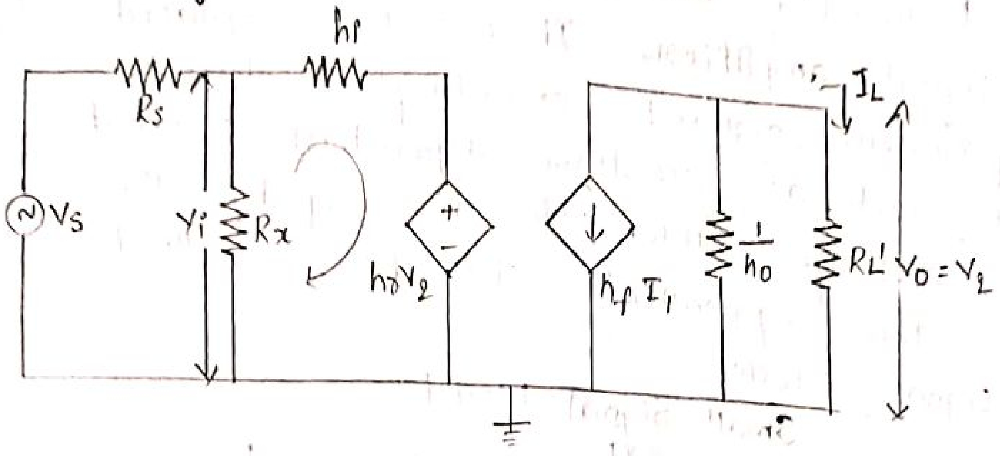
Unit - II

Multistage Amplifiers

Exact analysis of BJT with the h-parameter model:



Current Gain:-

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

Using current division

$$I_L = -h_f I_1 \times \frac{\frac{1}{h_o}}{\frac{1}{h_o} + R_L'} = \frac{\frac{-h_f I_1}{h_o}}{\frac{1 + R_L' h_o}{h_o}}$$

$$I_L = \frac{-h_f I_1}{1 + R_L' h_o}$$

$$A_I = \frac{I_L}{I_1} = \frac{-h_f \cancel{I_1}}{1 + R_L' h_o} \times \frac{1}{\cancel{I_1}} = \frac{-h_f}{1 + R_L' h_o}$$

$$A_I = \frac{-h_f}{1 + h_o R_L'}$$

Input Resistance (R_i):-

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

Apply KVL at input node

$$\Rightarrow -V_1 + h_i I_1 + h_r V_2 = 0$$

$$-V_1 + h_i I_1 + h_r I_L R_L' = 0$$

$$-V_1 + h_i I_1 + h_r R_L' A_I I_1 = 0$$

$$-V_1 + I_1 (h_i + h_r R_L' A_I) = 0$$

$$\cancel{-}V_1 = \cancel{-}I_1 (h_i + h_r R_L' A_I)$$

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$$R_i = \frac{V_1}{I_1} = h_i + h_{r} R_L' A_I$$

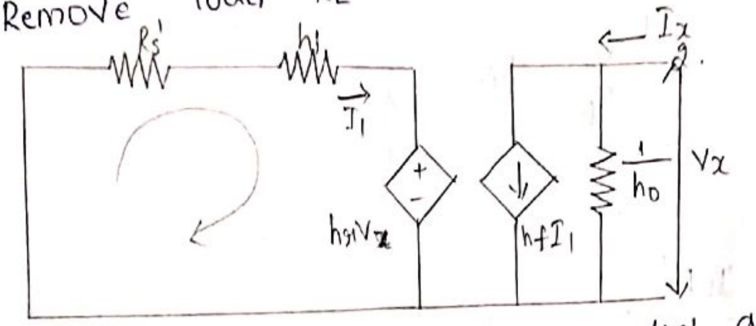
Voltage gain (A_V):

$$A_V = \frac{V_2}{V_1} = \frac{V_0}{V_1} = \frac{I_L R_L'}{V_1} = \frac{A_I I_1 R_L'}{V_1}$$

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

Output Resistance (R_0):

* voltage source is short circuited.
* Remove load R_L'.



Apply KVL at loop 1:

$$R_s' I_1 + h_i I_1 + h_r V_x = 0$$

$$I_1 (h_i + R_s') = -h_r V_x$$

$$\frac{I_1}{V_x} = \frac{-h_r}{h_i + R_s'} \quad (1)$$

Apply KCL at node 2:

$$I_x = h_f I_1 + \frac{V_x}{h_0}$$

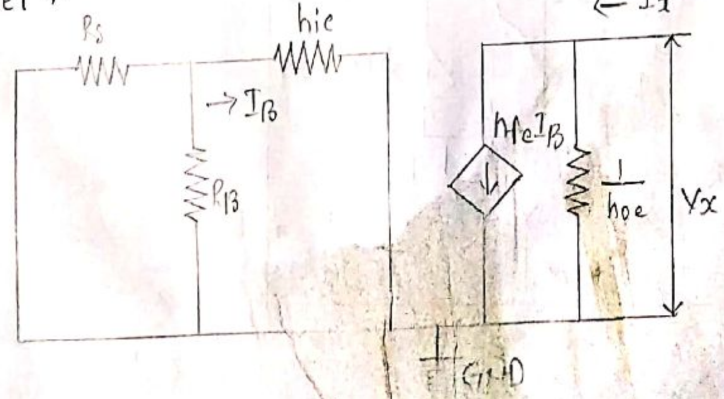
$$\frac{I_x}{V_x} = \frac{h_f I_1}{V_x} + \frac{1}{h_0} \quad (2)$$

Substitute eq (1) in eq (2)

$$\frac{I_x}{V_x} = h_f \left(\frac{-h_r}{h_i + R_s'}\right) + \frac{1}{h_0}$$

$$\frac{1}{R_0} = \frac{1}{h_0} - \frac{h_r h_f}{h_i + R_s'}$$

Approximate analysis of BJT with the h-parameter model:



Current Gain :-

$$A_I = \frac{I_L}{I_b} = \frac{-h_{fe}}{1+h_{oe}R_L'} \qquad \text{If } (h_{oe}R_L' \leq 0.1)$$

$$A_I \cong \frac{-h_{fe}}{1}$$

$$A_I \cong -h_{fe}$$

Input Resistance :-

$$R_i = \frac{V_i}{I_b}$$

$$V_i = I_b h_{ie} \Rightarrow \frac{V_i}{I_b} = h_{ie}$$

$$R_i = h_{ie}$$

Voltage Gain :-

$$A_V = \frac{V_o}{V_i} = \frac{I_L R_L'}{I_b h_{ie}}$$

$$A_V = \frac{-h_{fe} R_L'}{h_{ie}}$$

Output Resistance :-

$$R_o = \frac{V_x}{I_x}$$

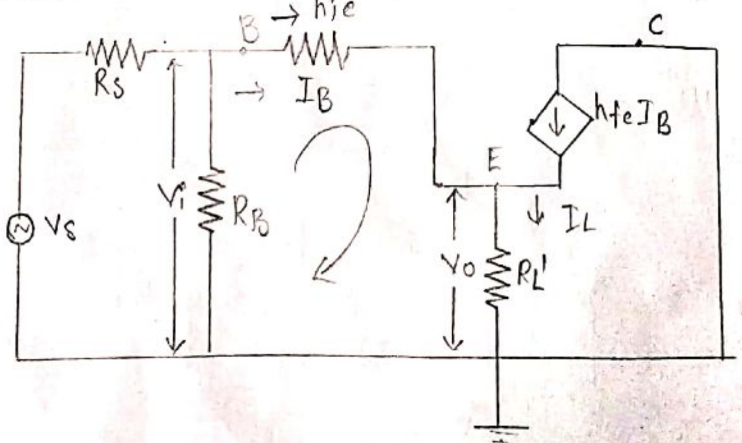
Apply KCL at node 2:

$$I_x = h_{fe} I_b + \frac{V_x}{h_{oe}} \qquad \because I_b = 0$$

$$I_x = \frac{V_x}{h_{oe}}$$

$$R_o = \frac{V_x}{I_x} = h_{oe}$$

Common Collector Amplifier :-



Current Gain :-

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

Apply KCL at node E :-

$$I_L = I_b + h_{fe} I_b = I_b(1+h_{fe})$$

$$\frac{I_L}{I_b} = 1+h_{fe}$$

$$A_I = 1+h_{fe}$$

Input Resistance :-

$$R_i = \frac{V_i}{I_b}$$

Using KVL in input loop

$$\Rightarrow -V_i + I_b h_{ie} + I_L R_L' = 0$$

$$\Rightarrow -V_i + I_b h_{ie} + I_b(1+h_{fe}) R_L' = 0$$

$$\Rightarrow V_i = I_b h_{ie} + I_b R_L'(1+h_{fe})$$

$$V_i = I_b\left[h_{ie} + R_L'(1+h_{fe})\right]$$

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

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

Voltage Gain :-

$$A_V = \frac{V_o}{V_i} = \frac{I_L R_L'}{V_i}$$

$$= \frac{\cancel{I_b}(1+h_{fe}) R_L'}{\cancel{I_b}\left[h_{ie} + R_L'(1+h_{fe})\right]}$$

