MODULE-I.

BJT BIASING & FET BIASING.

BJT BIASING :-

(1)

Need for biasing :- To produce a distortion free output in amplifier circuits, the supply voltages and resistances establish a set of dc voltage V_{CEQ} and I_{CQ} to operate the transistor in the active region. These voltages and currents are called Quiescent Values which determine the operating point (or) Q-point for the transistor.

** The process of giving proper supply voltages and resistances for obtaining the desired Q-point is called Biasing.

→ The circuits used for getting the desired and proper operating point are known as biasing circuits.

→ To establish the operating point in the active region, biasing is required for transistors to be used as an amplifier.

→ For an analog circuit operation, the Q-point is placed so that the transistor stays in active mode when input is applied. For digital circuit operation, the Q-point is placed so that the transistor does contrary (switches from on to off state).

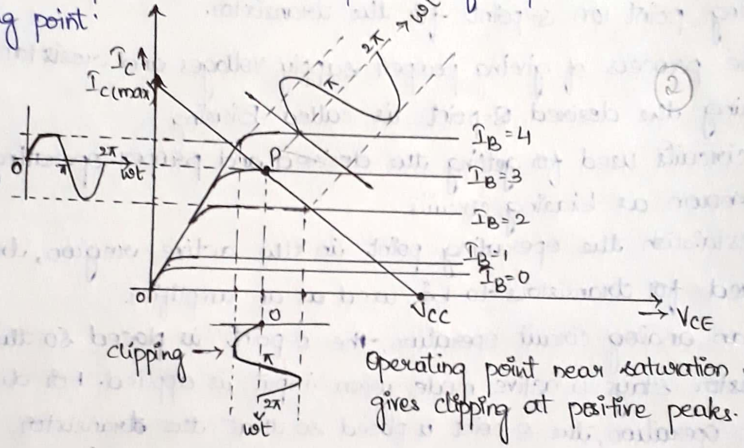
→ Often, Q-point is established near the center of active region of transistor characteristic to allow similar signal swings in positive and negative directions. Q-point should be stable.

→ In particular, it should be insensitive to variations in transistor parameters, variations in temperature, variations in power supply voltage and so forth.

Operating point :- When we bias a transistor we establish a certain current and voltage conditions for the transistor. These conditions are known as operating conditions (or) d.c. operating point (or) Quiescent Point. The operating point must be stable for proper operation of the transistor. However, the operating point shifts with changes in transistor parameters such as β, I_{CO} and V_{BE}.

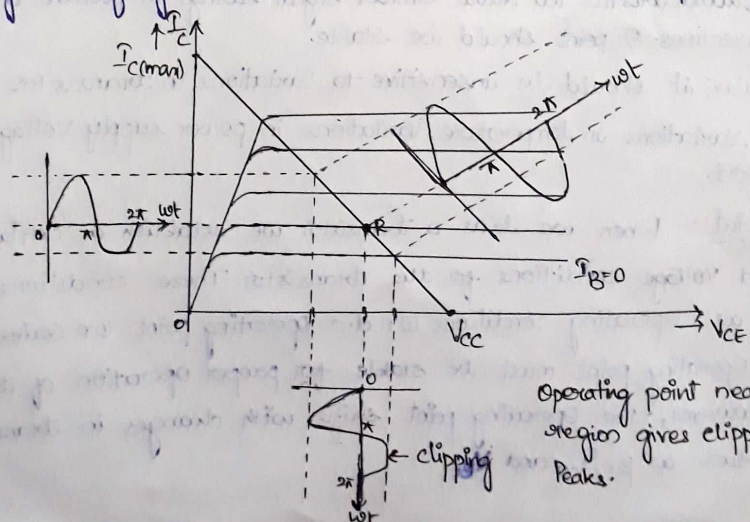
The operating point can be selected at three different positions on the d.c. load line; near saturation region, near cut-off region or near active region. When transistor is used as an amplifier, the Q-point should be selected at the Centre of the d.c load line to prevent any possible distortion in the amplified output signal.

<u>Case i</u> :- Biasing circuit is designed to fix a Q-point at point P. Point P is very near to the saturation region. The collector current is clipped at the positive half cycle. So, even though base current Varies Sinusoidally, collector current is not a useful sinusoidal wave form i.e., distortion is present at the output. Therefore, point P is not a suitable operating point.



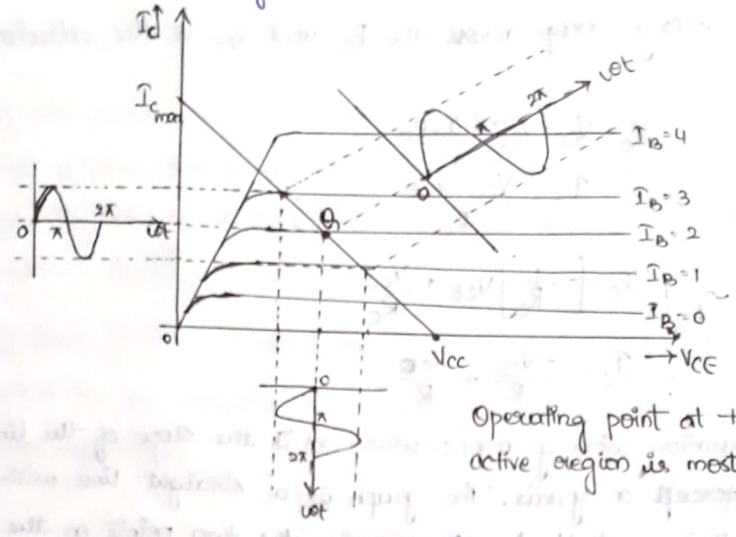
Operating point near saturation region gives clipping at positive peaks.

<u>Case ii</u> :- Biasing circuit is designed to fix a Q-point at point R. point R is Very near to the cut-off region. The collector current is clipped at the negative half cycle. So, point R is also not a suitable Operating point.



Operating point near cut off region gives clipping at negative Peaks.

Case 3:- Biasing circuit is designed to fix a Q-point at point Q. The output signal is sinusoidal waveform without any distortion. Thus Q point is the best operating point.

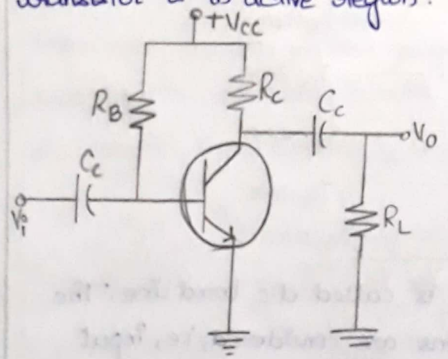


Operating point at the centre of active region is most suitable.

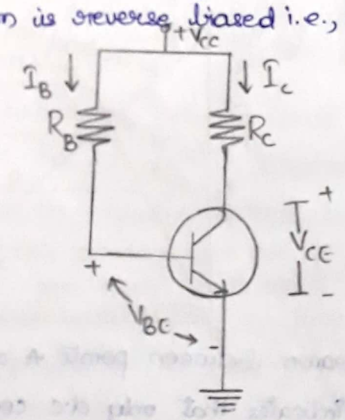
(3)

Load line Analysis :-

DC load line :- consider a common emitter circuit which is biased with a common supply such that the base-emitter junction is forward biased and the collector-base junction is reverse biased i.e., the transistor is in active region.



common emitter amplifier



Equivalent circuit

In the absence of ac signal, the capacitors provide very high impedance that is it acts like a open circuit. Therefore the equivalent circuit for common emitter amplifier does not have capacitors.

Applying Kirchoff's voltage law to the collector circuit,

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

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

$I_C R_C$ is the voltage drop across the R_C and V_{CE} is the collector to emitter voltage.

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

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

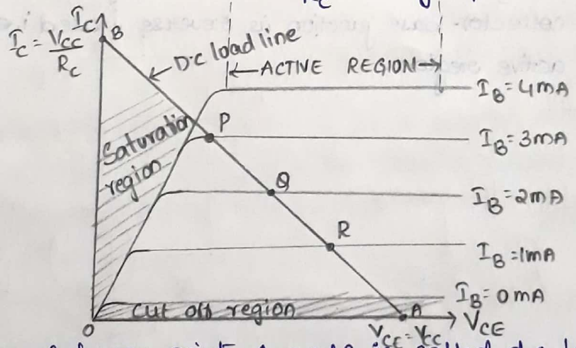
$$I_C = \left[-\frac{1}{R_C}\right] V_{CE} + \frac{V_{CC}}{R_C}$$

$$I_C = \frac{-V_{CE}}{R} + \frac{V_{CE}}{R}$$

compare the Equation with $y = mx + c$. where m is the slope of the line and c is the intercept on y-axis. The graph is a straight line with slope $-1/R_C$ and Y-intercept V_{CC}/R_C. To determine the two points on the line assume $V_{CE} = V_{CC}$ and $V_{CE} = 0$

(a) When $V_{CE} = V_{CC}$; $I_C = 0$ we get point A

(b) When $V_{CE} = 0$; $I_C = \frac{V_{CC}}{R_C}$ we get point B



The line drawn between points A and B is called d.c load line. The 'd.c' word indicates that only d.c conditions are considered, i.e, input signal is assumed to be zero. The graph represents all collector current levels and corresponding collector emitter voltages. knowing any one of I_C, I_B or V_{CE} it is easy to determine the other two from the load line. The slope of the d.c load line depends on the value of R_C.

Applying Kirchhoff's law to the base circuit

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

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

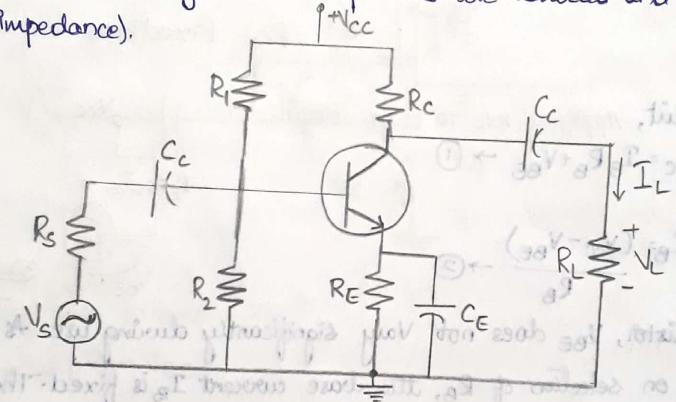
$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad \text{as } V_{CC} > V_{BE}$$

(5)

If we assume $V_{CC} = 10V$ and $R_B = 5k$ then $I_B = 2mA$. The curve and the line of intersection is the d.c load line. For different values of I_B, we get different intersection points such as P, Q and R. All these points are Quiescent points.

AC load line :- Consider the common emitter amplifier for ac analysis.

*** For AC analysis the capacitors are shorted and V_{CC} is shorted (zero impedance).



From the common emitter amplifier circuit, the collector circuit resistance seen by the d.c bias current I_{CQ} is $R_{dc} = R_C + R_E$. In equivalent circuit the collector signal current i_c sees a collector circuit resistance $R_{ac} = R_C \| R_L$

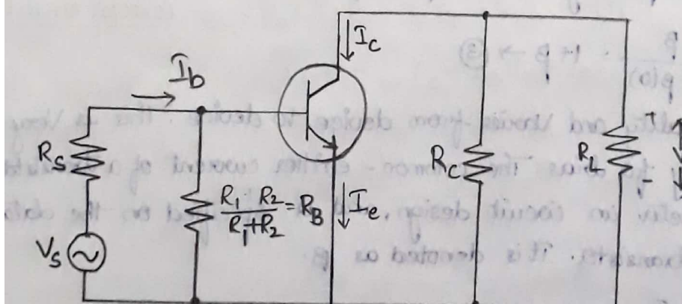
$$R_{ac} = \frac{R_C R_L}{R_C + R_L}$$

i_c = a.c collector current due to sig
I_C = zero signal collector current

$V_{ce} = I_c R_{ac}$

Since $R_{ac} \neq R_{dc}$ in general, the concept of a.c load line arises.

Since $\begin{cases} I_c = i_c - I_{CQ} \\ V_{CE} = V_{CEQ} - V_{CE} \end{cases}$



$$V_{CEQ} - V_{CE} = (i_c - i_{CQ}) R_{ac}$$

$$i_c = \frac{V_{CEQ}}{R_{ac}} - \frac{V_{CE}}{R_{ac}} + I_{CQ}$$

(i) $i_c = 0$, $V_{CE} = V_{CEQ} + I_{CQ} R_{ac}$

(ii) $V_{CE} = 0$, $I_{c\,max} = \frac{V_{CEQ}}{R_{ac}} + I_{CQ}$

Bias Stabilization techniques :- There are three biasing techniques. They are :-

→ Fixed bias (or) base resistor bias.
→ Collector to base bias (or) collector feedback bias
→ Self bias (or) emitter bias (or) potential divide bias

(6)

Fixed bias :-

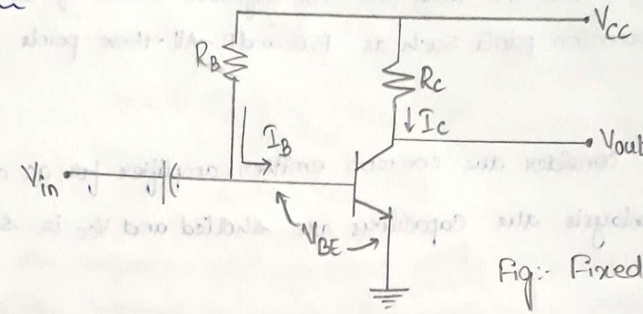


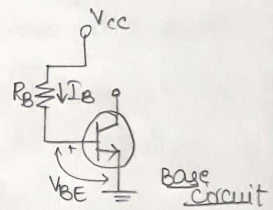
Fig:- Fixed bias circuit

In the given circuit, Applying KVL to base circuit

$$V_{CC} = I_B R_B + V_{BE} \rightarrow (1)$$

Therefore,

$$I_B = \frac{(V_{CC} - V_{BE})}{R_B} \rightarrow (2)$$



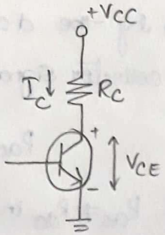
Base circuit

For a given transistor, V_{BE} does not vary significantly during use. As V_{CC} is of fixed value, on selection of R_B, the base current I_B is fixed. Therefore this type is called fixed bias type of circuit.

Also Apply KVL to collector circuit

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

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



Collector circuit

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

Since I_B is not depending on I_C as per eqn (2)

$$S = \frac{1+\beta}{1-\beta(0)} = 1+\beta \rightarrow (3)$$

Since β is a large quality and varies from device to device. This is very poor circuit for stability for bias. The common-emitter current of a transistor is an important parameter in circuit design, and is specified on the data sheet for a particular transistor. It is denoted as β.

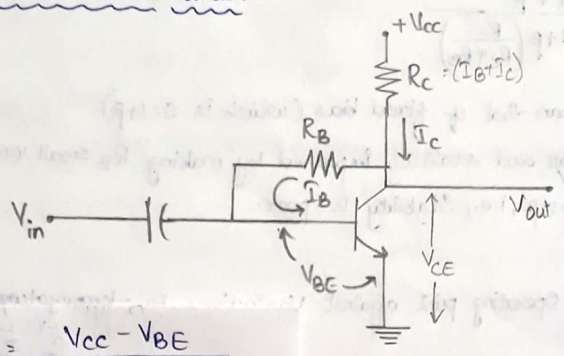
Because $I_C = \beta I_B$

We can obtain I_C.

Advantages: → A very small number of components are required.
→ It is simple to shift the operating point anywhere in the active region by merely changing the base resistor (R_B).

Disadvantages: – Since $I_C = \beta I_B$ and I_B is already fixed, I_C depends on β which changes unit to unit and shifts the operating point. Thus stabilization of operating point is very poor in fixed bias circuit.

Collector-to-base bias:-



Applying KVL to base circuit

$V_{CC} - (I_B + I_C)R_C - I_B R_B - V_{BE} = 0$

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

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

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

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

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

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

$\because \beta >> 1$

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

If the collector current increases due to increase in temperature or the transistor is replaced by one with higher β, the voltage drop across R_C increases.
→ So, less V_{CE} and less I_B, to compensate increase in I_C i.e, greater stability.

Apply KVL to collector circuit

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

$\boxed{V_{CE} = V_{CC} - (I_C + I_B)R_C}$

For stability factor,

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

There is no effect on V_{CC} & V_{BE}, so

$0 = \partial I_C R_C + \partial I_B (R_C + R_B)$

$-\partial I_C R_C = \partial I_B (R_C + R_B)$

$$\boxed{\frac{\partial I_B}{\partial I_C} = \frac{-R_C}{(R_C + R_B)}}$$

Stability factor

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

Substituting the value of $\frac{dI_B}{dI_C}$ from eqn ①

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

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

$$= \frac{1+\beta}{\frac{R_B+R_E+\beta R_E}{R_B+R_E}}$$

(10)

Dividing Nr & Dr by R_E

$$S = \frac{1+\beta \quad \frac{R_B+R_E}{R_E}}{\frac{R_B+R_E+\beta R_E}{R_E}}$$

$$= (1+\beta)\frac{1+\frac{R_B}{R_E}}{1+\beta+\frac{R_B}{R_E}} \rightarrow ②$$

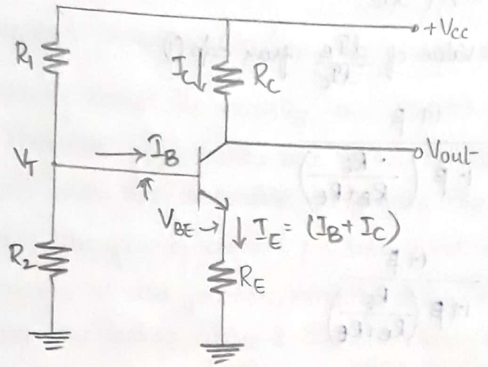
if $\frac{R_B}{R_E}=0$, $S=(1+\beta)\frac{1+0}{1+\beta-0} = \frac{1+\beta}{1-\beta} = 1 \rightarrow ③$

if $\frac{R_B}{R_E}=\infty$, $S = 1+\beta \frac{1+\infty}{1+\beta+\infty} = 1+\beta$

* For smaller value of R_B stability is better, but large power will be wasted in R_1 & R_2. S is independent of β.
* For fixed $\frac{R_B}{R_E}$, S increases with β i.e., stability decreases with increase in β.

Advantages: — → Unlike above circuits, only one dc supply is necessary.
* Operating point is almost independent of β variation.
* Operating point stabilized against shift in temperature.

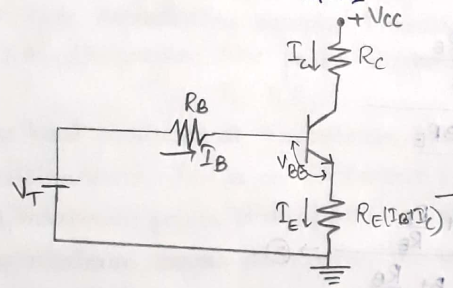
Whenever there is increase in this collector circuit voltage across R_E increases causing base current to diverse which compensate the increase in collector current. This circuit can be used with low collector resistance.



(9)

$V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$, By applying thevinins theorem, the ckt can be replaced and

$$R_B = \frac{R_1 R_2}{R_1 + R_2}$$



Thevinin's Equivalent Circuit

Writing loop eq^n for the basic loop shown

$$V_B = I_B R_B + V_{BE} + R_E(I_B + I_C)$$

$$V_B = I_B R_B + V_{BE} + I_B R_E + I_C R_E$$

$$V_B = I_B(R_B + R_E) + V_{BE} + I_C R_E$$

$$I_B(R_B + R_E) = V_B - V_{BE} - I_C R_E$$

Differentiating w.r.t I_C.

$$\frac{dI_B}{dI_C} R_B + R_E = \frac{dV_B}{dI_C} - \frac{dV_{BE}}{dI_C} - \frac{dI_C R_E}{dI_C}$$

$$\frac{dI_B}{dI_C}(R_B + R_E) = 0 - 0 - R_E$$

$$\frac{dI_B}{dI_C} = \frac{-R_E}{R_B + R_E} \rightarrow (1)$$

Stability factor

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

Putting the Value of $\frac{dI_B}{dI_C}$ from eqn ③

$$S = \frac{1+\beta}{1-\beta\left(\frac{-R_C}{R_C+R_B}\right)}$$ ②

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

* Value of S is less than that of fixed bias (which is $S = 1+\beta$).
* S can be made small and stability improved by making R_B small or R_C large. If R_C is small $S = 1+\beta$, i.e., Stability is poor.

Advantages:-

* Circuit stabilizes the Operating point against Variations in temperature and β.

Disadvantages:-

* In this circuit, to keep I_C independent of β, the following condition must be met

$$I_C = \beta I_b$$

$$= \frac{\beta(V_{CC}-V_{BE})}{R_b+R_C+\beta R_C} \approx \frac{(V_{CC}-V_{BE})}{R_C}$$

* The Resistor R_b causes an AC feedback, reducing the Voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point Stability.

Self bias :- The Voltage divider is formed using external resistors R_1 and R_2. The Voltage across R_2 forward biases the emitter junction. By proper selection of resistors R_1 and R_2, the Operating point of the transistor can be made independent of β. In this circuit, the Voltage divider holds the base Voltage fixed independent of base current provided the divider current is large compared to the base current. Required base bias is obtained from the power ... divider $R_1 + R_2$. In this circuit Voltage across Reverse

Disadvantages:-

* AC as well as DC feedback is caused by R_E, which reduces the AC voltage gain of the amplifier.

(11)

Stabilization against Variations in I_{CO}, V_{BE} and β for the Self-bias circuit.

Designing the biasing circuit to stabilize the Q-point is known as bias stability. Two important points factors are to be considered while designing the biasing circuit which are responsible for shifting the operating point.

(a) (1) Temperature :- The flow of current produces heat at junctions. As the temperature increases at the junction, minority charge carrier increases. This further increases the leakage current I_{CEO}. — current produced due to minority charge carriers is called leakage current.

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

Increase in I_{CEO} in-turn increases the collector current,

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

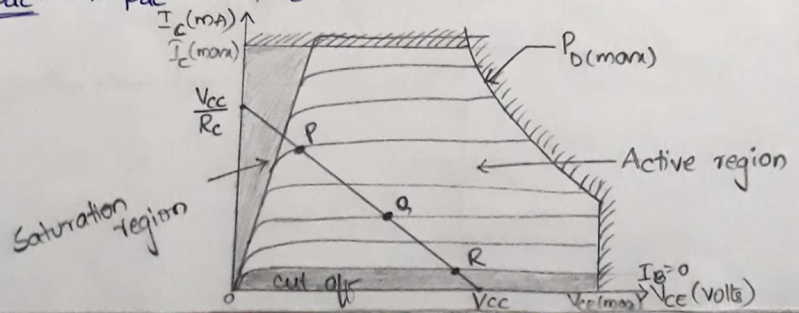
The increase in I_C further raises the temperature at the collector junction and same cycle repeats. This excessive increase in I_C shifts the operating point into saturation region. The power dissipated is given as

$$P_D = V_C I_C$$

The excess heat produced at the collector base junction may even burn and destroy the transistor. This is called thermal Runaway of transistor. For any transistor, maximum power dissipation is always a fixed value. This is known as maximum power dissipation. This value is specified by in data sheets. If this limit is crossed, the device will fail.

(2) V_{BE} :- Base-to-emitter voltage V_{BE} changes with temperature at the rate of 2.5 mV/°C. Base current, I_B depends upon V_{BE}. As base current I_B depends on V_{BE} and I_C depends on I_B, I_C depends on V_{BE}. Therefore collector current I_C changes with temperature due to change in V_{BE}. The change in collector current change the operating point.

