le \omega t \le 2\pi \end{array} \right\}$$

Where

$$I_m = Maximum\ value\ of\ the\ current$$

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

Where

R_F-Forward dynamic resistance of diode.

R_L-Load resistance.

(a) Average or DC value of output current (I_{dc}):

From Fig., it is seen that the output current is not steady but contains fluctuations even though it is DC current. The average value of this fluctuating current is called DC current (I_{dc}). It can be calculated as follows.

Average value = (Area under the curve / Period)

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

$$I_{dc} = \frac{1}{2\pi}[\int_0^{\pi} I_m * \sin\omega t\, d(\omega t)]$$

$$I_{dc} = \frac{1}{2\pi}[-\cos\omega t]_0^{\pi} = \frac{I_m}{2\pi}[-\cos\pi - (-\cos 0)] = \frac{I_m}{2\pi}[-(-1) - (-1)] = \frac{I_m}{\pi}$$

$$I_{dc} = \frac{V_m}{\pi(R_F + R_L)}$$

(b) Average or DC output voltage (V_o):

$$V_{dc} = \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi}$$

(c) RMS value of output current (I_{rms}):

$$\boldsymbol{I_{rms}} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2 d(\omega t)} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t * d(\omega t)} = \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} (\frac{1-\cos 2\omega t}{2}) * d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\int_0^\pi d(\omega t) - \int_0^\pi \cos 2(\omega t) * d(\omega t)} = \sqrt{\frac{I_m^2}{4\pi}\left[\omega t_0^\pi - \left(\frac{\sin 2\omega t}{2}\right)_0^\pi\right]}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[(\pi - 0) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 0}{2}\right)\right]} = \sqrt{\frac{I_m^2}{4\pi}[(\pi - 0) - 0]} = \sqrt{\frac{I_m^2}{4\pi}} = \frac{I_m}{2}$$

(d) Rectification Efficiency (η):

Rectification efficiency **(η)** $= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 \times R_L} = \frac{\frac{I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2} \times R_L} = \frac{I_m^2/\pi^2 \times R_L}{I_m^2/4 \times R_L} = \frac{4}{\pi^2} = 0.406$

(e) Ripple Factor (γ):

$$\gamma = \frac{I'_{rms}}{I_{dc}} = \sqrt{\frac{I_{rms}^2 - I_{dc}^2}{I_{dc}^2}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \mathbf{1.21}$$

(f) Peak inverse Voltage (PIV):

Peak inverse voltage is defined as the maximum voltage that is applied across the Diode when the diode is reverse biased. [n case of half wave rectifier, maximum Voltage across the diode when it is not conducting is equal to V_m.

$$\boldsymbol{PIV = V_m}$$

(g) From factor:

$$FF = \frac{rms\ value}{average\ value} = \frac{\pi}{2} = 1.57$$

(h) Peak factor:

$$PF = \frac{V_m}{\left(\frac{V_m}{2}\right)} = 2$$

(i) Transformer utilization factor:

$$TUF = \frac{P_{dc}}{P_{ac}}(Transformer\ secondary\ rated) = 0.287$$

Disadvantages of HWR:

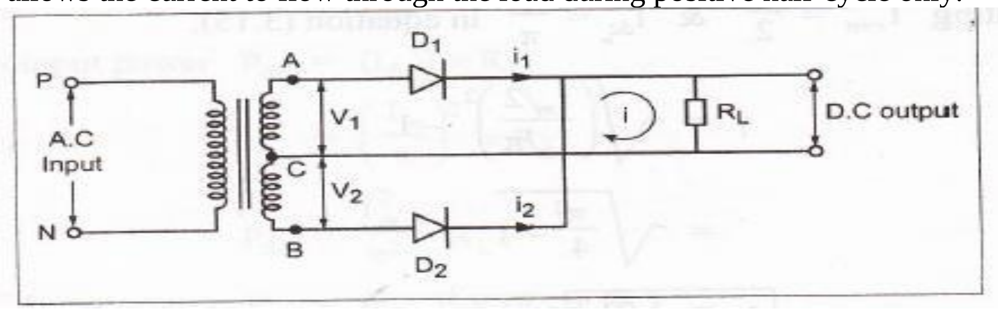
- Low output because one half cycle only delivers output
- A.C. component more in the output
- Requires heavy filter circuits to smooth out the output **Peak inverse Voltage.**

Rectifiers – Full Wave using center tap Transformer

In FWR, current flows through the load during both half cycles of the input a.c. supply. Like the half wave circuit, a *full wave rectifier circuit produces an output voltage or current which is purely DC or has some specified DC component*. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average (DC) output voltage is higher than for half wave, the output of the full wave rectifier has much less ripple than that of the half wave rectifier producing a smoother output waveform.

Full Wave Rectifier:

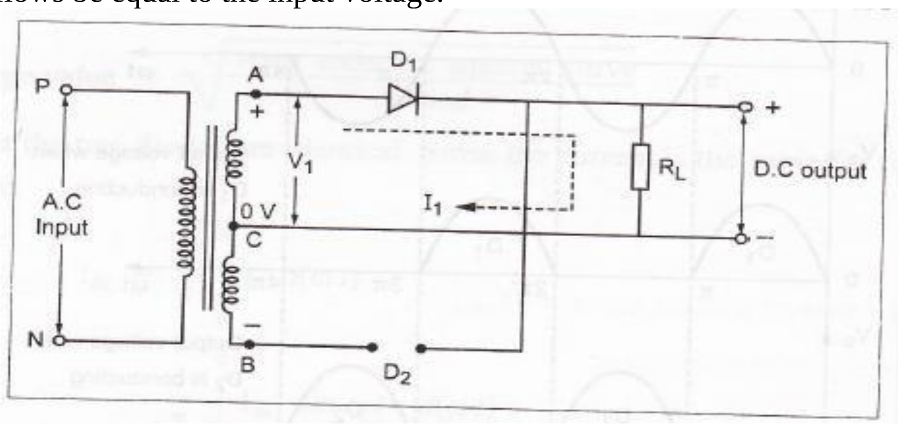
A full wave rectifier is an electronic circuit which converts AC voltage into a pulsating DC voltage using both half cycles of the applied AC voltage. A full wave rectifier is a circuit which allows a unidirectional current to flow through the load during the entire input cycle as shown in fig. The result of full wave rectification is a d.c. output voltage that pulsates every half-cycle of the input. On the other hand a half wave rectifier allows the current to flow through the load during positive half-cycle only.