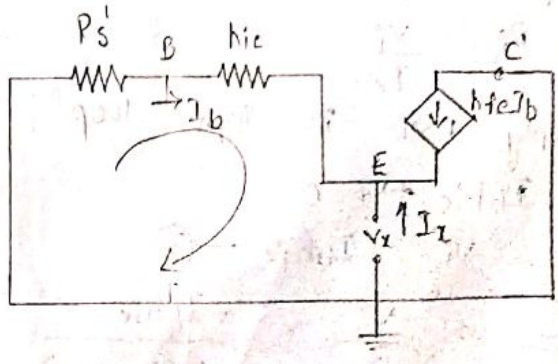
$(1+h_{fe}) R_L' >> h_{ie}$

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

$$A_V \cong 1$$

Output Resistance :-

$$R_o = \frac{V_x}{I_x}$$



Using KCL at E :-

$$I_x + I_b + h_{fe} I_b = 0$$

$$I_x = -I_b(1+h_{fe}) \quad \text{--(1)}$$

Using KVL in input loop:

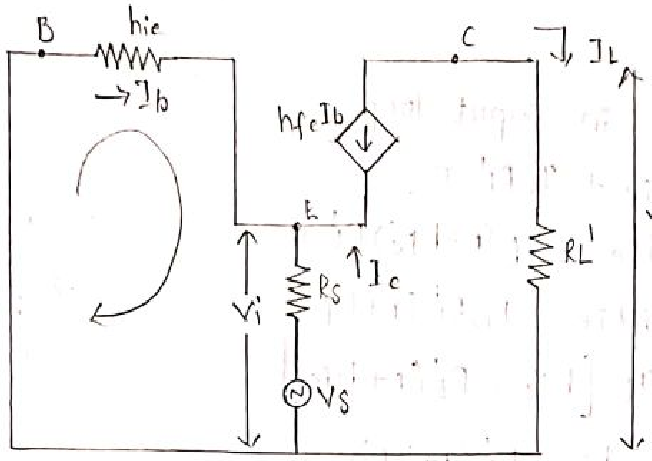
$\Rightarrow I_b R_s' + I_b h_{ie} + V_x = 0$

$$V_x = -I_b (R_s' + h_{ie}) \quad \text{---(2)}$$

$$\frac{(2)}{(1)} \Rightarrow \frac{V_x}{I_x} = \frac{-\cancel{I_b}(R_s' + h_{ie})}{-\cancel{I_b}(1+h_{fe})}$$

$$R_0 = \frac{R_s' + h_{ie}}{1+h_{fe}}$$

Common Base Amplifier :-



Current Gain :-

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

$$I_L = -h_{fe} I_b \quad \text{---(1)}$$

Apply KCL at node E :-

$$I_b + I_e + h_{fe} I_b = 0$$

$$I_e = -(1+h_{fe}) I_b \quad \text{---(2)}$$

$$\frac{(1)}{(2)} \Rightarrow \frac{I_L}{I_e} = \frac{-h_{fe}\cancel{I_b}}{-(1+h_{fe})\cancel{I_b}} = \frac{h_{fe}}{1+h_{fe}}$$

$$A_I \cong 1.$$

Input Resistance :-

$$R_i = \frac{V_i}{I_e}$$

Apply KVL in input loop.

$$I_b h_{ie} + V_i = 0$$

$$V_i = -I_b h_{ie} \quad \text{---(3)}$$

$$\frac{(3)}{(2)} \Rightarrow \frac{V_i}{I_e} = \frac{-\cancel{I_b} h_{ie}}{-\cancel{I_b}(1+h_{fe})} = \frac{h_{ie}}{1+h_{fe}}$$

$$R_i = \frac{h_{ie}}{1+h_{fe}}$$

Voltage Gain:

$$A_V = \frac{V_o}{V_i} \qquad I_L = -h_{fe} I_b$$

$$V_o = I_L R_L' = -h_{fe} I_b R_L'$$

From eq (3) $\Rightarrow$ $V_i = -I_b h_{ie}$

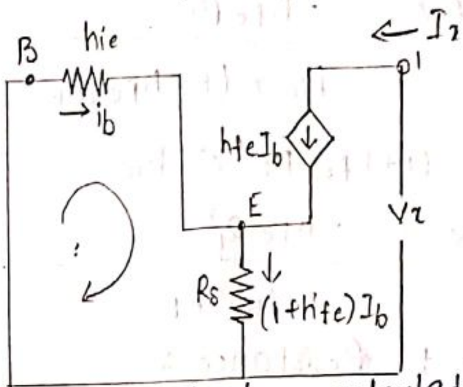
$$\frac{V_o}{V_i} = \frac{-h_{fe} \cancel{I_b} R_L'}{-\cancel{I_b} h_{ie}} = \frac{h_{fe} R_L'}{h_{ie}}$$

$$A_V = \frac{h_{fe} R_L'}{h_{ie}}$$

Output Resistance:-

$$R_o = \frac{V_x}{I_x}$$

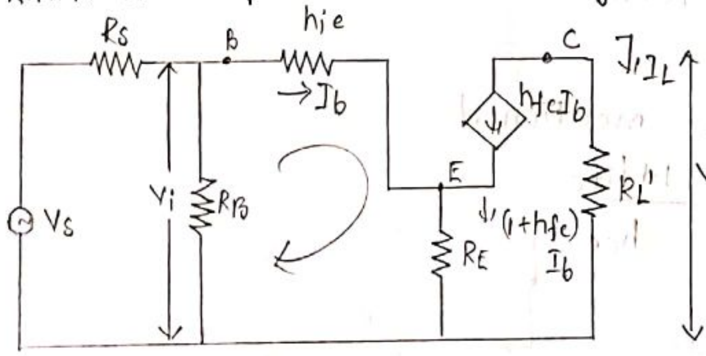
$$= \frac{V_x}{h_{fe} I_b} \qquad \because I_b = 0$$



$$R_o = \infty$$

If h_{oe} is mentioned then R_o should be calculated using $R_o = \frac{1+h_{fe}}{h_{oe}}$

Common Emitter Amplifier with unbypassed R_E:-



Current Gain:-

$$A_I = \frac{I_L}{I_b} \qquad \because I_L = -h_{fe} I_b$$

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

$$A_I = -h_{fe}$$

Input Resistance:-

$$R_i = \frac{V_i}{I_b}$$

Apply KVL in input loop;

$\Rightarrow \quad -V_i + I_b h_{ie} + (1+h_{fe}) I_b R_E = 0$

$$V_i = I_b \left[h_{ie} + (1+h_{fe}) R_E \right]$$

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

Voltage Gain:

$$A_V = \frac{V_o}{V_i} = \frac{-h_{fe} \cancel{I_b} R_L'}{\cancel{I_b} \left[h_{ie} + (1+h_{fe}) R_E \right]}$$

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

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

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

Output Resistance:

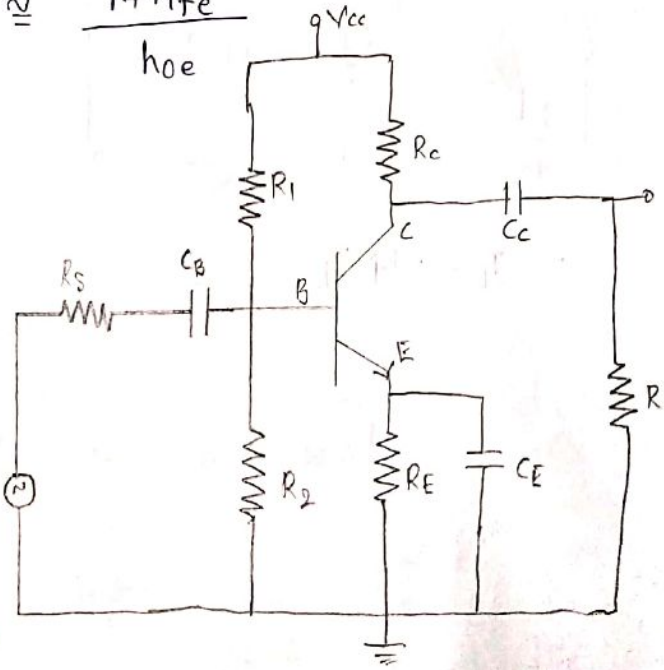
$$R_o = \frac{V_x}{I_x}$$

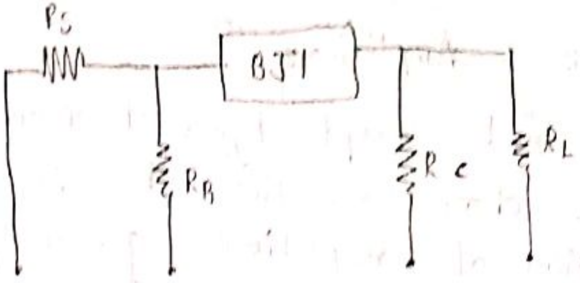
$$= \frac{V_x}{h_{fe} I_b}$$

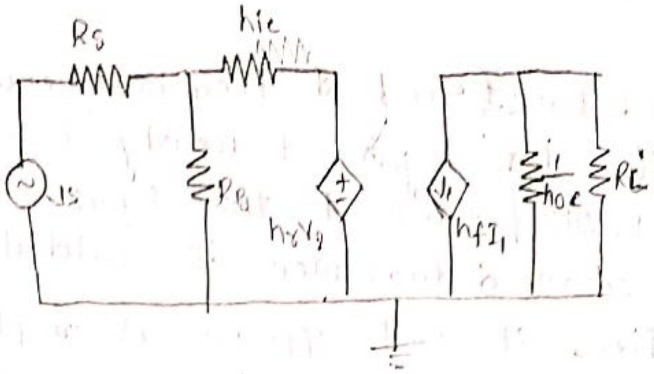
$$R_o = \infty$$

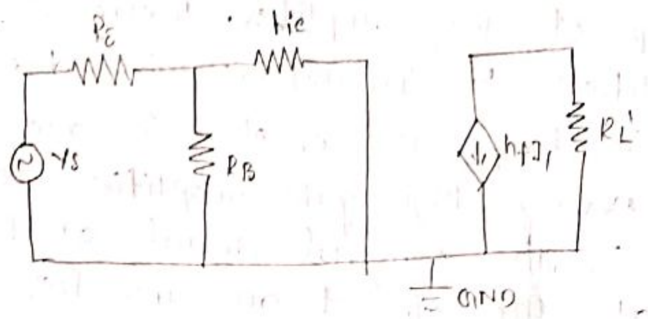
If h_{oe} is mentioned

$$R_o \cong \frac{1+h_{fe}}{h_{oe}}$$




Rs
BJT
RB
Rc
RL


Rs
hie
Vs
RB
hrVo
hfI1
1/hoe
RL'

