Multistage Amplifiers

Introduction:-

Amplifiers:-

*) An electronic amplifiers ckt is one, which modifies the characteristics of the input signal, when delievered the out-side.

*) The modification in the characteristics of the input signal can be w.r.t voltage, current, power or phase.

Classification of Amplifiers:-

*) Based on type of signal
1) Small signal
2) Large signal

*) Based on type of configuration
1) Common Emitter
2) Common Base
3) Common Collector

*) Based on class of ~~configur.~~ classification (Q-point)
1) class A amplifier
2) class B amplifier
3) class AB amplifier
4) Class C Amplifier

*) Based on frequency of operation,
1) Direct Current (DC)
2) Audio Frequencies (AF)
3) Radio Frequencies (RF)
4) VHF, UHF and SHF frequencies

*) Based on type of coupling
1) RC coupled amplifiers
2) Inductive coupled amplifiers.
3) Transformer coupled amplifiers
4) Direct Coupled amplifiers.

*) Based on Number of stages
1) Single stage Amplifiers
2) Two stage Amplifiers
3) Multistage Amplifiers
4) The number of stages = 'N'.

*) Based on the output
a) Voltage amplifier
b) Current amplifier

*) Based on the frequency response
a) Audio frequency (AF)
b) Intermediate frequency (IF)
c) ~~Frequ~~ Radio frequency (RF)

*) Based on the bandwidth
a) Narrow band amplifier
b) wide band amplifier

Multistage Amplifiers:-

*) If a Voltage or power gain obtained from a single stage small signal amplifier is not sufficient for a practical application, one have to use more than one stage of amplification to achieve necessary Voltage and power gain.

*) Such an amplifier's called multistage amplifiers.

*) In multistage amplifier, the output of one stage is fed as the input to the next stage.

*) Such a connection is commonly referred to as cascading.

*) A multistage amplifier using two or more single stage common emitter amplifier is called as 'cascading amplifier'.

*) If a multistage amplifier with common emitter amplifier as the first stage and common base as the second stage is called as cascode amplifier.

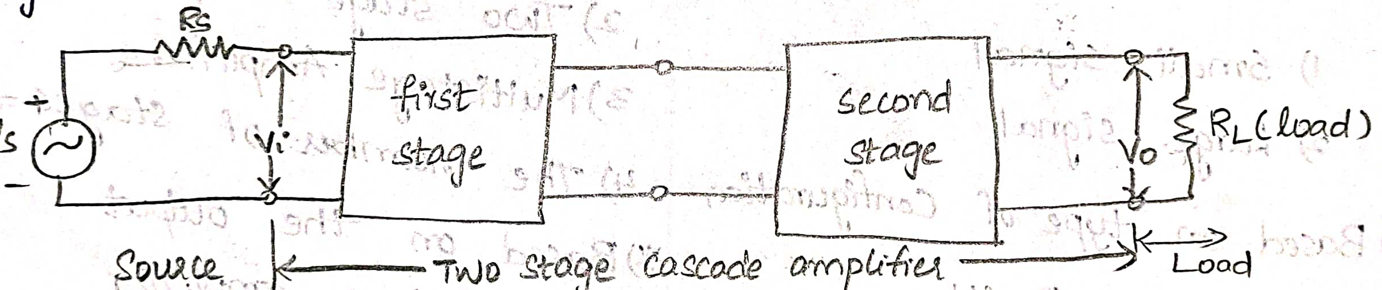


fig: Multistage Amplifier

Different Coupling Schemes used in Amplifiers:-

*) 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 inter stage coupling:

*) Basically, these coupling networks serve the following two purposes

1) It transfer the a.c output of one stage to

the input of the next stage.

2) It isolates the d.c condition of one stage to the next.

1) **Resistance - capacitance (RC) Coupling:-**

*) It is most commonly used discrete device amplifiers as it is least expensive and has satisfactory frequency response.

*) In this method, the signal developed across the collector resistor R_c of each stage is coupled through capacitor C_c into the next stage.

*) The coupling capacitor C_c isolates the dc conditions of one stage from the following stage.

*) The amplifiers using this coupling scheme are called RC coupled amplifiers.

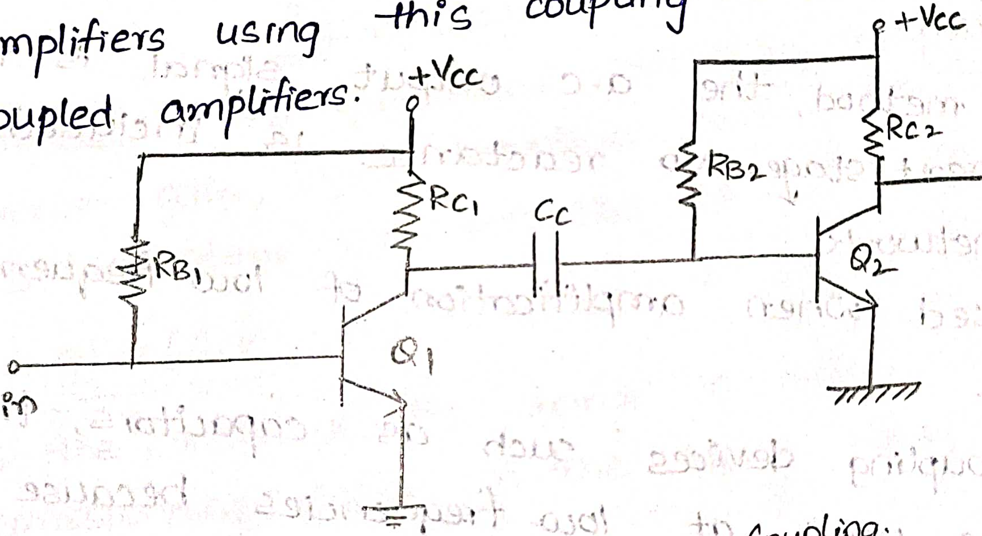


fig:- Resistance - capacitance Coupling.

2) **Transformer Coupling:-**

*) In this method, the primary winding of the transformer acts as a collector load and the secondary winding transfers ~~transforme~~ the a.c output signal directly to the base of the next stage.

*) Such a coupling increases the overall circuit gain and the level of inter stage impedence matching.

*) However, transformers with broad frequency response are very expensive and hence, this type of coupling is restricted mostly to power amplifiers where efficient

impedence matching is a critical requirement for maximum Power transfer and efficiency.

*) The amplifiers using this coupling scheme are called "Transformer- Coupling amplifiers."

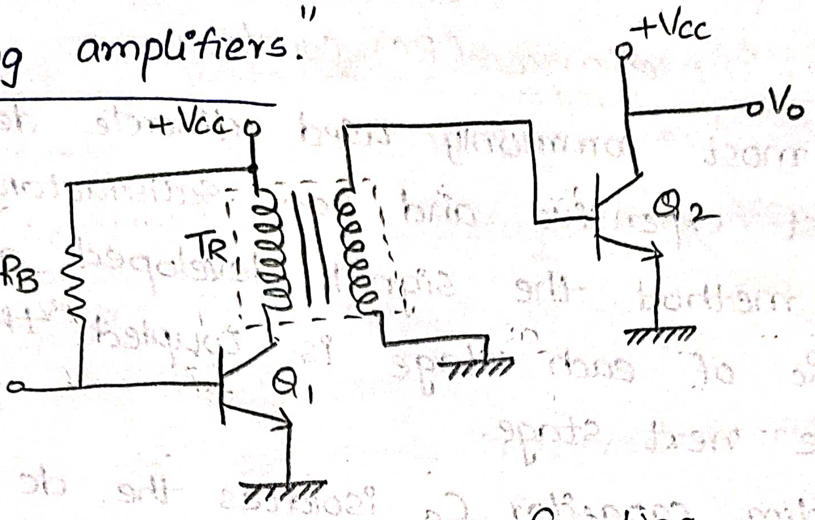


fig: Transformer Coupling.

