

VIKASH POLYTECHNIC

LECTURE NOTES

ON

ANALOG ELECTRONICS & OPAMP

Prepared by

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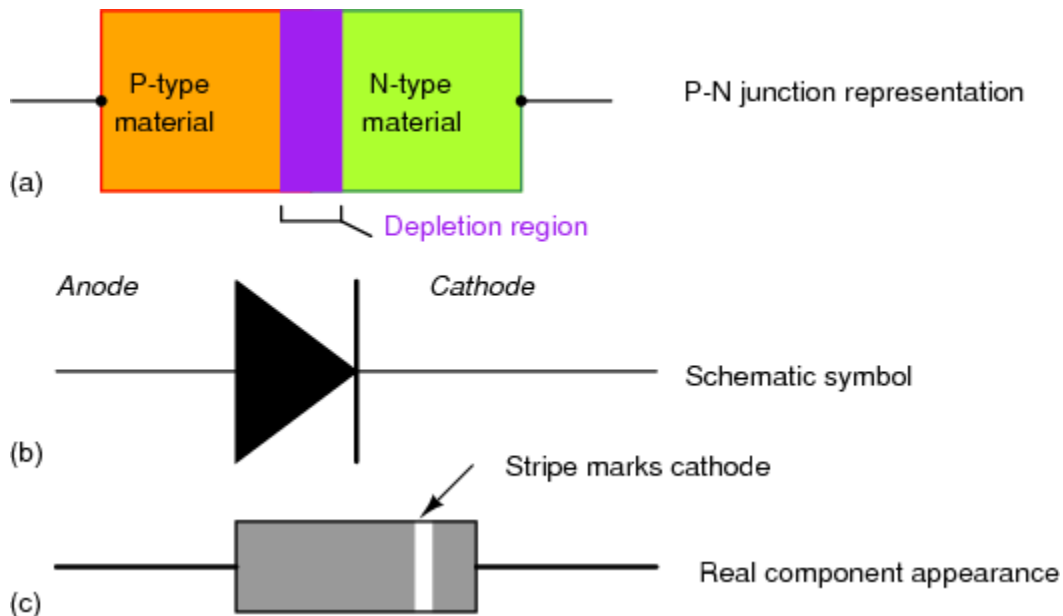
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CHAPTER-I

PN-JUNCTION

PN-JUNCTION :

- When a p-type & n-type material are suitably joined the contact region is called pn-junction.
- PN-junction is very important for manufacturing different electronic devices , like rectifier,LED, Zener diode.
- Structure :



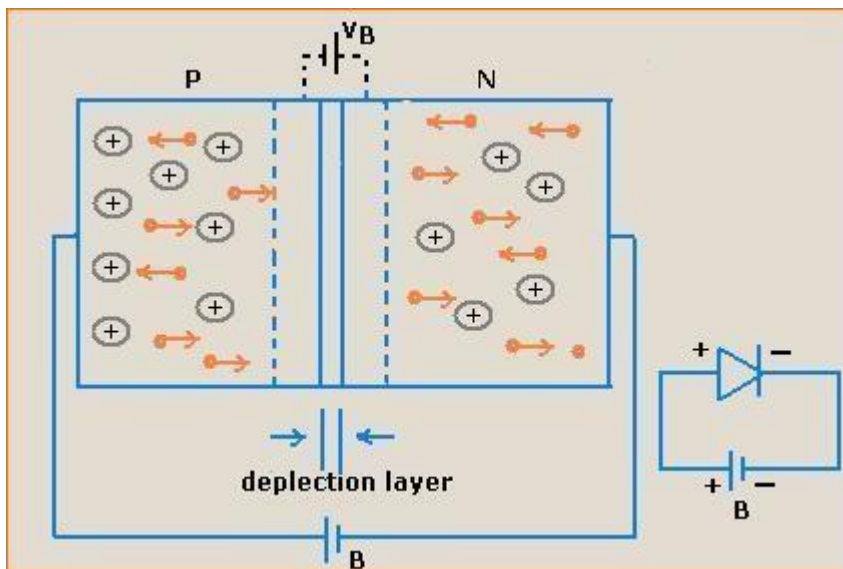
PROPERTIES OF PN-JUNCTION

- The p-type material has majority holes & minority free electrons .Each hole is associated by a -ve ion. Similarly the n-type material has majority free electrons & minority holes.
Each free electrons is associated by +ve ion.
- When this p-type & n-type material are joined to form pn-junction, at the junction the +ve hole on p-side & the -ve free electron on n-side attract each other & cancel after combination. Due to this combination a net -ve charge develops on p-side & net +ve charge

- The region across which barrier potential exist is called depletion layer, because this layer is depleted of charge carrier.

WORKING PRINCIPLE OF PN JUNCTION :

* For proper operation of pn-junction an external supply should be used. The external supply magnitude should be greater than barrier potential & applied in forward condition i.e. +ve terminal is connected to p-type & -ve to n-type as shown in figure below :



*If there is no external voltage applied across the pn-junction, a barrier potential exists across the junction & due to this the pn-junction is not conducting & current through pn-junction is zero.

*When external voltage is applied, the majority holes in p-type are repelled by the +ve terminal of the source & free electrons in n-type are repelled by the -ve terminal of the source. As a result both free electrons & holes move towards the junction & cancel barrier potential. This movement produces current flow through the pn-junction.

*It is clear from the figure that current flow inside the pn-junction is due to two types of charge carrier, i.e. free electrons & holes, but outside the junction current is due to only free electrons.

BIASING OF PN JUNCTION :

*The process of applying external voltage across the pn-junction is called biasing.

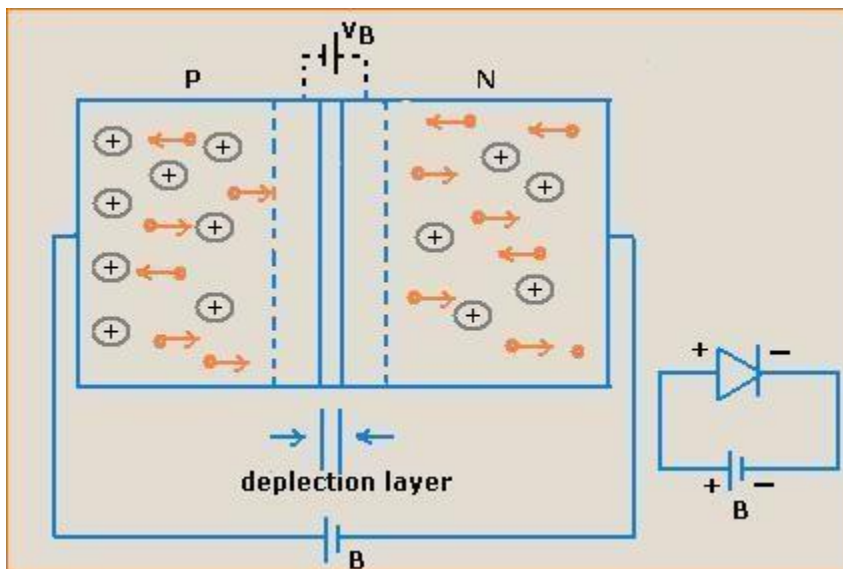
*Types of biasing :

- a) Zero bias
- b) Forward bias
- c) Reverse bias

Zero Bias: The pn-junction without any external supply is called zero bias. Under this condition the pn-junction is not conducting due to existence of barrier potential.

Forward Bias

- If p-type material is connected to +ve & n-type to -ve of external supply, the pn-junction is said to be forward bias.
- FIGURE :

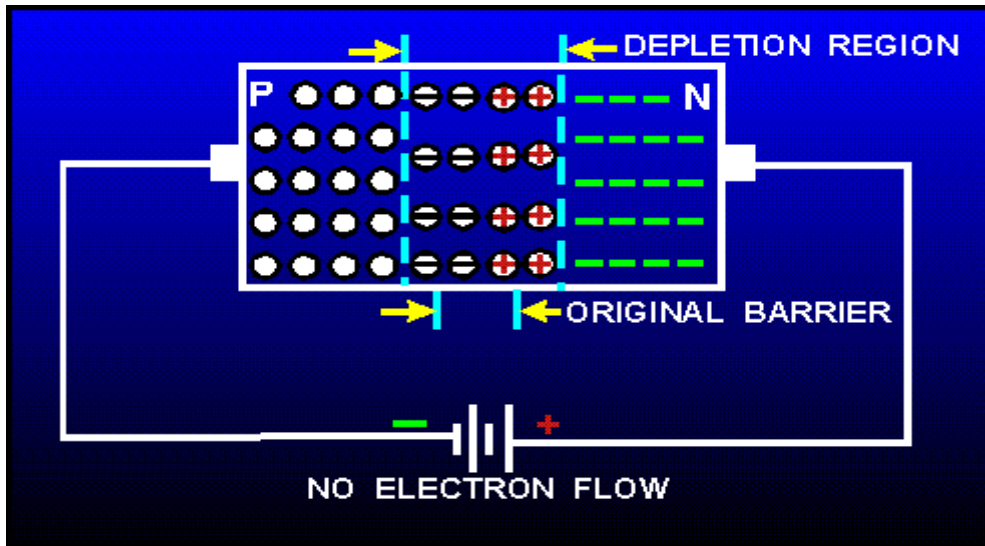


- Due to forward biasing the +ve terminal of external supply repels the holes towards the junction. Similarly the majority free electrons in n-region are repelled by the -ve terminal of the supply. As a result there is a continuous movement of free electrons & holes across the junction. The pn-junction is now conducting.
- It is clear from the figure that current inside the pn-junction is due to two types of charge carriers, that is free electrons & holes, but outside the junction current is due to only free electrons.
- Due to forward biasing the barrier potential is eliminated. Depletion width decreases.

Due to forward biasing resistance of pn-junction decreases & conductivity increases.

Reverse Biasing

- When p-type is connected to -ve & n-type to +ve of external supply the pn-junction is said to be reverse biased.
- Figure :



- Under reverse biased condition the majority holes of p-type are attracted by -ve terminal of the supply & majority free electrons of n-type are attracted by +ve terminal of supply. As a result the majority free electrons & holes are moving away from the junction. No majority carriers cross the junction. The PN-junction is said to not conducting & no current flow through the pn-junction.
- Due to minority carrier very small current, in the range of micro ampere flows across the pn-junction. This small minority current sometimes assumed as approximately zero.
- Due to reverse biasing the resistance of pn-junction increases & conductivity decreases to very small value.
- Due to reverse biasing depletion width increases. The barrier potential acts in the same direction as the external supply. Hence it can not be cancelled.

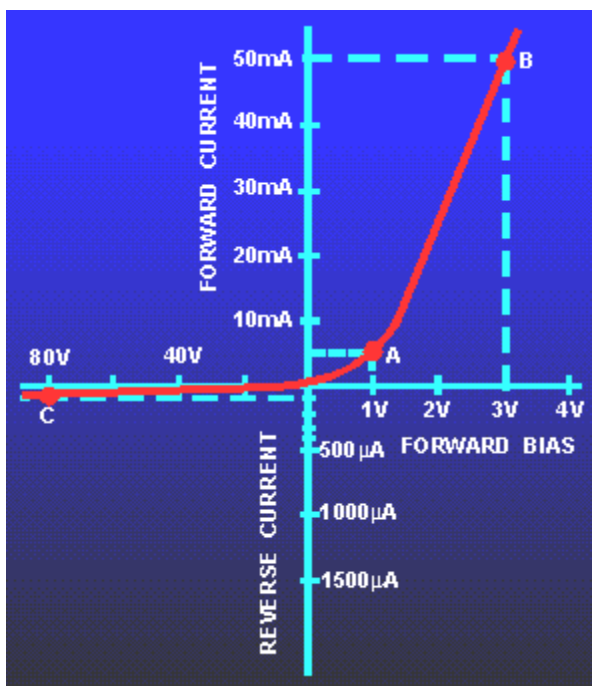
V~I CHARACTERISTIC OF PN-JUNCTION:

- The graph which shows the relation between voltage applied across a pn-junction & current flowing through it is called V~I characteristic.

- Two types of V~I characteristic :
 - a) Forward V~I characteristic
 - b) Reverse V~I characteristic

Forward V~I Characteristic:

- The characteristic under forward bias condition of pn-junction is called forward characteristic.
- By changing the position of variable resistor R number of readings are taken from voltmeter & ammeter. All readings are plotted on a graph paper & the resulting graph is called forward V~I characteristic.
- Graph:



- When the voltage across the pn-junction is zero, no current flows. If we increase the voltage across pn-junction in forward direction, at first current increases very slowly with voltage, but after certain voltage, current increases very rapidly with voltage. This voltage is called Knee voltage.
- Below Knee voltage current is very small due to barrier potential, because supply voltage is trying to cancel the barrier potential. But after knee voltage, barrier potential completely cancelled & current rises very rapidly.