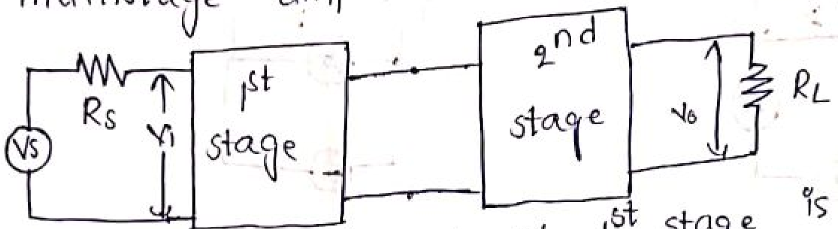

Rs
hie
Vs
RB
hfI1
RL'
GND

Unit - II

Multistage Amplifiers

Introduction :-

Single stage amplifiers may provide smaller voltage and current gains and these are insufficient to drive high resistive loads. There by using more than one stage of amplification to achieve sufficient voltage and current gains. Such an amplifier is called a multistage amplifier



In multistage amplifier, the o/p of 1st stage is connected as i/p to the 2nd stage as shown in above fig. Such a connection is commonly referred to as cascading.

In amplifiers, cascade is also used to achieve correct input and output impedances for specific applications.

Depending upon the type of amplifier used in individual stages, multistage amplifiers can be classified into several ch types.

A multistage amplifier using two or more singlestage CE amplifiers is called as cascaded amplifiers.

A multistage amplifier with common emitter as the 1st stage and common base as the second stage is called as cascode amplifier.

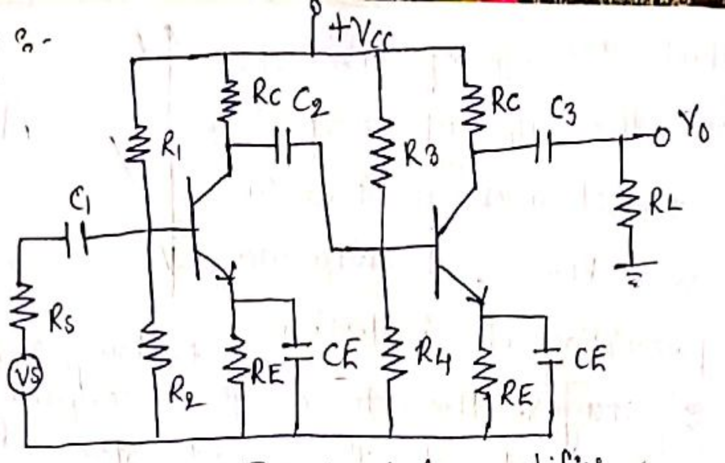
Methods of Interstage coupling :-

When amplifiers are cascaded, it is necessary to use a coupling network between the output of one amplifier and the input of the following amplifier. This type of coupling is called interstage coupling.

There are 3 coupling schemes commonly used in multistage amplifiers

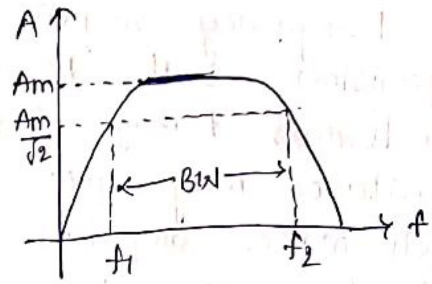
1. RC coupling
2. Transformer coupling
3. Direct Coupling

RC Coupling :-



a. RC Coupled amplifier.

In RC coupled amplifier, the output of 1st stage is coupled to the i/p of the next stage through a coupling capacitor and resistive load



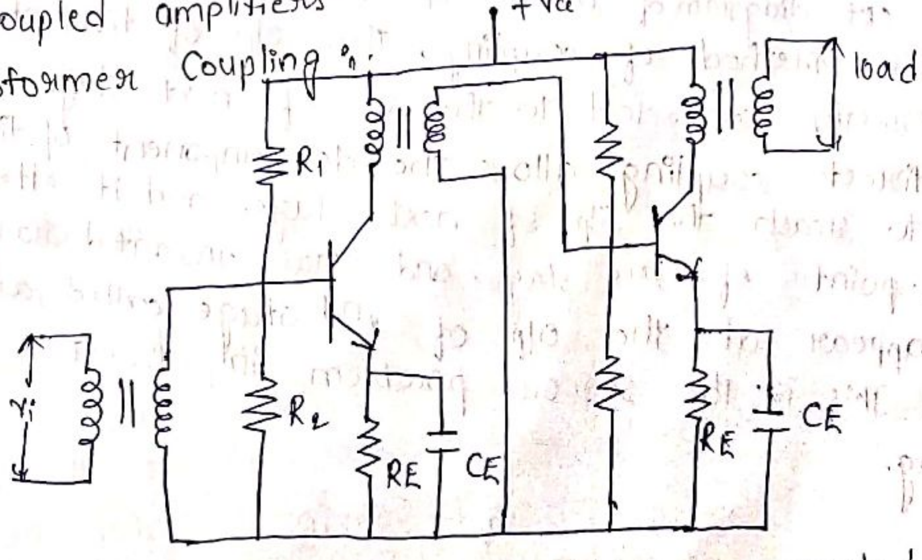
frequency response.

This coupling method doesnot effect the Q-point of the next stage since the coupling capacitor blocks the dc component ~~after~~ of the 1st stage from reaching the base of the 2nd stage.

The RC N/w is ~~block~~ broad band in nature. Therefore, it gives wide band frequency response without peak at any frequency.

However, its frequency response drops at very low frequencies due to coupling capacitors and also at high frequencies due to structural stray capacitance. The amplifiers using this scheme are called RC-coupled amplifiers

Transformer Coupling :-



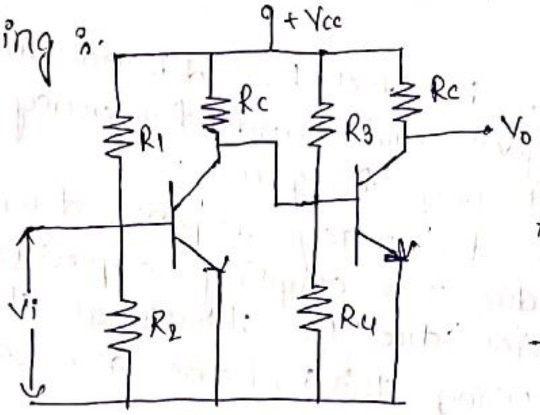
a. Ckt diagram of transformer coupled amplifier

In this method, the o/p of first stage is couple to the i/p of next stage through a transformer as shown in fig (a). As we know, transformer blocks dc, providing dc isolation b/w the 2 stages. Therefore, this coupling doesnot affect the Q-point of the next stage.

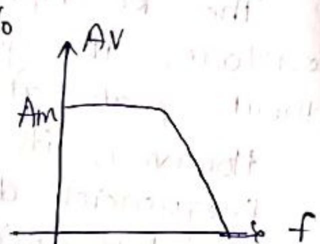
b. freq. response

Frequency response of this coupling is poor in comparision with RC coupled amplifier. The transformer leakage inductance and interwinding capacitance may give resonance at certain frequency which makes amplifier to give very high gain at that frequency. By putting shunting capacitors across each winding of the transformer, we can get resonance at any desired frequency. Such amplifiers are called tuned voltage amplifiers. These are used in the radio and tv receivers.

Direct Coupling :-



ckt diagram of Direct coupled amp.

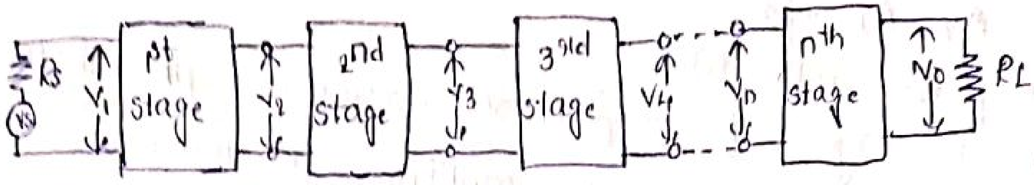


freq. response

In this method of coupling, the o/p of first stage is directly connected to the i/p of next stage. This direct coupling allows the dc component of first stage to reach the i/p of next stage and it effects the Q-point of 2nd stage and thus unwanted changes will appear at the o/p of 2nd stage called as drift. This is the serious problem in direct coupling.

Due to the absence of coupling capacitors, it has good frequency response at low frequencies. But at higher frequencies stray capacitances reduce the gain of the amplifier.

n - stage cascaded amplifier :-



B.D of n-stage cascaded amplifier

The above fig. shows the block diagram of n-stage cascaded amplifiers.