3) Direct Coupling:-

*) In this method, the a.c output signal is fed directly to the next stage. No reactance is included in the coupling network.

*) It is used when amplification of low frequency signals is to be done.

*) Further, coupling devices such as capacitors, transformers cannot be used at low frequencies because their size becomes very large.

*) The amplifiers using this coupling scheme are called 'Direct- Coupled Amplifiers'.

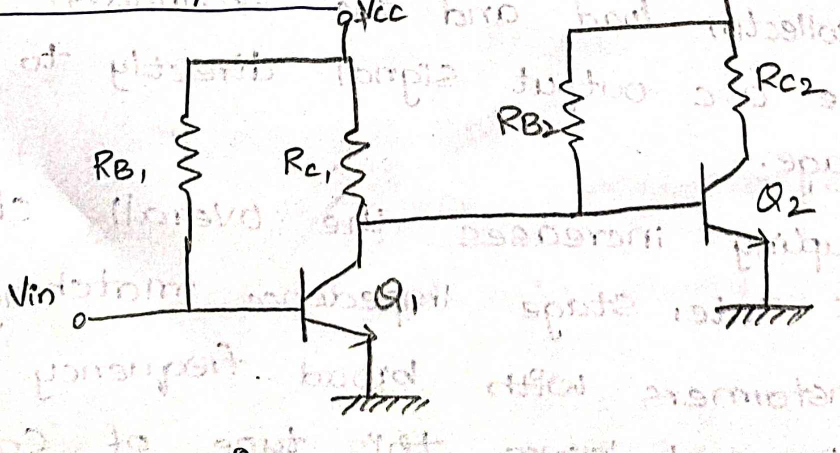


fig: Direct Coupling.

General Analysis of Cascade Amplifiers:-

*) The most popular cascade amplifier is formed by cascadin-g several CE amplifier stages.

*) Considering the analysis of general 'n' stages CE amplifier as shown in fig:

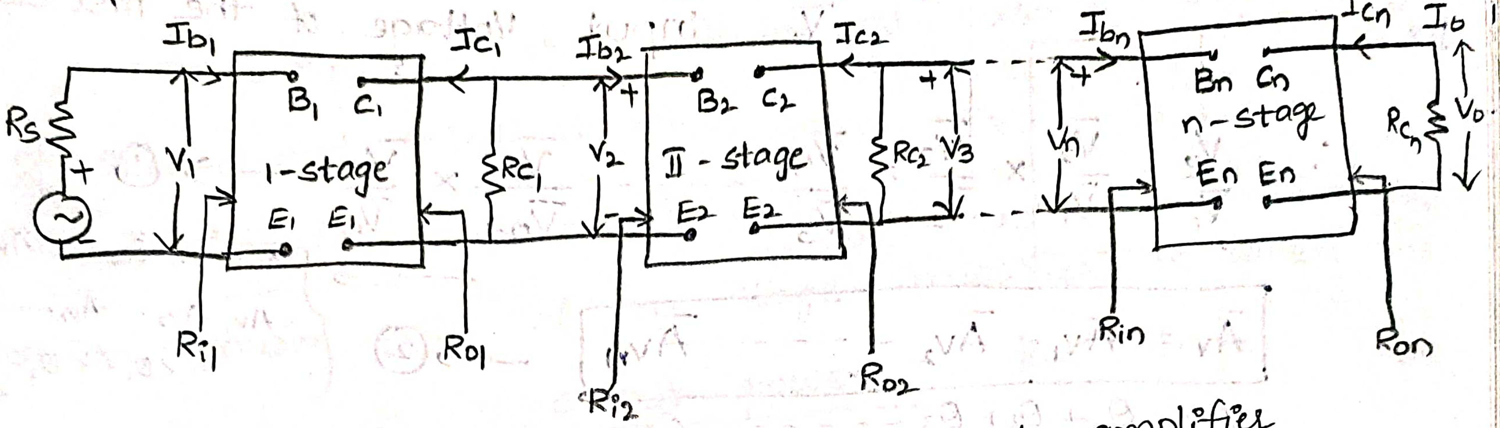


fig: n-Stage CE cascade amplifier

*) The expressions for quantities such as voltage gain, current gain, power gain, input impedence and output impedence of this 'n' stage CE amplifier are to be derived.

(a) Voltage gain (A_V):-

*) It is the ratio of the change in output voltage to the corresponding change in the input voltage

$$A_V = \frac{\Delta V_o}{\Delta V_i}$$

*) In a multistage amplifier, the output voltage of first stage acts as the input voltage to next stage. and so on

*) The voltage gain of the complete cascade amplifier is equal to the product of the voltage gain of the individual stages.

*) The voltage gain of the first stage,

$$A_{V_1} = \frac{V_2}{V_1} = \frac{\text{output voltage of first stage}}{\text{input voltage of first stage}}$$

*) Similarly expressions can be written for all the 'n' stages of the cascade amplifier.

*) The resultant voltage gain,

$\bar{A}_V = A_V \angle \theta$

$$\bar{A}_V = \frac{\bar{V}_o}{\bar{V}_1} = \frac{\text{output voltage of the } n^{th} \text{ stage}}{\text{input voltage of the first stage}}$$

$$\therefore \frac{\bar{V}_o}{\bar{V}_1} = \frac{\bar{V}_2}{\bar{V}_1} \times \frac{\bar{V}_3}{\bar{V}_2} \times \frac{\bar{V}_4}{\bar{V}_3} \text{-----} \frac{\bar{V}_n}{\bar{V}_{n-1}} \times \frac{\bar{V}_o}{\bar{V}_n} \longrightarrow (1)$$

$$\boxed{\bar{A}_V = \bar{A}_{V_1} \cdot \bar{A}_{V_2} \text{----} \bar{A}_{V_n}} \longrightarrow (2)$$

$\theta = \theta_1 + \theta_2 + \theta_3$ ------ θ_n

$\bar{A}_V = \bar{A}_{V_1} \cdot \bar{A}_{V_2}$ --- $\bar{A}_{V_n}$

$= A_{V_1} \cdot A_{V_2} \cdot$ -- A_{V_n} -- --- $\angle\theta_1 + \angle\theta_2 +$ --- $\angle\theta_n$

(b) Current Gain (A_I):-

*) In order to find the resultant voltage gain, the voltage gain, of the individual stages can be found out and the product of these gains gives the resultant voltage gain.

*) Alternatively the resultant voltage gain can be found directly by the relation.

$$\boxed{\bar{A}_V = \frac{\bar{A}_I \cdot R_{cn}}{R_{i_1}}} \longrightarrow (3)$$

Where, $\bar{A}_I$ is the current gain of the complete n-stage amplifier.

Now, $\bar{A}_I$ is given by,

$$\bar{A}_I = \frac{\bar{I}_o}{\bar{I}_{b_1}} = \frac{-\bar{I}_{cn}}{\bar{I}_{b_1}} \longrightarrow (4)$$

Now, $$\frac{-\bar{I}_{cn}}{\bar{I}_{b_1}} = \frac{-\bar{I}_{c_1}}{\bar{I}_{b_1}} \cdot \frac{\bar{I}_{c_2}}{\bar{I}_{c_1}} \text{---} \frac{\bar{I}_{cn}}{\bar{I}_{c(n-1)}} \longrightarrow (5)$$

or,

$$\bar{A}_I = \bar{A}_{I_1} \cdot \bar{A}'_{I_2} \cdot \bar{A}'_{I_3} \cdots \bar{A}_{I_n} \longrightarrow (6)$$

Here,

$\bar{A}_{I_1}$ is the base to collector gain of the first stage and equals $-\frac{\bar{I}_{c_1}}{\bar{I}_{b_1}}$

While,

$\bar{A}'_{I_2}$, $\bar{A}'_{I_3}$ are the collector to collector current gains, of second and third stages.

