Unit- 8
Basics of Electronics

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CHARUSAT

Content

Semiconductor

- A semiconductor is a substance which has resistivity in between conductors and insulators.
- Examples:- Germanium, Silicon, Carbon etc.

Properties of semiconductor

1. The resistivity of a semiconductor is less than an insulator but more than a conductor.
2. Semiconductors have negative temperature coefficient of resistance.
3. When a suitable metallic impurity is added to a semiconductor, its current conducting properties change appreciably.

Intrinsic Semiconductor

- A semiconductor in an extremely pure form is know as intrinsic semiconductor.

Extrinsic Semiconductor

- The intrinsic semiconductor has a little current conduction capability at room temperature.
- To be useful in electronic devices, the pure semiconductor must be altered so as to significantly increase its conducting properties.
- This is achieved by adding a small amount of suitable impurity to a semiconductor.
- It is then called extrinsic semiconductor.

PN junction diode

- A PN junction is known as a semi-conductor or crystal diode.
- The property of a crystal diode to conduct current in one direction only permits it to be used as a rectifier.

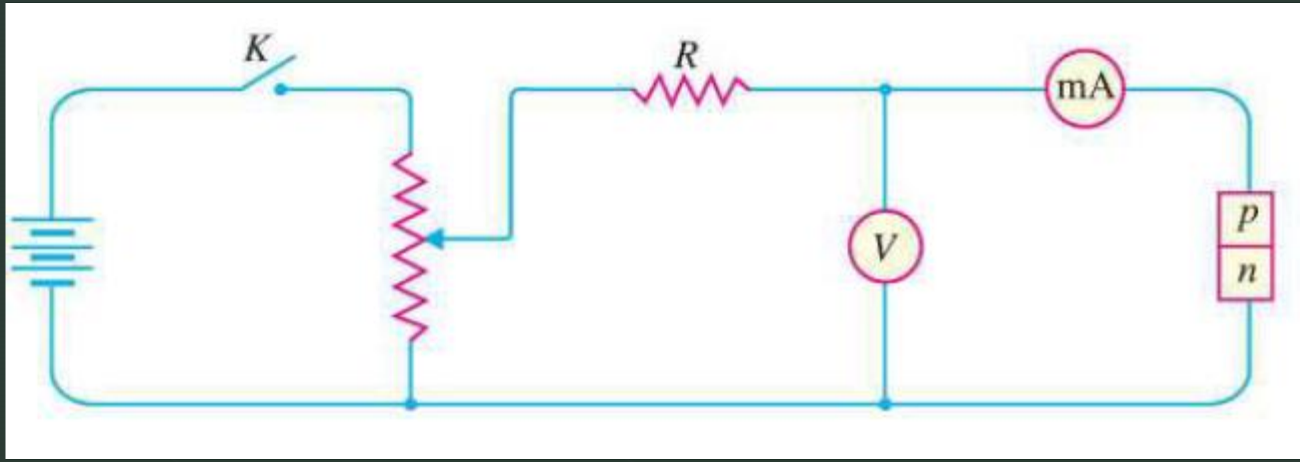
figure 1

- A crystal diode is usually represented by schematic symbol shown in figure 1.
- The arrow in the symbol indicates the direction of easier conventional current flow.

PN junction diode

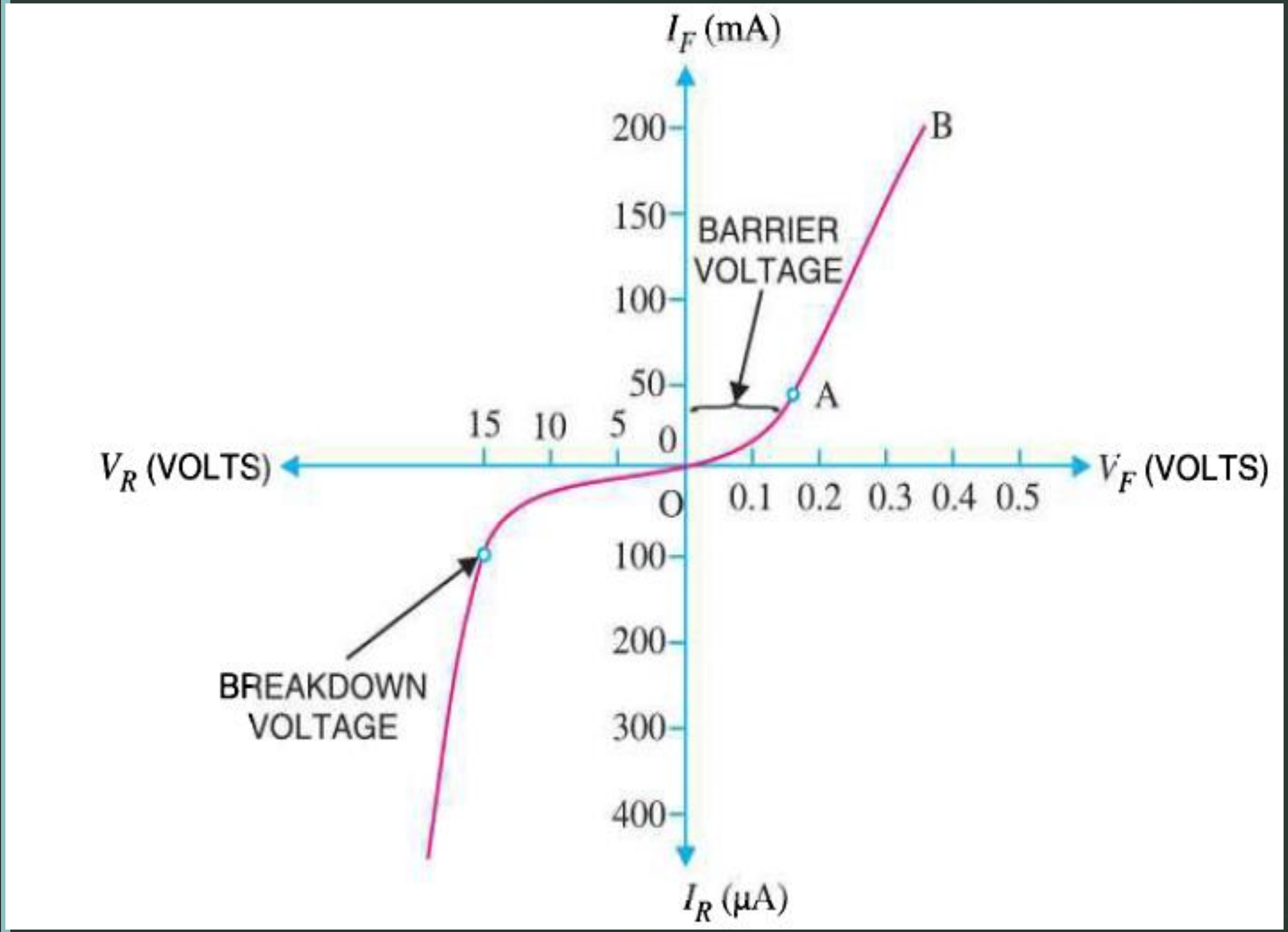
- A crystal diode has two terminals.
- When it is connected in a circuit, one thing to decide is whether the diode is forward or reverse biased.
- If the external circuit is trying to push the conventional current in the direction of arrow, the diode is forward biased.
- On the other hand, if the conventional current is trying to flow opposite to arrowhead, the diode is reverse biased.

V-I characteristics of PN junction diode



- The characteristics can be studied under three heads, namely: zero external voltage, forward bias and reverse bias.

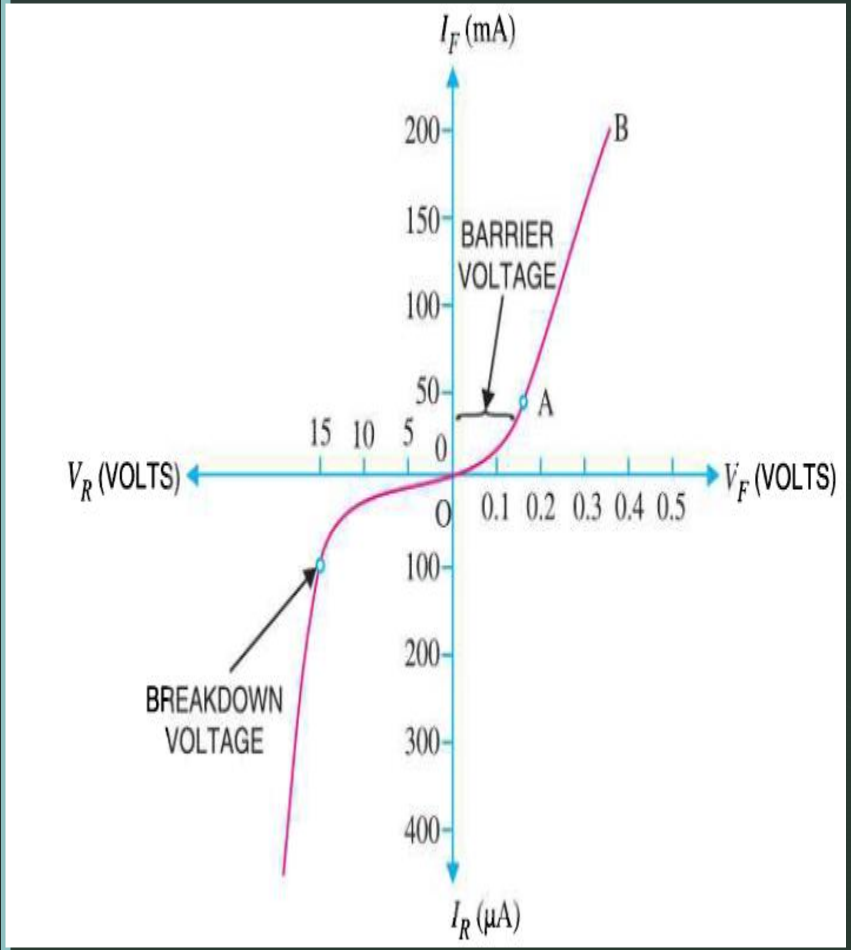
V-I characteristics of PN junction diode



1. Zero external voltage:-

- When the external voltage is zero, i.e. circuit is open at K, the potential barrier at the junction does not permit current flow.
- Therefore, the circuit is zero as indicated by point O in figure.

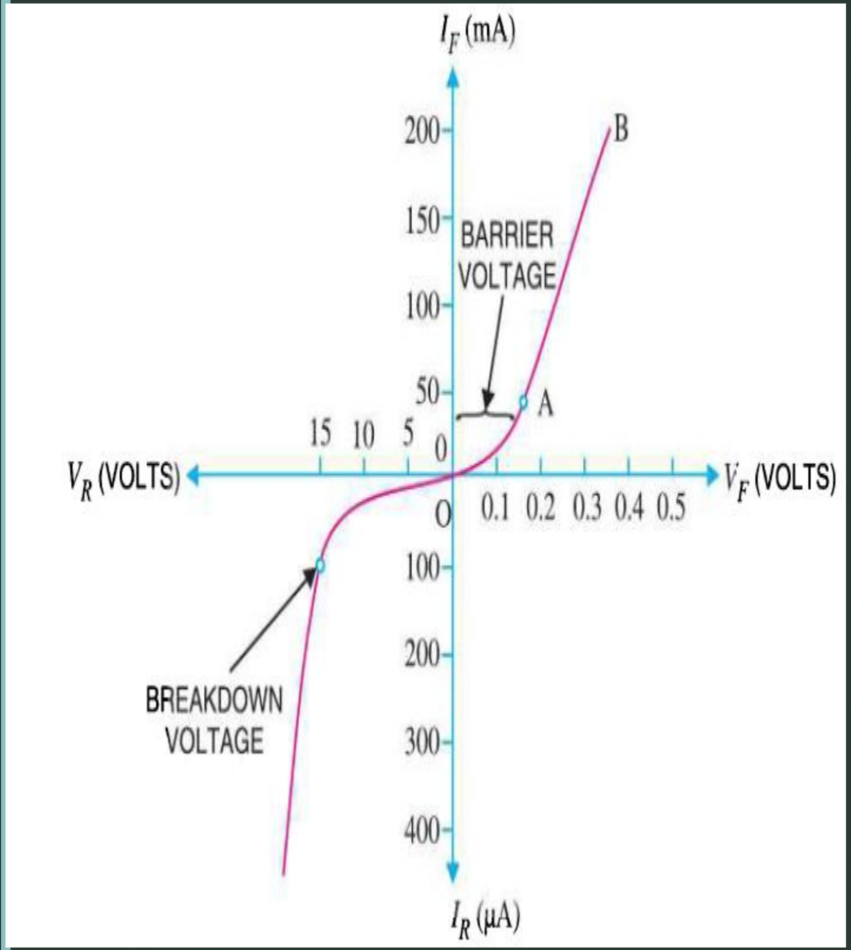
V-I characteristics of PN junction diode



2. Forward bias:-

- With forward bias to the pn junction, the potential barrier is reduced.
- At some forward voltage, the potential barrier is altogether eliminated and current starts flowing in the circuit.
- From that, the current increases with the increase in forward voltage.
- Thus, a rising curve OB is obtained with forward bias as shown in figure.
- Form the forward characteristics, it is seen that at first (region OA), the current increases very slowly and the curve is non-linear.
- It is because the external applied voltage is used up in overcoming the potential barrier.

V-I characteristics of PN junction diode

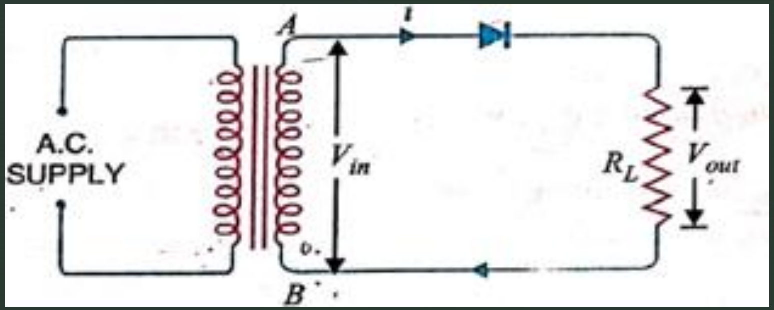


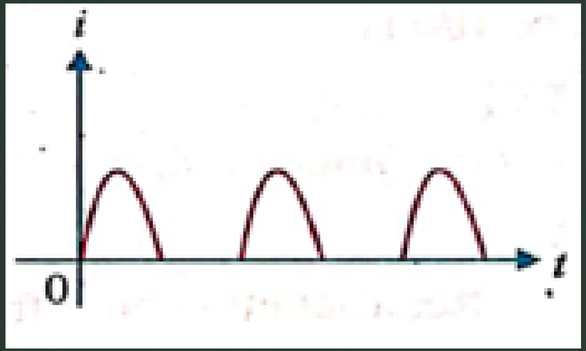
3. Reverse Bias:-

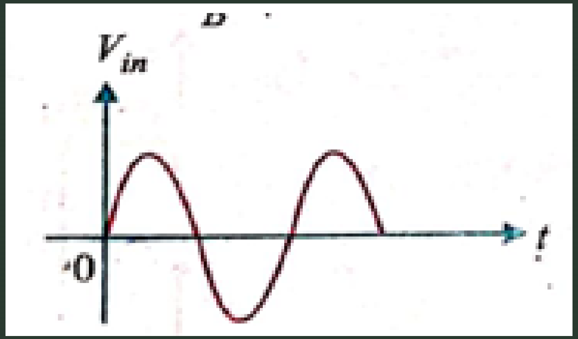
- With reverse bias to the pn junction, the potential barrier is increased.
- Therefore, the junction resistance becomes very high and practically no current flows through the circuit.
- However, in practice, a very small current flows in the circuit with reverse bias as shown in figure.
- This is called the reverse saturation current (Is) and is due to the minority carriers.
- If reverse voltage is increased continuously, the kinetic energy of electrons may become high enough to knock out electrons from the semiconductor atoms.
- At this stage breakdown of the junction occurs, characterised by a sudden rise of reverse current and a sudden fall of the resistance of barrier region.
- This may destroy the junction permanently.

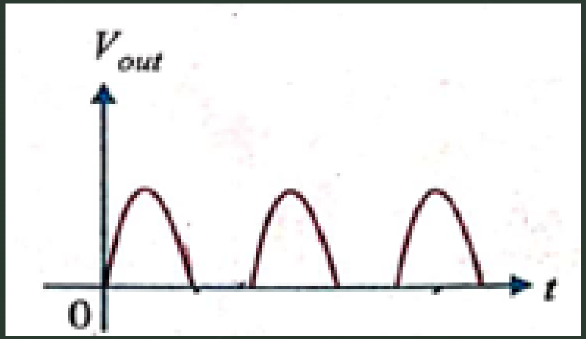
Half-wave rectifier

- In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply.
- During negative half-cycles, no current is conducted and hence no voltage appears across the load.
- Therefore, current always flows in one direction through the load though after every half-cycle.







