UNIT-I

MULTISTAGE AMPLIFIERS

Introduction:-

→ Single stage amplifiers have only one amplifying device.

→ The amplification is obtained from single stage amplifiers is not sufficient, So we need to connect two or more amplifying devices for large amplification.

→ There are two or more amplifying devices are connected in series or cascade.

→ Cascade / series is nothing but the output of the 1st stage is connected to the input of the 2nd stage.

→ The output of second stage have large amplification i.e., large large output voltage compared to the input voltage.

→ In multistage amplifiers the output of the 1st stage should be coupled to the input of next stage and so on.

Classification of Amplifiers:-

Depending upon the type of coupling, the multistage amplifiers are classified as

1. RC Coupled Amplifiers
2. Transformer coupled Amplifiers
3. Direct Coupled Amplifiers

1. RC Coupled Amplifier:-

In multistage RC coupled amplifier the output of the first stage is coupled to the input of the next stage [illegible] elements. But in this circuit there is no separate load [illegible] between collector and ground but R_C acts as a load [illegible]

RC coupled amplifier has good frequency response and less expensive. So this amplifier is widely used.

2. Transformer Coupled Amplifier:-

In this amplifier, the output of the 1st stage is coupled to the input of the next stage through Transformer.

Due to transformer coupling overall gain will be increased and impedance matching will be achieved.

This type of amplifiers will have large frequency response because inductance of transformer winding will be large.

→ So it is used in power amplifiers.

3. Direct Coupled Amplifier:-

In this type of amplifier, the output of the 1st stage is directly coupled to the input of the next stage without any coupling elements (i.e., R, L & C).

In this amplifier, we get large amplification at low frequency signals.

→ RC coupled amplifiers cannot be used for amplification at low frequency signals because X_C will become very large at low freq signals. So the coupling capacitor is open ckt for low freq. signals. i.e $X_C = \frac{1}{2\pi fC}$

if $f = 0$ then $X_C = \infty$

RC coupled Transistor Amplifier:-

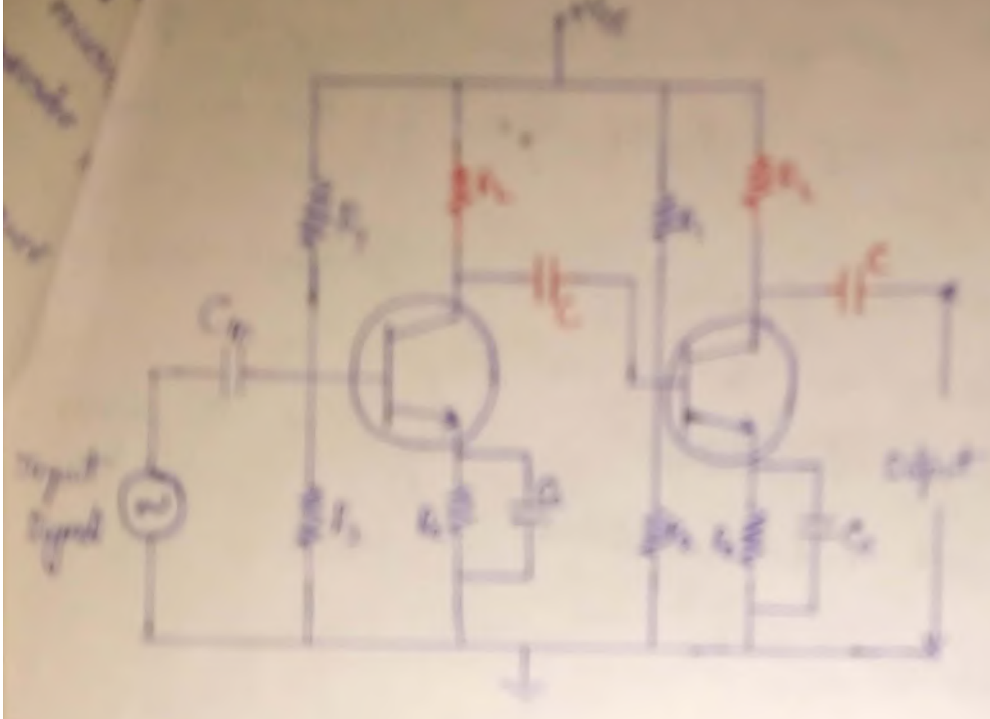


Fig: Circuit diagram of RC coupled Amplifier

The above fig shows the two stage RC coupled amplifier using common emitter configuration.