c) Power Gain (A_p):-

*) The power gain of n- stage amplifier is given by,

$$\bar{A}_p = \frac{\text{output power of last stage}}{\text{Input power of first stage.}}$$

$$= \frac{\bar{V}_o \bar{I}_o}{\bar{V}_1 \bar{I}_{b_1}} = \frac{-\bar{V}_o \bar{I}_{cn}}{\bar{V}_1 \cdot \bar{I}_{b_1}}$$

$$\boxed{\bar{A}_p = \bar{A}_V \cdot \bar{A}_I} \longrightarrow (7)$$

Substituting,

$\bar{A}_V = (\bar{A}_I) \frac{R_{cn}}{R_{i1}}$ in eq^n (7), we get

$$\boxed{\bar{A}_p = (\bar{A}_I)^2 \cdot \frac{R_{cn}}{R_{i1}}} \longrightarrow (8)$$

Input Impedence:-

*) By starting from last stage and proceeding towards the first stage, the input impedence can be found out as

Find i) $\bar{A}_{I_n} = \frac{-h_{fe}}{1 + h_{oe} R_{L_n}}$

ii) $R_{in} = h_{ie} + h_{re} \bar{A}_{I_n} R_{L_n}$

iii) $\bar{R}_{L(n-1)} = R_{c(n-1)} \,||\, R_{i(n)}$ $\quad$ $R_{L(n-1)}$ – $(n-1)^{th}$ stage load impedence

iv) Calculate $\bar{A}_{I(n-1)}$, $R_{i(n-1)}$ & $\bar{R}_{L(n-2)}$

v) Proceed in this manner to find the effective i/p imedence of first stage.

Output Impedence:-

*) The output impedence of each transistor amplifier stage and that of the complete multistage amplifiers may be calculated from the first stage.

$$Y_{o1} = h_{oe} - \frac{h_{fe}\, h_{re}}{h_{ie} + R_s}$$

$R_{o1} = \frac{1}{Y_{o1}}$ gives the output impedence of the first transistor.

*) Parallel combination of R_{o1} with R_{c1} forms the output impedence of the first stage.

$$R_{ot1} = \frac{R_{o1}\, R_{c1}}{R_{o1} + R_{c1}}$$

*) This R_{ot1} forms the source impedence of the second stage. ~~Since~~

find $R_{ot2} = R_{o2} \,||\, R_{c2}$, where $R_{o2} = \frac{1}{Y_{o2}}$

Similarly, proceed to find output impedence of the last stage.

(Problems)

Choice of transistor Configuration in a Cascade Amplifier:-

*) Cascading of amplifier stages is usually done to increase the total gain of the amplifier. However, Sometimes Cascading is done to get the desired output and input impedence for Specific applications.

*) Transistor amplifier may be connected in any of the three configurations namely common Emitter (CE), Common base (CB) and common Collector (CC).

*) However, in cascade amplifier meant for providing high gain, only CE amplifier stage are connected in cascade, CB and CC configurations can not be used for this Purpose.

*) Choice of transistor configuration to be used for intermed-iate stages in a multistage amplifier depends on the maximum voltage gain provided by the configuration.

*) Hence, CC amplifier gives voltage gain less than unity. A single stage CB amplifier, gives voltage gain more than unity but intermediate stages can't use even CB configuration since the overall voltage gain of multistage amplifier using CB configuration is low.

*) Hence, CE stage are popularly used for intermediate stages since its overall gain is much greater than unity.

Two-Stage RC Coupled Amplifier:-

*) The resistance-capacitance coupling is, in short term-ed as RC coupling. This is mostly used coupling technique in amplifiers.

Construction of a Two-stage RC Coupled Amplifier:-

*) The two stage amplifier circuit has two transistors, connected in CE configuration and a common power supply V_{cc} is used.

*) The potential (Voltage) divider network R_1 & R_2 and the resistor R_e form the biasing and stabilization network.

*) The emitter by-pass capacitor C_e offers a low reactance path to the signal.

*) The resistor R_L is used as a load impedence. The input capacitor C_{in} present at the initial stage of the amplifier couples AC signal to the base of the transistor.

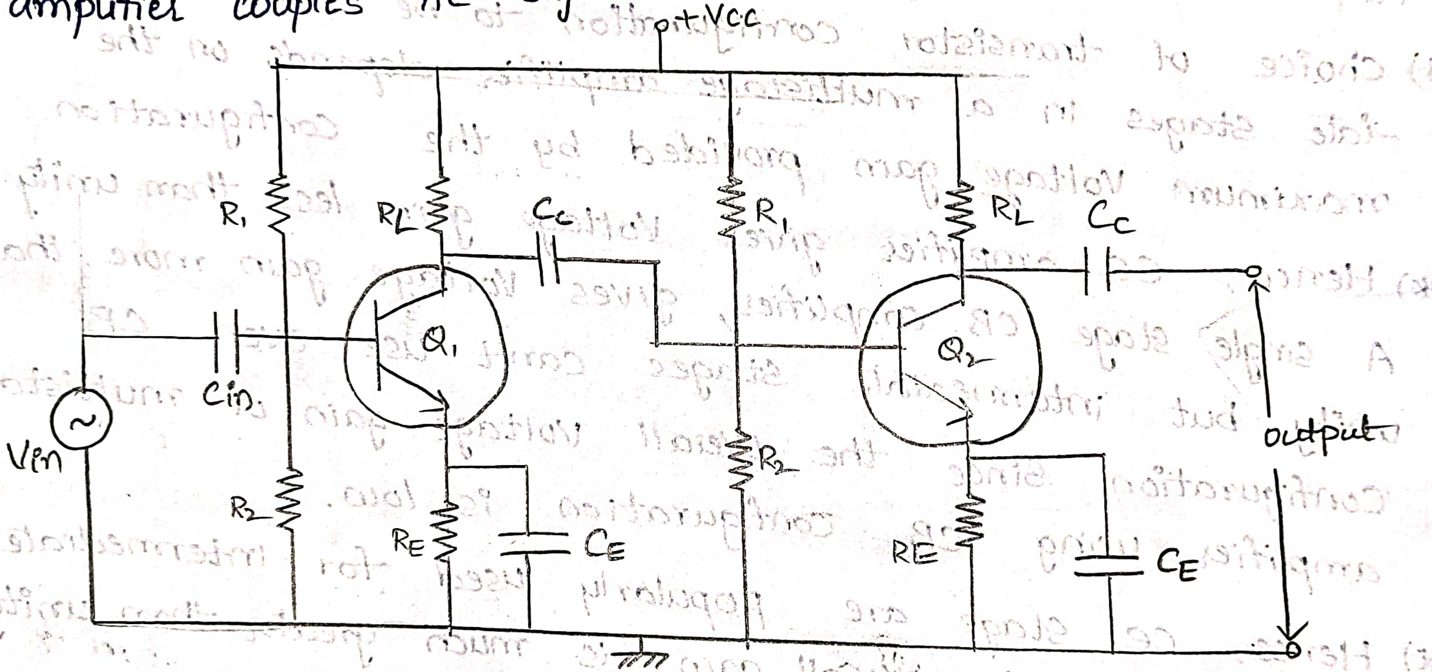


fig: RC Coupled CE Amplifier

*) The capacitor C_c is the coupling capacitor that connects two stages and prevent DC interference between the stages and control the shift of operating point.

Operation of RC Coupled Amplifier:-

*) When an AC input signal is applied to the base of first transistor, it gets amplified and appears at the collector load R_L which is then passed through the coupling capacitor C_c to the next stage.

*) This becomes the input to the next stage, whose amplified output again appears across its collector load. Thus the signal is amplified in stage by stage action.

*) The important point that has to be noted here is that the total gain is less than the product of the gains of individual stages.