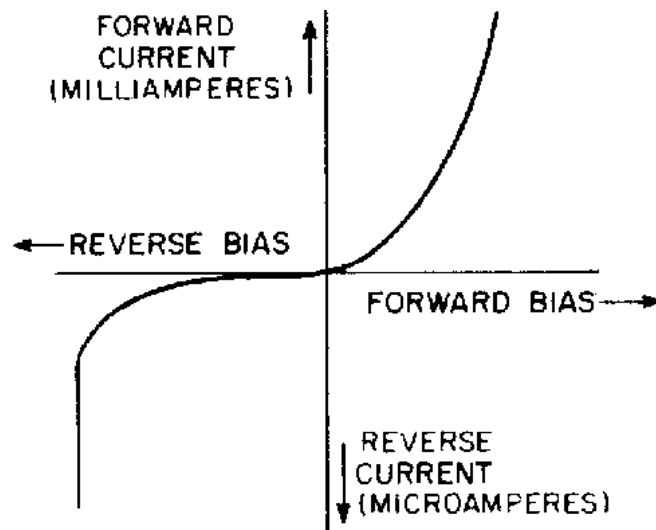
REVERSE CHARACTERISTIC:

- The characteristic under reverse condition of pn-junction is called reverse characteristic.

- The characteristic can be drawn by taking readings for different position of variable resistor.
- If the voltage increases from zero to onwards in –ve direction, at first current rises very slowly with voltage. This process continues upto a certain voltage known as avalanche breakdown voltage V_B .
- At V_B current suddenly increases to a very high value.
- Above break down voltage if voltage across pn-junction increases further, then it has no effect over the current .

At break down voltage the pn-junction may burnt due to excess heat.

Complete V~I Characteristic:



CHAPTER-2

RECTIFIER

RECTIFIER:

The electronic device which converts AC to DC is called rectifier.

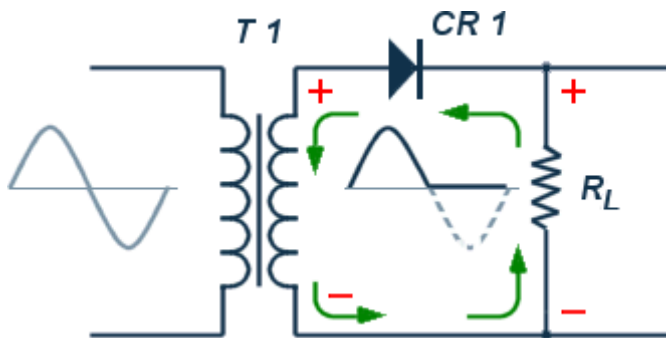
TYPES OF RECTIFIER:

1. Half wave rectifier
2. Full wave rectifier:
 - a) Center tapped full wave rectifier
 - b) Bridge type full wave rectifier

HALF WAVE RECTIFIER:

*The rectifier which rectifies only one half cycle of ac I/P supply is called half wave rectifier.

*Circuit Diagram:



Circuit details:

It consists of a step down transformer T, diode D, load resistor R_L . The transformer is used to transfer the input ac supply from primary to secondary in step down mode. Diode D is used for rectification. The dc output develops across load resistor R_L .

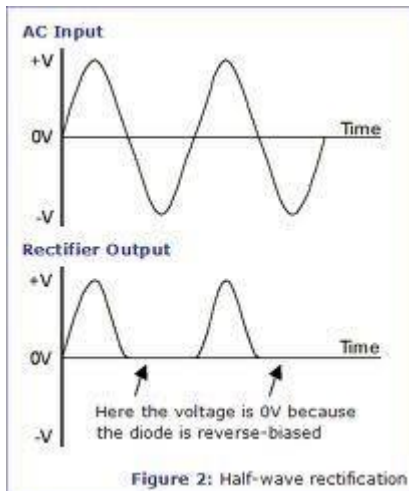
OPERATION:

1. During the +ve half cycle of ac input, terminal A is +ve & B is -ve. This makes diode D forward biased. Hence the diode acts as a closed switch. Now current flows through the secondary circuit & also through load resistor R_L .

2. During the $-ve$ half cycle of ac input supply, terminal A is $-ve$ & B is $+ve$. This makes diode D reverse biased & acts as an open switch. Due to open path, no current flows through the secondary circuit. Hence no output voltage.

3. It is clear from the above that current through RL always flows in one direction, i.e. only during the $+ve$ half cycle. This provides one direction o/p voltage. This o/p is dc.

4. I/P & O/P wave form:



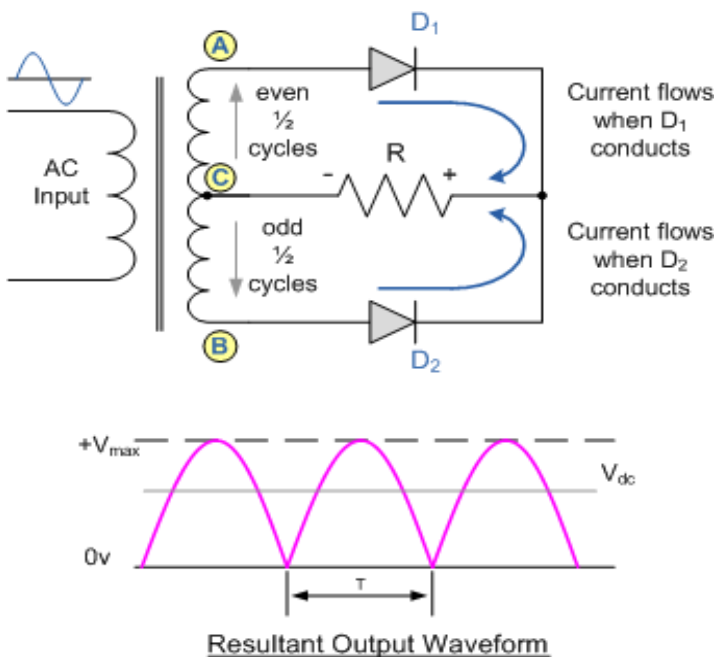
DISADVANTAGES:

- 1- It contains more ripple. Hence requires elaborate filtering.
- 2- Output power is low, because a.c. supply delivers power only half the time.

CENTER-TAPPED FULL WAVE RECTIFIER

It is one type of full wave rectifier, which rectifies both half cycle of ac I/P supply.

Circuit Diagram:



Circuit Detail:

It consists of a center tapped transformer T, two diodes D_1 & D_2 , load resistor R_L . The transformer T transfers the ac input from primer to secondary in step down mode. Diodes D_1 & D_2 used for rectification. The dc output develops across load resistor R_L .

Operation:

1. During the +ve half cycle of ac I/P supply, the terminal A is +ve & B is -v. This makes diode D_1 forward biased & diode D_2 reverse biased. Hence D_1 acts as a closed switch & D_2 as open switch. Due to open switch, no current flows through the lower portion of the secondary circuit. Current only flow only through the upper portion of secondary circuit as shown by solid arrow.
2. During the -ve half cycle of ac input supply terminal A is -ve & terminal B is +ve. This makes diode D_1 reverse biased & diode D_2 forward biased. Hence D_1 acts as open switch & D_2 as closed switch. No current flows through the upper portion of secondary circuit. Current flows only through the lower portion as shown by dotted arrow.
3. It is clear from the above that for both half cycle of ac input, current through R_L flows in same direction i.e. from D to C. This current is dc.

ADVANTAGES:

- 1- requires only two diodes.
- 2- It not requires elaborate filtering.

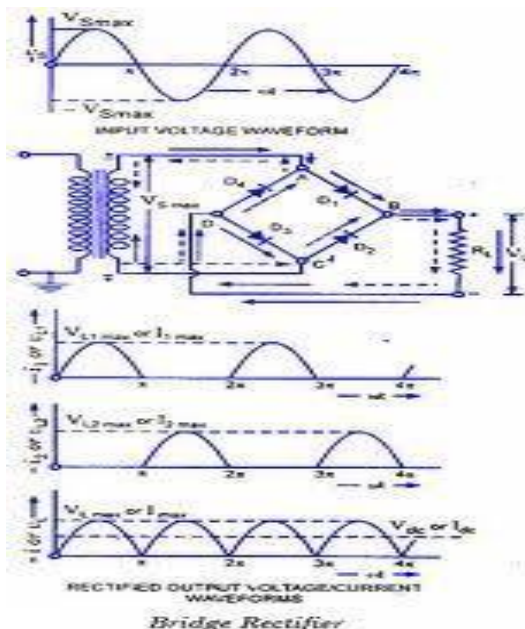
DISADVANTAGES:

- 1- It uses centertapped transformer & It is difficult to locate perfect centertapped on the secondary.
- 2- The dc output is small as each diode utilises only one half of the transformer secondary voltage.
- 3- Requires high PIV diodes.

BRIDGE RECTIFIER:

It is one type of full wave rectifier which rectifies both half cycle of ac input supply.

Circuit Diagram :



Operation:

1. During the +ve half cycle of ac i/p supply terminal A is +ve & terminal B is -ve. This makes diode D1 & D3 forward biased & D2, D4 reverse biased. Hence D1, D3 acts as closed switch but D2, D4 acts as open switch. Current flows through the secondary circuit as shown by solid arrow.
2. During the -ve half cycle of ac input supply, terminal A is -ve & terminal B is +ve. This makes diode D1 & D3 reverse biased & D2, D4 forward biased. Hence D1, D3 acts as open switch & D2, D4 closed switch. Current flows through the secondary circuit as shown by dotted arrow.
3. It is clear that for both half cycle of ac i/p, current through RL flows in same direction i.e. from C to D. This is dc output.

ADVANTAGES:

- 1- No need of centertapped transformer.
- 2- Output is twice that of centertapped circuit for same secondary voltage.
- 3- The PIV is one half of the center-tap circuit.

DISADVANTAGES:

- 1- It requires four diodes.
- 2- Not suitable for small secondary voltage.

AVERAGE /DC VOLTAGE & CURRENT OF RECTIFIER:

*FOR HALF WAVE RECTIFIER:

$$I_{dc}/I_{av} = I_m/\pi$$

$$V_{dc}/V_{av} = V_m/\pi$$

*FOR FULL WAVE RECTIFIER:

$$I_{dc}/I_{av} = 2I_m/\pi$$

$$V_{dc}/V_{av} = 2V_m/\pi$$

RECTIFIER EFFICIENCY :

It is the ratio of dc output power to ac input power of a rectifier.

Mathematically given by : $\eta = P_{dc}/P_{ac}$
In percentage $\eta = (P_{dc}/P_{ac}) \times 100$

Where P_{dc} = DC O/P power
 P_{ac} = AC O/P power

RECTIFIER EFFICIENCY OF HALF WAVE RECTIFIER:

We know for half wave rectifier , $I_{dc}/I_{av} = I_m/\pi$

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

$$P_{dc} = I_{dc}^2 \cdot R_L = (I_m/\pi)^2 R_L$$

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

$$\text{Hence Efficiency, } \eta = P_{dc}/P_{ac} = (I_m/\pi)^2 R_L / (I_m/2)^2 (R_L + r_f) = (4/\pi^2) (R_L / (R_L + r_f)) = (4/\pi^2) (1 / (1 + r_f/R_L)) \\ = 0.405 \times (1 / (1 + r_f/R_L))$$

Since $r_f/R_L \ll 1$, r_f/R_L can be neglected.

Finally, $\eta = 0.405 = 40.5\%$

RECTIFIER EFFICIENCY OF FULL WAVE RECTIFIER:

For full wave rectifier, $I_{dc}/I_{av} = 2I_m/\pi$

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

$$P_{dc} = I_{dc}^2 \cdot R_L = (2I_m/\pi)^2 R_L$$

$$P_{ac} = I_{rms}^2(R_L + r_f) = (I_m/\sqrt{2})^2(R_L + r_f)$$

$$\text{Hence Efficiency, } \eta = P_{dc} / P_{ac} = (2I_m/\pi)^2 R_L / (I_m/\sqrt{2})^2 (R_L + r_f) = (8/\pi^2) (R_L / (R_L + r_f)) = (8/\pi^2) (1 / (1 + r_f/R_L)) = 0.810(1 / (1 + r_f/R_L))$$

Since $r_f/R_L \ll 1$, r_f/R_L can be neglected.

Finally, $\eta = 0.810 = 81\%$

RIPPLE:

The amount of ac component present in rectifier output signal is called ripple.