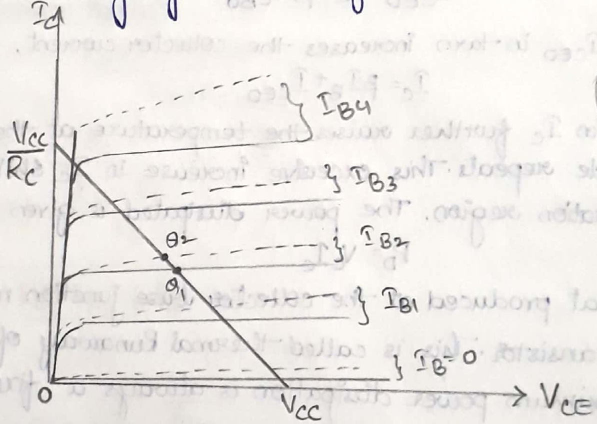
(3) β_{dc} :- As β_{dc} Varies, I_C also increases.



Therefore, to avoid thermal stability, the biasing circuit should be designed to provide a degree of temperature stability i.e., even though there are temperature changes, the changes in the transistor parameters (V_{CEQ}, I_{CQ}, P_{Dmax}) should be very less so that the operating point shifting is minimum in the middle of the active region.

<u>Transistor current gain h_{FE} / β</u> :- If two transistors units of same type (i.e., same number, construction, parameter specified etc). and use them in the circuit, there is change in the β value in actual practice. The biasing circuit is designed according to the required β value. But due to change in β from unit to unit, the operating point may shift.

so for stabilizing the operating point the factors discussed so far should be considered while designing the biasing circuit.



Graphs showing the collector characteristics for two transistors of the same type.

12

to negative feedback action. The negative feedback, although improves the stability of operating point, it reduces the gain of the amplifier. As the gain of the amplifier is a very important consideration, some compensation techniques are used to maintain excellent bias and thermal stabilization.

→ Temperature sensitive devices like thermistors and sensistors are used. Temperature sensitivity is defined as the behavioral response of a device to changing temperature conditions.

* The Compensation Techniques are

~~(i) compensation~~

(i) Diode compensation Technique

   (a) compensation for V_{BE}

   (b) compensation for I_{CO}

(ii) Thermistor compensation Technique

(iii) Sensistor compensation Technique.

(13)

Diode Compensation Technique :-

Applying KVL to base circuit

$$V_{CC} = I_B R_B + V_{BE} + I_E R_E - V_D$$

We know that $I_C = \beta I_B + (1+\beta) I_{CBO}$ and $I_E = I_C + I_B$.

$$I_B = \left[\frac{I_C - (1+\beta) I_{CBO}}{\beta}\right]$$

$$V_{CC} = \left[\frac{I_C - (1+\beta) I_{CBO}}{\beta}\right] R_B + V_{BE} + \left[I_C + I_B\right] R_E - V_D$$

$$V_{CC} = \left(\frac{I_C - (1+\beta) I_{CBO}}{\beta}\right] R_B + V_{BE} + \left[I_C + \frac{I_C - (1+\beta) I_{CBO}}{\beta}\right] R_E - V_D$$

$$V_{CC} - V_{BE} + V_D = \left[\frac{I_C - (1+\beta) I_{CBO}}{\beta}\right] R_B + \left(\frac{\beta I_C + I_C - (1+\beta) I_{CBO}}{\beta}\right] R_E$$

$$V_{CC} - \left[V_{BE} - V_D\right] = \frac{I_C}{\beta}\left[R_B + R_E + \beta R_E\right] - \frac{(1+\beta)}{\beta} I_{CBO} \left(R_B + R_E\right]$$

$$V_{CC} - \left[V_{BE} - V_D\right] = \frac{I_C}{\beta}\left[R_B + R_E(\beta+1)\right] - \frac{(1+\beta)}{\beta} I_{CBO} \left[R_B + R_E\right]$$

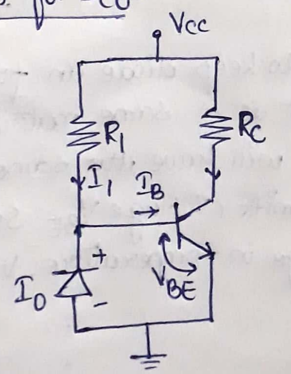
$$V_{CC} - \left[V_{BE} - V_D\right] + \frac{(1+\beta)}{\beta} I_{CBO}\left[R_B + R_E\right] = \frac{I_C}{\beta}\left[R_B + R_E(1+\beta)\right]$$

$$\beta\left[V_{CC} - \left[V_{BE} - V_D\right] + \frac{\beta(1+\beta)}{\beta} I_{CBO}\left[R_B + R_E\right]\right] = I_C\left[R_B + R_E(1+\beta)\right]$$

$$\boxed{I_C = \frac{\beta\left[V_{CC} - (V_{BE} - V_D) + (1+\beta) I_{CBO} (R_B + R_E)\right]}{\left[R_B + R_E(1+\beta)\right]}}$$

(14)

(B) compensation for I_{CO} :-



In case of germanium, changes in I_{CO} with temperature are comparitively larger than Si transistor. it offers stabilization against variation in I_{CO}. Here, the diode is kept in Reverse biased. In Reverse bias condition the current flowing through diode is only the leakage current (I_0). If the diode and the transistor are of same type material the leakage current I_0 of the diode will increase with temperature at the same rate as the collector leakage current I_{CO}.

$$I = \frac{V_{CC} - V_{BE}}{R_1} \quad , \quad I = I_B + I_0$$

$$\therefore I_B = I - I_0$$

→ For Ge transistor $V_{BE} = 0.3V$, which is very small and neglecting change in V_{BE} with temperature. So,

$$I = \frac{V_{CC}}{R_1}$$

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

Substitute I_B in I_C

$$I_C = \beta(I - I_0) + (1+\beta) I_{CO}$$

$$I_C = \beta I - \beta I_0 + (1+\beta) I_{CO}$$

if $\beta >> 1$ we get

$$I_C = \beta I - \beta I_0 + \beta I_{CO}$$

We assume $I_0 = I_{CO}$ we get.

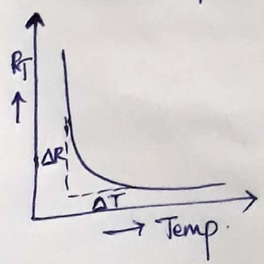
$$\boxed{I_C = \beta I}$$

→ As I is constant, I_C remains fairly constant.

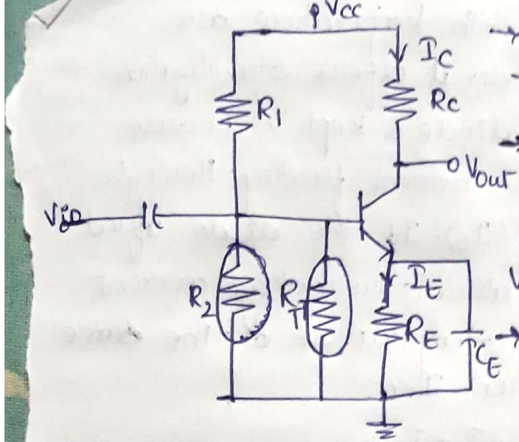
(ii) Thermistor compensation Technique :–

It is a negative temperature coefficient (NTC). Its resistance decreases exponentially with increasing temperature.

Slope of the curve $= \frac{\partial R_T}{\partial T}$



15

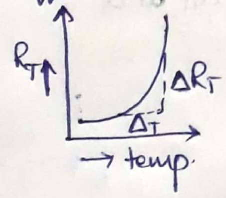


→ The resistor R_2 is replaced by Thermistor R_T in Self bias Circuit.

→ With increase in temperature, R_T decreases. Hence Voltage drop across it also decreases. Hence V_{BE} decreases which reduces I_B.

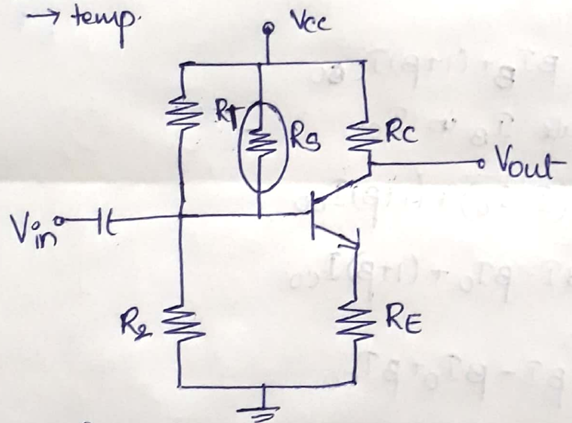
→ This will tend to decrease in collector current with temperature.

(iii) Sensistor compensation Technique:- It is a positive temperature coefficient (PTC). Its resistance increases with increasing temperature.



∴ slope of the curve $= \frac{\Delta R_T}{\Delta T}$

(16)



→ The resistor R_1 is replaced by Sensistor R_S in Self bias circuit. Now R_1 and R_2 are two resistors of potential divider.

→ As temperature increases, R_S increases which decreases the current flowing through it. Hence current through the resistor decreases which reduces the voltage drop across it.

→ So V_{BE} reduces which decreases I_B, and I_C remains fairly constant.

Thermal Run away :-

Since collector current is $I_C = \beta I_B + (\beta+1) I_{CBO}$

β, I_B, I_{CBO} all increases with temperature. I_{CBO} doubles for every 10°C rise in temperature.

* The maximum power is limited by the temperature that the collector-base junction can with stand for silicon junction this temperature is in the range of 150 to 225°C, and for germanium it is between 60 to 100
* The collector base junction temperature may rise because of two reasons. (i) Due to rise in ambient temperature (ii) Due to self heating.

$\theta = \frac{T_j - T_A}{P_D}$

* The increase in the collector current increases the power dissipated at the collector junction. This further increases the temp of the junction and hence increases the collector current. The excess heat produced at the collector base junction may even burn and destroy the transistor. This situation is called Thermal runaway of the transistor.

Stability factor :- The extent to which the collector current I_C is stabilized with varying I_{CO} is measured by a stability factor S. It is defined as the rate of change of collector current I_C with respect to the collector-base leakage current I_{CO}, keeping both the current I_B and the current gain β constant.

$$S = \frac{\partial I_C}{\partial I_{CO}} \approx \frac{dI_C}{dI_{CO}} \approx \frac{\Delta I_C}{\Delta I_{CO}}, \ \beta \text{ and } I_B \text{ constant}$$

$$I_E = I_B + I_C$$
$$I_C = \alpha I_E + I_{CBO}$$
$$I_C = \alpha(I_B + I_C) + I_{CBO}$$
$$I_C = \alpha I_B + \alpha I_C + I_{CBO}$$
$$(I_C - \alpha I_C) = \alpha I_B + I_{CBO}$$
$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$
$$I_C = \underbrace{\left(\frac{\alpha}{1-\alpha}\right)}_{\beta} I_B + \underbrace{\left(\frac{1}{1-\alpha}\right)}_{1+\beta} I_{CBO}$$
$$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$$

differentiate w.r.t to I_C.

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

if $S = \frac{\partial I_C}{\partial I_{CBO}}$

$$\frac{1}{S} = \frac{(1-\beta)\frac{\partial I_B}{\partial I_C}}{1+\beta}$$

$$\boxed{S = \frac{1+\beta}{(1-\beta)\frac{\partial I_B}{\partial I_C}}}$$

8

... this eqn, it is clear that this factor s should be as small as possible to have better thermal stability.

Stability factor S' and S'' :- The stability factor S' is defined as the rate of change of I_C with V_{BE}, keeping I_{CO} and β constant.

$$S' = \frac{\partial I_C}{\partial V_{BE}} \approx \frac{\Delta I_C}{\Delta V_{BE}} \quad (18)$$

The stability factor S'' is defined as the rate of change of I_C with respect to β, keeping I_{CO} and V_{BE} constant.

$$S'' = \frac{\partial I_C}{\partial \beta} \approx \frac{\Delta I_C}{\Delta \beta}$$

Biasing FET :- In FET, as temperature increases drain resistance also increases, reducing the drain current. unlike BJT, thermal runaway does not occur with FET. It is necessary to keep drain current I_D stable at its Quiescent Value.

The general relationships that can be applied to the d.c analysis of all FET amplifiers are:-

$$I_G = 0A$$

$$I_D = I_S$$

(Schockley's eq^n) $I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$ → I_{DSS} = current in saturation state, V_P = pinch off Voltage.

The Three Techniques are:-

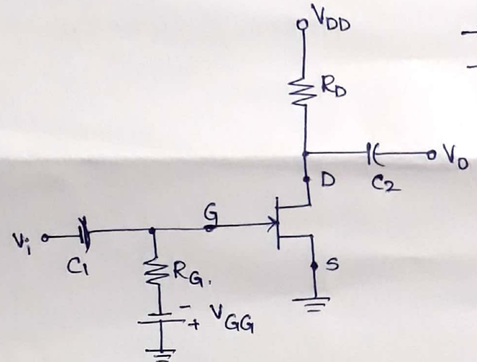
→ Fixed Bias circuit

→ Source - self bias

→ Voltage divider bias.

(19)

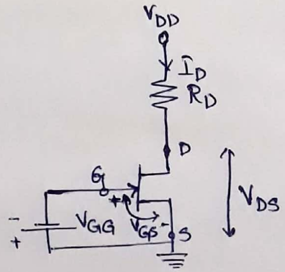
Fixed Bias Circuit :-



→ This is the simplest biasing arrangment.

→ To make gate-Source junction reverse-biased, a seperate supply V_{GG} is connected such that gate is more negative than the Source.

D.C Analysis:- For the d.c analysis coupling capacitors are open circuits. The current through R_G is I_G which is zero. This permits R_G to replace by short circuit equivalent.



We know that for D.C analysis

$$I_G = 0A$$

Applying KVL to i/p circuit

$$V_{GS} + V_{GG} = 0$$

$$V_{GS} = -V_{GG}$$

Since V_{GG} is fixed d.c supply, the voltage V_{GS} is fixed in magnitude, hence the name is given as fixed bias circuit

For fixed bias circuit the drain current I_D can be calculated by eqn

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

The drain to source voltage of o/p circuit can be determined by applying KVL

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

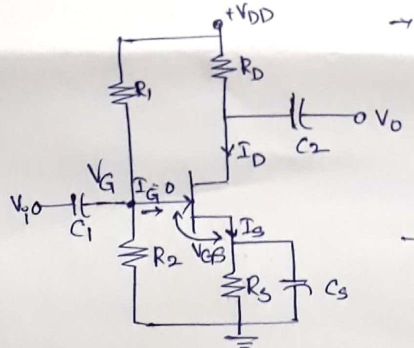
$$V_{DS} = V_{DD} - I_D R_D$$

The Q-point of the JFET amplifier with fixed bias circuit is given by (20)

$$I_{DQ} = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$V_{DSQ} = V_{DD} - I_{DQ} R_D.$$

→ **Voltage divider bias circuit :-**



→ The voltage at the source of the JFET must be more positive than the voltage at the gate in order to keep the gate-source junction reverse-biased.

→ The source voltage is

$$V_S = I_D R_S$$

→ The gate voltage is set by resistors R_1 and R_2 as expressed by using voltage divider formula.

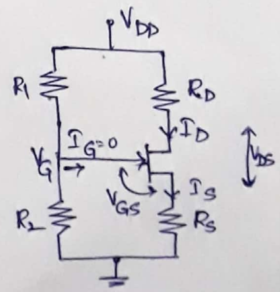
$$V_G = \left(\frac{R_2}{R_1 + R_2}\right) V_{DD}$$

D.C Analysis:- Applying KVL to i/p circuit

$$V_G - V_{GS} - V_S = 0$$

$$V_{GS} = V_G - V_S$$

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



Applying KVL to o/p circuit

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

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

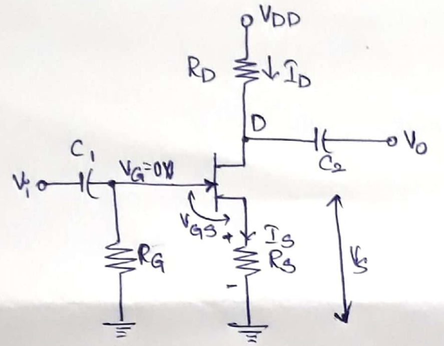
$$V_{DS} = V_{DD} - I_D (R_D + R_S).$$

The Q-point of a JFET amplifier using voltage divider is given by

$$I_{DQ} = I_{DSS} \left[1 - \frac{V_{GS}}{V_P}\right]^2$$

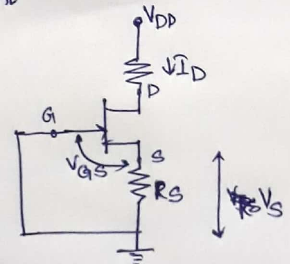
$$V_{DSQ} = V_{DD} - I_D (R_D + R_S)$$

<u>Self-Bias circuit</u> :- Self bias is the most common type of JFET bias. The gate resistor R_G does not affect the bias because it has essentially no voltage drop across it. and therefore gate remains at 0V. The voltage drop across. resistor R_S makes gate source junction reverse biased.



(21)

For DC analysis we can replace coupling analysis by open circuits and can be replaced by short circuit equivalent.



apply KVL to gate circuit

$$V_{GS} + V_{RS} = 0$$

$$V_{GS} = -V_{RS}$$

$$V_{GS} = -I_S R_S \qquad (\because I_S = I_D)$$

$$\boxed{V_{GS} = -I_D R_S}$$

The relation b/w I_D and V_{GS} is $I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$

Substitute V_{GS} in I_D

$$I_D = I_{DSS}\left[1 - \frac{-I_D R_S}{V_P}\right]^2$$

$$I_D = I_{DSS}\left[1 + \frac{I_D R_S}{V_P}\right]^2$$

(22)

Apply KVL to output circuit

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

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

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

$$= V_{DD} - I_D(R_D + R_S)$$

$$V_{DS} = V_{DD} - I_D(R_S + R_D)$$

Module - II

Small Signal Analysis of BJT

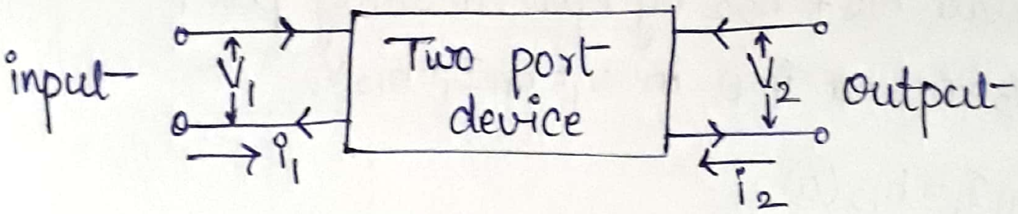
The term small signal amplifier refers that the signal will take a small percentage of an amplifiers operational range. With this small input signals the transistor can be replaced with small signal linear model. This is also called small signal equivalent circuit. By using these circuits, the analysis of transistors is easy.

(1)

Two port devices and hybrid parameters:-

A two port network is a electrical network or device with two pairs of terminals to connect to external circuits.

→ let us consider a transistor amplifier as two port device.



As we know that transistor is a current operated device, the input current is independent variable.

V_1 and I_2 are dependent variables

I_1 and V_2 are independent variables

→ There are different types of Two port parameters. They are

(i) Z-parameters

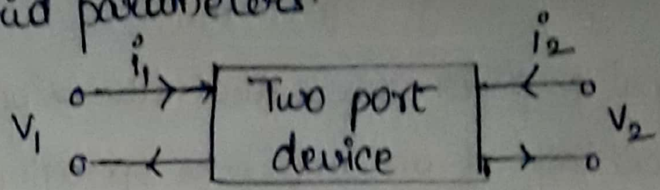
(ii) Y-parameters

(iii) H-parameters

(iv) g-parameters

(v) ABCD parameters or T-parameters.

Hybrid parameters :- h-parameters are also known as hybrid parameters.



From the figure we can write as

$$V_1 = f(I_1, V_2)$$

2

$$I_2 = f(I_1, V_2)$$

$$V_1 = h_{11} I_1 + h_{12} V_2 \rightarrow (1)$$

$$I_2 = h_{21} I_1 + h_{22} V_2 \rightarrow (2)$$

h_{11}, h_{12}, h_{21} and h_{22} are called as hybrid parameters because they do not have any dimension (h_{12} & h_{21}). The units of h_{11} and h_{22} are ohm and mho respectively.

We can calculate h_{11} & h_{21} by short circuiting port 2.

we can calculate h_{12} & h_{22} by open circuiting port 1.

Substitute $V_2 = 0$ and $i_1 = 0$ in $V_1 = h_{11} I_1 + h_{12} V_2$

$V_2 = 0 \rightarrow V_1 = h_{11} I_1 + h_{12}(0)$

$$V_1 = h_{11} I_1$$

$$\boxed{h_{11} = \frac{V_1}{I_1}}$$ (input resistance with output short circuted).

$i_1 = 0 \rightarrow V_1 = h_{11}(0) + h_{12} V_2$

$$V_1 = h_{12} V_2$$

$$\boxed{h_{12} = \frac{V_1}{V_2}}$$ (Reverse voltage gain).

Substitute $V_2 = 0$ and $i_1 = 0$ in $I_2 = h_{21} I_1 + h_{22} V_2$.

$V_2 = 0 \rightarrow I_2 = h_{21} I_1 + h_{22}(0)$

$$I_2 = h_{21} I_1$$

$$\boxed{h_{21} = \frac{I_2}{I_1}}$$ (Forward current gain)

$\underline{i_1 = 0} \rightarrow I_2 = h_{21}(0) + h_{22} V_2$

$I_2 = h_{22} V_2$

$\boxed{h_{22} = \frac{I_2}{V_2}}$ (output admittance with input open-circuited).

The standard notations can be given as

i = Input
f = Forward transfer
r = Reverse transfer
o = Output

(3)

For different parameters the standard h-parameters are

Parameter	CB	CE	CC	
input (i)	hib	hie	hic	→ h_{11}
Forward (f)	hfb	hfe	hfc	→ h_{21}
Reverse (r)	hrb	hre	hrc	→ h_{12}.
Output (o)	hob	hoe	hoc	→ h_{22}.

Benefits of h-parameters:-

(1.) Easy to measure
(2) convenient to use in circuit analysis and design
(3) Most of the manufacturers specify h-parameters.

