

NOTES ON
Analog ELECTRONICS
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OP-AMP

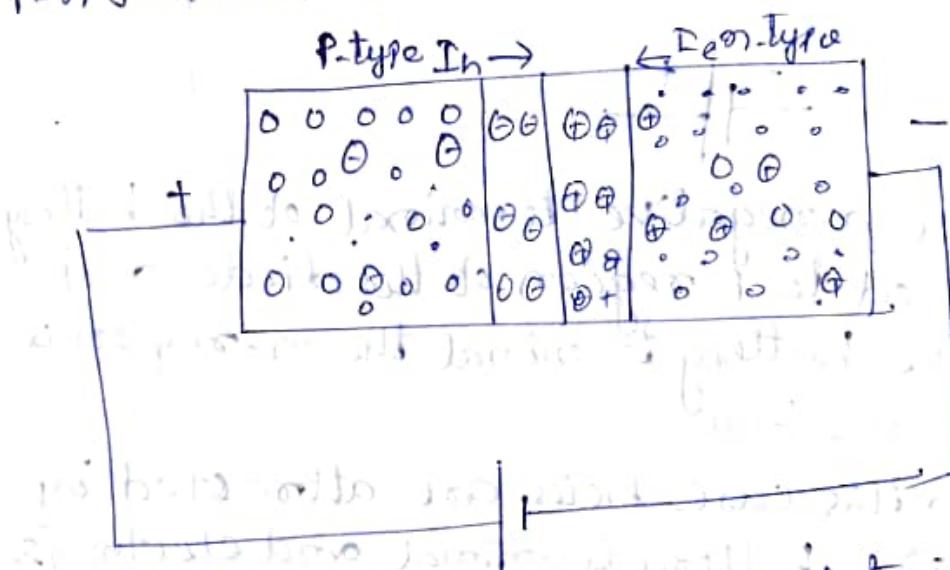
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P KAIET, BARGARH

p-n junction diode in forward bias

forward biased : When the external voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called forward biasing.

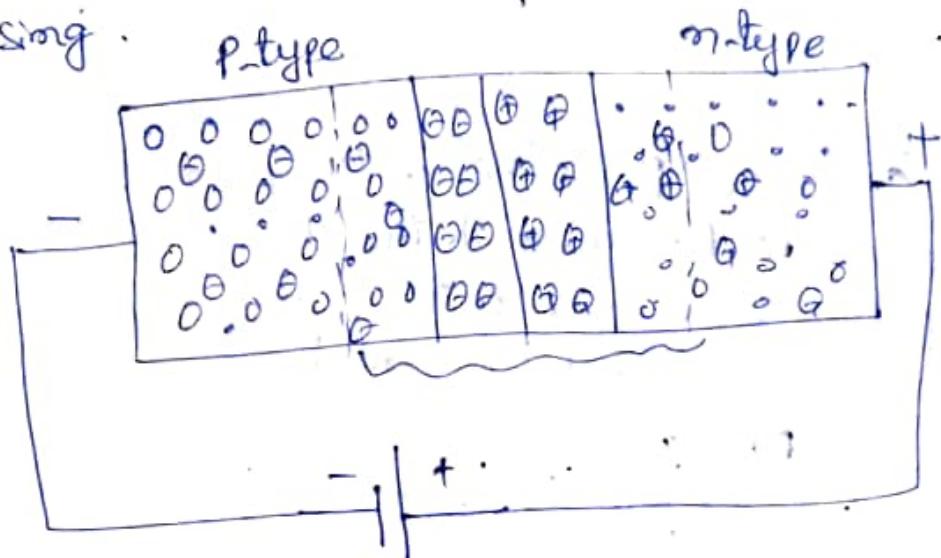
Suppose positive battery terminal is connected to P-region of the p-n junction and the negative terminal to the n-region of the p-n junction is called forward bias



The hole from P-side repel towards the junction due to equal positive charge on P-side and electron from N-side repel towards the junction due to equal negative charge on N-side. In forward biased condition current conduction takes place due to charge carriers move towards the junction.

p-n junction diode in Reverse biased

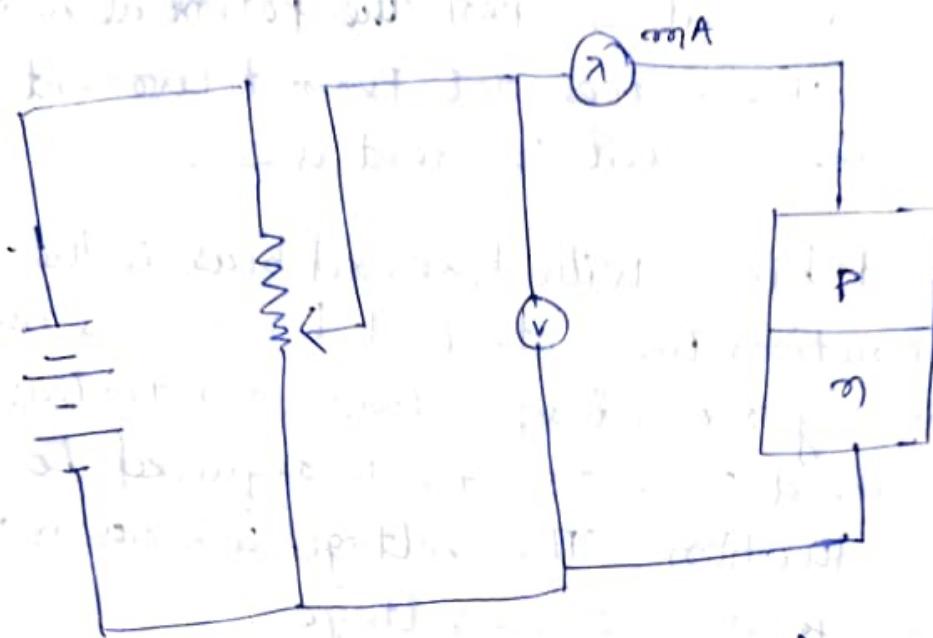
When the external voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing.



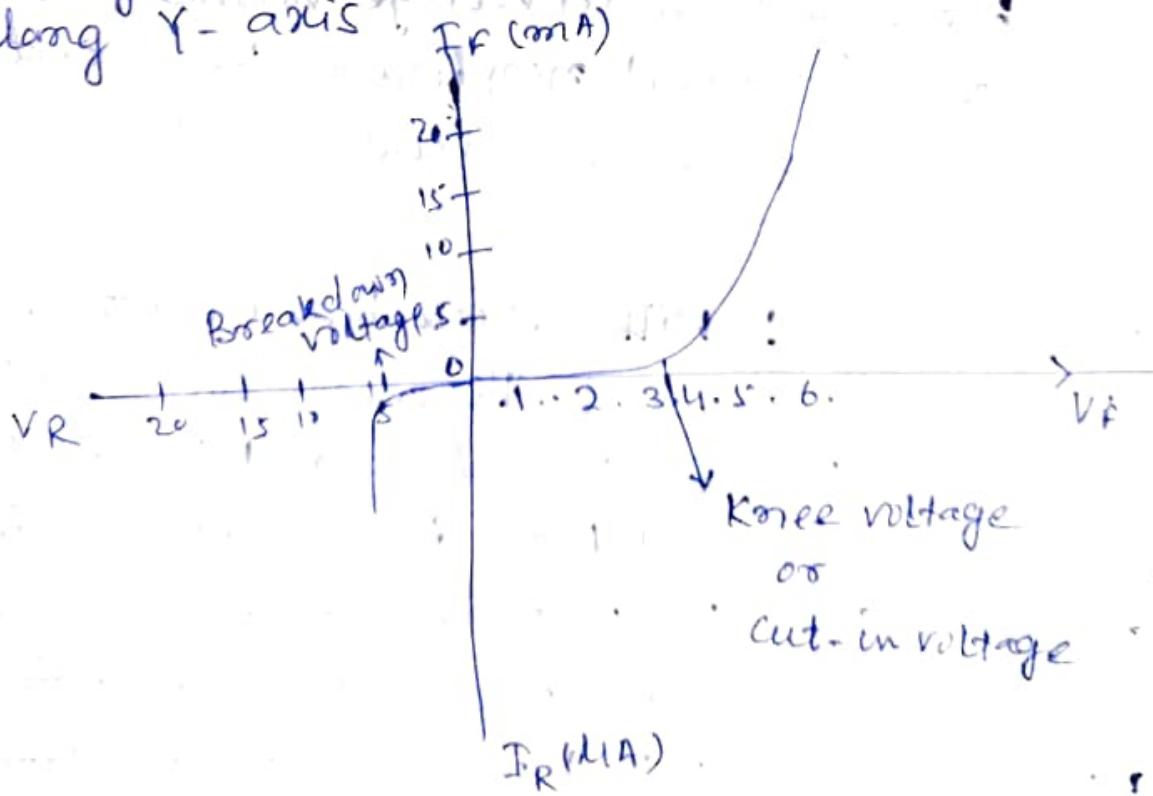
Suppose a negative terminal of the battery is connected to p-region of the diode and the positive battery terminal the n-region is called reverse bias.

In this case holes are attracted by the negative battery terminal and electrons by the positive terminal so that both holes and electrons move away from the junction. So the potential barrier and depletion layer is increased and the junction offers high resistance. There is no current ~~for~~ practically due to majority carrier but a small current due to minority carrier. This current is called reverse saturation current.

V-I characteristic of P-n junction diode



V-I characteristic of a P-n junction diode is the curve between voltage across the junction and the circuit current. The voltage is taken along X-axis and current along Y-axis.



1. No bias : When the external voltage is zero i.e the circuit is open, the potential barrier at the junction does not permit current flow. Therefore the circuit current is zero.

2. Forward bias : With forward bias to the P-n junction the potential barrier is reduced. At ordinary room temperature, a potential drop of about 0.3 V or 0.7 V is required to start conduction. This voltage is known as knee voltage or cut-in voltage.

Knee voltage : The forward voltage at which the junction starts ^{current} increase is called as knee voltage. For Ge - 0.3 V and Si - 0.7 V.

When the forward voltage increased the circuit is increased non linear. The current rises very sharply with increase in external voltage.

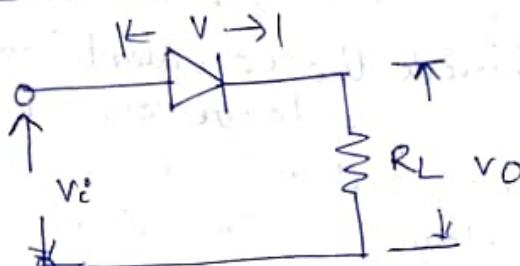
3) Reverse bias : With reverse bias the potential barrier is increased. Therefore the junction resistance become very high and practically no majority current flows through the circuit. A small current flows in the circuit with the high reverse voltage due to minority carrier. This current is called reverse saturation current. After the particular voltage the reverse current increase sharply and the junction may be break due to excessive heat. That voltage is known

Known as the breakdown voltage.

Breakdown voltage : The reverse voltage after which junction may be break is called Breakdown voltage.

Peak inverse voltage (PIV) : The maximum reverse voltage that junction can withstand is called Peak inverse voltage.

DC Load line



Applying KVL of the circuit

$$V_i = V + i R_L$$

$$\text{or, } V = V_i - i R_L$$

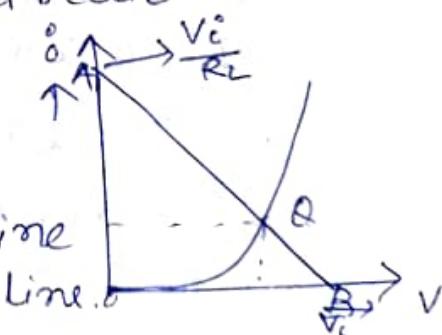
This eqn indicate straight line

and is called the dc load line.

$$\text{With } V=0 \quad V_i = i R_L \quad i = \frac{V_i}{R_L}$$

Point A

$$\text{With } i=0 \quad V=V_i \quad \text{Point B}$$



Junction Breakdown

As reverse voltage of diode increases the junction breakdown occurs characterized by a sudden rise of reverse current and a sudden fall of resistance of barriers region.

There are two junction breakdown

1. Zener breakdown

2. Avalanche breakdown

1. Zener breakdown: It usually occurs in

Silicon PN junction at reverse bias of less than 5V. Under the influence of high intensity electric field large no. of electrons with the depletion region break the co-valent bonds with their atoms and thus a large reverse current flows.

This is ionization by an electric field since a small reverse voltage can produce a very high intensity electric field with a narrow depletion region. This is known as Zener breakdown.

Avalanche Breakdown: It occurs because of cumulative action. The external voltage accelerates the minority carrier in the depletion region. They attain sufficient kinetic energy to ionize atom by collision. This creates new electrons which are again accelerated to high enough velocities to ionize more atoms. This way an avalanche of free electrons is obtained. The reverse current sharply increases.

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CLIPPING CIRCUITS

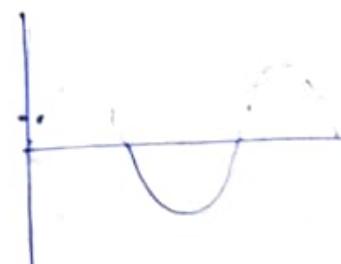
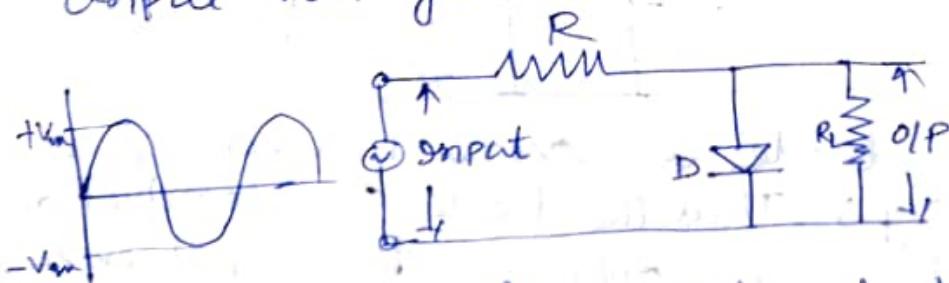
A circuit used to change the shape of an ac input wave by clipping or removing a portion of it is called as clipping circuit.

A clipping circuit is also called a clipper or limiter.

A clipper has the ability to remove signal voltage above or below a specified level and change the wave shape of input signal. most of the clippers employ diodes and are known as diode clipper.

1. Positive clipper and negative clipper
2. Biased positive and negative clipper
3. Combination clipper.

1) POSITIVE CLIPPER : - A positive clipper is that which removes the positive half-cycles of the input voltage.



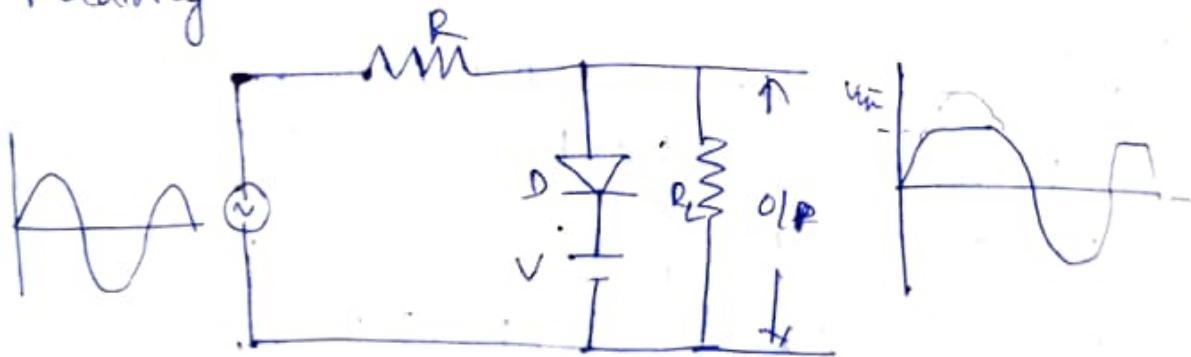
During the positive half-cycle of input voltage the diode is forward biased and conduct heavily. Therefore, the voltage across the diode (which behaves as short) and hence across the load R_L is zero. Hence the output during the positive half cycle is zero. During the negative half-cycle of the input voltage, the diode is reverse biased and behaves as an open.

In this condition the circuit behaves as voltage divider with an output given

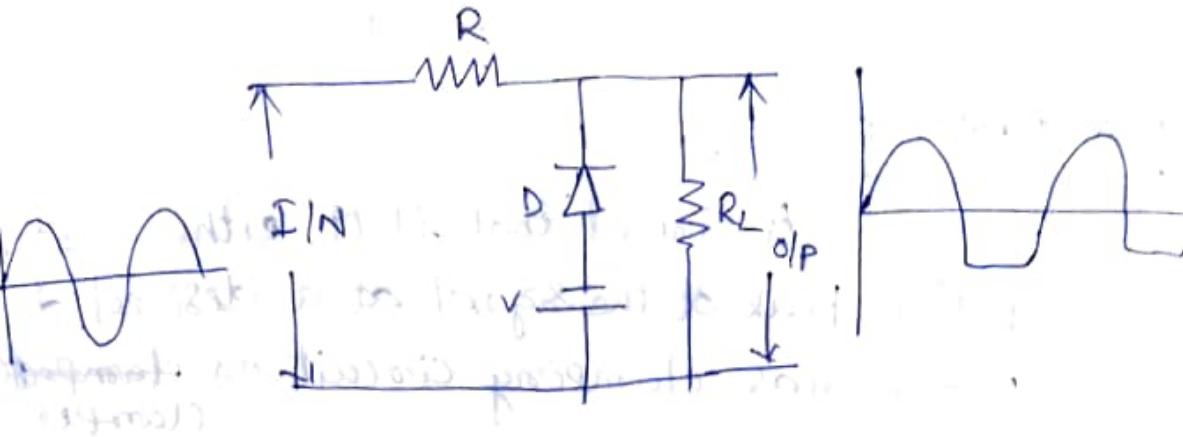
$$\text{OIP voltage} = \frac{R_L}{R+R_L} V_m, \text{ OIP voltage} = -V_m \quad (R_L > R)$$

Negative clipper! — A negative clipper removes the negative half cycle of the input voltage. Here the Polarity of the diode is reverse as used in positive clipper.

② Biased clipper! — A clipper used to remove a small portion of positive or negative half cycle of the signal voltage is called as biased clipper. In this circuit a diode is employed in clipper. In this circuit a diode is employed in series with a battery of voltage V volts having Polarity

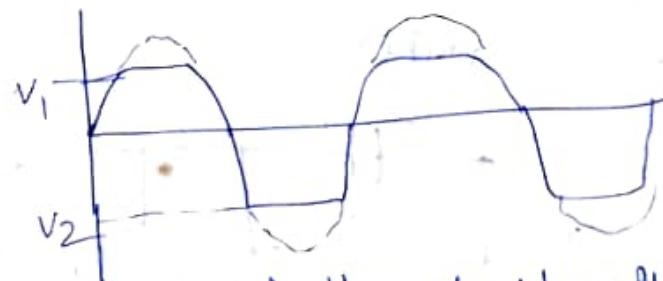
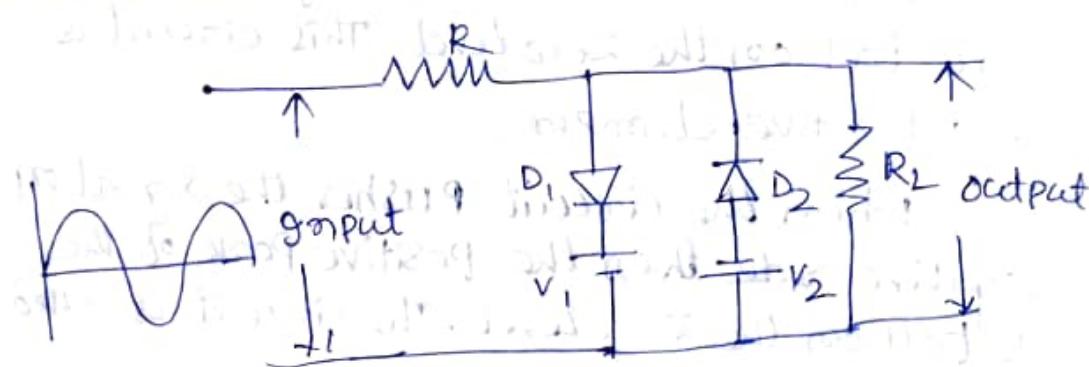


The diode is reverse biased by a biasing battery V . Thus the diode can conduct and short circuit the output only when the input exceeds the biasing potential V . When the input ~~exceeds V~~ the diode conducts and acts as short circuit positive half cycle of the input has a Potential that exceeds V the diode conducts and acts as short circuit but when the input signal has a magnitude lower than the biasing Potential V the diode is cut-off and output is available. The negative half cycle of the input is available at output.



③ Combination clipper:

A clipper used to remove a small portion of positive as well as a small portion of negative half-cycle of the signal voltage is called combination clipper.



During Positive half cycle when the input signal voltage is more than $+V_1$, the diode D_1 conduct heavily while diode D_2 remain reverse biased. Therefore positive half cycle beyond $+V_1$ is clipped off. During negative half cycle when the input signal is more than $-V_2$ volt diode D_2 conduct heavily while diode D_1 remains reverse biased. Therefore negative half cycle beyond $-V_2$ volts is clipped off. This clipper is mostly

Thermistors (NTC resistor)

Thermistor is the contraction of the term Thermal resistor. Most thermistors have a negative co-efficient of temperature that is their resistance decreases with the increase of temperature. The high sensitivity to temperature changes make thermistors extremely useful for precision temperature measurement, control and compensation.

Application

1. Used for measurement and control of temperature as in ovens.
2. Used for temperature compensation
3. Used power measurement

Barretters : A Barretter is a type of detector or control device employing a resistor that varies in proportion to its temperature. A Barretter consist of a thin wire or metal film having a positive temperature co-efficient of resistivity so that resistance increases with temperature.

(1) Power measurement in microwave device

Sensor :

A sensor is a device that detects events or changes in quantities and provide a corresponding output, generally as an electrical or optical signal for example a thermocouple converts temperature to output voltage. Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps which dim or brighten by touching the base.

Zener diode

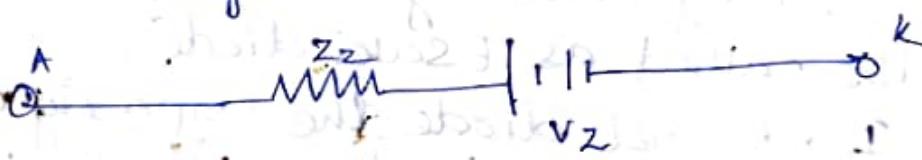
When an ordinary junction diodes are reverse biased, normally a small reverse saturation current I_0 flows. If the reverse voltage is increased sufficiently the junction breakdown and a large reverse current flows. This large current could be enough to destroy the junction.

A suitably designed diode, which have stable breakdown voltage over a wide range of reverse current is called Zener diode.

A properly doped crystal diode which has a sharp breakdown voltage is known as Zener diode.



Symbol of Zener diode



Equivalent circuit

- * It is a heavily doped diode, whose depletion layer is thin.
- * When forward biased, its characteristics are just that of ordinary diode.
- * A Zener diode has sharp breakdown voltage, called Zener voltage V_Z .
- * A Zener diode is not immediately burnt just because it has entered the breakdown region. As long as the external circuit connected to the diode limit the diode current to less than burnt out value, the diode will not burnout.

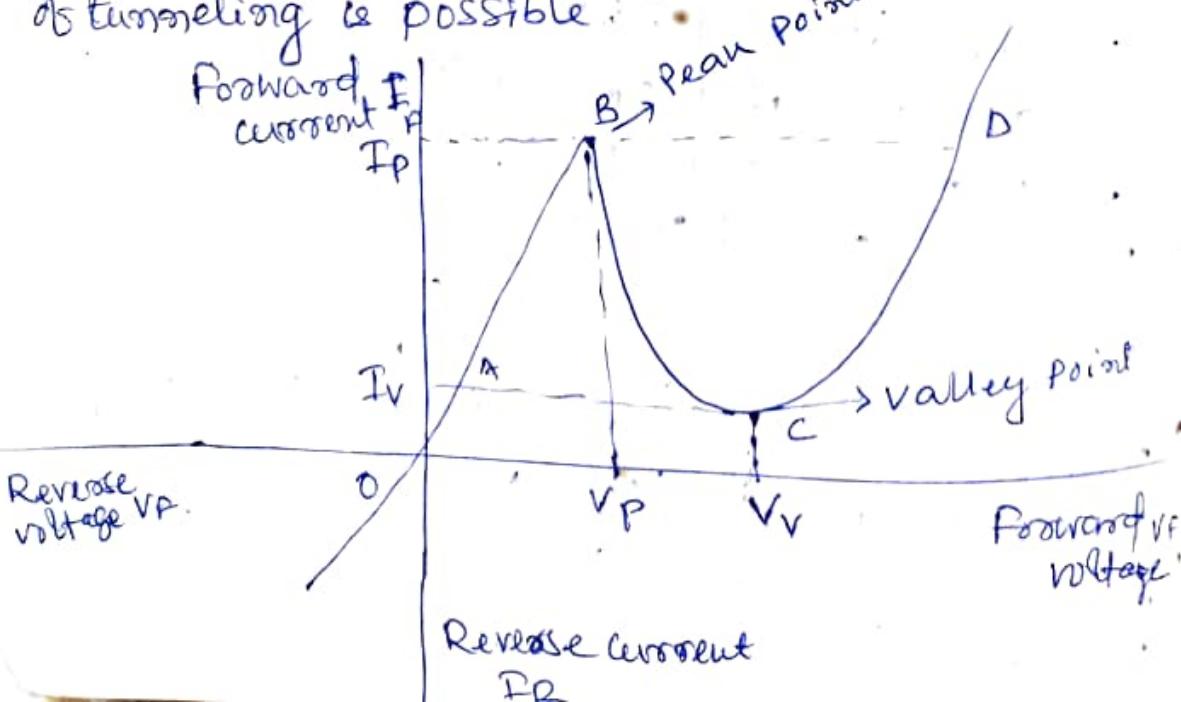
Application of Zener diode

1. used as voltage regulators
2. it is used as voltage reference standard in transistor biasing circuits.
3. it is used for clipping or by passing transient voltage above a specified level in wave shaping circuits.
4. it is also used for meter protection against damage from accidental application.

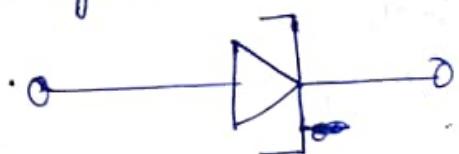
Tunnel diode

A tunnel diode is a PN junction which is heavily doped. It has a negative resistance region. It works on the principle of tunneling which is obtained by creating thin depletion layer. It is also called as Esaki diode.

In tunnel diode the carrier concentration is greatly increased in the order of $1 \text{ in } 10^3$. The depletion layer width reduces about 100 Å . because at this thin depletion layer the phenomenon of tunneling is possible.

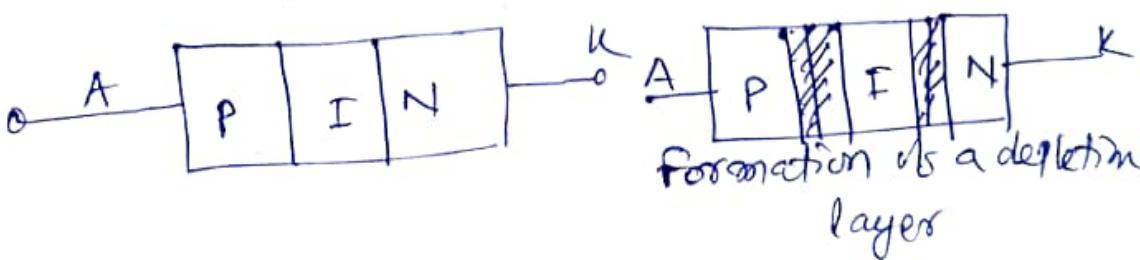
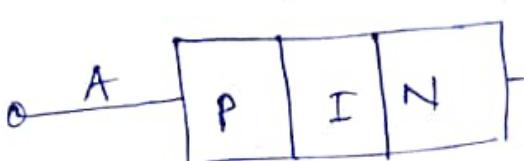


The tunnel diode has an excellent condition in the reverse direction. For small forward voltage the forward resistance remains small. This is because of tunneling phenomenon i.e. penetration of electrons through the potential energy barrier. At point B the current is maxⁿ. I_P. This corresponds to forward voltage V_P. In the region BC the diode exhibits the negative resistance characteristic between the peak current I_P and valley current I_V. Beyond point C the current region reaches the value I_P at the voltage so called peak forward voltage.



PIN diode

A PIN diode is made up of two heavily doped one P and one N-type material separated by an intrinsic (undoped) semiconductor. When PIN diode is unbiased there is a diffusion of electrons and holes across the junction due to different concentration of atoms in P, I and N regions. The diffusion of electrons and holes produce a depletion layer across the PI and IN junction. The depletion layer extends to a little distance in the P-type and N-type semiconductor region but to a larger distance in the I-region.