Positive half cycle:

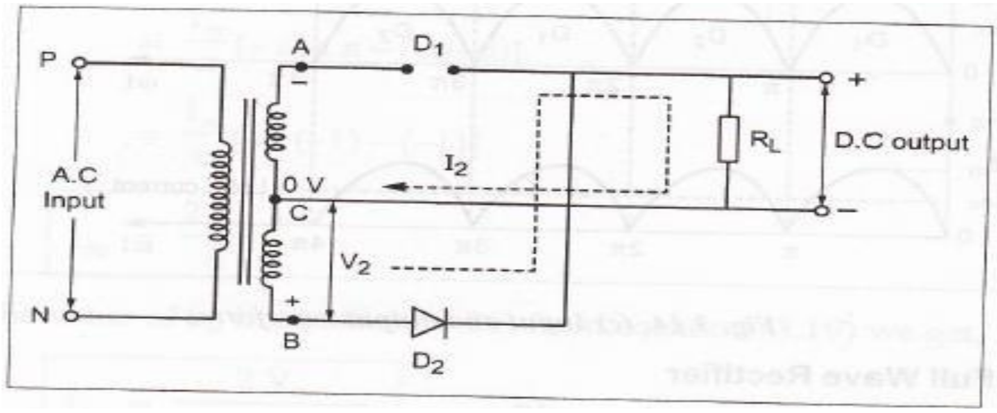
The circuit uses two diodes which are connected to secondary winding of the transformer. The input signal is applied to the primary winding of the transformer. During the positive input half cycle, the polarities of the secondary voltage is shown in fig. This forward bias the diode D, and reverse biases the diode D_1. As a result of this, the diode D, conducts some current whereas the diode D, is off.

The current through load R1 is as indicated in through D_1, and the voltage Drop across R_L will the fig. The load current flows be equal to the input voltage.



Negative half cycle:

During the negative input half cycle, the polarities of the secondary voltage are interchanged. The reverse-bias the diode D, and forward Biases the diode D_2. As a result of this, the diode D_1 is OFF and the diode D_2 conducts some current. The current through the load R, is an indicated in the fig. The load current flows through D_2 and the voltage drop across R_1 will be equal to the input voltage. The maximum efficiency of a fall-wave rectifier is 8l,2%Vo and ripple factor is 0.48.



Analysis of Full Wave Rectifier:

Let Vi be the input voltage to the rectifier, $V_i = V_m sin\omega t$

Where, V_m = Maximum value of the input voltage.

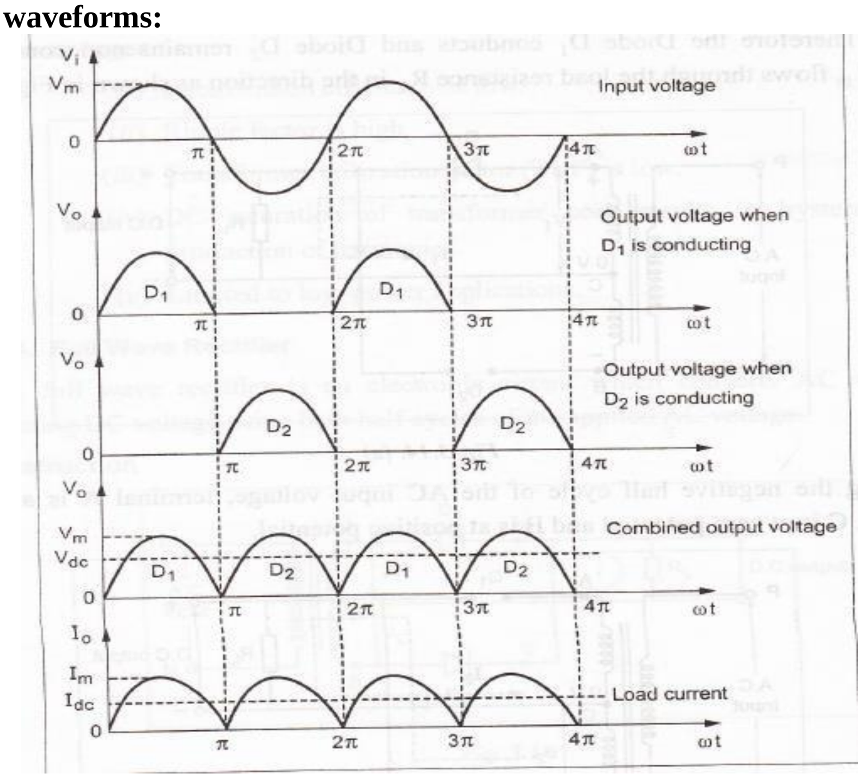
Let I be the current flowing though the circuit when the diode is conducting.

$$i = \begin{cases} I_m sin\omega t & For\ 0 \leq \omega t \leq \pi \\ 0 & For\ \pi \leq \omega t \leq 2\pi \end{cases}$$

Where, $I_m = Maximum\ value\ of\ the\ current;$ $I_m = \frac{V_m}{R_F + R_L}$

Where, R_F-Forward dynamic resistance of diode; R_L-Load resistance.

Input and output waveforms:



(a) Average or DC value of output current (I_{dc}):

Average value = (Area under the curve / Period)

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

$$I_{dc} = \frac{1}{\pi}\left[\int_0^{\pi} I_m * \sin\omega t\, d(\omega t)\right]$$

$$I_{dc} = \frac{1}{\pi}[-\cos\omega t]_0^{\pi} = \frac{I_m}{\pi}[-\cos\pi - (-\cos 0)] = \frac{I_m}{\pi}[-(-1) - (-1)] = \frac{2I_m}{\pi}$$

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

(b) Average or DC value of output voltage (V_{dc}) :

$$V_{dc} = \frac{2I_m}{\pi} \times R_L = \frac{2V_m}{\pi}$$

(c) RMS value of output current (I_{rms}):

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

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} d(\omega t) - \int_0^{\pi}\cos 2(\omega t) * d(\omega t)} = \sqrt{\frac{I_m^2}{2\pi}\left[\omega t_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\left[(\pi - 0) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 0}{2}\right)\right]} = \sqrt{\frac{I_m^2}{2\pi}[(\pi - 0) - 0]} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$$