There are n - no. of stages are cascaded, such that the o/p of each stage connected as i/p to the next stage.

Overall voltage gain :-

The voltage gain of 1st stage amplifier is given by

$A_{V1} = \frac{V_2}{V_1}$.

The voltage gain of 2nd stage amplifier is given by

$A_{V2} = \frac{V_3}{V_2}$

$||^{ly}$ the voltage gain of nth stage amplifier is given by

$A_{Vn} = \frac{V_0}{V_n}$

The overall voltage gain of n-stage cascaded amplifier is given by

$A_V = A_{V_1} \cdot A_{V_2} \cdot A_{V_3} \cdot \ldots \ldots A_{V_n}$ — (1)

$A_V = \frac{V_2}{V_1} \cdot \frac{V_3}{V_2} \cdot \frac{V_4}{V_3} \cdot \ldots \ldots \frac{V_0}{V_n}$ — (2)

From eq (1), we can say that the overall voltage gain is the product of voltage gains of individual stages.

Overall Current Gain :-

Similar to the overall voltage gain, the overall current gain is given by

$A_I = A_{I_1} \cdot A_{I_2} \cdot A_{I_3} \cdot \ldots \ldots A_{I_n}$ — (3)

It is the product of current gains of individual stages called overall current gain.

Overall Power gain :-

Overall power gain is the product of overall voltage gain and overall current gain and it is given by

$$A_p = A_V \cdot A_I \quad -(3)$$

Overall phase shift (θ) :-

The first stage of amplifier introduces phaseshift of $\angle\theta_1$, second stage of amplifier introduces phase shift of $\angle\theta_2$. Similarly, the n^{th} stage of amplifier introduces phase shift of $\angle\theta_n$.

The overall phase shift is the sum of phase shifts of individual stages.

$$\angle\theta = \angle\theta_1 + \angle\theta_2 + \cdots + \angle\theta_n \quad -(4)$$

From eq (4), we can say that, the total phase shift is the sum of phaseshifts of individual stages.

1) A 3-stage amplifier has a 1st stage voltage gain of 30, 2nd stage of voltage gain of 200 and 3rd stage voltage gain of 400. Find the total voltage gain in decibals.

Given, $A_{V_1} = 30$,

$A_{V_2} = 200$

$A_{V_3} = 400$

$A_V = A_{V_1} \cdot A_{V_2} \cdot A_{V_3} = 30 \times 200 \times 400$

$A_V = 2400000$

Total voltage gain in decibals $= 20 \log_{10} A_V$

$= 20 \log_{10} (2400000)$

$= 127.6 \text{ dB}$

2) a) A multistage amplifier uses 5 stages, Each of which has a power gain of 30. what is the total power gain of amplifier in decibals?

b) If the -ve fb of 20 dB is introduced, find the resultant power gain.

For a 5 stage of MSA,

a) $A_p = 5 \times 30 = 150$

Total power gain in decibals $= 20 \log A_p$

$= 20 \log 150$

$= 43.52\,dB$

b) ~~total power gain = 20 dB~~

$\cancel{20 \log_{10} A_p = 20}$

$\cancel{\log_{10} A_p = 1}$

if 20 dB of -ve fb,

$A_p(dB) = (43.52 - 20)\,dB = 23.52\,dB$

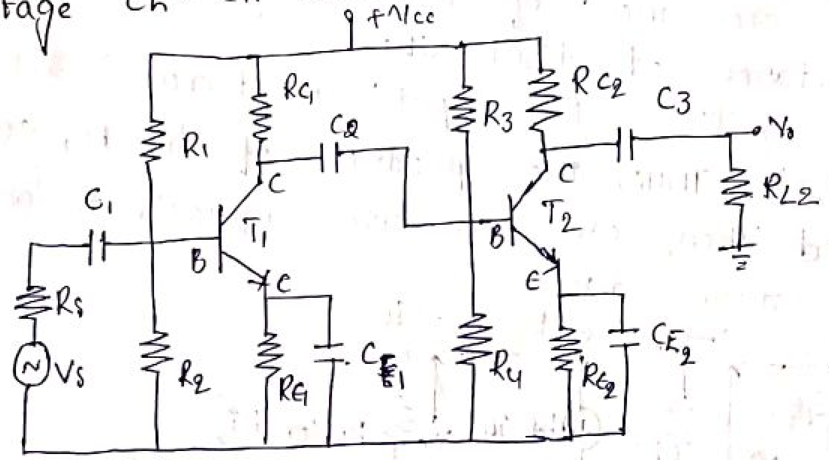
Configurations in Multistage amplifiers:

Based on using of configuration for individual stage, there are several types of multi stage amplifiers.

1. Two stage CE - CE cascaded amplifier
2. CE - CB cascoded amplifier
3. CC - CC darlington amplifier
4. Boot strapped Amplifier

(2–3: high i/p resistance transistor amp. ckts.)

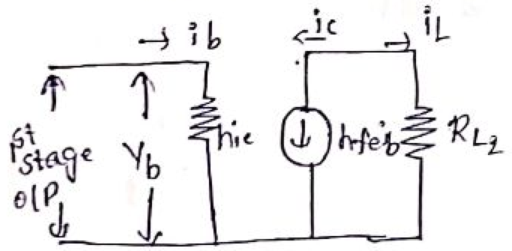
Two stage CE - CE cascaded amplifier:



The above fig. shows the circuit diagram of 2-stage CE-CE cascaded amplifier. The transistor T_1 and its associated component constitutes one CE amplifier and transistor T_2 and its associated component constitutes another CE amplifier The main objective of cascaded amplifier is to raise the voltage gain of an amplifier.

Analysis of second stage :-

To measure the characteristics of an amplifier circuit diagram is replaced by its equivalent circuit. Here we assume that $h_{oe} R_{L2} < 0.1$, then we can use approximate analysis for 2^{nd} stage



i) Current gain (A_{I_2}) :-

$$A_{I_2} = \frac{i_L}{i_b} = \frac{-i_c}{i_b} = \frac{-h_{fe} i_b}{i_b} = -h_{fe}$$

ii) input resistance (R_{I_2}) :-

$$R_{I_2} = \frac{V_b}{i_b} = \frac{h_{ie} i_b}{i_b} = h_{ie}$$

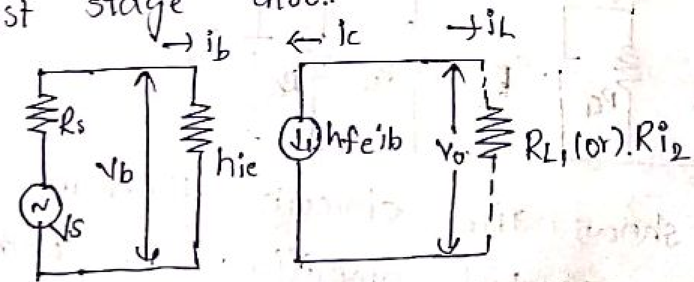
iii) Voltage gain (A_{V_2}) :-

$$A_{V_2} = \frac{A_{I_2} R_{L_2}}{R_{I_2}} = \frac{-h_{fe} R_{L_2}}{h_{ie}}$$

Analysis of first stage :-

The input resistance of second stage becomes the load resistance of first stage.

For CE amplifier, the input resistence is in order of ohms (Ω). Thus, the product of $h_{oe} R_{L_1} < 0.1$ is satisfied. Then, we can use approximate analysis for first stage also.



i) Current gain (A_{I_1}) :-

$$A_{I_1} = \frac{i_L}{i_b} = \frac{-i_c}{i_b} = \frac{-h_{fe} i_b}{i_b} = -h_{fe}$$

ii) input resistance (R_{I_1}):

$$R_{I_1} = \frac{V_b}{i_b} = \frac{h_{ie}\, i_b}{i_b} = h_{ie}$$

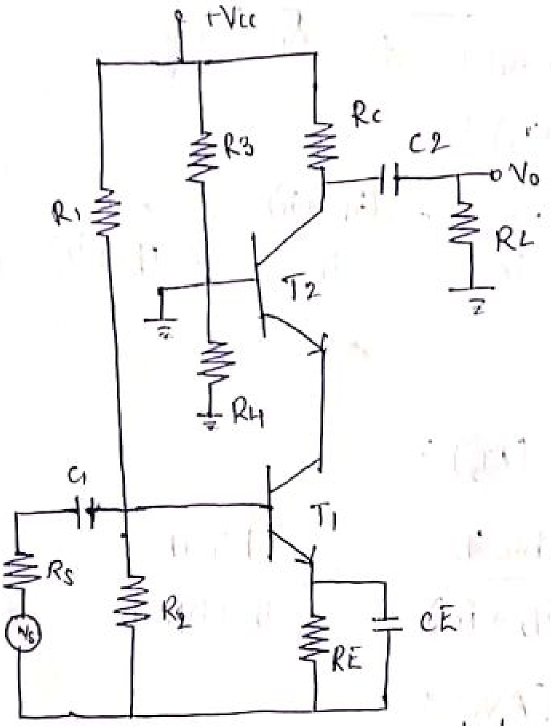
iii) Voltage gain (A_{V_1}):

$$A_{V_1} = \frac{A_{I_1} R_{L_1}'}{R_{I_1}} = \frac{-h_{fe} R_{L_1}}{h_{ie}}$$

iv) Output resistances (R_{O_1} & R_{O_2}):

$$R_{O_1} = R_{O_2} = \infty$$

CE - CB Cascoded amplifier:
**



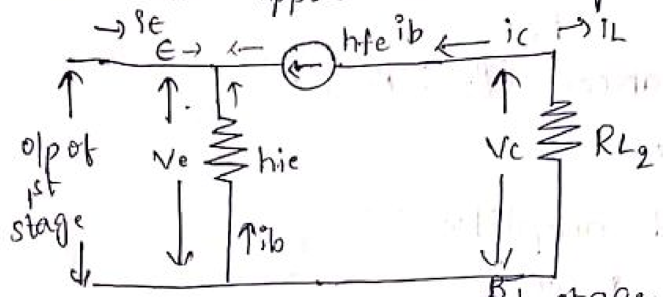
a) ckt diagram of cascoded amp.