When the PIN diode is forward biased, the width of depletion layer decreases. As a result of this more carriers are injected into I-region. This reduces the resistance of the I-region. Thus it acts like a variable resistance.

When the PIN diode is reverse biased, the depletion layers become thicker. As reverse bias is increased, the thickness of the depletion layer increases till the I-region becomes free mobile carriers. At this stage the PIN diode acts like an almost constant capacitance.

- ① High voltage rectifiers
- ② RF switch
- ③ Photodector

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Rectifier Circuits & Filters

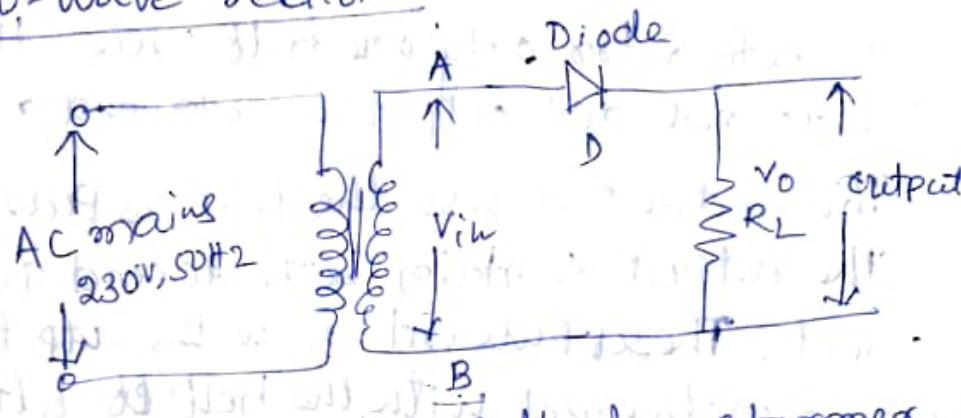
Niranjan Behara

A rectifier may be defined as electronic device used for converting ac voltage or current into unidirectional (dc) voltage or current.

① Half-wave rectifiers

② Full-wave rectifiers

Half-wave rectifiers



The primary of the transformer is connected to the ac mains. The transformer is step-down transformer. The diode D and load resistance connected in series with secondary of the transformer. The output is taken across the load resistance (R_L).

Operation

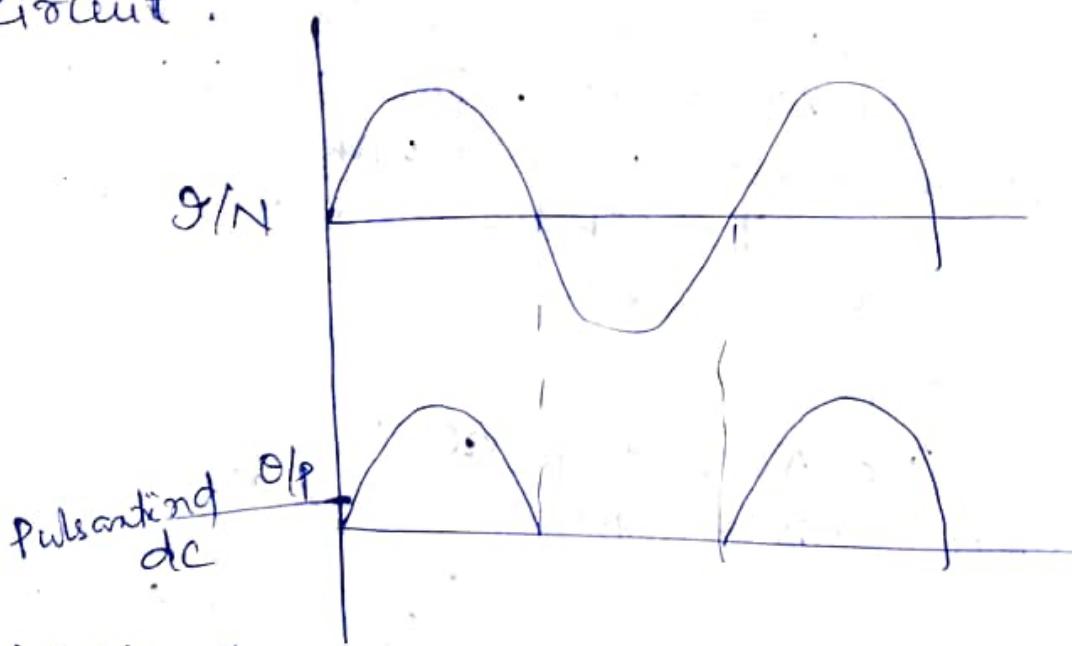
The AC voltage across the secondary winding AB changes polarity after every half-cycle.

During the positive half of input AC voltage end A become positive and end B negative. This make diode D is at forward biased and hence it conducts current.

During the negative half cycle end A is negative and end B is positive. Under this condition the diode is reverse biased and it conducts no current.

The current flows through the diode during positive half-cycles of input AC voltage only, it is blocked during the negative half-cycles. The current flows through load R_L always in same direction for only one half cycle. Hence unidirectional (dc) output is obtained across R_L .

The output across the load is pulsating DC. The output contains both dc and ac component. These pulsations in the output are further smoothed with the help of filter circuit.

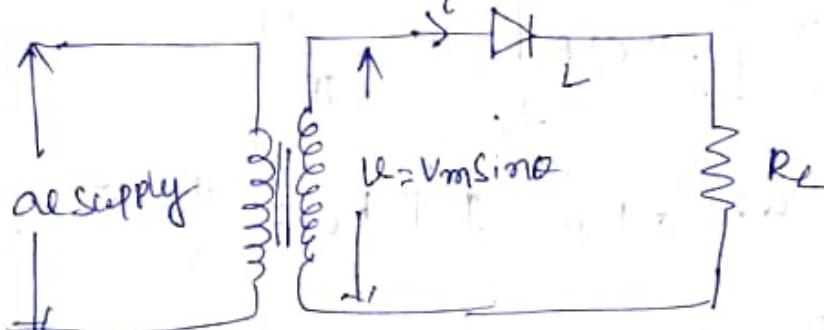


Disadvantage: It delivers output power only for one half cycle. Therefore the output is low.

Rectifier Efficiency of half wave rectifier

Rectifier Efficiency : The ratio of dc output power to the applied input ac power is known as rectifier efficiency.

$$\text{Rectifier Efficiency } \eta = \frac{\text{dc Power output}}{\text{Input ac Power}}$$



$V = V_m \sin \omega t$ be the alternating voltage that appears across the secondary winding. Let r_d and R_L be the diode resistance and load resistance respectively.

The diode conducts during Positive half-cycles of ac supply while no current conduction takes place during negative half-cycles.

Output DC Power

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

$$I_{dc} = I_{av} \quad I_{av} = \text{average current}$$

Average current $I_{av} = \frac{1}{2\pi} \int_0^{\pi} i d\theta$

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

$$I_{AV} = \frac{1}{2\pi} \int_0^{\pi} \underbrace{\text{Var Sin}\theta}_{\text{Or } \text{EffRL}}$$

$$\begin{aligned} I_{AV} &= \frac{1}{2\pi} \int_0^{\pi} I_m \sin \theta d\theta \\ &= \frac{I_m}{2\pi} \cdot \int_0^{\pi} \sin \theta d\theta \\ &= \frac{I_m}{2\pi} \left[-\cos \theta \right]_0^{\pi} = \frac{I_m}{\pi} \end{aligned}$$

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

AC input power

$$P_{ac} = I_{ac}^2 (\sigma f + R_L)$$

$$I_{ac} = I_{rms}$$

$$I_{rms} = \text{Root mean square current}$$

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

$$= \left[\frac{1}{2\pi} \int_0^{\pi} I_m^2 \sin^2 \theta d\theta \right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi} \int_0^{\pi} \sin^2 \theta d\theta \right]^{1/2}$$

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

$$= \left[\frac{I_m^2}{4\pi} \left(0 - \frac{\sin 2\theta}{2} \right)_0^\pi \right]^{1/2}$$

$$= \left[\frac{I_m^2}{4\pi} \times \frac{\pi}{2} \right]^{1/2} = \frac{I_m}{2}$$

ac input power: $P_{ac} = I_{rms}^2 (\gamma_f + R_L)$

$$P_{ac} = \frac{I_m}{4} \cdot (\gamma_f + R_L)$$

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

$$= \frac{\left(\frac{I_m}{2}\right)^2 \times R_L}{\left(\frac{I_m}{2}\right)^2 (\gamma_f + R_L)} = \frac{0.406 R_L}{\gamma_f + R_L}$$

$$\Rightarrow \frac{0.406}{\left(1 + \frac{\gamma_f}{R_L}\right)} \quad \begin{aligned} & \gamma_f \ll R_L \\ & \gamma_f \text{ is negligible} \end{aligned}$$

$$= 0.406 = 40.6\%$$

rectifier efficiency is 40.6%.

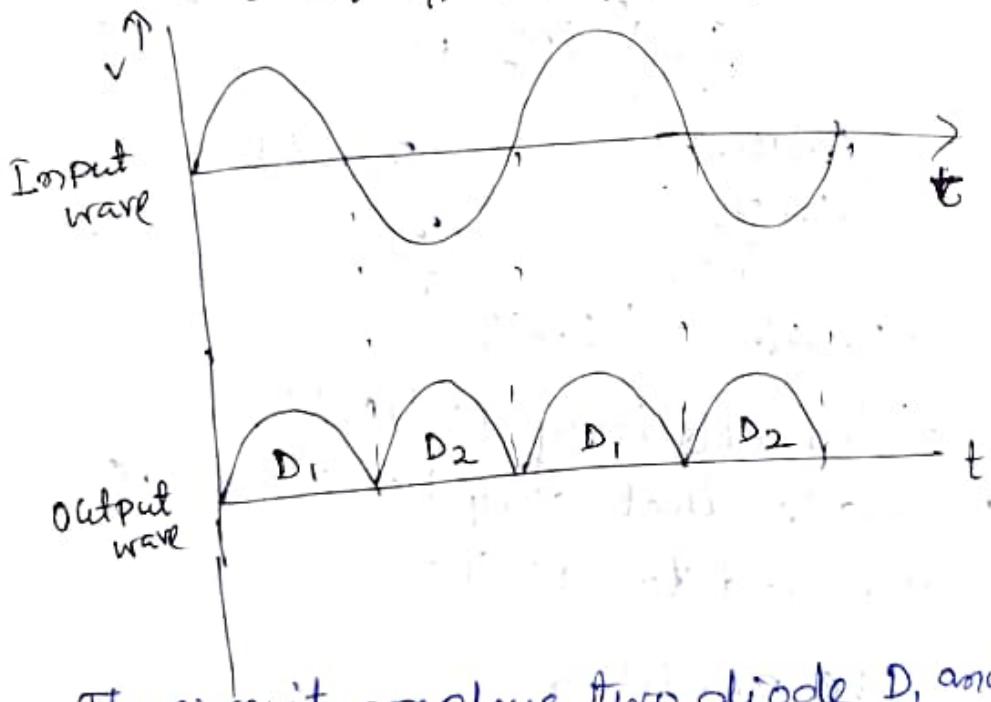
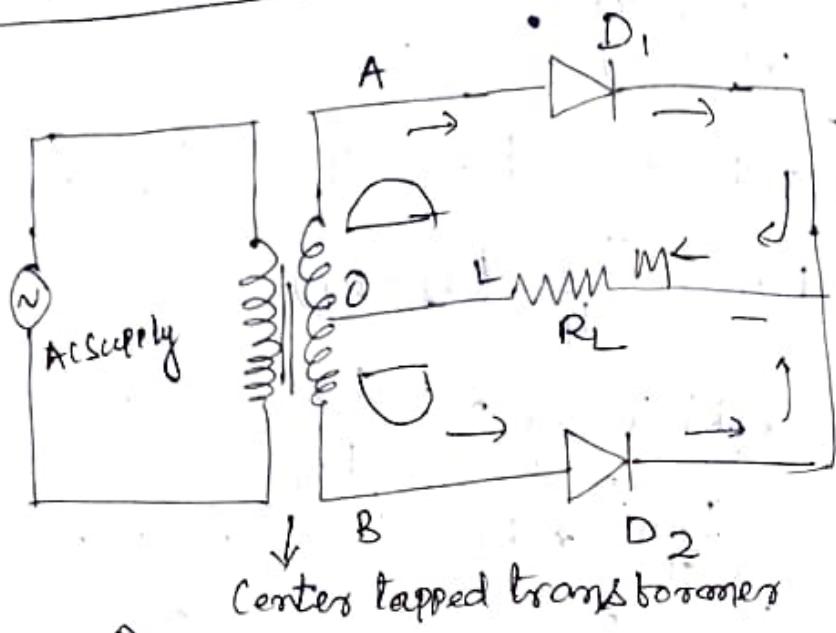
It shows that only 40.6% of ac power is converted to dc power.

Fullwave rectifiers

Full wave rectifiers utilize both the half cycle of ac input voltage. Hence, in a full wave rectifier an undirectional current flows through the load during the entire cycle of input voltage. There two type of full wave rectifier →

1. center tap full wave rectifier
2. full wave bridge rectifier.

Center tap full wave rectifier



The circuit employs two diodes D₁ and D₂.

A center tapped secondary winding AB is used with two diodes connected so that each uses half cycle of input A.C voltage. The diode D₁ utilizes the AC voltage appearing across the upper half OA of the secondary winding to rectify while diode D₂ uses the lower half winding OB.

Working

- During the positive half-cycle of secondary voltage, the end A of the secondary winding becomes positive and end B negative. This makes the diode D_1 , ~~utilizes the AC voltage appearing~~ forward biased and D_2 reverse biased.
- Therefore, the diode D_1 conducts while diode D_2 does not. The conventional current flow is through D_1 , the load resistor R_L and the upper half of secondary winding.
- During the negative half-cycle end A of the secondary winding becomes negative and end B positive.
- Therefore, the diode D_2 conducts while diode D_1 does not. The conventional current flow is through diode D_2 , load R_L & lower half winding.
- It may be seen that current in the R_L is in the same direction for both half-cycles of input A.C. voltage. ~~Therefore~~ Therefore DC is obtained across the load R_L .

Advantage

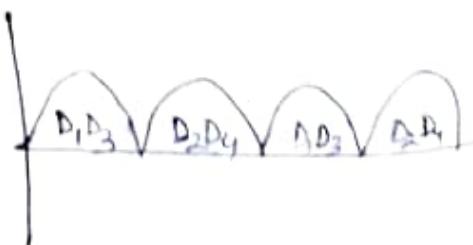
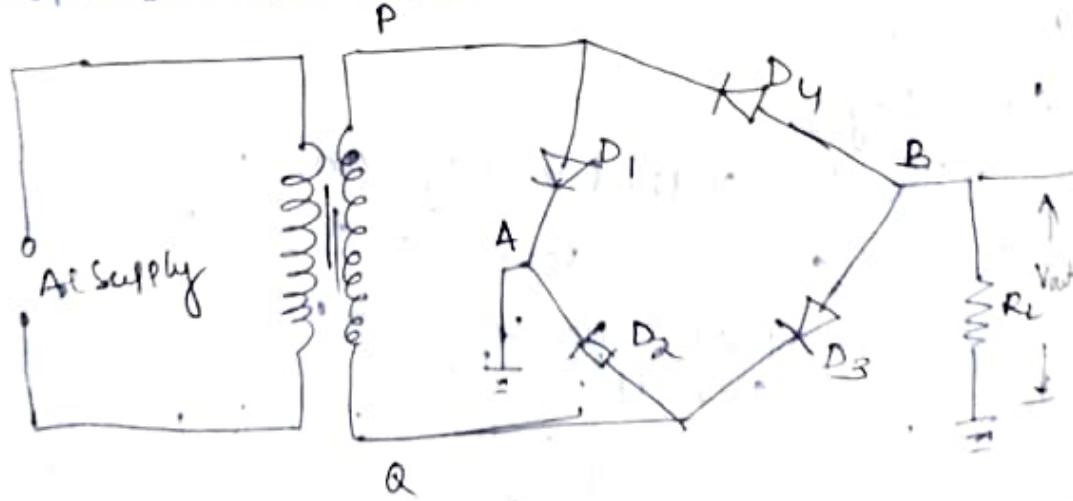
- i) The DC output voltage and load current values are twice than that of half wave rectifiers.
- ii) The ripple factor ^{wave} is much less (0.482) than that of half wave rectifiers (1.21)
- iii) The efficiency is twice (81.2%) than that of half wave rectifiers (50.6%).

Disadvantage :-

- i) It is difficult to locate the center tap on the secondary winding.
- ii) The DC output is small as each diode utilize only one-half of the transformer secondary voltage.
- iii) The diodes used must have high peak inverse voltage.

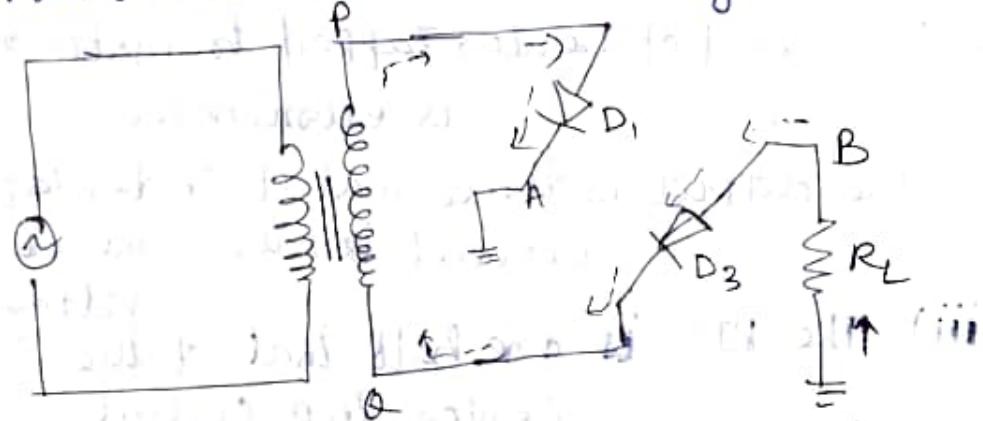
Full-wave Bridge rectifier :-

- The need for a center tapped transformer is eliminated in the bridge rectifier.
- It contains four diodes D_1, D_2, D_3 and D_4 connected to form bridge.
- The AC supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer.
- Between other two ends of the bridge, the load resistance R_L is connected.



working :-

- During the positive half-cycle of secondary voltage the end P of the secondary winding becomes positive and end Q negative.
- This makes diodes D_1 and D_3 forward biased while D_2 and D_4 are reverse biased.
- Therefore, only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L as in fig. The conventional current flow is shown by dotted arrows. It may be seen that current flows from A to B through the load R_L .



(full wave Bridge rectifier in +ve Half cycle)

- During the negative half-cycle of secondary voltage, end P is negative and end Q is positive. This makes diodes D_2 and D_4 forward biased whereas diodes D_1 and D_3 are reverse biased.
- Therefore only diode D_2 and D_4 conduct. These two diodes will be in series through load R_L as in fig. The current flow is shown in R_L by a solid arrow.
- It may be seen that again current flows from A to B through the load i.e. in the same direction as for the positive half cycle. Hence DC

Ripple factor (RF)

The AC component present in the rectified output is called as ripple. The ratio of rms value of AC component to the DC component in the rectified output is known as ripple factor.

$$\text{Ripple factor} = \frac{\text{rms value of ac component}}{\text{value of dc component}}$$

Ripple factor is very important in deciding the effectiveness of a rectifier.

$$\text{Ripple factor} = \frac{I_{ac}}{I_{dc}} = \frac{I_{ac}}{I_{rms}}$$

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

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

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

For half wave rectifier

$$I_{rms} = \frac{I_m}{2} \quad \text{and} \quad I_{dc} = \frac{I_m}{\pi}$$

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

For full wave rectifier

$$I_{rms} = \frac{I_m}{\sqrt{2}} \quad \text{and} \quad I_{dc} = \frac{2I_m}{\pi}$$

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

This shows that in the output of a full wave rectifier the dc component is more than the ac component. The pulsations in the output will be less than in half-wave rectifier.

Transformer Utilization factor (TUF)

Transformer utilization factor may be defined as the ratio of dc power delivered to the load and the ac rating of the transformer secondary.

$$TUF = \frac{\text{DC Power delivered to load}}{\text{AC power rating to the transformer}} \\ = \frac{P_{dc}}{P_{ac}}$$

For half wave rectifiers $TUF = 0.287$

Center tapped rectifier $TUF = 0.693$

Bridge rectifier $TUF = 0.812$

Filter

A filter circuit is a device which removes the AC component of rectifier output but allows the DC component to reach the load.

A filter circuit is generally a combination of inductor (L) and capacitor (C). The filter action of L and C depends upon the basic electrical properties.

Electrical Properties of capacitor.

$$X_C = \frac{1}{2\pi f C}$$

For DC $f = \text{frequency} = 0$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{0} = \infty$$

For ac $f = 50 \text{ Hz}$

$$X_C = \frac{1}{2\pi \times 50 \times C} = \frac{1}{100\pi C}$$

It shows that capacitor offers high reactance path to dc component and low reactance path to ac component.

OR

capacitor blocks the dc component and passes the ac component ~~as inductor~~.

Electrical Properties of Capacitor :-

$$X_L = \text{Inductive reactance} = 2\pi f L$$

For DC $f = 0 \text{ Hz}$

$$X_L = 2\pi \times 0 \times L = 0$$

For ac $f = 50 \text{ Hz}$

$$X_L = 2\pi \times 50 \times L = 100L$$

It means that inductor offers low reactance path to dc and high reactance path to ac.

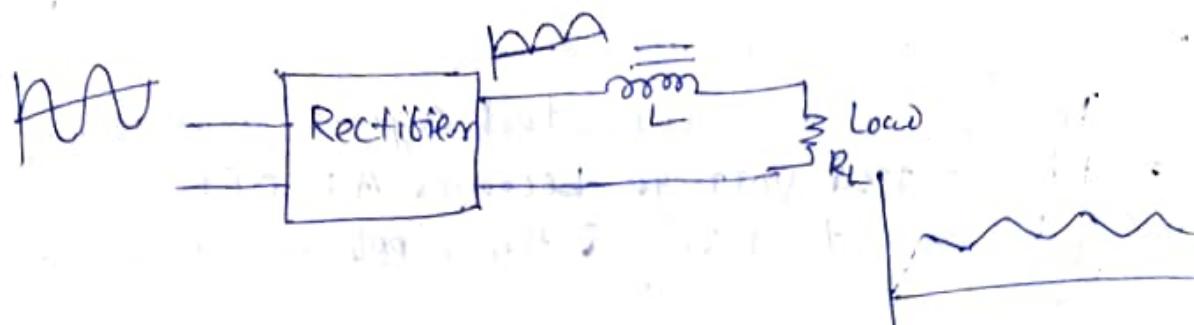
OR

Inductor blocks the ac component and passes the dc component.

Types of filters

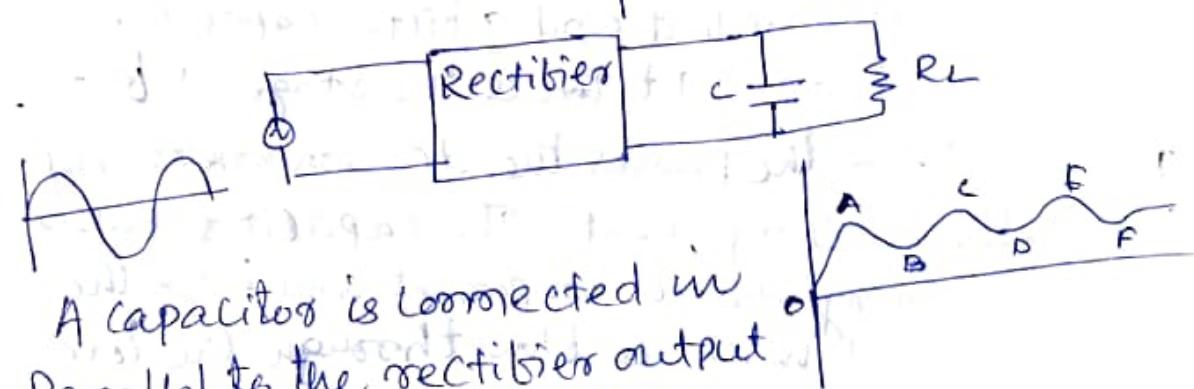
- 1) Series Inductor filter
- 2) Shunt Capacitor filter
- 3) Choke input LC filter
- 4) Capacitor input π -filter

1) Series Inductor filter! -



A conductor is connected in series with rectifier output and load resistance R_L . The choke (Inductor with iron core) offers high opposition to the passage of ac component but no opposition to the dc component. The result is that most of the ac component passes through the choke while whole of the dc component across the choke while whole of the dc component passes through the choke on its way to load. This results in the reduced pulsations at load resistance R_L .

2) Shunt Capacitor filter! -



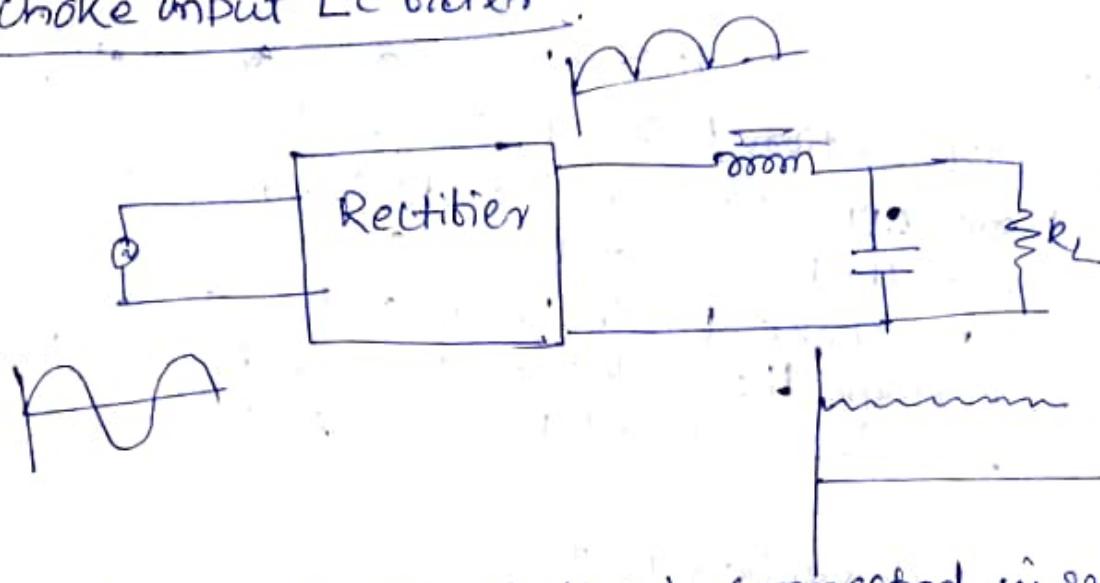
A capacitor is connected in parallel to the rectifier output and load resistance R_L .

The pulsating direct voltage of the rectifier is applied across the capacitor. As the rectifier voltage increases, it charges the capacitor and also supplies current to the load. At the end of quarter cycle the capacitor charged to the peak value V_m of the rectified voltage.

Now the rectifier's voltage starts to decrease. The capacitor discharges through the load and recharges the capacitor.

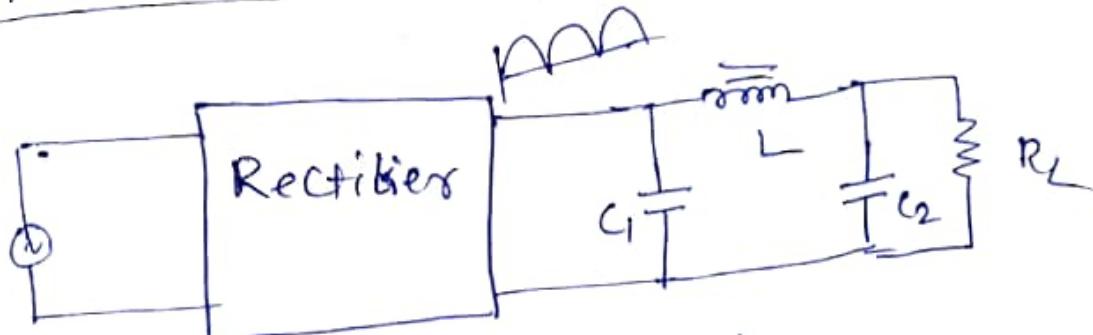
This process is repeated again and again and the output voltage becomes A B C D E F G. It may be seen that very little ripple is left in the output.

Choke input LC filter



It consists of a choke L connected in series with rectifier output and a filter capacitor C across the load. It is two stage of filter. The inductor passes the DC component and blocks the AC component. The capacitor passes the remaining the AC component and blocks the DC component which is now through the load resistance R_L . This result in the reduced pulsation as compared to single stage filter.