The output of the first stage is coupled to the input of second stage through coupling capacitor C followed by a resistor. The amplifier is known as resistance-capacitance coupled amplifier.

→ The resistors R_1, R_2 and R_E form the biasing and stabilization network.

→ The bypass capacitor C_E prevents the loss of amplification.

→ The coupling capacitors are also known as blocking capacitors which blocks DC and allows AC voltage.

Operation:-

AC signal is applied to the base of Q_1 transistor, the amplified signal will develop across the collector of Q_1 transistor.

→ This amplified signal ... coupling capacitor C.

→ The 2nd stage can be used for further amplification ... i.e. the cascaded stages amplifies the signal and then ... gain increases.

→ The 2nd stage o/p is out of phase with the i/p signal ... phase signal is fed to the i/p of next stage. Therefore the overall o/p voltage of 2 stages is in phase with the i/p signal with higher amplitude.

Frequency Response:

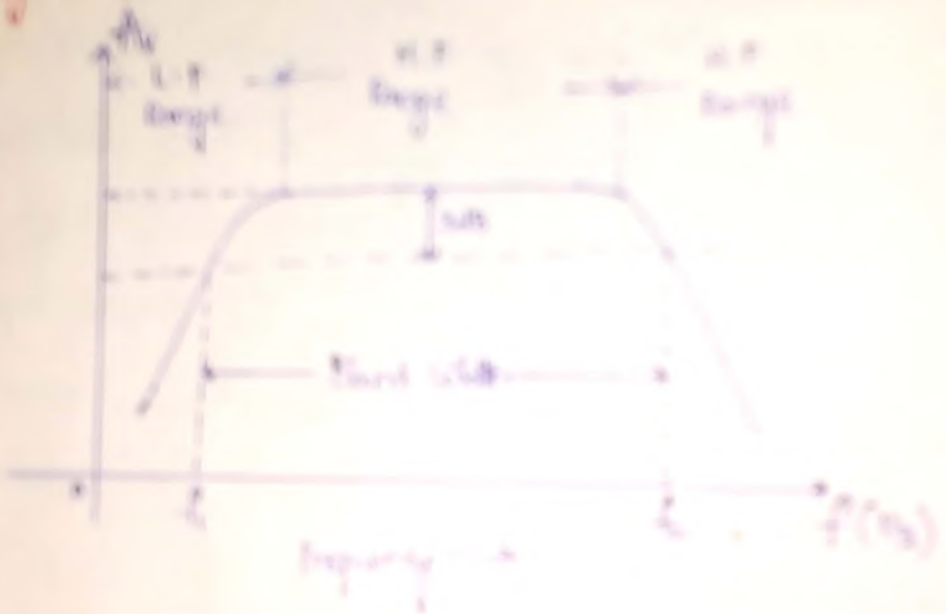


fig: Frequency Response of RC coupled amplifier

The above fig shows the freq response of ~~gain~~ RC coupled amplifier.

The freq response is the graph b/w frequency and gain.

can be seen from the freq response curve that the o/p gain is maximum and constant at mid frequencies. The voltage gain is low at lower and higher frequencies. The behaviour of the freq response is briefly explained below.

At lower frequencies:-

→ At low frequencies, the reactance of the coupling capacitor will increases. So very small o/p voltage of the stage will be transferred from one stage to another stage.

→ Due to large reactance, the capacitor C_e cannot permitted the emitter resistor R_e. Due to these 2 factors the voltage gain will decrease at low frequencies.

At high frequencies:-

→ At high frequencies the reactance of coupling capacitor will be very small and it behaves as a short circuit but due to junction capacitance the o/p voltage will decrease at high frequency. So the gain can be reduced at high frequencies.

At mid frequencies:-

At mid frequencies, the voltage gain of the amplifier is constant. The effect of coupling capacitor to maintain the uniform voltage gain at mid frequency range.

→ As freq increases ...

the capacitive decreases which tends to increase ...

at the same time.

