Electronic Circuit Analysis

UNIT – I

Single stage and Multi stage Amplifiers

UNIT – I(a) : Single stage Amplifiers

1. Classification of Amplifiers
2. Distortion in Amplifiers
3. Analysis of CE, CC and CB configurations with simplified Hybrid model.
4. Analysis of CE Amplifier with Emitter Resistance an Emitter follower.
5. Miller's Theorem and its dual
6. Design of Single stage RC Coupled Amplifier Using B

UNIT – I(b) : Multistage Amplifiers

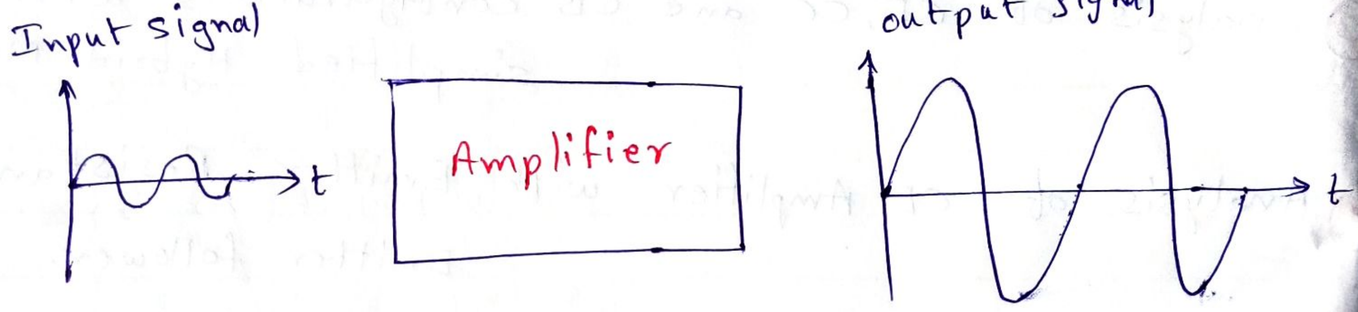
1. Analysis of Cascaded RC Coupled BJT Amplifiers.
2. Cascode Amplifier
3. Darlington Pair
4. Different Coupling Schemes used in Amplifiers
   - → RC Coupled Amplifier
   - → Transformer " "
   - → Direct " "

UNIT — I (a)

Single stage Amplifier

Amplifier :- Amplifier is a device, which is used to amplify the applied input signal.

Amplification :- It is the process of raising the strength of a weak signal without any change in its shape along the frequency.



Example :- ① BJT (Bipolar Junction Transistor)
② FET (Field Effect Transistor)

→ Amplifiers are used in - Essential part of Radio, TV, other communication circuit, etc.

Single stage Amplifier :- When only one Transistor with its associated circuit is used for ampliting the weak signal is known as single stage amplifier.

Multi stage Amplifier :- An amplifier which uses no. of stages (or) Transistors to obtain a desire amplification is known as Multi stage amplifier.

Small signal Amplifier :-

When the i/p signal is so weak as to produce a small fluxuation in the collector current compared to its operating point. This type of amplifier is known as small signal amplifier.

Large signal Amplifier :-

When the fluxuations in the collector current is large that is beyond the linear characteristics of the amplifier. This type of amplifier is the large signal amplifier.

Classification of Amplifiers :-

1. Based on configuration
   - → Common Emitter Amplifier
   - → " Base "
   - → " Collector "
2. Based on Input
   - → Small signal Amplifier (Voltage Amplifier)
   - → Large " " (Power ")

(3) Based on Output

→ Voltage Amplifier

→ Current "

→ Power "

(4) Based on Frequency

→ DC Amplifier (amplification from 0 Hz to 20 Hz)

→ Audio " (20 Hz – 20 KHz)

→ Video " (Amplifier up to few MHz)

→ Radio Frequency " (a few KHz to Hundreds of MHz)

→ Ultra high " " (hundreds (or) Thousands of MHz)

(5) Based on Bandwidth

→ Tuned Amplifier

→ Untuned "

(6) Based on Stages

→ Single stage Amplifier

→ Multi " "

(7) Based on Coupling

→ Direct coupling (DC) Amplifier

→ Resistance capacitance (RC) Coupled Amplifier

→ Inductor – Capacitor (LC) " "

→ Transformer coupled Amplifier

(8) Based on Biasing/ Position of operating Point:

→ Class A Amplifier

→ " B "

→ Class C Amplifier

→ " AB "

II Distortion in Amplifier :-

The change in the o/p waveform from the i/p waveform of an amplifier is known as "distortion".

Classification of Distortion :-

1. Amplitude / Non-Linear / Harmonic distortion
2. Frequency distortion
3. Phase / Delay distortion.

1. Amplitude / Non-Linear / Harmonic distortion :-

The transistor is perfectly linear device that is the dynamic characteristics of a transistor is a straight line over the operating range [$i_c = \beta i_b$]. But in practical ckt's, the dynamic characteristics is not perfectly linear. Due to such non-linearity in the dynamic char's, the waveform of the o/p voltage differs from that of the i/p signal. Such a distortion is called "non-linear distortion" (or) "amplitude distortion."

The harmonic distortion means the presence of the frequency components in the o/p waveform, which are not present in the i/p signal. The component with freq same as the i/p signal is called "fundamental freq component". The additional freq components present in the o/p signal are having freq components are called "harmonic components" or "harmonics."

② Frequency Distortion :-

This type of distortion exists when the signal components of different freq's are amplified differently.

This distortion is due to the various freq dependent "reactances" (both capacitive and inductive) associated with the circuit the active device (BJT or FET) itself.

③ Phase (or) Delay Distortion :-

Delay distortion is a phaseshift distortion, it results due to unequal phase shift of signals of different frequencies.

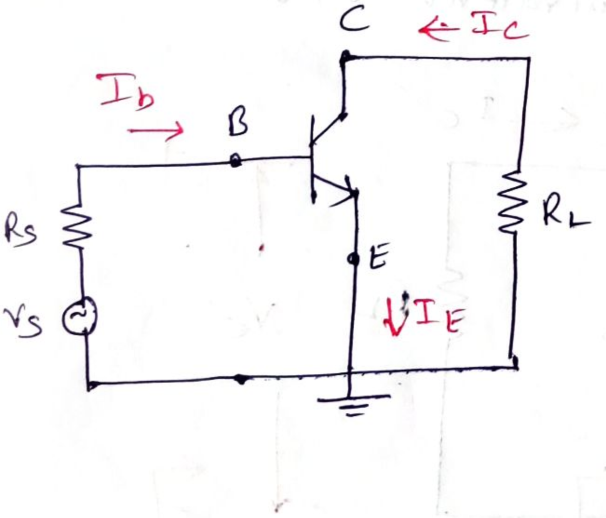
when this distortion exists the phase angle of the gain (A) depends upon the frequency.

III Analysis of CE, CC and CB configurations with simplified Hybrid Model :-

If $h_{oe} \cdot R_L < 0.1$ then the rule is satisfies then we can proceed for Approximate analysis otherwise do the exact analysis.

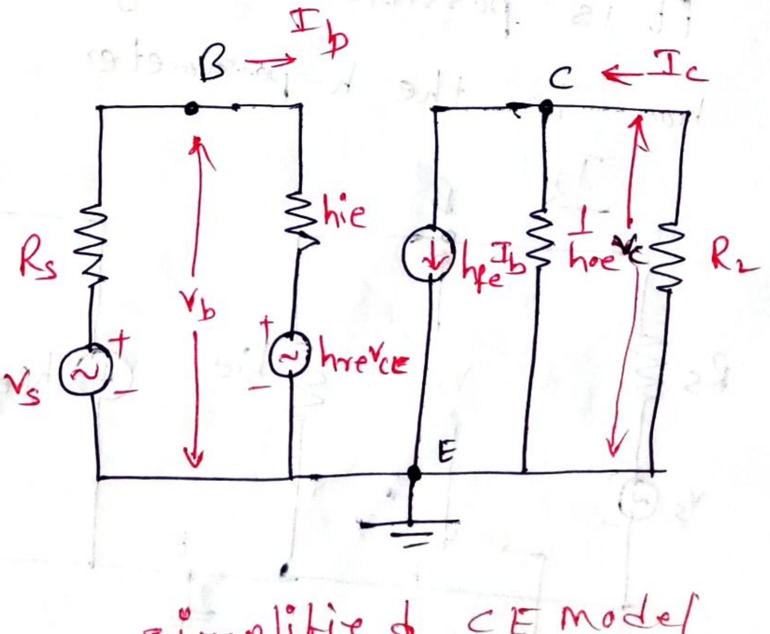
	CE	CC	CB
h_i	$1100\,\Omega$	$1100\,\Omega$	$22\,\Omega$
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	-50	0.98
h_o	$25\,\mu A/v$	$25\,\mu A/v$	0.49

① simplified CE Hybrid model :-



· CE Transistor ckt

$\equiv$



simplified CE model (equivalent ckt)

→ If $\frac{1}{h_{oe}} >> R_L \| R_c$, then h_{oe} may be neglected.

→ If we neglect h_{oe} the collector current I_c is given by

$$I_c = h_{fe} I_b$$

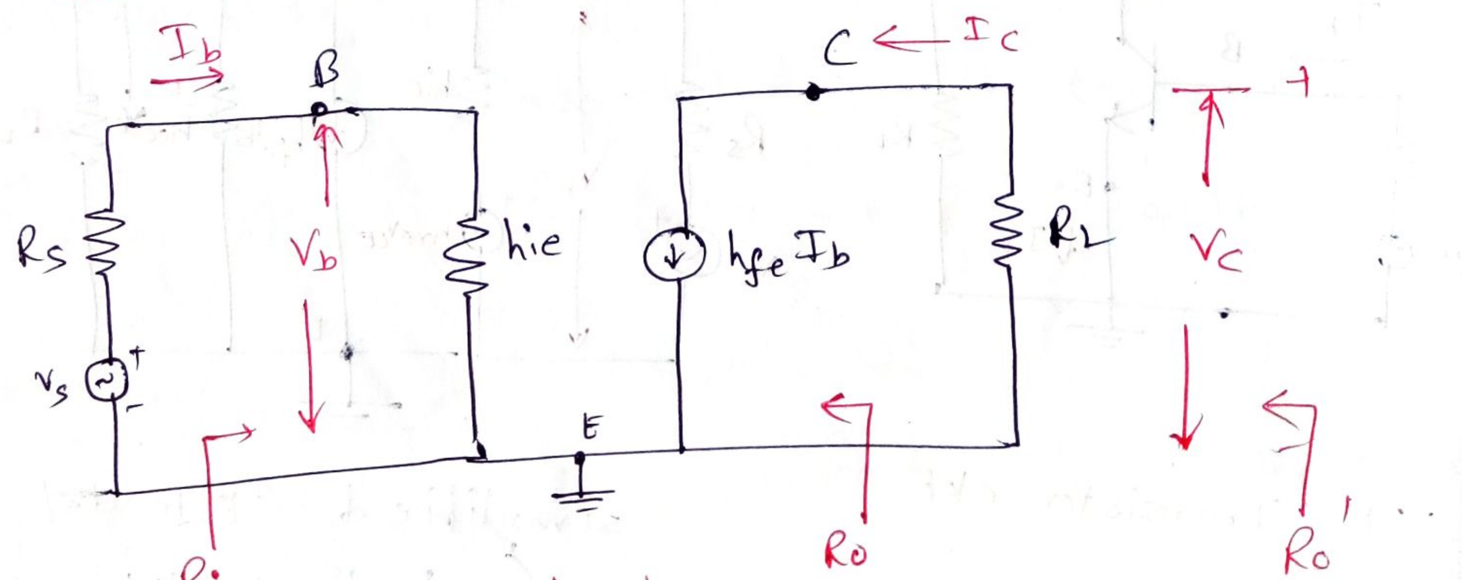
→ Under these conditions the magnitude of the voltage of the generator in the emitter ckt

$$h_{re} |V_{ce}| = h_{re} \, I_c (R_L \| R_c)$$

$$= h_{re} \, h_{fe} \, I_b (R_L \| R_c)$$

→ since $h_{re} \cdot h_{fe} \simeq 0.01$, this voltage may be neglected in comparision with the $h_{ie} I_b$ drop across h_{ie} provided that $R_L \| R_c$ is not too large.

→ Hence if the load resistance $R_L \| R_c$ is small it is possible to neglect the parameters h_{re} & h_{oe} in the h-parameter equivalent ckt.



Approximate CE model

current gain :- $A_i = \frac{-I_c}{I_b} = \frac{-h_{fe}}{1 + h_{oe} R_L}$

By neglecting hoe

$$\boxed{A_i \approx -h_{fe}}$$

Input Impedance :- $R_i = h_{ie} + h_{re} A_i R_L$

By neglecting hre

$$\boxed{R_i \approx h_{ie}}$$

voltage Gain :- $A_v = \frac{A_i R_L}{R_i}$

$$\boxed{A_v = A_i \frac{R_L}{h_{ie}}}$$

Output Impedance :-

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s}$$

By neglecting hoe and hre

$$Y_o = 0$$

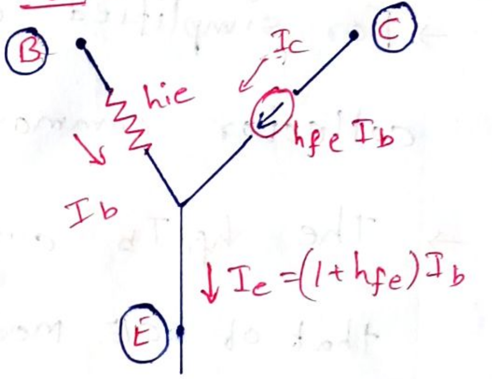
$$R_o = \frac{1}{Y_o} = \frac{1}{0} = \infty$$

$$R_o' = R_o \| R_L = \infty \| R_L = R_L$$

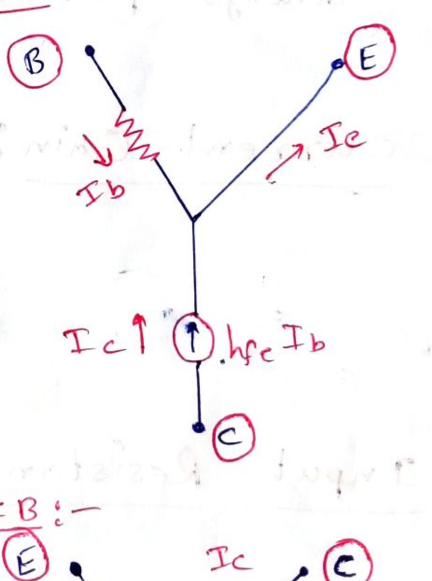
$$\boxed{R_o' = R_L}$$

Approximate Analysis

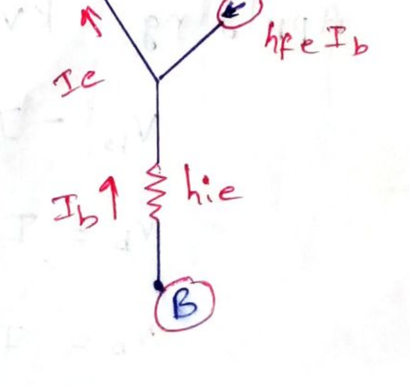
CE :-



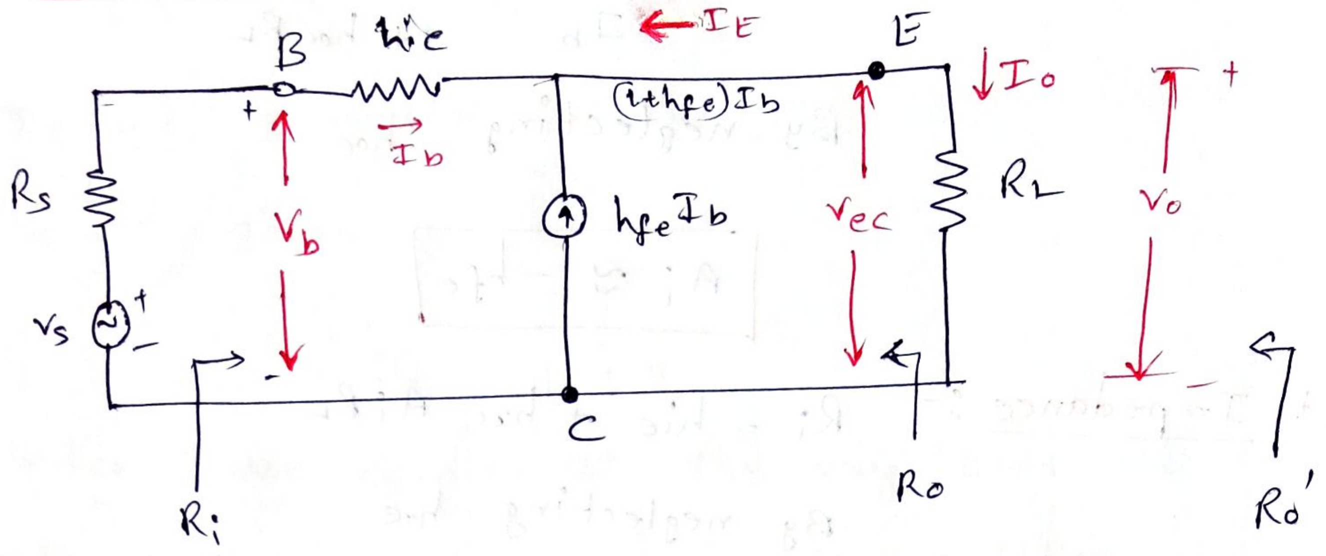
CC :-



CB :-



② simplified CC Hybrid model :-



→ For simplified CC model, we have to make collector common and take the o/p from emitter.

→ The $h_{fe}I_b$ current direction is now exactly opposite that of CE model because the current $h_{fe}I_b$ always points towards emitter.

Current Gain :- $A_i = \frac{I_o}{I_b} = \frac{-I_e}{I_b} = \frac{(1+h_{fe})\cancel{I_b}}{\cancel{I_b}}$

$$\boxed{A_i = 1 + h_{fe}}$$

Input Resistance :- $R_i = \frac{V_b}{I_b}$

Applying KVL to the i/p ckt, we get

$$V_b - I_b h_{ie} - I_o R_L = 0$$

$$V_b = I_b h_{ie} + I_o R_L$$

$$V_b = I_b \left(h_{ie} + \frac{I_o}{I_b} R_L \right)$$

$$\frac{V_b}{I_b} = hie + \frac{I_o}{I_b} R_L$$

$$\boxed{R_i = \frac{V_b}{I_b} = hie + (1+h_{fe}) R_L}$$

Voltage Gain :- $A_V = \frac{V_o}{V_b} = \frac{I_o R_L}{I_b R_i} = \frac{I_o}{I_b} \cdot \frac{R_L}{R_i}$

$$\boxed{A_V = A_i \frac{R_L}{R_i}}$$

Output Resistance :- $R_o = \left.\frac{V_o}{I_e}\right|_{V_S = 0}$

Applying KVL to the ckt, we get

$$V_s - I_b R_s - I_b hie - V_o = 0$$

$$V_o = - I_b R_s - I_b hie \qquad [\because V_s = 0]$$

$$V_o = - I_b (R_s + hie)$$

Emitter current, $I_e = -(1+ h_{fe}) I_b$

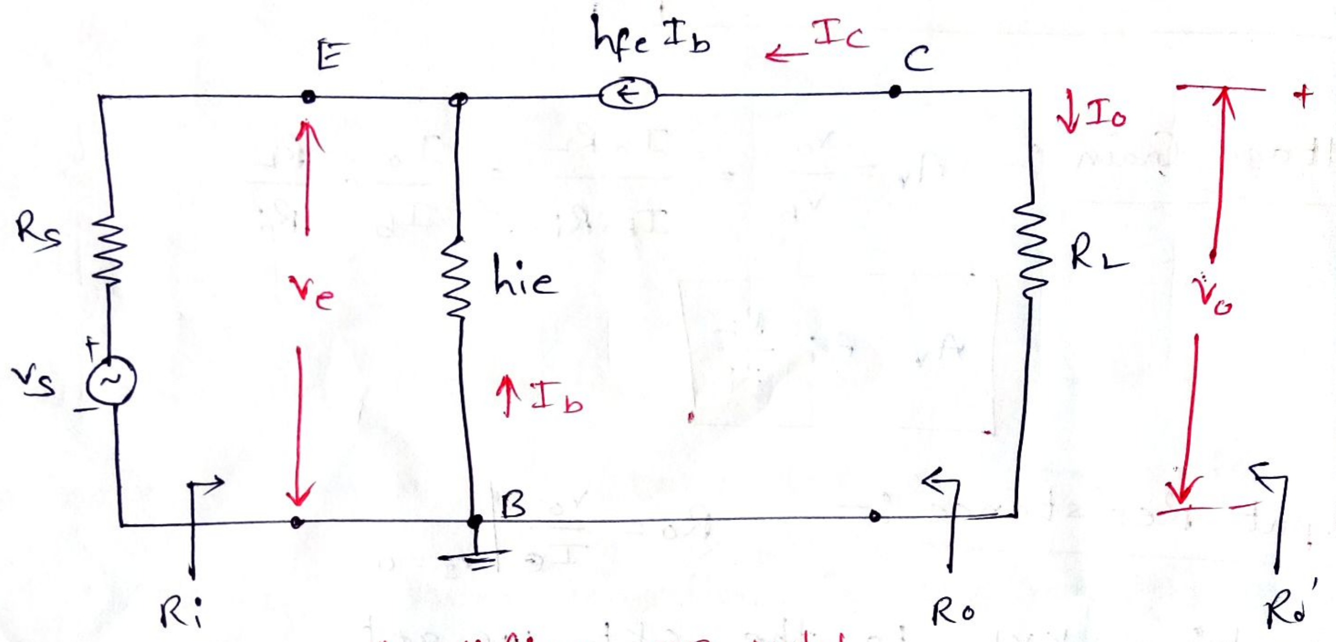
$$R_o = \frac{V_o}{I_e} = \frac{\cancel{+}\cancel{I_b} (R_s + hie)}{\cancel{+}(1+h_{fe}) \cancel{I_b}}$$

$$\boxed{R_o = \frac{R_s + hie}{1+h_{fe}}}$$

$$\boxed{R_o' = R_o \| R_L}$$

③ Simplified CB Hybrid Model :-

In this ckt, giving i/p to emitter, taking o/p from collector & making base common.



simplifier CB model

Current Gain :-

$$A_i = \frac{I_o}{I_e} = \frac{-I_C}{I_e} = \frac{-h_{fe} I_b}{-(1+h_{fe}) I_b}$$

$$\boxed{A_i = \frac{h_{fe}}{1+h_{fe}}}$$

Input Resistance :- $R_i = \frac{V_e}{I_e}$

$$V_e = -hie\, I_b$$

$$I_e = -(1+h_{fe}) I_b$$

$$R_i = \frac{V_e}{I_e} = \frac{-hie\, \cancel{I_b}}{-(1+h_{fe}) \cancel{I_b}} \Rightarrow \boxed{R_i = \frac{hie}{1+h_{fe}}}$$

Voltage Gain :-

$$A_V = \frac{V_o}{V_e} = \frac{I_o R_L}{I_e R_i} = \frac{I_o}{I_e} \cdot \frac{R_L}{R_i}$$

$$A_V = A_i \frac{R_L}{R_i}$$

substituting value of A_i & R_i we get

$$A_V = \frac{h_{fe}}{\cancel{1+h_{fe}}} \cdot \frac{R_L}{\frac{h_{ie}}{\cancel{1+h_{fe}}}} = \frac{h_{fe} \cdot R_L}{h_{ie}}$$

$$\boxed{A_V = \frac{h_{fe} \cdot R_L}{h_{ie}}}$$

Output Resistance :-

$$R_o = \left.\frac{V_o}{I_c}\right|_{V_s=0}$$

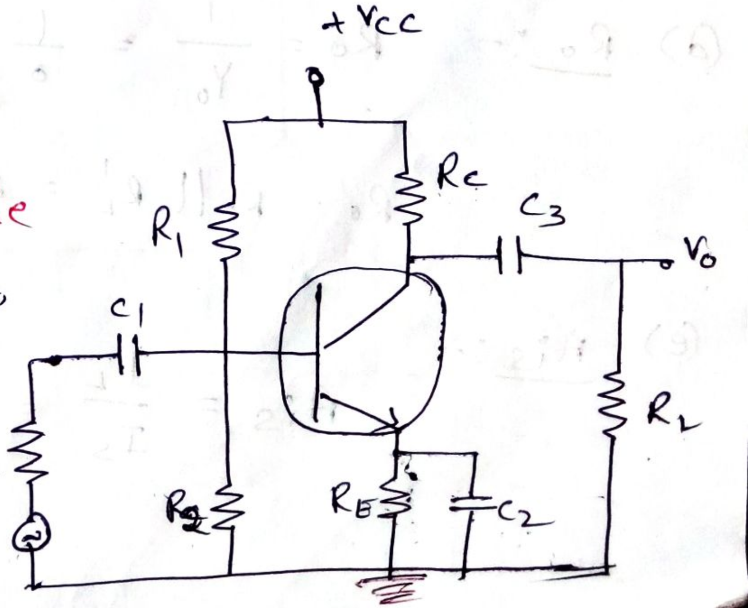
when $V_s = 0$, the current through i/p loop $I_b = 0$,

hence $I_c = 0$ and $R_o = \infty$

$$R_o' = R_o \| R_L = \infty \| R_L = R_L$$

$$\boxed{R_o' = R_L}$$

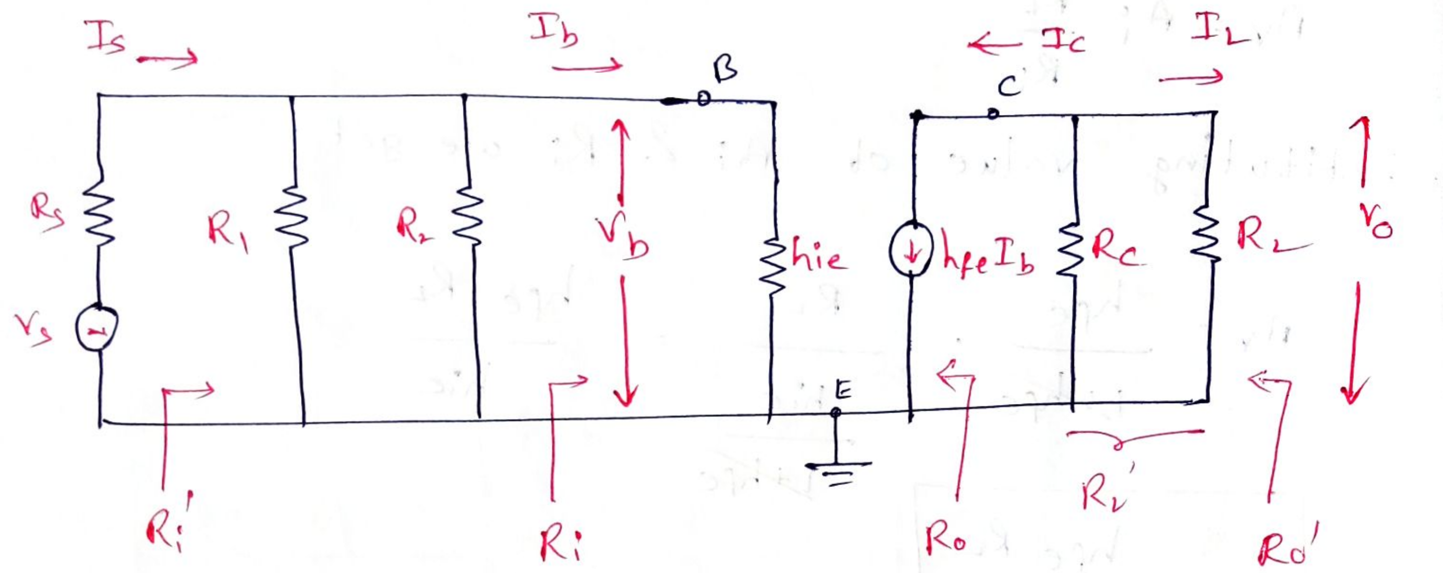
Problem ①:- Consider a single stage CE amp with $R_s = 1K\Omega$, $R_1 = 50K$, $R_2 = 2K$, $R_C = 2K$, $R_L = 2K$, $R_E = 2K$, $h_{fe} = 50$, $h_{ie} = 1.1K$, $h_{oe} = 25\,\mu A/V$ and $h_{re} = 2.5 \times 10^{-4}$



Find A_i, R_i, A_v, R_o, $A_{is} = \frac{I_L}{I_s}$ and $A_{vs} = \frac{V_o}{V_s}$.

Sol :- since $h_{oe} \cdot R_L' = 25 \times 10^{-6} \times (2K \| 2K) = 0.025$,

which is less than 0.1, we use approximate analysis



(a) A_i :- $A_i = -h_{fe} = -50$

(b) R_i :- $R_i = h_{ie} = 1.1 K\Omega$

$R_i' = h_{ie} \| R_1 \| R_2$

$= 1.1K \| 50K \| 2K = 700\Omega$

(c) A_v :- $A_v = A_i \frac{R_L'}{R_i} = -50 \times \frac{(2K \| 2K)}{1.1K} = -45.45$

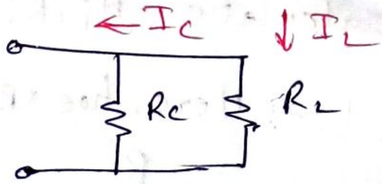
(d) R_o :- $R_o = \frac{1}{Y_o} = \frac{1}{0} = \infty$

$R_o' = R_o \| R_L' = \infty \| 2K \| 2K = 1 K\Omega$

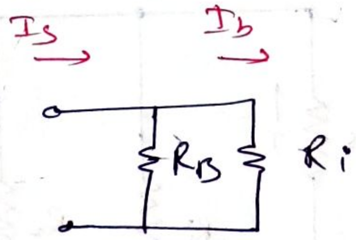
(e) A_{is} :-

$A_{is} = \frac{I_L}{I_s} = \frac{I_L}{I_c} \times \frac{I_c}{I_b} \times \frac{I_b}{I_s}$

$$\frac{I_L}{I_c} = \frac{R_c}{R_c + R_L} = \frac{-2k\Omega}{2k + 2k} = -0.5$$



$$\frac{I_c}{I_b} = h_{fe} = 50$$



$$\frac{I_b}{I_s} = \frac{R_B}{R_B + R_i} = \frac{(50 \| 2)}{(50 \| 2) + 1.1} = 0.636$$

$$\therefore A_{IS} = \frac{I_L}{I_s} = -0.5 \times 50 \times 0.636 = \underline{-15.9}$$

(f) A_{vs} :-

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_b} \times \frac{V_b}{V_s}$$

$$\frac{V_o}{V_b} = A_v = -45.45$$

$$\frac{V_b}{V_s} = \frac{R_i'}{R_i' + R_s} = \frac{700}{700 + 1k} = 0.411$$

$$\therefore A_{vs} = (-45.45) \times (0.411) = \underline{-18.71}$$

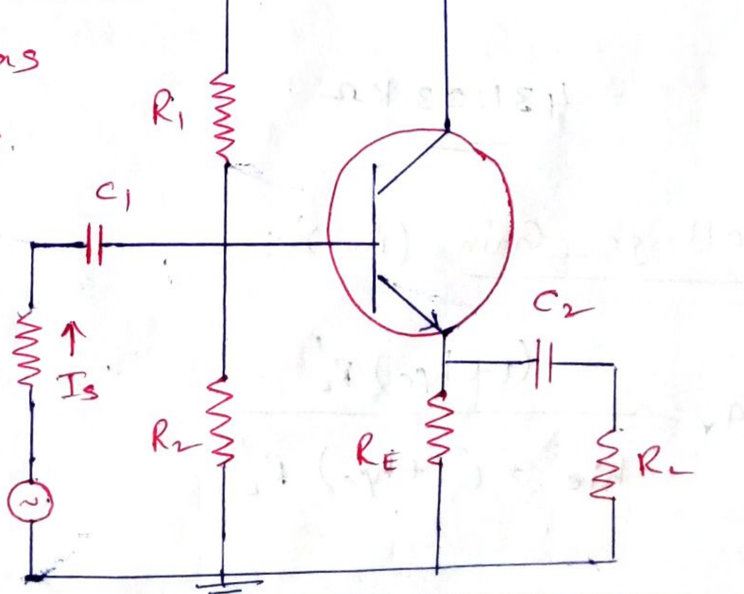
Problem (2) :- A common collector ckt as shown in Fig., has the following components.

$R_1 = 27\,k\Omega$, $R_2 = 27\,k\Omega$

$R_E = 5.6\,k\Omega$, $R_L = 47\,k\Omega$

$R_s = 600\,\Omega$. The transistor parameters are $h_{ie} = 1\,k\Omega$

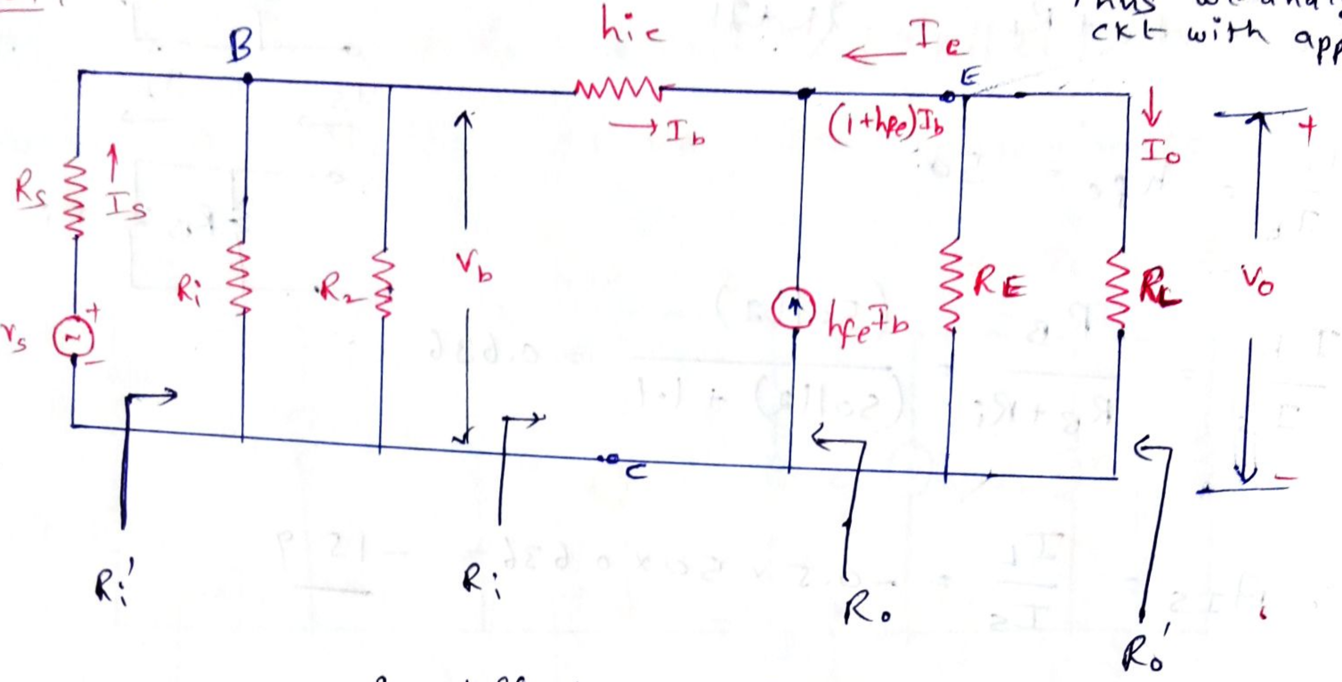
$h_{fe} = 85$ and $h_{oe} = 2\,\mu A/V$.



Calculate $A_i, R_i, A_v, R_o, A_{vs}$ and A_{is}.

Sol:- Here, $h_{oe} \times R_L' = (2\times10^{-6})(5.6K \| 47K) = 0.01$, which is less than 0.1

Thus we analyse the ckt with approximate method.



simplified Hybrid model

(a) Current Gain (A_i) :-

$$A_i = 1 + h_{fe} = 1 + 85 = 86$$

(b) Input Resistance (R_i) :-

$$R_i = h_{ie} + (1+h_{fe}) R_L'$$

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

$$= 1K + (1+85)(5.6K \| 47K)$$

$$= 431.33\ K\Omega$$

(c) Voltage Gain (A_v) :-

$$A_v = \frac{(1+h_{fe}) R_L'}{h_{ie} + (1+h_{fe}) R_L'}$$

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

$$= \frac{(1+85)(5.6K \| 47K)}{1K + (1+85)(5.6K \| 47K)}$$

$$= 0.997$$

(d) output Resistance (R_o) :-

$$R_o = \frac{R_s' + h_{ie}}{1+h_{fe}} = \frac{(R_1 \| R_2 \| R_s) + h_{ie}}{1+h_{fe}} = \frac{(27K \| 27K \| 600) + 1K}{1+85} = 18.3\,\Omega$$

$$R_o' = R_o \| R_E \| R_L = 18.3 \| 5.6K \| 47K = 18.23\,\Omega$$

(e) overall Voltage Gain (A_{vs}) :-

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_b} \times \frac{V_b}{V_s}$$

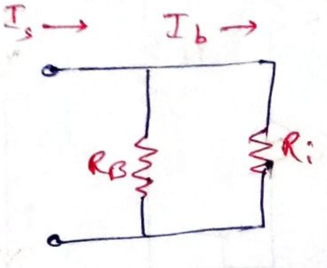
where, $\frac{V_o}{V_b} = A_v$, $\frac{V_b}{V_s} = \frac{R_i'}{R_i' + R_s}$

$$A_{vs} = A_v \cdot \frac{R_i'}{R_i' + R_s} = 0.997 \times \frac{13.09K}{13.09K + 600} = 0.953$$

(f) Overall Current Gain (A_{is}):-

$$A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_e} \times \frac{I_e}{I_b} \times \frac{I_b}{I_s}$$

where, $\frac{I_o}{I_e} = \frac{-R_E}{R_E + R_L} = \frac{-5.6K}{5.6K + 47K} = -0.106$

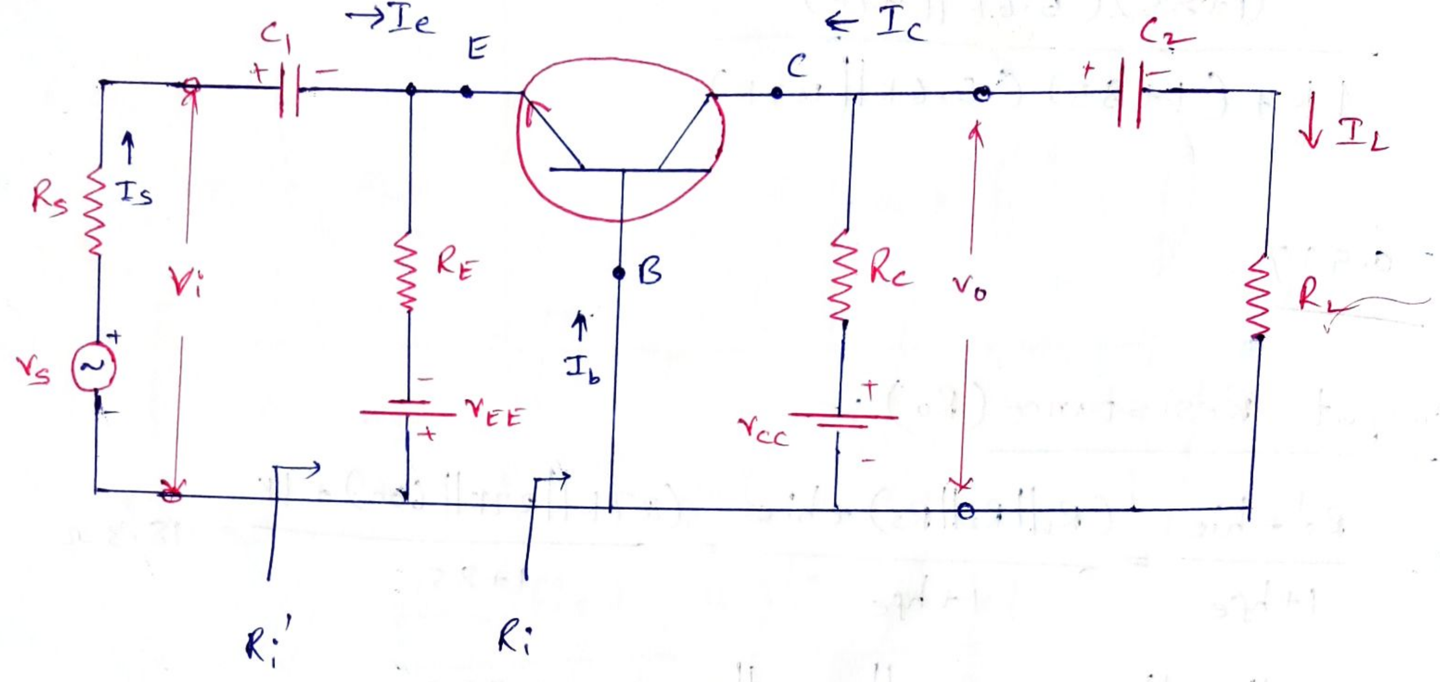


$$\frac{I_e}{I_b} = -(1+h_{fe}) = -(1+85) = -86.$$

$$\frac{I_b}{I_s} = \frac{R_B}{R_B + R_i} = \frac{(R_1 \| R_2)}{(R_1 \| R_2) + R_i} = \frac{(27K \| 27K)}{(27K \| 27K) + 431.93K} = 0.03$$

$$A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_e} \times \frac{I_e}{I_b} \times \frac{I_b}{I_s} = (-0.106)(-86)(0.03) = 0.273$$

Problem (3):-

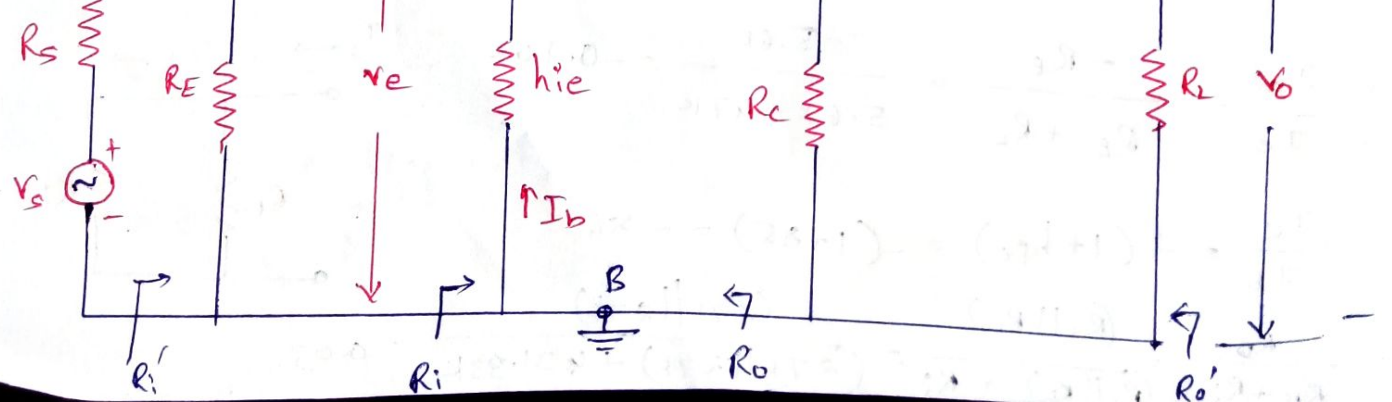


A Common Base amplifier, as shown in Fig., has the following components: $R_s = 600\Omega$, $R_C = 5.6\,K\Omega$, $R_E = 5.6\,K\Omega$, $R_L = 3.9\,K\Omega$. The transistor parameters are $h_{ie} = 1k\Omega$, $h_{fe} = 8$. and $h_{oe} = 2\,\mu A/V$. Calculate R_i, R_o, A_v, A_i, A_{vs}.

Sol:- Since $h_{oe} \times R_L' = h_{oe} \times (R_C \| R_L) = (2\times10^{-6}) \times (5.6K \| 39K\Omega)$

$= 9.79\times10^{-3} = 0.00979$

which is less than 0.1, we use approximate analysis method.



(a) Current Gain (A_i) :- $A_i = \frac{h_{fe}}{1+h_{fe}} = \frac{85}{1+85} = 0.988$

(b) Input Resistance (R_i) :- $R_i = \frac{h_{ie}}{1+h_{fe}} = \frac{1K}{1+85} = 11.627\Omega$

$R_i' = R_i || R_E = 11.627 || 5.6K = 11.6\Omega$

(c) Voltage Gain (A_v) :- $A_v = \frac{h_{fe} R_L'}{h_{ie}} = \frac{h_{fe} \times (R_C || R_L)}{h_{ie}}$

$= \frac{85 \times (5.6K || 39K)}{1K} = 416.23$

(d) Output Resistance (R_o) :- $R_o = \infty$

$R_o' = R_o || R_L' = R_o || R_C || R_L = \infty || 5.6K || 39K = 4.89K\Omega$

(e) Overall Voltage Gain (A_{vs}) :-

$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_e} \times \frac{V_e}{V_s} = A_v \times \frac{V_e}{V_s}$

where, $\frac{V_e}{V_s} = \frac{R_i'}{R_i' + R_s} = \frac{11.6}{11.6 + 600} = 0.0189$

$A_{vs} = 416.23 \times 0.0189 = 7.89$

IV Analysis of CE Amplifier with Emitter Resistance

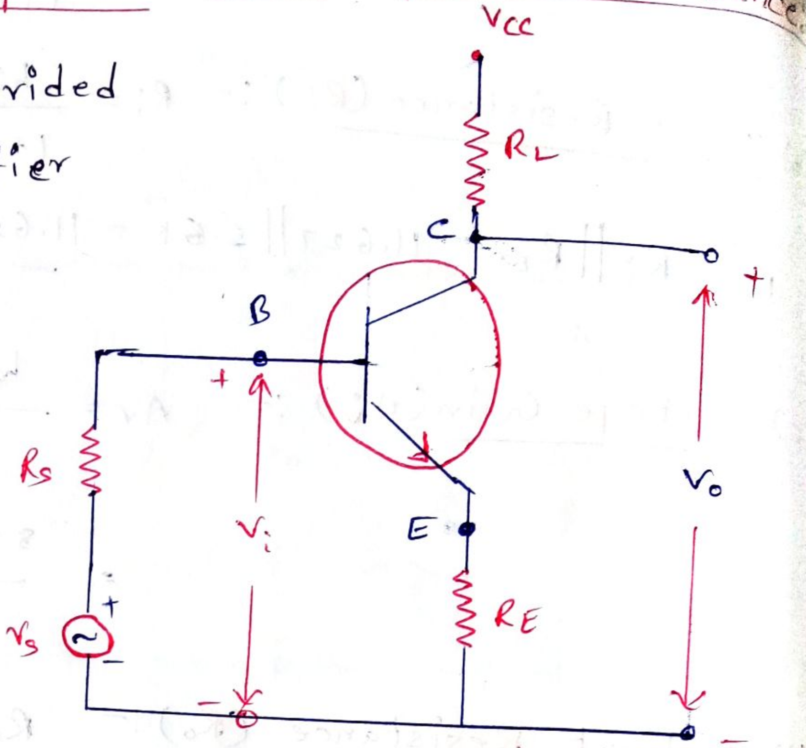
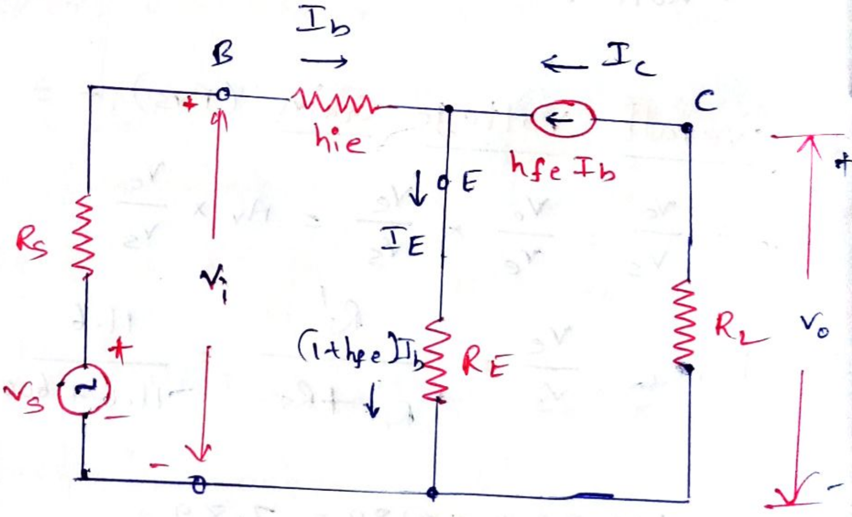


Fig (a)

→ Whenever the gain provided by a single stage amplifier is not subbicient, it is necessary to cascade the no. of stages of the amplifier.

→ In such situations, it becomes important to stabilize the voltage amplification of each stage, because instability of the first stage is amplified in the next.

→ This is not desired. The simple and effective way to obtain voltage gain stabilization is to add an emitter resistance R_E to a CE stage as shown in Fig(a)



Fig(b). Approximate model for CE Amplifier with R_E

→ The presence of emitter resistance has no. of better effects on the amplibier performance. these ebbects can be analysed with the help of h-parameter equivalent circuit.

Approximate Analysis :-

An approximate analysis of the common emitter circuit with R_E can be made using approximate h-parameter equivalent circuit shown in Fig.(b).

Current Gain (A_i):-

$$A_i = \frac{-I_c}{I_b} = \frac{-h_{fe}\cancel{I_b}}{\cancel{I_b}}$$

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

Input Resistance (R_i):-

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

The input resistance due to factor $(1+h_{fe})R_E$ may be very much larger than h_{ie}. Hence an emitter resistance greatly increases the input resistance.

Voltage Gain (A_V) :-

$$\boxed{A_V = A_i \cdot \frac{R_L}{R_i} = \frac{-h_{fe}R_L}{h_{ie} + (1+h_{fe})R_E}}$$

Output Resistance (R_o) :-

$$R_o = \left.\frac{V_o}{I_o}\right|_{V_s=0}$$

when $V_s = 0$, the current through the i/p loop $I_b = 0$. hence I_c and I_b both are zeros. Therefore $R_o = \infty$.

The output resistance R_o' of the stage, taking the load into account is given as,

$$R_o' = R_o \| R_L = \infty \| R_L = R_L \Rightarrow \boxed{R_o' = R_L}$$

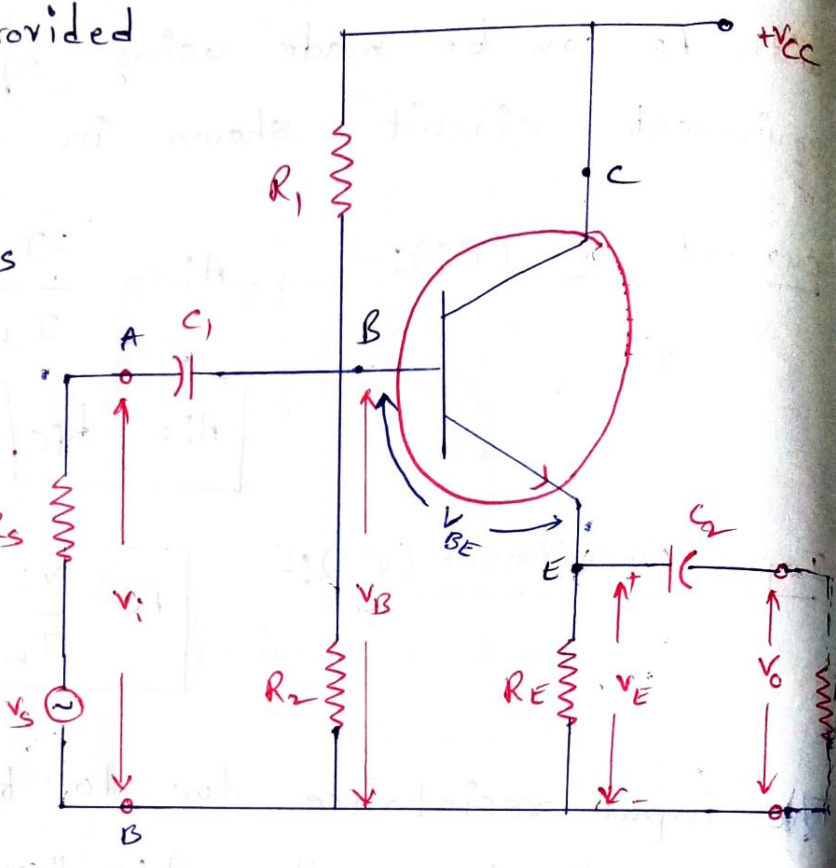
Emitter Follower (or) Common Collector Amplifier :-

→ The d.c. biasing is provided by R_1, R_2 and R_E.

→ The load resistance is capacitor coupled to the emitter terminal of the transistor.

→ When a signal is applied via to the base of the transistor, V_B is increased and decreased as the signal goes +ve and −ve respectively

i.e., $V_E = V_B - V_{BE}$



Common Collector Circuit

→ Considering V_{BE} fairly constant, we say that variation in the V_B appears at emitter and emitter voltage V_E will vary same as base voltage V_B.

→ Since the emitter is o/p terminal, it can be noted that the o/p voltage from a Common collector circuit is the same as its i/p voltage.

→ We can say that in Common Collector circuit emitter terminal follows the signal voltage applied to the base. Hence it is also known as "Emitter follower"

Miller's Theorem :-

The Miller theorem is used for converting any circuit having configuration to another configuration.

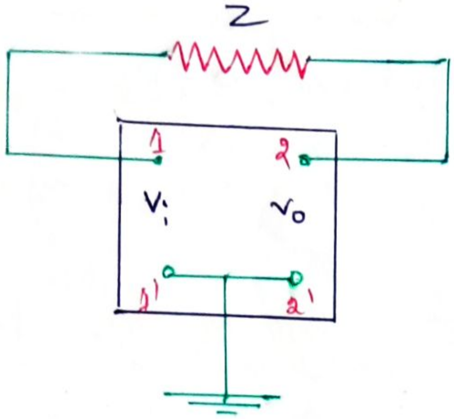


Fig.(a)

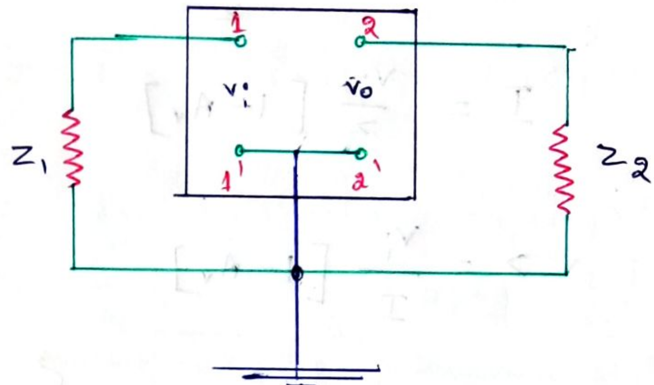


Fig.(b)

→ If z is the impedance connected between two nodes, node 1 and node 2, it can be replaced by two separate impedance z_1 and z_2.

→ where z_1 is connected b/w node 1 and ground.

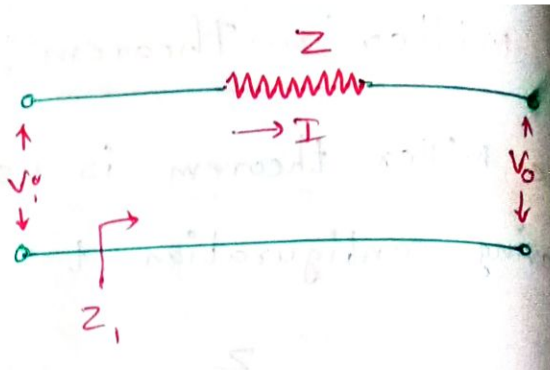
z_2 " " " 2 "

→ The V_i and V_o are the voltages at the node 1 and node 2 respectively. The values of z_1 and z_2 can be derived from the ratio of V_o and V_i, (V_o/V_i). denoted by $K\left(=\frac{V_o}{V_i}\right)$.

Proof of Miller's Theorem :-

→ Miller theorem states that, the effect of resistance z on the i/p ckt is a ratio of i/p voltage V_i to the current I which flows from the i/p to the o/p.

$$\therefore \quad Z_1 = \frac{V_i}{I} \quad \text{——— (1)}$$



where,

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

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

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

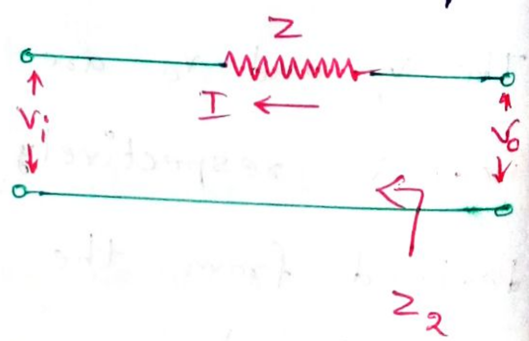
$$Z = \frac{V_i}{I}\left[1 - A_v\right]$$

$$Z = Z_1\left[1 - A_v\right] \quad \left[\because \text{from Eqn (1)}\right]$$

$$\boxed{Z_1 = \frac{Z}{1 - A_v} = \frac{Z}{1 - K}} \quad \left[\because \frac{V_o}{V_i} = A_v = K\right]$$

→ Miller theorem states that, the effect of resistance Z on the o/p ckt is a ratio of o/p voltage V_o to the current I which flows from the o/p to the i/p.

$$\therefore \quad Z_2 = \frac{V_o}{I} \quad \text{——— (2)}$$



where,

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

$$= \frac{V_o\left[1 - \frac{1}{A_v}\right]}{Z} = \frac{V_o\left[\frac{A_v - 1}{A_v}\right]}{Z} = \frac{V_o}{Z}\left[\frac{A_v - 1}{A_v}\right]$$

$$I = \frac{V_o}{Z}\left[\frac{A_v - 1}{A_v}\right]$$

$$Z = \frac{V_o}{I}\left[\frac{A_v - 1}{A_v}\right]$$

$$Z = Z_2\left[\frac{A_v-1}{A_v}\right] \qquad \left[\because \text{from Eqn } ②\right]$$

$$\boxed{Z_2 = Z \cdot \frac{A_v}{A_v - 1} = Z \cdot \frac{K}{K-1}} \qquad \left[\because \frac{V_o}{V_i} = A_v = K\right]$$

Dual of Miller's Theorem :-

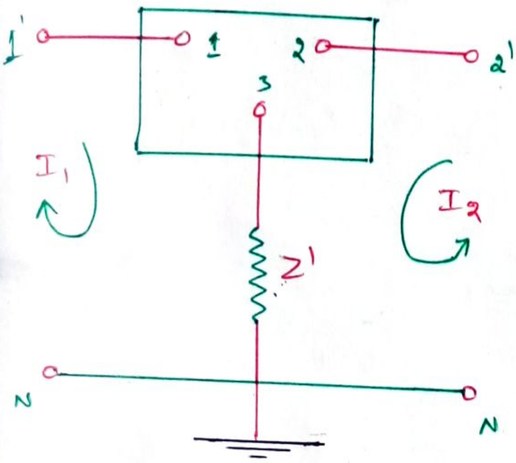


Fig. 1

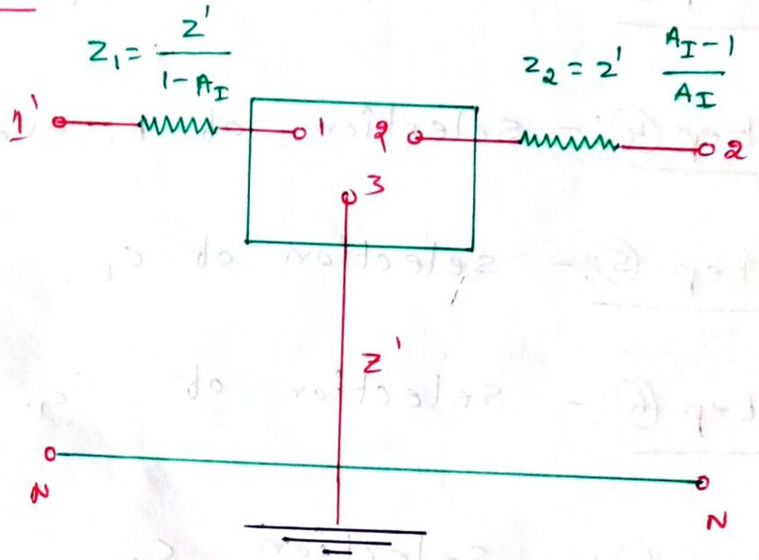


Fig. 2

→ where Z' is the impedance b/w 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 is added to mesh 2.

$$Z_1 = \frac{Z'}{1 - A_I}, \qquad Z_2 = Z'\left[\frac{A_I - 1}{A_I}\right]$$

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

VI Design of single stage RC coupled Amplifier using BJT :-

The following steps required for amplifier design.