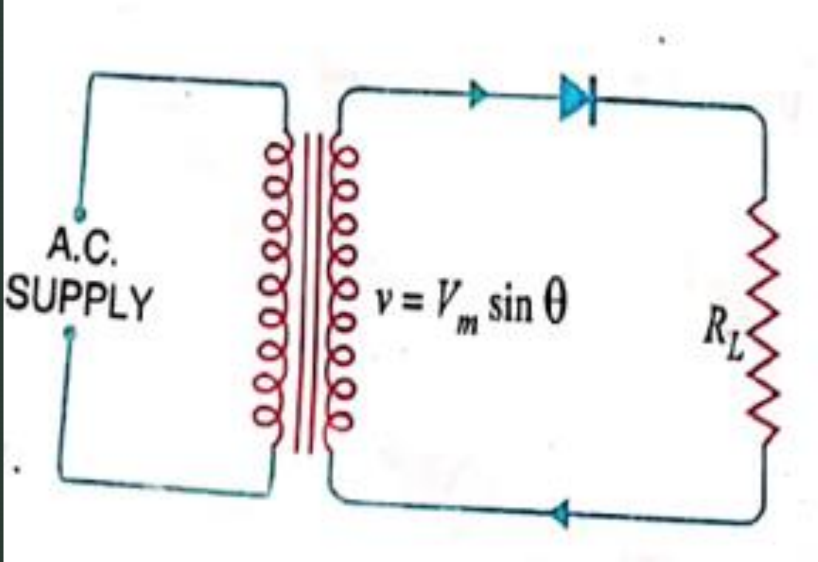


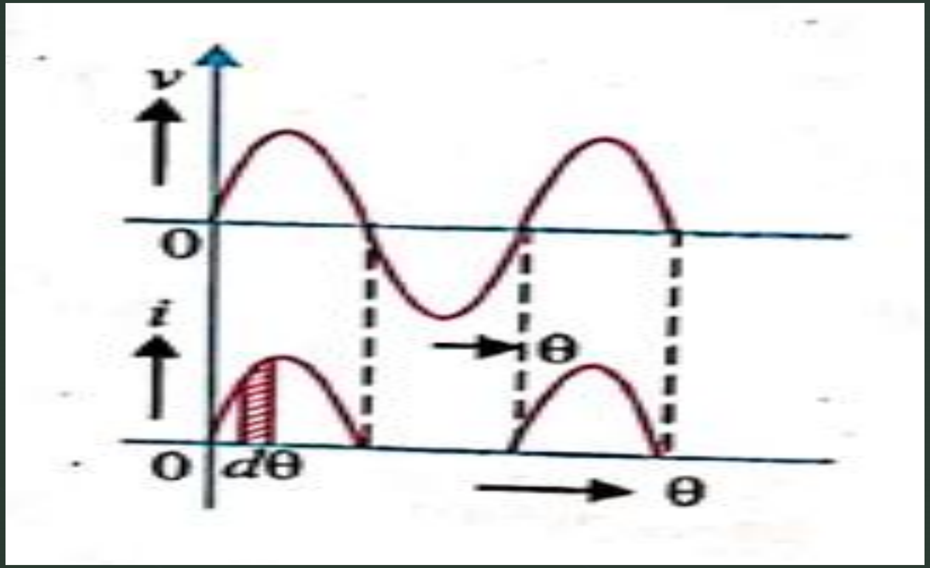
Disadvantages of Half- Wave Rectifier

1. The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.
2. The a.c. supply delivers power only half the time. Therefore, the output is low.

Efficiency of Half- Wave Rectifier

$$\text{Rectifier efficiency, } \eta = \frac{\text{d.c. power output}}{\text{Input a.c. power}}$$





D.C. Power:-

- The output current is pulsating direct current.

$$*I_{av} = I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i\, d\theta = \frac{1}{2\pi}\int_0^{\pi} \frac{V_m \sin\theta}{r_f + R_L}\, d\theta$$

$$= \frac{V_m}{2\pi(r_f + R_L)}\int_0^{\pi} \sin\theta\, d\theta = \frac{V_m}{2\pi(r_f + R_L)}[-\cos\theta]_0^{\pi}$$

$$= \frac{V_m}{2\pi(r_f + R_L)} \times 2 = \frac{V_m}{(r_f + R_L)} \times \frac{1}{\pi}$$

$$= {}^{**}\frac{I_m}{\pi} \qquad \left[\because I_m = \frac{V_m}{(r_f + R_L)}\right]$$

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

A.C. Power:-

- The a.c. power input is given by:

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

For a half-wave rectified wave, $I_{rms} = I_m/2$

$$P_{ac} = \left(\frac{I_m}{2}\right)^2 \times (r_f + R_L)$$

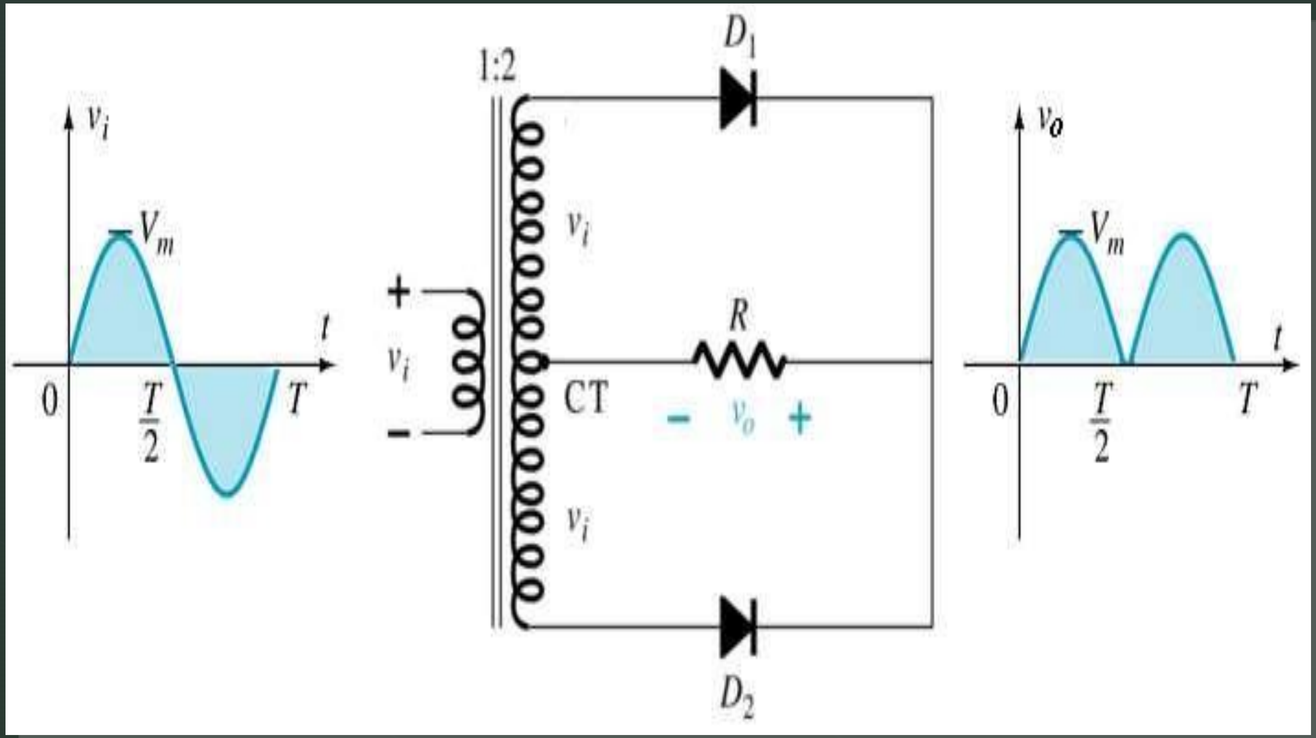
$$\text{Rectifier efficiency} = \frac{\text{d.c. output power}}{\text{a.c. input power}} = \frac{(I_m/\pi)^2 \times R_L}{(I_m/2)^2 \; (r_f + R_L)}$$

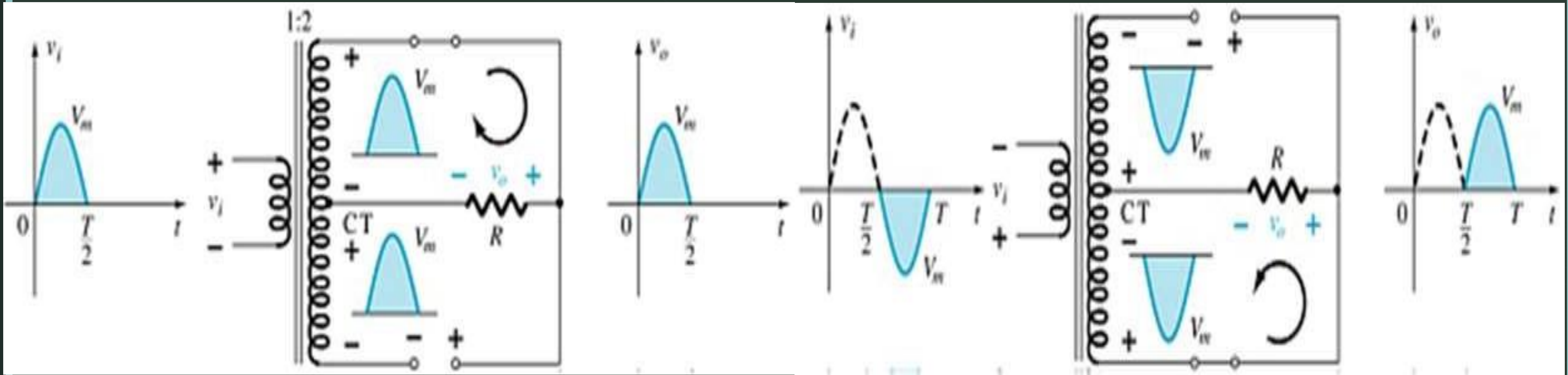
$$= \frac{0.406 \, R_L}{r_f + R_L} = \frac{0.406}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

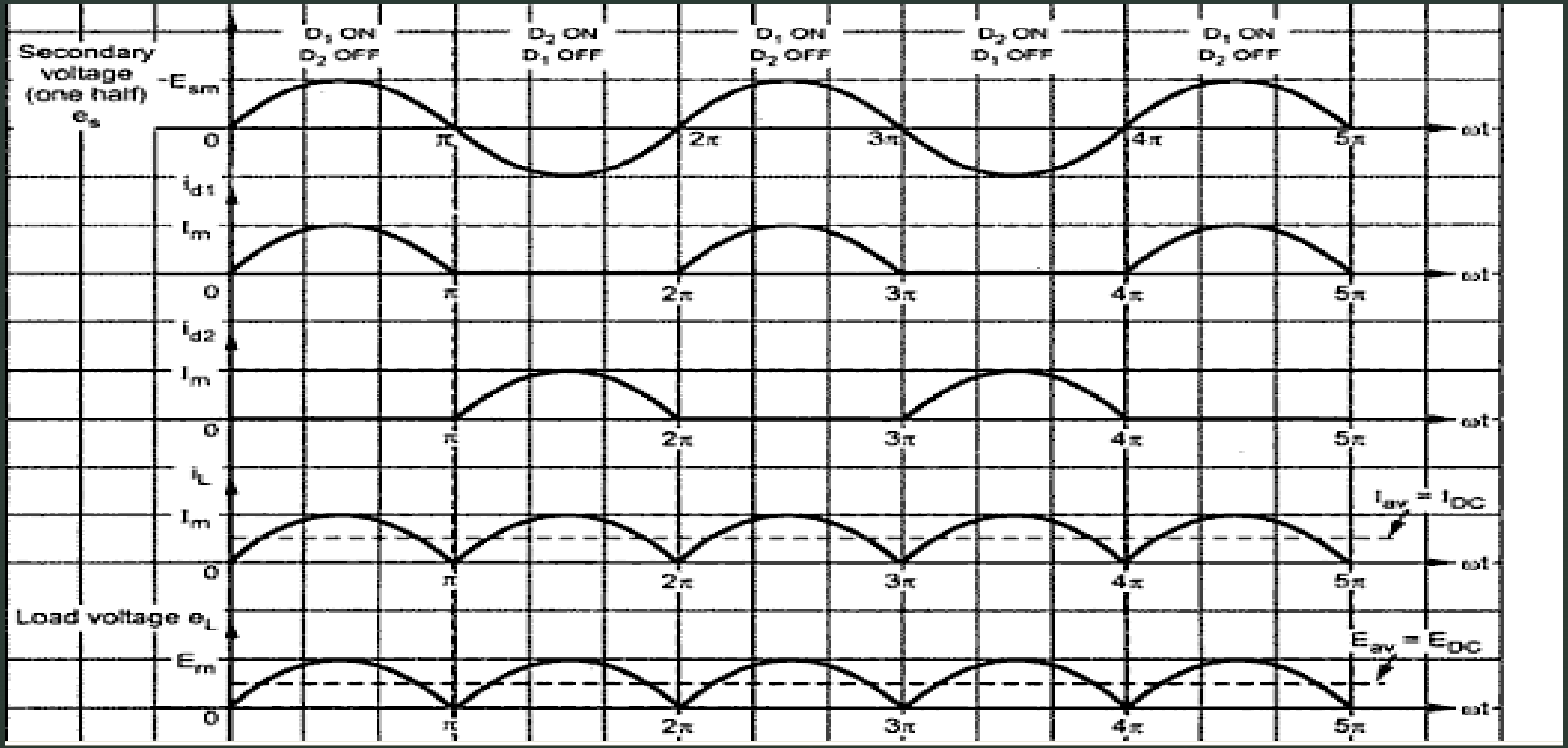
$\therefore$ Max. rectifier efficiency = 40.6%

Center-tap Full-wave rectifier





Center-tap Full-wave rectifier



Disadvantages of Center-tap Full-wave Rectifier

1. It is difficult to locate center-tap o n the secondary winding.
2. The d.c. output is small as each diode utilise only one-half of the transformer secondary voltage.
3. The diode used must have high peak inverse voltage.

Average (DC) current and Voltage

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

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

$$= \frac{I_m}{2\pi}[(-2)(-2)]$$

$$= \frac{I_m}{2\pi}.4 = \frac{2I_m}{\pi} = 0.637\,I_m.$$

$$\boxed{I_{dc} = 0.637 I_m.}$$

$\therefore$ I_{DC} FWR $= 2$ I_{DC} HWR.