→ The above two factors almost cancel each other resulting a uniform voltage gain at mid frequencies.

Advantages:-

→ It provides a good freq. response.

→ It has less expensive.

→ It is a small size.

→ It is less weight and less complexity.

Disadvantages:-

It provides poor impedance matching.

Applications:-

It is used in : Radio Receiver

: Tape Recording

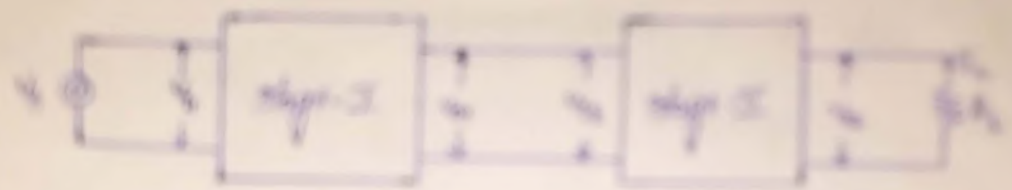
: TV Receiver.

The gain of the amplifier is independent of frequency between mid freq range but decreases at both high and low frequencies.

-Amplifiers-

Two or more stages may be connected in cascade when the stage amplification is not sufficient for particular purpose amplification when the i/p and o/p impedance is not matching for ~~which~~ applications.

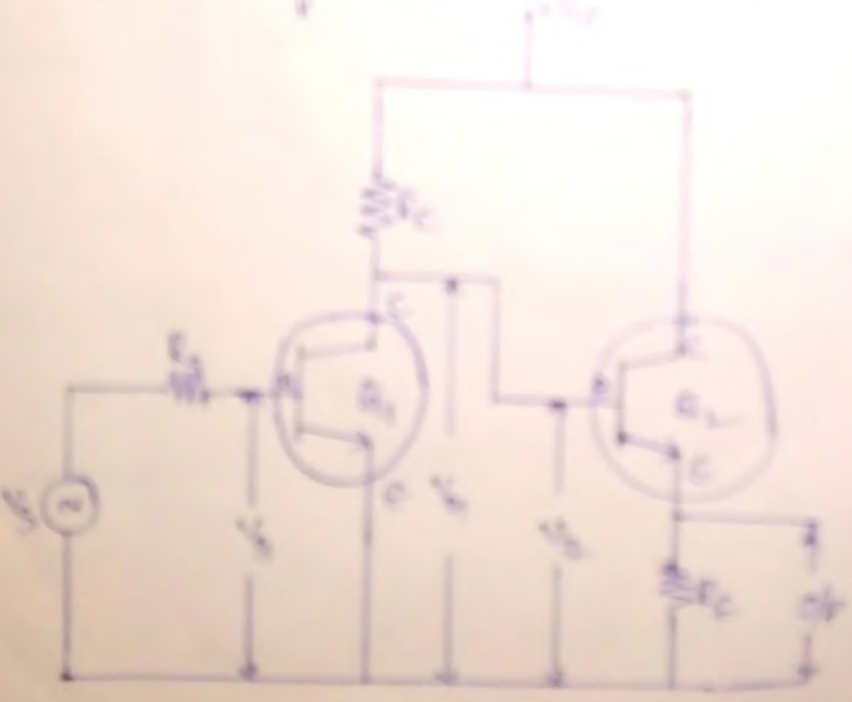
Cascade amplifier stages is shown in below fig.



Let us consider two stage cascaded amplifier. the 1st stage is connected in CE configuration & 2nd stage is connected in CC configuration. So current gain is high at 1st stage and 2nd stage provides high input impedance & low o/p impedance.

To get A_I, Z_i, A_v & Z_o expressions we must take the h-parameters of in and particulars.

The below fig shows the two stage cascaded amplifier.



→ The above circuit shows that two stages [illegible]

→ The transistor Q_1 is in first stage and [illegible] is in 2nd stage.

→ The transistor Q_1 is in CE configuration and [illegible] is in CC configuration.

→ The o/p is taken from the emitter terminal of Q_2 [illegible] there is no separate load resistor of 1st stage, [illegible] to acts as a load resistor.

→ The AC equivalent circuit for the above circuit is [illegible] in below fig.