Step ① :- Calculate the load resistance R_L.

step ② :- Selection of Q-point.

step ③ :- Calculate of R_E.

step ④ :- Selection of R_1 and R_2.

step ⑤ :- selection of C_E.

step ⑥ :- Selection of C_{c_1}.

step ⑦ :- Selection C_{c_2}.

step ⑧ :- Calculation of Power dissipation in Resistors.

UNIT – I(b)

Multi stage Amplifiers

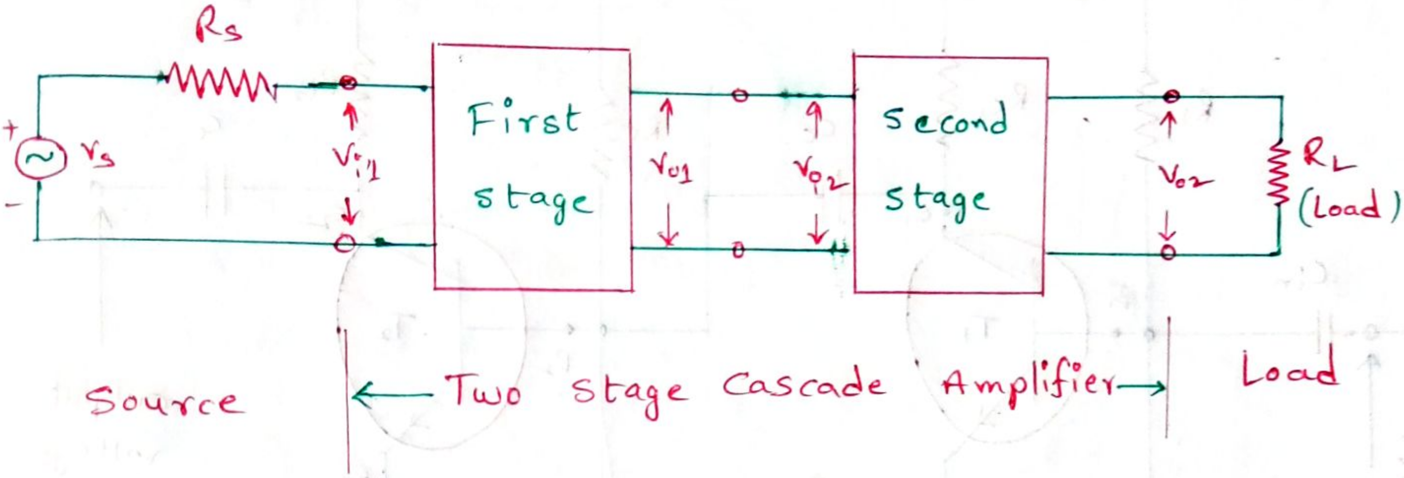


Fig 1. Multistage Amplifier

→ A multistage amplifier using two (or) more single stage common emitter amplifier is called as "cascade Amplifier".

1^{st} stage	2^{nd} stage	Amplifier Name
CE	CE	cascade Amplifier
CE	CB	cascode "
CE	CC	compound "
CC	CC	Darlington Pair "

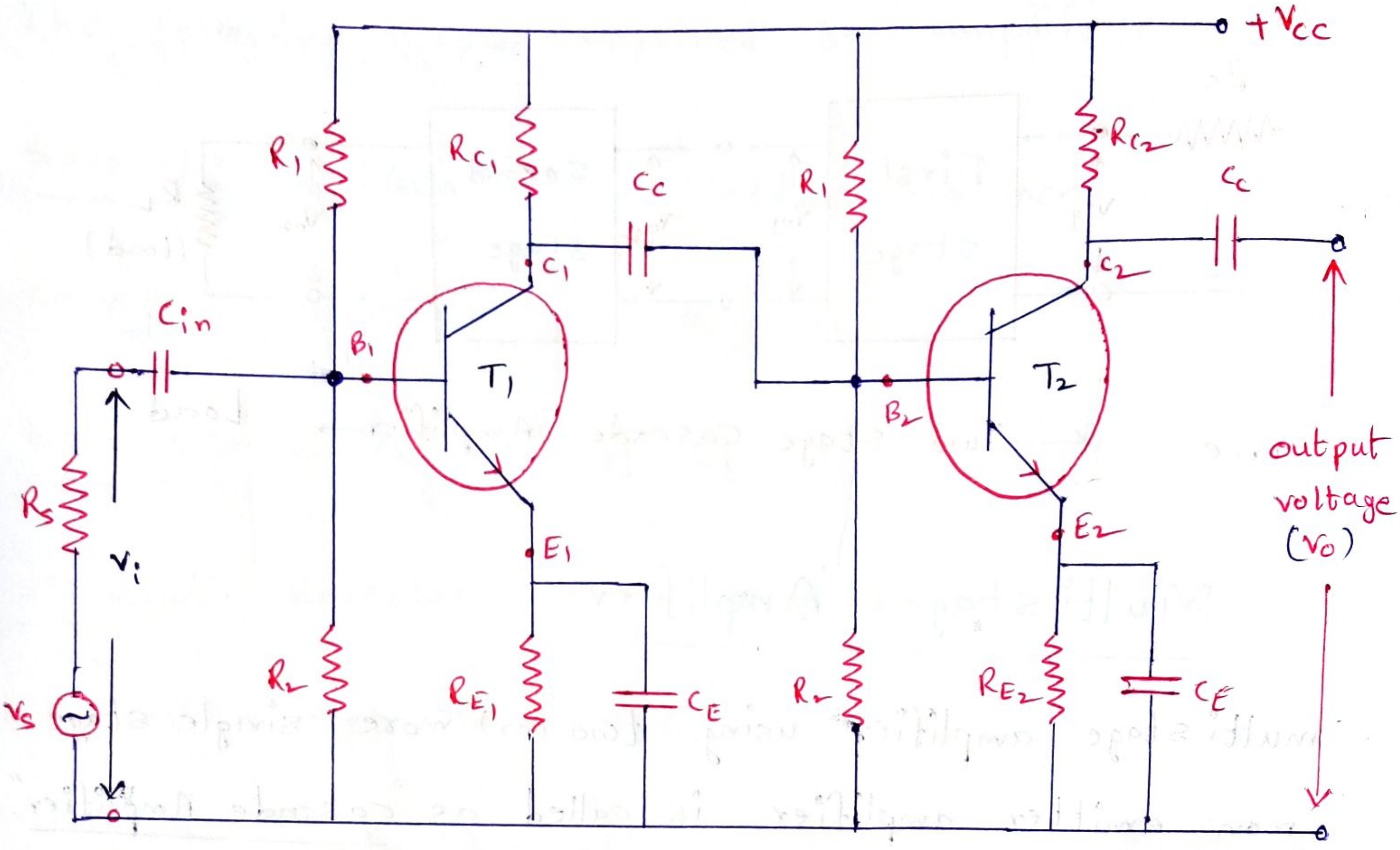
Voltage Gain of Two stage Amplifier :-

From Fig-1, overall voltage Gain, $A_v = \frac{V_{o2}}{V_{i1}} = \frac{V_{o2}}{V_{i2}} \cdot \frac{V_{i2}}{V_{i1}}$

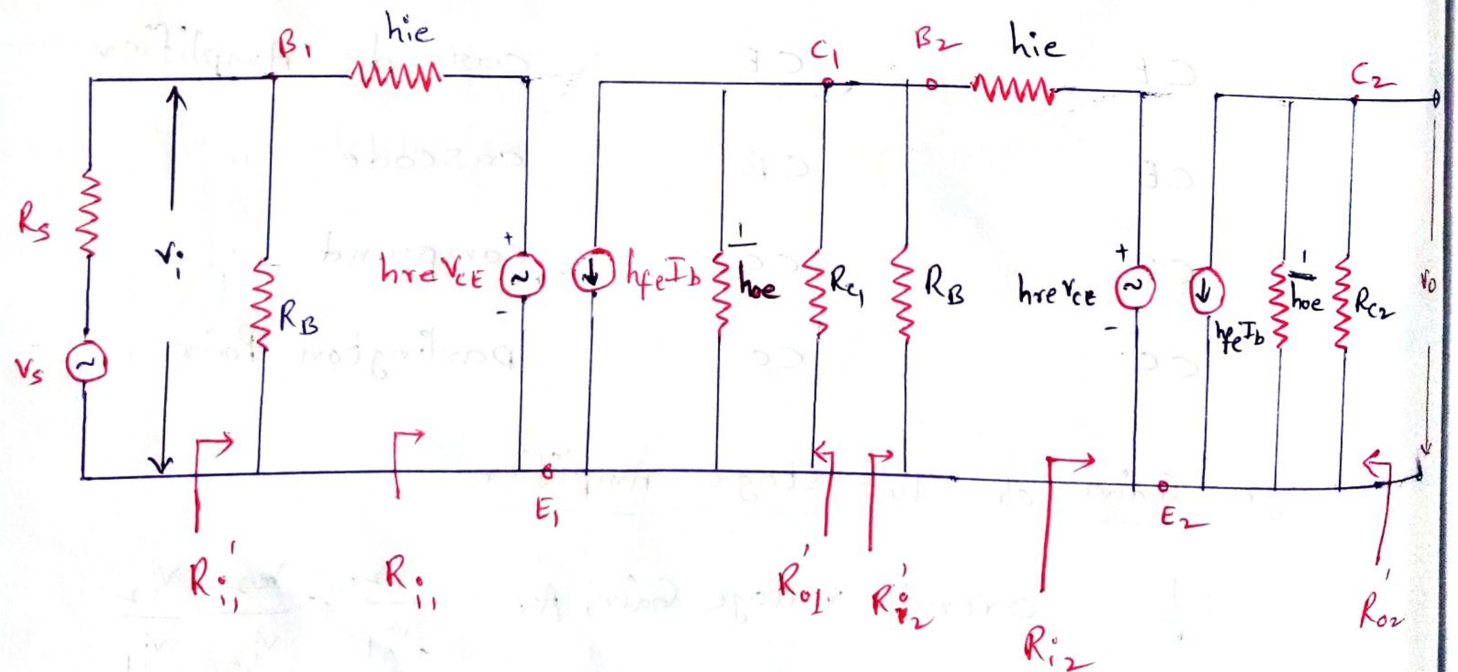
WKT. $V_{o1} = V_{i2}$, $A_v = \frac{V_{o2}}{V_{i1}} = \frac{V_{o2}}{V_{i2}} \cdot \frac{V_{i2}}{V_{i1}} = \frac{V_{o2}}{V_{i2}} \cdot \frac{V_{o1}}{V_{i1}} = A_{v_2} \cdot A_{v_1}$

$$\boxed{A_v = A_{v_2} \times A_{v_1}}$$

I Analysis of Two stage RC Coupled CE-CE cascade Amplifier:-



Two stage CE-CE cascade Amplifier



H-parameter Equivalent ckt for RC coupled Amplifier

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

Second stage Analysis :-

Current Gain (A_{i_2}) :-

$$A_{i_2} = \frac{-h_{fe}}{1 + h_{oe} \cdot R_L}$$

$$= \frac{-h_{fe}}{1 + h_{oe} \cdot R_{C2}} \qquad [\because R_L = R_{C2}]$$

Neglecting $h_{oe} R_{C2}$

$$\therefore \boxed{A_{i_2} = -h_{fe}}$$

Input Impedance (R_{i_2}) :-

$$R'_{i_2} = R_B \| h_{ie}$$

since $R_B >> h_{ie}$, hence neglecting R_B

$$\therefore \boxed{R'_{i_2} = h_{ie}}$$

Voltage Gain (A_{v_2}) :-

$$A_{v_2} = A_{i_2} \frac{R_L}{R_{i_2}}$$

$$\boxed{A_{v_2} = -h_{fe} \frac{R_{C2}}{h_{ie}}}$$

First stage Analysis :-

Current Gain (A_{i_1}) :-

$$\boxed{A_{i_1} = -h_{fe}}$$

Input Resistance (R_{i_1}) :-

$$\boxed{R_{i_1} = h_{ie}}$$

Voltage Gain (A_{v_1}) :-

$$A_{v_1} = A_{i_1} \frac{R_L}{R_{i_1}}$$

$R_L = R_{c_1} \| R_B \| h_{ie}$ and $R_{i_1} = h_{ie}$; we get

$$\boxed{A_{v_1} = -h_{fe} \frac{R_{c_1} \| R_B \| h_{ie}}{h_{ie}}}$$

Overall voltage Gain (A_v) :-

$$\boxed{A_v = A_{v_1} \cdot A_{v_2}}$$

Output Impedance (R_o) :-

$$\boxed{R_{o_1} = R_{c_1} \| h_{oe_1}}$$

$$\boxed{R_{o_2} = R_{c_2} \| h_{oe_2}}$$

Problem 1 :- Using a CE-CE amplifier circuit diagram and find the voltage gain, current gain, i/p impedance output impedance for the ckt parameters given as

First stage	Second stage	Assume that
$R_{C_1} = 10\,k\Omega$	$R_{C_2} = 5\,k\Omega$	$h_{ie} = 1.2\,k\Omega$
$R_1 = 20\,k\Omega$	$R_1 = 50\,k\Omega$	$h_{re} = 2.5 \times 10^{-4}$
$R_2 = 200\,k\Omega$	$R_2 = 300\,k\Omega$	$h_{oe} = 2.5\,\mu A/V$
$R_{E_1} = 10\,k\Omega$, $R_S = 1\,k\Omega$	$R_{E_2} = 100\,k\Omega$	$h_{fe} = 50$

Sol :- $h_{oe} \cdot R_L = h_{oe} \cdot R_{C_2} = 2.5 \times 10^{-6} \times 5 \times 10^3 = 0.0125$

since $h_{oe} \cdot R_L < 1$, we can use simplified model for Analysis.

Second stage Analysis:

current gain, $A_{i_2} = -h_{fe} = -50$

Input Impedance, $R_{i_2} = h_{ie} = 1.2\,k\Omega$

voltage gain, $A_{v_2} = A_{i_2} \cdot \dfrac{R_{C_2}}{h_{ie}} = -50 \times \dfrac{5 \times 10^3}{1.2 \times 10^3} = -208.33$

First stage Analysis:-

current gain, $A_{i_1} = -h_{fe} = -50$

Input impedance, $R_{i_1} = h_{ie} = 1.2\,k\Omega$

voltage gain, $A_{v_1} = A_{i_1} \dfrac{(R_{C_1} \| R_B \| h_{ie})}{h_{ie}}$

$= -50 \times \dfrac{(10k \| 20k \| 200k \| 1.2k)}{1.2k}$ $[\because R_B = R_1 \| R_2]$

$= -50 \times \dfrac{1012.14}{1200} = -42.17$

Overall voltage Gain, $A_v = A_{v_1} \cdot A_{v_2}$

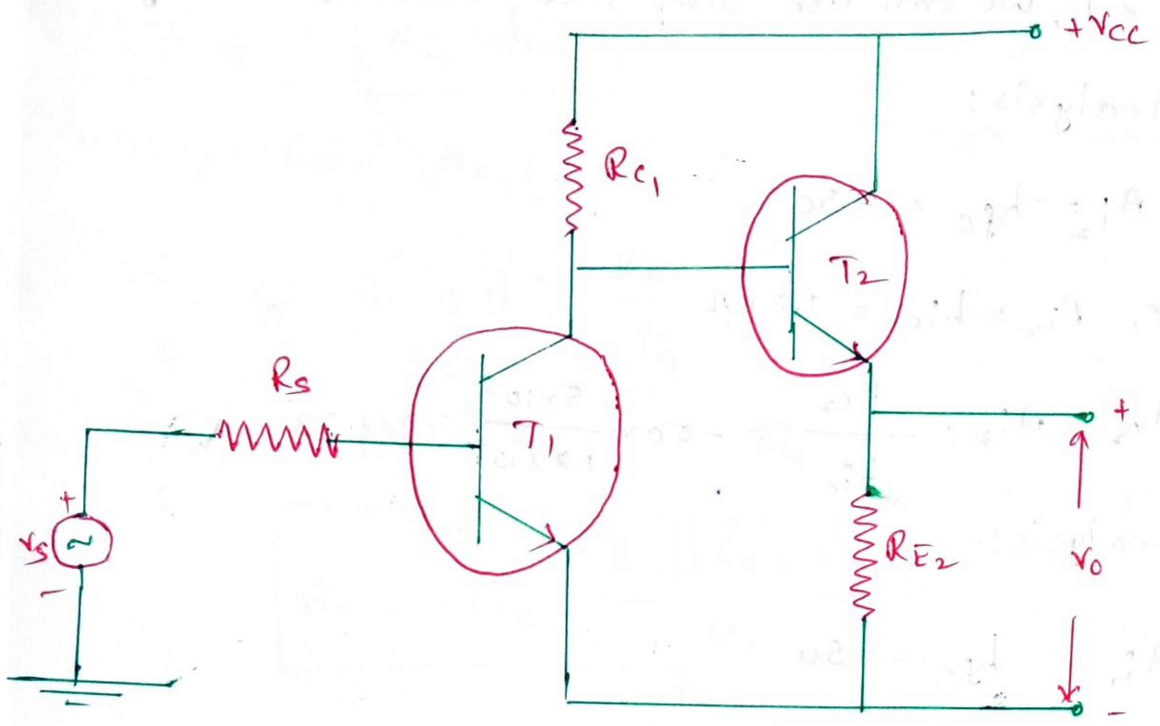
$= (208.33)(42.17)$

$A_v = 8785.27$

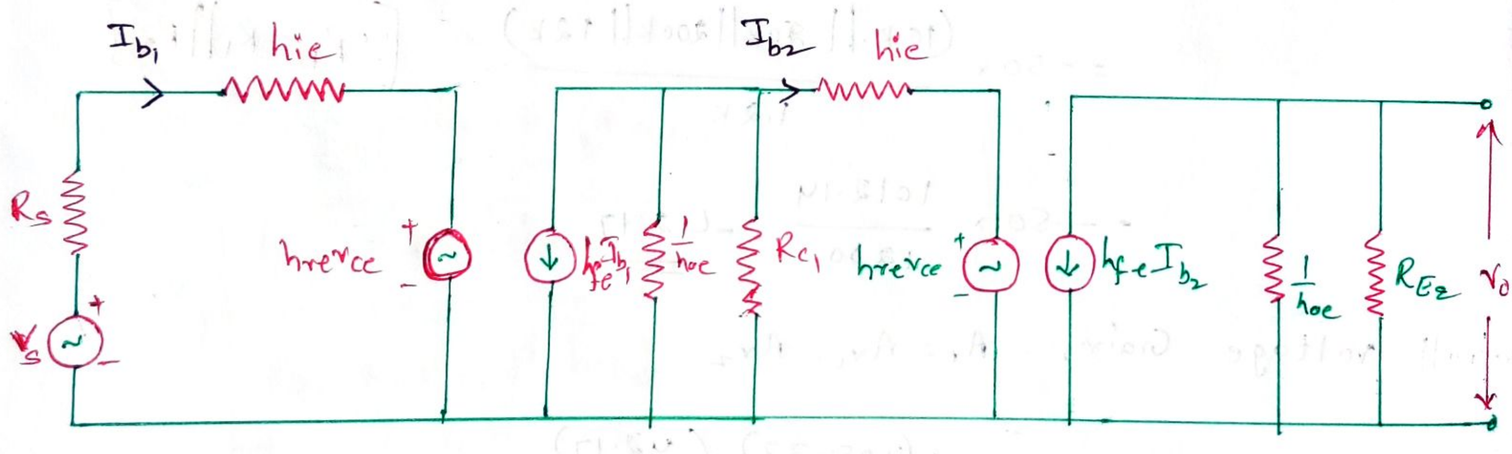
output Impedance, $R_{o_1} = R_{C_1} = 10\,k\Omega$

$R_{o_2} = R_{C_2} = 5\,k\Omega$

Two stage RC Coupled CE-CC Amplifier :-



Two stage Amplifier in CE-CC configuration



h-parameter Equivalent ckt of Two-stage Amplifier in CE-CC

Second stage Analysis (CC stage)

current Gain (A_{i_2}) :-

$$A_{i_2} = \frac{-I_{E_2}}{I_{b_2}} = \frac{-h_{fc}}{1 + h_{oe} \cdot R_{E_2}}$$

Input Impedance (R_{i_2}) :-

$$R_{i2} = h_{ic} + h_{rc} A_{i_2} R_{E_2}$$

Voltage Gain (A_{v_2}) :-

$$A_{v_2} = \frac{v_o}{v_2} = A_{i_2} \frac{R_{E_2}}{R_{i_2}}$$

First stage Analysis (CE stage) :-

The net load impedance R_{L_1} of first stage is obtained by

$$R_{L_1} = R_{C_1} \| R_{i_2}.$$

Current Gain (A_{i_1}) :-

$$A_{i_1} = \frac{-I_{C_1}}{I_{b_1}} = \frac{-h_{fe}}{1 + h_{oe} \cdot R_{E_1}}$$

Input Impedance (R_{i_1}) :-

$$R_{i_1} = h_{ie} + h_{re} A_{i_1} R_{L_1}$$

Voltage Gain (A_{v_1}) :-

$$A_{v_1} = \frac{v_2}{v_1} = A_{i_1} \cdot \frac{R_{L_1}}{R_{i_1}}$$

Output Impedance (R_o)

$$Y_{o_1} = h_{oe} - \frac{h_{fe} \cdot h_{re}}{h_{ie} + R_s}$$

$$R_{o_1} = \frac{1}{Y_{o_1}}$$

$$Y_{o2} = h_{oc} - \frac{h_{fc} \cdot h_{rc}}{h_{ic} + R'_{s_2}}$$

$[\because R'_{s_2} = R'_{o_1}]$

$$R_{o2} = \frac{1}{Y_{o2}}$$

Problem ②:- Using a CE–CC amplifier circuit diagram, and $R_s = 1\,k\Omega$, $R_{C_1} = 2\,k\Omega$, $R_{E_2} = 1.2\,k\Omega$. The h-parameter are

$h_{ie} = 1\,k\Omega$, $h_{fe} = 50$, $h_{re} = 1\times10^{-4}$, $h_{oe} = 10^{-4}\,A/V$

$h_{ic} = 1\,k\Omega$, $h_{fc} = 51$, $h_{rc} = 1$, and $h_{oc} = 10^{-4}\,A/V$

Compute (a) Input Impedance, (b) = output Admittance (c) Current gain, voltage gain for individual stages

Sol:-

Second stage Analysis (CC stage):-

$$\text{Current Gain, } A_{i_2} = \frac{-h_{fc}}{1 + h_{oc}R_{E_2}} = \frac{-51}{1 + (10^{-4}\times 1.2\times10^{3})}$$

$$\therefore A_{i_2} = -45.54$$

$$\text{Input Impedance, } R_{i_2} = h_{ic} + h_{rc}A_{i_2}R_{E_2}$$

$$= (1\times10^{3}) + (1\times 45.54\times 1.2\times10^{3})$$

$$R_{i_2} = 55.65\,k\Omega$$

$$\text{voltage Gain, } (A_{v_2}) = A_{i_2}\cdot\frac{R_{E_2}}{R_{i_2}} = 45.54\times\frac{1.2\times10^{3}}{55.65\times10^{3}}$$

$$\therefore A_{v_2} = 0.982$$

First stage Analysis (CE stage):-

$$R_{L_1} (\text{or}) R_{E_1} = R_{C_1} \| R_{i_2} = \frac{R_{C_1}\times R_{i_2}}{R_{C_1} + R_{i_2}} = \frac{2\times10^{3}\times 55.65\times10^{3}}{2\times10^{3} + 55.65\times10^{3}} = 1.93\,k\Omega$$

current Gain (A_{i_1}) :-

$$A_{i_1} = \frac{-h_{fe}}{1+h_{oe}R_{E_1}} = \frac{-50}{1+(10^{-4}\times 1.93\times 10^{3})} = \underline{-41.67}$$

Input impedance (R_{i_1}) :-

$$R_{i_1} = h_{ie} + h_{re}A_{i_1}R_{L_1} = 1\times 10^{3} + (10^{-4}\times 41.67\times 1.93\times 10^{3})$$

$$= \underline{1008\,\Omega}$$

Voltage Gain (A_{v_1}) :-

$$A_{v_1} = \frac{v_2}{v_1} = A_{i_1}\cdot\frac{R_{L_1}}{R_{i_1}} = \frac{+41.67\times 1.93\times 10^{3}}{1008} = \underline{+79.78}$$

output Admittance :-

$$Y_{o_1} = h_{oe} - \frac{h_{fe}\cdot h_{re}}{h_{ie}+R_s} = 10^{-4} - \frac{50\times 10^{-4}}{(1\times 10^{3})+(1\times 10^{3})} \quad \left[\because \text{Assume } R_s = 1k\Omega\right]$$

$$= 10^{-4} - 25\times 10^{-7} = 9.75\times 10^{-5}\ A/V$$

$$R_{o_1} = \frac{1}{Y_{o_1}} = \frac{1}{9.75\times 10^{-5}} = \underline{10.26\ k\Omega}$$

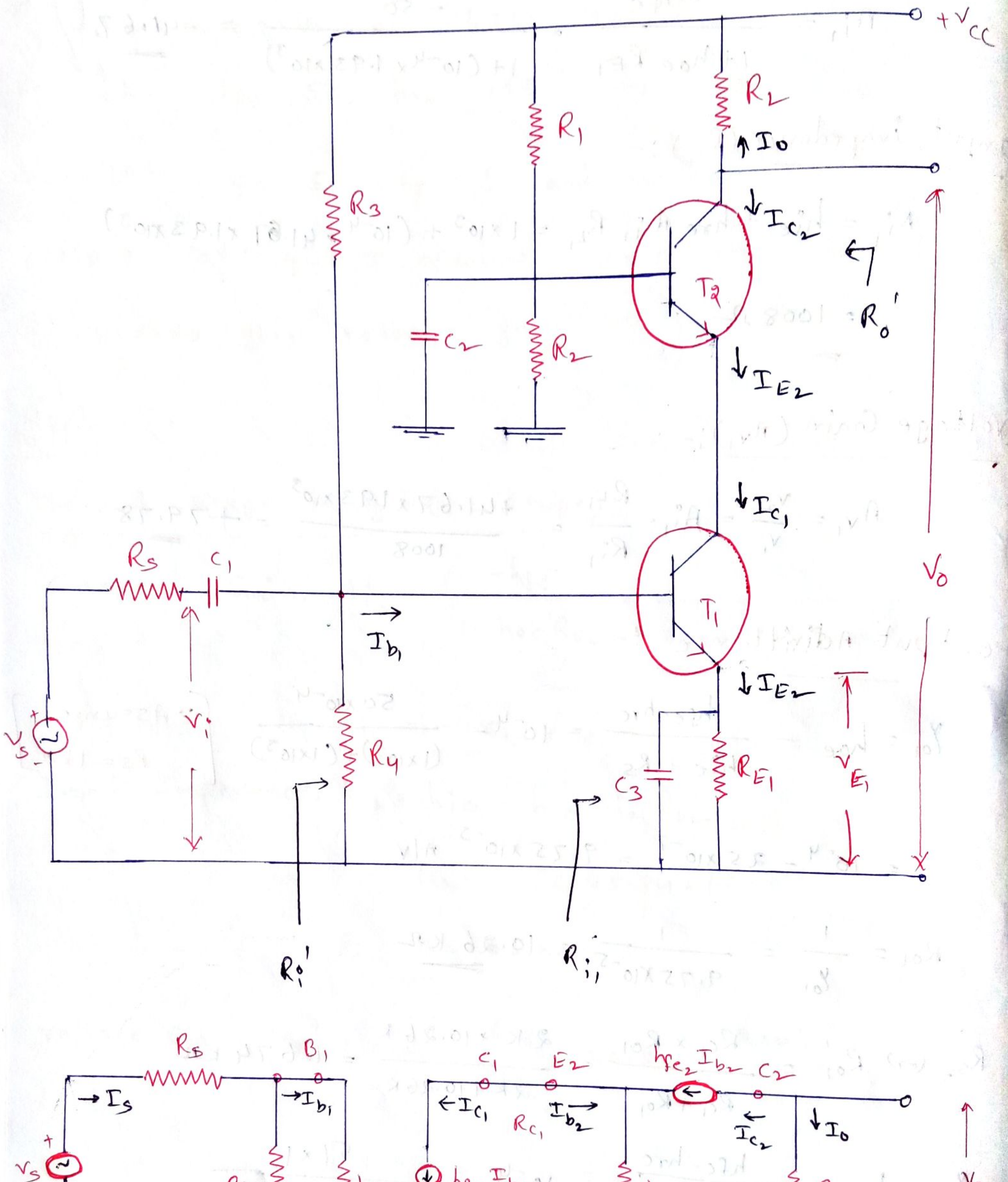
$$R'_{s_2} \text{ (or) } R'_{o_1} = \frac{R_{C_1}\times R_{o_1}}{R_{C_1}+R_{o_1}} = \frac{2K\times 10.26K}{2K+10.26K} = 1.674\ k\Omega$$

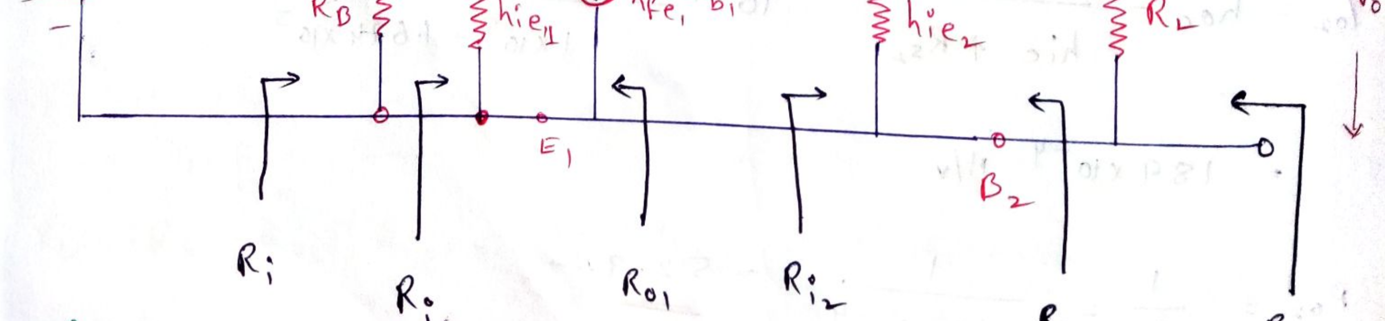
$$Y_{o_2} = h_{oe} - \frac{h_{fe}\cdot h_{re}}{h_{ie}+R'_{s_2}} = 10^{-4} - \frac{51\times 1}{1\times 10^{3}+1.674\times 10^{3}}$$

$$= 189\times 10^{-4}\ A/V$$

$$R_{o_2} = \frac{1}{Y_{o_2}} = \frac{1}{189\times 10^{-4}} = \underline{52.9\,\Omega}$$

II Cascode Amplifier (CE-CB) :-





Simplified h-parameter Equivalent ckt for CE-CB Amplifier

Second stage Analysis (CB Amplifier)

(i) Current Gain (A_{i_2}) :-

$$A_{i_2} = \frac{h_{fe}}{1+h_{fe}}$$

(ii) Input Impedance (R_{i_2}) :-

$$R_{i_2} = \frac{h_{ie}}{1+h_{fe}}$$

(iii) Voltage Gain (A_{v_2}) :-

$$A_{v_2} = A_{i_2} \cdot \frac{R_{L_2}}{R_{i_2}}$$

First stage Analysis (CE amplifier)

(iv) Current Gain (A_{i_1}) :- $A_{i_1} = -h_{fe}$

(v) Input Impedance (R_{i_1}) :- $R_{i_1} = h_{ie}$

(vi) Voltage Gain (A_{v_1}) :- $A_{v_1} = A_{i_1} \cdot \dfrac{R_{L_1}}{R_{i_1}}$

(vii) Overall Voltage Gain (A_v) :- $A_v = A_{v_1} \times A_{v_2}$

(viii) Overall Input Resistance (R_i) :-

$$R_i = R_{i_1} \| R_B = R_{i_1} \| R_3 \| R_4$$

(ix) Overall Voltage Gain (A_{vs}) Considering Source Resistance

$$A_{vs} = \frac{v_o}{v_s} = \frac{v_o}{v_i} \times \frac{v_i}{v_s} = A_v \cdot \frac{R_i}{R_i + R_s}$$

(x) Overall Current Gain (A_{is}) Considering Source Resistance :-

$$A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_{c_2}} \times \frac{I_{c_2}}{I_{e_2}} \times \frac{I_{e_2}}{I_{c_1}} \times \frac{I_{c_1}}{I_{b_1}} \times \frac{I_{b_1}}{I_s}$$

(xi) Output Resistance (R_o) :-

$$R_o = R_{o_2} \parallel R_L$$

Problem (3) :- Using a CE−CB amplifier circuit diagram, and $R_s = 1\ k\Omega$, $R_3 = 200\ k\Omega$, $R_4 = 10\ k\Omega$, $R_L = 3\ k\Omega$ and $h_{ie} = 1.1\ k\Omega$, $h_{fe} = 50$, $h_{re} = h_{oe} = 0$. Find current gain, input impedance, voltage gain and output impedance.

Sol:- Analysis of second stage (CB amplifier)

(i) current gain, $A_{i_2} = \frac{h_{fe}}{1+h_{fe}} = \frac{50}{1+50} = 0.98$

(ii) Input Impedance, $R_{i_2} = \frac{h_{ie}}{1+h_{fe}} = \frac{1.1k}{1+50} = 21.56\ \Omega$

(iii) voltage gain, $A_{v_2} = A_{i_2} \cdot \frac{R_{L_2}}{R_{i_2}} = 0.98 \times \frac{3\times10^3}{21.56} = 136.36$

Analysis of First stage (CE Amplifier)

(iv) current gain, $A_{i_1} = -h_{fe} = -50$

(v) Input Impedance, $R_{i_1} = h_{ie} = 1.1\ k\Omega$

(vi) Voltage Gain, $A_{v_1} = A_{i_1} \cdot \frac{R_{L_1}}{R_{i_1}} = +50 \times \frac{21.56}{1.1\times10^3} = +0.98$ $[\because R_{L_1} = R_{i_2}]$

(vii) overall voltage Gain, $A_v = A_{v_1} \times A_{v_2} = +0.98 \times 136.36 = +133.6$

(viii) Overall Input Resistance, $R_i = R_{i_1} \| R_B = R_{i_1} \| R_3 \| R_4$

$$= 1.1k \| 200k \| 20k = 986.1\,\Omega$$

(ix) overall voltage Gain (A_{vs}) considering source Resistance,

$$A_{vs} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \times \frac{V_i}{V_s} = A_v \times \frac{R_i}{R_i + R_s}$$

$$= +133.63 \times \frac{986.1}{986.1 + 1000} = +66.35$$

(x) Overall Current Gain (A_{is}) Considering source Resistance,

$$A_{is} = \frac{I_o}{I_s} = \frac{I_o}{I_{c_2}} \times \frac{I_{c_2}}{I_{e_2}} \times \frac{I_{e_2}}{I_{c_1}} \times \frac{I_{c_1}}{I_{b_1}} \times \frac{I_{b_1}}{I_s}$$

where, $\frac{I_o}{I_{c_2}} = -1$, $\frac{I_{c_2}}{I_{e_2}} = +A_{i_2}$, $\frac{I_{e_2}}{I_{c_1}} = +1$,

$\frac{I_{c_1}}{I_{b_1}} = -A_{i_1}$, $\frac{I_{b_1}}{I_s} = \frac{R_B}{R_B + R_{i_1}}$

$$A_{is} = -1 \times +A_{i_2} \times +1 \times -A_{i_1} \times \frac{R_B}{R_B + R_{i_1}}$$

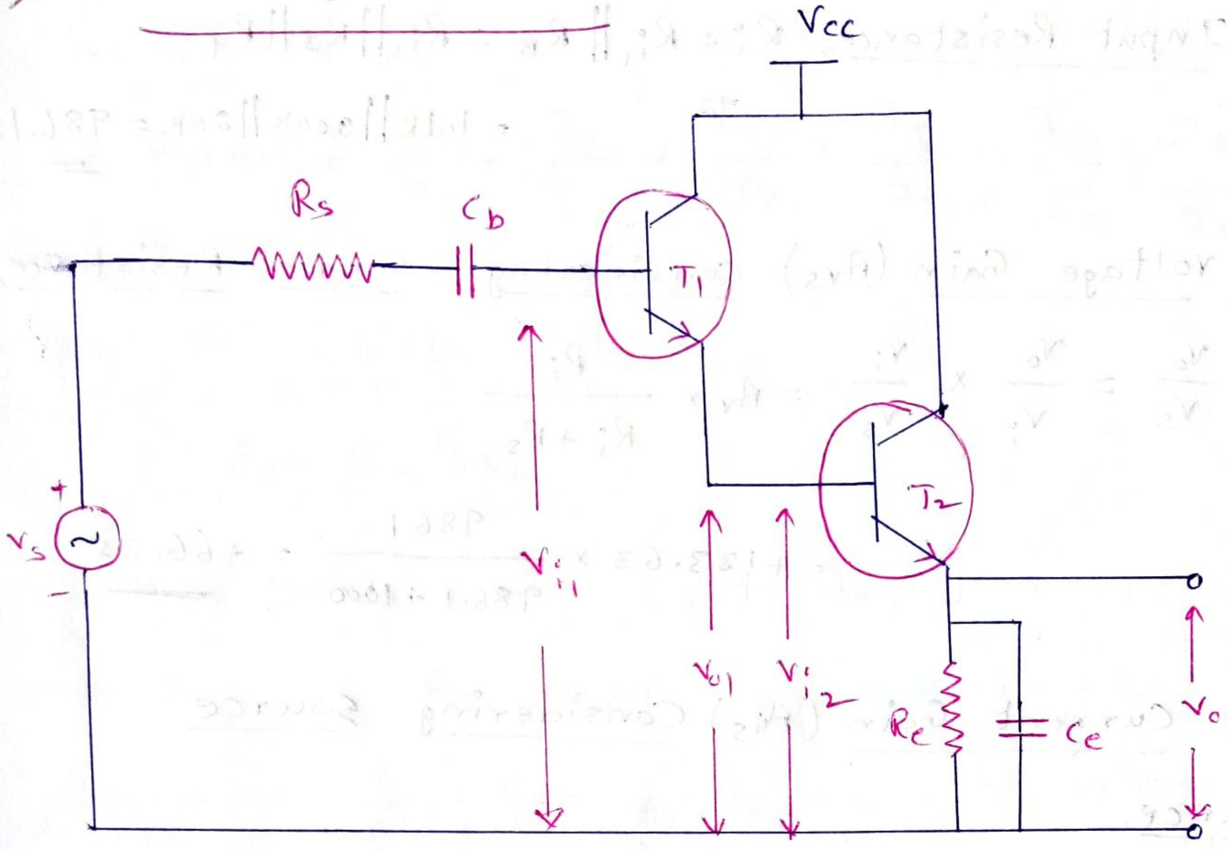
$$= (-1) \times (+0.98) \times (+1) \times (-50) \times \frac{(200k \| 10k)}{(200k \| 10k) + 1.1k} = -43.9$$

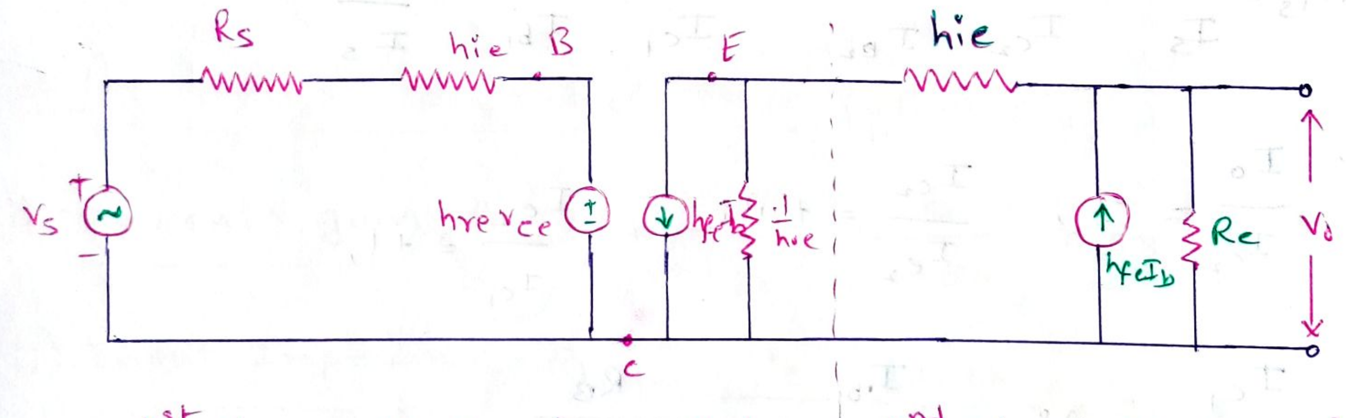
(xi) Output Resistance (R_o).

$R_{o_1} = \infty$, $R_{o_2} = \infty$

$R_o = R_{o_2} \| R_L = \infty \| 3k = 3\,k\Omega$

III Darlington Pair :-





1^{st} stage CC Exact method

2^{nd} stage CC approximation method

Because $h_{oe} \cdot R_L < 0.1$ rule not satisfied i.e., the load resistance 1^{st} is connected || i/p resistance of 2^{nd} stage. I/p resistance is very high in CC.

Second stage :-

(i) Current gain, $A_{i_2} = 1 + h_{fe}$

(ii) Input Resistance, $R_{i_2} = h_{ie} + (1 + h_{fe}) R_E$

(iii) Voltage gain, $A_{v_2} = A_{i_2} \cdot \dfrac{R_L}{R_{i_2}}$ $[\because R_L = R_E]$

(iv) Output Resistance, $R_{o_2} = \dfrac{R_s + h_{ie}}{1 + h_{fe}}$

First stage :-

(v) Current gain, $A_{i_1} = \dfrac{-h_{fe}}{1 + h_{oe} \cdot R_L} = \dfrac{-h_{fe}}{1 + h_{oe} \cdot h_{ie}}$

(vi) Input Resistance, $R_{i_1} = h_{ie} + h_{re} \cdot A_{i_1} \cdot R_L$

(vii) Voltage gain, $A_{v_1} = A_{i_1} \cdot \dfrac{R_L}{R_{i_1}}$

(viii) Output Resistance, $R_{o_1} = \dfrac{1}{Y_{o_1}}$

where, $Y_{o_1} = h_{oe} - \dfrac{h_{re} \cdot h_{fe}}{R_s + h_{ie}}$

Overall

(ix) Voltage gain, $A_v = A_{v_1} \cdot A_{v_2}$

(x) Current gain, $A_i = A_{i_1} \cdot A_{i_2}$

(xi) Voltage gain

Consider source resistance, $A_{vs} = A_v \cdot \dfrac{R_{i_1}}{R_s + R_{i_1}}$

Problem (4) :- Find the characteristics of Darlington pair amplifier, use the standard h-parameter values i.e., $h_{ie} = 1K\Omega$, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$, $h_{oe} = 25 \mu A/V$ and $R_S = 3k\Omega$, $R_E = 3K\Omega$.

Sol :- Second stage : ($R_L = R_E$)

Current gain, $A_{i_2} = 1 + h_{fe} = 1 + 50 = 51$

Input resistance, $R_{i_2} = h_{ie} + (1 + h_{fe}) R_E$

$$= 1 \times 10^3 + (1 + 50) \times 3 \times 10^3 = 154 \, K\Omega$$

voltage gain, $A_{v_2} = A_{i_2} \times \frac{R_L}{R_{i_2}} = 51 \times \frac{3 \times 10^3}{154 \times 10^3} = 0.99$

output resistance, $R_{o_2} = \frac{R_s + h_{ie}}{1 + h_{fe}} = \frac{3 \times 10^3 + 1 \times 10^3}{1 + 50} = 78.43 \, \Omega$

First stage : ($R_L = R_E$)

Current gain, $A_{i_1} = \frac{-h_{fe}}{1 + h_{oe} \cdot R_L} = \frac{-50}{1 + (25 \times 10^{-6} \times 3 \times 10^3)} = -46.51$

Input impedance, $R_{i_1} = h_{ie} + h_{re} \cdot A_{i_1} \cdot R_L$

$$= 1 \times 10^3 + (2.5 \times 10^{-4} \times 46.51 \times 3 \times 10^3)$$

$$= 1.034 \, K\Omega$$

voltage gain, $A_{v_1} = A_{i_1} \cdot \frac{R_L}{R_{i_1}} = (-46.51) \times \frac{3 \times 10^3}{1.034 \times 10^3} = -134.94$

output resistance, $Y_{o_1} = h_{oe} - \frac{h_{re} \cdot h_{fe}}{R_s + h_{ie}} = 25 \times 10^{-6} - \frac{2.5 \times 10^{-4} \times 50}{3 \times 10^3 + 1 \times 10^3}$

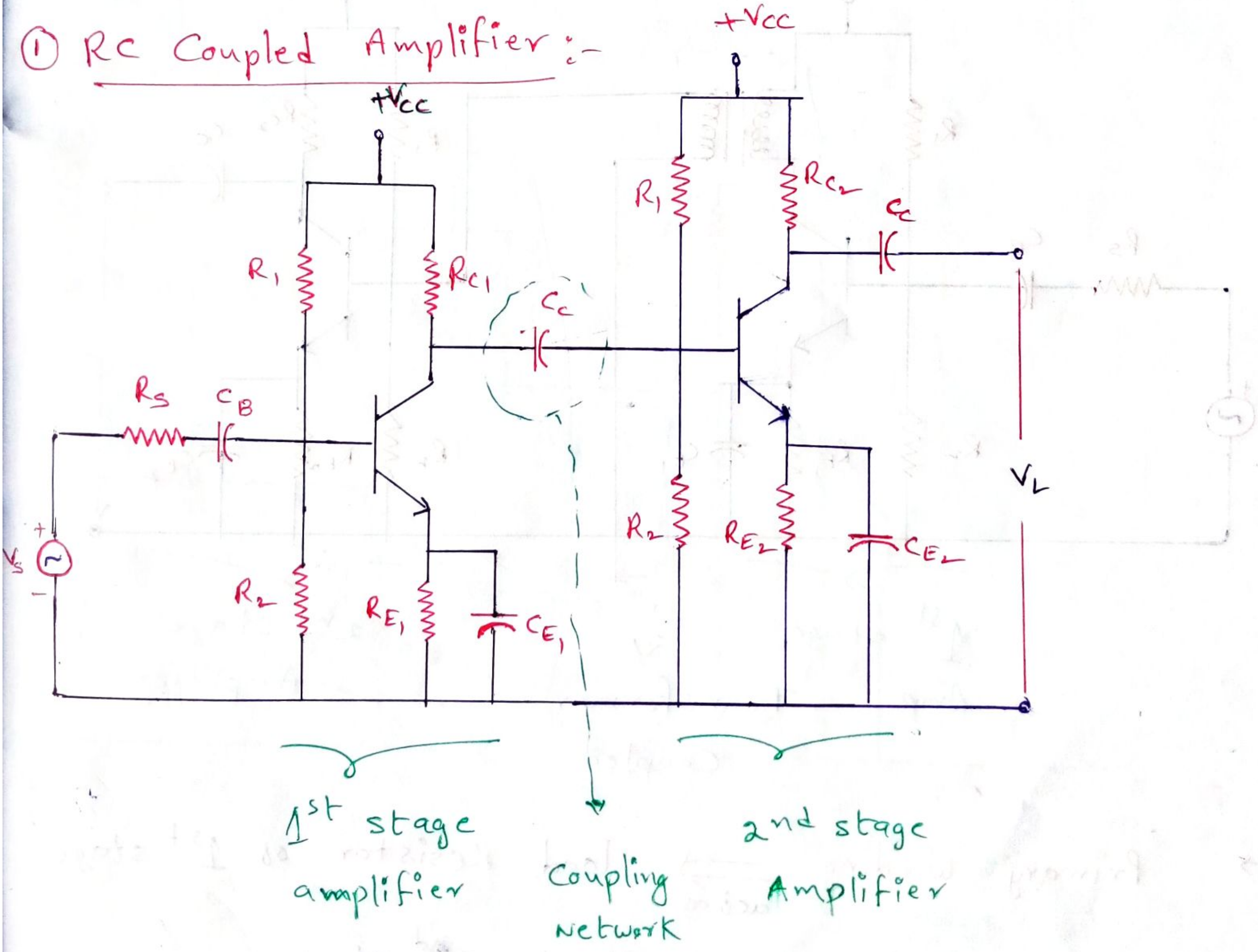
$= 25\times10^{-6} - 3.125\times10^{-6} = 21.875\,\mu A/V$

$R_{o1} = \frac{1}{Y_{o1}} = \frac{1}{21.875\times10^{-6}} = 0.04571\times10^{6} = 45.71\times10^{3} = 45.71\,K\Omega$

IV Different Coupling schemes used in Amplifiers:-

1. RC Coupled Amplifier
2. Transformer Coupled Amplifier
3. Direct Coupled Amplifier.

1. RC Coupled Amplifier :-



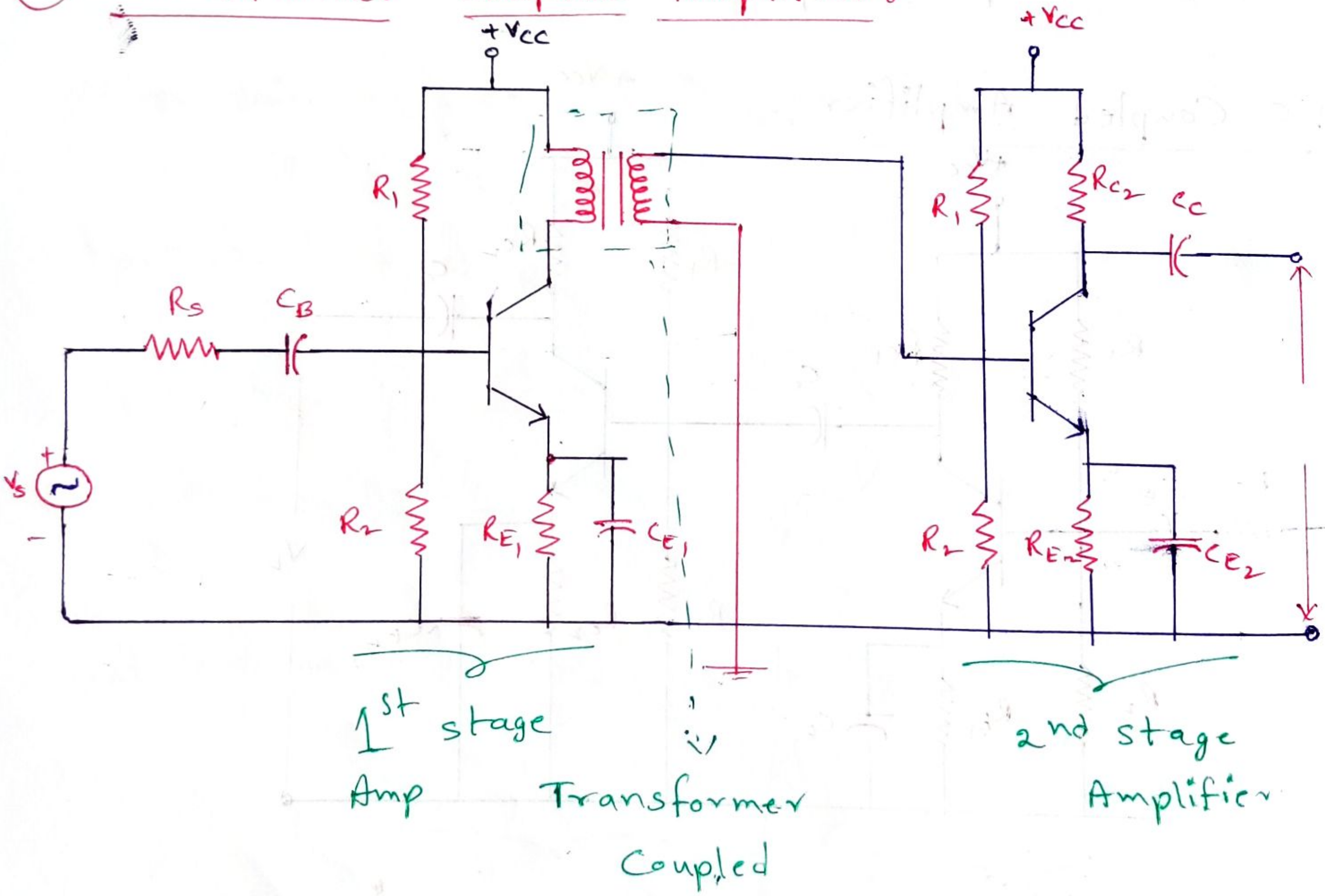
→ In this coupling network resistor and capacitor are used for overall gain. It is mostly widely used circuit.

→ It's satisbying the frequency response (or) it gives the good frequency response.

→ It is less expensive compared to other circuits.

→ It is a simple circuit.

② Transformer Coupled Amplifier :-



→ Primary winding $\xRightarrow{\text{act as}}$ load Resistor of 1st stage

Secondary " $\Longrightarrow$ i/p to 2nd stage.

→ In this network, the primary winding of the transformer acts as collector resistance (or) Collector load of 1^{st} stage and the 2^{nd} winding of the transformer acts as i/p of the 2^{nd} stage and a.c. power supply.

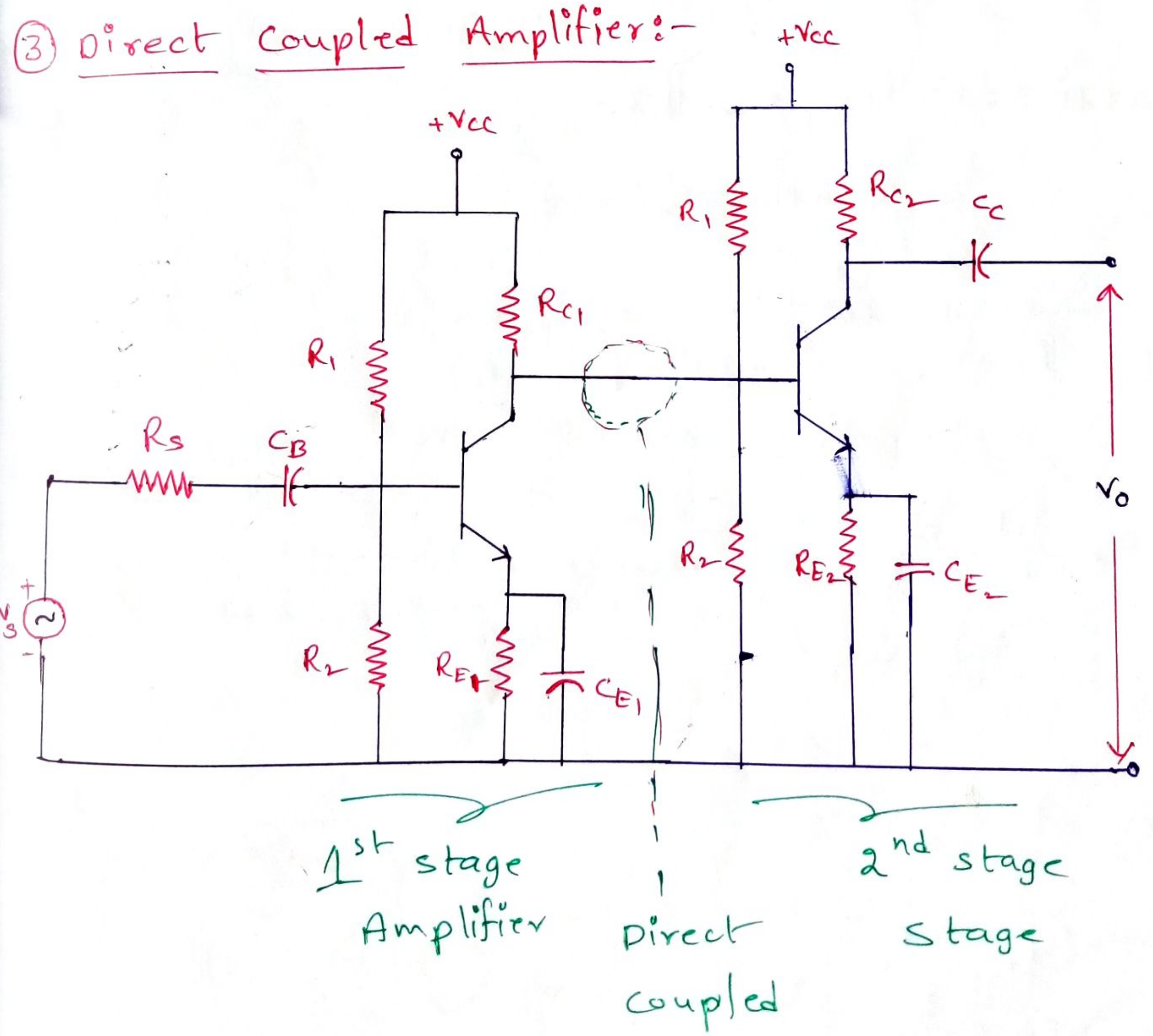
→ The transformer coupled network gives more d.c. isolation between the 2 stages.

→ The transformer Coupled network mostly used in power amplifier.

→ It is more expensive compared to others.

→ It is low frequency response.

(3) Direct Coupled Amplifier:-



→ In this coupling network, the 1^{st} stage of the o/p is given to the i/p of the 2^{nd} stage.

→ It is less expensive coupling network.

→ low frequency response, it is not suitable for application point of view.