Average (DC) current and Voltage

Average DC current

$$I_{av} = I_{DC} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t) = \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \, d\omega t$$

$$\boxed{I_{DC} = \frac{2I_m}{\pi}}$$ for full wave rectifier

Average (DC) Voltage

$$E_{DC} = I_{DC} R_L = \frac{2 I_m R_L}{\pi}$$

Substituting value of I_{av} $$E_{DC} = \frac{2 E_{sm} R_L}{\pi [R_f + R_s + R_L]} = \frac{2 E_{sm}}{\pi \left[1 + \frac{R_f + R_s}{R_L}\right]}$$

But as R_f and $R_s << R_L$ hence $\frac{R_f + R_s}{R_L} << 1$

$$\boxed{E_{DC} = \frac{2E_{sm}}{\pi}}$$

RMS Load Current (I_{rms})

$$RMS\ Value = \sqrt{\left(\frac{1}{\pi}\right)\int_0^{\pi}(Im\sin\omega t)^2 d(\omega t)}$$

$$= Im\sqrt{\left(\frac{1}{2\pi}\right)\int_0^{\pi}2(\sin\omega t)^2 d(\omega t)}$$

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

$$= Im\sqrt{\left(\frac{1}{2\pi}\right)[\pi-0]}$$

$$= \frac{Im}{\sqrt{2}}$$

D.C. Power output $= E_{DC}I_{DC} = I_{DC}^2 R_L$

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

$$P_{DC} = \frac{4}{\pi^2} I_m^2 R_L$$

The a.c. power input is given by,

$$\boxed{P_{AC} = I_{RMS}^2(R_f+R_s+R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2(R_f+R_s+R_L)}$$

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

Rectifier Efficiency (η)

$$\eta = \frac{P_{DC}\ \text{output}}{P_{AC}\ \text{input}}$$

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

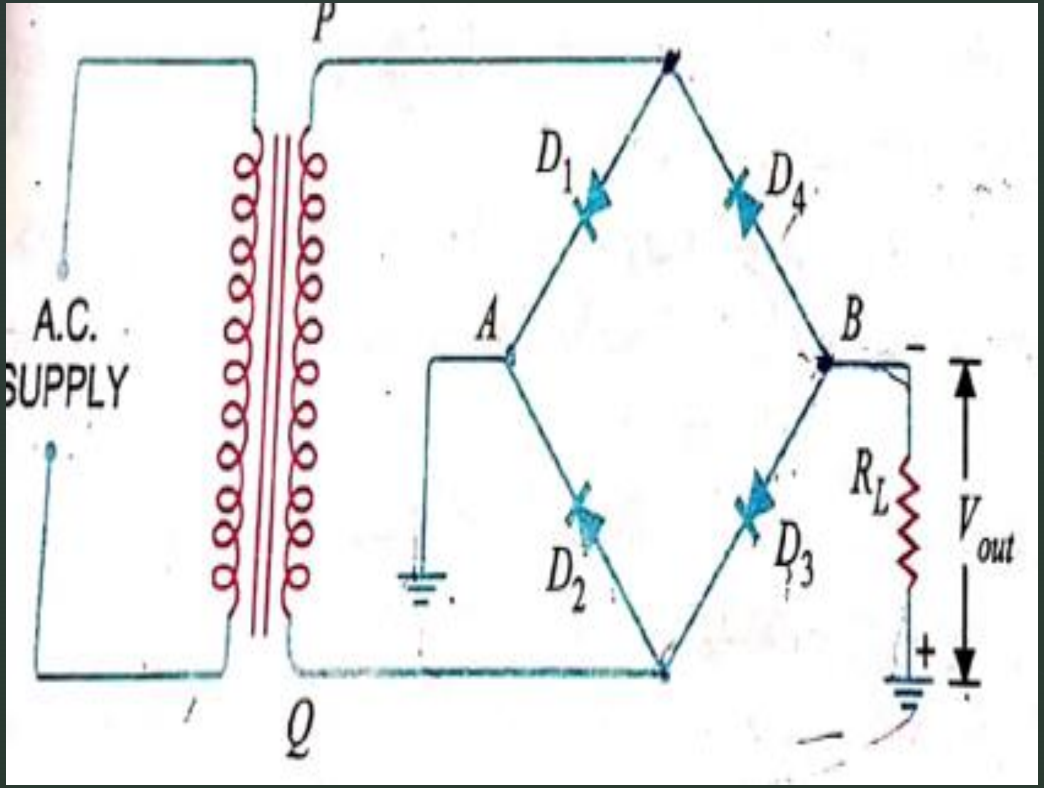
$$\eta = \frac{8\ R_L}{\pi^2 (R_f + R_s + R_L)}$$

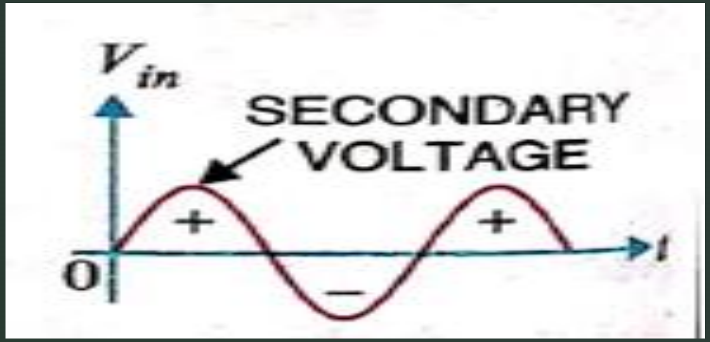
But if $R_f + R_s << R_L$, neglecting it from denominator

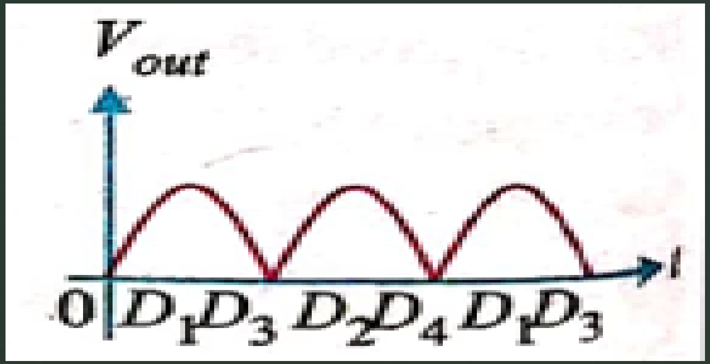
$$\eta = \frac{8\ R_L}{\pi^2 (R_L)} = \frac{8}{\pi^2}$$

$$\%\ \eta_{max} = \frac{8}{\pi^2} \times 100 = 81.2\ \%$$

Full-wave bridge rectifier







D.C. Power:-

- The output current is pulsating direct current.
- Therefore, in order to find d.c. power, average current has to be find out.

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

$$\therefore \quad \text{d.c. power output, } P_{dc} = I_{dc}^2 \times R_L = \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

A.C. Power:-

- The a.c. power input is given by:

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

For a full-wave rectified wave, we have,

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

$$\therefore \quad P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

$\therefore$ Full-wave rectification efficiency is

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{(2 I_m / \pi)^2 R_L}{\left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812 R_L}{r_f + R_L} = \frac{0.812}{1 + \frac{r_f}{R_L}}$$

The efficiency will be maximum if r_f is negligible as compared to R_L.

$\therefore$ Maximum efficiency $= 81.2\%$

This is double the efficiency due to half-wave rectifier. Therefore, a full-wave rectifier is twice as effective as a half-wave rectifier.

Advantages of Full- Wave Bridge Rectifier

1. The need for center tap is eliminated.
2. The output is twice that of the center-tap circuit for the same secondary voltage.
3. The PIV is one-half that of the center-tap circuit.

Disadvantage of Full- Wave Bridge Rectifier

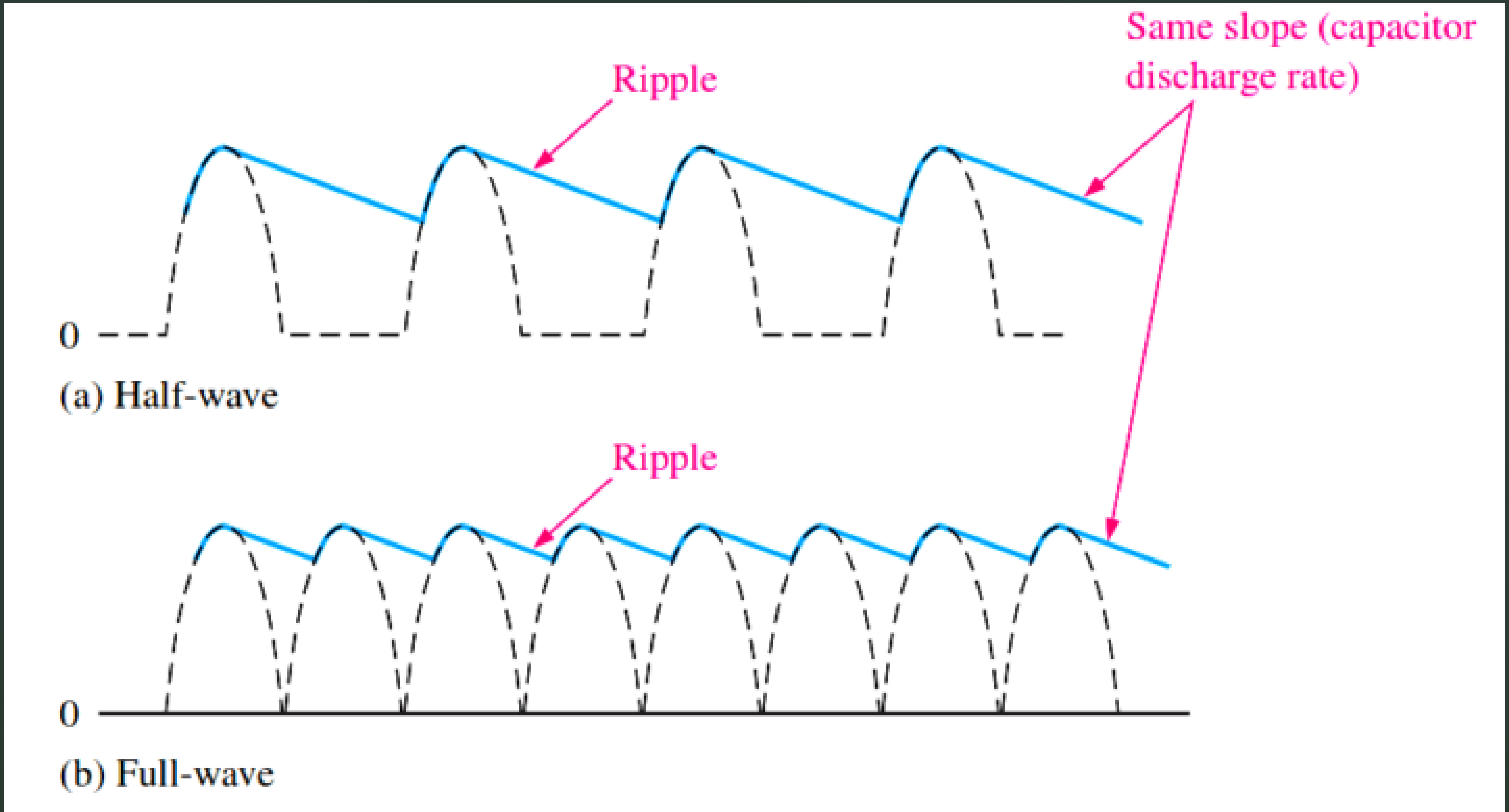
1. It requires four diodes.
2. As during each half-cycle of a.c. input two diodes that conduct are in series , therefore voltage drop in the internal resistance of the rectifying unit will be twice as great as in the center-tap circuit.

Ripple Factor

- The output of a rectifier consists of a d.c. component and an a.c. component known as ripple factor.
- The a.c. component is undesirable and accounts for the pulsations in the rectifier output.
- The effectiveness of a rectifier depends upon the magnitude of a a.c. component in the output: the smaller this component, the more effective is the rectifier.
- The ratio of r.m.s value of a.c. component to the d.c. component in the rectifier output is known as ripple factor.

$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

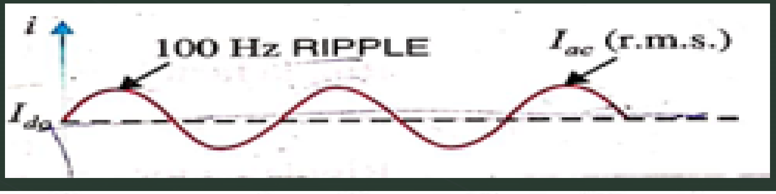
Ripple Factor



$$\text{Ripple factor} = \frac{\text{r.m.s. value of a.c component}}{\text{value of d.c. component}} = \frac{I_{ac}}{I_{dc}}$$

Mathematical Analysis

- The output of a rectifier contains d.c. as well as a.c. components.
- The undesired a.c. component has a frequency of 100 Hz and is called the ripple.
- It is fluctuation superimposed on the d.c. component.



By definition, the effective (*i.e.* r.m.s.) value of total load current is given

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

or

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

Dividing throughout by I_{dc}, we get,

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2}$$

But I_{ac}/I_{dc} is the ripple factor.

$$\therefore \quad \text{Ripple factor} = \frac{1}{I_{dc}} \sqrt{I_{rms}^2 - I_{dc}^2} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

(*i*) **For half-wave rectification.** In half-wave rectification,

$$I_{rms} = I_m/2 \quad ; \quad I_{dc} = I_m/\pi$$

$$\text{Ripple factor} = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = 1.21$$

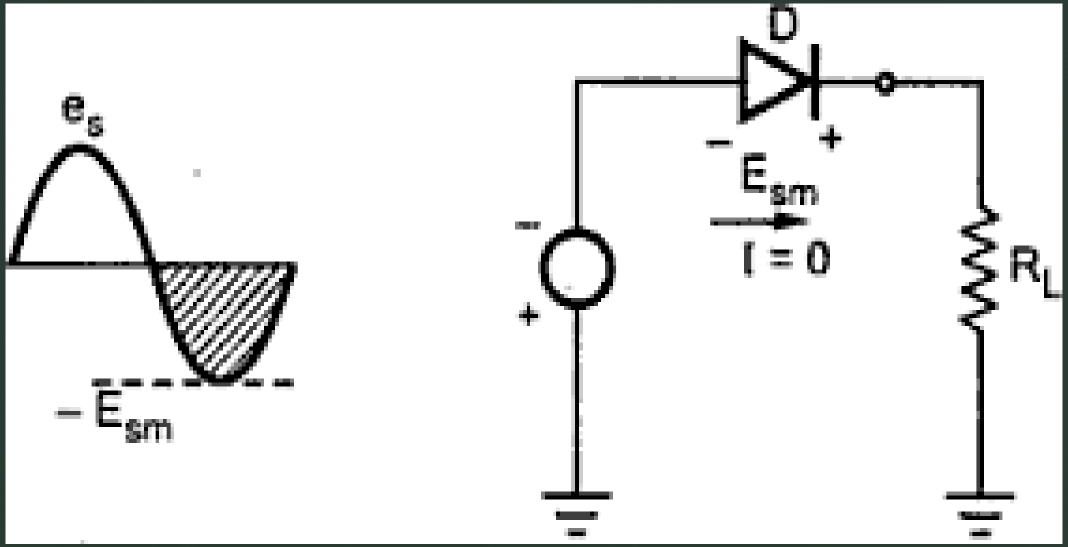
(*ii*) **For full-wave rectification.** In full-wave rectification,

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

$$\therefore \quad \text{Ripple factor} = \sqrt{\left(\frac{I_m/\sqrt{2}}{2\,I_m/\pi}\right)^2 - 1} = 0.48$$

- This shows that in the output of a full-wave rectifier, the d.c. component more than the a.c. component.

Peak Inverse Voltage (PIV)



Thus PIV occurs at the peak of each negative half cycle of the input, when diode is reverse biased and not conducting.

$$PIV = Em$$

Diode must be selected based on the PIV rating and the circuit specification.

Equivalent circuit of crystal diode

It is generally profitable to replace a device or system by its equivalent circuit. An equivalent circuit of a device (*e.g.* crystal diode, transistor etc.) is a combination of electric elements, which when connected in a circuit, acts exactly as does the device when connected in the same circuit. Once the device is replaced by its equivalent circuit, the resulting network can be solved by traditional circuit analysis techniques. We shall now find the equivalent circuit of a crystal diode.

(*i*) ***Approximate Equivalent circuit.** When the forward voltage V_F is applied across a diode, it will not conduct till the potential barrier V_0 at the junction is overcome. When the forward voltage exceeds the potential barrier voltage, the diode starts conducting as shown in Fig. 6.7 (*i*). The forward current I_f flowing through the diode causes a voltage drop in its internal resistance r_f. Therefore, the forward voltage V_F applied across the *actual* diode has to overcome :

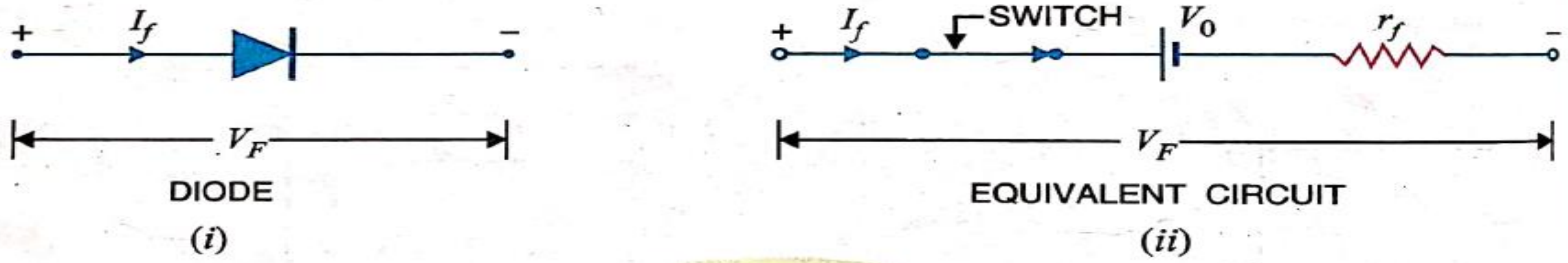
(*a*) potential barrier V_0

(*b*) internal drop $I_f r_f$

$$\therefore \quad V_F = V_0 + I_f r_f$$

For a silicon diode, $V_0 = 0.7$ V whereas for a germanium diode, $V_0 = 0.3$ V.

Therefore, approximate equivalent circuit for a crystal diode is a switch in series with a battery V_0 and internal resistance r_f as shown in Fig. 6.7 (*ii*). This approximate equivalent circuit of a diode is very helpful in studying the performance of the diode in a circuit.



(*ii*) **Simplified Equivalent circuit.** For most applications, the internal resistance r_f of the crystal diode can be ignored in comparison to other elements in the equivalent circuit. The equivalent circuit then reduces to the one shown in Fig. 6.8 (*ii*). This simplified equivalent circuit of the crystal diode is frequently used in diode-circuit analysis.