(d) Rectification Efficiency (η):

Rectification efficiency **(η)** $= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 \times R_L} = \frac{\frac{2I_m^2}{\pi} \times R_L}{\frac{I_m^2}{\sqrt{2}} \times R_L} = \frac{4I_m^2/\pi^2 \times R_L}{I_m^2/2 \times R_L} = \frac{0.812}{(1+\frac{R_F}{R_L})} = 81.2\%$

(e) Ripple Factor (γ):

$$y = \frac{\text{RMS value of Ac component}}{\text{Dc value of wave}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2I_m/\pi}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = \mathbf{0.48}$$

(f) Peak inverse Voltage (PlV):

Peak inverse voltage is the maximum possible voltage across a diode when it is not conducting. During positive half cycle of the AC input voltage Diode D1, is conducting and Diode D, is not conducting. In this case a voltage V, is developed across the load resistor R_1. Now the voltage across the non-conducting Diode D, is the sum of the voltage across R1 and voltage across the lower half of transformer secondary V_m.

Hence, PIV of Diode D2 = $V_m + V_m = 2V_m$

Similary, PIV of Diode D1 = $V_m + V_m = 2V_m$

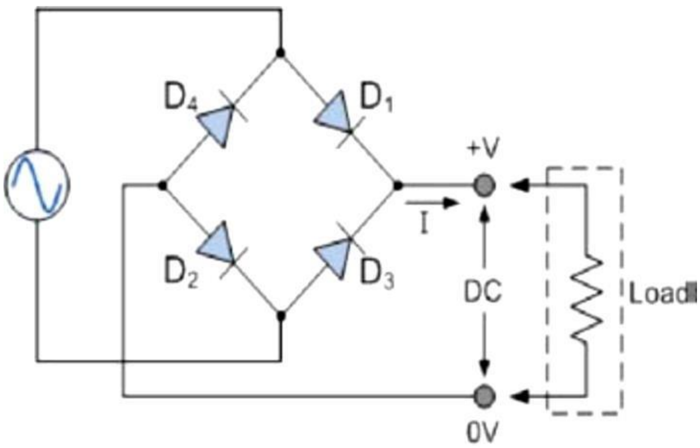
Advantages:
1. The D.c load voltage and current are more than halfwave.
2. No D.c current thro transformer windings hence no possibility of saturation.
3. TUF is better.
4. Efficiency is higher.
5. Ripple factor less.

Disadvantages:
1. PIV rating of diode is higher
2. Higher PIV diodes are larger in size ad costlier.
3. Cost of transformer is high.

Rectifiers – Full Wave Bridge type

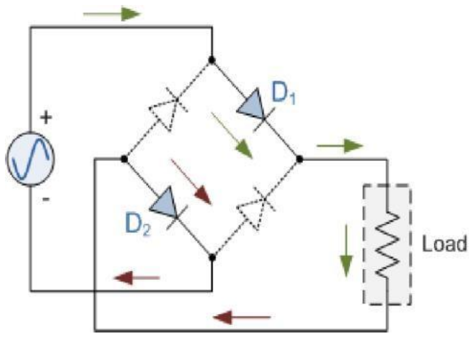
Bridge rectifier (Full Wave Bridge rectifier):

Another type of circuit that produces the same output waveform as the full wave rectifier circuit above is that of the **Full Wave Bridge Rectifier**. This type of single-phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The main advantage of this bridge circuit is that it does ***not require a special center tapped transformer***, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.

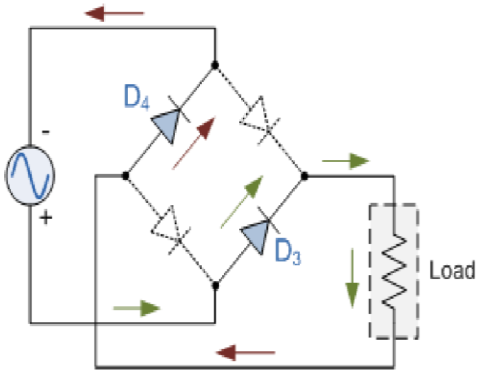


The four diodes labeled D1 to D4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. *During the positive half cycle of the supply, diodes D1 and D2 conduct* in series while diodes D3 and D4 are reverse biased and the current flows through the load as shown below.

During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch of as they are now reverse biased. The current flowing through the load is the same direction as before. As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the previous two diode full-wave rectifier.

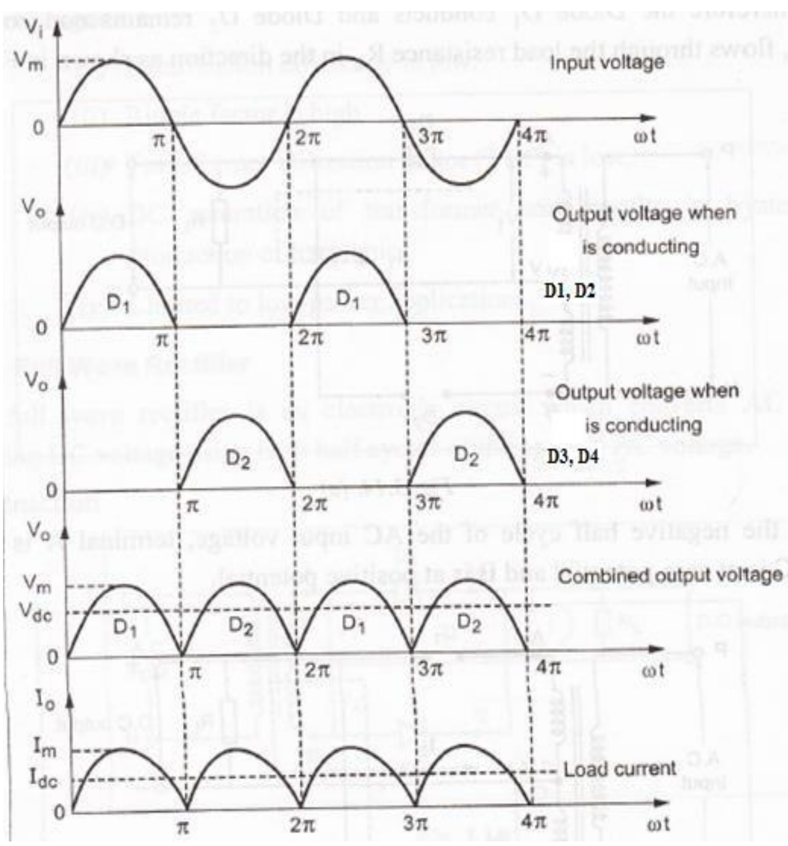


Positive half cycle



Negative half cycle

Waveform:



Analysis of Full Wave Rectifier:

Let Vi be the input voltage to the rectifier, $V_i = V_m sin\omega t$
Where,
V_m = Maximum value of the input voltage.
Let I be the current flowing though the circuit when the diode is conducting.

$$i = \begin{cases} I_m sin\omega t & For\ 0 \le \omega t \le \pi \\ 0 & For\ \pi \le \omega t \le 2\pi \end{cases}$$

Where

$$I_m = Maximum\ value\ of\ the\ current$$

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

Where, R_F-Forward dynamic resistance of diode; R_L-Load resistance.

(a) Average or DC value of output current (I_{dc}):

Average value = (Area under the curve / Period)

$$I_{dc} = \frac{1}{\pi}\int_0^\pi i\, d(\omega t) \qquad I_{dc} = \frac{1}{\pi}[\int_0^\pi I_m * sin\omega t\, d(\omega t)]$$

$$I_{dc} = \frac{1}{\pi}[-cos\omega t]_0^\pi = \frac{I_m}{\pi}[-cos\pi - (-cos0)] = \frac{I_m}{\pi}[-(-1) - (-1)] = \frac{2I_m}{\pi}$$

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

(b) Average or DC value of output voltage (V_{dc}): $V_{dc} = \frac{2I_m}{\pi} \times R_L = \frac{2V_m}{\pi}$

(c) RMS value of output current (I_{rms}):

$$\boldsymbol{I_{rms}} = \sqrt{\frac{1}{\pi}\int_0^\pi i^2 d(\omega t)} = \sqrt{\frac{1}{\pi}\int_0^\pi I_m^2 sin^2\omega t * d(\omega t)} = \sqrt{\frac{I_m^2}{\pi}\int_0^\pi (\frac{1 - cos2\omega t}{2}) * d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^\pi d(\omega t) - \int_0^\pi cos2(\omega t) * d(\omega t)} = \sqrt{\frac{I_m^2}{2\pi}[\omega t_0^\pi - (\frac{sin2\omega t}{2})_0^\pi]}$$

$$= \sqrt{\frac{I_m^2}{2\pi}[(\pi - 0) - (\frac{sin2\pi}{2} - \frac{sin0}{2})]} = \sqrt{\frac{I_m^2}{2\pi}[(\pi - 0) - 0]} = \sqrt{\frac{I_m^2}{2}} = \frac{I_m}{\sqrt{2}}$$

(d) Rectification Efficiency (η):

Rectification efficiency **(η)** $= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 \times R_L} = \frac{\frac{2I_m}{\pi}^2 \times R_L}{\frac{I_m}{\sqrt{2}}^2 \times R_L} = \frac{4I_m^2/\pi^2 \times R_L}{I_m^2/2 \times R_L} = \frac{0.812}{(1 + \frac{R_F}{R_L})} = 81.2\%$

(e) Ripple Factor (γ):

$$y = \frac{\text{RMS value of Ac component}}{\text{Dc value of wave}} = \sqrt{(\frac{I_{rms}}{I_{dc}})^2 - 1} = \sqrt{(\frac{I_m/\sqrt{2}}{2I_m/\pi})^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = \mathbf{0.48}$$

(f) Peak inverse Voltage (PIV):

Peak inverse voltage is the maximum possible voltage across a diode when it is not
Conducting. During positive half cycle of the AC input voltage Diode D1, is conducting and Diode D, is not conducting. In this case a voltage V, is developed across the load resistor R_1. Now the voltage across the non-conducting Diode D, is the sum of the voltage across R1 and voltage across the lower half of transformer secondary V_m.
Hence, PIV of Diode D2 = $V_m + V_m = 2V_m$
Similary, PIV of Diode D1 = $V_m + V_m = 2V_m$

Advantages:

1. The D.c load voltage and current are more than half wave.
2. No D.c current thro transformer windings hence no possibility of saturation.
3. TUF is better.
4. Efficiency is higher.
5. Ripple factor less.
6. No centre tapped is required.

Disadvantages:

4 diodes are used therefore voltage drop across the diode is increased. This reduces output voltage.

Applications:
1. In power supply circuits.
2. Used as rectifier in power circuits to convert A.C to D.C

7. Compare different types of rectifiers?

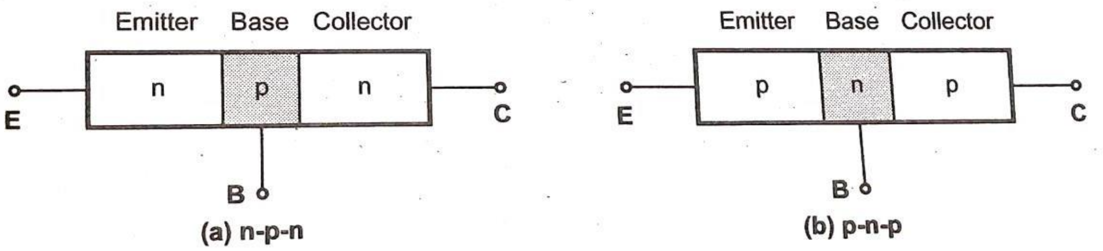
Type	HW	CT FW	FW BR
No of diodes used	1	2	4
Need of transformer	Not necessary	Necessary	Not necessary
Ripple factor	1.21	0.48	0.48
Efficiency	40.6%	81.2%	81.2%
PIV	V_m	$2V_m$	V_m
TUF	0.287	0.812	0.693
From factor	1.57	1.11	1.11
Peak factor	2	$\sqrt{2}$	$\sqrt{2}$
Ripple frequency	f	2f	2f