Capacitor Input filter or PI filter:



It consists of a filter capacitor C_1 connected across the rectifier output, a choke L in series and another filter capacitor C_2 connected across the ~~rectifier~~ load.

Several identical sections are often used to improve the smoothing action.

(a) The filter capacitor C_1 offers low reactance to all component of rectifier output while it offers infinite reactance to the DC component. Therefore capacitor C_1 passes the AC component while DC component blocks and passes to the choke L .

(b) The choke L offers high reactance to the AC component but it offers almost zero reactance to the DC component. Therefore it allows the DC component to flow through it, while the AC component is blocked.

(c) The filter capacitor C_2 bypasses the AC component which the choke has failed to block. Therefore only DC component appears across the load and that is what we desire.

TRANSISTOR (BJT)

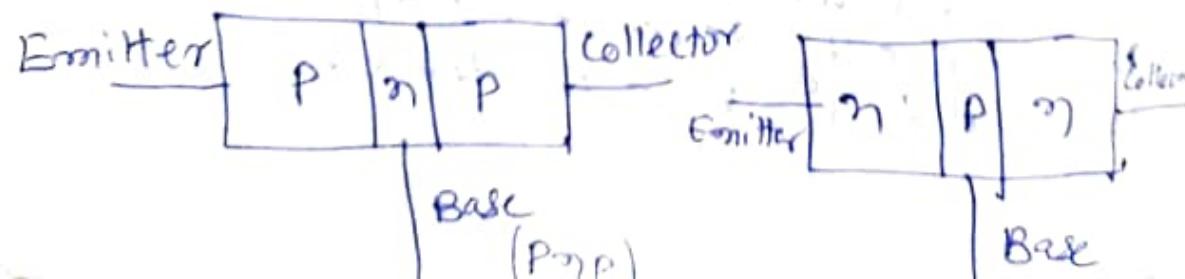
Niranjan Rode
SYL¹ Dept PKAIEZ
B.S.U.

TRANSISTOR

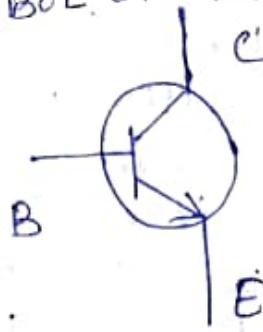
A transistor can also be called as bipolar junction transistor (BJT). It has two P-n junctions formed by sandwiching either P-type or n-type semiconductor between a pair of opposite type. There are two types of transistors:

- 1) PNP Transistor, 2) NPN Transistor

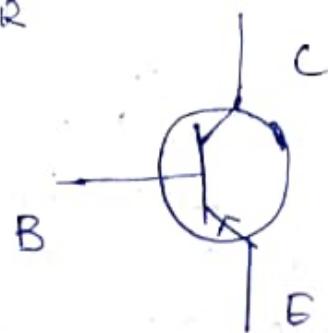
- It is named as Bipolar Junction because as both majority carriers and minority carriers take part in current flow.
- It has three terminals: emitter, base and collector.
- It has two P-n junctions.
- Emitter-base junction is E/P junction and collector-emitter junction is O/P junction.
- E/P junction is always forward biased and O/P junction is reverse biased.



SYMBOL OF TRANSISTOR

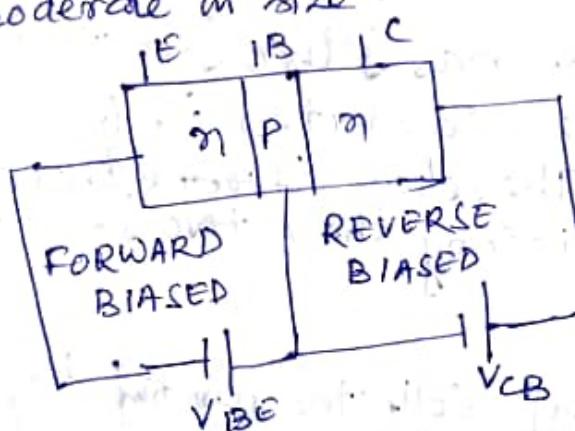


N-P-N

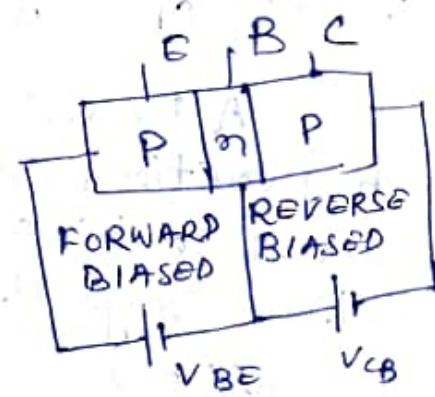


P-N-P

Emitter : The section on one side of the transistor that supplies a large number of majority carriers is called emitter. The emitter is always forward biased w.r.t base so that it can supply a large number of majority carriers to its junction with the base. Since emitter is to supply or inject a large amount of majority carriers into the base, it is heavily doped but moderate in size.



(Biasing of NPN Transistor)



(Biasing of PNP transistor)

COLLECTOR : The section on the other side of the transistor that collects the major portion of the majority carriers supplied by the emitter is called collector. The collector-base junction of is always reverse biased. Its main function is to remove majority carrier (or charges) from its junction with base. The collector is moderately doped but larger in size so that it can collect most of the majority carriers supplied by the emitter.

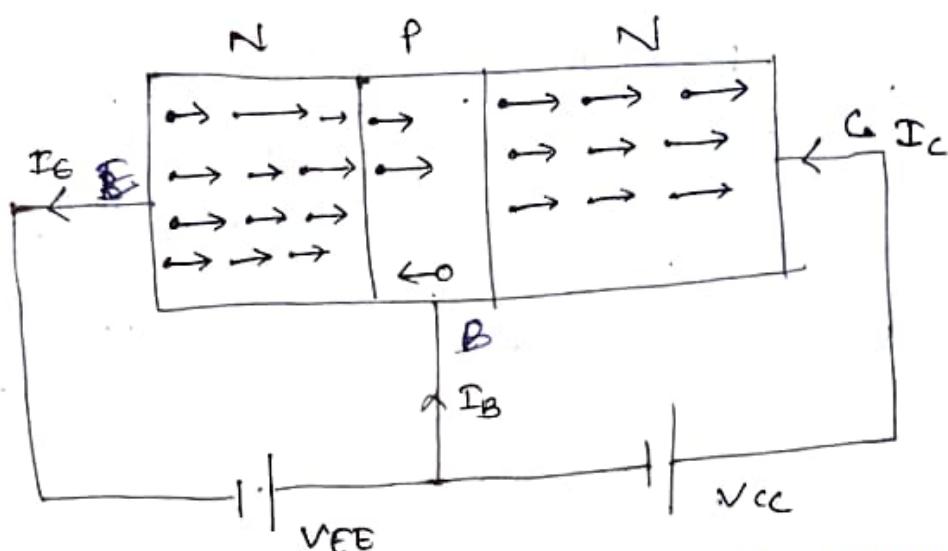
Base: The middle section which bears two junctions between emitter and collector is called base. The base bears two circuits, one input circuit with emitter and the other output circuit with collector. The base-emitter junction is forward biased providing low resistance for the emitter circuit. The base-collector junction is reverse biased obtaining high resistance path to the collector circuit. The base is lightly doped and very thin so that it can pass most of the majority carriers supplied by the emitter to the collector.

Biasing of Transistor

A transistor has two junctions. Each junction can be connected in forward or reverse bias. Therefore there are four ways of biasing these two junctions of transistor:

	<u>Emitter junction</u>	<u>Collector junction</u>	<u>Region of operation</u>
FR	Forward bias	Reverse biased	Active
FF	Forward bias	Forward biased	Saturation
RR	Reverse bias	Reverse bias	Cut-off
RF	Reverse bias	Forward bias	Invert

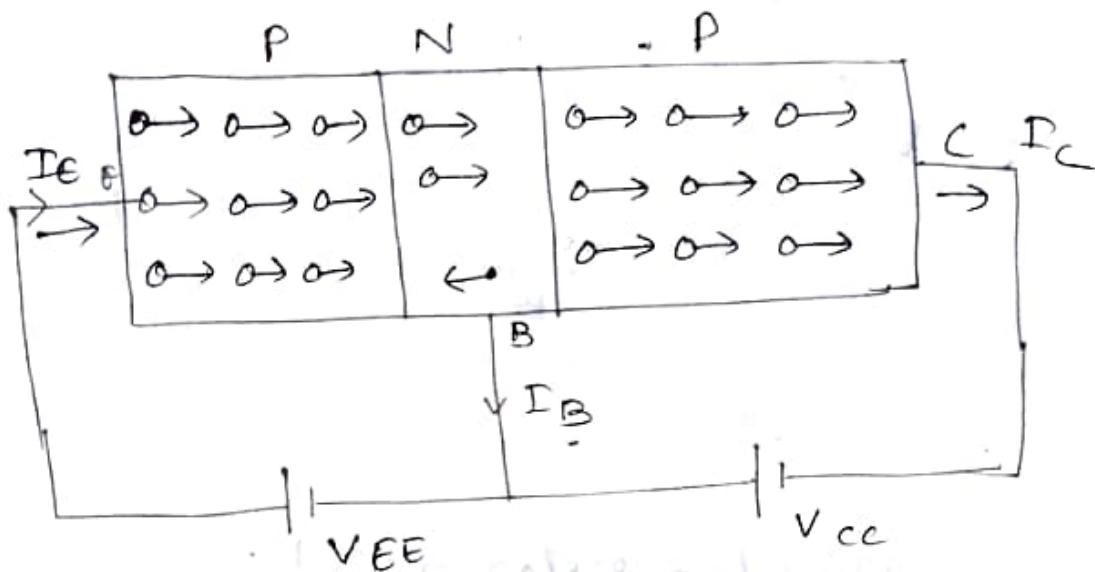
Working Of NPN Transistor



The NPN transistor biased in active region is emitter junction is forward biased by V_{EE} and collector junction reverse biased by V_{CC} . The forward bias in the emitter junction causes the electrons blow from N-type emitter to P-type base. This constitutes the emitter current I_E . As these electrons blow 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 (less than 5%) combine with holes to constitute base current I_B . The base current is very less. The remaining electrons (more than 95%) cross over into the collector region because collector base junction is in reverse bias. This constitutes 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 current.

$$I_E = I_B + I_C$$

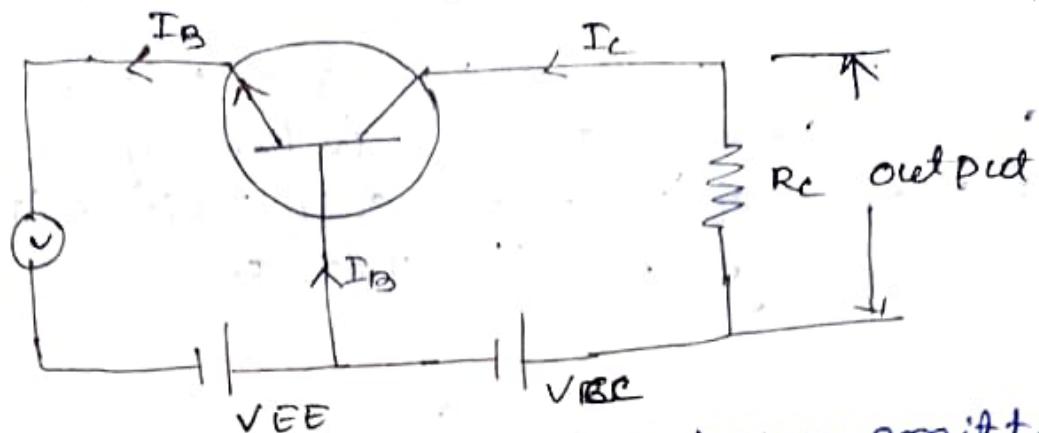
Working of PNP transistor! -



The PNP transistor connected in active region emitter junction is forward biased by V_{EE} and collector junction is reverse biased by V_{CC} . The forward biased in emitter junction causes the blow of holes between P-type emitter to N-type base. This constitutes the emitter current I_E . In this holes blow through the N-type base, they tend to combine with electrons. To constitute the base current I_B . The base current is very less. The remaining holes (more than 95%) cross over into the collector region because base junction is in reverse biased. This constitutes collector current I_C . In this way almost the entire emitter current flows in the collector circuit. It is clear that emitter current is source of collector and base current.

$$I_E = I_B + I_C$$

TRANSISTOR AS AN AMPLIFIER



The signal is applied between emitter and base junction and output is taken across the load R_c connected in the collector circuit. To achieve amplification, the input circuit should always remain forward biased. This is a dc voltage V_{EE} is applied in the series with the signal. The dc voltage is known as bias voltage and its magnitude should always be such that it keeps the input circuit forward biased.

The input junction is forward biased and a small change in the input voltage causes a large change in emitter current. The change in emitter current is transferred to collector due to transistor action. This causes large change in collector current. The collector current flowing through load resistance R_c produces a large change in voltage across it because the load resistance is of the order of $k\Omega$. The transistor is increasing the small input to a large current output. Hence transistor acts as a current amplifier, which raises the signal strength.

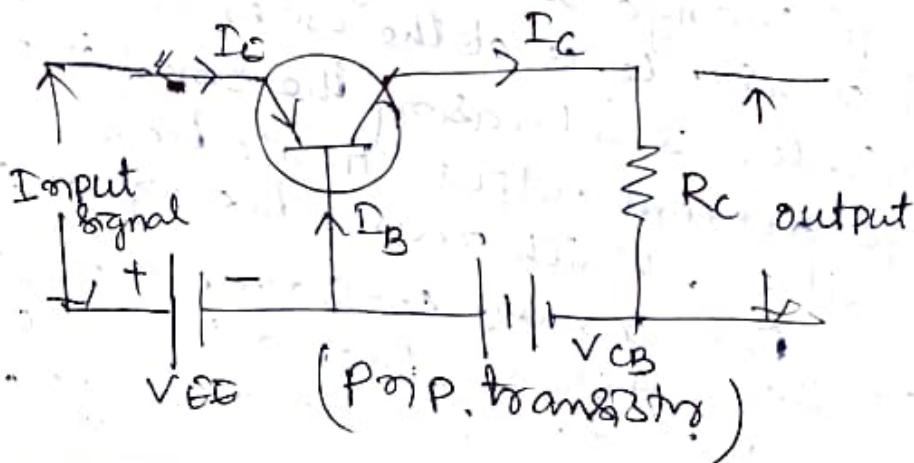
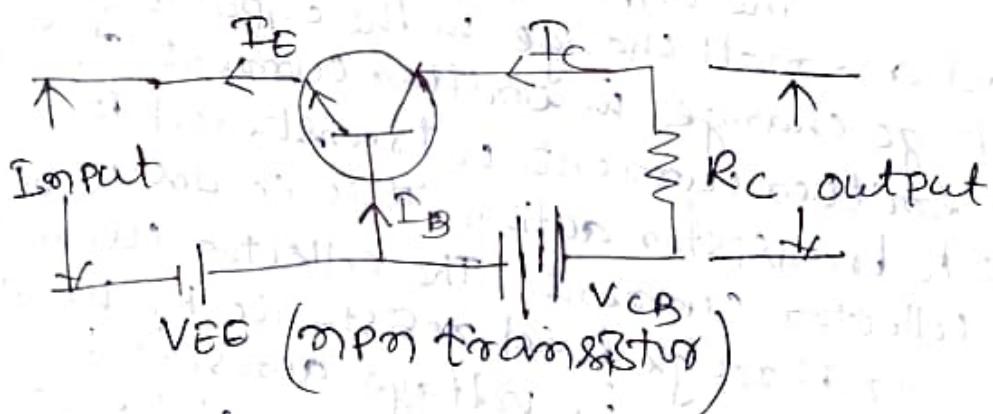
For example consider load resistance $R_c = 5k\Omega$. Assume that a change of $0.2V$ in signal voltage produces a change of $1mA$

in emitter current. The change on collector current would also be approximately 1 mA . This collector current through R_C would produce a voltage $= 5 \text{ k}\Omega \times 1 \text{ mA} = 5 \times 10^3 \times 1 \times 10^{-3} = 5 \text{ V}$. Thus a change of 0.2 V in the signal produce a change of 5 V in the output circuit. It means the voltage amplification is 25 .

Transistor configuration

- i) common base connection
(CB configuration)
- ii) common emitter connection.
(CE configuration)
- iii) common collector connection
(CC configuration)

Common base connection



In Commonbase circuit the ~~input~~ input is connected between emitter and base while output is taken across collector and base. Thus the base of the transistors is common to both input and output circuits and hence the name common base connection or common base configuration.

current amplification factor (α)

The ratio of change in collector current to the change in emitter current at constant collector base voltage V_{CB} is known as current amplification factor (α).

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

ΔI_C = change in collector current

ΔI_E = change in emitter current

V_{CB} = collector base voltage

$$I_E = I_e + I_B$$

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

$$\text{or, } \frac{\Delta I_E}{\Delta I_E} = \frac{\Delta I_C}{\Delta I_E} + \frac{\Delta I_B}{\Delta I_E}$$

$$\text{or, } 1 = \alpha + \frac{\Delta I_B}{\Delta I_E}$$

$$\text{or, } \alpha = 1 - \frac{\Delta I_B}{\Delta I_E}$$

It is clear that the value of current amplification factor is less than unity. The practical value of α is 0.95 to 0.99.

Collector current I_C

Total collector current consist of :-

- A large Percentage of emitter current that reaches the collector terminal i.e αI_E
- The leakage current I_{leakage} . This current is due to movement of minority carriers across the collector-base junction as the junction is heavily reverse biased.

Total collector current :-

$$I_C = \alpha I_E + I_{\text{leakage}}$$

or,
$$\boxed{I_C = \alpha I_E + I_{CBO}}$$

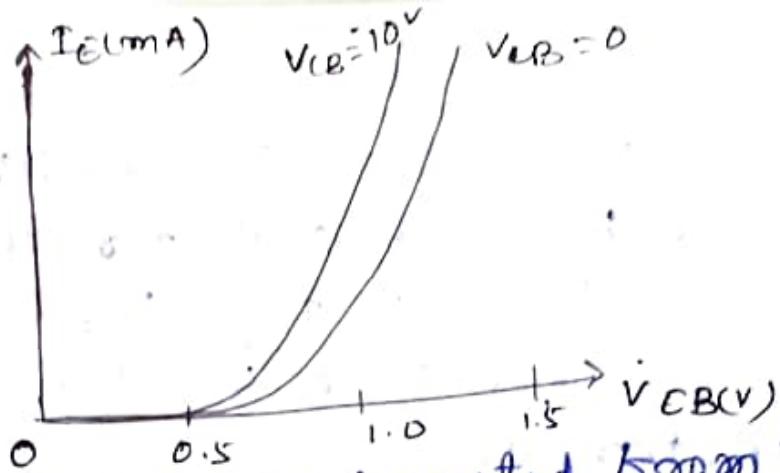
I_{CBO} = collector base current with emitter cut open.

Characteristic of common base (CB)

Configuration:

i) Input characteristic :

In CB configuration the curve plotted between current I_E and the emitter-base voltage V_{EB} at constant collector-base voltage V_{CB} is called input characteristic.



The following point may be noted from these characteristics! -

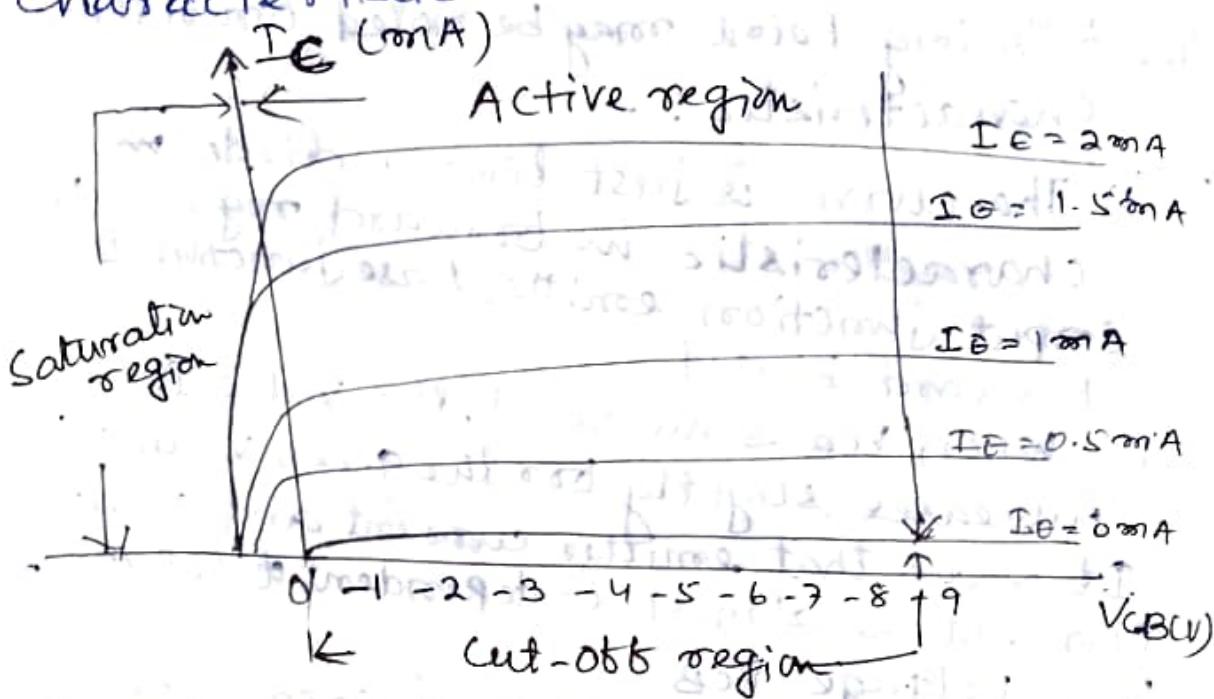
- The curve is just like a diode in characteristic in forward region. The input junction, emitter-base junction is forward biased.
 - When V_{CB} is increased, the value I_E increases slightly for the given value of V_{EB} . It shows that emitter current and collector current is almost independent of collector-base voltage V_{CB} .
 - The emitter current I_E increases rapidly with a small increase in emitter-base voltage V_{EB} it shows that input resistance is very small.
- Input resistance: The ratio of change in emitter-base voltage ΔV_{EB} to the resulting change in emitter current ΔI_E at constant collector-base voltage V_{CB} is known as input resistance

$$r_i = \frac{\Delta V_{EB}}{\Delta I_E} \text{ at constant } V_{CB}$$

The value of r_i is very low. The typical value is few ohms to 100 ohms

Output characteristic :

In CB configuration the curve plotted between collector current I_C and collector-base voltage V_{CB} at constant emitter current I_E is called output characteristic.



- i) In the active region, where collector-base junction is reverse biased, the collector current I_C is almost equal to emitter current I_E . The transistor is always operated in the region.
- ii) When V_{CB} becomes positive i.e. the collector-base junction is forward biased, the collector current I_C is decrease suddenly. This is the saturation region. In this region I_C does not depend much upon I_E .
- iii) When $I_E = 0$, collector current I_C is not zero. Its value is very small. This is reverse leakage current I_{CBO} that flows in collector cut. This is the cut-off region.

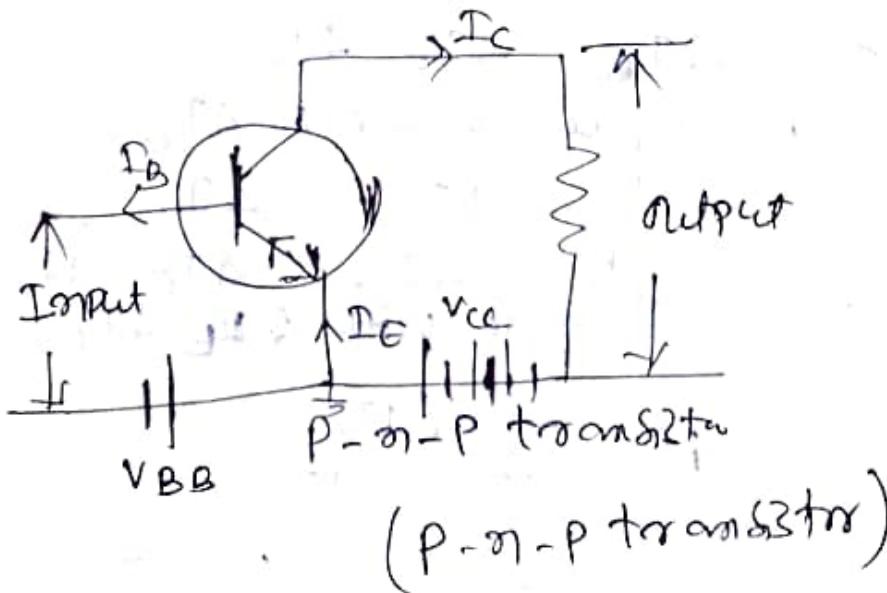
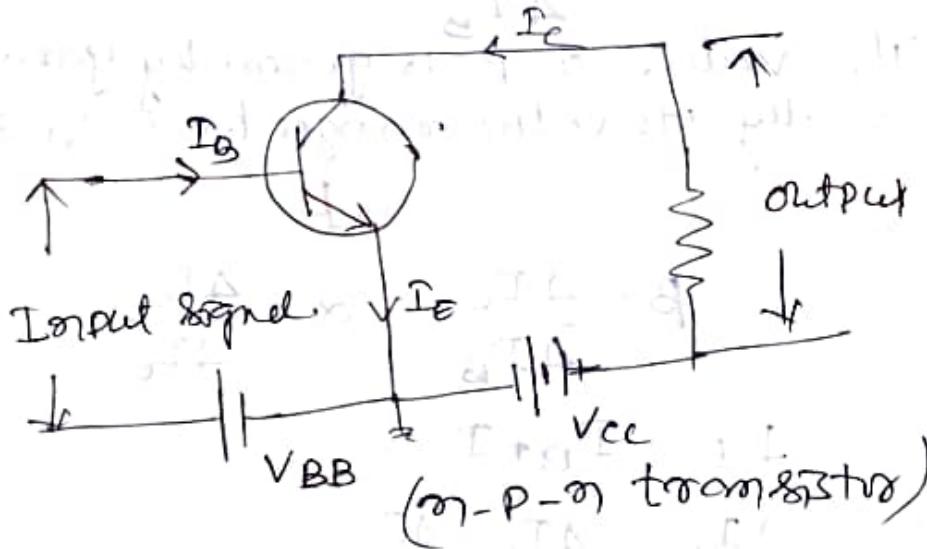
Output resistance: The ratio of change in collector-base voltage ΔV_{CB} to the resulting change in collector current ΔI_C at constant emitter current I_E is known as output characteristic.

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

The output resistance of CB configuration is very high of the order of tens k-Ω.

Common emitter connection OR

CE configuration



In this arrangement, the input is connected between base and emitter while output is taken from the collector and emitter. Thus, the emitter of the transistor is common to both input and output circuits and hence the same common emitter connection or common emitter configuration.

Base current amplification factor of CE (β)

The ratio of change in collector current to the change in base current is known as current amplification factor of CE (β).

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

The value of β is generally greater than 20. Usually its value ranges from 20 to 500.