Example 6.2. *An a.c. voltage of peak value 20 V is connected in series with a silicon diode and load resistance of 500 Ω. If the forward resistance of diode is 10 Ω, find :*

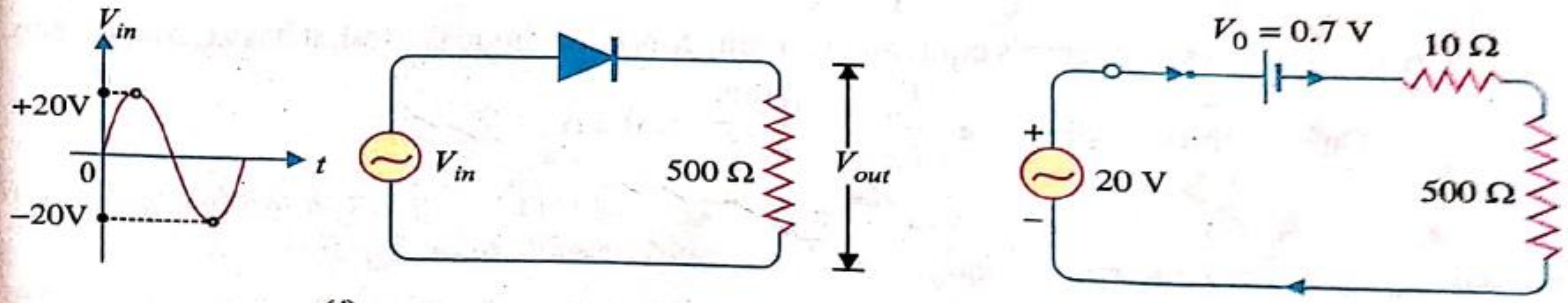
(i) peak current through diode *(ii) peak output voltage*

What will be these values if the diode is assumed to be ideal ?

Solution.

$$\text{Peak input voltage} = 20 \text{ V}$$
$$\text{Forward resistance, } r_f = 10\ \Omega$$
$$\text{Load resistance, } R_L = 500\ \Omega$$
$$\text{Potential barrier voltage, } V_0 = 0.7 \text{ V}$$

The diode will conduct during the positive half-cycles of a.c. input voltage only. The equivalent circuit is shown in Fig. 6.9 (*ii*).



(*i*) (*ii*)

(*i*) The peak current through the diode will occur at the instant when the input voltage reaches positive peak *i.e.* $V_{in} = V_F = 20$ V.

$$\therefore \quad V_F = V_0 + (I_f)_{peak}\,[r_f + R_L] \quad \text{...}(i)$$

$$\text{or} \quad (I_f)_{peak} = \frac{V_F - V_0}{r_f + R_L} = \frac{20 - 0.7}{10 + 500} = \frac{19.3}{510}\ \text{A} = 37.8\ \text{mA}$$

(*ii*) Peak output voltage $= (I_f)_{peak} \times R_L = 37.8\ \text{mA} \times 500\ \Omega = 18.9\ \text{V}$

Ideal diode. For an ideal diode, put $V_0 = 0$ and $r_f = 0$ in equation (*i*).

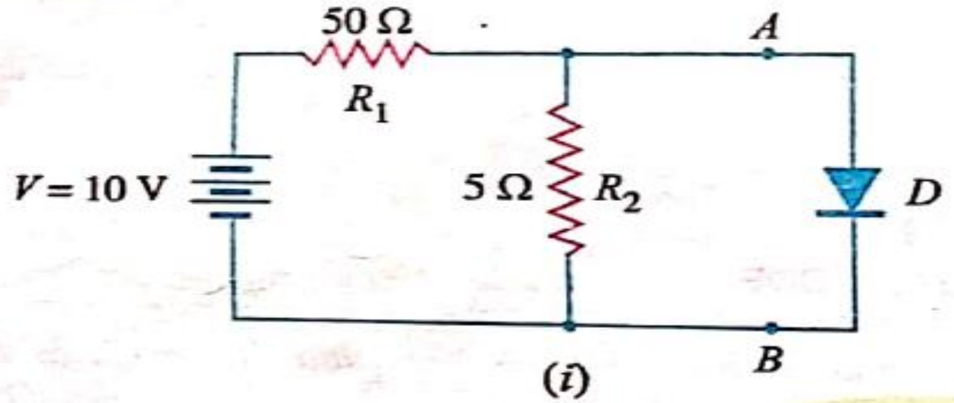
$$\therefore \quad V_F = (I_f)_{peak} \times R_L$$

$$\text{or} \quad (I_f)_{peak} = \frac{V_F}{R_L} = \frac{20\ \text{V}}{500\ \Omega} = 40\ \text{mA}$$

Peak output voltage $= (I_f)_{peak} \times R_L = 40\ \text{mA} \times 500\ \Omega = 20\ \text{V}$

Comments. It is clear from the above example that output voltage is *nearly* the same whether the actual diode is used or the diode is considered ideal. This is due to the fact that input voltage is quite large as compared with V_0 and voltage drop in r_f. Therefore, nearly the whole input forward voltage appears across the load. For this reason, diode circuit analysis is generally made on the ideal diode basis.

Example 6.3. *Find the current through the diode in the circuit shown in Fig. 6.10 (i). Assume the diode to be ideal.*



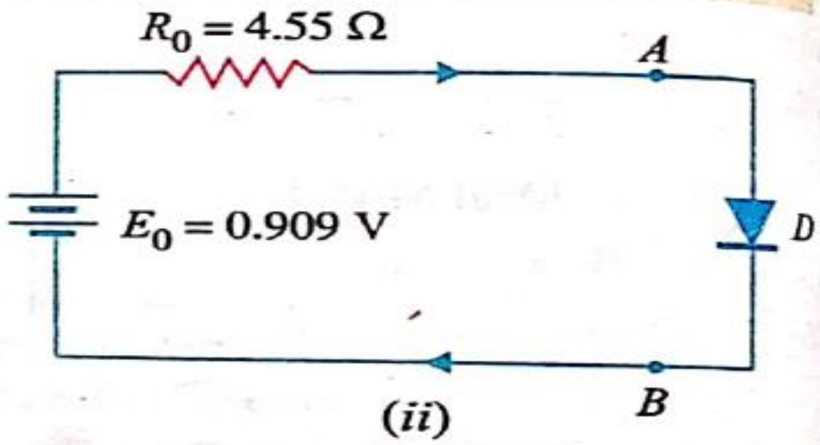


Fig. 6.10

Solution. We shall use Thevenin's theorem to find current in the diode. Referring to Fig. 6.10(*i*),

$$E_0 = \text{Thevenin's voltage}$$

$$= \text{Open circuited voltage across } AB \text{ with diode removed}$$

$$= \frac{R_2}{R_1 + R_2} \times V = \frac{5}{50 + 5} \times 10 = 0.909 \text{ V}$$

$$R_0 = \text{Thevenin's resistance}$$

$$= \text{Resistance at terminals } AB \text{ with diode removed and battery replaced by a short circuit}$$

$$= \frac{R_1 R_2}{R_1 + R_2} = \frac{50 \times 5}{50 + 5} = 4.55\ \Omega$$

Fig. 6.10 (*ii*) shows Thevenin's equivalent circuit. Since the diode is ideal, it has zero resistance.

$$\therefore \quad \text{Current through diode} = \frac{E_0}{R_0} = \frac{0.909}{4.55} = 0.2 \text{ A} = 200 \text{ mA}$$

Example 6.9. *Determine the currents I_1, I_2 and I_3 for the network shown in Fig. 6.16(i). Use simplified model for the diodes.*

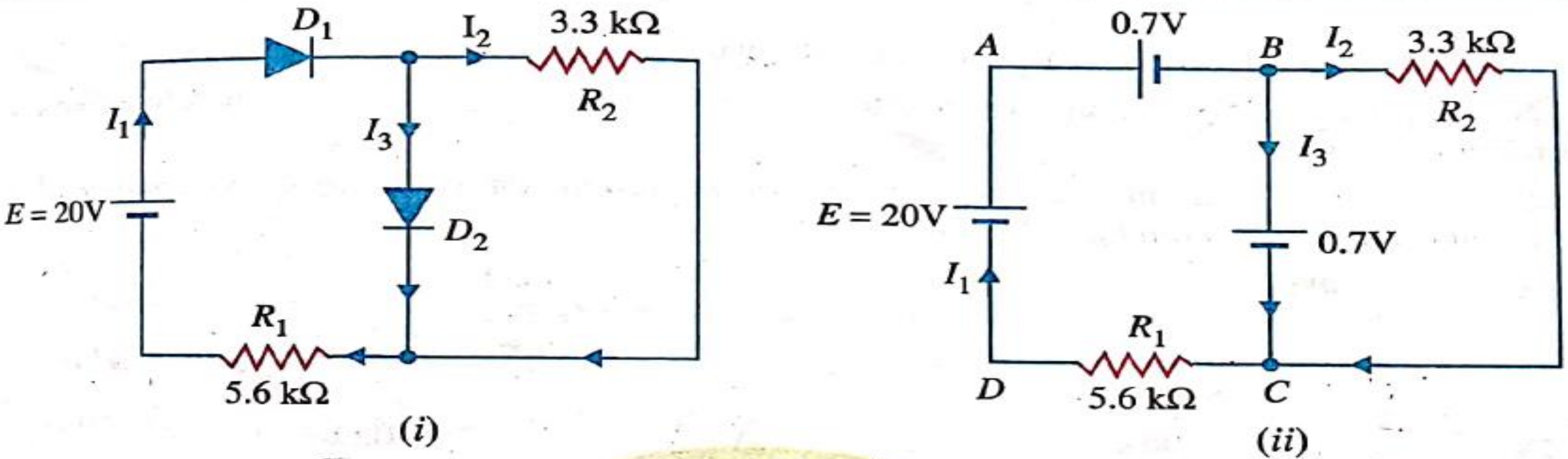


Fig. 6.16

Solution. An inspection of the circuit shown in Fig. 6.16 (*i*) shows that both diodes D_1 and D_2 are forward biased. Using simplified model for the diodes, the circuit shown in Fig. 6.16 (*i*) becomes the one shown in Fig. 6.16 (*ii*). The voltage across R_2 (= 3.3 k Ω) is 0.7V.

$$\therefore \quad I_2 = \frac{0.7\ \text{V}}{3.3\ \text{k}\Omega} = \mathbf{0.212\ mA}$$

Applying Kirchhoff's voltage law to loop *ABCDA* in Fig. 6.16 (*ii*), we have,

$$-0.7 - 0.7 - I_1 R_1 + 20 = 0$$

$$\therefore \quad I_1 = \frac{20 - 0.7 - 0.7}{R_1} = \frac{18.6\ \text{V}}{5.6\ \text{k}\Omega} = \mathbf{3.32\ mA}$$

Now $\quad I_1 = I_2 + I_3$

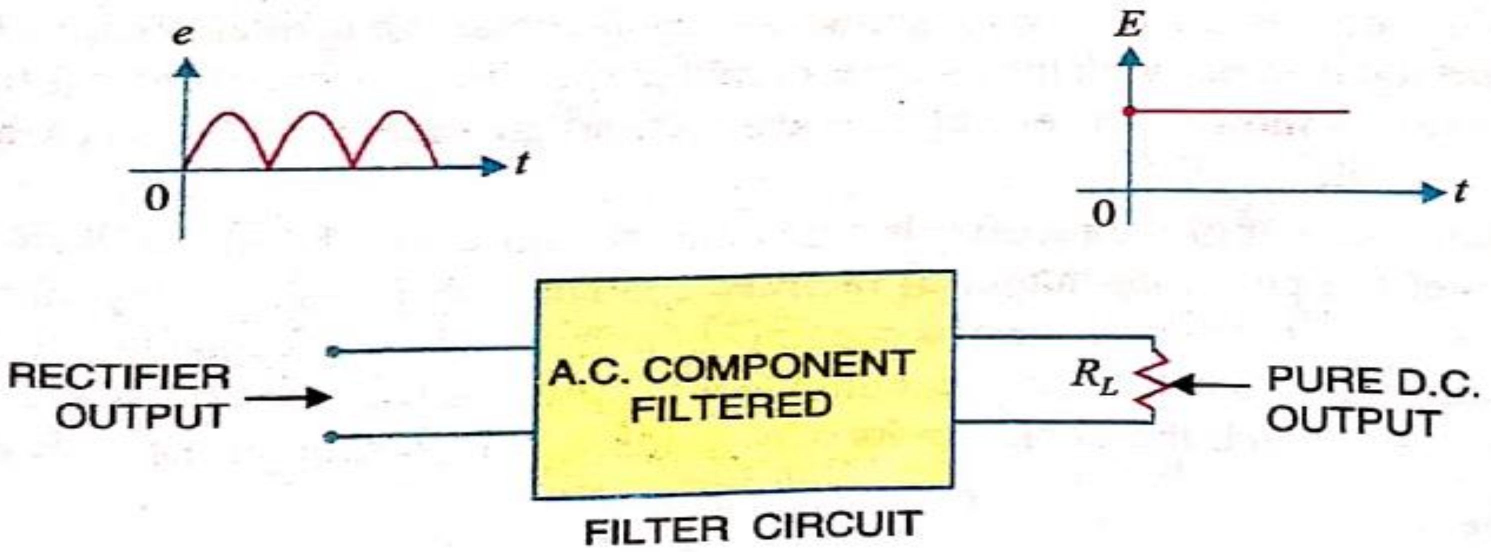
$$\therefore \quad I_3 = I_1 - I_2 = 3.32 - 0.\ 212 = \mathbf{3.108\ mA}$$

Filter Circuit

Generally, a rectifier is required to produce pure d.c. supply for using at various places in the electronic circuits. However, the output of a rectifier has pulsating *character *i.e.* it contains a.c. and d.c. components. The a.c. component is undesirable and must be kept away from the load. To do so, a *filter circuit* is used which removes (or *filters out*) the a.c. component and allows only the d.c. component to reach the load.

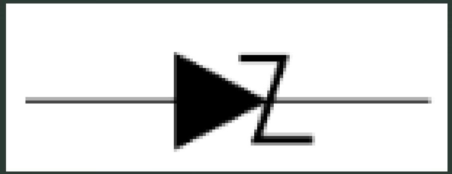
A **filter circuit** *is a device which removes the a.c. component of rectifier output but allows the d.c. component to reach the load.*

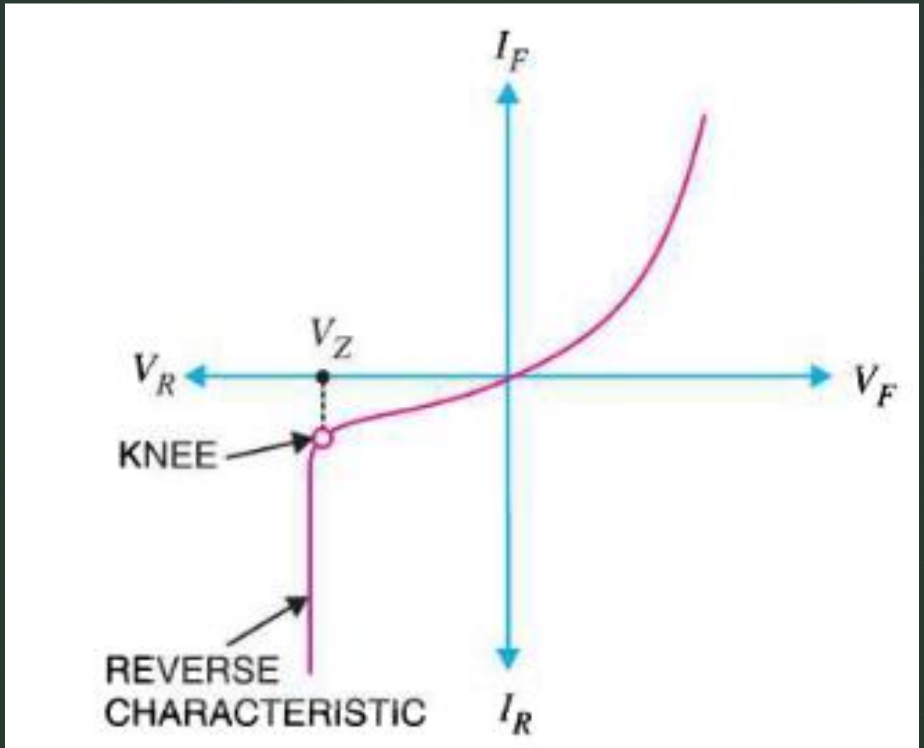
Obviously, a filter circuit should be installed between the rectifier and the load as shown in Fig. 6.40. A filter circuit is generally a combination of inductors (L) and capacitors (C). The filtering action of L and C depends upon the basic electrical principles. A capacitor passes a.c. readily but does not **pass d.c. at all. On the other hand, an inductor †opposes a.c. but allows d.c. to pass through it. It then becomes clear that suitable network of L and C can effectively remove the a.c. component, allowing the d.c. component to reach the load.



Zener Diode

- A properly doped crystal diode which has a sharp breakdown voltage is know as a Zener diode.
- Figure shows the symbol of a Zener diode.
- It may be seen that the bar is turned into z-shape.





