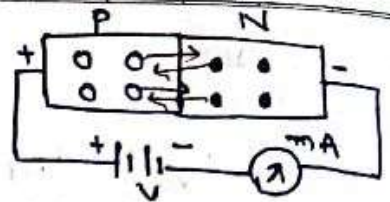


OPAMP

CP-1 P-N Junction Diode

Working of Diode -:



Forward bias -:

- * When an external voltage is applied to P-N junction in such a direction that it cancels the potential barrier and permits the current flow is called as forward bias.
- * To apply a forward bias, the +ve terminal of a battery is connected to P-type semiconductor while the negative terminal is connected to N-type semiconductor.
- * The applied forward potential establishes an electric field opposite to the potential barrier.
- * The potential barrier is very small (0.3 volt for Ge and 0.7 volt for Si), therefore, a small forward voltage is sufficient to completely eliminate the potential barrier.
- * When potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero & current flows across P-N junction Diode.
- * In case of the forward bias, the holes from P-type semiconductor are repelled by the +ve battery terminal towards the junction & the electrons in N-type semiconductor are repelled by -ve battery terminal towards junction.
- * Here, the battery voltage should be high into to move the charge carrier across the potential barrier.
- * When an electron hole combination takes place near the junction, a covalent bond near the

Covalent bond - Sharing of electron pairs between atoms.

Date

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Page No.

Positive terminal of a battery breaks down & electron will enter to the +ve terminal. (P-region)

* Due to the combination, a free space will be created near the junction.

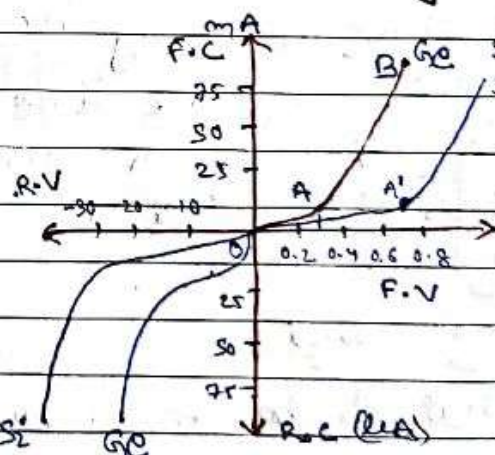
* The constant movement of electrons towards the positive terminals and the holes towards the -ve terminal produces a high forward current.
Reversed biased:-

* When an external voltage is applied to P-N junction in such a direction that it increases the potential barrier, it is called as reverse bias.

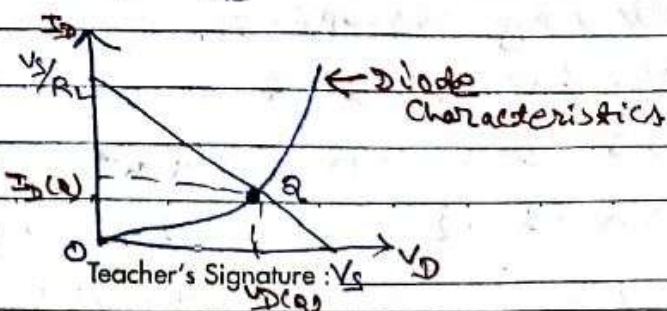
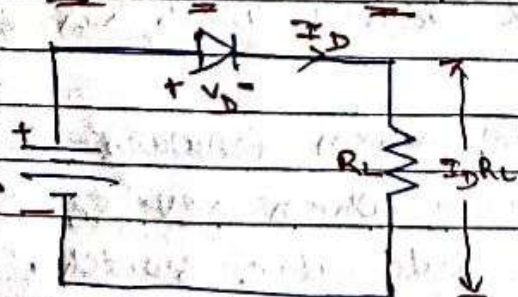
* For reversed bias, the positive terminal of the battery is connected to N-type semiconductor and -ve terminal is connected to P-type Semiconductor.

* Here both the charge carriers attracted toward the respective terminal, so that potential barrier ^{will} be wider, current is not flowing during this condition.

V-I Characteristics of Diode



D.C. LOAD LINE - I



* Consider a diode connected in series with a load resistance R_L across a supply voltage V_s .

* Here, the diode is forward biased.

* A line drawn on the characteristics of the device that represents all d.c. conditions that could exist within the circuit for given values of V_s & R_L is called as d.c. load line.

* By applying KVL

$$V_s - V_D - I_D R_L = 0$$

$$\Rightarrow I_D = \frac{V_s}{R_L} - \frac{V_D}{R_L}$$

Case (1) when $V_D = 0$

$$\Rightarrow I_D = \frac{V_s}{R_L}$$

Case (2) when $I_D = 0$

$$V_D = V_s$$

* A line passing through the points (V_s/R_L) and V_s is called a load line.

* The intersection point betⁿ d.c. load line & diode characteristics ^{line} is called as bias point & is denoted by 'Q'.

Important terms:-

→ Ideal diode:-

→ An ideal diode is a two terminal device which has the following properties.

→ conducts with zero resistance when forward-biased &
→ offers an infinite resistance when reverse-biased.

→ An ideal diode acts like an automatic switch. The switch is closed when the diode is forward bias and

is open when it is reversed biased.

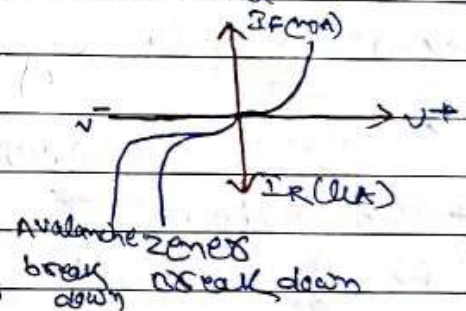


Knee voltage :-

- Knee voltage is defined as the forward voltage at which the current through the junction starts increasing rapidly.
- When a diode is FB, the forward current increases ~~very~~ ^{es} very slowly in the beginning. After it exceeds the knee voltage, the current starts increasing rapidly.
- * Knee voltage of Si = 0.7 Volt, Ge = 0.3 Volt.

Zener breakdown

- The zener breakdown takes place in junctions which are heavily doped (having narrow depletion layers).
- When breakdown voltage is applied, a very strong electric field appears across the narrow depletion layer which breaks the bonds & electron-hole pairs are generated.
- A small further increase in reverse voltage produces large no. of current carriers which suddenly increase the reverse current.



Avalanche breakdown :-

- The avalanche breakdown occurs in junctions which are lightly doped (having wide depletion layers) and the electric field across the junction is not so strong to produce zener breakdown.

Teacher's Signature : _____

P-N Diode Clipping Circuits - Used - to protect the electronic devices from overvoltage condition.

* A wave shaping circuit which controls the shape of output waveform by removing or clipping a portion of the applied wave is known as clipping circuit.

* For a clipping circuit, a diode (which acts as a closed switch when forward-biased & an open switch when reversed biased) & a resistor are required.

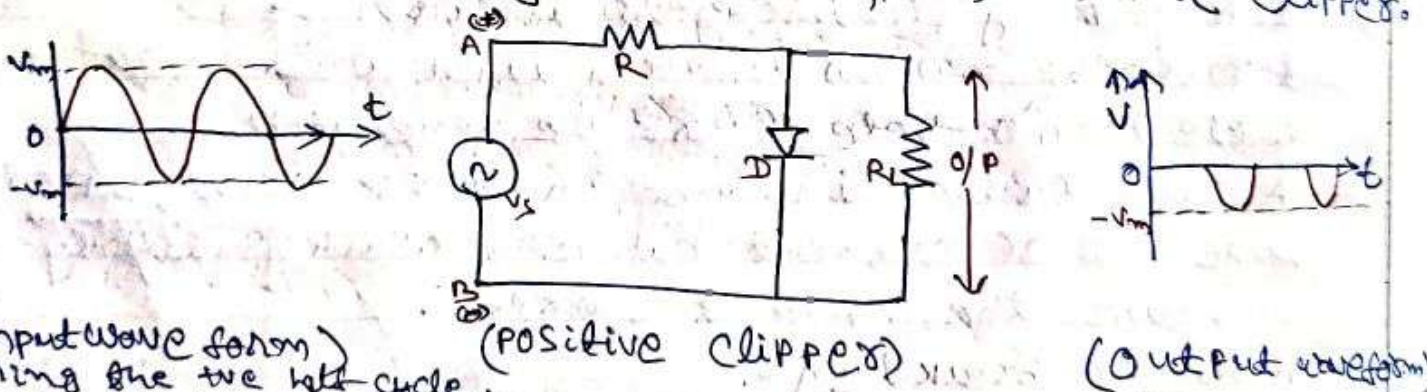
* Here we used AC voltage source for clipping purpose, but sometimes we used a DC battery for this purpose.

* It is of 3 types.

a) positive & negative clippers -

→ positive clipper -

* The clipper which removes the positive half-cycles of the input voltage is known as positive clipper.



(Input wave form)
During the $+$ ve half cycle,
* when 'A' is $+$ ve w.r.t 'B', the diode (D) is forward-biased & acts like a closed switch. (short cut)

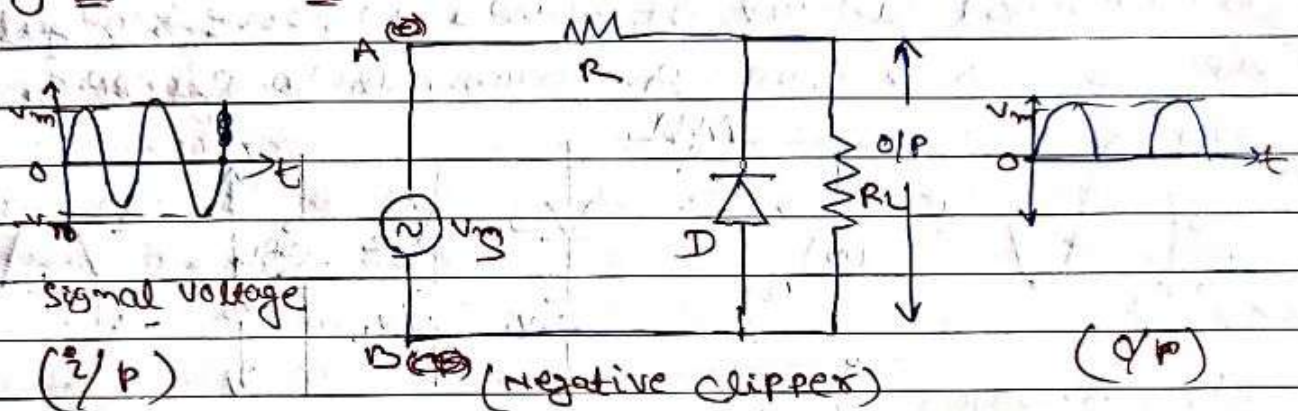
* Here voltage drop across the diode or across the load resistor R_L is zero. So the output during the $+$ ve half cycle will be zero.

* During the -ve half cycle, when 'b' is +ve w.r.t 'A', the diode (D) is Reverse-biased & it acts like an open switch.

* Here the entire i/p voltage appears across the load resistor (R_L)

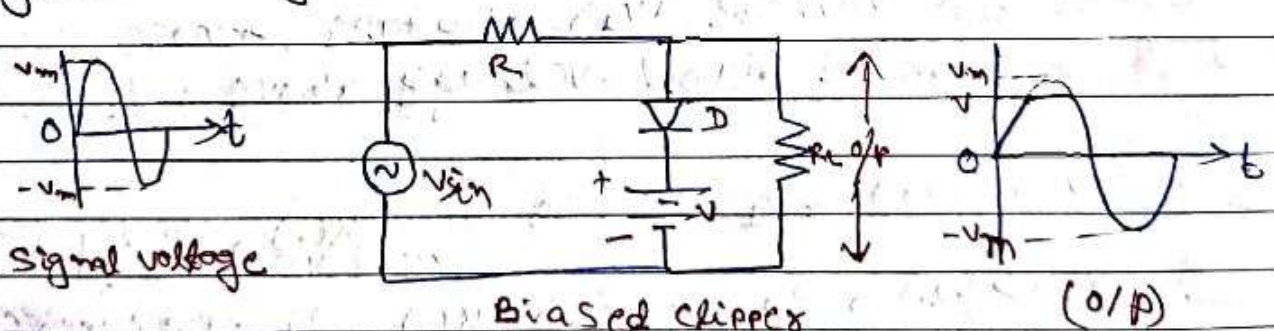
$$\text{output voltage} = \frac{R_L}{R+R_L} V_m$$

Negative clipper -



Biased clipper -

→ A biased clipper is used, when it is desired to remove a small portion of positive or negative cycle of the signal voltage.



Case ① - $V_{in} < V$ for +ve half cycle -

* In this case, the diode (D) is reverse-biased & it acts as an open cut. Therefore, most of the i/p voltage appears across the o/p.

Teacher's Signature : _____

Case ② - $V_{in} > V$ for positive half cycle -

→ In this case, the Diode (D) is forward biased.

→ The o/p voltage is equal to $+V$.

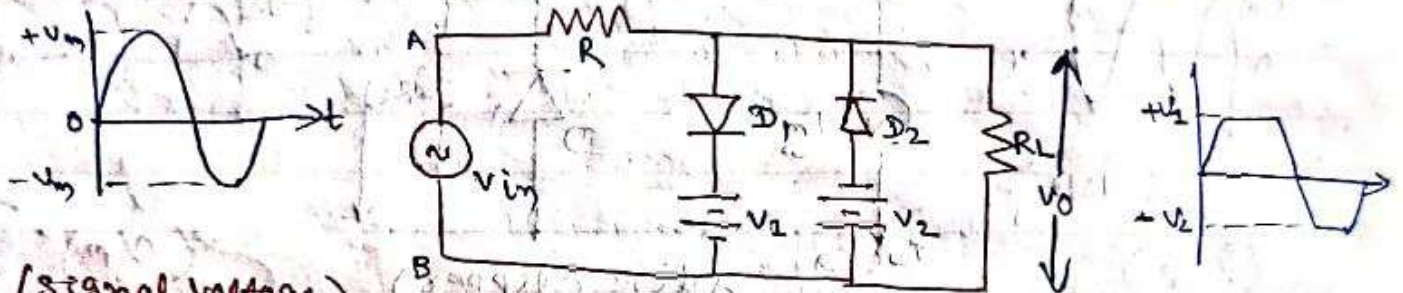
Case ③ - V_{in} is negative -

→ In this case, the diode D is reverse-biased & acts as open switch.

→ Therefore, entire -ve half cycle appears across the load.

Combination clipper

* A Combined circuit of biased positive & negative clippers is known as combination clipper.



(signal voltage) Case - 1 ($V_{in} < +V_1$) (Combination clipper ckt) (o/p waveform) $D_1, D_2 = RB$ (open ckt.), o/p v_{ky} = $+V_1$

Case - 2 when +ve i/p voltage (V_{in}) $> +V_1$, diode (D_1) is forward-biased while diode D_2 is reversed-biased.

→ Therefore, a voltage ($+V_1$) appears across the load and the positive signal voltage above $+V_1$ is clipped off.

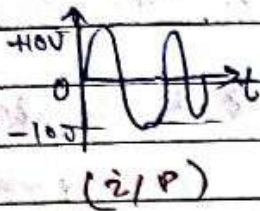
Case - 3 ($V_{in} < -V_2$), $D_1, D_2 = RB$ (open ckt.), o/p v_{ky} = $-V_2$

Case - 4 ($V_{in} > -V_2$), $D_2 = FB$ (sh. ckt.), $D_1 = RB$ (open ckt.)

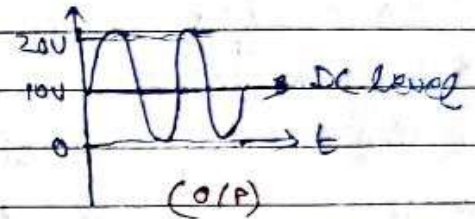
→ Therefore, a voltage ($-V_2$) appears across the load & the negative signal voltage above $-V_2$ is clipped off.

P-N diode clamping Circuits:-

- * Clamping is a process of introducing a d.c level into an ac signal. (Restore dc value in AC waveform) (without changing the shape of applied signal)
- * A clamping circuit is a device that places either the positive or negative peak of a signal at a desired level.



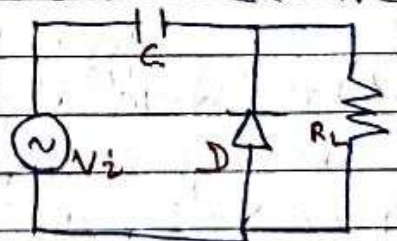
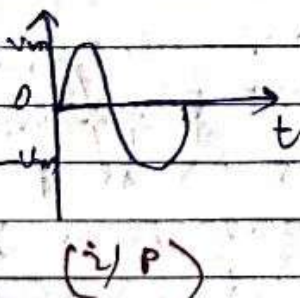
Positive
Clamper



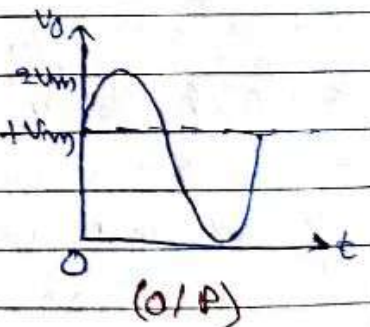
- * For clamping circuit, we required a diode, a capacitor & a resistor.
- * Here, the waveforms of i/p & o/p remain the same, of course, there is a vertical shift either upward or downward.

Positive clamper:-

- * When a clamper shifts the original signal in vertical upward direction in such a way that the negative peak of the signal falls on zero level, it is known as positive clamper.



positive clamper

Negative clamper:-

- * When a clamper shifts the original signal in vertical downward direction in such a way that the positive peak of the signal falls on zero level, it is known as negative clamper.

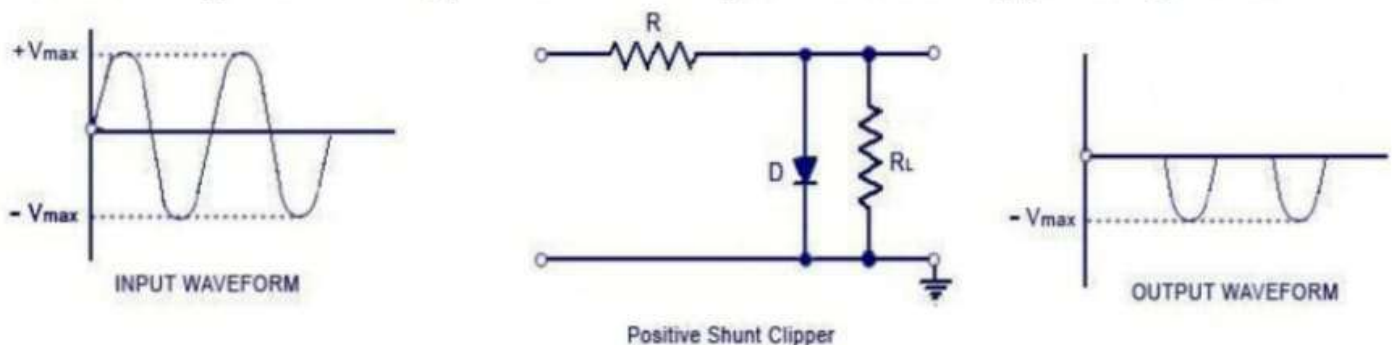
Teacher's Signature : _____

➤ CLIPPING CIRCUITS

- The circuit with which the waveform is shaped by removing (or clipping) a portion of the applied wave is known as a clipping circuit.
- Clippers find extensive use in radar, digital and other electronic systems.
- Although several clipping circuits have been developed to change the wave shape, we concentrate only on diode clippers.
- These clippers can remove signal voltages above or below a specified level.
- The important diode clippers are:-
 1. Positive clipper and negative clipper
 2. Biased positive clipper and biased negative clipper
 3. Combination clipper.

➤ POSITIVE CLIPPER

- A positive clipper is that which removes the positive half-cycles of the input voltage.
- The positive clipper is of two types
 1. Positive series clipper
 2. Positive shunt clipper
- The below Fig. shows the typical circuit of a positive shunt clipper using a diode.



- Here the diode is kept in parallel with the load.
- During the positive half cycle, the diode 'D' is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily.
- This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the positive half cycles is zero.
- During the negative half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L .
- Actually the circuit behaves as a voltage divider with an output voltage of $-\frac{R_L}{R + R_L} V_{max} \cong -V_{max}$ (Taking or assuming when $R_L \gg R$).

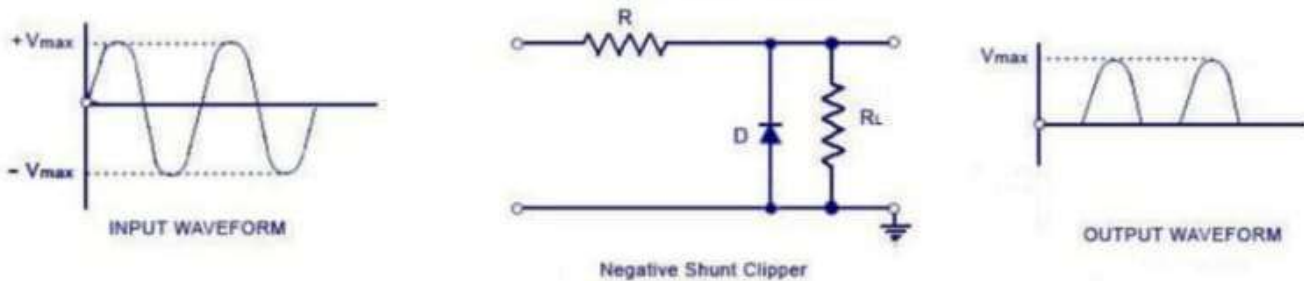
➤ NEGATIVE CLIPPER

➤ A negative clipper is that which removes the positive half-cycles of the input voltage.

The negative clipper is of two types

1. Negative series clipper
2. Negative shunt clipper

➤ The below Fig. shows the typical circuit of a negative shunt clipper using a diode.

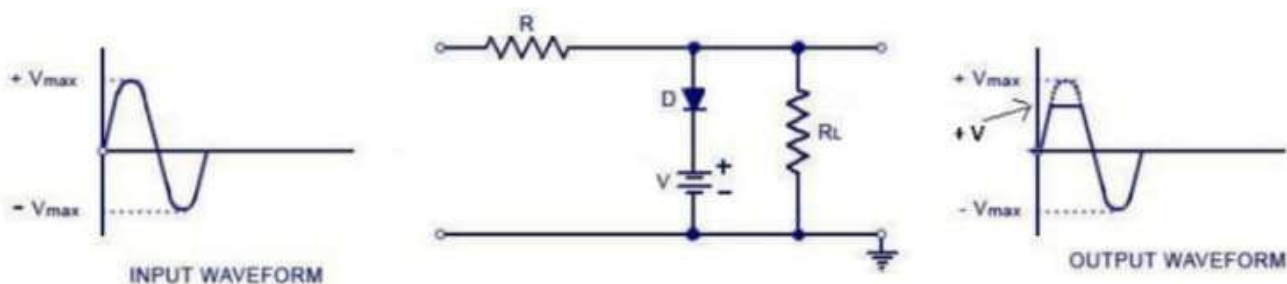


- During the negative half cycle, the diode 'D' is forward biased and the diode acts as a closed switch. This causes the diode to conduct heavily.
- This causes the voltage drop across the diode or across the load resistance R_L to be zero. Thus output voltage during the negative half cycles is zero.
- During the positive half cycles of the input signal voltage, the diode D is reverse biased and behaves as an open switch. Consequently the entire input voltage appears across the diode or across the load resistance R_L if R is much smaller than R_L .
- Actually the circuit behaves as a voltage divider with an output voltage of $[R_L / R + R_L]$
 $V_{\max} \cong V_{\max}$ (Taking or assuming when $R_L \gg R$).

➤ BIASED POSITIVE CLIPPER

➤ When a small portion of the positive half cycle is to be removed, it is called a biased positive clipper. The circuit diagram and waveform is shown in the figure below.

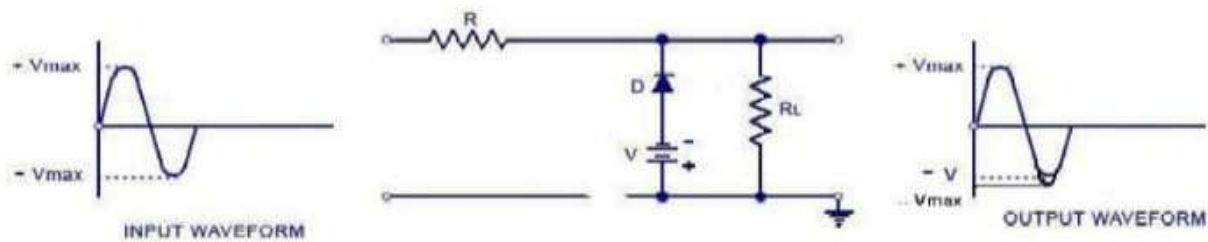
BIASED POSITIVE CLIPPER



- During negative half cycle, when the input signal voltage is negative, the diode 'D' is reverse-biased. This causes it to act as an open-switch. Thus the entire negative half cycle appears across the load, as illustrated by output waveform.
- During positive half cycle, when the input signal voltage is positive but does not exceed battery the voltage 'V', the diode 'D' remains reverse-biased and most of the input voltage appears across the output.

- When during the positive half cycle of input signal, the signal voltage becomes more than the battery voltage V , the diode D is forward biased and so conducts heavily. The output voltage is equal to $+V$ and stays at $+V$ as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, V .
- Thus a biased positive clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.
- **BIASED NEGATIVE CLIPPER**
- When a small portion of the negative half cycle is to be removed, it is called a biased negative clipper. The circuit diagram and waveform is shown in the figure below.

BIASED NEGATIVE CLIPPER

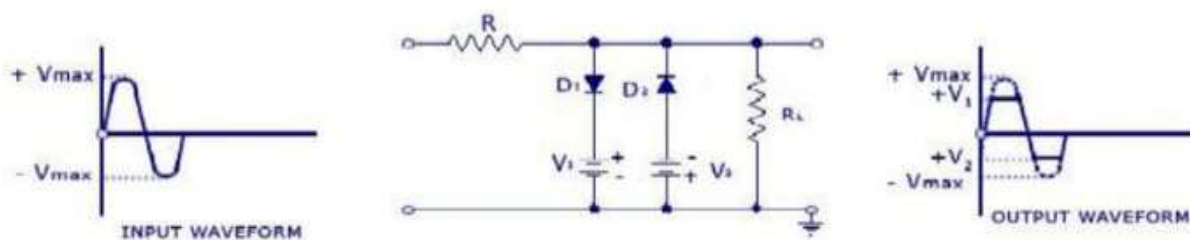


- During positive half cycle, when the input signal voltage is positive, the diode ' D ' is reverse-biased. This causes it to act as an open-switch. Thus the entire positive half cycle appears across the load, as illustrated by output waveform.
- During negative half cycle, when the input signal voltage is negative but does not exceed battery the voltage ' V ', the diode ' D ' remains reverse-biased and most of the input voltage appears across the output.
- When during the negative half cycle of input signal, the signal voltage becomes more than the battery voltage V , the diode D is forward biased and so conducts heavily. The output voltage is equal to $-V$ and stays at $-V$ as long as the magnitude of the input signal voltage is greater than the magnitude of the battery voltage, V .
- Thus a biased negative clipper removes input voltage when the input signal voltage becomes greater than the battery voltage.

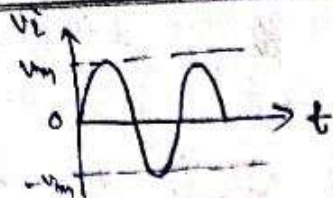
➤ COMBINATION CLIPPER:-

- Combination clipper is employed when a portion of both positive and negative of each half cycle of the input voltage is to be clipped (or removed) using a biased positive and negative clipper together. The circuit for such a clipper is given in the figure below.

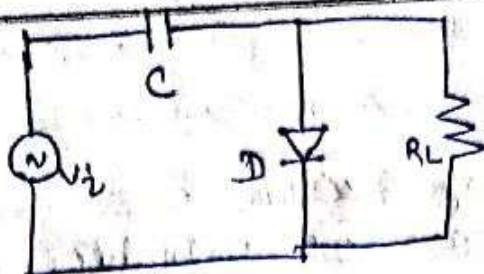
COMBINATION CLIPPER



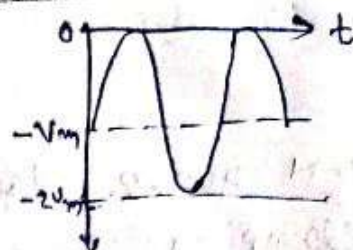
- For positive input voltage signal when input voltage exceeds battery voltage $+V_1$ diode D_1 conducts heavily while diode D_2 is reversed biased and so voltage $+V_1$ appears across the output. This output voltage $+V_1$ stays as long as input signal voltage exceeds $+V_1$.
- On the other hand for the negative input voltage signal, the diode D_1 remains reverse biased and diode D_2 conducts heavily only when input voltage exceeds battery voltage V_2 in magnitude.
- Thus during the negative half cycle the output stays at $-V_2$ so long as the input signal voltage is greater than $-V_2$.



(i/p)



(Negative clamper)



(o/p)

CP-2 Special semiconductor Devices

Thermistor -:

- * Thermistor is a combination of thermal & resistor. (thermally sensitive resistor)
- * It is a type of resistor whose resistance is dependent on temperature. Used-: as temp. sensor.
Ex: fire alarms, ovens and refrigerators.
- * Classification of thermistors in terms of temp. coefficient of resistance -:
- a) Positive temp. coefficient (PTC) thermistors -:
- They have positive temp. coefficient of resistivity. (the resistance increases as temperature increases).
- b) Negative temp. coefficient (NTC) thermistors -:
- They have negative temp. coefficient of resistivity. (the resistance decreases as temp. increases)
Ex: Air conditioners, refrigerators etc.
- * Most thermistors have a negative temp. coefficient.

* The reason of NTC of a thermistor is that when its temp. is increased, the concentration of charge carriers (free electrons & holes) also increases which results a decrease in resistance.

* Resistance value of thermistor -: 100 Ω to 10 mega Ω .