UNIT – II Problems

(6) Determine the low frequency response of CE amplifier using the following specifications

$V_{CC} = 12V$, $R_C = 3\,k\Omega$; $R_E = 10\,k\Omega$; $R_1 = 52\,k\Omega$, $R_2 = 12\,k\Omega$, $R_S = 600\,\Omega$

$C_b = 0.1\,\mu F$, $C_e = 10\,\mu F$, $C_c = 0.1\,\mu F$, $h_{ie} = 1.6\,k\Omega$, $h_{fe} = 49$

Sol :-

C_b

$$f_{LC_b} = \frac{1}{2\pi R_{eq} C_b}$$

$$\therefore R_{eq} = R_s + z_i'$$

$$z_i' = R_B \| z_i$$

$$R_B = R_1 \| R_2 = 52k \| 12k = 9.75\,k\Omega$$

$$z_i = h_{ie} = 1.6\,k\Omega$$

$$z_i' = R_B \| z_i = 9.75k \| 1.6k = 1.37\,k\Omega$$

$$R_{eq} = 600 + 1.37k = 1.974\,k\Omega$$

$$f_{LC_b} = \frac{1}{2 \times 3.14 \times 1.974 \times 10^3 \times 0.1 \times 10^{-6}} = \frac{1}{1.239 \times 10^{-3}} = 0.8071 \times 10^3 = 807.1\ Hz$$

C_e

$$f_{LC_e} = \frac{1}{2\pi R_{eq} C_e}$$

$$R_{eq} = R_E \,\Big\|\, \left(\frac{R_s' + h_{ie}}{1 + h_{fe}}\right)$$

$$R_s' = R_s \| R_B$$

$$R_B = R_1 || R_2 = 52k || 12k = 9.75\,k\Omega$$

$$R_s' = R_s || R_B = 600 || 9.75\,k\Omega = 565.21\,\Omega$$

$$R_{eq} = R_E \,\Bigg|\Bigg|\, \left(\frac{R_s' + h_{ie}}{1 + h_{fe}} \right) = 10k \,\Bigg|\Bigg|\, \left(\frac{565.21 + 1.6k}{1 + 49} \right)$$

$$= 10k \,||\, \left(\frac{2165.21}{50} \right) = 10k \,||\, 43.3$$

$$= 43.11\,\Omega$$

$$f_{Lce} = \frac{1}{2\pi R_{eq} C_e} = \frac{1}{2 \times 3.14 \times 43.11 \times 10 \times 10^{-6}} = \frac{10^6}{2707.308}$$

$$f_{Lce} = 369.37\,Hz$$

C_c

$$f_{Lcc} = \frac{1}{2\pi R_{eq} C_c}$$

$$R_{eq} = R_C + R_L = 3k + 10\,k\Omega \quad [\because R_L = R_E]$$

$$= 13\,k\Omega$$

$$f_{Lcc} = \frac{1}{2\pi R_{eq} C_c} = \frac{1}{2 \times 3.14 \times 13 \times 10^3 \times 0.1 \times 10^{-6}} = \frac{10^3}{8.164}$$

$$f_{Lc} = 122.48\,Hz$$

Lower cut-off frequency.

$$f_L = \max(f_{Lcb}, f_{Lce}, f_{Lcc})$$

$$= \max(807.1, 369.37, 122.48)$$

$$\boxed{f_L = 807.1\,Hz}$$

(7) A transistor amplifier in CE configuration in operating at high frequency with the following specifications

$f_T = 5\,MHz$, $g_m = 0.05$ siemens, $h_{fe} = 50$, $r'_{bb} = 100\Omega$, $R_s = 500\Omega$

$C_c = 10\,pF$, $R_L = 10\,k\Omega$. Compute the overall voltage gain, Upper 3dB cut-off frequency, and GBW.

sol:- overall voltage gain, $A_v = -h_{fe} \cdot \frac{R_L}{(R_s + h_{ie})}$

$$h_{ie} = r'_{bb} + r'_{be}$$

$$r'_{be} = \frac{h_{fe}}{g_m} = \frac{50}{0.05} = 1000\,\Omega$$

$$h_{ie} = 100 + 1000 = 1100\,\Omega$$

$$A_v = -h_{fe}\frac{R_L}{(R_s + h_{ie})} = -50 \times \frac{10 \times 10^3}{500 + 1100} = \frac{-500 \times 10^3}{1600} = -312.5$$

The Upper 3dB cut-off frequency,

$$f_H = \frac{1}{2\pi RC} = \frac{1}{2 \times 3.14 \times 10 \times 10^3 \times 10 \times 10^{-12}} = \frac{1}{6.28 \times 10^{-7}} = 0.159 \times 10^7$$

$$= 1.59\,MHz$$

Gain - Bandwidth Product (GBW) = $A_v \cdot f_H$

$$= -312.5 \times 1.59 \times 10^6$$

$$= 496.8\,MHz$$

(8) Given the following transistor measurements mode at $I_c = 10\,mA$, $V_{CE} = 10V$ and at room temperature, $h_{fe} = 50$, $h_{ie} = 1\,k\Omega$, $|A_{ie}| = 20$, at $20\,MHz$, $C_c = 3\,pF$, Find f_β, f_T, C_e, r_{be} and r_{bb}.

Sol :- Given data, $I_C = 10mA$, $V_{CE} = 10V$, $h_{fe} = 50$, $h_{ie} = 1k\Omega$.

$|A_{ie}| = 20$ at $20MHz$, $C_c = 3pF$, $V_T = 26mV$ (at room temp)

$$|A_{ie}| = \frac{h_{fe}}{\sqrt{1+\left(\frac{f}{f_\beta}\right)^2}}$$

squaring on both sides

$$|A_{ie}|^2 = \frac{h_{fe}^2}{1+\left(\frac{f}{f_\beta}\right)^2}$$

$$1+\left(\frac{f}{f_\beta}\right)^2 = \frac{h_{fe}^2}{|A_{ie}|^2}$$

$$\left(\frac{f}{f_\beta}\right)^2 = \left[\frac{h_{fe}}{|A_{ie}|}\right]^2 - 1$$

$$\frac{f}{f_\beta} = \sqrt{\left[\frac{h_{fe}}{|A_{ie}|}\right]^2 - 1}$$

$$f_\beta = \frac{f}{\sqrt{\left[\frac{h_{fe}}{|A_{ie}|}\right]^2 - 1}}$$

$$= \frac{20\times10^6}{\sqrt{\left[\frac{50}{20}\right]^2 - 1}} = \frac{20\times10^6}{\sqrt{(2.5)^2-1}} = \frac{20\times10^6}{\sqrt{5.25}}$$

$$= \frac{20\times10^6}{2.3} = 8.69\ MHz$$

$$f_T = h_{fe} \cdot f_\beta$$

$$= 50 \times 8.69 \times 10^6 = 173.9 \text{ MHz}$$

$$r_{be} \text{(or)} \; r_{b'e} = \frac{h_{fe}}{g_m}$$

$$g_m = \frac{|I_c|}{V_T} = \frac{10 \times 10^{-3}}{26 \times 10^{-3}} = 0.192 \text{ A/v}$$

$$r_{b'e} = \frac{h_{fe}}{g_m} \cdot \frac{50}{0.192} = 260.41 \, \Omega$$

$$r_{bb} \text{(or)} \; r_{bb'} = h_{ie} - r_{b'e} = 1000 - 260.41 = 739.59 \, \Omega$$

$$f_T = \frac{g_m}{2\pi C_e}$$

$$\therefore C_e = \frac{g_m}{2\pi f_T} = \frac{0.192}{2 \times 3.14 \times 173.9 \times 10^6} = \frac{0.192}{1092.092 \times 10^6} = 0.175 \times 10^{-3} \times$$

$$= 0.0001758 \times 10^{-6} = 0.1758 \times 10^{-3} \times 10^{-6} = 175.8 \times 10^{-12} = 175.8 \text{ pF}$$

(9) A high frequency amplifier uses a transistor which is driven from a source with $R_s = 1 \text{ k}\Omega$. Calculate value of f_H, $A_{vs\,low}$ and $A_{vs\,HIGH}$ if $R_L = 0$ and $R_L = 1 \text{ k}\Omega$. Assume typical values for hybrid π-parameters.

Sol:- (i) For $R_L = 0$

$$f_H = \frac{1}{2\pi R_{eq} C_{eq}}$$

$R_{eq} = r_{b'e} \| (r_{bb'} + R_s)$; $C_{eq} = C_e + C_c(1 + g_m R_L)$

$(\because R_L = 0)$

$C_{eq} = C_e + C_c(1 + g_m(0))$

$= C_e + C_c(1+0)$

$C_{eq} = C_e + C_c$

Assume

* typical values. $r_{b'e} = 1K\Omega$, $r_{bb'} = 100\Omega$, $h_{ie} = 1K\Omega$

$C_e = 100pF$, $C_c = 3pF$, $g_m = 50\, mA/V$

$$f_H = \frac{1}{2\pi [r_{b'e} \| (r_{bb'} + R_s)] [C_e + C_c]}$$

$$= \frac{1}{2 \times 3.14 [1K \| (100 + 1K)] [100pF + 3pF]}$$

$\therefore f_H = 2.95\, MHz$

$$A_{vs\,LOW} = -h_{fe} \cdot \frac{R_L}{R_s + h_{ie}} = -h_{fe} \frac{0}{R_s + h_{ie}} = 0$$

$$A_{vs\,HIGH} = \frac{-g_m r_{b'e} \cdot R_s}{R_s + r_{bb'} + r_{b'e}}$$

$$= \frac{-50 \times 1K \times 1K}{1K + 100 + 1K} = \frac{-50 \times 1000 \times 1000}{1000 + 100 + 1000}$$

$A_{vs\,HIGH} = -23.8$

$R_L = 1\,k\Omega$

$$f_H = \frac{1}{2\pi R_{eq} C_{eq}}$$

$$R_{eq} = r_{b'e} \,||\, (r_{bb'} + R_s) \;;\quad C_{eq} = C_e + C_c\,[1 + g_m R_L]$$

$$f_H = \frac{1}{2\pi [r_{b'e} \,||\, (r_{bb'} + R_s)]\,[C_e + C_c (1 + g_m R_L)]}$$

$$= \frac{1}{2 \times 3.14 [1k \,||\, (100 + 1k)]\,[100pF + 3pF (1 + 50\times10^{-3} \times 1\times10^{3})]}$$

$$= \frac{1}{2 \times 3.14 \times 523.8 \times (100p + 151p)} = \frac{1}{825.655\times10^{3}\times10^{-12}}$$

$$= 1.21\,MHz$$

$$A_{vs\,low} = -h_{fe} \cdot \frac{R_L}{R_s + h_{ie}} = -50 \times \frac{1K}{1K + 1K} = -50 \times \frac{1K}{2K}$$

$$\therefore A_{vs\,low} = -25$$

$$A_{vs\,HIGH} = \frac{-g_m r_{b'e} \cdot R_s}{R_s + r_{bb'} + r_{b'e}}$$

$$= \frac{-50 \times 1K \times 1K}{1K + 100 + 1K}$$

$$\therefore A_{vs\,HIGH} = -23.8$$

UNIT – II

BJT Amplifiers – Frequency

UNIT – II (a) : BJT Amplifiers – Frequency Response

1. Logarithms,
2. Decibels
3. General Frequency considerations.
4. Frequency response of BJT Amplifier.
5. Analysis at low and High frequencies
6. Effect of Coupling and Bypass capacitors.
7. The Hybrid - pi - Common Emitter Transistor Model
8. CE short circuit current Gain
9. Current Gain with Resistive load
10. Single stage CE Transistor Amplifier Response
11. Gain – Bandwidth Product.
12. Emitter follower at higher frequencies.

UNIT – II (b) : MOS Amplifiers

1. Basic Concepts
2. MOS small signal model
3. Common Source Amplifier with Resistive load.

UNIT - II (a)

BJT Amplifiers - Frequency Response

I Logarithms :- The analysis of amplifiers normally extends over a wide frequency range. Use of logarithmic scale makes it comfortable plotting the response between wide limits.

→ Logarithm taken to the "base 10" is common logarithm.

Example : logarithm of a variable "a" is $\log_{10} a$.

→ Logarithm taken to the "base e" is natural logarithm.

Example : logarithm of a variable "a" is $\log_e a$ (or) $\ln a$.

II Decibels :- Decibel is used to compare two power levels on a logarithmic basis.

→ The term "bel" is derived from the name of telephone invention, Alexander Graham Bell.

→ The unit "bel" (B) is defined relating two power levels P_1 and P_2 is

$$G = \log_{10}\left(\frac{P_2}{P_1}\right) \text{ bel}$$

→ As "bel" was found to be a large unit for measuremen(t) ②
the "decibel"(dB) is defined where 10 decibels = 1 bel.

Hence,

$$\boxed{G_{dB} = 10 \log_{10}\left(\frac{P_2}{P_1}\right) dB}$$

III General Frequency Consideration:-

① Mid-band (or) Middle Frequency Range:-

In the entire midband, gain A is almost constant say at value A_M and the time delay D is also almost constant at value D_0 seconds. In this midband gain is normalized to unity i.e., $A_M = 1$.

② Low Frequency Range:-

This frequency range lies below the midband. In low frequency range, the gain A decreases with decreases of frequency and tends to become zero at frequency $f=0$ (D.C signal).

→ Thus in this frequency range, the amplifier behaves as a simple high pass circuit.

(3)

(3) High Frequency Range:-

This frequency range lies above the mid-band. In high frequency range, the gain decreases with increases of frequency.

→ Thus in this frequency range, the amplifier behaves as a simple low pass circuit.

IV Frequency Response of BJT Amplifier:- (or)

X Single stage CE Transistor Amplifier Response:

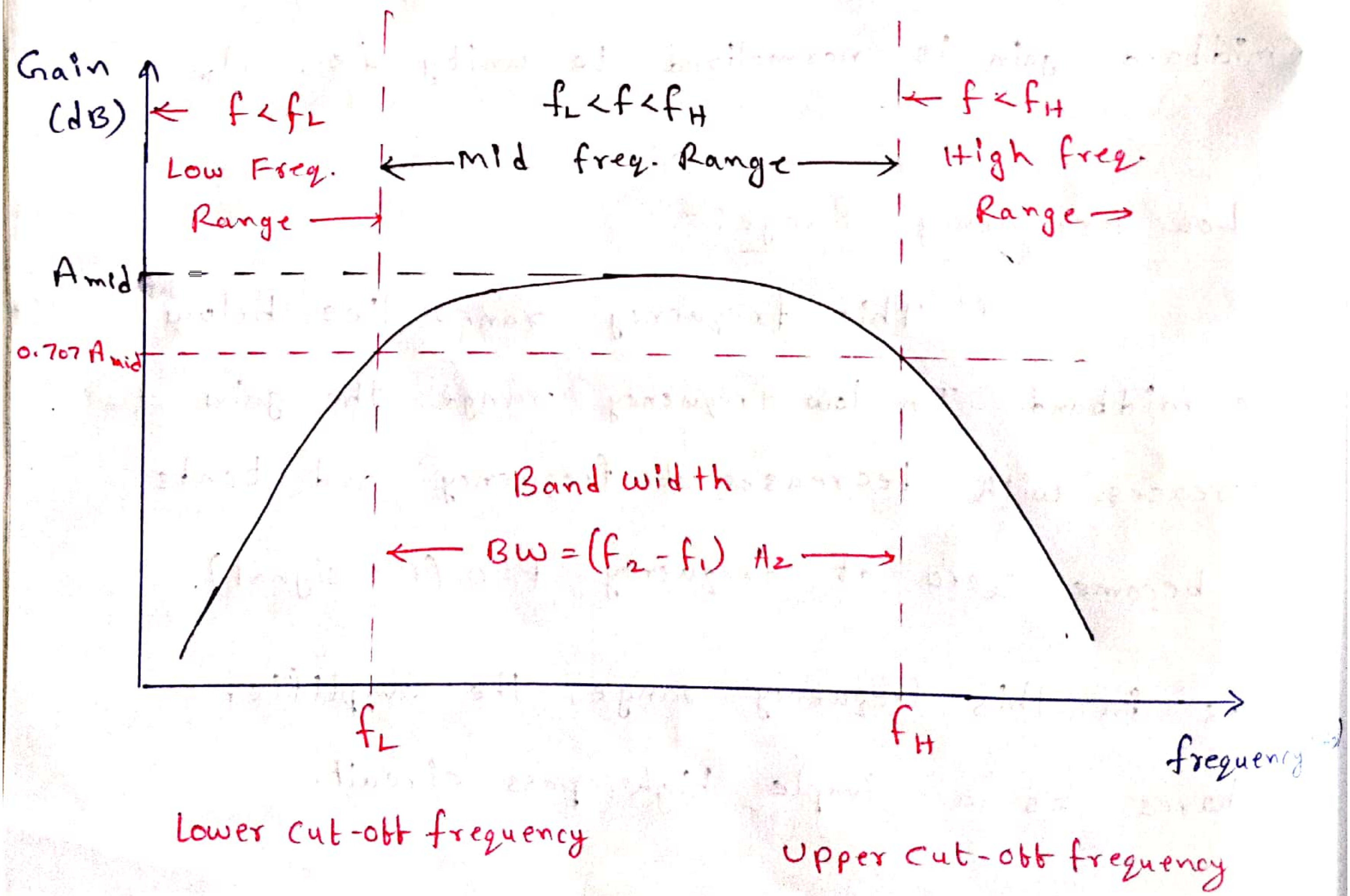


Fig. Frequency Response of RC Coupled Amplifier

→ The main aim of any amplifier should be to provide a constant amplification at any frequency (at all freq's over a selected range). This is analysed by means of a curve called frequency response curve.

→ To plot this curve, we measure the voltage gain $\left(\frac{V_{out}}{V_{in}}\right)$ at different frequencies (over a frequency range) and plot it with the corresponding frequency value on a semi-log graph sheet.

→ The voltage gain is measured in Decibels (dBs), whereas the frequencies are taken on log scale.

Lower cut-off frequency (f_L) :- This is the freq at which the gain of amplifier rises to 0.707 (or) $\frac{1}{\sqrt{2}}$ of its midband gain. It is denoted by f_L.

High cut-off Frequency (f_H) :- This is the freq at which the gain of amplifier falls to 0.707 (or) $\frac{1}{\sqrt{2}}$ of its midban gain. It is denoted by f_H.

Bandwidth :- The frequency range extending from f_L to f_H constitutes the bandwidth of the amplifier.

→ In this frequency range, the magnitude of gain remains constant, ⑤ ignoring the 3dB variation. In most cases $f_H >> f_L$

Hence the bandwidth BW is given by,

$$\text{Band width (BW)} = f_H - f_L$$
$$\simeq f_H$$

Low Frequency Response of Amplifier:-

The low freq response of the amplifier is the calculation of lower cut-off frequency of amplifier.

The lower cut-off freq. of amplifier due to C_b, C_c, C_e.

Procedure to calculate the cut-off frequency of an Amplifier:-

① Draw the A.C. equivalent ckt of the given amplifier by considering all capacitors and all the sources (a-c and d-c) set equal to zero.

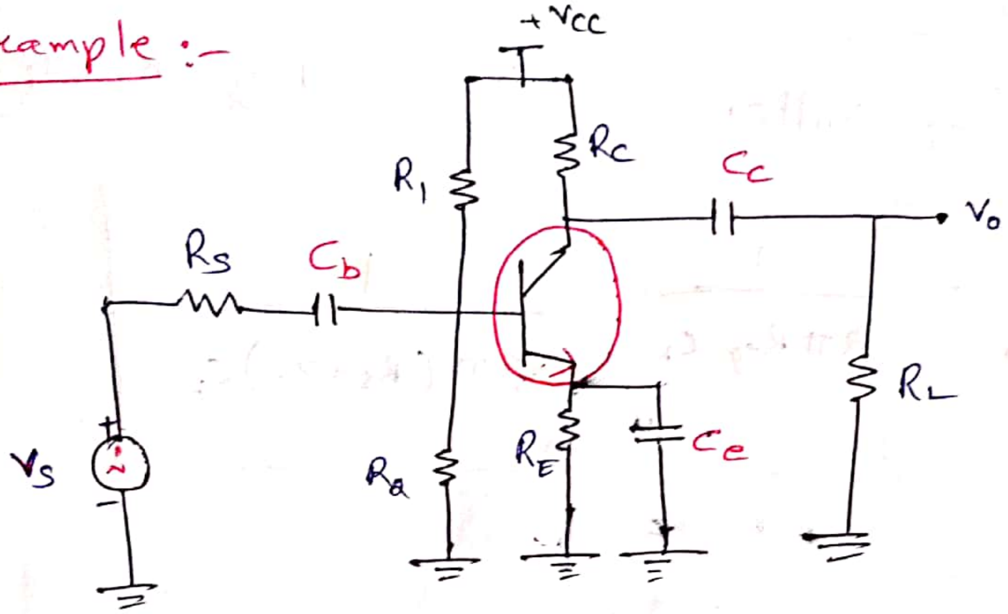
② Draw the a.c. equivalent ckt related to any one capacitor and remaining capacitors replaced by short circu

③ Calculate the equi. resistance looking across the terminals of capacitor, then the cut-off freq. due to that capacitor is

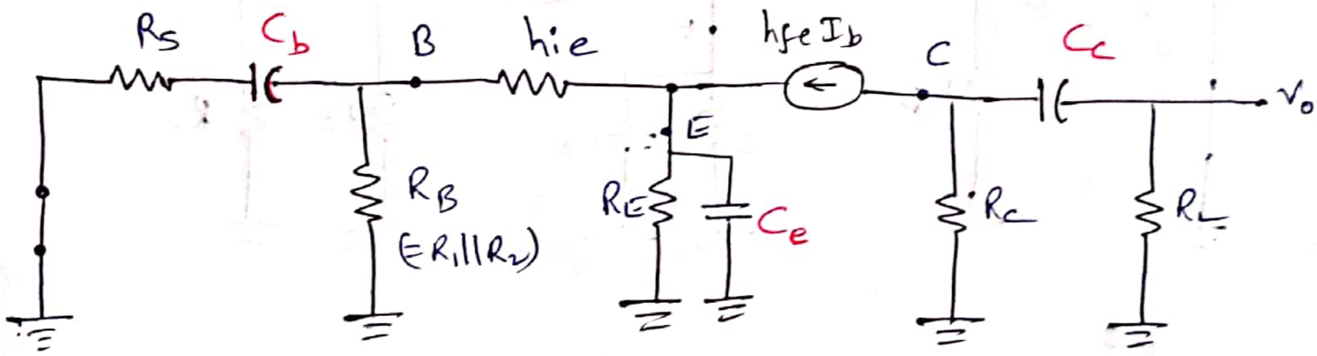
$$f_L = \frac{1}{2\pi R_{eq} \cdot C}$$

(4) The cut-off freq. of the amplifier is the largest value of cut-off frequency due to C_b, C_e, C_c

Example :-

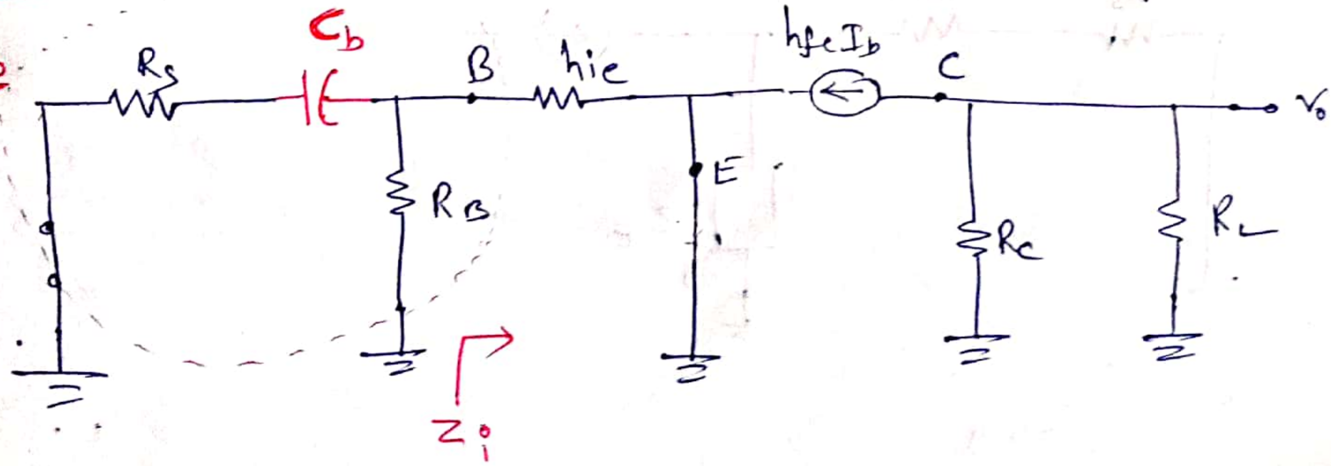


Step (1) :-

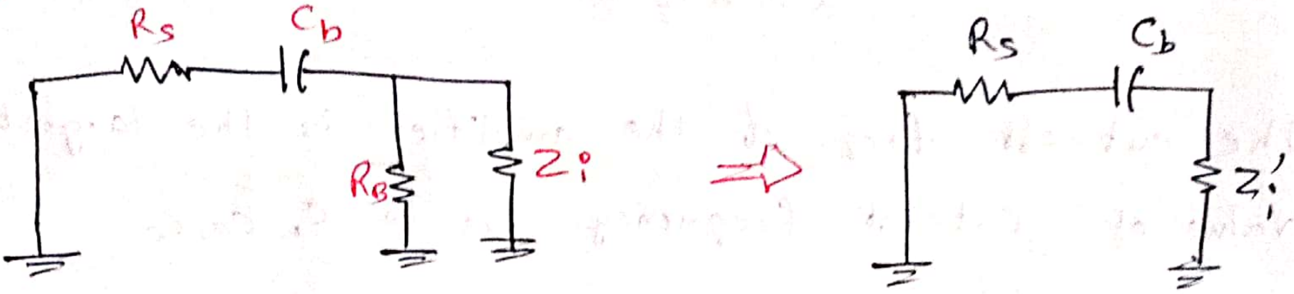


Step (2) :-

C_b :



7 step ③ :-

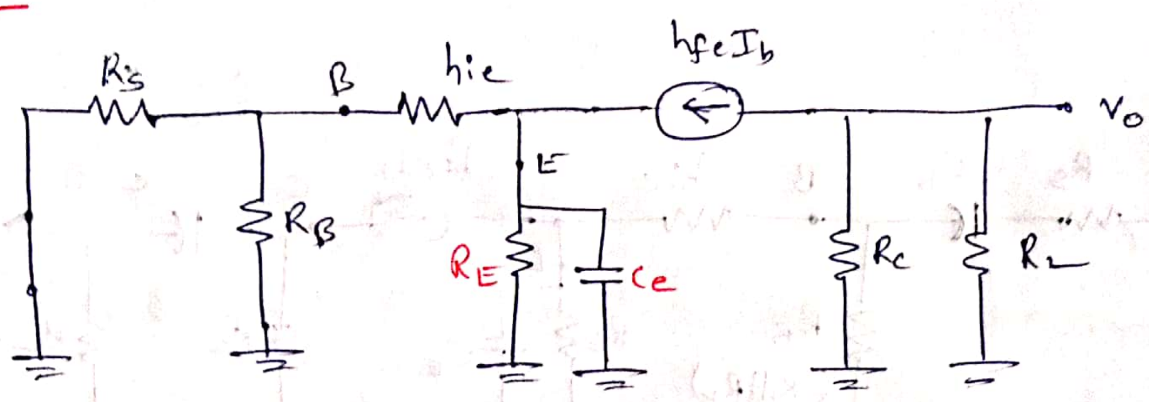


$Z_i' = R_B \| Z_i$

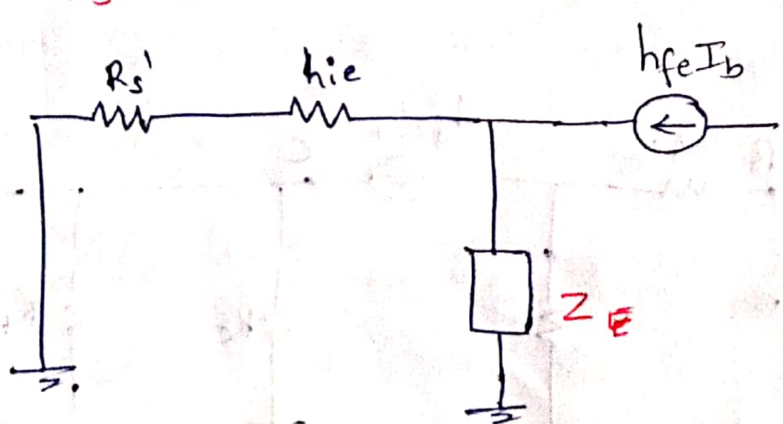
$R_{eq} = R_s + Z_i'$

$$\boxed{f_{L_{C_b}} = \frac{1}{2\pi R_{eq} \cdot C_b} = \frac{1}{2\pi (R_s + Z_i')C_b}}$$

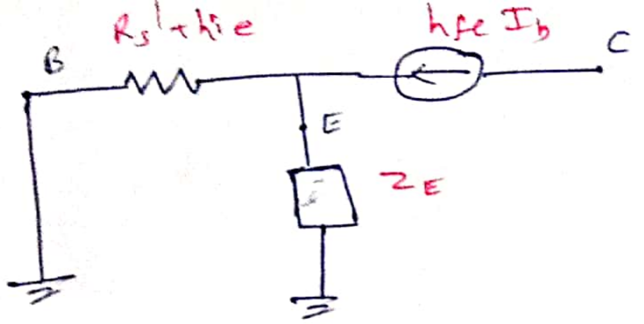
Ce



$R_s' = R_s \| R_B$



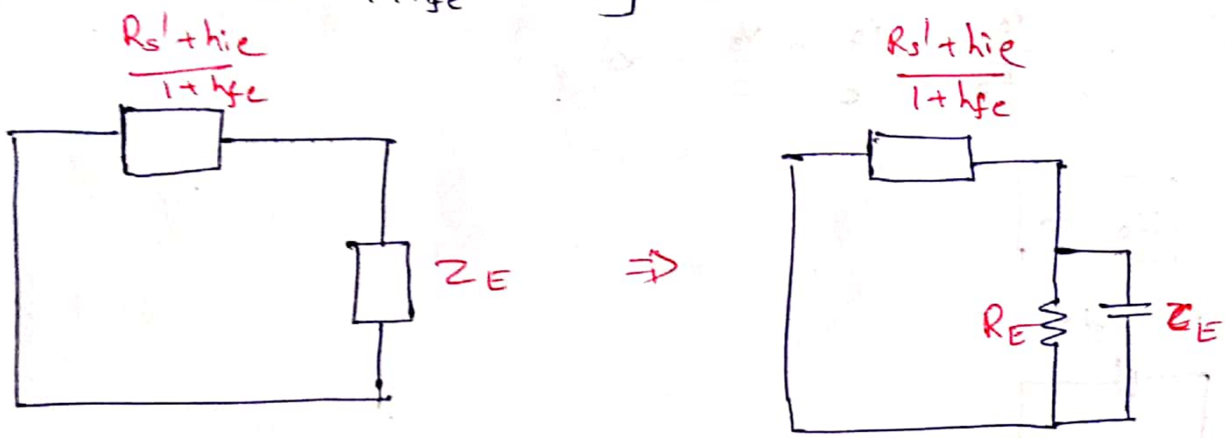
serly



Apply KVL

$$I_b(R_s' + h_{ie}) + (1+h_{fe}) I_b Z_E = 0$$

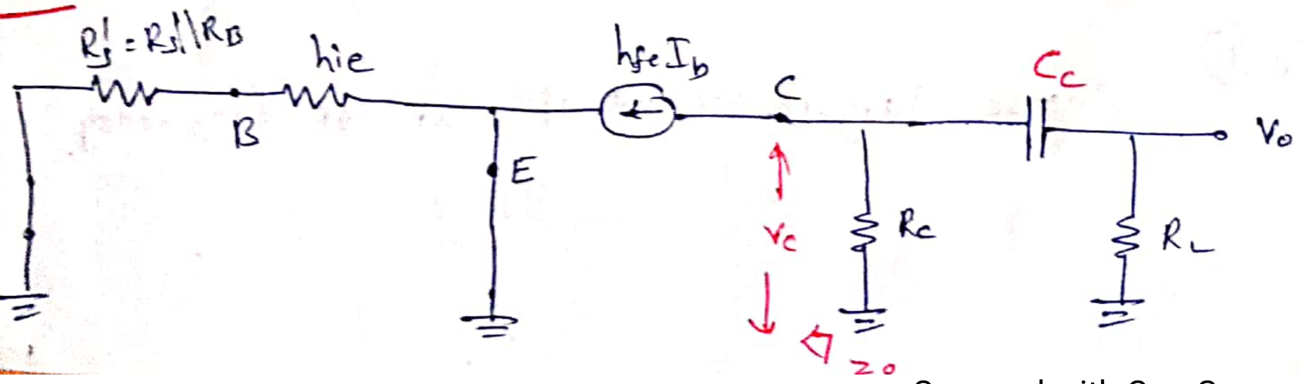
$$I_b (1+h_{fe}) \left[\frac{R_s' + h_{ie}}{1+h_{fe}} + Z_E \right] = 0$$



$$R_{eq} = R_E \,||\, \frac{R_s' + h_{ie}}{1+h_{fe}}$$

$$\boxed{f_{L_{C_e}} = \frac{1}{2\pi\left(R_E \,||\, \frac{R_s' + h_{ie}}{1+h_{fe}}\right) C_e}}$$

C_c



9 Apply KVL to i/p loop

$$I_b(R_s' + h_{ie}) = 0$$

$R_s' + h_{ie} \neq 0$, $\boxed{I_b = 0}$

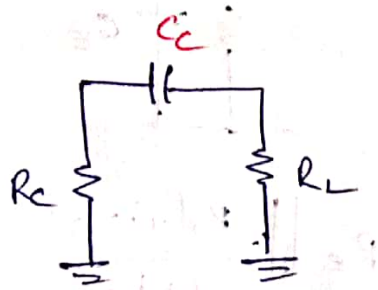
$$\therefore I_C = h_{fe} I_b$$

$$= h_{fe}(0) = 0$$

$$\boxed{I_C = 0}$$

$$\therefore Z_o = \frac{V_o}{I_o} = \frac{V_o}{I_C} = \frac{V_o}{0} = \infty$$

$$\boxed{Z_o = \infty}$$



$$R_{eq} = R_C + R_L$$

$$\boxed{f_{L_{C_C}} = \frac{1}{2\pi R_{eq} C_C} = \frac{1}{2\pi (R_C + R_L) C_C}}$$

Step 4 :- Choose largest value of cut-off frequency.

(10)

Problem ① :- $h_{ie} = 1\,k\Omega$, $h_{fe} = 100$, $R_S = R_E = 1\,k\Omega$, $R_1 = 16\,k\Omega$, $R_2 = 4\,k\Omega$, $R_C = 3\,k\Omega$, $R_L = 7\,k\Omega$. $C_b = C_c = 10\,\mu F$, $C_e = 100\,\mu F$.

Calculate lower-cut-off frequency of amplifier.

Sol :-

C_b

$$f_{LC_b} = \frac{1}{2\pi (R_s + Z_i') C_b}$$

$$Z_i' = Z_i \| R_B = h_{ie} \| R_1 \| R_2$$

[where $Z_i = h_{ie}$
$R_B = R_1 \| R_2$ $= 3.2k$]

$$= 1k \| 16k \| 4k$$

$$= 0.7619\,k\Omega$$

$$f_{LC_b} = \frac{1}{2 \times 3.14 \times (1 \times 10^3 + 0.7619 \times 10^3) \times 10 \times 10^{-6}}$$

$$\boxed{f_{LC_b} = 9.033\ Hz}$$

C_e

$$f_{LC_e} = \frac{1}{2\pi \left[R_E \| \frac{R_s' + h_{ie}}{1 + h_{fe}} \right] C_e}$$

$$R_s' = R_s \| R_B = R_s \| R_1 \| R_2 = 1k \| 16k \| 4k$$

$$R_s' = 0.7619\,k\Omega$$

(11)

$$= \frac{1}{2 \times 3.14 \left[1K + \frac{0.7619K + 1K}{1+100} \right] \times 100 \times 10^{-6}}$$

$$\boxed{f_{L_{Ce}} = 92.826 \text{ Hz}}$$

$\underline{C_c}$

$$f_{L_{Cc}} = \frac{1}{2\pi (R_C + R_L) C_c}$$

$$= \frac{1}{2 \times 3.14 (3 \times 10^3 + 7 \times 10^3) \times 10 \times 10^{-6}}$$

$$\boxed{f_{L_{Cc}} = 1.59 \text{ Hz}}$$

$$f_L = \max(f_{L_{Cb}}, f_{L_{Ce}}, f_{L_{Cc}})$$

$$= \max(9.033, 92.826, 1.59)$$

$$\boxed{f_L = 92.826 \text{ Hz}}$$

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High Frequency Response of Amplifier:-

↓

Calculate "Higher cut-off frequency / Upper cut-off freq.

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

→ At high frequencies, the h-parameters become complex in nature and varies with frequencies. So, that h-parameter model is not valid at high frequencies.

→ At high freq's, Hybrid π-model is used.

VII Hybrid-π Common Emitter Transistor model :-

$r_{bb'}$ → Base spreading Resistance
($r_{bb'} \leq 100\Omega$ always)

g_m → Transconductance

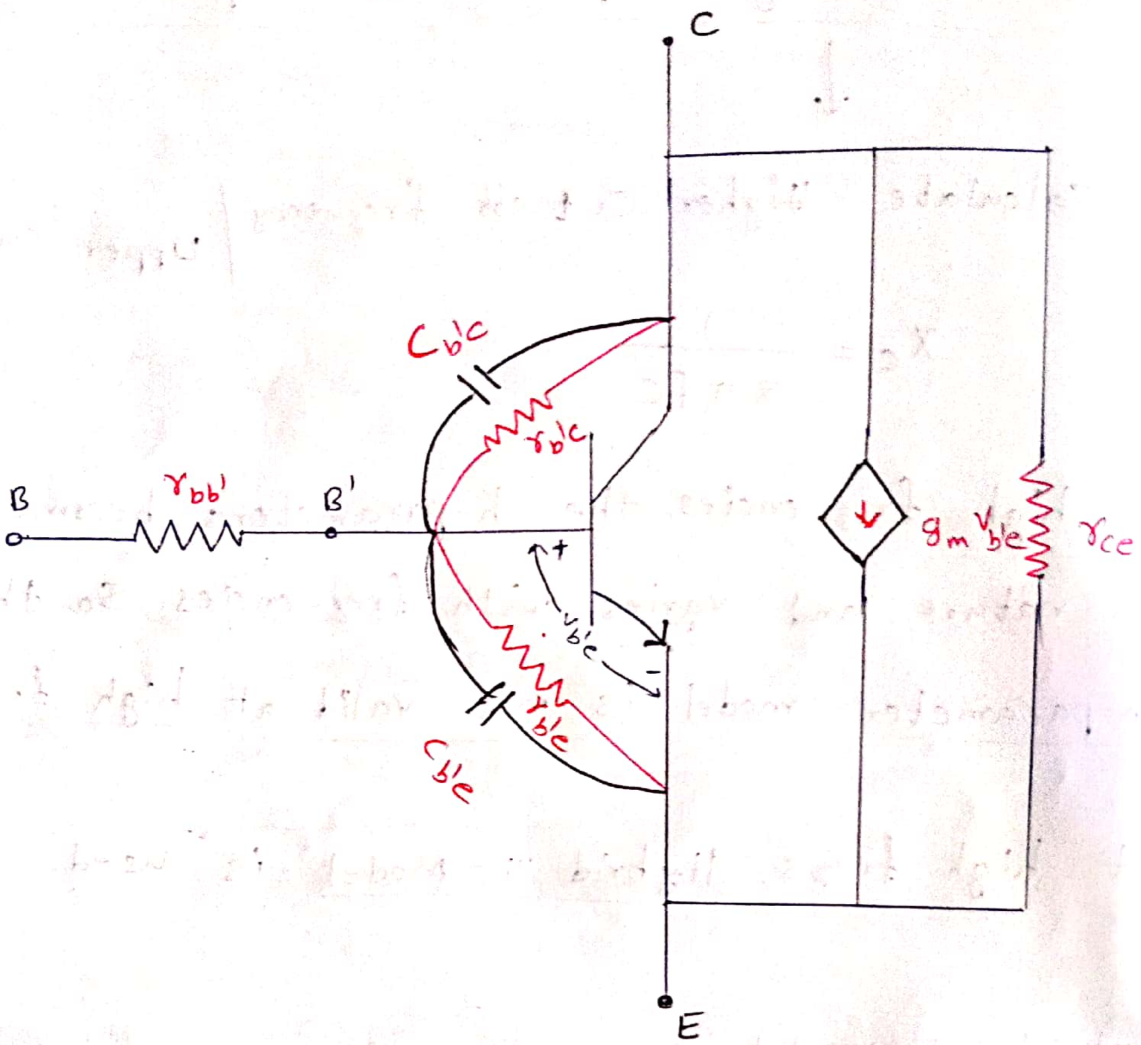
$r_{b'c}$ → reverse bias resistance
($r_{b'c} \cong 4M\Omega$, it is very high)

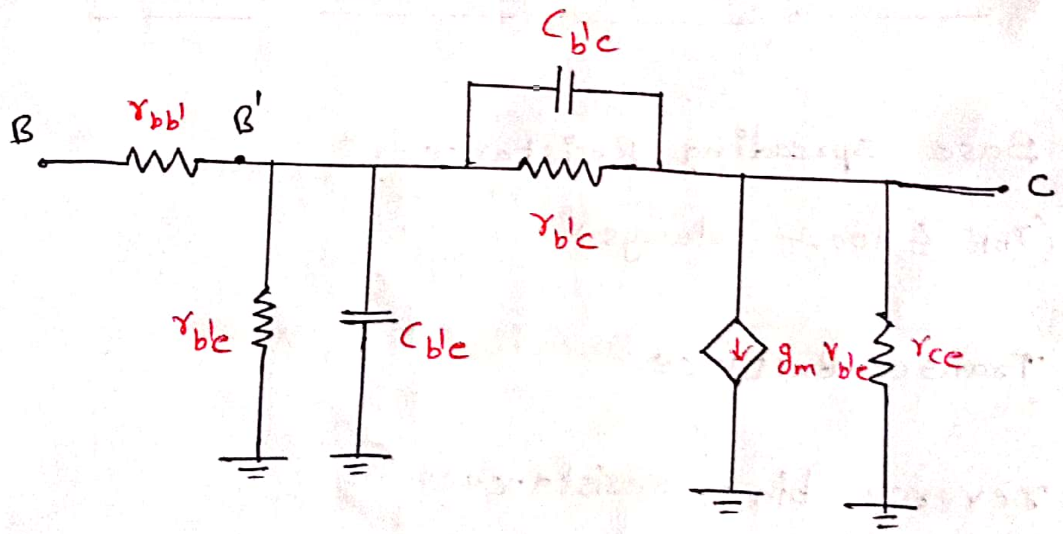
r_{ce} → output resistance ($80 k\Omega$)

$C_{b'e}$ → Diffusion capacitance ($100pF$)

$C_{b'c}$ → Transition capacitance ($1pF$)

(13)





Equivalent circuit diagram.

Notation

$r_{b'e} \rightarrow r_{\pi}, r_{be}, r_e$

$C_{b'e} \rightarrow C_{\pi}, C_{be}, C_e$

$V_{b'e} \rightarrow v_{\pi}, v_{be}, v_e$

$r_{b'c} \rightarrow r_{\mu}, r_{bc}, r_c$

$C_{b'c} \rightarrow C_{\mu}, C_{bc}, C_c$

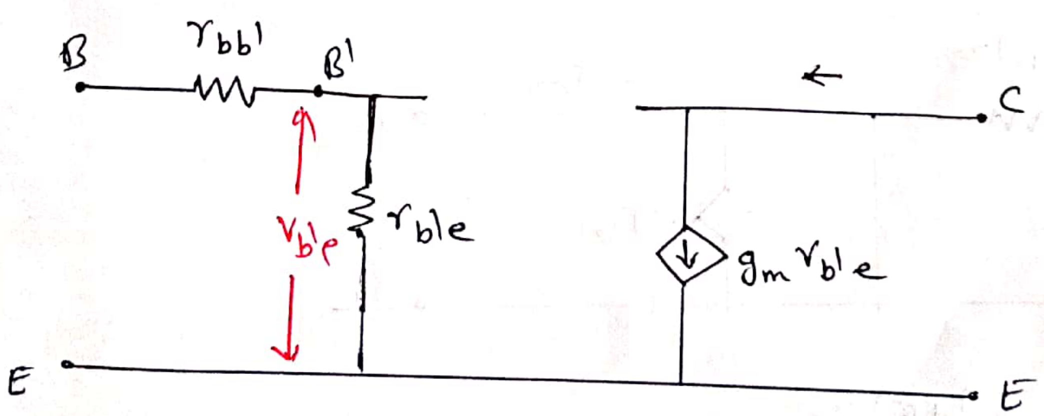
→ At low frequency, hybrid-π model, h-parameter model, $r_e - C_e$ model same.

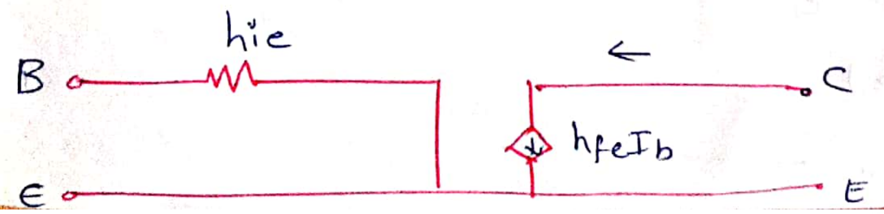
→ high freq $\xrightarrow[\text{becomes}]{}$ low freq.

at $C_{b'e}$ & $C_{b'c} \longrightarrow$ open ckt

$r_{b'c}$ & $r_{ce} \longrightarrow$ neglected (due to high value)

$X_c \longrightarrow \infty$





15 compare to circuit diagram

$$I_c = h_{fe} I_b = g_m V_{b'e} \quad \text{--- (1)}$$

$$I_c = \beta I_b$$

$$h_{fe} \cancel{I_b} = \beta \cancel{I_b}$$

$$\boxed{h_{fe} = \beta}$$

$\therefore$ from Eqn (1),

$$h_{fe} I_b = g_m V_{b'e}$$

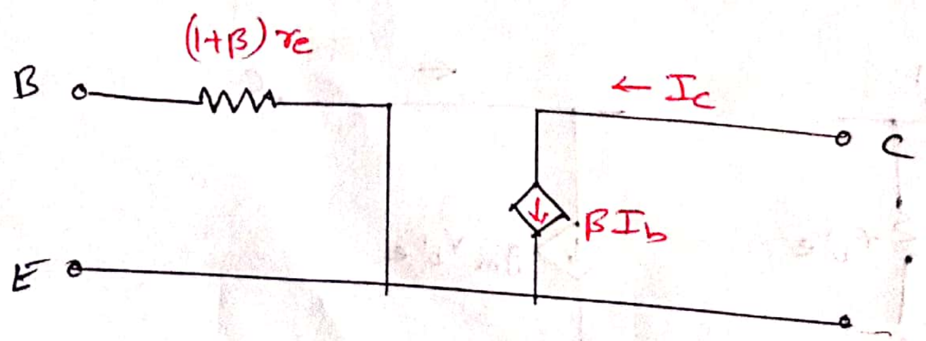
$$h_{fe} \cancel{I_b} = g_m \cancel{I_b} r_{b'e} \quad [\because V_{b'e} = I_b r_{b'e}]$$

$$h_{fe} = g_m r_{b'e}$$

$$\boxed{h_{fe} = g_m r_{b'e} = \beta} \quad \text{--- (2)}$$

from circuits,

$$h_{ie} = r_{bb'} + r_{b'e} = (1+\beta) r_e \quad [\because h_{fe} = \beta]$$



$$h_{ie} = (1+\beta) r_e$$

$$\beta >> 1$$

$$h_{ie} \simeq \beta r_e \quad \text{--- (3)}$$

$\because$ from Eqn ②, $h_{ie} \cong g_m r_{b'e} r_e$ $[\because \beta = g_m r_{b'e}]$

but $g_m = \frac{1}{r_e}$, $r_e = \frac{V_T}{I_C}$

$$h_{ie} = \frac{\cancel{I_C}}{\cancel{V_T}} \cdot r_{b'e} \frac{\cancel{V_T}}{\cancel{I_C}}$$

$$\boxed{h_{ie} = r_{b'e} = \beta r_e}$$ $[\because$ from eqn ③$]$

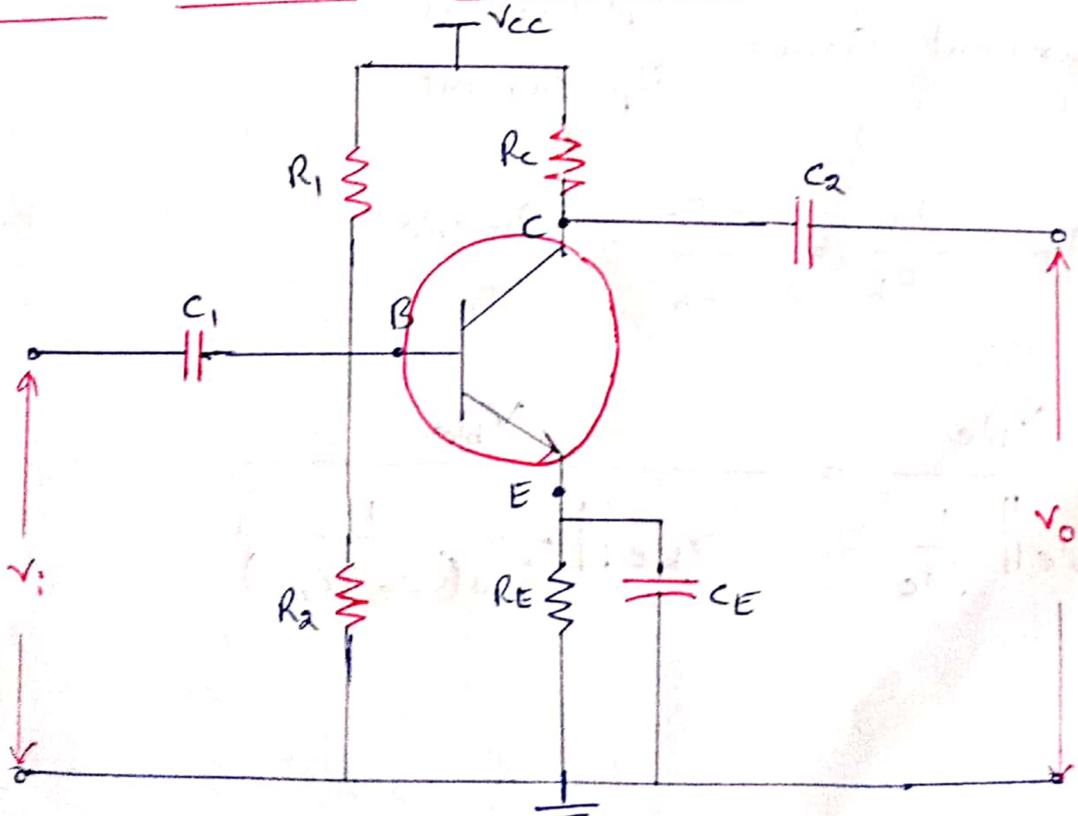
$h_{fe} = \beta = g_m r_{b'e}$

$h_{fe} = \beta = g_m h_{ie}$

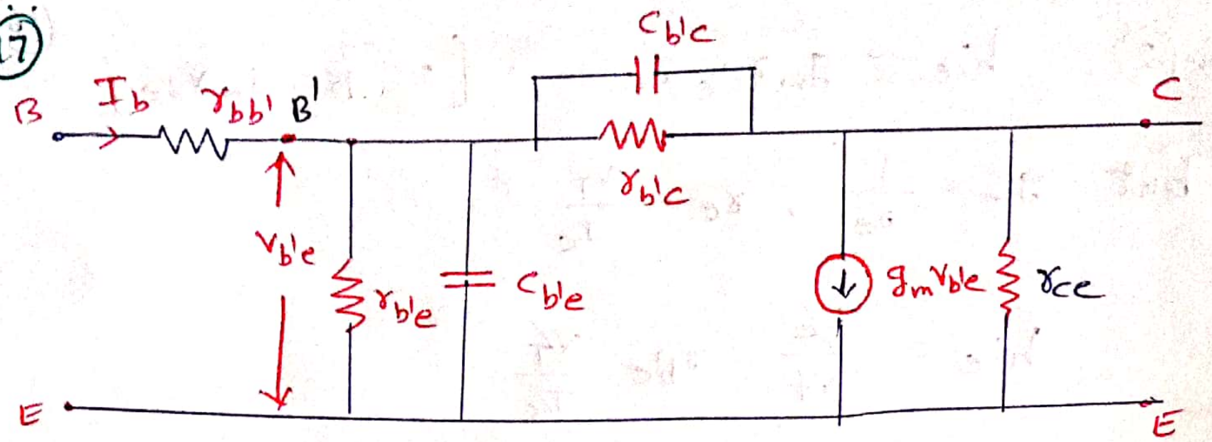
$h_{fe} = g_m h_{ie}$

$$\boxed{g_m = \frac{h_{fe}}{h_{ie}}}$$ $\rightarrow$ Transconductance.

viii) Common Emitter short-circuit Gain of Amplifier:-



(17)

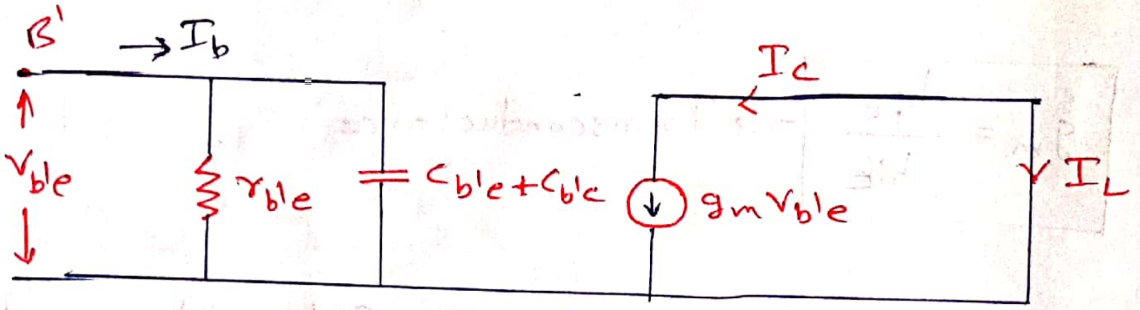


Equivalent hybrid-π model of CE Amplifier

Assumptions:

(1) $r_{b'c}$ is neglected since $r_{b'c} >> r_{b'e}$

(2) r_{ce} disappears, since it is shunt with s.c.



$$\text{Current Gain} = \frac{\text{o/p current}}{\text{i/p current}}$$

$$\therefore \; A_I = \frac{I_L}{I_b} = \frac{-I_c}{I_b} = \frac{-g_m V_{b'e}}{I_b}$$

$$I_b = \frac{V_{b'e}}{r_{b'e} \parallel \frac{1}{jX_c}} = \frac{V_{b'e}}{r_{b'e} \parallel \frac{1}{j\omega(C_{b'e}+C_{b'c})}}$$

$$= \frac{V_{b'e}}{\dfrac{r_{b'e}}{1 + j\omega(C_{b'e} + C_{b'c})\, r_{b'e}}} = \frac{V_{b'e}}{\dfrac{\cancel{r_{b'e}}}{\cancel{r_{b'e}}\left(\dfrac{1}{r_{b'e}} + j\omega(C_{b'e} + C_{b'c})\right)}}$$

$$= \frac{V_{b'e}}{\dfrac{1}{g_{b'e} + j\omega(C_{b'e} + C_{b'c})}} = V_{b'e}\left[g_{b'e} + j\omega(C_{b'e} + C_{b'c})\right]$$

$$\therefore \quad A_I = \frac{-g_m V_{b'e}}{I_b} = \frac{-g_m \cancel{V_{b'e}}}{\cancel{V_{b'e}}\left[g_{b'e} + j\omega(C_{b'e} + C_{b'c})\right]}$$

$$A_I = \frac{-g_m}{g_{b'e} + j\omega(C_{b'e} + C_{b'c})}$$

Dividing Numerator & Denominator by $g_{b'e}$, we get

$$A_I(\omega) = \frac{\dfrac{-g_m}{g_{b'e}}}{\dfrac{\cancel{g_{b'e}}}{\cancel{g_{b'e}}} + \dfrac{j\omega(C_{b'e} + C_{b'c})}{g_{b'e}}}$$

but $\quad g_m = \dfrac{h_{fe}}{h_{ie}} = \dfrac{h_{fe}}{r_{b'e}} = h_{fe} \cdot g_{b'e}$

$$g_m = h_{fe} \cdot g_{b'e}$$

$$\frac{g_m}{g_{b'e}} = h_{fe}$$

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$$A_I(\omega) = \frac{-h_{fe}}{1 + j\omega(C_{b'e} + C_{b'c})\, r_{b'e}} \quad \text{--- (1)} \qquad \left[\because \frac{1}{g_{b'e}} = r_{b'e}\right]$$

From Eqn (1), current gain is not constant, It depends on the frequency.

$$A_I(f) = \frac{-h_{fe}}{1 + j\left(\frac{f}{f_\beta}\right)}$$

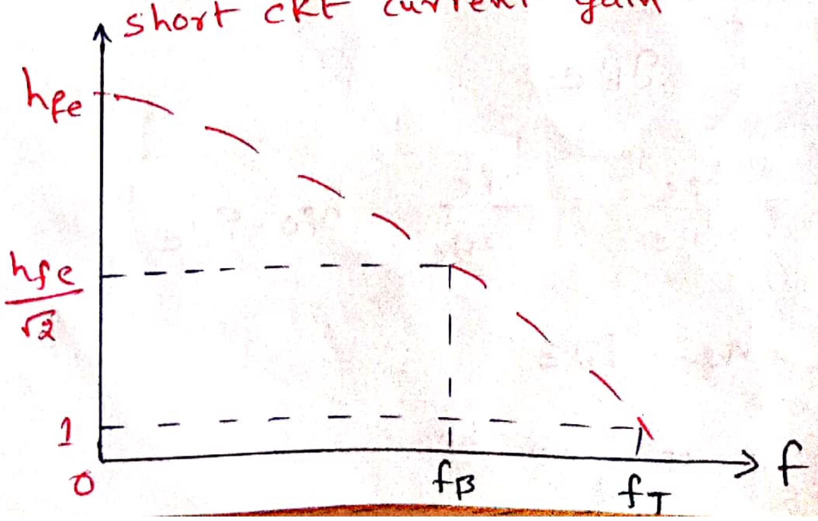
where $f_\beta = \dfrac{1}{2\pi r_{b'e}(C_{b'e} + C_{b'c})}$

$$|A_I| = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f}{f_\beta}\right)^2}}$$

at $f = 0$, $|A_I| = h_{fe} = \beta = g_m r_{b'e}$

$f = f_\beta$, $|A_I| = \dfrac{h_{fe}}{\sqrt{2}} = 0.707\, h_{fe}$

$f = \infty$, $|A_I| = 0$



where

$f_\beta \rightarrow$ corner freq

(or)

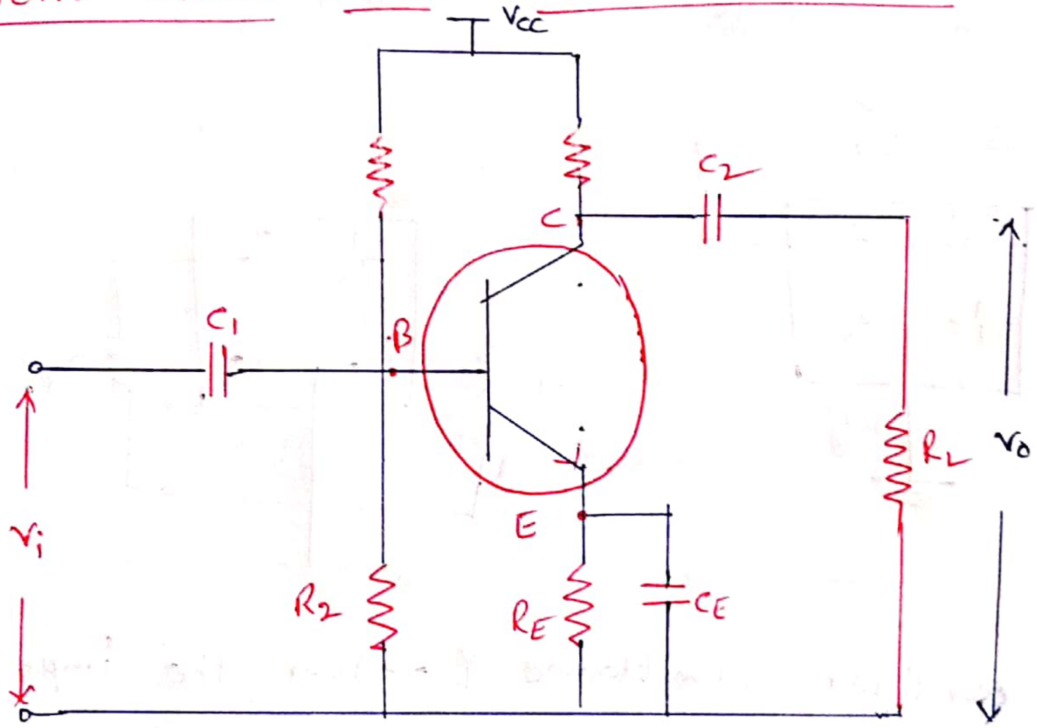
Beta cut-off freq

$f_T \rightarrow$ Transition freq

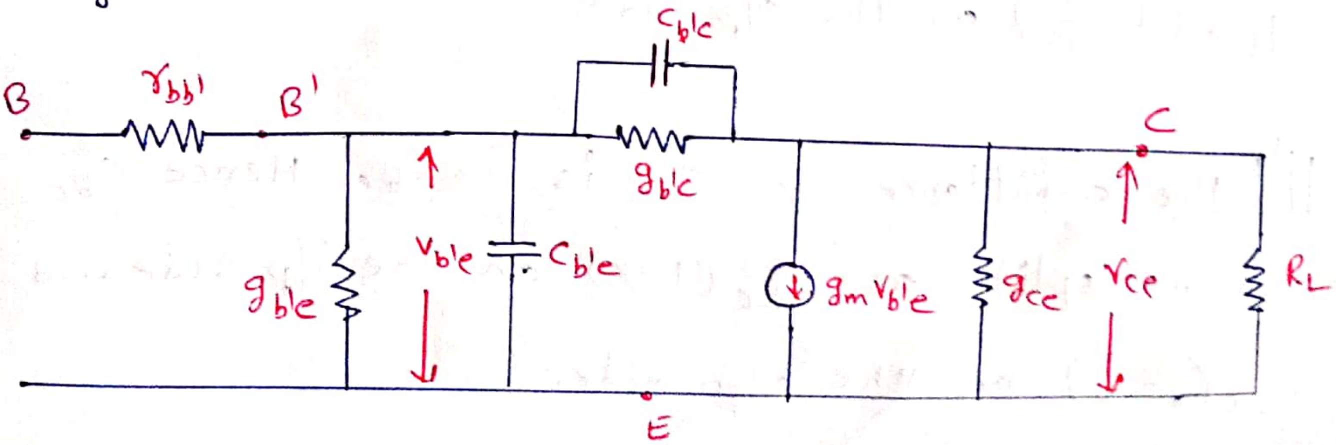
$$f_\beta = \frac{1}{2\pi r_{b'e}(C_{b'e} + C_{b'c})} = \frac{g_{b'e}}{2\pi(C_{b'e} + C_{b'c})}$$

$$\boxed{f_\beta = \frac{1}{h_{fe}}\left[\frac{g_m}{2\pi(C_{b'e} + C_{b'c})}\right]} \qquad \left[\because g_{b'e} = \frac{g_m}{h_{fe}}\right]$$

IX. Current Gain with Resistive Load :-



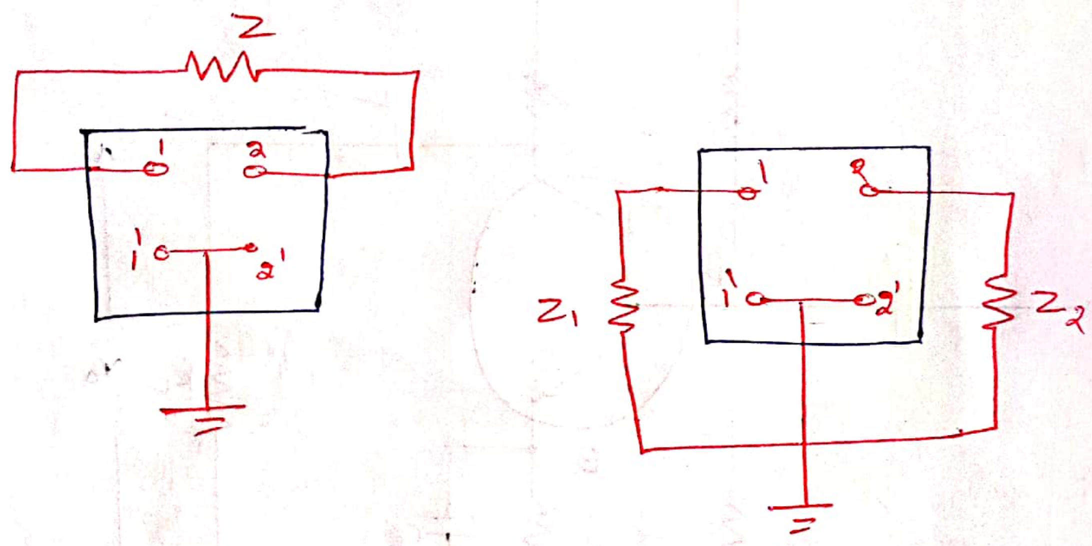
→ The Hybrid-π model with a load resistance R_L is connected across collector & emitter terminals and To understand the Analysis, we consider conductance in place of resistance.