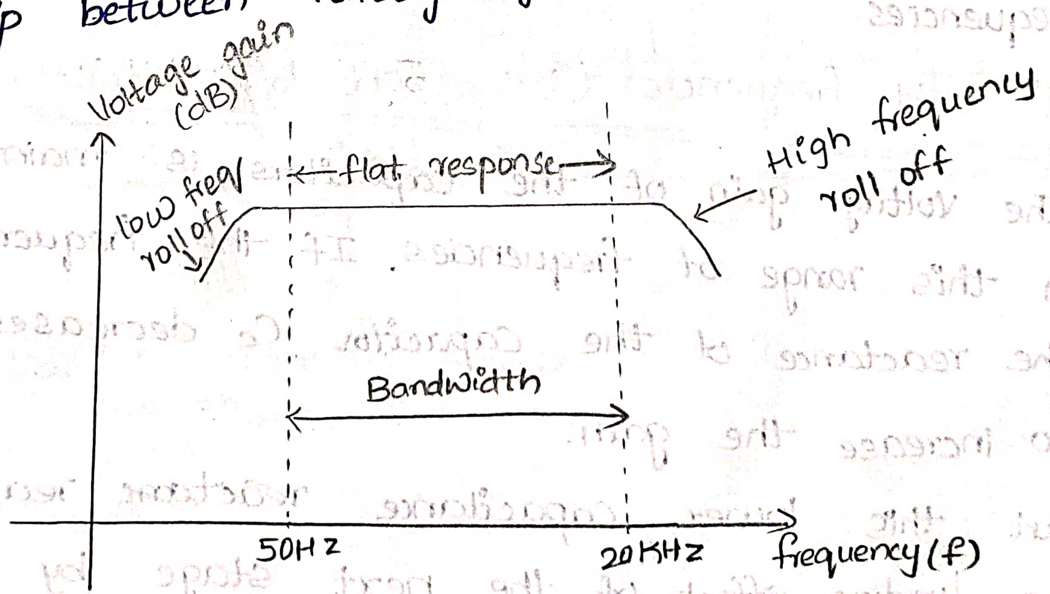
*) This is because when a second stage is made to follow the first stage, the effective load resistance of the first stage is reduced due to the shunting effect of the input resistance of the second stage.

*) Hence, in a multistage amplifier, only the gain of the last stage remains unchanged.

Frequency of RC Coupled Amplifier:-

*) The frequency response curve is a graph that indicates the relationship between voltage gain and function of frequency.

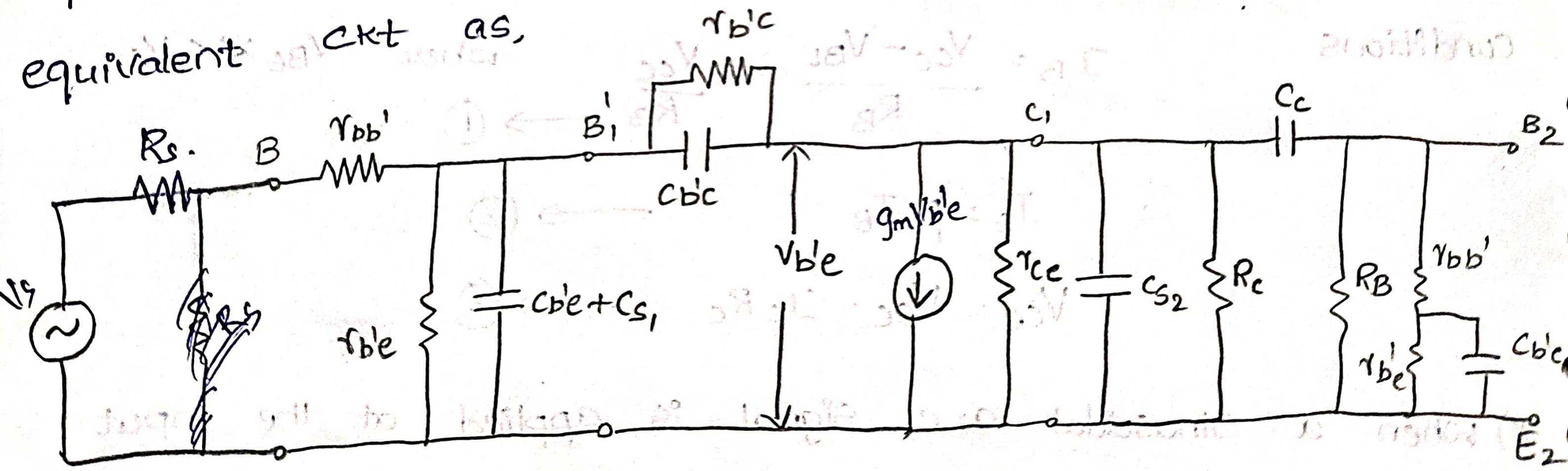
*)



Voltages of CE Amplifier

Analysis & frequency response of RC coupled amplifier :-

*) For finding the response of the RC coupled amplifier in the three frequency ranges, the transistor Q_1 is replaced by its high frequency π- model yielding the equivalent ckt as,



*) Here, C_{s_1}, C_{s_2} represent stray capacitances caused by wiring. $R_B = R_1 || R_2$ is the biasing resistance of

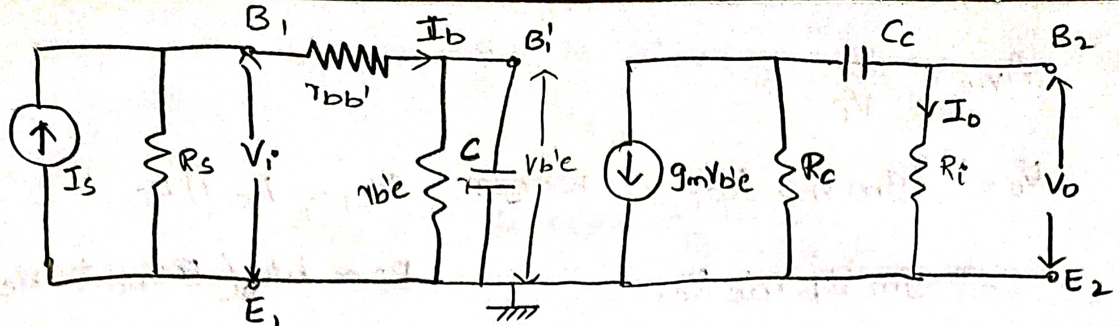


fig: Simplified equivalent ckt of RC coupled Amplifier ~~at mid frequency.~~

*)

*) **Mid-frequency range:-**

⇒ In mid-frequency range, the reactance offered by C_c is small enough so that it can be omitted.

→ The frequency is small enough to make shunt capacitance - reactance $\left(X_c = \frac{1}{\omega c}\right)$ extremely large.

⇒ Hence, 'C' can be omitted in the equivalent circuit

⇒ Let I_o be the current through the resistance R_i. This current I_o is useful output current from the first stage and forms the input current for the next stage.

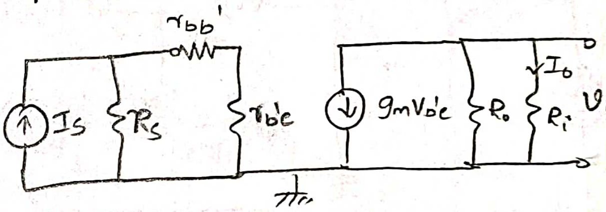


fig: Simplified equivalent ck of Rc coupled amplifier at mid freq

i) current gain:- $A_{Im} = \frac{I_o}{I_b}$

$$I_o = -g_m V_{b'e} \cdot \frac{R_c}{R_c + R_i}$$

$$A_{Im} = -\frac{g_m V_{b'e}}{I_b} \cdot \frac{R_c}{R_c + R_i}$$

But, $V_{b'e} = I_b \cdot r_{b'e}$

Hence,

$$A_{Im} = -g_m r_{b'e} \cdot \frac{R_c}{R_c + R_i}$$

$g_m r_{b'e} \approx h_{fe}$ [Simplified using approximate model]