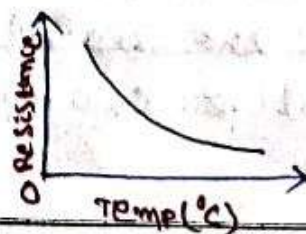
Characteristic of thermistor -:

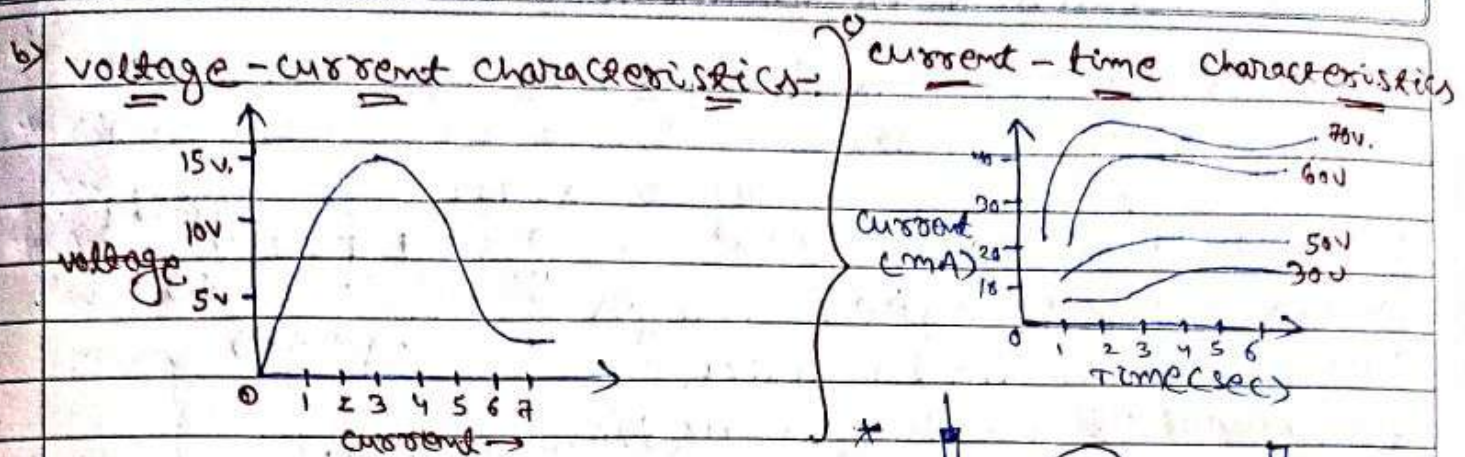
a) Resistance vs temp. characteristics

$$R = R_0 \alpha e^{\beta/T}$$

Where -: α & β = Constant

R_0 = Resistance at 0°C . T = Temp.





Sensistor:-

- * It is a heavily doped bulk semiconductor which has positive temperature coefficient of resistance.
(Bulk semiconductor:- It is a single semiconductor crystal, appropriately doped & provided with ohmic contacts at either end.) (junction)
- * When the temp. of a sensistor is increased, the mobility of charge carriers is decreased & hence the resistivity is increased.
- * Resistance value of sensistor:- 0.7% per degree C over the temp. range of -60 to $+150^{\circ}\text{C}$.

Application:-

- i) It is used in an electronic circuit.
- ii) It is used as temp. sensor for electronic thermometer.
- iii) It is used as a thermal relay.

* (Thermal relay:- It is a protector that uses the thermal effect of current to cut off the circuit.)

Baxetlex:-

- A baxetlex have a positive temp. coefficient of resistance.

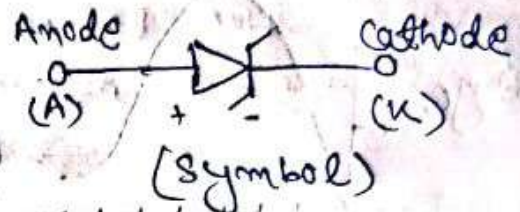
Teacher's Signature : _____

→ It is used to measure or detect power at radio, microwave and optical frequencies.

→ Power range - 10^{-5} mW to 20 mW.

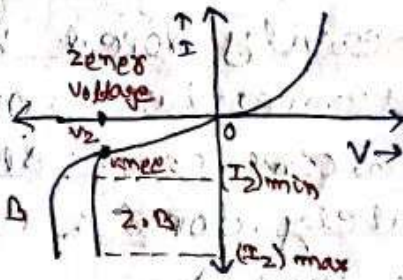
Zener Diode -:

* Zener diode is a reverse biased heavily-doped (si or ge) P-N junction diode which is operated in the breakdown region.



* Due to higher temp. & current capability, Silicon is preferred over germanium.

V-I Characteristics -:



Zener diode specifications

a) Zener voltage (V_z) -:

→ This is the reverse voltage across the Zener diode at which the reverse current increases sharply.

b) Maximum power dissipation (P_z) -:

$$P_z = V_z \times I_z$$

V_z = Zener voltage.
 I_z = Reverse current.

c) Zener resistance (r_z) -:

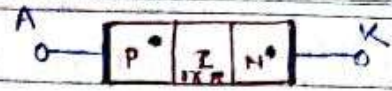
$$r_z = \frac{\Delta V_z}{\Delta I_z}$$

Application -:

a) voltage regulation.

b) Switching operation.

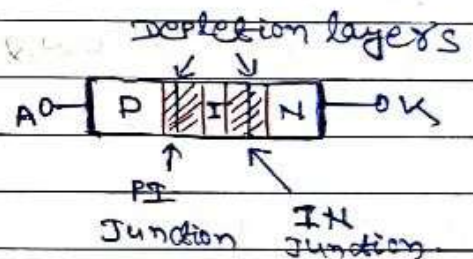
c) Meter protection.

PTN Diode:-

- * It is otherwise known as Positive - Intrinsic - Negative diodes.
- * In this diode, a high resistive intrinsic layer is sandwiched between P⁺ and N⁺ regions.
- * Due to increased separation between P and N regions, the capacitance decreases.
- * So PTN diode has faster response time as compared to PN diode (switching time) & are useful at high frequency.
- * I layer has a resistivity of $10\ \Omega\text{-cm}$.
- * When a PTN diode is forward biased, it offers a variable resistance and when it is reverse biased, it offers infinite resistance.

Working:-

Bias condn.

Case-1) (No voltage / Current)

- * With no bias applied, there will be a diffusion of charge carriers take place across the junction.
- * The diffusion^{of} electrons and holes produce a depletion layer across PI and IN junction.
- * The depletion layers penetrate to a little distance in P and N regions while a larger distance in I region. Thus, the device has a high value of resistance.

Case-2) Forward biased^{V_{FB}} condn)

- * When forward biased voltage is applied, charge carrier inject~~ed~~ into I layer from P and N region and reduces its forward Resistance. (Depletion layer decreases)
- * Thus, when a PTN diode is forward biased, it acts like a variable resistance.
- * Resistance value ~ 0.5 to $10\ \Omega$.

Teacher's Signature : _____

Case-3 (Reverse biased ^{with} V_{th} ^{condⁿ}) -;

* When reverse bias ^{with} V_{th} is applied, the depletion layer gradually increased & become more thick until the entire I region is swept free of charge carriers.

* This voltage is called as swept out voltage & PIN diode is act like a constant capacitance.

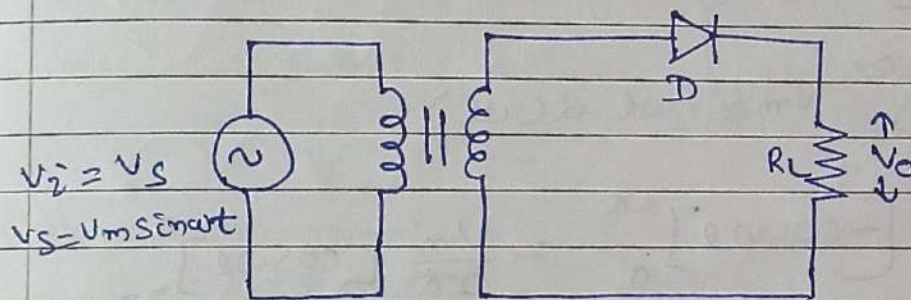
* Resistance value $\therefore$ 5 to $10k\Omega$

Application -;

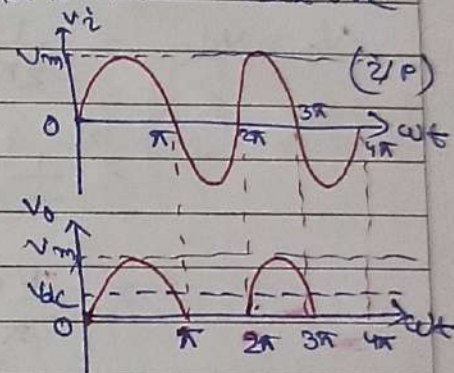
1. It can be used as an alternator.
2. It is used as constant impedance device.
3. PIN diode can be used in construction of phase modulator & amplitude modulator.
4. It can be used as phase shifter.
5. It can be used as T-R switch, in radar applications.

Half-wave Rectifier (uncontrolled)

- * A rectifier is defined as an electronic device used for converting A.C voltage or current into d.c voltage or current (unidirectional voltage or current).
- * A halfwave rectifier is one which converts A.C voltage into a pulsating voltage using only one half cycle of the applied A.C voltage.
- * Pulsating Dc voltage:- It is a Dc voltage whose value changes between '0' & a maximum positive value. (V_{max})



(circuit diagram)



(O/P)

(wave form)

- * In this circuit, we used a diode (D) connected in series with the load resistor (R_L).
- * Here a transformer is used to step up or step down the input voltage.

Working:-

- * Case - (1) ($0 \leq \omega t \leq \pi$) [+ve half cycle]
- During +ve half cycle, the diode (D) is forward biased & hence it conducts.
- Thus, current is flowing in the circuit & we can find the output voltage & output current at the load side.
- Here, voltage drop across diode is '0'. ($V_D = 0$)

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Case-(2) ($\pi \leq \omega t \leq 2\pi$) (-ve half cycle)

* For negative half cycle, the diode (D) is reversed biased and hence it does not conduct.

* So, no current is flowing through the ckt. i.e.

$$V_o = 0, \quad i_o = 0. \quad \text{---}$$

* Here, the voltage drop across the diode is equal to the supply voltage. ($V_D = V_S$)

Analysis -:

a) D.C output voltage -:

$$\begin{aligned} V_o = V_{dc} &= \frac{1}{2\pi} \int_0^\pi V_i d(\omega t) \\ &= \frac{1}{2\pi} \int_0^\pi V_m \sin \omega t d(\omega t) \\ &= \frac{V_m}{2\pi} \left[-\cos \omega t \right]_0^\pi = \frac{V_m}{2\pi} \left[\cos \omega t \right]_{-\pi}^0 \\ &= \frac{V_m}{2\pi} [1 - (-1)] = \frac{V_m}{2\pi} \times 2 = \frac{V_m}{\pi} \end{aligned}$$

$$\therefore \boxed{V_o = V_{dc} = \frac{V_m}{\pi} = 0.318 V_m}$$

b) D.C output current -:

$$\boxed{i_o = i_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L} = 0.318 \frac{V_m}{R_L}}$$

c) R.M.S. voltage -:

$$V_{RMS} = \left[\frac{1}{2\pi} \int_0^\pi V_i^2 d(\omega t) \right]^{1/2}$$

(V_{ac})

$$= \left[\frac{1}{2\pi} \int_0^\pi V_m^2 \cdot \sin^2 \omega t d(\omega t) \right]^{1/2}$$

$$\cos 2x = 1 - 2\sin^2 x$$

$$\Rightarrow \left[\sin^2 x = \frac{1 - \cos 2x}{2} \right]$$

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

$$= \left[\frac{V_m^2}{4\pi} \left[\omega t - \frac{\sin 2\omega t}{2} \right]_0^\pi \right]^{1/2}$$

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

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

∴ RMS current -

$$I_{RMS} = \frac{V_{RMS}}{R} = \frac{V_m}{2R}$$

∴ Form factor - (F)

$$F = \frac{\text{RMS value}}{\text{Avg. value}} = \frac{V_m/2}{V_m/\pi} = 1.57$$

∴ Peak factor -

$$\text{Peak factor} = \frac{\text{Peak value}}{\text{R.M.S value}} = \frac{V_m}{V_m/2} = 2$$

∴ Peak inverse voltage (PIV)

→ It is defined as the maximum voltage across the diode in the reverse direction. (V_m)

∴ Rectifier efficiency -

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{0.5 \times V_m}{\frac{V_m^2}{\pi^2} \times R_L} = \frac{4}{\pi^2}$$

$$P_{dc} = (V_{dc})^2 \times R_L = \frac{V_m^2}{\pi^2} \times R_L = 0.406$$

$$P_{ac} = \frac{V_m^2}{4} \times R_L = 40.6\%$$

Teacher's Signature: _____

∴ Ripple factor (r)

$$= \sqrt{F^2 - 1} = \sqrt{1.57^2 - 1} = 1.21$$

→ Ripple factor Tapping:- the connection point along the T/F winding to select the suitable no. of turns.

$$r = \frac{\text{Ripple Voltage}}{\text{d.c. voltage}} = \frac{V_{RMS}}{V_{DC}} = \frac{V_m/2}{V_m/\pi}$$

Full wave Rectifier:-

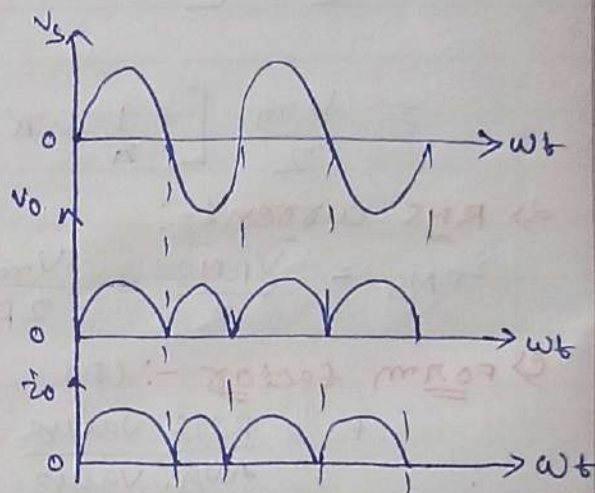
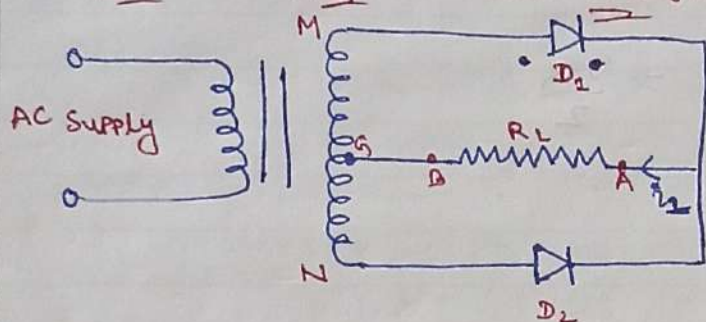
* In full wave rectifier, both half cycle of the input are utilized with the help of two diodes working alternately.

→ It is of two type.

a) Center tapped rectifier

b) Bridge Rectifier.

Center tapped Rectifier:-



Working:-

* When input A.C supply is switched on, the ends M and N of the transformer secondary becomes positive and negative alternately.

* During +ve half cycle, terminal M is +ve, G is at zero potential & N is at negative potential.

* At that time, Diode (D_1) is forward biased & conduct, causes a current (i_1) is flowing through the load. Diode D_2 is reversed biased & off condition.

* During -ve half cycle, terminal N is +ve, G is at zero potential & M is at negative potential.

* At that time, Diode (D_2) is forward biased & conduct, But Diode (D_1) is reversed biased & off condition.

* During this condition, current (i_2) is flowing through the load resistance (R_L).

Note:- current flowing path:-

+ve half cycle:- ('M' terminal - D_1 - R_L - G terminal)

-ve half cycle:- ('M' terminal - D_2 - R_L - G terminal)

* In both the cases, the current flows direction is same. (A to B direction)

Analysis:-

a) D.C. output voltage:-

$$\begin{aligned} V_o = V_{dc} &= \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t \, d(\omega t) \\ &= \frac{V_m}{\pi} [-\cos \omega t]_0^{\pi} = \frac{V_m}{\pi} [\cos \omega t]_{\pi}^0 \\ &= \frac{V_m}{\pi} [1 - (-1)] = \frac{2V_m}{\pi} = 0.637 V_m \end{aligned}$$

b) D.C. output current:-

$$i_o = i_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = 0.637 \frac{V_m}{R_L}$$

c) RMS voltage:-

$$\begin{aligned} V_{RMS} = V_{ac} &= \left[\frac{1}{\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t \, d(\omega t) \right]^{1/2} \\ &= \left[\frac{V_m^2}{\pi} \int_0^{\pi} \left(\frac{1 - \cos 2\omega t}{2} \right) d(\omega t) \right]^{1/2} \\ &= \left[\frac{V_m^2}{2\pi} \left[\omega t - \frac{\sin 2\omega t}{2} \right]_0^{\pi} \right]^{1/2} \\ &= \left[\frac{V_m^2}{2\pi} \left[(\pi - 0) - \left(\frac{\sin 2\pi}{2} - \frac{\sin 0}{2} \right) \right] \right]^{1/2} \\ &= \left[\frac{V_m^2}{2\pi} \times \pi \right]^{1/2} = \frac{V_m}{\sqrt{2}} = 0.707 V_m \end{aligned}$$

Teacher's Signature:

d) RMS current -:

$$i_{RMS} = i_{ac} = \frac{V_{RMS}}{R_L} = \frac{V_m}{\sqrt{2} R_L} = 0.707 \frac{V_m}{R_L}$$

e) Rectifier Efficiency -:

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{\frac{4V_m^2}{\pi^2 R_L}}{\frac{V_m^2}{2 R_L}} = \frac{8}{\pi^2} = 0.812 = 81.2\%$$

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

$$P_{ac} = \frac{V_{ac}^2}{R_L} = \frac{\left(\frac{V_m}{\sqrt{2}}\right)^2}{R_L} = \frac{V_m^2}{2 R_L}$$

f) Peak inverse voltage (PIV) ($2V_m$)

g) Form factor -: (F)

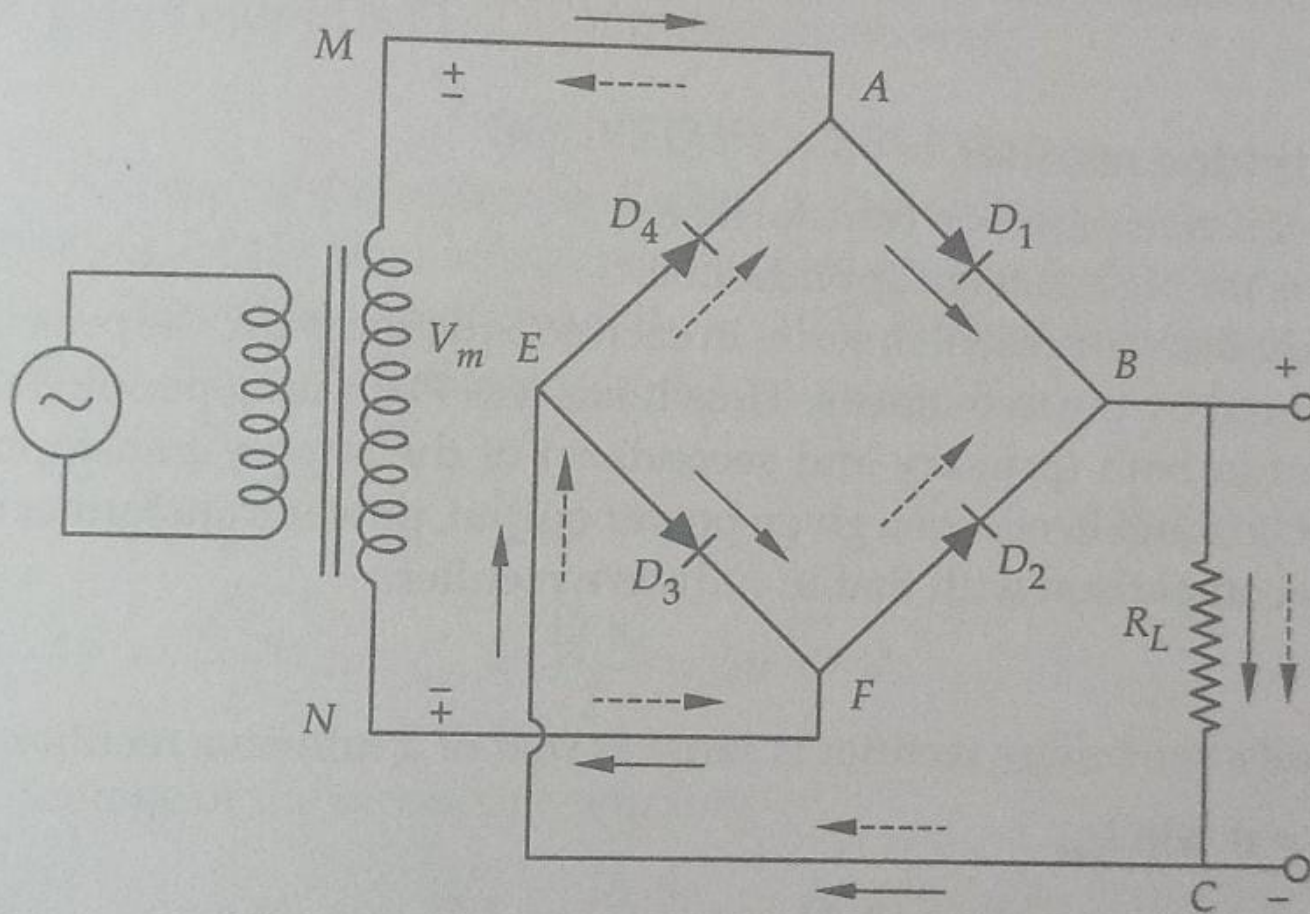
$$F = \frac{\text{RMS value}}{\text{Avg. o/p value}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{1}{\sqrt{2}} \times \frac{\pi}{2} = 1.11$$

h) Peak factor -: $\frac{\text{Peak value}}{\text{RMS value}} = \frac{V_m}{V_m/\sqrt{2}} = \sqrt{2}$

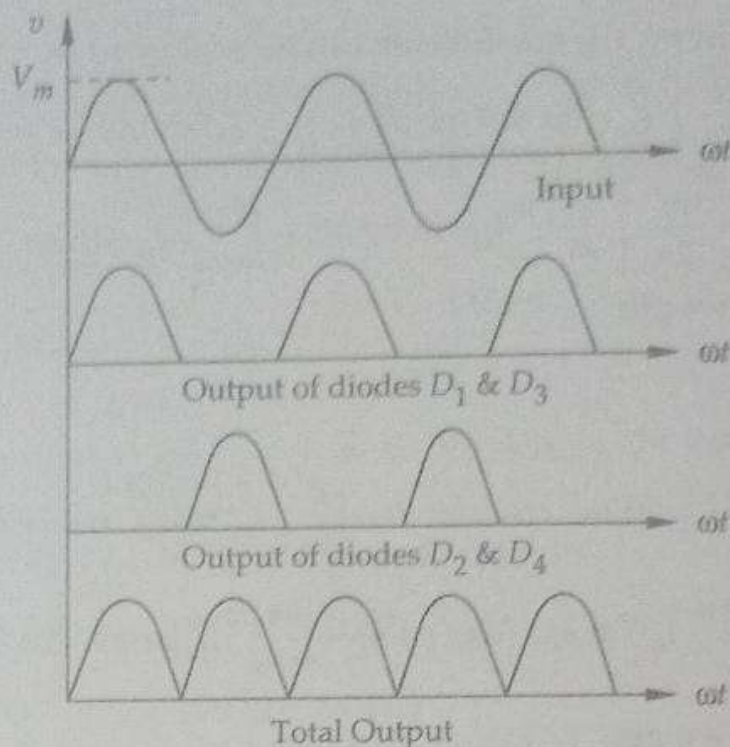
i) Ripple factor -: $\sqrt{F^2 - 1} = \sqrt{(1.11)^2 - 1} = 0.48$

8.4 FULL-WAVE BRIDGE RECTIFIER

A circuit frequently used for electronic d.c. power supplies is a fullwave bridge rectifier. In fullwave bridge rectifier four diodes are used as shown in fig. (8.13).



(a) Fullwave bridge rectifier circuit



(b) Output waveform

Fig. 8.13

During the positive input half cycle, terminal M of the secondary of the transformer is positive while the terminal N is negative. In this situation diodes D_1 and D_3 are forward biased (ON position) *i.e.*, they conduct whereas diodes D_2 and D_4 are reversed biased (OFF position) *i.e.*, they do not conduct. So a current flows along $MABCEFN$ as shown by arrow in fig. [8.13 (a)]. There will be a voltage drop across R_L .

During the negative input half cycle, terminal N of the secondary of transformer becomes positive while the terminal M becomes negative. Under this situation diodes D_2 and D_4 are forward biased (ON position) *i.e.*, they conduct whereas diodes D_1 and D_3 are reversed biased (OFF position) *i.e.*, they do not conduct. Now a current flows along $NFBCEAM$ as shown by dotted arrow in fig. [8.13 (a)]. The current produces a voltage drop across R_L .

It is obvious from the figure that current through load resistance R_L is in the same direction AB during both half cycle of the input a.c. supply. The output waveforms are shown in fig. [8.13 (b)]. Here, the waveform of the load current is essentially the same as in case of a fullwave rectifier.

Advantages of bridge rectifier

- (i) No centre-tap is required on transformer.
- (ii) It is suitable for high voltage applications.
- (iii) Since two diodes are present in series in each conduction path, the peak inverse voltage is equally shared by the two diodes. Thus it has less PIV rating per diode.
- (iv) The current in both (primary and secondary) of the supply transformer flows for the entire a.c. cycle and hence for a given power output, power transformer of small size may be used in comparison with that in fullwave rectifier.

❖ **FILTER CIRCUITS:-**

- Generally, a rectifier is required to produce pure D.C. supply for using at various places in the electronic circuits.
- However, the output of a rectifier has pulsating character i.e. it contains A.C. and D.C. components.
- The A.C. component is undesirable and must be kept away from the load.
- To do so, a filter circuit is used which removes (or filters out) the A.C. component and allows only the D.C. component to reach the load.
- A **filter circuit** is a device which removes the A.C. component of rectifier output but allows the D.C. component to reach the load.
- A filter circuit is generally a combination of inductors (L) and capacitors (C).
- The filtering action of L and C depends upon the basic electrical principles.
- A capacitor offers infinite reactance to d.c.
- We know that $X_C = 1/2\pi fC$. But for D.C., $f = 0$.

$$\therefore X_C = 1/2\pi fC = 1/2\pi \times 0 \times C = \infty \quad (\text{Means Capacitor shows infinite reactance to DC})$$

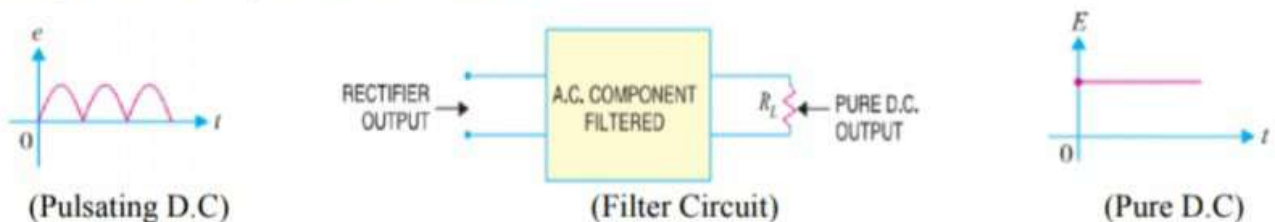
♣ **Hence, a Capacitor does not allow d.c. to pass through it.**

- We know $X_L = 2\pi fL$. For d.c., $f = 0$

$$\therefore X_L = 2\pi \times 0 \times L = 0 \quad (\text{Means Inductor shows zero reactance to DC})$$

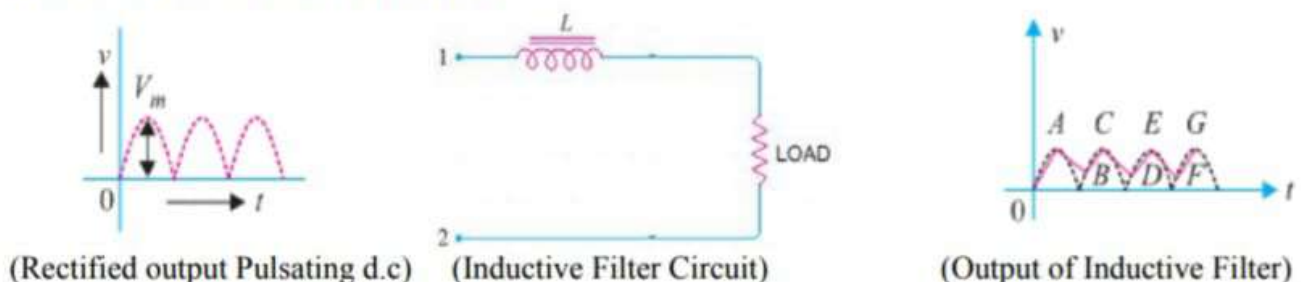
♣ **Hence Inductor passes d.c. quite readily.**

- A Capacitor passes A.C. but does not pass D.C. at all. On the other hand, an Inductor opposes A.C. but allows D.C. to pass through it.
- It then becomes clear that suitable network of L and C can effectively remove the A.C. component, allowing the D.C. component to reach the load.

➤ **Types Of Filter Circuits:-**

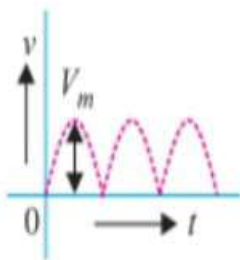
- There are different types of filter circuits according to their construction. The most commonly used filter circuits are :-

- ♣ Inductive Filter or Series Inductor.
- ♣ Capacitor Filter or Shunt Capacitor.
- ♣ Choke Input Filter or LC Filter and
- ♣ Capacitor Input Filter or π -Filter.

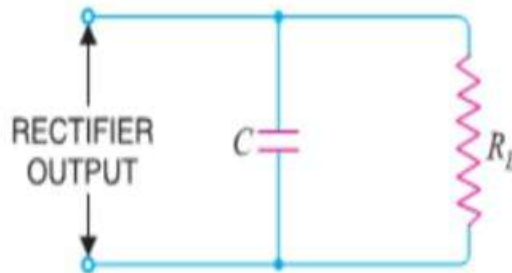
✓ **Inductive Filter Or Series Inductor:-**

- Fig. (ii) Shows a typical Inductive filter circuit. It consists of an Inductor L placed across the rectifier output in series with load R_L .