RIPPLE FACTOR:

The ratio of r.m.s. value of ac component to dc component of rectifier output is called rectifier efficiency.

i.e. ripple factor, $\gamma = I_{ac}/I_{dc}$

Basically the total current is given by: $I_{ac}^2 = I_{rms}^2 + I_{dc}^2$
 $I_{rms} = \sqrt{I_{ac}^2 - I_{dc}^2}$
 $I_{rms}^2 / I_{dc}^2 = (I_{ac}^2 - I_{dc}^2) / I_{dc}^2$
 $\gamma^2 = (I_{ac}/I_{dc})^2 - 1$
 $\gamma = \sqrt{\left(\frac{I_{ac}}{I_{dc}}\right)^2 - 1}$

IMPORTANT TERMS IN DIODE:

*BREAK DOWN VOLTAGE :

>The voltage under reverse bias condition at which current suddenly rises to high value is called break down voltage.

>At breakdown voltage the diode is not behaving as a diode.

>The region over which this occurs is called breakdown region.

>There are two types of breakdown voltage

(a) Avalanche Breakdown Voltage

(b) Zener Breakdown Voltage

*PIV/PRV (Peak Inverse Voltage/Peak Reverse voltage) :

>It is the maximum reverse voltage that can be given to a diode just before entering to the breakdown region.

>It is the maximum safe operating voltage of diode.

*KNEE VOLTAGE:

>It is the minimum forward voltage after which current rises rapidly with voltage.

>Its value is 0.7v for Si & 0.3v for Ge.

COMPARISION BETWEEN AVALANCHE BREAKDOWN & ZENER BREAKDOWN

AVALANCHE BREAKDOWN

- 1- This breakdown occurs due to higher velocity of minority carriers.
- 2- This occurs in a diode with lower doping level.
- 3- It occurs at higher reverse voltage.
- 4- This breakdown is not sharp.
- 5- It occurs in general diode.

ZENER BREAKDOWN

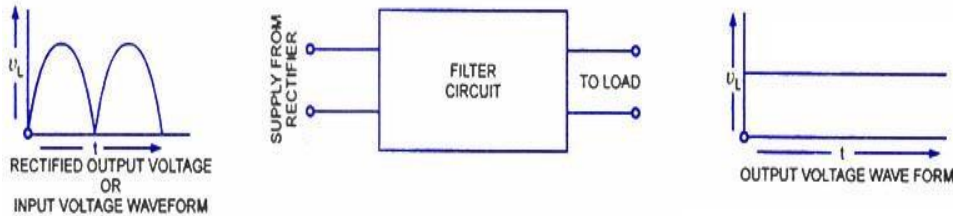
- 1- This occurs due to stronger electric field the diode.
- 2- It occurs in a heavily doped diode.
- 3- It occurs at lower reverse voltage.
- 4- This breakdown is sharp.
- 5- It occurs in zener diode.

CHAPTER-3

FILTER CIRCUITS

FILTER:

- The device which converts pulsating dc to pure dc is called filter.
- Figure:



- Basically consists of capacitors & inductors.

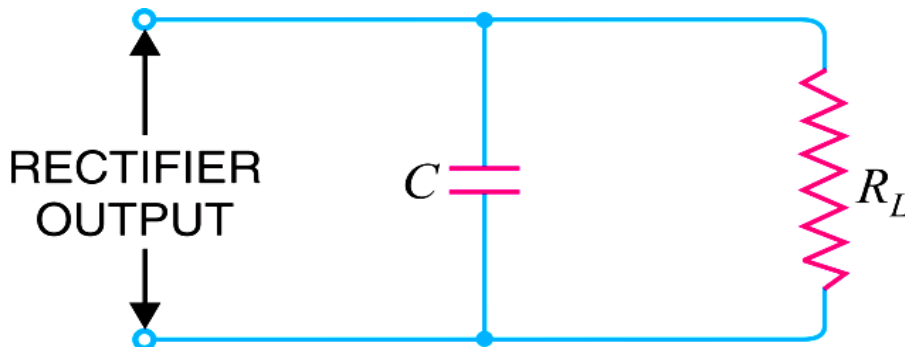
TYPES OF FILTER:

There are three types of filters:

- (a) capacitor filter
- (b) choke input filter
- (c) Pi-filter

CAPACITOR FILTER:

Circuit diagram:



Circuit Detail:

It consists of capacitor C & load resistor R_L . Capacitor C used for filtering purpose. The pure dc output develops across load resistor R_L .

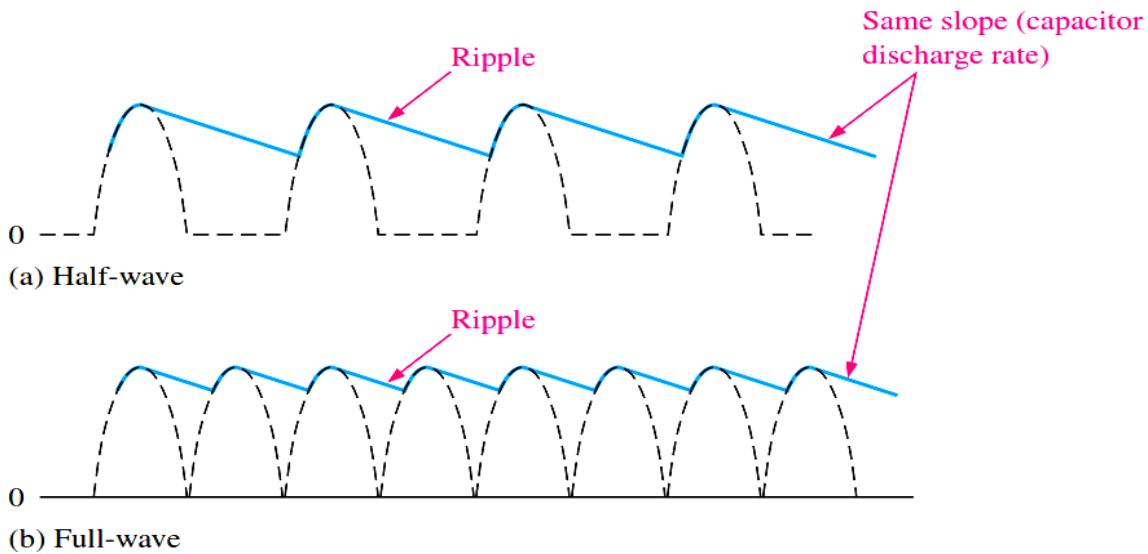
Operation:

- When the pulsating dc is applied input is applied across the input terminal, it produces a pulsating dc current $I = I_{ac} + I_{dc}$.
Where I_{ac} = ac component current

I_{dc} = dc component current

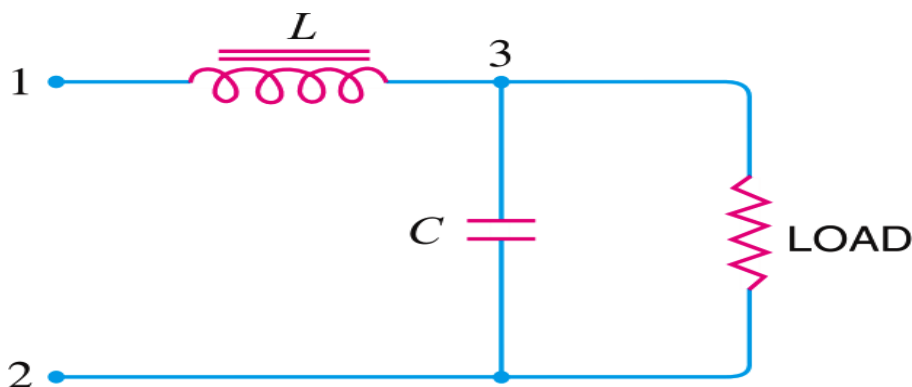
- When this current I face capacitor C , capacitor C opposes the dc component & bypass the ac component through it. As a result the dc component current flows towards load resistor R_L . In this way pulsating dc is converted to pure dc.

➤ Input & output wave form:



CHOKE INPUT FILTER:

Circuit Diagram:



Circuit Detail:

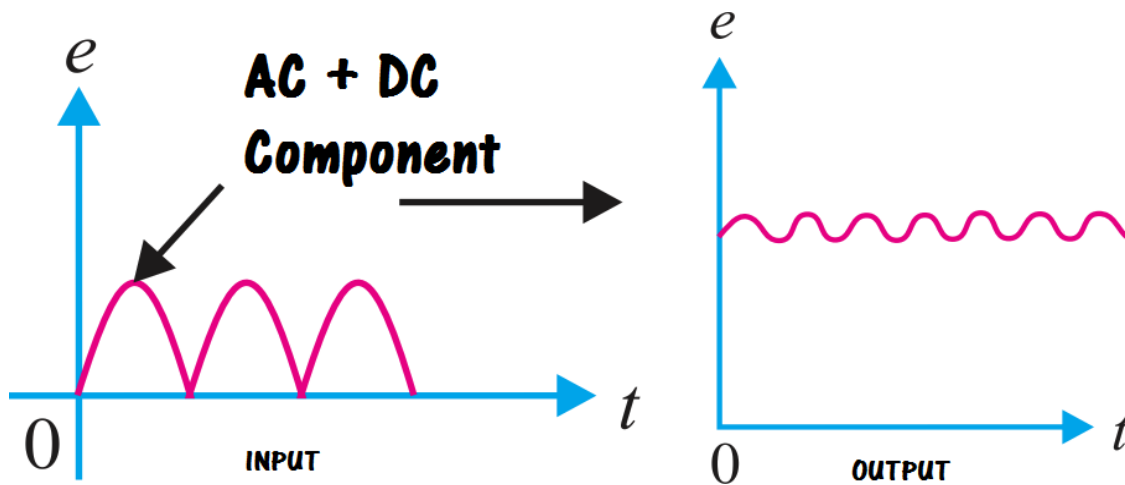
It consists of choke L & capacitor C & load resistor R_L . Choke L & capacitor C used for filtering purpose. The pure dc output develops across load resistor R_L .

Operation:

- When the pulsating dc input is applied across the input, it produces pulsating current $I = I_{ac} + I_{dc}$. This mixing signal when flows through choke L , it opposes blocks ac components & allows through it the dc component. But the choke L can not able to block all the ac components. As a result at the output of the choke we get again dc component with some ac component. The output current of choke when face the capacitor C , the remaining ac component bypasses through it. But the dc component blocked by C . As a result the dc component flows towards load resistor R_L . In this way pulsating dc is converted to pure dc.

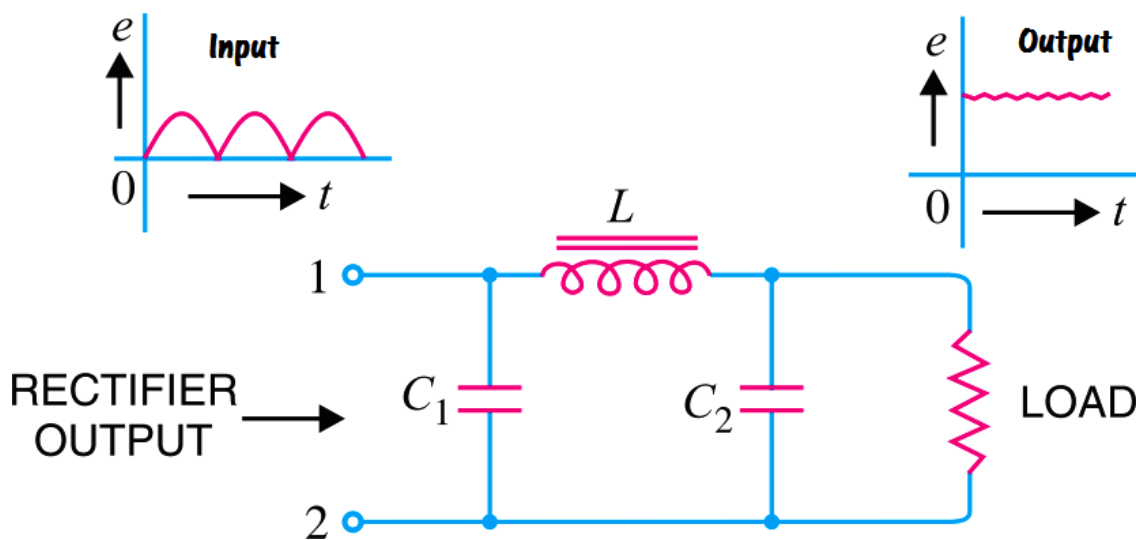
It is clear from the output signal that the variation is less than the capacitor input filter in the output. Hence this filter provides better dc as compared to capacitor input filter.