Relation between α and β

$$\beta = \frac{4I_C}{4I_B}, \alpha = \frac{4I_C}{4I_E}$$

$$I_E = I_B + I_C$$

$$\text{Or, } 4I_E = 4I_B + 4I_C$$

$$\text{Or, } 4I_B = 4I_E - 4I_C$$

Substituting the value of $4I_B$

$$\beta = \frac{4I_C}{4I_B} = \frac{4I_C}{4I_E - 4I_C}$$

Dividing both side with $4I_E / 4I_E$

$$\beta = \frac{4I_C / 4I_C}{4I_E / 4I_E - 4I_C / 4I_C}$$

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

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

$$\beta(1-\alpha) = \alpha$$

$$\text{or, } \beta + \beta\alpha = \alpha$$

$$\text{or, } \beta = \alpha + \alpha\beta = \alpha(1+\beta)$$

$$\text{or, } \beta = \boxed{\alpha = \frac{\beta}{\beta+1}}$$

Expression for collector current for CE circuit

$$I_E = I_B + I_C$$

$$\text{or, } I_C = \alpha I_E + I_{CBO} - (\epsilon \cdot B \text{ cu})$$

$$\text{or, } I_C = \alpha(I_B + I_D) + I_{CBO}$$

$$\text{or, } I_C = \alpha I_B + \alpha I_D + I_{CBO}$$

$$\text{or, } I_C - \alpha I_D = \alpha I_B + I_{CBO}$$

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

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

$$\text{or, } I_C = \beta + D_B + \Phi.$$

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

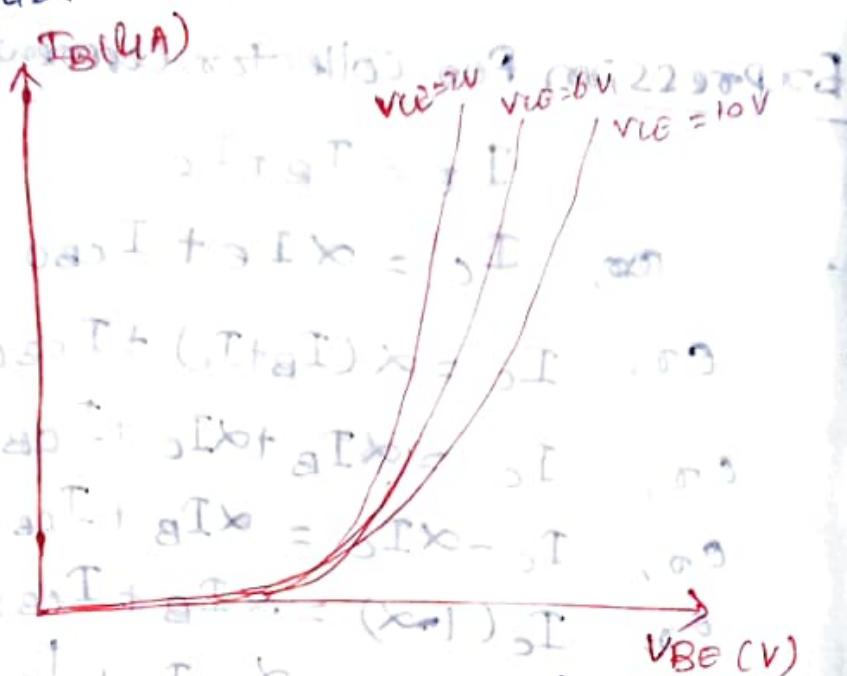
$$\text{where } I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

I_{CEO} = collector emitter current
at base is open.

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

Input characteristics of CE configuration

In CE configuration, the curve plotted between base current I_B and base-emitter voltage V_{BE} at constant collector-emitter voltage V_{CE} is called Input characteristic.



- i) These curves are similar to those obtained in CB configuration i.e like a forward diode characteristic. The only difference is that in this case I_B increases less rapidly with increase in V_{BE} so the input resistance of CE configuration is higher than that of CB configuration.
- ii) The change in V_{CE} does not result in a large deviation of the curves. Hence the effect of change in V_{CE} on the input characteristic is ignored.

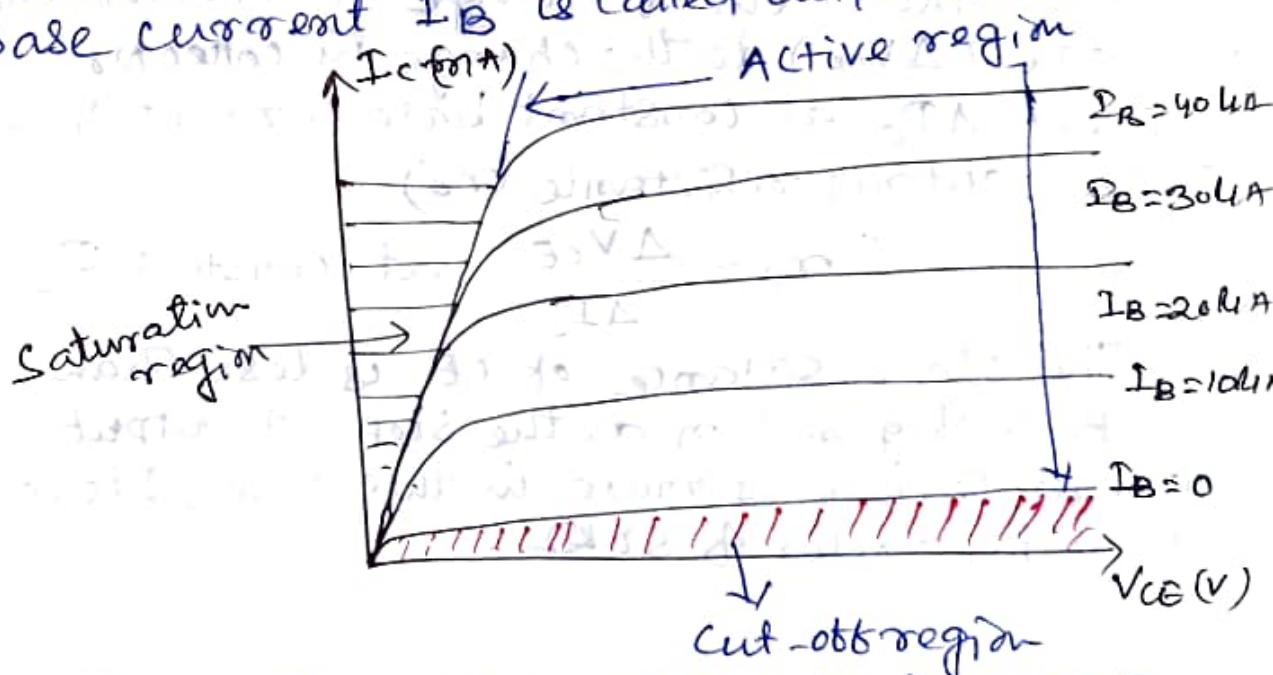
Input resistance: The ratio of change in base-emitter voltage ΔV_{BE} to the resulting change in base current ΔI_B at constant collector-emitter voltage V_{CE} is known as input resistance.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

In CE configuration, the typical value of input resistance is of the order of a few hundred ohms.

OUTPUT CHARACTERISTICS OF CE Configuration

In CE configuration, the curve plotted between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B is called output characteristic.



- i) In the active region, I_C increases slightly as V_{CE} increases. The slope of the curve is little bit more than the output characteristic of CB configuration.

- ii) Since the value of I_C increases with the increase in V_{CE} at constant I_B , the value of B also increases as ($B = I_C/I_B$)
- iii) When V_{CE} falls below the value of V_{BE} , I_C decreases rapidly. At this stage the collector-base junction is also forward biased and the transistor works in the saturation region.
- iv) In active region $I_C = B I_B$, hence a small change in base-current I_B produces a large change in output current I_C .
- v) When input current $I_B > 0$, the collector current I_C is not zero but its value is equal to the reverse leakage current I_{CEO} .

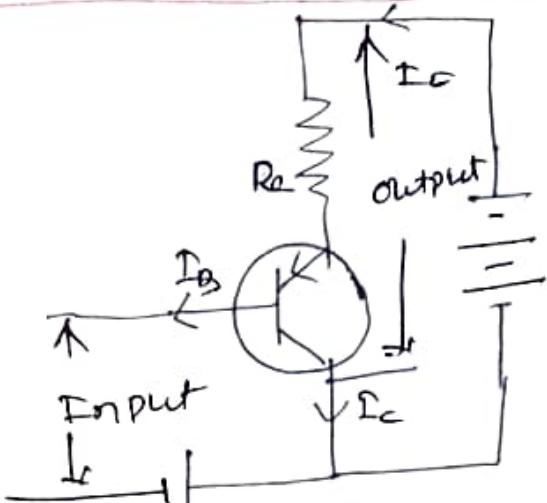
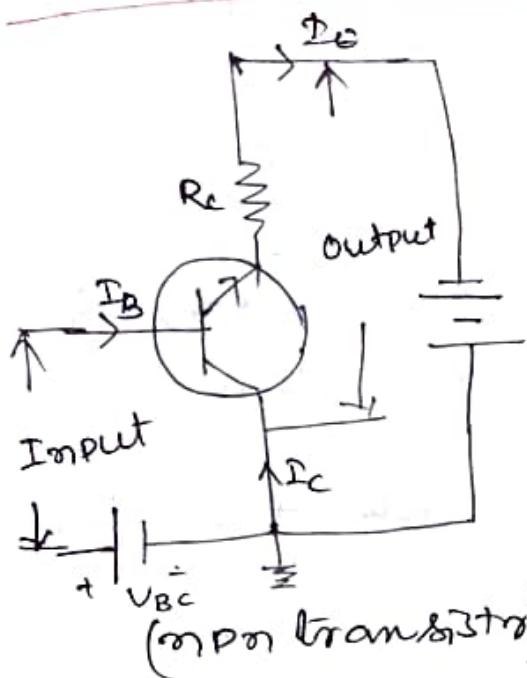
Output resistance (r_o)

The ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current ΔI_C at constant base current I_B is called output resistance (r_o)

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at Constant } I_B$$

The output resistance of CE is less than CB configuration as the slope of output characteristic is more in this case, Its value is of the order of $50\text{ k}\Omega$.

Common collector connection (CC configuration)



In this arrangement, the input is connected between base and collector while output is taken across the emitter and collector.

current amplification factor (γ)

The ratio of change in emitter current to the change in base current is known as current amplification factor (γ)

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

Relation between γ and α

$$\gamma = \frac{\Delta I_E}{\Delta I_B}, \quad \alpha = \frac{\Delta I_C}{\Delta I_E}$$

$$I_E = I_B + I_C$$

$$\text{or, } \Delta I_E = \Delta I_B + \Delta I_C$$

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

$$\text{Putting the value of } \Delta I_B \quad \gamma = \frac{\Delta I_E}{\Delta I_E - \Delta I_C}$$

$$= \frac{\Delta I_E / \Delta I_E}{\Delta I_E / \Delta I_E - \Delta I_C / \Delta I_E} = \frac{1}{1 - \alpha}$$

COMPARISON OF TRANSISTOR

CONFIGURATION

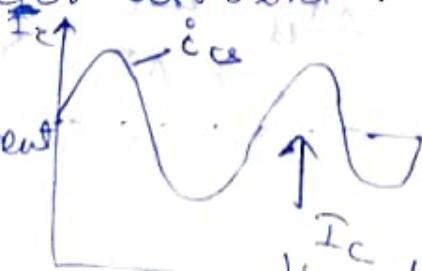
<u>characteristic</u>	<u>CB</u>	<u>CE</u>	<u>CC</u>
1. Input resistance	Low (150Ω)	Low ($1k\Omega$)	Very high ($150k\Omega$)
2. Output resistance	Very high ($500k\Omega$)	High ($1k\Omega$)	Low (50Ω)
3. Current gain	Less than unity (0.98)	High (100)	High (100)
4. Voltage gain	Small (100)	High. Less than (500)	Less than one
5. Application	For high frequency	For audio frequency	For low frequency, matching

Out of the three transistor configurations, the common emitter connection are used in about 90 to 95 percent of all the transistor application because of the reasons high current gain, high voltage and power gain and moderate output to input impedance ratio.

Zero signal collector current! -

When no signal is applied, the input circuit i.e. emitter-base junction is forward biased by the battery V_{BB} . Therefore a dc collector current I_C flows in the collector circuit. This current is called Zero signal collector current.

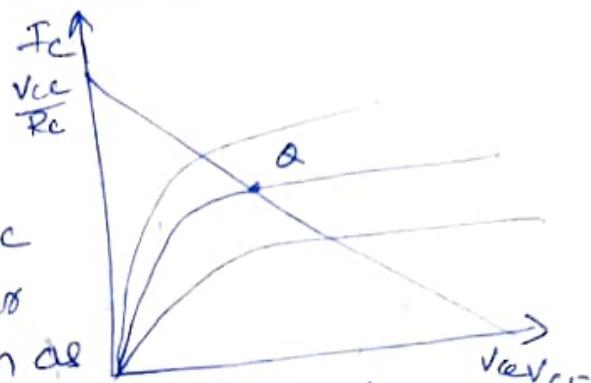
$$I_C = \text{Zero signal collector current}$$



~~QUIESCENT POINT~~

QUIESCENT POINT (Q-point)

OR OPERATING POINT



The zero-signal values of collector current I_c and collector-to-emitter voltage V_{CE} are known as the operating point. This point is also called as quiescent point or Q-point. It is called as operating point because the variation in V_{CE} and I_c takes place about this point when signal is applied.

Faithful amplification! -

The process by which the strength of a weak signal is raised without changing its general shape is known as faithful amplification.

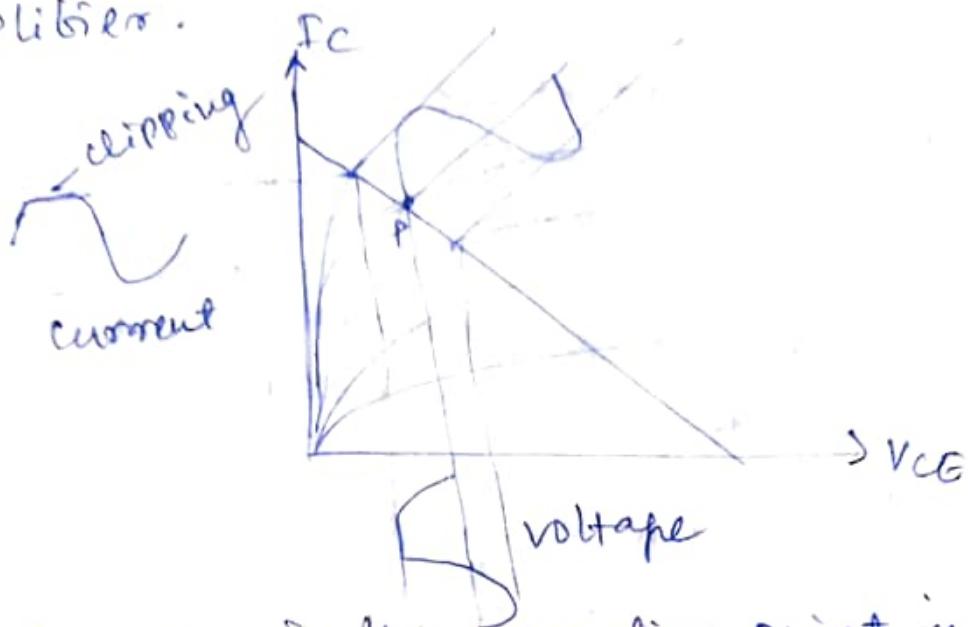
For faithful amplification is to keep the emitter junction in forward-biased and the collector junction is in reverse-biased during all parts of the signal.

- i) Minimum zero-signal collector current
- ii) Minimum base-emitter voltage
- iii) Minimum collector-emitter voltage.

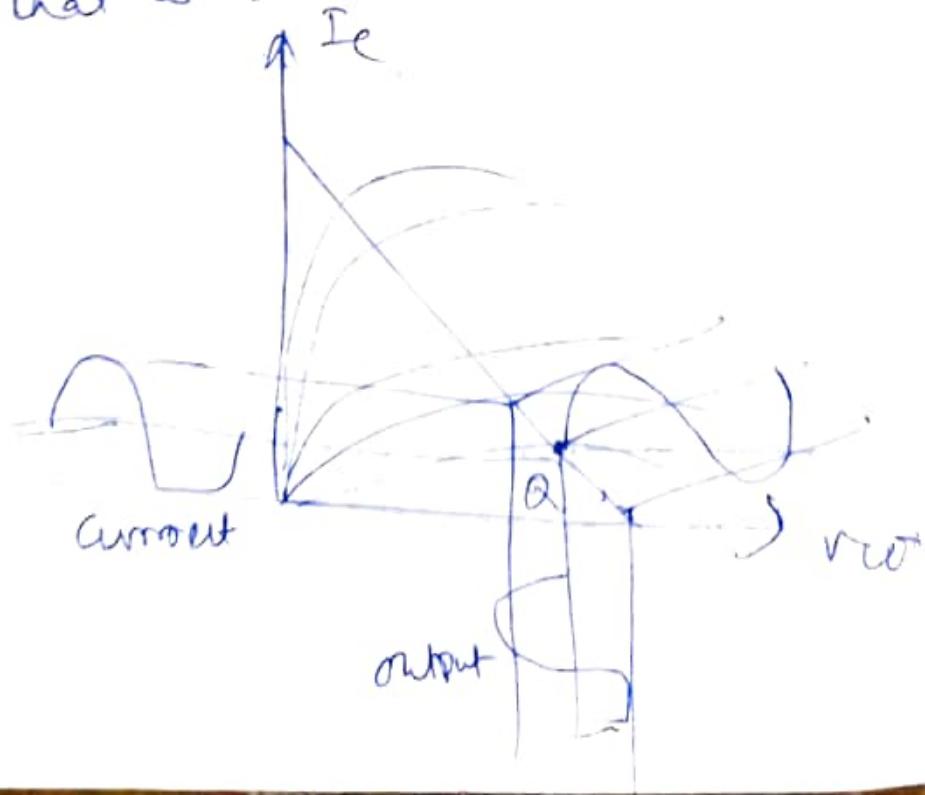
Niranjan Behara
Sr. Lect PKEIET, BARGARU

Selection of operating point

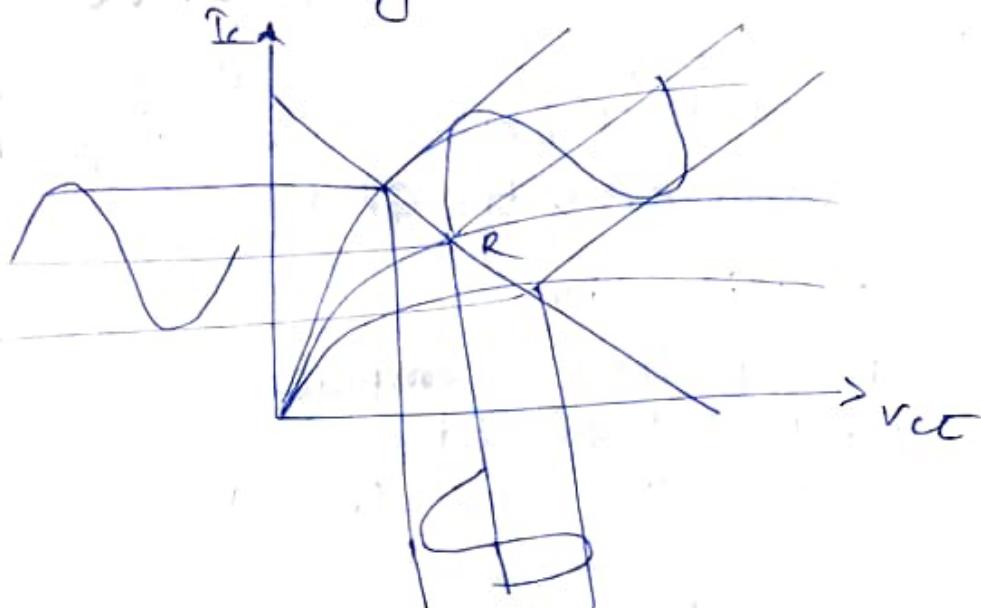
The operating point is fixed somewhere in the active region for ensuring the proper operation of the transistor as an amplifier.



Suppose if the operating point is chosen at a point P close to the saturation region, then the output current will be clipped at the positive peaks as the big so that is not a correct selection.



Similarly if we choose the point Q close to the cut-off region then the output signal will be clipped at the negative peaks as in fig. so that this point is also not a correct operating point.



Suppose we choose the operating point at the middle of the load line at R then the output will be developed without any clipping. Thus the correct operating point is selected.

Transistor Biasing

The process of raising the strength of a weak signal without any change in its general shape is referred to as faithful amplification.

1. Proper Zero Signal Collector Current. → Zero signal collector current should be at least equal to the maximum collector current

due to signal alone.

2. Minimum Proper base emitter voltage! -

The base emitter voltage V_{BE} should not fall below 0.7V for silicon transistor at any instant.

3. Minimum Proper collector emitter Voltage

The collector emitter Voltage V_{CE} should not fall below knee voltage (1V for silicon and 0.5V for Ge)

Bias Stabilization :

For faithful amplification the operating point should be at the middle of the load line. The operating point must remain stable throughout the operating following factors which are responsible for the shift of operating point! -

i) Temperature Dependence of Transistor Parameters! -

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

The variable β , I_B and I_{CBO} are temperature dependent. Hence with the increase in temperature any of these parameters change. Hence collector current changes and operating point is shifted.

ii) Variation in Parameters : The value of β and V_{BE} are not exactly the same for any two transistors even the same type. Thus when a transistor is replaced by

another of the same type the operating point may shift.

iii) Thermal runaway :

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

If temperature changes then I_{CBO} changes which in turn changes I_c and operating point. Flow of collector current in the collector circuit produces heat at the collector junction. This raises the temperature. Hence I_{CBO} increases which in turn increases collector current I_c . This again increases the temperature of collector junction and the whole process repeat again. Such a successive increase in I_c will drive the operating point into saturation region. This process is called thermal runaway.

Thermal runaway : Self destruction of transistor due rise in temperature is called thermal runaway.

Stability factor :

The rate of change of collector current I_c w.r.t the rate of change of collector leakage current I_{CBO} (I_0) at constant I_B and β is called stability factor.

$$S = \frac{dI_c}{dI_0} \text{ at constant } I_B \text{ & } \beta.$$

The stability factor shows the change in collector current I_c because of the change in

collector leakage current I_{C0} . The lower the value of stability factor s greater is the thermal stability of the transistor. The ideal value of stability factor is 1 but it is never achieved in practice. However the values of s below 25 results in ~~the~~ satisfactory.

$$I_C = \beta I_B + (\beta+1) I_{C0}$$

Differentiating the above expression w.r.t T :

$$1 = \beta \frac{d}{dT} I_B + (\beta+1) \frac{d}{dT} I_{C0}$$

$$= \beta \frac{dI_B}{dI_C} + \frac{\beta+1}{dI_C/dI_{C0}} = \beta \frac{dI_B}{dI_C} = \frac{B+1}{s}$$

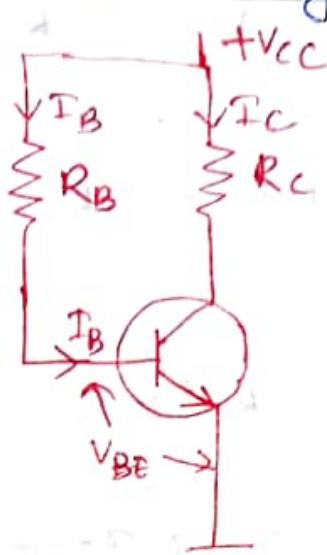
$$\text{or, } \frac{\beta+1}{s} = 1 - \beta \frac{dI_B}{dI_C}$$

$$\therefore s = \frac{(\beta+1)}{1 - \beta \frac{dI_B}{dI_C}}$$

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Methods of Transistor Biasing

① Base resistor biasing (fixed biased)



Here a single supply V_{ce} is used. The required value of zero signal base current to blow by selecting the proper value of base resistor R_B .

Now we will find the value of dc bias voltage and current in the base and collector of transistor.

Applying KVL for the input side, we get

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

$$\text{or, } I_B R_B = V_{ce} - V_{BE}$$

$$\text{or, } I_B = \frac{V_{ce} - V_{BE}}{R_B}$$

The value of voltages V_{ce} and V_{BE} are fixed. Therefore the value of base current depends on the base resistor R_B . The value of V_{BE} is small so neglected.

$$\text{Hence Base Current } I_B = \frac{V_{ce}}{R_B}$$

Applying KVL for output portion.

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

$$\text{or, } V_{CE} = V_{CC} - I_C R_C$$

The collector current I_C is given by

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

$$\text{or, } I_C = \beta I_B$$

$$\text{or, } I_C = \beta \frac{V_{CC}}{R_B}$$

Therefore the collector current does not depend on collector resistor.

Stability factor $S = \frac{\beta+1}{1-\beta \frac{dI_B}{dI_C}}$

In fixed bias circuit $\frac{dI_B}{dI_C} = 0$

because I_B is independent of I_C

$$\text{Hence } S = \frac{\beta+1}{1-\beta(0)} = (\beta+1)$$

Thus the stability factor of fixed bias is $(\beta+1)$ which is large value.

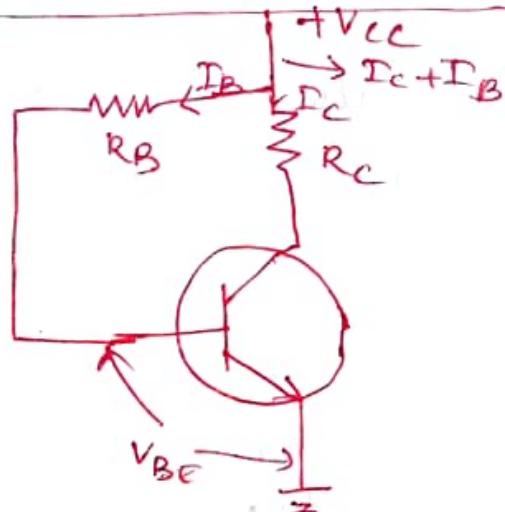
Advantage:

1. The biasing circuit is very simple as one resistance R_B is required.
2. Biasing condition can be easily set and the calculation are simple.

Disadvantage:

1. This method provides poor stability.
2. The stability factor is very high. Therefore, there are strong chances of thermal runaway.

Collector to Base resistor bias



In this circuit the base resistor is connected to the collector terminal of the transistor. The resistor R_B works as a feed back resistor.

Applying KVL to input loop,

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

$$\text{Or, } I_B (R_C + R_B) + I_C R_C + \cancel{V_{BE}} = V_{CC} - V_{BE}$$

$$\text{Or, } I_B (R_C + R_B + \beta R_C) = V_{CC} - V_{BE} \quad \boxed{I_C = \beta I_B}$$

$$\text{Or, } I_B (R_B + R_C (1 + \beta)) = V_{CC} - V_{BE}$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + R_C (1 + \beta)}$$

Since β is quite large, therefore

$$1 + \beta \approx \beta$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_C}$$

Collector current is given $I_C = \beta I_B$ is

$$I_C = \frac{V_{CC} - V_{BE}}{R_C + R_B / \beta}, \quad V_{CC} \gg V_{BE}$$

$$\text{Therefore } I_C = \frac{V_{CC}}{R_C + R_B/\beta}$$

consider the output or collector & emitter loop. Applying KVL

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

$$\text{Since } I_C \gg I_B$$

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

stability factor

$$S = \frac{\beta + 1}{1 + \beta \left(\frac{dI_B}{dI_C} \right)}$$

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

$$\text{or, } I_B (R_B + R_C) + I_C R_C = V_{CC} - V_{BE}$$

$$\text{or, } I_B (R_B + R_C) = V_{CC} - V_{BE} - I_C R_C$$

$$\text{or, } I_B = \frac{V_{CC} - V_{BE} - I_C R_C}{R_B + R_C}$$

Differentiating the above eqn. with respect to I_C .

$$\frac{dI_B}{dI_C} = \frac{-R_C}{R_B + R_C}$$

$$S = \frac{\beta + 1}{1 + \beta \left(\frac{R_C}{R_B + R_C} \right)}$$

Stability factor of collector & base bias circuit is smaller than its fixed bias circuit. Therefore this circuit has greater stability than fixed bias circuit.

Advantage:

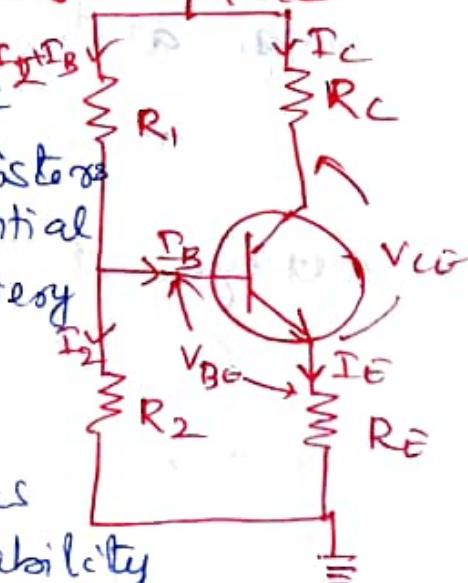
1. It is simple method. It requires only one resistor R_B .
2. The circuit provides some stabilization.

Disadvantage:

1. The operating point is not perfectly stabilized against variation in transistor parameter.
2. Because of negative feedback term of β to pass through resistor R_B the operating of circuit will be affected adversely and reduce the gain of the amplifier.

Self Bias OR Voltage Divider Bias

This is mostly used dc bias circuit. The resistors R_1 and R_2 form a potential divider across the battery V_{CC} . The voltage drop across the R_2 forward biases the emitter junction. The dc stability is provided by emitter resistor R_E . Let the input resistance or resistance looking into the base is much larger than resistor R_1 . Hence the base current flowing into the input resistance is negligibly small therefore current flow through resistor R_1 is



~~opposite~~ approximately equal to I_2 . Therefore two resistors R_1 and R_2 effectively come in series. Let voltage across the resistor R_2 is V_B which is also the base voltage V_B

$$V_B = \frac{V_{CE}}{R_1 + R_2} \cdot R_2$$

The voltage across the emitter resistor R_E is $V_E = V_B - V_{BE}$

the emitter current is then

$$I_E = \frac{V_E}{R_E} = \frac{V_B - V_{BE}}{R_E}$$

Hence, the value of collector current

$$I_C = I_E = \frac{V_B - V_{BE}}{R_E}$$

The voltage at the collector current

$$I_C = I_E = \frac{V_B - V_{BE}}{R_E}$$

The voltage at the collector

$$V_C = V_{CE} - I_C R_C$$

The collector to emitter voltage is given by

$$V_{CE} = V_C - V_E = V_{CE} - I_C R_E - I_E R_E$$

$$\text{Since } I_E = I_C$$

Therefore

$$V_{CE} = V_{CE} - I_C R_C - I_C R_E$$

$$\text{Or, } V_{CE} = V_{CE} - I_C (R_C + R_E)$$

From this equation it is clear that operating point is independent of β .