H-parameter representation of a transistor:- (or) approximation model:-

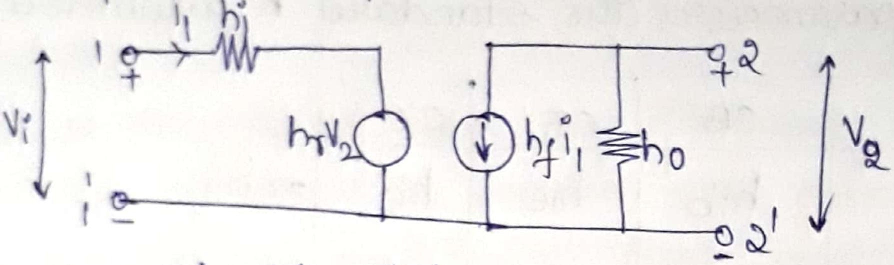
Based on hybrid parameters, the h-parameter representation of a transistor is drawn from the eqns

$$V_1 = h_{11} I_1 + h_{12} V_2$$
$$I_2 = h_{21} I_1 + h_{22} V_2$$

By using standard notations the Equations are written as

$$V_1 = h_i I_1 + h_r V_2$$
$$i_2 = h_f i_1 + h_o V_2.$$

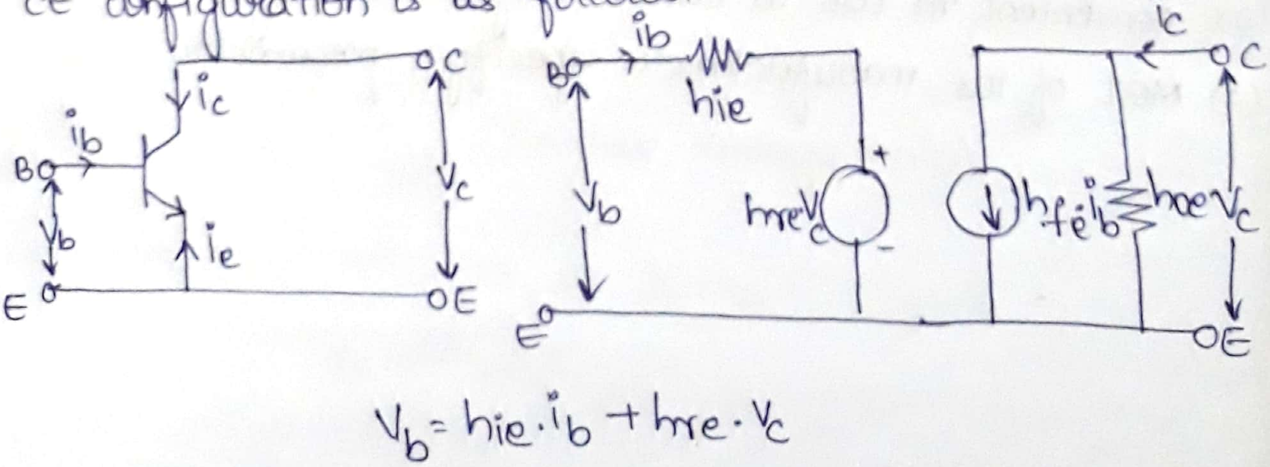
The h-parameter representation of a transistor is (4)



This model should satisfy these two equations and Verified by writing Kirchoff's Voltage law eqn in the input loop and Kirchoff's current law eqn for output node. In the circuit the i/p circuit has a depedent Voltage generator and the output circuit contains a dependent current generator.

The transistor configurations are CE, CB and CC.

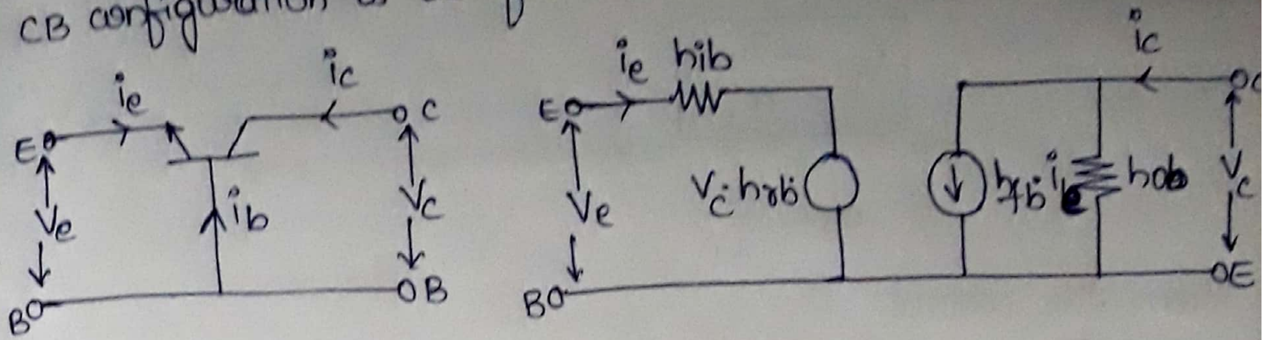
CE configuration:- The h-parameter representation of CE configuration is as follows.



$$V_b = h_{ie} \cdot i_b + h_{re} \cdot V_c$$

$$i_c = h_{fe} \cdot i_b + h_{oe} \cdot V_c$$

CB configuration:- The h-parameter representation of CB configuration is as follows.

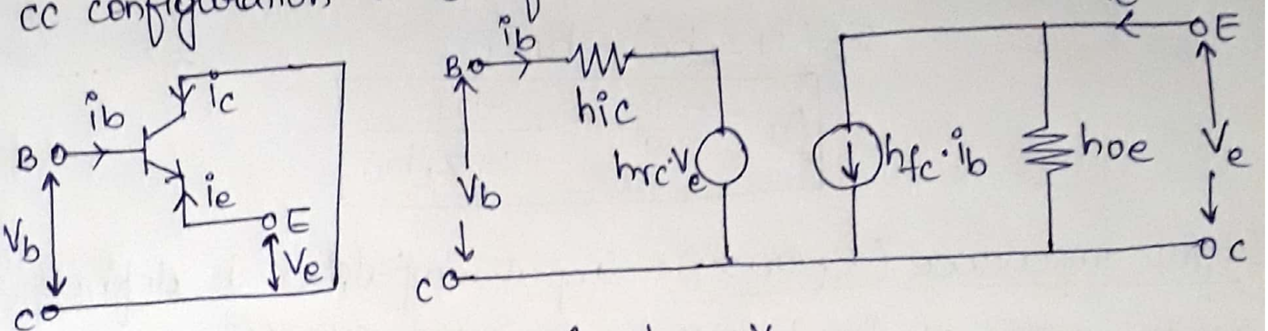


$$V_e = h_{ib} \cdot i_e + h_{rb} \cdot V_c$$

$$i_c = h_{fb} \cdot i_e + h_{ob} \cdot V_c$$

(5)

CC configuration:- The h-parameter representation of CC configuration is as follows.

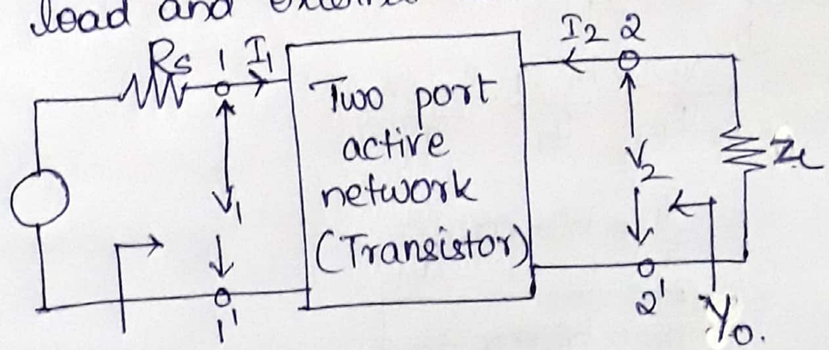


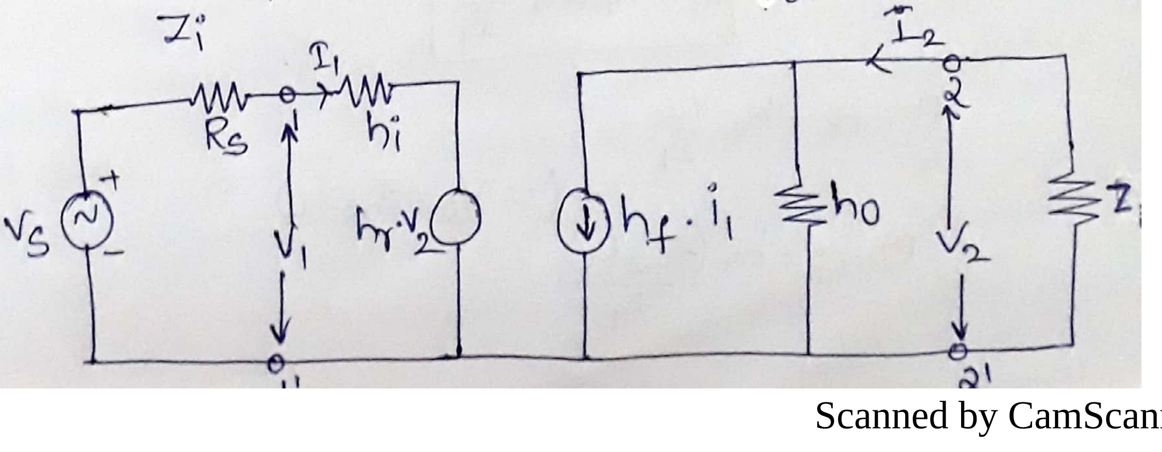
$$V_b = h_{ic} \cdot i_b + h_{rc} \cdot V_e$$

$$i_e = h_{fc} \cdot i_b + h_{oe} \cdot V_e$$

Analysis of single stage Amplifier :-

A transistor amplifier can be constructed by connecting an external load and external source.





Current gain (A_I):- Current gain is defined as the ratio of output current to the input current.

$$\boxed{A_I = \frac{-I_2}{I_1}}$$

$$A_I = \frac{I_L}{I_1}$$

From the circuit

$$I_2 = h_f I_1 + h_o V_2 \qquad (\because V_2 = I_L Z_L)$$

$$I_2 = h_f I_1 + h_o(-I_2 Z_L) \qquad V_2 = -I_2 Z_L$$

$$I_2 = h_f I_1 - I_2 Z_L h_o$$

$$I_2 + I_2 Z_L h_o = h_f I_1$$

(6)

$$I_2(1 + Z_L h_o) = h_f I_1$$

$$\boxed{A_I = \frac{-I_2}{I_1} = \frac{-h_f}{1+Z_L h_o}}$$

Input impedance (R_i or Z_i):- Input impedance is defined as the ratio of input voltage to input current.

$$\boxed{R_i = \frac{V_1}{I_1}}$$

From the circuit

$$V_1 = h_i I_1 + h_r \cdot V_2$$

dividing with I_1

$$\frac{V_1}{I_1} = \frac{h_i I_1}{I_1} + \frac{h_r \cdot V_2}{I_1}$$

$$\frac{V_1}{I_1} = h_i + h_r \frac{V_2}{I_1}$$

$$\boxed{R_i = h_i + h_r \frac{V_2}{I_1}}$$

$$R_i - h_i = h_r \frac{V_2}{I_1}$$

$$(\because V_2 = -I_2 Z_L)$$

$$R_i - h_i = h_r \frac{(-I_2 R_L)}{I_1}$$

$$R_i = \frac{h_r - I_2 R_L}{I_1} + h_i \qquad \left(\because A_I = \frac{-I_2}{I_1}\right)$$

$$\boxed{R_i = h_r A_I R_L + h_i}$$

~~RTF~~ Substitute Value of A_I

$$R_i = h_i + \frac{(-h_r R_L h_f)}{1+h_o R_L}$$

$$\boxed{R_i = h_i - \frac{h_r h_f R_L}{1+h_o R_L}}$$

(7)

<u>Voltage gain (A_V)</u>:- Voltage gain is defined as the ratio of output voltage to input voltage.

$$A_V = \frac{V_2}{V_1} \qquad (\because V_2 = I_L R_L = -I_2 R_L)$$

$$= \frac{I_L R_L}{V_1}$$

$$= \frac{-I_2 R_L}{V_1} \qquad (\because -I_2 = A_I I_1)$$

$$= \frac{A_I I_1 R_L}{V_1} \qquad \left(\because \frac{V_1}{I_1} = R_i, \ \frac{I_1}{V_1} = \frac{1}{R_i}\right)$$

$$= \frac{A_I \cdot R_L}{R_i}$$

$$= \left(\frac{-h_f}{1+h_o R_L}\right) \cdot R_L \cdot \left(\frac{1}{h_i - \frac{h_r h_f R_L}{1+h_o R_L}}\right)$$

$$= \frac{-h_f}{1+h_o R_L} \cdot R_L \cdot \left(\frac{1+h_o R_L}{h_i + h_i h_o R_L - h_f h_r R_L}\right)$$

$$\boxed{A_V = \left(\frac{-h_f \cdot R_L}{h_i + h_i h_o R_L - h_f h_r R_L}\right)}$$

<u>Output admittance (Y_o)</u>:- Output admittance is defined as the ratio of output current to output voltage.

$$\boxed{Y_o = \frac{I_2}{V_2}}$$

From the circuit

$$I_2 = h_f I_1 + h_o V_2$$

Divide with V_2.

$$\frac{I_2}{V_2} = \frac{h_f I_1}{V_2} + \frac{h_o V_2}{V_2}$$

$$Y_o = h_f \frac{I_1}{V_2} + h_o.$$

with $V_s = 0$, apply KVL to i/p circuit

$$R_s I_1 + h_i I_1 + h_r V_2 = 0$$

$$I_1 (R_s + h_i) + h_r V_2 = 0$$

$$\frac{I_1}{V_2} = \frac{-h_r}{R_s + h_i}$$

8

$$Y_o = h_f \left[\frac{-h_r}{R_s + h_i}\right] + h_o$$

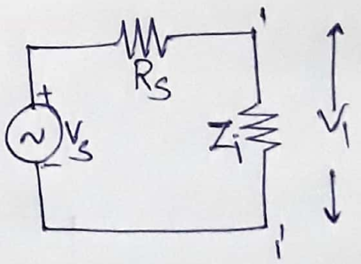
$$\boxed{Y_o = h_o - \frac{h_f h_r}{R_s + h_i}}$$

Voltage amplification (A_{vs}):- The Overall Voltage gain A_{vs} is given as

$$A_{vs} = \frac{V_2}{V_s} = \frac{V_2 V_1}{V_1 V_s} = A_V \frac{V_1}{V_s}$$

From equivalent circuit using Thevenin's equivalent for i/p is

$$V_1 = \frac{V_s Z_i}{Z_i + R_s}$$



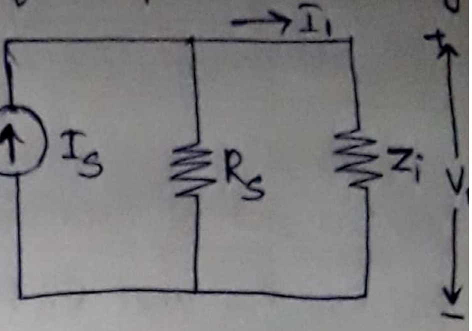
$$\frac{V_1}{V_s} = \frac{Z_i}{Z_i + R_s}$$

Then $$A_{vs} = \frac{A_V Z_i}{Z_i + R_s}$$

substituting $A_V = \frac{A_I Z_L}{Z_i}$

$$\boxed{A_{vs} = \frac{A_I Z_L}{Z_i + R_s}}$$

Current amplification (A_{IS}):- The modified input circuit using Norton's equivalent circuit is



Overall current gain

$$A_{IS} = \frac{-I_2}{I_S}$$

$$= \frac{-I_2}{I_1} \cdot \frac{I_1}{I_S}$$

$$= A_I \frac{I_1}{I_S}$$

From figure

$$I_1 = I_S \cdot \frac{R_S}{R_S + Z_i}$$

$$\frac{I_1}{I_S} = \frac{R_S}{R_S + Z_i}$$

$$A_{IS} = A_I \frac{R_S}{R_S + Z_i}$$

$$A_{VS} = \frac{A_I Z_L}{Z_i + R_S} \frac{R_S}{R_S}$$

$$\boxed{A_{VS} = \frac{A_{IS} Z_L}{R_S}}$$

(9)

Power gain (A_P):- The over all power gain is

$$A_P = \frac{P_2}{P_1}$$

$$= \frac{-V_2 I_2}{V_1 I_1}$$

$$= A_V A_I$$

$$= A_I A_I \frac{R_L}{R_i}$$

$$\boxed{A_P = (A_I)^2 \left(\frac{R_L}{R_i}\right)}$$

Analysis of single stage transistor amplifier (CE, CB, CC) using h-parameters:- (NOTES).

Comparision of transistor configurations in terms of A_i, R_i, A_v and R_o:-

10

	CE	CB	CC
A_i	$\frac{-h_{fe}}{1+h_{oe}R_L}$	$\frac{-h_{fb}}{1+h_{ob}R_L}$	$\frac{-h_{fc}}{1+h_{oc}R_L}$
R_i	$h_{ie}-\frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L}$	$h_{ib}-\frac{h_{fb}h_{rb}R_L}{1+h_{ob}R_L}$	$h_{ic}-\frac{h_{fc}h_{rc}R_L}{1+h_{oc}R_L}$
A_V	$\frac{-h_{fe}R_L}{h_{ie}+h_{oe}h_{ie}R_L-h_{fe}h_{re}R_L}$	$\frac{-h_{fb}R_L}{h_{ib}+h_{ob}h_{ib}R_L-h_{fb}h_{rb}R_L}$	$\frac{-h_{fc}R_L}{h_{ic}+h_{oc}h_{ic}R_L-h_{fc}h_{rc}R_L}$
R_o	$h_{oe}-\frac{h_{fe}h_{re}}{R_s+h_{ie}}$	$h_{ob}-\frac{h_{fb}h_{rb}}{R_s+h_{ib}}$	$h_{oc}-\frac{h_{fc}h_{rc}}{R_s+h_{ic}}$

CE:- * The input resistance (R_i) of a CE circuit is high because of small I_B. Therefore R_i for a CE circuit is much higher than that of CB circuit.

→ The Output resistance (R_o) of a CE circuit is smaller than that of CB circuit.

→ The current gain of CE circuit is large because I_c is much larger than I_B.

→ The voltage gain of CE circuit is larger than that of CB circuit.

Applications :-

→ CE amplifier is popular because it is well suited for Voltage amplification, especially at low frequencies.

→ CE amplifiers are also used in radio frequency transceiver circuits.
→ CE configuration is used commonly in low noise amplifiers.

CB :- The input resistance (Ri) of CB circuit is low, because I_E is high.
→ The output resistance (Ro) is high because of reverse voltage at the collector.
→ current gain is low ($\alpha < 1$) but voltage gain is high.

11

Applications :-
→ It is used in moving coil microphones pre amplifiers.
→ It is used in UHF and VHF, RF amplifiers.

CC :-
→ The input resistance (Ri) and output resistance (Ro) of CC circuit are high. ~~and low~~
→ There is no voltage gain ($A_V < 1$) in a CC circuit.

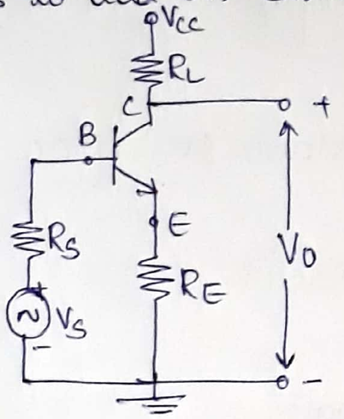
Applications :-
→ It is used in digital circuits with logic gates
→ It is also used for cascade amplifier circuit.
→ It is used as a switching circuit.

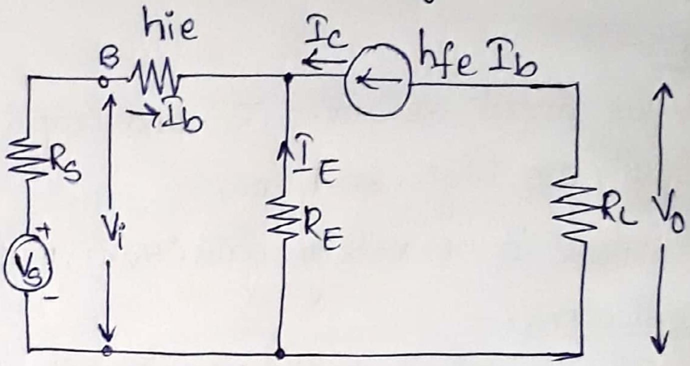
Parameters	CE	CB	CC
current gain (A_i)	High	low	High
Input resistance (Ri)	Medium	low	High
Voltage gain (A_V)	High	High	low
Output resistance (Ro)	Mediumhigh	High	low
Power gain	High	Moderate	low
Phase shift	180°	0°	0°.

Analysis of CE amplifier with Emitter resistance and Emitter follower:-

Analysis of CE amplifier with emitter resistance :-

The gain provided by the single stage amplifier is not sufficient, so cascading of amplifiers is necessary. In such cases voltage amplification should be stabilized at each stage, because instability in the first stage is amplified in the next stage and it is further amplified in the next. This is not desired. so, the simple and effective way to obtain voltage gain stabilization is to add an emitter resistance R_E to CE stage.





By adding Re in the circuit it leaves current gain unchanged, it increases the input impedance by $(1+h_{fe})R_e$, it increases the output impedance by $(1+h_{fe})R_e >> h_{fe}$, it stabilizes the voltage gain.

Current gain :- $A_I = \frac{-I_2}{I_1}$

$= \frac{-I_c}{I_b}$

$= \frac{-h_{fe} I_b}{I_b}$

$\boxed{A_I = -h_{fe}}$

12

Input resistance :- $R_i = \frac{V_1}{I_1} = \frac{V_i}{I_b}$

$= \frac{I_b h_{ie} + (1+h_{fe}) R_E I_b}{I_b}$

$$= \frac{I_b(h_{ie} + (1+h_{fe})R_E)}{I_b}$$

$$\boxed{R_i = h_{ie} + (1+h_{fe})R_E}$$

Voltage gain :- $A_V = \frac{A_I R_L}{R_i}$

$$= \frac{-h_{fe} R_L}{h_{ie} + (1+h_{fe})R_E}$$

If $(1+h_{fe})R_E >> h_{ie}$ and

$h_{fe} >> 1$, then

(13)

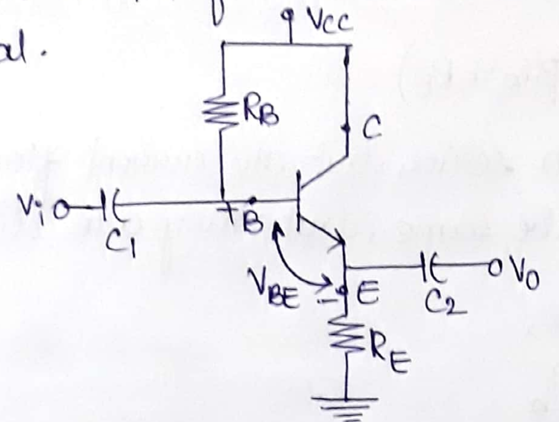
$$A_V = \frac{-h_{fe} R_L}{(1+h_{fe})R_E}$$

$$\boxed{A_V = -\frac{R_L}{R_E}}$$

Output Resistance :- Output resistance r_o with R_L excluded is infinite and with R_L included it is equal to R_L and is independent of R_E.

Analysis of CE amplifier with emitter follower :-

Generally in CE amplifier output is taken from collector, but in this emitter follower case, we take output across emitter terminal.



* The barrier potential is represented as V_{BE}. In case of Silicon transistor $V_{BE} = 0.7$, and for Germanium transistor $V_{BE} = 0.3$.

By applying Kirchoff's voltage law

$V_i - V_{BE} = V_o$ (i.e, The o/p is nearly equal to i/p).

if $V_i = 40V$

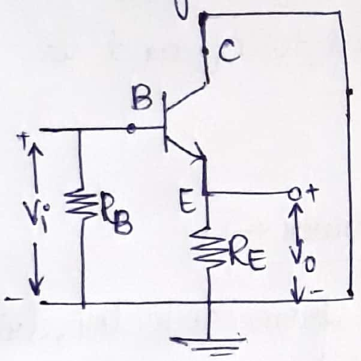
$$V_0 = 40 - 0.7 = 39.3V \text{ (for Si)}$$

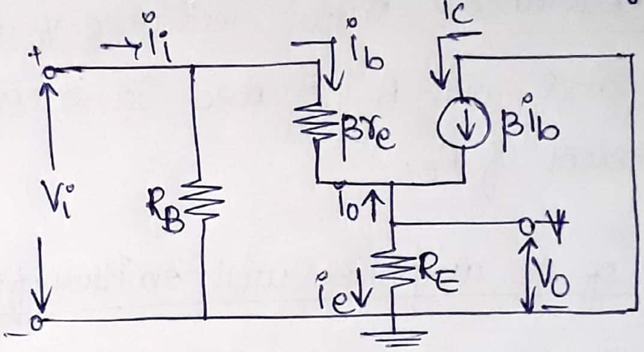
$$V_0 = 40 - 0.3 = 39.7V \text{ (for Ge)}$$

$$\therefore A_V = \frac{V_0}{V_i} = 1$$

When we take output from collector terminal, their is 180° phase shift, but when we take output from emitter follower configuration, the output voltage is in phase with the input voltage i.e., the input and output voltages attain their positive and Negative peaks at same time and are in-phase with each other. Because of this reason, we call this as emitter follower configuration.