PART-B

BJT-Structure, Operation & Characteristics

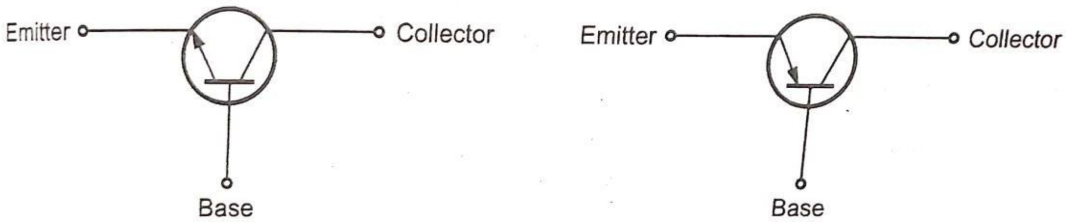
1. **Explain about the transistor (BJT) operation.**

Structure:



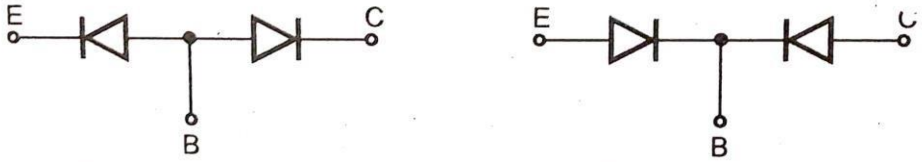
(a) n-p-n **(b) p-n-p**

Symbol:



(a) n-p-n (b) p-n-p

Two-diode transistor analogy



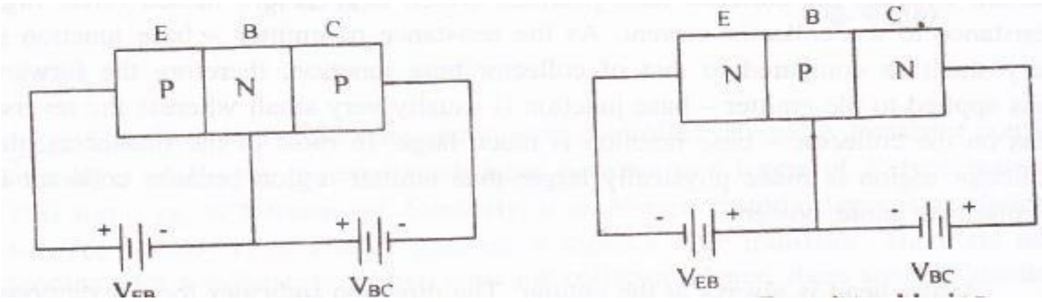
(a) n-p-n transistor **(b) p-n-p transistor**

Applying external voltage to a transistor is called biasing. In order to operate transistor properly as an amplifier, it is necessary to correctly bias the two PN junctions with external voltages. Depending upon external bias voltage polarities used, the transistor works in one of the three regions.

1. Active region ***2. Cut-off region*** ***3. Saturation region***

S. No.	Region	Emitter Base	Collector Base	Operation of a transistor
1	Active	Forward biased	Reverse biased	Acts as an amplifier
2	Cut off	Reverse biased	Reverse biased	Acts as an open switch
3	Saturation	Forward biased	Forward biased	Acts as a closed switch

To bias the transistor in its active region the emitter base junction is forward biased, while the collector-base junction in reverse-biased as shown in Fig. The Fig. shows the circuit connections for active region for both NPN and PNP transistors.



Operation of NPN transistor:

As shown in fig. the forward bias 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 give the emitter current i.e. $I_E=-(I_C+I_B)$.

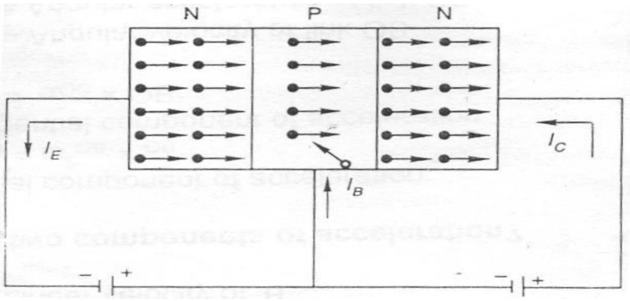


Fig. Current in NPN transistor

In the external circuit of the NPN 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 $I_E=I_C+I_B$.

Operation of PNP transistor:

As shown in fig. the forward bias applied to the emitter – base junction of a PNP transistor causes a lot of hoses from the emitter regions to cross over to the base region as the base is lightly doped with N-type impurity. The number of electrons in the base regions is very small and hence the number of holes combined with electrons in the N – type base region is also very small. Hence a few holes combined with electrons to constitute a base current I_B.

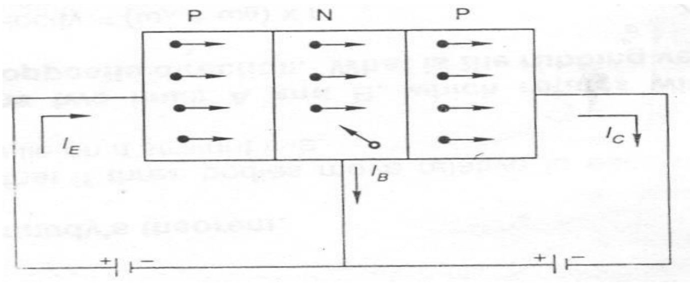


Fig. Current in PNP transistor

The remaining holes (more than 95%) cross over into the collector region to constitute a collector current I_C. Thus, the collector and base current when summed up gives the emitter current.

i.e. $I_E = -(I_C+I_B)$.

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

$$I_E=I_C+I_B$$

The equation gives the fundamental relationship between the currents in a bipolar transistor circuit. Also, this fundamental equation shows that there are current amplification factors α and β in common base transistor configuration and common emitter transistor configuration respectively for the static (d.c) currents, and for small changes in the currents.

Large – signal current gain (α). The large signal current gain of a common base transistor is defined as the ratio of the negative of the collector – current increment to the emitter – current change from cut off ($I_E=0$) to I_E,i.e.

$$\alpha = -\frac{(I_C - I_{CBO})}{I_E - 0}$$

where I_{CBO} (or I_{CO}) is the reverse saturation current flowing through the reverse biased collector – base junction. i.e. the collector to base leakage current with emitter open. As the magnitude of I_{CBO} is negligible when compared to I_E, the above expression can be written as

$$\alpha = \frac{I_C}{I_E}$$

Since I_C and I_E are flowing in opposite directions, α is always positive. Typical value of α ranges from 0.90 to 0.995. Also, α is not a constant but varies with emitter current I_E, collector voltage V_{CB} and the temperature.