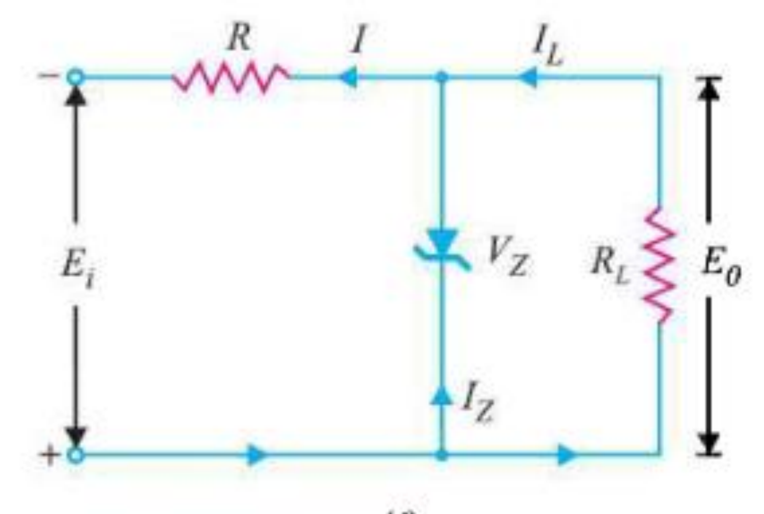
Zener Diode

- The following points noted about the Zener diode.

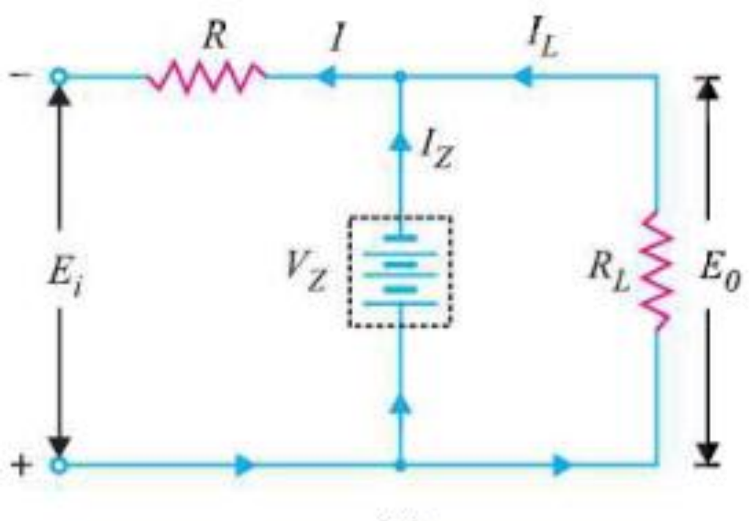
1. A Zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.
2. A Zener diode is always reverse connected i.e. it is always reverse biased.
3. A Zener diode has sharp breakdown voltage, called Zener voltage Vz.
4. The Zener diode is not immediately burnt just because it has entered the breakdown region.

Zener Diode as Voltage Stabiliser

- A Zener diode can be used as a voltage regulator to provide a constant voltage from a source whose voltage may vary over sufficient range.
- The circuit arrangement is shown in figure (i).
- The Zener diode of Zener voltage Vz is reverse connected across the load RL across which constant output is desired.



(i)



(ii)

- The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across load.
- It may be noted that the Zener will maintain a constant voltage Vz across the load so long as the input voltage does not fall below Vz.
- When the circuit is properly designed, the load voltage Eo remains essentially constant even though the input voltage Ei and load resistance RL may vary over a wide range.
- Suppose the input voltage increases. Since the Zener is in the breakdown region, the Zener diode is equivalent to a battery Vz as shown in figure.
- The excess voltage is dropped across the series resistance R.
- This will cause an increase in the value of total current I. The Zener will conduct the increase of current in I while the load current remains constant.

Example 6.26. *For the circuit shown in Fig. 6.62 (i), find the maximum and minimum values of zener diode current.*

Solution. The first step is to determine the state of the zener diode. It is easy to see that for the given range of voltages (80 – 120 V), the voltage across the zener is greater than V_Z (= 50 V). Hence the zener diode will be in the "on" state for this range of applied voltages. Consequently, it can be replaced by a battery of 50 V as shown in Fig. 6.62 (*ii*).

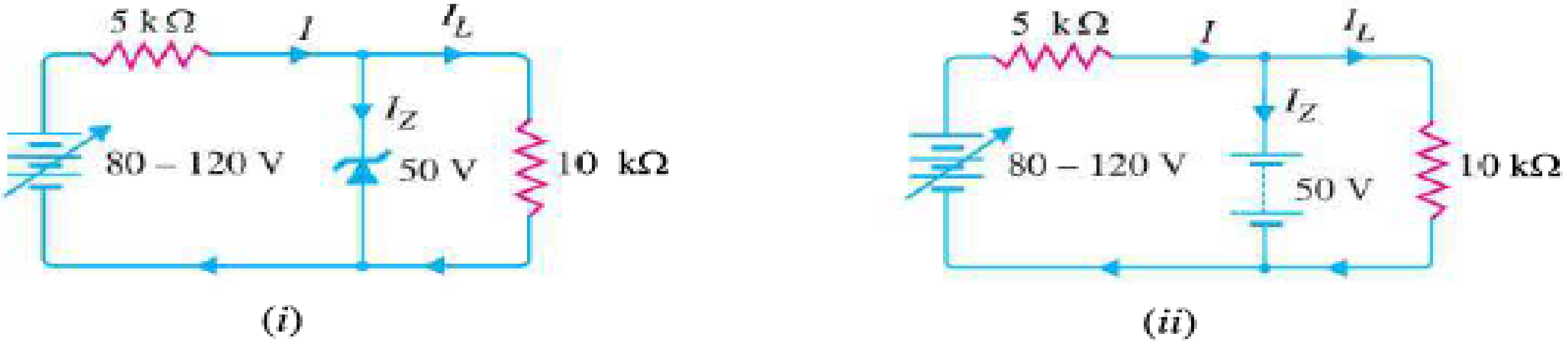


Fig. 6.62

Maximum zener current. The zener will conduct *maximum current when the input voltage is maximum *i.e.* 120 V. Under such conditions :

$$\text{Voltage across } 5\text{ k}\Omega = 120 - 50 = 70\text{ V}$$

$$\text{Current through } 5\text{ k}\Omega,\ I = \frac{70\text{ V}}{5\text{ k}\Omega} = 14\text{ mA}$$

$$\text{Load current, } I_L = \frac{50\text{ V}}{10\text{ k}\Omega} = 5\text{ mA}$$

$$\text{Applying Kirchhoff's first law, } I = I_L + I_Z$$

$$\therefore \quad \text{Zener current, } I_Z = I - I_L = 14 - 5 = \mathbf{9\text{ mA}}$$

Example 6.29. *A 10-V zener diode is used to regulate the voltage across a variable load resistor [See fig. 6.65]. The input voltage varies between 13 V and 16 V and the load current varies between 10 mA and 85 mA. The minimum zener current is 15 mA. Calculate the value of series resistance R.*

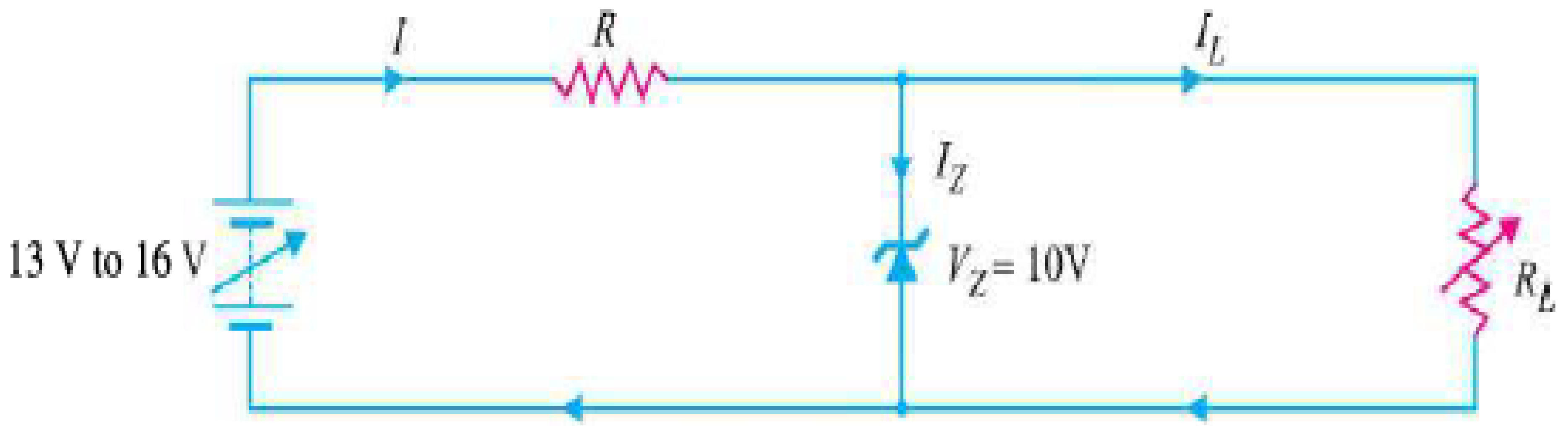


Fig. 6.65

Solution. The zener will conduct minimum current (*i.e.* 15 mA) when input voltage is minimum (*i.e.* 13 V).

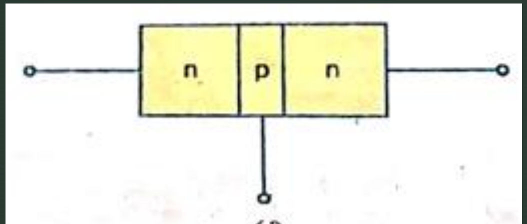
$$\therefore \qquad R = \frac{E_i - E_0}{(I_Z)_{min} + (I_L)_{max}} = \frac{(13 - 10)\text{ V}}{(15 + 85)\text{ mA}} = \frac{3\text{ V}}{100\text{ mA}} = \mathbf{30\ \Omega}$$

Transistor

- A transistor consists of two pn junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types.
- Accordingly, there are two types of transistors, namely:

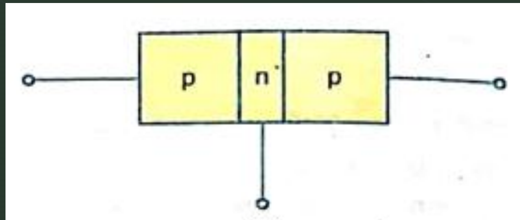
1. n-p-n transistor
2. p-n-p transistor

- An n-p-n transistor is composed of two n-type semiconductors separated by a thin section of p- type as shown in Fig (i).



(i)

- However, a p-n-p transistor is formed by two p-sections separated by a thin section of n-type as shown in Fig (ii).



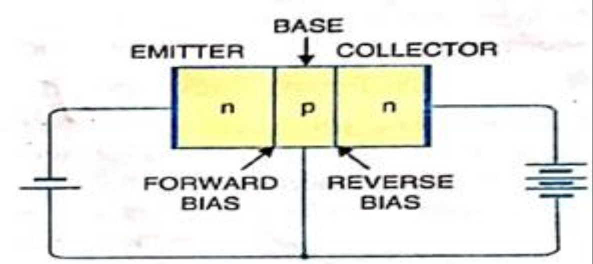
(ii)

Transistor Terminology

1. Emitter:- The section on one side that **supplies charge** carriers (electrons or hole) is called the emitter.

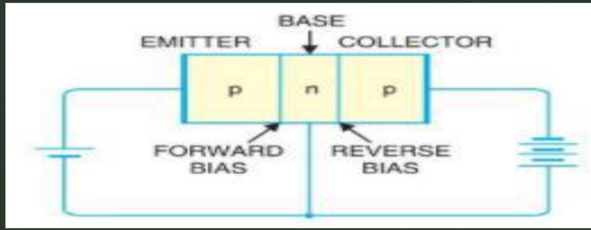
- The emitter is always forward biased w.r.t base so that it can supply a large number of majority carriers.

2. Collector:- The section on the other side that **collects the charges** is called the collector.



- The collector is always reverse biased.
- Its function is to remove charges from its junction with the base.

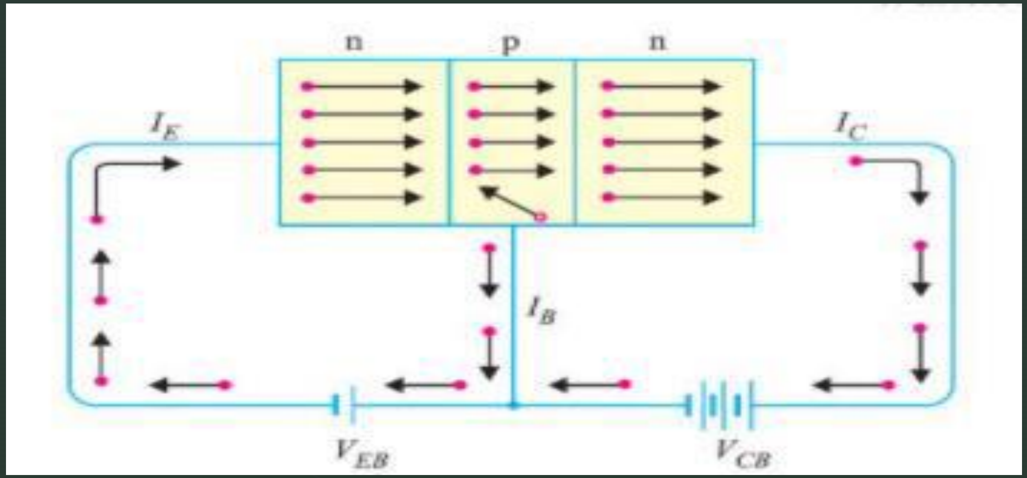
3. Base:- The middle section which forms two pn-junctions between the emitter and collector is called the base.



Applications of Transistor

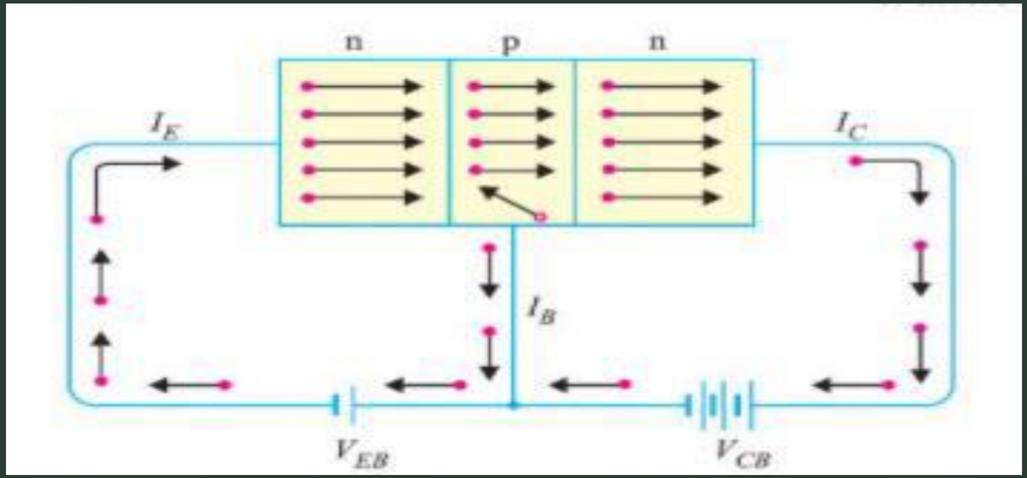
- Transistors are used in oscillators and modulators as amplifiers.
- They are used in digital circuits as switches.
- Transistors are used in Radio-frequency circuits for wireless systems.
- Transistor switches are used in Burglar alarms, industrial control circuits, memories and microprocessors.

Working of Transistor



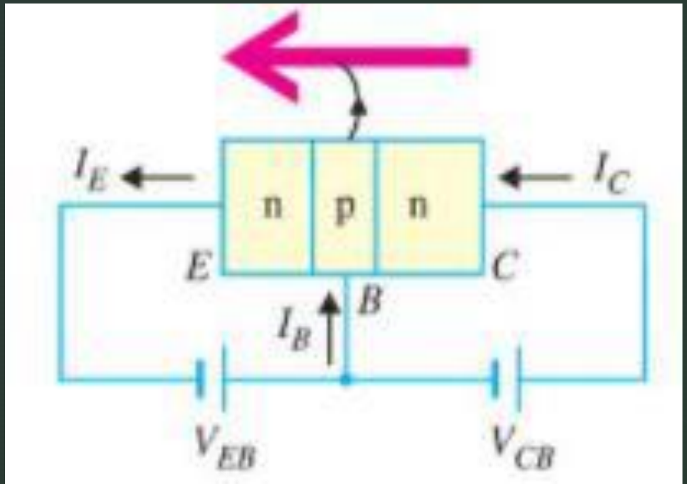
- Figure shows the npn transistor with forward bias to emitter base junction and reverse bias to collector-base junction.
- The forward bias causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E.
- As these electrons flow through the p-type base, they tend to combine with holes. As the base is lightly doped and very thin, therefore, only a few electrons (lessthan5%) combine with holes to constitute base current I_B.