$$\therefore \boxed{A_{Im} = -h_{fe} \cdot \frac{R_c}{R_c + R_i}}$$

2) Voltage gain:- $A_{vm} = \frac{V_o}{V_i}$

$V_o = -g_m V_{b'e} R_{ci}$ where, $R_{c1} = R_c \parallel R_i$

$= -g_m I_b r_{b'e} R_{ci}$ $R_i \approx h_{ie} (r_{bb'} + r_{b'e})$

$V_i = I_b(r_{bb'} + r_{b'e})$

$V_i = I_b h_{ie}$

Hence,

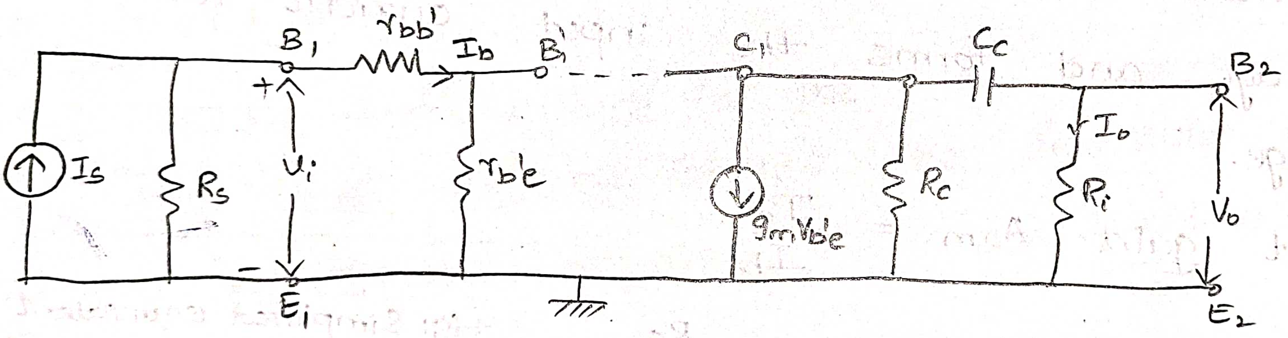
$$A_{vm} = \frac{V_o}{V_i} = \frac{-g_m V_{b'e} R_{ci}}{I_b h_{ie}} = \frac{-g_m \cancel{I_b} r_{b'e} R_{ci}}{\cancel{I_b} h_{ie}}$$

Substituting $g_m r_{b'e} \approx h_{fe}$ then, $\boxed{A_{vm} = \frac{-h_{fe} \cdot R_{ci}}{h_{ie}}}$

*) Low frequency range:-

⇒ In low frequency range capacitor 'C' is omitted since its reactance is extremely large as $X_c \parallel r_{b'e} \approx r_{b'e}$.

⇒ However, C_c capacitor cannot be neglected.



1) Current gain:- $A_{Il} = \frac{I_o}{I_b}$

From fig:-

$$I_o = -g_m V_{b'e} \cdot \frac{R_c}{R_c + (R_i - jX_c)}$$

$$= -g_m V_{b'e} \cdot \frac{R_c}{R_c + R_i + \frac{1}{jX_c}}$$

$$= -g_m V_{b'e} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega_c}}$$

$$A_{Il} = \frac{-\cancel{g_m V_{b'e}} \cdot \cancel{R_c}}{}$$

$$A_{Il} = \frac{-g_m I_b r_{b'e}}{I_b} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$A_{Il} = -g_m r_{b'e} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$= -h_{fe} \cdot \frac{R_c}{R_c + R_i + \frac{1}{j\omega C_c}}$$

{dividing N & D with $R_c + R_i$)

$$= \frac{-h_{fe} R_c}{R_c + R_i} \cdot \frac{R_c + R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$= A_{Im} \cdot \frac{R_c + R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$= A_{Im} \frac{R_c + R_i}{R_c + R_i} \left[\frac{1}{1 + \frac{1}{j\omega C_c (R_c + R_i)}} \right]$$

$$= A_{Im} \left[\frac{1}{1 - j/\omega C_c (R_c + R_i)} \right]$$

$$= A_{Im} \left[\frac{1}{1 - j/2\pi f C_c (R_c + R_i)} \right]$$

$$A_{Il} = \frac{A_{Im}}{1 - \frac{jf_L}{f}} \quad \text{where, } f_L = \frac{1}{2\pi C_c (R_c + R_i)}$$

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

*) The phase angle of current gain at any freq 'f' is given by,

$$\phi_{li} = \text{phase angle of } A_{Im} + \tan^{-1}(f_L/f)$$

$$= 180° + \tan^{-1}(f_L/f)$$

At, $f_L = f$ then, $|A_{Il}| = \frac{|A_{Im}|}{\sqrt{1 + (1)^2}} = \frac{|A_{Im}|}{\sqrt{2}}$

$$= 0.707 |A_{Im}|$$

Thus, f_L forms the lower 3 dB frequency for the current gain.

(ii) Voltage gain:-

$$A_{vl} = \frac{V_o}{V_i}$$

$$V_o = I_o \cdot R_i$$

$$= -g_m r_{b'e} \cdot I_b \cdot \frac{R_c R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$V_i = I_b (r_{bb'} + r_{b'e}) \simeq I_b \cdot h_{ie}$$

$$A_{vl} = \frac{V_o}{V_i} = \frac{-g_m r_{b'e} \cdot \cancel{I_b}}{\cancel{I_b} \cdot h_{ie}} \left(\frac{R_c R_i}{R_c + R_i + \frac{1}{j\omega C_c}} \right)$$

Substituting $g_m r_{b'e} = h_{fe}$ we get,

$$A_{vl} = \frac{-h_{fe}}{h_{ie}} \cdot \frac{R_c R_i}{R_c + R_i + \frac{1}{j\omega C_c}}$$

$$= \frac{-h_{fe}}{h_{ie}} \underbrace{\left(\frac{R_c R_i}{R_c + R_i} \right)}_{R_c \| R_i} \left[\frac{1}{1 + \frac{1}{j\omega C_c (R_c + R_i)}} \right]$$

$R_c \| R_i = R_{ci}$;"

$$= \frac{-h_{fe}}{h_{ie}} \cdot R_{ci} \left[\frac{1}{1 - \frac{j}{\omega C_c (R_c + R_i)}} \right]$$

$$= \underbrace{\frac{-h_{fe} R_{ci}}{h_{ie}}}_{A_{vm}} \left[\frac{1}{1 - \frac{j}{2\pi f C_c (R_c + R_i)}} \right]$$

where,

$$f_L = \frac{1}{2\pi C_c (R_c + R_i)}$$

$$A_{vl} = A_{vm} \left(\frac{1}{1 - \frac{j f_L}{f}} \right)$$

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

*) The phase angle of voltage gain

$$\phi_{ve} = \text{phase angle of } A_{vm} + \tan^{-1}(f_L/f)$$

$$= 180^\circ + \tan^{-1}(f_L/f)$$

At $f = f_L$,

$$|A_{ve}| = \frac{|A_{vm}|}{\sqrt{2}} = 0.707\,|A_{vm}|$$

Thus, f_L forms the lower 3dB frequency for the voltage gain. Since in both derivations 'f_L' are same.