Common Base Configuration (CB configuration):

This configuration is also called the grounded base configuration. In this case the input is connected between emitter and base while the output is taken across the collector and base. Thus the base of the transistor is common to both input and output circuits and hence the name, common base configuration. The common base circuit arrangement for NPN transistors is shown in Fig.

Current Amplification Factor (α):

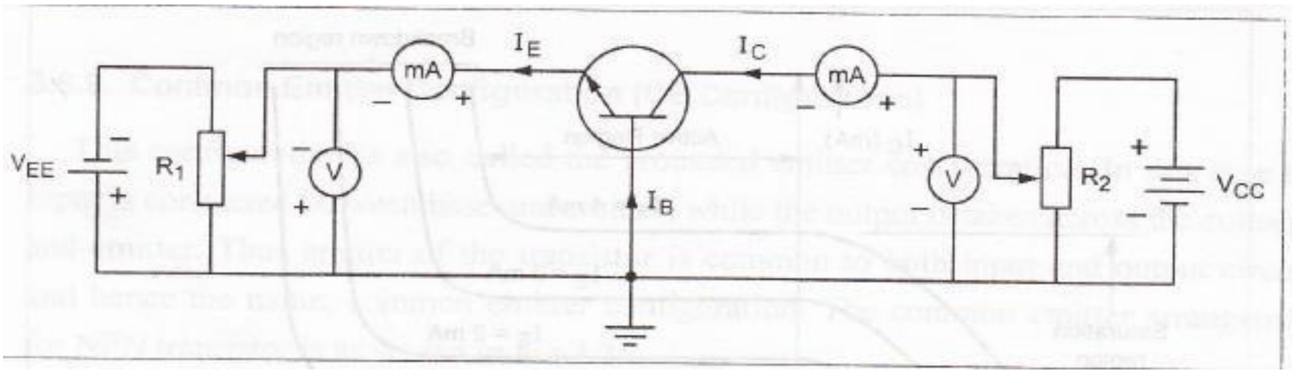
The current amplification factor is defined as the ratio of changes in Collector current (ΔI_C) to the change in emitter current (ΔI_E) when the collector to base voltage (V_{CB}) is maintained at a constant value.

$$\alpha=(\Delta I_C)/(\Delta I_E) \text{ (at constant } V_{CB})$$

The value of α is always less than unity. The practical value of transistors lie between 0.95 and 0.99.

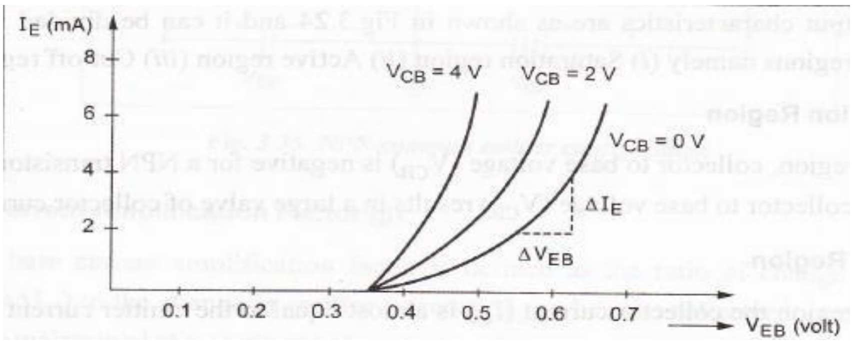
Characteristics of Common Base Configuration:

The circuit arrangement for determining the characteristics of a common base NPN transistors is shown in Fig.In this circuit, the collector to base voltage (V_{CB}) can be varied by adjusting the potentiometer R_2. The emitter to base voltage (V_{EB}) can be varied by adjusting the potentiometer R_l. The DC voltmeters and DC milliammeters are connected in the emitter and collector circuits to measure the voltages and currents.



a). Input Characteristics:

The curve plotted between the emitter current (I_E) and the emitter to base voltage (V_{EB}) at constant collector to base voltage (V_{CB}) are known as input characteristics of a transistor in common base configuration.



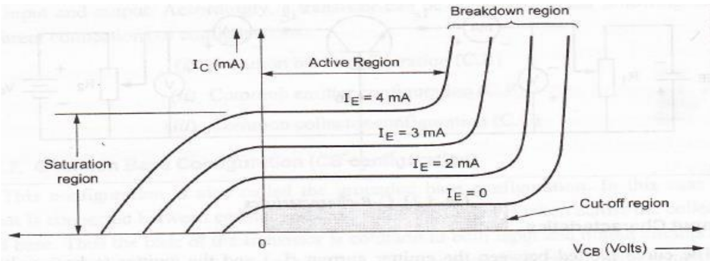
Input Resistance (R_i):

It is the ratio of change in emitter to base voltage (ΔV_{EB}) to the corresponding change in emitter current (ΔI_E) for a constant collector to base voltage (V_{CB}).

$$R_i = \frac{\Delta V_{EB}}{\Delta I_E} \quad \text{(at constant } V_{CB}\text{)}$$

b). Output Characteristics:

The curve plotted between the collector current (I_C) and the collector to base voltage (V_{CB}) at constant emitter current (I_E) are known as output characteristics of a transistor is common base configuration.



The output characteristics are as shown in Fig. and ***it can be divided into three important regions namely (i) Saturation region (ii) Active region (iii) Cut-off region.***

(i). Saturation Region:

In this region, collector to base voltage (V_{CB}) is negative for a NPN transistor. A small change in collector to base voltage (V_{CB}) results in a large valve of collector current.

(ii). Active Region:

In this region the collector current (I_C) is almost equal to the emitter current (I_E). The transistor is always operated in this region. In the active region, the curves are almost flat. A very large change in V_{CB} produces only a very small change in I_C. It means that the circuit has very high output resistance about 500 K Ω.