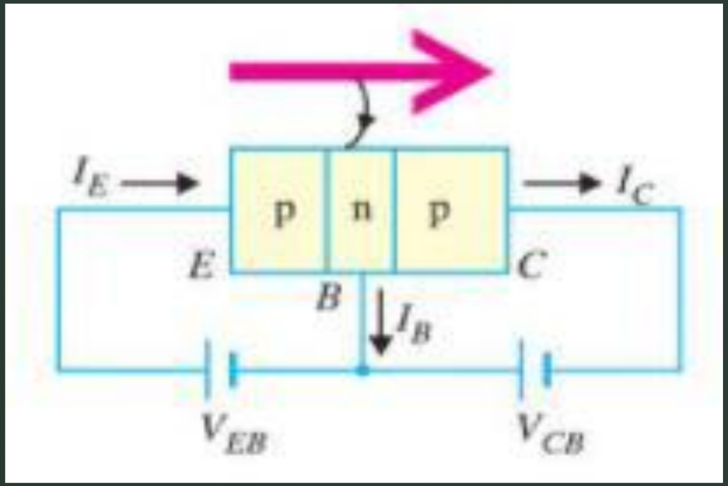
Working of Transistor

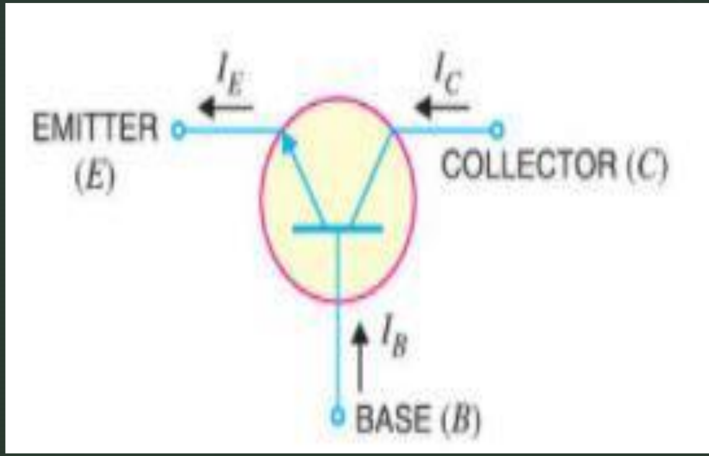


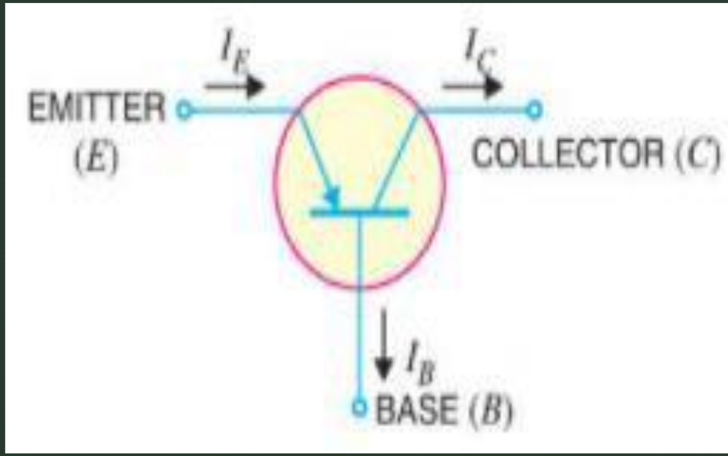
- The remainder (morethan95%) cross over into the collector region to constitute collector current **I_C**. In this way, almost the entire emitter current flows in the collector circuit. It is clear that emitter current is the sum of collector and base currents i.e. **$I_E = I_B + I_C$**

Symbol for Transistor





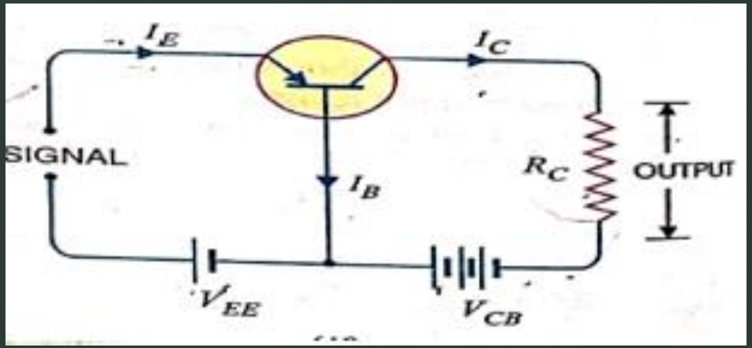


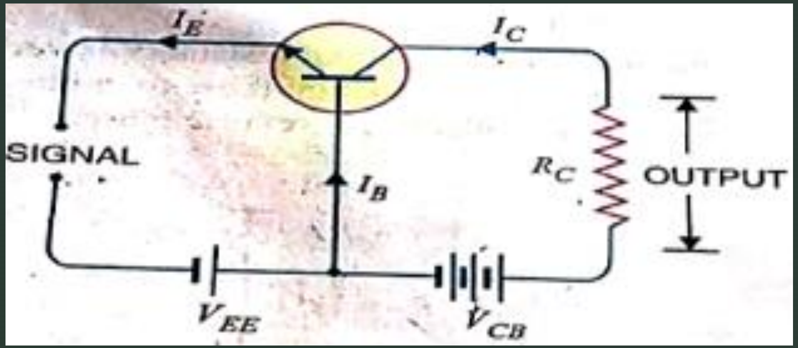


Transistor Connection

- There are three leads in a transistor viz., emitter, base, and collector terminals.
- However, when a transistor is to be connected in a circuit, we require four terminals; two for the input and two for the output.
- This difficulty is over come by making one terminal of the transistor common to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. The output is obtained between the common terminal and the remaining terminal.
- Accordingly; a transistor can be connected in a circuit in the following three ways : (i) common base connection, (ii) common emitter connection, and (iii) common collector connection

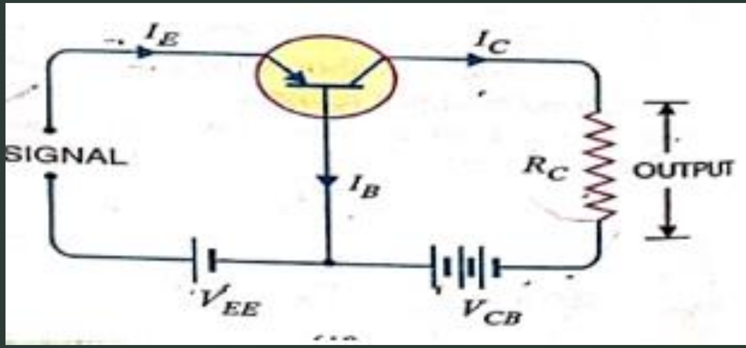
Common Base Connection

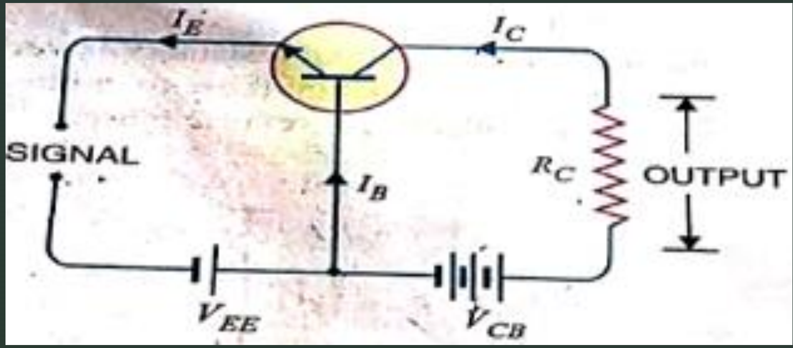




- In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base.
- In Fig. (i), a common base npn transistor circuit is shown whereas Fig. (ii) shows the common base pnp transistor circuit.
- Here, base of the transistor is common to both input and output circuits and hence the name common base connection.

Common Base Connection





- Current amplification factor (α):- It is the ratio of output current to input current.
- In a common base connection, the input current is the emitter current I_E and output current is the collector current I_C.
- The ratio of change in collector current to the change in emitter current at constant collector base voltage V_{CB} is know as current amplification factor

$$*\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$

2. Expression for collector current:- The whole of emitter current does not reach the collector.

- It is because a small percentage of it, as a result of electron- hole combinations occurring in base area, gives rise to base current.
- Moreover, as the collector-base junction is reverse biased, therefore, some leakage current flows due to minority carriers.
- Therefore, total collector current consists of

i. That part of emitter current which reaches the collector terminal αI_E.

ii. The leakage current $I_{leakage}$. This current is due to the movement of minority carriers across base-collector junction on account of it being reverse biased.

$$\text{Total collector current, } I_C = \alpha I_E + I_{leakage}$$

- It is clear that if $I_E=0$, a small leakage current still flows in the collector circuit.
- This $I_{leakage}$ is abbreviated as I_{CBO}, meaning collector-base current with emitter open.

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

$$I_E = I_C + I_B$$

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

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

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

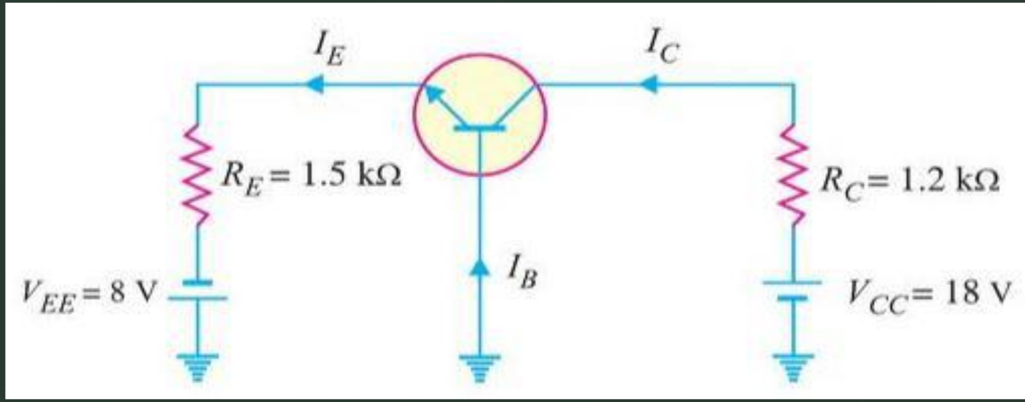
In a common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50 μA. Find the total collector current. Given that $\alpha = 0.92$.

Solution. Here, $I_E = 1$ mA, $\alpha = 0.92$, $I_{CBO} = 50\ \mu A$

$\therefore$ Total collector current, $I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 + 50 \times 10^{-3}$

$= 0.92 + 0.05 = $ **0.97 mA**

For the common base circuit shown in Figure, determine Ic and VCB . Assume the transistor to be of silicon.



Solution :

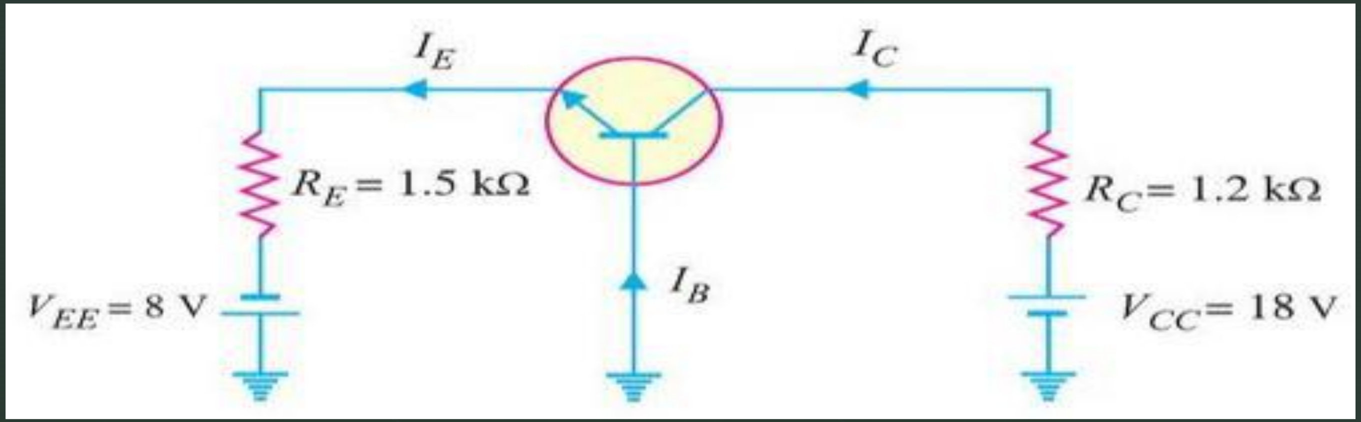
Since the transistor is of silicon, VBE = 0.7 V.

Applying Kirchhoff's voltage law to the emitter-side loop, we get $V_{EE} = I_E R_E + V_{BE}$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8V - 0.7V}{1.5\text{ k}\Omega} = 4.87\text{ mA}$$

$$\therefore \quad I_C \simeq I_E = \mathbf{4.87\text{ mA}}$$



Applying Kirchhoff's voltage law to the collector-side loop, we have,

$$V_{CC} = I_C R_C + V_{CB}$$

$$\therefore \quad V_{CB} = V_{CC} - I_C R_C$$

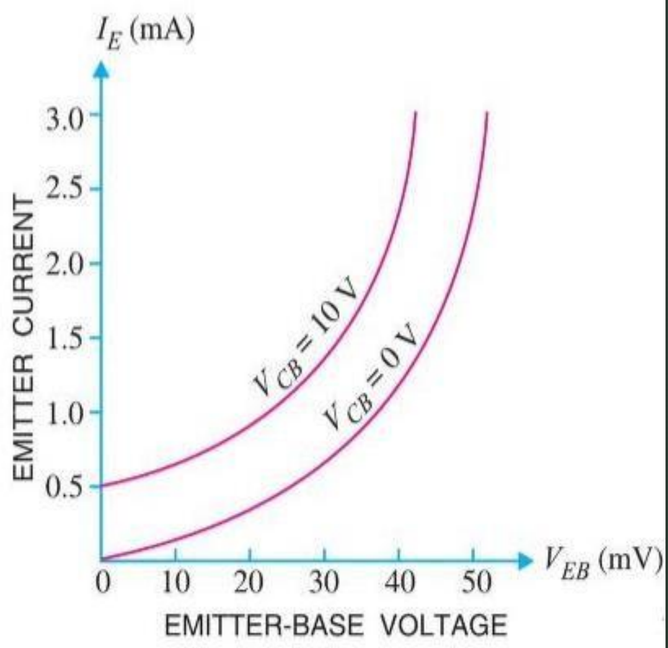
$$= 18\text{ V} - 4.87\text{ mA} \times 1.2\text{ k}\Omega = \mathbf{12.16\text{ V}}$$

Characteristics of common base connection

- The complete electrical behavior of a transistor can be described by stating the interrelation of the various currents and voltages. These relationships can be conveniently displayed graphically and the curves thus obtained are known as the characteristics of transistor.
- The most important characteristics of common base connection are
- (i) input characteristics
- (ii) output characteristics

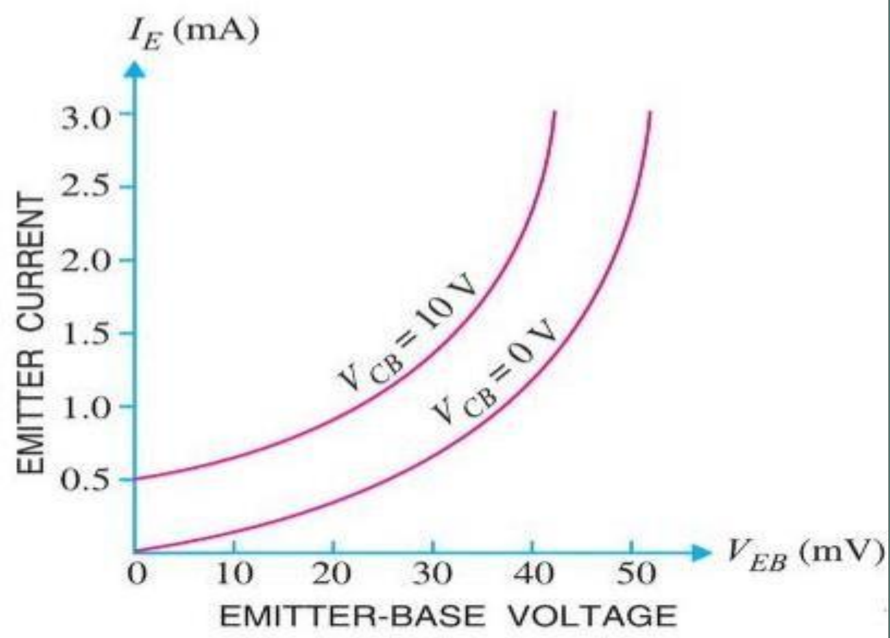
Characteristics of common base connection

- (i) Input characteristics
- It is the curve between emitter current IE and emitter-base voltage VEB at constant collector-base voltage VCB . The emitter current is generally taken along y-axis and emitter-base voltage along x-axis.
- Fig. shows the input characteristics of a typical transistor in CB arrangement .