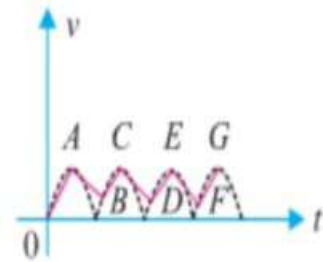
- The choke (Inductor with iron core) offers high opposition to the passage of a.c. component but no opposition to the d.c. component.
- The result is that most of the a.c. component appears across the choke while whole of d.c. component passes through the choke on its way to load. This results in the reduced pulsations at Load resistance R_L .
- ✓ **Capacitor Filter Or Shunt Capacitor:-**



(Rectified output Pulsating d.c)



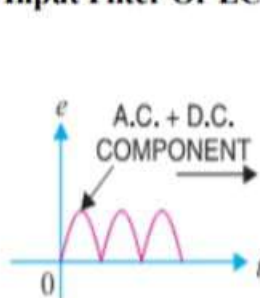
(Capacitor Filter Circuit)



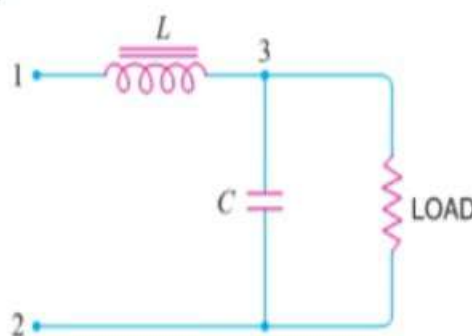
(Output of Capacitor Filter)

- Fig. (ii) Shows a typical capacitor filter circuit. It consists of a capacitor C placed across the rectifier output in parallel with load 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 [Point A in Fig. (iii)], the capacitor is charged to the peak value V_m of the rectifier voltage.
- Now, the rectifier voltage starts to decrease. As this occurs, the capacitor discharges through the load and voltage across it decreases as shown by the line AB in Fig. (iii).
- The voltage across load will decrease only slightly because immediately the next 30/76 and recharges the capacitor.
- This process is repeated again and again and the output voltage waveform becomes ABCDEFG. It may be seen that very little ripple is left in the output.
- Moreover, output voltage is higher as it remains substantially near the peak value of rectifier output voltage.
- The capacitor filter circuit is extremely popular because of its low cost, small size, little weight and good characteristics.

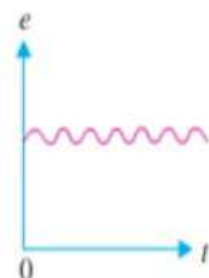
- ✓ **Choke Input Filter Or LC Filter:-**



(Rectified output Pulsating d.c)



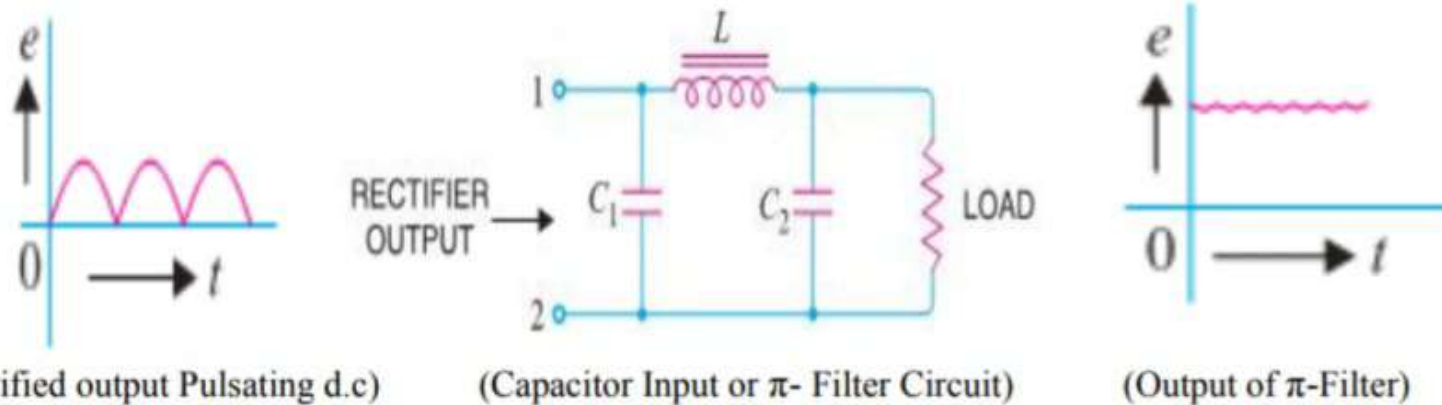
(Choke Input Filter Circuit)



(Output of Choke Input Filter)

- Fig. shows a typical choke input filter circuit. It consists of a choke L connected in series with the rectifier output and a filter capacitor C across the load.
- Only a single filter section is shown, but several identical sections are often used to reduce the pulsations as effectively as possible.
- The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit.
- As discussed before, the pulsating output of rectifier contains a.c. and d.c. components. The choke offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component.
- The result is that most of the a.c. component appears across the choke while whole of d.c. component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3.

- At terminal 3, the rectifier output contains d.c. component and the remaining part of a.c. component which has managed to pass through the choke.
- Now, the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load.
- In this way, the filter circuit has filtered out the a.c. component from the rectifier output, allowing d.c. component to reach the load.
- ✓ **Capacitor Input Filter or π -Filter:-**



- Fig. shows a typical capacitor input filter or π -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 load.
- Only one filter section is shown but several identical sections are often used to improve the smoothing action. The pulsating output from the rectifier is applied across the input terminals (i.e. terminals 1 & 2) of the filter.
- The filtering action of the three components viz C_1 , L and C_2 of this filter is described below :
 - (a) The **filter capacitor C_1** offers low reactance to a.c. component of rectifier output while it offers infinite reactance to the d.c. component. Therefore, capacitor C_1 bypasses an appreciable amount of a.c. component while the d.c. component continues its journey to the choke L .
 - (b) The **choke L** offers high reactance to the a.c. component but it offers almost zero reactance to the d.c. component. Therefore, it allows the d.c. component to flow through it, while the un bypassed a.c. component is blocked.
 - (c) The **filter capacitor C_2** bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load and that is what we desire

Transistor

* Transistor = Trans + istor

→ Trans means the signal transfer property of the device.

→ istor means a solid element like resistors.

* A transistor is basically a solid state semiconductor device which acts like a switch and an amplifier.

* It also used to control or regulate the flow of electronic signals.

→ The weak signal is introduced in the low resistance circuit & output is taken from the high resistance. Therefore, a transistor transfers a signal from a low resistance to high resistance.

→ It is of two type a) BJT - Bipolar junction transistor
b) FET - Field effect transistor.

Bipolar Junction Transistor (BJT)

→ A BJT is a type of transistor that used both the charge carriers (electrons & holes) for the current conduction.

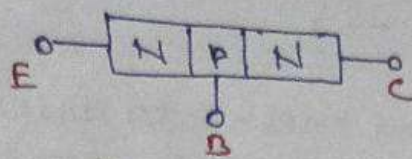
→ It is of two type. a) N-P-N transistor.

b) P-N-P transistor.

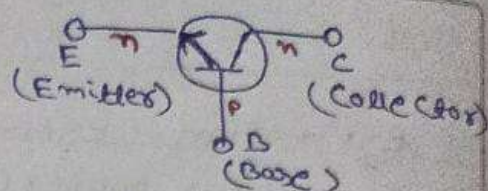
→ BJT has 3 terminals (Emitter (E), Base (B), collector (C)) & 2 junctions.

Teacher's Signature: _____

NPN Transistor:-



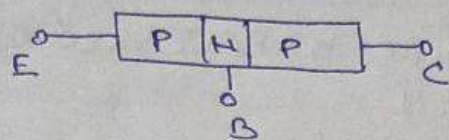
(Structure)
diagram



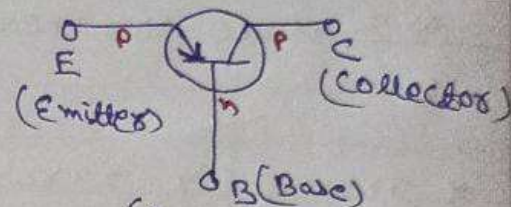
(Symbol)
diagram.

→ When a layer of 'p' type semiconductor is sandwiched between two layers of 'n' type semiconductor, then NPN transistor will form.

PNP Transistor:-



(Structure)
diagram.



(Symbol)

→ When a layer of 'n' type semiconductor is sandwiched between two layers of 'p' type semiconductor, then PNP transistor will form.

Note:- A transistor has two PN junction, one junction is forward biased & the other is reverse biased.

→ The forward biased junction has a low resistance path where as a reverse biased junction has a high resistance path.

Transistor terminals:-

→ A transistor has three sections of doped semiconductors.

→ The section on one side is the emitter and the section on the opposite side is the collector.

→ The middle section is called the base & forms two junction between the emitter & the collector.

i) Emitter:- This forms the left hand section or region of the transistor.

→ The main function of this region is to supply majority charge carriers (either electrons or holes) to the base.

- Hence, it is heavily doped in comparison to other regions.
- The arrowhead is always indicates the conventional direction of current flow & always located on the emitter terminal.
- The emitter is always forward biased w.r.t base so that it can supply a large no. of majority carriers.
- In case of N-P-N transistor it is from base to emitter (base is +ve w.r.t emitter), while in case of P-N-P transistor, it is from emitter to base (emitter is +ve w.r.t base)
- Base**:- The middle section of the transistor is known as base.
- This is very lightly doped & is very thin (10^{-6}m) as compared to either emitter or collector. So that it may pass most of the injected charge carriers to the collector.
- Collector**:- The right hand section of the transistor is called as collector.
- The main function of the collector is to collect majority charge carriers through the base.
- This is moderately doped.
- The collector is always Reversed biased w.r.t base & it offer high resistance.
- In most of the transistors, the collector region is made physically larger than the emitter region. This is due to the fact that collector has to dissipate much greater power.
- Due to this difference, collector & emitter are not interchangeable.

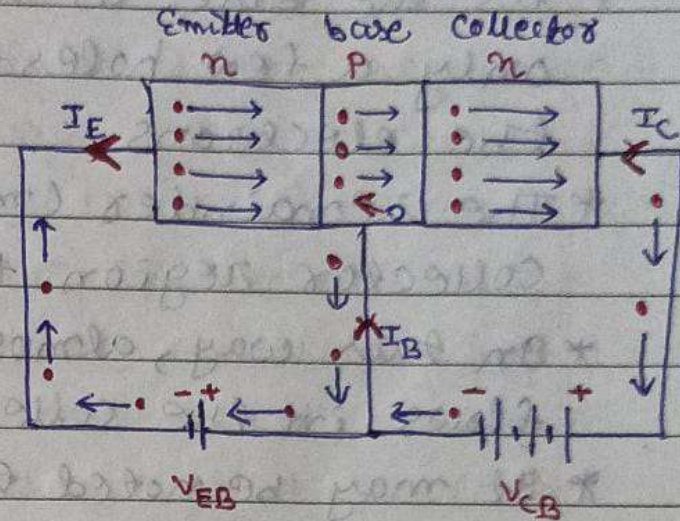
thickness	wide	thin	wider
doping level	Heavily doped (emitter)	lightly doped (base)	Moderately doped. (collector)

Teacher's Signature: _____

Transistor Action -!

Working of NPN transistor -!

- * In this circuit diagram, the npn transistor with forward biased to emitter-base junction & reverse bias to collector-base junction.



- * The forward bias causes the electrons in the n-type emitter to flow towards the base.
- * As these electrons flow through the p-type base, they tend to combine with holes.
- * As the base is lightly doped and very thin, therefore, only a few electrons (less than 5%) combine with holes to constitute base current I_B .
- * The remainder (more than 95%) cross over into the collector region to constitute collector current I_C .
- * In this way, almost the entire emitter current flows in the collector circuit & the current conduction in so $I_E = I_B + I_C$ NPN transistor is carried out by electron.

Working of PNP transistor -

* This circuit diagram shows the basic connection of a PNP transistor.

* The forward bias causes the holes in the P-type emitter to flow towards the base.

* This constitutes the emitter current I_E .

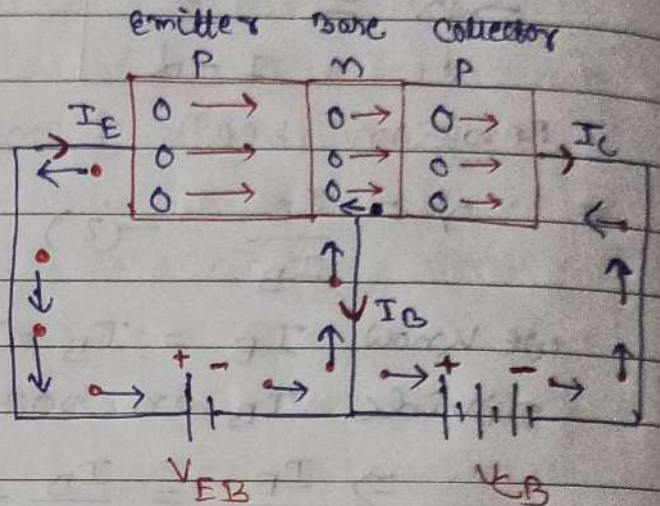
* As these holes cross into n-type base, they tend to combine with the electrons.

* As the base is lightly doped & very thin, therefore only a few holes (less than 5%) combine with the electrons.

* The remainder (more than 95%) cross into the collector region to constitute collector current I_C .

* In this way, almost the entire emitter current flows in the collector circuit.

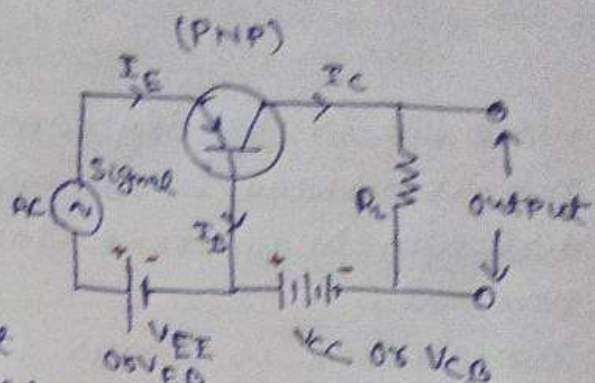
* It may be noted that current conduction within PNP transistor is by holes. However, in the external connecting wires, the current is still by electrons.



TRANSISTOR AS AN AMPLIFIER :-

→ This figure shows the basic circuit diagram of a transistor amplifier.

→ Here, the weak signal to be amplified is applied between emitter-base circuit & the output is taken across the load resistor (R_L) connected in the collector circuit.



→ A d.c voltage (V_{EE}) is connected to the input side along with 'AC' signal & another d.c voltage (V_{CC}) is connected to the output side. (Note :- $V_{CC} > V_{EE}$)

V_{EE} & V_{EB} :- Emitter base voltage.

V_{CC} & V_{CB} :- Collector base voltage.

→ If we don't connect (V_{EE}), then only the 'AC' signal will work. But we know that the emitter-base junction is always forward biased. So it don't work during negative half cycle of AC signal voltage.

→ Due to this reason we used (V_{EE}) voltage source.

→ A small change in signal voltage produces an appreciable change in emitter current because the input circuit has low resistance.

→ Due to the transistor action, the change in emitter current causes almost the same change in collector current.

→ When the collector current flows through the load resistance (R_L), a large voltage is developed across it.

→ In this way, a weak signal applied in the input circuit appears in the amplified form across the output circuit.

→ If ΔV_o = small output voltage change
 ΔV_i = small input voltage change

ΔI_E = Change in emitter current

ΔI_C = Change in collector current

β_{dc} = current amplification factor

Thus $\alpha_{dc} = \frac{\Delta I_C}{\Delta I_E} \Rightarrow \Delta I_C = \alpha_{dc} \cdot \Delta I_E$ — (i)

Now, the change in output voltage across the load resistor

$$\Delta V_o = R_L \times \Delta I_C \quad \text{(ii)}$$

$$= R_L \times \alpha_{dc} \times \Delta I_E \quad (\because \Delta I_C = \alpha_{dc} \cdot \Delta I_E)$$

then, the voltage amplification

$$A = \frac{\Delta V_o}{\Delta V_i} \quad \text{--- (iii)}$$

If r_e = resistance of the emitter base junction

then $\Delta V_i = r_e \times \Delta I_E$ — (iv)

$$\therefore A = \frac{\Delta V_o}{\Delta V_i} = \frac{R_L \times \alpha_{dc} \times \Delta I_E}{r_e \times \Delta I_E} \Rightarrow \boxed{A = \frac{\alpha_{dc} R_L}{r_e}} \quad \text{--- (v)}$$

Q. $r_e = 20 \Omega$, $R_L = 100 k\Omega$, AC signal $= 400 mV$, then
Find voltage amplification (A). Assume $\alpha_{dc} = 1$.

Ans. we know $\Delta V_i = r_e \cdot \Delta I_E$

$$\Rightarrow 400 = 20 \times \Delta I_E$$

$$\Rightarrow \Delta I_E = \frac{400}{20} = 20 mA$$

then $\Delta I_C = \alpha_{dc} \Delta I_E = 1 \times 20 mA = 20 mA$

output voltage $\Delta V_o = \Delta I_C \times R_L = 20 mA \times 100 k\Omega$

$$= 20 \times 10^{-3} \times 100 \times 10^3 = 2000 V.$$

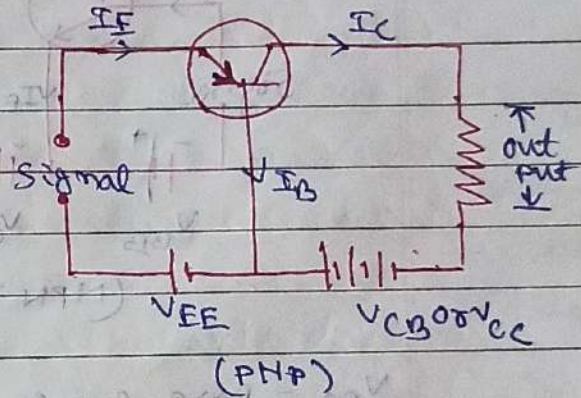
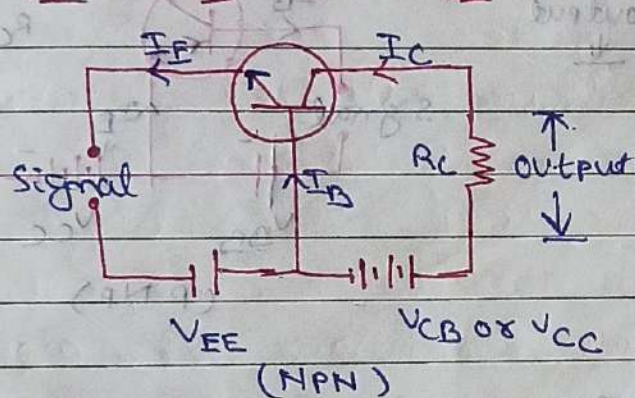
$$\therefore \text{voltage amplification (A)} = \frac{\Delta V_o}{\Delta V_i} = \frac{2000}{400 \times 10^{-3}} = \frac{2000 \times 10^3}{400} = 5000 \quad \text{(Ans)}$$

Transistor connections -

* There are 3 types of transistor connection.

- a) common base connection
- b) Common emitter connection
- c) Common collector connection.

a) Common Base connection -



V_{EE} = emitter supply Vtg. (emitter base voltage)

V_{CB} = collector base Vtg. or V_{CC}

* In this circuit, i/p is applied between emitter and base and output is taken from collector and base.

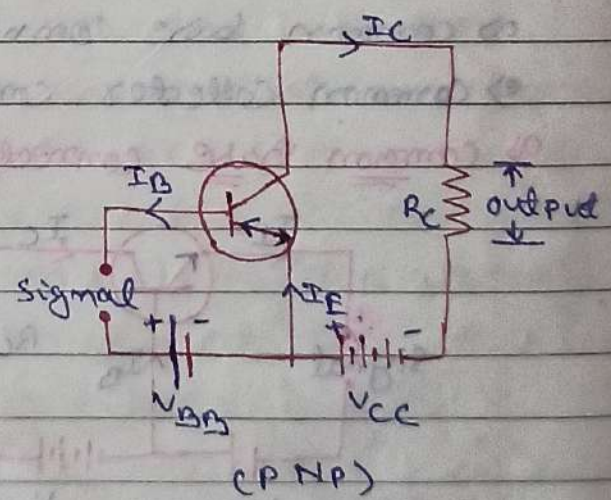
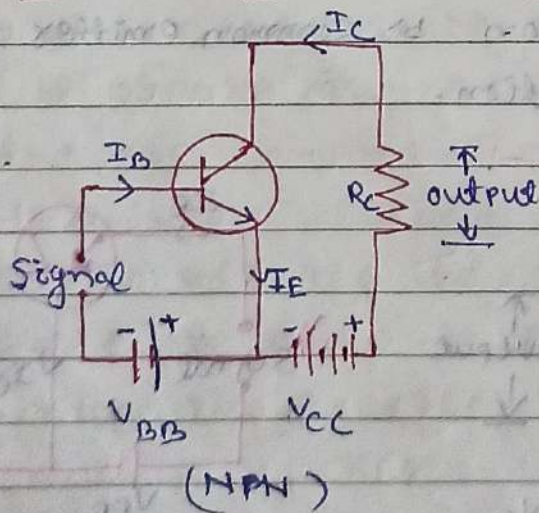
* Here, base of the transistor is common to both input and output circuits & hence the name is common base connection.

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.

$$\alpha = \frac{I_C}{I_E} \text{ at } V_{CB} = \text{constant. (Range = 0.9 to 0.99)}$$

Common Emitter Connection -:



V_{BB} = Base supply voltage

V_{CC} = Collector supply voltage

* In this circuit, input is applied between base and emitter and output is taken from the collector

and emitter.

- * Here, emitter of the transistor is common to both input and output circuits and hence the name is common emitter connection.

Base current amplification factor (β):-

- * The ratio of change in collector current to the change in base current is known as Base current amplification factor.

$$\boxed{\beta = \frac{I_C}{I_B}} \quad (\text{Range} = 20 \text{ to } 500)$$

Relation between α & β :-

we know $I_E = I_C + I_B$

Divide I_C on both the side

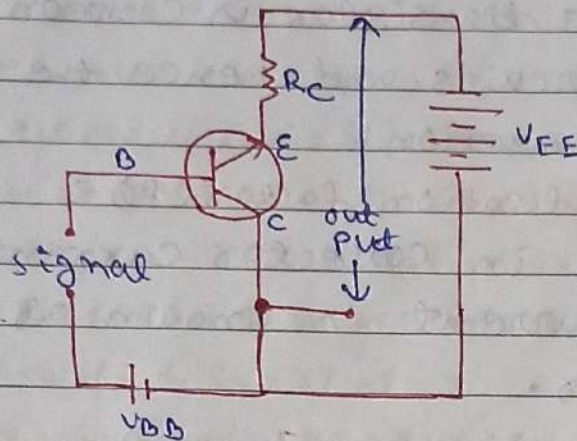
$$\Rightarrow \frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

$$\Rightarrow \frac{1}{\alpha} = 1 + \frac{1}{\beta} \quad \Rightarrow \frac{1}{\alpha} = \frac{1 + \beta}{\beta}$$

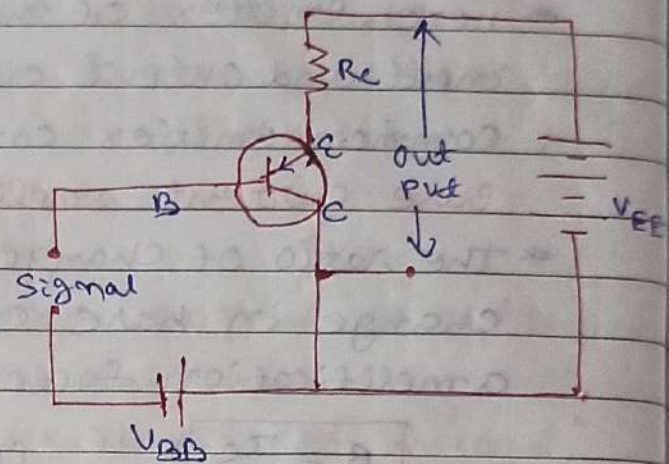
$$\Rightarrow \boxed{\alpha = \frac{\beta}{1 + \beta}}$$

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

Common collector connection -:



(NPN)



(PNP)

- * In this circuit, the input is applied between base and collector while output is taken between the emitter and collector.
- * Here, collector of the transistor is common to both input and output circuit and hence the name common collector connection.

current amplification factor (γ) -:

- * The ratio of change in emitter current to the change in base current is known as current amplification factor in common collector arrangement.

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

Relation between γ and α -:

we know $\alpha = \frac{I_C}{I_E}$ (i) and $\gamma = \frac{I_E}{I_B}$ (ii)

For $I_E = I_B + I_C$

$\Rightarrow I_B = I_E - I_C$ (iii)

Substitute eqn (iii) in eqn (ii)

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

$$\Rightarrow \gamma = \frac{I_E/I_E}{I_E/I_E - I_C/I_E}$$

(Divide I_E on both the numerator & denominator)

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

Relation betⁿ γ and β :-

$$* \quad \gamma = \frac{I_E}{I_B} \quad \text{---(i)} \quad \beta = \frac{I_C}{I_B} \quad \text{---(ii)}$$

we know $I_E = I_B + I_C$ ---(iii)

Divide I_B on both side

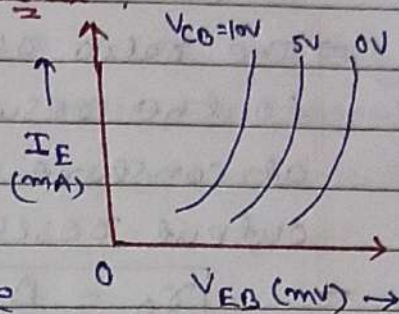
$$\Rightarrow \frac{I_E}{I_B} = \frac{I_B}{I_B} + \frac{I_C}{I_B}$$

$$\Rightarrow \boxed{\gamma = 1 + \beta} \quad \text{or} \quad \boxed{\beta = \gamma - 1}$$

Characteristics of Common Base circuit:-

Input Characteristics:-

→ The input characteristics curve is drawn between emitter current (I_E) and emitter base voltage (V_{EB}) at constant collector base voltage (V_{CB}).



(input characteristics)

→ The emitter current (I_E) increases rapidly with small increase in emitter-base voltage (V_{EB}). This shows that the input resistance is very small.

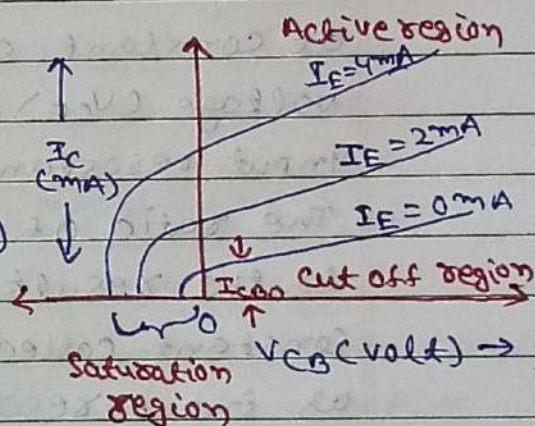
Input resistance (r_i):-

→ 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 defined as input resistance.

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

Output Characteristics:-

→ The output characteristics curve is drawn between collector current (I_C) and collector base voltage (V_{CB}) at constant emitter current (I_E).



(output characteristics)

I_{CBO} = Collector leakage current.

→ In the active region (emitter junction is in forward biased & collector junction is in Reverse biased).

→ In the cut off region (when both emitter and collector junctions are reversed-biased), but a small amount of collector leakage current (I_{CBO}) is flow.

→ In the saturation region (when both emitter and collector junctions are forward biased).

Output resistance - (r_o)

→ 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 defined as output resistance.

$$\rightarrow \boxed{r_o = \frac{\Delta V_{CB}}{\Delta I_C}} \quad I_E = \text{constant.}$$

Q/ CB configuration, $\Delta V_{EB} = 200 \text{ mV}$, $\Delta I_E = 5 \text{ mA}$.

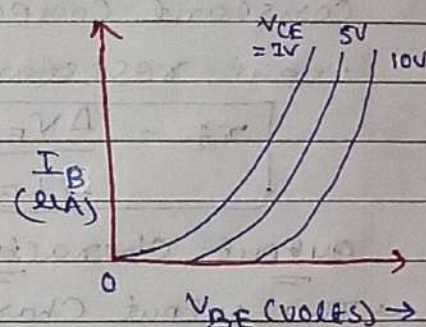
Find r_i .

$$\text{Ans-} \quad r_i = \frac{\Delta V_{EB}}{\Delta I_E} = \frac{200 \text{ mV}}{5 \text{ mA}} = 40 \Omega$$

Characteristics of Common Emitter Circuit -

Input Characteristics -

→ The input characteristics curve is drawn between base current (I_B) and base-emitter voltage (V_{BE}) at constant collector-emitter voltage (V_{CE}).



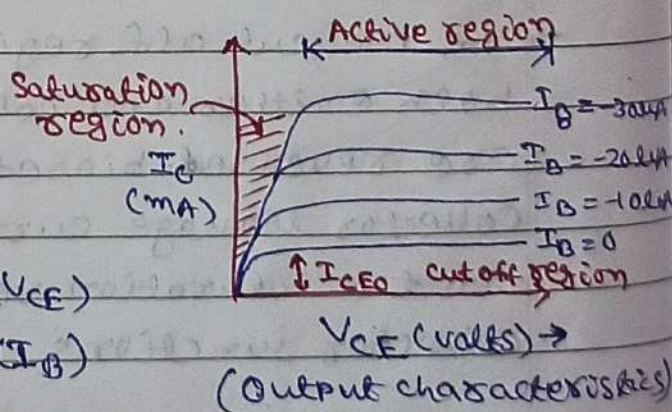
Input resistance - (r_i)

→ 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 defined as input resistance.

$$\boxed{r_i = \frac{\Delta V_{BE}}{\Delta I_B}} \quad V_{CE} = \text{constant.}$$

Output Characteristics -

→ The output characteristics curve is drawn between collector current (I_C) and collector emitter voltage (V_{CE}) at constant base current (I_B).



output resistance-: (r_o)

→ The ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current (I_B) is defined as output resistance.

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \quad I_B = \text{constant.}$$

Q/ A change of 300mV in base-emitter voltage causes a change of 100 μ A in the base current. Find the input resistance?