Fig: AC equivalent ckt for Cascading amplifier.

→ In the above circuit biasing resistors are not shown since their purpose is only to provide the proper operating point & they do not affect the response of the amplifier.

→ In the fig V_i is the i/p of the 1st stage & V_{o2} is the o/p of the 2nd stage. So the overall voltage gain is defined as the ratio of o/p voltage of 2nd stage to the i/p voltage of 1st stage

$$A_V = \frac{V_{o2}}{V_{i1}}$$

$$A_V = \frac{V_{o2}}{V_{i2}} \times \frac{V_{i2}}{V_{i1}}$$

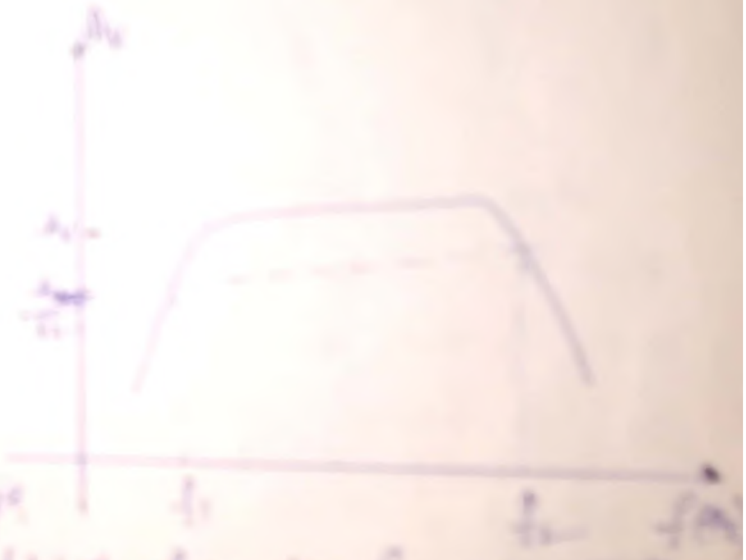
$$A_V = \frac{V_{o2}}{V_{i2}} \times \frac{V_{i2}}{V_{i1}}$$

$$A_V = A_{V2} \times \frac{V_{i2}}{V_{i1}}$$

we know that $V_{i2} = V_{o1}$ ⇒ ∴ $A_V = A_{V2} \times \frac{V_{o1}}{V_{i1}}$

$$\boxed{\therefore A_V = A_{V2} \times A_{V1}}$$

Band width :-



Band width is defined as the difference b/w upper cut off freq and lower cut off freq

∴ $BW = f_2 - f_1$

where f_1 & f_2 are the cut off freqs.

→ A_V is max value of gain obtained from the frequency response characteristics.

→ Gain at cut off freq ie f_1 or f_2 = $\frac{A_V}{\sqrt{2}}$

→ The calculation of gain in decibels with the help of voltage is

→ let us consider the max voltage gain [illegible]

voltage gain in dB = $20 \log A_v$

$= 20 \log 1$

$$\boxed{A_v = 0\,dB}$$

$$A_v = 20 \log \frac{1}{\sqrt{2}}$$

$$A_v = -3\,dB$$

$$A_v = 20 \log 100$$

$$\boxed{A_v = 40\,dB}$$

→ For a single stage amplifier, the voltage gain in the high freq region of the frequency response characteristic of an amplifier is given by the following eq assuming the normalised mid band gain of the amplifier to be unity.

$$A_{vH} = \frac{1}{\sqrt{1+\left(\frac{f}{f_2}\right)^2}}$$

where A_{vH} denotes n of amplifier stages in the cascaded amplifier. So A_{vH} is the gain of the 1st stage in high freq region & that A_{vH}^n is the gain of the n^{th} amplifier stage in the high frequency region.