→ This emitter follower is used for impedance matching and current gain.





Input impedance :- R_i

$$R_i = R_B \| (\beta r_e + R_E)$$

βr_e and R_E are connected in series, but the current flowing through the resistors should be same, but they are different.

To make the currents same,

$$i_e = (\beta+1) i_b$$

Voltage drop across R_E is $i_e R_E$

$$= (\beta+1) i_b \cdot R_E.$$

→ To make same current $\beta r_e + R_E$ we take $(\beta+1)R_E$ in place of R_E, so that current i_b passes through the resistor.

$R_i = R_B || (\beta r_e + (\beta+1) R_E)$ $\quad \because \beta+1 \simeq \beta$

$R_i = R_B || (\beta r_e + \beta R_E)$

$= R_B || \beta (r_e + R_E)$

R_E is larger than r_e (Dynamic emitter resistance)

$R_E >> r_e$

$R_i = R_B || \beta R_E$

$$\boxed{R_i = \frac{\beta R_B R_E}{R_B + \beta R_E}}$$

<u>Output impedance:-</u> $R_o = \frac{I_2}{V_2}$

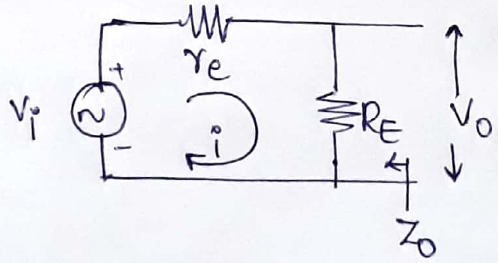
$i_b = \frac{V_i}{\beta r_e + \beta R_E}$, $i_e = (\beta+1) i_b$

$= \frac{(\beta+1) V_i}{\beta r_e + \beta R_E}$

$= \frac{\beta V_i}{\beta (r_e + R_E)}$

$i_e = \frac{V_i}{r_e + R_E}$.

From the eqn i_e, we can draw a circuit



$R_o = r_e || R_E$

$= \frac{r_e R_E}{r_e + R_E}$ $\quad (\because R_E >> r_e)$

$= \frac{r_e R_E}{R_E}$

$$\boxed{R_o \simeq r_e}$$

Voltage gain :- $A_v = \frac{V_o}{V_i}$

$V_o = i_e R_E$ (from circuit)

$$V_o = \frac{V_i \times R_E}{r_e + R_E}$$

$$A_v = \frac{V_o}{V_i} = \frac{R_E}{r_e + R_E}$$

$$A_v = \frac{R_E}{r_e + R_E}$$

$R_E >> r_e$

$$A_v = \frac{R_E}{R_E}$$

$$\boxed{A_v \simeq 1}$$

16

Current gain :- $A_I = \frac{I_2}{I_1} = \frac{i_e}{i_b}$

$i_e = i_c + i_b$. $\quad (\because i_c = \beta i_b)$

$i_e = \beta i_b + i_b$

$i_e = (\beta + 1) i_b$

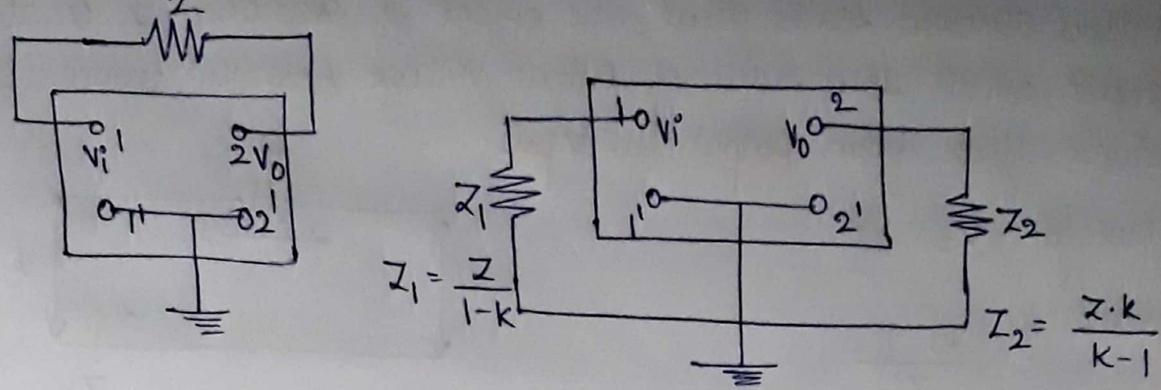
$$\frac{i_e}{i_b} = \frac{(\beta+1) i_b}{i_b}$$

$$\frac{i_e}{i_b} = (1+\beta)$$

$$\boxed{A_I = \beta.}$$

Millers Theorem and its dual :-

Miller's theorem is used for converting one circuit of one configuration to another configuration.



Z is the impedance connected between two nodes node 1 and node 2, it can be replaced by two seperate impedances Z_1 and Z_2. Z_1 is connected between node 1 and ground. Z_2 is connected between node 2 and ground. V_i and V_o are the voltages of node 1 and node 2. The values of Z_1 and Z_2 can be derived from the ratio of V_o and V_i

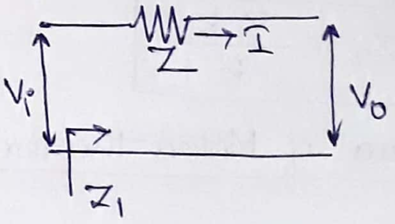
(17)

$\frac{V_o}{V_i}$ is denoted as k.

The values of impedances Z_1 and Z_2 are $Z_1 = \frac{Z}{1-K}$ and $Z_2 = \frac{Z \cdot k}{K-1}$

Proof :- Miller's theorem states that, the effect of resistance Z on the input circuit is a ratio of input voltage V_i to the current I which flows from input to output.

Therefore $Z_1 = \frac{V_i}{I}$



where $I = \frac{V_i - V_o}{Z}$

$$= \frac{V_i\left[1 - \frac{V_o}{V_i}\right]}{Z} \qquad \left(\because A_V = \frac{V_o}{V_i} = k\right)$$

$$I = \frac{V_i\left[1 - A_V\right]}{Z}$$

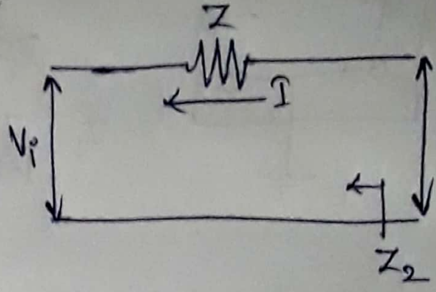
$$Z_1 = \frac{V_i}{\frac{V_i\left[1 - A_V\right]}{Z}}$$

$$Z_1 = \frac{Z}{1 - A_V}$$

$$\boxed{Z_1 = \frac{Z}{1-k}.}$$

Millers theorem states that, the effect of resistance Z on the output circuit is a ratio of output voltage V_0 to the current I which flows from output to input.

Therefore $Z_2 = \frac{V_0}{I}$



where $I = \frac{V_0 - V_i}{Z}$

$= \frac{V_0\left[1 - \frac{V_i}{V_0}\right]}{Z}$ $\quad \left(\because \frac{V_0}{V_i} = A_V \text{ \& } \frac{V_i}{V_0} = \frac{1}{A_V}\right)$

$= \frac{V_0\left[1 - \frac{1}{A_V}\right]}{Z}$

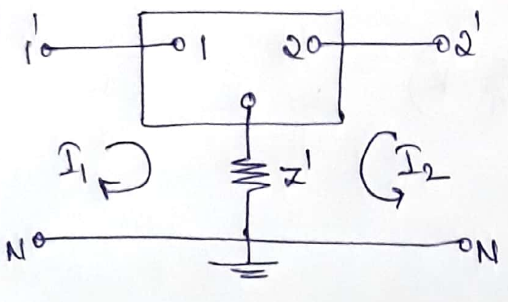
$I = \frac{V_0\left[\frac{A_V - 1}{A_V}\right]}{Z}$

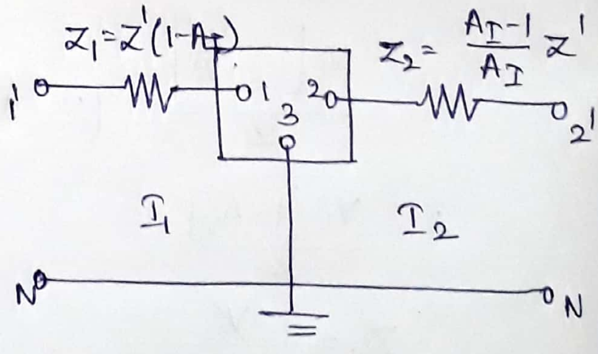
$Z_2 = \frac{V_0}{\frac{V_0\left[\frac{A_V-1}{A_V}\right]}{Z}}$

$= \frac{Z A_V}{A_V - 1}$

$$\boxed{Z_2 = \frac{Z \cdot k}{k-1}}$$

Dual of Miller's theorem :-





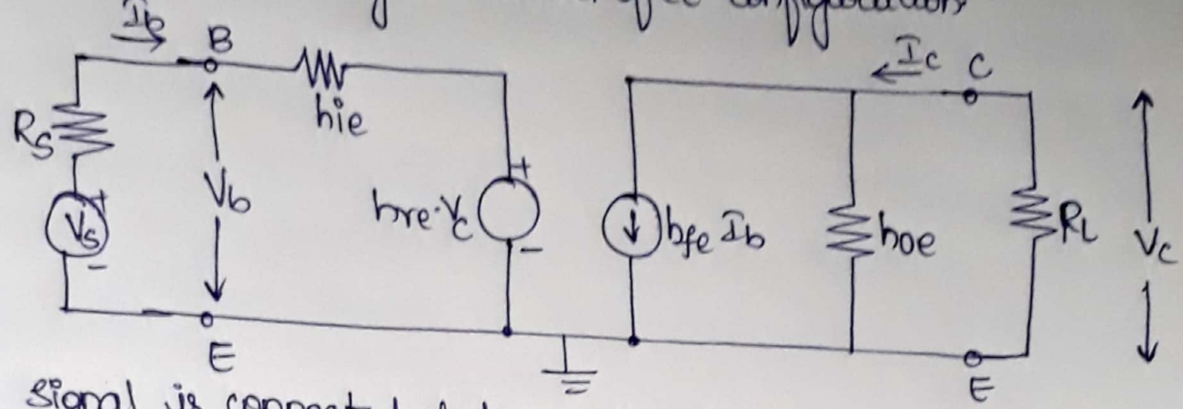
Z' is the impedance between node 3 and ground N. According to dual of Miller's theorem Z' can be split into Z_1 and Z_2 such that Z_1 is placed in mesh 1 and Z_2 can be placed in mesh 2, and node 3 is grounded. A_I is the current ratio and is given by

$$A_I = \frac{-I_2}{I_1}$$

Advantage:– using Miller's theorem, complex circuits can be easily simplified.

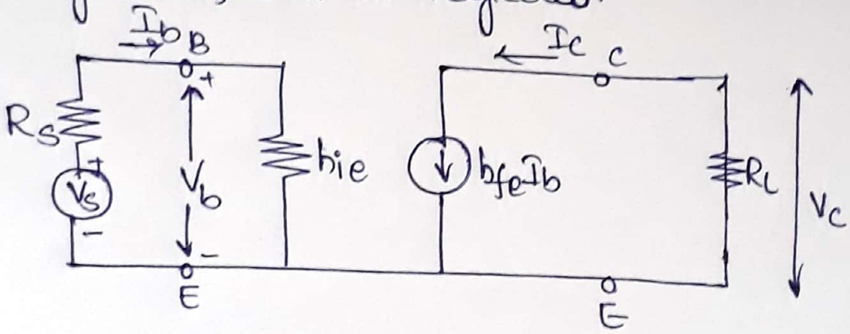
Simplified h-parameter model :–

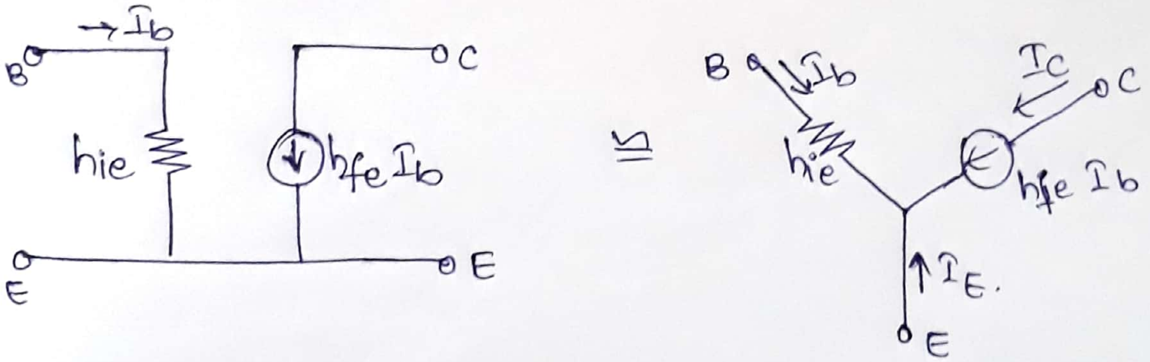
let us consider the hybrid model of CE configuration



The signal is connected between the input terminal and ground, and load is placed between the output terminal and ground.

hoe is very small, so it is neglected.





Source resistance is connected b/w i/p and ground, where as load resistance is connected b/w o/p and ground.

→ The simplified hybrid circuit of CE circuit may be used for CC and CB circuit by simply grounding the appropriate terminal.

MODULE - III

SINGLE STAGE AMPLIFIERS

Single stage Amplifiers :- In an amplifier circuit only one transistor is used for amplifying a weak signal, this type of circuit is known as single stage amplifier. If the power or voltage gain of a single stage amplifier is not sufficient, then we use more than one stage of amplification. Such an amplifier is called a multistage amplifier.

Classification of Amplifiers :-

A circuit that increases the amplitude of the given input signal is an amplifier. A small ac signal fed to the amplifier is obtained as a larger ac signal of same frequency at the output. In discrete circuits, BJT and FET are commonly used as amplifying elements. Depending on the nature and level of amplification and the impedance matching requirements, different types of amplifiers can be considered. They are :-

(1) Based on transistor configurations
- (a) common - emitter (CE) amplifier
- (b) common - collector (CC) amplifier
- (c) common - Base (CB) amplifier.

(2) Based on active device
- (a) BJT Amplifier
- (b) FET Amplifier.

(3) Based on the Q-point
- (a) class A amplifier
- (b) class B amplifier
- (c) class AB amplifier
- (d) class C amplifier.

(4) Based on number of stages
(a) Single-stage amplifier
(b) Multi-stage amplifier

(5) Based on the Output
(a) Voltage amplifier
(b) power amplifier

(6) Based on the frequency response
(a) Audio frequency (AF) amplifier (20Hz - 20KHz)
(b) Intermediate frequency (IF) amplifier (
(c) Radio frequency (RF) amplifier. (3KHz - 300 GHz)

(7) Based on bandwidth
(a) Narrow-band amplifier (RF amplifier) short distances
(b) Wide-band amplifier (video amplifier). longer distances

Distortion in Amplifiers :-

An amplifier should produce an output waveform which does not differ from the input signal waveform in any aspect except amplitude. i.e., the output is an amplified signal of the input. But in practise, it is highly impossible to construct an ideal amplifier whose output waveform is an exact replica of the input signal waveform because of non-linearity of the characteristic of an active device. The output differs from the input either in its waveform or frequency content. The difference between the output waveform and the input waveform is an called distortion.

Harmonic distortion (or) Amplitude distortion :- Harmonic distortion is seen by the non-linear active device. In this type of distortion, the new frequencies are produced in the output, which are not present in the input signal. This is also known as non-linear distortion.

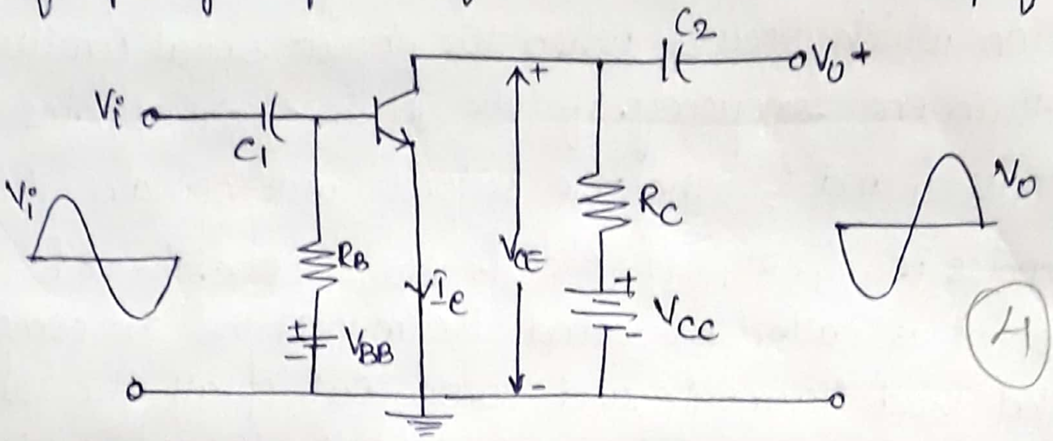
The intermodulation distortion is also a type of non-linear distortion which occurs when the input signal consists of more than one frequency. If the input signal contains two frequencies f_1 and f_2, then the output will contain their harmonics i.e., f_1, $2f_1$, $3f_1$ etc f_2, $2f_2$, $3f_2$ etc. The 2f component is called ~~as~~ second harmonic, the 3f component is called third harmonic, and so on. Out of all the harmonic components, the second harmonic has the largest amplitude.

Frequency distortion :- This type of distortion exists when the signal components of different frequencies are amplified differently. This distortion may be caused by the internal device capacitances, (or) it may arise because of the associated circuit. A plot of gain (magnitude) Vs frequency of an amplifier is called the frequency response of an amplifier. If this plot is not a horizontal straight line over the range of frequencies, the circuit is said to exhibit frequency distortion over the range.

(3)

Delay distortion (or) phase distortion :- In this type of distortion, the phase shift between input and output waveforms depends upon the signals of different frequencies. when this distortion exists the phase angle of the gain A depends upon the frequency. If the phase shift varies with frequency, different frequency components of the signal are delayed by different amounts of time and hence a television picture is smeared.

Low frequency response of common emmitter amplifiers:-



The circuit is a single stage CE amplifier using a NPN transistor. The emitter-base junction is forward biased by the power supply V_{BB}, and the collector-base junction is reverse biased by the power supply V_{CC}, so that the transistor remains in active region throughout its operation. The quiescent point (Q) is determined by V_{CC}, R_B and R_C. The input signal is applied to the base-emitter circuit and the amplified output signal is taken from collector-emitter circuit. C_1 and C_2 are coupling capacitors to provide dc isolation at the input and output of the amplifier.

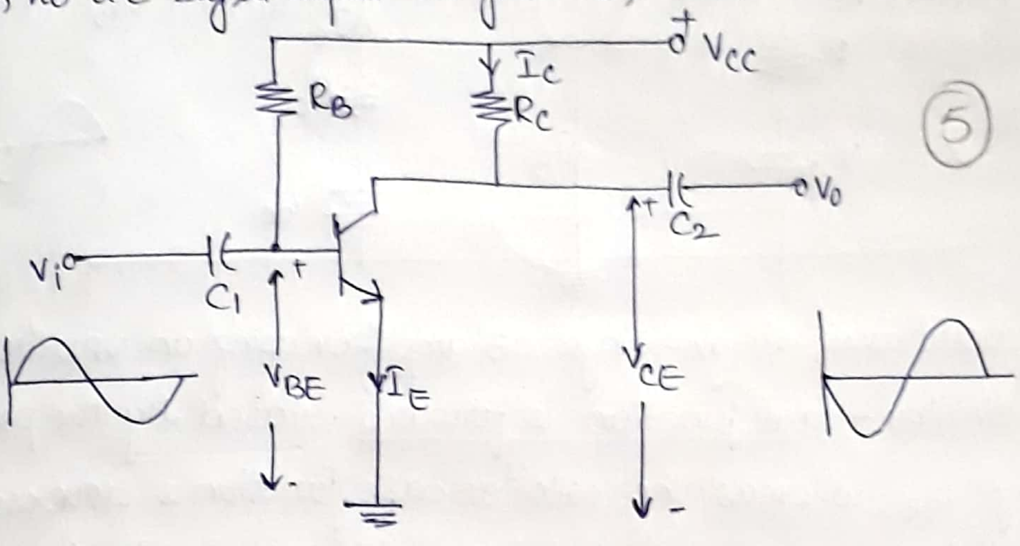
→ The resistances R_B, R_C and R_E forms the voltage divider biasing circuit. It sets the proper operating point for CE amplifier.

→ Input capacitor couples the signal to the base of the transistor. It blocks any d.c component present in the signal and passes only a.c signal for amplification. Because of this, biasing conditions are maintained constant.

→ Bypass capacitor C_E is connected in parallel with the emitter resistance, R_E to provide a low reactance path to the amplified a.c signal. If it is not inserted, the amplified a.c signal passing through R_E will cause a voltage drop across it. This reduces the output voltage, reducing the gain of the amplifier.

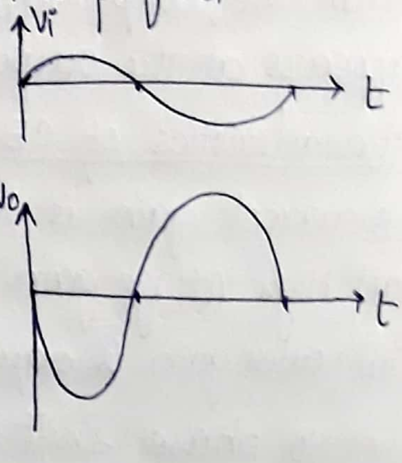
→ The coupling capacitor C_2 couples the output of the amplifier, to the next stage of the amplifier.

when no a.c signal input is given i.e., under d.c conditions



$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad , \quad V_{CE} = V_{CC} - I_C R_C$$

when a sinusoidal ac input signal is applied at the ~~output~~ input terminals of the circuit, during the positive half cycle, the forward bias of the base-emitter junction V_{BE} is increased, resulting in an increase in I_B. The collector I_C is increased by β times the increase in I_B. From V_{CE}, the output voltage gets decreased. Thus in a CE amplifier, a positive going input signal is converted into a negative-going output signal i.e., a phase shift is introduced between the output and input signal and further amplified.



Characteristics of CE amplifier :-

(i) large current gain (A_I)

(ii) large voltage gain (A_V)

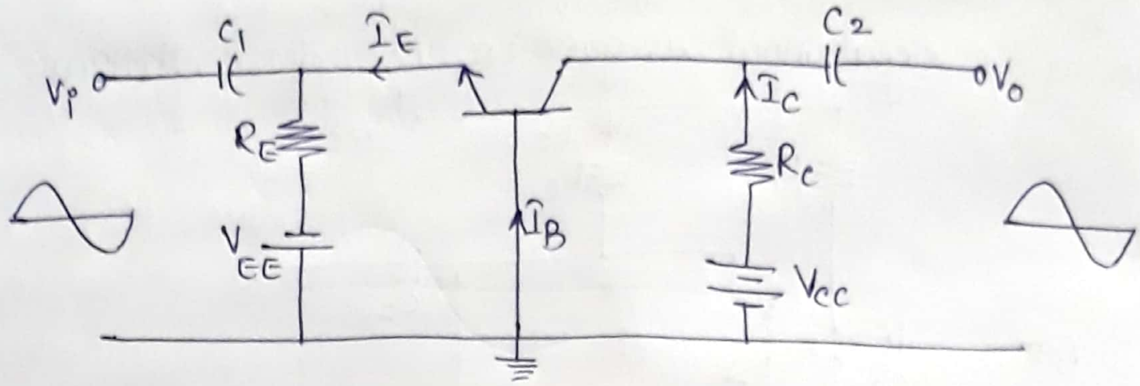
(iii) large power gain (A_P)

(iv) voltage phase shift of 180°

(v) Moderate input impedance.