Ans: $r_i = \frac{\Delta V_{BE}}{\Delta I_B} \Big|_{V_{CE} = \text{constant}}$

$$\Rightarrow r_i = \frac{300 \times 10^{-3}}{100 \times 10^{-6}} = 3 \times 10^3 = 3 \text{ k}\Omega \text{ (Ans)}$$

Q/ Increase in collector emitter voltage from 5V to 8V. causes increase in collector current from 5mA to 5.3mA. Find the output resistance?

Ans: $\Delta V_{CE} = 8 - 5 = 3\text{V}$, $\Delta I_C = 5.3 - 5 = 0.3 \text{ mA}$

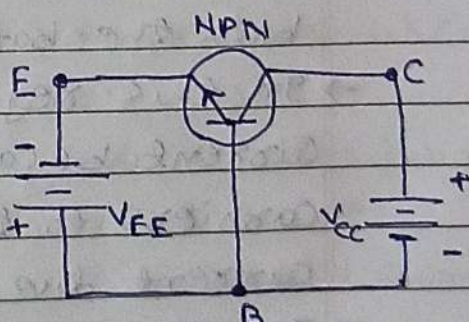
$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} = \frac{3}{0.3 \times 10^{-3}} = 10^4 = 10 \text{ k}\Omega \text{ (Ans)}$$

Different modes of operation of a transistor -

Case	Emitter-base Junction (E_B)	Collector-base Junction	Region of operation
I	Forward-biased	Reverse-biased	Active
II	Forward-biased	Forward-biased	Saturation
III	Reverse-biased	Reverse-biased	Cut-off
IV	Reverse-biased	Forward-biased	Inverted

Case (I) Active Region -

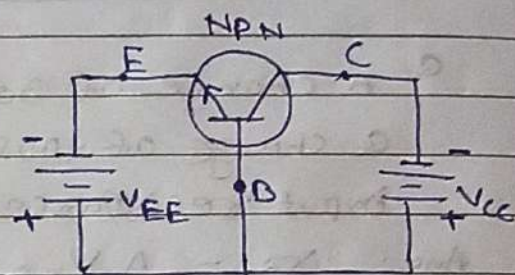
→ In this mode, the emitter-base junction is forward-biased while collector-base junction is reversed biased.



- In the emitter-base circuit, a battery V_{EE} is connected such that negative of the battery is connected to emitter while positive is connected to base.
- Similarly, a battery V_{CC} is connected to collector-base circuit. Positive terminal of battery is connected to collector while negative is connected to base.
- In this region, the transistor is used for amplification.

Case (i) - Saturation region -

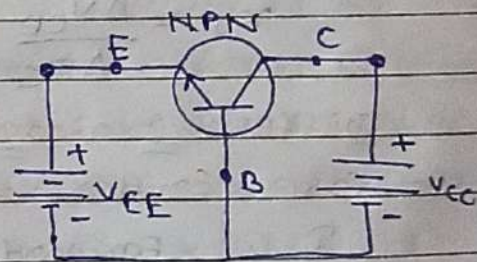
- In this mode, emitter-base junction as well as collector-base junction both are forward biased.



- The negative of battery V_{EE} is connected to emitter and similarly the negative of battery V_{CC} is connected to collector. The positive terminals of both the batteries are connected to base.
- In this case, the collector current becomes independent of base current. So, the transistor acts like a closed switch.

Case (ii) Cut-off region -

- In this mode, both the junctions are reverse biased.



- Here the positive of battery V_{EE} is connected to emitter & similarly the positive of battery V_{CC} is connected to collector. The negative terminals of both the batteries are connected to base.
- In this region, the transistor has practically zero current because the emitter does not emit charge carriers to the base. Of course, there is negligibly current due to minority carrier (leakage current).
- In this situation, the transistor acts as open switch.

Case IV Inverted region

→ In this region, emitter-base junction is reversed-biased while collector-base junction is forward-biased.

→ In the emitter-base circuit, a battery V_{EE} is connected such that positive of the battery is connected to emitter while negative is connected to base.

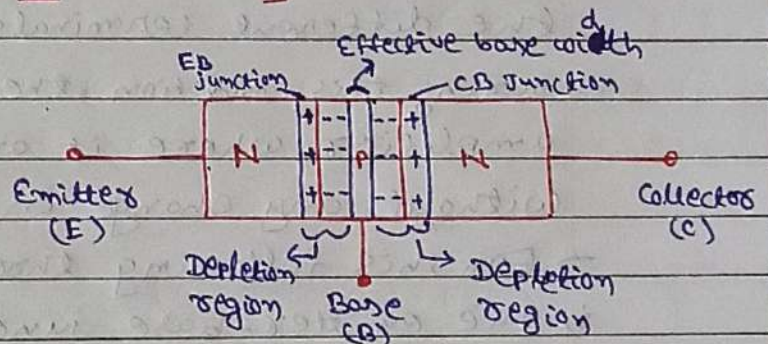
→ Similarly, a battery V_{CC} is connected to collector-base circuit. Negative terminal of battery is connected to collector while positive is connected to base.

→ Here, the collector cannot inject the majority carriers into the base because the doping level of emitter and collector is not the same.

→ In this region, the action of transistor is very poor.

CP-5 Transistor circuitUnbiased Transistor -

→ When no external supply is connected to a transistor, the transistor is said to be in unbiased condition.



→ A transistor is just like two diodes.

→ The junction between emitter and base may be called as emitter base diode or emitter diode.

→ Similarly, the junction between base and collector may be called as collector base diode or collector diode.

→ When no battery is connected between different terminals, the transistor is said to be unbiased or in open circuit state.

→ There are two depletion regions at the two junctions of a transistor.

→ The width of the two depletion layers will be different.

- because the regions are doped at different levels
- The depletion region penetrates more deeply into lightly doped side so as to include an equal number of impurity atoms in each side of junction.
 - Therefore, the depletion region at emitter junction penetrates less in heavily doped emitter and extends more in base region.
 - Similarly, the depletion region at collector junction penetrates less in heavily doped collector and extends more in base region.
 - So, the depletion layer formed at collector junction is larger than depletion layer formed at emitter junction.

Transistor biasing -

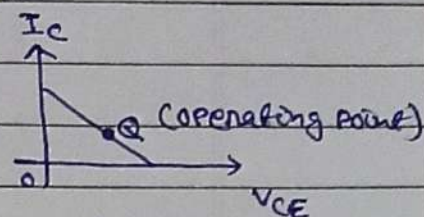
- The process of applying external d.c voltages across the different terminals of transistor is called biasing.
- During this condition, the transistor works as an amplifier where it amplifies the magnitude of signal without any change in shape.
- For this following three conditions must be satisfied:
 - i) The emitter-base junction should be forward biased.
 - ii) The collector-base junction should be reverse biased.
 - iii) There should be proper zero signal collector current.
- When a transistor is not properly biased, it works inefficiently and produces distortion in the output signal. Hence a transistor should be biased correctly.
- A transistor is biased either with the help of battery or associating a circuit with the transistor.
- The circuit used with the transistor is known as biasing circuit.
- The proper flow of zero signal collector current (proper operating point of a transistor) and

the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.

Stabilisation:-

→ The process of making operating point independent of temperature changes or variations in transistor parameter is known as stabilisation.

or The maintenance of the operating point stable is known as stabilisation.



→ Stabilization of the operating point depends on

- a) Temperature dependence of I_C .
- b) Individual Variation. (β and V_{BE})
- c) Thermal runaway.

→ Thermal runaway depends upon the construction of a transistor

→ The collector junction temp. range lies between 60°C to 100°C for Ge transistor and 150°C to 225°C for Si transistor.

→ If the temperature increases beyond this range then the transistor burns out.

→ The self-destruction of an unstabilized transistor is known as thermal runaway.

Stability factor:- (S)

→ The stability factor (S) is defined as the rate of change of collector current (I_C) w.r.t the reverse saturation current (I_{CO} - collector leakage current), keeping β and V_{BE} constant.

$$S = \frac{\partial I_C}{\partial I_{CO}} = \frac{\Delta I_C}{\Delta I_{CO}}$$

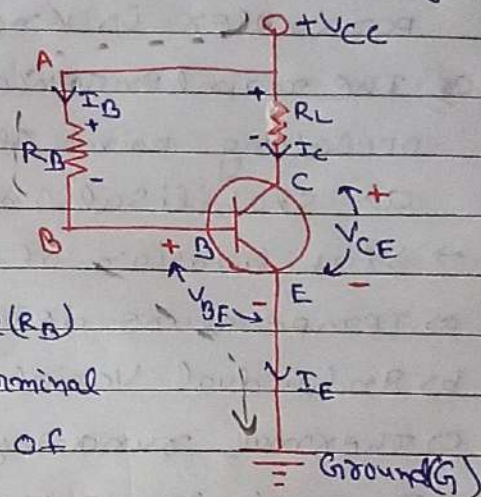
→ Note:- The smaller is the value of S , higher is the stability. So the stability factor (S) should be kept as small as possible.

Different Methods for Transistor Biasing -

- Some of the methods used for providing bias for a transistor are a) Base resistor method b) collector to base bias c) voltage divider bias
- To simplify the calculation, we used only one source of supply (V_{CC}) instead of two source of supply (V_{BB} & V_{CC})

Base Resistor Method

- This figure shows an NPN transistor connected in common-emitter (CE) configuration with resistor biased.



- In this method, a high resistance (R_B) is connected between positive terminal of supply voltage (V_{CC}) and base of the transistor.
- Here, the required zero signal base current flows through R_B and is provided by V_{CC} .
- The base-emitter junction is forward biased because the base is positive w.r.t emitter.
- The required value of zero signal base current I_B ($I_C = \beta I_B$) can be made to flow by selecting the proper value of base resistor (R_B).

Circuit analysis -

- By applying KVL (Kirchhoff's voltage law) in closed circuit ABEGA, we have got

$$V_{CC} - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B R_B = V_{CC} - V_{BE}$$

$$\Rightarrow \boxed{R_B = \frac{V_{CC} - V_{BE}}{I_B}} \quad \text{--- (1)}$$

Further $\beta = \frac{I_C}{I_B} \Rightarrow \boxed{I_B = \frac{I_C}{\beta}} \quad \text{--- (2)}$ $\beta = \text{Base current amplification factor}$

Put the value of I_B in Eqn (1)

$$R_B = \frac{V_{CC} - V_{BE}}{I_C / \beta} \Rightarrow \boxed{R_B = \frac{(V_{CC} - V_{BE}) \beta}{I_C}} \quad \text{--- (3)}$$

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Since V_{BE} is generally very small as compared to V_{CC} ,
hence $R_B = \frac{\beta V_{CC}}{I_C}$ — (4)

→ The whole method is ^{also} called as fixed-bias method.

Q. A germanium transistor is to be operated at zero signal $I_C = 1 \text{ mA}$. If the collector supply $V_{CC} = 10 \text{ V}$, what is the value of R_B in base resistor method? ($\beta = 100$)

Ans:- $R_B = \frac{(V_{CC} - V_{BE})\beta}{I_C}$ for Germanium ($V_{BE} = 0.3 \text{ V}$)
 $V_{CC} = 10 \text{ V}$, $\beta = 100$
 $I_C = 1 \text{ mA} = 1 \times 10^{-3} \text{ A}$

$$= \frac{(10 - 0.3) 100}{1 \times 10^{-3}} = 970000 \Omega$$

 or $970 \text{ k}\Omega$ (Ans)

Q. A silicon transistor with $\beta = 100$, $V_{CC} = 10 \text{ V}$, $R_B = 930 \text{ k}\Omega$ & $R_L = 4 \text{ k}\Omega$. Determine the operating point? (V_{CE}, I_C)

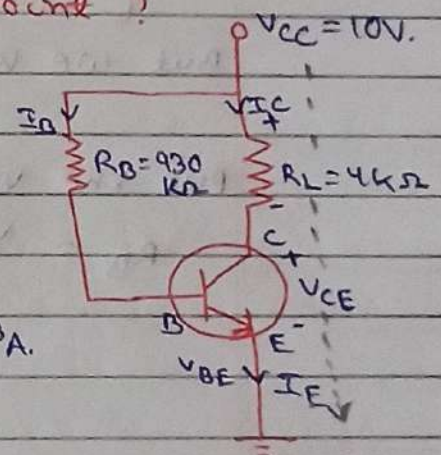
Given
Ans:- $V_{CC} = 10 \text{ V}$, $\beta = 100$, $R_B = 930 \text{ k}\Omega$

$R_L = 4 \text{ k}\Omega$, $V_{BE} = 0.7 \text{ V}$ (Silicon)

then $I_C = \frac{(V_{CC} - V_{BE})\beta}{R_B}$

$$= \frac{(10 - 0.7) \times 100}{930 \times 10^3} = 1 \text{ mA}$$

 or $1 \times 10^{-3} \text{ A}$



Now Apply KVL on outside loop,

$$V_{CC} - I_C R_L - V_{CE} = 0$$

$$\Rightarrow V_{CE} = V_{CC} - I_C R_L \Rightarrow V_{CE} = 10 - 1 \times 10^{-3} \times 4 \times 10^3 = 6 \text{ V}$$

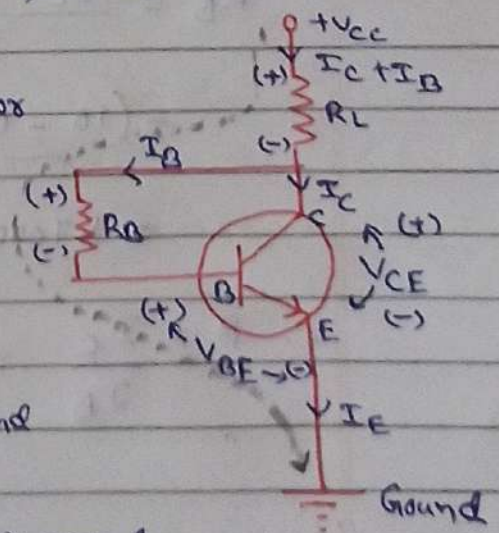
∴ Operating point (V_{CE}, I_C) = (6 V, 1 mA) (Ans)

Collector to Base Bias

→ This figure shows an NPN transistor connected in common-emitter (CE) configuration with collector to base bias.

→ In this method, one end of (R_B) is connected to the base & the other end to the collector.

→ Here, the required zero signal base current



is determined not by V_{CC} but by the collector-base voltage (V_{CB})
 → Since V_{CB} is forward bias, hence I_B flows through R_B . This causes the zero signal collector current to flow in the circuit.

Circuit analysis:-

→ For finding R_B :-

$$\text{voltage drop across } (R_L)^V = (I_C + I_B) R_L \approx I_C R_L$$

(∵ Since I_B has very small value)

* By Applying KVL, inside the circuit:-

$$V_{CC} - I_C R_L - I_B R_B - V_{BE} = 0$$

$$\Rightarrow I_B R_B = V_{CC} - V_{BE} - I_C R_L$$

$$\Rightarrow R_B = \frac{V_{CC} - V_{BE} - I_C R_L}{I_B} \quad \text{--- (1)}$$

But we know $\beta = \frac{I_C}{I_B} \Rightarrow I_B = \frac{I_C}{\beta} \quad \text{--- (2)}$

Put the value of I_B in Eqn (1)

$$R_B = \frac{V_{CC} - V_{BE} - I_C R_L}{I_C / \beta} \Rightarrow R_B = \frac{(V_{CC} - V_{BE} - I_C R_L) \beta}{I_C} \quad \text{--- (3)}$$

$$\text{or } I_C = \frac{(V_{CC} - V_{BE} - I_C R_L) \beta}{R_B}$$

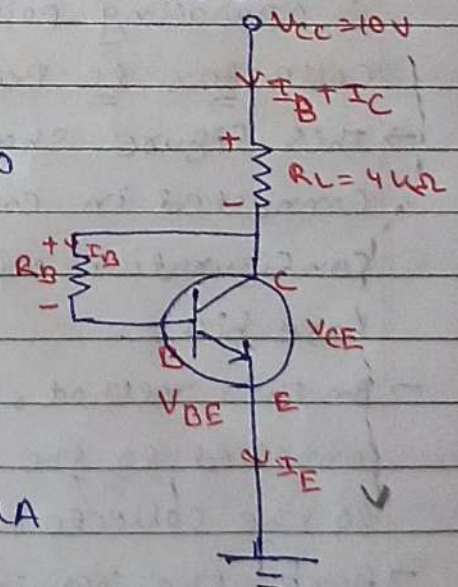
Q/ In a collector to Bias circuit $I_C = 1\text{mA}$, $V_{CE} = 5\text{V}$, $\beta = 100$
 $R_L = 4\text{k}\Omega$, $V_{CC} = 10\text{V}$, $V_{BE} = 0.3\text{V}$, Find R_B , I_B & operating point? (V_{CE}, I_C)

Ans:- $R_B = \frac{(V_{CC} - V_{BE} - I_C R_L) \beta}{I_C}$

$$= \frac{(10 - 0.3 - 1 \times 10^{-3} \times 4 \times 10^3) 100}{1 \times 10^{-3}}$$

$$= 570000 \Omega \text{ or } 570\text{k}\Omega$$

$$\therefore \beta = \frac{I_C}{I_B} \Rightarrow I_B = \frac{I_C}{\beta} = \frac{1 \times 10^{-3}}{100} = 1 \times 10^{-5} = 10\mu\text{A}$$



Applying KVL,

$$V_{CC} - (I_B + I_C)R_L - V_{CE} = 0$$

(Since the value of I_B is very small, so we neglected I_B)

$$\Rightarrow V_{CE} = V_{CC} - I_C R_L$$

$$\Rightarrow V_{CE} = 10 - 1 \times 10^{-3} \times 4 \times 10^3 = 6V.$$

$\therefore$ operating point $(V_{CE}, I_C) = (6V, 1mA)$ (Ans)

Self Bias or Emitter Bias (Voltage Divider Bias)

→ This is the most widely used method of providing biasing and stabilization to a transistor.

→ This is also known as universal bias stabilization circuit.

→ In this method, two resistance R_1 and R_2 are connected across the supply voltage V_{CC} and provide biasing.

→ The emitter resistance (R_E) provides stabilization.

→ The name "Voltage divider" comes from the voltage divider formed by R_1 and R_2 .

→ The voltage drop across R_2 is forward biases for the base-emitter junction.

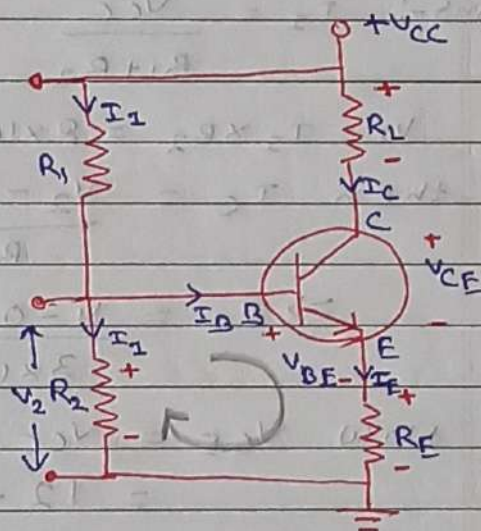
Circuit analysis:-

→ Let current I_1 flows through R_1 .

→ As the base current (I_B) is very small, the current flowing through R_2 can also be taken as I_1 .

→ The calculation of collector current (I_C) is as follows:-

$$I_1 = \frac{V_{CC}}{R_1 + R_2} \quad (1)$$



→ The voltage (V_2) developed across R_2 is given by

$$V_2 = I_1 R_2 = \left(\frac{V_{CC}}{R_1 + R_2} \right) R_2 \quad (2)$$

→ Applying KVL to the base circuit, we have

$$I_1 R_2 - V_{BE} - I_E R_E = 0 \quad (\because V_2 = I_1 R_2)$$

$$\Rightarrow V_2 - V_{BE} - I_E R_E = 0$$

$$\Rightarrow V_2 - V_{BE} - I_C R_E = 0$$

$$(\because I_E = I_B + I_C)$$

$$\Rightarrow I_C R_E = V_2 - V_{BE}$$

But I_B is very small, so neglected)
therefore $I_E \approx I_C$

$$\Rightarrow I_C = \frac{V_2 - V_{BE}}{R_E} \quad \text{--- (3)}$$

→ Now, for the collector emitter voltage (V_{CE}) can be calculated as follows:-

* By Applying KVL to the collector side, we have

$$V_{CC} - I_C R_L - V_{CE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} - I_C R_L - V_{CE} - I_C R_E = 0 \quad \because I_E \approx I_C$$

$$\Rightarrow V_{CE} = V_{CC} - I_C R_L - I_C R_E$$

$$\Rightarrow V_{CE} = V_{CC} - I_C (R_L + R_E) \quad \text{--- (4)}$$

Q. A silicon transistor uses potential divider method of biasing. $V_{CC} = 12V$, $R_1 = 10k\Omega$, $R_2 = 5k\Omega$, $R_L = 1k\Omega$ and $R_E = 3k\Omega$. Find the operating point (V_{CE} , I_C)

$$\text{Ans:- } I_1 = \frac{V_{CC}}{R_1 + R_2} = \frac{12}{(10 + 5) \times 10^3} = 8 \times 10^{-4} = 0.8 \text{ mA}$$

$$V_2 = I_1 \times R_2 = 8 \times 10^{-4} \times 5 \times 10^3 = 4V$$

$$\text{then } I_C = \frac{V_2 - V_{BE}}{R_E} \quad \left(\begin{array}{l} \text{for silicon} \\ V_{BE} = 0.7V \end{array} \right)$$

$$\Rightarrow I_C = \frac{4 - 0.7}{3 \times 10^3} = 1.1 \times 10^{-3} = 1.1 \text{ mA}$$

$$\begin{aligned} \text{Now } V_{CE} &= V_{CC} - I_C (R_L + R_E) \\ &= 12 - 1.1 \times 10^{-3} (1 \times 10^3 + 3 \times 10^3) \\ &= 12 - 1.1 \times 10^{-3} \times 10^3 (1 + 3) \\ &= 12 - 4.4 = 7.6V \end{aligned}$$

$\therefore$ So the operating point (Q) = (V_{CE} , I_C) = (7.6V, 1.1mA)
(Ans)

Transistor Amplifier & Oscillators

Transistor Amplifier:-

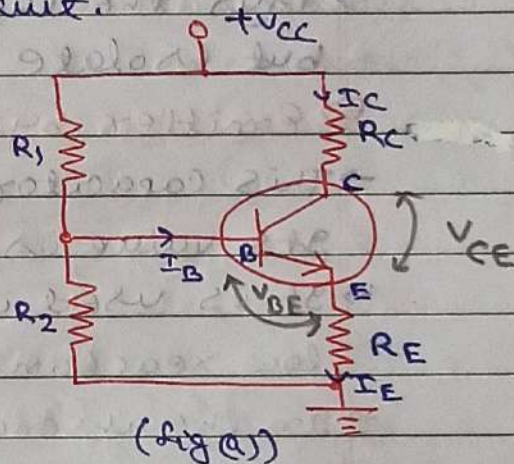
- A transistor acts as an amplifier by raising the strength of a weak signal and converts it into strong signal.
- This device may increase voltage, current or power of an input signal.
- When only one transistor with its associated circuit is used for amplifying a weak signal, the amplifier is known as Single stage transistor Amplifier.
- If we used more than one transistor with its associated circuit for its amplification purpose, then it is called as Multi stage transistor Amplifier.

Practical Circuit of Transistor Amplifier:-

- Here we used common emitter configuration represent the voltage divider biasing circuit.

a) Biasing Circuit:-

- The resistors R_1 , R_2 and R_E form the biasing and stabilization circuit.
- The biasing circuit must establish a proper operating point (Q).



(fig a)

b) Load (R_L):-

- The resistance (R_L) connected at the output terminal is known as load.
- When a number of stages are used, then R_L represents the input resistance of the next stage.

c) Coupling Capacitor (C_c):-

- This coupling capacitor (C_c) couples one stage of amplification to the next stage.
- It passes AC signal from one side to other side. Its value is approximately 10 μF .
- This is also known as blocking capacitor because it does not allow the d.c. voltage/current to pass through.

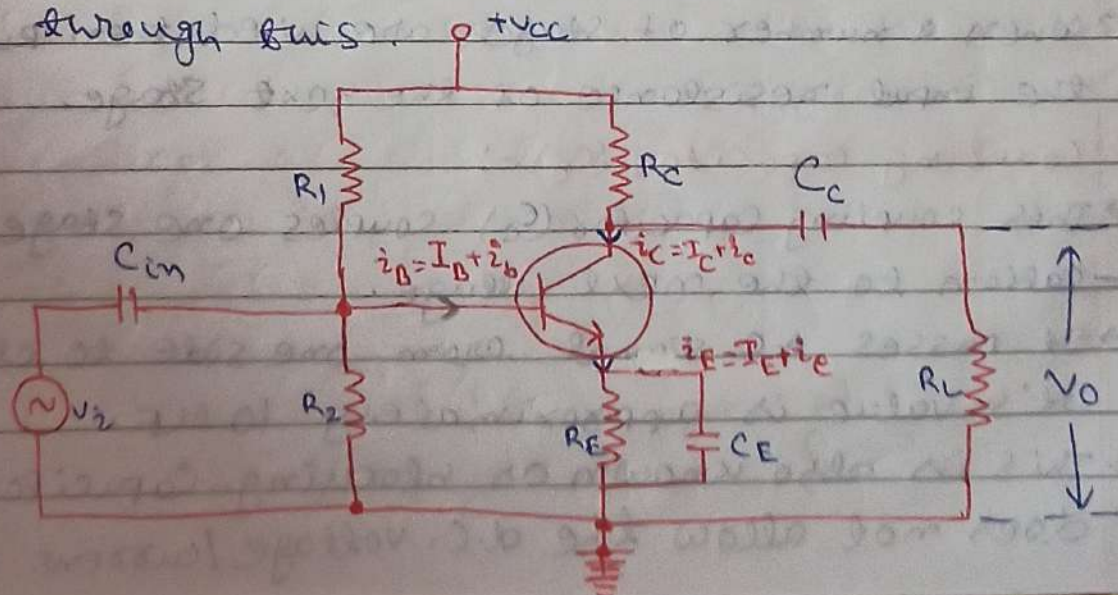
- Due to the presence of C_c , the output across the resistor (R_L) is free from the collector's d.c. voltage.
- In the absence of C_c , R_c will come in parallel with the resistance (R_1) of the biasing network of next stage and thereby changing the biasing conditions of next stage.

d) Input Capacitor (C_{in}) :-

- This capacitor couples the signal to the base of the transistor. This is an electrolytic capacitor of value approximately $10\mu F$.
- In the absence of this capacitor, the source resistor (R_E) will come in parallel with R_2 and thus change the bias.
- Thus the capacitor allows only a.c. signal to flow but isolate the signal source from R_2 .

e) Emitter bypass Capacitor - (C_E)

- This capacitor (C_E) works as a bypass capacitor. Its value is approximately $100\mu F$.
- It is used in parallel with (R_E) to provide a low reactance path to amplified a.c. signal.
- In the absence of this capacitor, the voltage developed across R_E will feed back to the input side thereby reducing the output voltage.
- Thus, in presence of (C_E) amplified a.c. will pass through this.



Circuit Current:-

i) base current- when no signal is applied in the base circuit, D.C. base current (I_B) flows due to biasing circuit.
 → when A.C. signal is applied, A.C. base current (i_b) also flows.

→ Therefore, with the application of signal, Total base current ($\tilde{i}_B$) is given by $\tilde{i}_B = I_B + i_b$.

ii) collector current- when no signal is applied, a D.C. collector current (I_C) flows due to biasing circuit.
 → when A.C. signal is applied, A.C. collector current (i_c) also flows.

→ Then, the total collector current $\tilde{i}_C = I_C + i_c$.

iii) emitter current- when no signal is applied, a D.C. emitter current (I_E) flows due to biasing circuit.

→ when A.C. signal is applied, A.C. emitter current (i_e) also flows.

→ So, the total emitter current $\tilde{i}_E = I_E + i_e$

Note:- $I_E = I_B + I_C$, so $\tilde{i}_E = \tilde{i}_B + \tilde{i}_C$

Load line Analysis:-1) D.C. load line:-

→ The d.c. load line is a line on the output characteristics of a transistor which gives the value of I_C and V_{CE} corresponding to zero signal conditions.

→ By applying KVL on this diagram, we get

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$\Rightarrow V_{CC} = I_C R_C + V_{CE} + I_E R_E \quad (\because I_E \approx I_C)$$

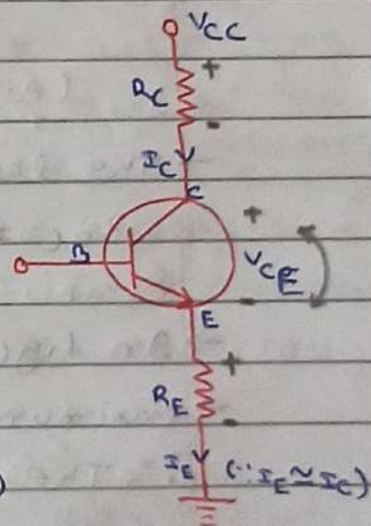
$$\Rightarrow V_{CC} = V_{CE} + I_C R_C + I_C R_E$$

$$\Rightarrow \boxed{V_{CC} = V_{CE} + I_C (R_C + R_E)}$$

Case (1):- Put $I_C = 0$, then

$$\boxed{(V_{CE})_{\max} = V_{CC}}$$

→ This locates a point (B) of the load line on x-axis. The co-ordinate of this point are $(V_{CC}, 0)$

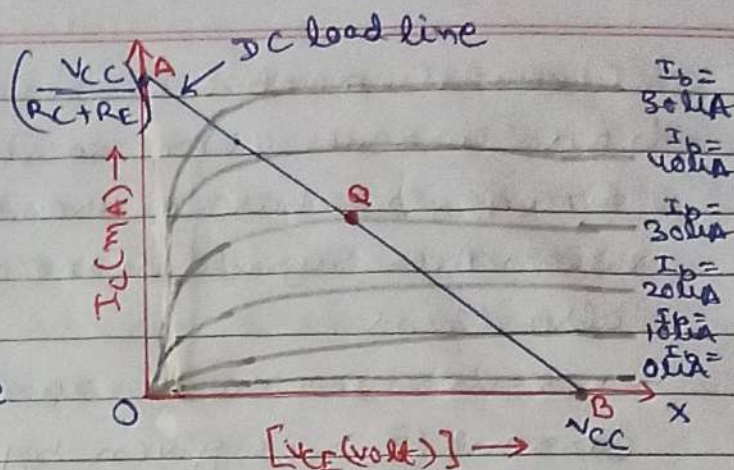


Case (2) If $V_{CE} = 0$

$$2) V_{CC} = I_C (R_C + R_E)$$

$$\Rightarrow I_C = \left(\frac{V_{CC}}{R_C + R_E} \right)$$

→ This locates the second point (A) of the load line on Y-axis.