Similarly f_2 is the upper cut off freq.

$$f_2 = f_{21} = f_{22} = f_{23} \ldots f_{2n}$$

→ let us consider the upper cut freq of n identical stages as f_{2n}, it is the freq for which the overall gain falls to $\frac{1}{\sqrt{2}}$ of the mid band value i.e.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_{Hn}}{f_2}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

If f_{Hn} is the upper 3-dB f

$$\left(\frac{A_v}{A_m}\right)^n = \frac{1}{\sqrt{2}} \text{ for } f = f_{Hn}$$

f_2 is the frequency at which $A_v = \frac{A_m}{\sqrt{2}}$

$$\frac{1}{\left[\sqrt{1+\left(\frac{f_{Hn}}{f_2}\right)^2}\right]^n} = \frac{1}{\sqrt{2}}$$

$$\left(\sqrt{1+\left(\frac{f_{Hn}}{f_2}\right)^2}\right)^n = \sqrt{2}$$

Taking squaring on both sides

$$\left(1+\left(\frac{f_{Hn}}{f_2}\right)^2\right)^n = 2$$

Taking n^{th} root on both sides.

$$1+\left(\frac{f_{Hn}}{f_2}\right)^2 = 2^{1/n}$$

$$\left(\frac{f_{Hn}}{f_2}\right)^2 = 2^{1/n}-1$$

$$\frac{f_{Hn}}{f_2} = \sqrt{2^{1/n}-1}$$

$$\boxed{f_{Hn} = f_2\sqrt{2^{1/n}-1}}$$

For a single stage amplifier, the voltage gain in frequency response characteristic of an amplifier is given by following eq. Assuming that its normalized mid band gain to be unity.

$$A_v' = \frac{1}{\sqrt{1+\left(\frac{f}{f_2}\right)^2}}$$

A_{v1} is gain of 1st stage amplifier

A_{v2} is 2nd of amplifier stage

A_{vn} is the gain of nth amplifier stage.

$A = A_{v1} \cdot A_{v2} \cdot A_{v3} \cdots A_{vn}$

Let us consider lower cut frequency of an 'n' identical cascaded stages as f_{Ln}. It is the freq response for which overall gain falls to $\frac{1}{\sqrt{2}}$ of its midband value.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_1}{f_{Ln}}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\sqrt{2} = \left[\sqrt{1+\left(\frac{f_1}{f_{Ln}}\right)^2}\right]^n$$

$$2 = \left[1+\left(\frac{f_1}{f_{Ln}}\right)^2\right]^n$$

$$2^{1/n} = 1+\left(\frac{f_1}{f_{Ln}}\right)^2$$

$$\sqrt{2^{1/n}-1} = \left(\frac{f_1}{f_{Ln}}\right)$$

$$\boxed{\therefore\ f_{Ln} = \frac{f_1}{\sqrt{2^{1/n}-1}}}$$

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Gain Bandwidth product:-

Gain band width product is referred as figure of merit. This is used to measure the performance of an amplifier.

→ Any amplifier circuit must have high gain and large bandwidth.

→ For certain amplifier circuit, without gain may be large but not bandwidth and vice versa.

→ Different amplifier circuits can be compared with this parameter, the expression for gain bandwidth product of BJT

$$A_i f_\beta = f_T = \frac{h_{fe}}{h_{ie}} \cdot \frac{1}{2\pi C_e}$$

Where C_e - shunt capacitor

At $f = f_T$ Current gain $A_i = 1$

So, value of gain bandwidth product is f_T itself. The expression for f_T of the high frequency amplifier

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

Decibel:-

It is convenient to compare two powers on a logarithmic scale rather than on a linear scale. The unit of this logarithmic scale is called the decibel abbreviated as dB.

Suppose P_2 is the o/p power & P_1 is the input power, then the gain in decibels is $N = 10 \log \frac{P_2}{P_1}$

If 'A' is normal voltage gain $A = \frac{V_2}{V_1}$

Decibel voltage gain $A' = 20\log A$

If R_1 is I/P Resistance, Input power, $P_1 = \frac{V_1^2}{R_1}$

If R_2 is O/P Resistance, Output power $P_2 = \frac{V_2^2}{R_2}$

$\therefore$ Power gain $G = \frac{P_2}{P_1} = \frac{V_2^2 \cdot R_2}{V_1^2 \cdot R_1}$

If the impedances are matched, i.e input resistance R_1 = O/P R

power gain $G = \frac{V_2^2}{V_1^2} = A^2$

In dB's $\quad 10\log G = 10\log A^2$

$= 20\log A.$

Note:-

In the analysis of R-C coupled amplifier, the following simplifying assumptions are made:

① h_{re} is so small that the voltage source $h_{re}V_o$ can be neglected.