(vi) Moderate output impedance.

Low frequency response of common Base amplifiers:-



The circuit is a single-stage CB amplifier using an NPN transistor. The emitter-base junction is forward biased by the power supply V_{EE}, whereas the collector-base junction is reverse biased by V_{CC}, so that the transistor remains in the active region throughout its operation. The input signal is applied to the emitter-base circuit, and the output signal is taken from collector-base circuit.

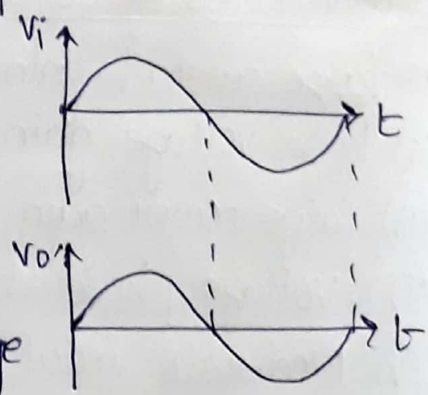
(6)

The output voltage is given by the eqn

$$V_O = V_{CB} = V_{CC} - I_C R_C$$

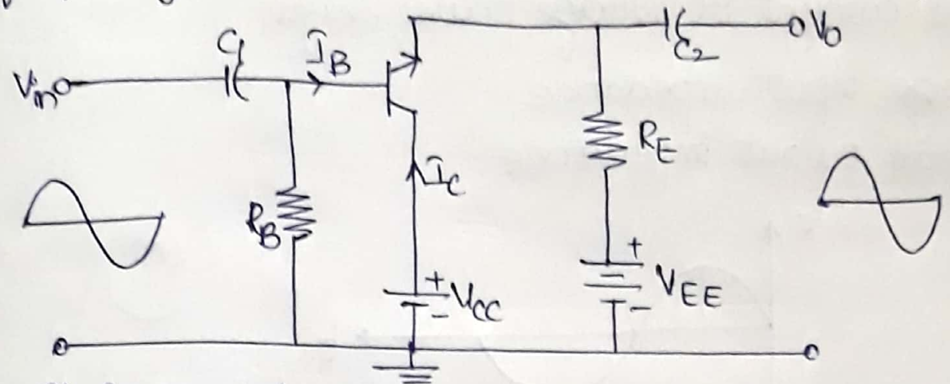
When a sinusoidal ac signal is applied at the input, during the positive half cycle of the applied signal, the amount of forward bias to bias-emitter junction is decreased, resulting in a decrease in I_B. As a result I_C also decreases. From the voltage drop $I_C R_C$ decreases. Thus, a positive half cycle appears at the output without any phase reversal.

Characteristics of CB amplifier:-



(i) current gain is less than unity
(ii) High voltage gain.
(iii) power gain is equal to voltage gain
(iv) No phase shift for current or voltage
(v) Small input impedance
(vi) large output impedance.

low frequency response of common collector amplifiers:-



The circuit is a single stage CC amplifier using an NPN transistor. The emitter-base junction is forward biased by the power supply V_{EE}, and the collector-base junction is reverse biased by V_{CC}, so that the transistor remains in the active region throughout its operation. The input signal is given to the base-collector circuit and the output signal is taken from the emitter-collector circuit.

Output voltage

$$V_0 = I_E R_E$$

$$V_0 = \beta I_B R_E \qquad \left(\beta = \frac{I_E}{I_B}\right)$$

When a sinusoidal ac signal is applied at the input, during the positive half cycle of the signal applied, the base potential V_B increases, thereby increasing the base current I_B. Hence, emitter current $I_E = I_C + I_B$ increases and voltage drop across R_E i.e., output voltage increases. Thus a positive going input signal results in a positive-going output signal. Hence in a CC amplifier, input and output signals are in phase with each other and voltage gain is approximately unity. As, the output signal taken at the emitter terminal almost follows the input signal, the CC amplifier is called as emitter follower.

Characteristics of CC amplifier:-

(i) High current gain

(ii) Voltage gain is approximately unity

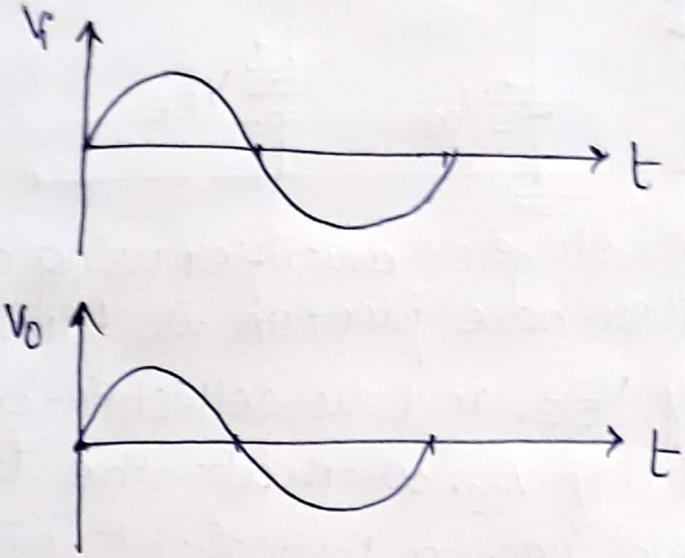
(iii) power gain is equal to current gain

(iv) No current or voltage phase shifts

(v) large input impedance

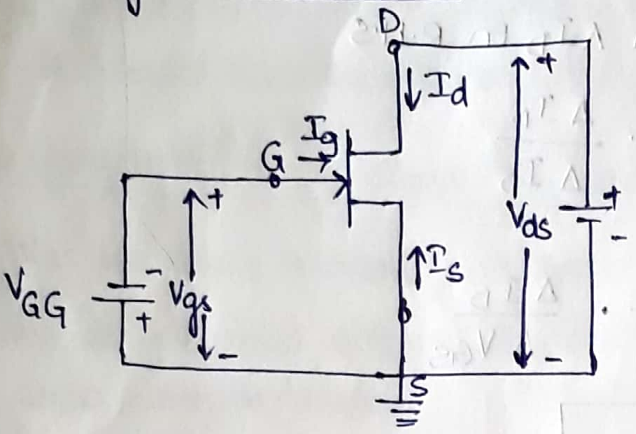
(vi) Small output impedance

(8)



MODULE - III : SINGLE STAGE AMPLIFIERS (B).

Small Signal JFET model :-



(1)

There are three important parameters of JFET. They are

(i) Drain Resistance :- Drain resistance is offered by the drain terminal. It is the ratio of change in drain to source voltage to the change in drain current at a constant gate to source voltage

$$r_{ds} = \frac{\Delta V_{DS}}{\Delta I_D}\Bigg|_{V_{GS} = \text{constant}}$$

(ii) Mutual conductance (or) Transconductance [gm] :- Transconductance is the ratio of change in drain current to change in gate to source voltage at a constant drain to source voltage.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}\Bigg|_{V_{DS} = \text{constant}}$$

it has a units of mA/V or m℧ (or) milli Simen.

(iii) Amplification factor :- The amplification factor is defined as the ratio of change of drain voltage to the change in gate to source voltage

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}\Bigg|_{I_D = \text{constant}}$$

(or)

$$\mu = r_d \cdot g_m$$

$$= \frac{\Delta V_{DS}}{\Delta I_D} \cdot \frac{\Delta I_D}{\Delta G_S}$$

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

Relation between three parameters :-

We know that $\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$

Multiply and Divide with ΔI_D on R.H.S

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

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

$$\boxed{\mu = r_{ds} \cdot g_m}$$

* The drain current I_d is the function of V_{GS} and V_{DS}. If both gate and drain voltages are varied, change in drain current is given as

$$\Delta I_d = \frac{\Delta I_D}{\Delta V_{GS}} \cdot \Delta V_{GS} + \frac{\Delta I_D}{\Delta V_{DS}} \cdot \Delta V_{DS}$$

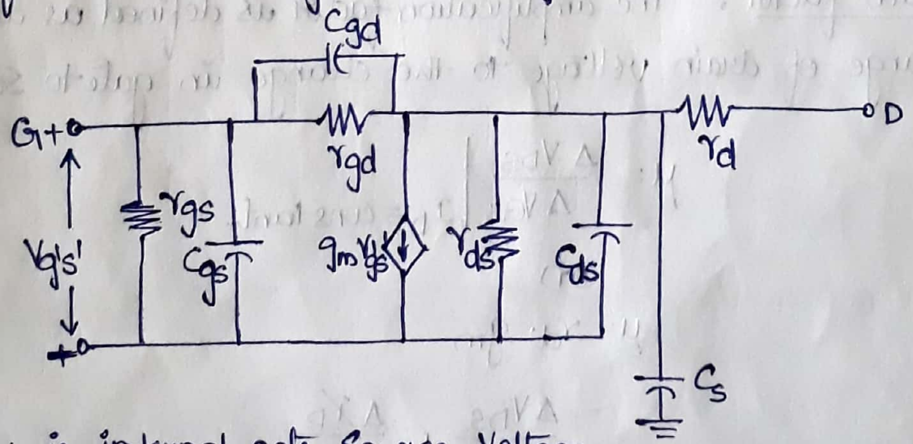
in Small signal notation $\Delta I_d = i_d$, $\Delta V_{GS} = V_{gs}$, $\Delta V_{DS} = V_{ds}$ (2)

$$i_d = g_m \cdot V_{gs} + \frac{1}{r_{ds}} \cdot V_{ds}$$

Therefore

$\underset{(o/p)}{I_d} = g_m \cdot \underset{(i/p)}{V_{gs}}$, whereas in BJT it is $\underset{(o/p)}{I_C} = \beta \cdot \underset{(i/p)}{I_B}$

Therefore the small signal model is given as



Vg's' is internal gate-Source Voltage

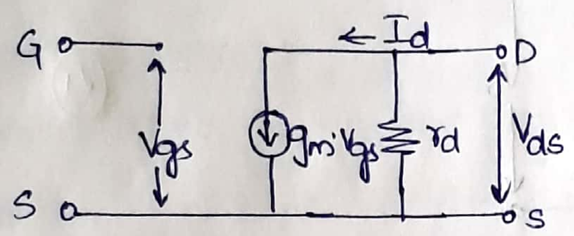
rgs is Diffusion resistance of gate to Source

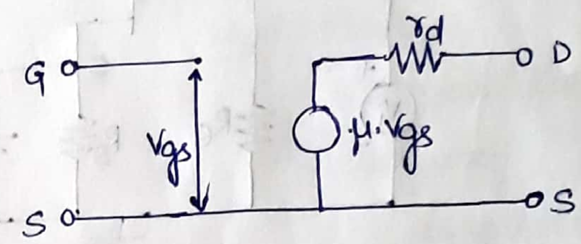
Cgs is Junction resistance of gate to Source

r_{gd} is gate to drain resistance
C_{gd} is gate to drain capacitence
r_{ds} is drain to source resistance
C_{ds} is drain to source capacitence
C_s is drain - Substrate capacitence.

low frequency small signal JFET model :-

In this we have Norton's and thevenin's circuits in which current source is in parallel with resistance in Nortons and voltage source is in series with resistance.



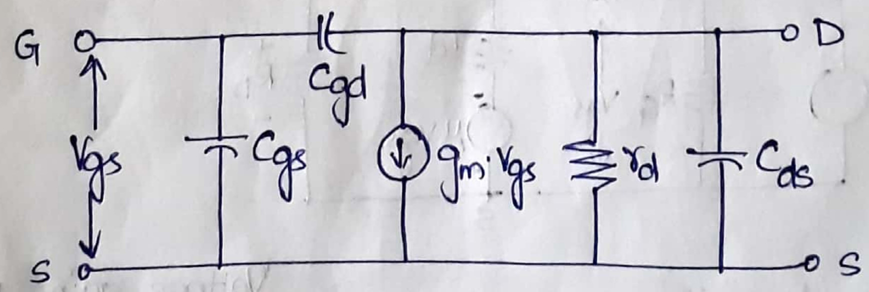


In nortons circuit the current generator is proportional to gate to source voltage. The i/p resistance R_{gs} and R_{gd} are infinite. Also there is no feedback at low frequency from o/p to i/p in FET.

(3)

High frequency model :-

In high frequency model the barrier capacitances or junction capacitances are internally connected, and feedback exists between i/p and o/p circuits and as a result voltage amplification drops rapidly as frequency is increased.

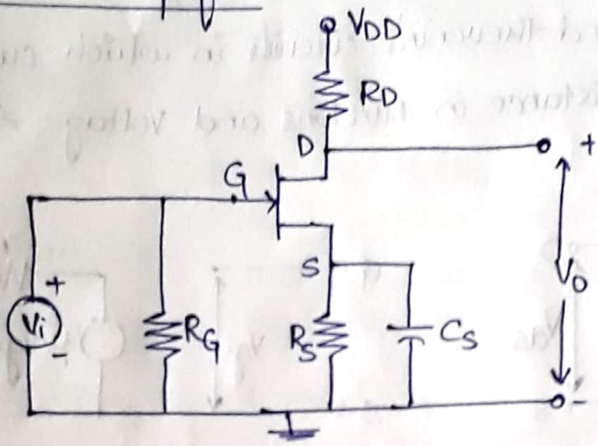


FET AMPLIFIERS :- FET amplifiers provide an excellent voltage gain with the added feature of high impedance. FET's has good frequency range, minimal size and weight.

There are three basic FET amplifier configurations.

(i) Common Source (ii) Common Drain (iii) Common Gate

Common Source Amplifier :-



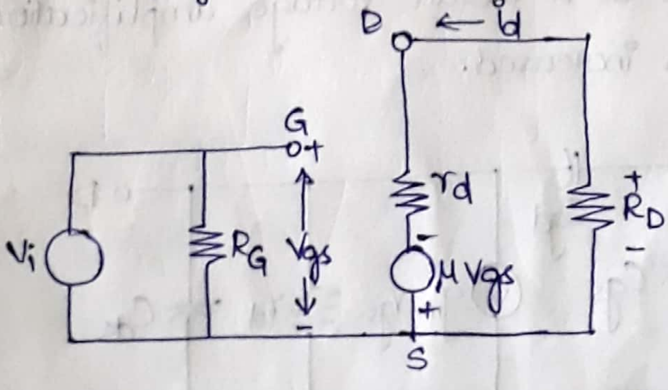
(4)

The common source is widely used because it provides high input impedance, good voltage gain and a moderate output impedance. However, the circuit produces a phase reversal of 180°.

→ Here source is common between input and output i.e., drain and gate.

→ R_s and C_s provides temperature stabilization.

→ In small signal analysis all the capacitors are short circuited and d.c voltage power supply's are short circuited.



Voltage gain - Medium
Current gain - Medium
Power gain - High
Phase shift -180°
i/p resistance - Medium
o/p resistance - Medium.

Voltage gain :- $A_v = \frac{V_o}{V_i}$

$$V_o = -I_d \cdot R_D$$

$$I_d = \frac{+\mu V_{gs}}{r_d + R_D}$$

$$V_0 = \left[\frac{-\mu V_{gs}}{r_d + R_D}\right] R_D$$

$$\frac{V_0}{V_{gs}} = \frac{-\mu R_D}{r_d + R_D} \quad (\because V_i = V_{gs})$$

$$\boxed{A_v = \frac{V_0}{V_i} = \frac{-\mu R_D}{r_d + R_D}}$$

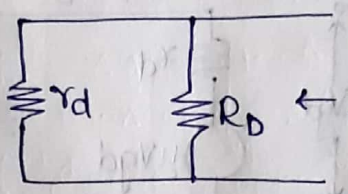
Input impedance :- $\boxed{Z_i = R_G}$

where $R_G = R_1 \| R_2$

Output impedance :-

When $V_i = 0$, $V_{gs} = 0$ and $\mu V_{gs} = 0$

Therefore the equivalent circuit is



Applications:-
→ Audio amplifiers
→ Frequency amplifiers.

⑤

$$Z_0 = r_d \| R_D$$

$$= \frac{r_d R_D}{r_d + R_D}$$

Normally r_d is far greater than R_D, so $\boxed{Z_0 = R_D}$

Problem :- In a CS amplifier let $R_D = 5k\Omega$, $R_G = 10M\Omega$, $\mu = 50$ and $r_d = 35k\Omega$. evaluate A_v, Z_i, Z_0

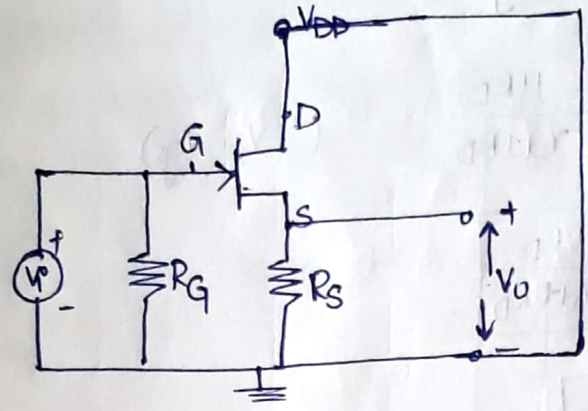
Solution:- Voltage gain :-

$$A_v = \frac{V_0}{V_i} = \frac{-\mu R_D}{r_d + R_D} = \frac{-50 \times 5 \times 10^3}{35 \times 10^3 + 5 \times 10^3} = -6.25$$

Input impedance :- $Z_i = R_G = 10M\Omega$

Output impedance :- $Z_0 = R_D = 5k\Omega$.

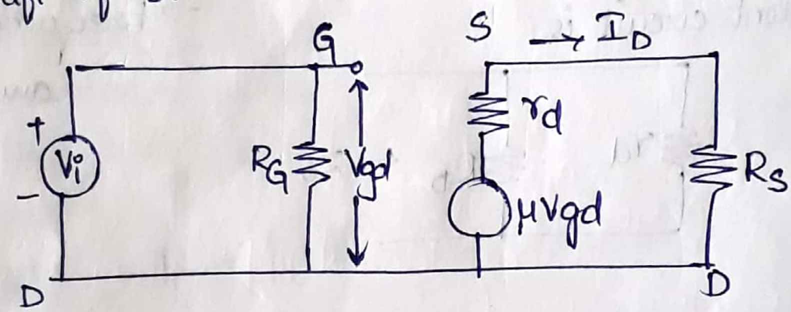
Common Drain Amplifier:-



The common drain amplifier is also known as source follower amplifier.

→ Here drain is common between input and output i.e., gate and Source.

It has high input resistance and low output resistance with a Phase shift of 0°.



(6)

Voltage gain :- $A_v = \frac{V_o}{V_i}$

From circuit $V_i = V_{gd} + I_D(r_d + R_s)$

$= V_{gd} + I_D r_d + I_D R_s$

$(\because I_D = \mu \cdot V_{gd})$

$= V_{gd} + \mu \cdot V_{gd} r_d + \mu \cdot V_{gd} R_s$

$= V_{gd}[1 + \mu(r_d + R_s)]$

$V_o = I_D R_s$

$= \mu \cdot V_{gd} R_s$

$$\frac{V_o}{V_i} = \frac{\mu \cdot V_{gd} R_s}{V_{gd}[1 + \mu(r_d + R_s)]}$$

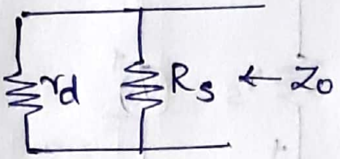
$$\boxed{\frac{V_o}{V_i} = \frac{\mu \cdot R_s}{1 + \mu(r_d + R_s)}}$$

Input impedance:- $\boxed{Z_i = R_G}$

Output impedance :-

when $V_i = 0$, $V_{gd} = 0$, $\mu \cdot V_{gd} = 0$

Therefore the equivalent circuit is



$Z_o = r_d \| R_s$

$\boxed{Z_o \simeq R_s}$

Voltage gain is ~~high~~ low
current gain is high
Power gain is Medium
input resistance is high
output resistance is low
Phase shift is 0°.

(7)

Applications:-

used in Buffer amplifiers.

Problem :- In a CD amplifier let $R_s = 4k\Omega$, $R_G = 10M\Omega$, $\mu = 50$ and $r_d = 35k\Omega$. Evaluate A_v, Z_i, Z_o

Solution:-

Voltage gain :- $A_v = \frac{V_o}{V_i} = \frac{\mu R_s}{1+\mu(R_s + r_d)}$

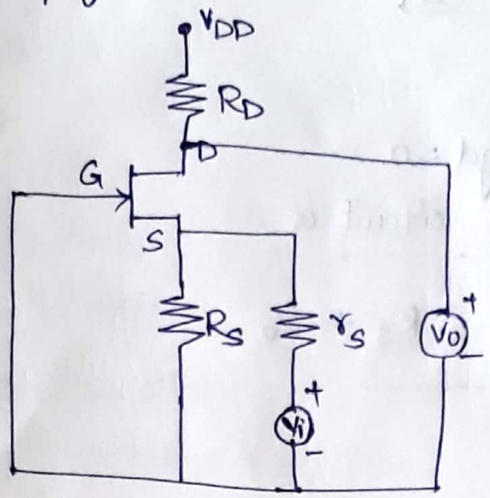
$$= \frac{50 \times 4 \times 10^3}{(1+50) \times 4 \times 10^3 + 35 \times 10^3}$$

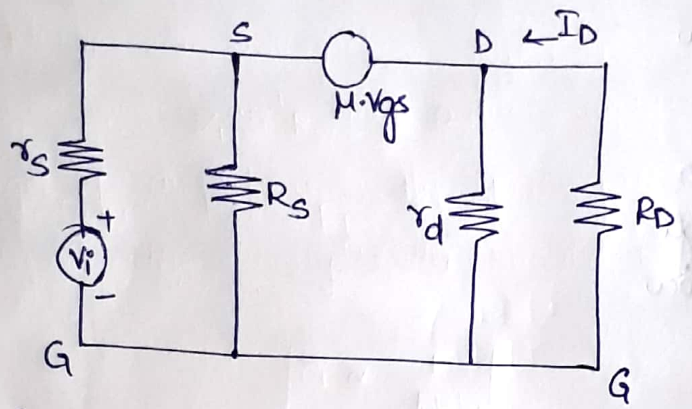
$$= 0.836.$$

Input impedance :- $Z_i = R_G = 10M\Omega$

output impedance :- $Z_o = R_s = 4k\Omega$

Common Gate Amplifier :-





(8)

Voltage gain :-

$$A_v = \frac{V_o}{V_i}$$

$$= \frac{I_D(r_d \| R_D)}{V_{gs}}$$

$$= \frac{\mu \cdot V_{gs}(r_d \| R_D)}{V_{gs}}$$

$$\boxed{A_v = \mu(r_d \| R_D)}$$

Input impedance :-

$$Z_i = r_s \| R_s$$

$$\boxed{Z_i \simeq R_s}$$

output impedance :-

$$Z_o = r_d \| R_D$$

$$\boxed{Z_o \simeq R_D}$$

Voltage gain is high
Current gain is less
Power gain is less
Phase shift is 0°
input resistance is low
output resistance is high.

Applications:- → RF amplifiers
→ Microphone amplifiers.

Problem:- In a common gate amplifier let $R_D = 2k\Omega$, $R_S = 1k\Omega$, $g_m = 1.43 \times 10^{-3}$ ℧, $r_d = 35k\Omega$. Evaluate A_v, Z_i, Z_o.