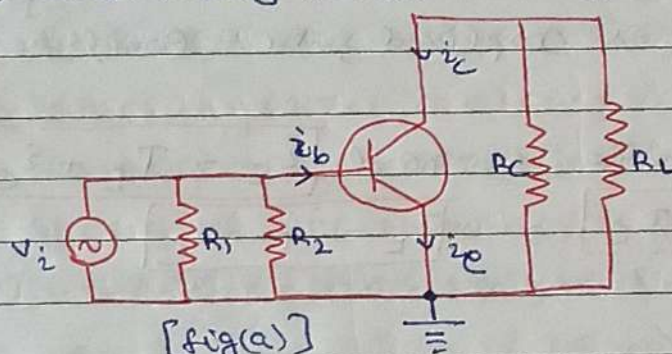


→ The Co-ordinates of this point are $[0, \frac{V_{CC}}{R_C + R_E}]$.

→ If $I_B = 30 \mu A$, then the intersection point betⁿ I_B & DC load line is known as operating point (Q).

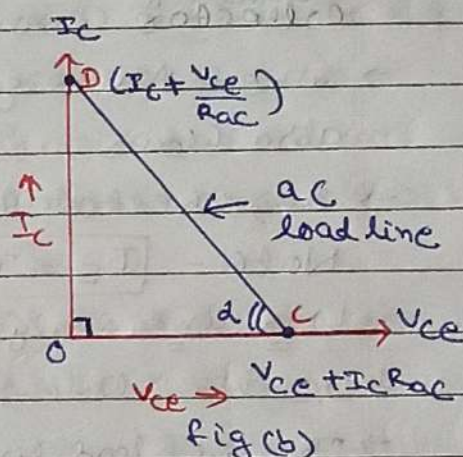
A.C. load line:-

→ The a.c load line is a line on the out-put characteristics of a transistor circuit which gives the values of I_C & V_{CE} when signal is applied.



[fig(a)]

(A.C. equivalent circuit)



→ The transistor amplifier's a.c load R_{ac} is

$$R_{ac} = R_C \parallel R_L = \frac{R_C R_L}{R_C + R_L}$$

→ In fig(b), Maximum collector-emitter voltage = $V_{CE} + I_C R_{ac}$ (Point C)

→ Maximum collector current = $I_C + V_{CE} / R_{ac}$ (Point D)

∴ The slope of load line is

$$\text{slope} = \frac{OD}{OC} = \frac{(I_C + V_{CE} / R_{ac})}{(V_{CE} + I_C R_{ac})}$$

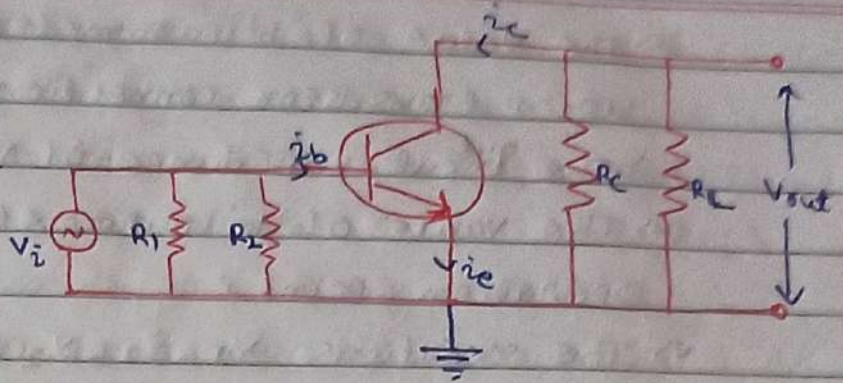
$$= \frac{(I_C + V_{CE} / R_{ac})}{R_{ac} [V_{CE} / R_{ac} + I_C]} = \frac{1}{R_{ac}}$$

Calculation of Gain :-

* $R_{ac} = R_C \parallel R_L = \frac{R_C R_L}{R_C + R_L}$

* R_{in} = input resistance

$R_{in} = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$



$\therefore$ Out put Voltage (V_o) = $i_c \times R_{ac}$

input voltage (V_i) = $i_b \times R_{in}$

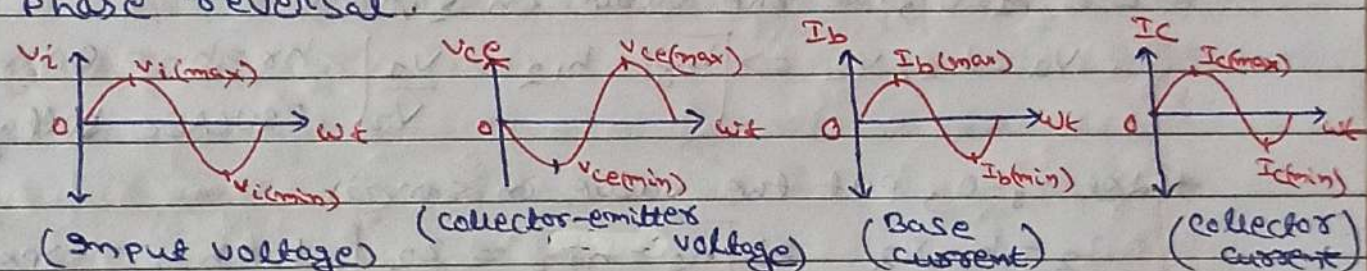
$\rightarrow$ Now, voltage gain (A_v) = $\frac{\text{Output voltage}}{\text{input voltage}}$

$\Rightarrow A_v = \frac{V_o}{V_i} = \frac{i_c R_{ac}}{i_b R_{in}} = \beta \frac{R_{ac}}{R_{in}} \quad \left(\because \beta = \frac{i_c}{i_b} \right)$

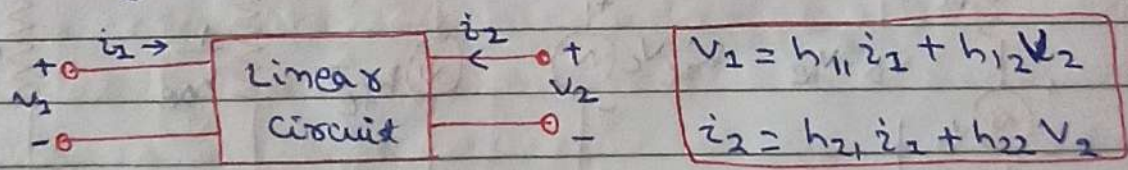
$\rightarrow$ Power gain $A_p = \frac{i_c^2 R_{ac}}{i_b^2 R_{in}} = \beta^2 \frac{R_{ac}}{R_{in}}$

Phase Reversal :-

$\rightarrow$ The phase difference of 180° between input voltage and output voltage in common emitter amplifier is known as phase reversal.



Hybrid Parameters (H) :- Every linear circuit having input and output terminal can be analysed by four parameters [one measure in ohm, one in mho & two dimensionless] called hybrid parameters.



$V_1 = h_{11} i_1 + h_{12} V_2$
 $i_2 = h_{21} i_1 + h_{22} V_2$

H-Parameters of a transistor :-

$\rightarrow$ For small AC signals, a transistor behaves as a linear circuit, i.e. its operation can be described in terms of 'h' parameters.

ii) The value of 'h' parameter of a transistor will depend upon transistor connection.

iii) The ^{out}put impedance of voltage gain ($\gamma_2 = R_c \parallel R_L$)

iv) The value of 'h' parameters depend upon the operation point.

v) The notations V_1, i_1, V_2 & i_2 are used for general circuit.

$$V_1 = V_{be}, i_1 = I_b, V_2 = V_{ce}, i_2 = I_c$$

Here V_{be}, I_b, V_{ce} & I_c are the R.M.S value.

Calculate the hybrid parameter -

→ we know the hybrid parameter eqn's $V_1 = h_{11}i_1 + h_{12}V_2$ (i)

* Let $V_2 = 0$, put the value in eqn (i) $i_2 = h_{21}i_1 + h_{22}V_2$ (ii)

$$V_1 = h_{11}i_1 \Rightarrow \boxed{h_{11} = h_i = \frac{V_1}{i_1}} \quad h_{11} = h_i = \text{Short circuit input impedance } (\Omega)$$

* Let $V_2 = 0$, put the value in eqn (ii)

$$i_2 = h_{21}i_1 \Rightarrow \boxed{h_f = h_{21} = \frac{i_2}{i_1}} \quad h_f = h_{21} = \text{Short circuit forward current gain (unitless)}$$

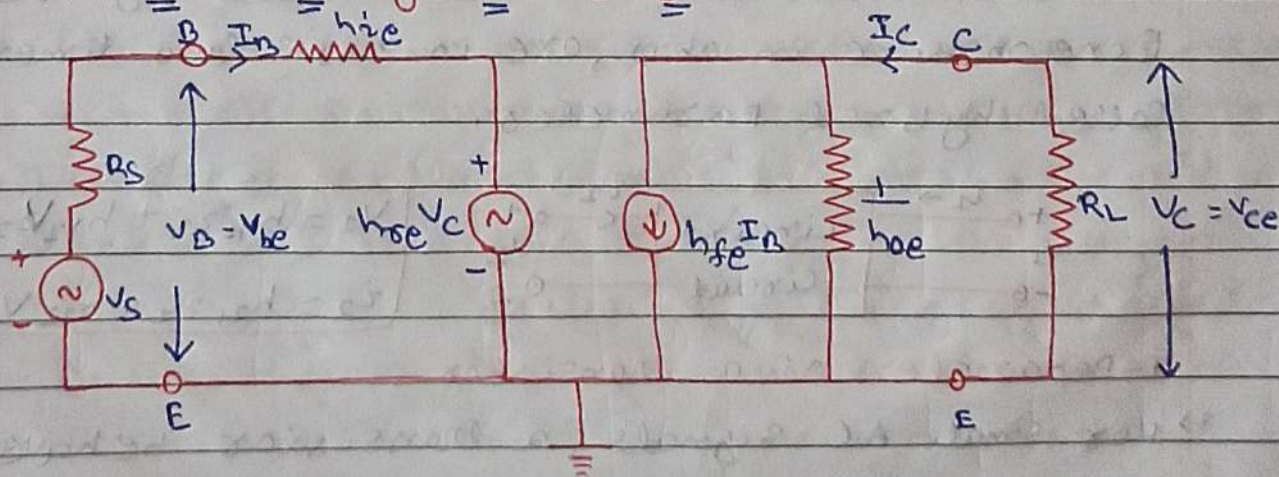
* Let $i_1 = 0$, put the value in eqn (i)

$$V_1 = h_{12}V_2 \Rightarrow \boxed{h_r = h_{12} = \frac{V_1}{V_2}} \quad h_r = h_{12} = \text{Open circuit reverse voltage gain (unitless)}$$

* Let $i_1 = 0$, put the value in eqn (ii)

$$i_2 = h_{22}V_2 \Rightarrow \boxed{h_o = h_{22} = \frac{i_2}{V_2}} \quad h_o = h_{22} = \text{Open circuit output Admittance } (\Omega^{-1})$$

Simplified CE Hybrid Model -



(Exact CE hybrid model)

→ This is the circuit diagram of common-emitter Hybrid model.
 → Here, we calculate current gain, voltage gain, input impedance and output admittance in different configurations of a transistor using h-parameters.

→ From this circuit diagram, we know that $(1/h_{oe})$ is in parallel with load resistance (R_L) .

→ $(1/h_{oe})$ is often large enough to be ignored in comparison to a parallel load. So, we omitted h_{oe} .

→ Then, the collector current $I_C = h_{fe} I_B$ — (i)

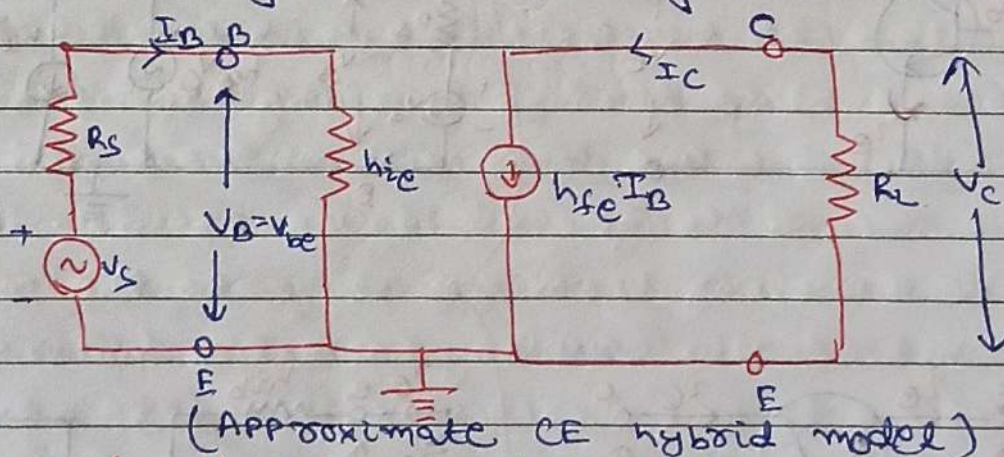
→ Now, $V_C = I_C R_L = h_{fe} I_B R_L$ — (ii)

→ Accordingly the magnitude of the voltage of generator in the emitter circuit also gets modified.

$$h_{re} V_C = h_{re} h_{fe} I_B R_L \text{ — (iii)}$$

→ Since $h_{re} \cdot h_{fe} = 0.01$, this voltage may be neglected in comparison with the voltage drop across h_{ie} . (Voltage drop $h_{ie} I_B$).

→ Thus it becomes possible to neglect the parameters h_{oe} & h_{re} in simplified or approximate CE h-model and use only the remaining two h-parameters.



Generalized Approximate Model —

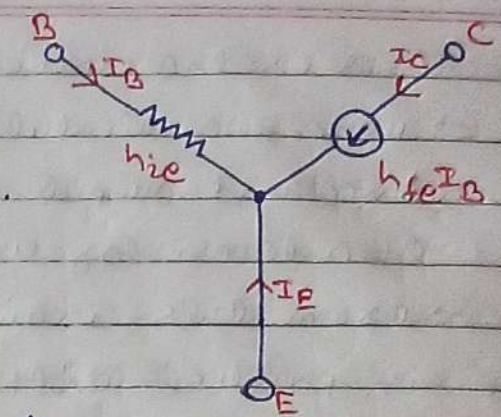
	CE	CB	CC
* $h_{11} = h_i$	h_{ie}	h_{ib}	h_{ic}
* $h_{12} = h_r$	h_{re}	h_{rb}	h_{rc}
* $h_{21} = h_f$	h_{fe}	h_{fb}	h_{fc}
* $h_{22} = h_o$	h_{oe}	h_{ob}	h_{oc}

→ The approximate CE h-model is redrawn. This is known as generalised approximate model.

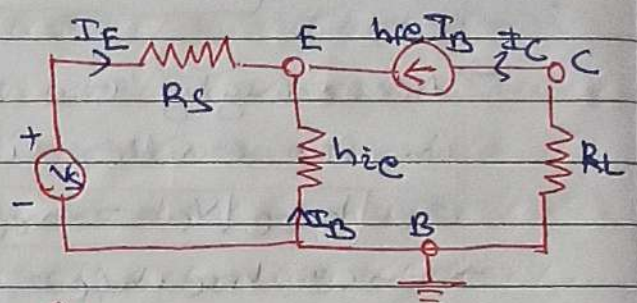
→ This model can be used for any configuration by simply grounding the appropriate terminal.

→ The signal is always applied between the input terminal and ground while the load impedance is connected between output terminal and the ground.

→ This figure(1) represent the circuit diagram of C.B. generalised approximate model.

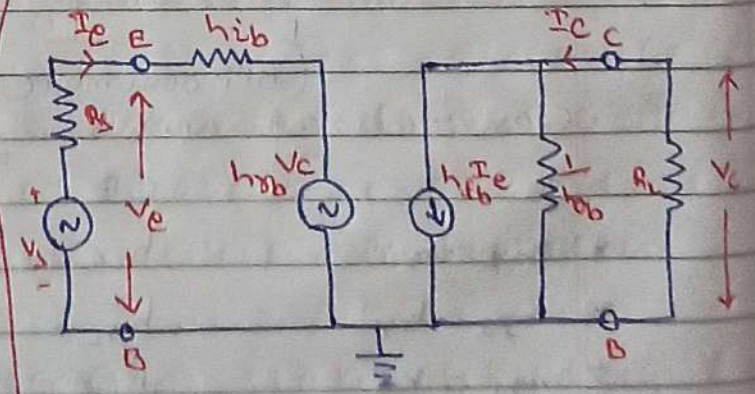
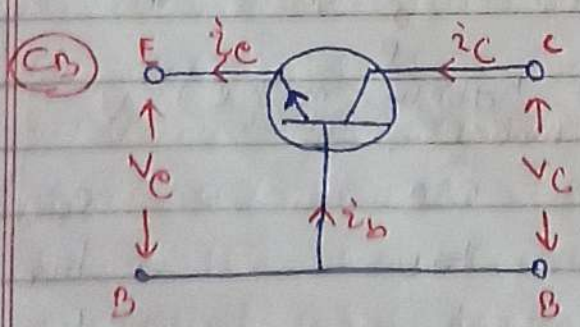
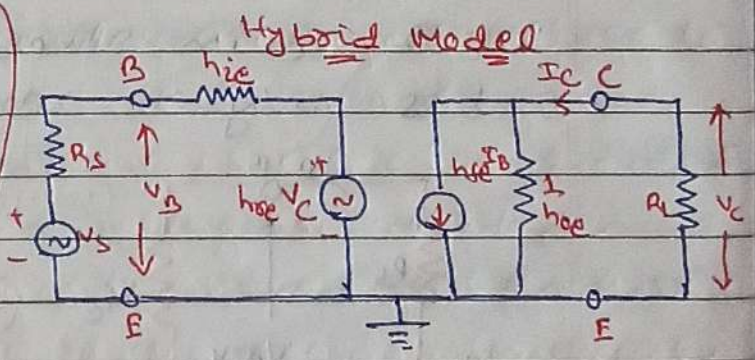
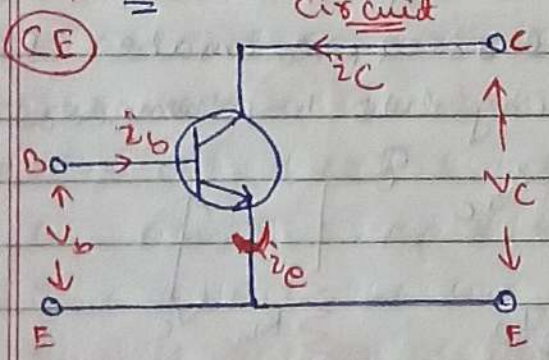


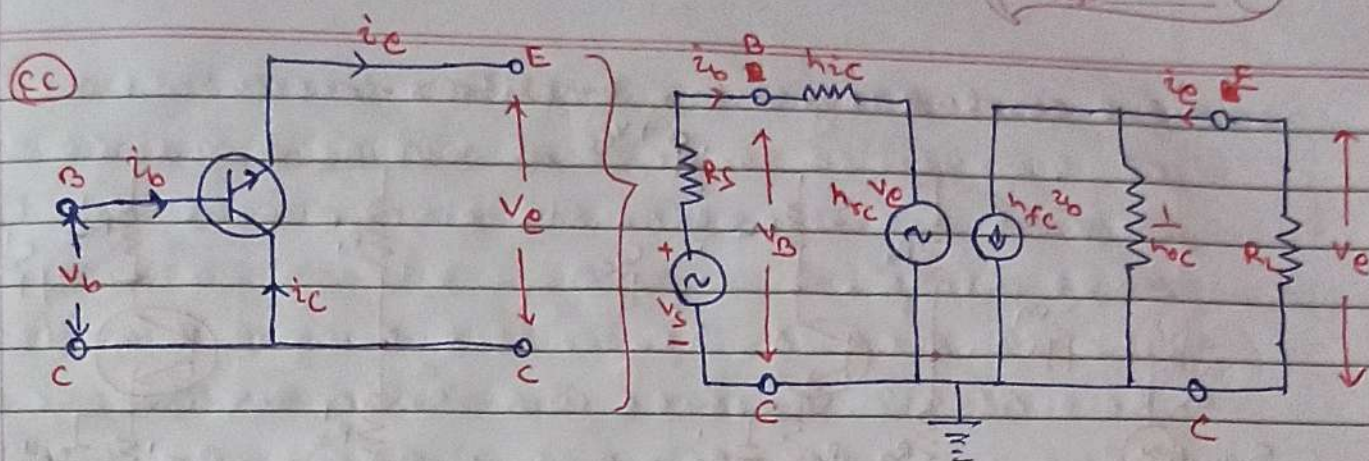
(Approximate hybrid model)
(valid for all configurations)



Analysis of CB, CE, CC amplifiers using generalised approximate model -;

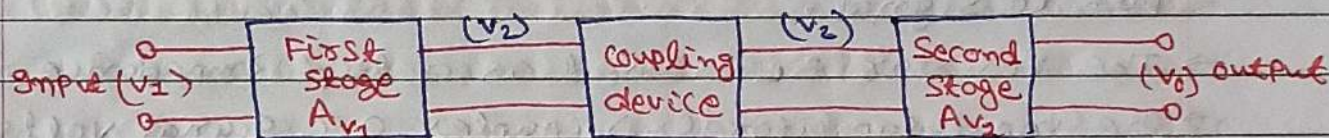
(C.B. generalised approximate model) fig(1)





Multi-stage Transistor Amplifier:-

- A transistor circuit containing more than one stage of amplification is known as multi-stage transistor amplifier.
- When the voltage amplification or power gain of a single amplifier is insufficient to meet the requirement, then multi-stage transistor amplifier is used.
- In multi-stage amplifier, the output of the first stage is combined to the next stage through a coupling device. This process is known as cascading.



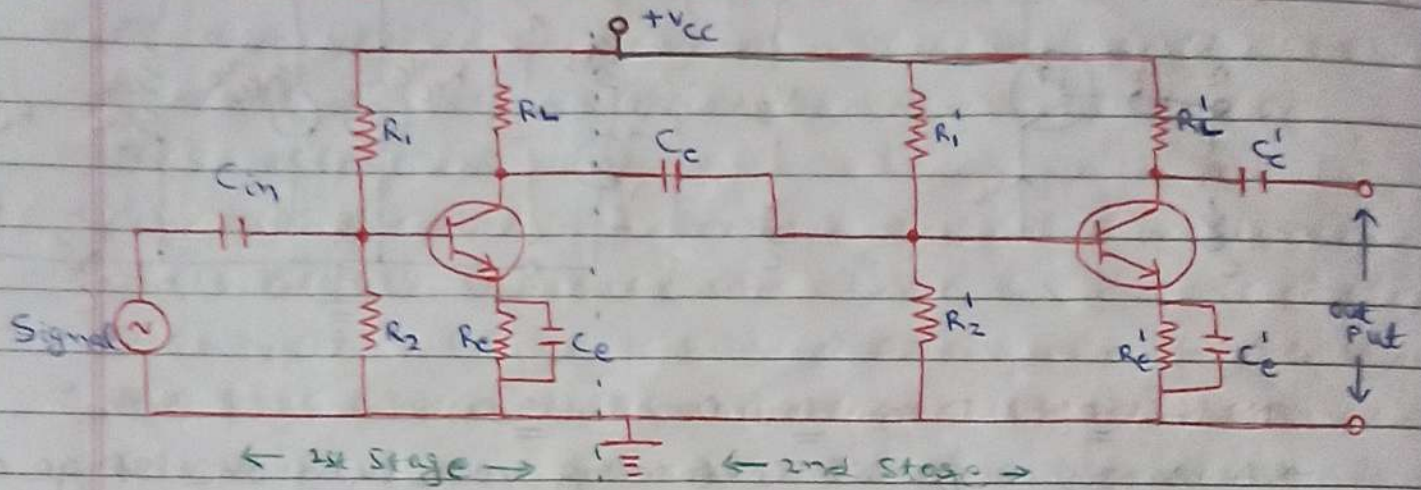
- The overall voltage gain of cascade of two stages is the product of voltage gain of individual stages.
- If A_V = Overall gain, then

$$A_V = A_{V1} \times A_{V2} = \frac{V_2}{V_1} \times \frac{V_0}{V_2} = \frac{V_0}{V_1}$$

Purpose of a Coupling device:-

- To transfer the a.c. output of one stage to the input of next stage.
 - To block the d.c. to pass from one stage to the next stage i.e. to isolate the d.c. conditions.
- Coupling methods are of 4 types.
- R-C (Resistance-capacitance) Coupling.
 - Impedance Coupling.
 - Transformer Coupling.
 - Direct Coupling.

R-C coupled Transistor Amplifier -



- This figure shows a two stage R-C coupled amplifier using common-emitter configuration.
- The two transistors are identical and a common power supply V_{CC} is used.
- The resistors R_1, R_2 are used for biasing purpose & R_E are used for stabilisation of a circuit network.
- The emitter bypass capacitor C_E offers low reactance path to signal.
- The resistor R_L is used as a load impedance.
- The input capacitor (C_{in}) couples a.c signal voltage to the base of transistor.
- The output of the first stage is coupled to the input of second stage through coupling capacitor (C_c).
- This allows the a.c component of the signal to pass to the second stage and blocks the d.c. component.
- As the coupling from one stage to the next stage is achieved via coupling capacitor followed by a connection to shunt resistor, therefore, the amplifier is known as resistance-capacitance coupled amplifier.
- When a.c signal is applied to the base of the first transistor, it appears across collector load (R_L) in the amplified form.
- Through coupling capacitor (C_c), the amplified signal is transferred to the next stage of the amplifier.

- This is further amplified by the next stage and the overall gain is increased.
- The phase of output is the same as that of input because the phase is reversed twice by two transistors.

Advantages:-

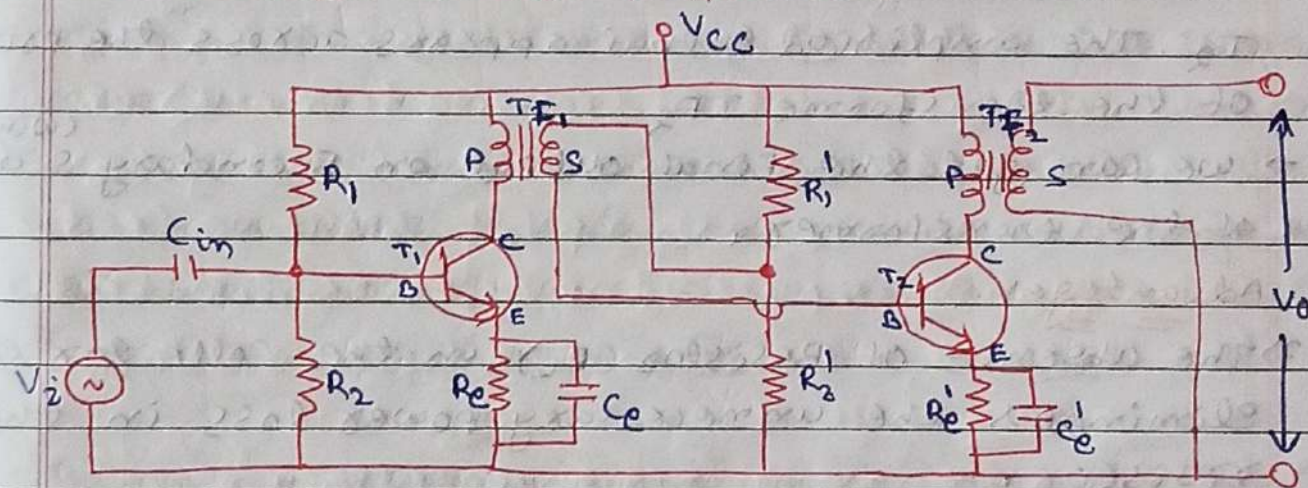
- It has better frequency response.
- Cost of RC coupled amplifier is low.
- It takes less space because of small size of resistance and capacitance & also light in weight.

Disadvantages:-

- It has low voltage & power gain because of the effective load resistance.
- They become noisy with age.
- Due to poor impedance matching, power transfer will be low.

Application:- It is widely used as voltage amplifier.

Transformer Coupled Amplifier:-



(Two Stages transformer Coupled Amplifier)

- Transformer coupling is generally made when the load is small. It is mostly used for power amplification.
- A coupling transformer TF_1 is used to feed the output of first stage to the input of next stage.
- The collector load is replaced by primary winding of the transformer.

- The secondary winding is connected between base of the second stage and voltage divider (i.e. the secondary of transformer gives input to the next stage).
- The transformer TF_2 is the output transformer.
- Rest of the components are same as in R-C coupled amplifier. (R_1, R_2 = Biasing purpose, R_E = stabilisation purpose, C_E = by pass capacitor (offer low reactance). C_{in} = input capacitor).
- There is no coupling capacitor (C_c).
- The d.c. isolation between the two stages is provided by the transformer itself.
- When the input is applied to the base of transistor T_1 , it is amplified & appears across the primary of transformer TF_1 .
- By magnetic induction, it is passed to the secondary.
- Now the output is applied to the base of transistor T_2 . The amplified output appears across the primary of the transformer TF_2 .
- We can get the final output on secondary side (winding) of the transformer.

Advantages :-

- 1) The absence of Resistor (R_L) in the collector circuit eliminates the unnecessary power loss in the resistor.
- 2) The operation of a transformer coupled system is more efficient because of low d.c. resistance of primary connected in collector circuit.
- 3) It has excellent power matching. So it helps in transferring max^m power from the amplifier to the load.
- 4) Due to excellent impedance matching, the transformer coupling provides higher gain.

Disadvantages -

- It has poor frequency response.
- The coupling transformer is bulky and costly.
- It introduces hum (buzzing sound) in the output.

Application -

- It is widely used for amplification of radio frequency signals.

Feedback in Amplifiers -

- The process of combining a fraction of output energy back to input is known as feedback.
- It is of two types.
 - a) Negative feedback
 - b) Positive feedback

Positive feedback -

- When the feedback signal is in phase with the input signal, then it is known as positive feedback.
- Positive feedback is also called as direct or regenerative feedback because it increases the magnitude of input signal, thus the gain of the amplifier is also increases.
- It is used in oscillator.
- The positive feedback has the disadvantage of increased distortion and instability. So it is seldom used in amplifiers.

Negative feedback -

- When the feedback signal is 180° out of phase with the input signal, then it is called as negative feedback.
- It is also called as inverse or degenerative feedback.
- Negative feedback reduces the gain of the amplifier.