② h_{oe} is so large that it can be considered as an open circuit.

③ The reactance of C_E at any given input frequency is so small that the parallel combination of R_E and C_E can be effectively considered as a short circuit.

④ The bias resistors R_1 and R_2 are usually large as compared to h_{ie}.

With these assumptions, the simplified equivalent circuit is shown in fig.

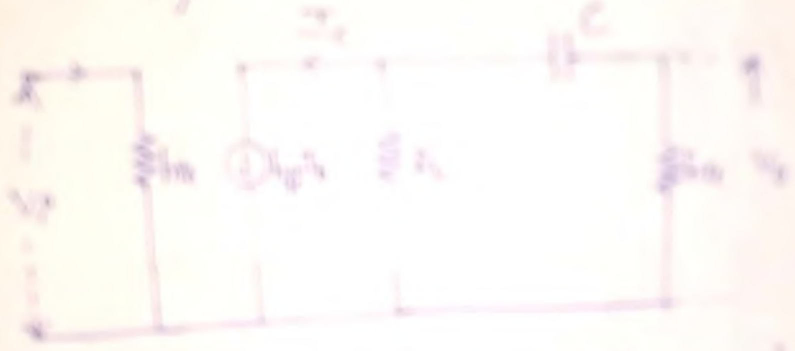
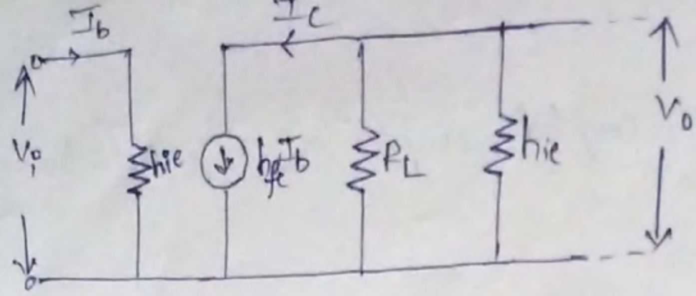


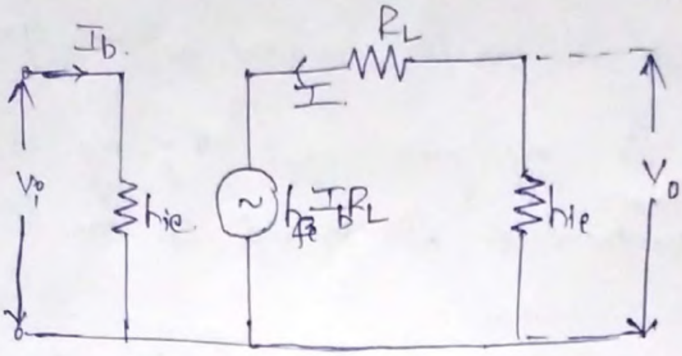
fig. simplified equivalent circuit of R.C coupled amplifier

Middle frequency range:-

At mid frequencies, the impedance offered by coupling capacitor C is so small as to be an effective short circuit. Hence at mid frequencies, the effect of coupling capacitor C can be neglected. Now the equivalent ckt is shown in fig. ⓐ The Thevenin's equivalent ckt is shown in fig ⓑ



(a) Equivalent circuit at mid frequency range



(b) Thevenin's equivalent circuit.

From fig (b). $I = \dfrac{-h_{fe} I_b R_L}{R_L + h_{ie}} \longrightarrow (1)$

$\therefore$ Current gain $(A_i)_m = \dfrac{I}{I_b} = -\dfrac{h_{fe} R_L}{R_L + h_{ie}} \longrightarrow (2)$

The magnitude of current gain is given by.

$$|(A_i)_m| = \frac{h_{fe} R_L}{R_L + h_{ie}} \longrightarrow (3)$$

The output voltage $V_o = h_{ie} I_c$.

$$= -\frac{h_{ie} h_{fe} I_b R_L}{R_L + h_{ie}} \longrightarrow (4)$$

The input voltage $V_i = h_{ie} I_b \longrightarrow (5)$

$\cancel{V_o = -\dfrac{h_{ie} h_{fe} I_b R_L}{R_L + h_{ie}}}$

$\therefore$ Voltage gain $(A_v)_m = \frac{V_o}{V_i} = -\frac{h_{fe} R_L}{R_L + h_{ie}} \longrightarrow (6)$