Stabilization Provided by R_E

Since $V_B = V_E + V_{BE}$

$$V_B = I_E R_E + V_{BE} = I_C R_E + V_{BE}$$

As collector current I_C increases due to rise in temperature the voltage drop across emitter resistor R_E increases. But voltage drop V_B is independent of I_C . Therefore V_{BE} decreases thus will decrease the value of I_B which in turn reduce the value of I_C to its original level.

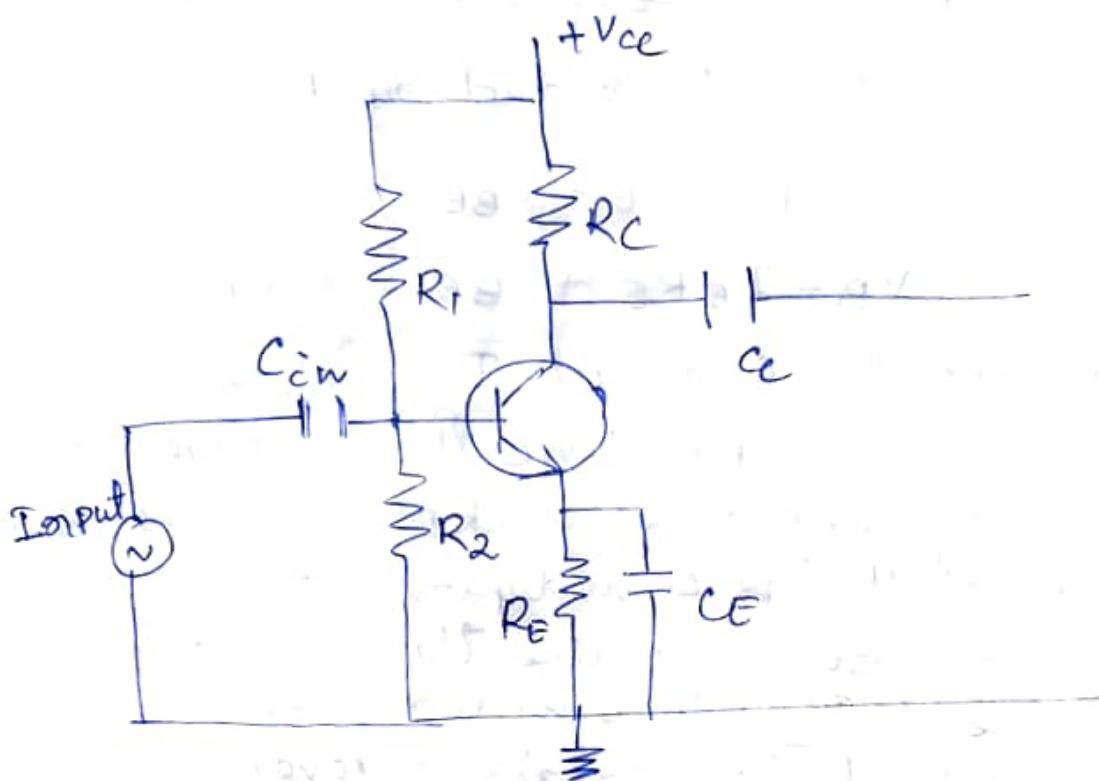
Stability factor:

In the above analysis we have seen that β does not appear in any of the expressions. It reveals that the operating point is independent of this parameter (β)!

The stability factor of this biasing circuit is 1. which is an ideal one. However in actual practice, its stability factor is around 10.

Advantage : The voltage divider biasing circuit provide scope of stabilisation, therefore the biasing circuit is invariably employed for transistor biasing.

Practical Transistor Amplifiers

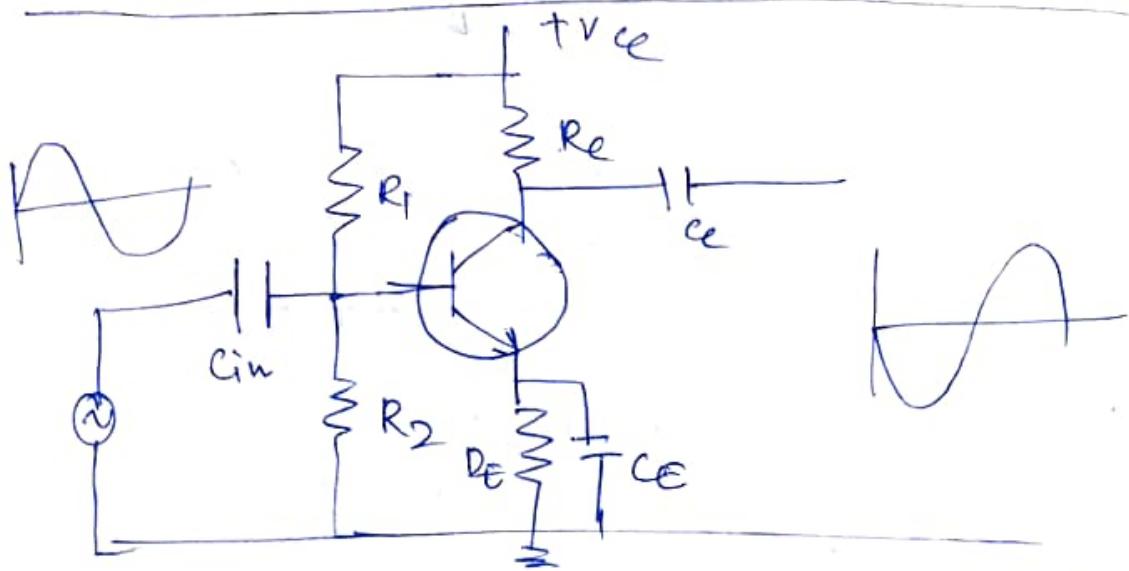


1. Biasing Circuit: - The resistors R_1 , R_2 and R_E form the biasing and stabilisation circuit.
2. Input capacitor C_{in} : An electrolytic capacitor C_{in} is used to couple the signal to the base of the transistor. The capacitor C_{in} allows only ac signal to flow but isolates the signal source from R_2 . If it is not used the signal source resistance will come across R_2 and thus change the bias. Typical value of C_{in} is $10\text{ }\mu\text{F}$.
3. Emitter bypass capacitor C_E : An emitter bypass capacitor C_E is used in parallel with R_E to provide a low ~~resistance~~ reactance path to the amplified ac signal.

If it is not used, then amplified ac signal flowing through R_E will cause a voltage drop across it thereby reducing the output voltage. Typical value of C_E is 100 μF .

4. Coupling capacitor C_C : - The coupling capacitor C_C couples one stage of amplifier to the next stage. If not used, the bias conditions of the next stage will be drastically changed due to the shunting effect of R_C . This is because R_C will come in parallel with the resistance R_1 of the biasing network of the next stage. Thereby it alters the biasing conditions of next stage. The coupling capacitor C_C isolates the dc of one stage from the next stage but allows the passage of ac signal. Typical value of C_C is 10 μF .

Phase Reversal of Input and output

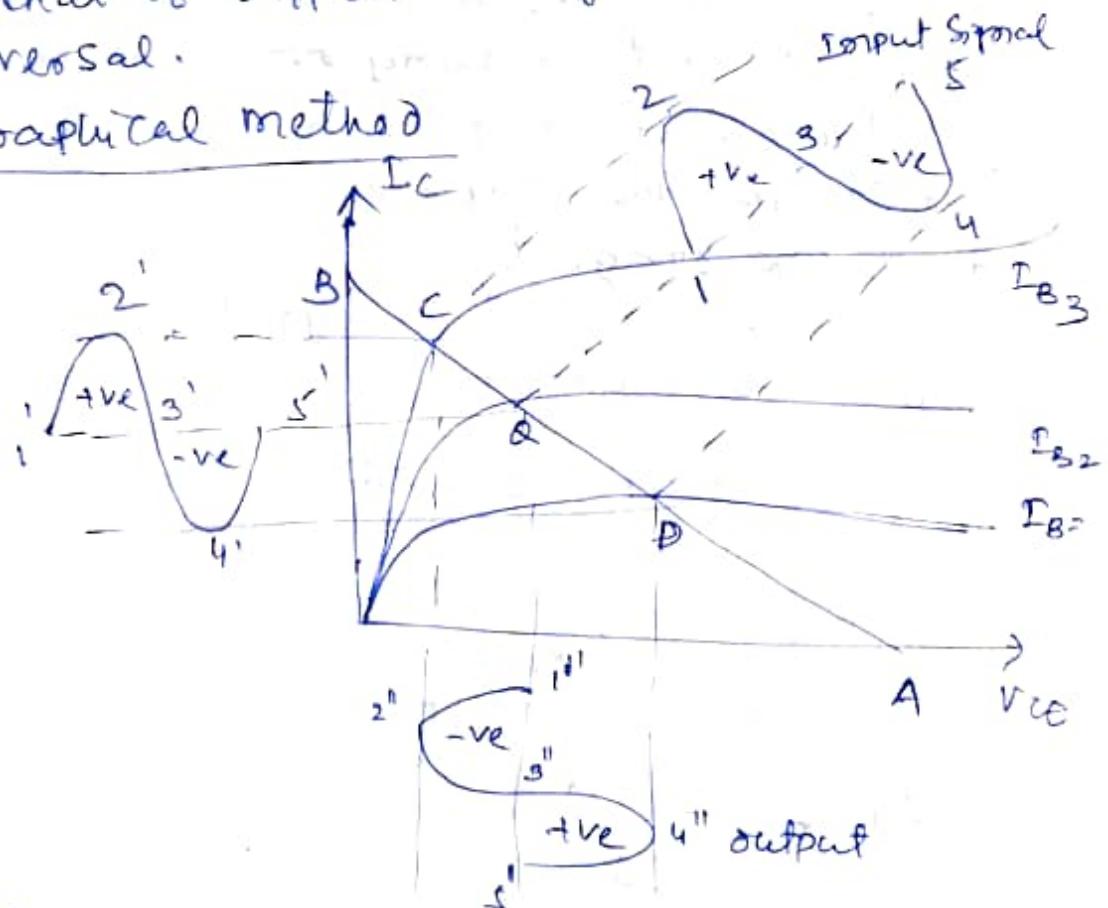


The output voltage is given by the expression $V_{CE} = V_{CC} - i_C R_C$.

When ac signal voltage increase in the positive half-cycle, this increase the bias

Potential for emitter junction which is turned increases the base current. This result in increase in collector current ($i_c = B i_B$) and hence the voltage drop $i_c R_C$ also increases. Since V_{CE} is constant the output voltage ($V_{CE} = V_{CC} - i_c R_C$) decrease. It can be stated that when signal voltage V_{in} increases in the positive half-cycle, the output voltage V_{out} increases in the negative half-cycle. It shows that the output voltage is 180° out of phase to that of input voltage. This is called phase reversal.

Graphical method



From the above graph when the base current is maximum at point 2 (Point C on load line), the collector-emitter voltage V_{CE} becomes minimum at point 2''. On the other hand when the base current is minimum at Point 4 (Point D on load line), the collector-emitter V_{CE} voltage becomes

maximum at Point 4 (Point D on load line). Hence the input and output voltage are 180° out of phase from each other.

Niranjan Behera

Sr. Lect PKAIEI BGH

MULTI-STAGE TRANSISTOR

Niranjan Behera

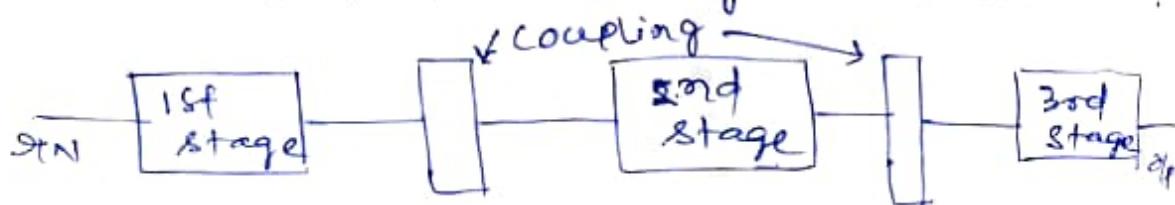
AMPLIFIER

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A transistor circuit in which a number of amplifier stages are used in succession is called a multi-stage or cascaded amplifier.

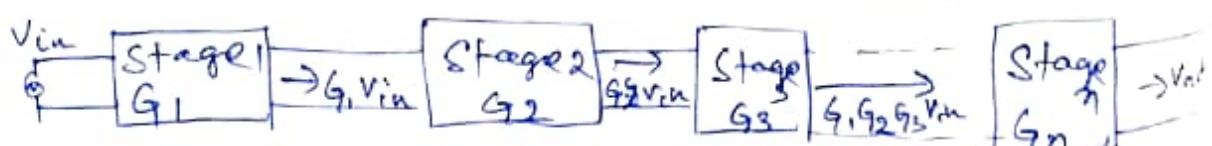
In multi-stage amplifier, the output of one stage is connected to the input of the next stage through a suitable coupling device and so on. The function of coupling device is

- i) to transfer only ac output of one stage to the input of the next stage.
- ii) to block dc component and isolate the dc condition of one stage from the other.



Gain: The ratio of output to the input of an amplifier is called gain. usually it is represented by letter "G".

Gain of a multi-stage amplifier



Let V_{in} be the input of the first stage and $G_1, G_2, G_3 \dots G_n$ be the gain of the first, second, third and n^{th} stage of the amplifier respectively.

OIP of the 1st stage = $G_1 V_{in}$

OIP of the 2nd stage = $(G_1 G_2) V_{in}$

OIP of the 3rd stage = $(G_1 G_2 G_3) V_{in}$

OIP of the nth stage = $(G_1 G_2 G_3 \dots G_n) V_{in}$

Overall gain of multistage amplifier

$$G = \frac{V_{out}}{V_{in}} = \frac{(G_1 G_2 G_3 \dots G_n) V_{in}}{V_{in}}$$

$$G = G_1 G_2 G_3 \dots G_n$$

The overall gain of a multistage amplifier is equal to the product of gains of individual stages. In practical the overall gain G is always less than $G_1 G_2 G_3 \dots G_n$ because of the loading effect of the next stages.

Decibel :

The common logarithm (log to the base 10) of power gain is known as bel power gain i.e.

$$\text{Power gain} = \log_{10} \frac{P_{out}}{P_{in}} \text{ bel}$$

In other words bel is the unit of gain and is defined as the common logarithm of power gain.

$$\text{No. of bels} = \log_{10} \frac{P_{out}}{P_{in}}$$

$$1 \text{ bel} = 10 \text{ dB}$$

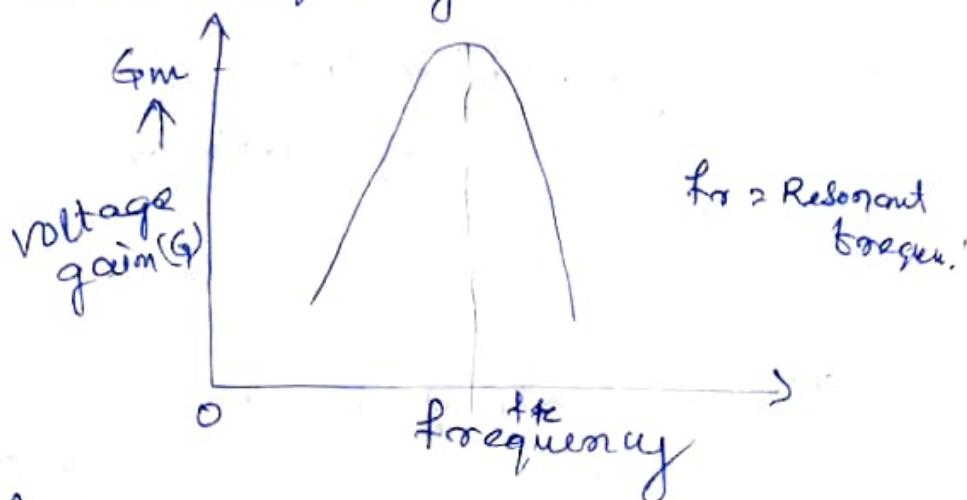
$$\text{Power gain} = 10 \log_{10} \frac{P_{out}}{P_{in}} \text{ dB}$$

$$\text{Voltage gain} = 20 \log_{10} \frac{V_{out}}{V_{in}} \text{ dB} \quad (P = \frac{V^2}{R})$$

$$\text{Current gain} = 20 \log_{10} \frac{I_{out}}{I_{in}} \text{ dB}$$

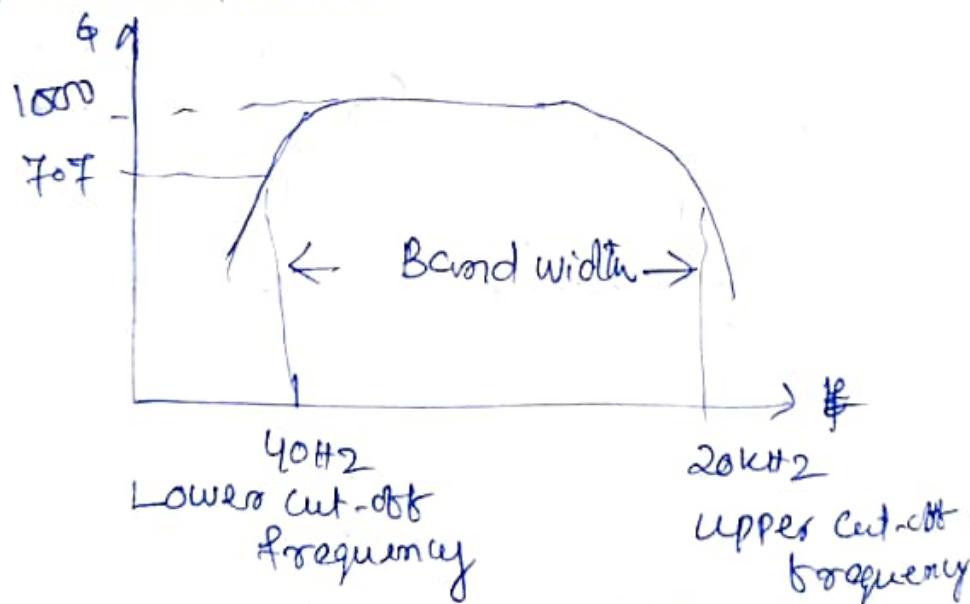
Frequency Response :-

The curve drawn between voltage gain and signal frequency of an amplifier is known as its frequency response.



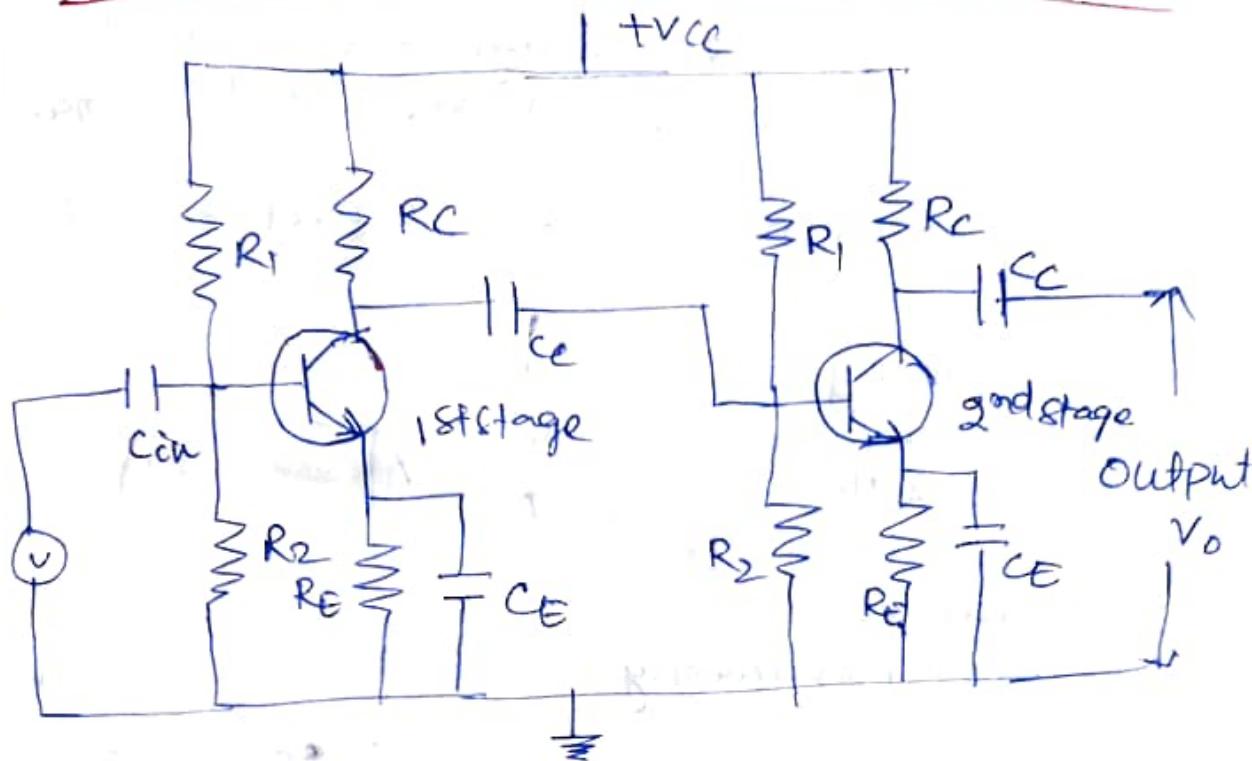
Bandwidth :-

The range of frequency over which the gain of an amplifier is equal to or greater than 70.7% of its maximum gain is known as bandwidth.



The range of frequency within which the voltage gain of an amplifier falls by 3dB from its maximum gain is called bandwidth of that amplifier.

R-C coupled amplifier (Two stage)



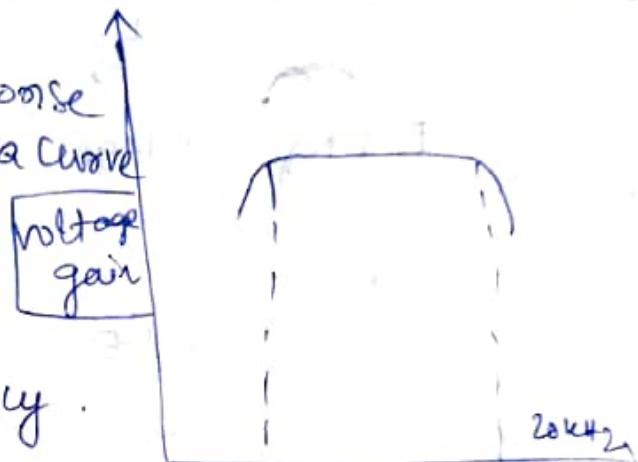
In R-C coupled amplifier signal developed across the collector resistor of each stage is coupled through the capacitors into the base of next stage. The overall gain is equal to the product of gain of individual stages.

Working: When the input voltage V_{in} applied to the base of the first transistor through a input capacitor C_{in} it appears in the amplified form across its collector load R_C . The output of the first stage is given to the base of the next stage through coupling capacitor C_{CE} . The second stage does the further amplification of the signal. The coupling capacitor here helps, the blocking of flow of dc component from first stage to the second

stage, thus the biasing of the second stage will not be disturbed. However the output signal of two stage R-C coupled amplifiers is in phase with the input signal.

Frequency Response of RC Coupled Amplifier

The frequency response of an amplifier is a curve which shows the relationship between the voltage gain as a function of frequency.



It may be observed that the voltage gain drops off at low frequency i.e. below 50 Hz and at high frequency i.e. above 20 kHz and remains constant in the mid-frequency range.

i) At low frequencies (below 50 Hz)

$X_C = \frac{1}{2\pi f_C}$ At low frequencies the capacitance C_C is quite large. Therefore it will allow only a small part of the signal to pass from one stage to the next stage. The emitter bypass capacitors cannot short the emitter capacitors effectively due to its large reactance at low frequencies. Thus because of these two factors, the voltage gain rolls off at low frequencies.

ii) At high frequencies (above 20 kHz)

In this frequency range the reactance of C_C becomes quite small; therefore it will behave like a short circuit. As a result of this the loading effect of next stage increases which reduces the voltage gain.

iii) At Mid frequencies (i.e. 50 Hz to 20 kHz)

The effect of coupling capacitor, in this frequency range is such that it maintains constant voltage gain. Hence as the frequency increases, the reactance of capacitor C_C decreases which tends to increases the gain. However at the same time the lower capacitive reactance increases the loading effect of the next stage due to which the gain reduces. These two factors almost cancel each other. Therefore a constant gain is maintained throughout this frequency range.

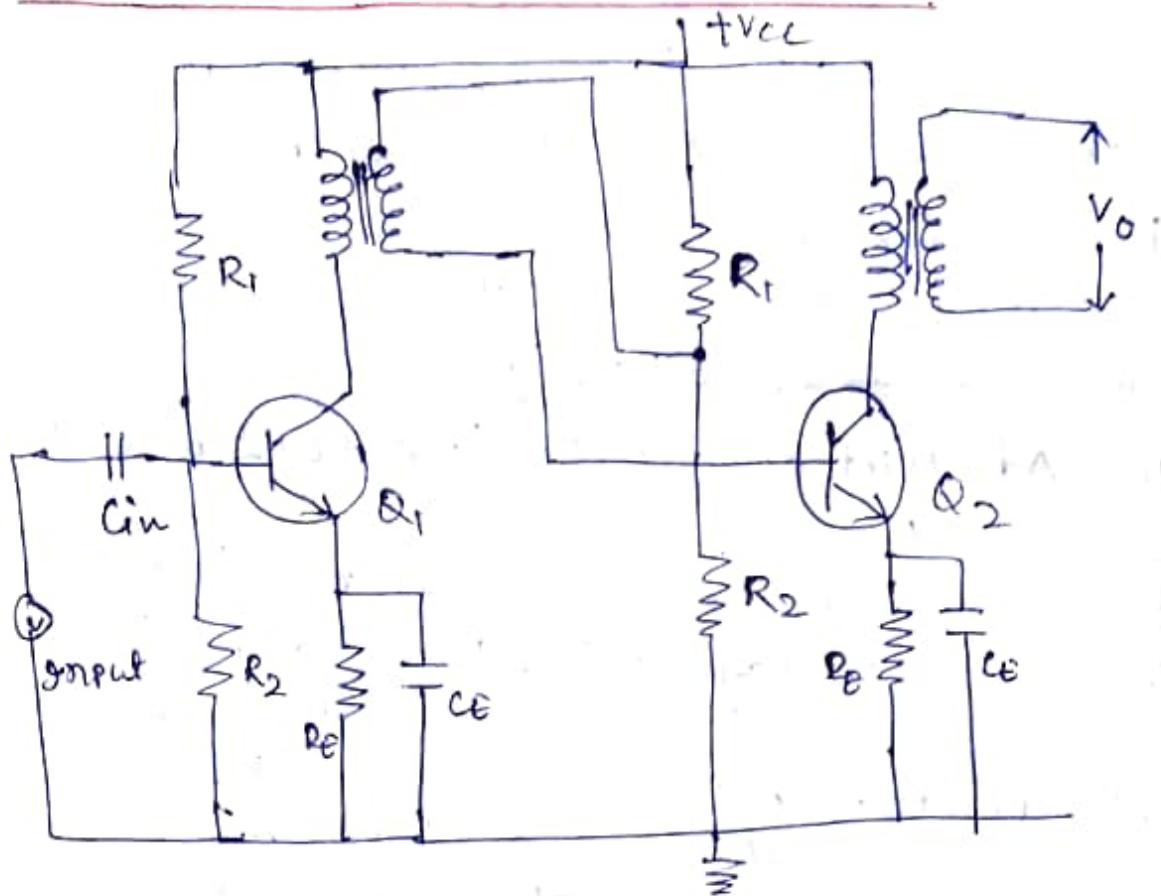
Advantage

1. It is the most convenient and least expensive multistage amplifiers.
2. It has a wide frequency response.
3. It provides less frequency distortion.

Disadvantage :-

1. The overall gain of the amplifier is comparatively small due to the loading effect of successive stage.
2. It has tendency to become noisy with age, especially in moist climates.
3. It provides poor resistance matching between stages.