(21) → The analysis get simplified by splitting the bridging elements $C_{b'c}$ and $g_{b'c}$ by miller theorem.

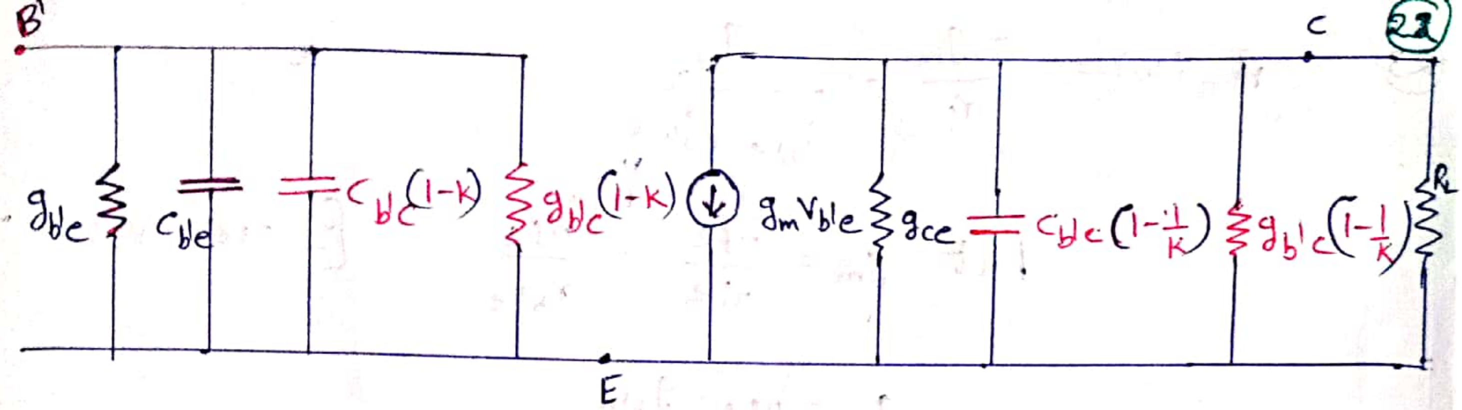
→ If an impedance Z is connected across i/p & o/p of an amplifier with gain K then it can be split into two impedances Z_1 and Z_2.

where $Z_1 = \frac{Z}{1-K}$ and $Z_2 = \frac{Z \cdot K}{K-1}$



→ If we consider admittance Y rather the impedance Z then $Y_1 = Y(1-K)$ and $Y_2 = Y(1-\frac{1}{K})$. Hence $g_{b'c}$ can be split as $g_{b'c}(1-K)$ on the i/p side and $g_{b'c}(1-\frac{1}{K})$ on the o/p side.

→ $||^{ly}$ the admittance of $C_{b'c}$ is $j\omega C_{b'c}$. Hence $C_{b'c}$ can be split as $C_{b'c}(1-K)$ on the i/p side and $C_{b'c}(1-\frac{1}{K})$ on the o/p side.

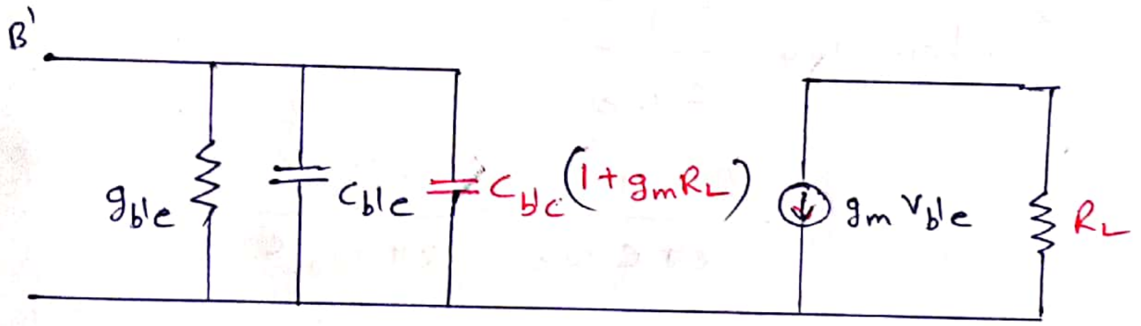


→ The o/p side g_{ce}, $g_{b'c}(1-\frac{1}{K})$ & $j\omega C_{b'c}(1-\frac{1}{K})$ are smaller than the load resistance and hence can be ignored.

Voltage gain (K), $K = \frac{V_o}{V_i} = \frac{V_o}{V_{b'e}} = \frac{I_L R_L}{V_{b'e}} = \frac{-I_c R_L}{V_{b'e}} = \frac{-g_m \cancel{V_{b'e}} R_L}{\cancel{V_{b'e}}}$

$$\boxed{K = -g_m R_L}$$

→ $g_{b'c}(1-K)$ is smaller than $g_{b'e}$, ignore $g_{b'c}(1-K)$



Current gain (A_I),

$$A_I = \frac{I_L}{I_i} = \frac{-g_m \cancel{V_{b'e}}}{Y_i \cancel{V_{b'e}}} = \frac{-g_m}{Y_i}$$

where $Y_i = g_{b'e} + j\omega[C_{b'e} + C_{b'c}(1+g_m R_L)]$

$$\boxed{Y_i = g_{b'e} + j\omega C}$$

where, $C = C_{b'e} + C_{b'c}(1+g_m R_L)$

(23) $$A_I(\omega) = \frac{-g_m}{Y_i} = \frac{-g_m}{g_{b'e} + j\omega c}$$

but $$g_m = \frac{h_{fe}}{h_{ie}} = \frac{h_{fe}}{r_{b'e}} \qquad [\because h_{ie} = r_{b'e}]$$

$$g_m = h_{fe} \cdot g_{b'e}$$

$$A_I(\omega) = \frac{-g_m}{g_{b'e} + j\omega c} = \frac{-h_{fe}\, g_{b'e}}{g_{b'e} + j\omega c} = \frac{-h_{fe}\, \cancel{g_{b'e}}}{\cancel{g_{b'e}}\left[1 + \frac{j\omega c}{g_{b'e}}\right]}$$

$$= \frac{-h_{fe}}{1 + j\omega c \cdot r_{b'e}}$$

$$A_I(\omega) = \frac{-h_{fe}}{1 + j\left(\frac{\omega}{\omega_H}\right)}$$

where $$\omega_H = \frac{1}{c\, r_{b'e}}$$

$$f_H = \frac{1}{2\pi c\, r_{b'e}} = \frac{1}{2\pi r_{b'e} c}$$

$$\therefore A_I(\omega) = \frac{-h_{fe}}{1 + j\left(\frac{f}{f_H}\right)}$$

$$\boxed{|A_I(\omega)| = \frac{h_{fe}}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}}$$

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XI Gain - Bandwidth Product :-

$$|A_{vs\,low}\, f_H| = |A_{vso}\, f_H| = \frac{-h_{fe}\cdot R_L}{R_s + h_{ie}} \times \frac{1}{2\pi R_{eq}\cdot C_{eq}}$$

$$= \frac{-h_{fe}\cdot R_L}{R_s + h_{ie}} \times \frac{1}{2\pi C_{eq}\left[\frac{r_{b'e}(r_{bb'} + R_s)}{r_{b'e} + r_{bb'} + R_s}\right]}$$

$$= \frac{-h_{fe}\cdot R_L}{\cancel{R_s + h_{ie}}} \times \frac{1}{2\pi C_{eq}\left[\frac{r_{b'e}(r_{bb'} + R_s)}{\cancel{h_{ie} + R_s}}\right]}$$

$$\left[\because h_{ie} = r_{b'e} + r_{bb'}\right]$$

$$= \frac{-h_{fe}\cdot R_L}{2\pi C_{eq}\left[r_{b'e}(r_{bb'} + R_s)\right]}$$

$$= \frac{-g_m \cancel{r_{b'e}}\cdot R_L}{2\pi C_{eq}\, \cancel{r_{b'e}}(r_{bb'} + R_s)} \qquad \left[\because h_{fe} = g_m r_{b'e}\right]$$

$$|A_{vso} \times f_H| = \frac{-g_m R_L}{2\pi C_{eq}(r_{bb'} + R_s)}$$

→This eqn can be simplified as follow. where $C_{eq} = C_e + C_c(1 + g_m R_L)$

$$|A_{vso} \times f_H| = \frac{g_m}{2\pi\left[C_e + C_c(1 + g_m R_L)\right]} \times \frac{R_L}{R_s + r_{bb'}}$$

$$= \frac{g_m}{2\pi\left[C_e + C_c(g_m R_L)\right]} \times \frac{R_L}{R_s + r_{bb'}} \qquad \left[\because g_m R_L >> 1\right]$$

$$= \frac{R_L}{R_s + r_{bb'}} \times \frac{2\pi f_T C_e}{2\pi\left[C_e + C_c(2\pi f_T C_e R_L)\right]}$$

$$\left[\because g_m = 2\pi f_T C_e\right]$$

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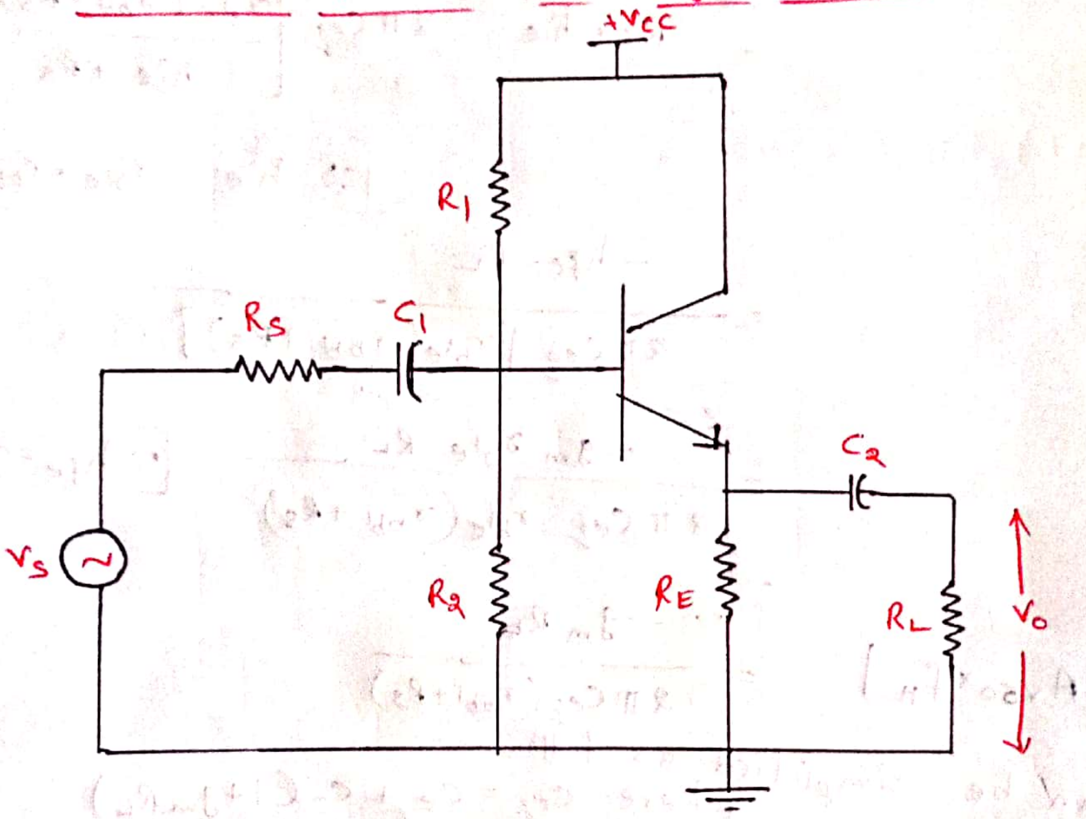
$$= \frac{R_L}{R_s + r_{bb'}} \times \frac{2\pi C_e f_T}{2\pi C_e [1 + 2\pi f_T C_c R_L]}$$

$$\therefore \boxed{|A_{vso} \times f_H| = \frac{R_L}{R_s + r_{bb'}} \times \frac{f_T}{1 + 2\pi f_T C_c R_L}}$$

XI Emitter follower at high frequencies:-

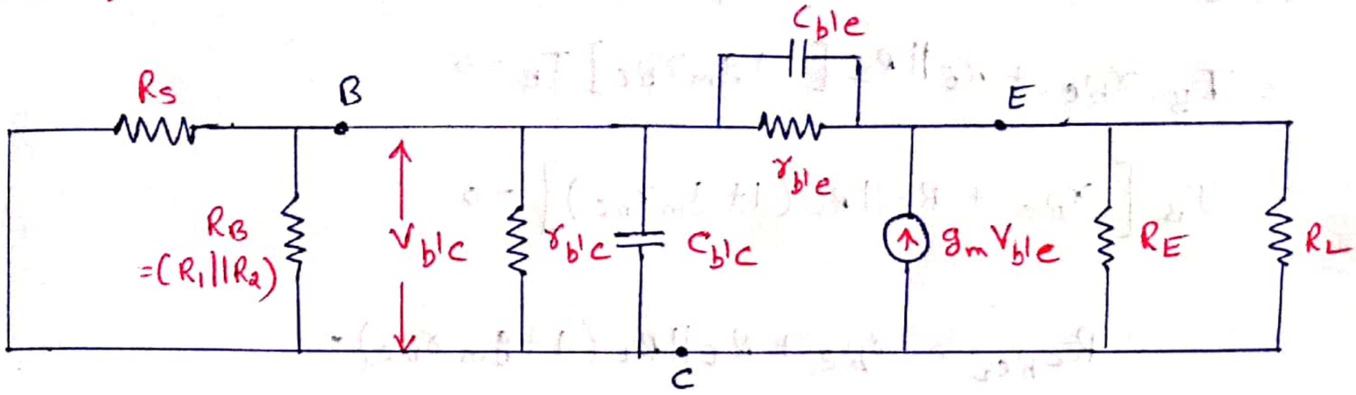


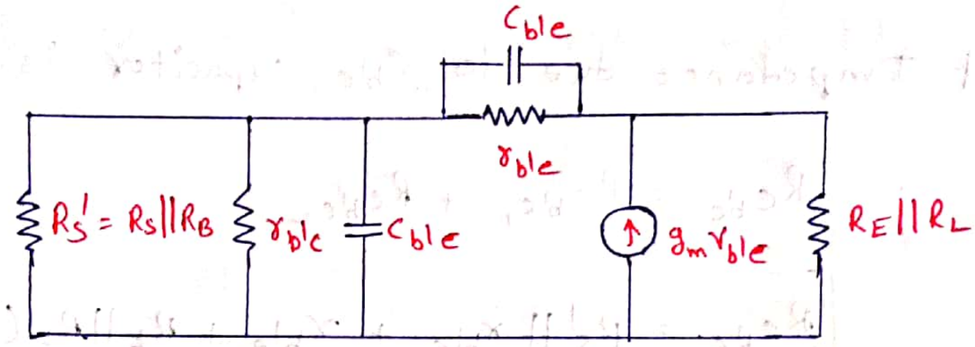
→ Emitter follower is the common collector amplifier at high frequency response.

Procedure :-

1. Draw the A.C. equi. ckt of π-model parameter of the Transistor
2. All the capacitors i.e., coupling capacitors are short circuited at high frequencies.
3. All the A.C. and D.C. sources are made to zero.

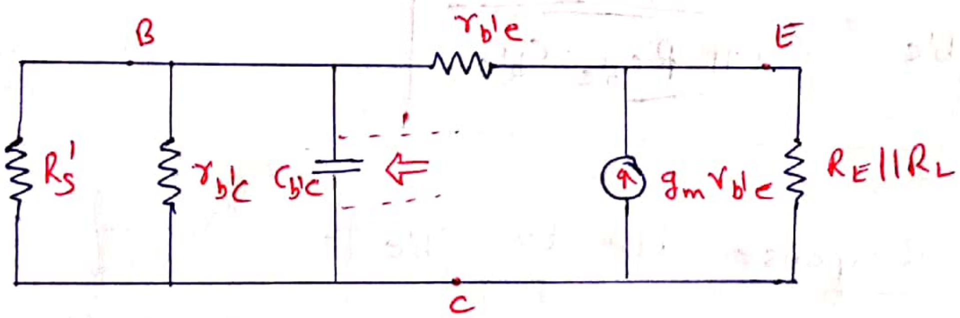
A.C. Equivalent circuit of Emitter follower:





Frequency Response due to $C_{b'c}$:

Except $C_{b'c}$, all capacitors are open circuited



Impedance of the left side of $C_{b'c}$ capacitor

i.e., $$R_{C_{b'c},1} = R_s' \| r_{b'c}$$

Impedance of the right side of $C_{b'c}$ capacitor

i.e.
$$I_E = I_B + I_C$$
$$= I_B + g_m V_{b'e}$$
$$= I_B + g_m r_{b'c} I_B$$
$$I_E = I_B (1 + g_m r_{b'c})$$

(27) Apply KVL to the o/p loop

$$I_B r_{b'e} + R_E \| R_L [1 + g_m r_{b'c}] I_B = 0$$

$$I_B [r_{b'e} + R_E \| R_L (1 + g_m r_{b'c})] = 0$$

$$R_{C_{b'c_2}} = r_{b'e} + R_E \| R_L (1 + g_m r_{b'c}).$$

Total Impedance due to $C_{b'c}$ capacitor is

$$R_{C_{b'c}} = R_{C_{b'c_1}} + R_{C_{b'c_2}}$$

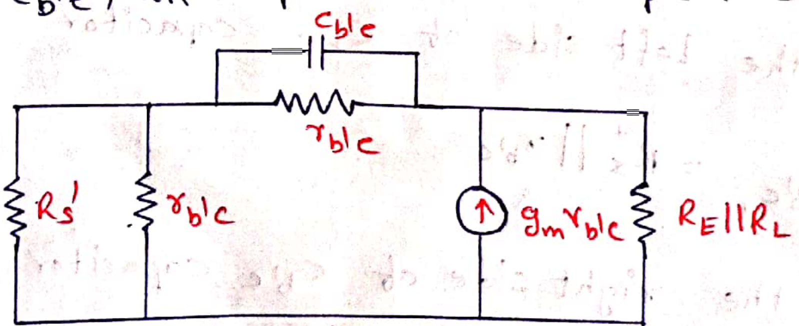
$$\boxed{R_{C_{b'c}} = R_s' \| r_{b'c} + r_{b'e} + R_E \| R_L (1 + g_m r_{b'c})}$$

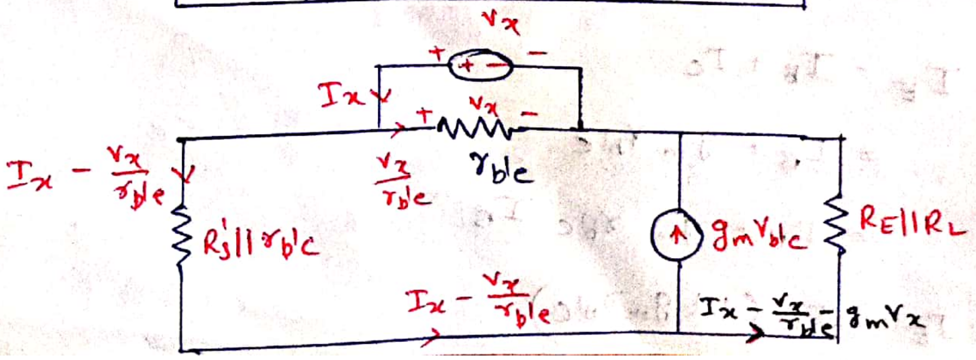
The frequency response due to $C_{b'c}$ capacitor is

$$\boxed{f_{C_{b'c}} = \frac{1}{2\pi R_{C_{b'c}} C_{b'c}}}$$

Frequency Response due to $C_{b'e}$:-

Except $C_{b'e}$, all capacitors are open circuited.





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Apply KVL to the above ckt

$$V_x - (R_s' \| r_{b'c})\left[I_x - \frac{V_x}{r_{b'e}}\right] - (R_E \| R_L)\left[I_x - \frac{V_x}{r_{b'e}} - g_m V_x\right] = 0$$

$$V_x - (R_s' \| r_{b'c}) I_x + (R_s' \| r_{b'c}) \frac{V_x}{r_{b'e}} - (R_E \| R_L) I_x + (R_E \| R_L) \frac{V_x}{r_{b'e}} + (R_E \| R_L) g_m V_x = 0$$

$$V_x + \frac{V_x}{r_{b'e}} (R_s' \| r_{b'c}) + \frac{V_x}{r_{b'e}} (R_E \| R_L) + g_m V_x (R_E \| R_L) = I_x (R_s' \| r_{b'c}) + I_x (R_E \| R_L)$$

$$V_x\left[1 + \frac{R_s' \| r_{b'c}}{r_{b'e}} + \frac{R_E \| R_L}{r_{b'e}} + g_m (R_E \| R_L)\right] = I_x\left[(R_s' \| r_{b'c}) + (R_E \| R_L)\right]$$

$$V_x\left[\frac{R_s' \| r_{b'c}}{r_{b'e}} + \frac{R_E \| R_L}{r_{b'e}} + 1 + g_m (R_E \| R_L)\right] = I_x\left[(R_s' \| r_{b'c}) + (R_E \| R_L)\right]$$

$$V_x\left[\frac{1}{r_{b'e}} (R_s' \| r_{b'c} + R_E \| R_L) + (1 + g_m (R_E \| R_L))\right] = I_x\left[R_s' \| r_{b'c} + R_E \| R_L\right]$$

$$\frac{I_x}{V_x} = \frac{1}{r_{b'e}} \frac{\cancel{R_s' \| r_{b'c} + R_E \| R_L}}{\cancel{R_s' \| r_{b'c} + R_E \| R_L}} + \frac{1 + g_m (R_E \| R_L)}{R_s' \| r_{b'c} + R_E \| R_L}$$

$$\boxed{\frac{I_x}{V_x} = \frac{1}{r_{b'e}} + \frac{1 + g_m (R_E \| R_L)}{R_s' \| r_{b'c} + R_E \| R_L}}$$

$$\boxed{R_{C_{b'c}} = \frac{V_x}{I_x}}$$

Frequency Response due to $C_{b'e}$ capacitor is

$$\boxed{f_{C_{b'e}} = \frac{1}{2\pi R_{C_{b'e}} \cdot C_{b'e}}}$$

UNIT – II (b)

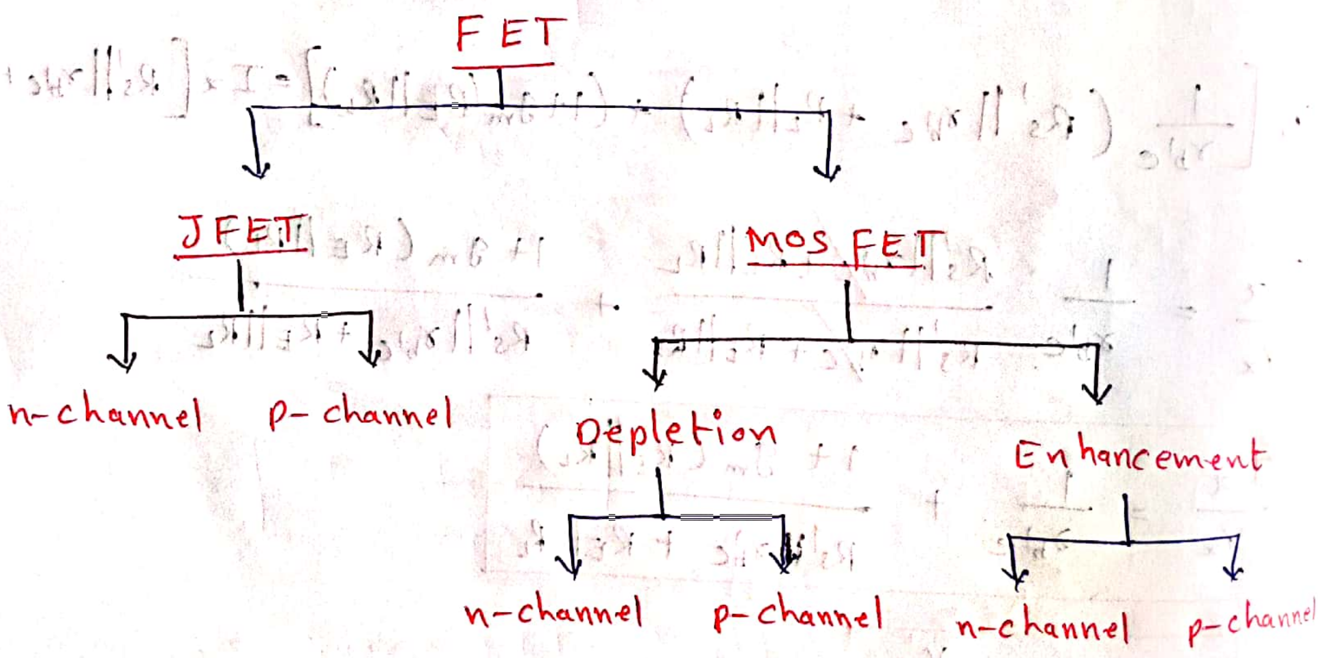
MOS Amplifiers

I Basic Concept :–

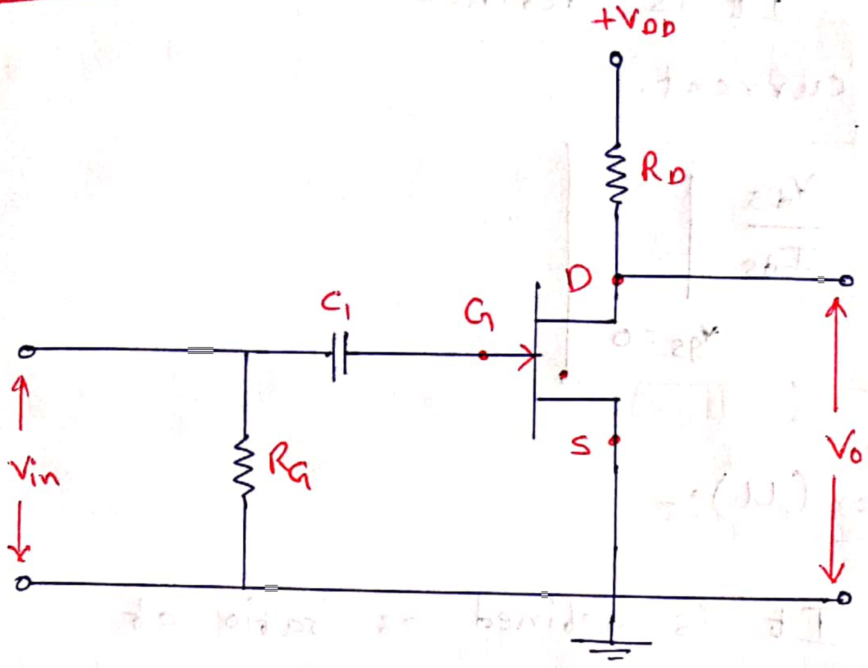
FET is a device in which the current flowing in the conduction region is controlled by i/p electric field, so it is called Field Effect Transistor (FET).

→ In BJT → o/p current is controlled by i/p current.

In FET → " " " " " voltage.



II MOS Small signal Model :-



$$R_G = \frac{V_G}{I_G}$$

Theoretical

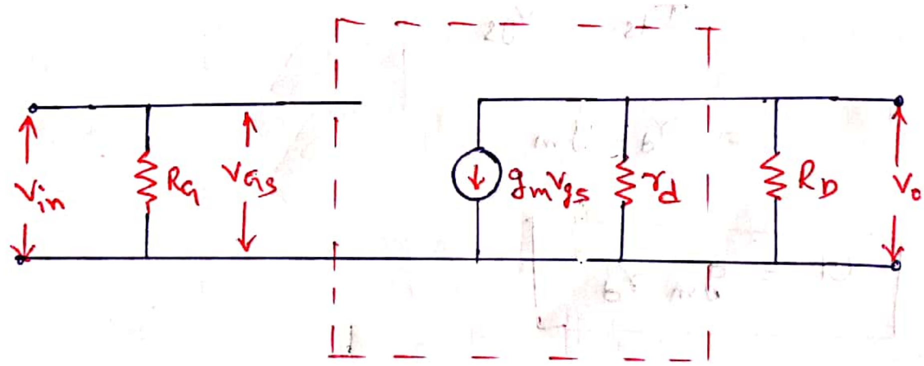
$I_G \approx 0$

$R_G = \frac{V_G}{0} = \infty$ (openckt)

Practical

$I_G = 10^{-9}$

$R_G = \frac{V_G}{10^{-9}} = 1000\,M\Omega$



FET Parameters :-

TransConductance (g_m):- It is defined as the ratio of o/p current to i/p voltage.

$$\boxed{g_m = \left.\frac{I_{ds}}{V_{gs}}\right|_{V_{ds}=0}}$$

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③ Drain Resistance (r_d):-

It is defined as ratio of o/p voltage to o/p current.

$$\boxed{r_d = \frac{V_{ds}}{I_{ds}}\bigg|_{V_{gs}=0}}$$

Amplification Factor (μ):-

It is defined as ratio of o/p voltage to i/p voltage.

$$\mu = \frac{V_{ds}}{V_{gs}}\bigg|_{I_{ds}=0}$$

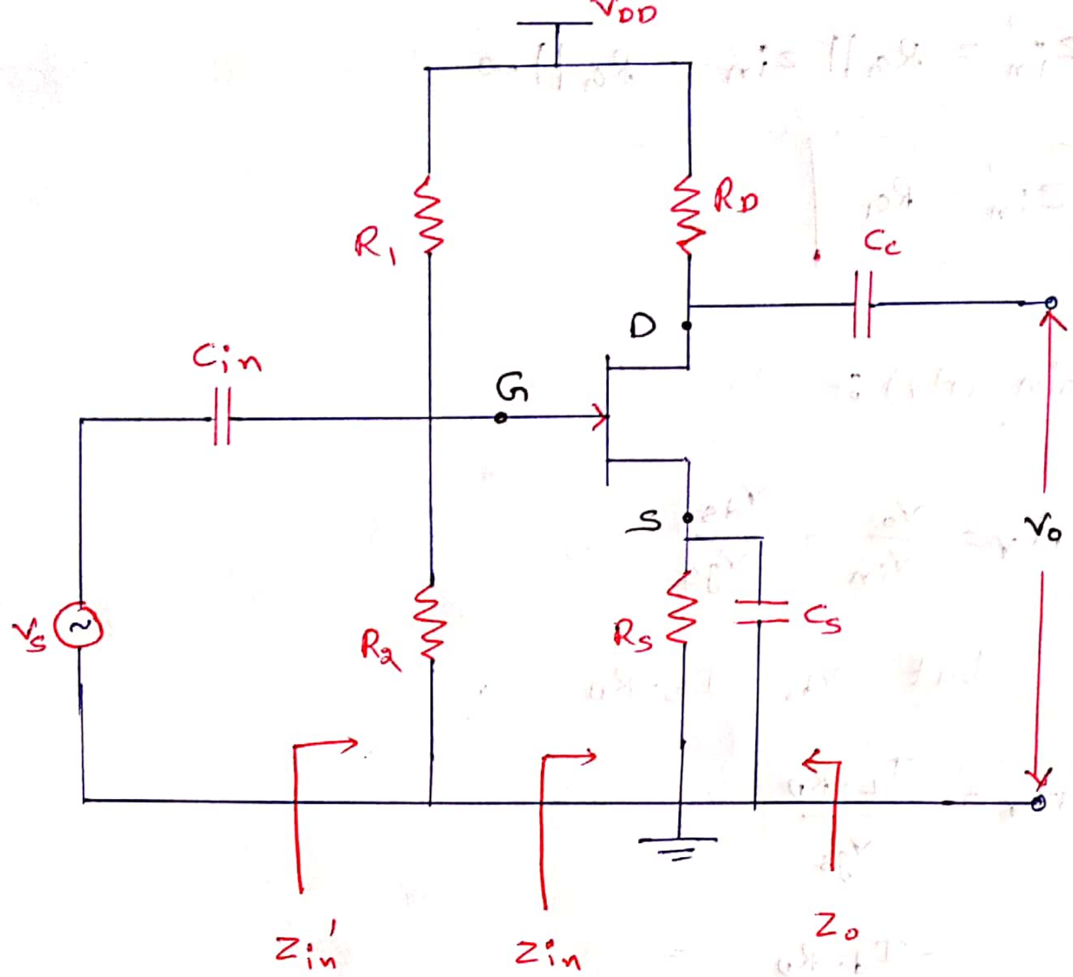
$$= \frac{V_{ds}}{I_{ds}} \cdot \frac{I_{ds}}{V_{gs}}$$

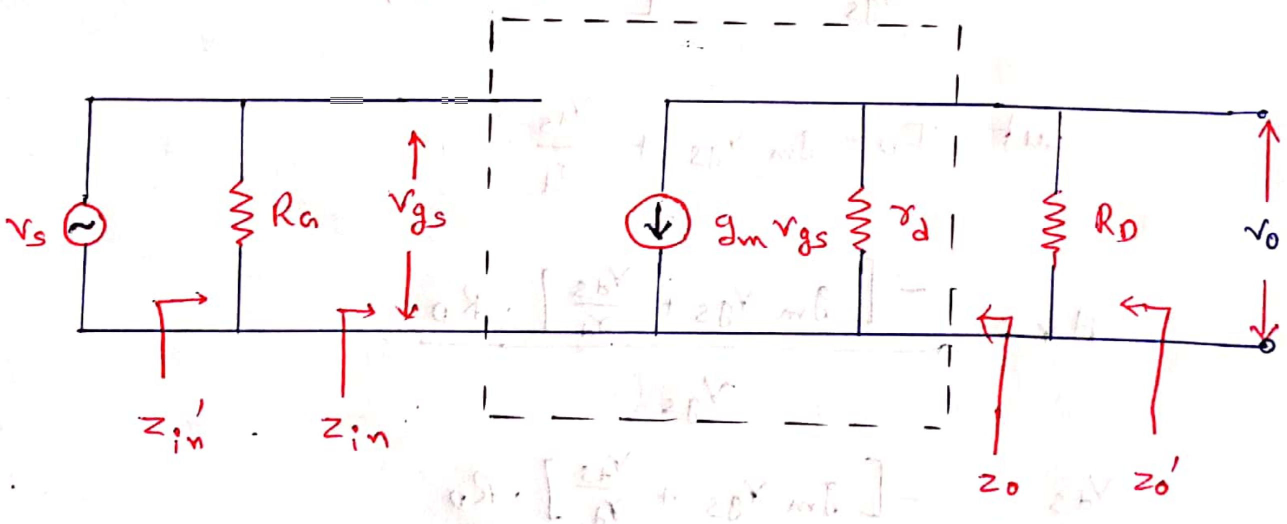
$$= r_d \cdot g_m$$

$$\boxed{\mu = g_m r_d}$$

11 Common Source FET Amplifier:-

The i/p current is very low value nA or pA i.e., negligible thats why FET device is not used for current amplification purpose.





Input Impedance (zin):-

$$Z_{in} = \frac{V_G}{I_G}$$

but $I_G = 0$

$$Z_{in} = \frac{V_G}{0}$$

$$\boxed{Z_{in} = \infty\ \Omega}$$

5

$$z_{in}' = R_a \| z_{in} = R_a \| \infty$$

$$\boxed{z_{in}' = R_a}$$

Voltage Gain (A_v) :-

$$A_v = \frac{V_o}{V_{in}} = \frac{V_{ds}}{V_{gs}}$$

but $V_{ds} = I_L \cdot R_D$

$$A_v = \frac{I_L \cdot R_D}{V_{gs}}$$

$$A_v = \frac{-I_d \cdot R_D}{V_{gs}} \qquad [\because I_L = -I_D]$$

but $I_D = g_m V_{gs} + \frac{V_{ds}}{r_d}$

$$A_v = \frac{-\left[g_m V_{gs} + \frac{V_{ds}}{r_d}\right] \cdot R_D}{V_{gs}}$$

$$\frac{V_{ds}}{\cancel{V_{gs}}} = \frac{-\left[g_m V_{gs} + \frac{V_{ds}}{r_d}\right] \cdot R_D}{\cancel{V_{gs}}}$$

$$V_{ds} = -\left[g_m V_{gs} + \frac{V_{ds}}{r_d}\right] \cdot R_D$$

$$V_{ds} = -g_m V_{gs} R_D - \frac{V_{ds}}{r_d} \cdot R_D$$

$$V_{ds} + \frac{V_{ds}}{r_d} R_D = -g_m V_{gs} R_D$$

$$V_{ds}\left(1+\frac{R_D}{r_d}\right) = -g_m V_{gs} R_D$$

$$\frac{V_{ds}}{V_{gs}}\left(1+\frac{R_D}{r_d}\right) = -g_m R_D$$

$$\frac{V_{ds}}{V_{gs}} = \frac{-g_m R_D}{\left(1+\frac{R_D}{r_d}\right)}$$

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

$$= \frac{-g_m \cdot r_d \cdot R_D}{r_d + R_D}$$

$$= -g_m \cdot \left(\frac{r_d \cdot R_D}{r_d + R_D}\right)$$

$$\boxed{A_v = \frac{V_{ds}}{V_{gs}} = -g_m \cdot (r_d \| R_D)}$$

Output Impedance (Z_o) :-

$$Z_o = \left.\frac{V_{ds}}{I_{ds}}\right|_{V_{gs}=0}$$

but $I_{ds} = g_m V_{gs} + \frac{V_{ds}}{r_d}$

where $V_{gs} = 0$

$$I_{ds} = 0 + \frac{V_{ds}}{r_d} = \frac{V_{ds}}{r_d}$$

7

$$I_{ds} = \frac{V_{ds}}{r_d}$$

$$I_{ds} \cdot r_d = V_{ds}$$

$$r_d = \frac{V_{ds}}{I_{ds}}$$

$$\therefore \boxed{Z_0 = \frac{V_{ds}}{I_{ds}} = r_d}$$

$$\boxed{Z_0' = r_d \,||\, R_D}$$

UNIT – III (a)

Feedback Amplifier

Syllabus

1. Concepts of Feedback
2. Classification of Feedback Amplifiers
3. General characteristic of Negative Feedback Amplifier
4. Effect of Feedback on Amplifier characteristics
   - → Voltage Series Feedback Configuration
   - → " shunt " "
   - → Current Series " "
   - → " shunt " "
5. Illustrative Problems.

Introduction :-

Feedback plays an important role in almost all electronic circuits.

→ Feedback is process where by a portion of the o/p signal of the amplifier is fed back to the i/p of the amplifier.

→ The feedback signal can be either voltage or current, being applied in series or shunt respectively with the i/p signal.

→ The path over which the feedback is applied is the feedback loop.

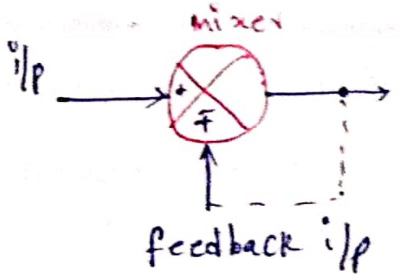
① Concept of Feedback :-

Feedback is nothing but a simple passive network which is used to improve the performance of amplifiers.

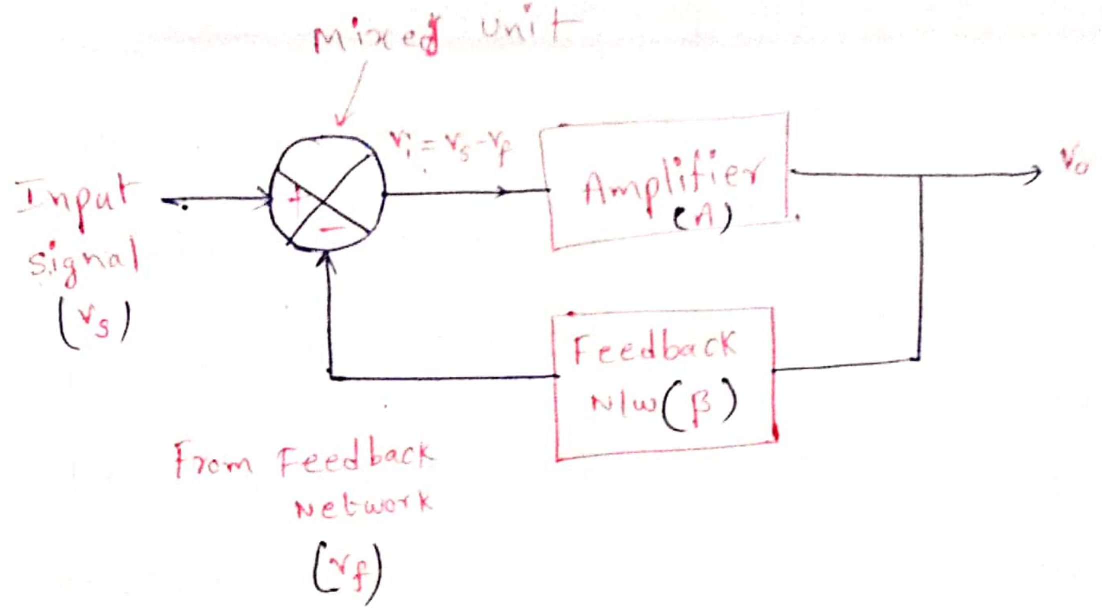
→ It is a process in which a part of the o/p voltage is taken and mixed with i/p. This technique is two methods as follows

① Negative Feedback

② Positive Feedback



① Negative Feedback:-



→ The feedback voltage v_f was opposite phase to the i/p voltage v_s, thereby the resultant input voltage v_i to the amplifier become the difference of the external i/p voltage v_s and the feedback voltage v_f,

i.e.. $\boxed{v_i = v_s - v_f}$

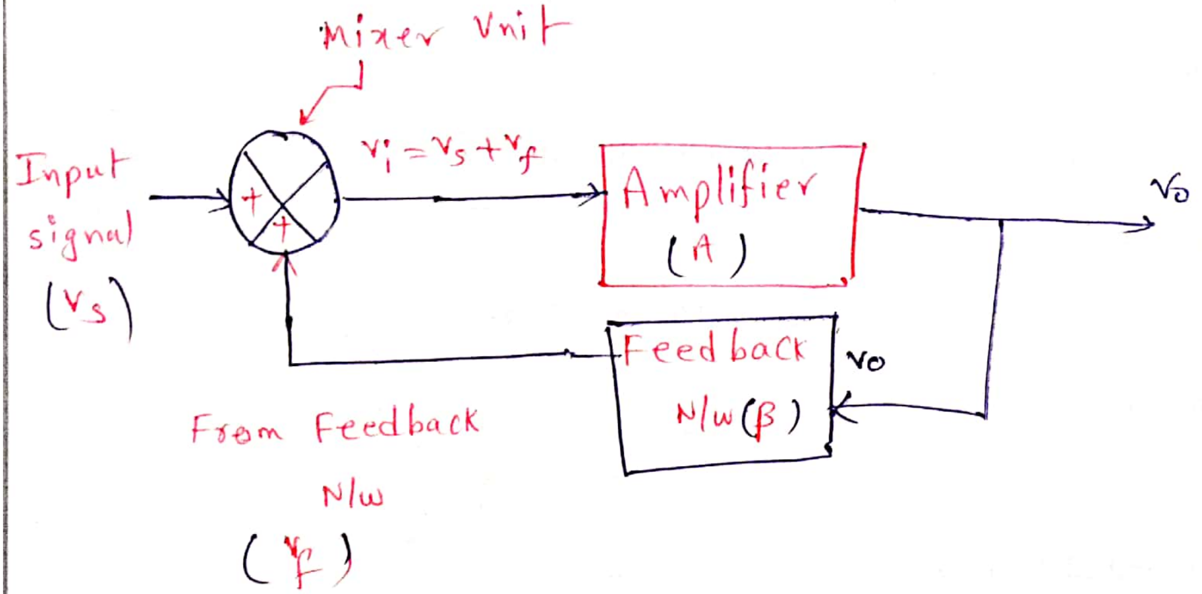
→ The resultant i/p to the amplifier is reduced the o/p of the amplifier also reduce voltage.

In otherwards, the gain of the amplifier reduce because of the feedback. This type of feedback is known "-ve feedback" (or) "degenerative feedback".

(2) Positive Feedback :-

Another one possibility exists in feedback is called positive feedback. That is the feedback voltage can be in the same phase as the external i/p voltage.

In this case, the effective i/p to the amplifier is increased obviously, Hence the gain of the amplifier increases.



→ Even through the gain of the amplifier is increased in this method, But

(1) It brings more distortion

(2) Poor gain instability

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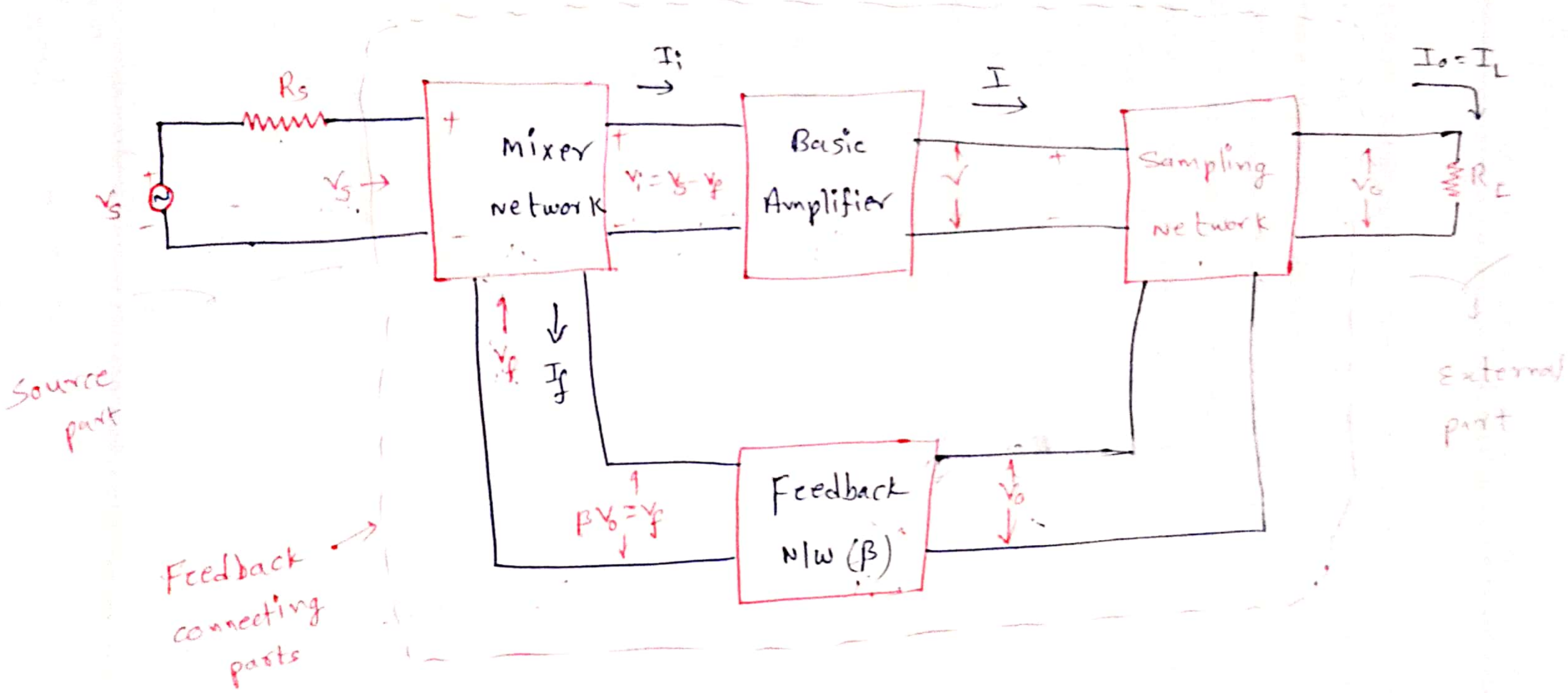
Block diagram of Feedback Amplifier :-

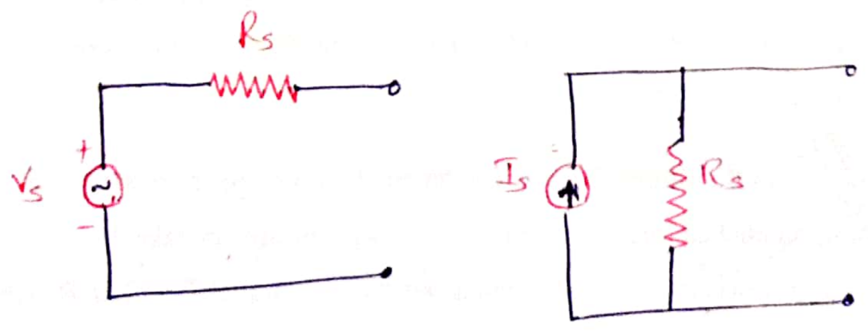


Block diagram of feedback amplifier consisting of the following parts.

1. signal source
2. Mixer Block
3. Amplifier Block
4. Feedback Network Block
5. Sampling Block

1. Signal Source :-

→ The signal source is either a voltage or a current source depending on the type of amplifier as classified.



fig(a). Thevenin's representation of voltage source

(b) Norton's Representation of current source

→ A voltage source is represented by a signal source V_s in series with a source resistance R_s, commonly known as Thevenin's representation.

A current source represented by a signal source I_s in parallel with a source resistance R_s, commonly known as Norton's representation.

(2) Mixer (or) Comparator Block :-

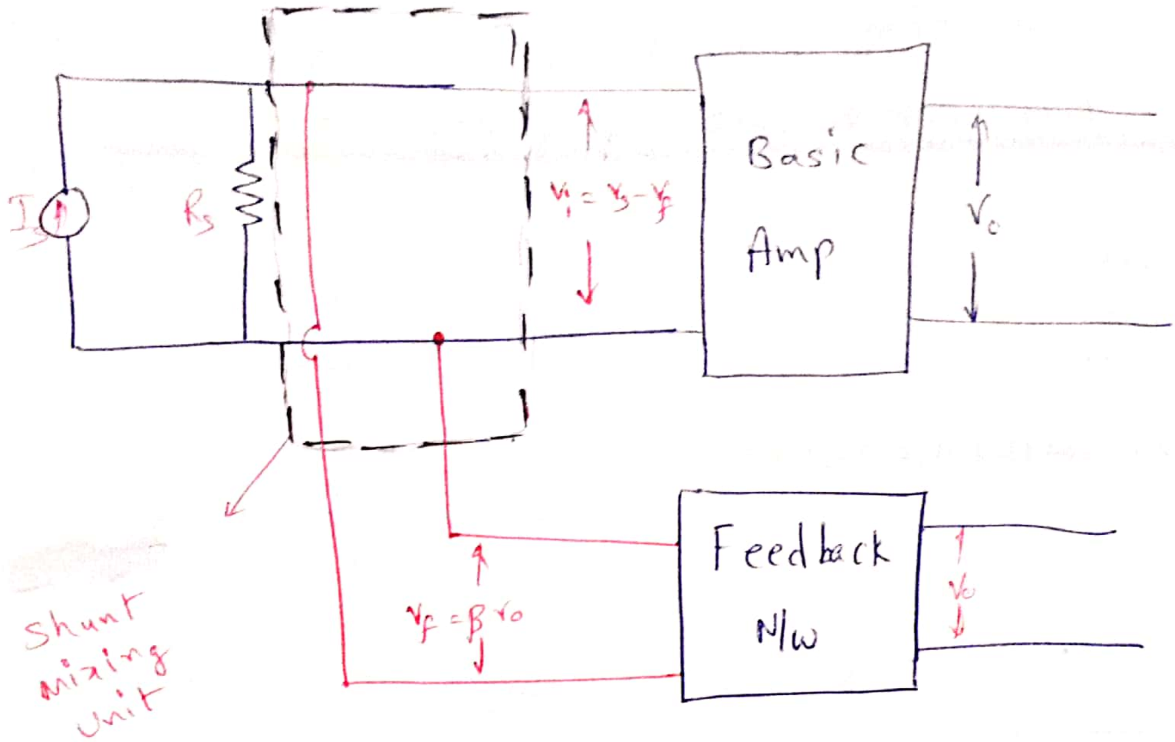
→ Mixer block is used to combine the source signal with the signal from feedback network.

→ There are two types

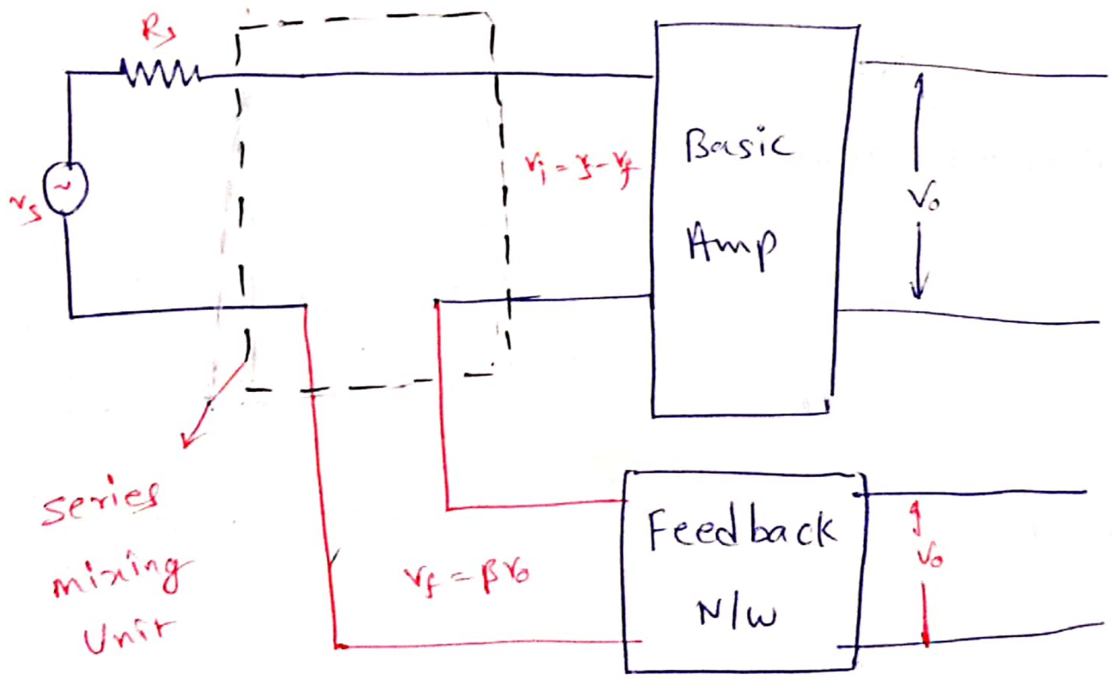
(a) shunt Mixing

(b) series "

(a) Shunt mixing :- when the signal source and the feedback signal are both currents, then shunt mixing is used



(b) series mixing :-



→ When the signal source and the feedback signal are both voltages, then series mixing is used.