*) High frequency range:-

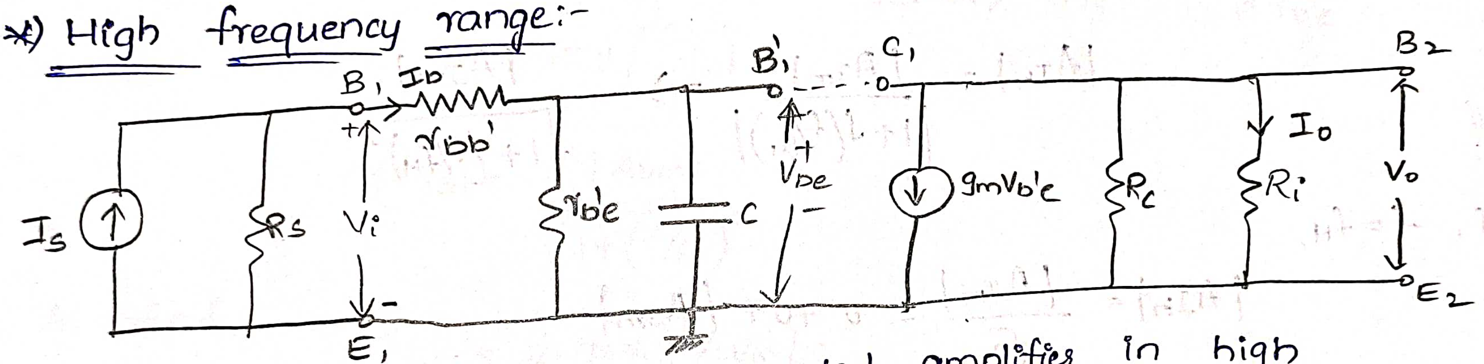


fig: Equivalent circuit of RC coupled amplifier in high frequency range

*) In this frequency range coupling capacitance 'C_c' is neglected since its reactance is small, whereas the shunt capacitance 'C' cannot be neglected to the equivalent ckt.

i) Current Gain:-

$$I_o = -g_m V_{b'e} \cdot \frac{R_c}{R_c + R_i}$$

where,

$$V_{b'e} = \frac{I_b}{\frac{1}{r_{b'e}} + j\omega C} = \frac{I_b \cdot r_{b'e}}{1 + j\omega C\, r_{b'e}}$$

$$\therefore I_o = -g_m \frac{I_b \cdot r_{b'e}}{1 + j\omega C\, r_{b'e}} \cdot \frac{R_c}{R_c + R_i}$$

*) Hence, current gain in high frequency range,

$$A_{Ih} = \frac{I_o}{I_b} = -g_m r_{b'e} \cdot \frac{R_c}{R_c + R_i} \cdot \frac{1}{1 + j\omega C r_{b'e}}$$

$$= \underbrace{-h_{fe} \cdot \frac{R_c}{R_c + R_i}}_{A_{Im}} \cdot \frac{1}{1 + j\omega C r_{b'e}}$$

$$= A_{Im} \cdot \frac{1}{1 + j\omega C r_{b'e}}$$

let,

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

$$A_{Ih} = \frac{A_{Im}}{1 + j(f/f_H)}$$

$$|A_{Ih}| = \frac{|A_{Im}|}{|1 + j(f/f_H)|} \Rightarrow \frac{|A_{Im}|}{\sqrt{1 + (f/f_H)^2}}$$

If, $f = f_H$,

$$|A_{Ih}| = \frac{|A_{Im}|}{\sqrt{2}} = 0.707 \, |A_{Im}|$$

Hence,
'f_H' forms the upper 3 dB frequency.

*) Phase angle of current gain at any frequency f is given by,

$$\phi_{Ih} = \text{phase angle of } A_{Im} - \tan^{-1}(f/f_H)$$

$$= 180^\circ + \tan^{-1}(f/f_H)$$

ii) Voltage gain :-

$$V_o = -g_m V_{b'e} R_{ci} \qquad R_{ci}(R_c \parallel R_i)$$

$$V_o = -g_m R_{ci} \cdot \frac{I_b}{\frac{1}{r_{b'e}} + j\omega C}$$

$$= -g_m R_{ci} \frac{r_{b'e} I_b}{1 + j\omega C r_{b'e}}$$

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

$$V_o = -h_{fe} \frac{R_{ci} I_b}{1+j\omega C r_{b'e}}$$

$$V_i = I_b h_{ie} \qquad h_{ie} = r_{bb'} + r_{b'e}$$

$$A_{vh} = \frac{V_o}{V_i} = \frac{-h_{fe}}{h_{ie}} \cdot \frac{R_{ci}}{1+j\omega C r_{b'e}}$$

Since, $A_{vm} \; \frac{-h_{fe} R_{ci}}{h_{ie}}$ then, $A_{vh} = \frac{A_{vm}}{1+j\omega C r_{b'e}}$

$$= \frac{A_{vm}}{1+j2\pi f C r_{b'e}}$$

$$= \frac{A_{vm}}{1+j\left(f/f_H\right)} \qquad \text{where, } f_H = \frac{1}{2\pi C \cdot r_{b'e}}$$

$$|A_{vh}| = \frac{|A_{vm}|}{\sqrt{1+(f/f_H)^2}}$$

At, $f = f_H$

$$= 0.707 \, |A_{vm}|$$

Thus, f_H forms the upper 3 dB frequency.

*) Phase angle of Voltage gain at any frequency 'f'

$$\phi_{vh} = \text{phase angle of } A_{vm} - \tan^{-1}(f/f_H)$$

$$= 180° - \tan^{-1}(2\pi f C r_{b'e})$$

Since, $f_H = \frac{1}{2\pi C r_{b'e}}$ in both cases, upper 3 dB frequencies of A_{Ih} and A_{vh} are the same. (freq response graph)

*) Gain - Bandwidth product:-

~~It is~~ for the current gain,

$$|A_{Im} \cdot f_H| = h_{fe} \cdot \frac{R_c}{R_c + R_i} \cdot \frac{1}{2\pi C r_{b'e}}$$

$$= \frac{g_m r_{b'e}}{2\pi C r_{b'e}} \cdot \frac{R_c}{R_c + R_i}$$

$$= \frac{g_m}{2\pi C} \cdot \frac{R_c}{R_c + R_i}$$

⇒ For Voltage gain,

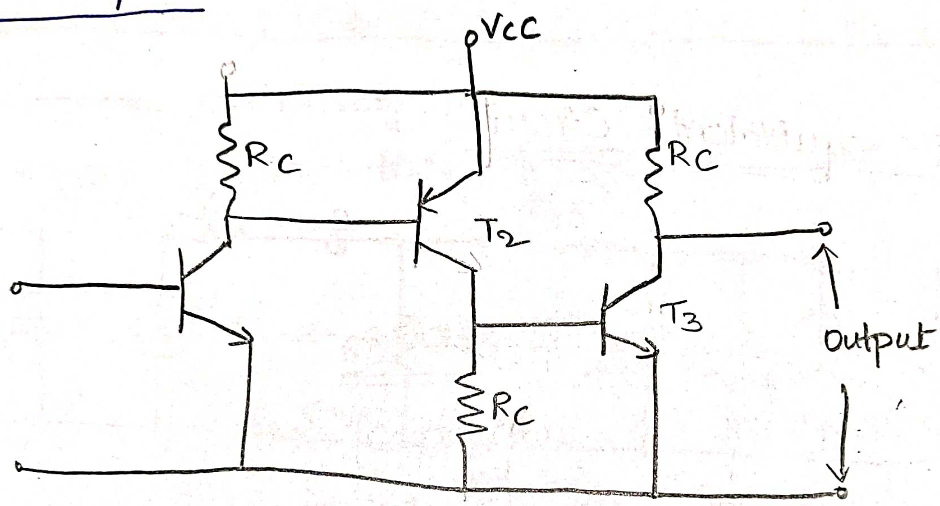
$$\boxed{|A_{vm} \cdot f_H| = \frac{h_{fe}}{h_{ie}} \cdot R_{ci} \cdot \frac{1}{2\pi C r_{b'e}}}$$

$$= \frac{g_m}{2\pi C} \cdot \frac{R_{ci}}{h_{ie}}$$

Direct- Coupled Amplifier:-

*) As no coupling devices are used, the coupling of the amplifier stages is done directly and hence called as "Direct- Coupled Amplifier".

Construction: -



*) The figure below indicates the three stage direct coupled transistor amplifier.

*) The output of first stage T_1 is connected to the input of second stage transistor T_2.

*) The transistor in the first stage is NPN transistor, while the transistor in the next stage is PNP and so on.

*) This is because, the variations in one transistor tend to cancel the variations in the other. The rise in the collector current and the variation in β of one transistor gets cancelled by the decrease in the other.