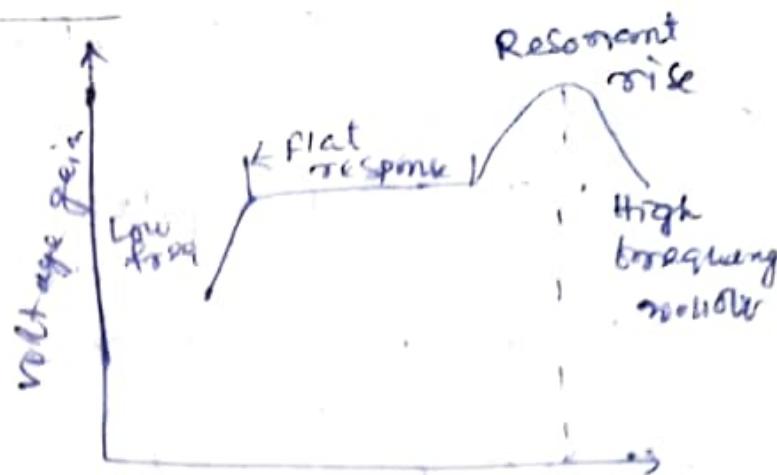
Transformer coupled amplifier



The function of transformer is to couple the ac output signal from the output of the first stage to input of next stage. The input coupling capacitor is C_{in} and the CE is emitter by pass capacitor.

Working: When an ac input signal is applied to the base of transistor Q₁, it appears in the amplified form across primary winding of the transformer T₁. The voltage developed across the primary winding is then transferred to the input of the next stage by the secondary winding of the transformer T₁. The second stage does amplification in an exactly similar manner.

Frequently Response



From the frequency response frequency curve that the voltage gain drop off at low as well as at high frequencies. It remains a constant in mid-frequency range. At low frequencies the reactance of primary winding ($X_L = W_L$) starts to decrease and thus the voltage gain reduces. At high frequencies the effect of leakage inductance and distributed capacitance (i.e. the capacitance between the turns of the winding) becomes significant. Therefore voltage gain reduces. The peak gain results because of the resonant effect of inductance and distributed capacitance, which forms a resonant circuit. It has been observed that there is less flat part in frequency response curve of transformer coupled amplifiers. Because of this, these amplifiers cannot be used over a wide range of frequencies.

Advantage

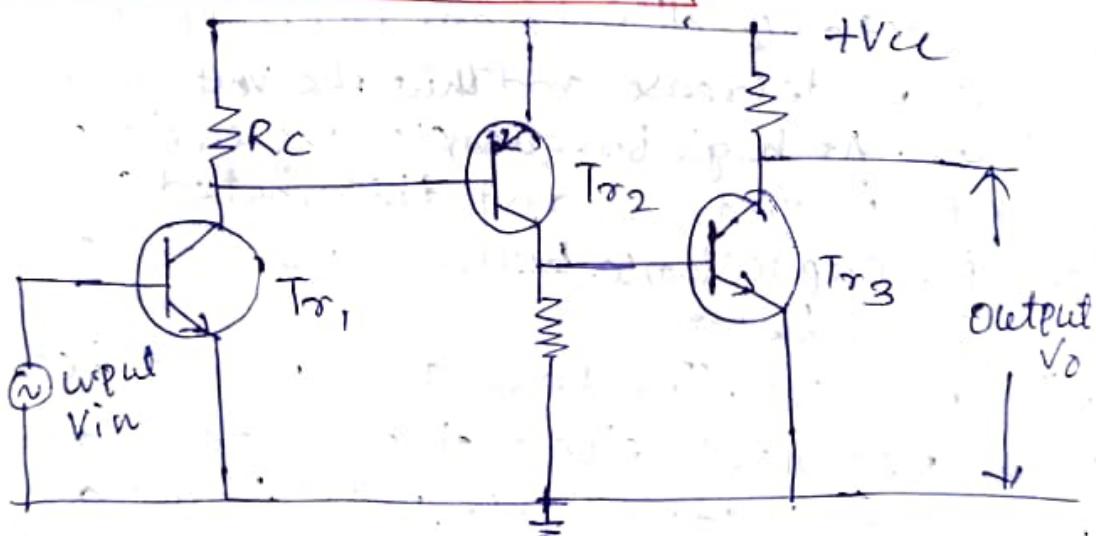
1. No signal power is lost in the collector or base resistor because of the low winding resistance of the transformer.
2. It provides a higher voltage gain than the RC coupled amplifiers.

3. It provides an excellent impedance matching between the stages.

Disadvantage:

1. The coupling transistor is expensive and bulky
2. At radio frequencies the winding inductance and distributed capacitance produce reverse frequency response.
3. It tends to produce hum in the circuit which is highly undesirable.

Direct-coupled amplifier:



In this method of coupling complementary transistors are used. If NPN transistor is used in the first stage then PNP transistor is used in the second stage and so on. The o/p of 1st stage is fed directly to the input of next stage, hence the name direct coupled amplifier. No coupling device like capacitor or transistor is used.

Operation

A weak signal of very low frequency (10Hz) is applied to the base of first transistor T_1 . Due to transistor action, an amplified signal is obtained across the collector resistor R_C . This amplified signal is further fed to the base of the next transistor and so on.

The complementary transistors are applied in this case to make the circuit stable w.r.t temperature change since no other biasing/stability circuitry is provided. When base current increases due to temperature rise, the collector current increases by β but it is opposite for the other transistor. Hence the variation in one transistor tends to cancel that in the other.

Advantage

- i) The circuit arrangement is simple as a few components (i.e. resistors) are used
- ii) The cost of this amplifier circuit is low as no expensive coupling device is used.

Disadvantage

- i) It cannot be used to amplify high frequency signals
- ii) Temperature may shift the operating point.

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(COMPARISON OF DIFFERENT TYPE OF MULTI-STAGE AMPLIFIER)

<u>Particular</u>	<u>R-C coupled</u>	<u>Transistor coupled</u>	<u>DC coupled</u>
1. Cost	Low	High	Minimum
2. Space	Less	More	Least
3. Weight	Less	More	Least
4. Impedance Matching	Not So Good	Excellent	Good
5. Frequency Response	Excellent in audio-freq range	Poor	Best
6. Uses	i) Voltage amplification ii) Audio frequency amplification	Power amplification Radio frequency amplification	For amplification of extremely low frequencies

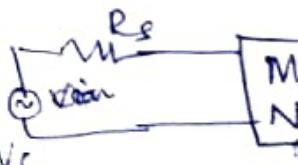
FEED BACK

The process of injecting a portion of output energy of some device back to the input is known as feedback. Depending upon whether the feedback energy adds or opposes the input signal, there are two basic types of feedback in amplifiers.

These are

1. Positive feedback
2. Negative feedback

1. Positive feedback
is in Phase add it.
the amplifier and insta oscillator
2. Negative feedback
the feed out of Phase opposes it to the amplifier noise and bandwidth compensation feedback
Negative

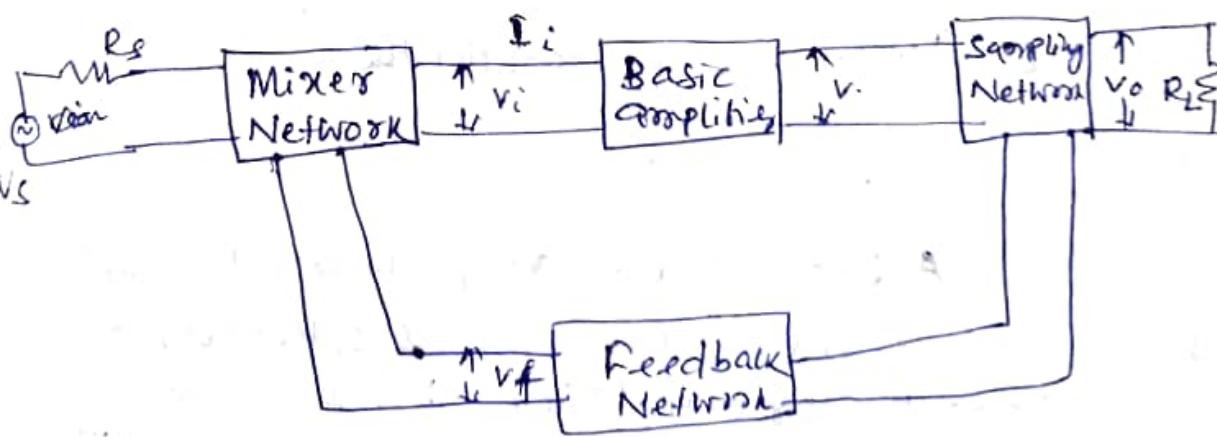


1. Basic
the signal gain

1. positive feedback: In positive feedback, the feedback energy (voltage or current) is in phase with the input signal and thus adds it. Positive feedback increases gain of the amplifier also increases distortion, noise and instability. Positive feedback is used in oscillators.

2. Negative feedback: In negative feedback the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it. Negative feedback reduces gain of the amplifier. It also reduces distortion, noise and instability. This feedback increases bandwidth and improves input and output impedance. Due to these advantages, the negative feedback is frequently used in amplifiers.

Negative feedback amplifier:



Block diagram of feedback amp.

1. Basic amplifier: This stage simply amplifies the signal that present at its input. The voltage gain of this amplifier is A .

2. Sampling Network : Using this network we sample the output voltage or current. The sampled energy is fed to feedback network.

3. Feedback Network : This network is a passive two-port network and it gives feedback energy (current or voltage) at its output multiplied by the feedback factor by having the input from sampling network.

4. ~~Mixer~~ Network : This network mixes the feedback energy with the applied input.

Advantages of Negative feedback :

1. Stability of transfer gain
2. Reduction in distortion
3. Reduction in noise
4. Improvement in frequency response
5. Modification of input and output resistance
6. Increase in bandwidth

Power amplifier :

A transistor amplifier which raises the power level of the signals is known as transistor power amplifier. In the communication system the last stage of multistage amplifier is the power stage. A power amplifier differs from the voltage amplifier.

<u>Particular</u>	<u>Voltage amplifier</u>	<u>Power amplifier</u>
1. Current gain B	High > 100	Low (20 to 50)
2. Output resistance R_C	High ($4-10\text{k}\Omega$)	Low ($5-20\Omega$)
3. Coupling	R-C coupling	Transformer coupling
4. Input voltage	Low of few mV	High (2-4 V)
5. Collector current	Low ($\times 1\text{mA}$)	High $> 100\text{mA}$
6. Power output	Low	High
7. Output impedance	High ($12\text{k}\Omega$)	Low (20Ω)
8. Power dissipation rating of active device	Need not be large	Should have large rating
9. Necessity of cooling arrangements	Not necessary	Cooling arrangement and heat sinks are needed.
10. Application	As a pre-amplifier	In output stage.

CLASSIFICATION OF POWER AMPLIFIERS

The power amplifiers can be classified in the following ways.

- According to the usage of frequency signals.
 - Audio frequency power amplifier
 - Radio frequency power amplifier
 - Video frequency power amplifier

Operation: The input signal appears across the secondary terminal AB of the driver transformer. During the first half cycle (ive) of the signal, end A becomes positive and end B negative. This will make the base-emitter junction of transistors Tr_1 forward biased and that of transistors Tr_2 reverse biased. The current will be conducted through transistor Tr_1 only. Whereas transistor Tr_2 is cut-off state and will not conduct any current. Therefore first half-cycle of the signal is amplified by the transistor Tr_1 and appears in the upper half of the primary of the output transformer.

During the second half-cycle (ive) of the signal, end B becomes positive and A negative. This will make the base-emitter junction of transistor Tr_2 forward biased (conducting state) and that of transistor Tr_1 reverse biased (cut-off state). Hence current is conducted by the transistor Tr_2 . This half cycle of the signal is amplified by Tr_2 and appears in the lower half of the output transformer primary.

The center tapped primary of the output transformer combines the two halves of the cycle and forms a complete sine wave output at the in the secondary.

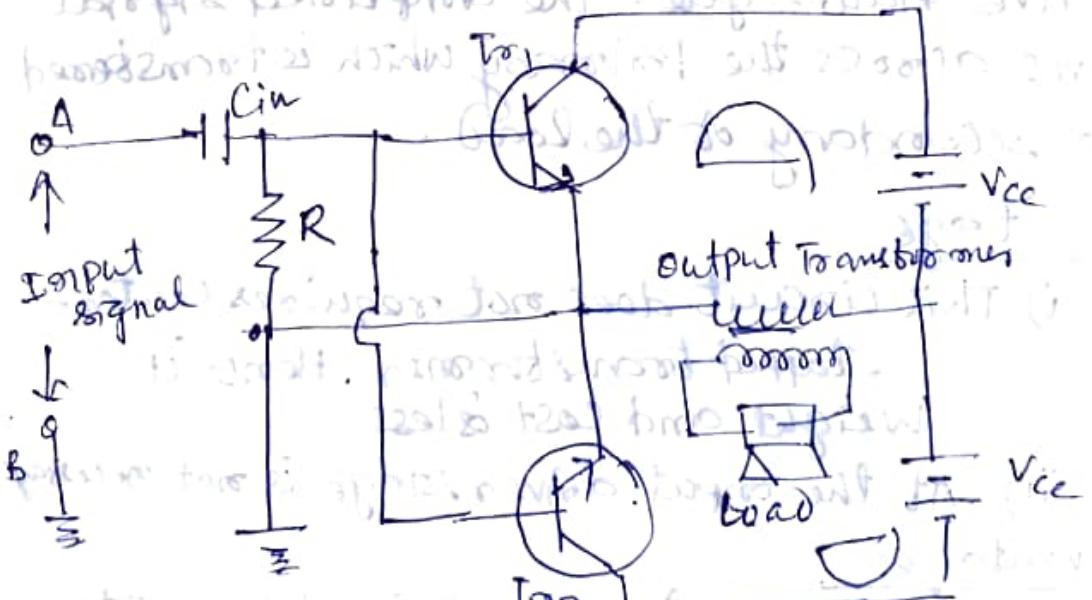
Advantage

- i) collector efficiency is quite high ($\approx 75\%$) due to class-B operation
- ii) Distortion free output is obtained
- iii) They give more ac o/p power per device

Disadvantage

- i) two identical transistors are required
- ii) It requires two equal and opposite voltage at input, therefore driver stage has to be employed.
- iii) If the parameters of two transistors differs, there will be unequal amplification of two halves of the signal which introduces more distortion.

~~COMPLEMENTARY-SYMMETRY PUSH-PULL AMPLIFIER~~



The circuit employs two transistors one npn and the other pnp. No centre tap transformer is used. An ordinary output transformer is employed for impedance matching to get maximum output across the load. The dc supply is provided by the center tap battery or by two separate batteries of half the voltage.

Operation: The input signal approaches the terminal AB. During the positive half cycle of the input signal, the transistor Tr₁ (NPN) conducts current while transistor Tr₂ (PNP) does not conduct as it is at cut-off state. During the negative half-cycle of the input signal, the transistor Tr₂ (PNP) conducts current while transistor Tr₁ (NPN) does not. Hence NPN transistor amplifies the positive half-cycle whereas PNP transistor amplifies the negative half-cycle. The amplified signal appears across the primary which is transferred to the secondary of the load.

Advantage

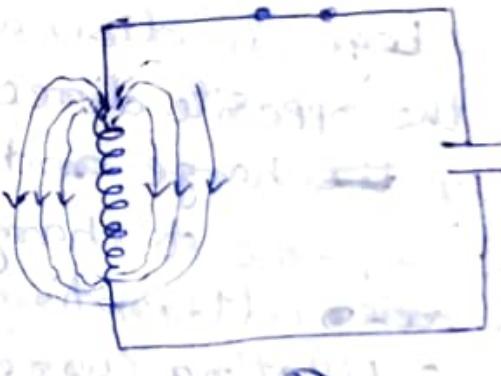
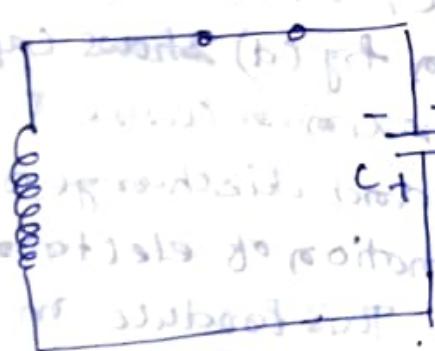
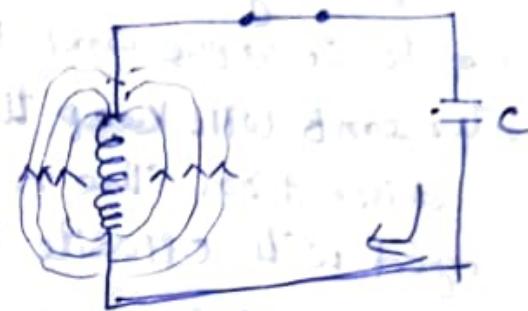
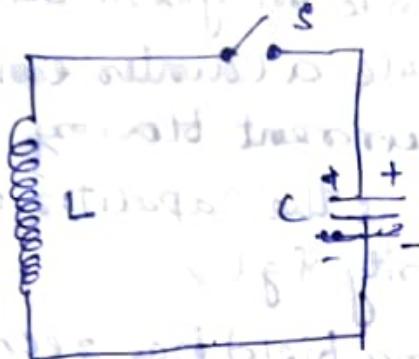
- i) This circuit does not require center-tapped transformer. Hence it weight and cost is less
- ii) At the input driver stage is not required

Disadvantage

- i) It is difficult to get a pair of transistors (NPN and PNP) having exactly same characteristic
- ii) We requires two batteries although of half the voltage.

Oscillator circuit:

A circuit which produce electrical oscillations of any desired frequency is known as an oscillatory circuit or tank circuit. A simple oscillator circuit consists of a capacitor (C) and inductance (L) in parallel.



Theoretically the capacitor is charged from a DC source with a Polarity as in fig (a). In the position, the upper plate of capacitor charge with positive and lower plate with negative. Therefore, there is a voltage across the capacitor and the capacitor has electrostatic energy.

When switch is closed. The capacitor will discharge through inductance and the electron flow will be in direction indicated by arrow. This current flow step up magnetic

field around the coil. Due to the inductive effect, the current build up slowly towards a maximum value. The circuit current will be maximum when the capacitor is fully discharged. At this instant electrostatic energy is zero but the magnetic field around the coil is maximum. Obviously the electrostatic energy stored in the capacitor is completely converted into magnetic field will begin to collapse and produce a counter emf. The counter emfs will keep the current flowing in the same direction. The result is the capacitor is now charged with opposite polarity fig (c).

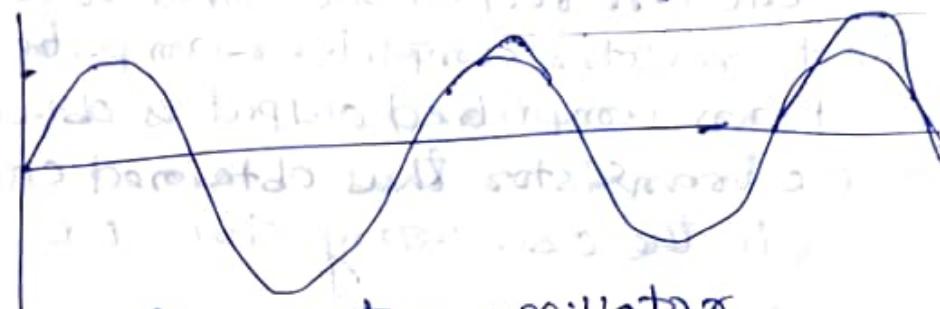
After the collapsing field has recharged the capacitor now begins to discharge, current now begins to discharge, current now flowing in the opposite direction fig (d) shows capacitor fully ~~dis~~charge and maximum current flowing. The sequence of charge and discharge results in ~~the~~ alternating motion of electrons or an oscillating current. This produce an oscillation.

Types of oscillation :

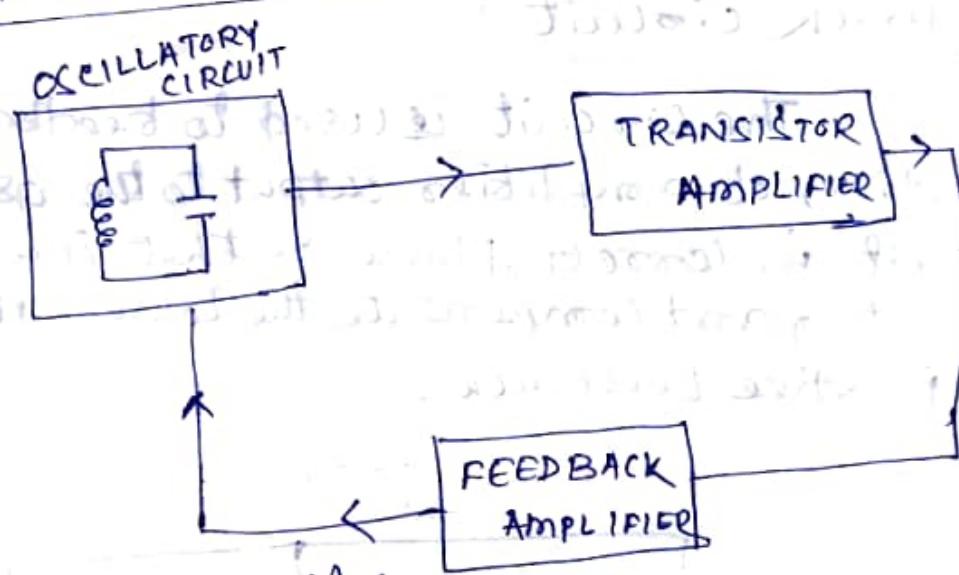
- 1) Damped Oscillation : The electrical oscillations in which amplitude decrease with time are known as damped oscillation. These oscillations are produced by the system in which no means are provided to compensate the losses.



② Undamped oscillation: The electrical oscillations in which amplitude does not change with time, are known as undamped oscillations. These oscillations are produced by the system in which some means are provided to compensate for losses.



Essentials of a transistor oscillator



Oscillatory circuit:

An oscillatory circuit contains inductive coil L and capacitor C connected in parallel with each other. The frequency of oscillations depends upon the value of inductance of the coil and capacitance of the capacitor

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

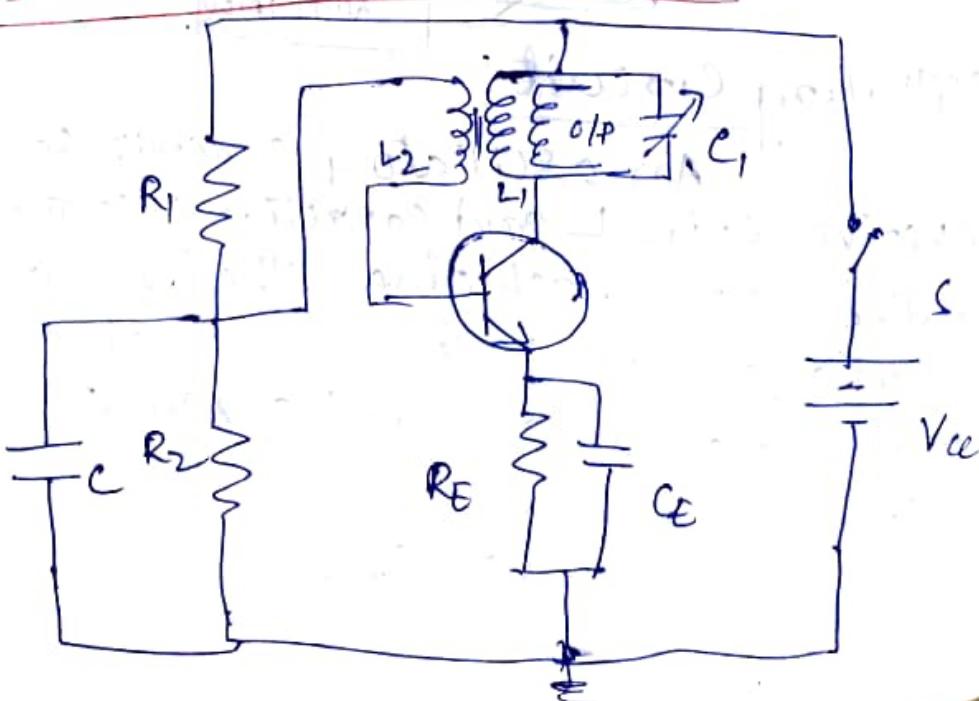
Transistor amplifiers! -

To compensate losses that occur in the oscillatory circuit, a source energy is required. That source of energy is combination of battery and transistor working as an amplifier. The oscillations produced by the oscillatory circuit are fed at the input of a transistor amplifier. The transistor amplifier amplifies these oscillations. An amplified output is obtained. The output of the transistor thus obtained can now be supplied back to the oscillatory circuit to compensate the losses.

Feedback circuit :

The circuit is used to feedback a fraction of amplifier's output to the oscillatory circuit in correct phase so that it aid the oscillation and compensate the losses. This is the positive feedback.

TUNED COLLECTOR OSCILLATORS !

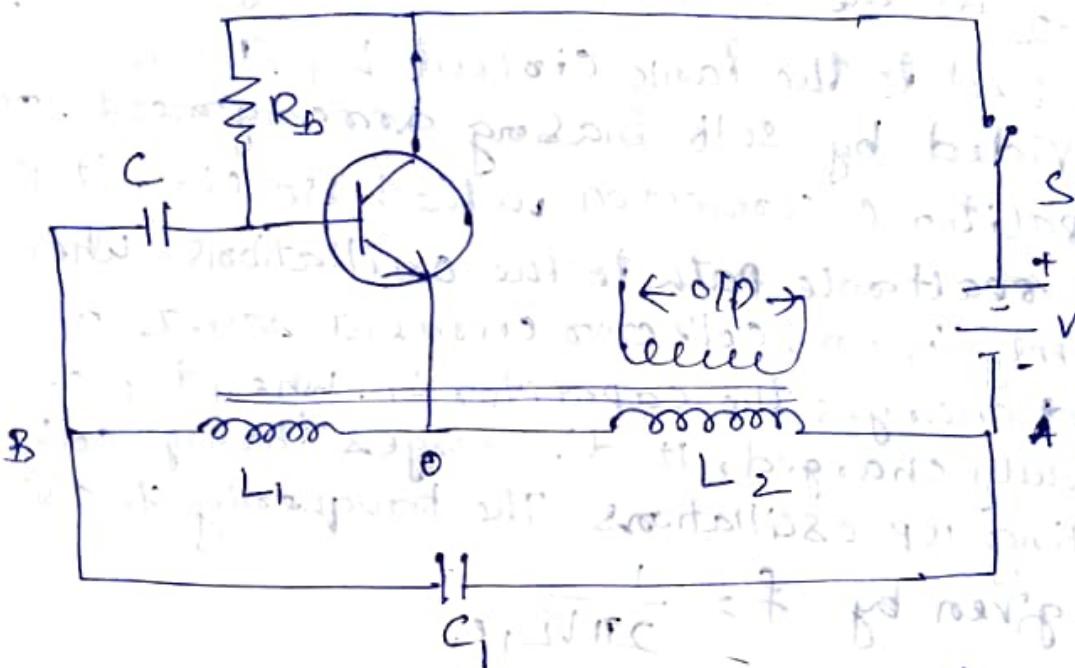


It contains a tuned ~~collector~~ ^{Circuit} oscillator L_1, C_1 in the collector load. The feedback coil L_2 in the base circuit is magnetically coupled to the tank circuit L_1 . The biasing is provided by self biasing arrangement. The capacitor C connected in the base circuit provides low reactance path to the oscillations. When the supply is on, collector current starts rising and charges the capacitor C_1 . When the capacitor is fully charged, it discharges through coil L_1 setting up oscillations. The frequency of oscillation is given by $f = \frac{1}{2\pi VL_1C_1}$

These oscillations induced some voltage in coil L_2 . The voltage across L_2 is applied between base and emitter and appears in the amplified form in the collector circuit; thus overcoming the losses occurring in the tank circuit.

A phase shift of 180° is created between the voltage L_1 and L_2 due to transformer action. A further phase shift of 180° takes place between base-emitter and collector circuit of transistor. As a result the energy feedback to the tank circuit is in phase with the generated oscillations.

Hartley oscillator



It is the most popular oscillator and is commonly used in radio receivers, it is because of its easy adaptability to a wide range of frequencies.

Ckt. analysis: It consists of two coils L_1 and L_2 wound over the same core. Thus mutual inductance exists between them. A capacitor C_1 is connected across the combination of L_1, L_2 to form the L-C circuit. The frequency of oscillation is determined by L_1, L_2 and C_1 .

Operation: When switch is closed, capacitor C_1 is charged. The capacitor discharges through L_1 and L_2 setting up oscillations of ~~constant~~ frequency.