Input output wave form :



PI-FILTER/CAPACITOR INPUT FILTER:

Circuit Diagram:



Circuit details

It consists of two filter capacitor C_1 & C_2 & choke L . C_1 is connected across the input, choke L in series & capacitor C_2 across the load resistor R_L .

Operation:

- The pulsating DC output from the rectifier output is applied across the input terminal of the filter. First of all input faces the capacitor C_1 .
- The filter capacitor C_1 offers low reactance to a.c. component of rectifier output & infinite reactance to DC component. Hence C_1 bypasses some amount of ac component & dc components flows towards the choke L .

- The choke L offers high reactance to the ac component & almost zero reactance to the dc component. Hence it allows the dc component to flow through it & blocks the ac component not able to be bypassed by C_1 .

CHAPTER-4

Bipolar Junction Transistor

TRANSISTOR:

The electronic device in which a dissimilar type of semiconductor material is sandwiched between two similar type of semiconductor is called transistor.

In this either a p-type is sandwiched between two n-type or an n-type is sandwiched between two p-type material.

Transistor consists of two words: transistor. Trans means the signal transfer property of the device & istor means resistor property of the device.

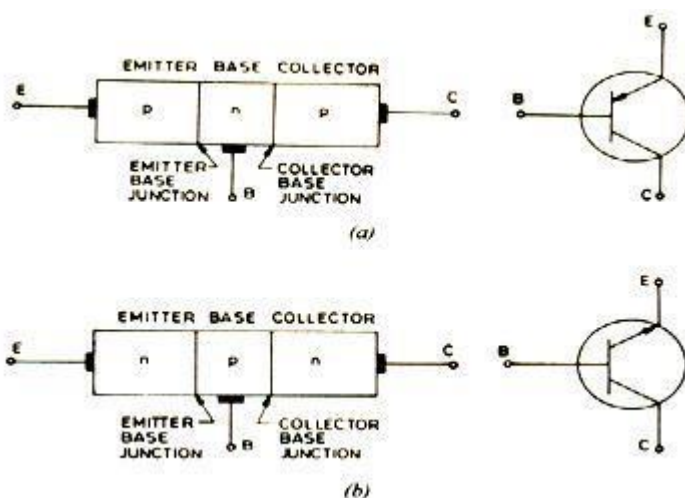
A transistor transfers a signal from a low resistance to high resistance.

TYPES OF TRANSISTOR:

There are two types of transistors:

- a) n-p-n transistor
- b) p-n-p transistor

- Structure & Symbol:



- It has three terminals, one taken from each type of semiconductor. The terminals are named as base(B), emitter(E), collector(C).
- It has two pn-junction & three semiconductor layers.

TERMINALS OF TRANSISTOR:

It has three terminals, named as base, emitter & collector. The two end terminals are known as emitter(E) & collector(C), middle is called as base.

Emitter:

- a) This layer provides charge carriers.
- b) It is always forward biased w.r.t. base.
- c) It is wider than base.
- d) It is heavily doped. Hence it provides large numbers of charge carriers into base.

Base:

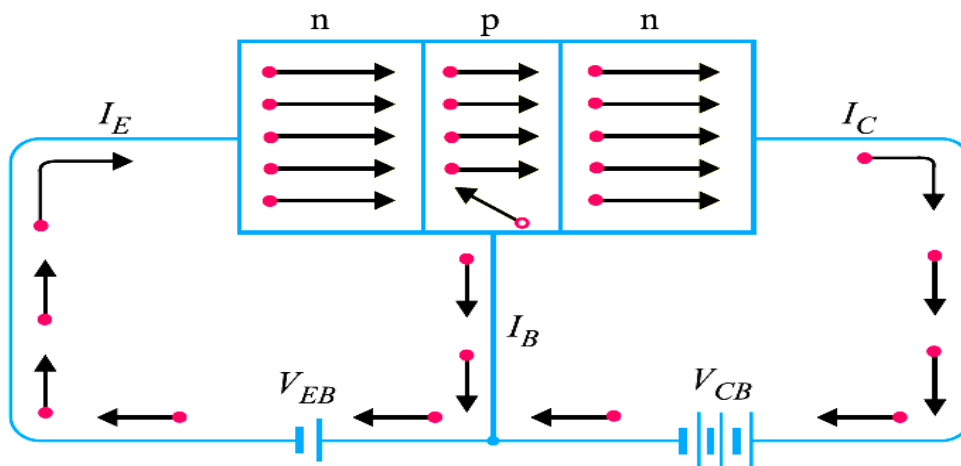
- a) This layer controls the amount of charge carrier flow from emitter to collector.
- b) It is forward connected w.r.t. emitter & reverse biased w.r.t. collector.
- c) It is much thinner than emitter.
- d) It is lightly doped. Hence it passes most of the charge carriers coming from emitter to collector.

Collector:

- a) This layer removes charges from its junction with the base.
- b) It is reverse biased w.r.t. base.
- c) It is wider than emitter & base.
- d) It is moderately doped.

WORKING PRINCIPLE OF NPN TRANSISTOR:

*Figure shows the circuit for showing the working principle.



Basic connection of *npn* transistor

*For proper operation of transistor, base emitter junction is forward biased by V_{EB} & base-collector is reverse biased by V_{CB} .

*The n-type emitter has majority free electrons. The forward bias on emitter, causes the free electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E .

*When the free electrons flow through p-type base, they try to combine with majority holes in base region. Since the base is lightly doped & very thin, only a few electrons combine with holes & constitute base current I_B .

*The remaining free electrons flow towards the collector attracted by strong positive terminal of the biasing supply $+V_{CC}$. This constitutes the collector current I_C .

*It is clear that almost the entire emitter current flows in the collector circuit. Hence emitter current is the sum of collector & base current i.e.

$$I_E = I_B + I_C$$

*The current conduction within the transistor is due to free electrons & also through the external circuit is due to free electrons.

*For proper operation of transistor, base emitter junction is forward biased by V_{EE} & base-collector is reverse biased by V_{CC} .

*The p-type emitter has majority holes. The forward bias on emitter, causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current I_E .

*When the holes flow through n-type base, they try to combine with majority free electrons in base region. Since the base is lightly doped & very thin, only a few holes combine with free electrons & constitute base current I_B .

*The remaining holes flow towards the collector attracted by strong negative terminal of the biasing supply $-V_{CC}$. This constitutes the collector current I_C .

*It is clear that almost the entire emitter current flows in the collector circuit. Hence emitter current is the sum of collector & base current i.e.

$$I_E = I_B + I_C$$

*The current conduction within the transistor is due to holes & through the external circuit is due to free electrons.

TRANSISTOR CONNECTION:

There are three types of connections:

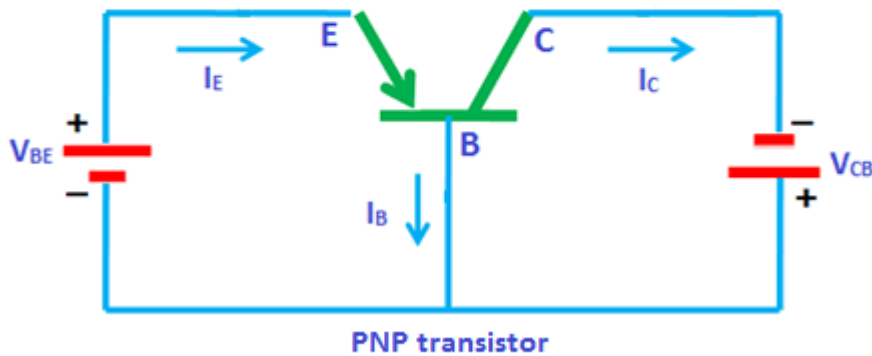
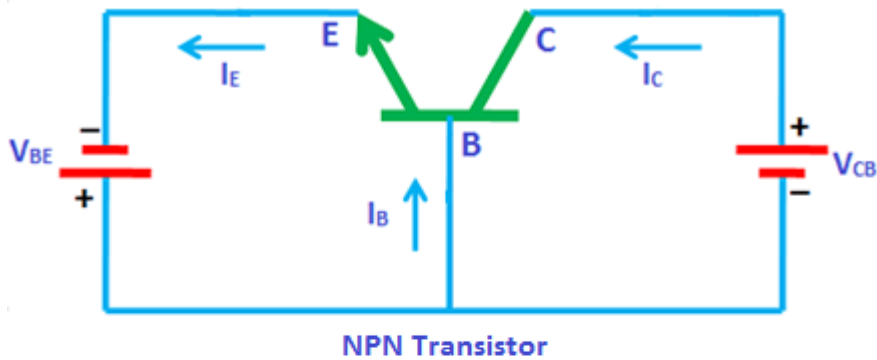
- a) Common-Base Connection(CB)
- b) Common-Emitter Connection(CE)
- c) Common-Collector Connection(CC)

COMMON-BASE CONNECTION:

* The transistor connection in which base is common for both input & output circuit is called common-base connection.

*In this input is applied between emitter & base & output is taken from collector & base.

*Circuit Diagram:



Common base configuration

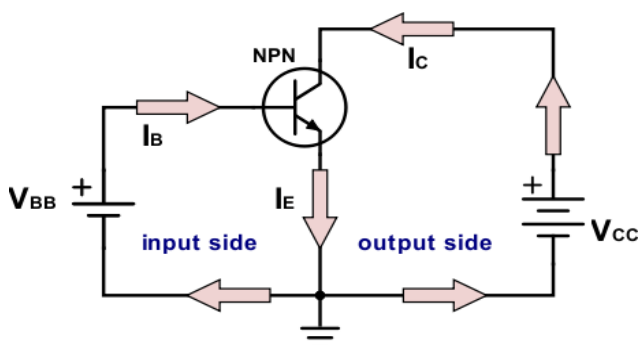
*D.C. supply V_{EE} provides forward biasing & V_{cc} provides reverse biasing.

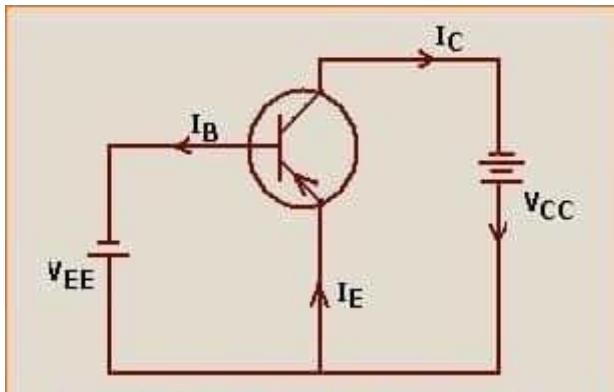
COMMON-EMITTER CONNECTION

* The transistor connection in which emitter is common for both input & output circuit is called common-emitter connection.

*In this input is applied between emitter & base & output is taken from collector & emitter.

*Circuit Diagram:





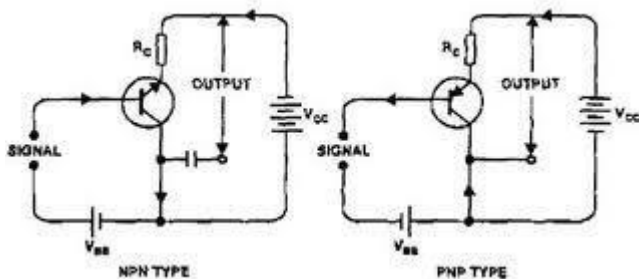
*D.C. supply V_{BB} provides forward biasing & V_{CC} provides reverse biasing.

COMMON-COLLECTOR CONNECTION:

* The transistor connection in which collector is common for both input & output circuit is called common-collector connection.

*In this input is applied between base & collector & output is taken from collector & emitter.

*Circuit Diagram:



*D.C. supply V_{BB} provides forward biasing across base to collector & V_{CC} provides reverse biasing across emitter to collector.

CURRENT AMPLIFICATION FACTOR IN COMMON BASE CONNECTION(α):

*The ratio between change in collector current to change in emitter current at constant collector to base voltage V_{CB} is called current amplification factor α .

*Mathematically, $\alpha = \Delta I_C / \Delta I_E$ at constant V_{CB}

*Its value is less than unity. Practical values of α ranges from 0.9 to 0.99.

CURRENT AMPLIFICATION FACTOR IN COMMON EMITTER (β):

*The ratio between change in collector current to change in base current at constant collector to emitter voltage V_{CE} is called current amplification factor β .

*Mathematically, $\beta = \Delta I_C / \Delta I_B$ at constant V_{CE}

*Its value is greater than 20. Practical values of β ranges from 20 to 500.

CURRENT AMPLIFICATION FACTOR IN COMMON COLLECTOR(Y)

*The ratio between change in emitter current to change in base current at constant collector to emitter voltage V_{CE} is called current amplification factor β .