Fig (a) shows the circuit diagram of CE - CB cascoded amplifier. It consists of CE amplifier followed by CB amplifier and they are direct coupled with each other.

The CB amplifier has two greater advantages over CE amplifier and they are larger bandwidth and high voltage gain, but it suffers with very smaller input impedance. This problem of CB amplifier is solved by connecting CE amplifier at the input side of CB amplifier. Therefore, CE-CB cascoded amplifier gives the added advantages of both CE and CB amplifiers i.e., higher input impedance of CE amplifier, and larger band width and higher voltage gain of CB amplifier

Analysis of Second Stage :-

For the analysis of second stage, we assume that the product of $h_{oe} R_L < 0.1$ condition is satisfied. Thus, we can use approximate analysis.



b) app. model of 2nd stage

i) Current gain (A_{I_2}) :-

$$A_{I_2} = \frac{i_L}{i_E} = \frac{-i_c}{i_e} = \frac{\cancel{-(i_b+i_e)}}{i_e} = \frac{-i_c}{-(i_b+i_c)} = \frac{h_{fe} i_b}{i_b + h_{fe} i_b}$$

$$A_{I_2} = \frac{h_{fe}}{1+h_{fe}}$$

ii) Input resistance (R_{I_2}) :-

$$R_{I_2} = \frac{V_E}{I_E} = \frac{-h_{ie} i_b}{-(i_b+i_c)} = \frac{h_{ie} i_b}{i_b + h_{fe} i_b} = \frac{h_{ie}}{1+h_{fe}}$$

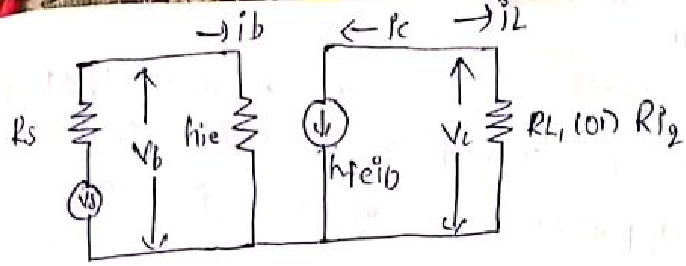
iii) Voltage gain (A_{V_2}) :-

$$A_{V_2} = \frac{A_{I_2} R_{L_2}}{R_{I_2}} = \frac{\left(\frac{h_{fe}}{1+h_{fe}}\right) R_{L_2}}{\frac{h_{ie}}{1+h_{fe}}} = \frac{h_{fe} R_{L_2}}{h_{ie}}$$

Analysis of first stage :-

For the analysis of 1st stage, we assume that, the product of $h_{oe} R_{L_1} < 0.1$. By the input impedance of CB amplifier, which is very small value become the load impedance of 1st stage. Thus the product of $h_{oe} R_{L_1} < 0.1$ is satisfied.

Hence we can use approximate analysis.



Current gain :-

$$A_{I_1} = \frac{i_L}{i_b} = \frac{-h_{fe}\,i_b}{i_b} = -h_{fe}$$

$$R_{I_1} = \frac{V_b}{i_b} = \frac{h_{ie}\,i_b}{i_b} = h_{ie}$$

$$A_V = \frac{V_c}{V_b} = \frac{-h_{fe}R_{L_1}}{h_{ie}}$$

For both 1 & 2 stages.

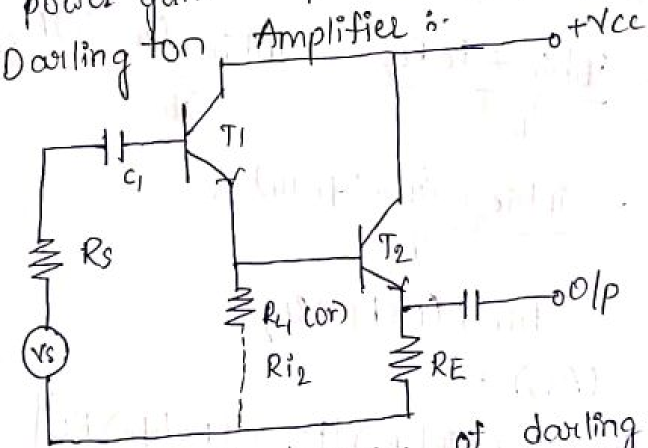
$R_{o1} = R_{o2} = \infty$

over all voltage gain $A_V = A_{V_1} \cdot A_{V_2}$

over all current gain $A_I = A_{I_1} \cdot A_{I_2}$

over all power gain $A_P = A_V \cdot A_I$

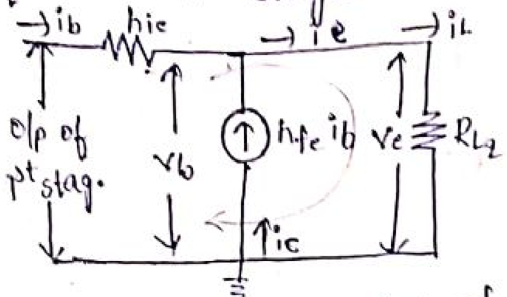
CC - CC Darlington Amplifier :-



fig(a) shows the ckt diagram of darling ton amplifier. The o/p of 1st stage is directly connected to the i/p of nxt stage.
For some application it has necessary to have an amplifier with high input impedance. Emitter follower may be used to have input resistance are about 500kΩ. For achieving still higher i/p impedances, the Darling ton connection is used. The Darlington connection has two transistors forming a composite pair. the darling ton ckt consists of two cascaded CC- amplifiers as shown in fig.

Analysis of ~~first~~ Second stage :

For the analysis of ~~first~~ second stage, we assume that the product of $h_{oe}R_{L_2} < 0.1$ condition is satisfied. Thus, we can use approximate analysis for the analysis of second stage.



a) approximate model of second stage.

i) Current gain (AI_2) :-

$$AI_2 = \frac{i_L}{i_b} = \frac{i_e}{i_b} = \frac{i_b + i_c}{i_b} = \frac{i_b + h_{fe}i_b}{i_b} = 1 + h_{fe}$$

ii) input resistance (RI_2) :-

$$RI_2 = \frac{V_b}{i_b} = \frac{i_b h_{ie} + i_e R_{L_2}}{i_b} = \frac{i_b h_{ie} + (i_b + i_c)R_{L_2}}{i_b}$$

$$= \frac{i_b h_{ie} + (i_b + h_{fe} i_b) R_{L_2}}{i_b}$$

$$RI_2 = h_{ie} + (1 + h_{fe})R_{L_2}$$

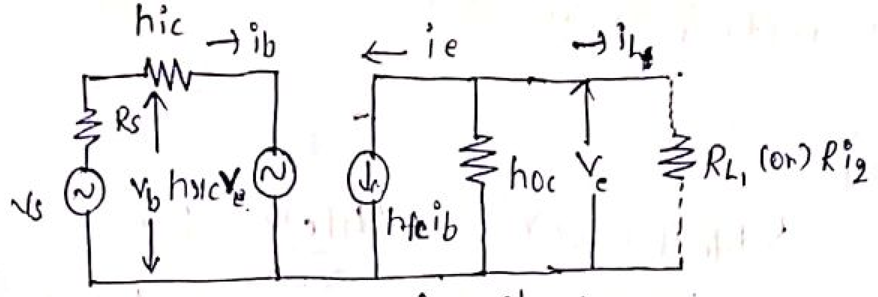
iii) Voltage gain (Av_2) :-

$$Av_2 = \frac{AI_2 R_{L_2}}{RI_2} = \frac{(1 + h_{fe})}{\left[h_{ie} + (1 + h_{fe})R_{L_2}\right]}$$

$$= \frac{(1 + h_{fe})R_{L_2}}{h_{ie} + (1 + h_{fe}) R_{L_2}}$$

Analysis of first stage :-

For the analysis of first stage, $h_{oe}R_{L_1} < 0.1$ condition is not satisfied, since the i/p resistance of second stage which is very large value becomes the load resistance of first stage. Hence we can use exact analysis for the analysis of first stage



Exact model of 1st stage

i) Current gain (AI_1):-

$$AI_1 = \frac{i_L}{i_b} = \frac{-i_e}{i_b} = -\frac{h_{fe} i_b}{}$$

where $i_e = h_{fc} i_b + h_{oc} V_e$

$$= h_{fc} i_b + h_{oc}(i_L R_{L1})$$

$$i_e = h_{fc} i_b + h_{oc}(-i_e R_{L1})$$

$$i_e + h_{oc} i_e R_{L1} = h_{fc} i_b$$

$$i_e(1 + h_{oc} R_{L1}) = h_{fc} i_b$$

$$\frac{i_e}{i_b} = \frac{h_{fc}}{1 + h_{oc} R_{L1}}$$

$$AI_1 = \frac{-i_e}{i_b} = \frac{-h_{fc}}{1 + h_{oc} R_{L1}} = \frac{1 + h_{fe}}{1 + h_{oe} R_{L1}}$$