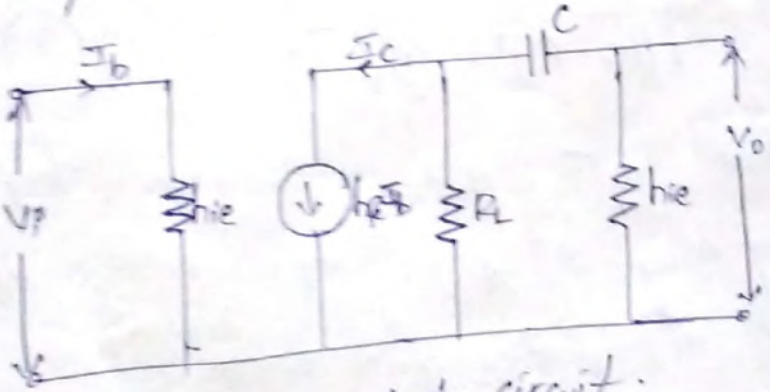
The magnitude of voltage gain at mid frequency is given by

$$|(A_v)_m| = \frac{h_{fe} R_L}{h_{ie} + R_L}$$

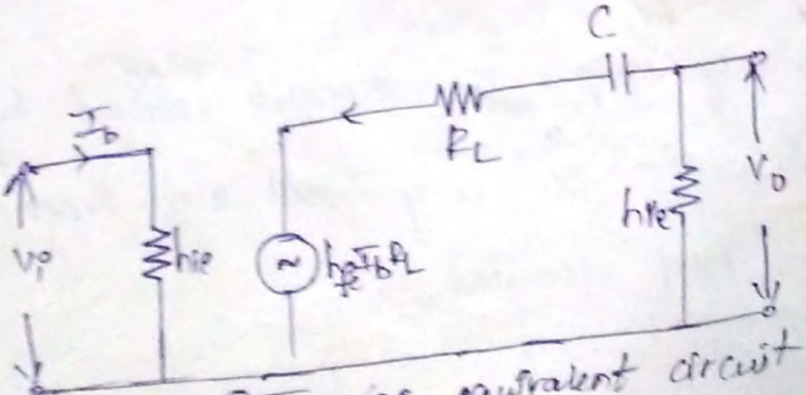
The negative sign shows the phase angle of 180°. It is obvious from eq (2) & eq (6) that $(A_i)_m = (A_v)_m$.

Low frequency Range :-

In low frequency range the impedance offered by coupling capacitor is comparable to the load resistance. Hence it largely affects current amplification. Therefore, it is included in the equivalent circuit. The equivalent ckt is shown in fig(a). fig (b) represents the thevenin's equivalent circuit.



(a) Equivalent circuit.



(b) Thevenin's equivalent circuit

Fig : Equivalent circuits at low frequency range

The current flowing in the

$$I = \frac{-h_{fe} I_b R_L}{h_{ie} + R_L - j/\omega C}$$

The current gain at low frequencies is given by

$$(A_i)_l = \frac{I}{I_b} = \frac{-h_{fe} R_L}{h_{ie} + R_L - j/\omega C}$$

Output voltage V_o = Resistance × Current

$$\therefore \quad V_o = h_{ie} \times \frac{-h_{fe} I_b R_L}{h_{ie} + R_L - j/\omega C} = \frac{-h_{fe} h_{ie} I_b R_L}{h_{ie} + R_L - j/\omega C}$$

Input voltage $V_i = h_{ie} \times I_b$

$$\therefore \quad (A_v)_l = \frac{V_o}{V_i} = -\frac{h_{fe} R_L}{h_{ie} + R_L - j/\omega C}$$

The magnitude of $(A_v)_l$ is given by

$$(A_v)_l = \frac{h_{fe} R_L}{\sqrt{(h_{ie} + R_L)^2 + (1/2\pi f C)^2}} \longrightarrow (7)$$

It is obvious from eq (7) that in the low frequency range, as the frequency f of the input voltage decreases, the magnitude of the voltage gain decreases.