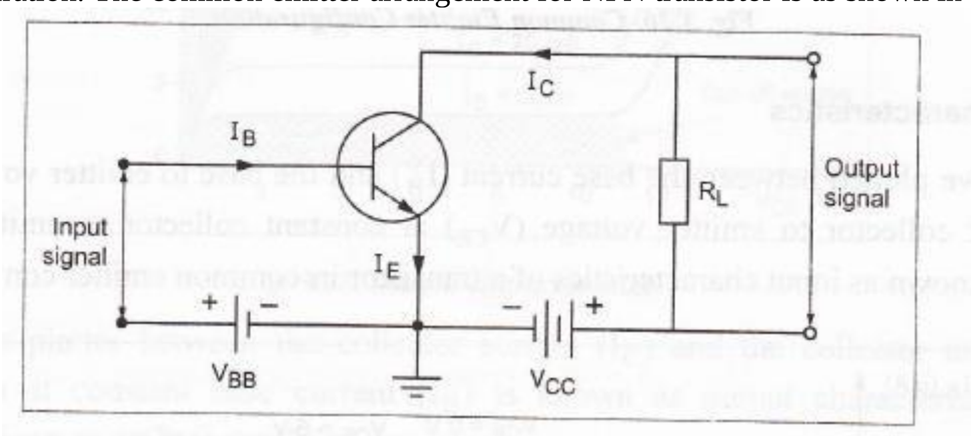
(iii). Cut-off Region:

It is the region along the X-axis as shown by shaded or dotted portion. This corresponds to the curve marked I_E=0. In the cut-off region both the junctions of a Transistor are reverse biased. A small collector current flows even when the emitter Current (I_E) is equal to zero.

If the collector to base voltage (V_{CB}) is increased beyond a certain large value, the collector current (I_C) increases rapidly due to avalanche breakdown and the transistor action is lost. This region is called breakdown region.

Common Emitter Configuration (CE Configuration):

This configuration is also called the grounded emitter configuration. In this case the input is connected between base and emitter, while the output is taken across the collector and emitter. Thus emitter of the transistor is common to both input and output circuits and hence the name, common emitter configuration. The common emitter arrangement for NPN transistor is as shown in Fig.



Base Current Amplification Factor (β):

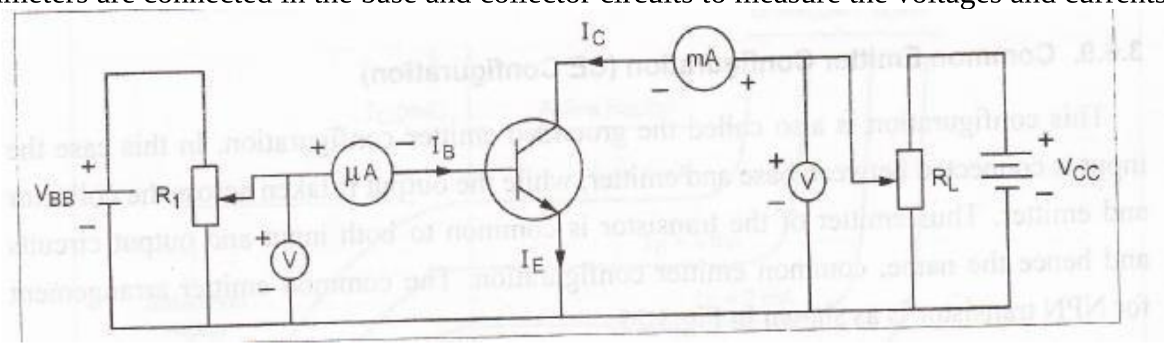
The base current amplification factor is defined as the ratio of change in collector current (ΔI_C) to the change in emitter current (ΔI_E) when the collector to emitter voltage(V_{CE}) is maintained at a constant value.

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{(at constant } V_{CE}\text{)}$$

The value of β is always greater then unity. Practical value of β in commercial transistors lie between 20 to 500.

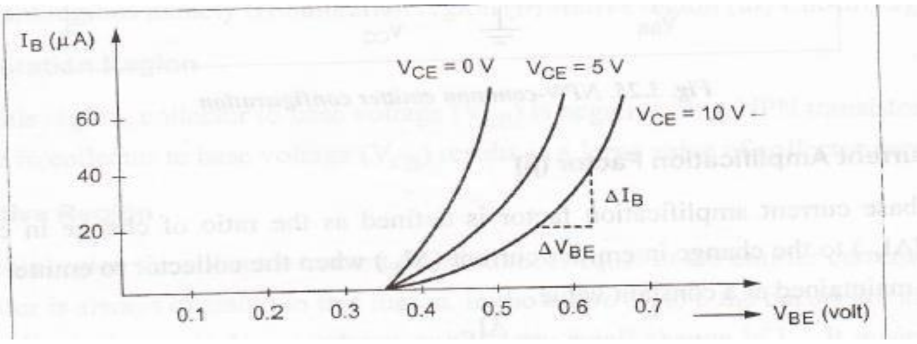
Characteristics of common Emitter configuration:

The circuit arrangement for determining the characteristics of a common emitter NPN transistor is shown inFig.In this circuit, the collector to emitter voltage (V_{EC}) can be varied by adjusting the potentiometer R_2. The base to emitter voltage (V_{BE}) can be varied by adjusting the potentiometer R_1. The DC voltmeters and milliammeters are connected in the base and collector circuits to measure the voltages and currents.



1. **Input Characteristics:**

The curve plotted between the base current (I_B) and the base to emitter voltage (V_{BE}) at constant collector to emitter voltage (V_{CE}) at constant collector to emitter voltage (V_{CE})are known as input characteristics of a transistor in common emitter configuration.

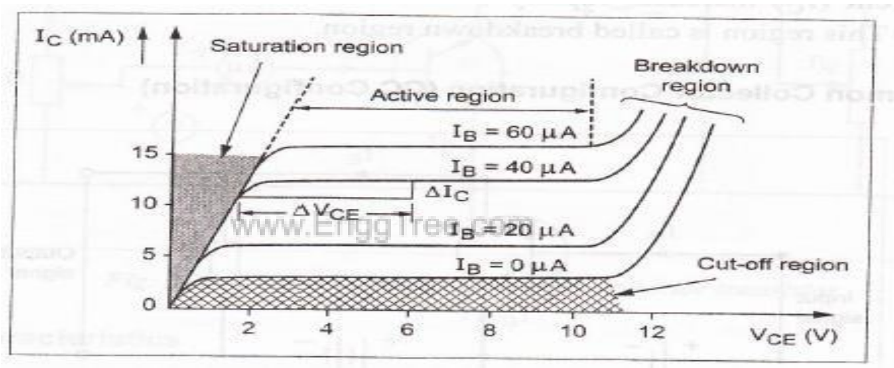


Input Resistance (R_i): It is the ratio of change in base to emitter voltage (V_{BE}) to the Corresponding change in base current (ΔI_B) for a constant collector to emitter voltage (V_{CE}).

$$R_i = \frac{\Delta V_{BE}}{\Delta I_B} \quad \text{(at constant } V_{CE}\text{)}$$

When the collector to emitter voltage (V_{CE}) is increased, the value of base current (I_B) decreased slightly as shown in Fig.