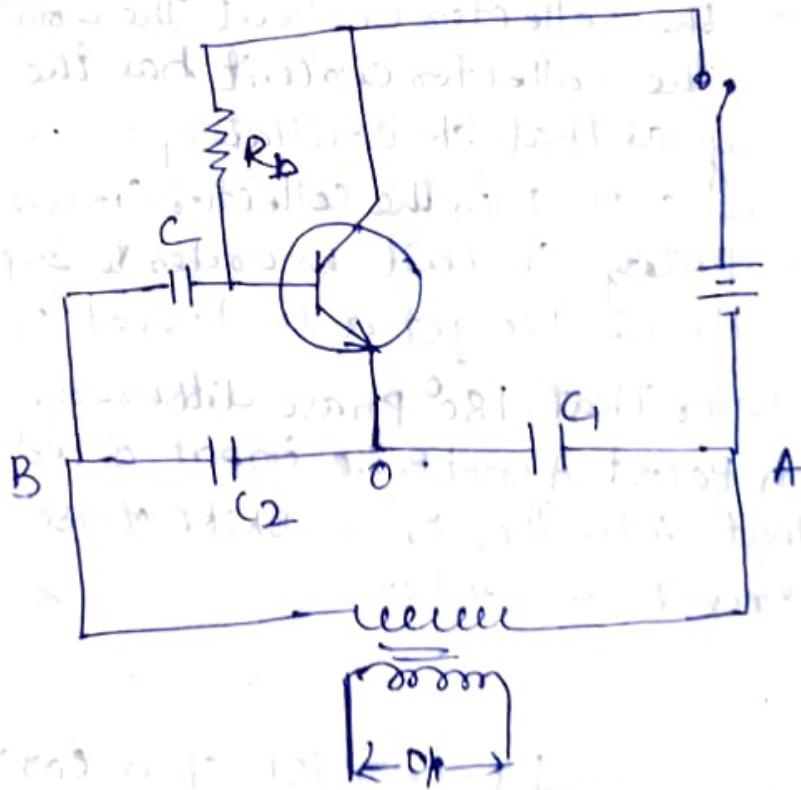
$$f = \frac{1}{2\pi V_{cc} L_T}$$

$$L_T = L_1 + L_2 + m$$

m = mutual inductance

The oscillations between O and B are applied in the base circuit and appear in the amplified form in the collector circuit. The amplified output has the same frequency as that of oscillatory circuit and supplies the losses which are occurring in the oscillatory circuit. This energy is supplied by the collector battery. Thus energy is being continuously supplied by the collector battery to make up the losses occurring in the oscillatory circuit and hence undamped oscillation is obtained.

CULPITT'S OSCILLATOR



It is similar to Hartley oscillator. The only difference is that coupling is capacitive instead of being inductive.

The tank circuit consists of an inductive coil in parallel with two capacitors C_1 and C_2 which are in series. The resistor R_b provides the necessary biasing. The frequency of oscillation is given by.

$$f = \frac{1}{2\pi\sqrt{LC_T}} \quad \text{where } C_T = \frac{C_1 C_2}{C_1 + C_2}$$

Operation : - When switch S is closed capacitor C_1 and C_2 are charged and these capacitors discharge through the coil L . Setting up oscillation frequency

$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

The oscillations across C_2 are applied to the base circuit and appear in the amplifier section in the collector circuit. The amplified output in the collector circuit has the same frequency as that of oscillatory circuit. The amplified output in the collector circuit is fed to the oscillatory circuit in order to supply the losses. Hence we get a undamped oscillation.

It is clear that 180° phase difference is created between Point A and B i.e. input is 180° out of phase with output. A further phase shift of 180° is produced by the transistor action.

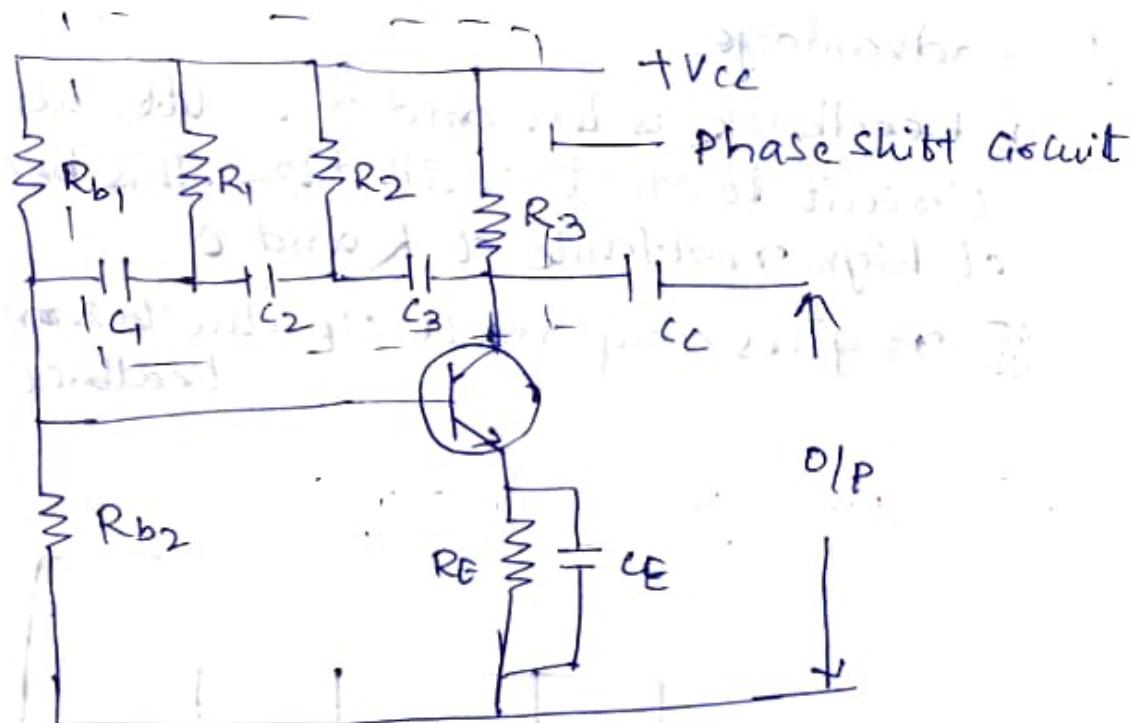
R-C Phase Shift oscillator

It consists of a conventional single transistor and RC phase shift network. The collector is connected to the base through Phase shift network. It may be seen that the Phase shift network consists of three similar sections $R_1 C_1$, $R_2 C_2$, and $R_3 C_3$. The values are so

selected that each section produces a phase shift of 60° . Thus the total phase shift of 180° is produced by the three sections.

R_1, R_2, R_3 are equal value

C_1, C_2, C_3 are equal value



Operation: When the circuit is switched on, current through R_3 starts increasing because of biasing. This charging current induces voltage across R_2 through C_3 . The voltage across R_2 leads the voltage across R_3 by 60° . Since the $R-C$ sections are provided, therefore the phase shift produced by each section is 60° . Therefore the total phase shift produced by three sections is 180° . Due to the properties of the transistor, a further phase shift of 180° is produced due to the transistor properties. So a total shift of 360° is produced. Therefore the frequency of oscillation is in phase with the input signal.

$$\text{Frequency of oscillation } f = \frac{1}{2\pi CR\sqrt{b}}$$

$$R_1 = R_2 = R_3$$

$$C_1 = C_2 = C_3$$

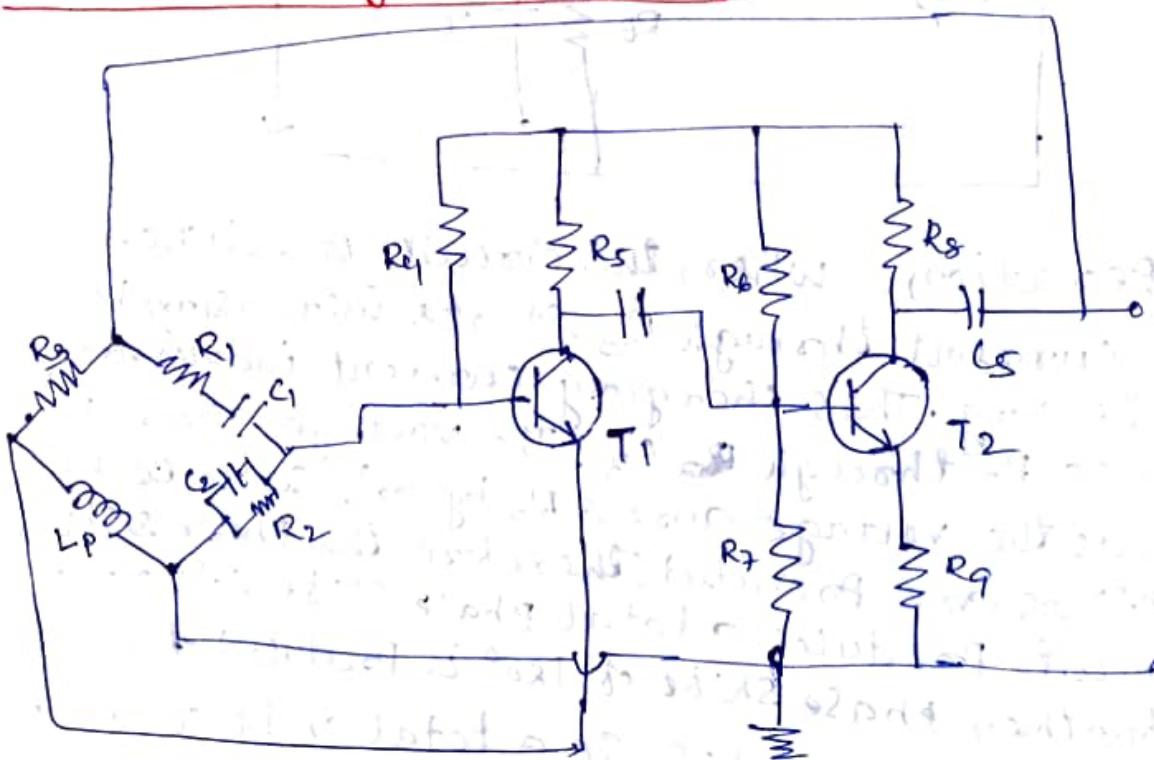
Advantage! -

- ① It does not require transformer
Less bulky,
- ② cheap and simple circuit as it
contains resistors and capacitors
only

Dis-advantage

- ① Feedback is less and it is difficult for the circuit to start oscillations. This because of high reactance of R and C.
- ② It gives only small op due to smaller feedback.

Wein-bridge oscillator



In this circuit an RC coupled amplifier that employs two stages is used. The output of last stage is coupled to the input of the first stage through coupling network. This provides necessary positive feedback for the circuit to work as an oscillator. The two transistor stages combine

produced a total phase shift of 360° .

The bridge circuit has the arms $R_1 C_1$, R_3 , $R_2 C_2$ and tungsten Lamp L_P . Resistors R_3 and L_P are used to stabilize the amplitude of the output. The circuit uses positive and negative feedback. The positive feedback is through $R_1 C_1$, $R_2 C_2$ to transistor T_1 . The negative feedback is through the voltage divider to the input of transistor T_2 . The frequency of oscillation is determined by the series elements $R_1 C_1$ and parallel elements $R_2 C_2$ of the bridge.

$$f = \frac{1}{2\pi \sqrt{R_1 C_1 R_2 C_2}}$$

The circuit gives constant output. This is achieved by the temperature sensitive tungsten lamp L_P . Its resistance increases with current. Should the amplitude of output tends to increase, more current would produce more negative feedback. The result is that the output would return to original value. A reverse action would take place if the output tends to decrease. The Wein bridge oscillator used for the variable frequency range of 10Hz to 1MHz .

Advantage

1. It gives constant output
2. The circuit works quite easily
3. The overall gain is high because of two transistors

4. The frequency of oscillation can be easily changed by using a potentiometer.

Disadvantage

- ① The circuit requires two transistors and a large number of components
- ② It cannot generate very high frequencies,

Field effect transistors (FET)

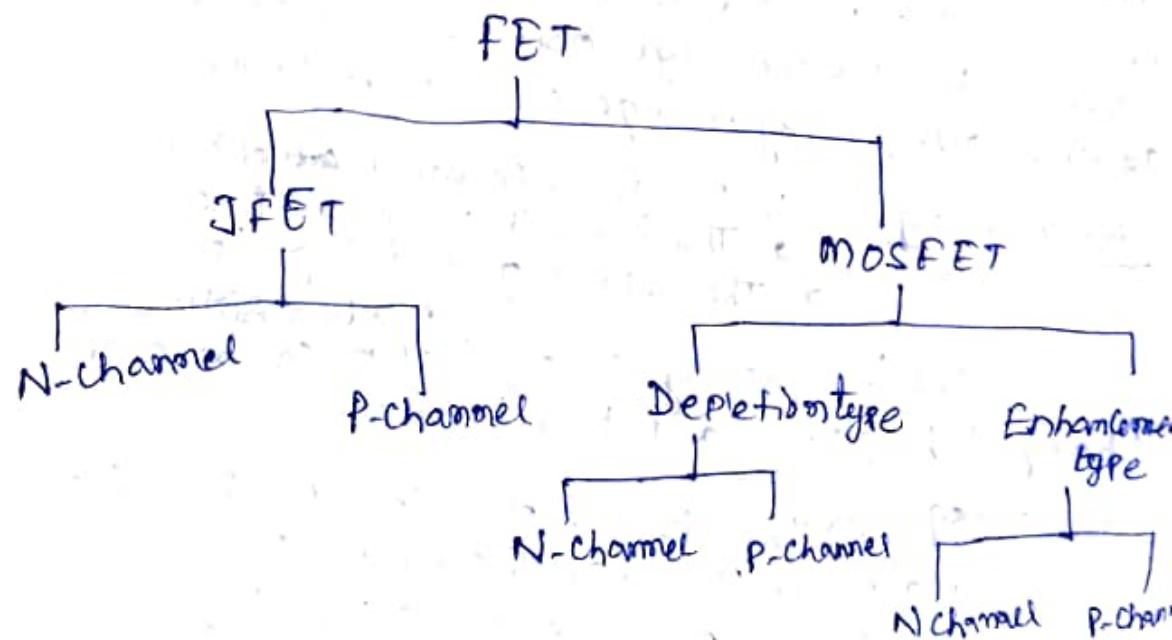
A field effect transistor is a three terminal semiconductor device in which current conduction is by one type of carrier (i.e either electrons or holes) and is controlled by the effect of electric field.

FET was first given by Shockley
in 1952.

Classification of FET's

There are two types of Field-effect transistors

1. Junction field effect transistors (JFET)
2. Metal oxide semiconductor field effect transistors (MOSFET) or insulated gate field effect transistors (IGFET)



Advantages & Disadvantages of FET over BJT

Advantages:

1. very high input impedance
2. Better thermal stability
3. very small input current, hence no loading on the input source.
4. Produces less noise
5. Long life and small size
6. Higher power gain
7. Immune to radiation

Disadvantage:

1. It cannot be used as current amplifier
2. The value of transconductance g_m is small.
3. The voltage gain of JFET amplifiers is lower than that of the transistor amplifiers.
4. Special handling precautions are required to be taken.

Structure of JFET:

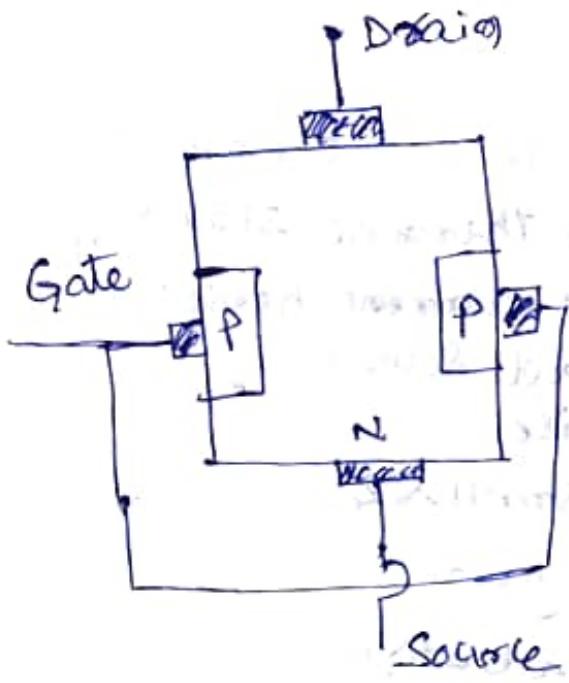
Junction field effect transistors may be divided depending on their structure into two categories.

1. N-channel JFET

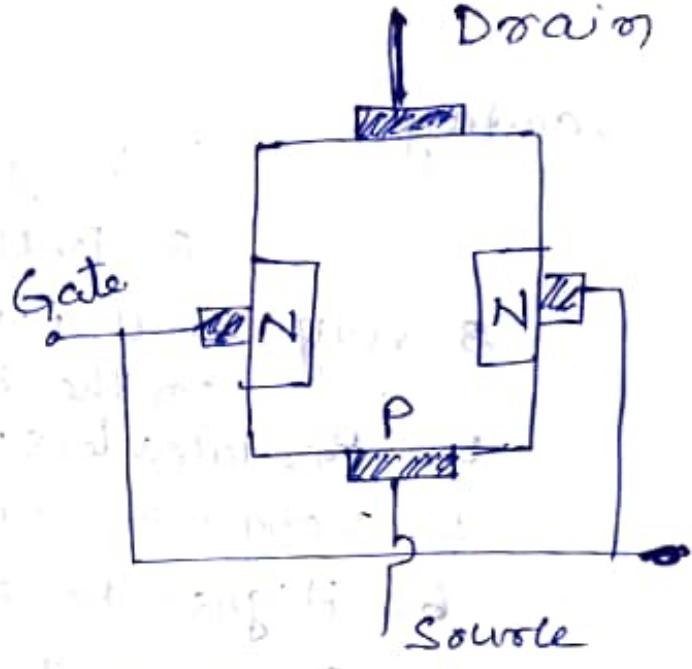
2. P-channel JFET

Niranjan Behere

Sr. Lect PkAIST, 12G1T



N channel JFET



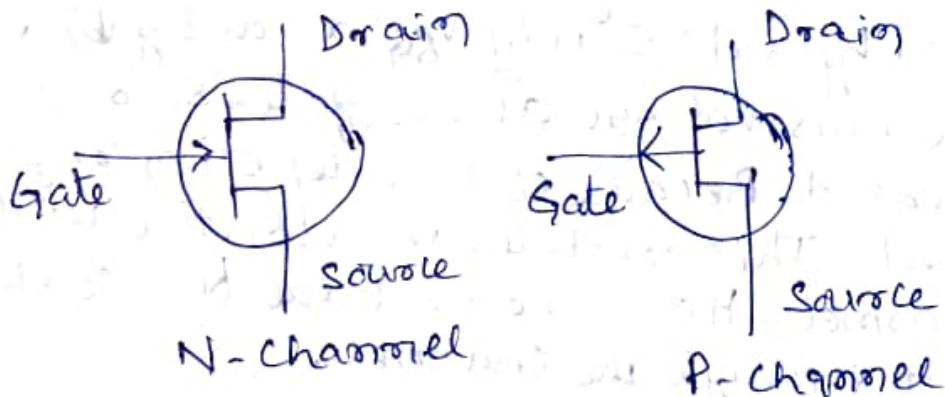
P-channel JFET

N channel JFET consists of an N-type semiconductor bar with two P-type doped regions diffused on opposite sides of semiconductor bar with two P-type doped regions in its middle parts. The P-type region between two P-junctions. The space between the junction i.e. N type region is known as Channel. Both P-type regions are connected internally and a single wire is taken out in the form of a terminal known as gate (G). The electrical connections are made to both ends of the N type bar taken in the form of two terminals known as Drain (D) and Source (S). Through the source terminal electrons enters and leaves through drain terminals.

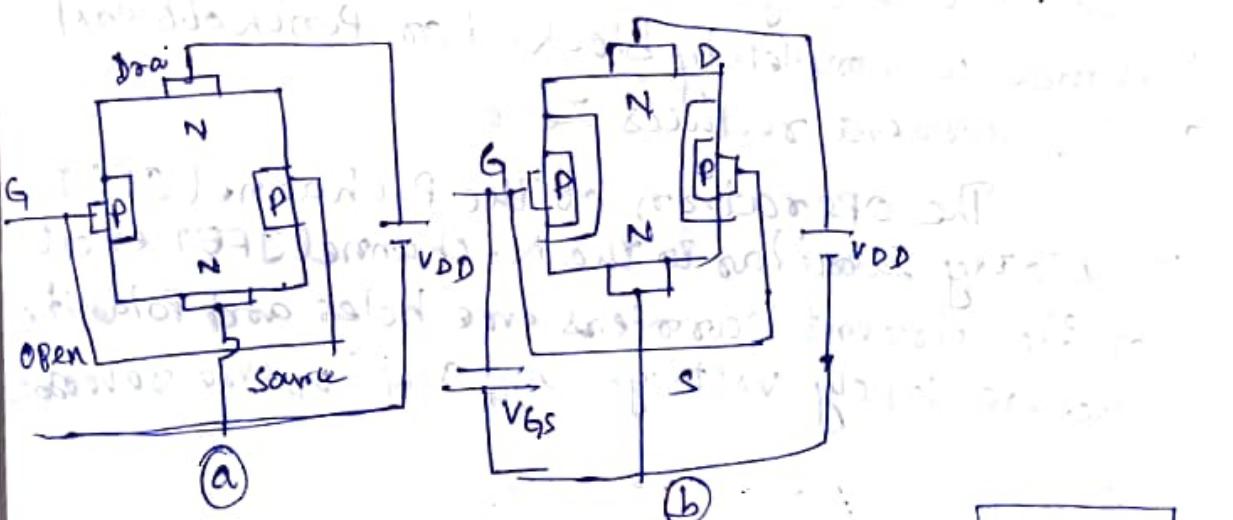
P-channel JFET construction is similar to that N-channel JFET except that it consists of a channel and N-type junctions. The carriers in JFET are the

holes which flows through the P-type, channel

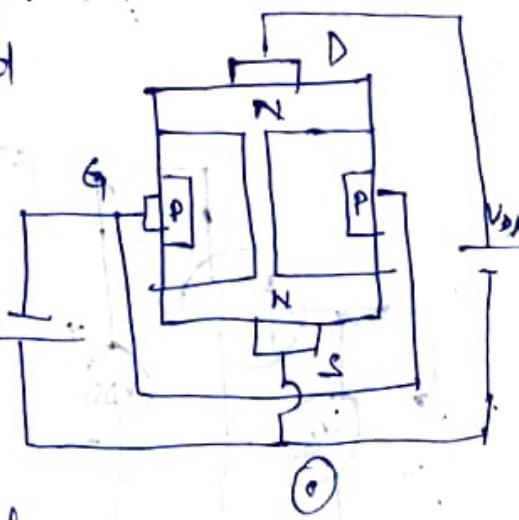
Symbol of JFET



Principle of operation of JFET



When a voltage is applied between the drain and source with a DC supply V_{DD} . The two p-n junctions at sides of the bar establish depletion layers as in fig. The electron tends to flow from source to drain. This constitutes drain current.



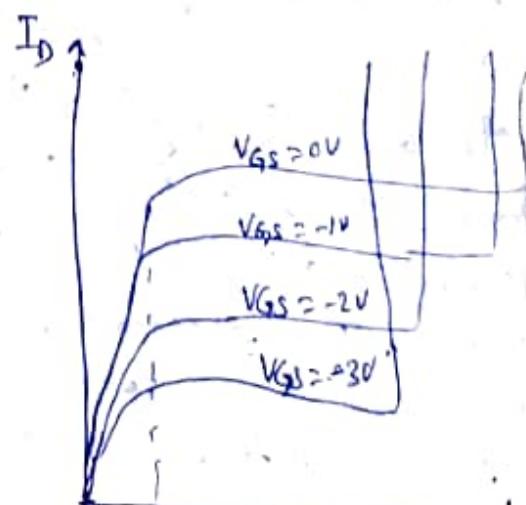
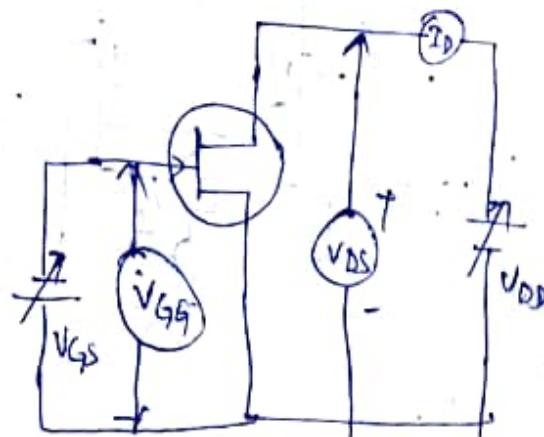
The value of the drain current is maximum when no external voltage is applied between the gate and source.

When the gate to source voltage V_{GS} is applied by a dc supply V_{GS} as in fig (b) the reverse bias voltage across gate-source junction is increased. Because if this depletion region is widened. This reduces the effective width of the channel. Hence control the flow of drain current through the channel.

When the gate to source voltage (V_{GS}) is further increased the stage is reached at which two depletion regions touch each other as fig (c). At this gate to source voltage, the channel is completely blocked or Pinch off and drain current reduces zero.

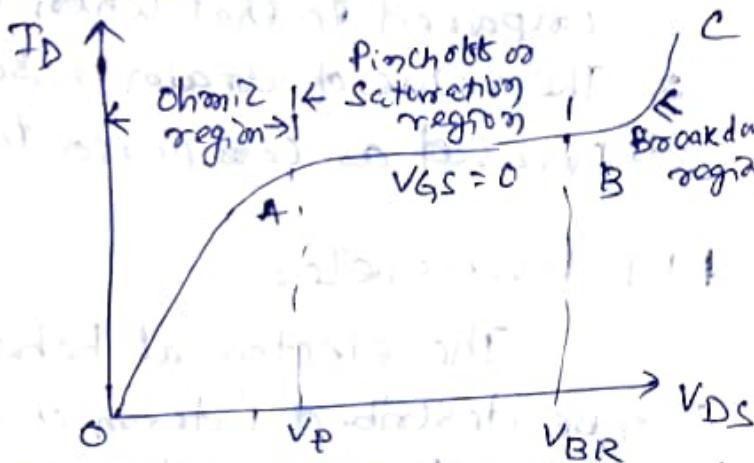
The operation of the P-channel JFET is exactly similar to the N-channel JFET except that the current carriers are holes and polarities of the dc supply voltage V_{GS} and V_{DS} are reversed.

DRAIN CHARACTERISTIC OF FET



A plot drawn for V_{DS} versus I_D at different values of V_{GS} is called drain characteristic.

Let us select the curve with $V_{GS} = 0$. The curve can be subdivided into the following regions.



i) Ohmic region : In this region, the drain current increases linearly with the increase in drain to source voltage. The linear increase in drain current is due to the fact that N-type semiconductor acts like a simple resistor. This region is shown as OA in the graph.

ii) Pinch-off or Saturation region :-

As the voltage V_{DS} is progressively increased, a value of V_{DS} is reached at which the channel is pinched-off. The current I_D begins to level off and approaches a constant value. This region is also known as saturation region. This region is shown as AB in the graph.

iii) Breakdown region : - Further increase in V_{DS} the drain current I_D increases rapidly. It happens because of breakdown of gate to source junction due to avalanche effect. This region is shown by BC in graph.

As the gate source voltage increases (V_{GS}) two effects takes as under.

1. The value of pinchoff voltage is reached at a smaller value of drain current as compared to that when $V_{GS} = 0$ and
2. The value of drain to source voltage V_{DS} is decreased as compared to that when $V_{GS} = 0$.

FET Parameters

The electrical behaviour of the JFET can be described in terms of certain parameters known as JFET parameters.

i) AC Drain resistance (r_d): - The ratio of change in drain-source voltage (ΔV_{DS}) to the change in drain current (ΔI_D) at constant gate-source voltage (V_{GS}).

$$\text{ac drain resistance } r_d = \frac{\Delta V_{DS}}{\Delta I_D} \text{ at constant } V_{GS}$$

ii) Trans conductance (g_{fs}): The ratio of change in drain current (ΔI_D) to the change in gate-source voltage (ΔV_{GS}) at constant drain source voltage (V_{DS}).

$$\text{transconductance } g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}} \text{ at constant } V_{DS}$$

iii) Amplification factor: - (k_f)

The ratio of change in drain-source voltage (ΔV_{DS}) to the change in gate-source voltage (ΔV_{GS}) at constant drain current I_D .

amplification factor

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \text{ at constant } I_D$$

Relation between σ_d , g_f and μ

$$\text{Amplification factor } \mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

Multiplying and dividing RHS by ΔI_D

$$\mu = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$= \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}}$$

$$= \sigma_d \times g_f$$

amplification factor = ac drain resistance
x transconductance.

comparison of FET and BJT

FET

- 1. g_f is a unipolar device i.e. the current is carried either by electrons only or holes only
- 2. It is a voltage driven device
- 3. Its input impedance is very high and is of the order of several megohms.

BJT

- 1. It is a bipolar device i.e. the current carried by both electrons and holes
- 2. It is current controlled device
- 3. Its input impedance is very low as compared to FET and is of the order of few kilohm.