*Mathematically, $Y = \Delta I_E / \Delta I_B$ at constant V_{CE}

*Its value is greater than 20. Practical values of β ranges from 20 to 500 i.e. same as common emitter value.

RELATION BETWEEN α & β :

We know $\beta = \Delta I_C / \Delta I_B$ (1)

$$\alpha = \Delta I_C / \Delta I_E \text{ (2)}$$

$$I_E = I_B + I_C$$

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

$$\text{Hence } \Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the values of ΔI_B in equation (1), we get,

$$\beta = \Delta I_C / \Delta I_E - \Delta I_C \text{ (3)}$$

Dividing both numerator & denominator by ΔI_E of R.H.S. in eqn.(3),

$$\beta = (\Delta I_C / \Delta I_E) / (\Delta I_E / \Delta I_E) - (\Delta I_C / \Delta I_E) = \alpha / (1 - \alpha)$$

$$\beta = \alpha / 1 - \alpha$$

RELATION BETWEEN γ & α :

We know

$$\gamma = \Delta I_E / \Delta I_B \text{ (4)}$$

$$\alpha = \Delta I_C / \Delta I_E \text{ (5)}$$

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

$$\text{Hence } \Delta I_B = \Delta I_E - \Delta I_C$$

Substituting the value of ΔI_B in eqn. (4),

$$\gamma = \Delta I_E / \Delta I_B = \Delta I_E / \Delta I_E - \Delta I_C \text{ (6)}$$

Dividing both numerator & denominator by ΔI_E of eqn. (6),

$$\gamma = \Delta I_E / \Delta I_B = (\Delta I_E / \Delta I_E) / (\Delta I_E / \Delta I_E) - (\Delta I_C / \Delta I_E) = 1 / 1 - \alpha$$

$$\gamma = 1 / 1 - \alpha$$

RELATION BETWEEN α , β & γ :

We know

$$\alpha = \Delta I_C / \Delta I_E \text{ (7)}$$

$$\beta = \Delta I_C / \Delta I_B \text{ (8)}$$

$$\gamma = \Delta I_E / \Delta I_B \text{ (9)}$$

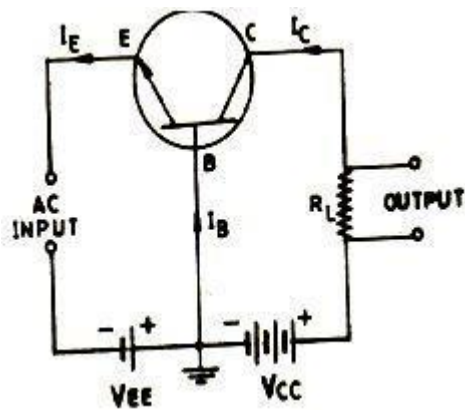
Multiplying $\Delta I_E / \Delta I_E$ in R.H.S. of eqn. (8),

$$\beta = (\Delta I_C / \Delta I_B) \times (\Delta I_E / \Delta I_E) = (\Delta I_C / \Delta I_E) \times (\Delta I_E / \Delta I_B) = \alpha \cdot \gamma$$

$$\beta = \alpha \cdot \gamma$$

COMMON BASE TRANSISTOR AMPLIFIER:

*Circuit diagram



***Circuit Details:**

It consists of transistor Q, load resistor R_L , biasing supply V_{EE} & V_{CC} .

Transistor Q used for amplification. Amplified output develops across load resistor R_L .

V_{EE} provides proper forward biasing across emitter to base.

V_{CC} provides proper reverse biasing across collector to base.

V_i is the input supply to be amplified.

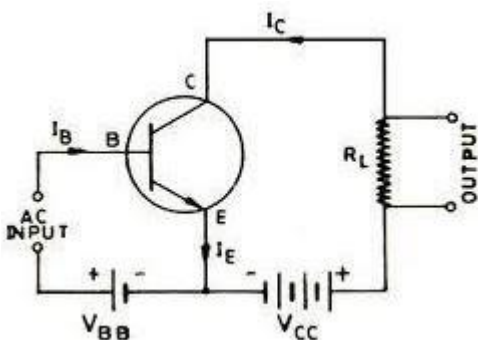
V_o is the amplified output.

***Circuit operation:**

When the input signal to be amplified is applied across the emitter to base, for a small change in input we get a large change in output current. This large change in current when flows through a high load resistance R_L , produces a large voltage drop across R_L . Now if we compare the input voltage & output voltage, output is more than the input. In this way we get amplified output.

COMMON EMITTER AMPLIFIER:

***Circuit diagram:**



***Circuit details:**

It consists of transistor Q, load resistor R_L , biasing supply V_{BB} & V_{CC} .

Transistor Q used for amplification. Amplified output develops across load resistor R_L .

V_{BB} provides proper forward biasing across emitter to base.

V_{CC} provides proper reverse biasing across collector to emitter.

V_i is the input supply to be amplified.

V_o is the amplified output.

*Operation:

1) During the positive half cycle of the input signal, forward bias across the emitter-base junction is increased. Hence more electrons flow from the emitter to the collector through the base. This causes an increase in collector current. The increased collector current when flows through a high load resistance R_L , produces high voltage drop.

2) During the negative half cycle of the input signal, the forward bias across emitter-base junction is decreased. Hence collector current decreases. This decreased collector current when flows through load resistance, produces decreased output voltage in opposite direction. Hence an amplified output is obtained across the load.

V-I CHARACTERISTIC OF COMMON BASE TRANSISTOR CONNECTION:

Two types of V-I characteristic,

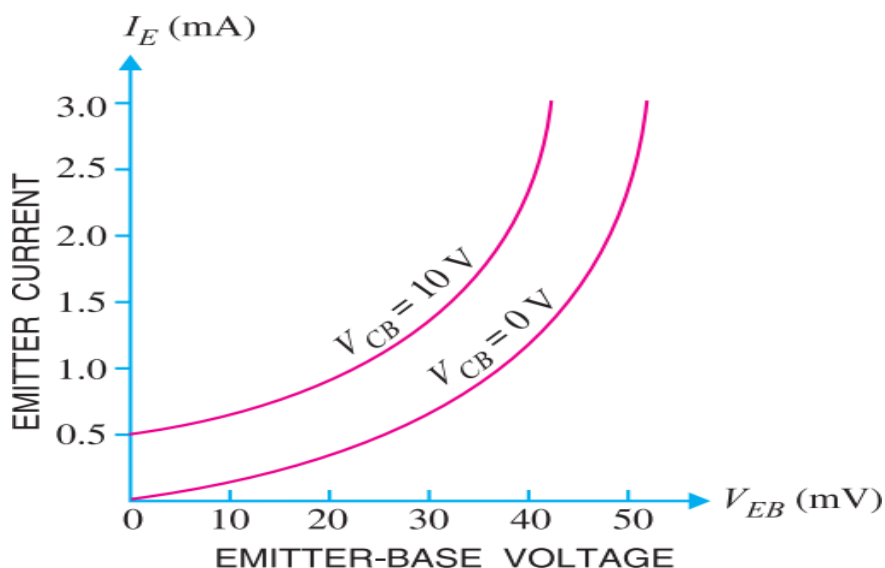
- Input V-I characteristic
- Output V-I characteristic

INPUT V-I CHARACTERISTIC OF CB:

*The graph which shows the relation between emitter current I_E & emitter-base voltage V_{EB} at constant collector-base voltage V_{CB} is called input characteristic.

* V_{EB} is taken along x-axis & I_E is taken along y-axis.

*Graph:



*It is clear from the graph that , emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB} .

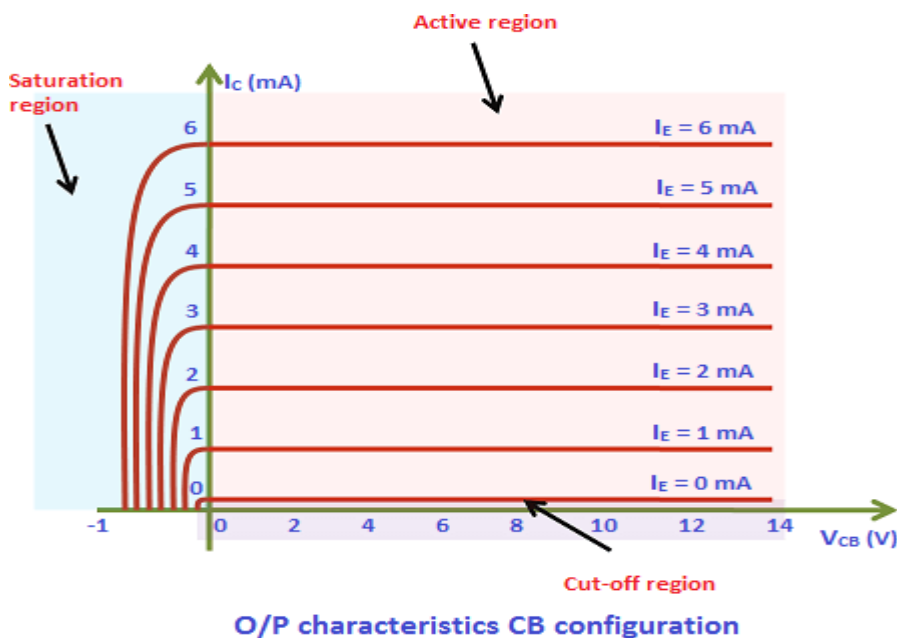
*The emitter current is almost independent of collector-base voltage V_{CB} .

OUTPUT V-I CHARACTERISTIC OF CB:

*The graph which shows the relation between collector current I_c & collector-base voltage V_{CB} at constant emitter current I_E is called output characteristic.

* V_{CB} is taken along x-axis & I_c is taken along y-axis.

*Graph:



*It is clear from the graph that,

- Collector current I_c varies with V_{CB} only at very low voltage (< 1 V).
- For V_{CB} greater than 1 V, collector current remains constant.
- A very large change in collector-base voltage produces only a small change in collector current.

V-I CHARACTERISTIC OF COMMON-EMITTER CONNECTION:

There are two types of V-I characteristic:

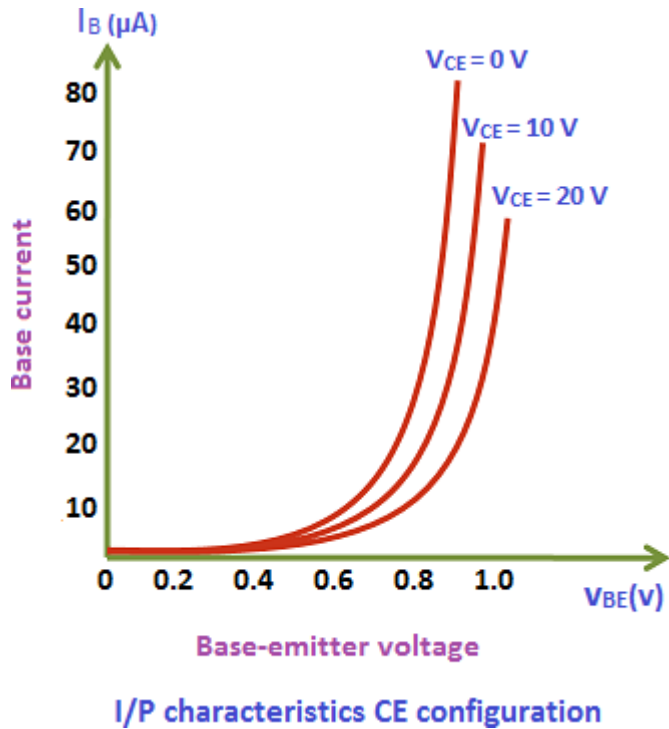
- 1) Input V-I Characteristic
- 2) Output V-I characteristic

INPUT V-I CHARACTERISTIC OF CE:

*The graph which shows the relation between base current I_B & base-emitter voltage V_{BE} at constant collector emitter voltage V_{CE} is called input characteristic.

* V_{BE} is taken along x-axis & I_B is taken along y-axis.