CC-CE

* $h_{ic} = h_{ie}$
$h_{fc} = -(1 + h_{fe})$
$h_{rc} = 1$
$h_{oc} = h_{oe}$

ii) Input resistance (R_{I_1}):-

$$R_{I_1} = \frac{V_b}{i_b} = \frac{i_b h_{ic} + h_{rc} V_e}{i_b} = \frac{i_b h_{ic} + h_{rc}(i_L R_{L1})}{i_b}$$

$$= \frac{i_b h_{ic} + h_{rc}(-i_e R_{L1})}{i_b}$$

$$= h_{ic} - h_{rc} R_{L1} \frac{i_e}{i_b}$$

$$R_{I_1} = h_{ic} + h_{rc} R_{L1} AI_1 = h_{ie} + R_{L1} AI_1$$

iii) Voltage gain (AV_1):-

$$AV_1 = \frac{AI_1 R_{L1}}{R_{I_1}} = \frac{V_e}{V_b} = \frac{i_L R_{L1}}{V_b} = \frac{-i_e R_{L1}}{V_b}$$

$$AV_1 = \frac{-i_e}{i_b} \cdot \frac{i_b}{V_b} \cdot R_{L1}$$

$$AV_1 = \frac{AI_1 R_{L1}}{R_{I_1}}$$

iv) Output resistance (R_{o1}):-

$$R_{o1} = \frac{1}{y_{o1}}$$

$$y_{o1} = \frac{i_e}{V_e} = \frac{h_{fc} i_b + h_{oc} V_e}{V_e} = \frac{h_{fc} i_b}{V_e} + h_{oc}$$

The relation b/w i_b and V_e is obtained by appling KVL to the i/p loop with $V_s = 0$.

$$(h_{ic} + R_s) i_b + h_{rc} V_e = 0$$

$$(h_{ic} + R_s) i_b = -h_{rc} V_e$$

$$\frac{i_b}{V_e} = \frac{-h_{rc}}{h_{ic} + R_s}$$

$$y_{o1} = h_{fc}\left(\frac{-h_{rc}}{h_{ic} + R_s}\right) + h_{oc}$$

$$y_{o1} = h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic} + R_s}$$

$$R_{o1} = \frac{1}{y_{o1}} = \frac{1}{h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic} + R_s}}$$

$$R_{o1} = \frac{1}{h_{oe} + \frac{(h_{fe} + 1)}{h_{ie} + R_s}}$$

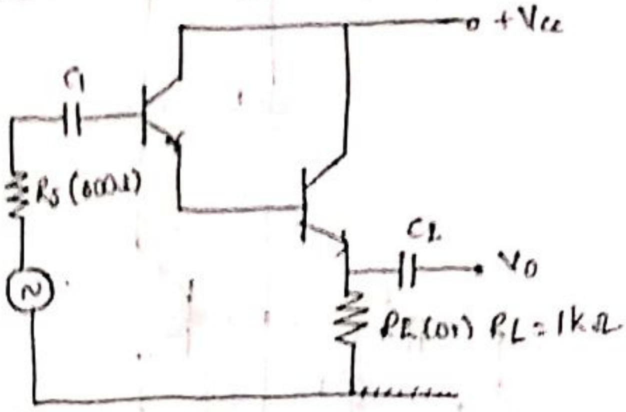
As $\frac{h_{fe} + 1}{h_{ie} + R_s} >> h_{oe}$. h_{oe} is neglected, then

$$y_{o1} = \frac{1 + h_{fe}}{h_{ie} + R_s}$$

$$R_{o1} = \frac{h_{ie} + R_s}{1 + h_{fe}}$$

Similarly, $R_{o2} = \frac{R_{s2} + h_{ie}}{1 + h_{fe}}$

For the ckt shown, calculate i/p resistance, current gain, voltage gain and o/p resistance. For both the stages given $h_{ie} = 1.1K\Omega$, $h_{fe} = 50$, $h_{re} = 2.5\times10^{-4}$, $h_{oe} = 25\mu A/V$



For Second stage:

$A_{I_2} = 1 + h_{fe} = 1 + 50 = 51$

$R_{I_2} = h_{ie} + (1+h_{fe}) R_L = 1.1\times10^3 + (51)\times10^3$

$= 52.1 K\Omega$

$$A_{V_2} = \frac{51\times10^3}{52.1\times10^3} = 0.978$$

For first stage: $R_{L_1} = R_{i_2}$

$$A_{I_1} = \frac{1+h_{fe}}{1+h_{oe}R_{L_1}} = \frac{1+50}{1+(25\times10^{-6})\times10^3\times52.1} = \frac{51}{1+(25\times10^{-3})}$$

$A_{I_1} = \cancel{49.7}\ 22.14$

$R_{I_1} = h_{ie} + R_{L_1} A_{I_1} = 1.1\times10^3 + 10^3(\overset{22.1}{\cancel{49.7}})\times52.1$

$R_{I_1} = \cancel{50.8 k\Omega}\ 1.15 M\Omega$

$$A_{V_1} = \frac{\overset{22.14}{\cancel{49.7\times10^3}}}{\cancel{50.8\times10^3}} = \cancel{0.978}$$

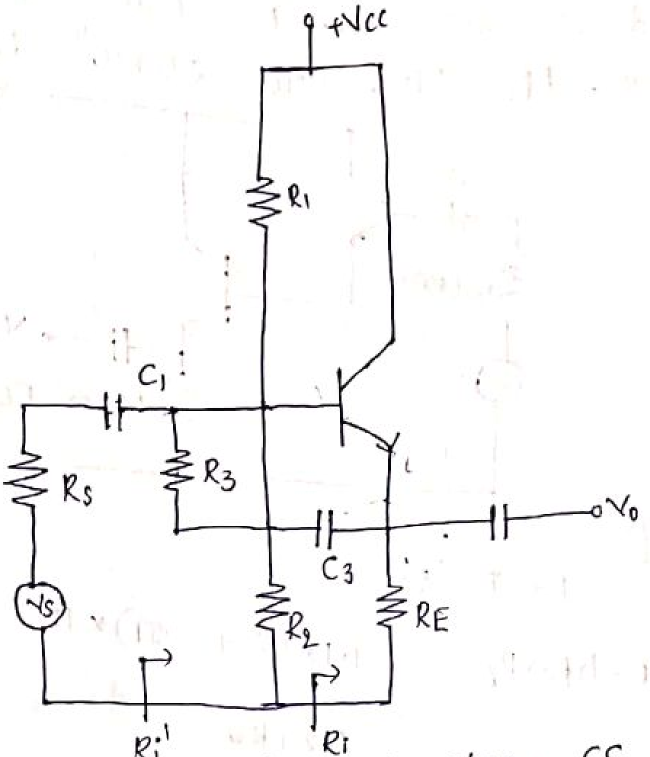
$$A_{V_1} = \frac{A_{I_1} R_{L_1}}{R_{I_1}} = \frac{22.14\times52.1\times10^3}{1.15\times10^6} = 1.0030$$

$$R_{o1} = \frac{h_{ie}+R_s}{1+h_{fe}} = \frac{1.1\times10^3 + 600}{1+50} = 33.33\Omega$$

$(R_{o_1} = R_{s_2})$

$$R_{o2} = \frac{R_{s_2}+h_{ie}}{1+h_{fe}} = \frac{1.1\times10^3 + 33.33}{51} = 22.22\Omega$$

Boot - Strapped Emitter Follower :-



→ The main feature of single stage CC amplifier and two stage CC amplifier is their high i/p resistance. But this high i/p resistance is decreased by the presence of biasing resistor. To overcome this decrease in i/p resistance due to biasing resistors, the single stage emitter - follower circuit is modified by the addition of a resistor R_3 b/w the emitter terminal and the base junction. The bottom of R_3 is connected to the emitter terminal through a capacitor C_3 and the top of R_3 is connected to the base - junction.

→ This modified ckt is called boot strapped emitter follower.

→ Even for low frequency of the i/p signal the capacitor C_3 acts as a short ckt. Thus the resistors R_1 & R_2 pulled to the o/p side. Then the effect of R_1 & R_2 not considered on i/p side.

Using Millers Theorem, the effective resistance due to R_3 on i/p side is given by

$$R_{eff} = \frac{R_3}{1 - A_V}$$

For an emitter follower (CC amp) voltage gain $A_V \cong 1$, then R_{eff} becomes extremely large

For example with $A_V = 0.995$, $R_3 = 100K\Omega$ then

$$R_{eff} = \frac{100K\Omega}{1-0.995}$$

$$R_{eff} = 20M\Omega$$

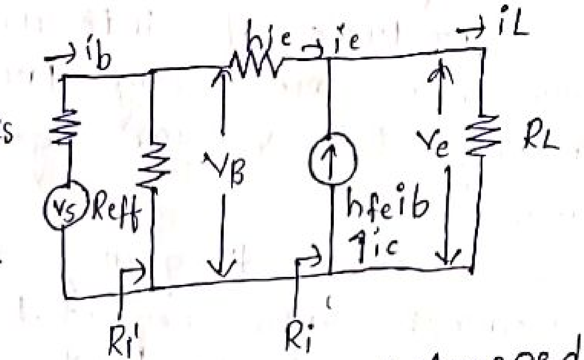
If $R_i = 500K\Omega$, then $R_i' = R_i \| R_{eff}$

$$= 500K\Omega \| 20M\Omega$$

$$R_i' = 487.8K\Omega$$

Hence the high i/p resistance is maintained by the addition resistor R_3.