High Frequency range :

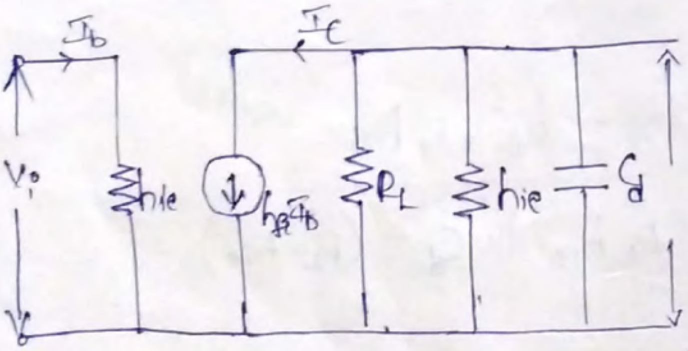
(1) In high frequency range, the reactance offered by coupling capacitor 'C' is very small and hence it can be considered as short circuited.

In a bipolar transistor, there are two depletion regions across two PN junctions. They behave like a dielectric media and hence give rise to two internal capacitances. At high frequency range the reactance of these capacitances (C_{be} & C_{bc}) considered.

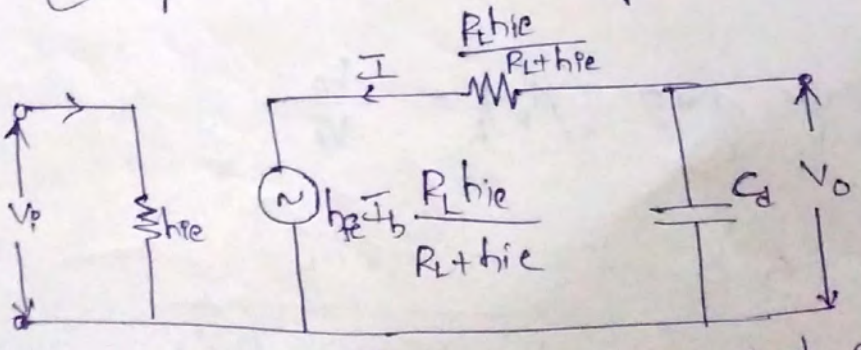
The C_{be} and C_{bc} may be replaced with a single capacitance C_d across the input resistance hie of the transistor.

(iii) The value of shunt capacitance C_d in the input circuit of the first stage is small because it depends on the o/p impedance of the first transistor. But in the output circuit of the first stage C_d is increased by stray capacitance of the wiring. Therefore, the reactance $1/\omega C_d$ will have appreciable shunting effect on R_2 and hie.

The equivalent ckt's are shown in fig (a) & fig (b).



(a) Equivalent ckt at high frequencies.



(b) Thevenin equivalent circuit.

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Current flowing in the circuit is given by

$$I = \frac{-h_{fe} I_b \dfrac{R_L h_{ie}}{R_L + h_{ie}}}{\dfrac{R_L h_{ie}}{R_L + h_{ie}} + \dfrac{1}{j\omega C_d}} = \frac{-h_{fe} I_b R_L h_{ie}}{R_L h_{ie} + \dfrac{1}{j\omega C_d}(R_L + h_{ie})}$$

$\therefore$ Current gain $(A_i)_h = \dfrac{I}{I_b} = \dfrac{-h_{fe} h_{ie} R_L}{R_L h_{ie} + \dfrac{1}{j\omega C_d}(R_L + h_{ie})}$

Output voltage $V_o = I \times \dfrac{1}{j\omega C_d}$

$$V_o = \frac{-h_{fe} I_b R_L h_{ie} / (R_L + h_{ie})}{\left[(R_L h_{ie}) / (R_L + h_{ie}) + \dfrac{1}{j\omega C_d}\right]} \times \frac{1}{j\omega C_d}$$

$$= \frac{-h_{fe} I_b R_L h_{ie}}{R_L h_{ie}\, j\omega C_d + (R_L + h_{ie})}$$

Input voltage $V_i = I_b h_{ie}$

$\therefore$ Voltage gain $(A_v)_h = \dfrac{V_o}{V_i}$

$$(A_v)_h = \frac{-h_{fe} R_L}{\quad}$$