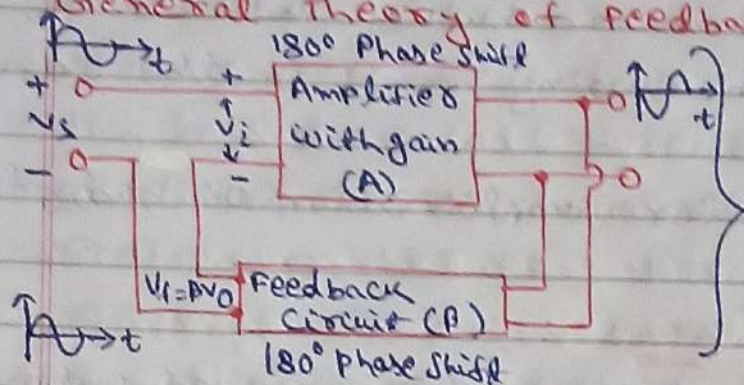
Advantages of Negative feedback -

- i) Stabilization of gain.
- ii) Reduction in distortion.
- iii) Reduction in noise.
- iv) Increases in input impedance.

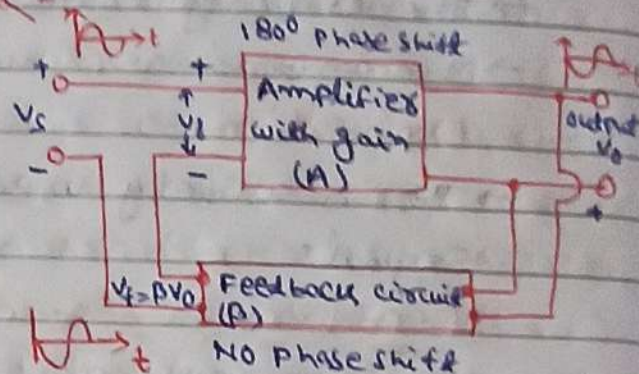
→ decrease in output impedance.

→ increase in the range of uniform amplification.

General Theory of feedback -



(Positive feedback)



(Negative feedback)

→ The feedback amplifier has two parts (i.e. amplifier and feedback circuit). The feedback circuit usually consists of resistors.

→ Here a fraction of o/p voltage (say β) back to the input.

→ If A = gain of the amplifier (i.e. $A = V_o/V_i$)

→ This gain of the amplifier is without feedback.

→ The feedback network extracts a voltage (V_f) from the output (V_o) of the amplifier.

→ This voltage is added (positive feedback) or subtracted (negative feedback) from the signal voltage (V_s).

* Now $V_i = V_s + V_f = V_s + \beta V_o$ (Positive feedback)
 $V_i = V_s - V_f = V_s - \beta V_o$ (Negative feedback)

β = feedback ratio or feedback fraction = V_f/V_o

* Consider the case of Negative feedback.

We know $A_v = \frac{V_o}{V_i} \Rightarrow V_o = A_v V_i$

$\Rightarrow V_o = A_v (V_s - \beta V_o)$

$\Rightarrow V_o = A_v V_s - A_v \beta V_o \Rightarrow A_v V_s = V_o + A_v \beta V_o$

$\Rightarrow A_v V_s = V_o (1 + A_v \beta) \Rightarrow \frac{V_o}{V_s} = \frac{A_v}{1 + A_v \beta}$

* Let A_f = Overall gain (gain with feedback) of the amplifier.

$A_f = \frac{\text{Output voltage}}{\text{Input Signal voltage}} = \frac{V_o}{V_s}$

$$\therefore A_f = \frac{V_o}{V_s} = \frac{A_v}{1 + A_v \beta} \quad (\text{negative feedback})$$

$$\text{Similarly, } A_f = \frac{V_o}{V_s} = \frac{A_v}{1 - A_v \beta} \quad (\text{positive feedback})$$

Note - i) For negative feedback $A_f < A$

ii) For positive feedback $A_f > A$

iii) If $A_v \beta = 1$, $A_f = \infty$, then input is zero (positive feedback)

Power Amplifiers -

→ The power amplifiers are large signal amplifiers which raise the power level of the signals.

→ The power amplifier may also be defined as a device which converts d.c. power to a.c. power and whose action is controlled by the input signal.

(d.c. power input = a.c. power output + losses)

Types of Power Amplifiers -

→ It is of two types.

1. Audio Power amplifier - The audio power amplifiers raise the power level of signals that have audio frequency range (20 Hz to 20 kHz).

→ They are also known as small signal power amplifiers.

2. Radio power amplifier - Radio power amplifiers or tuned power amplifiers raise the power level of signals that have radio frequency range (3 kHz to 300 GHz).

→ They are also known as large signal power amplifiers.

→ They amplify a specific frequency or narrow band of frequencies while rejecting all other frequencies.

* On the basis of the mode of operation, the power amplifiers may be classified as -

i) Class A power Amplifier - When the collector current flows at all times during the full cycle of the signal, the power amplifier is known as class A power amplifier.

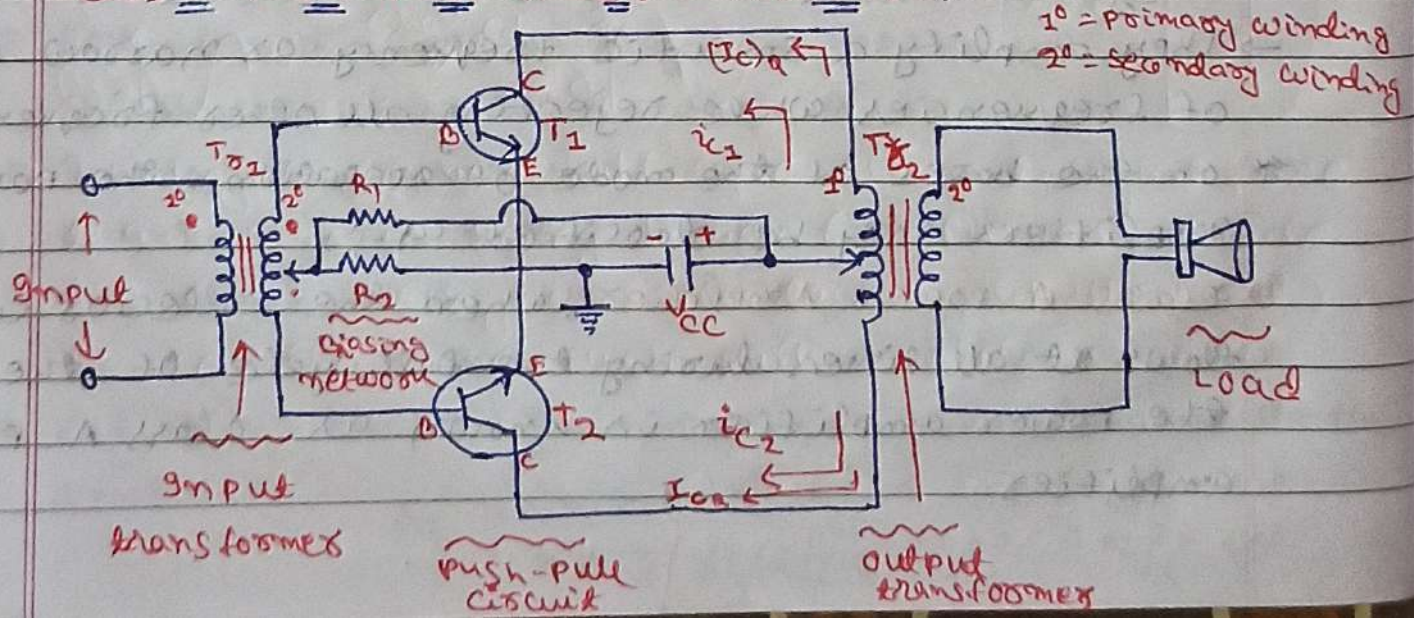
ii) Class B power amplifiers - When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as class B power amplifier.

iii) Class C power amplifier - When the collector current flows for less than half cycle of the input signal, the amplifier is known as class 'C' power amplifier.

Difference between Voltage Amplifiers & Power Amplifiers

<u>Voltage amplifier</u>	<u>Power Amplifier</u>
1. β value is high (100)	2. β value is low (20 to 50)
2. R_c (load resistance or collector resistance) is high. ($\approx 10\text{ k}\Omega$)	2. R_c (load resistance or collector resistance) is low. ($\approx 20\Omega$)
3. Here the i/p voltage is low (few mv)	3. Here the i/p voltage is high (few V)
4. Power output is low for voltage amplifiers.	4. Power output is high for power amplifiers.
5. Collector current is low up to (1mA)	5. Collector current is high (100mA)
6. For voltage amplifiers, the output impedance is high low.	6. For power amplifiers, the output impedance is high.
7. R-C coupling is used in this type of amplifier	7. Transformer coupling is used for power amplifiers

Class A Push-Pull Power Amplifier -



Circuit arrangement:-

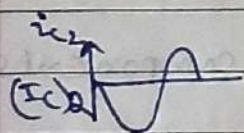
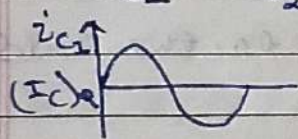
- In push-pull arrangement two identical transistors T_1 & T_2 are used.
- The emitter terminals of the two transistors are connected together.
- The input signal is applied to the inputs of two transistors through centre tapped transformer T_{s1} .
- This transformer provides opposite polarity signals to the two transistor inputs.
- The collectors of both the transistors are connected to the primary of output transformer T_{s2} . This transformer is also centre tapped.
- The collector terminals of the two transistors are connected to the supply V_{CC} through the primary of output transformer.
- Resistors R_1 & R_2 provide the biasing arrangement.
- The load (generally a loudspeaker) is connected across the secondary of output transformer.
- The turns ratio of the output transformer is chosen in such a way that the load is well matched with the output impedance of the transistor.
- So, maximum power is delivered to the load by the amplifier.

Circuit operation:-

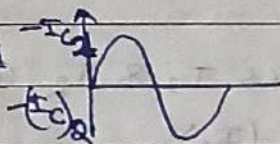
- The two transistors T_1 & T_2 carry d.c components of collector currents $(I_C)_Q$.
- These currents are equal in magnitude and flow in opposite directions through the primary of transformer T_{s2} .
- So, there is practically no net d.c component of current through the primary of transformer T_{s2} .
- This will increase the a.c. power output which is obtained by a single transistor.

- * Let us consider that AC signal is applied to the input.
- When the input signal voltage is +ve, the base of transistor T_1 is more positive while the base of transistor T_2 is less positive.
- Hence the collector current i_{c1} of transistor (T_1) increases, while the collector current i_{c2} of transistor (T_2) decreases.
- These currents flow in opposite directions in two halves of the primary of output transformer.
- The flux produced by these currents will also be in opposite directions.
- So the voltage across the load will be induced voltage whose magnitude will be proportional to the difference of collector currents, (i.e. $i_{c1} - i_{c2}$).
- Similarly, for the negative signal, the collector current i_{c2} will be more than i_{c1} .
- In this case the voltage developed across the load will again be due to the difference ($i_{c2} - i_{c1}$).
- As $i_{c2} > i_{c1}$, the polarity of voltage induced across load will be reversed.
- The difference of two collector currents

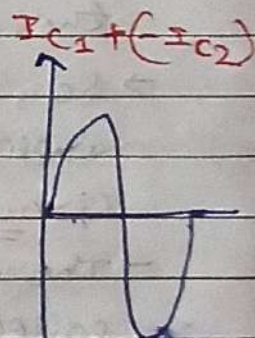
$$i_{c1} - i_{c2} = i_{c1} + (-i_{c2})$$



Changed $\Rightarrow$



Addition



- During any given half cycle of input signal, one transistor is being driven (or pushed) while the other being non-conducting (pulled out). Hence, the name push-pull amplifier.

13.9 CLASS B PUSH-PULL AMPLIFIER

We have seen that class *A* push-pull amplifier reduces the harmonic distortion but the conversion efficiency is only 50%. To increase the efficiency and output power for a given transistor dissipation capability, class *B* push pull amplifier is used. The circuit arrangement of *B*-push-pull amplifier is shown in fig. (13.11).

The circuit arrangement of class *B* push-pull amplifier is the same as that of class *A* push-pull amplifier except that the transistors are biased at cut-off. This is done by providing zero bias on

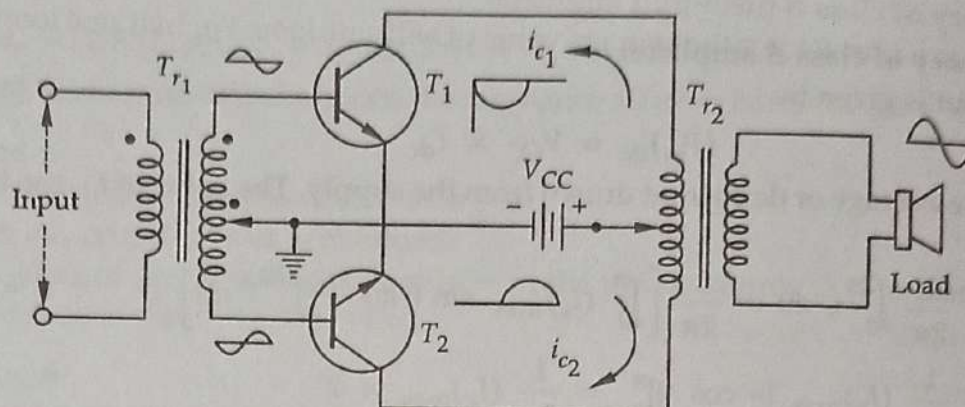


Fig. 13-11 Class B-push-pull amplifier

the base of each transistor by connecting the base and emitter together. As shown in the figure, the bases of the two C-E connected identical transistors have been connected to the opposite ends of the secondary of the input transformer T_{r1} and collectors ends to the primary of the output transformer T_{r2} . In order to get the balanced circuit, the emitters of the transistors are connected to the centre tap of the secondary of transformer T_{r1} and V_{CC} is connected to the centre tap on the primary of transformer T_{r2} . The two bases have been earthed.

Circuit operation

When no signal is applied, both the transistors are cut-off. Hence, no current is drawn from supply source V_{CC} . So, there is no power wastage on standby. When the input signal is applied, the phase splitter transformer T_{r1} produces two signals which are 180° out of phase with each other. The transistors T_1 and T_2 are driven by these two signals. During positive half cycle of the signal, transistor T_1 conducts because its base is driven positive. Now, collector current i_{c1} flows as shown in fig. (13-11). Meanwhile, transistor T_2 does not conduct because its base has negative voltage. Thus, i_{c2} is zero. In this way one positive half cycle of output signal appears across secondary. During negative half of the input signal, transistor T_2 becomes forward-biased and allows a current i_{c2} to flow [as shown in fig. (13-11)] while transistor T_1 becomes nonconducting. Thus only one transistor conducts at a time. The output transformer serves to join the two currents producing an almost undistorted output waveform as shown in fig. (13-12).

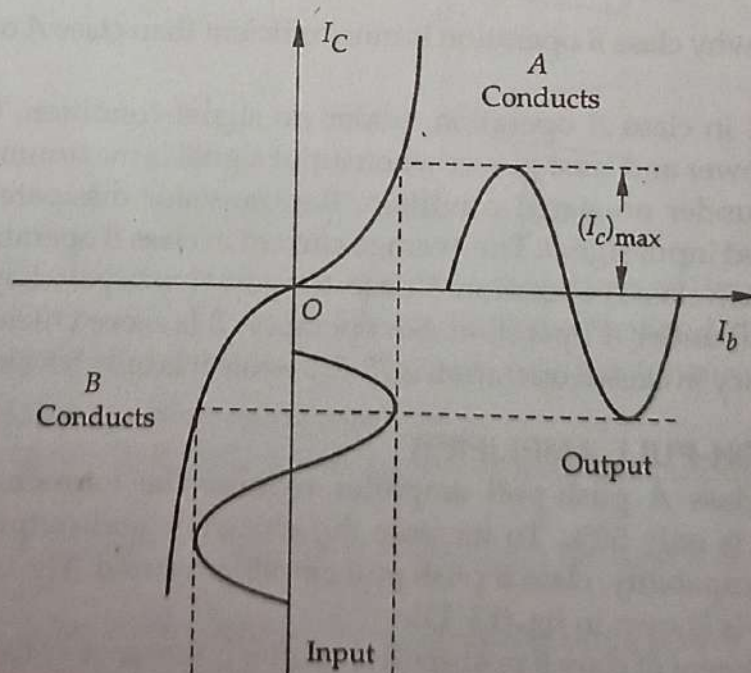


Fig. 13-12 Output waveform of class B push-pull amplifier

14.1 INTRODUCTION

An oscillator is a device which generates an alternating voltage. This may also be defined as a circuit which generates an a.c. output signal without requiring any externally applied input signal. The oscillator converts d.c. energy into a.c. energy at a very high frequency. So the function of an oscillator is opposite to that of a rectifier which converts a.c. power into d.c. power.

The function of an oscillator circuit is similar to that of an amplifier circuit. The main difference between an amplifier and an oscillator fig. (14.1) can be stated as follows:

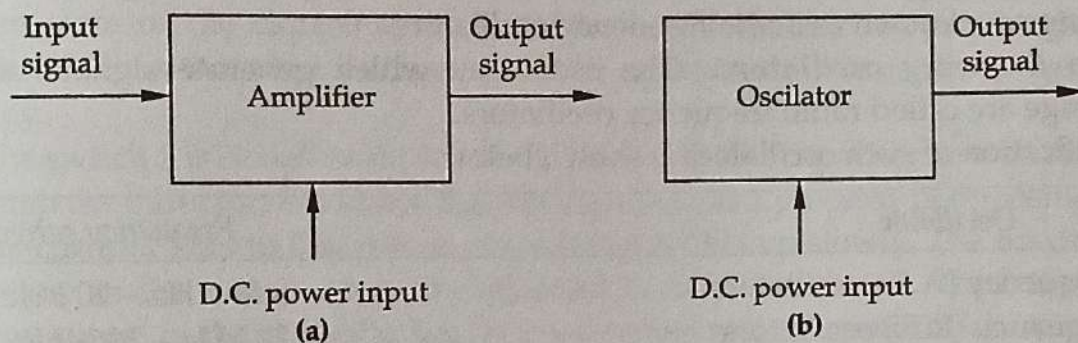


Fig. 14.1

The amplifier takes energy from d.c. power source and converts it into a.c. energy at signal frequency. In an amplifier circuit, the frequency, waveform and magnitude of a.c. power generated is controlled by a.c. signal voltage applied at the input of amplifier. On the other hand, in an oscillator, the frequency, waveform and magnitude of a.c. power generated is controlled by the circuit itself *i.e.*, no external controlling voltage is required. In oscillator, the frequency of the output is determined by the passive components used in the oscillator and can be varied at will.

Thus, an oscillator may be considered as an amplifier which provides its own input signal.

An alternator (a.c. generating machine) can be used to generate frequencies upto 1000 Hz. To generate higher frequencies, either the number of poles has to be made large or the speed of rotation of the armature has to be made extremely high. Both are impracticable. To generate high frequencies, we have to depend upon electronic circuits. Hence, an alternator cannot be called as an oscillator. Following are the differences between an alternator and oscillator:

- (i) An alternator is a mechanical device having rotating parts while an oscillator is a non-rotating electronic device.
- (ii) The alternator converts mechanical energy into a.c. energy whereas the oscillator converts d.c. energy into a.c. energy.

- (iii) An alternator cannot produce high frequency oscillations while an oscillator can produce oscillations ranging from few Hz to several MHz. In oscillators, the frequency of oscillations can easily be changed when desired.

The oscillators have a variety of applications. Audio frequency and radio frequency signal generators are extensively used for testing and repairing of radio, television and other electronic equipments. In radio and television broadcasting, the oscillators are used to generate high frequency carrier waves. For example, in radio and television broadcasting, the transmitter radiates the signal using a carrier of very high frequency (from 550 kHz to 22 MHz in radio broadcasting and from 47 MHz to 230 MHz in TV broadcasting). In radio and TV receivers too, there is an oscillator circuit which generates very high frequencies in the tuning stages.

14.2 TYPES OF OSCILLATORS

Oscillators may be classified in a variety of ways:

(a) According to the nature of generated waveform

(i) *Sinusoidal or harmonic oscillators.* The oscillators which produce sinusoidal or nearly a sinusoidal waveform of a definite frequency are known as sinusoidal oscillators.

(ii) *Relaxation oscillators or non-sinusoidal oscillators.* The oscillators which produce square waves, triangular waves, pulses or sawtooth waves are known as relaxation oscillators.

(b) According to the frequency of the generated signals

(i) *Audio frequency oscillators.* The oscillators which generate signals in the audio frequency range are known as audio frequency oscillators.

(ii) *Radio frequency oscillators.* The oscillators which generate signals in the radio frequency range are called radio frequency oscillators.

The classification of such oscillators is shown below:

Oscillator	Frequency range
Audio frequency (A.F.) oscillators	a few Hz – 20 kHz
Radio frequency (R.F.) oscillators	20 kHz – 30 MHz

14.4 ESSENTIALS OF TRANSISTOR OSCILLATOR

Figure (14.4) shows the essential components of a feedback LC oscillator.

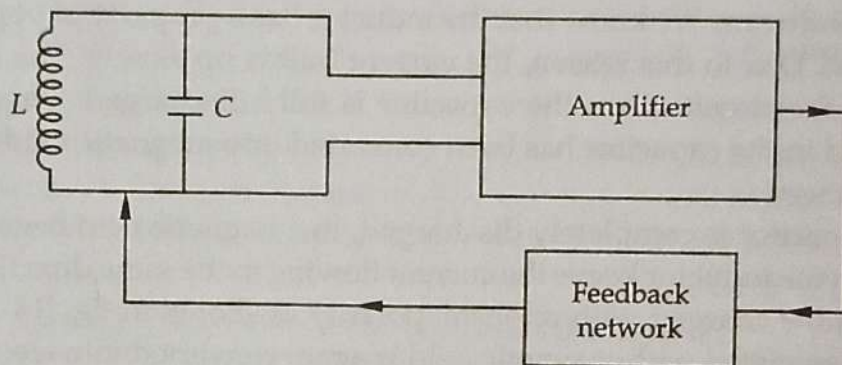


Fig. 14.4

(i) **Tank circuit.** The tank circuit consists of an inductance L connected in parallel with capacitor C . It is known as frequency determining network. The frequency of oscillations in the circuit depends upon the values of inductance and capacitance.

(ii) **Transistor amplifier.** The function of the amplifier is to amplify the oscillations produced by LC circuit. The amplifier receives d.c. power from battery and converts it into a.c. power for supplying to the tank circuit. The oscillations produced in tank circuit are applied to the input of the transistor. The transistor increases the output of these oscillations.

(iii) **Feedback circuit.** The function of feedback circuit is to transfer a part of the output energy to LC circuit in proper phase.

When the feedback is positive, the overall gain of the amplifier is written as

$$A_f = \frac{A}{1 - A\beta}$$

where, $A\beta$ is feedback factor or loop gain.

If $A\beta = 1$, $A_f = \infty$. Thus the gain becomes infinity *i.e.*, there is output without any input. In another words, the amplifier works as oscillator. The condition

$$A\beta = 1$$

is known as *Barkhausen criterion of oscillation*.

14-5 TUNED COLLECTOR OSCILLATOR

Circuit arrangement

The circuit arrangement of a tuned collector oscillator is shown in fig. (14.5). Here, the capacitance C in conjunction with the transformer primary winding inductance L forms the tank

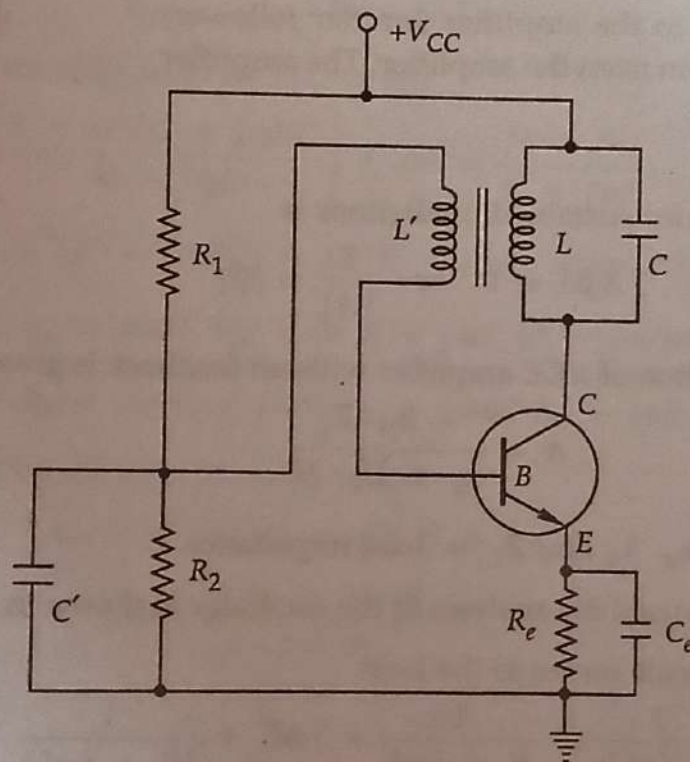


Fig. 14-5

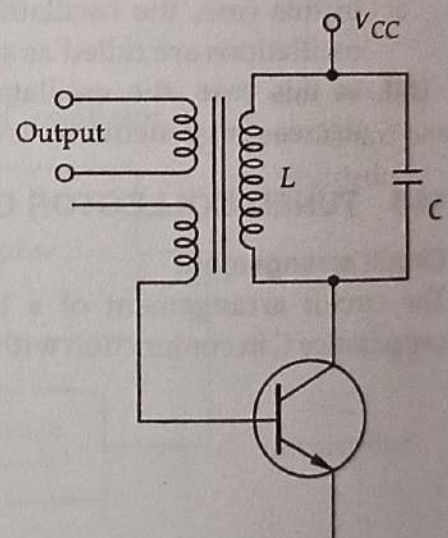
circuit (frequency determining circuit). As the tank circuit is connected in the collector circuit, the oscillator is known as tuned collector oscillator. The resistors R_1 , R_2 and R_e are used to d.c. bias of the transistor. Capacitors C_e and C' are bypass capacitors. They bypass resistances R_e and R_2 respectively so that they have no effect on the a.c. operation of the circuit. The secondary of the transformer provides a.c. feedback voltage. The feedback voltage appears across base-emitter junction because the junction point of R_1 and R_2 is at a.c. ground due to bypass capacitor C' . Here, it is important to note that in the absence of C' , the voltage induced in the secondary of transformer would not be directly going to the input of the transistor but a part of this voltage will drop across R_2 . As the transistor is connected in the CE configuration, it produces a phase shift of 180° between its input and output circuits. An additional phase shift of 180° is produced by transformer. Hence, the net phase-shift of 360° appears between input and output voltages i.e., a positive feedback between input and output voltages.

Working of the circuit

When the supply is switched on, the collector current starts increasing and charging of capacitor C takes place. When the capacitor is fully charged, it discharges through inductance L . Now, oscillations are produced. These oscillations induce some voltage in inductance L' by mutual induction. The frequency of voltage in L' is the same as that of tank circuit and its magnitude depends upon the number of turns in L' and coupling between L and L' . The voltage induced causes corresponding variations in base current. These variations in I_B are amplified β times and appear in collector circuit. A part of the amplified energy is used to overcome the losses of tank circuit and rest is radiated in the form of electromagnetic waves.

Now, the question is that how we can make use of these oscillations. Generally, these oscillations are to be coupled to the next stage in the electronic system. Usually, the output is taken from the tank circuit using inductive coupling as shown in fig. (14.6). When too high a load is connected across the output terminals of the oscillator, it may damp the oscillations. This is the reason that in a signal generator, the output is first connected to the amplifier (emitter follower) and then the output is taken from the amplifier. The amplifier is called as *buffer amplifier*.

Frequency of oscillation



14.10 WIEN-BRIDGE OSCILLATOR

This is audio frequency R-C oscillator. The advantage of this oscillator is that the frequency may be varied in the range of 10 Hz to about 1 MHz whereas in R-C oscillators, the frequency can not be varied. The oscillator consists of two stages of R-C coupled amplifier and a feedback network. The block diagram is shown in fig. (14.15). The voltage across the parallel combination of R and C is fed to the input of amplifier I. The net phase shift through the two amplifiers is zero. Now, the question is that why we could not feed the output of amplifier II to amplifier I to

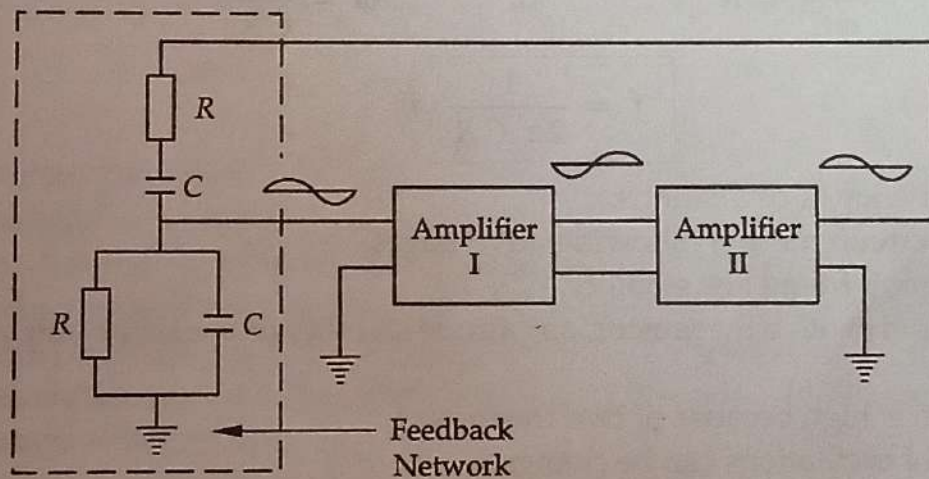


Fig. 14.15

provide regeneration needed for oscillation operation. The answer is that amplifier I will amplify signals over a wide range of frequencies and hence the direct coupling would result in poor frequency stability. By adding Wien-Bridge feedback network, the oscillator becomes sensitive to a signal of only one particular frequency. Hence, good frequency stability is obtained. It is now essential that the feed back network should not introduce any phase shift between its input and output voltages. It can be shown that this is achieved at a frequency $f = 1/2\pi RC$ when $\beta = 1/3$. This is obtained by introducing two resistances R_1 and R_2 in the feedback network as shown in fig. (14.16).