*Graph:



*It is clear from the graph that,

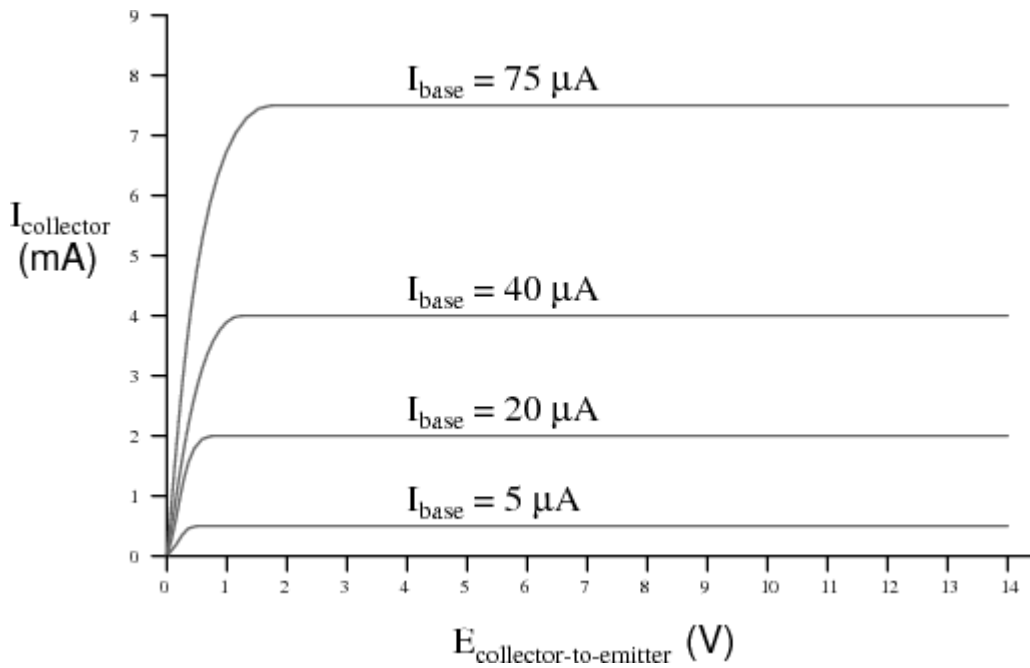
- The characteristic is similar to characteristic of forward biased pn-junction.
- At first current I_B increases very slowly. After certain voltage known as knee voltage, the current increases rapidly.

OUTPUT V-I CHARACTERISTIC OF CE:

*The graph which shows the relation between collector current I_c & collector-emitter voltage V_{CE} at constant base current I_B is called output characteristic.

* V_{CE} is taken along x-axis & I_c is taken along y-axis.

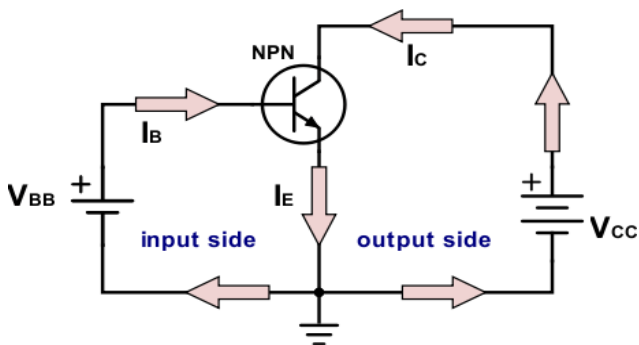
*Graph:

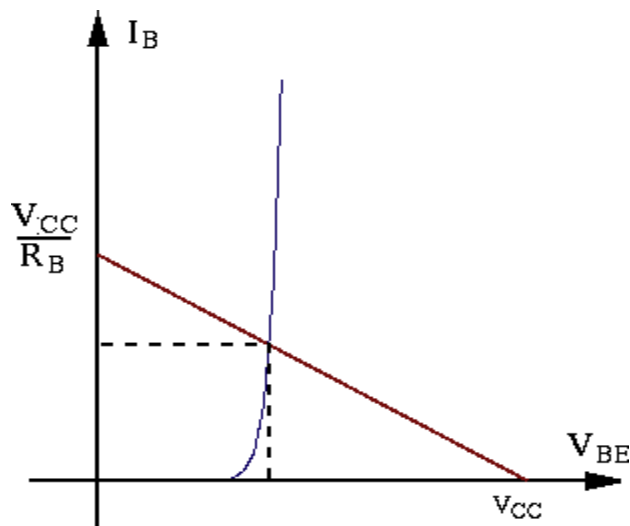


- It is clear from the graph that,
 - a) Collector current I_C varies with V_{CE} only at very low voltage ($< 1V$).
 - b) For V_{CE} greater than $1V$, collector current remains constant.
 - c) A very large change in collector-emitter voltage produces only a small change in collector current.

TRANSISTOR DC LOAD LINE:

- It is a method of measuring collector current I_C for different values of collector-emitter voltage accurately.
- Circuit for getting dc load line:





➤ Applying output KVL:

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

$$V_{CE} = V_{CC} - I_C R_C \dots \dots \dots (10)$$

This equation is in the form of a straight line. Hence its graph is a straight line & can be drawn on output characteristics. The graph can be drawn as follows:

a) If $I_C = 0$, then equation (10) is: $V_{CE} = V_{CC}$

This forms the coordinate $(V_{CE}, I_C) = (V_{CC}, 0)$. This point is indicated by the point A on V_{CE} axis.

b) Putting $V_{CE} = 0$ in eqn. (10):

$$0 = V_{CC} - I_C R_C$$

$$\text{i.e. } I_C = V_{CC} / R_C$$

This forms the coordinate $(V_{CE}, I_C) = (0, V_{CC} / R_C)$. This point is indicated by the point B on I_C axis.

By joining the points A & B, the straight line AB is called dc load line.

OPERATING POINT:

- The zero signal values of collector current I_C & collector –emitter voltage V_{CE} is called operating point.
- The intersection of output V-I characteristic & dc load line is also called operating point.
- Also named as Q-point or quiescent point.

S. No.	Characteristic	Common base	Common emitter	Common collector
1.	Input resistance	Low (about 100 Ω)	Low (about 750 Ω)	Very high (about 750 k Ω)
2.	Output resistance	Very high (about 450 k Ω)	High (about 45 k Ω)	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

CHAPTER-5

TRANSISTOR BIASING

Transistor biasing:

- The proper flow of zero signal collector current & the maintenance of proper collector-emitter voltage during the passage of signal is called as transistor biasing.
- The purpose of biasing is to make base-emitter junction properly forward biased & collector-base junction reverse biased during the application of signal.

STABILISATION:

- The process of making operating point independent of temperature changes or variation in transistor parameters is known as stabilisation.

NEED OF STABILISATION:

Stabilisation of the operating point is necessary due to the following reasons:

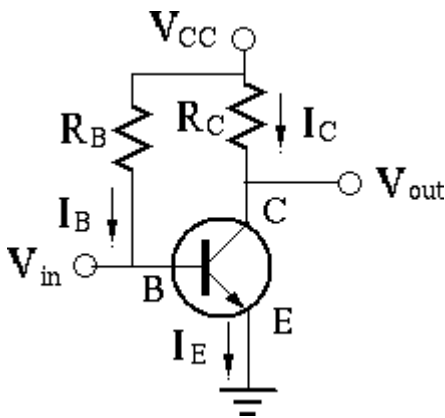
- a) Temperature dependence of I_C .
- b) Individual variations.
- c) Thermal runaway.

METHODS OF TRANSISTOR BIASING:

- a) Base resistor method
- b) Emitter bias method
- c) Feedback resistor method
- d) Voltage divider bias method

BASE RESISTOR METHOD:

- Circuit diagram:



- Circuit detail:

In this method a high resistance R_B is connected between the base & +ve end of supply for npn transistor & between base & negative end of supply for pnp transistor. This provides the input biasing.

$+V_{CC}$ is the biasing supply. R_C is the collector load.

- Circuit Analysis:

The required zero signal base current is provided by $+V_{CC}$ & it flows through R_B . This makes base terminal positive & produces proper forward biasing across base-emitter junction. The proper zero signal base current I_B & also collector current I_C depends on proper value of base

resistor R_B .

$$I_C = \beta I_B$$

Applying input KVL,

$$V_{CC} = I_B R_B + V_{BE}$$

$$R_B = (V_{CC} - V_{BE}) / I_B$$

Advantages:

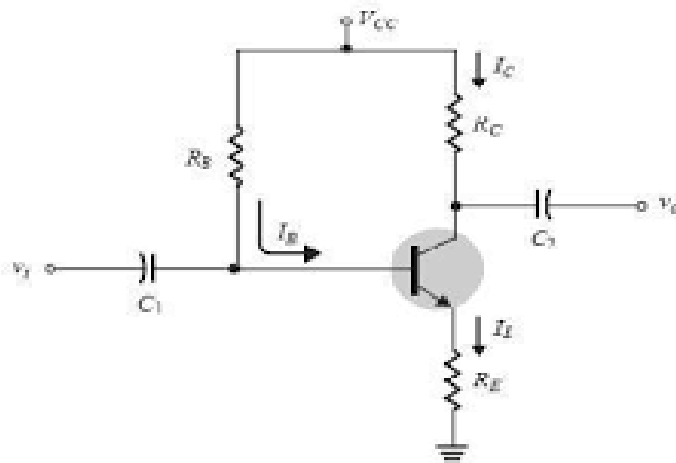
- 1- The circuit is very simple.
- 2- Requires simple calculations.
- 3- There is no loading of the source, because no resistor is employed across base-emitter junction.

Disadvantages:

- 1- This method provides poor stabilization.
- 2- This method is less stable.
- 3- There is a chance of thermal runaway.

Emitter-Biasing

Circuit diagram:



➤ Circuit detail:

In this method a high resistance R_B is connected between the base & +ve end of supply for npn transistor & between base & negative end of supply for pnp transistor. This provides the input biasing.

$+V_{CC}$ is the biasing supply. R_C is the collector load. R_E is the emitter resistor & it provides stabilization

➤ Circuit analysis:

The required zero signal base current is provided by $+V_{CC}$ & it flows through R_B . This makes base terminal positive & produces proper forward biasing across base-emitter junction. The proper zero signal base current I_B & also collector current I_C depends on proper value of base resistor R_B .

$$I_C = \beta I_B$$

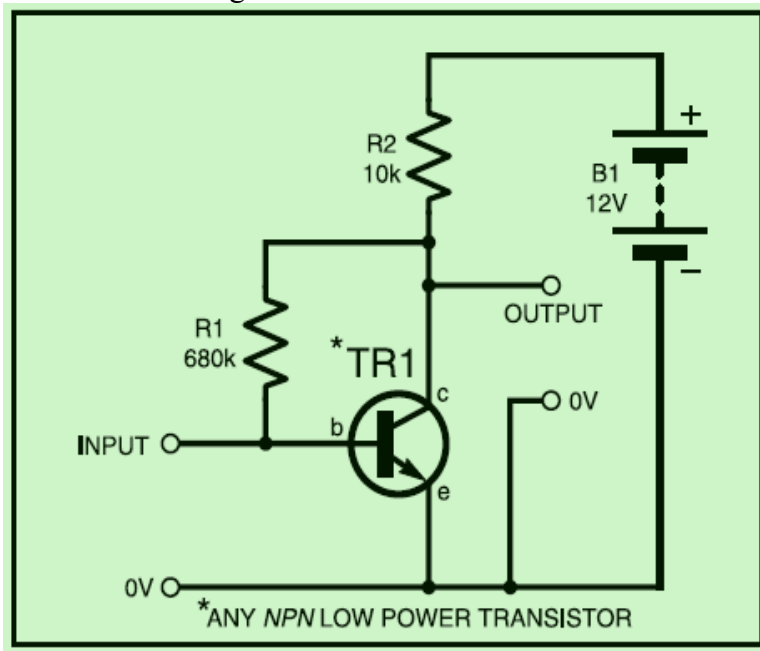
Applying input KVL,

$$V_{CC} = I_B R_B + V_{BE} + I_E R_E = I_B R_B + V_{BE} + (\beta + 1) I_B R_E = I_B R_B + V_{BE} + \beta I_B R_E$$

$$I_B = (V_{CC} - V_{BE}) / (R_B + R_E)$$

FEEDBACK RESISTOR METHOD:

➤ Circuit diagram:



➤ Circuit Details:

In this method a high resistance R_B is connected between the base & collector of transistor. This provides the input biasing.

$+V_{CC}$ is the biasing supply. R_C is the collector load.

➤ Circuit analysis:

The required zero signal base current is provided by collector-base voltage V_{CB} but not by $+V_{CC}$ & it flows through R_B . This makes base terminal positive & produces proper forward biasing across base – emitter junction. The proper zero signal base current I_B & also collector current I_C depends on proper value of base resistor R_B .

$$I_C = \beta \cdot I_B$$

Applying input KVL,

$$V_{CC} = (I_C + I_B)R_C + I_B R_B + V_{BE}$$

$$R_B = (V_{CC} - V_{BE} - I_C R_C) / I_B$$

ADVANTAGES:

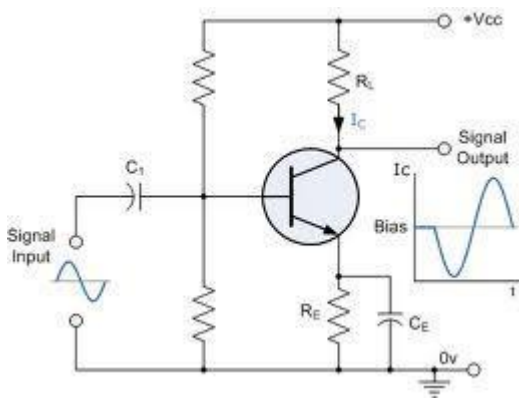
- 1- It is a simple method.
- 2- It provides better stabilization than fixed bias method.