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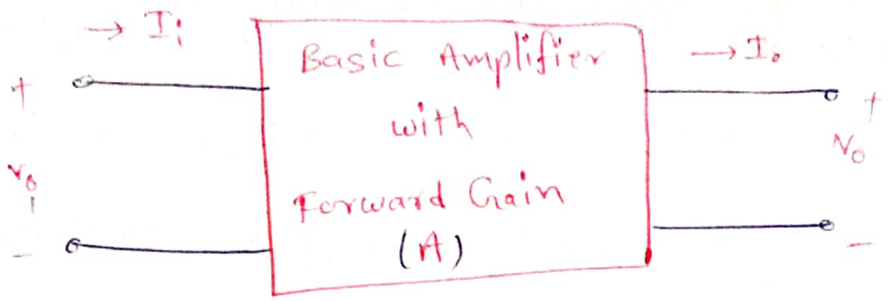
③ Amplifier Block :- The forward gain of amplifier block is defined as



The ratio of o/p signal to the i/p signal and the amplifier gain depends on the type of amplifier.

$\frac{V_o}{V_i} = A_v$ = Voltage Amplication (or) Voltage Gain

$\frac{I_o}{I_i} = A_I$ = Current " (or) Current "

$V \propto I$

$V = RI$

$R = \frac{V}{I}$

$\frac{V_o}{I_i} = R_M$ = Trans resistance

$\frac{I_o}{V_i} = G_M$ = Tran conductance.

→ A_v, A_I, R_m, G_m — Transfer gain of Basic Amplifier without feedback

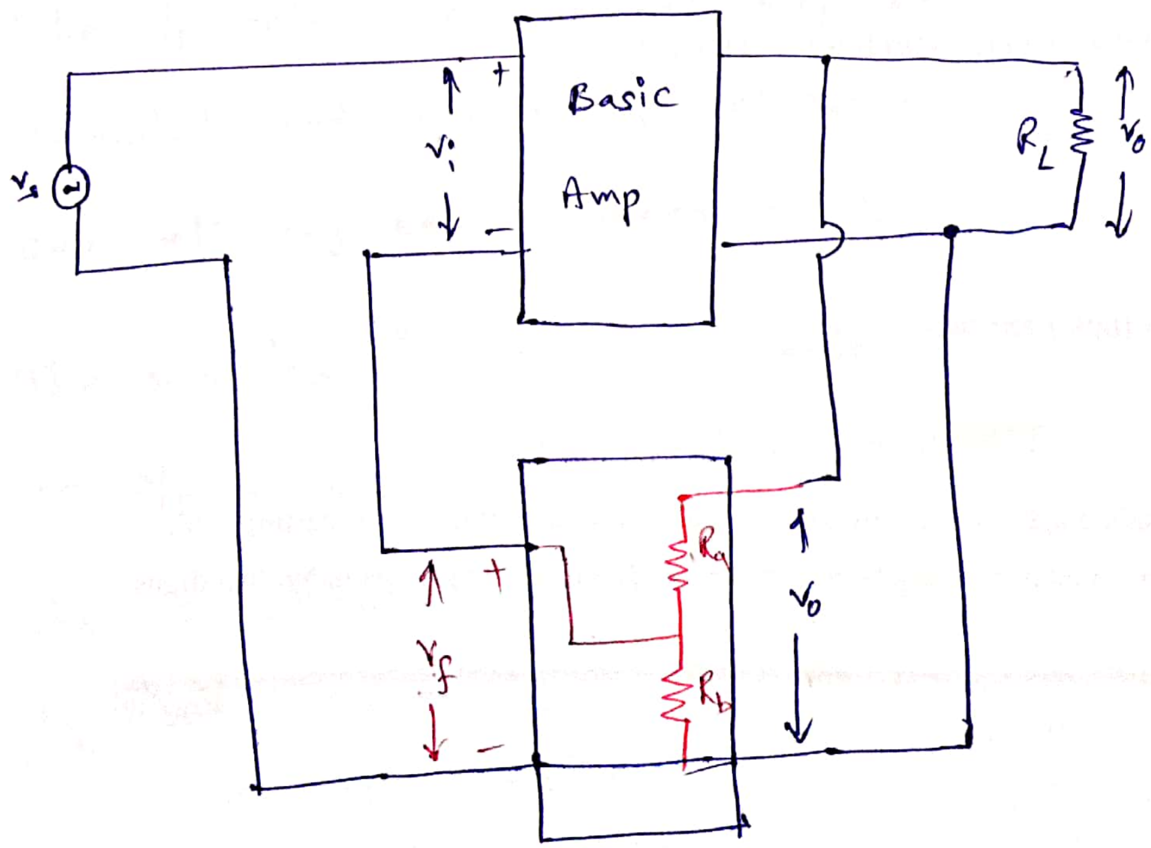
$A_{vf}, A_{If}, R_{mf}, G_{mf}$ — " with "

④ Feedback Network Block :-

→ This is a passive two-port N/w configured using passive elements such as resistors, inductors and capacitors. The feedback n/w is simply a resistive n/w.

→ The ratio of the o/p signal to the i/p signal of the feedback n/w is called feedback factor(β) feedback ratio.

→ β lies b/w 0 to 1 $[V_f = \beta V_o]$



Voltage sampling and Series Mixing Configuration

Applying voltage-divider rule, we get

$$V_f = \frac{R_b}{R_a + R_b} \cdot V_o$$

$$\frac{V_f}{V_o} = \frac{R_b}{R_a + R_b}$$

By Def, $V_f = \beta V_o \Rightarrow \beta = \frac{V_f}{V_o}$

$$\boxed{\beta = \frac{V_f}{V_o} = \frac{R_b}{R_a + R_b}}$$

5 Sampling Block :-

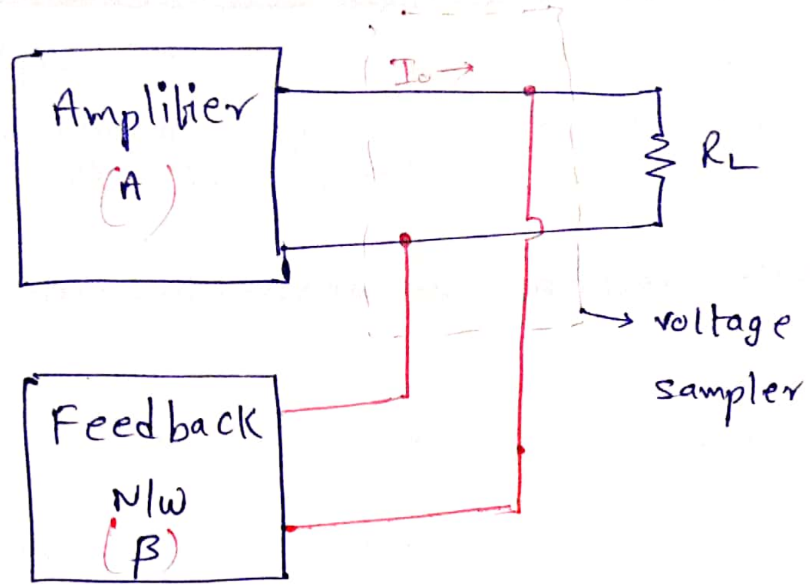
→ The o/p voltage or current may be sampled and either o/p voltage or current may be returned to i/p.

→ The sampling is generally refferred to o/p stage of the feedback amplifier.

→ The sampling can be divided into two basic types.

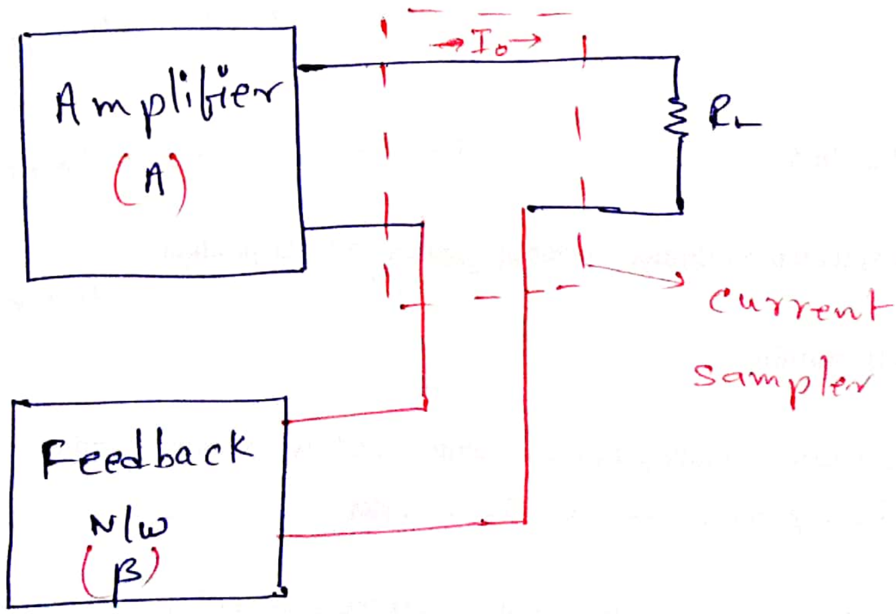
1. voltage sampler
2. current sampler.

(1) voltage sampler :-



→ The feedback n/w is connected across (parallel to) the o/p load (R_L).

(2) Current Sampler :-



→ The feedback n/w is connected in series with the o/p load resistor R_L.

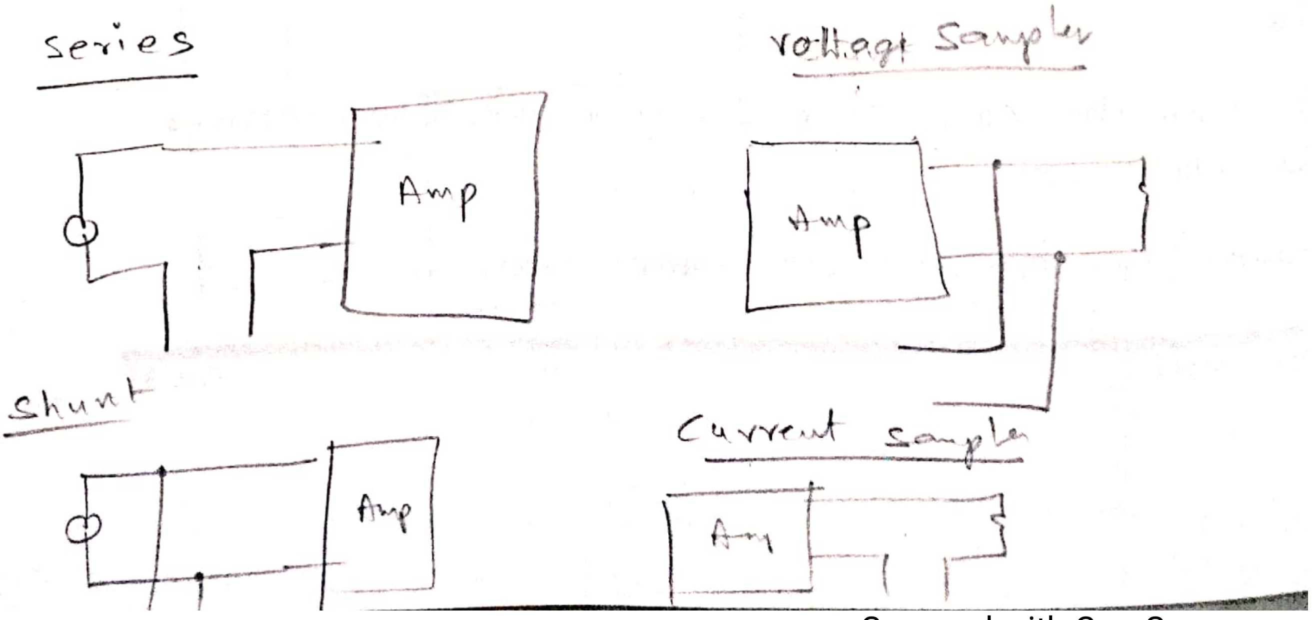
(2) Classification of Feedback Amplifier:-

→ Two types of sampling either current or voltage of two types mixer block i.e., either shunt or series mixer.

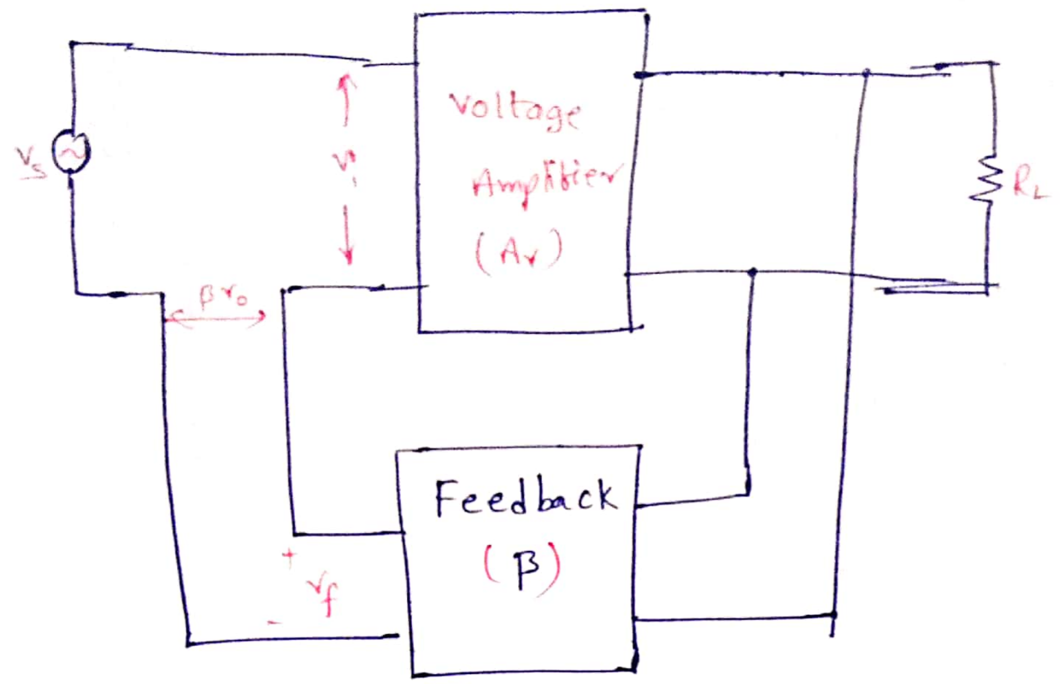
→ Thus, with two types of sampling and two types of mixer, there could be four amplifiers topologies.

→ Four types of feedback amplifiers are

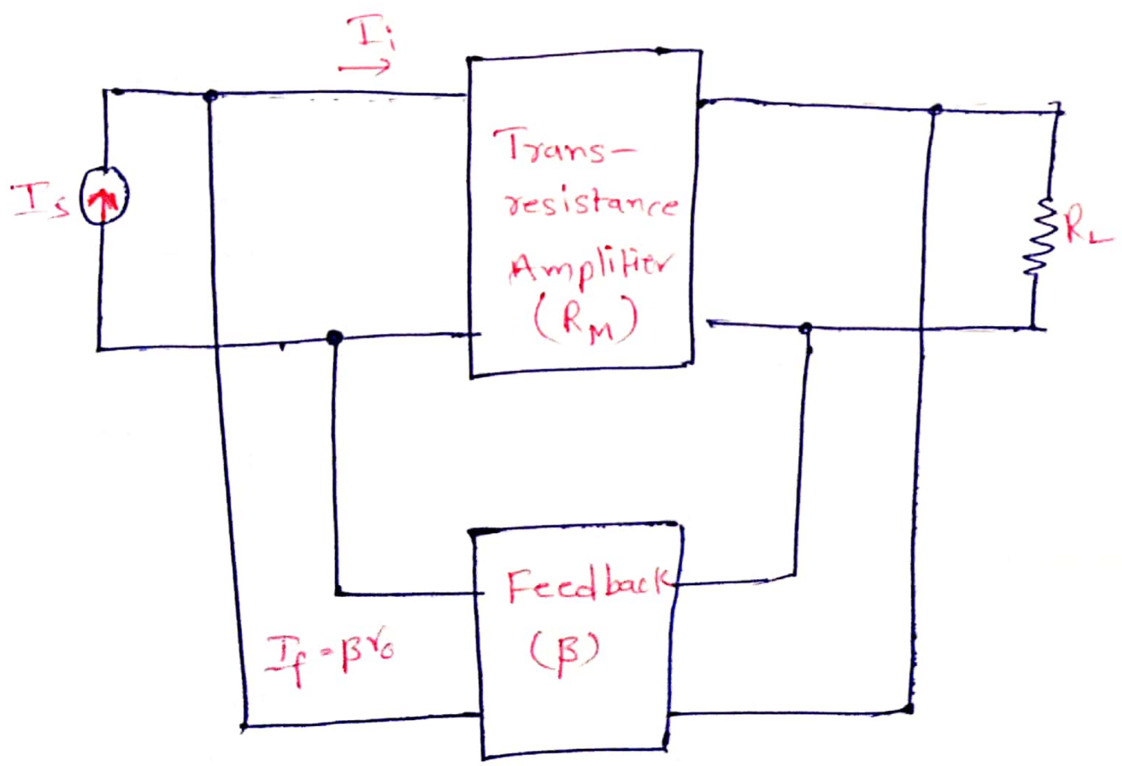
1. voltage - Series Feedback (Voltage Amplifier)
2. voltage-shunt Feedback (Transresistance)
3. current-series Feedback (Transconductance)
4. current-shunt Feedback (Current Amplifier)



① Voltage series feed back :-



② Voltage shunt Feedback :-



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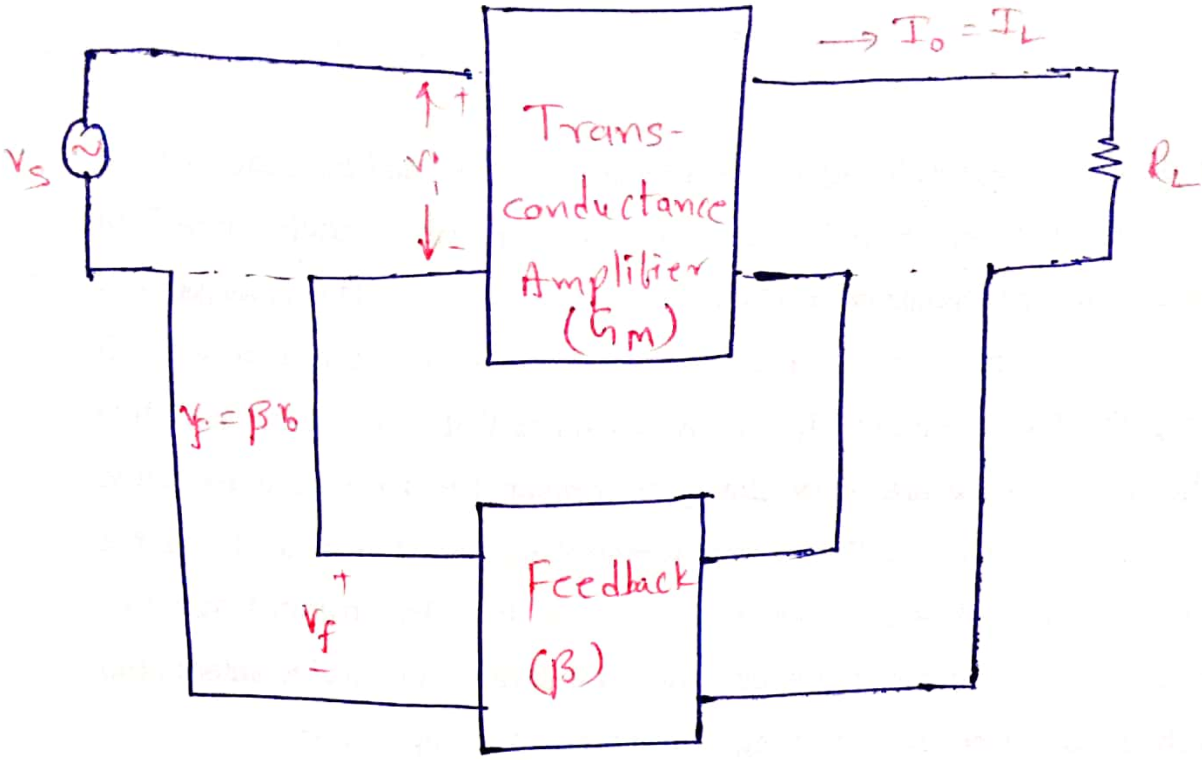
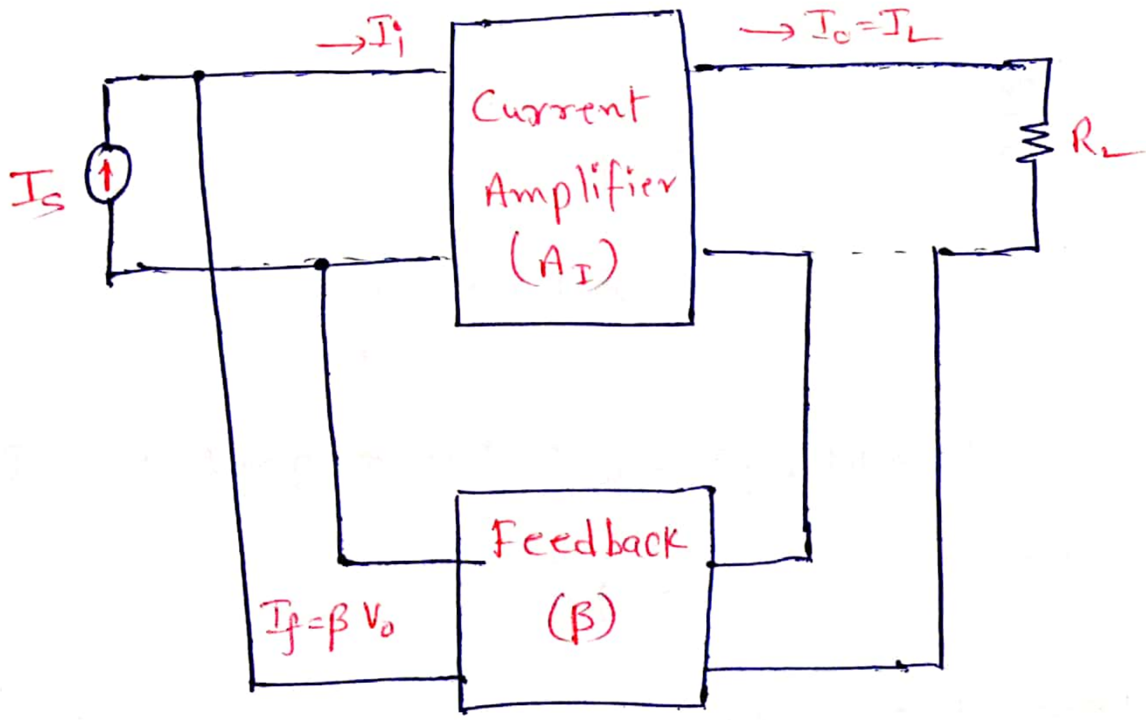
(3) Current Series Feedback :-



(4) Current shunt Feedback :-



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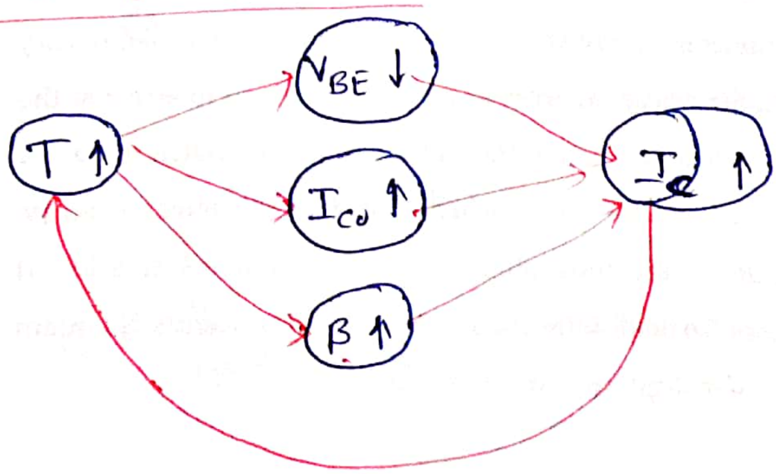
3) General characteristics of Negative Feedback Amplifier :-

1) Stability of Gain
2) Reduction in forward gain
3) Reduction in non-linear distortion
4) change in Input Impedance
5) change in output Impedance
6) Increase in Bandwidth
7) Reduction in noise.

1) **Stability of Gain :-** Depending on β value.



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

Eg: $A = 20, \; \beta = 0.1$

$$A_f = \frac{A}{1+\beta A} = \frac{20}{1+(0.1)20} = \frac{20}{3} = 6.66$$

at $\beta = 0.2$

$$A_f = \frac{A}{1+\beta A} = \frac{20}{1+(0.2)20} = \frac{20}{5} = 4$$

② Reduction in forward Gain :-

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

where, A_f = forward Gain

due to $(1+\beta A)$ value

Eg:- $A = 20$, $1+\beta A = 1.2$

$$A_f = \frac{A}{1+\beta A} = \frac{20}{1.2} = 16.66$$

$A = 20$, $1+\beta A = 0.6$

$$A_f = \frac{A}{1+\beta A} = \frac{20}{0.6} = 33.33$$

$(1+\beta A)\uparrow \Rightarrow A_f \downarrow$

$\downarrow \qquad \uparrow$

③ Reduction in non-linear distortion:-

Net distortion = original distortion + Distorted o/p

$$D_f = D - A\beta D_f$$ where -ve → o/p is out of phase

$$D_f + A\beta D_f = D$$

$$(1+A\beta) D_f = D$$

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

④ Change in input impedance:-

$$Z_{if} > Z_i$$

↓

Due to -ve feedback, V_f is in opposite polarity with respect to V_s and hence I_i with -ve Feedback is less than with FB.

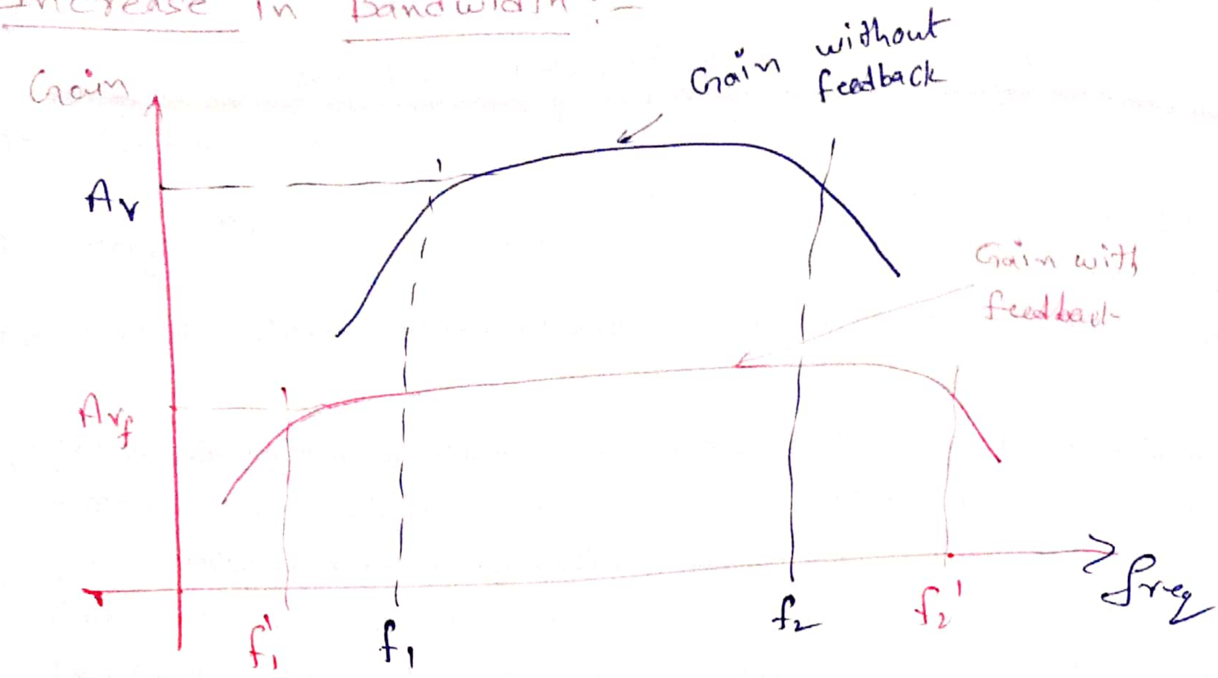
series →	$Z_{if} > Z_i$
shunt →	$Z_{if} < Z_i$

⑤ Change in output Impedance :-

depends on Nature of Sampling

- voltage sampling (Rof ↓)
- current sampling (Rof ↑)

(6) Increase in Bandwidth :-



$(B.W)_f = f_2' - f_1'$ $\qquad$ $(B.W) = f_2 - f_1$

$$\boxed{(B.W)_f > (B.W)}$$

$f_2' > f_2$, $f_1' > f_1$

(7) Reduction in noise :-

$$\boxed{N_f = \frac{N}{1+A\beta}}$$

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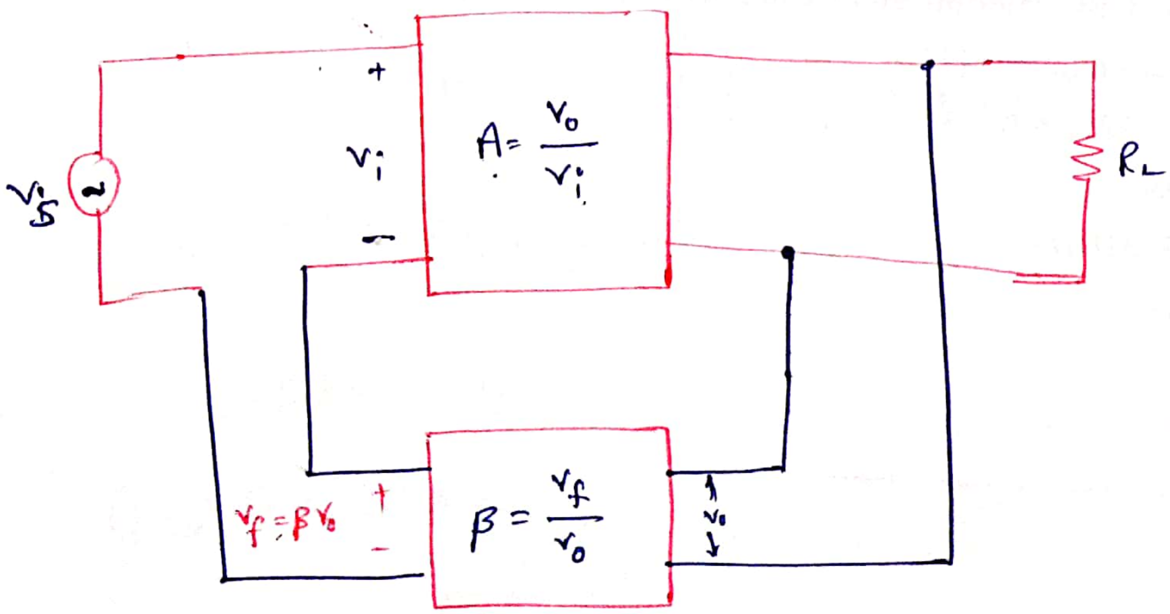
(4) Effect of Feedback on Amplifier Characteristics :-

→ The three most important basic char's of amplifiers are gain, input impedance and output impedance.

→ This is four types of feedback.

1. Voltage – series feedback Amplifier
2. " shunt " "
3. current Series " "
4. " shunt " "

(1) Voltage – Series Feedback Amplifier :-



(i) Gain :- If there is no Feedback ($v_f = 0$), the voltage gain of amp. stage is

$$A = \frac{v_o}{v_i} \quad \text{—— (1)}$$

If a feedback signal (v_f) is connected in series with the i/p, then

$$v_i = v_s - v_f \quad \text{—— (2)}$$

since $v_o = A v_i$ [$\because$ from Eqn (1)]

$= A(v_s - v_f)$ [$\because$ from Eqn (2)]

$= A v_s - A v_f$

$= A v_s - A(\beta v_o)$ [$\because \beta = \frac{v_f}{v_o} \Rightarrow v_f = \beta v_o$]

$\therefore$ $v_o = A v_s - \beta A v_o$

$v_o + \beta A v_o = A v_s$

$(1 + \beta A) v_o = A v_s$

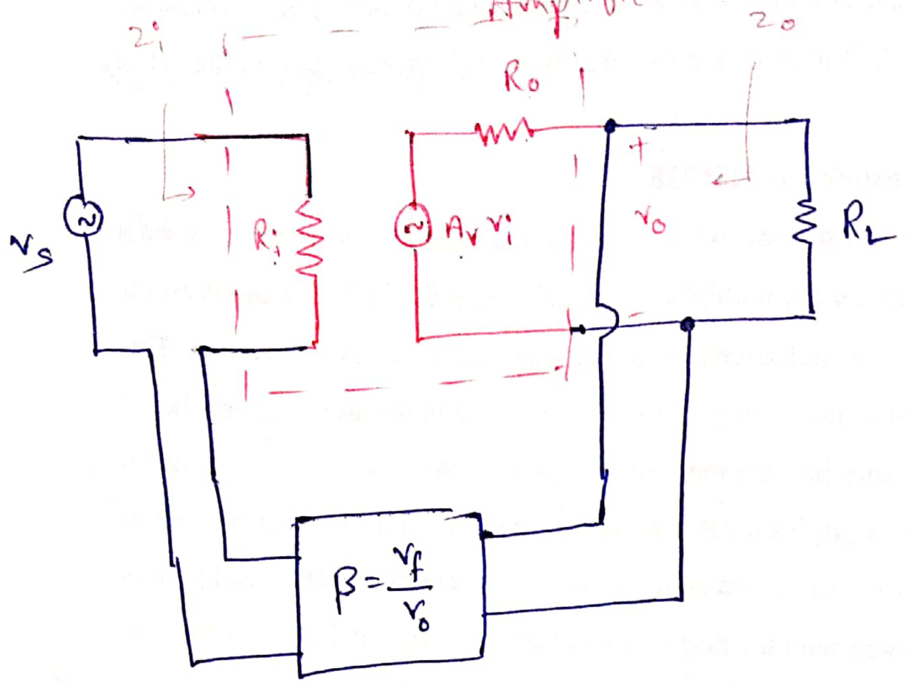
$$\boxed{A_f = \frac{v_o}{v_s} = \frac{A}{1 + \beta A}} \quad \text{—— (3)}$$

→ Eqn (3) show that the gain with Feedback is the amplifier gain reduced by the factor $(1 + \beta A)$

(ii) Input Impedance :-

Input Impedance without FB is given by

$$Z_i = \frac{V_i}{I_i} \quad \text{--- (4)}$$



I/p imp with FB is defined as

$$Z_{if} = \frac{V_s}{I_i}$$

From Fig., $V_i = V_s - V_f$

$$= V_s - (\beta V_o) \quad \left[\because \beta = \frac{V_f}{V_o}\right]$$

But $V_o = AV_i$ [$\because$ from Eqn (1)]

$$V_i = V_s - \beta(AV_i)$$

$$V_i + \beta AV_i = V_s$$

$$V_s = V_i + \beta AV_i$$

$$V_s = V_i(1 + \beta A)$$

$$V_s = (1+\beta A) V_i$$

From Eqn (4), $Z_i = \frac{V_i}{I_i}$

$$\Rightarrow V_i = Z_i I_i$$

$$V_s = (1+\beta A) Z_i I_i$$

$$\frac{V_s}{I_i} = Z_i (1+\beta A)$$

$$\boxed{Z_{if} = \frac{V_s}{I_i} = Z_i (1+\beta A)} \quad \text{— (6)}$$

→ From Eqn (6) it is clear that input imp. of voltage series fB Amp increases by a factor of $(1+\beta A)$

(iii) Output Impedance :-

- The o/p imp. is computed by following two steps as

(1) Voltage Source (V_s) is replaced by s.c

(2) Load resistance (R_L) " " " voltage source (V).

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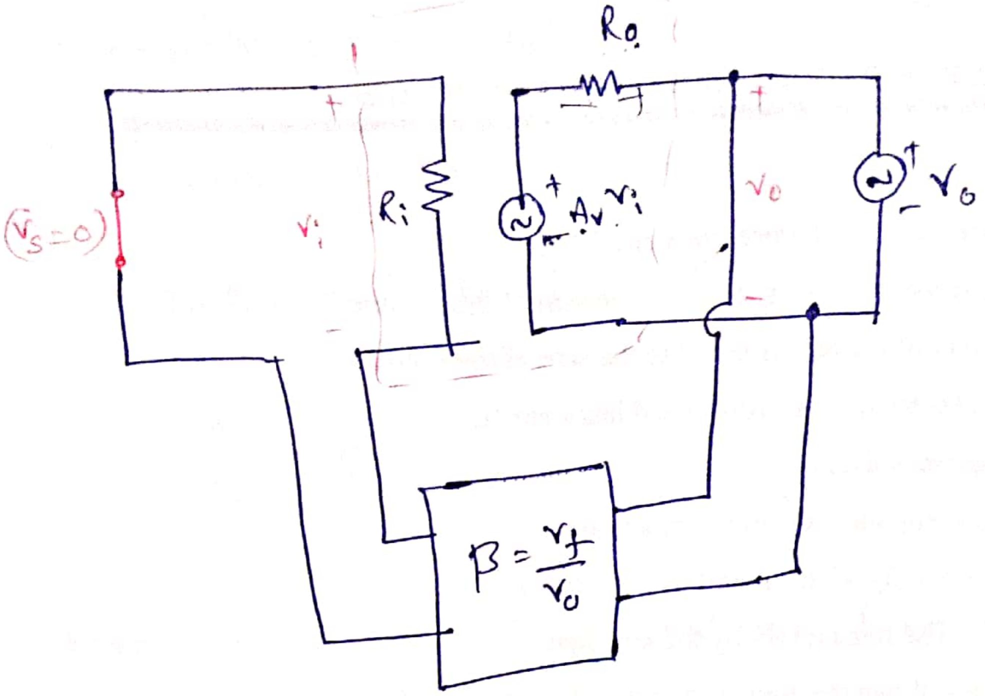

o/p imp. is defined as

$$Z_{of} = \frac{V_o}{I_o}$$

Applying KVL to o/p ckt, we get

$$A_v V_i + I_o R_o - V_o = 0 \quad \text{——— (7)}$$

Applying KVL to i/p ckt, we get

$$V_i = V_s - V_f$$

$$= 0 - V_f$$

$$V_i = -V_f$$

but $V_f = \beta V_o$

$$\therefore V_i = -\beta V_o$$

substituting V_i value in Eqn (7), we get

$$A(-\beta V_o) + I_o R_o - V_o = 0$$

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$$-\beta A V_o + I_o R_o - V_o = 0$$

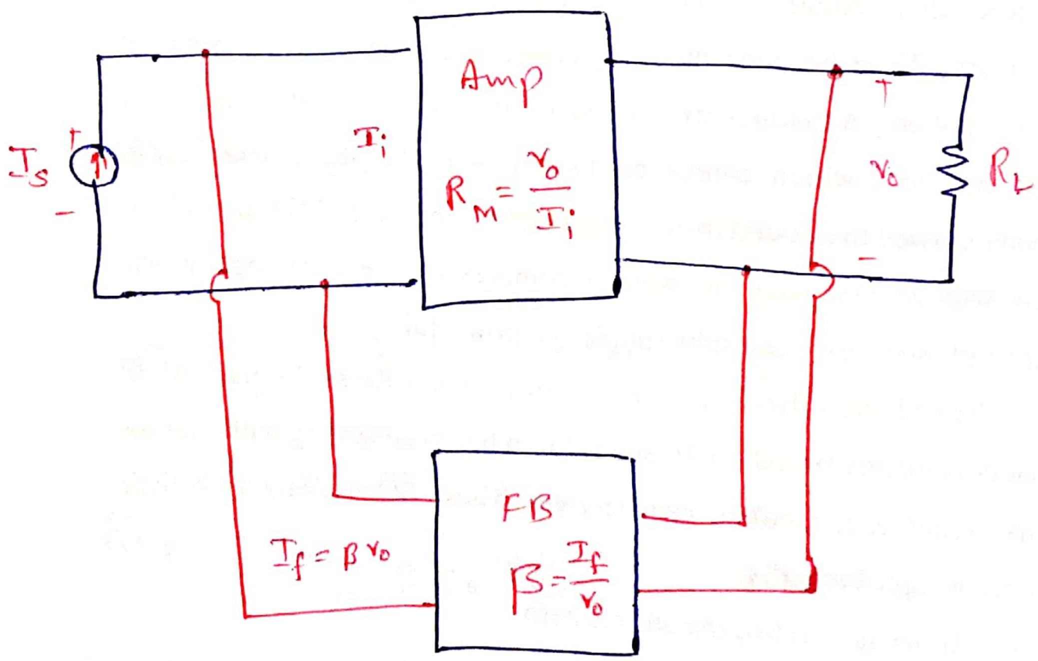
$$I_o R_o = V_o + \beta A V_o$$

$$I_o R_o = V_o (1+\beta A)$$

$$Z_{of} = \boxed{\frac{V_o}{I_o} = \frac{R_o}{(1+\beta A)}}$$

→ Hence, it is clear that, output Impedance of voltage series feedback amplifier gets reduced by a factor $(1+\beta A)$.

(2) Voltage - shunt Feedback Amplifier



Gain :- Consider there is no feedback.

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

If a feedback signal (I_f) is connected in shunt with i/p then

$$I_i = I_s - I_f$$

$$I_s = I_i + I_f$$

Gain of an amplifier is defined by

$$R_{mf} = \frac{V_o}{I_s}$$

$$= \frac{V_o}{I_i + I_f}$$

But $I_f = \beta V_o$ $\left[\because \beta = \frac{I_f}{V_o}\right]$

$$R_{mf} = \frac{V_o}{I_i + \beta V_o}$$

But $V_o = R_m I_i$ $\left[R_m = \frac{V_o}{I_i}\right]$

$$R_{mf} = \frac{R_m I_i}{I_i + \beta R_m I_i}$$

$$= \frac{R_m \cancel{I_i}}{\cancel{I_i}(1 + \beta R_m)}$$

$$\boxed{R_{mf} = \frac{R_m}{1 + \beta R_m}}$$

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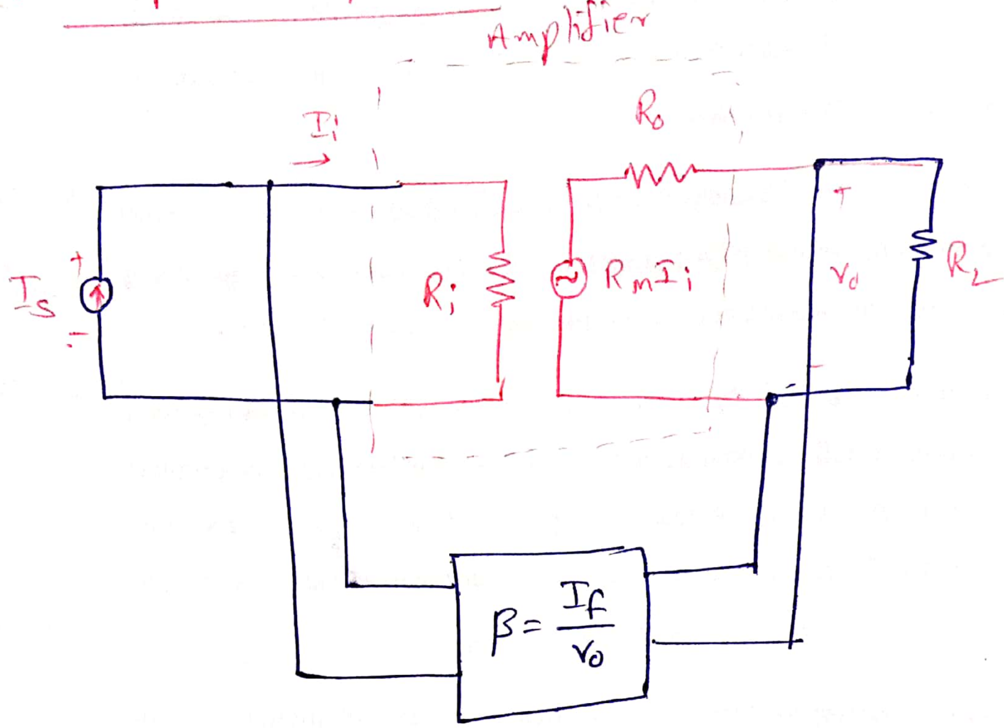
→ Hence, for voltage shunt feedback amplifier gain gets reduced by a factor of $(1+\beta R_m)$.

(ii) Input Impedance :-



The input impedance without feedback is

$$Z_i = \frac{V_i}{I_i}$$

The input impedance with Feedback is .

$$Z_{if} = \frac{V_i}{I_s}$$

$$= \frac{V_i}{I_i + I_f} \quad \left[\because I_s = I_i + I_f\right]$$

$$= \frac{V_i}{I_i + \beta V_o} \quad \left[\because \beta = \frac{I_f}{V_o}\right]$$

$$= \frac{V_i / I_i}{I_i/I_i + \beta\, V_o / I_i} \quad \text{—— (10)}$$

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since $\frac{V_i}{I_i} = Z_i$, $\frac{V_o}{I_i} = R_M$ — (11)

substituting Eqn (11) in (10), we get

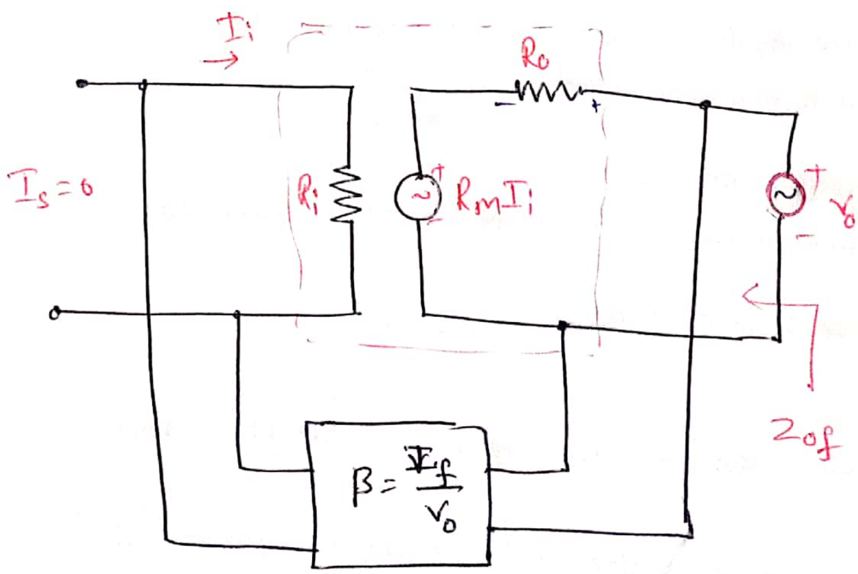
$$\boxed{Z_{if} = \frac{Z_i}{1+\beta R_M}} \quad (12)$$

Hence, for voltage shunt feedback amplifier input impedances gets reduced by a factor $(1+\beta R_m)$.

(iii) Output Impedance :-

(1) Replacing current source with o.c.

(2) Replacing Load resistance by voltage source.



Applying KVL at i/p ckt.

$$I_i + I_f = 0$$

$$I_i = -I_f$$

But $I_f = \beta V_o$ $\left[\because \beta = \frac{I_f}{V_o}\right]$

$I_i = -\beta V_o$

Applying KVL at output ckt,

$$R_M I_i + R_o I_o - V_o = 0 \quad \text{—} (13)$$

substituting I_i value in Eqn (13), we get

$$R_m(-\beta V_o) + R_o I_o - V_o = 0$$

$$-\beta R_m V_o + R_o I_o - V_o = 0$$

$$R_o I_o = V_o + \beta R_m V_o \quad \text{—} (14)$$

$$R_o I_o = V_o(1+\beta R_m)$$

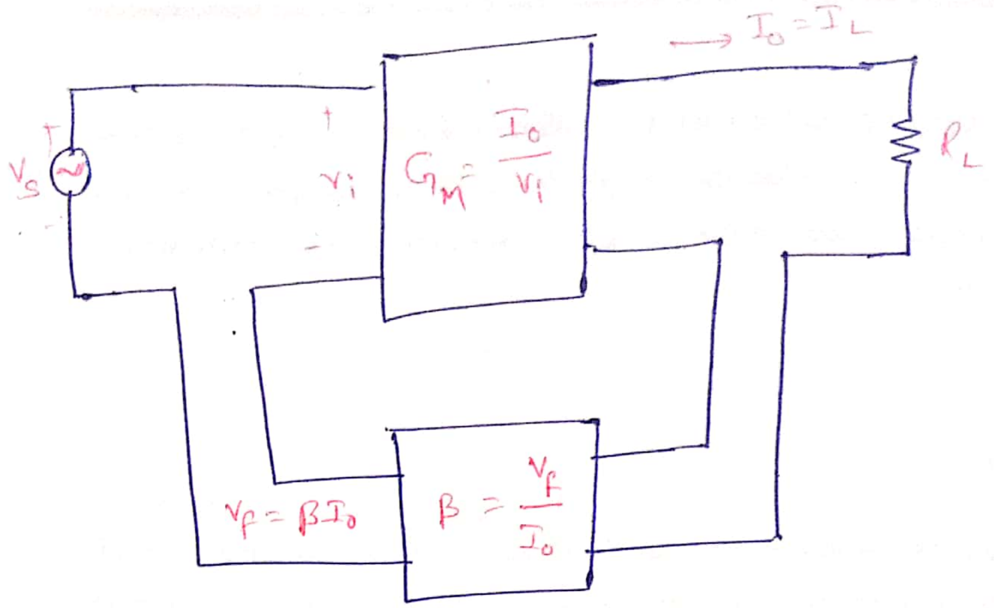
$$\frac{R_o}{1+\beta R_m} = \frac{V_o}{I_o}$$

$$\frac{V_o}{I_o} = \frac{R_o}{1+\beta R_m}$$

$$\boxed{Z_{of} = \frac{V_o}{I_o} = \frac{R_o}{(1+\beta R_m)}}$$

→ Hence, output impedance of voltag-shunt feedback amplifier gets reduced by a factor $(1+\beta R_m)$.

③ Current Series Feedback Amplifier :-



(i) Gain :-

The gain of the Amplifier without feedback is

$$G_M = \frac{I_0}{V_i}$$

The gain with feedback is

$$G_{Mf} = \frac{I_0}{V_s}$$

From Fig. $V_s = V_i + V_f$

But $\beta = \frac{V_f}{I_0} \Rightarrow V_f = \beta I_0$

$$V_s = V_i + \beta I_0$$

$$G_{Mf} = \frac{I_0}{V_i + \beta I_0}$$

From fig, $G_M = \frac{I_o}{v_i} \Rightarrow I_o = G_M v_i$

$$\therefore G_{Mf} = \frac{G_M v_i}{v_i + \beta G_M v_i}$$

$$= \frac{G_M \cancel{v_i}}{\cancel{v_i}(1+\beta G_m)}$$

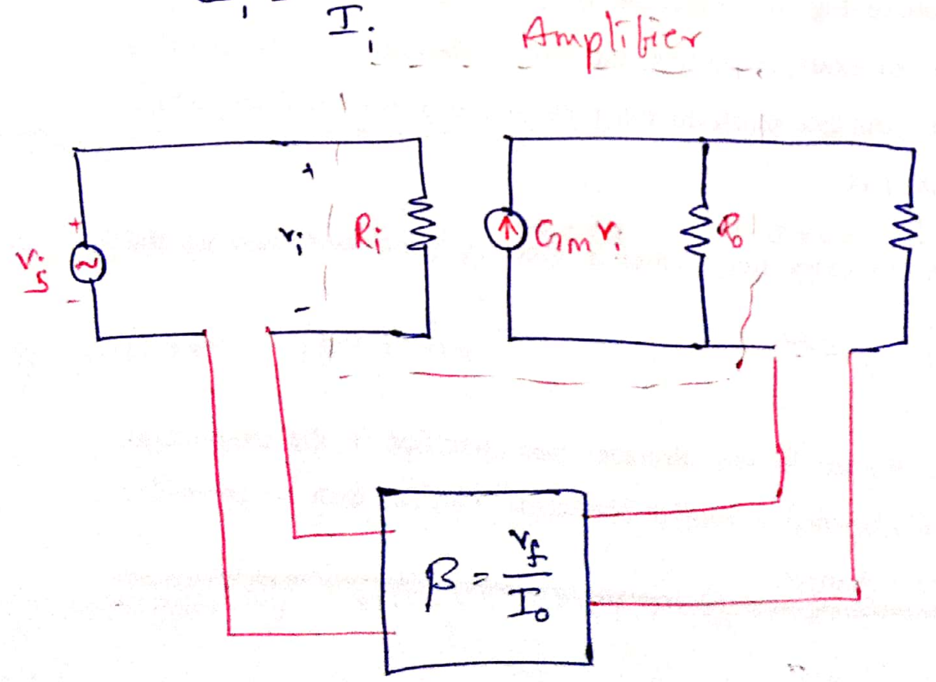
$$\boxed{G_{Mf} = \frac{G_M}{(1+\beta G_m)}}$$

→ Gain of current series Feedback Amplifier gets reduced by a factor $(1+\beta G_m)$.

(ii) Input Impedance :-

Input impedance without Feedback Feedback is

$$Z_i = \frac{v_i}{I_i}$$



i/p imp. with FB is

$$Z_{if} = \frac{V_s}{I_s} = \frac{V_s}{I_i}$$

But $V_s = V_i + V_f = V_i + \beta I_o$ $\left[\because \beta = \frac{V_f}{I_o}\right]$

$$Z_{if} = \frac{V_i + \beta I_o}{I_i}$$

$$= \frac{V_i + \beta G_m V_i}{I_i}$$ $\left[\because G_m = \frac{I_o}{V_i} \Rightarrow I_o = G_m I_i\right]$

$$= \frac{V_i}{I_i} + \frac{\beta G_m V_i}{I_i}$$

But $\frac{V_i}{I_i} = Z_i$

$$Z_{if} = Z_i + \beta G_m Z_i$$

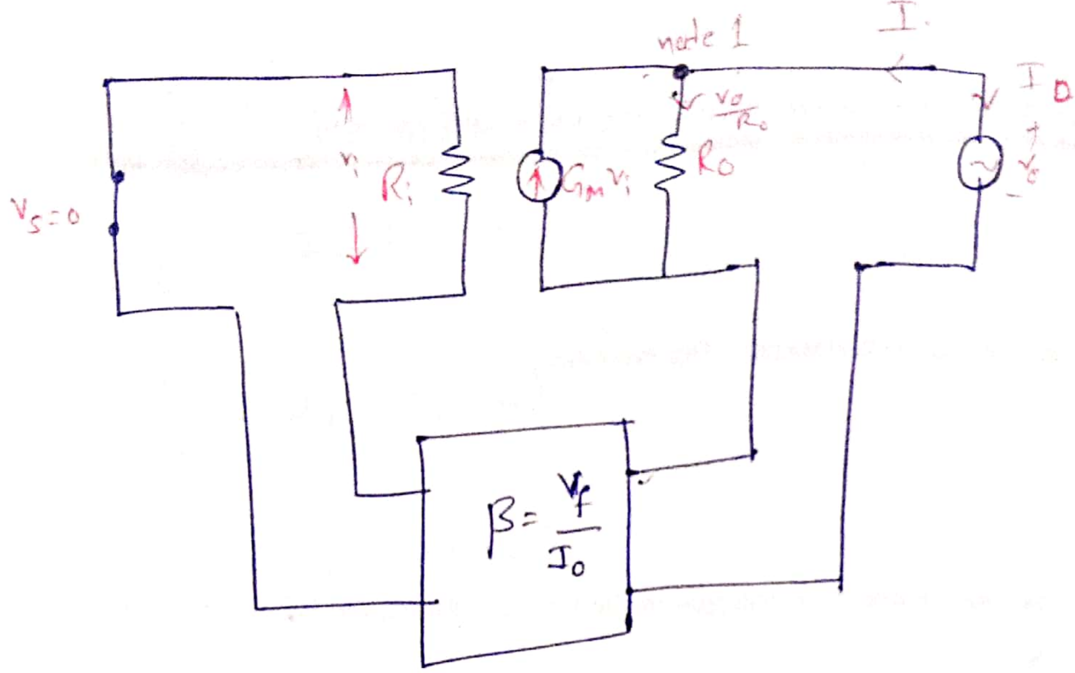
$$\boxed{Z_{if} = Z_i(1+\beta G_m)} \quad — (17)$$

→ Input Impedance of a current series Feedback amplifier gets increased by a factor $(1+\beta G_m)$

(iii) Output Impedance :-

(1) Replacing voltage source (V_s) with S.C.

(2) " Load resistance with voltage source.



Applying KVL at i/p ckt, we get

$[\because V_i = V_s - V_f]$

$V_i = 0 - V_f$

$V_i = -V_f$

But $\beta = \frac{V_f}{I_o} \Rightarrow V_f = \beta I_o$

$V_i = -\beta I_o$

Applying KCL at node (1) of the o/p ckt, we get

$G_m V_i + I - \frac{V_o}{Z_o} = 0 \quad [\because Z_o = R_o]$ — (18)

Substituting V_i value in Eqn (18), we get

$G_m(-\beta I_o) + I - \frac{V_o}{Z_o} = 0$

From Fig. $I = -I_o$

$G_m(\beta I) + I - \frac{V_o}{Z_o} = 0$

$$\frac{V_o}{Z_o} = G_m \beta I + I$$

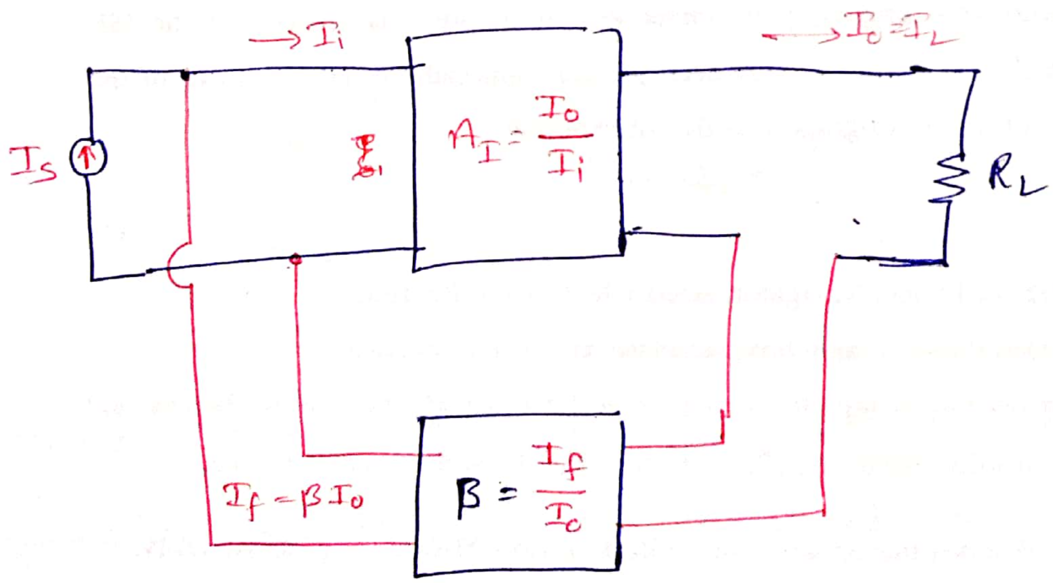
$$\frac{V_o}{Z_o} = I(1+\beta G_m)$$

$$\frac{V_o}{I} = Z_o(1+\beta G_m)$$

$$\boxed{Z_{of} = Z_o(1+\beta G_m)}$$

→ Output Impedance of current series Feedback amplifier gets increased by a factor $(1+\beta G_M)$

(4) Current shunt Feedback Amplifier:-



(i) Gain :-

Gain without feedback is

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

Gain with Feedback is

$$A_{If} = \frac{I_o}{I_s}$$

But $A_I = \frac{I_o}{I_i} \Rightarrow I_o = A_I I_i$

and $I_s = I_i + I_f$

$= I_i + \beta I_o \quad \left[\because \beta = \frac{I_f}{I_o} \Rightarrow I_f = \beta I_o\right]$

$$A_{If} = \frac{I_o}{I_s} = \frac{I_o}{I_i + \beta I_o}$$

Dividing numerator & denominator by I_i

$$A_{If} = \frac{I_o / I_i}{I_i/I_i + \beta\, I_o/I_i}$$

$$\boxed{A_{If} = \frac{A_I}{1 + \beta A_I}} \quad \left[\because A_I = \frac{I_o}{I_i}\right]$$

→ Hence, current gain of Current shunt Feedback amplifier gets reduced by a factor $(1+\beta A_I)$.