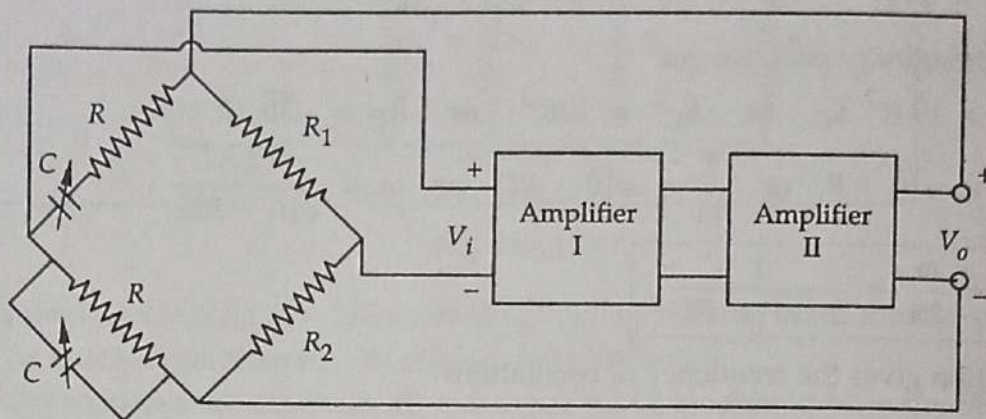


Fig. 14-16

We can vary the frequency of this oscillator by varying the two capacitors simultaneously. We can also change the range of the frequency of the oscillator by using different values of resistors R .

Frequency of oscillations.

Advantages. The circuit has the following advantages :

- (i) This gives good frequency stability.
- (ii) By replacing R_2 with a thermistor, amplitude stability of oscillator output voltage can be increased.
- (iii) Overall gain is high because of two transistors.
- (iv) Frequency of oscillations can be changed.
- (v) Exceedingly good sine wave output.

Disadvantages

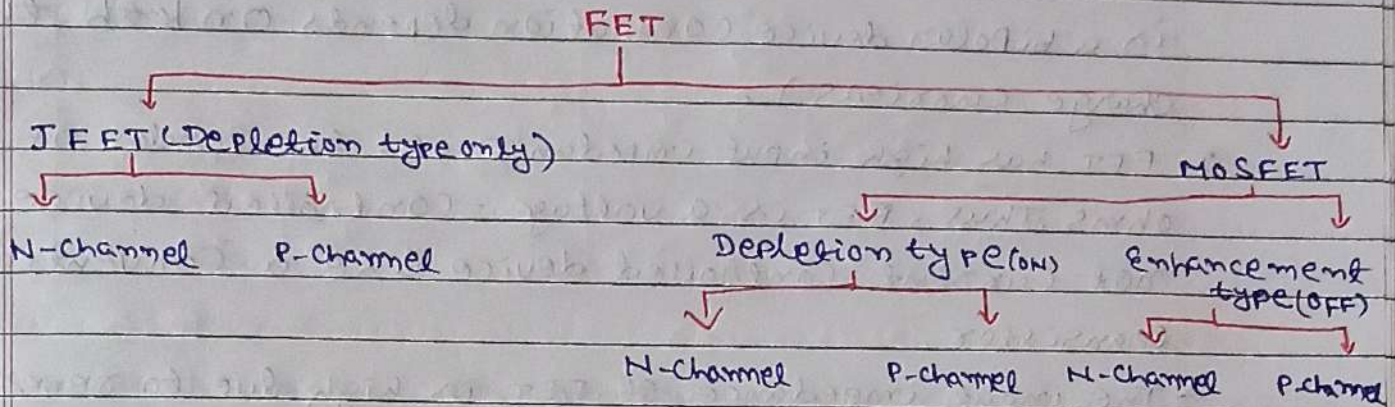
- (i) It requires two transistors and large number of components.
- (ii) It cannot generate very high frequencies.

CP-7 Field effect transistor (FET)

Introduction:-

→ The field-effect transistor (FET) is a three terminal unipolar semiconductor device in which current is controlled by an electric field.

Classification of FET:-



Difference between BJT & FET:-

BJT

FET

- | | |
|---|---|
| 1) BJT means Bipolar Junction Transistor. | 1) FET means field effect transistor. |
| 2) It has three terminals. (i.e. Emitter, base, collector) | 2) It has also three terminals. (i.e. Drain, Source, Gate) |
| 3) It is a Bipolar device. (Conduction, by both types of charge carriers, i.e. electron or holes) | 3) It is a unipolar device. (Conduction is only by one type of charge carrier, either electron or hole) |
| 4) It is current controlled device. | 4) It is a voltage controlled device. |
| 5) BJT has high noise level. | 5) FET has low noise level. |
| 6) It has low input impedance (Z _i) (Due to forward bias) | 6) It has high input impedance (Z _i) (Due to reverse bias) |
| 7) In BJT, thermal stability is less. | 7) In FET, thermal stability is more. |
| 8) It has shorter life span with low efficiency. | 8) It has longer life span with high efficiency. |
| 9) It has -ve temp. coefficient. (T↑, R↓) | 9) It has +ve temp. coefficient. (T↑, R↑) |
| 10) BJT has low power gain (P _o /P _i) | 10) FET has high power gain. |

Advantages of FET over the conventional transistor:-

1. The FET is a unipolar device, depending only upon majority charge carriers (either electrons in N-channel type or hole in p-channel type).
Ex:- vacuum tube, where as the conventional transistor is a bipolar device (operation depends on both the charge carriers).
2. FET has high input impedance, of the order of 10^{10} to 10^{15} ohms. Thus, FET is a voltage-controlled device and not current controlled device like a conventional transistor.
→ The input impedance of FET is high due to reverse bias at input where as the input impedance of BJT is low due to forward bias.
3. FET is less noisy than conventional transistor.
4. FET is less affected by radiation as compared to conventional transistor.
5. It has better thermal stability.
6. The structure of FET is simpler & it occupies less space.
7. FET has small size, longer life and high efficiency.
8. FET has very high power gain.

Disadvantages of FET over conventional transistor:-

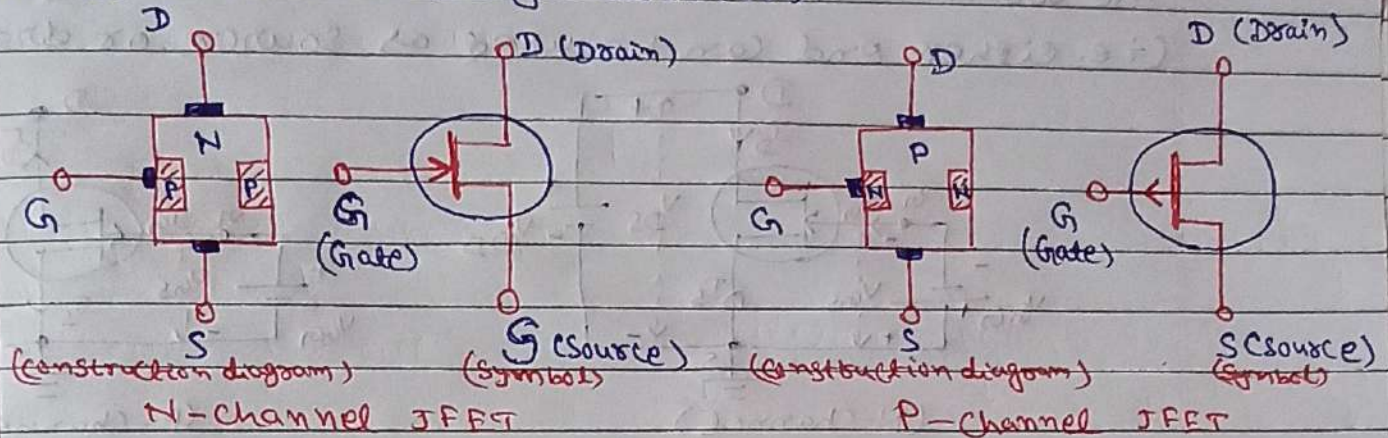
1. Transconductance is low and hence the voltage gain is low. In case of transistor transconductance is high, so the voltage gain is high.
 2. They are more costly than junction transistor.
- 2a Note:- Transconductance = O/P current / i/p. voltage.

Junction field effect transistor (JFET)

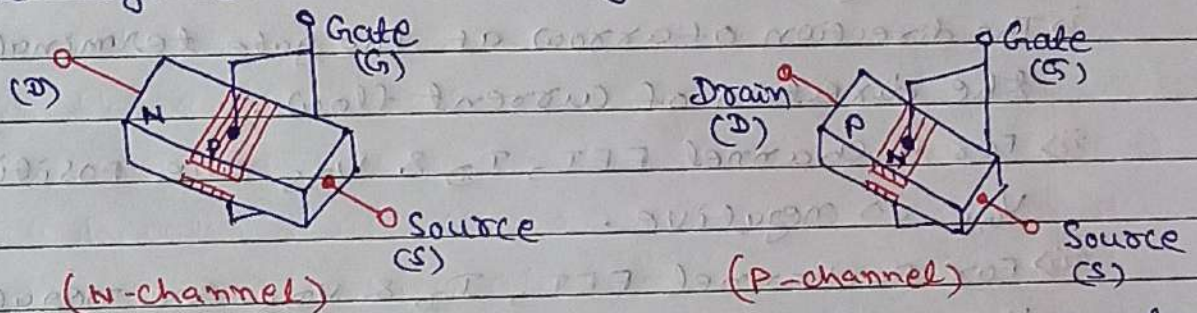
- A junction field effect transistor is a three terminal semiconductor device in which current conduction is takes place either by electrons or by holes.

Basic Construction:-

- JFET are of two types. a) N-channel JFET b) P-channel JFET
- Generally N-channel is preferred (Due to the dimension & speed of flow of charge carriers).



- For the construction of N-channel JFET, a narrow bar of N-type semiconductor material is taken.
- Now on opposite side of its middle part, two heavily doped P-type regions are formed by diffusion.

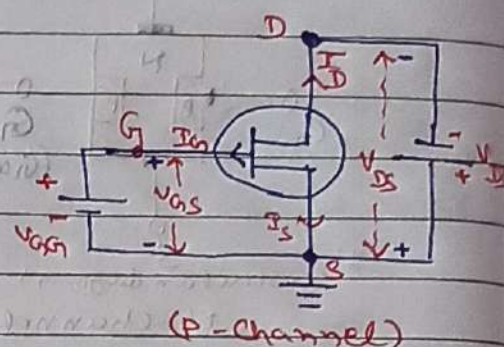
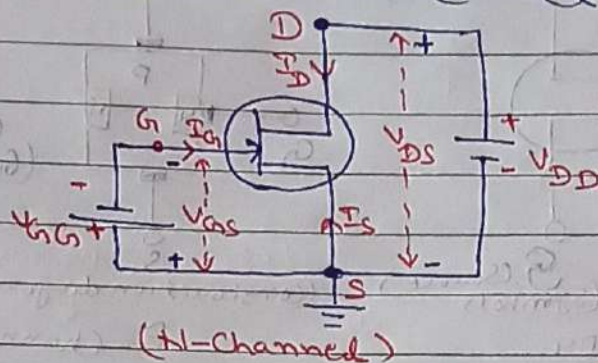


- Similarly for P-channel JFET, a narrow bar of P-type semiconductor material is taken & n-type semiconductor is diffused.

- **Source**:- The source (S) is a terminal through which the majority carriers enter into the bar.
- **Drain**:- The drain (D) is a terminal through which the majority carriers leave the bar.
- **Gate**:- These are two internally connected heavily doped impurity regions which form two P-N junction. This terminal is known as Gate terminal.
- **Channel**:- The space between two gates through which majority carriers pass is known as channel.
- The source and drain terminals may be interchanged.

Circuit Symbol & notation -:

- Here the voltage between gate and source is always reverse biased.
- The drain & Source terminals are interchangeable. (i.e. either end can be used as source or drain).



- V_{DD} = drain supply voltage, V_{DS} = drain to source voltage
- V_{GS} = gate supply voltage, V_{GS} = gate to source voltage
- I_D = drain current, I_S = source current, I_G = gate current

Some key points -:

- i) The direction of arrow at the gate terminal indicates the direction of current flow.
- ii) For N-channel FET, I_D & V_{DS} are positive while V_{GS} is negative.

- iii) For P-channel FET, I_D & V_{DS} are negative while V_{GS} is positive.

Note -: When a potential difference (V_{DD} or V_{DS}) is applied between source and drain, a current flows from one end to the other end in N-type material which forms a sort of channel.

- This current consists of majority charge carriers which are electrons (N-channel).

- Similarly, for P-channel JFET, this current consists of majority charge carriers which are holes.

Operation of N-channel JFET:-

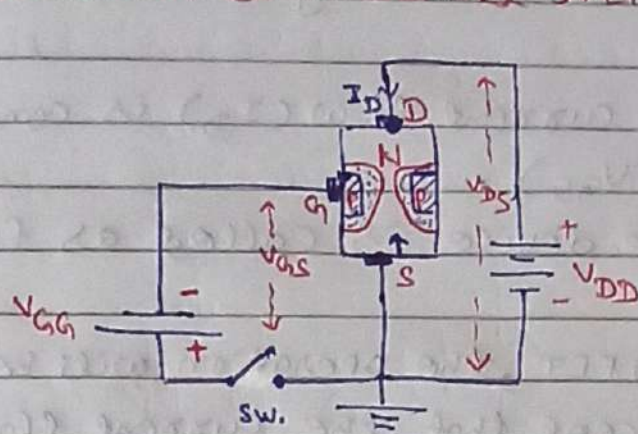
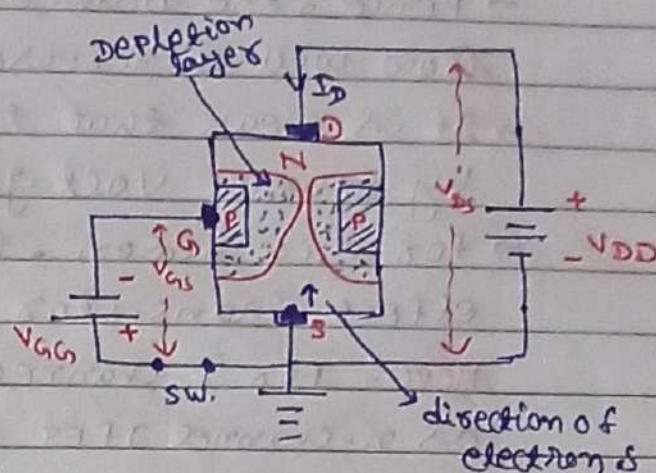
Fig (1) (V_{GG} or $V_{GS} = 0$)

Fig (2)

- Fig (1) & Fig (2) are the normal circuit diagram of JFET.
- In fig (1) gate to source voltage ($V_{GS} = 0$) & in fig (2) we applied both the supply voltage V_{GG} & V_{DD} .

Case - (1) (V_{GG} or $V_{GS} = 0$)

- When the voltage source ($V_{DD} = V_{DS}$) is applied between drain & source terminal and ($V_{GG} = V_{GS}$) is zero, depletion layers will be create at the sides of two P-N junction.
- Here, the drain current (I_D) will flow from drain to source, where as the electron will flow from source to drain.
- This movement is takes place through a channel.
- The size of these layers determine the width of the channel & hence current conduction through the bar.

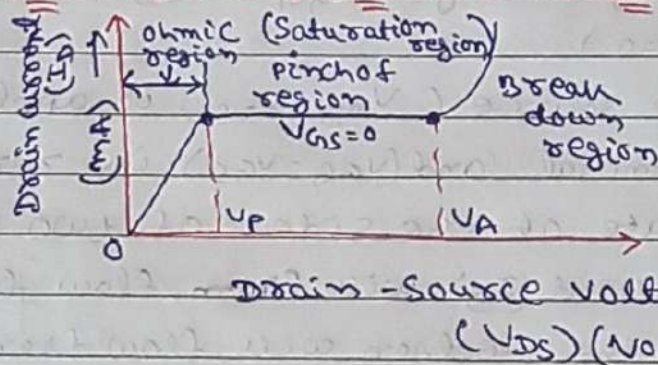
Case - (2)

- when a reverse voltage (V_{GS}) is applied between the gate & source, the width of depletion layers is increased.
- This reduces the width of conducting channel, there by increasing the resistance of n-type bar. So that the current flow will decrease.
- on the other hand, if we decrease the reverse voltage (V_{GS}), then the width of the depletion layers is also decrease.

- Hence, the width of the conducting channel & current flow will increase.
- It is clear that the current flow (I_D) is controlled by reverse voltage (V_{GS}).
- For this reason, the device is called as field effect transistor.

Note:- For P-channel JFET, the operation will be same as n-channel JFET except that the current flow charge carriers is holes in stand of electron and the polarities of the voltage source V_{GS} and V_{DS} are reversed.

Static Characteristic Curves of JFET



V_P = Pinch off Voltage
 V_A = Avalanche Break down voltage

JFET Parameters:-

a) DC drain resistance (R_{DS}):-

→ This is the static or ohmic resistance of the channel.

$$R_{DS} = \frac{V_{DS}}{I_D}$$

V_{DS} - Drain to Source Voltage
 I_D - Drain Current

b) AC drain resistance (r_d)

→ It is the ratio of change in drain to source voltage (ΔV_{DS}) to the change in drain current at constant gate to source voltage (V_{GS})

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

c) Transconductance - (g_{fs}) or (g_m)

→ It is the ratio of change in drain current (ΔI_D) to the change in gate to source voltage (ΔV_{GS}) at

constant drain to source voltage. $g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}}$ $V_{DS} = \text{constant}$

Biasing of FET Circuits -

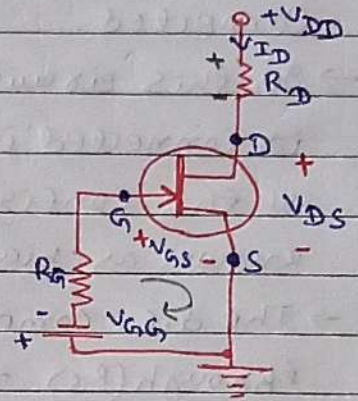
→ FET Biasing are of 3 types.

- a) Fixed-bias configuration b) Self-bias configuration
c) voltage divider bias.

Fixed-bias Configuration

→ This is the simplest type of biasing arrangement & is also known as gate bias circuit.

→ A battery (V_{GG}) is used such that its negative is connected to the gate through gate resistance (R_G) and positive is grounded.



→ This battery source ensures that gate-source junction is reverse-biased.

→ Here, there is no gate current (i.e. $I_G = 0$). So, no voltage drop across (R_G).

→ The zero voltage drop across R_G permit us to replace it by short circuit in case of d.c analysis.

* For d.c analysis, $I_G = 0$ - (i)

Applying KVL to the input circuit, we have

$$-V_{GS} - V_{GG} = 0 \Rightarrow V_{GS} = -V_{GG} \quad \text{--- (ii)}$$

* The drain current is given by $I_D = I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right]^2$ --- (iii)

I_D = Drain current.

Where I_{DSS} = Drain to Source Saturation current.

V_P = pinch off voltage, V_{GS} = Gate to Source voltage

* Applying KVL to output circuit,

$$V_{DD} - I_D R_D - V_{DS} = 0$$

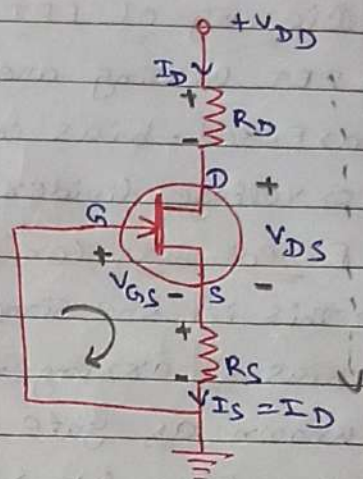
$$\Rightarrow V_{DS} = V_{DD} - I_D R_D \quad \text{--- (iv)}$$

→ Since V_{GG} is fixed value of d.c supply and the magnitude of V_{GS} is also fixed, hence the circuit is named as fixed bias circuit.

Self-Bias Configuration

→ The circuit required only one supply voltage (i.e. drain supply V_{DD}) and no gate supply (V_{GG}) is connected.

→ In this circuit, a resistor (R_S) is connected in the source leg of the configuration. This is known as bias resistor.



→ The d.c. component of drain current (I_D) flowing through (R_S) makes a voltage drop across resistor (R_S). This voltage drop makes the gate to source reverse voltage required for FET operation.

* Applying KVL to the input circuit, we have

$$-V_{GS} - I_S R_S = 0$$

$$\Rightarrow \boxed{V_{GS} = -I_D R_S} \quad (\because I_S = I_D) \quad \text{--- (i)}$$

* The drain current is given by

$$\boxed{I_D = I_{DSS} \left[1 - \frac{V_{GS}}{V_P} \right]^2} \quad \text{--- (ii)}$$

* Now Applying KVL to output circuit, we have

$$V_{DD} - I_D R_D - V_{DS} - I_S R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_S R_S \quad (\because I_S = I_D)$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_D R_S$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D (R_D + R_S)} \quad \text{--- (iii)}$$

Voltage Divider Bias

→ The name voltage divider is given due to the fact that resistor R_1 and R_2 form a voltage divider across drain supply V_{DD} .

→ The voltage developed across R_2 provides the necessary bias.

→ The gate voltage (V_G) is given by

$$\boxed{V_G = V_{DD} \left(\frac{R_2}{R_1 + R_2} \right)} \quad \text{--- (1)}$$

* Applying KVL to the input circuit,

$$V_G - V_{GS} - I_S R_S = 0$$

$$\Rightarrow V_{GS} = V_G - I_D R_S \quad - (2) \quad (\because I_S = I_D)$$

then $I_D R_S = V_G - V_{GS}$

$$\Rightarrow I_D = \frac{V_G - V_{GS}}{R_S} \quad - (3)$$

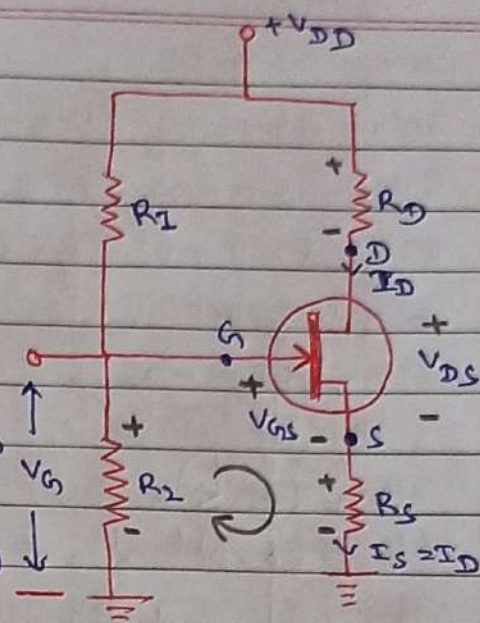
* Now Applying KVL to the output circuit,

$$V_{DD} - I_D R_D - V_{DS} - I_S R_S = 0$$

$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_S R_S \quad (\because I_S = I_D)$$

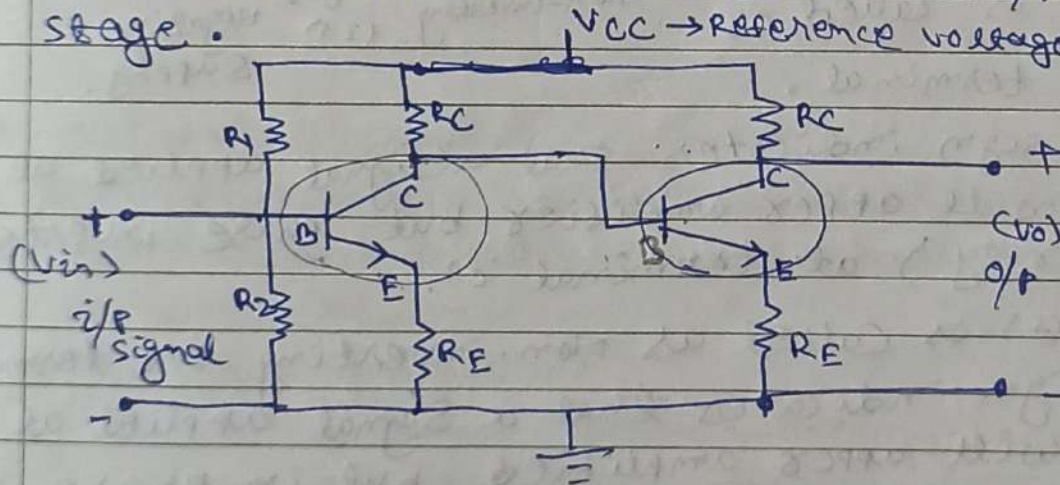
$$\Rightarrow V_{DS} = V_{DD} - I_D R_D - I_D R_S$$

$$\Rightarrow V_{DS} = V_{DD} - I_D (R_D + R_S) \quad - (4)$$



By determine the value of I_D & V_{DS} , we can get the operating point $(Q) = (I_D, V_{DS})$.

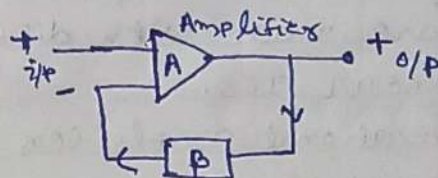
- * The operational amplifier is a direct-coupled, high gain negative feedback amplifier.
- * They are made with different internal configurations in linear ICs.
- * The operational amplifier was originally used for the d.c. amplifiers which perform mathematical operations as summation, subtraction, integration & differentiation in analog computers.
- * Analog computer -: It is a type of comp. that uses the continuously changeable aspects of physical phenomena such as electrical, mechanical model ~~to~~ for problem solving.
- * Direct-coupled amplifier -: (DC amplifier)
- It is a type of amplifier in which the o/p of one stage of the amplifier is coupled to the i/p of the next stage.



- * Now a days, OP-AMPS are used ~~as~~ as voltage regulator, phase shift and oscillator circuits, pulse generators, square wave generator etc.
- * frequency range of OP-AMP -: 0 Hz to 1 MHz
- * OP-AMP can be used to amplify d.c signal as well as A.C signal.

* Positive feedback -! when feedback voltage is applied to increase the i/p signal is called +ve feedback. (Distortion & instability)

* Negative feedback -! when feedback voltage is applied to decrease the i/p signal is called -ve feedback. (gain stability, reduction of distortion)



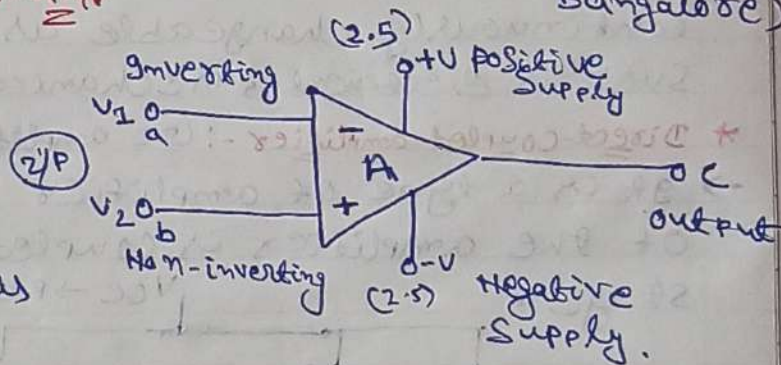
Advantages

Advantages of OP-AMP -:

* Small size, reduced cost, high reliability, less power consumption etc. ex-: CA741 OPAMP (manufactured by BEL, Bangalore)

Circuit Symbol of an OP-AMP

* The OP-AMP has two i/p terminals and a single o/p terminals.



* Terminal 'a' (-) is called as inverting i/p terminal.

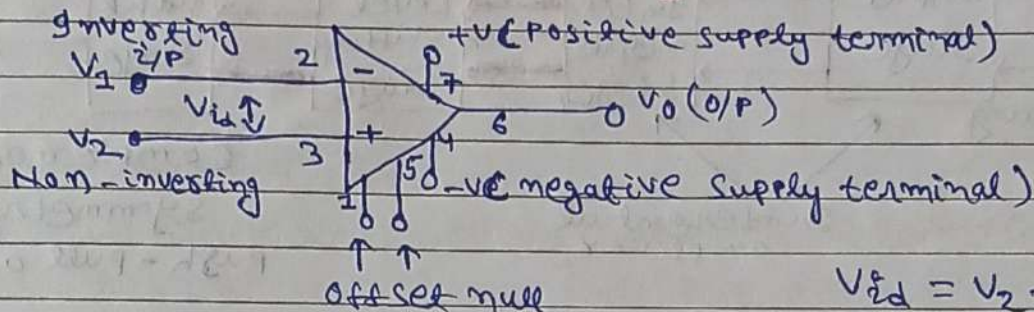
→ Here (-)ve sign indicates that a signal applied at the terminal 'a' will appear amplified but phase inverted (opposite polarity) at terminal 'c'.

→ Terminal 'b' (+) is called as Non-inverting i/p terminal.

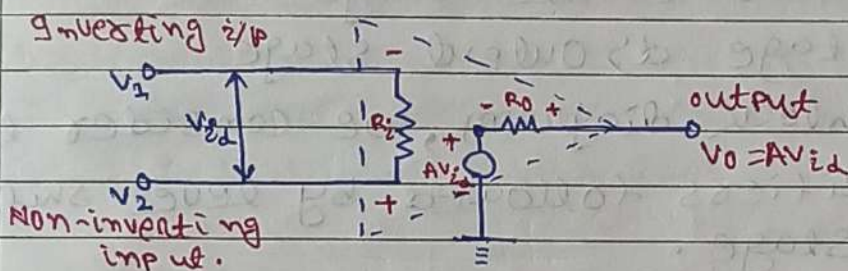
→ Here (+)ve sign indicates that a signal applied at the terminal 'b' will appear amplified but in phase (same polarity) at the terminal 'c'.

→ The two D.C sources, (+V and -V) are required for the biasing of OP-AMP. (Biasing -! Steady state condⁿ, where no. ^{signal} voltage is applied)

→ These voltages are equal in magnitude with opposite polarities.

Circuit Symbols of CA 741 OP-AMP

Offset null condⁿ - Here the O/P should be 0V when there is no difference betⁿ its inputs (i/p^s are same)

Equivalent circuit of OP-AMP -

* V_1 = voltage at the inverting terminal

V_2 = voltage at the non-inverting terminal

V_{id} = difference of two input voltage ($V_2 - V_1$)

R_i = i/p resistance

R_o = O/P resistance

AV_{id} = Equivalent Thevenin voltage source.

* Here the output voltage is directly proportional to the algebraic difference betⁿ the two i/p voltages.