Solution:-

Voltage gain:- $A_v = \frac{V_o}{V_i} = \mu (r_d \| R_D)$

$$= \mu \left(\frac{r_d R_D}{r_d + R_D} \right)$$

$$= 1.43 \times 10^{-3} \left(\frac{35 \times 2}{35 + 2} \right)$$

$$=$$

(9)

Input impedance:- $Z_i \simeq R_S = 1k\Omega$

Output impedance:- $Z_o \simeq R_D = 2k\Omega$

GAIN BANDWIDTH PRODUCT:-

Gain is a measure of ability to amplify a signal which is represented by $|A|$ and measured in db (decibels).

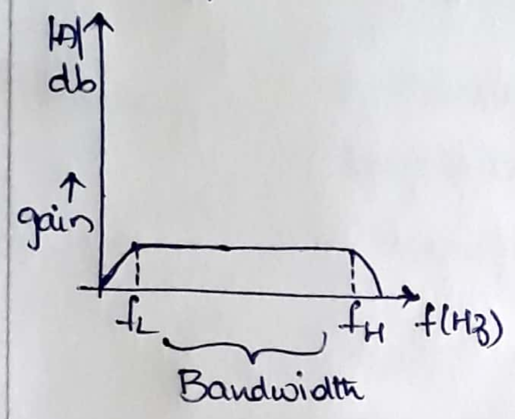
Bandwidth is the difference between upper and lower frequencies of a signal generated represented by B measured in Hz (Hertz).

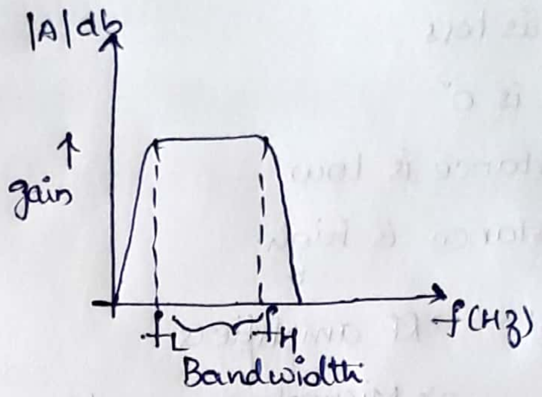
Gain Bandwidth product is the result of specifications of amplifiers. it is represented by F and is given by

$$F = |A_o| f_2 \frac{g_m}{2\pi (C_o + C_i)} \quad \text{(or)} \quad F = |A_o| f_2 \frac{g_m}{2\pi C}$$

Here $|A_0|$ is gain

f_2 is upper 3dB frequency.





As gain decreases, the bandwidth increases and As gain increases, the bandwidth decreases.

Ex:- Common source and Common gate amplifiers.

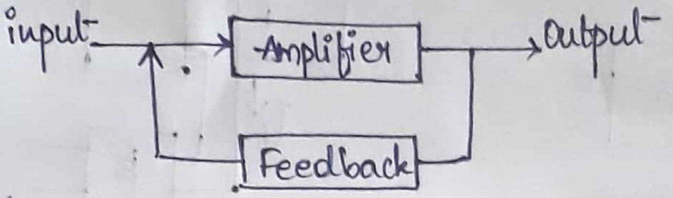
Disadvantages of amplifiers is, the poor gain bandwidth product, to maintain bandwidth exactly, Gain should be proportional to Bandwidth

$$G \propto \frac{1}{BW}.$$

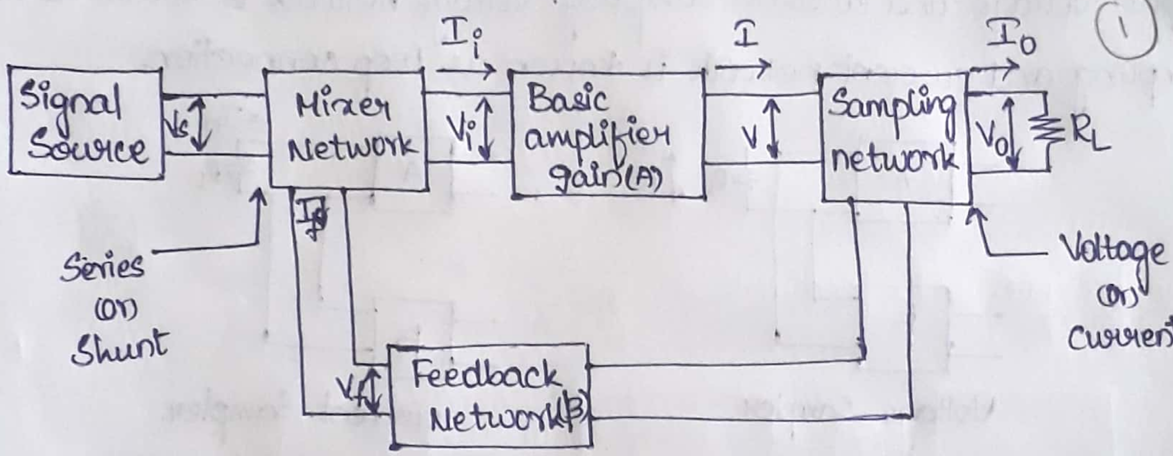
MODULE - 4

FEEDBACK AMPLIFIERS.

Feedback Concept and types :- A portion of output from the amplifier is combined with input. This is known as feedback.



Feedback is used to improve the performance and reduces sensitivity to parameter variations due to manufacturing (or) environment.



The output Quantity is sampled by a sampler which is of two types, namely voltage sampler and current sampler, and fed to the feedback network.

The output of feedback network, which has a fraction of the output signal, is combined with external source signal V_s through a mixer and fed to the basic amplifier. Mixers are also known as comparators which is of two types, namely series and shunt mixer.

Here A = gain of an amplifier $= \frac{V_o}{V_i}$

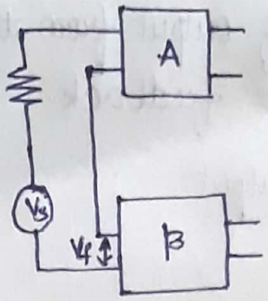
β = feedback ratio $= \frac{V_f}{V_o}$

A_f = gain of feedback amplifier $= \frac{V_o}{V_s}$

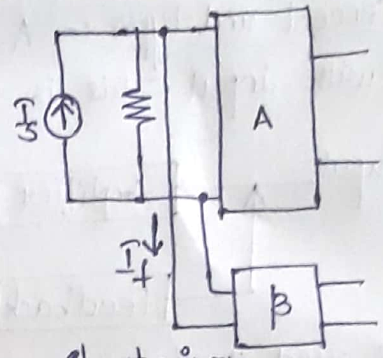
V_s = AC signal in the input side.

V_f = Feedback Signal.

Mixer network:- There are two ways of mixer network at the input. Series and shunt mixers. Series connection is known as loop connection and shunt connection is known as node connection.

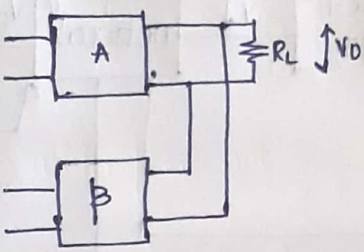


Series mixer

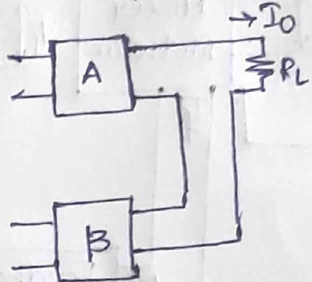


Shunt mixer.

Sampling network:- There are two ways of sampling at the output. Voltage and current sampling. Voltage network is known as node Sampling and current network is known as loop connection.



Voltage Sampler



current Sampler.

(2)

Feedback Network:- The feedback network is a passive two-port network which consists of resistors, capacitors and inductors. Most often it is a resistive configuration. It provides a reduced portion of output as feedback signal to the input mixer network and it is given as $V_f = \beta V_0$. where β is feedback factor.

Transfer Ratio or gain:- The symbol A represents the ratio of output signal to input signal.

The transfer ratio $\frac{V}{V_i}$ is the voltage gain represented by A_V

The transfer ratio $\frac{I}{I_i}$ is the current gain represented by A_I.

The transfer ratio $\frac{I}{V_i}$ is the Transconductance represented by G_M.

The transfer ratio $\frac{V}{I_i}$ is the Transresistance represented by R_M.

There are two types of feedback networks :-
(a) Positive Feedback (b) Negative Feedback.

(a) Positive Feedback :- If the feedback signal V_f is in-phase with the input signal V_s, then

$$V_i = V_s + V_f$$

Hence, the input voltage applied to the basic amplifier is increased. This type of feedback is known as positive (or) Regenerative feedback.

$$\text{Gain } A_f = \frac{V_o}{V_s}$$

$$= \frac{V_o}{V_i - V_f}$$

$$= \frac{1}{\frac{V_i}{V_o} - \frac{V_f}{V_o}}$$

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

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

Here $|A_f| > |A|$

Open gain is A, feedback factor is β. The product of open gain and feedback factor is Aβ known as loop gain

If $|A\beta| = 1$, then $A_f = \infty$.

Hence gain of amplifier is infinite, it acts as Oscillator.

Positive feedback helps to ~~reduce bandwidth, increase distortion and noise.~~ increase overall gain.

(b) Negative feedback :- If the feedback signal V_f is out of phase with the input signal V_s then

$$V_i = V_s - V_f$$

Hence, the input voltage applied is decreased. This type of feedback is known as negative (or) Degenerative feedback.

$$\text{Gain } A_f = \frac{V_o}{V_s}$$

$$= \frac{V_0}{V_i + V_f}$$

$$= \frac{1}{\frac{V_i}{V_0} + \frac{V_f}{V_0}}$$

$$= \frac{1}{\frac{1}{A} + \beta}$$

$$\boxed{A_f = \frac{A}{1 + A\beta}}$$

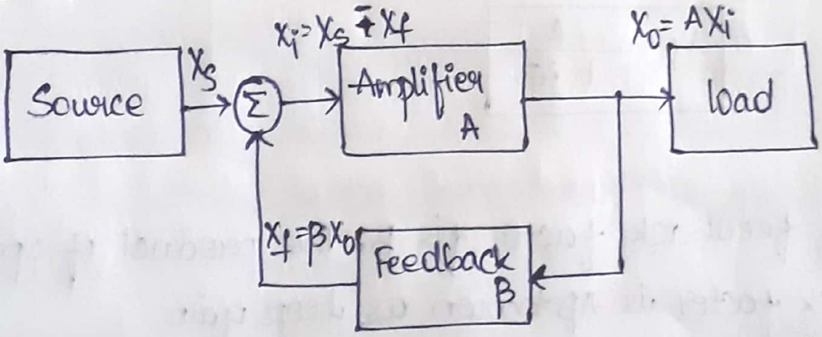
Here $|A_f| < |A|$

If $|A\beta| >> 1$, then $A_f = \frac{1}{\beta}$.

Negative feedback always helps to increase the bandwidth, decrease distortion and noise.

(4)

Transfer gain with feedback :-



The transfer gain is represented as the ratio of output signal to input signal.

Here X_s is input signal
X_o is output signal
X_f is feedback signal
X_d is difference signal (or) error signal (or) comparision signal.

The transfer gain without feedback A is given as

$$A = \frac{X_o}{X_i}$$

Feedback factor $\beta = \frac{X_f}{X_o}$

The transfer gain with feedback is given as

$$A_f = \frac{x_o}{x_s}$$

$$= \frac{x_o}{x_i + x_f}$$

$$= \frac{x_o}{x_i + \beta x_o}$$

$$= \frac{x_o}{x_i\left(1+\beta \frac{x_o}{x_i}\right)} \qquad \left(\because \frac{x_o}{x_i} = A\right)$$

$$\boxed{A_f = \frac{A}{1+\beta A}}$$

⑤

Here A represents open loop gain

β represents closed loop gain.

General characteristics of Negative Feedback Amplifiers :-

By using negative feedback, there is a reduction in overall Voltage gain and there are some improvements in using negative feedback They are :-

(a) Increased Stability
(b) Desensitivity of transfer gain
(c) Frequency distortion
(d) Reduction in noise.
(e) Reduction in Distortion
(f) Bandwidth
(g) loop gain.

(a) Increased Stability :-

Voltage gain due to negative feedback is given as

$$\boxed{A_{vf} = \frac{A_v}{1+\beta A_v}}$$

Due to negative feedback, gain is reduced by a factor $1+\beta A_v$

If $\beta A_V >> 1$

then $A_{vf} = \frac{A_V}{\beta A_V} = \frac{1}{\beta}$.

Thus gain of amplifier depends upon feedback network. It does not depend on voltage gain.

(b) Desensitivity of transfer gain :- The fractional change in amplification with feedback divided by the fractional change without feedback is called Sensitivity of transfer gain.

$$S = \frac{\left(\frac{dA_f}{A_f}\right)}{\left(\frac{dA}{A}\right)}$$

closed loop gain with feedback $A_f = \frac{A}{1+\beta A}$.

Differentiating with respect to A,

$$\frac{|dA_f|}{|dA|} = \frac{(1+\beta A) - \beta A}{(1+\beta A)^2} = \frac{1}{(1+\beta A)^2}, \quad dA_f = \frac{dA}{(1+\beta A)^2}$$

Dividing both sides with A_f

$$\frac{dA_f}{A} = \frac{dA}{(1+\beta A)^2} \times \frac{1}{A_f}$$

$$= \frac{dA}{(1+\beta A)^2} \times \frac{(1+\beta A)}{\beta A}$$

$$= \frac{dA}{A} \times \frac{1}{1+\beta A}$$

$$\frac{dA_f}{A} = \frac{dA/A}{(1+\beta A)}$$

$$S = \frac{\frac{dA_f}{A}}{\frac{dA}{A}} = \frac{1}{1+\beta A}.$$

(6)

The reciprocal of Sensitivity is called desensitivity represented by D

$$\boxed{D = (1+\beta A)}$$

(c) Frequency Distortion :- Frequency distortion is arised because of Varying gain A.

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

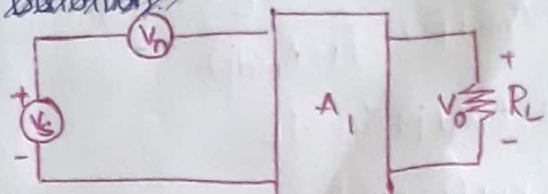
if $\beta A >> 1$, $A_f = \frac{A}{\beta A} = \frac{1}{\beta}$

$$\boxed{A_f = \frac{1}{\beta}.}$$

(d) Reduction in Noise :- Negative feedback can be employed to reduce the noise in an amplifier (i.e., to increase signal-to-noise ratio). It is represented as N_f

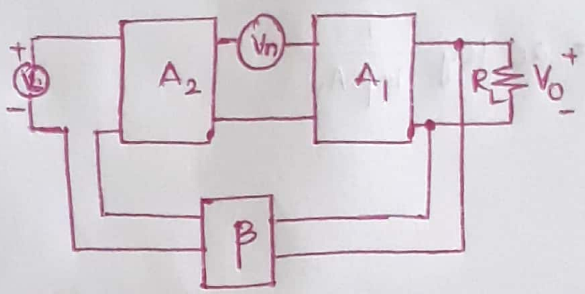
$$N_f = \frac{N}{1+\beta A_V}$$

~~(e) Reduction in Distortion :-~~



Signal to noise ratio for A_1 amplifier is given as $\frac{S}{N} = \frac{V_s}{V_n}$.

A_1 amplifier is preceded with A_2 amplifier and apply negative feedback



$$V_o = \frac{V_s A_1 A_2}{1+A_1 A_2 \beta} + \frac{V_n A_1}{1+A_1 \beta A_2}$$

$$\frac{S}{N} = \frac{V_s A_1 A_2}{1+A_1 A_2 \beta} \Big/ \frac{V_n A_1}{1+A_1 A_2 \beta}$$

$$\frac{S}{N} = \frac{V_s}{V_n} A_2$$

(e) Reduction in Distortion :- Consider an amplifier with an open-loop voltage gain (A) and a total harmonic distortion without feedback (D), then due to negative feedback, with the feedback ratio (β), the distortion is reduced by a factor $1+A\beta$ and the distortion with feedback D_f is given by

$$D_f = \frac{D}{1+A\beta}.$$

(f) Bandwidth :- Gain with feedback is given by

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

$$A_{f\,mid} = \frac{A_{mid}}{1+\beta A_{mid}}, \quad A_{f\,low} = \frac{A_{low}}{1+\beta A_{low}}, \quad A_{f\,high} = \frac{A_{high}}{1+\beta A_{high}}$$

Bandwidth of an amplifier without feedback is given as

$$BW = f_H - f_L$$

Bandwidth with feedback is given as ..

$$BW_f = f_{Hf} - f_{Lf}$$

$$= f_H(1 + A_{mid}\beta) - \frac{f_L}{(1 + A_{mid}\beta)}$$

$$BW_f = (1 + A_{mid}\beta) f_H - f_L$$

$$\boxed{BW_f = BW(1 + A\beta)}$$

(9) <u>loop gain</u> :-

(8)

$$F = 20 \log \frac{A_{vf}}{A_v}$$

$$F = 20 \log \frac{1}{1 + \beta A_v}$$

<u>Types of Negative Feedback Connections / Method of Identifying Feedback Topology</u> :-

Based on the sampling at output and mixer in input, there are 4 types of negative feedback (or) 4 topologies. They are :-

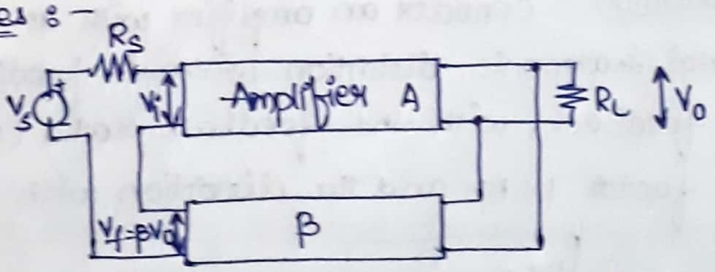
(i) Voltage Series (or) voltage amplifier

(ii) current series (or) Transconductance

(iii) current shunt (or) current amplifier

(iv) voltage shunt (or) Transresistance.

(i) <u>Voltage series</u> :-



* A portion of output which is in shunt, is applied as a feedback to the input in series.
* When allied in shunt, the output decreases and the input increases.
* The output voltage is in proportional to input voltage source.
* Such an amplifier is called voltage controlled voltage series

(VCVS) on Series shunt amplifier. (5)

* An ideal Voltage amplifier must have infinite input resistance and zero output resistance.

* The units are Volts/Volts.

* The Transfer gain of an amplifier is given as

$$A = \frac{V_o}{V_i}$$

* The feedback factor of an amplifier is given as

$$\beta = \frac{V_f}{V_o}$$

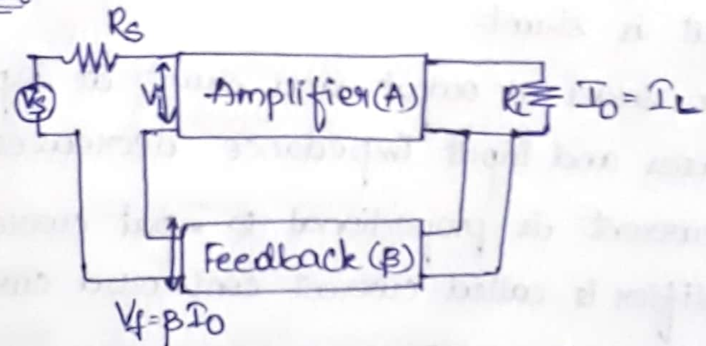
* The input resistance is given as

$$R_{if} = R_i (1+A\beta)$$

* The output resistance is given as

$$R_{of} = \frac{R_o}{(1+A\beta)}$$

(ii) Current Series :-



* The portion of output which is in series is applied as a feedback to input in series.

* When allied in series at input and output, the input & output resistances increases.

* The output current is in proportional to the Voltage source.

* Such an amplifier is called Voltage controlled current series (VCCS) on Series- Series amplifier.

* An ideal Transconductance must have high input and output resistances.

* The units are Transfer gain of an amplifier is given as

$$A = \frac{I_o}{V_i}$$

* The feedback factor of an amplifier is given as

$$\beta = \frac{V_f}{I_o}.$$

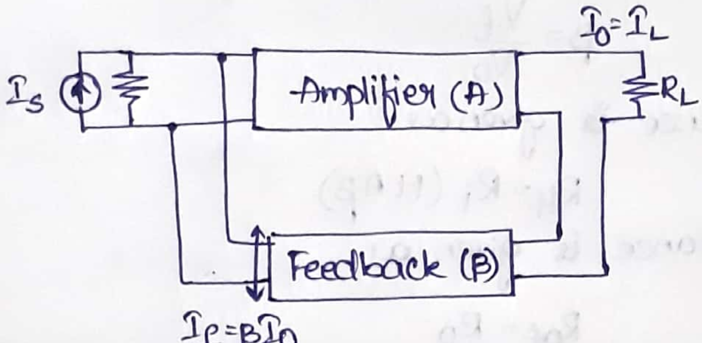
* The input resistance of an amplifier is given as

$$R_{if} = R_i(1+A\beta)$$

* The output resistance of an amplifier is given as

$$R_{of} = R_o(1+A\beta).$$

(iii) <u>Current shunt</u> :-



(10)

* A portion of output which is in series is applied as a feedback to input is shunt.
* When allied in series at output and shunt at input, the output impedance increases and input impedance decreases.
* The output current is proportional to input current source.
* Such an amplifier is called current controlled current source (CCCS) on shunt series amplifier.
* An ideal current amplifier must have low input resistance and high output resistance.
* The gain of an amplifier is given as

$$A = \frac{I_o}{I_i}$$

* The feedback of an amplifier is given as

$$\beta = \frac{I_f}{I_o}$$

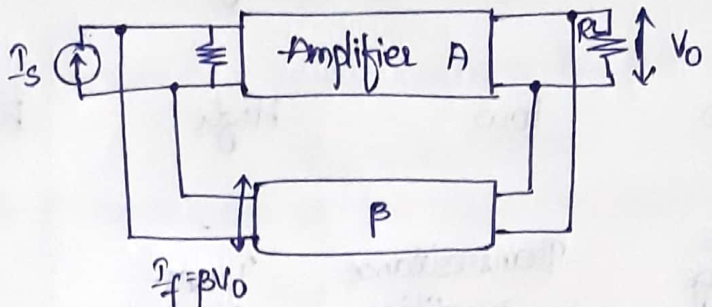
* The input resistance of an amplifier is given as

$$R_{if} = \frac{R_i}{(1+A\beta)}$$

* The output resistance of an amplifier is given as

$$R_{of} = R_o(1+A\beta).$$

(iv) Voltage shunt :-



* A portion of output which is in shunt is applied as feedback to input in shunt.
* When allied in shunt at output, and shunt at input, the input and output impedance decreases.
* The output voltage is proportional to input current.
* Such an amplifier is called current controlled voltage source (CCVS) or Transresistance or shunt-shunt amplifier.
* The Ideal Transresistance must have low input and low output resistance.
* The gain of an amplifier is given as

$$A = \frac{V_o}{I_i}$$

* The feedback of an amplifier is given as

$$\beta = \frac{I_f}{V_o}$$

* The input resistance of an amplifier is given as

$$R_{if} = \frac{R_i}{(1+A\beta)}$$

* The output resistance of an amplifier is given as

$$R_{of} = \frac{R_o}{(1+A\beta)}.$$

Comparisions:-

Characteristics	Voltage series	Voltage shunt	Current Series	Current shunt
Voltage gain	low	low	low	low
Bandwidth	High	High	High	High
Harmonic distortion	low	low	low	low
Noise	low	low	low	low

input resistance	high	low	high	Low
output resistance	low	low	High	High
Another name	True Voltage amplifier	Transresistance amplifier	Trans-Conductance amplifier	True current amplifier.