DISADVANTAGES:

- 1- This circuit does not provide good stabilization.
- 2- It provides negative feedback which reduces the gain of amplifier.

VOLTAGE DIVIDER METHOD OF BIASING:

➤ Circuit diagram:



➤ Circuit details:

In this a single battery supply V_{CC} is used to provide biasing to both input & output side. Resistor R_1 - R_2 provides proper forward biasing to base. Biasing supply V_{CC} provides directly biasing to collector. Emitter resistance R_E used for biasing & stabilization. Emitter bypass capacitor C_E bypasses the a.c. component of emitter current.

➤ Circuit analysis:

In this $V_2 = (V_{CC}/R_1 + R_2) \times R_2$

$$V_{BE} = V_2 - I_E R_E$$

$$I_E = (V_2 - V_{BE}) / R_E$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E)$$

CHAPTER-6

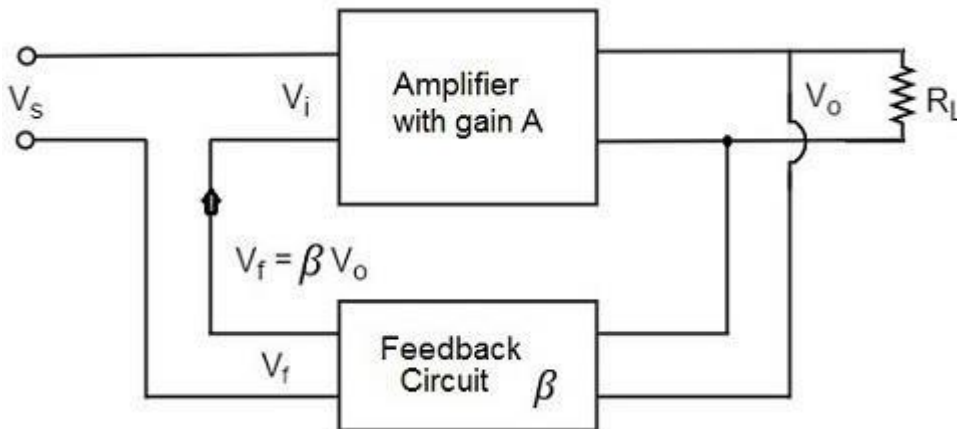
FEEDBACK AMPLIFIER

FEED BACK:

The process of applying a fraction of output energy of some device back to the input is known as feedback.

FEEDBACK AMPLIFIER:

The amplifier using feed back process is called feedback amplifier.



TYPES OF FEEDBACK AMPLIFIER:

There are two types of feedback amplifier:

- Positive feedback amplifier
- Negative feedback amplifier

POSITIVE FEEDBACK AMPLIFIER:

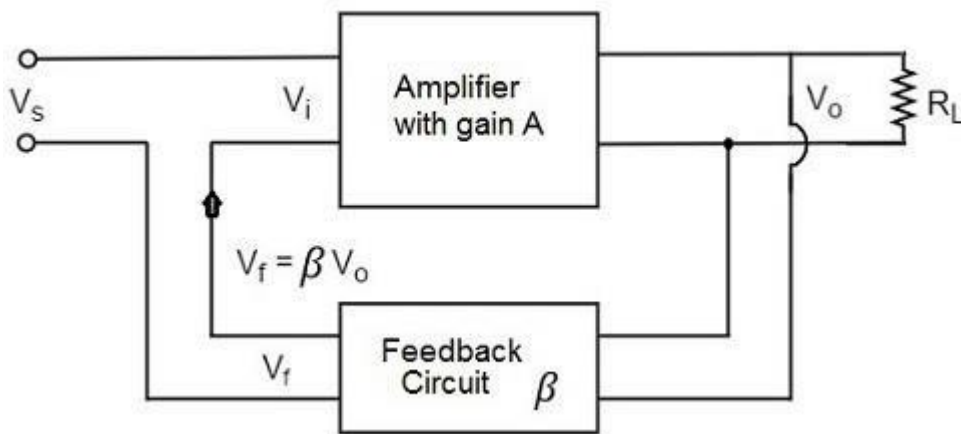
- The amplifier in which feedback energy is applied in the same polarity or in same phase is called as positive feedback amplifier.
- It increases the voltage gain of amplifier.
- In this distortion is more.
- It has increased instability.
- It seldom used as an amplifier. Mostly used in oscillator.

NEGATIVE FEEDBACK AMPLIFIER:

- The amplifier in which feedback energy is applied in the opposite polarity or out of phase with input is called negative feedback amplifier.
- It decreases the voltage gain.
- In this distortion is less.
- It is more stable.
- It is mostly used as an amplifier.

PRINCIPLE OF NEGATIVE FEEDBACK AMPLIFIER:

- Block diagram of negative feedback amplifier:



➤ A = Voltage gain without feedback.

A_f = voltage gain with feedback.

V_s = Input signal to be amplified.

V_o = Output signal of amplifier

V_i = Actual input signal to the amplifier.

V_f = Feedback signal applied to input side.

β = feedback fraction

➤ From block diagram it is clear that,

$$\beta = V_f / V_o \text{ i.e. } V_f = \beta V_o$$

$$V_i = V_s - V_f = V_s - \beta V_o$$

$$\text{Again } A = V_o / V_i \text{ i.e. } V_o = A V_i = A(V_s - \beta V_o)$$

$$\text{i.e. } V_o = A V_s - A \beta V_o$$

$$\text{i.e. } V_o + A \beta V_o = A V_s$$

$$\text{i.e. } V_o(1 + \beta A) = A V_s$$

$$V_o / V_s = A / (1 + \beta A)$$

$$A_f = A / (1 + \beta A)$$

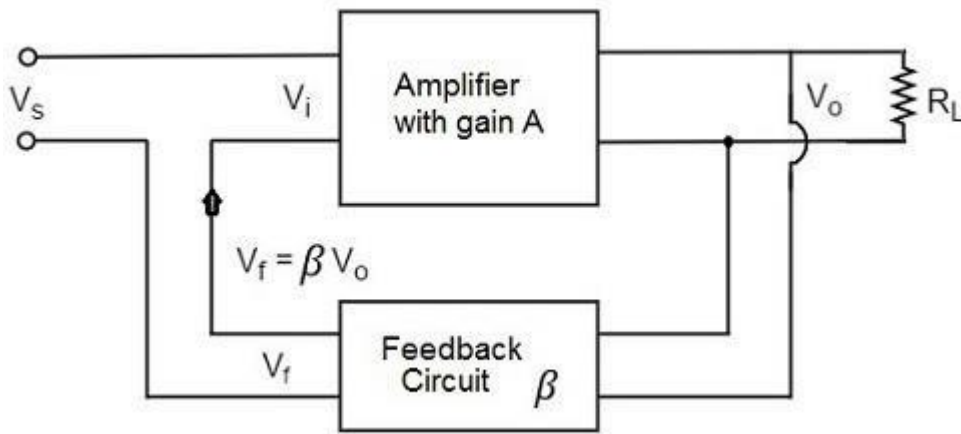
It is clear that voltage gain with feedback decreases by a factor $(1 + \beta A)$.

ADVANTAGES OF NEGATIVE FEEDBACK AMPLIFIER:

- Resultant gain is independent of transistor parameters or supply voltage fluctuation. Hence gain is stable.
- It reduces non-linear distortion by a factor $(1 + \beta A)$.
- It improves frequency response.
- It increases circuit stability.
- It increases input impedance & decreases output impedance.

INPUT IMPEDANCE & OUTPUT IMPEDANCE WITH FEEDBACK:

- Figure shows the block diagram:



➤ Given that:

A = Voltage gain without feedback.

A_f = voltage gain with feedback.

V_s = Input signal to be amplified.

V_o = Output signal of amplifier

V_i = Actual input signal to the amplifier.

V_f = Feedback signal applied to input side.

β = feedback fraction

Z_i = input impedance without feedback = V_i/i_i

Z_{if} = Input impedance with feedback = V_s/i_i

Z_o = Output impedance without feedback

Z_{of} = Output impedance with feedback

i_i = input current

➤ From block diagram it is clear that

$$V_i = V_s - \beta V_o = i_i Z_i$$

$$\text{Now } V_s = (V_s - \beta V_o) + \beta V_o = (V_s - \beta V_o) + \beta A(V_s - \beta V_o) = (V_s - \beta V_o)(1 + \beta A) = i_i Z_i(1 + \beta A)$$

$$\text{Or } V_s/i_i = Z_i(1 + \beta A)$$

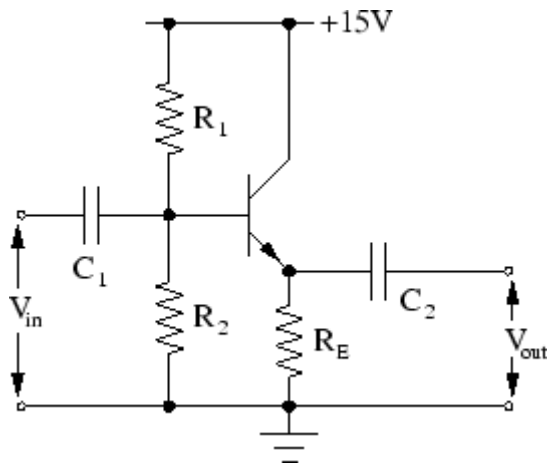
It is clear that input impedance with feedback increases by a factor $(1 + \beta A)$.

Similarly, it can be derived that output impedance without feedback decreases by a factor $(1 + \beta A)$.

$$\text{i.e. } Z_{of} = Z_o/(1 + \beta A)$$

EMITTER FOLLOWER:

- It is a current amplifier that has no voltage gain.
- It is a negative current feedback circuit.
- It has high input impedance & low output impedance.
- It is used for impedance matching.
- It is also known as common collector amplifier.
- Circuit diagram:



➤ Circuit details:

It consists of transistor Q, biasing resistor R_1 & R_2 , emitter resistor R_E , input coupling capacitor C_{in} , biasing supply $+V_{CC}$, output coupling capacitor C_C . Emitter resistance R_E acts as the load & a.c. output voltage V_o is taken across R_E . Here biasing is provided by voltage divider method. It has no collector resistance & no emitter bypass capacitor.

➤ Operation:

The input voltage to be amplified is applied across the base & emitter. The resulting ac emitter current produces an output voltage across R_E . This voltage opposes the input voltage, thus providing negative feedback.

The output voltage V_o is equal to input voltage i.e. output voltage follows the input voltage. Hence the name is voltage follower.

CHARACTERISTIC OF EMITTER FOLLOWER:

- No voltage gain. Practically close to one.
- It has high current gain & power gain.
- It has high input impedance & low output impedance.
- Input & output ac voltages are in phase.

CHAPTER-7

MULTISTAGE AMPLIFIER

MULTISTAGE AMPLIFIER:

- When more than one stage of amplifier is connected in series then the resulting amplifier is called multistage amplifier or cascade amplifier.
- In this output of one stage acts as the input of next stage.

GAIN OF MULTISTAGE AMPLIFIER:

Suppose we consider a three stage amplifier.

A_{v1} = Gain of first stage

A_{v2} = Gain of second stage

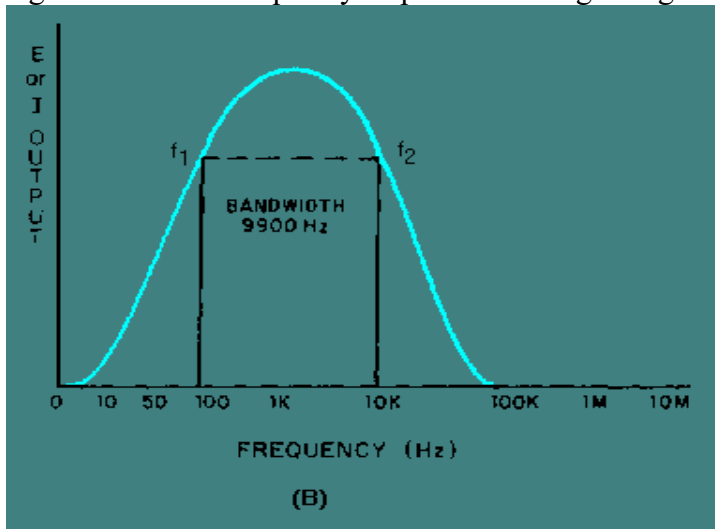
A_{v3} = Gain of third stage

Then the total voltage gain, known as overall voltage gain is given by; $A_v = A_{v1} \cdot A_{v2} \cdot A_{v3}$

FREQUENCY RESPONSE:

The graph which shows the relation between voltage gain & frequency of an amplifier is called frequency response.