* The gain of the amplifier (A) = $\frac{\text{Output}}{\text{Diff. betⁿ two i/p signals.}}$

$$\Rightarrow A = \frac{V_0}{V_2 - V_1} = \frac{V_0}{V_{id}}$$

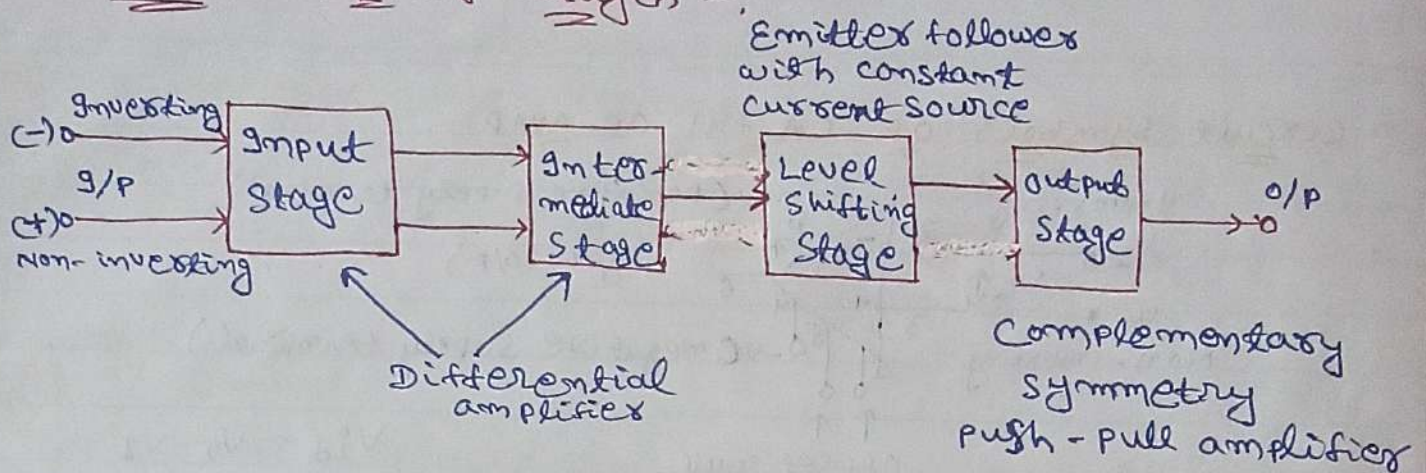
for case of ideal OP-AMP

* $R_i = \infty$, $R_o = 0$, $A = \infty$

$$\Rightarrow V_0 = A V_{id}$$

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Operational amplifier Stages -:



* OP-AMP is a multi-stage circuit & it consists of four stages.

- a) Input stage b) Intermediate stage
c) Level Shifting stage d) Output stage

* In the above block diagram, we consider two differential amplifiers followed by level shifter and an output stage.

Differential amplifier -: It is a type of electronic amplifier that amplifies the difference betⁿ two input voltages and provided output voltage.

a) Input stage -:

→ The input stage is a dual-input, balanced o/p differential amplifier.

→ The function of differential amplifier is to provide most of the voltage gain to OP-AMP.

→ The differential amplifier in the input stage rejects the common noise signals present at the input terminals and amplifies only the difference between the input signals.

Note: OPAMP uses direct coupling method, therefore DC voltage level at the emitter terminal rises from stage to stage.

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b) Intermediate Stage -

- The intermediate stage is a dual input, unbalanced output differential amplifier.
- This is driven by the output of first stage and is used to provide some additional gain.
- There is a direct coupling between the first two stages. So, the d.c level at the output of this stage is well above the ground level.

c) Level Shifting stage -

• This circuit

- Here we used the level shifter circuit. This is an emitter follower using constant current source.
- The function of level shifter is to shift the d.c level at the output of intermediate stages downwards to zero volt with respect to ground.

d) Output stage -

- The output stage is generally push-pull amplifier.
- Its function is to increase large output voltage swing capability, large output current swing capability of the amplifier and to provide low output resistance.

(* output voltage swing - It is the max^m positive or negative o/p voltage that can be obtained without wave clipping.)

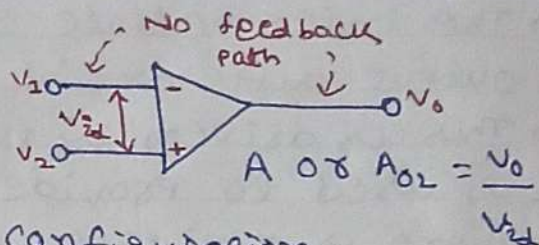
(* push-pull amplifier - It is a type of electronic circuit that uses a pair of active devices that alternately supply current or absorb current from a load.)

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Open-loop OP-AMP Configurations -:

* The term open-loop indicates that there is no feedback path from output side to the input side of the OP-AMP.

* In this diagram, the maximum possible open-loop voltage gain (A or A_{OL}) is 20000.



* There are three open loop configurations.

a) Differential amplifier.

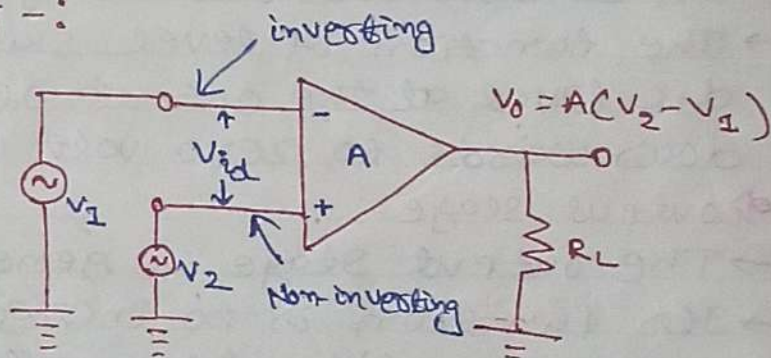
b) Inverting amplifier.

c) Non-inverting amplifier.

* These configurations are based on the numbers of inputs used and the terminal to which the input is applied.

Differential amplifier -:

* In this figure, V_1 and V_2 are signals applied to inverting and non-inverting terminals respectively.



* V_1 & V_2 may be either A.C or D.C as OP-AMP can amplify both types of signals.

* Here, the source resistance are not considered because they are very small in comparison with the very high input resistance of OP-AMP.

* As the OP-AMP amplifies the difference between two input signals, hence this configuration is called as differential amplifier.

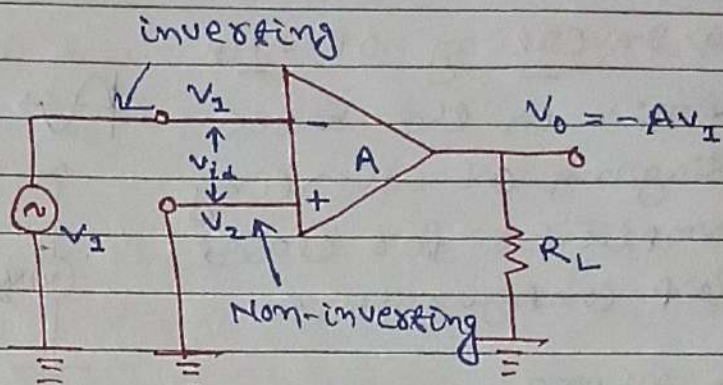
* Output voltage $V_o = A V_{id} = A(V_2 - V_1)$ $A = \frac{V_o}{V_{id}}$

where A = large signal voltage gain or open loop gain

* Here the polarity of the output voltage depends on the difference of input voltage.

Inverting Amplifier -:

- * In this diagram, the input signal is applied to the inverting input terminal and the non-inverting terminal is grounded (i.e. $V_2 = 0$)

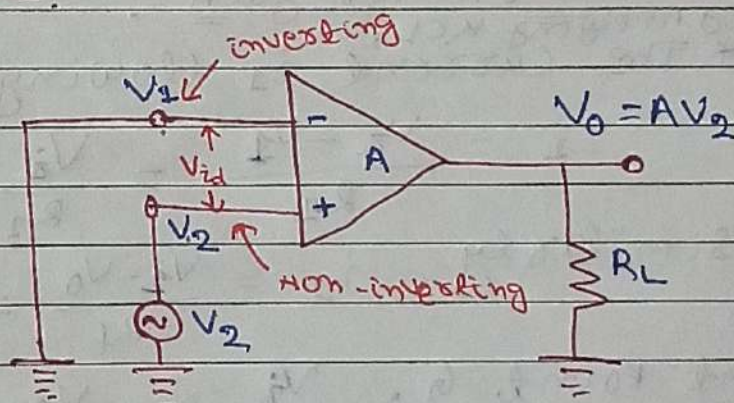


- * So the output voltage $V_0 = AV_{1d} = A(V_2 - V_1)$
or $V_0 = -AV_1$

- * The negative sign indicates that the output voltage is 180° out of phase with respect to input voltage.
- * Here the polarity of output voltage is changed with respect to input voltage.

Non-inverting Amplifier -:

- In this diagram, the input signal is applied to the non-inverting input terminal of the OP-AMP and the inverting input terminal is grounded (i.e. $V_1 = 0$).



- * So the output voltage $V_0 = AV_{1d} = A(V_2 - V_1)$
or $V_0 = AV_2$

- * The positive sign indicates that the output voltage is in phase with respect to the input voltage.
- * Here, the input signal is amplified by gain (A) without change in polarity.

Teacher's Signature : _____

Concept of virtual ground

Figure (17-13) shows the inverting amplifier with virtual ground.

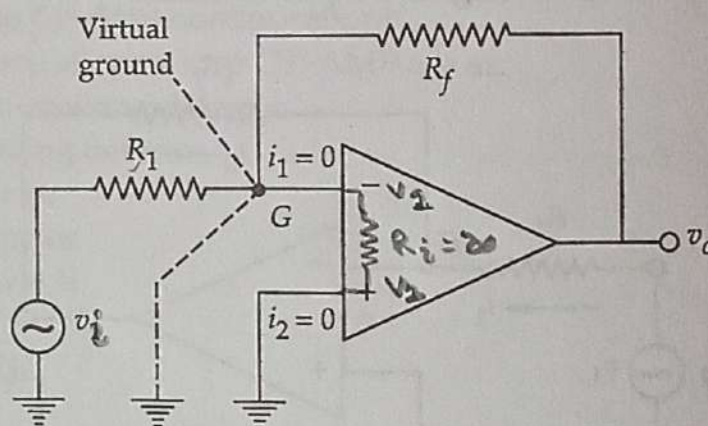


Fig. 17-13 Inverting amplifier with virtual ground

Let us explain the concept of virtual ground. When at any point of the circuit, the potential becomes the same as that on ground (the point is on ground potential), although physically no path for current from that point to ground actually exist, the point is said on ground potential. The point G in fig (17-13) is on ground potential.

The open-loop gain is given by

$$A = \frac{v_o}{v_{id}} = \frac{v_o}{(v_2 - v_1)}$$

$$\therefore (v_2 - v_1) = \frac{v_o}{A} = \frac{v_o}{\infty}$$

($\because$ for ideal OP-AMP, $A = \infty$)

or $(v_2 - v_1) = 0$ or $v_2 = v_1$

Therefore, the potential difference between two terminals is zero. In inverting amplifier, the non-inverting terminal is grounded i.e., $v_2 = 0$.

From eq. (1), $v_o = 0$

($\because v_2 = 0$)

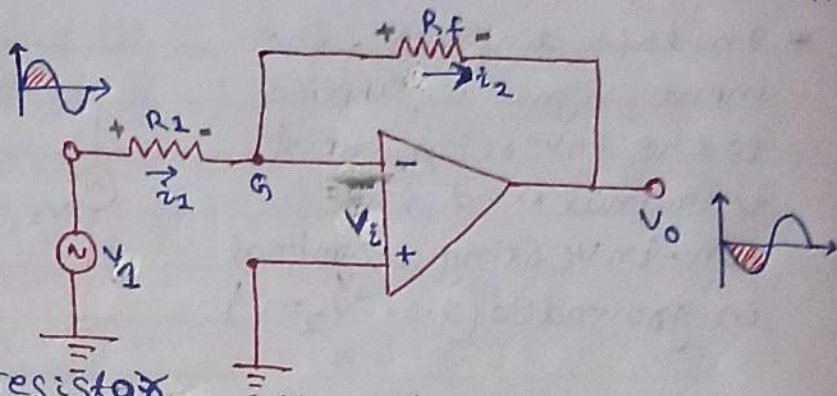
So, point G is on virtual ground.

Closed loop OP-AMP Configurations -:

* The term closed-loop indicates that there is a feedback path from output side to the input side of the OP-AMP.

a) Inverting OP-AMP -:

* This is the basic diagram of inverting amplifier for closed loop configuration.



* Where R_1 = input resistor, R_f = feedback resistor, V_0 = output voltage, V_i = input voltage

* In this mode of operation, the positive input terminal of the amplifier is grounded & the input signal is applied to the negative input terminals.

* The point 'G' is called as summing point because the output is added to the input at point 'G'.

Expression for gain -:

By applying KCL,

* The current i_1 flowing through point 'G' is given by

$$i_1 = \frac{V_1 - V_i}{R_1} \quad (V_i = 0)$$

$$= \frac{V_1}{R_1}$$

($\because$ G is at ground potential)

Similarly, $i_2 = \frac{V_i - V_0}{R_f} = \frac{-V_0}{R_f}$ ($V_i = 0$)

Apply KCL

At point G, $i_1 - i_2 = 0 \Rightarrow i_1 = i_2$

$$\Rightarrow \frac{V_1}{R_1} = -\frac{V_0}{R_f}$$

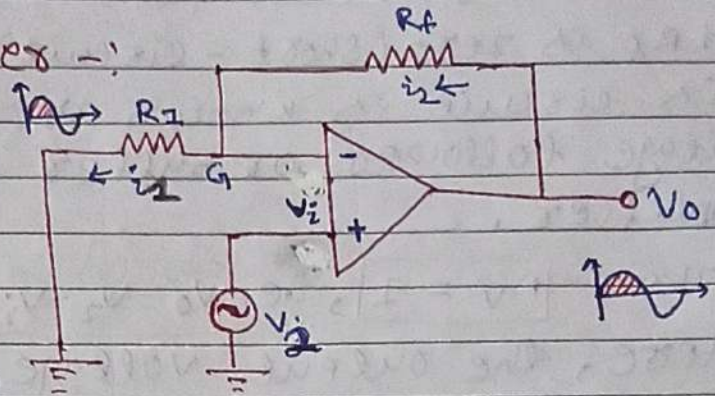
* The ratio of output voltage (V_0) and input voltage (V_i) is known as the closed loop gain.

$$A_v = \frac{V_0}{V_i} = -\frac{R_f}{R_1}$$

* The negative sign signifies that the output voltage is inverted with respect to input voltage.

Non-inverting amplifier -

- * This is the basic diagram of non-inverting amplifier for closed loop configuration.



- * In this mode of operation, the negative input terminal of the amplifier is grounded & the input signal is applied to the positive input terminals.

Expression for gain -

- * The values of currents i_1 and i_2 are given as (By applying KVL)
- $$i_1 = \frac{V_2}{R_1} \quad \text{and} \quad i_2 = \frac{V_o - V_2}{R_f} \quad (V_o - R_f i_2 - V_2 = 0) \quad (V_2 = V_2)$$

Applying Kirchhoff's 1st law at point G, we get (KCL)

$$(-i_1) + i_2 = 0$$

$$\Rightarrow -\frac{V_2}{R_1} + \frac{V_o - V_2}{R_f} = 0$$

$$\Rightarrow \frac{V_o}{R_f} = \frac{V_2}{R_1} + \frac{V_2}{R_f}$$

$$\Rightarrow \frac{V_o}{R_f} = V_2 \left(\frac{1}{R_1} + \frac{1}{R_f} \right)$$

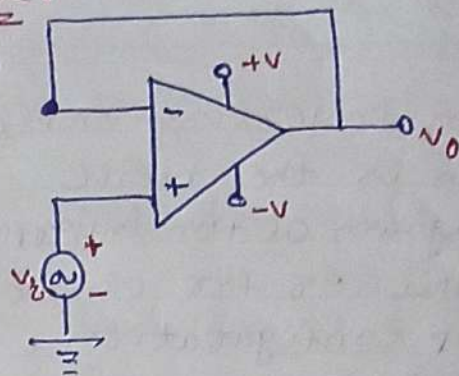
$$\Rightarrow \frac{V_o}{R_f} = V_2 \left(\frac{R_1 + R_f}{R_1 R_f} \right)$$

$$\Rightarrow \frac{V_o}{V_2} = \cancel{R_f} \left(\frac{R_1 + R_f}{R_1 \cancel{R_f}} \right) = \left(1 + \frac{R_f}{R_1} \right)$$

$$\Rightarrow \boxed{A_v = 1 + \frac{R_f}{R_1}}$$

Voltage follower or buffer Amplifier

* If R_1 is infinite (open-circuit) and R_f is zero (short-circuit), this circuit is known as voltage follower or buffer amplifier.



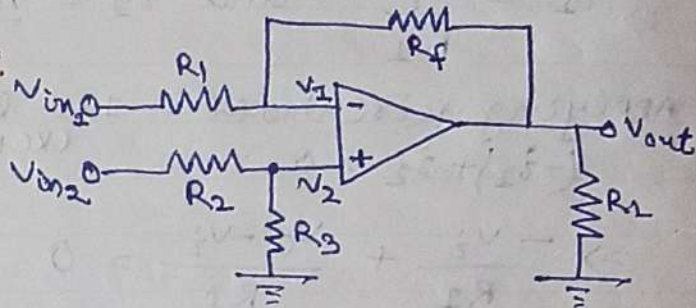
* Then $A_v = 1$, i.e. $V_o = V_i = V_z$

* Here, the output voltage is equal and in-phase with the input i.e. OP-AMP circuit acts as a voltage follower.

* It is required when a signal from high-impedance source is to be amplified and no signal current is to be drawn.

Differential amplifier -

* A differential amplifier is a circuit which amplifies the difference between two voltages.



* Voltages are applied at both the input terminals of OP-AMP and their amplified difference appears at the output terminal.

* Such a circuit is required when neither of the input lines are grounded.

$$A_v = -\frac{R_f}{R_1}$$

A_v = voltage gain.

Adder or Summing Amplifier :-

→ Summing Amplifier circuit used in Analog Computer.

→ It has 3 input Summing circuit.

→ The circuit provides a means of algebraically summing three input voltages each multiplied by a constant gain factor.

→ In this circuit, G is a virtual ground and the output voltage is phase inverted.

→ Here, the different current are given by

$$V_1 = i_1 R_1, \quad V_2 = i_2 R_2, \quad V_3 = i_3 R_3$$

$$\Rightarrow i_1 = \frac{V_1}{R_1}$$

$$\Rightarrow i_2 = \frac{V_2}{R_2}$$

$$\Rightarrow i_3 = \frac{V_3}{R_3}$$

$$\text{and } -V_0 = i R_f$$

$$\Rightarrow i = \frac{-V_0}{R_f}$$

Apply KCL at point 'G', we get

$$i_1 + i_2 + i_3 - i = 0 \Rightarrow i_1 + i_2 + i_3 = i$$

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

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

$$\Rightarrow V_0 = - \left[\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3 \right] \quad \text{--- (i)}$$

Consider $\frac{R_f}{R_1} = K_1, \quad \frac{R_f}{R_2} = K_2, \quad \frac{R_f}{R_3} = K_3$ & $\frac{R_f}{R} = K$

$$\Rightarrow V_0 = - [K_1 V_1 + K_2 V_2 + K_3 V_3] \quad \text{--- (ii)}$$

Case-1 If $R_1 = R_2 = R_3 = R$

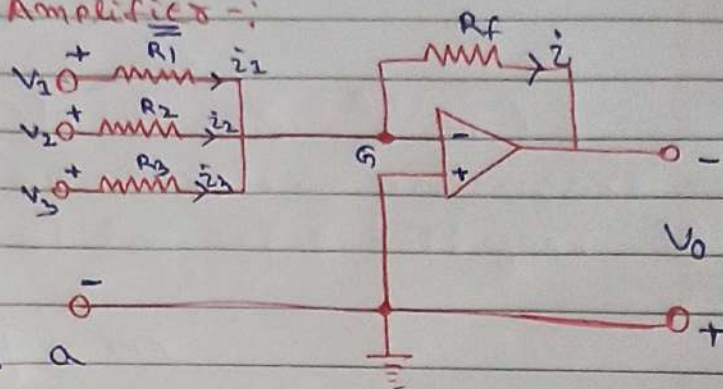
Put the value in eqn (i)

$$\Rightarrow V_0 = - \left[\frac{R_f}{R} V_1 + \frac{R_f}{R} V_2 + \frac{R_f}{R} V_3 \right] = - \frac{R_f}{R} [V_1 + V_2 + V_3] \quad \text{--- (iii)}$$

Case-2 If $R_f = R$

Put the value in eqn (iii)

$$\Rightarrow V_0 = - [V_1 + V_2 + V_3] \quad \text{--- (iv)}$$



case-3 If $\frac{R_f}{R} = \frac{1}{n}$ $n = \text{no. of inputs}$

put the value in Eqn (ii)

$$V_o = -\frac{1}{3} [V_1 + V_2 + V_3] \quad - (V)$$

→ In this case, the output is equal to the average of the three inputs.

Subtractor -

→ The function of the subtractor

is to provide an output

which is equal to the

difference of two input signals.

→ Here, one signal is applied at the inverting terminal while the second signal is applied at the non-inverting terminals of an OP-AMP.

→ By Applying Superposition theorem,

V_1 is active & V_2 is Grounded.

$$A_v = -\frac{R_f}{R_1} \Rightarrow \frac{(V_o)_1}{V_i} = -\frac{R_f}{R_1}$$

Here V_1 is active, so the input voltage $V_i = V_1$

$$\Rightarrow (V_o)_1 = -\left(\frac{R_f}{R_1}\right) V_1 \quad - (1)$$

→ By Applying Superposition theorem,

V_2 is active & V_1 is Grounded.

$$A_v = \left(1 + \frac{R_f}{R_1}\right) \quad (\text{Non-inverting ckt})$$

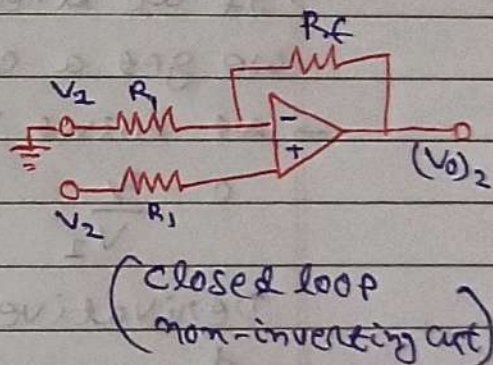
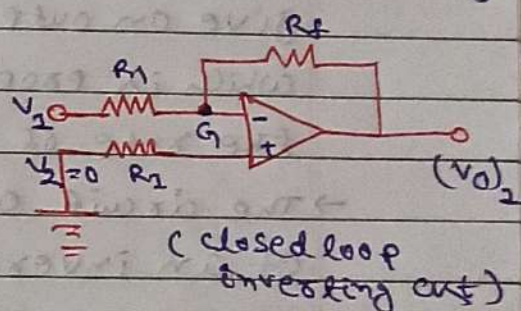
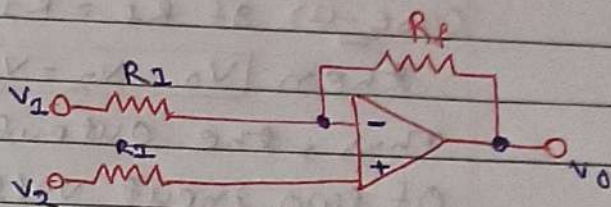
$$\Rightarrow \frac{(V_o)_2}{V_i} = 1 + \frac{R_f}{R_1}$$

$$\Rightarrow \frac{(V_o)_2}{V_2} = \frac{R_f}{R_1} \quad (\because V_i = V_2, \frac{R_f}{R_1} \gg 1)$$

$$\Rightarrow (V_o)_2 = \left(\frac{R_f}{R_1}\right) V_2 \quad - (2)$$

* Total output $V_o = (V_o)_1 + (V_o)_2$

$$= -\left(\frac{R_f}{R_1}\right) V_1 + \frac{R_f}{R_1} (V_2)$$



$$\Rightarrow V_0 = \frac{R_f}{R_1} (V_2 - V_1)$$

$$\Rightarrow V_0 = K (V_2 - V_1) \quad \text{--- (3)} \quad \left(\because K = R_f / R_1 \right)$$

* Eqn (3) shows that output voltage is proportional to the difference of two input voltages.

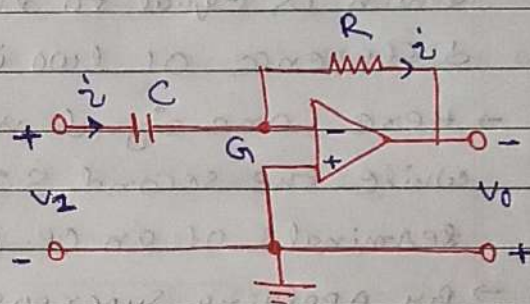
Case - (1) If $R_f = R_1$

$$\text{then } V_0 = V_2 - V_1 \quad \text{--- (4)}$$

Thus, the output voltage is equal to the difference of two input voltages.

Differentiator :-

→ The function of the differentiator is to give an output voltage which is proportional to the rate of change of the input voltage.



→ The circuit of a differentiator is the same as that of an inverting OP-AMP except that the input resistance (R_1) is replaced by a capacitor.

→ If we linearly increasing voltage to the differentiator, we get a constant d.c output.

→ At point 'G', the value of capacitor

$$C = \frac{q}{V_1} \Rightarrow V_1 = \frac{q}{C} \quad \text{--- (1)} \quad \left(\text{where } q = \text{charge on capacitor} \right)$$

Derivative both side of Eqn (1)

$$\Rightarrow \frac{d}{dt} (V_1) = \frac{1}{C} \frac{dq}{dt}$$

$$\Rightarrow \frac{d}{dt} (V_1) = \frac{i}{C} \quad \left(\because \frac{dq}{dt} = i \right) \quad \text{--- (2)}$$

$$\Rightarrow i = C \frac{d}{dt} (V_1)$$

$$\text{Again } V_0 = -iR \quad \text{--- (3)}$$

Substitute the value of Eqn (2) in Eqn (3)

$$V_0 = -C \frac{d}{dt} (V_1) \cdot R \Rightarrow V_0 = -CR \frac{dV_1}{dt} \quad \text{--- (4)}$$

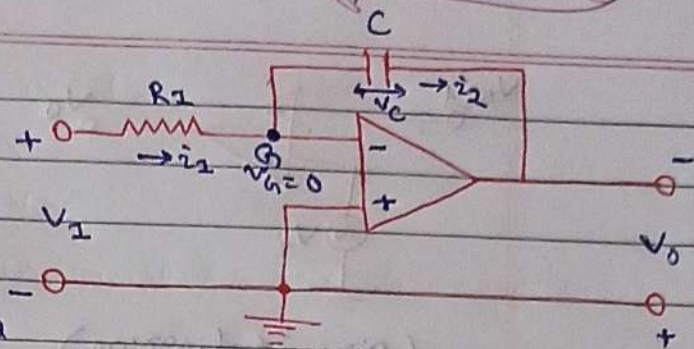
* output voltage (V_0) is equal to a constant (CR) of derivative of the input voltage (V_1).

Integrator -:

→ The op-amp integrator is an electronic integration circuit.

→ It performs the mathematical operation of integration with respect to time (i.e. its output voltage is proportional to the input voltage integrated over time).

→ The integrator is an inverting OP-AMP in which feedback resistor (R_f) has been replaced by a capacitor (C).



Mathematical derivation -:

Applying KCL on point 'G'.

$$i_1 - i_2 = 0 \Rightarrow i_1 = i_2$$

$$\left(\because i_1 = \frac{V_1}{R_1} \right)$$

As we know $C = \frac{q}{V_c} \Rightarrow q = C V_c$

$$\Rightarrow \frac{dq}{dt} = C \frac{dV_c}{dt}$$

$$\left(\because i_2 = C \frac{dV_c}{dt} \right)$$

then $i_1 = i_2$

$$\Rightarrow \frac{V_1}{R_1} = C \frac{dV_c}{dt}$$

$$\left(V_c = V_G - V_0 \right)$$

$$= 0 - V_0 = -V_0$$

$$\Rightarrow \frac{V_1}{R_1} = -C \frac{d}{dt}(V_0)$$

$$\Rightarrow d(V_0) = -\frac{V_1}{R_1 C} dt$$

Integrate both side (LHS & RHS)

$$\Rightarrow \boxed{V_0 = -\frac{1}{R_1 C} \int V_1 \cdot dt}$$

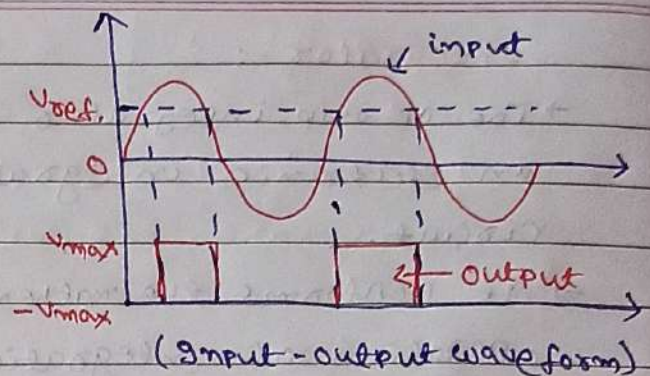
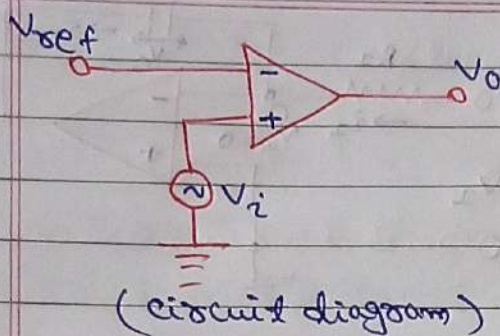
Comparator -:

→ comparator is a circuit which compares two voltages and provides an output that indicates the relationship between them.

→ Comparator may be used to Compare -:

→ Two changing voltages like two sine waves.

→ A changing voltage with a set d.c. reference voltage.



- Here, the OP-AMP is operated in open-loop configuration.
- The input voltage is applied to the non-inverting input terminal and a set D.C. reference voltage (V_{ref}) is applied to the inverting terminal of the OP-AMP.
- The output voltage (V_o) is varying from V_{max} to $-V_{max}$ or vice versa.