Stability of Feedback Amplifier:-

The feedback amplifier should be designed in such a way that the circuit is stable at all frequencies. Otherwise, a transient response may make the stable feedback amplifier unstable and suddenly start oscillating. Also, a feedback amplifier with more than two poles may become unstable and break into oscillations, if too much feedback is applied.

(12)

For the system to be stable, all the poles of transfer function or the zeros of $(1+A\beta)$ must lie in the left half of the complex plane.

Nyquist Criterion:- Nyquist method is a popular Technique used to find stability. This is used to find and plot gain and Phase shift on complex plane.

* Nyquist criterion for stability states that an amplifier is unstable if Nyquist curve encloses $-1+j0$ point, and stable when it does not enclose the point

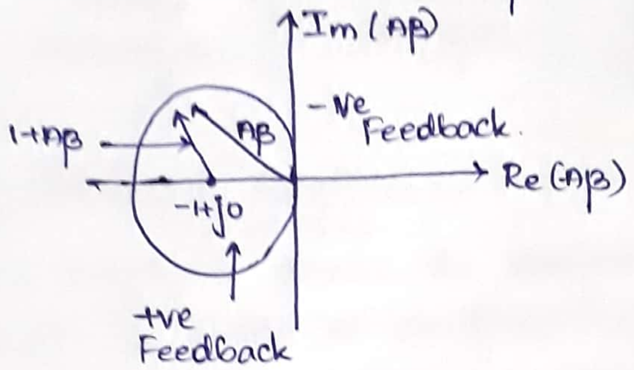
* Nyquist criterion also represents in complex plane for positive and Negative feedback.

Scanned by CamScanner

→ $|1+A\beta| = 1$ represents a circle of unit radius, with $-1+j0$ as center.

→ For any frequency if $A\beta$ extends outside the circle, it is negative feedback.

→ If $A\beta$ lies within the circle it is positive feedback.



13

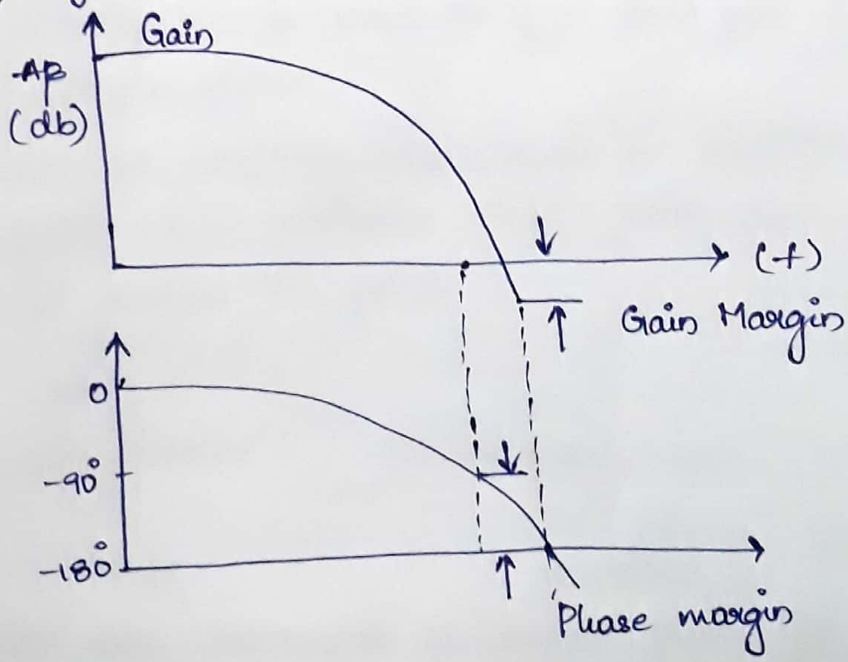
Gain & phase Margins :-

Gain Margin (GM) is defined as the value of $|A\beta|$ in db at frequency at which phase angle of $A\beta$ is $180°$.

If gain margin is negative, the amplifier is stable.

If gain margin is positive, the amplifier is unstable.

Phase margin (PM) is defined as the angle of $180°$ minus the magnitude of angle of $A\beta$ at which $|A\beta|$ is unity (0 db).

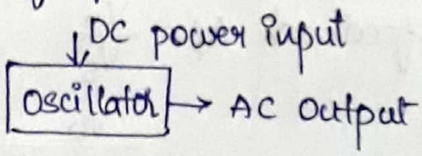


MODULE - 5.
OSCILLATORS

Constituents of an oscillator:-

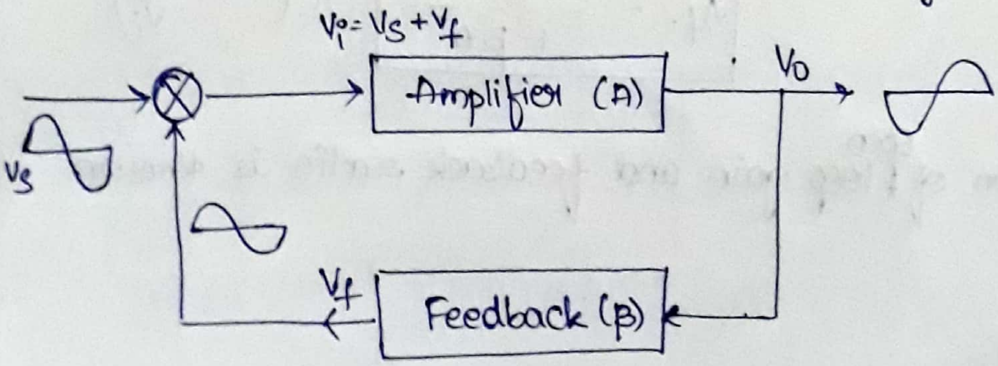
* A circuit which is used to generate a periodic voltage without an A.C input signal is called an oscillator. It is also known as waveform generator.
* To generate the periodic voltage, the circuit is supplied with energy from a d.c source.
* If the output voltage is a sine wave then the oscillator is called "sinusoidal" or "harmonic" oscillator.
* An oscillator uses a vaccum tube or a transistor to generate a AC output. The output oscillations are produced by the tank circuit components either as R and C or L and C.
* An electronic oscillator is a circuit which converts dc energy into ac at very high frequencies.

1



Amplifier Vs Oscillator:- An amplifier increases the signal strength of input signal applied, but an oscillator generates a signal without that input signal.

Alternator Vs Oscillator:- An alternator is a mechanical device that produces sinusoidal waves without any input.



The open loop gain $A = \frac{V_o}{V_i}$

The loop gain with feedback $A_f = \frac{V_o}{V_s}$

Feedback factor $\beta = \frac{V_f}{V_o}$; $V_f = \beta V_o$

~~Substitute V_f in V_i~~

V_s is the input signal given to the amplifier, V_o is the output of the amplifier with 180° phase shift. A part of output is given as a feedback. The output of feedback network is also 180°. So, the input signal and the feedback signal are in-phase to each other. It is known as positive feedback network.

$$V_i = V_s + V_f$$

Substitute V_f in V_i ②

$$V_i = V_s + \beta V_o$$

$$V_s = V_i - \beta V_o$$

The loop gain with feedback $A_f = \frac{V_o}{V_s}$

$$= \frac{V_o}{V_i - \beta V_o}$$

divide by V_i

$$= \frac{V_o/V_i}{V_i/V_i - \beta V_o/V_i}$$

$$\boxed{A_f = \frac{A}{1-\beta A}} \quad \left(\because A = \frac{V_o}{V_i}\right)$$

The multiplication of open loop gain and feedback ratio is known as loop gain.

$A\beta$ = loop gain.

<u>Applications of oscillators</u> :- Oscillators are used to generate

audio frequencies ranging from 0 to 20KHz

ex:- RC phase shift Oscillator & Wein bridge Oscillator.

→ Oscillators are used to generate radio frequencies ranging from 20KHz to 30MHz

ex:- Hartley oscillator & colpitts oscillator.

Barkhausen Criterion:-

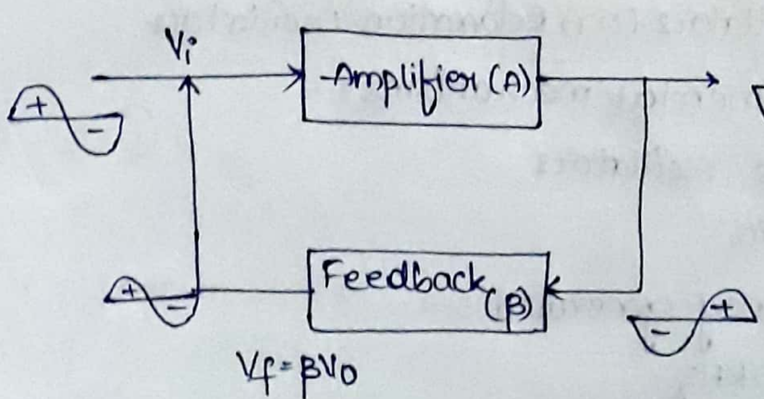
The oscillator produces oscillations by variations caused in base current due to noise component (or) changes in dc power supply. When no external signal is applied, the internal noise will cause small signal at the output of the signal amplifier. The output of amplifier is fed back to the amplifier with proper phase relation, then the signal becomes larger and this process continous. The output voltage remains constant at frequency fo, called frequency of oscillations.

The circuit will oscillate in two conditions called as Barkhausen criterion. These ③

(i) The loop gain must be unity (or) greater.

(ii) The phase shift must be 0° (or) 360°.

let us consider the oscillator circuit. The amplifier is a basic amplifier and it produces a phase shift of 180° between i/p & o/p. so, the feedback network must ensure a phase shift of 180° while feeding the output to the input.



V_i is applied as input to the amplifier. so $V_o = AV_i$

The feedback is $V_f = -\beta V_0$ (-ve sign indicates 180° phase shift).

Substitute V_0 in V_f

$$V_f = -\beta A V_i$$

In oscillator, the feedback output must drive the amplifier. Hence V_f must be equal to V_i. To acheive this term $-A\beta$ should be 1

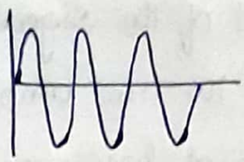
$$V_f = V_i \quad , \text{when } -A\beta = 1.$$

This condition is called Barkhausen criterion.

Depending on the nature of oscillations, they are of 3 types.

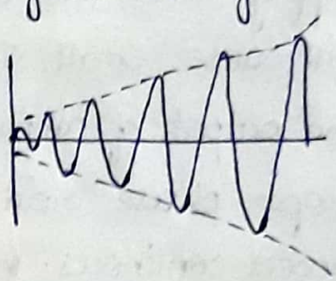
(i) Sustained Oscillations

$A\beta = 1$



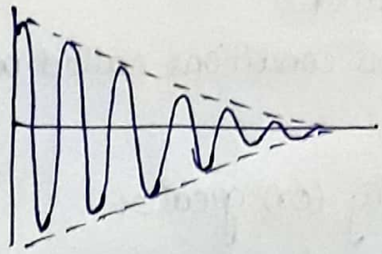
(ii) Exponentially increasing

$A\beta > 1$



(iii) Exponentially decreasing.

$A\beta < 1$



(4)

Classification of Oscillators :-

Oscillators are classified in different types

(i) According to waveforms generated :-

(a) Sinusoidal Oscillators (or) Harmonic oscillators.

(b) Non sinusoidal oscillators (or) Relaxation oscillators.

(ii) According to fundamental mechanisms :-

(a) Negative resistance oscillators

(b) Feedback oscillators.

(iii) According to Frequency generated :-

(a) Audio - 0 to 20KHz

(b) Radio - 20 KHz to 30MHz

(c) VHF (very high frequencies) - 30MHz to 300 MHz

ⓓ UHF (ultra high frequencies) - 300 MHz to 3GHz.

ⓔ Microwave frequencies - above 3GHz.

(iv) According to type of circuit used :-

ⓐ LC tuned

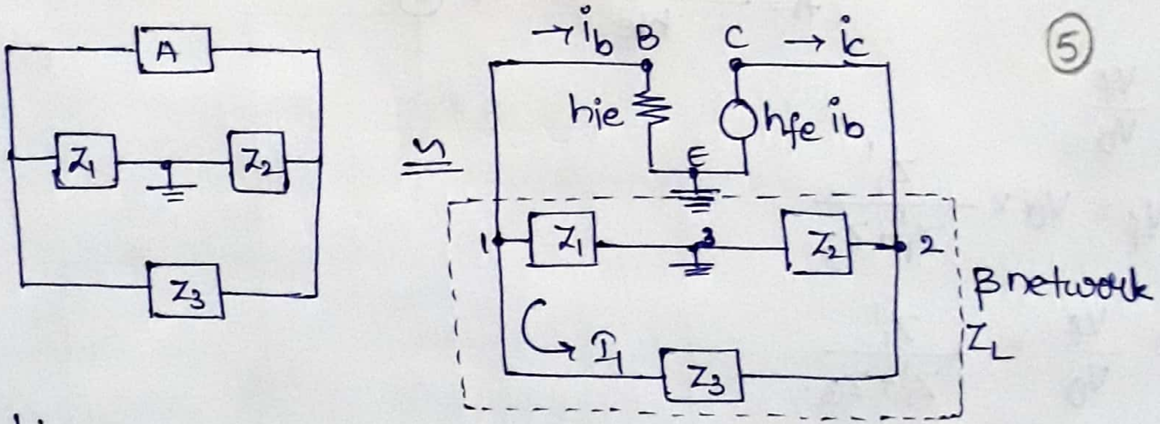
ⓑ RC tuned.

Sine wave Feedback Oscillators of LC Type - General form of oscillator circuit :-

* The active devices in the oscillator circuits are Vaccum-tubes, transistor, FET and operational Amplifier.

* Z_1, Z_2 and Z_3 are reactive elements constituting the feedback tank circuit which determines the frequency of oscillations.

* Here Z_1 & Z_2 serves as AC voltage divider for output voltage and feedback signal. Therefore the voltage across Z_1 is feedback signal.



Z_1 & hie are in series

Z_1' is parallel combination of Z_1 and hie

$$Z_1' = Z_1 \| hie = \frac{Z_1 \cdot hie}{Z_1 + hie}$$

$A\beta = 1 \rightarrow (1)$

$$Z_L = (Z_1' + Z_3) \| Z_2$$

Z_1 & Z_3 are in series, Z_2 is parallel to Z_1' & Z_3, because the current is spliting at nodes.

$$Z_L = \frac{(Z_1' + Z_3) \cdot Z_2}{Z_1' + Z_3 + Z_2}$$

Substitute Z_1' in Z_L

$$Z_L = \frac{\left[\frac{Z_1 \cdot hie}{Z_1 + hie} + Z_3\right] \cdot Z_2}{\frac{Z_1 \cdot hie}{Z_1 + hie} + Z_2 + Z_3}$$

$$Z_L = \frac{\left[\frac{Z_1 hie + Z_1 Z_3 + Z_3 hie}{Z_1 + hie}\right] \cdot Z_2}{\left[\frac{Z_1 hie + Z_1 Z_2 + Z_1 Z_3 + Z_2 hie + Z_3 hie}{Z_1 + hie}\right]}$$

$$Z_L = \frac{hie(Z_1 + Z_3) + Z_1 Z_3 \cdot Z_2}{hie(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3} \rightarrow (2)$$

$$A = \frac{V_o}{V_i} = \frac{I_o \times R_o}{I_i \times R_i} = \frac{I_c \times R_L}{I_b \times hie} = \frac{-h_{fe} \cdot I_b \times Z_L}{I_b \times hie}$$

$$A = \frac{-h_{fe} \times Z_L}{hie} \rightarrow (3)$$

$$\beta = \frac{V_f}{V_o}$$

$$V_f = V_o \times \frac{Z_1'}{Z_1' + Z_3}$$

$$\beta = \frac{V_f}{V_o} = \frac{Z_1'}{Z_1' + Z_3}.$$

Substitute Z_1' in β.

$$\beta = \frac{\left(\frac{Z_1 \cdot hie}{Z_1 + hie}\right)}{\left(\frac{Z_1 \cdot hie}{Z_1 + hie}\right) + Z_3} = \frac{\left(\frac{Z_1 \cdot hie}{Z_1 + hie}\right)}{\left(\frac{Z_1 hie + Z_1 Z_3 + Z_3 hie}{Z_1 + hie}\right)}$$

$$\beta = \frac{Z_1 hie}{(Z_1 + Z_3) hie + Z_1 Z_3} \rightarrow (4)$$

Substitute (2), (3) + (4) in (1)

$$\frac{-h_{fe} \times Z_L}{h_{ie}} \times \frac{Z_1 \, h_{ie}}{(Z_1+Z_3)h_{ie}+Z_1Z_3} = 1$$

$$-h_{fe} \times Z_L \times Z_1 = (Z_1+Z_3)h_{ie} + Z_1Z_3$$

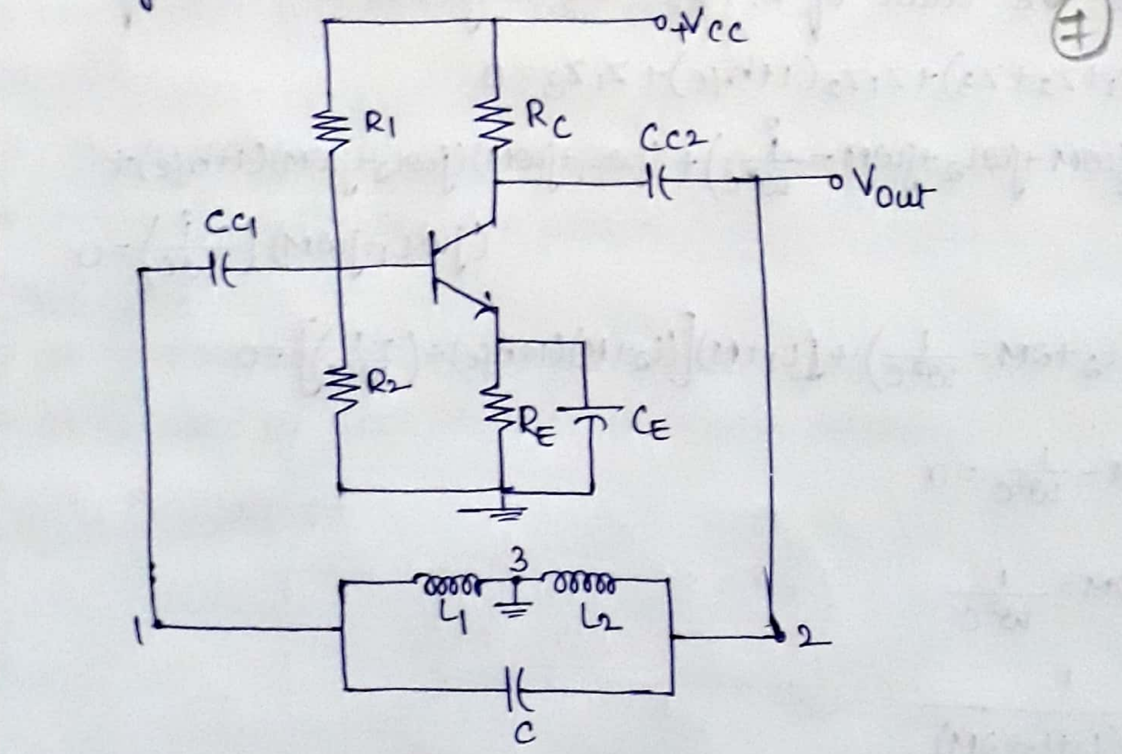
$$-h_{fe} \times Z_1 \times \frac{\cancel{h_{ie}(Z_1+Z_3)+Z_1Z_3} \cdot Z_2}{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3} = \cancel{(Z_1+Z_3)h_{ie}+Z_1Z_3}$$

$$\frac{-h_{fe} \, Z_1 Z_2}{h_{ie}(Z_1+Z_2+Z_3)+Z_1Z_2+Z_1Z_3} = 1$$

$$h_{ie}(Z_1+Z_2+Z_3) + Z_1Z_2 + Z_1Z_3 + h_{fe} Z_1 Z_2 = 0$$

$$\boxed{h_{ie}(Z_1+Z_2+Z_3) + (1+h_{fe})Z_1Z_2 + Z_1Z_3 = 0}$$

Hartley Oscillator :-



Resistors R_1, R_2 and R_E are resistors which provides dc bias to the transistor.

C_E is the bypass capacitor, Cc1 + Cc2 are Coupling Capacitors.

* The feedback consists of inductors L_1 and L_2 and capacitor 'c' determines the frequency of the oscillator.

Working :- When the supply voltage $+V_{cc}$ is switched ON, a transient current is produced in the tank circuit and oscillations are produced.

* As the terminal 3 is grounded, it has zero potential. If terminal 1 is positive, then terminal 2 will be a negative potential. Thus the phase difference is 180°.

* In CE mode, the phase shift produced is 180° between i/p and o/p. Therefore, the total phase shift is 360°. If the feedback is adjusted so that the loop gain $A\beta = 1$, the circuit acts as an oscillator.

* The frequency of oscillations is $f_0 = \frac{1}{2\pi\sqrt{LC}}$

$$Z_1 = j\omega L_1 + j\omega M \rightarrow (1)$$

$$Z_2 = j\omega L_2 + j\omega M \rightarrow (2)$$

$$Z_3 = \frac{1}{j\omega C} = \frac{-j}{\omega C} \rightarrow (3)$$

(8)

Substitute the value of $Z_1, Z_2 + Z_3$ in general oscillator eqn.

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 (1 + h_{fe}) + Z_1 Z_3 = 0$$

$$h_{ie}\left(j\omega L_1 + j\omega M + j\omega L_2 + j\omega M - \frac{j}{\omega^2 C}\right) + (j\omega L_1 + j\omega M)(j\omega L_2 + j\omega M)(1 + h_{fe}) + (j\omega L_1 + j\omega M)\left(\frac{-j}{\omega C}\right) = 0$$

$$j\omega h_{ie}\left(L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right) + \{L_1 + M)\left[(L_2 + M)(1 + h_{fe}) + \left(\frac{-1}{\omega^2 C}\right)\right] = 0$$

$$L_1 + L_2 + 2M - \frac{1}{\omega^2 C} = 0$$

$$L_1 + L_2 + 2M = \frac{1}{\omega^2 C}$$

$$\omega^2 = \frac{1}{C(L_1 + L_2 + 2M)}$$

$$\omega = \frac{1}{\sqrt{C(L_1 + L_2 + 2M}}$$

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi\sqrt{C(L_1 + L_2 + 2M)}}$$

$$(L_2+M)(1+h_{fe})-\frac{1}{\omega^2 C}=0$$

$$(L_2+M)(1+h_{fe})=\frac{1}{\omega^2 C}$$

$$(L_2+M)(1+h_{fe})=L_1+L_2+2M$$

$$1+h_{fe}=\frac{L_1+L_2+2M}{L_2+M}$$

$$h_{fe}=\frac{L_1+L_2+2M}{L_2+M}-1$$

$$h_{fe}=\frac{L_1+L_2+2M-L_2-M}{L_2+M}$$

$$\boxed{h_{fe}=\frac{L_1+M}{L_2+M}}$$

Advantages:-

* Frequency can be varied by employing either a variable capacitor or a variable inductor.
* Less number of components are used.