Figure shows the frequency response of a single stage amplifier.



A_o = maximum gain of amplifier

f_o = resonant frequency

f_1 = lower cutoff frequency

f_2 = higher cutoff frequency

BANDWIDTH:

The difference between higher cutoff frequency & lower cutoff frequency is called bandwidth.

i.e. $BW = f_2 - f_1$

Its unit is Hz.

SPECIAL UNIT OF GAIN:

Special unit is decibel(db) or bel. One bel = 10 decibel.

There are three types of gain ;

(a) Voltage gain, $A_v = V_o/V_i = 20\log_{10} A_v$ in db

(b) Current gain, $A_i = I_o/I_i = 20\log_{10} A_i$ in db

(c) Power gain, $A_p = P_o/P_i = 10\log_{10} A_p$ in db

TYPES OF MULTISTAGE AMPLIFIER:

There are three types of multistage amplifier:

(a) RC-Coupled Amplifier

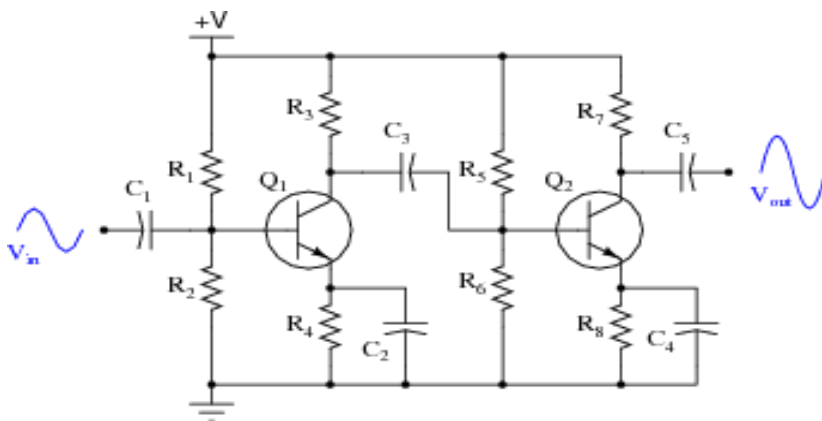
(b) Transformer Coupled Amplifier

(c) Direct coupled amplifier

RC-COUPLED AMPLIFIER:

➤ It is one type of multistage amplifier, in which one stage output is coupled to the next stage by using resistor & capacitor. Hence the name is RC-coupled.

➤ Circuit Diagram:



➤ Circuit detail:

Suppose we consider two stage of amplifier.

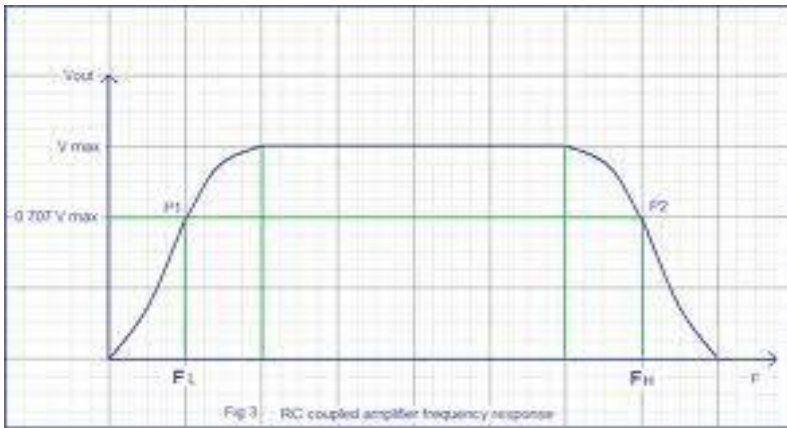
- It consists of two transistors Q_1 & Q_2 . First stage consists of resistors R_1, R_2, R_4, R_3 , capacitors C_2, C_3 , transistor Q_1 . Second stage consists of transistor Q_2 , resistors R_5, R_6, R_8, R_7 , capacitors C_4, C_5 .
- C_1 = Input coupling capacitor used for coupling the input signal to base of transistor Q_1 . It blocks dc & allows ac only.
- C_3 = Output coupling capacitor, which couples the amplified output of Q_1 to Q_2 .
- C_5 = output coupling capacitor of second stage, which couples the amplified output of second stage.
- R_1, R_2 = Biasing resistor for Q_1 . It provides biasing in voltage divider method.
- R_5, R_6 = Provides voltage divider biasing to Q_2 .
- R_3, R_7 = collector resistor of Q_1 & Q_2 respectively.
- C_2 & C_4 = Emitter bypass capacitor of Q_1, Q_2 respectively. It provides low reactance path to ac emitter current.
- R_4, R_8 = emitter resistor of Q_1, Q_2 respectively. It provides stabilisation.
- $+V$ = Biasing supply.

➤ OPERATION:

- The a.c. signal input to be amplified is applied to the base of first transistor. The amplified output develops across R_3 .
- This amplified output is applied to base of transistor Q_2 through coupling capacitor C_3 . It further amplified by Q_2 & amplified output develops across R_7 .
- In this way, the cascaded stages amplify the signal & overall gain is considerably increased.

FREQUENCY RESPONSE:

- Figure:



- The graph consists of three parts:
 - (a) Low frequency region
 - (b) High frequency Region
 - (c) Mid-frequency region
- Gain decreases at low & high frequencies, remains constant at mid-frequency.
- At low frequencies: Gain decreases due to C_c & C_E . At low frequencies the reactance of C_c & C_E increases, hence very small part of the signal will pass from one stage to another. This reduces the voltage gain.
- At high frequencies, gain reduces due to parasitic/stray capacitance existing across the base emitter junction. At high frequencies, reactance of C_c reduces & acts as short path. This increases loading effect of next stage also reduces voltage gain. The reactance of emitter base junction also reduces, which reduces β & hence voltage gain.
- At midfrequency, as the frequency increases reactance of coupling capacitor decreases. This increases the gain. But decrease of reactance increases the loading effect & hence gain. These two effects cancel each other. Hence gain remains constant.

ADVANTAGES:

- 1- It has excellent frequency response.
- 2- It has lower cost, since only uses capacitors & resistors which are cheap.
- 3- The circuit is very compact & light in weight.

DISADVANTAGES:

- 1- It has low voltage & power gain.

2- They have the tendency to become noisy with age.

3- It has poor impedance matching.

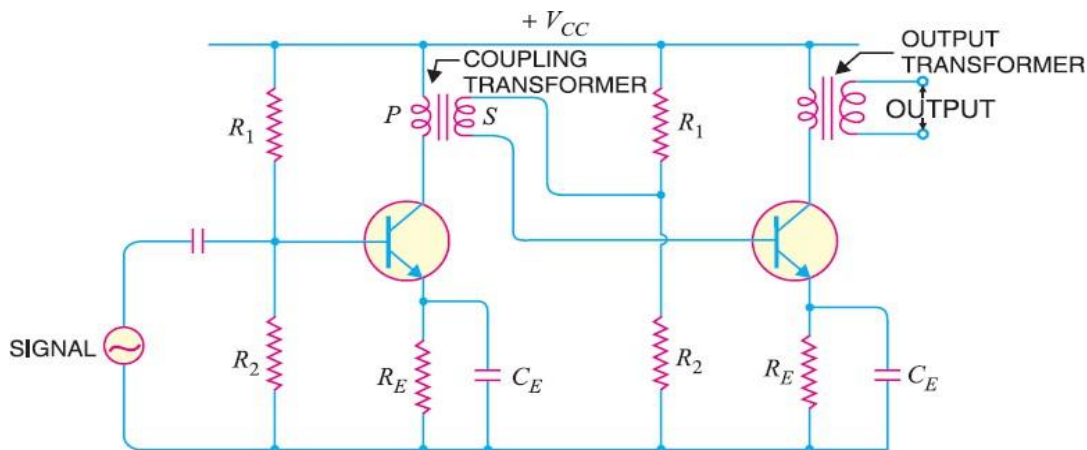
APPLICATION:

Widely used as voltage amplifier.

TRANSFORMER COUPLED AMPLIFIER:

➤ The multistage amplifier in which one stage is connected to next stage using a coupling transformer is called transformer coupled amplifier.

➤ Circuit Diagram:



➤ Circuit Detail:

R_1, R_2 = biasing resistor for both stages in voltage divider rule.

R_E = Emitter resistor of Q_1 & Q_2 & provides stabilisation.

C_E = Emitter bypass capacitor for Q_1 & Q_2 respectively.

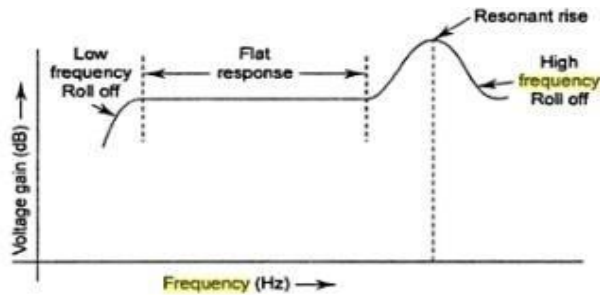
T_1, T_2 = Coupling transformers. It increases the effective load resistance of each stage, hence increase the voltage & power gain. It also provides good impedance matching.

C_{in} = input coupling capacitor, which couples the input to Q_1 .

➤ OPERATION:

- The input signal to be amplified is applied to the base of Q_1 & amplified output develops across the primary of T_1 . It transfers to the secondary & applied to base of transistor Q_2 i.e. to second stage for further amplification.
- Due to transformer coupling the effective load resistance of each stage increases. This increases the voltage gain & power gain.
- It provides good impedance matching between two stages of amplifier.
- It is mostly used for power amplification.
- Transformer coupling is used in case of small load resistance.

FREQUENCY RESPONSE:



It is clear from the graph that frequency response is poor as compared to RC-coupled amplifier. It provides constant gain only over a small range of frequencies. Gain decreases at low & high frequencies. At low frequencies, reactance of primary winding decreases & this decreases the gain. At high frequencies, capacitance between turns of windings act as a bypass capacitor to reduce the output voltage & hence gain.

ADVANTAGES:

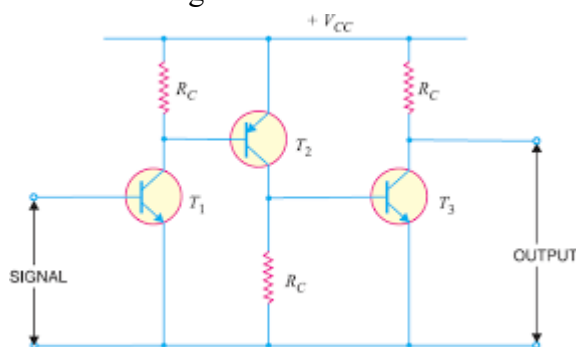
- No signal power is lost in the collector or base resistors.
- Provides good impedance matching.
- Provides higher power gain & voltage gain.

DISADVANTAGES:

- It has poor frequency response.
- Coupling transformers are bulky & fairly expensive at audio range.
- It has frequency distortion. Low frequency signals are less amplified as compared to high frequency signals.

DIRECT COUPLED AMPLIFIER:

- The multistage amplifier in which one stage is connected to next stage directly without using any coupling element is called direct coupled amplifier.
- Circuit diagram:



- Circuit Detail:
 - Suppose we consider a three stage amplifier. It uses complementary transistors i. e. if first stage uses npn, the second stage uses pnp transistor & so on.
 - It consists of three transistors T_1 , T_2 , T_3 , three identical collector resistors R_C for each stage.
- Operation:

The input signal to be amplified is applied to base of T1 & the amplified output from collector of T1 is applied to base of T2 for further amplification & so on.

- It is suitable for amplifying very low frequencies i.e. $<10\text{Hz}$.
- It amplifies photo-electric current, thermocouple current etc.

REFERENCES

- 1- Principle of Electronics- By V.K. Meheta
- 2- Electronic Devices and Circuits- By David A. BELL
- 3- Basic Electronics – By J.B. Gupta
- 4- Google site for circuits.