(ii) Input Impedance :-

Input impedance without feedback

$$Z_i = \frac{V_i}{I_i}$$

Input Impedance with feedback is

$$Z_{if} = \frac{V_i}{I_s}$$

But $I_s = I_i + I_f$

$= I_i + \beta I_o \quad \left[\because \beta = \frac{I_f}{I_o}\right]$

$$Z_{if} = \frac{V_i}{I_i + \beta I_o}$$

Divide numberator & Denominator by I_i

$$Z_{if} = \frac{V_i / I_i}{I_i / I_i + \beta I_o / I_i}$$

since $Z_i = \frac{V_i}{I_i}$, $A_I = \frac{I_o}{I_i}$

$$\boxed{Z_{if} = \frac{Z_i}{1 + \beta A_I}} \quad \text{—— (20)}$$

→ Input impedance of current shunt Feedback amplifier gets reduced by a factor $(1+\beta A_I)$.

(iii) Output Impedance :-

1. Replacing current source by o.c
2. " Load resistance by voltage source.

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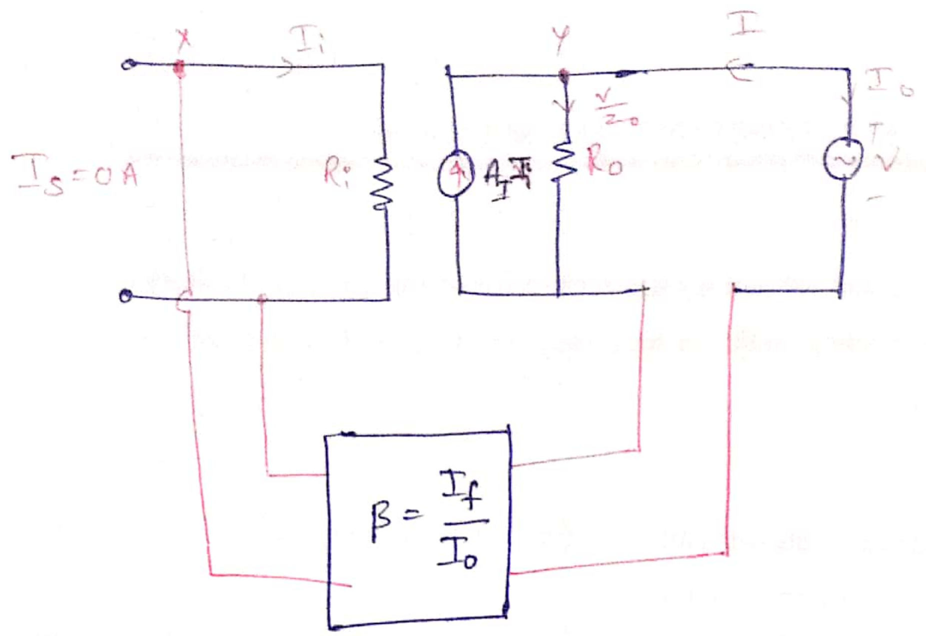

Applying KCL at node X, we get

$$I_i + I_f = 0$$

$$I_i = -I_f$$

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

$$I_i = -\beta I_o$$

Applying KCL at node Y, we get

$$A_I I_i + I - \frac{V}{Z_o} = 0 \quad \text{--- (21)}$$

Substituting $I_i = -\beta I_o$ in eqn (21), we get

$$A_I(-\beta I_o) + I - \frac{V}{Z_o} = 0$$

From Fig. output ckt, $I = -I_o$

$$A_I(\beta I) + I - \frac{V}{Z_o} = 0$$

$$\frac{V}{Z_o} = I + A_I(\beta I)$$

$$\frac{V}{Z_o} = I(1+\beta A_I)$$

$$\frac{V}{I} = Z_o(1+\beta A_I)$$

$$\boxed{Z_{of} = \frac{V}{I} = Z_o(1+\beta A_I)} \quad (22)$$

→ Output impedance of voltage shunt Feedback amplifier increases by a factor $(1+\beta A_I)$.

Problems :-

1. A Voltage - series negative feedback amplifier has a voltage gain without feedback of $A = 500$, input resistance, $R_i = 3\,k\Omega$, output resistance $R_o = 20\,k\Omega$, and feedback ratio $\beta = 0.01$. Calculate the voltage Gain (A_{vf}), input resistance (R_{if}) and output resistance (R_{of}) of the amplifier with feedback.

Sol: Given $A = 500$, $R_i = 3\,k\Omega$, $R_o = 20\,k\Omega$, $\beta = 0.01$

Voltage Gain,

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

$$= \frac{500}{1+(0.01 \times 500)} = \frac{500}{1+5} = \frac{500}{6} = 83.33$$

$$\boxed{A_{vf} = 83.33}$$

Input Impedance, $Z_{if} = Z_i\,(1+\beta A)$

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

$$= 3 \times 10^3\,(1+(0.01 \times 500))$$

$$= 3 \times 10^3\,(1+5)$$

$$= 3 \times 10^3\,(6) = 18 \times 10^3$$

$$\boxed{R_{if} = 18\,k\Omega}$$

(iii) output impedance, $Z_{of} = \frac{Z_o}{1+\beta A}$

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

$= \frac{20\times10^3}{1+(0.01\times500)}$

$= \frac{20\times10^3}{1+5}$

$= \frac{20\times10^3}{6} = 3.33\times10^3$

$\boxed{R_{of} = 3.33\,K\Omega}$

(2) A Voltage shunt negative feedback Amplifier has a proportionality constant $(R_m) = 300$, input impedance $Z_i = 2K\Omega$, output impedance $Z_o = 20K\Omega$. and feedback ratio $\beta = 0.05$. Calculate R_{mf}, Z_{if} & Z_{of} of the amplified with feedback.

Sol:- Given $R_m = 300$, $Z_i = 2K\Omega$, $Z_o = 20K\Omega$, & $\beta = 0.05$

$R_{Mf} = \frac{R_M}{1+\beta R_m}$

$= \frac{300}{1+(0.05\times300)} = \frac{300}{1+15} = \frac{300}{16} = 18.75$

$\boxed{R_{mf} = 18.75}$

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$$Z_{if} = \frac{Z_i}{1+\beta R_m}$$

$$= \frac{2\times10^3}{1+(0.05\times300)} = \frac{2\times10^3}{1+15} = \frac{2000}{16} = 125$$

$$\boxed{Z_{if} = 125\ \Omega}$$

$$Z_{of} = \frac{Z_o}{1+\beta R_m}$$

$$= \frac{20\times10^3}{1+(0.05\times300)} = \frac{20\times10^3}{1+15} = \frac{20{,}000}{16} = 1250$$

$$\boxed{Z_{of} = 1.25\ K\Omega}$$

3) A current series feedback amplifier has a proportionality factor (G_M) = 500, input impedance $z_i = 3\ K\Omega$, output Impedance $Z_o = 30\ K\Omega$ and feedback ratio $\beta = 0.01$. Calculate G_{mf}, Z_{if} & Z_{of}.

Sol:- Given, $G_M = 500$, $Z_i = 3K\Omega$, $Z_o = 30K\Omega$, & $\beta = 0.01$

$$G_{mf} = \frac{G_M}{1+\beta G_M}$$

$$= \frac{500}{1+(0.01\times500)} = \frac{500}{1+5} = \frac{500}{6} = 83.33$$

$$\boxed{G_{mf} = 83.33}$$

$$Z_{if} = Z_i(1+\beta G_m)$$

$$= 3\times10^3(1+(0.01\times500)) = 3\times10^3(1+5) = 3\times10^3(6) = 18\times10^3$$

$$\boxed{Z_{if} = 18K\Omega}$$

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$Z_{of} = Z_o(1+\beta G_m)$

$= 30\times10^3(1+(0.01\times500)) = 30\times10^3(1+5) = 30\times10^3(6) = 180\times10^3$

$\boxed{Z_{of} = 180\,K\Omega}$

(4) A current-shunt feedback amplifier has a current gain $A_I = 100$, input impedance $Z_i = 2\,K\Omega$, output impedance $Z_o = 15\,K\Omega$. and feedback ratio $\beta = 0.05$. Calculate A_{If}, Z_{if} and Z_{of}?

Sol:- Given, $A_I = 100$, $Z_i = 2\,K\Omega$, $Z_o = 15\,K\Omega$ & $\beta = 0.05$

$$A_{If} = \frac{A_I}{1+\beta A_I}$$

$$= \frac{100}{1+(0.05\times100)} = \frac{100}{1+5} = \frac{100}{6} = 16.66$$

$\boxed{A_{If} = 16.66}$

$$Z_{if} = \frac{Z_i}{1+\beta A_I}$$

$$= \frac{2\times10^3}{1+(0.05\times100)} = \frac{2\times10^3}{1+5} = \frac{2000}{6} = 333.33$$

$\boxed{Z_{if} = 333.33\,\Omega}$

$Z_{of} = Z_o(1+\beta A_I)$

$= 15\times10^3(1+(0.05\times100)) = 15\times10^3(1+5) = 15\times10^3(6)$

$= 90\times10^3$

$\boxed{Z_{of} = 90\,K\Omega}$

Problems :-

(5) An amplifier voltage gain with feedback is 100. If the gain without feedback changes by 20% and the gain with feedback should not vary more than 2% determine the values of open loop gain A and feedback ratio β.

Sol: Given

$A_f = 100$

$\frac{dA_f}{A_f} = 2\% = 0.02$

$\frac{dA}{A} = 20\% = 0.2$

$A = ?$

$\beta = ?$

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

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

$$0.02 = 0.2 \frac{1}{(1+\beta A)}$$

$$\frac{0.02}{0.2} = \frac{1}{(1+\beta A)}$$

$$\frac{1}{(1+\beta A)} = \frac{0.02}{0.2}$$

$$\frac{0.02}{0.2} = \frac{\cancel{2}}{10\cancel{0}} \times \frac{1\cancel{0}}{\cancel{2}} = \frac{1}{10}$$

$$\frac{1}{(1+\beta A)} = \frac{1}{10}$$

$$(1+\beta A) = 10$$

The gain with feedback is given by

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

$$100 = \frac{A}{10}$$

$$A = 100 \times 10 = 1000$$

$$\therefore \boxed{A = 1000}$$

$$1 + A\beta = 10$$

$$A\beta = 10 - 1$$

$A\beta = 9$

$$\beta = \frac{9}{A} = \frac{9}{1000} = 0.009$$

$$\boxed{\beta = 0.009}$$

(6) The overall gain of a multistage amplifier is 100. When negative feedback is applied, the gain reduces to 10. Find the fraction of the output that is feedback to the input.

Sol:- Given, $A = 100$, $A_f = 10$, $\beta = ?$

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

$$10 = \frac{100}{1 + 100\beta}$$

$$1 + 100\beta = \frac{10\cancel{0}}{1\cancel{0}}$$

$$1 + 100\beta = 10$$

$$100\beta = 10 - 1$$

$$100\beta = 9$$

$$\beta = \frac{9}{100} = 0.09$$

$$\boxed{\beta = 0.09}$$

7) A negative feedback amplifier has $A = 100$, $\beta = 0.04$ and $V_s = 50mV$. Find,

(i) Gain with feedback

(ii) Output voltage

(iii) Feedback factor

(iv) Feedback voltage

Sol:- Given $A = 100$, $\beta = 0.04$ & $V_s = 50mV$.

(i) Gain with feedback

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

$$= \frac{100}{1 + (100 \times 0.04)} = \frac{100}{1+4} = \frac{100}{5} = 20$$

$$\boxed{A_f = 20}$$

(ii) Output voltage:

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

$$\therefore V_o = A_f \times V_s$$

$$= 20 \times 50 \times 10^{-3}$$

$$= 1000 \times 10^{-3} = 1$$

$$\boxed{V_o = 1V}$$

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(iii) Feedback factor,

$A\beta = 100 \times 0.04 = 4$

(iv) Feedback voltage,

$\beta V_o = 0.04 \times 1 = 0.04V$

(8) With a negative feedback, an amplifier gives an output of 10V with an input of 0.5V. When the feedback is removed, it requires 0.25V input for the same output. Calculate (i) Gain without feedback (ii) Feedback fraction β.

Sol:- (i) Gain without feedback,

$$A = \frac{\text{o/p voltage}}{\text{i/p voltage}}$$

$$= \frac{10}{0.25} = \frac{10 \times \cancel{100}^{4}}{\cancel{25}_{1}} = 40$$

$$\boxed{A = 40}$$

(ii)

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

$$A_f = \frac{\text{o/p voltage with feedback}}{\text{i/p voltage with feedback}}$$

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$$= \frac{10}{0.5} = \frac{10 \times \cancel{10}^{2}}{\cancel{5}_{1}} = 20$$

$$\therefore A_f = 20$$

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

$$20 = \frac{40}{1 + (40\beta)}$$

$$1 + 40\beta = \frac{\cancel{40}^{2}}{\cancel{20}}$$

$$1 + 40\beta = 2$$

$$40\beta = 2 - 1$$

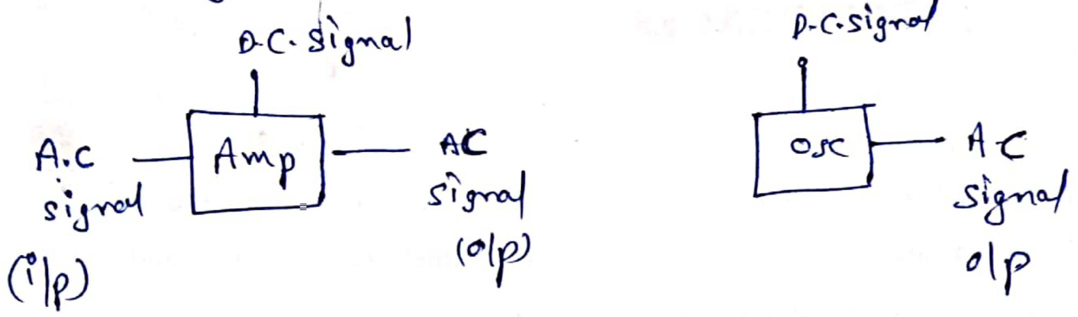
$$40\beta = 1$$

$$\beta = \frac{1}{40} = 0.025$$

$$\boxed{\beta = 0.025}$$

UNIT – III (b) – Oscillators

Def:- Oscillator is an electronic ckt. which generates an a.c. o/p signal without requesting any externally applied i/p signal.



→ Oscillator works on the Principle of +ve FB.

Applications:- Radio, Television Receivers etc

+ ve FB	−ve FB
① when the FB is applied such that it is inphase with the original i/p signal then it is called +ve FB.	① when the FB is applied such that it is out of phase with the original i/p signal then it is called −ve FB
② It is regenerative (or) direct FB	② It is degenerative (or) inverse FB.
③ It increases the gain of the amplifier $A_f = \frac{A}{1-A\beta}$	③ It decrease the gain of the amplifier $A_f = \frac{A}{1+A\beta}$

(4) It makes the amplifier Unstable.	(4) It makes the amplifier stable.
(5) It reduces the B.W.	(5) It increases the B.W.
(6) It is used in the oscillators.	(6) It is used in the small signal Amplifier

I) Classification of Oscillators :-

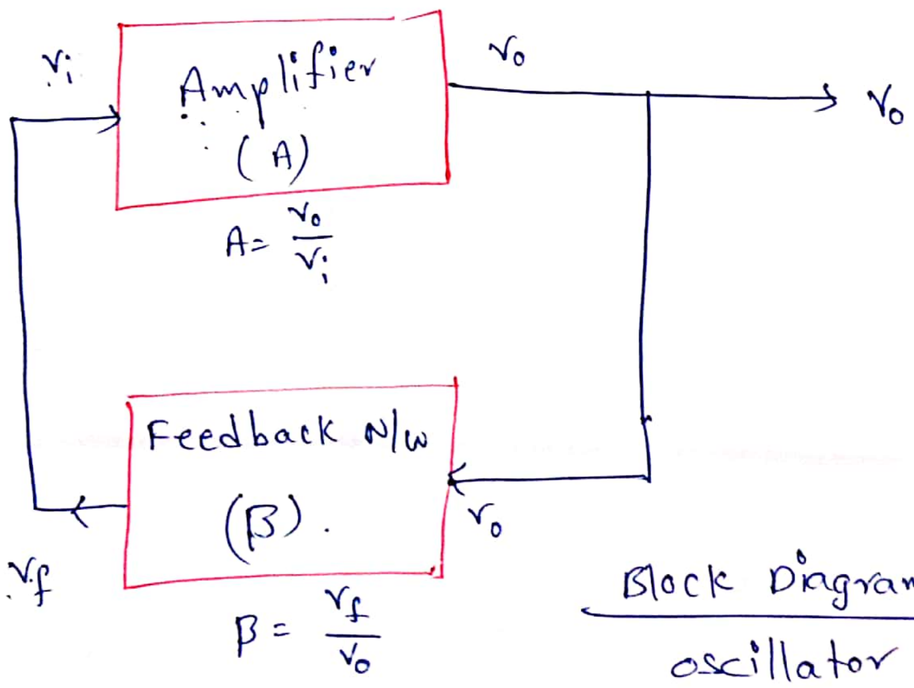
(1) RC oscillators → (a) RC Phase shift oscillator; (b) Wien-Bridge "

(2) LC oscillators → (a) Hartley oscillator; (b) colpitt's "

(3) crystal oscillators

II Conditions for oscillations / Barkhausen Criterion :-

$v_i = v_f$



Block Diagram of oscillator

Def. of Amp. $A = \frac{V_o}{V_i}$

$$\therefore V_o = A \cdot V_i \quad \text{——} \quad (1)$$

Def. of FB Ratio, $\beta = \frac{V_f}{V_o}$

$$V_o = \frac{V_f}{\beta} \quad \text{——} \quad (2)$$

Substituting Eqn (2) in (1), we get

$$\frac{V_f}{\beta} = A \cdot V_i$$

But $V_i = V_f$

$$\frac{\cancel{V_i}}{\beta} = A \cancel{V_i}$$

$$A\beta = 1$$

$$\boxed{A\beta = 1 + j0}$$

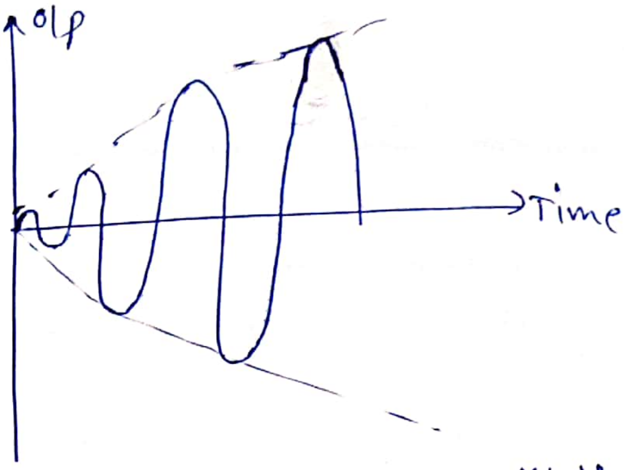
$\therefore |A\beta| = 1 \quad , \quad \angle A\beta = 0^\circ$ (or) 360°

→ The magnitude of loop gain $|A\beta| = 1$ & Total phase of the loop is 0° or 360°.

These two Conditions are called as "<u>Barkhausen Criteria Conditions</u>"

① $|A\beta| > 1$

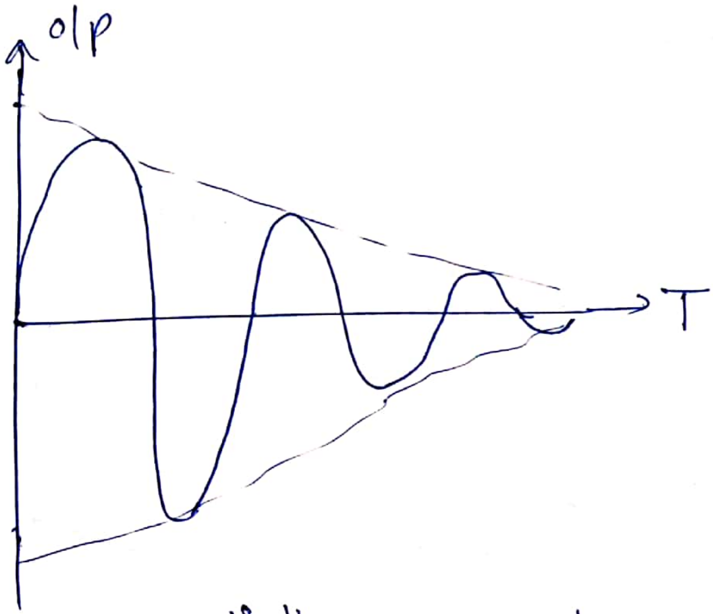
Damped Exponential Rise oscillations.



Growing type of oscillations

② $|A\beta| < 1$

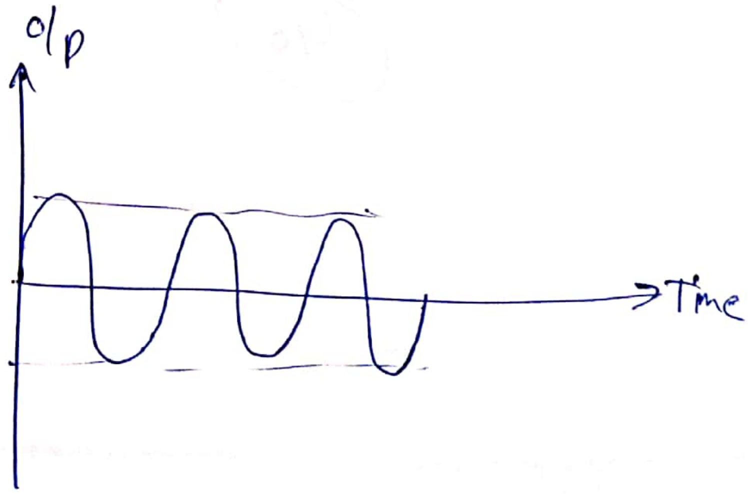
Damped Exponential Decay oscillations.



Exponentially Decay of oscillations

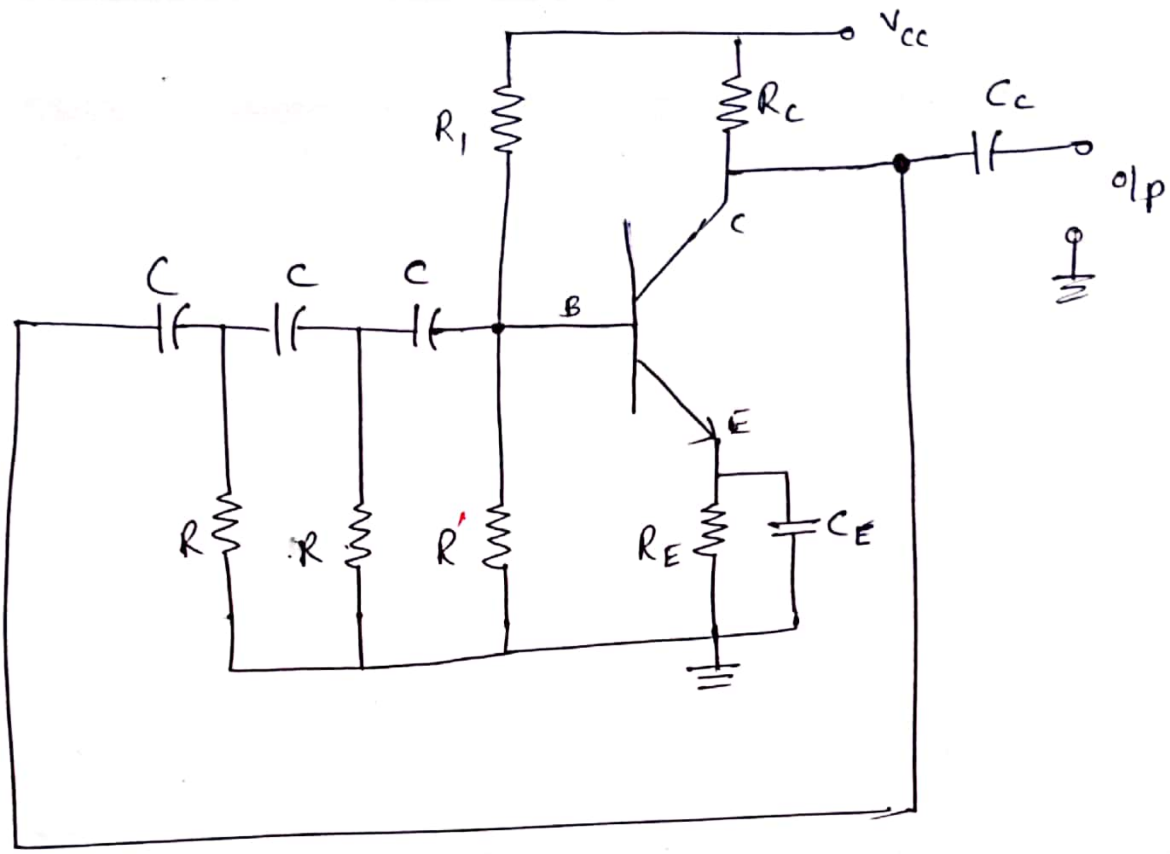
③ $|A\beta| = 1$

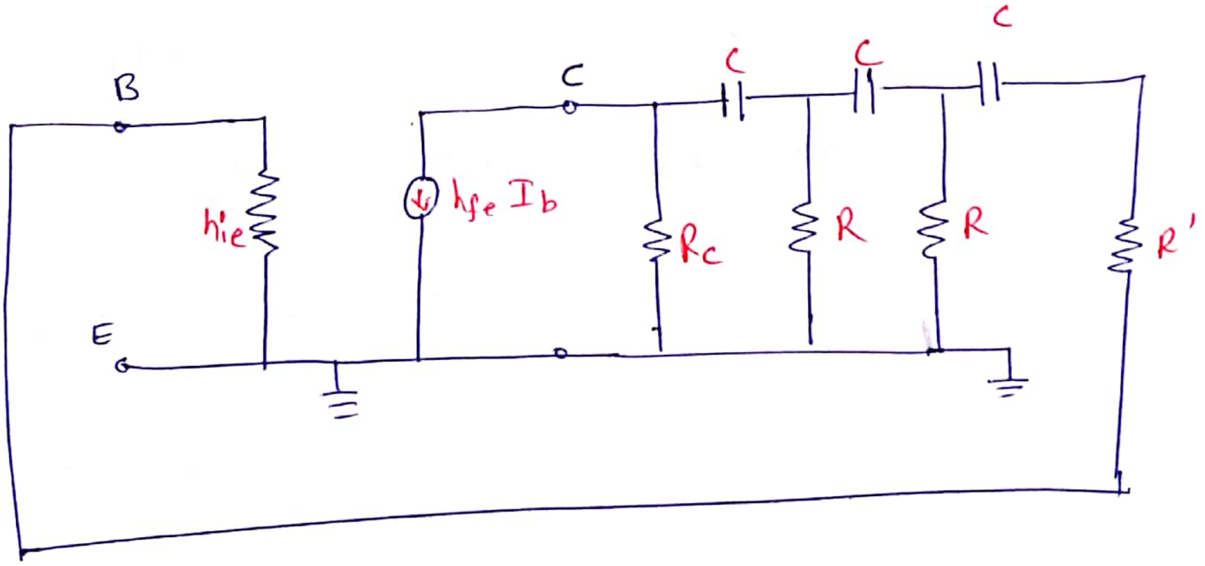
Undamped oscillations



Sustained Oscillations.

1(a) RC Phase shift oscillator :-

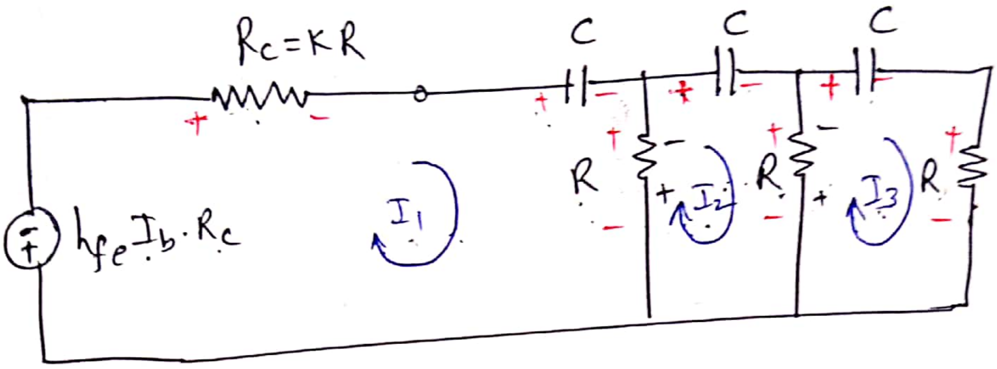




Now, we can replace hie + R' as R ||'r replacing the current source ($h_{fe} I_b$) by its equivalent voltage source. Assume the ratio of the resistance Rc to R be K.

$$\boxed{K = \frac{R_c}{R}}$$

$\therefore R_c = KR$



Apply KVL for loop 1

$$-R_c I_1 - \frac{1}{j\omega c} I_1 - R I_1 + I_2 R - h_{fe} I_b R_c = 0$$

but $R_c = KR$, $j\omega = s$

$$-I_1 KR - \frac{1}{sc} I_1 - R I_1 + I_2 R - h_{fe} I_b R_c = 0$$

$$-I_1 \left[KR + \frac{1}{sc} + R \right] + I_2 R = h_{fe} I_b R_c$$

$$-\left[I_1 \left[(K+1)R + \frac{1}{sc} \right] - I_2 R \right] = h_{fe} I_b R_c$$

$$I_1 \left[(K+1) R + \frac{1}{sc} \right] - I_2 R = - h_{fe} I_b R_c \quad \text{— (1)}$$

Loop 2

$$-\frac{1}{j\omega c} I_2 - R I_2 + R I_3 - R I_2 + R I_1 = 0$$

$$I_1 R - I_2 \left[\frac{1}{j\omega c} + R + R \right] - I_3 R = 0$$

$$I_1 R - I_2\left[2R + \frac{1}{sc}\right] + I_3 R = 0 \quad \text{—— (2)}$$

Loop3 :-

$$-\frac{1}{jwc} I_3 - R I_3 - R I_3 + R I_2 = 0$$

$$I_2 R - I_3\left[R + R + \frac{1}{jwc}\right] = 0$$

$$I_2 R - I_3\left[2R + \frac{1}{jwc}\right] = 0$$

$$I_2 R - I_3\left[2R + \frac{1}{sc}\right] = 0 \quad \text{—— (3)}$$

Using Cramer's Rule to solve for I_3

$$D = \begin{vmatrix} (K+1)R + \frac{1}{sc} & -R & 0 \\ R & -\left[2R + \frac{1}{sc}\right] & R \\ 0 & R & -\left[2R + \frac{1}{sc}\right] \end{vmatrix}$$

To solve above matrix, we get

$$D = s^3 c^3 R^3 (3K+1) + s^2 c^2 R^2 [4K+6] + scR[5K+1] + 1$$

$$D_3 = \begin{vmatrix} (K+1)R + \frac{1}{sC} & -R & -h_{fe} I_b R_c \\ R & -\left[2R + \frac{1}{sC}\right] & 0 \\ 0 & R & 0 \end{vmatrix}$$

$$= -h_{fe} I_b R_c \left[R^2 - 0\right]$$

$$= -h_{fe} I_b (KR) R^2$$

$$D_3 = -KR^3 h_{fe} I_b \quad \text{——— (4)}$$

$$\therefore \quad I_3 = \frac{D_3}{D}$$

$$I_3 = \frac{-KR^3 h_{fe} I_b s^3 c^3}{s^3 c^3 R^3 [3K+1] + s^2 c^2 R^2 [4K+6] + sCR[5K+1] + 1} \quad \text{—— (5)}$$

where, $I_3 \rightarrow$ o/p current of the feedback amplifier

$I_b \rightarrow$ i/p " " " amplifier

$I_3 = h_{fe} I_b \rightarrow$ i/p current of the feedback amplifier

$$A = \frac{\text{o/p of amplifier ckt}}{\text{i/p to amplifier ckt}} = \frac{I_3}{I_b} = h_{fe}$$

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$$\beta = \frac{o/p \text{ of feedback ckt}}{i/p \text{ to feedback ckt}} = \frac{I_3}{h_{fe} I_b}$$

$$A\beta = \cancel{h_{fe}} \times \frac{I_3}{\cancel{h_{fe}} I_b} = \frac{I_3}{I_b} \quad \text{— (6)}$$

$$A\beta = \frac{-KR^3 h_{fe} s^3 c^3}{s^3 c^3 R^3 [3K+1] + s^2 c^2 R^2 [4K+6] + sCR[5K+1] + 1} \quad \text{— (7)}$$

substituting $s = j\omega$, $s^2 = j^2\omega^2 = -\omega^2$, $s^3 = j^3\omega^3 = -j\omega^3$ in the

Eqn (7), we get

$$A\beta = \frac{-KR^3 h_{fe} (-j\omega^3) c^3}{-j\omega^3 c^3 R^3 [3K+1] - \omega^2 c^2 R^2 [4K+6] + j\omega CR[5K+1] + 1}$$

seperating the Real & Imaginary parts in the denominator, we get

$$A\beta = \frac{j\omega^3 KR^3 c^3 h_{fe}}{[1 - \omega^2 c^2 R^2 [4K+6]] - j\omega [\omega^2 c^3 R^3 [3K+1] - cR(5K+1)]}$$

Dividing numerator and denominator by

$j\omega^3 R^3 c^3$

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$$A\beta = \frac{K h_{fe}}{\left[\frac{1-4K\omega^2 C^2R^2 - 6\omega^2 C^2 R^2}{j\omega^3 R^3 C^3}\right] - \left[\frac{\cancel{j}\omega\left[3K\omega^2 R^3C^3 + \omega^2 R^3 C^3 - 5RC - KR\right]}{\cancel{j}\omega^3 R^3 C^3}\right]}$$

but $\frac{1}{j} = -j$

$$A\beta = \frac{K h_{fe}}{-j\left[\frac{1-4K\omega^2 C^2R^2 - 6\omega^2 C^2 R^2}{\omega^3 R^3 C^3}\right] - \left[\frac{3K\omega^3 R^3C^3 + \omega^3 R^3 C^3 - 5\omega RC - K\omega RC}{\omega^3 R^3 C^3}\right]}$$

$$= \frac{K h_{fe}}{-j\left[\frac{1}{\omega^3R^3C^3} - \frac{4K\omega^2C^2R^2}{\omega^3R^3C^3} - \frac{6\omega^2C^2R^2}{\omega^3R^3C^3}\right] - \left[\frac{3K\omega^3R^3C^3}{\omega^3R^3C^3} + \frac{\omega^3R^3C^3}{\omega^3R^3C^3} - \frac{5\omega RC}{\omega^3R^3C^3} - \frac{K\omega RC}{\omega^3R^3C^3}\right]}$$

$$= \frac{K h_{fe}}{-j\left[\frac{1}{\omega^3R^3C^3} - \frac{4K}{\omega RC} - \frac{6}{\omega RC}\right] - \left[3K+1 - \frac{5}{\omega^2R^2C^2} - \frac{K}{\omega^2R^2C^2}\right]}$$

$$\frac{1}{\omega RC} = \alpha$$

$$\therefore A\beta = \frac{K h_{fe}}{-j\left[\alpha^3 - 4K\alpha - 6\alpha\right] - \left[3K+1 - 5\alpha^2 - K\alpha^2\right]}$$

$$A\beta = \frac{k h_{fe}}{-\left[3k+1-5\alpha^2-k\alpha^2\right]-j\left[\alpha^3-4k\alpha-6\alpha\right]}$$

∴ Two condition's ($\angle A\beta = 0°$, $|A\beta| = 1$)

∴ The imaginary part is equal to

due to $\angle A\beta = 0°$

$$\alpha^3 - 4k\alpha - 6\alpha = 0$$

$$\alpha(\alpha^2 - 4k - 6) = 0$$

$$\alpha^2 - 4k - 6 = 0 \quad , \quad \alpha = 0 \ (\because \text{neglect})$$

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

$$\alpha = \sqrt{4k+6}$$

but $\alpha = \frac{1}{\omega RC}$

$$\frac{1}{\omega RC} = \sqrt{4k+6}$$

$$\omega RC = \frac{1}{\sqrt{4k+6}}$$

$$\omega = \frac{1}{RC\sqrt{4k+6}}$$

since $\omega = 2\pi f$

$$2\pi f = \frac{1}{RC\sqrt{4K+6}}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{4K+6}}}$$

Advantages :-

1. It doesn't require transformers (or) Inductors.

2. It can be used to produce very low frequency.

3. The circuit provide good frequency stability.

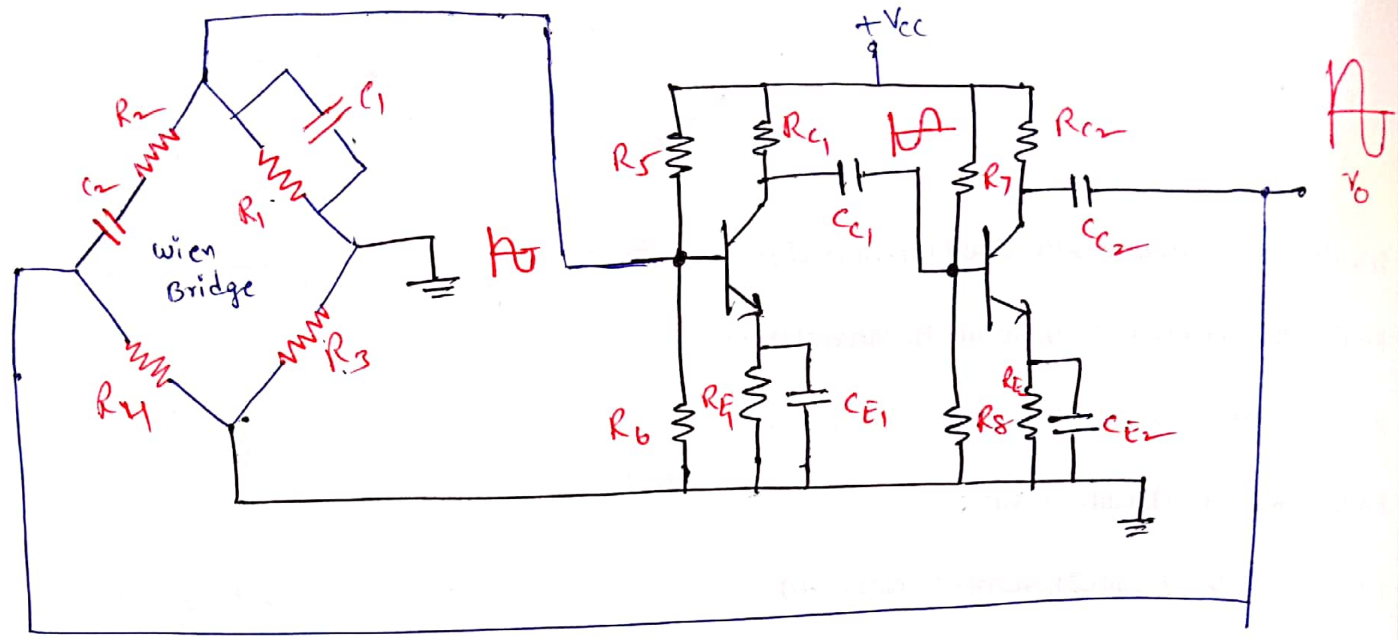
Disadvantages :-

1. It is difficult for the ckt to start oscillations as the feedback is generally small.

2. The ckt gives small o/p.

3. The three capacitors or resistors should be changed simultaneously change the frequency of oscillation and it is difficult to control the amplitude of oscillation without affecting the frequency of oscillation.

6) Wien-Bridge Oscillator :-



From Fig,

$z_1 = R_1$ parallel with C_1 $(R_1 \| C_1)$

$z_2 = R_2$ series with C_2 $(R_2 + C_2)$

$z_3 = R_3$

$z_4 = R_4$

The wien bridge must be in Balance mode

i.e.. $\quad z_1 z_4 = z_2 z_3 \quad$ —— (1)

$$\therefore \frac{z_4}{z_3} = \frac{z_2}{z_1}$$

As WKT,

$$z_1 = R_1 \| C_1 = R_1 \| \frac{1}{j\omega C_1}$$

$$Z_1 = \frac{R_1 \cdot \frac{1}{j\omega C_1}}{R_1 + \frac{1}{j\omega C_1}} = \frac{\frac{R_1}{\cancel{j\omega C_1}}}{\frac{j\omega R_1 C_1 + 1}{\cancel{j\omega C_1}}}$$

$$Z_1 = \frac{R_1}{1 + j\omega R_1 C_1} \quad \text{—— (2)}$$

$$Z_2 = R_2 + C_2 = R_2 + \frac{1}{j\omega C_2} \quad \text{—— (3)}$$

$$Z_3 = R_3 \quad \text{—— (4)}$$

$$Z_4 = R_4 \quad \text{—— (5)}$$

substituting eqn's (2), (3), (4) & (5) in (1), we get

$$Z_1 Z_4 = Z_2 Z_3$$

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

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

$$\frac{R_1 R_4}{R_3} = R_2 + \frac{1}{j\omega C_2} + j\omega R_1 R_2 C_1 + \frac{R_1 C_1}{C_2}$$

$$\underbrace{-\frac{R_1 R_4}{R_3} + R_2 + \frac{R_1 C_1}{C_2}}_{\text{Real part}} + \underbrace{j\omega R_1 R_2 C_1 + \frac{1}{j\omega C_2}}_{\text{imaginary part}} = 0 \quad \text{—— (6)}$$

To get the frequency of oscillations, equate the imaginary part to zero for 0° phase shift

From Eqn (6),

$$j\omega R_1 R_2 C_1 + \frac{1}{j\omega C_2} = 0$$

$$j\omega R_1 R_2 C_1 - \frac{j}{\omega C_2} = 0 \qquad \left[\because \frac{1}{j} = -j\right]$$

$$\cancel{j}\omega R_1 R_2 C_1 = \frac{\cancel{j}}{\omega C_2}$$

$$\omega R_1 R_2 C_1 = \frac{1}{\omega C_2}$$

$$\omega^2 = \frac{1}{R_1 R_2 C_1 C_2}$$

$$\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

but $\omega = 2\pi f$

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

$$\boxed{f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}} \longrightarrow (7)$$

This is the frequency of sustained oscillations.

→ If $R_1 = R_2 = R$ and $C_1 = C_2 = C$ then

$$f = \frac{1}{2\pi\sqrt{R \cdot R \cdot C \cdot C}}$$

$$= \frac{1}{2\pi\sqrt{R^2 C^2}}$$

$$\boxed{f = \frac{1}{2\pi RC}} \quad (8)$$

For changing the frequency, we must change R & C values.

Conditions for maximum Oscillations :

To get the maximum oscillations, we equate the Real part to zero in Eqn (6)

$$\frac{-R_1 R_4}{R_3} + R_2 + \frac{R_1 C_1}{C_2} = 0$$

$$\frac{R_1 R_4}{R_3} = R_2 + \frac{R_1 C_1}{C_2}$$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

If $R_1 = R_2 = R$ & $C_1 = C_2 = C$ then

$$\frac{R_4}{R_3} = \frac{\cancel{R}}{\cancel{R}} + \frac{\cancel{C}}{\cancel{C}}$$

$$\frac{R_4}{R_3} = 1+1$$

$$\frac{R_4}{R_3} = 2$$

$$\boxed{R_4 = 2R_3} \quad \text{—— (9)}$$

Advantages :-

1. This gives good frequency stability.
2. Overall gain is high because of two Transistors
3. It produces a very good sinewave o/p.
4. Frequency of oscillations can be changed.
5. By replacing R_4 with a thermistor, amplitude stability of oscillator o/p voltage can be increased.

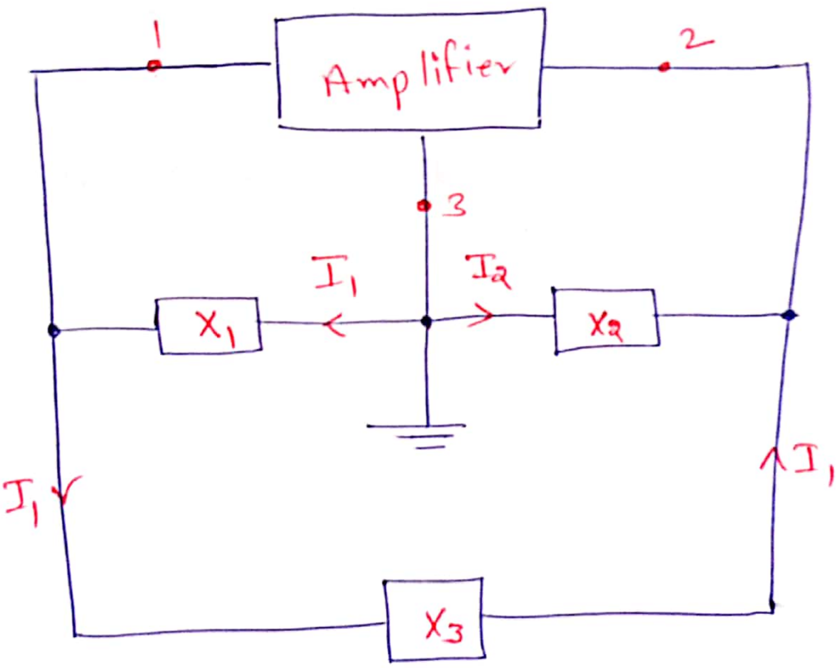
Disadvantages :-

1. It cannot generate very high frequencies.
2. It requires two transistors & large no. of components.

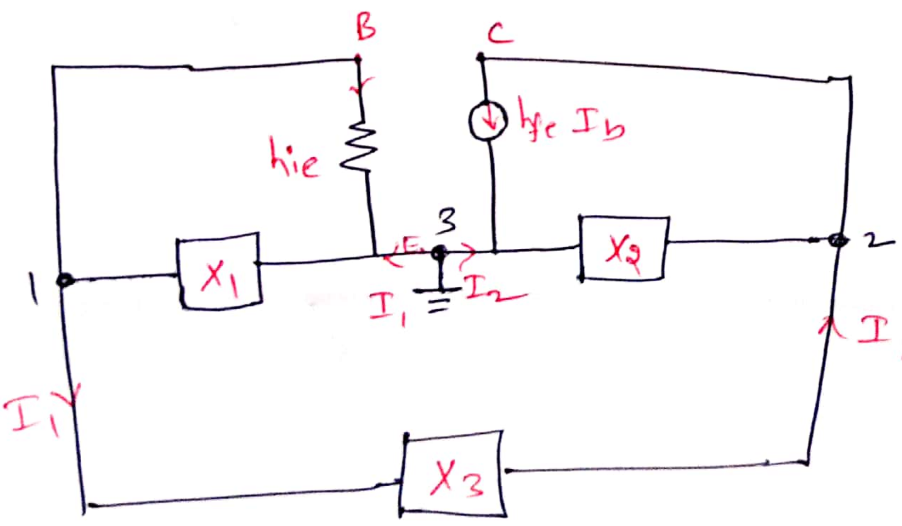
Applications :-

1. Audio Frequency range.
2. low frequency of oscillations.
3. For laboratory purpose.

Generalized Analysis of LC oscillators :-



General form of an oscillator



Any of the active devices such as Vaccume tube, Transistor, FET and Operational amplifier (op-amp) may be used in the amplifier section.

→ X_1, X_2 and X_3 are reactive elements constituting the feedback tank circuit which determines the frequency of oscillation.

→ Here, X_1 and X_2 serves as an ac voltage divider for the o/p voltage and feedback signal. Therefore, the voltage across X_1 is the feedback signal. The frequency of oscillation of the LC oscillator is

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

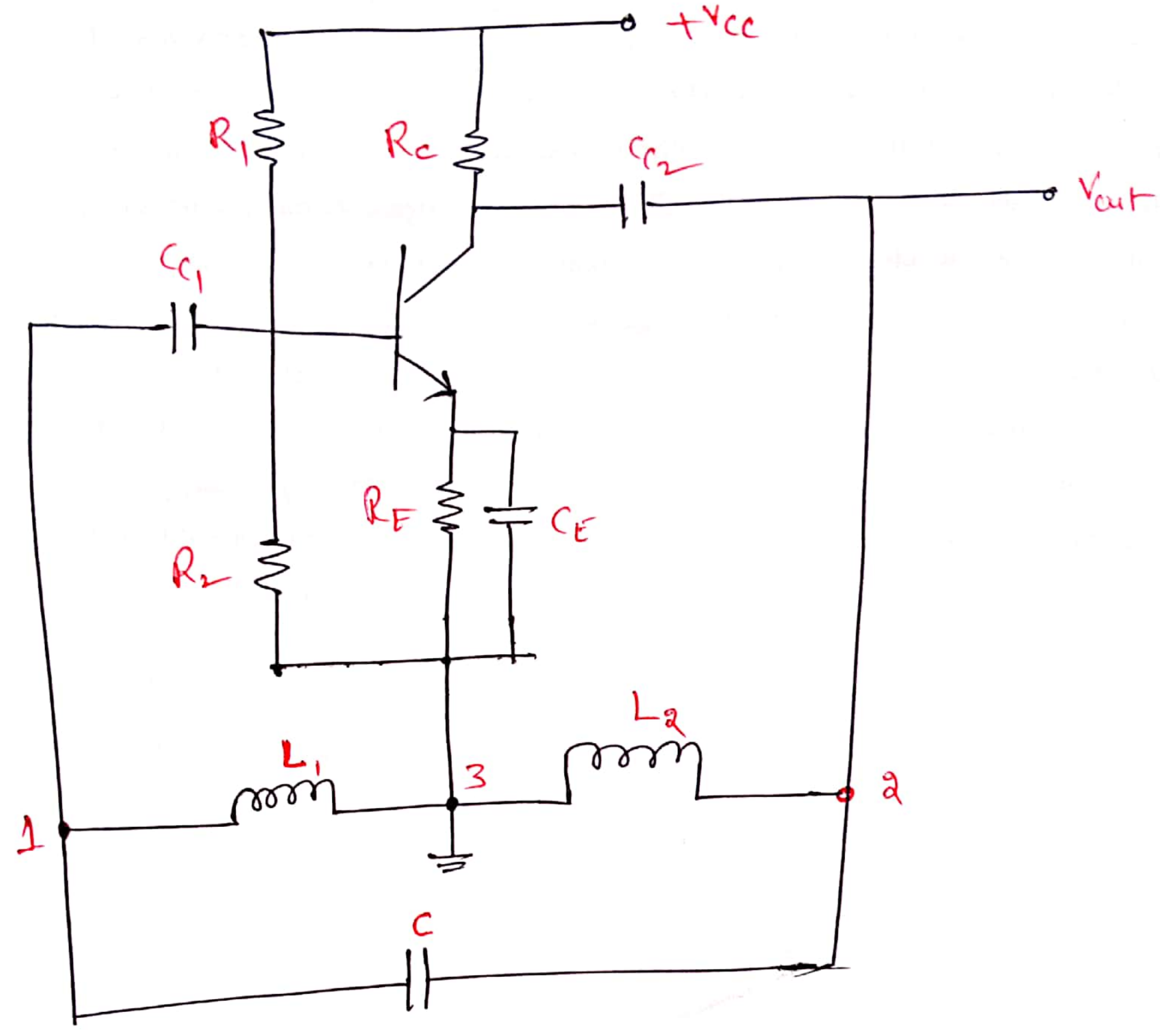
→ The inductive (or) Capacitive reactances are represented by X_1, X_2 and X_3. The o/p terminals are 2 and 3, and i/p terminals are 1 and 3.

∴ Final Equation,

$$\boxed{h_{ie}(X_1 + X_2 + X_3) + X_1X_2(1+h_{fe}) + X_1X_3 = 0}$$

Oscillator.	Reactive Components	
Hartley	$X_1 = X_2 = L$	$X_3 = C$
Colpitts	$X_1 = X_2 = C$	$X_3 = L$

Hartley Oscillator :-



Analysis of Hartley Oscillator:-

X_1, X_2 } Inductive Reactances

$X_3 \rightarrow$ Capacitive "

$M \rightarrow$ Mutual Inductance b/w inductors.

$$X_1 = j\omega L_1 + j\omega M$$

$$X_2 = j\omega L_2 + j\omega M$$

$$X_3 = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

Substituting these values in General Eqn

$$h_{ie}(X_1 + X_2 + X_3) + X_1 X_2 (1 + h_{fe}) + X_1 X_3 = 0$$

$$h_{ie}\left[(j\omega L_1 + j\omega M) + (j\omega L_2 + j\omega M) + \left(\frac{-j}{\omega C}\right)\right]$$

$$+ (j\omega L_1 + j\omega M)(j\omega L_2 + j\omega M)(1 + h_{fe})$$

$$+ (j\omega L_1 + j\omega M)\left(\frac{-j}{\omega C}\right) = 0$$

$$h_{ie}\left[j\omega L_1 + j\omega L_2 + 2j\omega M - \frac{j}{\omega C}\right]$$

$$+ j\omega (L_1 + M)\, j\omega (L_2 + M)(1 + h_{fe})$$

$$+ j\cancel{\omega}(L_1 + M)\left(\frac{-j}{\cancel{\omega} C}\right) = 0$$

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

$$\underbrace{j\omega h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right]}_{\text{Imaginary part}} - \underbrace{\omega^2 (L_1 + M)\left[(L_2 + M)(1 + h_{fe}) - \frac{1}{\omega^2 C}\right]}_{\text{Real parts}} = 0 \qquad (2)$$

Equating the Imaginary Part Equal to zero, we get

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

$$L_1+L_2+2M-\frac{1}{\omega^2 C}=0 \quad [\because \omega h_{ie} \neq 0]$$

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

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

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

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

$$\therefore \boxed{f=\frac{1}{2\pi\sqrt{(L_1+L_2+2M)C}}} \quad [\because \omega=2\pi f] \quad \text{—— (3)}$$

Condition for sustained oscillations :-

Equating Real part equal to zero, we get

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

$$\omega^2(L_1+M)\neq 0, \quad (L_2+M)(1+h_{fe})-\frac{1}{\omega^2 C}=0$$

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

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

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

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

$$= \frac{L_1+L_2+2M}{L_2+M}$$

$$= \frac{L_1+L_2+M+M}{L_2+M}$$

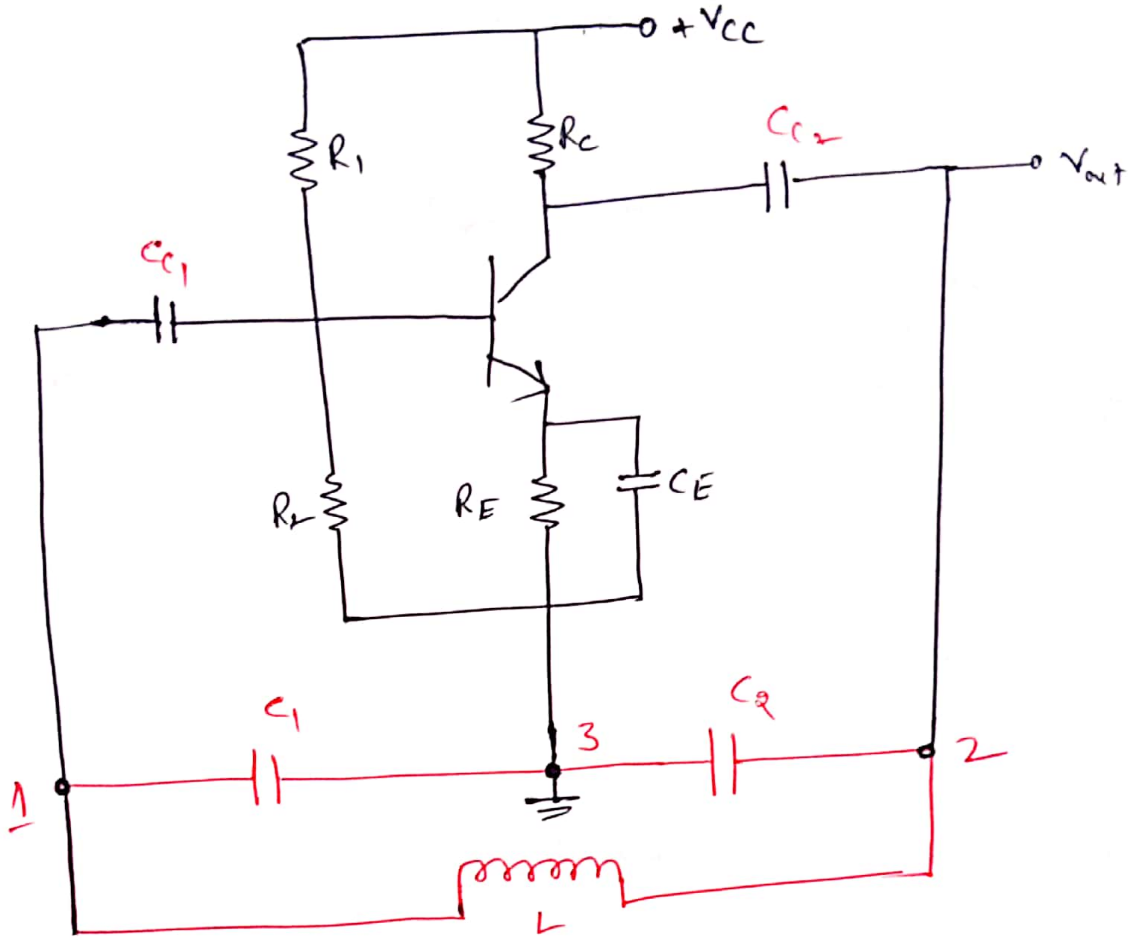
$$= \frac{(L_1+M)+(L_2+M)}{(L_2+M)}$$

$$= \frac{L_1+M}{L_2+M} + \frac{\cancel{L_2+M}}{\cancel{L_2+M}}$$

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

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

Colpitt's oscillator :-



Analysis of Colpitt's Oscillator :-

The General Eqn of the oscillator is given by

$$h_{ie}(X_1+X_2+X_3)+X_1X_2(1+h_{fe})+X_1X_3=0$$

$$X_1=\frac{1}{j\omega C_1}=\frac{-j}{\omega C_1}$$

$$X_2=\frac{1}{j\omega C_2}=\frac{-j}{\omega C_2}$$

$$X_3=j\omega L$$

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Substituting x_1, x_2 & x_3 value in General Eqn,

we get

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

$$+\left(\frac{-j}{\cancel{\omega} C_1}\right)(j\cancel{\omega} L) = 0$$

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

$$\underbrace{jh_{ie}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right]}_{\text{Imaginary part}} + \underbrace{\left[\frac{1+h_{fe}}{\omega^2 C_1 C_2}\right] - \frac{L}{C_1}}_{\text{Real part}} = 0 \quad \text{--- (2)}$$

Equating the Imaginary Part of Eqn (2) equal to zero, we get

$$h_{ie}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right] = 0$$

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

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

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

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

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

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

$$\omega = \frac{1}{\sqrt{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{L\left(\frac{C_1 C_2}{C_1 + C_2}\right)}}} \quad \text{--- (3)} \qquad [\because \omega = 2\pi f]$$

Condition for Sustained Oscillation :-

It can obtained by Equating the coefficient of Real part of Eqn (2) equal to zero, we get

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

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

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

But $\omega^2 = \dfrac{1}{L\left(\dfrac{C_1 C_2}{C_1+C_2}\right)} = \dfrac{C_1+C_2}{L C_1 C_2}$

$$1+h_{fe} = \frac{C_1+C_2}{\cancel{L} C_1 \cancel{C_2}} \times \cancel{L} \cancel{C_2}$$

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

$$= \frac{\cancel{C_1}}{\cancel{C_1}} + \frac{C_2}{C_1}$$

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

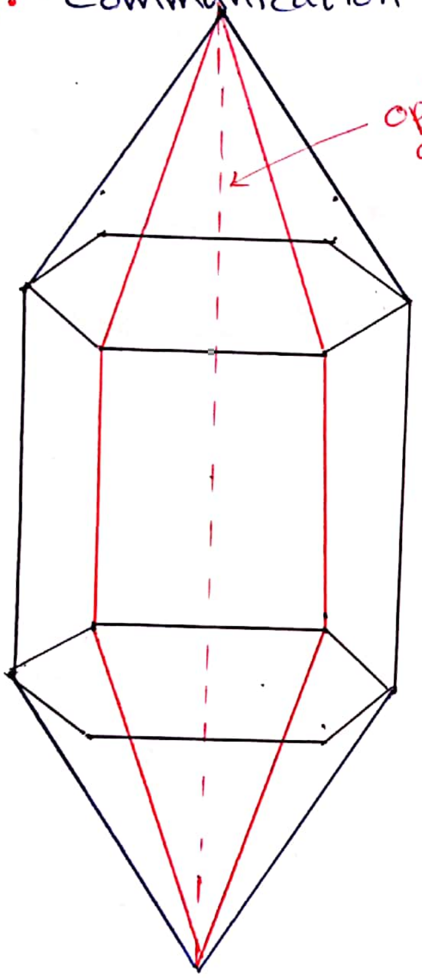
$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

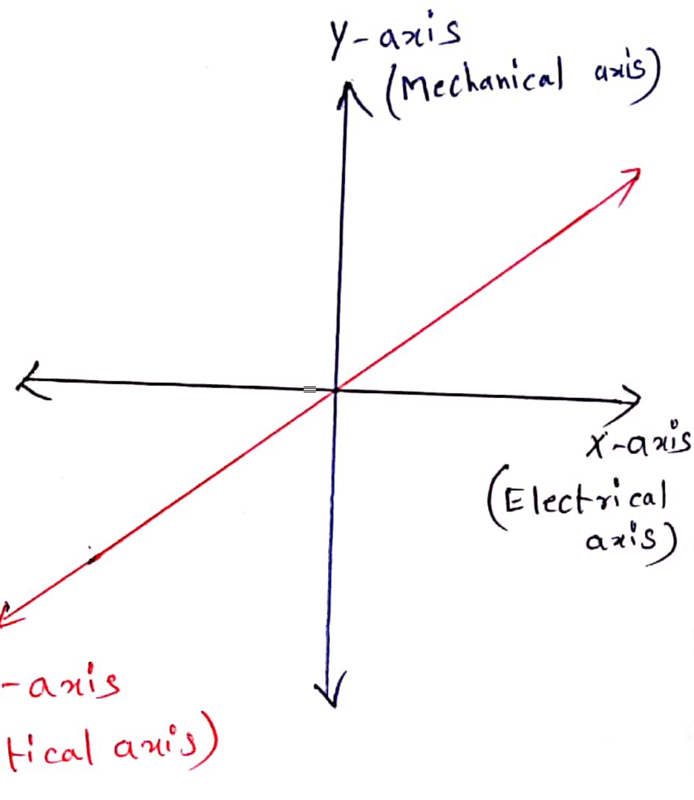
Crystal Oscillator :-

→ A crystal oscillator is basically a tuned circuit using a Piezoelectric crystal as a resonant tank circuit.