- The following points noted from these characteristics:
- (i) The emitter current IE increases rapidly with small increase in emitter-base voltage VEB . It means that input resistance is very small.
- (ii) The emitter current is almost independent of collector-base voltage VCB. This leads to the conclusion that emitter current (and hence collector current) is almost independent of collector voltage.

Characteristics of common base connection



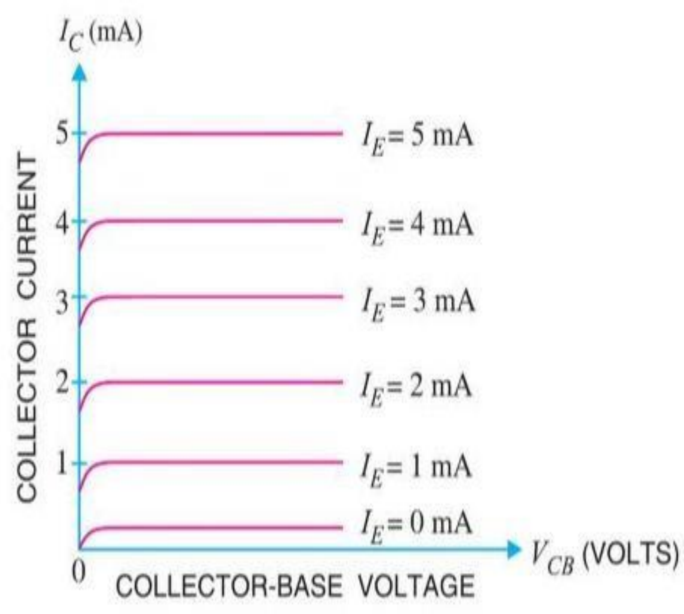
- (i) Input characteristics
- <u>Input resistance</u>:
- It is the ratio of change in emitter-base voltage (Δ VEB) to the resulting change in emitter current (Δ IE) at constant collector-base voltage (VCB) i.e.

$$\text{Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_E} \quad \text{at constant } V_{CB}$$

- In fact, input resistance is the opposition offered to the signal current.
- As a very small VEB is sufficient to produce a large flow of emitter current IE, therefore, input resistance is quite small, of the order of a few ohms.

Characteristics of common base connection

- (ii) Output characteristics:
- It is the curve between collector current IC and collector-base voltage VCB at constant emitter current IE. Generally, collector current is taken along y-axis and collector-base voltage along x-axis.



- The following points noted from the characteristics :
- (i) The collector current IC varies with VCB only

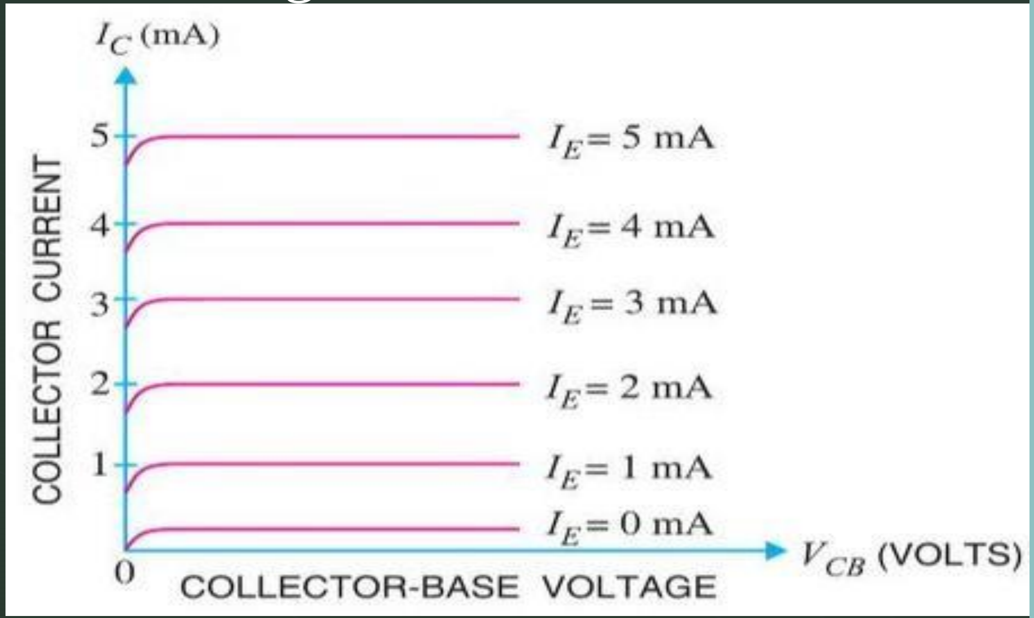
at very low voltages (< IV). The transistor is never operated in this region.

- (ii) A very large change in collector-base voltage produces only a tiny change in collector current. This means that output resistance is very high.

Characteristics of common base connection

- (iii)When the value of VCB is raised above 1-2 V, the collector current becomes constant as indicated by straight horizontal curves. It means that now IC is independent of VCB and depends upon IE only. This is consistent with the theory that the emitter current flows almost entirely to the collector terminal. The transistor is always operated in this region.
- <u>Output resistance:</u>
- It is the ratio of change in collector-base voltage (Δ VCB) to the resulting change in collector current (ΔIC) at constant emitter current (IE) i.e.

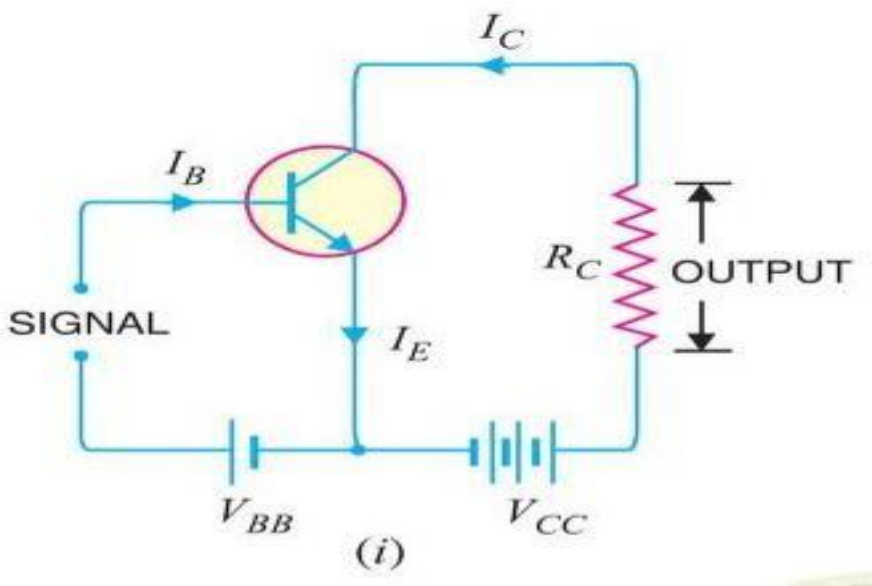
$$\text{Output resistance, } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

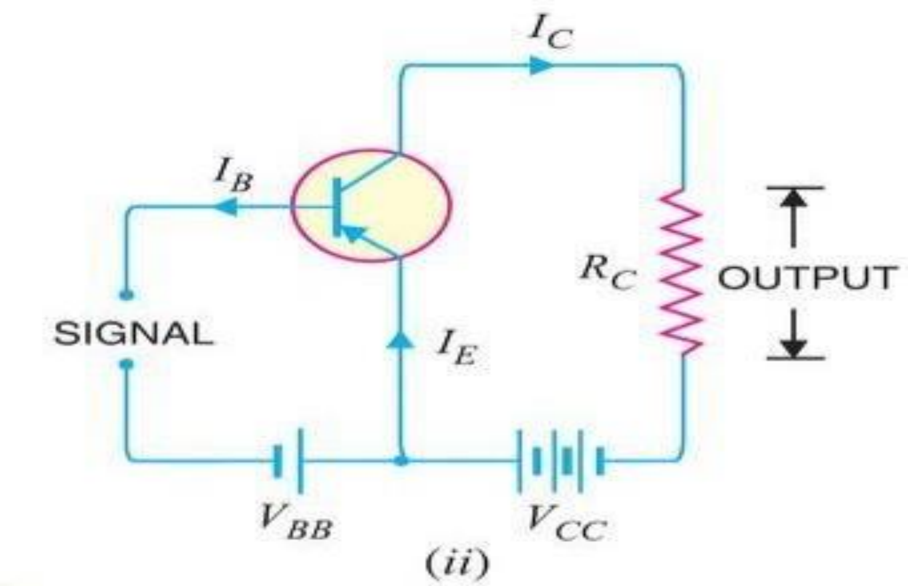


- The output resistance of CB circuit is very high, of the order of several tens of kilo-ohms. This is not surprising because the collector current changes very slightly with the change in VCB.

Common Emitter Connection

- In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter. Here, emitter of the transistor is common to both input and output circuits and hence the name common emitter connection. Fig. (i) shows common emitter npn transistor circuit whereas Fig. (ii) shows common emitter pnp transistor circuit.





Common Emitter Connection

- 1. Base current amplification factor (β) :
- In common emitter connection, input current is IB and output current is IC . The ratio of change in collector current (ΔIC) to the change in base current (ΔIB) is known as base current amplification factor i.e.

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

- **<u>Relation between β and α :</u>**
- A simple relation exists between β and α . This can be derived as follows :

$$\beta = \frac{\Delta I_C}{\Delta I_B} \qquad \alpha = \frac{\Delta I_C}{\Delta I_E} \qquad I_E = I_B + I_C \qquad \Delta I_E = \Delta I_B + \Delta I_C \qquad \Delta I_B = \Delta I_E - \Delta I_C$$

Dividing numerator and denominator by ΔIE

$$\beta = \frac{\Delta I_C}{\Delta I_B} \qquad \beta = \frac{\Delta I_C}{\Delta IE - \Delta IC} \qquad \beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \qquad \left\{\alpha = \frac{\Delta I_C}{\Delta I_E}\right\} \qquad \beta = \frac{\alpha}{1-\alpha}$$

Common Emitter Connection

- 2. Expression for collector current (IC) :
- In common emitter circuit, IB is the input current and IC is the output current.

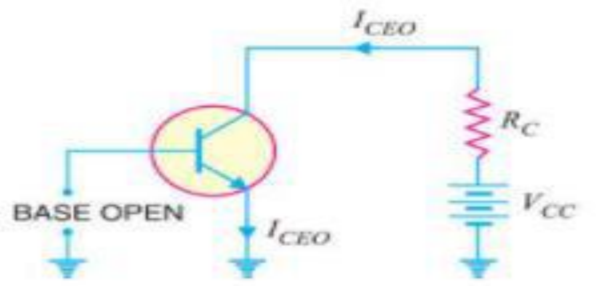
We know, $I_E = I_B + I_C$

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

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

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

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



- From equation, it is apparent that if $IB = 0$ (i.e. base circuit is open), the collector current will be the current to the emitter. This is abbreviated as $ICEO$, meaning collector-emitter current with base open.

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

- Substituting the value of $ICEO$ in above equation, we get

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

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

but $\beta = \frac{\alpha}{1-\alpha}$

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

Examples Common Emitter

EX-1: The collector leakage current in a transistor is 300μA in CE arrangement. If now the transistor is connected in CB arrangement, what will be the leakage current? Given that $\boldsymbol{\beta}$ = 120.

Solution. $I_{CEO} = 300\ \mu A$

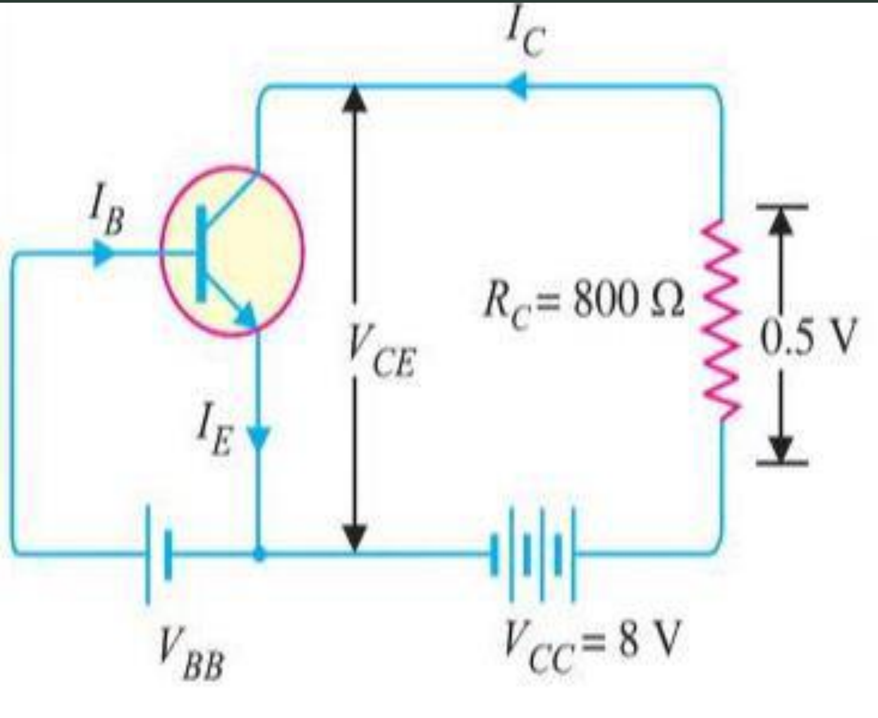
$$\beta = 120 \quad ; \quad \alpha = \frac{\beta}{\beta + 1} = \frac{120}{120 + 1} = 0.992$$

Now, $$I_{CEO} = \frac{I_{CBO}}{1 - \alpha}$$

$$\therefore \quad I_{CBO} = (1 - \alpha)\, I_{CEO} = (1 - 0.992) \times 300 = \mathbf{2.4\ \mu A}$$

Examples Common Emitter

EX-2: A transistor is connected in common emitter (CE) configuration in which collector supply is 8V and the voltage drop across resistance Rc connected in the collector circuit is 0.5V. The value of Rc = 800 Ω. If α = 0.96, determine : (i) collector-emitter voltage (ii) base current.