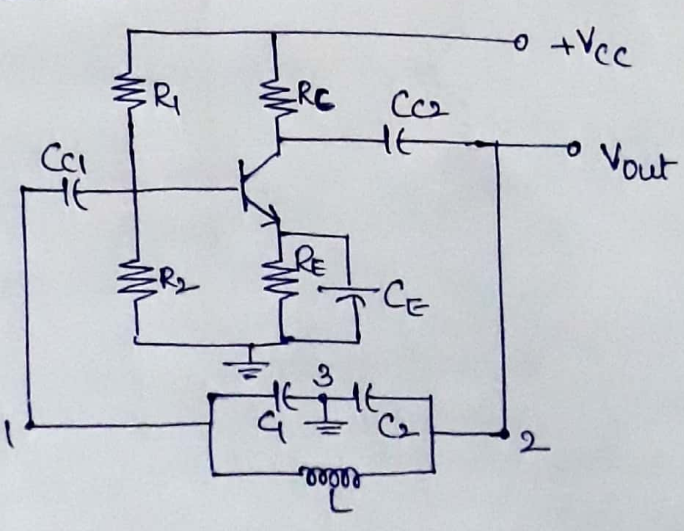
Disadvantages:-

* It cannot be a low frequency oscillator.
* Harmonic distortions are present.

Applications:-

* It is used as R.F oscillator
* It is used as local oscillator in radio receivers.

Colpitt's Oscillator:-



Working:- When the supply voltage $+V_{cc}$ is switched ON, a transient current is produced in the tank circuit and oscillations are produced. AC voltages are produced across C_1 and C_2. The terminal 3 is earthed, and has zero potential.

→ If terminal 1 is positive, then terminal 2 will be negative, and a phase shift produced is 180°. CE mode gives 180°. Thus total phase shift is 360°. If the feedback is adjusted so that the loop gain $A\beta = 1$, then the circuit acts as an oscillator.

The frequency of oscillations is

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$$Z_1 = \frac{1}{j\omega C_1} = \frac{-j}{\omega C_1} \rightarrow (1)$$

$$Z_2 = \frac{1}{j\omega C_2} = \frac{-j}{\omega C_2} \rightarrow (2)$$

$$Z_3 = j\omega L \rightarrow (3)$$

Substitute (1), (2), (3) in general oscillator equation.

$$h_{ie}(Z_1+Z_2+Z_3) + (1+h_{fe})Z_1Z_2 + Z_1Z_3 = 0$$

$$h_{ie}\left(\frac{-j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L\right) + (1+h_{fe})\left(\frac{-j}{\omega C_1}\right)\left(\frac{-j}{\omega C_2}\right) + \left(\frac{-j}{\omega C_1}\right)(j\omega L) = 0$$

$$-jh_{ie}\left(\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right) + \left(\frac{1+h_{fe}}{\omega^2 C_1 C_2} - \frac{L}{C_1}\right) = 0$$

$$\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L = 0$$

$$\frac{\omega C_2 + \omega C_1}{\omega^2 C_1 C_2} = \omega L$$

$$\frac{\omega(C_1+C_2)}{\omega^2 C_1 C_2} = \omega L$$

$$C_1 + C_2 = L(\omega^2 C_1 C_2)$$

$$\omega^2 = \frac{C_1+C_2}{LC_1C_2}$$

$$\omega = \sqrt{\frac{C_1+C_2}{LC_1C_2}}$$

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{C_1+C_2}{LC_1C_2}}$$

$$\left(\frac{1+h_{fe}}{\omega^2 C_1 C_2} - \frac{L}{C_1}\right) = 0$$

$$\frac{1+h_{fe}}{\omega^2 C_1 C_2} = \frac{L}{C_1}$$

$$1+h_{fe} = L\omega^2 C_2$$

$$1+h_{fe} = L\left(\frac{C_1+C_2}{L C_1 C_2}\right) C_2$$

$$h_{fe} = \frac{C_1+C_2}{C_1} - 1$$

$$h_{fe} = \frac{C_1+C_2-C_1}{C_1}$$

$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

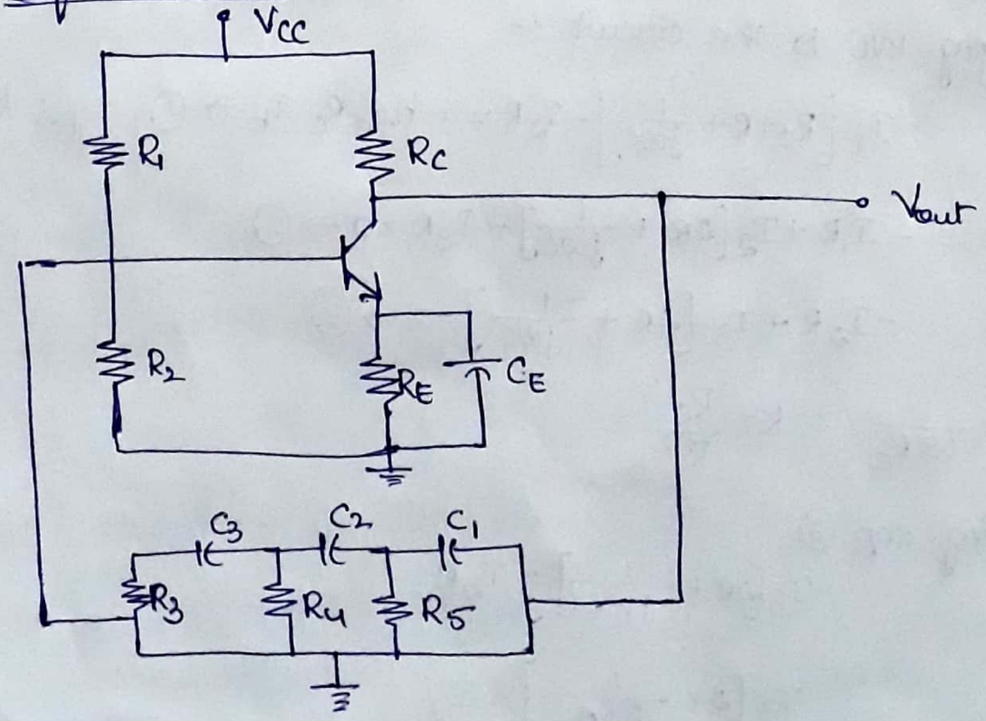
Advantages:-

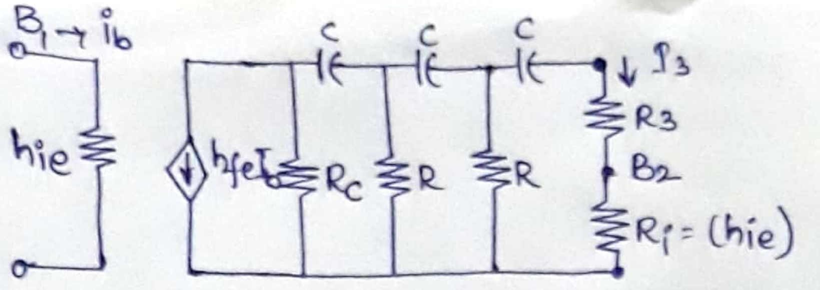
* Frequency can be varied by using both the variable capacitors
* The frequency stability is high.

Applications:-

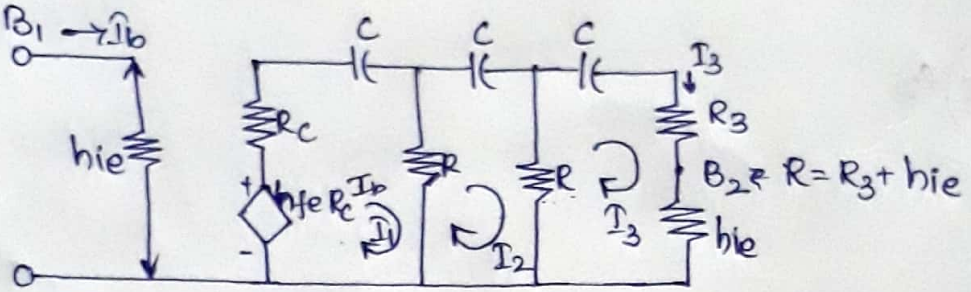
* It is used in mobile applications
* This can be used as temperature sensor.

RC phase shift Oscillator:-





Small signal ac equivalent model using h-parameters



Simplified small signal ac equivalent model.

The phase-shift oscillator circuit consists of a single transistor amplifier section and a RC phase shift network. The phase shift network consists of three RC sections. At the resonant frequency f_0 the phase shift in each RC section is 60°, so that the total phase shift produced by RC network is 180°. (12)

The small signal equivalent model is represented with current source. By simplifying the circuit, the current source is replaced by voltage source.

Applying KVL to the circuit :-

$$I_1\left[R_c + R + \frac{1}{j\omega C}\right] - I_2 R = -h_{fe} R_c I_b \rightarrow (1) \quad (\because R_3 = R - R_i)$$

$$-I_1 R + I_2\left[2R + \frac{1}{j\omega C}\right] - I_3 R = 0 \rightarrow (2)$$

$$-I_2 R + I_3\left[2R + \frac{1}{j\omega C}\right] = 0 \rightarrow (3)$$

I_3, I_1
I_2, I_2

$$\alpha = \frac{1}{\omega R_c} \; ; \; K = \frac{R_c}{R}$$

Solving eqn (3)

$$I_3\left[2R + \frac{1}{j\omega C}\right] = I_2 R$$

$$I_3\left[2 + \frac{1}{j\omega R C}\right] = I_2$$

$$\boxed{I_2 = I_3[2-j\alpha]} \quad \left(\because \alpha = \frac{1}{\omega RC}, \frac{1}{j} = -j\right)$$

Solve eqn (2)

$$I_2\left[2R + \frac{1}{j\omega C}\right] = R[I_1 + I_3]$$

$$I_2\left[2 + \frac{1}{j\omega RC}\right] = I_1 + I_3$$

$$I_2[2-j\alpha] = I_1 + I_3$$

Substitute $I_2 = I_3[2-j\alpha]$

$$I_3(2-j\alpha)(2-j\alpha) = I_1 + I_3$$

$$I_3[4-(j\alpha)^2 - 2(2)(-j\alpha)] = I_1 + I_3$$

$$I_3[4-\alpha^2-4j\alpha] = I_1 + I_3$$

$$I_3[4-\alpha^2-4j\alpha-1] = I_1$$

$$\boxed{I_3[3-\alpha^2-4j\alpha] = I_1}$$ (13)

Substitute I_1 & I_3 values in eqn (1)

$$I_1\left[R_C + R + \frac{1}{j\omega C}\right] - I_2 R = -h_{fe} R_C I_b.$$

$$R\left(I_1\left[\frac{R_C}{R} + 1 + \frac{1}{j\omega RC}\right] - I_2\right) = -h_{fe} R_C I_b.$$

$$I_1[K+1-j\alpha] - I_2 = -h_{fe} k I_b$$

$$I_3\left([K+1-j\alpha][3-\alpha^2-4j\alpha]\right) - I_3[2-j\alpha] = -h_{fe} k I_b.$$

$$I_3[3k+3-3j\alpha - k\alpha^2 - \alpha^2 - j\alpha^3 - j4k\alpha - j4\alpha - 4\alpha^2 - 2 + j\alpha] = -h_{fe} k I_b$$

$$I_3[(3k+1) - \alpha^2(k+5) - j((6+4k)\alpha - \alpha^3)] = -h_{fe} k I_b$$

$$\frac{I_3}{I_b} = \frac{-h_{fe} k}{(3k+1) - \alpha^2(k+5) - j[(6+4k)\alpha - \alpha^3]}$$

Since the loop gain is real quantity, we have

$$(6+4k)\alpha - \alpha^3 = 0$$

$$\alpha^2 = 6+4k$$

$\alpha = 6+4k$.

The frequency of oscillation f_0 is given by

$$f_0 = \frac{1}{2\pi RC\sqrt{6+4k}}$$

At this frequency the loop gain I_3/I_b becomes

$$\frac{I_3}{I_b} = \frac{h_{fe}\,k}{4k^2+23k+29}.$$

For sustained oscillations $I_3/I_b > 1$

to determine the value of k

$$\frac{dh_{fe}}{dk} = 4 - \frac{29}{k^2} = 0$$

$$k = \left(\frac{29}{4}\right)^{1/2}$$

(14)

$$k = 2.7.$$

Therefore,

$$(h_{fe})_{min} = 4(2.7) + 23 + \frac{29}{2.7} = 44.5.$$

The value of h_{fe} for a transistor must be at least 45 for the circuit to oscillate.

Advantages:-

* It can be used to produce very low frequencies.
* The circuit provides good frequency stability.

Disadvantages:-

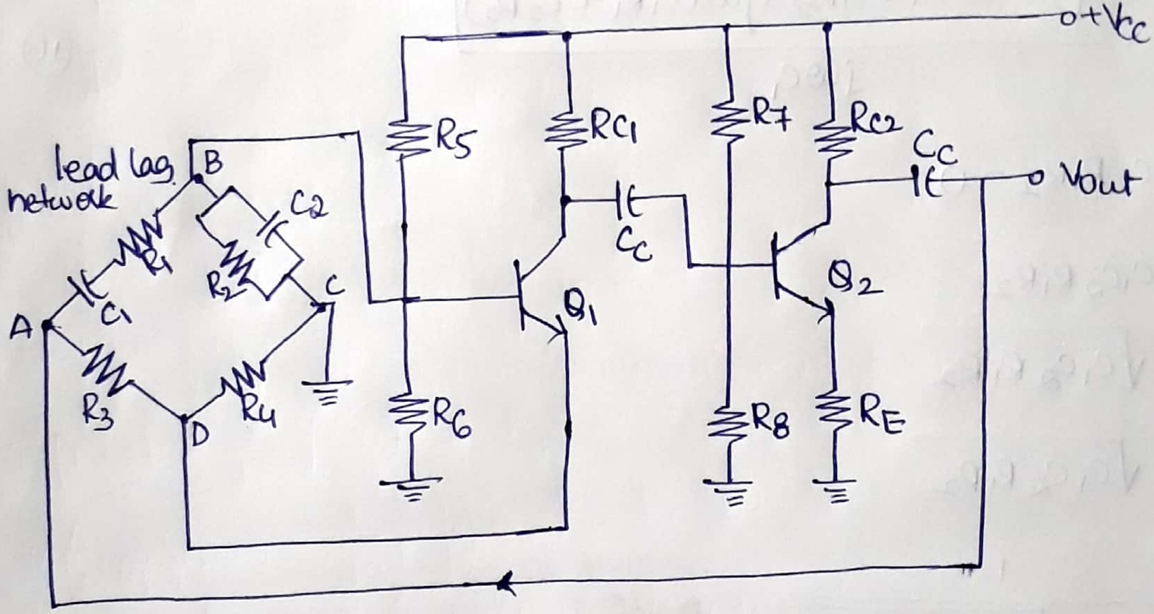
* At the starting oscillations are difficult as the feedback is small.
* The output produced is small.

Wein Bridge Oscillator:-

It is a two stage amplifier with RC bridge circuit. The bridge circuit has the arms R_1, C_1, R_2, C_2. The transistor Q_1 serves as an oscillator and an amplifier while the other transistor Q_2 serves as an inverter. The inverter operation provides a phase shift of 180°. This circuit provides positive feedback through R_1C_1, R_2C_2 to the transistor Q_1 and negative feedback through the transistor Q_2.

Operation :- When the circuit is switched ON, the bridge current Produces oscillations of the frequency stated above. The two transistors produce a total phase shift of 360° so that proper Positive feedback is ensured. The negative feedback in the circuit ensures constant output. This is achieved by temperature Sensitive tungsten lamp Lp. Its resistance increases with current. If the amplitude of the output increases, more current is produced and more negative feedback is achieved. Due to this, the output would return to the original value. Whereas, if the output decreases, reverse action would take place.

(15)



From the circuit;

$$\left[\frac{R_2 \cdot \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}}\right] R_3 = R_4 \left[R_1 + \frac{1}{j\omega C_1}\right]$$

$$\frac{R_3}{R_4} = \frac{\left[R_1 + \frac{1}{j\omega C_1}\right] \cdot \left[R_2 + \frac{1}{j\omega C_2}\right]}{R_2 \cdot \frac{1}{j\omega C_2}}$$

$$= \frac{\left(\frac{j\omega C_1 R_1 + 1}{j\omega C_1}\right)\left(\frac{j\omega C_2 R_2 + 1}{j\omega C_2}\right)}{\frac{R_2}{j\omega C_2}}$$

$$= \frac{R_2\left[-\omega^2 C_1 C_2 R_1 R_2 + j\omega C_1 R_1 + j\omega C_2 R_2 + 1\right]}{j\omega C_1}$$

$$\frac{R_3}{R_4} = \frac{R_2\left[(1-\omega^2 C_1 C_2 R_1 R_2) + j\omega(C_1 R_1 + C_2 R_2)\right]}{j\omega C_1}$$

(16)

$$1-\omega^2 C_1 C_2 R_1 R_2 = 0$$

$$\omega^2 = C_1 C_2 R_1 R_2$$

$$\omega = \sqrt{C_1 C_2 R_1 R_2}$$

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

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

Advantages :-

* It provides constant output
* The overall gain is high because of two transistors
* The circuit provides good frequency stability.

Disadvantages :-

* The circuit cannot generate very high frequencies.
* Two transistors and number of components are required for the circuit construction.

Applications:-

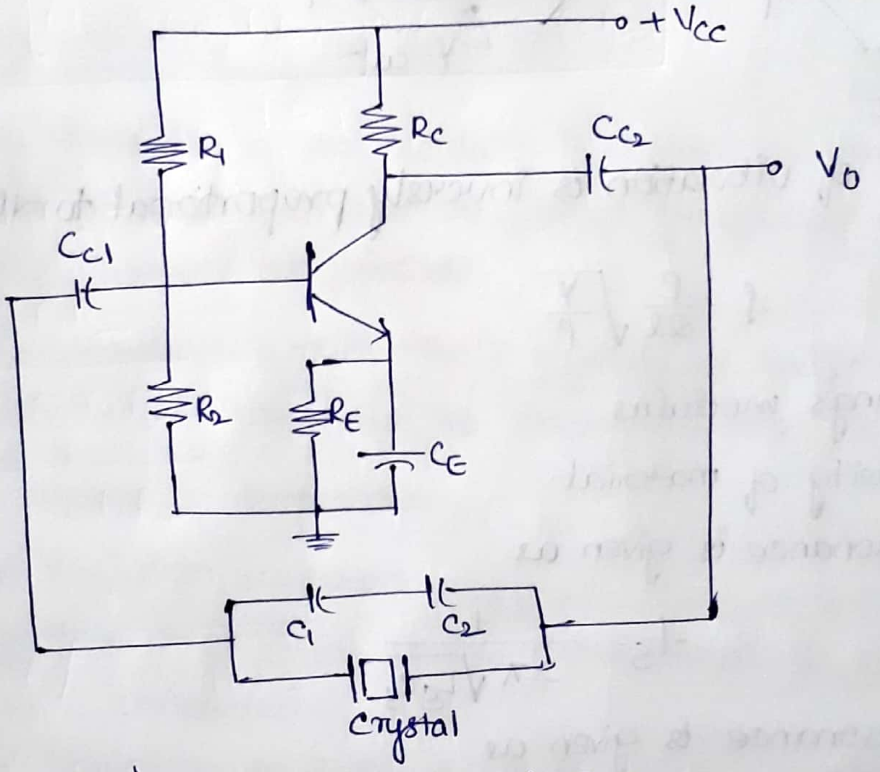
* It is used to measure the audio frequency.

* Wien bridge oscillator designs the long range of frequencies.

* It produces sine wave.

Crystal Oscillator :- Crystal oscillator is based on ~~in~~ piezoelectric effect.

(17)

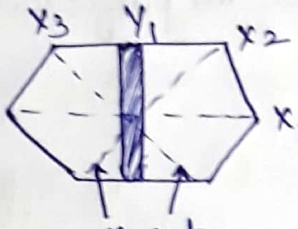


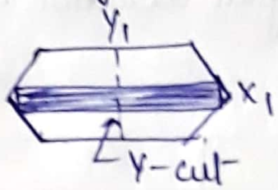
This is a colpitt's oscillator in which inductor is replaced by the crystal.

* A piezoelectric crystal, usually Quartz, is used as a resonant circuit. The crystal is a thin slice of piezoelectric material such as Quartz, tourmaline and rochelle salt. The piezoelectric effect represents the characteristics that the crystal reacts to any mechanical stress by producing an electric change, in the reverse effect, an electric field results in mechanical strain.

* Crystal is a wafer of quartz placed between two metal Plates. There are two different methods of cutting this crystal wafer. The method of cutting determines the natural resonant frequency and temperature coefficient of the crystal.

* When the wafer is cut in such a way that its flat surfaces are perpendicular to its electrical axis (x-axis), it is called x-cut crystal. When the flat surfaces are perpendicular to its mechanical axis (Y-axis) it is called Y-cut crystal.





(18)

The frequency of vibration is inversely proportional to thickness of the crystal.

$$f = \frac{P}{2l}\sqrt{\frac{Y}{\rho}}$$

where Y is Young's modulus

ρ is density of material.

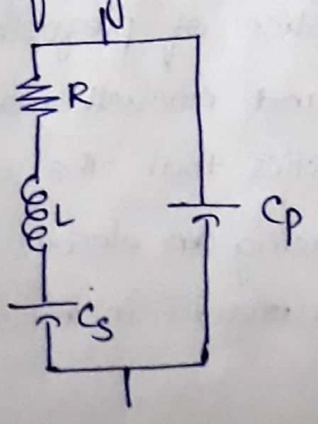
The series resonance is given as

$$f_s = \frac{1}{2\pi\sqrt{L_s C_s}}$$

The parallel resonance is given as

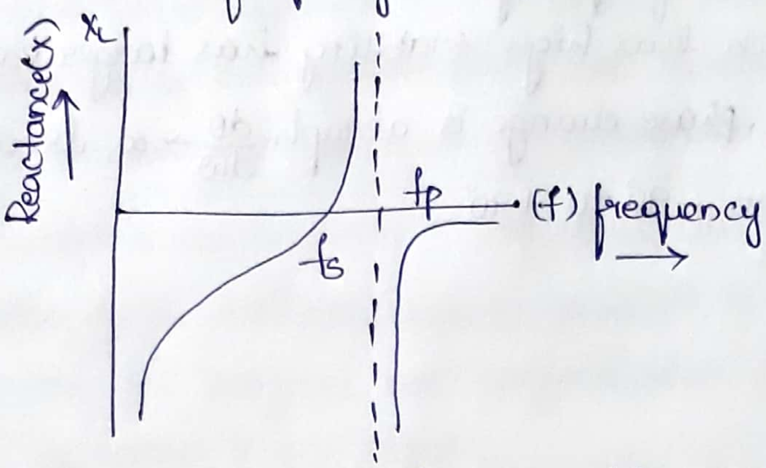
$$f_p = \frac{1}{2\pi\sqrt{L_p C_{eq}}} \qquad C_{eq} = \frac{C_p C_s}{C_p + C_s}.$$

The internal circuit of crystal is



~~The resonance and~~

The reactance and frequency are plotted as



The advantage of crystal is it has very high Q as a resonant circuit, which results in good frequency stability.

Frequency stability of an oscillator :- (19)

Frequency stability of an oscillator is defined as the ability of the oscillator to maintain the required frequency constant over a long time interval as possible.

* The main drawback is that the frequency of oscillations are not stable during a long time due to other factors. They are

(1). Due to change in temperature.

(2) Due to Variation in power supply.

(3) The effective resistance of the tank circuit is changed when the load is connected.

(4) Due to Variation in biasing conditions and loading conditions.

* The Variation of frequency with temperature is given by

$$S_{\omega,T} = \frac{\Delta\omega / \omega_0}{\Delta T / T_0} \text{ ppm (parts per million)}$$

ω_0, T_0 are desired frequency oscillations

$\Delta\omega, \Delta T$ are change in frequency and temperature.

* The frequency stability is defined as

$$S_\omega = \frac{d\theta}{d\omega}$$

where $d\theta$ is phase-shift

$d\omega$ is frequency

* The circuit which has high stability has larger value of $\frac{d\theta}{d\omega}$.

* If Q is infinite, phase change is abrupt, $\frac{d\theta}{d\omega} \to \infty$, because the Phase changes from $-90°$ to $+90°$.