→ The crystal (usually - Quartz) has a great stability in holding constant at whatever frequency the crystal is originally cut to operate crystal oscillator are used whenever great stability is required.

Eg:- Communication Transmitter and Receivers.

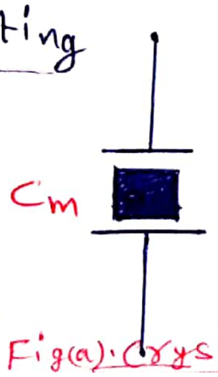




Circuit of crystal :-

case(i): When the crystal is not Vibrating

→ It is equivalent to capacitance (C_m) because it has two metal plates separated by dielectric this capacitance



Fig(a): Crystal

is known as Mounting Capacitance (C_m).

Case (ii): When the crystal is vibrating:

It is Equivalent to R-L-C series ckt. Therefore, the Equivalent ckt of a vibrating crystal is R-L-C series ckt shunted by the mounting capacitance (C_m).

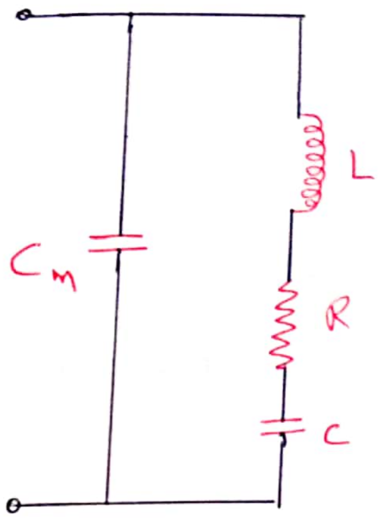


Fig (b). Equivalent ckt

Two Types of Frequency :-

① Series Resonant Frequency (f_s):

$$X_L + X_c = 0$$

$$j\omega L + \frac{1}{j\omega C} = 0$$

$$j\omega L - \frac{j}{\omega C} = 0 \qquad \left[\because \frac{1}{j} = -j\right]$$

$$\cancel{j}\omega L = \frac{\cancel{j}}{\omega C}$$

$$\omega L = \frac{1}{\omega C}$$

$$\omega^2 = \frac{1}{LC}$$

$$\omega = \frac{1}{\sqrt{LC}}$$

$$\boxed{f_s = \frac{1}{2\pi\sqrt{LC}}} \qquad [\because \omega = 2\pi f]$$

(2) Parallel Resonant frequency (f_p):-

$$X_L + X_C + X_{Cm} = 0$$

$$X_L + X_C = -X_{Cm}$$

$$j\omega L + \frac{1}{j\omega C} = \frac{-1}{j\omega C_m}$$

$$j\omega L - \frac{j}{\omega C} = \frac{j}{\omega C_m}$$

$$\cancel{j}\left(\omega L - \frac{1}{\omega C}\right) = \frac{\cancel{j}}{\omega C_m}$$

$$\omega L - \frac{1}{\omega C} = \frac{1}{\omega C_m}$$

$$\omega L = \frac{1}{\omega C} + \frac{1}{\omega C_m}$$

$$= \frac{1}{\omega}\left[\frac{1}{C} + \frac{1}{C_m}\right]$$

$$\omega L = \frac{1}{\omega}\left[\frac{C + C_m}{C C_m}\right]$$

$$\omega^2 L = \frac{C + C_m}{C C_m}$$

$$\omega^2 = \frac{C + C_m}{L C C_m}$$

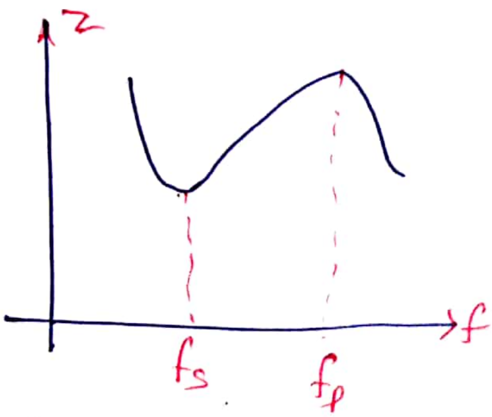
$$\omega = \sqrt{\frac{C + C_m}{L C C_m}}$$

$$\boxed{f_p = \frac{1}{2\pi}\sqrt{\frac{C + C_m}{L C C_m}}}$$

(or)

$$\boxed{f_p = \frac{1}{2\pi\sqrt{\frac{L C C_m}{C + C_m}}}}$$

→ At this frequency Crystal offers a very high impedance to external circuit.



Advantages :-

(1) They have a high order of frequency stability.

(2) The Quality factor (Q) of the crystal is very high.

Disadvantages :-

(1) They are easily damaged & consequently can only be used in low power circuits.

(2) The Frequency of oscillations cann't be changed.

Stability of oscillations :- Two types

(1) Frequency stability

(2) Amplitude stability

(1) Frequency stability :-

The freq. stability of an oscillator is a measure of its ability to maintain the required freq as indicating exactness as possible over as long time interval.

→ The following are the factors, which contribute to the change in freq. stability

(i) change in operating point → due to Temp.

(ii) Variation in Temparature → R, L, C are Temp. depend.

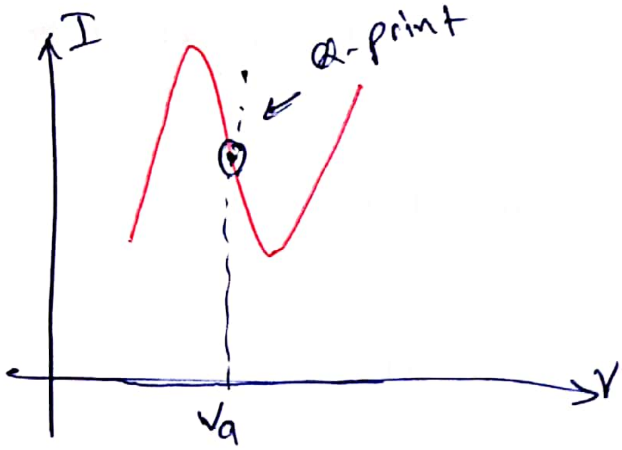
(iii) Due to Power Supply → Supply is Poor

(iv) Change in o/p load.

② Amplitude stability :-

A → Amplifier Transfer gain

β → Feedback network factor



At oscillator frequency,

If $|A\beta| = 1$, The feedback signal connected to i/p terminals, the removal of the external generator will make no difference.

If $|A\beta| < 1$,

The removal of the external generator will result in a stopping of oscillations.

If $|A\beta| > 1$,

The amplitude of the oscillations will continue to increase without limit.

UNIT – IV

Large Signal Amplifiers

Concept of large signal Amplification :-

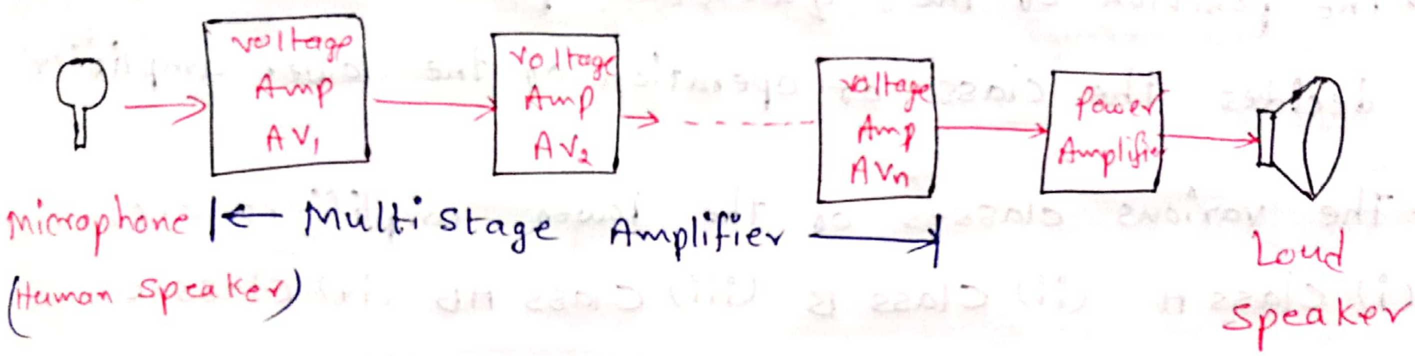


Fig. Block Diagram of Public Address System

The main aim is to develop sufficient Power hence the voltage gain is not important, in the last stage. Such an stage, which develops and feeds sufficient power to the load handling the large signals is called "Large signal Amplifier" (or) "Power Amplifier."

Applications :-

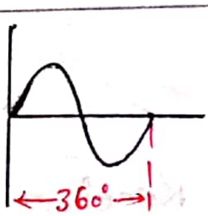
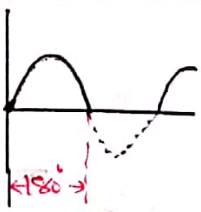
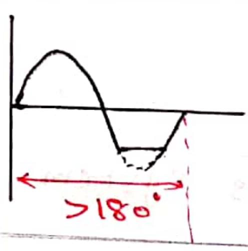
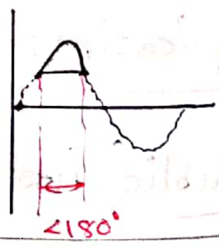
1. Public Address system
2. Radio Receivers
3. Tape Players
4. Driving servometer in industrial Control System.
5. T.V. Receivers
6. Cathode Ray Tubes (CRT's) etc.

Classification of Large Signal Amplifiers :-

→ For an amplifier, a quiescent operating Point (Q-Point) is fixed by selecting the proper d.c. biasing to the transistors used.

→ The position of the quiescent point on the load line decides the class of operation of the Power amplifier.

→ The various classes of the Power amplifiers are:
(i) class A (ii) Class B (iii) class AB (iv) Class C.

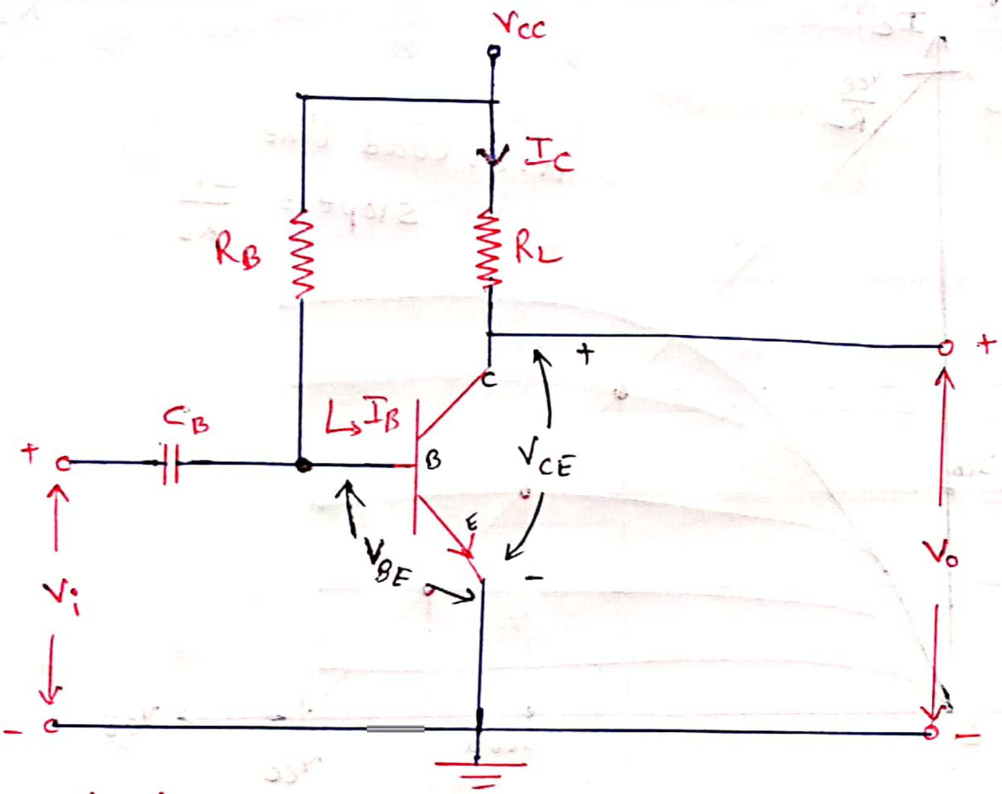
S.N	Class	A	B	AB	C
①	Operating cycle	360°	180°	180° to 360°	Less than 180°
②	Position of Q-point	Centre of Load line	on x-axis	Above x-axis but below the centre of load line	Below x-axis
③	Efficiency	Poor (25% to 50%)	Better (78.5%)	Higher than A but less than B (50 to 78.5%)	High
④	Nature of o/p current wave form				
⑤	Distortion	Absent No distortion	Present More than class A	Present	Highest
⑥	Power dissipation in Tr's	very high	Low	Moderate	Very low

Class - A Large Signal Amplifiers :- It is two types

① Series - fed (or) Directly coupled class A Power Amp

② Transformer - Coupled class A power amplifiers.

① Series - fed (or) Directly Coupled Class A Power Amp :-



D.C. Analysis :-

Applying KVL to the collector - Emitter ckt, we have

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

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

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

$$= \frac{V_{CC}}{R_L} - \frac{V_{CE}}{R_L}$$

$$= -\frac{V_{CE}}{R_L} + \frac{V_{CC}}{R_L}$$

$$= \frac{-V_{CE}}{R_L} + \frac{V_{CC}}{R_L}$$

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

The slope of the D.C. load line is $\left[\frac{-1}{R_L}\right]$ and the intercept on the current axis is $\frac{V_{CC}}{R_L}$.

A.C. Analysis :-

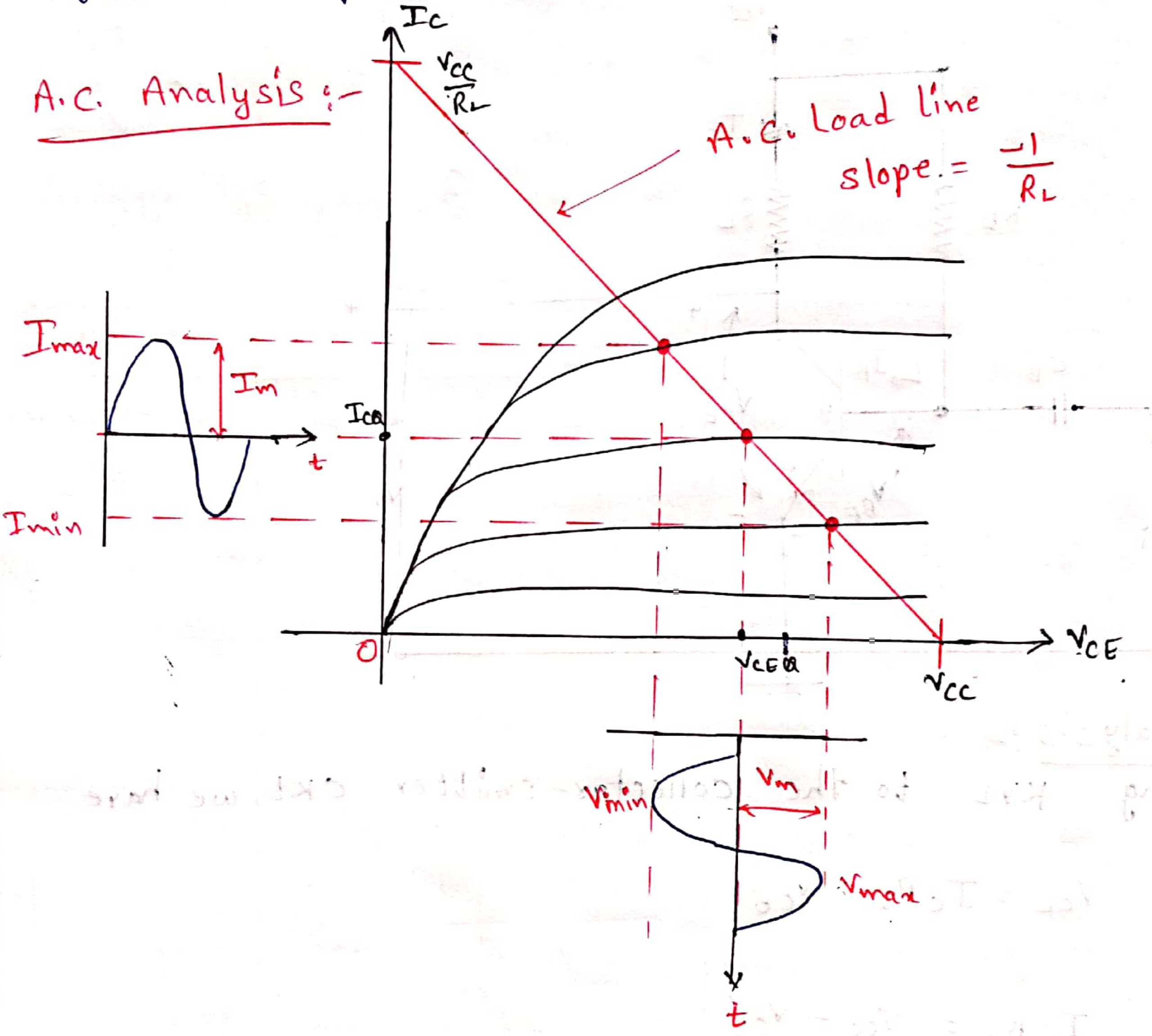


Fig. o/p voltage & current of the Series-Fed class A Power Amplifier

0 and $\frac{V_{CC}}{R_L}$ for Output Current

0 and V_{CC} for " Voltage

D.C. Power Input, $P_{in(DC)} = V_{CC} \cdot I_{CQ}$ —— (1)

A.C. Power output, $P_{out(A.C)} = V_{rms} \cdot I_{rms}$ —— (2)

But $V_{rms} = \frac{V_m}{\sqrt{2}}$, $I_{rms} = \frac{I_m}{\sqrt{2}}$

$$P_{out(A.C)} = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}}$$

$$\therefore P_{out(A.C)} = \frac{V_m \cdot I_m}{2} \quad \text{—— (3)}$$

From Fig.,

$$V_{max} - V_{min} = 2V_m$$

$$V_m = \frac{V_{max} - V_{min}}{2}$$

||'y $$I_m = \frac{I_{max} - I_{min}}{2}$$

substituting V_m & I_m values in Eqn (3), we get

$$P_{out(A.C)} = \frac{\left(\frac{V_{max} - V_{min}}{2}\right)\left(\frac{I_{max} - I_{min}}{2}\right)}{2}$$

$$P_{out(A.C)} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8} \quad \text{—— (4)}$$

Efficiency :-

$$\eta = \frac{\text{A.C. Power Delievered to the Load } P_{out(A.C)}}{\text{Total Power Drawn from D.C. supply } P_{in(DC)}}$$

$$\% \eta = \frac{P_{out(A.C)}}{P_{in(D.C)}} \times 100 \quad \text{— (5)}$$

Substituting Eqn's (1) & (4) in Eqn (5), we get

$$\% \eta = \frac{\dfrac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}}{V_{cc} \cdot I_{CQ}} \times 100$$

$$\% \eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{cc} \cdot I_{CQ}} \times 100 \quad \text{— (6)}$$

Maximum Power and Efficiency

$$\left.\begin{aligned} V_{max} &= V_{CE(peak-to-peak)} = V_{cc}, \quad V_{min} = 0 \\ I_{max} &= I_{CE(peak-to-peak)} = \frac{V_{cc}}{R_L}, \quad I_{min} = 0 \end{aligned}\right\} \text{— (7)}$$

$$\therefore P_{out(A.C), max} = \frac{1}{8} V_{cc} \times \frac{V_{cc}}{R_L} \qquad [\because \text{from Eqn (4)}]$$

$$= \frac{V_{cc}^2}{8R_L} \quad \text{— (8)}$$

$$P_{in(DC), max} = \frac{V_{cc} \cdot I_{CQ}}{2}$$

$$= \frac{V_{cc} \times V_{cc}/R_L}{2} \qquad \left[\because I_{CQ} = \frac{V_{cc}}{R_L}\right]$$

$$= \frac{V_{cc}^2}{2R_L} \quad \text{— (9)}$$

substituting Eqn's (8) & (9) in (5), we get

$$\% \eta_{max} = \frac{P_{out(A.C), max}}{P_{in(D.C), max}} \times 100 = \frac{\cancel{V_{CC}^2} / \cancel{8}^{4} \cancel{R_L}}{\cancel{V_{CC}^2} / \cancel{2} \cancel{R_L}} \times 100 = \frac{1}{4} \times 100$$

$$\boxed{\% \eta_{max} = 25\%}$$

↓

Maximum Efficiency of Class A Power Amplifier.

Note :- Power Dissipation :- D.C. power i/p without a.c. i/p signal is the maximum power dissipation.

$$\boxed{P_{D(max)} = V_{CC} \cdot I_{CQ}}$$

Advantages :-

(1) The circuit is simple to design and to implement.

(2) The load is connected directly in the collector circuit hence the o/p transformer is not necessary. This makes the circuit cheaper.

(3) Less no. of components required as load is directly coupled.

(4) No coupling element is required.

Disadvantages :-

1. The load resistance is directly connected in collector and carries the quiescent collector current. This causes considerable wastage of power.

2. Power dissipation is more. Hence power dissipation arrangements like heat sink are essential.

3. The efficiency is very poor, due to large dissipation.

2. Transformer - Coupled Class A Power Amplifier:-

→ One of the serious drawback of Series-fed Power amplifier was impedance mismatch.

→ To over come this problem, we go for "Transformer Coupled class A power amplifier".

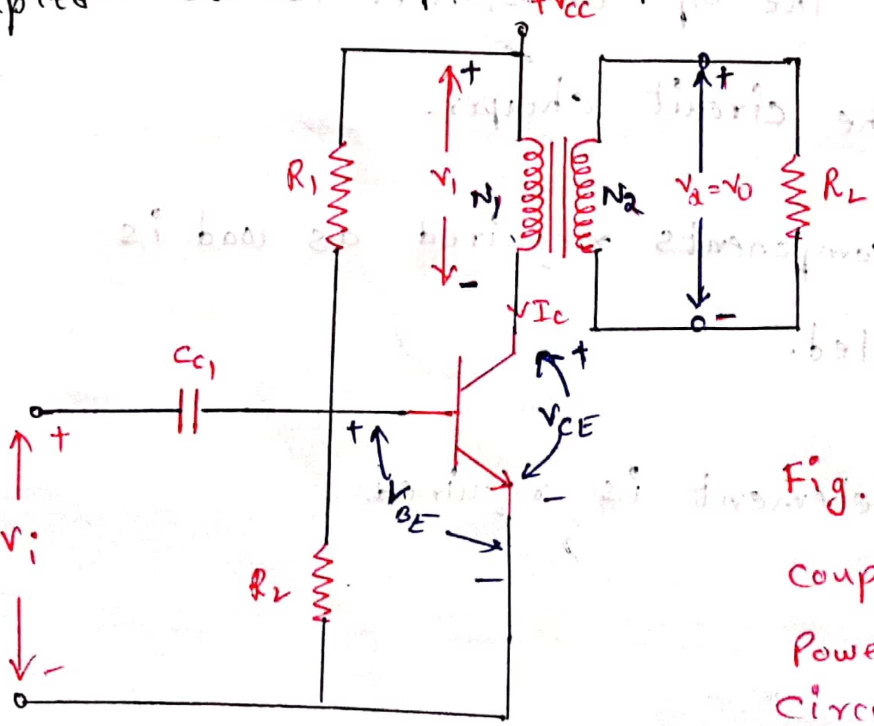


Fig. Transformer-coupled class A Power Amplifier Circuit Diagram

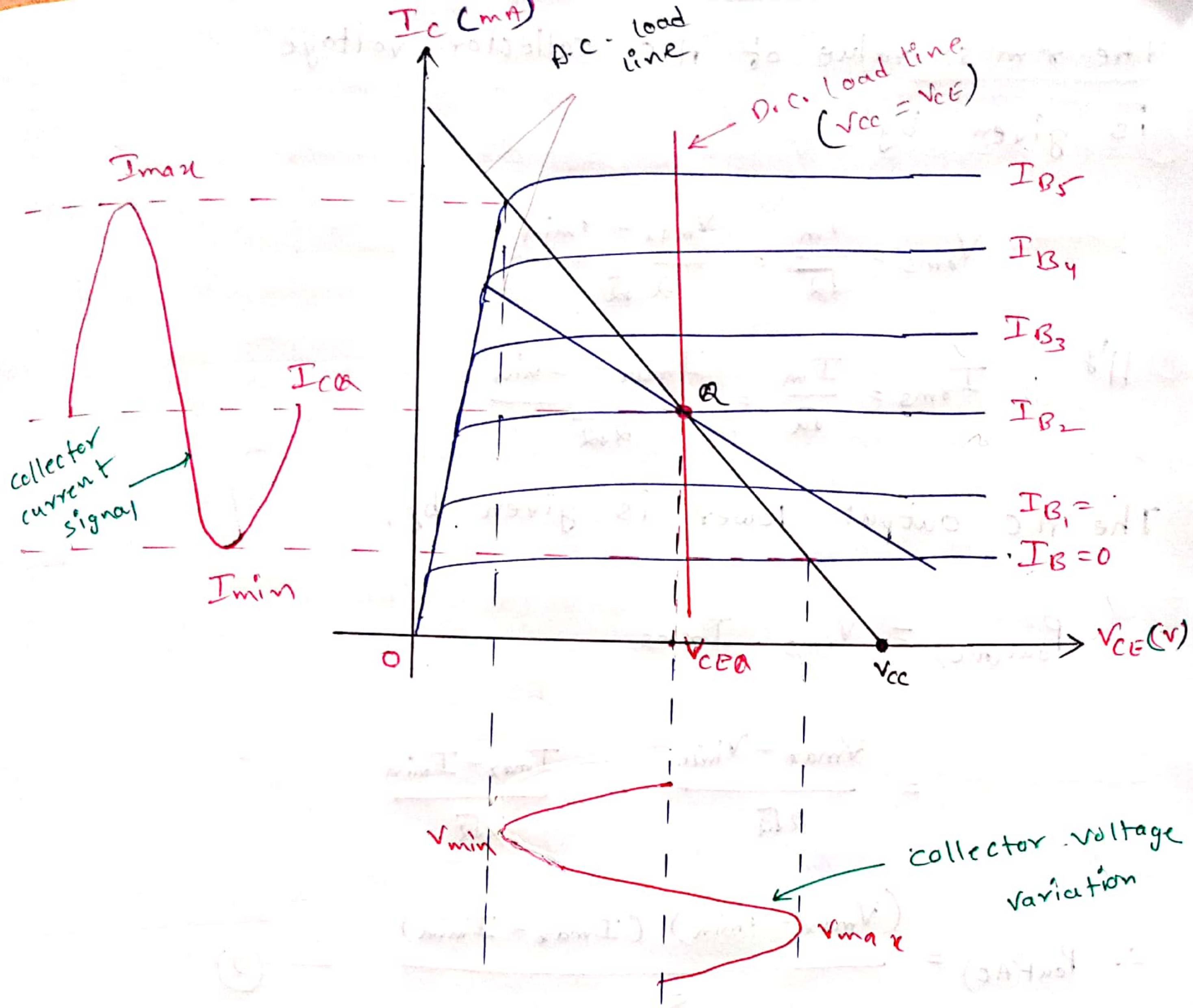


Fig. collector characteristics of a Power Amplifier.

Maximum Efficiency:- $$\%\eta = \frac{P_{out(A.C)}}{P_{in(D.C)}} \times 100 \quad \text{--- (1)}$$

From fig. the maximum value of sine wave output voltage is,

$$V_m = \frac{V_{max} - V_{min}}{2} \; ; \; I_C = I_{CQ}$$

The r.m.s. value of A.C. collector voltage is given by,

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{V_{max} - V_{min}}{2\sqrt{2}}$$

||'y $$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{I_{max} - I_{min}}{2\sqrt{2}}$$

The A.C. output Power is given by,

$$P_{out(A.C)} = V_{rms} \cdot I_{rms}$$

$$= \frac{V_{max} - V_{min}}{2\sqrt{2}} \cdot \frac{I_{max} - I_{min}}{2\sqrt{2}}$$

$$\therefore P_{out(A.C)} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8} \quad \text{--- (2)}$$

The Power supplied to the circuit is given by,

$$P_{in(D.C)} = V_{CC} \cdot I_{CQ} \quad \text{--- (3)}$$

Substituting Eqn's (2) & (3) in (1), we get

$$\% \eta = \frac{P_{out(AC)}}{P_{in(DC)}} \times 100$$

$$= \frac{\frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}}{V_{CC} \cdot I_{CQ}} \times 100$$

$$\% \eta = \frac{(V_{max} - V_{min})\ (I_{max} - I_{min})}{8\, V_{cc}\, I_{CQ}} \times 100 \quad \text{--- (4)}$$

The maximum Efficiency will be obtained, when $V_{min} = 0$, $I_{min} = 0$, $V_{max} = 2V_{cc}$ and $I_{max} = 2\, I_{CQ}$ substituting these values in eqn (4), we get

$$\% \eta = \frac{(2V_{cc} - 0)\ (2I_{CQ} - 0)}{8\, V_{cc}\, I_{CQ}} \times 100$$

$$= \frac{\cancel{2} \cancel{V_{cc}} \times \cancel{2}\, \cancel{I_{CQ}}}{\cancel{8}\, \cancel{V_{cc}} \cdot \cancel{I_{CQ}}} \times \cancel{100}^{\,50}$$

$$\boxed{\% \eta = 50\,\%}$$

Maximum Efficiency of Transformer Coupled class A power amplifier

Note :- Power Dissipation,

$$P_D = V_{CEQ} \cdot I_C$$

Advantages:-

1. It provides increased efficiency over the series fed (or) Directly coupled class A P.A.

2. The transformer coupled amplifier is easily converted in to a type of amplifier that is used extensively in communications.

3. It provides a higher voltage gain.

Disadvantages:-

1. Harmonic distortion is high.

2. As load resistance is connected directly in the output circuit of the power stage, the power is wasted.

3. Frequency response is poor and it is expensive.

Comparision of Series-fed and Transformer Coupled Class-A Amplifier :-

Series – Fed	Transformer Coupled
① The series-fed class-A amplifier, there is no transformer.	① Transformer is used in the circuit of transformer coupled class-A amplifier.
② Maximum efficiency is 25%	② Maximum efficiency is 50%.
③ There is a D.C. Power drop across R_L.	③ D.C. drop across the primary of the transformer is negligible
④ simple to design & implement.	④ Complicated to design.
⑤ The o/p impedance is high hence can not be used for low impedance.	⑤ Low impedance matching is possible due to transformer.
⑥ Load resistance carries the I_{CQ} hence considerable wastage of power.	⑥ The I_{CQ} flows through primary of transformer which has zero d.c. resistance. Hence power wastage is small.
⑦ Less no. of components are required.	⑦ More no. of components required
⑧ The circuit is not heavier bulkier and costlier.	⑧ The transformer makes the circuit heavier, bulkier and costlier.
⑨ The freq response is better.	⑨ The freq. response is poor.

III Class-B Power Amplifier :-

Class-B large signal amplifiers, the Q-point is located on cut-off point (on X-axis). Hence, the transistor conducts current for only one-half of the signal cycle.

→ To obtain output for full cycle of signal, it is necessary to use two transistors. and each conducts on opposite half of the cycles, the combined operation provides full cycle of output signal.

→ since one part of the circuit pushes the signal high during one half-cycle and the other part pulls the signal low during the other half-cycle.

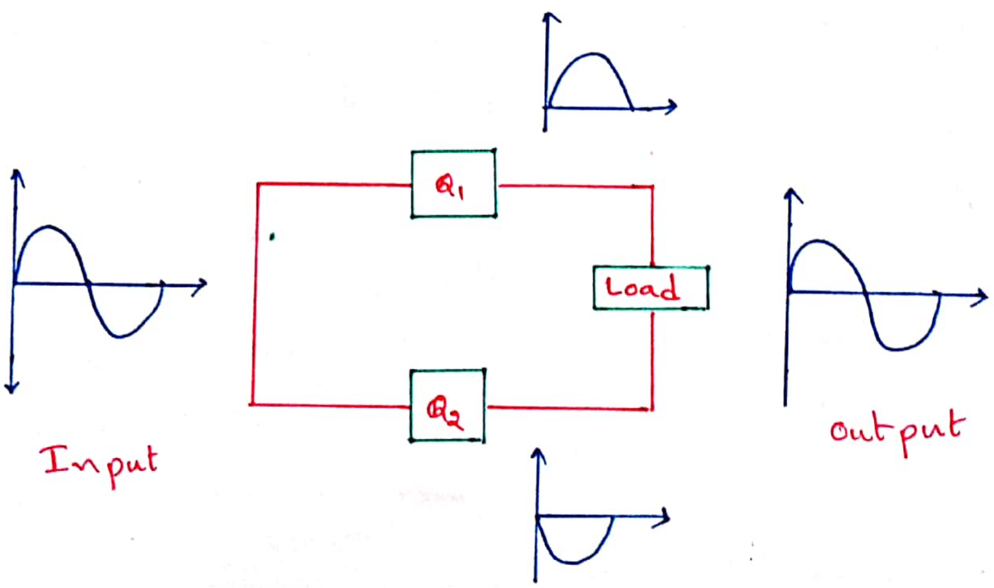


Fig.11. Basic Operation Diagram (Push Pull operation)

An A.C. input signal is applied to the push-pull circuit, with each half operating on alternate half cycle, the load then receive a signal for the full A.C. cycle.

→ The power transistor used in the push-pull circuit are capable of delivering the desired power to the load and the class-B operation of these transistors provides greater efficiency than was possible using a single transistor in class-A operation.

→ Depending on the types of two transistor configuration used, there are two configurations of class-B amplifier (i.e., NPN (or) PNP) are available as follows,

When both Transistors	Amplifier Name
① Same Type i.e., NPN (or) PNP	"Push-Pull" class-B Power Amplifier.
② Different Type i.e., PNP & NPN (or) NPN & PNP	"Complementary symmetry" class-B Power Amplifier.

① Push Pull Class-B Power Amplifier:-

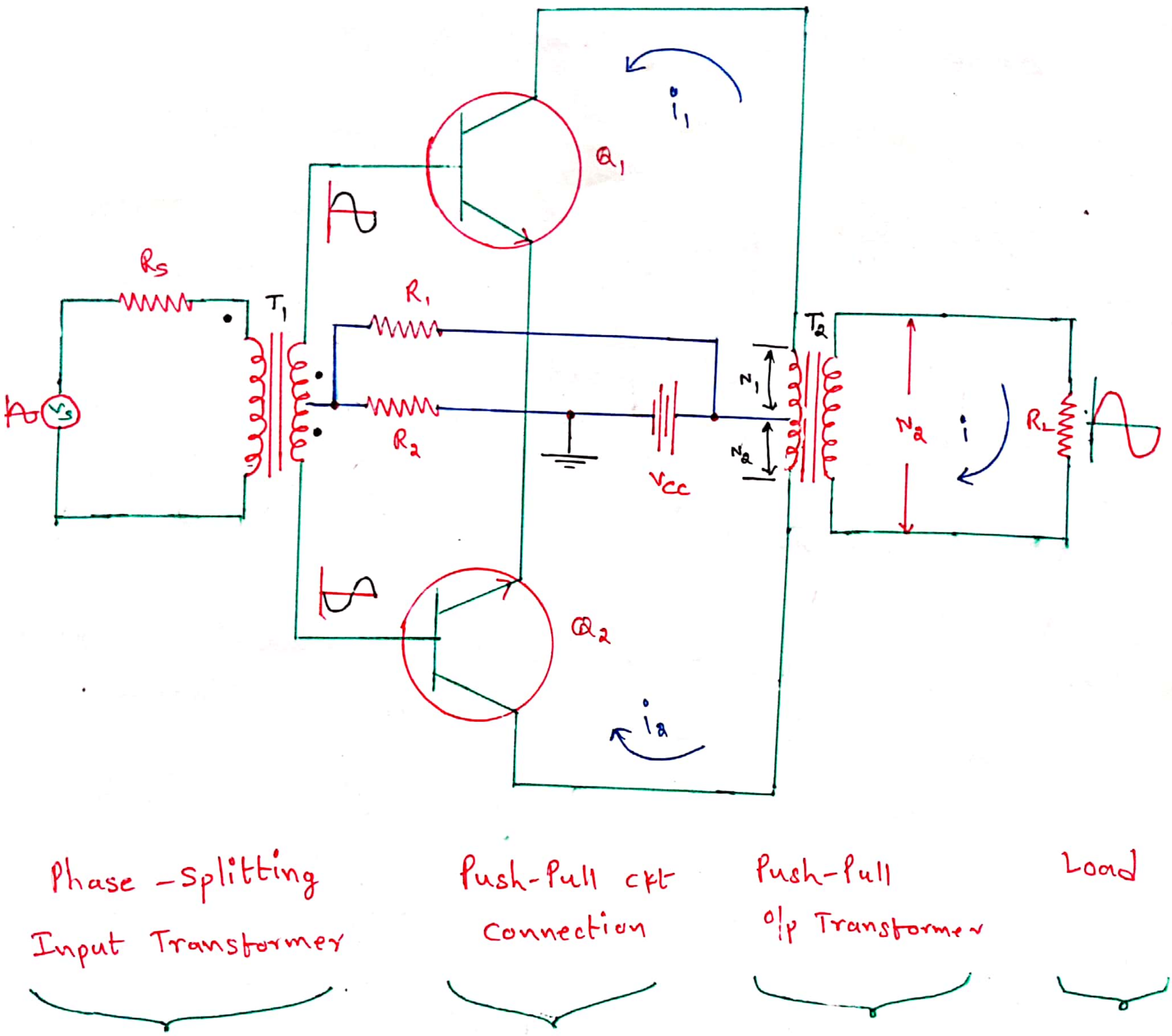


Fig. 12. Transformer-Coupled Class-B Push-Pull Amplifier

The circuit consists of two center tapped transformers T_1 and T_2 and two identical transistors Q_1 and Q_2.

→ The input transformer is also known as phase splitter, which provides opposite polarity signals to the inputs of transistors Q_1 and Q_2. The output transformer T_2 couples the A.C. output signal to the load from collector.

Power Relations:-

The A.C. output power in a class-B amplifier is developed only during one-half cycle of the input signal.

The Effective load resistance is given by,

$$R_L' = \left[\frac{N_1}{N_2}\right]^2 R_L.$$

i) D.C. Power Input:-

The D.C. i/p power is given by

$$\underbrace{P_i = 2\, I_{D.C.}\, V_{cc}}$$ → indicate Two transistors used

since,

$$I_{D.C} = \frac{I_m}{\pi}, \quad P_i = \frac{2 I_m V_{cc}}{\pi}$$

(ii) A.C. Power Output :-

The output of transistor Q_2 is a series of sine loop pulses that are 180° out of phase with those of transistor Q_1.

→ The load current, which is proportional to the difference between the two collector currents, is therefore a perfect sine wave.

→ The output power is given by,

$$P_o = \frac{V_m I_m}{2} = \frac{I_m}{2}(V_{cc} - V_{min})$$

$$\therefore V_m = V_{cc} - V_{min}$$

(iii) Power Dissipation :-

The power dissipation P_D in both transistors is the difference between the A.C. power output and D.C. power input.

$$P_D = P_{D.C} - P_{A.C}$$

$$= \frac{2 V_{cc} I_m}{\pi} - \frac{V_m I_m}{2}$$

$$P_D = \frac{2 V_{cc} V_m}{\pi R_L'} - \frac{V_m^2}{2 R_L'} \quad \text{---} (1) \qquad \left[\because I_m = \frac{V_m}{R_L'}\right]$$

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This equation shows that the collector dissipation is zero under at two conditions,

1) When no signal is used ($V_m = 0$)

2) when $\frac{2}{\pi} V_{cc} \frac{V_m}{R_L'} = \frac{V_m^2}{2R_L'}$

Maximum Power Dissipation :

The condition for maximum power dissipation can be found by differentiating Eqn 1 w.r.t V_m and Equating to zero.

$$\frac{dP_D}{dV_m} = \frac{d}{dV_m}\left[\frac{2V_{cc} \cdot V_m}{\pi R_L'} - \frac{V_m^2}{2R_L'}\right] = 0$$

$$\frac{2V_{cc}}{\pi R_L'} \frac{d}{dV_m}(V_m) - \frac{1}{2R_L'} \frac{d}{dV_m}(V_m^2) = 0$$

$$\frac{2V_{cc}}{\pi R_L'} - \frac{\cancel{2} V_m}{\cancel{2} R_L'} = 0$$

$$\frac{V_m}{\cancel{R_L'}} = \frac{2V_{cc}}{\pi \cancel{R_L'}}$$

$$V_m = \frac{2}{\pi} \cdot V_{cc} \quad \text{--- (2)}$$

Substituting Eqn 2 in Eqn 1, we get

$$P_{D,max} = \frac{2}{\pi} \frac{V_{cc}}{R_L'} \left(\frac{2}{\pi} V_{cc}\right) - \left(\frac{2}{\pi} V_{cc}\right)^2 \times \frac{1}{2R_L'}$$

$$= \frac{4V_{cc}^2}{\pi^2 R_L'} - \frac{2V_{cc}^2}{\pi^2 R_L'}$$

$$P_{D,max} = \frac{2}{\pi^2} \frac{V_{cc}^2}{R_L'} \quad \text{——— (3)}$$

For maximum efficiency, $V_m = V_{cc}$, hence the power dissipation is not maximum when the efficiency is maximum.

→ Maximum output A.C. Power is

$$P_{o,max} = \frac{V_m^2}{2R_L'}$$

when, $V_m = V_{cc}$

$$\therefore P_{o,max} = \frac{V_{cc}^2}{2R_L'} \quad \text{——— (4)}$$

Using Eqns (4) & (3) can be written as

$$P_{D,max} = \frac{4}{\pi^2}\left(\frac{V_{cc}^2}{2R_L'}\right)$$

$$P_{D,max} = \frac{4}{\pi^2} P_{o,max}$$

$$\therefore \boxed{P_{D,max} = 0.4\, P_{o,max}}$$

→ The maximum power is dissipated by both the transistors and therefore the maximum power dissipation per Tr is $\frac{P_{D,max}}{2}$.

$\therefore P_{o,max}$ per Transistor $= \dfrac{4}{\pi^2} \dfrac{P_{o,max}}{2}$

$$\frac{2}{\pi^2} P_{o,max} = 0.2\, P_{o,max}$$

Example :- 10 W maximum power is to be delivered from a class-B push-pull amplifier to the load, then power dissipation rating of each transistor should be $0.2 \times 10\,W = 2\,W$.

(iv) Conversion Efficiency :-

The conversion efficiency of an active device is its ability to convert the D.C. power supply to A.C. power supply.

$$\eta\,\% = \frac{\text{Signal Power Delievered to load}}{\text{D.C. Power Supplied to output circuit}} \times 100$$

$$\%\eta = \frac{P_{o(A.C)}}{P_{in(D.C)}} = \frac{\cancel{I_m}\,(V_{cc} - V_{min})}{2 \times 2 \times \frac{\cancel{I_m} V_{cc}}{\pi}} \times 100$$

$$= \frac{\pi}{4}\left[1 - \frac{V_{min}}{V_{cc}}\right] \times 100$$

since, $V_{min} \ll V_{cc}$

$$\%\eta = \frac{\pi}{4} \times 100 = 0.785 \times 100$$

$$\boxed{\%\eta = 78.5\,\%}$$

Advantages :-

1. The efficiency is much higher than Class-A operation.
2. If the input signal is absent, there is no power dissipation.
3. Due to push-pull connection all even harmonics are cancelled. thus, it reduces the harmonic distortion.
4. Due to the transformer, it provides impedance matching.
5. Due to the centre tapped transformer being used, ripple present due to the supply eliminated.

Disadvantages :-

1. Two centre tapped transformers are needed.
2. The transformers make the circuit bulky and costly.
3. Frequency response is poor.
4. Supply voltage V_{cc} should have good regulation. since, if V_{cc} changes the Q-point changes. Therefore transistor may not be at cut-off.

(2) Complementary - Symmetry Class-B Push-Pull Amplifier:

→ The standard class-B push-pull amplifier requires a centre tapped transformer, as only one transistor will conduct for 180°. So, if two transistors were to be conducted for complete 360°, there should be centre tapped transformer (or) there should be a phase inverter circuit.

→ The need of centre tapped transformer (or) phase inverter circuit can be eliminated by the use of complementary symmetry circuit which needs only one phase.

→ The complementary means the circuit uses two identical transistors, but one is NPN and the other is PNP.

→ The symmetry means the biasing resistors connected in both transistors are equal. As a result of this emitter base junction of each transistors is biased with the same voltage.

→ The main requirement of complementary symmetry circuit is a pair of closely matched transistors.

→ Since, it is a class-B operation the Q-point is at cut-off i.e., emitter and base are shorted (or) $V_{EB} = 0$.

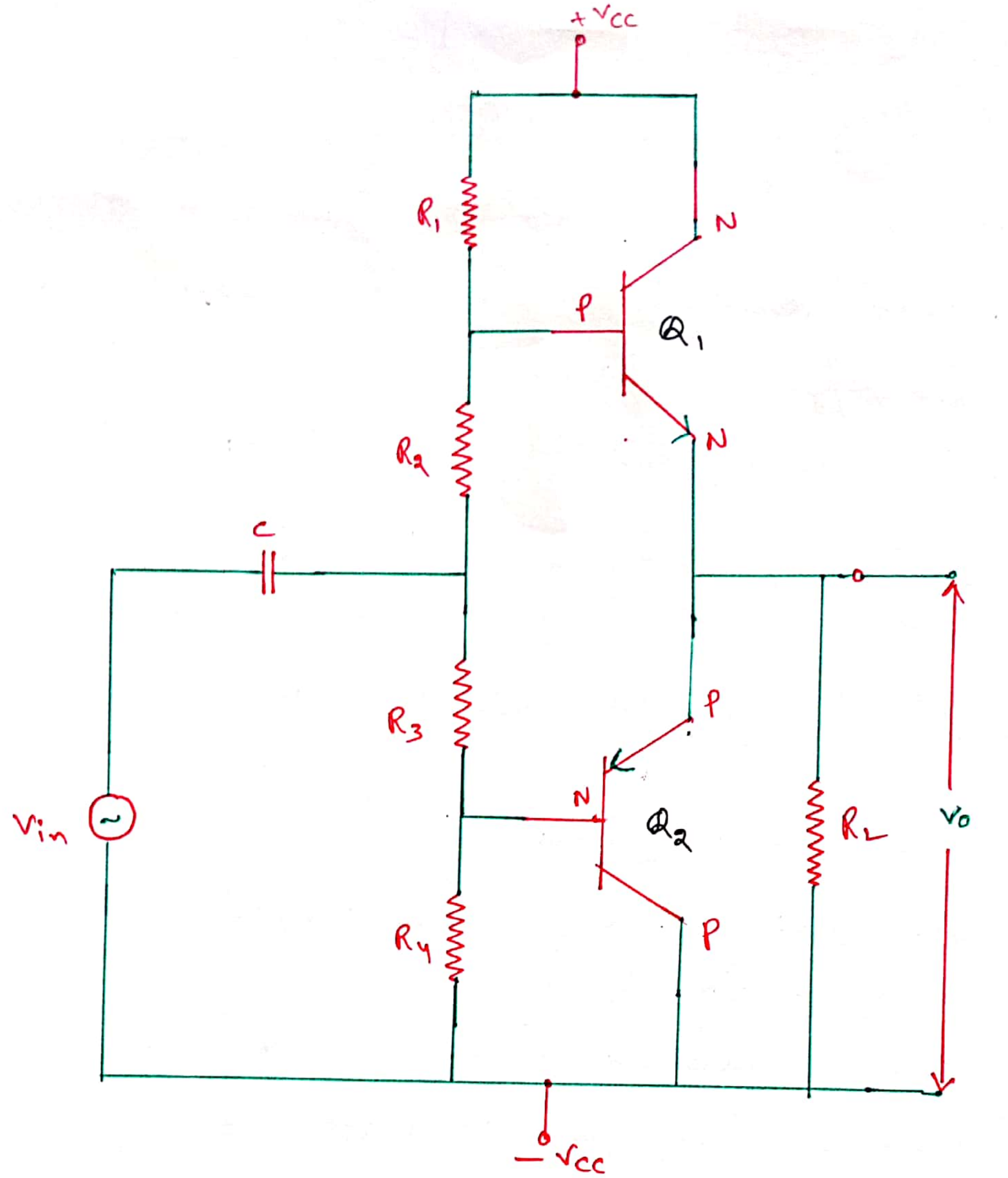

Fig. 13. Complementry Symmetry Class-B Power Amplifier

Circuit Operation :- When the input signal is +ve i.e., during the positive half cycle of A.C. input the base to emitter voltage of both transistors becomes positive.

→ At this condition, only N-P-N transistor conducts, while the P-N-P transistor doesn't conduct. During this process, only positive half-cycle current flows through R_L.

→ During the negative half-cycle of A.C. input only the PNP transistor conducts N-P-N transistor is OFF and the negative half-cycle current flows through R_L.

→ Since, when the output is tapped across R_L, we get a complete amplified waveform of the input signal.

→ It may be noted that the amplifier circuit has a unity gain, because of the emitter follower configuration.

→ The use of split supply in the circuit gives us an advantage that the D.C. component of output voltage can be made to zero. Thus, only A.C. component of the power is available at the output, hence no need of coupling capacitor in the output.

→ As there is no D.C. current through R_L, hence an electromagnetic load such as a loud speaker can be connected directly without coupling capacitor.

→ The main disadvantage of this circuit is that they need to use two power supplies.

→ Secondly, the transistor will not conduct till the input signal magnitude exceeds the cut-in voltage V_i. Therefore, a type of distortion called crossover distortion will be present as shown in Fig. 14.

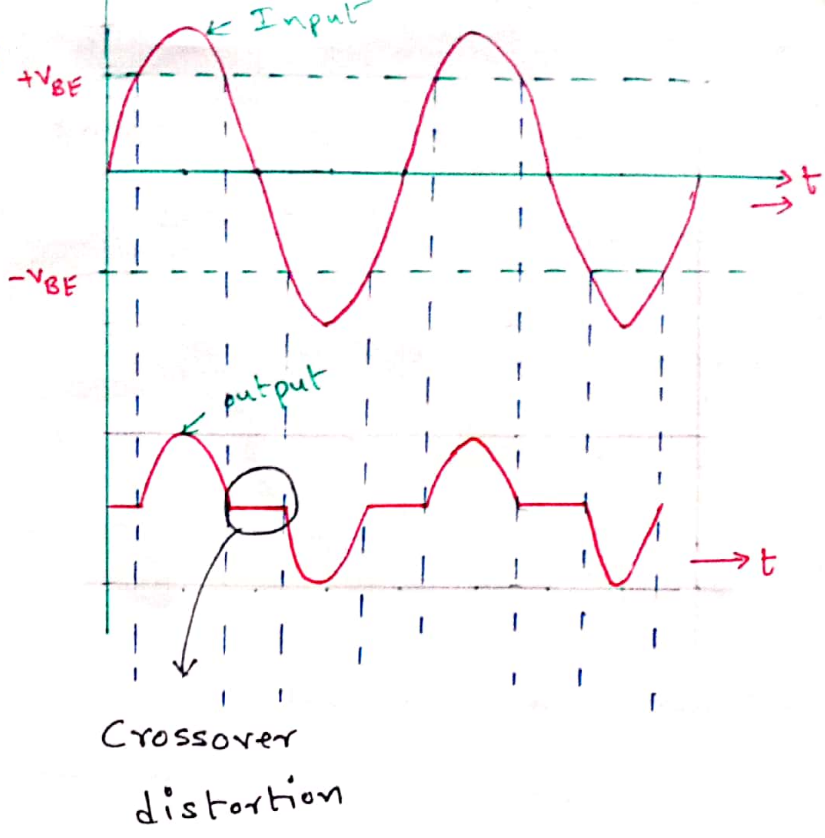

Fig. 14. Crossover Distortion

Analysis :-

(i) Input DC Power :-

$$P_{idc} = P_{dc}(T_1 \text{ ON}) + P_{2dc}(T_2 \text{ ON})$$

$$= \frac{V_{cc}}{2} I_1 + \frac{V_{cc}}{2} I_2$$

$$= \frac{V_{cc}}{2} (I_1 + I_2)$$

Let, $I_1 = I_2 = \frac{I_m}{\pi}$ because the current flows only half cycle period.

$$\therefore P_{idc} = \frac{V_{cc}}{2} \left(\frac{I_m}{\pi} + \frac{I_m}{\pi} \right)$$

$$= \frac{V_{cc} I_m}{\pi}$$

(ii) Output AC Power :-

$$P_{oac} = V_{rms} I_{rms} (T_1 \text{ ON}) + V_{rms} I_{rms} (T_2 \text{ ON})$$

$$= I_{1rms}^2 R_L + I_{2rms}^2 R_L$$

we know, $I_{1rms} = \frac{I_m}{\sqrt{2}}$

$$\therefore P_{oac} = \frac{I_m^2}{2} R_L + \frac{I_m^2}{2} R_L$$

$$= I_m^2 \cdot R_L = \frac{V_{cc}^2}{8 R_L}$$

where, $I_m = \frac{V_{cc}}{2 R_L}$

$$P_{idc} = \frac{V_{cc} I_m}{\pi} = \frac{V_{cc}^2}{2\pi R_L}$$

(iii) Efficiency :-

$$\eta_o = \frac{P_{oac}}{P_{idc}}$$

$$= \frac{V_{cc}^2 / 8R_L}{V_{cc}^2 / 2\pi R_L}$$

$$\% \eta = \frac{\pi}{4} \times 100$$

$$\boxed{\% \eta = 78.54 \%}$$

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(iv) Power Dissipation :-

Power dissipated by the transistor (collector dissipation)

$$P_D = P_{idc} - P_{oac}$$

$$= \frac{V_{CC}^2}{2\pi R_L} - \frac{V_{CC}^2}{8 R_L}$$

$$= \frac{V_{CC}^2}{R_L}\left(\frac{1}{2\pi} - \frac{1}{8}\right)$$

$$\boxed{P_D = \frac{0.034\, V_{CC}^2}{R_L}}$$

Advantages :-

1. Due to absence of transformer, the weight, size and cost is less.
2. Frequency response is good.
3. Due to common collector configuration, impedance matching is possible.

Disadvantages :-

1. It produces the crossover distortion.
2. Proper matching of transistors are required (which is difficult to get practically).

Distortion in Power Amplifiers :-

The purpose of an amplifier is to boost up the voltage (or) power level of a signal. During this process the wave shape of the signal should not change. If the wave shape of the output is not an exact replica of the wave shape of the input, we say that distortion has been introduced by the amplifier.

→ An ideal amplifier will amplify a signal without changing its wave shape at all frequencies. Such an amplifier faithfully amplifies the signal and we say it has a good fidelity, such an amplifier is called Hi-Fi (High Fidelity) amplifier.

→ The change in the output waveform from the i/p waveform of an amplifier is known as "distortion."