(*i*) Collector-emitter voltage,

$$V_{CE} = V_{CC} - 0.5 = 8 - 0.5 = \mathbf{7.5\ V}$$

(*ii*) The voltage drop across R_C (= 800 Ω) is 0.5 V.

$$\therefore \quad I_C = \frac{0.5\ V}{800\ \Omega} = \frac{5}{8}\ \text{mA} = 0.625\ \text{mA}$$

$$\text{Now} \quad \beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24$$

$$\therefore \quad \text{Base current,}\ I_B = \frac{I_C}{\beta} = \frac{0.625}{24} = \mathbf{0.026\ mA}$$

Example 8.8. *Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.*

Solution. (*i*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \mathbf{9}$$

(*ii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \mathbf{49}$$

(*iii*)
$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \mathbf{99}$$

Example 8.9. *Calculate I_E in a transistor for which β = 50 and I_B = 20 μA.*

Solution. Here $\beta = 50, \quad I_B = 20\mu A = 0.02 \text{ mA}$

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

∴
$$I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$$

Using the relation, $I_E = I_B + I_C = 0.02 + 1 = \mathbf{1.02\ mA}$

Example 8.10. *Find the α rating of the transistor shown in Fig. 8.20. Hence determine the value of I_C using both α and β rating of the transistor.*

Solution. Fig. 8.20 shows the conditions of the problem.

$$\alpha = \frac{\beta}{1+\beta} = \frac{49}{1+49} = \mathbf{0.98}$$

The value of I_C can be found by using either α or β rating as under :

$$I_C = \alpha I_E = 0.98 \text{ (12 mA)} = \mathbf{11.76\ mA}$$

Also
$$I_C = \beta I_B = 49 \text{ (240 μA)} = \mathbf{11.76\ mA}$$

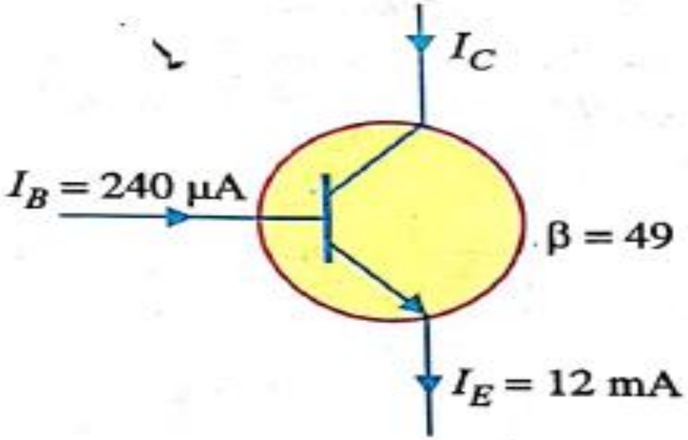
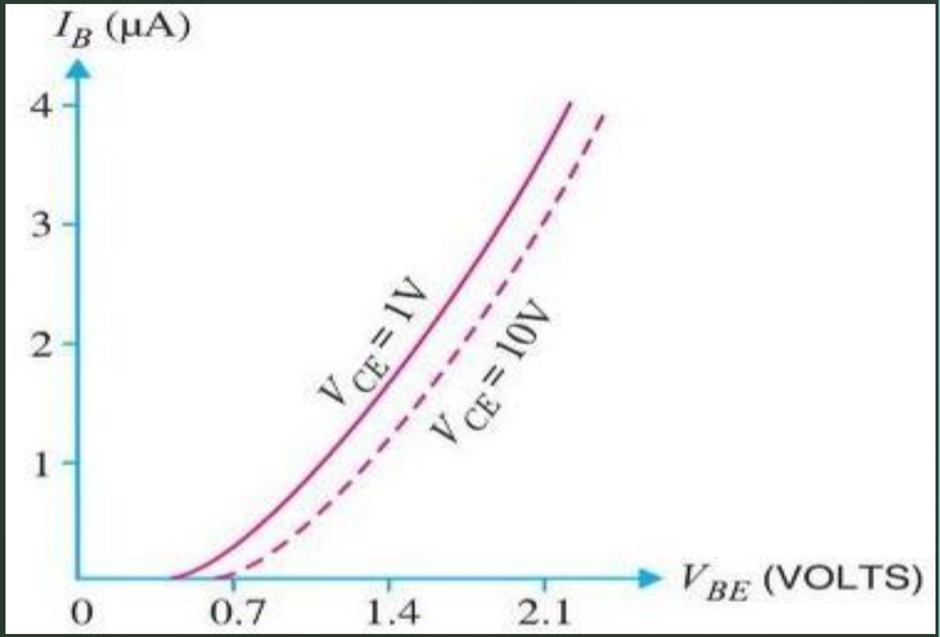


Fig. 8.20

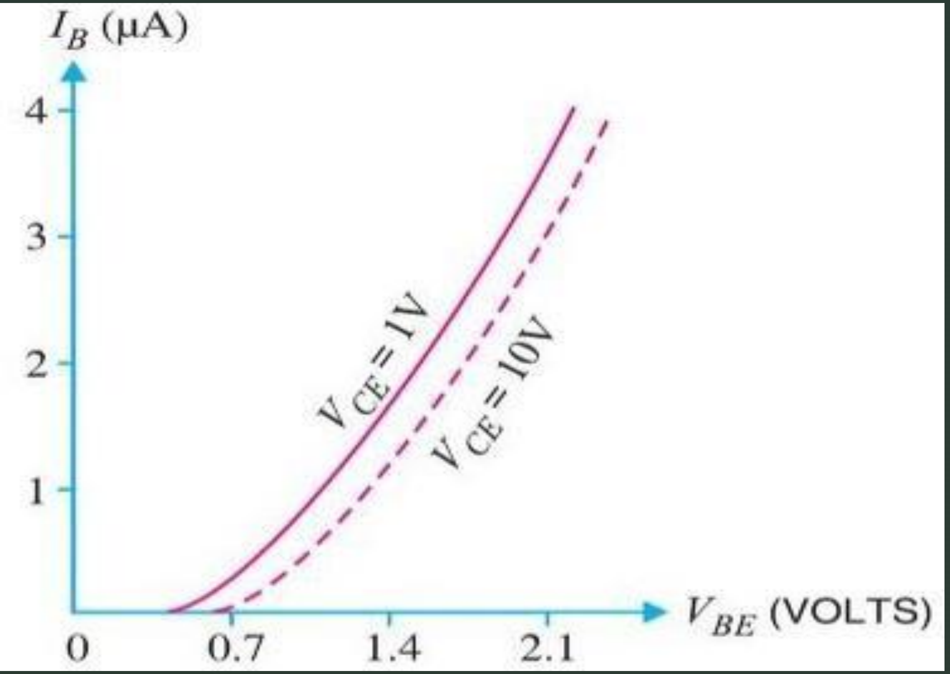
Characteristics of common Emitter connection

- It is the curve between base current I_B and base- emitter voltage V_{BE} at constant collector-emitter voltage V_{CE}.
- The input characteristics of a CE connection can be determined by the circuit shown in Fig. Keeping VCE constant (say at 10 V), note the base current IB for various values of VBE.
- Then plot the readings obtained on the graph, taking IB along y- axis and VBE along x-axis.
- The following points noted from the characteristics :
- (i) The characteristic resembles that of a forward biased diode curve. This is expected since the base- emitter section of transistor is a diode and it is forward biased.
- (ii) As compared to CB arrangement, IB increases less rapidly with VBE. Therefore, input resistance of a CE circuit is higher than that of CB circuit.



Characteristics of common Emitter connection

- (i) Input characteristics
- <u>Input resistance</u>:
- It is the ratio of change in base-emitter voltage (Δ VBE) to the change in base current (ΔIB) at constant VCE i.e.



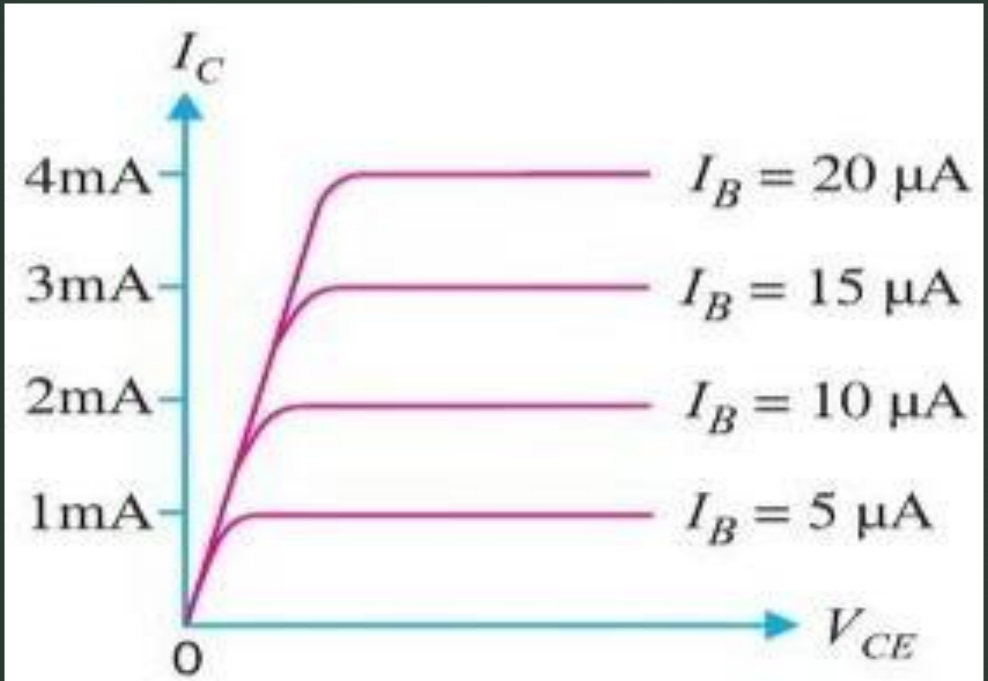
$$\text{Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_E} \quad \text{at constant } V_{CB}$$

- The value of input resistance for a CE circuit is of the order of a few hundred ohms.

Characteristics of common Emitter connection

- (ii) Output characteristics:

It is the curve between collector current IC and collector-emitter voltage VCE at constant base current IB.

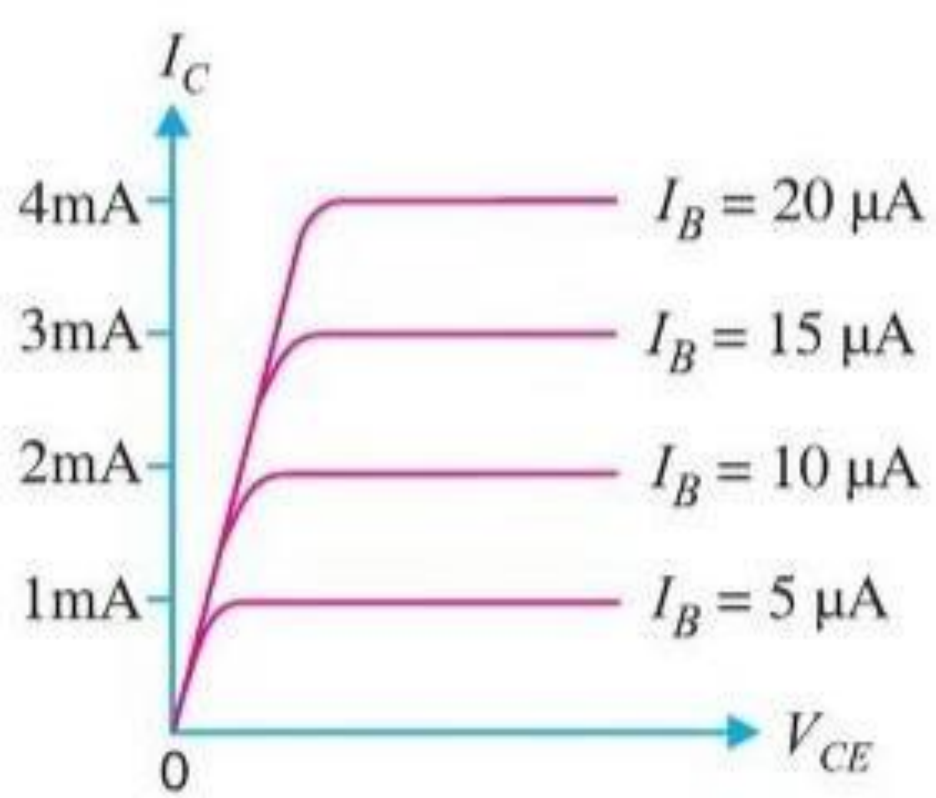


- The following points noted from the characteristics :
- (i) The collector current IC varies with VCE for VCE between 0 and 1 V only. After this, collector current becomes almost constant and independent of VCE. This value of VCE up to which collector current IC changes with VCE is called the knee voltage (V knee). The transistors are always operated in the region above knee voltage.
- (ii) For any value of VCE above knee voltage, the collector current IC is approximately equal to (***β*** x IB).

Characteristics of common Emitter connection

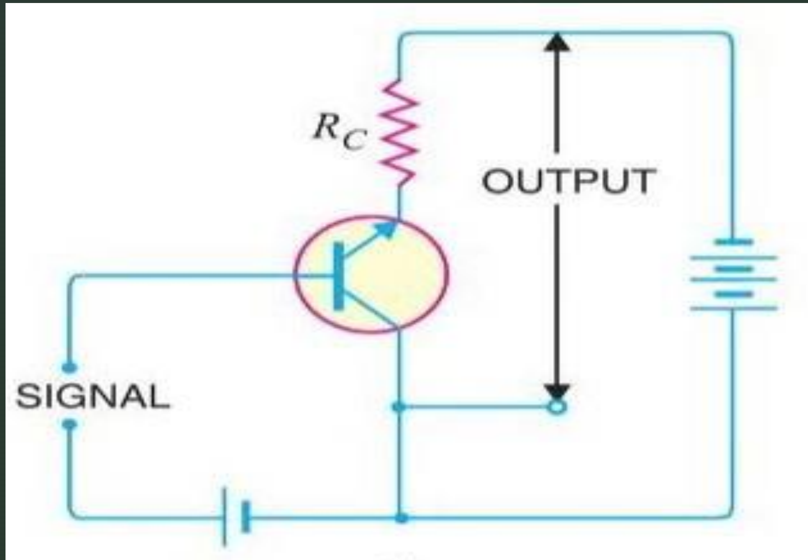
- (iii)Above knee voltage, IC is almost constant. However, a small increase in IC with increasing VCE is caused by the collector depletion layer getting wider and capturing a few more majority carriers before electron-hole combinations occur in the base area.
- <u>Output resistance</u>:
- It is the ratio of change in collector-emitter voltage (Δ VCE) to the change in collector current (ΔIC) at constant IB i.e.

$$\text{Output resistance, } r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

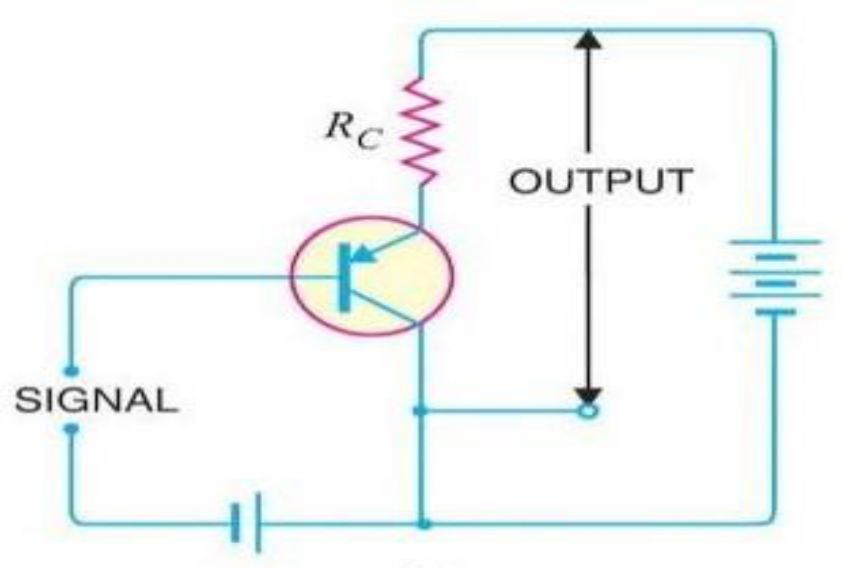


Common Collector Connection

- In this circuit arrangement, input is applied between base and collector while output is taken between the emitter and collector. Here, collector of the transistor is common to both input and output circuits and hence the name common collector connection. Fig. (i) shows common collector npn transistor circuit whereas Fig. (ii) shows common collector pnp circuit.



(i)



(ii)

Common Collector Connection

- 1. Current amplification factor ($\boldsymbol{\gamma}$) :
- In common collector circuit, input current is the base current $\boldsymbol{IB}$ and output current is the emitter current $\boldsymbol{IE}$.
- Therefore, current amplification in this circuit arrangement can be defined as under :
- The ratio of change in emitter current ($\Delta \boldsymbol{IE}$) to the change in base current ($\Delta \boldsymbol{IB}$) is known as current amplification factor in common collector (CC) arrangement i.e.

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

Common Collector Connection

- Relation between γ and α:
- A simple relation exists between γ and α . This can be derived as follows,

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

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

$$I_E = I_B + I_C$$

$$\Delta I_E = \Delta I_B + \Delta I_C$$

$$\Delta I_B = \Delta I_E - \Delta I_C$$

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

$$\gamma = \frac{\Delta I_E}{\Delta IE - \Delta IC}$$

Dividing numerator and denominator by ΔIE

$$\gamma = \frac{\frac{\Delta I_E}{\Delta I_E}}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}}$$

$$\gamma = \frac{1}{1-\alpha}$$

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

Common Collector Connection

- 2. Expression for output current (IE):
- In common collector circuit, IB is the input current and IE is the output current.

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

$$I_E = I_B + I_C$$

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

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

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

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

Comparison of Transistor Connections

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 kΩ)
2.	Output resistance	Very high (about 450 kΩ)	High (about 45 kΩ)	Low (about 50 Ω)
3.	Voltage gain	about 150	about 500	less than 1
4.	Applications	For high frequency applications	For audio frequency applications	For impedance matching
5.	Current gain	No (less than 1)	High (β)	Appreciable

Modulation:- The process of changing some characteristic (e.g. amplitude, frequency or phase) of a carrier wave in accordance with the intensity of the signal is known as modulation.

Modulation means to "change". In modulation, some characteristic of carrier wave is changed in accordance with the intensity (*i.e.* amplitude) of the signal. The resultant wave is called modulated wave or radio wave and contains the audio signal. Therefore, modulation permits the transmission to occur at high frequency while it simultaneously allows the carrying of the audio signal.

The process of recovering the audio signal from the modulated wave is known as **demodulation** *or* **detection.**

At the broadcasting station, modulation is done to transmit the audio signal over larger distances to a receiver. When the modulated wave is picked up by the radio receiver, it is necessary to recover the audio signal from it. This process is accomplished in the radio receiver and is called demodulation.

Thank You