Analysis :-



app. model of boot strapped emitter follower

i) $R_i = \frac{V_b}{i_b}$

$$= \frac{h_{ie} i_b + i_e R_L}{i_b}$$

$$= \frac{h_{ie} i_b + i_c R_L + i_b R_L}{i_b}$$

$$= \frac{h_{ie} i_b + (i_b + h_{fe} i_b) R_L}{i_b}$$

$$R_i = h_{ie} + R_L + h_{fe} R_L$$

$$R_i' = R_i \| R_{eff}, \quad \text{where } R_{eff} = \frac{R_3}{1-A_V}$$

$$A_I = 1 + h_{fe}$$

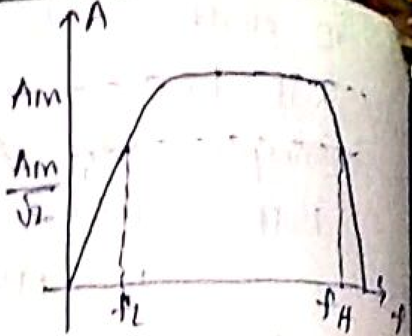
$$A_V = \frac{A_I R_L}{R_I}$$

$$R_o = \frac{R_S + h_{ie}}{1 + h_{fe}}$$

Frequency Response of an amplifier :-

It is the plot of voltage gain of an amplifier against the frequency of the i/p signal. In general the entire frequency range can be divided into 3 parts.

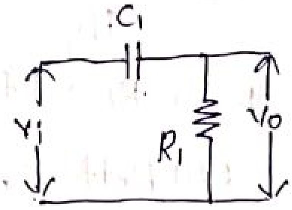
i) Low freq. region
ii) Mid " "
iii) High " "



* freq. response of an amplifier

Mid Frequency Region:-
In mid frequency range the voltage gain is practically constant i.e., it is not effected by the capacitances of the amplifier ckt.
→ The reactance of the coupling capacitors is very small so that they are not effecting the voltage gain in mid frequency range.
The reactance of internal capacitances of the transistors are very large and they are not effecting the voltage gain in mid frequency range.
Thus in mid frequency range all the capacitive reactances are neglected and the gain is maximum and constant.

Low frequency Region:-
In low frequency region, the amplifier ckt behaves like the simple high pass filter and it is shown in fig (b).



From the ckt diagram shown in fig (b).

$$V_0 = \frac{V_i \times R_1}{R_1 + \frac{1}{j\omega C_1}}$$

$$A_L = \frac{V_0}{V_i} = \frac{R_1}{R_1 + \frac{1}{j\omega C_1}}$$

Both NR & D.R is divided with R_1.

$$A_L = \frac{V_0}{V_i} = \frac{1}{1 - j\frac{1}{\omega R_1 C_1}}$$

$$= \frac{1}{1 - j\left[\frac{1}{2\pi f R_1 C_1}\right]}$$

Let $\frac{1}{2\pi R_1 C_1} = f_L$

$$A_L = \frac{1}{1 - j\left(\frac{f_L}{f}\right)}$$

$$|A_L| = \frac{1}{\sqrt{1 + \left(\frac{f_L}{f}\right)^2}}$$

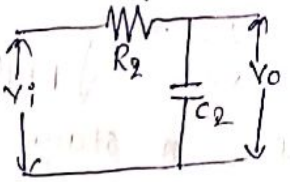
at $f = f_L$

$$|A_L| = \frac{1}{\sqrt{2}}$$

Therefore the frequency at which the gain is $\frac{1}{\sqrt{2}}$ times the its mid band value is called the lower cut off frequency. This drop corresponds to a dB reduction of 3 dB and hence it is also called as lower 3 dB frequency.

High frequency Region:-

In high frequency region the amplifier behaves like low pass filter and it is shown in fig (c).



From the ckt diagram shown in fig (c).

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

$$A_H = \frac{V_o}{V_i} = \frac{1/j\omega C_2}{R_2 + \frac{1}{j\omega C_2}}$$

$$= \frac{1/j\omega C_2}{\frac{R_2 j\omega C_2 + 1}{j\omega C_2}} = \frac{1}{1 + R_2 j 2\pi f C_2}$$

Let $2\pi R_2 C_2 = 1/f_H$

$$A_H = \frac{1}{1 + j\left(\frac{f}{f_H}\right)}$$

$$|A_H| = \frac{1}{\sqrt{1 + \left(\frac{f}{f_H}\right)^2}}$$

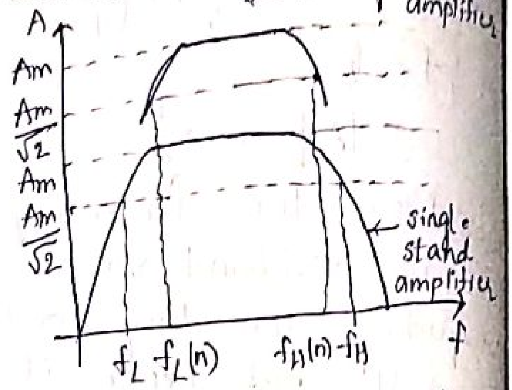
At $f = f_H$, $|A_H| = \frac{1}{\sqrt{2}}$

At which the gain of an amplifier $\frac{1}{\sqrt{2}}$ times of its mid band value is called higher cut off frequency. This drop corresponds to a dB reduction of 3 dB and hence it is also called as higher 3 dB frequency.

Effect of cascading on Band width :-

WKT,

The gain of an amplifier at low frequencies is given by



$$A_L = \frac{1}{\sqrt{1+(f_L/f)^2}} \quad \text{(Single stand)}$$

frequency response of single staged n-stage cascaded amplifier

The lower 3 dB frequency at $f = f_L$, the gain becomes $1/\sqrt{2}$.

$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+(f_L/f)^2}}$$

$|||^{ly}$, for n-stage cascaded amplifier the lower 3 dB frequency is given by

$$\frac{1}{\sqrt{2}} = \left[\frac{1}{\sqrt{1+\left(f_L/f_L(n)\right)^2}}\right]^n$$

$$\frac{1}{\sqrt{2}} = \frac{(1)^n}{\left[\sqrt{1+\left(f_L/f_L(n)\right)^2}\right]^n}$$

$$\left[\sqrt{1+\left(f_L/f_L(n)\right)^2}\right]^n = \sqrt{2}$$

$$\left[1+\left(f_L/f_L(n)\right)^2\right]^n = 2$$

$$1+\left(f_L/f_L(n)\right)^2 = 2^{1/n}$$

$$\left(f_L/f_L(n)\right)^2 = 2^{1/n}-1$$

$$f_L/f_L(n) = \sqrt{2^{1/n}-1}$$

$f_L(n) > f_L$

$$\boxed{f_L(n) = \frac{f_L}{\sqrt{2^{1/n}-1}}} \quad \text{—} (1)$$

WKT,
The gain of single stage amplifier at high frequencies is given by

$$A_H = \frac{1}{\sqrt{1+(f/f_H)^2}}$$

The higher 3 dB frequency at $f = f_H$

$$\frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+(f_H/f_H)^2}}$$

$|||^{ly}$, for n-stage cascaded amplifier the higher 3dB frequency is given by

$$\frac{1}{\sqrt{2}} = \left[\frac{1}{\sqrt{1+\left(\frac{f_H(n)}{f_H}\right)^2}}\right]^n$$ [Equating D.R & S.O.B.S]

$$2 = \left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^n$$

$$1+\left(\frac{f_H(n)}{f_H}\right)^2 = 2^{1/n}$$

$$\left(\frac{f_H(n)}{f_H}\right)^2 = 2^{1/n}-1$$

$$\boxed{f_H(n) = f_H\sqrt{2^{1/n}-1}} \quad \text{— } 2$$

From eq 1 & 2 we conclude that as $f_L(n)$ is greater than f_L and $f_H(n) < f_H$, the band width of n-stage cascaded amplifier. decreases over the band width of single stage amplifier

Differential Amplifier :-

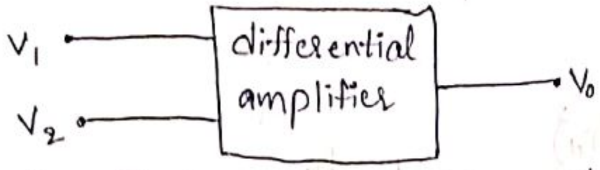


fig: Block diagram representation of differential amplifier.

The differential amplifier (or) difference amplifier amplifies the difference b/w two i/p signals. For an ideal differential amplifier we can write that

$$V_0 \propto V_1 - V_2$$

$$V_0 = A_d (V_1 - V_2)$$

where A_d = constant proportionality (or) differential mode gain.

with this gain differential amplifier amplifies the difference of two i/p's

$$V_0 = V_d A_d \quad \text{—— (1)}$$

But in practical cases the o/p voltage is also proportional to the average (or) common level of two inputs.

i.e., $$V_0 \propto \frac{V_1 + V_2}{2}$$

$$V_0 = A_c \left(\frac{V_1 + V_2}{2}\right)$$

$$V_0 = A_c V_c \quad \text{—— (2)}$$

where A_c = constant of proportionality (or) common mode gain.

Therefore, the total o/p voltage

$$V_0 = A_d V_d + A_c V_c \quad \text{—— (3)}$$

In the design of differential amplifier one goal is to minimize the effect of common mode signal.

These are used in microphone pre-amplifiers, audio pre-amplifiers, radio & T.V signal recovery, digital to analog converters and so on.

Common Mode Rejection Ratio (CMRR)

It is the ability of differential amplifiers to reject the common mode signal and it is expressed in the ratio and it is defined as the ratio of differential mode gain to the common mode gain.