FET

4. Drain current decrease with rise in temperature.
5. Noise is less.
Low noisy operation
6. It is much simpler to fabricate as an integrated circuit.
7. It has small gain bandwidth product.

BJT

4. Collector current increases with rise in temperature.
5. Noise is more.
High noisy operation
6. It is comparatively difficult to fabricate as circuit IC on IC.
7. It has large gain bandwidth product.

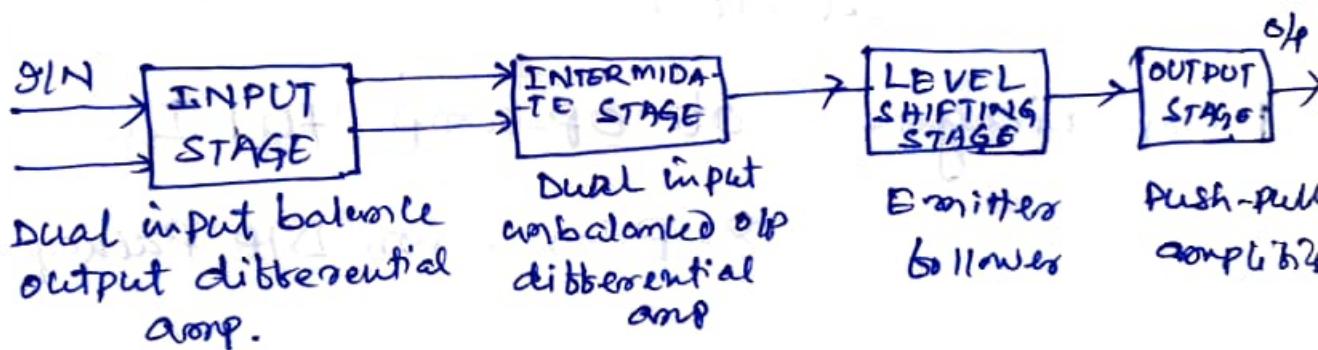
Nirayam Behera

Sr. Lect. PKAET,
BARGARH

Operational Amplifiers (OP-amp)

An operational amplifiers is a high gain amplifiers consist of one or more differential amplifiers. It is applicable for the amplification of both ac and dc input signal. The OP-amp designed for computing mathematical function such as addition, subtraction, multiplication, integration, differentiation etc. Due to its use in mathematical operations, it's named so.

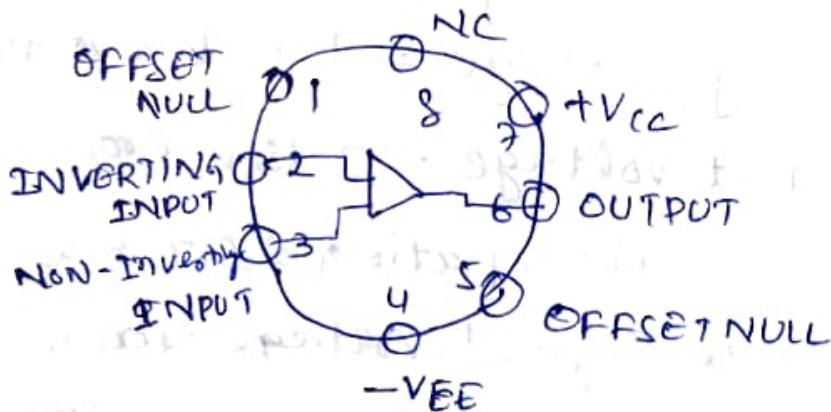
BLOCK DIAGRAM OF OP-amp



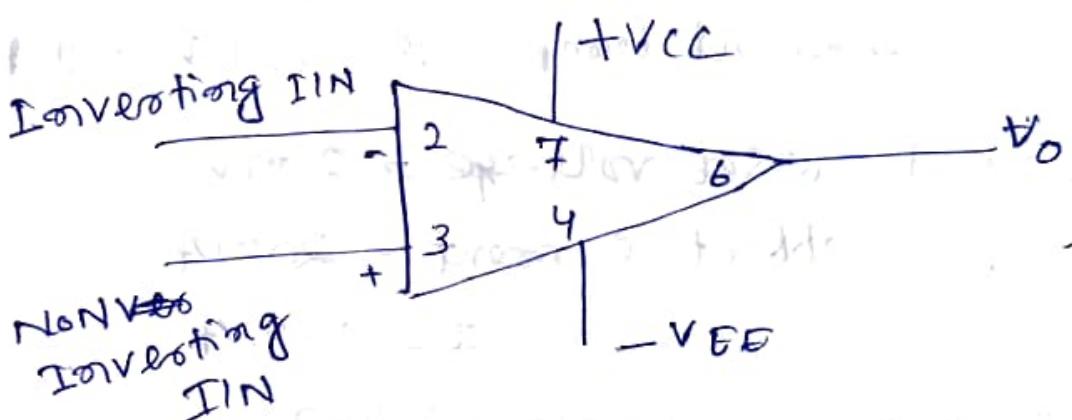
INPUT STAGE : The input stage is a dual-input balance output differential amplifiers. This stage provide most of the voltage gain and established input resistance of op-amp.

INTERMEDIATE STAGE : The intermediate stage is also a differential amplifier which is driven by the output of the first stage. The amplifier used in this stage is a dual input unbalanced output. The DC voltage at the output of the intermediate stage is well above the ground potential due to use of direct coupling.

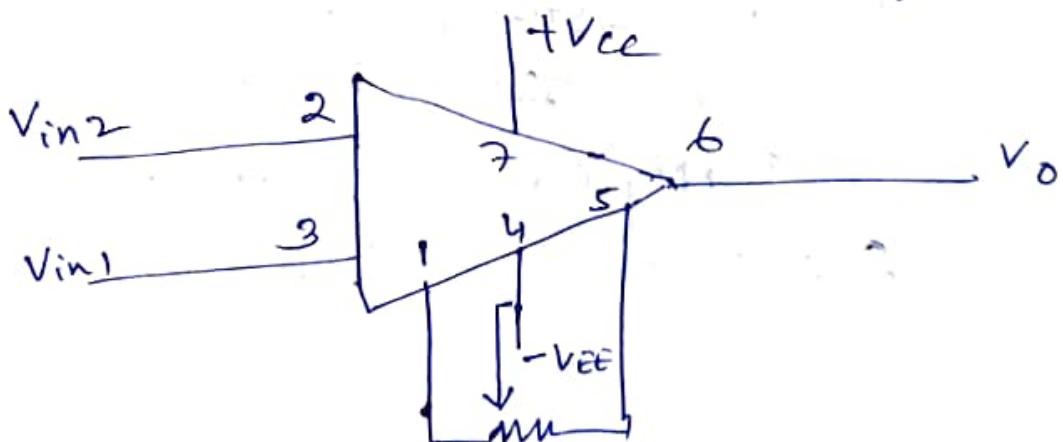
8-Pin Metal Can / TO-5 Package



CIRCUIT SYMBOL OF OP-AMP



Schematic diagram of OP-amp



$V_{in1} = V_1 = \text{voltage at non-inverting i/p}$

$V_{in2} = V_2 = \text{voltage at inverting i/p}$

$V_o = A(V_1 - V_2) = AV_{id} = \text{output voltage}$

$A = \text{open loop gain of an OP-amp}$

Important ratings of IC741

1. Supply voltage = $\pm 18V$ (max)
2. Input voltage = $\pm 15V$ (max)
3. Power dissipation = $500mW$ (max)
4. Large signal voltage gain
 $= 2,00,000$ (max)

Typical values of some parameters at ambient temp = 25° and $V_S = \pm 15V$

Input offset voltage = $2mV$

Input offset current = $20nA$

Input Bias current = $80nA$

Input resistance = $2M\Omega$

common mode rejection ratio (CMRR) = $90dB$

Output resistance = 75Ω

Power consumption = $50mW$

Supply current = $1.7mA$

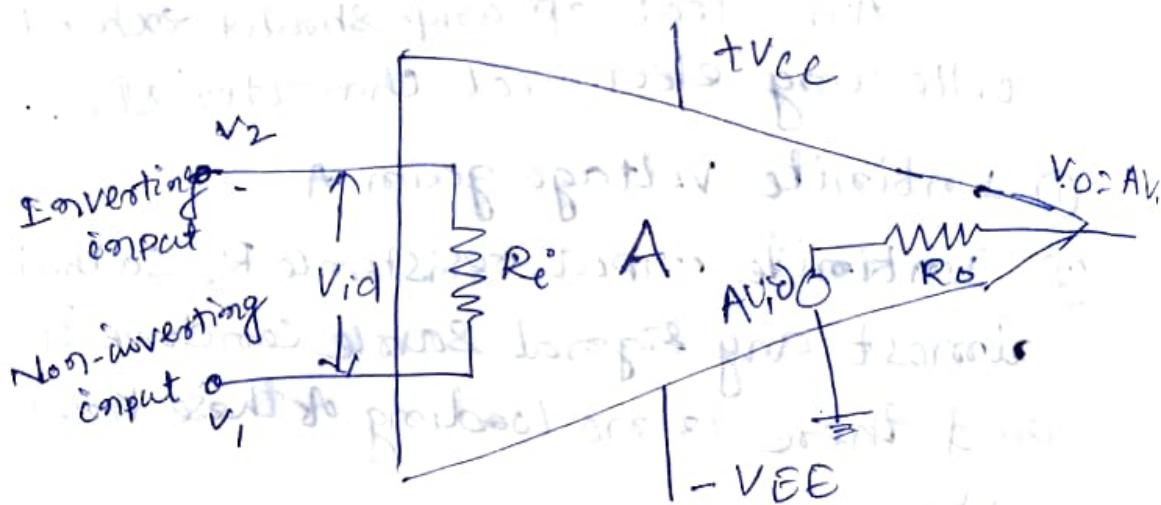
Slew rate = $0.5 V/\mu\text{sec}$

Ideal OP-amp ! -

An ideal op-amp should exhibit the following electrical characteristics:-

- ① Infinite voltage gain A
- ② Infinite input resistance R_i , so that almost any signal source can drive it and there is no loading of the preceding stage.
- ③ Zero output resistance R_o so that the output can drive an infinite number of other devices.
- ④ Zero output voltage when input voltage is zero.
- ⑤ Infinite bandwidth so that any frequency signal from 0 to ∞ can be amplified without attenuation.
- ⑥ Infinite common-mode Rejection ratio so that the output common-mode voltage is zero.
- ⑦ Infinite slew rate so that the output voltage change occurs instantaneously with input voltage change.

Equivalent circuit of an op-amp



$$V_o = A v_{id} = A (v_1 - v_2)$$

where A = large signal voltage gain

v_{id} = difference input voltage

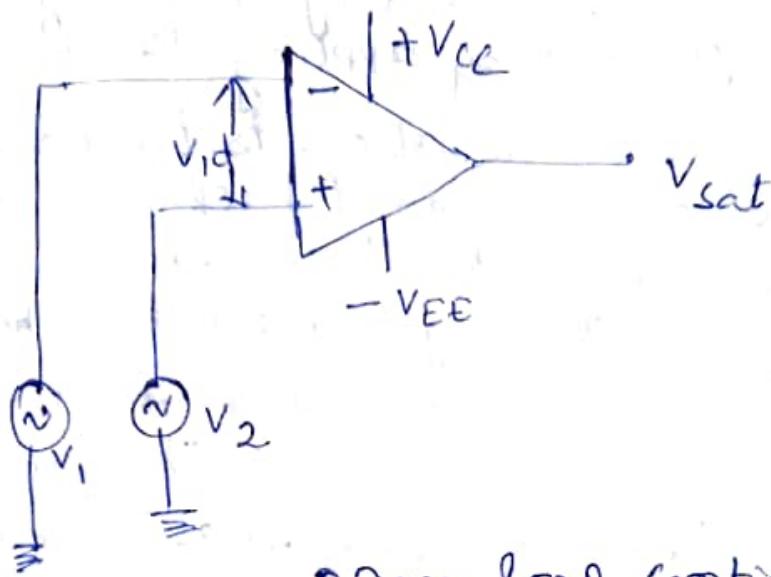
v_1 = voltage at non-inverting input terminal with respect to ground

v_2 = voltage at inverting input terminal with respect to ground.

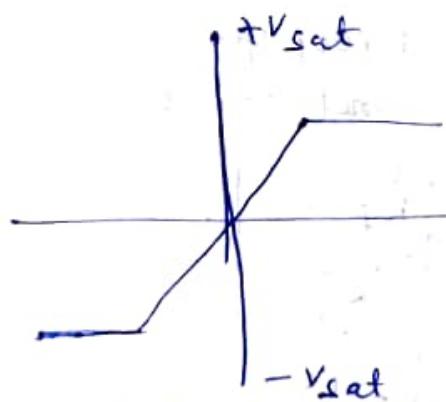
A , R_i , R_o from the data sheet.

The output voltage V_o is directly proportional to the algebraic difference between two input voltage op-amp amplifies the difference between the two input voltage. It does not amplify the input voltage themselves. For this reason the polarity of the output voltage depends on the polarity of the difference voltage.

Open-Loop Configuration of op-amp



Open-Loop configuration



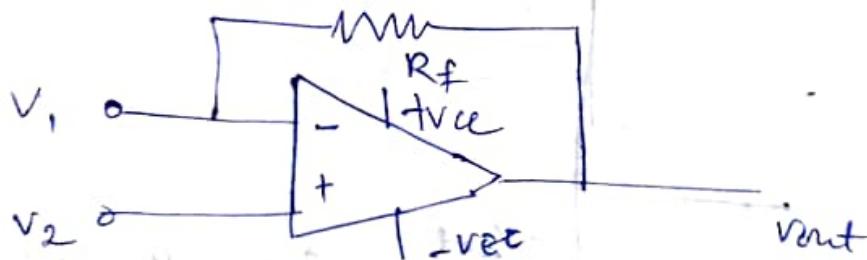
Ideal voltage transfer curve

The output varies linearly between $+V_{CC}$ and $-V_{EE}$. Because gain is very large in open condition, the output V_{out} is either at $+V_{sat}$ or at $-V_{sat}$. Thus it proves the inability of op-amp to work as a linear small signal amplifier in the open level mode. Therefore the op-amp is generally not used in the Open-Loop configuration. But such a behavior of the op-amp also finds some rare application in practice like voltage comparators, zero crossing detector etc.

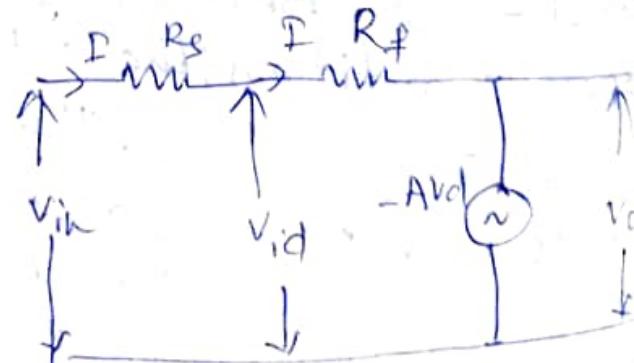
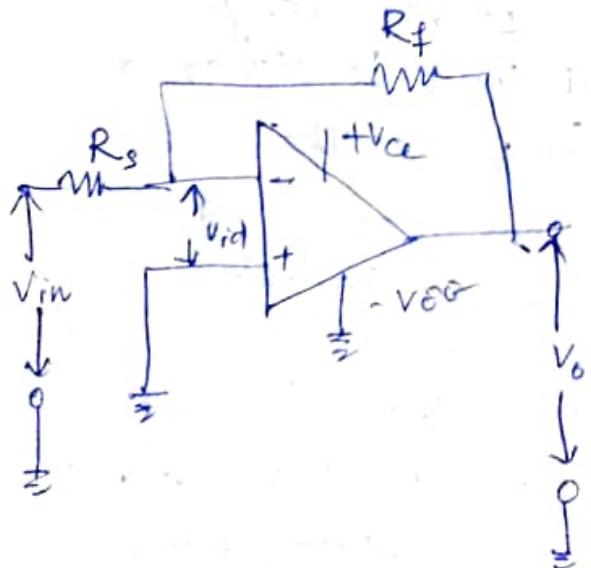
OP-amp with feedback:

The utilization of an OP-amp can be considerably increased by operating it in closed-loop mode by applying feedback.

The feedback allows to feed some portion of the output signal back to the input terminals. The negative feedback helps in controlling gain. The negative feedback is achieved by adding a resistor R_f called feedback resistor as in the figure. The gain resulting with feedback is called as closed loop gain of the OP-amp. Because of negative feedback, the closed loop gain is much less than open-loop gain and independent of it.



INVERTING AMPLIFIER:



The inverting operation performed by the circuit is determined by the feedback resistor R_f and input resistance R_s . Consider the OP-amp as an ideal, so that it will have infinite gain. With this the potential difference between input terminals must be zero, since the input impedance of the amplifier is infinite, input current to the amplifier is zero.

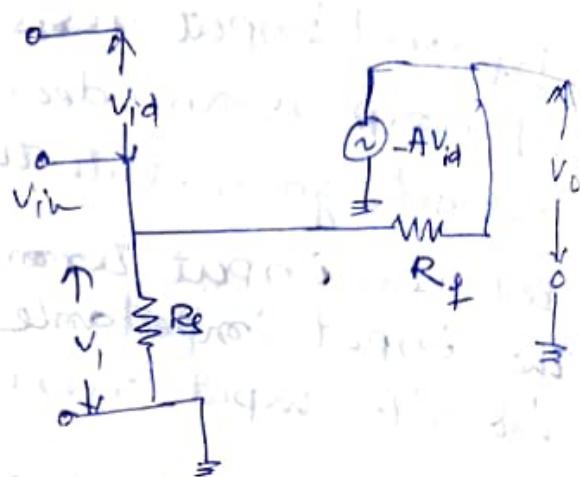
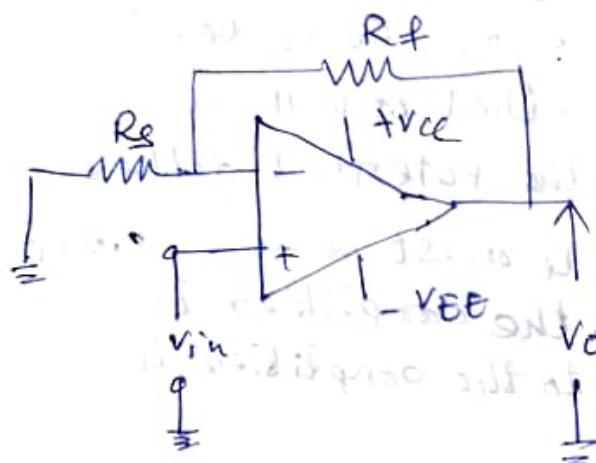
Under ideal conditions, the voltage difference V_{id} is equal to zero. It implies that terminal 1 has same potential as terminal 2 since terminal 2 is grounded hence terminal 1 is also virtually ground. Thus we can say that there is a virtual ground at negative terminal. Thus the current I flowing through R_f also flows through R_f . So

$$I = \frac{V_{in}}{R_s} = \frac{V_o}{R_f}$$

$$A_v = \frac{V_o}{V_{in}} = \frac{R_f}{R_s}$$

A_v is referred to as the closed loop gain of the inverting amplifier. The output is out of phase with input.

Non-Inverting amplifier



Equivalent circuit.

In this case the input signal is applied directly to the non-inverting terminal of the amplifier. Feedback resistor is connected to inverting terminal.

Under ideal condition $V_{id} = 0$. Then the voltage v_i from the negative terminal to ground is equal to the input voltage V_{in} . v_i is not equal to zero in this case, meaning that the non-inverting circuit has no virtual ground at either one of its input terminals. Since $v_i > V_{in}$.

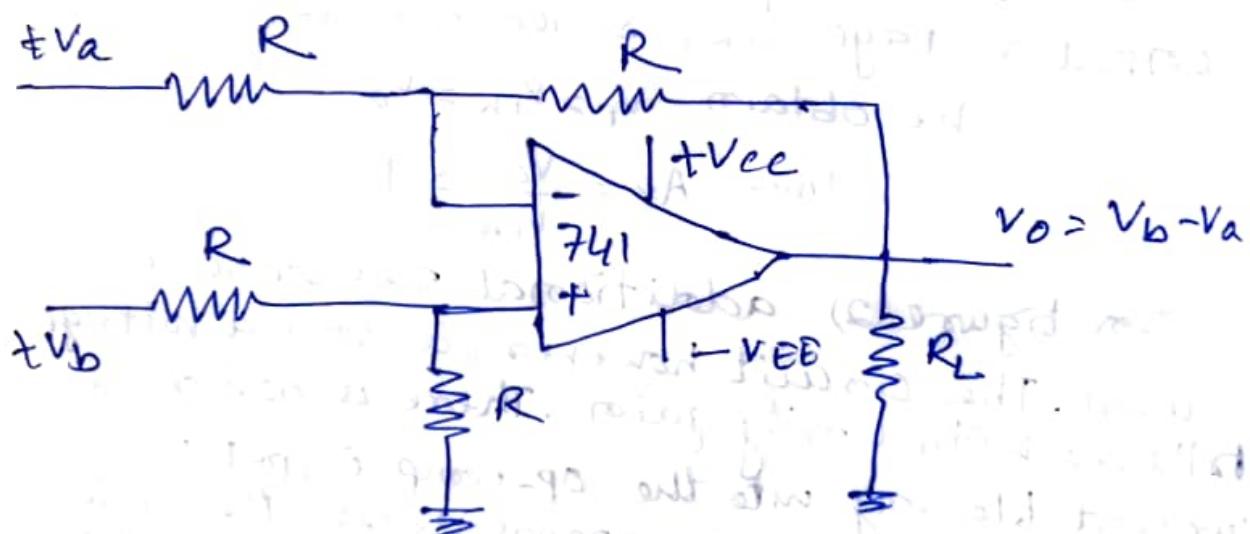
$$v_i = \frac{R_s}{R_f + R_s} v_o = V_{in}$$

$$\text{thus } A_v = \frac{v_o}{V_{in}} = \frac{R_f + R_s}{R_s} = 1 + \frac{R_f}{R_s}$$

In this case the output is in same phase with input.

Differential configuration: - (Subtractor)

Basically differential amplifiers can be used as a subtractor. Input signals can be scaled to desired values by selecting appropriate values for the external resistors. When this is done the circuit is referred to as scaling amplifier. However all external resistors are equal in value so the gain of the amplifier ~~is~~ equal to 1.



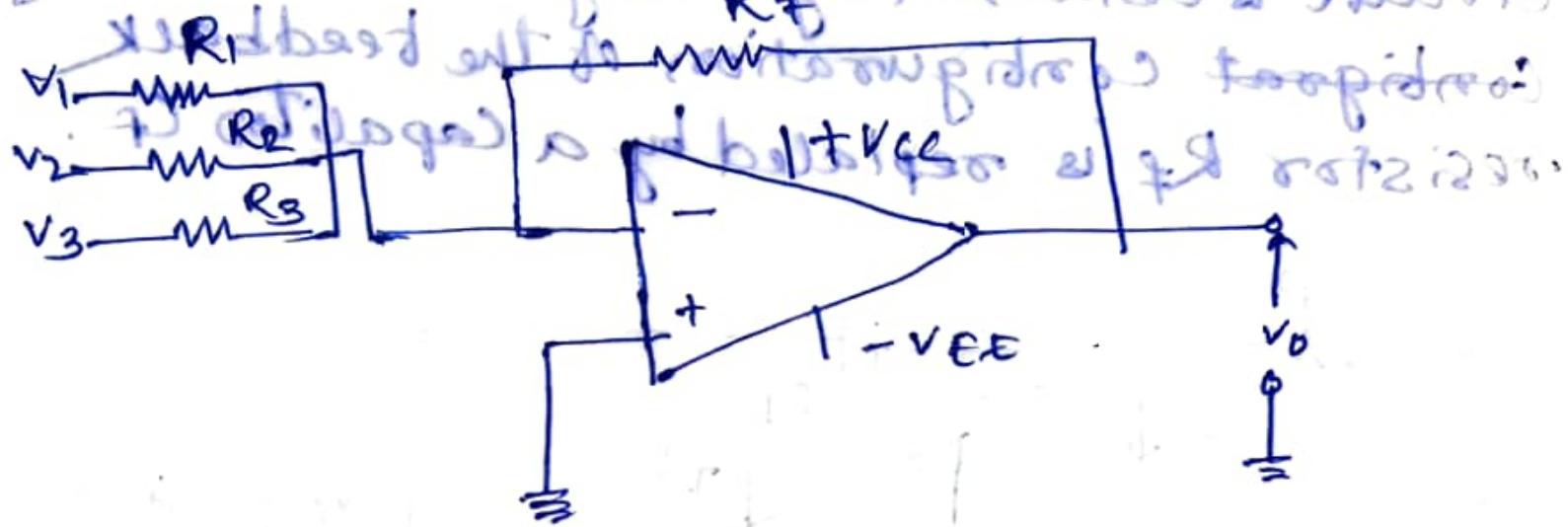
The output voltage of the differential amplifier with a gain of 1 is

$$V_o = -\frac{R_{out}}{R}(V_a + V_b)$$

$$\text{So } V_o = V_b - V_a$$

Thus the output voltage V_o is equal to the voltage V_b applied to the non-inverting terminal minus the voltage V_a applied to the inverting terminal, hence the circuit is called as subtractor.

Same as the converting amplifiers except that it has several input terminals giving out no feedback and feed back is through



The feedback here forces a virtual ground to exist at the inverting input to the ideal amplifier. Further more, the current to the ideal amplifier is zero. Thus the current equation for the node at the inverting terminal gives

$$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \frac{V_0}{R_f} = 0$$

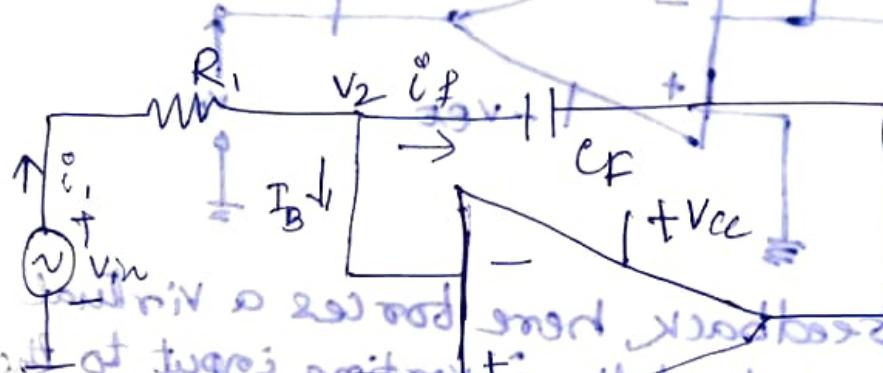
The output voltage therefore result as

$$V_0 = \left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 \right]$$

Thus the output voltage is equal to the negative weighed sum of the input voltages.

INTEGRATOR:

A circuit in which the output voltage waveform is the integral of its input voltage waveform is the integrator or the integrating amplifier. The integrator circuit is obtained by using a basic inverting configuration of the feedback resistor R_f is replaced by a capacitor C_f .



$$V_o = \frac{1}{R_L C_f} \int V_{in} dt + V_{cc}$$

Applying KCL at node V_2

$$I_1 = C_f \frac{dV_2}{dt} + I_B$$

Since I_B is negligible & small

$$\left[\frac{V_2}{R_1} + \frac{V_2}{R_L} + C_f \frac{dV_2}{dt} \right] + I_B = 0$$

The relation between current through and voltage across the capacitor is

$$i_c = C_f \frac{dV_c}{dt}$$

$$\frac{V_{in} - V_2}{R_1} = C_f \frac{d}{dt} (V_2 - V_o)$$

$V_1 = V_2 \approx 0$ because A is very large

$$\frac{V_{in}}{R_i} = C_F \frac{d}{dt} (0 - V_o)$$

The output voltage can be obtained by integrating both side with respect to time.

$$\int_0^t \frac{V_{in}}{R_i} dt = \int_0^t C_F \frac{d}{dt} (-V_o) dt$$
$$= [C_F (-V_o) + V_o]_{t=0}$$

Therefore

$$V_o = -\frac{1}{R_C F} \int_0^t V_{in} dt + C$$

Where C is the integrating constant and is proportional to the value of the output voltage V_o at time $t = 0$ second.

The output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant $R_C F$. If the input is a sine wave the output will be cosine wave or if the input is a squarewave the output will be square wave.

When the difference voltage is negative the output voltage will be at logic '0'

$$V_O = \text{Logic '0' when } V_I - V_R < 0$$

The output voltage changes state when

$$V_I = V_R = 0$$

$$\text{or, } V_I = V_R$$

The output voltage is at logic '0' whenever V_I is more negative than the reference voltage V_R . The output voltage comparator can also work if the V_I and V_R terminals are interchanged. This will cause inversion of the output voltage waveform. It should be noticed that voltage comparator does not reproduce any part of the original input signal waveform.

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