Operation:-

*) The input signal when applied at the base of transistor T_1, it gets amplified due to the transistor action and the amplified output appears at the collector resistor R_c of the transistor T_1.

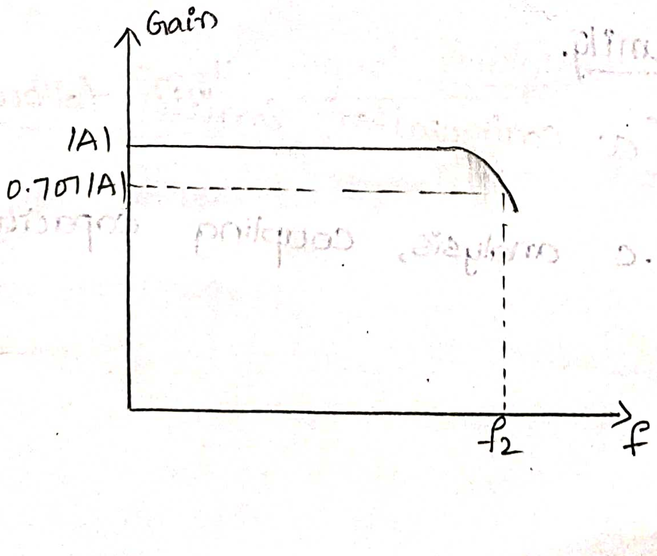
*) This output is applied to the base of transistor T_2 which further amplifies the signal. In this way, a signal is amplified in a direct coupled amplifier circuit.

Frequency Response:-

*) The frequency response curve of a directly coupled amplifier is flat up at an upper cut-off frequency f_2.

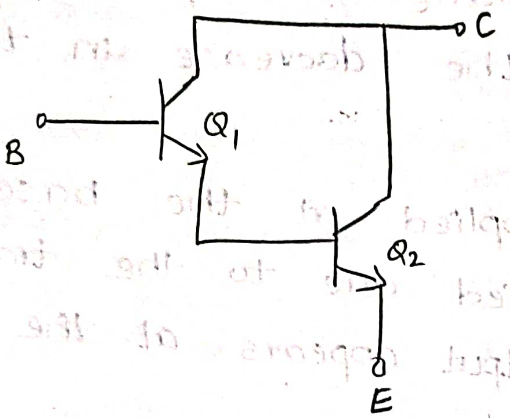
*) After this cut-off frequency, stray wiring capacitances and internal transistor capacitances play their role.

*) As a result the gain falls.

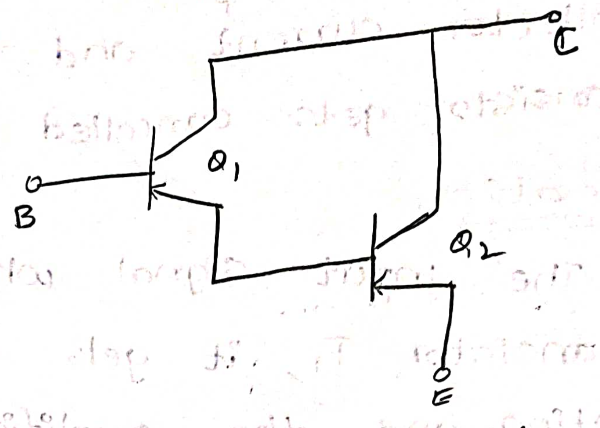


Principle of Darlington Amplifier:-

*) In order to increase the overall values of circuit current gain and input impedence, two transistors are connected in series in CC configuration. Such circuit is called as "Darlington pair".



NPN Transistors



PNP Transistors.

*) The Darlington transistor acts like a single transistor that has high current gain and high input impedence.

*) Note that emitter of first transistor is connected to the base of the second transistor and the collector terminals of the two transistors are connected together.

*) The result is that emitter current of the first transistor is the base current of the second transistor.

*) Therefore the current gain of the pair is equal to the product of individual current gains i.e., $\beta = \beta_1 \beta_2$

*) It can be shown that the voltage gain of the Darlington pair is less than unity.

Darlington Amplifier:- (CC Configuration, Emitter follower)

1) DC Analysis:- In D.C analysis, coupling capacitors acts as open circuited.

where, $Z_b \cong \beta_D \left[\frac{1}{gm_2} + R_E \right]$

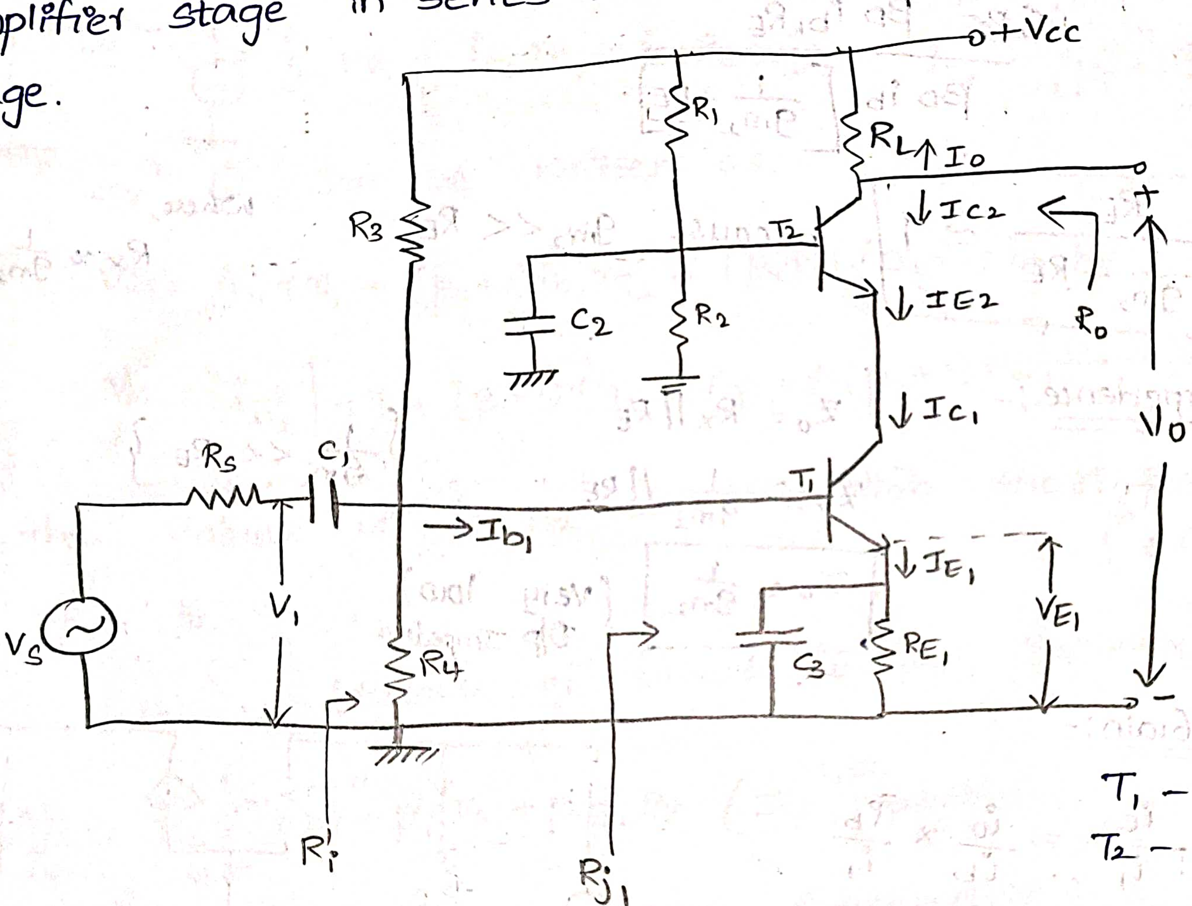
$A_i = \frac{i_o}{i_b} \times \frac{i_b}{i_{in}}$

$\boxed{A_i = \beta_D \times \frac{R_B}{R_B + Z_b}}$ $\Rightarrow$ if $R_B = Z_b$ then, $A_i = \frac{\beta_D}{2}$

*) ~~A_V~~ is high, A_V is low.