In ideal cases $A_d = \infty$ & $A_c = 0$

$$\rho = \frac{A_d}{A_c}$$

$$\boxed{\rho = \infty}$$

The o/p voltage interms of CMRR :-

The o/p voltage interms of differential amplifier.

WKT, the o/p voltage

$$V_o = A_d V_d + A_c V_c$$

$$= A_d V_d \left(1 + \frac{A_c V_c}{A_d V_d}\right)$$

$$V_o = A_d V_d \left(1 + \frac{1}{\rho} \frac{V_c}{V_d}\right)$$

The o/p voltage in terms of CMRR.

In ideal condition CMRR is infinity then the o/p is proportional to difference of two i/p's only. In practical cases CMRR is very large and it greatly rejects the common mode signals i.e., the o/p voltage mostly proportional to the difference sgl.

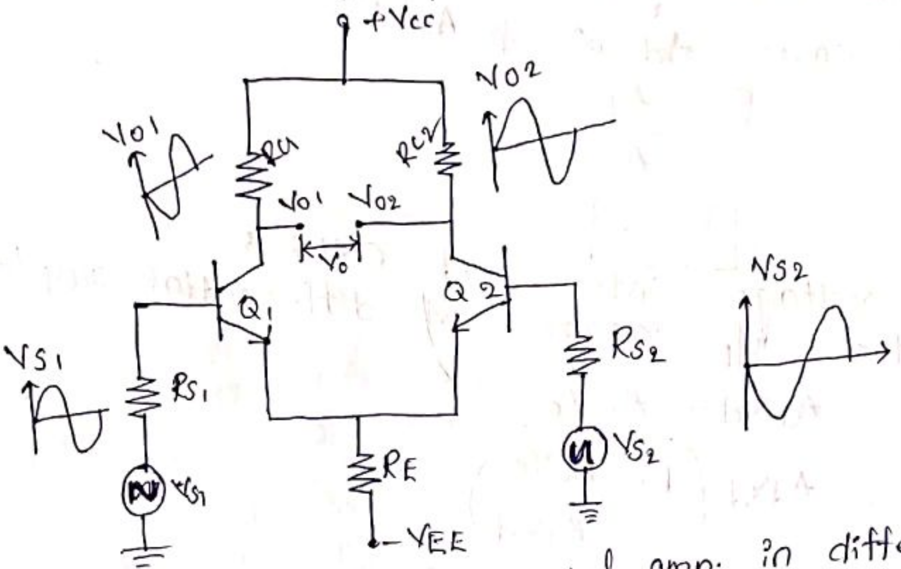
The differential amplifier used in BJT :-

Operating mode of differential amplifier :-

Based on polarities of two inputs of differential amplifier, there are two modes of operations.

1. differential mode of operation.
2. Common mode of operation

Differential Mode of operation :-



a) ckt diagram of differential amp. in differential mode

→ When a differential amplifier as shown in fig (a), has two inputs are equal in magnitude with opposite phase, the mode of operation is called differential mode. Thus the amplified outputs at collector of transistor Q_1 and collector of transistor Q_2 are equal in magnitude with opposite phase.

→ The total o/p voltage is the difference of two individual o/p's.

i.e., $V_0 = V_{01} - V_{02}$

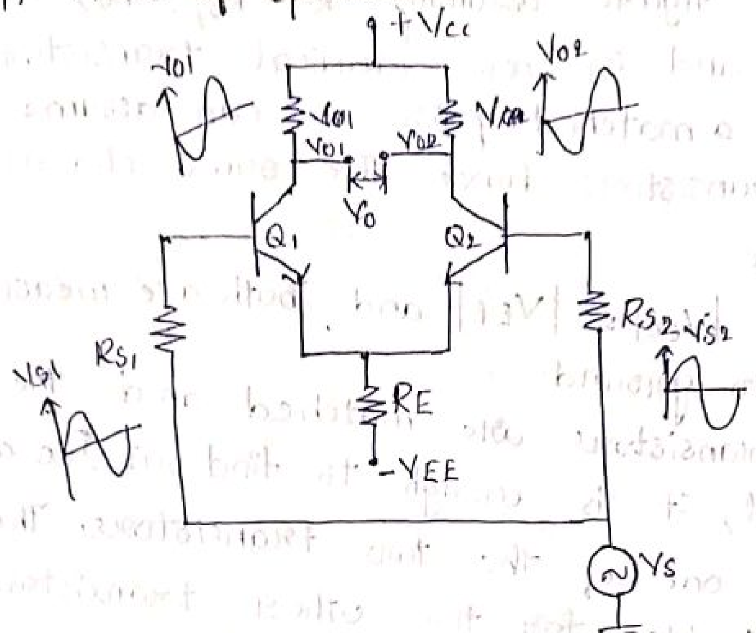
For ex :- $V_{01} = 10V$; $V_{02} = -10V$

$$V_0 = 10-(-10) = 20V$$

Thus, the total o/p voltage = 20V

From the above value, we conclude that in differential mode of operation the total o/p is twice that of the individual o/p's voltage

Common Mode of operation :-



b) ckt diagram of common mode in differential amp. as shown in fig (b),
→ when a differential amplifier the transistors Q_1 and Q_2, with same input for the is called common mode. the mode of operation at collector of transistor Thus two amplified o/p's are equal in Q_1 and collector of transistor Q_2 magnitude and phase.
→ Hence, the total output voltage is equal to difference of two individual outputs and it is equal to zero.

The dc analysis of differential amplifier :-
The dc analysis means to obtain the operating point values. I_{CQ} & V_{CEQ}. The supply voltages are dc, while the input voltages/signals are AC. so, dc equivalent circuit can be obtained by reducing the ac input signals to zero. The dc equivalent ckt is obtained as shown in below figure.

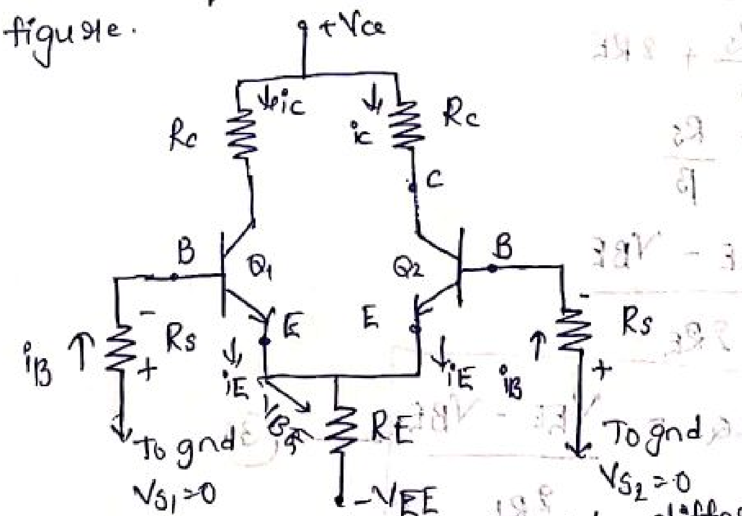


fig: dc equivalent ckt of differential amplifier

From the above figure, assuming $R_{S1} = R_{S2} = R_S$, the transistors Q_1 and Q_2 are identical transistors and hence for such a matched pair we can assume

i) Both the transistors have the same characteristics

ii) $R_{C1} = R_{C2} = R_C$

iii) Magnitude $|V_{CC}| = |V_{EE}|$ and both are measured with respect to ground.

As the two transistors are matched and the ckt is symmetrical, it is enough to find out I_{CQ} and V_{CEQ} for any one of the two transistors. The same is applicable for the other transistor.

Applying KVL to base emitter loop of transistor Q_1

$$i_B R_S + V_{BE} + 2I_E R_E - V_{EE} = 0 \quad -(1)$$

$\because I_C \simeq I_E$

we know that $i_C = \beta i_B$

$$i_B = \frac{i_E}{\beta} \quad -(2)$$

Substitute eq (2) in eq (1)

$$\left(\frac{i_E}{\beta}\right) R_S + V_{BE} + 2I_E R_E - V_{EE} = 0$$

$$i_E \left[\frac{R_S}{\beta} + \frac{V_{BE}}{i_E} + 2R_E - \frac{V_{EE}}{i_E}\right] = 0$$

$$i_E \left[\frac{R_S}{\beta} + 2R_E\right] + V_{BE} - V_{EE} = 0$$

$$i_E = \frac{V_{EE} - V_{BE}}{\frac{R_S}{\beta} + 2R_E}$$

As $2R_E$ is $\gg \frac{R_S}{\beta}$

$$i_E = \frac{V_{EE} - V_{BE}}{2R_E}$$

$$\boxed{i_E = i_C = i_{CQ} = \frac{V_{EE} - V_{BE}}{2R_E}} \longrightarrow (3)$$

From the collector to emitter loop,

$$V_{CE} = V_C - V_E \quad \text{—(4)}$$

$$V_C = V_{CC} - i_C R_C \quad \text{—(5)}$$

The voltage at emitter terminal by neglecting the voltage drop across resistor R_S is given by

$$V_E = -V_{BE} \quad \text{—(6)}$$

Sub. eq 6, 5 in (4)

$$\boxed{V_{CE} = V_{CC} - i_C R_C + V_{BE} = V_{CEQ}} \quad \text{—(7)}$$

Now the Q point coordinates are $Q(V_{CEQ}, I_{CQ})$

$$Q\left(V_{CC} - i_C R_C + V_{BE},\ \frac{V_{EE} - V_{BE}}{2R_E}\right)$$