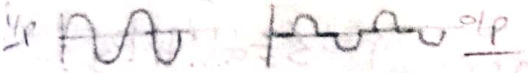
① Harmonic Distortion :-

The distortion caused by the presence of frequencies that are not present in the input signal.

→ There are two types ① Even-order
② Odd-order

Even - order	Odd - order
① If the frequencies of the distortion are 2, 4, 6, etc., times the fundamental frequency	① If the frequencies of the distortion are 3, 5, 7, etc., times the fundamental frequency.
② These are caused by the (i) Permanently magnetized magnetic head. (ii) Faulty circuits. (iii) Asymmetrical (or) Unbalanced bias signals.	② These are caused by the magnetic tape itself.

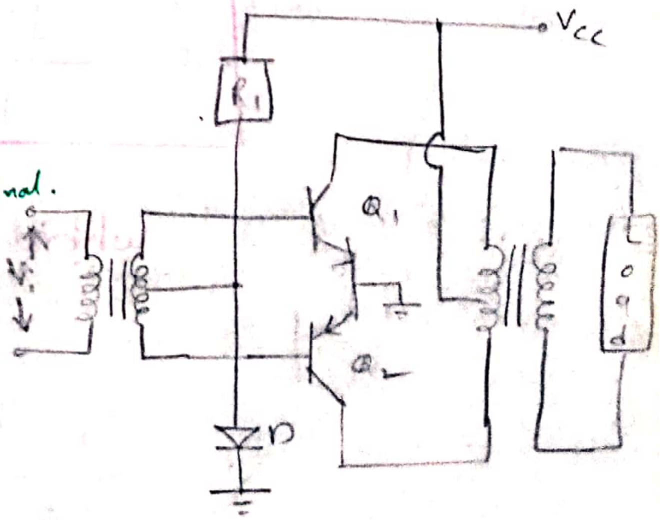
② Cross over Distortion :-



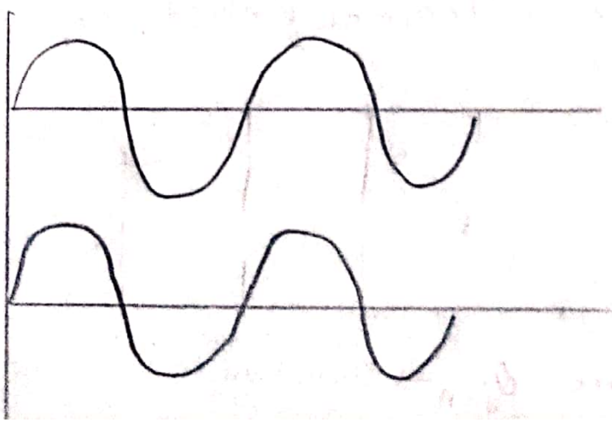
This is caused by non-linearity of the input characteristic of the transistors. Transistors do not turn on at zero volt applied to the emitter junction but only when the emitter junction is forward biased by the cut in voltage $V_\gamma = 0.3\,V$ for Ge. and 0.7 V for si.

Elimination of Cross over Distortion :- By using class-AB amplifier we can eliminate the crossover distortion. In class-AB amplifier, we always maintain the base voltage equal to 'V_γ', so that, when the input is applied to the transistor, it conducts instantly and reproduces the input signal without any crossover distortion.

→ To maintain the two transistor' at V_γ we add/connect a diode b/w base of the tr Q_2 & ground terminal.



A class-AB power Amp.



Thermal stability :-

Collector current, $I_c = \beta I_b + (\beta + 1) I_{CBO}$

$\downarrow$ I_{co}

PN Junction, $I_{o2} = I_{o1} \times 2^{(T_2 - T_1)/10}$;

Let $T_2 = T_1 + 10$

$T_2 - T_1 = 10$

$$I_{o2} = I_{o1} \times 2^{10/10}$$

$$= I_{o1} \cdot 2^1$$

$$\therefore I_{o2} = 2 I_{o1}$$

$\therefore$ For every 10°c raise in Temp $\Rightarrow$ current becomes double

$T \uparrow$ $I_{co} \uparrow$ $I_c \uparrow$ $P_d \uparrow$ Jun Temp $\uparrow$ $I_{co} \uparrow$

Conclusion :- Collector current increases with increase Temperature.

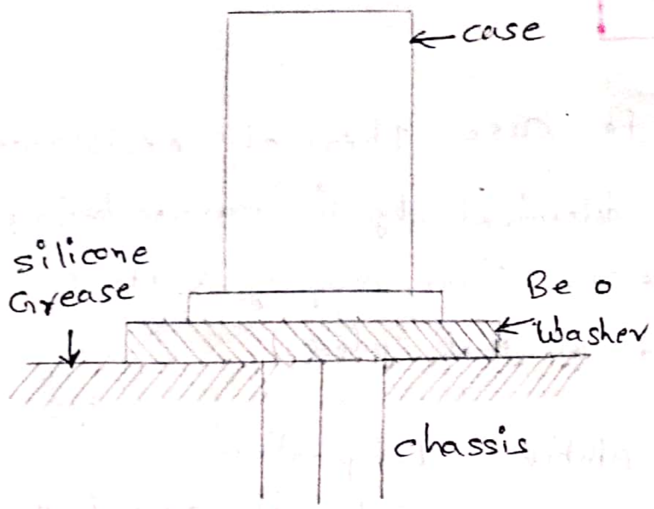
→ If we maintain proper biasing & stability of transistor, then collector current should be in proper limit. The Conditions satisfied then this concept we called Thermal stability.

Heat sinks :-

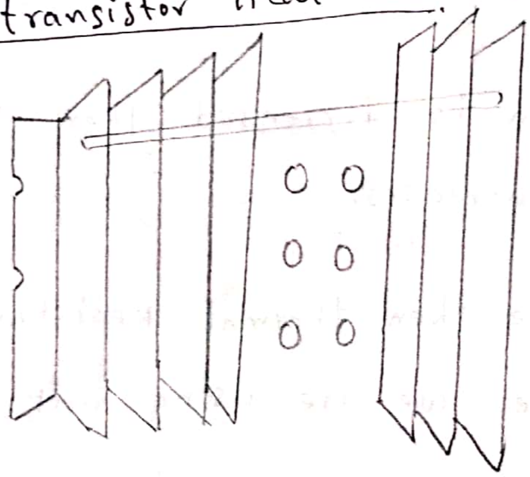
Heat sinks are relatively larger, usually Black metallic conducting device and it is placed at the surface area.

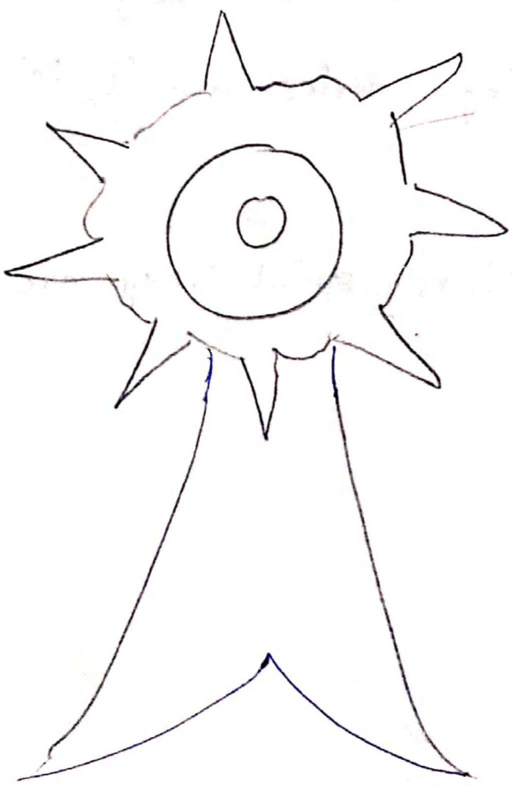
→ Many type of Heat sinks exist, depending upon the shape and size.

Examples:-



Power transistor Heat sink





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ECA

UNIT – V

UNIT – V (Tuned Amplifier)

1. Introduction
2. Q – Factor
3. Small signal Tuned Amplifiers
4. Effect of cascading single Tuned Amplifiers on Band Width
5. " " " Double " " " "
6. Stagger Tuned
7. Stability

UNIT – V

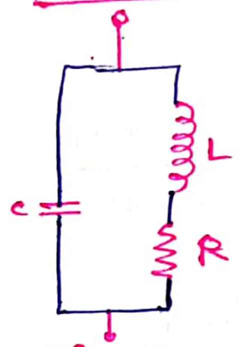
Tuned Amplifiers

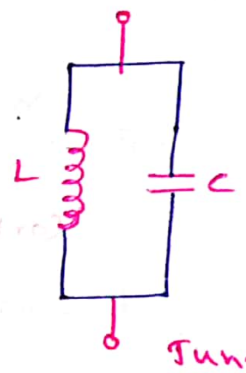
1) Introduction :-

The amplifier with tuned circuit as a load is known as tuned amplifier. (or) Narrow band Amplifier.

Uses :- wireless, communications etc.

Parallel Resonant ckt

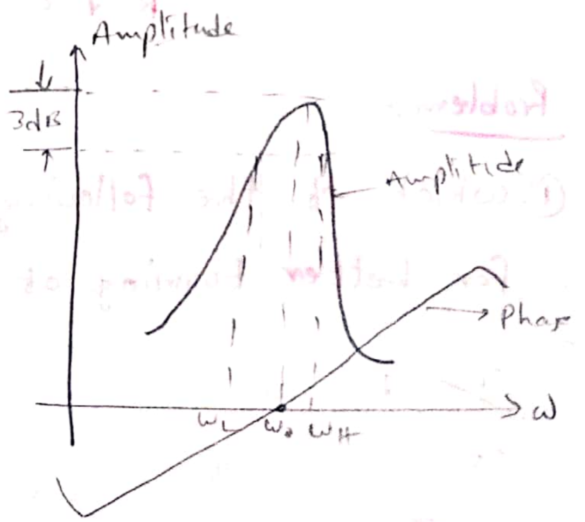




Tuned ckt

Classification of Tuned Amplifiers :-

- Tuned Amplifier
  - Small signal Tuned Amplifier
    - Single Tuned Amplifier
      - Inductively coupled
      - Capacitively coupled
    - Double Tuned Amplifier
    - Stagger Tuned Amplifier
  - Large signal Tuned Amplifier



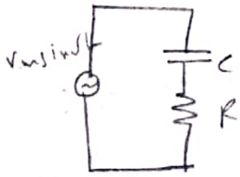
Freq. Response for Tuned ckt

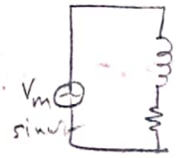
$$\omega_0 = \frac{1}{\sqrt{LC}}$$

II Q-Factor :- The characteristic of a series Resonant circuit is determined by the Quality Factor (Q-Factor) of the circuit.

→ It define the sharpness of I-V curves at resonance. When Q-factor is large the sharpness of resonance curve is more and vise-versa.

$$Q = 2\pi \times \frac{\text{Maximum Energy stored}}{\text{Energy dissipation}}$$



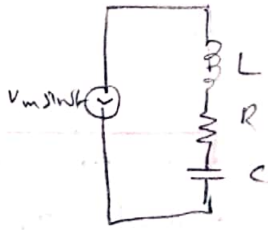


(or)

$$Q = \frac{\text{Resonant frequency}}{\text{Band width}} = \frac{\omega_0}{\Delta\omega}$$

$\text{Q-Factor} = \omega_0 CR$ $\qquad$ $\text{Q-Factor} = \frac{\omega L}{R}$

$$\text{Q-Factor} = \frac{V_L}{V_R} \text{ (or) } \frac{V_C}{V_R} \text{ (or) } \frac{\omega_0 L}{R} \text{ (or) } \frac{1}{\omega_0 CR}$$



$$\boxed{\text{Q-Factor} = \frac{1}{R}\sqrt{\frac{L}{C}}}$$

$\text{Q-Factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$

Problem :- (Gate Question)

① which of the following combinations should be selected for better turning of an R-L-C ckt used for communication.

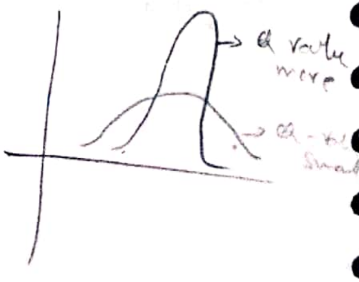
(1) $R = 20\Omega$, $L = 1.5H$, $C = 35\mu F$

(2) $R = 25\Omega$, $L = 2.5H$, $C = 45\mu F$

(3) $R = 15\Omega$, $L = 3.5H$, $C = 30\mu F$

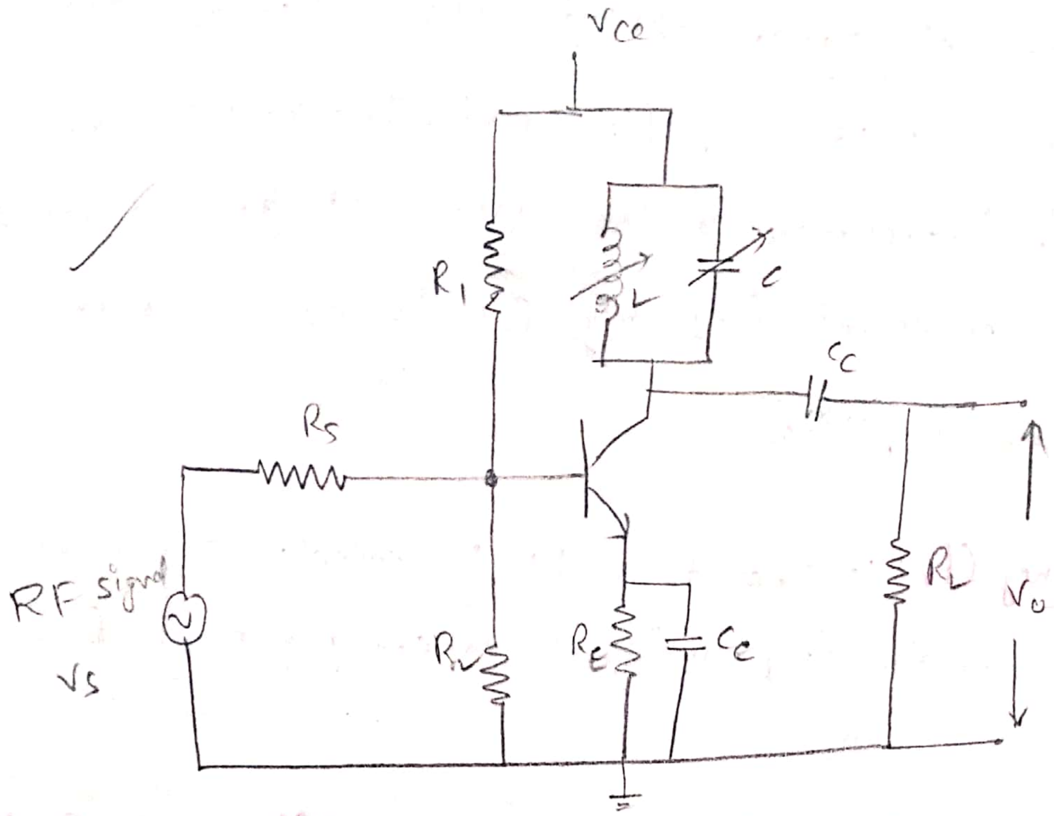
(4) $R = 25\Omega$, $L = 1.5H$, $C = 45\mu F$

Q value high



Sol :- $Q = \frac{1}{R}\sqrt{\frac{L}{C}} = \frac{1}{15}$

III Small signal Tuned Amplifier :-



A simple transistor amplifier circuit consisting of parallel tuned ckt in its collector load, makes a single tuned amplifier ckt. The values of capacitance and inductance of the tuned ckt are selected such that it resonant frequency (f_r) is equal to the frequency to be amplifier.

Resonant Frequency (f_r) :- The tank ckt in collector terminal is tuned to certain freq which is called resonant freq.

IV Effect of Cascading Single Tuned Amplifiers on Bandwidth

In order to obtain a high overall gain, several identical stages (or) tuned amplifiers can be used in cascade. The overall voltage gain is the product of the voltage gains of the individual stages. At the same time, the high voltage gain is accompanied by a narrower B.w. than for a single stage.

→ The relative gain of a single tuned amplifier w.r.t the gain at resonant frequency (f_0) is given

$$\left|\frac{A}{A_{res}}\right| = \frac{1}{\sqrt{1+(2\delta Q_e)^2}}$$

where → δ = Fractional freq variation $= \frac{\omega-\omega_0}{\omega_0}$

Q_e = Effective Quality factor

Now, the gain of n stage cascaded amplifier becomes

$$\left|\frac{A}{A_{res}}\right|^n = \left[\frac{1}{\sqrt{1+(2\delta Q_e)^2}}\right]^n = \frac{1}{\left[1+(2\delta Q_e)^2\right]^{n/2}}$$

(3)

The 3dB freq's for the n-stage cascaded amplifier can be found by equating $\left|\frac{A}{A_{res}}\right|^n$ to $\frac{1}{\sqrt{2}}$

$$\left|\frac{A}{A_{res}}\right|^n = \frac{1}{\left[\sqrt{1+(2\delta Q_e)^2}\right]^n} = \frac{1}{\sqrt{2}}$$

$$\left[\sqrt{1+(2\delta Q_e)^2}\right]^n = \sqrt{2}$$

$$\left[1+(2\delta Q_e)^2\right]^{\frac{n}{2}} = 2^{\frac{1}{2}}$$

$$1+(2\delta Q_e)^2 = 2^{1/n}$$

$$(2\delta Q_e)^2 = 2^{1/n}-1$$

$$2\delta Q_e = \pm\sqrt{2^{1/n}-1}$$

Substituting for δ, the fractical frequency variation

i.e., $\delta = \frac{\omega-\omega_o}{\omega_o} = \frac{f-f_o}{f_o}$

$$2\left(\frac{f-f_o}{f_o}\right)Q_e = \pm\sqrt{2^{1/n}-1}$$

$$2(f-f_o)Q_e = \pm f_o\sqrt{2^{1/n}-1}$$

$$f-f_o = \pm\frac{f_o}{2Q_o}\sqrt{2^{1/n}-1}$$

$$\therefore\ f_2-f_o = +\frac{f_o}{2Q_o}\sqrt{2^{1/n}-1}$$

similarly, $f_o-f_1 = +\frac{f_o}{2Q_o}\sqrt{2^{1/n}-1}$

Bandwidth of n stage identical amplifier is

$$B_{1n} = f_2 - f_1 = (f_2 - f_0) + (f_0 - f_1).$$

$$= \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1} + \frac{f_0}{2Q_e}\sqrt{2^{1/n}-1}$$

$$= \frac{f_0}{Q_e}\sqrt{2^{1/n}-1}$$

$$\boxed{B_{1n} = B_1\sqrt{2^{1/n}-1}} \quad (\text{or}) \quad \boxed{B_{1n} = B_1\left[2^{1/n}-1\right]^{1/2}}$$

3 dB BW of the single tuned amp

where $B_{1n} \rightarrow$ B.W of n stages of the cascade amplifier

$B_1 \rightarrow$ B.W for single stage.

→ B.W of n stages B_{1n} is equal to B_1 multiplied by a factor of $\sqrt{2^{1/n}-1}$

when. $n=2$; $\sqrt{2^{1/2}-1} = 0.643$

$n=3$; $\sqrt{2^{1/3}-1} = 0.510$

V Effect of Cascading Double Tuned Amplifier on B.W:-

The Problem of Potential instability in single tuned amplifier is overcome in Double Tuned amplifier.

→

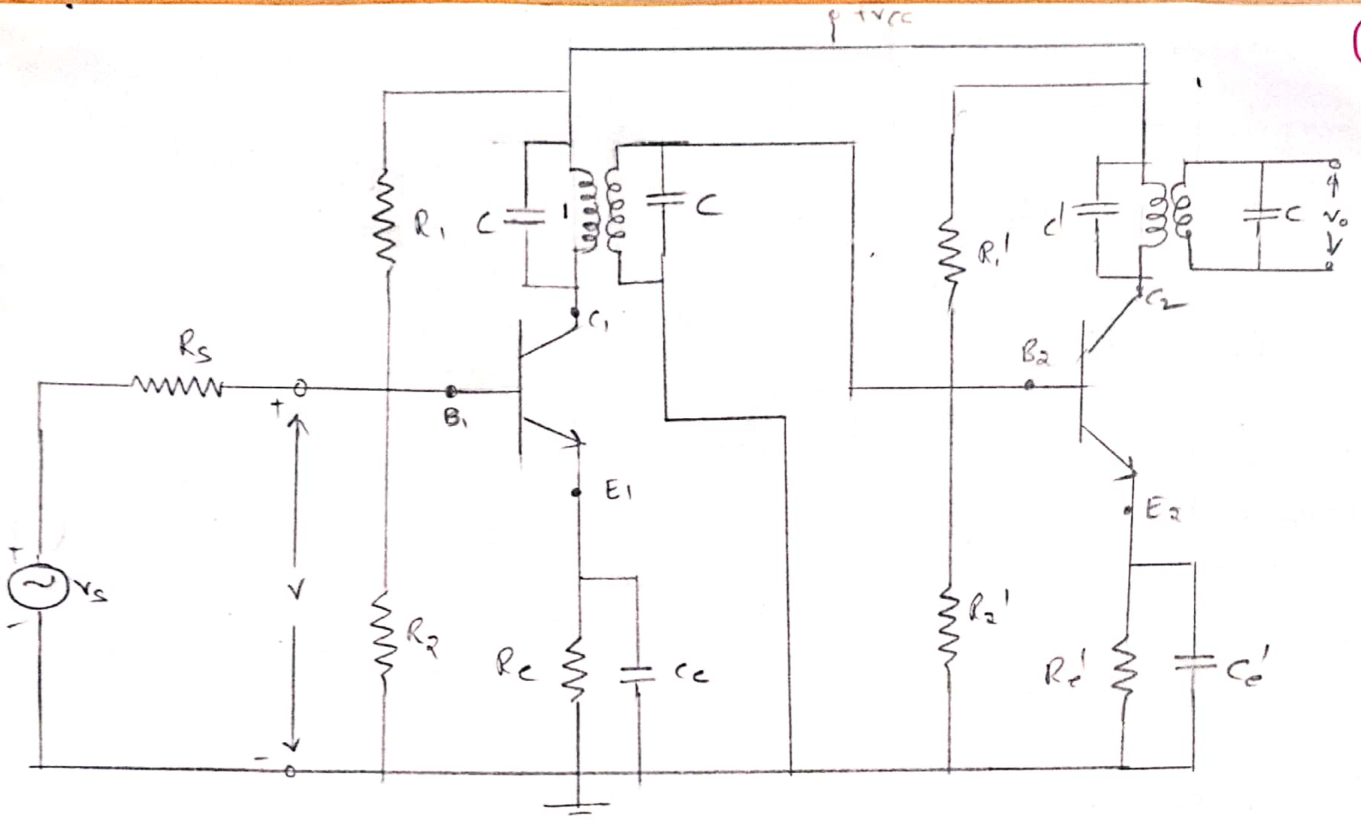


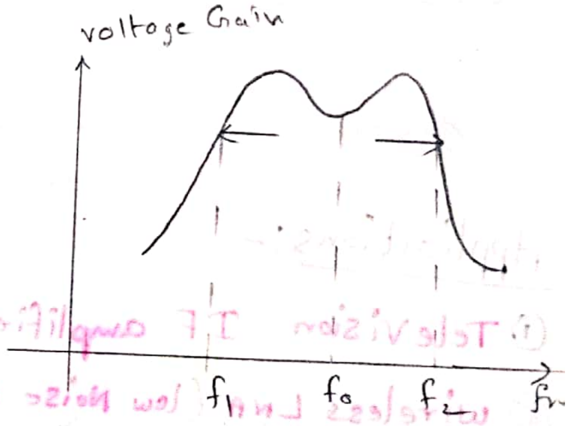
Fig. circuit Diagram for Double Tuned Amplifier

→ The 3dB Bandwidth of the cascaded double tuned amplifier

$$B_{2n} = B_2 \left[2^{1/n} - 1\right]^{1/4}$$

where $B_2 \rightarrow$ 3 dB B.w of the single stage double tuned amplifier

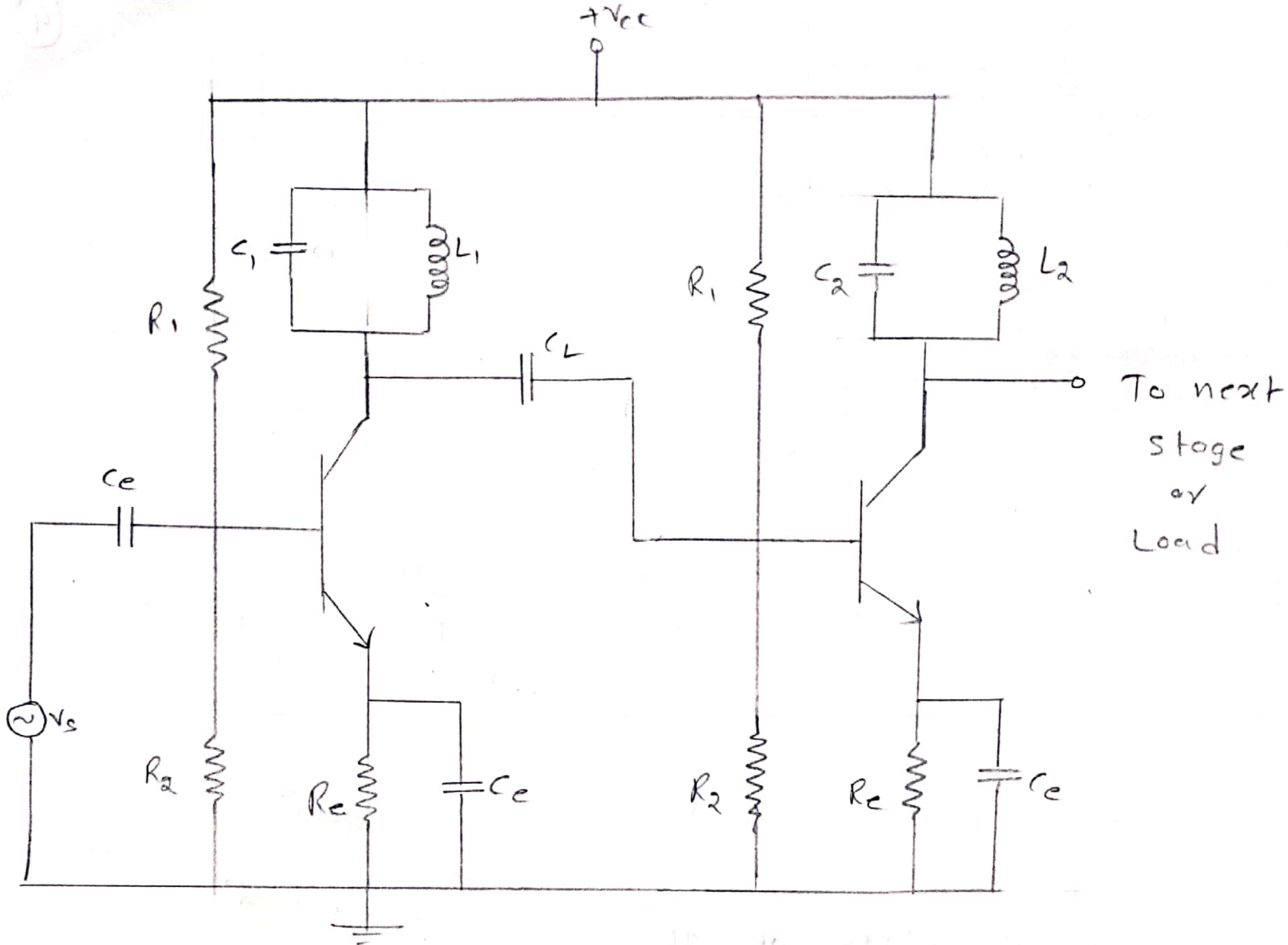
$n \rightarrow$ no. of identical stages connected in cascade.



Frequency Response

VI) Stagger Tuned Amplifier:-

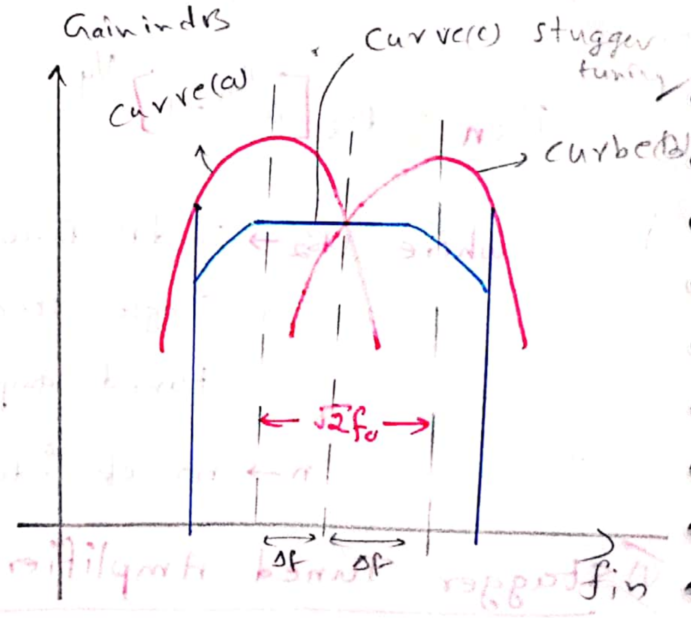
→ In the double tuned amplifier, it is observed that if two or more tuned circuits are cascaded and tuned to the same freq, the overall B.w reduces. It is known as "synchronous - tuning"



Circuit diagram of Stagger-Tuned Amplifier

Applications:-

1. Television IF amplifier. (950MHz – 2150MHz)
2. wireless LNA (low Noise Amplifier)
3. Radio Application such as wireless line
4. Implementing IC's



Frequency Response

curve (a) → gain vs freq response of L_1C_1

curve (b) → " " " " " L_2C_2

curve (c) → Combined (or) overall response of the ckt

→ The double tuned amplifier gives wider decrease in B.W with steeper sides and flat top, but alignment of double tuned amplifier is difficult. To overcome this problem stagger tuned amplifier is employed.

→ In this case, two single tuned circuits are connected in a cascade and the resonant frequency of both the stages is different.

The gain of the single tuned amplifier is given by

$$\frac{A}{A_{res}} = \frac{1}{1+j2Q_e\delta}$$

$$= \frac{1}{1+jX} \quad \text{where } X \rightarrow 2Q_e\delta$$

One stage is tuned to the frequency below f_o i.e., $f_o-\delta$ and the other is tuned to a freq above $f_o+\delta$

The corresponding selectivity fn of the ckt's are,

$$\left(\frac{A}{A_{res}}\right)_1 = \frac{1}{1+j(X-1)} \quad \text{and}$$

$$\left(\frac{A}{A_{res}}\right)_2 = \frac{1}{1+j(X+1)}$$

since, overal Gain, $A_{ov} = \left(\frac{A}{A_{res}}\right)_1 \left(\frac{A}{A_{res}}\right)_2$

$$= \frac{1}{1+j(x-1)} \cdot \frac{1}{1+j(x+1)}$$

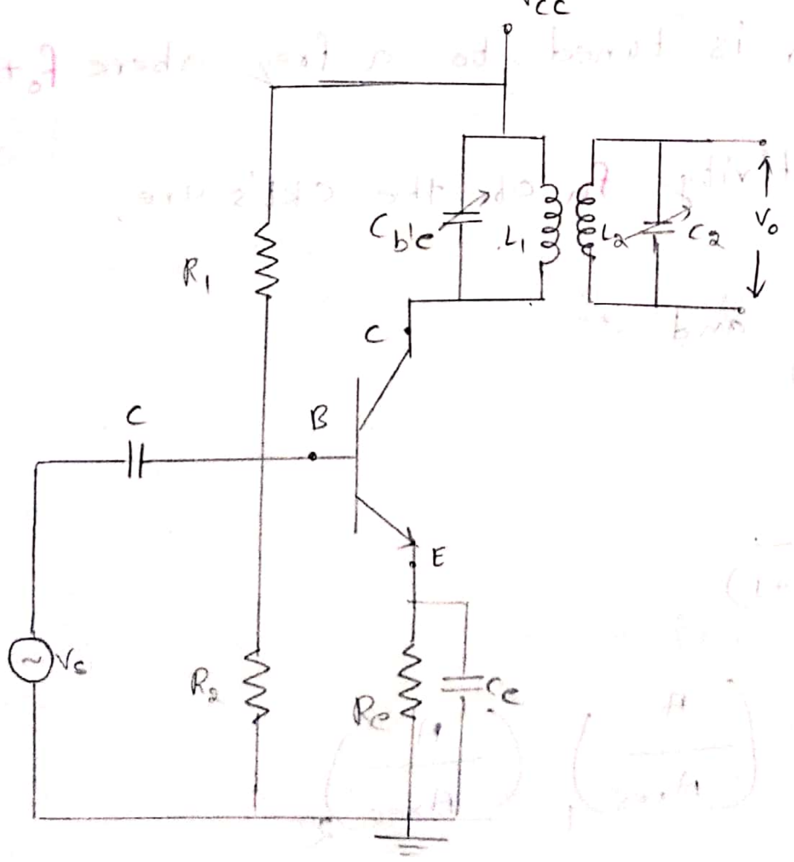
$$= \frac{1}{2-x^2+2jx}$$

$$\boxed{\left|\left(\frac{A}{A_{res}}\right)\right|_{overall} = \frac{1}{\sqrt{(2-x^2)^2+(2x)^2}}}$$

where $x \Rightarrow 2\delta Q_e$

VII Stability of Tuned Amplifier :-

In Radio frequency tuned Amplifiers the transistor used at high frequencies. At that high frequencies inter-junction capacitance are dominated i.e., the reactance of that capacitor value is low. i.e. shown below.



→ In the above CE configuration the inter junction capacitance from collector to base i.e., $C_{b'c}$ feedback to the i/p from the o/p. This feedback converted the ckt into its open oscillators. (6)

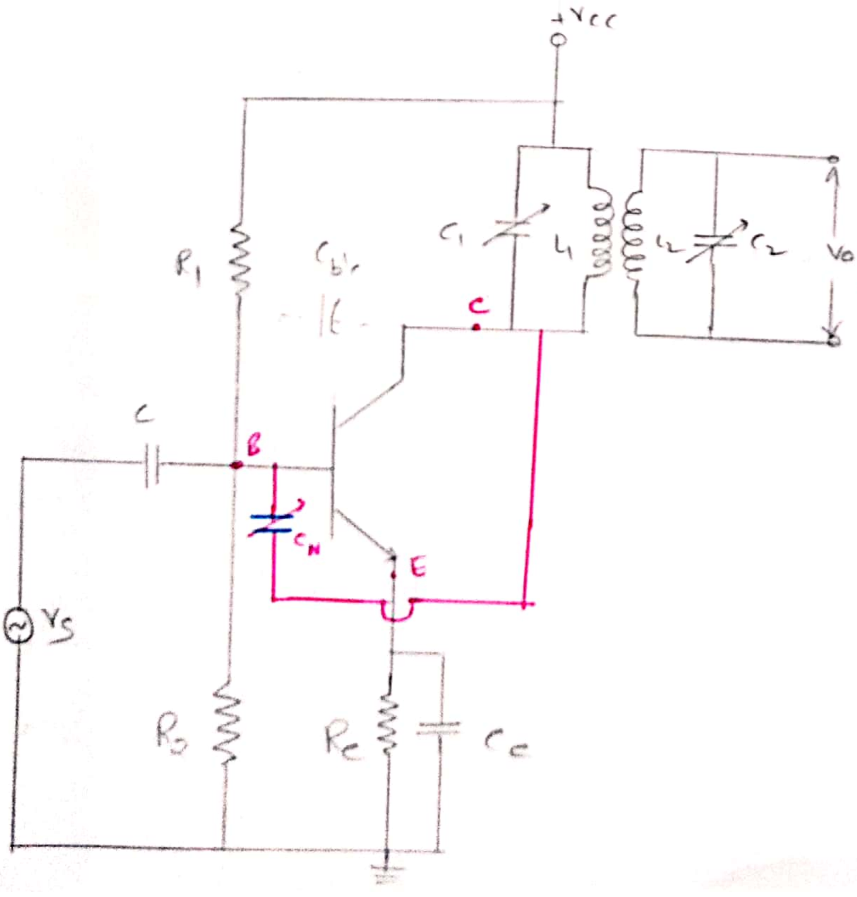
→ This oscillation can stop the working of an amplifier.

→ To overcome the oscillations the gain of amplifier is reduced. The gain of amplifier is reduced then Q-factor (Quality factor) is reduced.

→ To overcome this entire problem the Professor L.A. Hazenlton introduced a ckt called Hazenlton Neutralization.

→ The Hazenlton neutralization ckt having a small variable capacitance i.e., C_N Connected between base to the collector of that ckt as shown below.

→



→ This variable capacitance C_N is so adjusted that any feedback signal is cancelled.

VIII) Multivibrations :-

The word multivibrator is a combination of multi (many) and vibrator (oscillator). Multivibrator is defined as an electronic circuit that oscillate at many frequencies.

→ Multivibrators are classified based on their output states i.e., stable and Quasi stable states.

Stable state :- Multivibrators are designed by cross-coupling two inverters, which contain transistors and the state indicates the ON (or) OFF condition of the transistor.

→ Stable-state of a multivibrator means, the circuit can remain only in one state permanently. That is, if one transistor is ON and the other transistor is OFF. The circuit remains in that state unless triggered by an external signal to change its state.

Quasi state :-

Quasi stable - state of multivibrator means, the circuit cannot remain in one state permanently. That is, if one transistor is ON and another transistor is OFF, it remains in that state for a predefined time only. After the completion of predefined time, the ON transistor turns OFF and the OFF transistor turns ON.

→ Multivibrators are categorized as,

1. Bistable multivibrator
2. Monostable "
3. Astable "

Application : These multivibrators, are used to generate non-sinusoidal waveforms.

Principle of working : Multivibrator is a two stage amplifier with feedback i.e., output of one stage is connected to the i/p of the second stage and vice versa.

Thus, the active devices are set either in saturation (or) cut-off region as per their requirement.

① Bistable Multivibrator :-

→ Multivibrators that has two stable states is called bistable multivibrator. This is also referred as Eccles-Jordan circuit, flip-flop, binary, trigger circuit, scale-of-two toggle circuit.

→ In this case, the stable state represents the state where Kirchoff's voltage and current laws are satisfied.

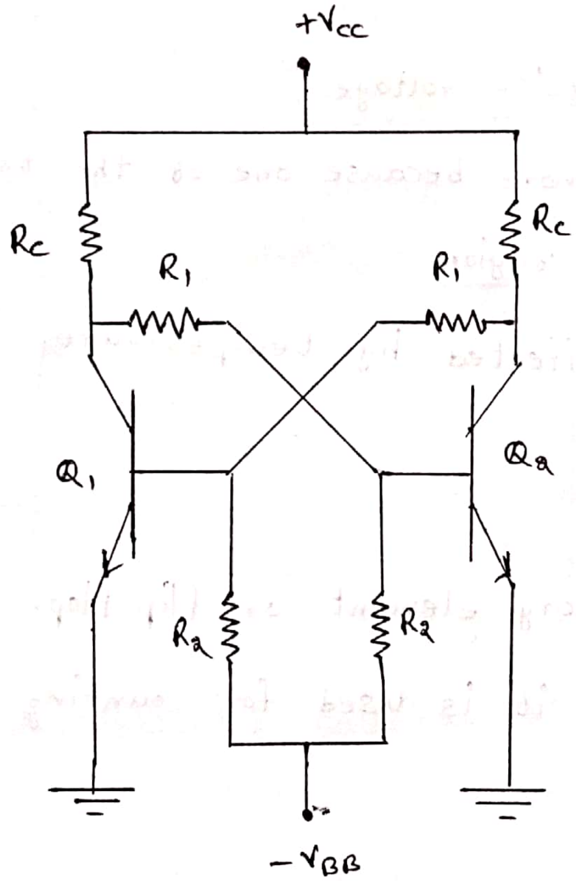


Fig. (1) circuit arrangement of Bistable Multivibrator

→ The coupling elements used in this circuit are two resistors i.e., both are d.c. coupled in bistable multivibrator.

→ It requires triggering signal to change its state and another trigger for backward transition.

Merits :-

1. Bistable multivibrator is simple to design.
2. Power dissipation is less.
3. Transistor with lower breakdown voltage rating are used in circuit.
4. Dual voltage supply is not necessary for the operation.

Limitations :-

1. It is sensitive to noise voltage.
2. Its storage time is more because one of the transistor operates in saturation region.
3. It can be easily affected by temperature.

Applications :-

1. It is used as memory element or flip flop.
2. In digital operations, it is used for counting and storing binary data.
3. It is also used in generation and processing of pulse type wave form.

② Monostable Multivibrator :-

→ Monostable multivibrator has one stable state and one quasi state. It is also named as one-shot, single - shot, a single cycle, gating circuit (or) delay circuit, univibrator.

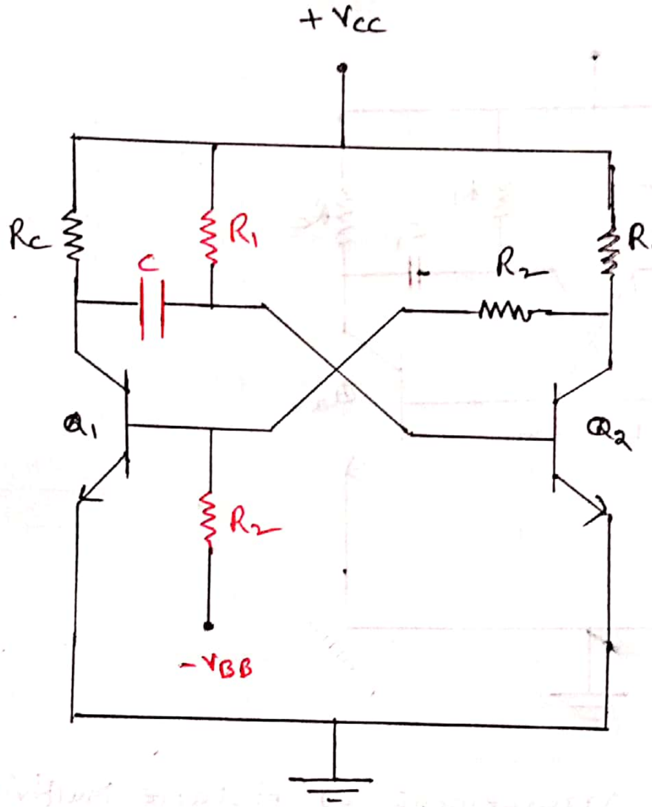


Fig (2). Circuit arrangement of Monostable Multivibrator

→ The coupling element used in this ckt are one capacitor and one resistor i.e., one a.c. coupling and one d.c. coupling.

→ It requires a trigger signal to change stable state to quasi state and no signal for vice versa.

Applications :-

① It is used in pulse circuits.

② It is also used as gating circuit as it generates rectangular waveforms.

③ It is also be used to introduce delay.

③ Astable Multivibrator :-

→ Astable multivibrator has no stable states i.e., both the states are quasi states. It is also called as free-running multivibrator, square wave generator and relaxation oscillator.

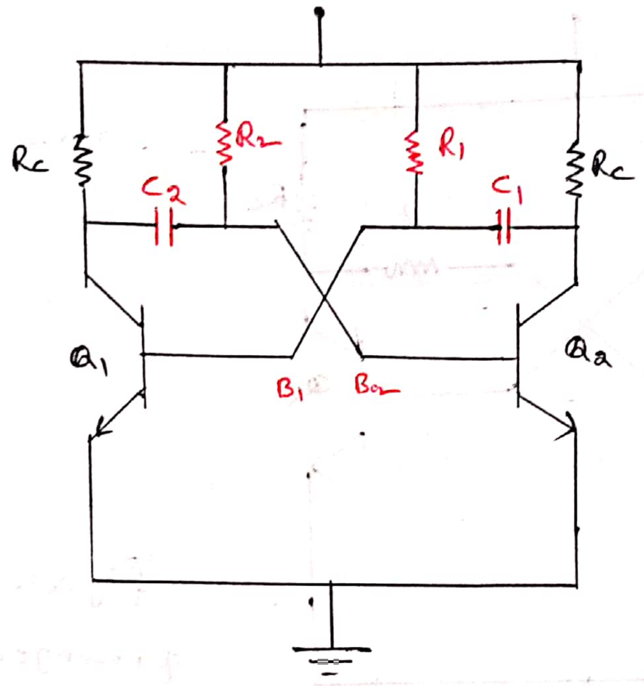


Fig (3). circuit arrangement of Astable Multivibrator

→ The coupling elements used in this circuit are capactors i.e., both are ac coupling. It does not require any triggering signal to change its state.

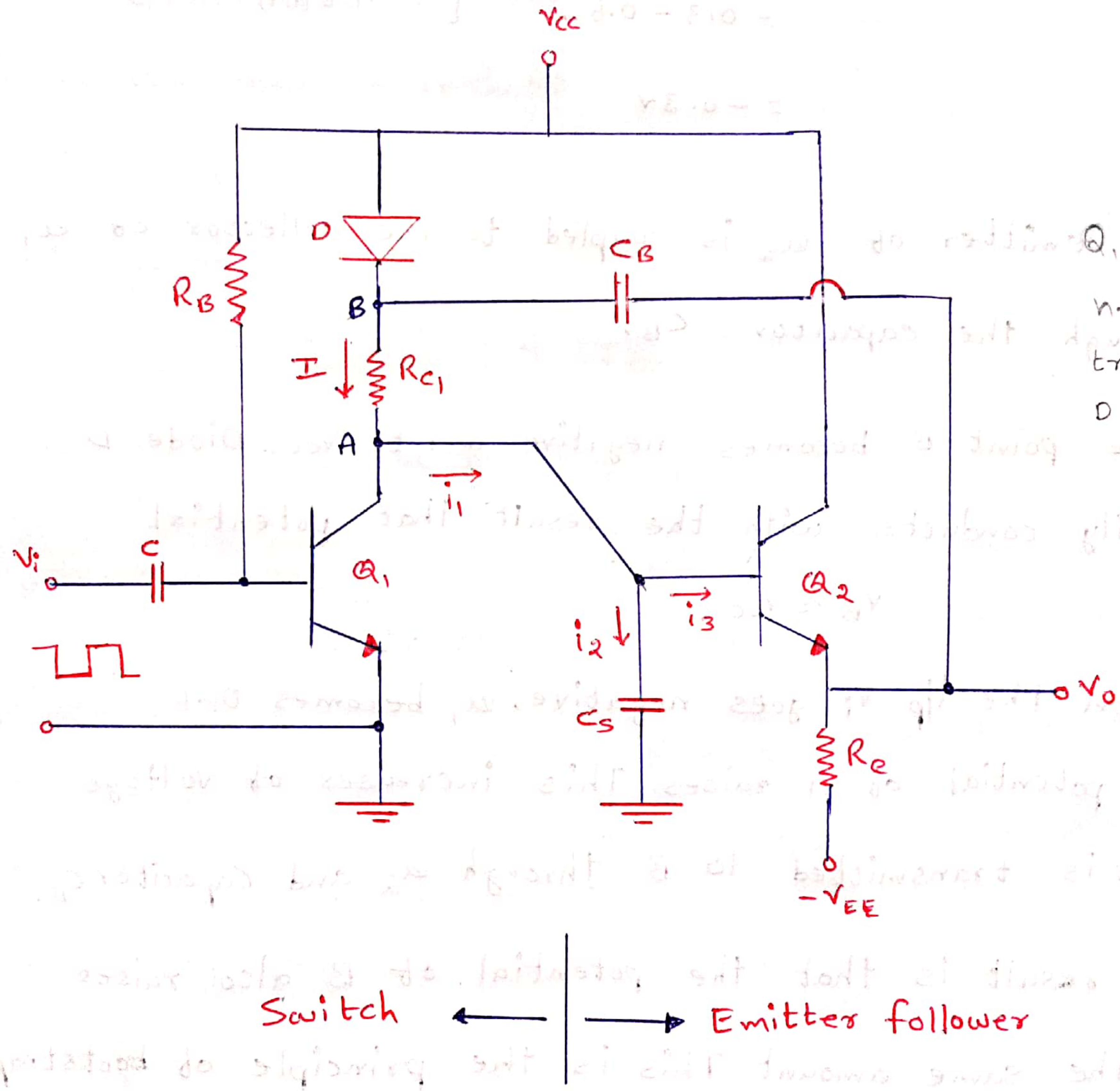
Applications :-

① Used to generate square waveforms.

② It is a basic source of fast waveforms.

IX Boot-strap Generator:-

The bootstrap sweep circuit (or) generator uses the Principle in its functioning and generates a ramp voltage.



Q1, Q2 :- n-p-n transistors

D ... Diode

→ The transistor Q_1 acts as ON-OFF switch, and the transistor Q_2 is an emitter-follower.

→ The i/p V_i is a pulse voltage, (or) rectangular wave.

→ When the i/p signal V_i is positive, transistor Q_1 becomes ON i.e., goes into saturation.

$\therefore$ Potential of point A, $V_A = V_{CE(sat)}$

If Q_1 is silicon transistor, $V_{CE\,sat} = 0.3\,V$

$\therefore V_A = 0.3V$

Output voltage $V_o = V_A - V_{BE(Q_2)}$ (in active region)

$= 0.3 - 0.6$ $[\because V_{BE(act)} = 0.6V]$

$= -0.3V$

→ The emitter of Q_2 is coupled to the collector of Q_1 through the capacitor C_B.

→ Hence point B becomes negative w.r.t. V_{cc}. Diode D readily conducts, with the result that potential

$$V_B \approx V_{cc}$$

→ When the i/p V_i goes negative, Q_1 becomes OFF. The potential of A raises. This increases of voltage at A is transmitted to B through Q_2 and Capacitor C_B.

→ The result is that the potential of B also raises by the same amount. This is the principle of bootstrap. Thus V_B raises from V_{cc} to $(V_{cc} + V_A)$.

→ Let I denotes the current through R_{c_1}

we have $I = \dfrac{V_B - V_A}{R_{c_1}} = \dfrac{V_{cc}}{R_{c_1}}$ $[\because V_B = V_{cc} + V_A]$

→ since both V_{cc} and R_{c_1} are fixed magnitude, the ratio $\left(\frac{V_{cc}}{R_{c_1}}\right)$ is constant. Hence current I is of constant magnitude.

→ From the circuit, we have $I = i_1$, since Q_1 is now cut off and its collector current is zero. But $i_1 = i_2 + i_3$.

i_3 is the base current of Q_2. since Q_2 is an emitter follower, its i/p impedance is very, very high and hence i_3 is practically zero.

$\therefore i_1 = i_2$ But $i_1 = I$

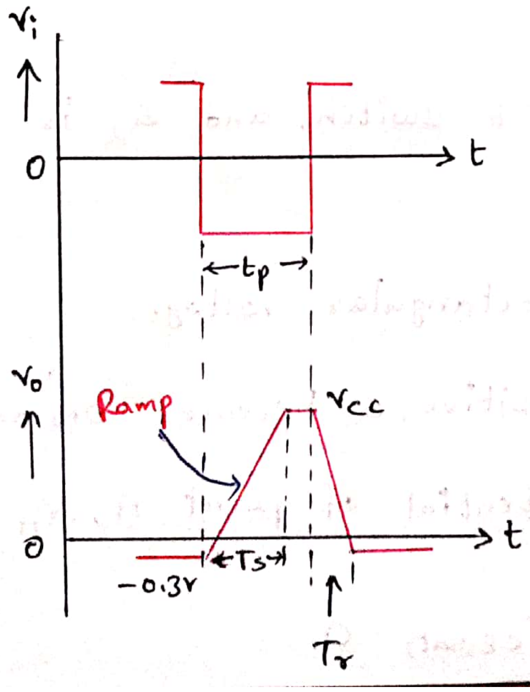
$\therefore i_2 = I$, a constant current.

→ As this current flows through the capacitor C_s, a "ramp voltage" develops across it.

→ For an emitter follower, voltage gain is almost unity.

→ Therefore the o/p voltage V_o is also a ramp voltage.

Thus the bootstrap ckt generates a ramp voltage.



t_p = Pulse width

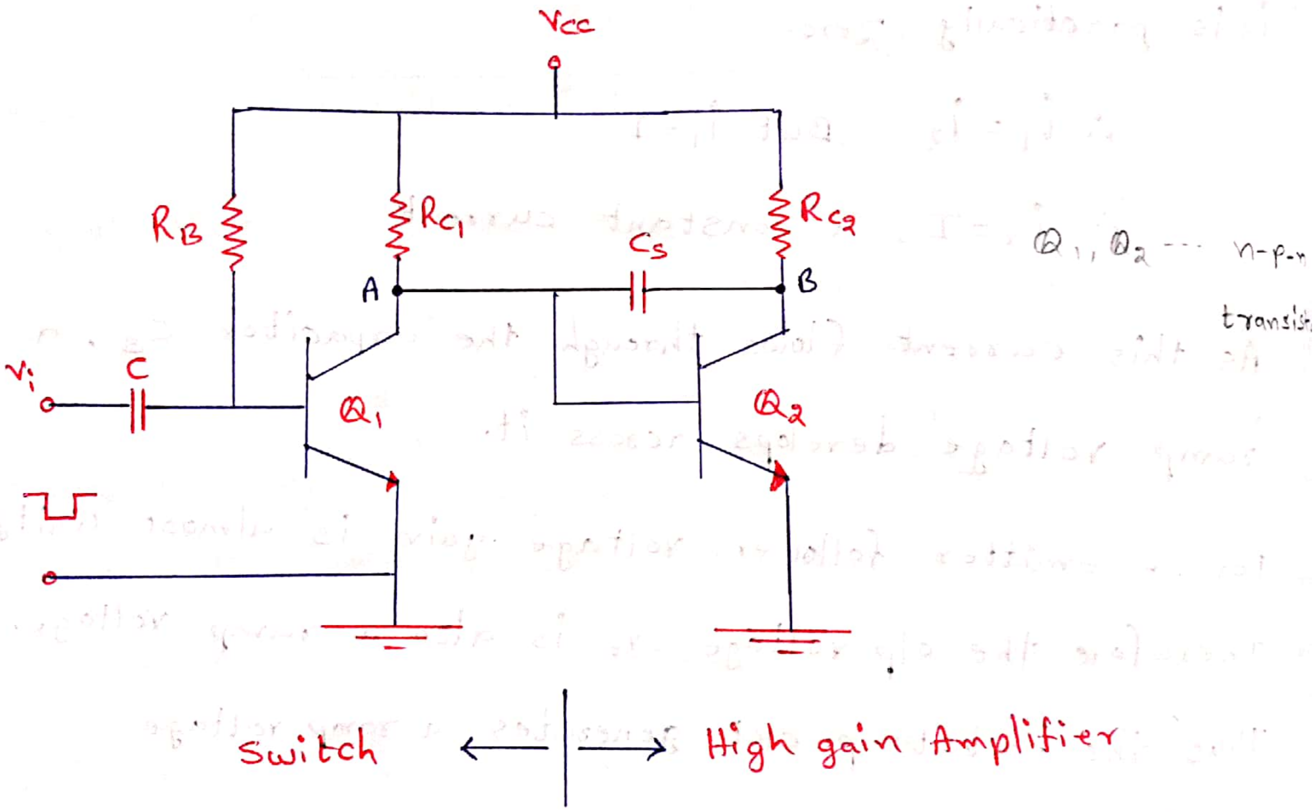
T_s = sweep time $\leq t_p$

T_r = Return time = $\frac{T_s}{10}$

Time constant = $R_{c_1} \cdot C_s = T_s$

X Miller Circuit :-

The Miller sweep circuit also generates a ramp voltage using the basic principle. But it differs from the bootstrap sweep circuit in that it generates a negative ramp. Also it makes use of a high gain amplifier and it incorporates negative feedback.



→ Transistor Q_1 acts as ON-OFF switch, and Q_2 is a high gain amplifier.

→ The i/p V_i is a pulse (or) rectangular voltage.

→ When the i/p signal V_i is positive, Q_1 becomes ON and goes into saturation. The potential of point A, V_A becomes zero, since $V_A = V_{CE(sat)} = 0$.

→ Transistor Q_2 remains OFF, since it cannot get the necessary base drive. Point B would be at potential V_{cc}

∴ Voltage across the capacitor, $C_S = V_{cc}$

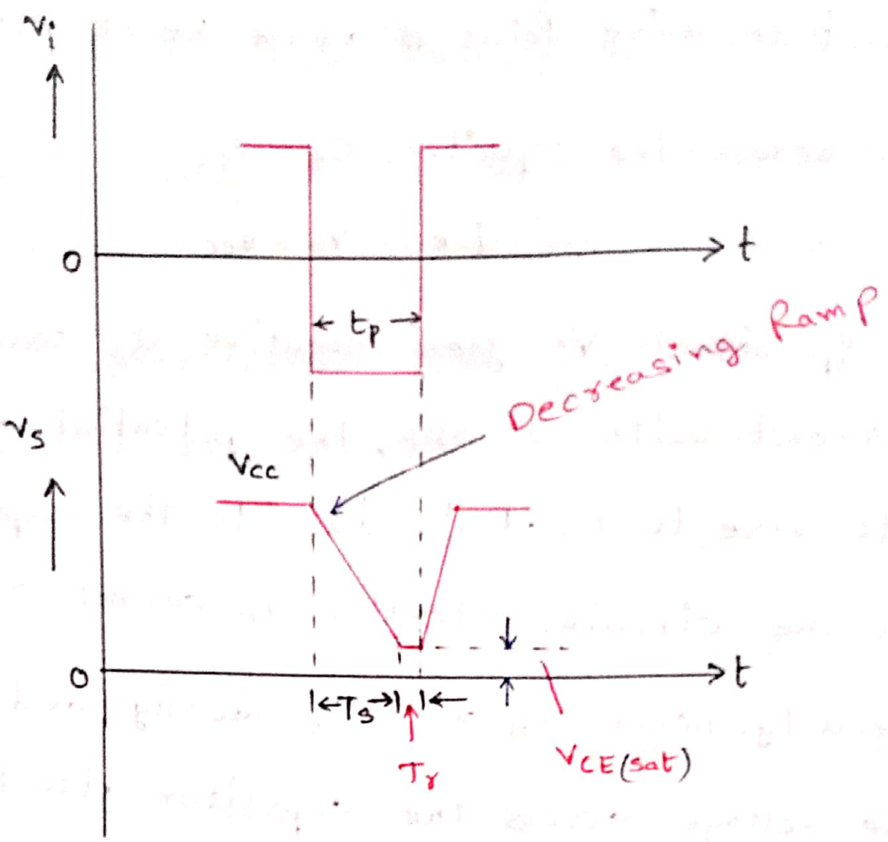
i.e., $V_S = V_{cc}$.

→ When the i/p signal V_i goes negative, Q_1 cannot obviously conduct. With Q_1 OFF, the potential of point A tends to rise to V_{cc}. But, due to the capacitor C_s present in the circuit, potential V_A cannot rise to V_{cc} instantaneously. Hence V_A rises gradually and as a result, the voltage across the capacitor also falls gradually.

[with Q_1 OFF and potential of A going up, Q_2 becomes ON. The potential of B tends to decrease to zero, but because of the capacitor C_s, V_B cannot abruptly come down. As V_A gradually increases, and V_B gradually decreases, the voltage across the capacitor progressively falls. The result is that C_s discharges linearly.]

→ Thus the voltage V_s across the capacitor C_s is a decreasing i.e., negative going ramp.

Wave forms of input & output



$T_s \le t_p$

$T_s = R_{c_1} C_s$

$T_r = R_{c_2} C_s.$