Cascode Amplifier:-

*) The cascode amplifier consists of a common emitter amplifier stage in series with a common base amplifier stage.



T_1 – CE Amplifier
T_2 – CB "

*) It is one approach to solve low impedence problem of a common base circuit.

*) It gives high input impedence of a common emitter amplifier, as well as the good voltage gain and high frequency preformance of a common base circuit.

DC Analysis:- (O.C capacitors & AC supply)

*) For the dc bias conditions of the circuit, it is seen that the emitter current for T_1 is set by V_{E_1} and R_{E_1}.

*) Collector current I_{C_1} approximately equals I_{E_1}, and I_{E_2} is same as I_{C_2}

*) Therefore, I_{C_2} approximately equals I_{E_1}. This current remains constant regardless of the level of V_{B_2}, as long as V_{CE_1} remains large enough for current operation of T_1.

AC Analysis:-

*) For AC equivalent circuit, short circuit the dc supply and capacitors.

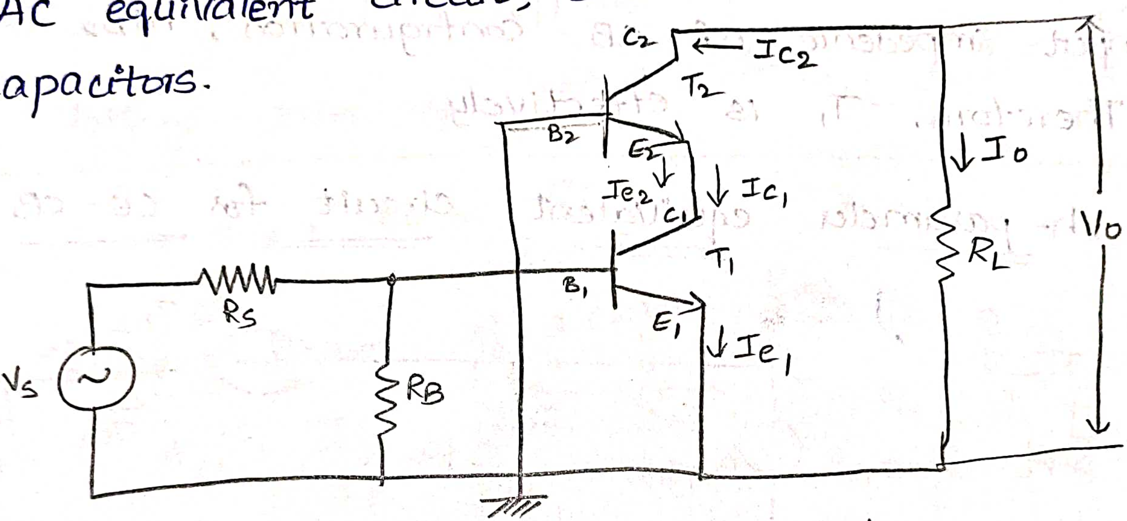
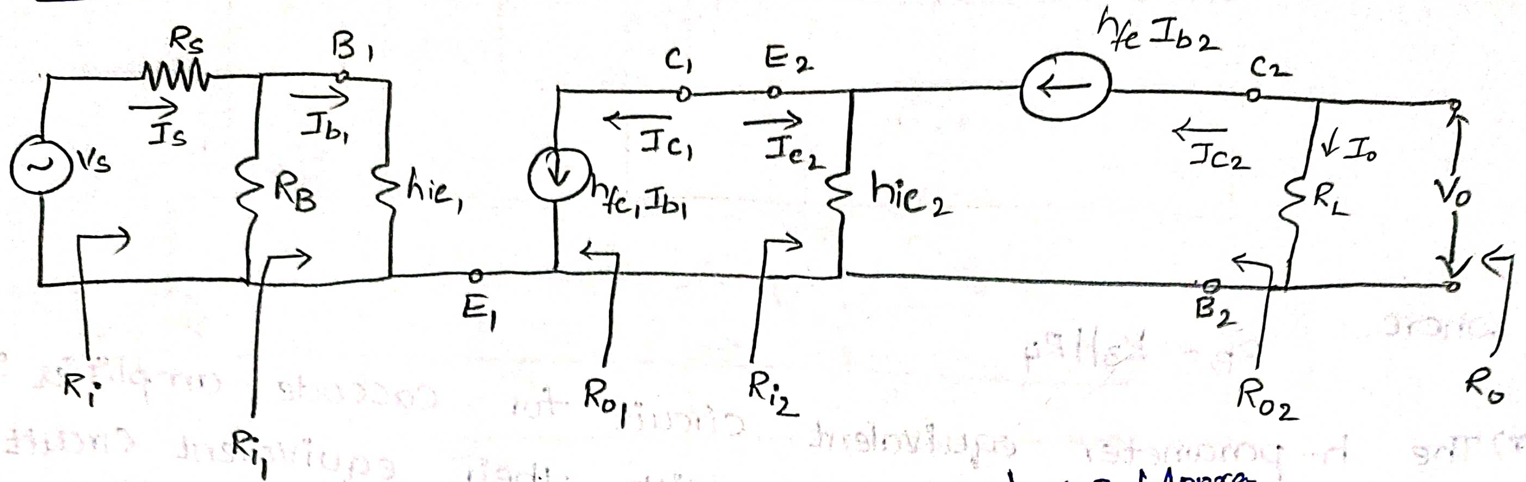


fig: AC equivalent

where, $R_B = R_3 \| R_4$

Simplified h-parameter equivalent circuit for CE-CB amplifier



Analysis of Second stage (CB amplifier)

a) Current gain:- $A_{I_2} = \frac{h_{fe}}{1+h_{fe}}$

Input resistance:- $R_{i_2} = \frac{h_{ie}}{1+h_{fe}}$

Voltage gain:- $A_{V_2} = \frac{A_{I_2} R_{L_2}}{R_{i_2}}$

CB (Appro

$A_I = -h_{fb} = \frac{h_{fe}}{1+h_{fe}}$

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

$A_V = \frac{A_I R_L}{R_i} = \frac{h_{fe} R_L}{h_{ie}}$

$R_o = \infty$

Analysis of first stage (CE Amplifier)

a) Current gain $(A_{I_1}) = -h_{fe}$

b) Input resistance $(R_{i_1}) = h_{ie}$

c) Voltage gain $(A_{V_1}) = \dfrac{A_{I_1} R_{L_1}}{R_{i_1}}$

CE (Approx.)

$A_I = -h_{fe}$

$R_i \approx h_{ie}$

$A_V = \dfrac{h_{fe} R_L}{h_{ie}}$

$R_o = \infty$

*) Overall Voltage gain, $\left(\frac{V_o}{V_i}\right)$

$$A_V = A_{V_1} \times A_{V_2}$$

*) Overall Input resistance,

$$R_i = R_{i_1} \,||\, R_B$$

*) Overall Voltage gain of entire s/m, $\left(\frac{V_o}{V_s}\right) = \frac{V_o}{V_i} \times \frac{V_i}{V_s}$

$$= A_{VS} = A_V \times \frac{R_i}{R_i + R_S}$$

*) Overall current gain of entire s/m,

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

where, $I_o = -I_{c_2}$; $\dfrac{I_{c_2}}{I_{e_2}} = -A_{I_2}$; $I_{e_2} = -I_{c_1}$; $\dfrac{I_{c_1}}{I_{b_1}} = -A_{I_1}$

$$\frac{I_{b_1}}{I_s} = \frac{R_B}{R_B + R_{i_1}}$$

*) O/p resistance,

$$R_{o_1} = \infty$$

$$R_{o_2} = \infty$$

$$R_o = R_{o_2} \,||\, R_L \approx R_L$$