2. **Output Characteristics:**



The curves plotter between the collector current (I_C) and the collector to emitter Voltage (V_{CE}) at constant base current (I_B) is known as output characteristic of a transistor in common emitter configuration.
The output characteristic may be divided into three important regions namely saturation region, active region, and cut-off region.

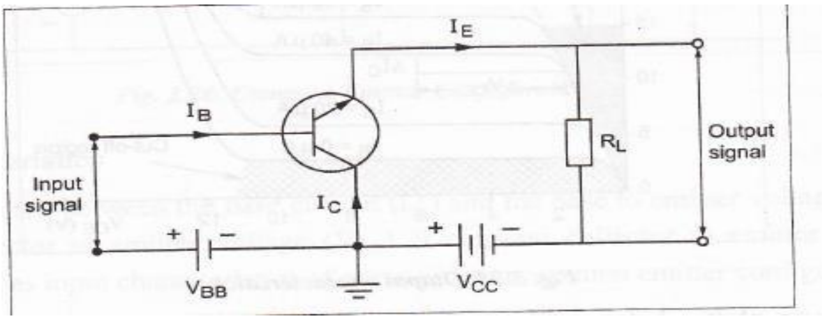
(i) Saturation Region:
In this region (shown by dotted area) a small change in collector to emitter voltage (V_{CE}) results in a large value of collector current.

(ii) Active Region:
It is the region between saturation and cut-off region. In this region the curves are almost flat. When the collector to emitter voltage (V_{CE}) is increased. Further, the collector current I. slightly increases. The slope of the curve is little bit more than the output characteristics of common base configuration. Therefore, the output resistance (R_o) of this configuration is less as compared to common base configuration.

(iii) Cut-off Region:
It is the region along the X-axis is shown by shaded area. This corresponds to the curve marked $I_B = 0$. In the cut-off region both the junctions of a transistor are reverse biased. A small collector current flows even when the base current (I_B) is equal to zero. It is the reverse leakage current (I_{CEo})that flows in the collector circuit.

If the collector to emitter voltage (V_{CE}) is increased beyond a certain large collector current (I_C) increases rapidly due to avalanche breakdown and the action is lost. This region is called breakdown region.

Common collector configuration (CC configuration):



This configuration is also called the grounded collector configuration' In this case the input is common between base and Collector. While the output is taken across the emitter and collector. Thus the collector of the transistor is common to both input and output circuits and hence the name common collector configuration. The common collector circuit arrangement for NPN transistor as shown in Fig.

Current Amplification Factor (γ):

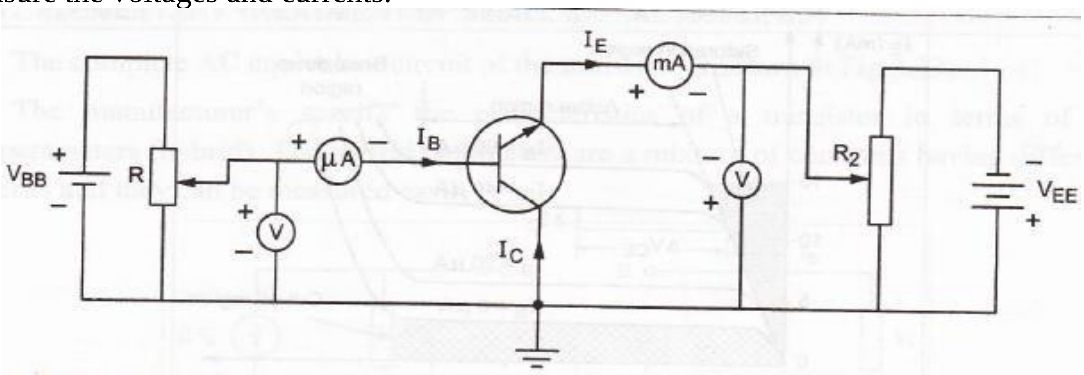
The current amplification is defined as the ratio of change in emitter current (ΔI_E) to the change in base current (ΔI_B). It is generally denoted by γ.

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

The value of γ is nearly equal to β.

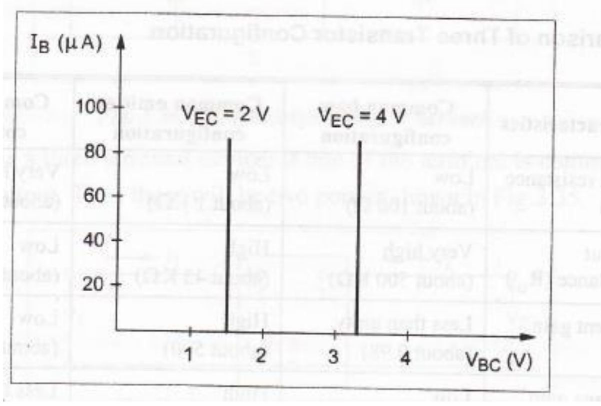
Characteristics of common Collector configuration:

The circuit arrangement for determining the characteristics of a common collector NPN transistor is shown in Fig. In this circuit, the emitter to collector voltage (V_{EC}) can be varied by adjusting the potentiometer R_2. The base to collector voltage (V_{BC}) can be varied by adjusting the potentiometer R_1. The DC voltmeter and millimeters are connected in the base and emitter circuits to measure the voltages and currents.



1. **Input Characteristics:**

The curves plotted between the base current (I_B) and the base to collector voltage (V_{BC}) at constant emitter to collector voltage (V_{EC}) are known as input characteristics of a transistor in common collector configuration.



2. **Output Characteristics:**

The curves plotted between the emitter current (I_E) and the emitter to collector voltage (V_{EC}) at constant base current (I_B) are known as output characteristics of a transistor is common collector configuration.