Cascading of Amplifier:

The block diagram of a cascade amplifier is shown in Fig-1

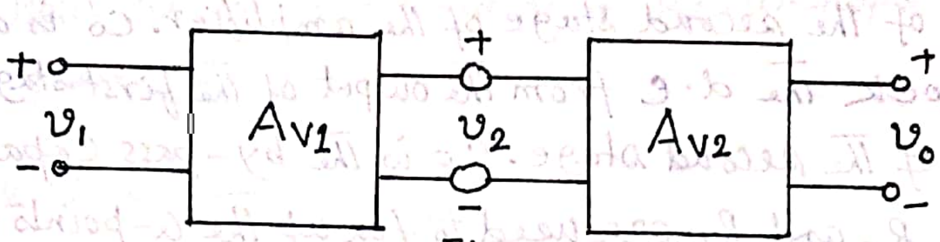

Fig-1

The effective voltage gain of the cascade amplifier is given by

$$A_v = A_{v1} \times A_{v2} \quad \text{------ (1)}$$

Thus in cascading, we increase the voltage gain. But common collector amplifiers are not cascaded because their voltage gain is less than unity. Only CE amplifiers are cascaded.

R-C Coupled Transistor Amplifier:

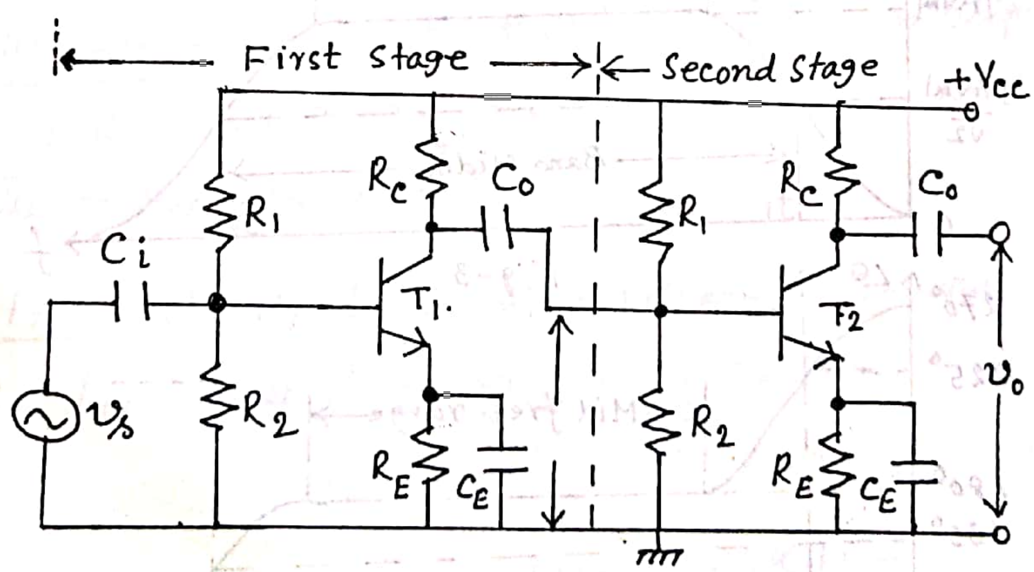

Fig-2

A two stage R-C Coupled transistor amplifier in CE mode Connection is shown in Fig-2. C_o is the coupling capacitor which Couples the output voltage v_2 of the first stage to the input of the second stage of the amplifier. C_o is also used to block the d.c from the output of the first stage to the input of the second stage. C_E is the by-pass Capacitor. R_1, R_2, R_c and R_E are used to fix up the Q-points of the transistors T_1 and T_2

The voltage gain of the first stage of the R-C Coupled amplifier is given by

$$A_v = \frac{v_2}{v_s} = |A_v| \angle\theta \quad ------(2)$$

The variations of $|A_v|$ and $\angle\theta$ with frequency f are shown in Fig-3 and Fig-4.

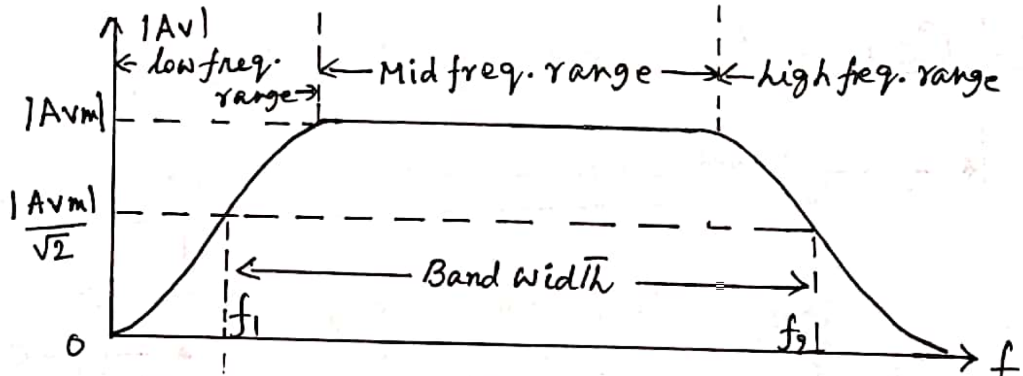

Fig-3

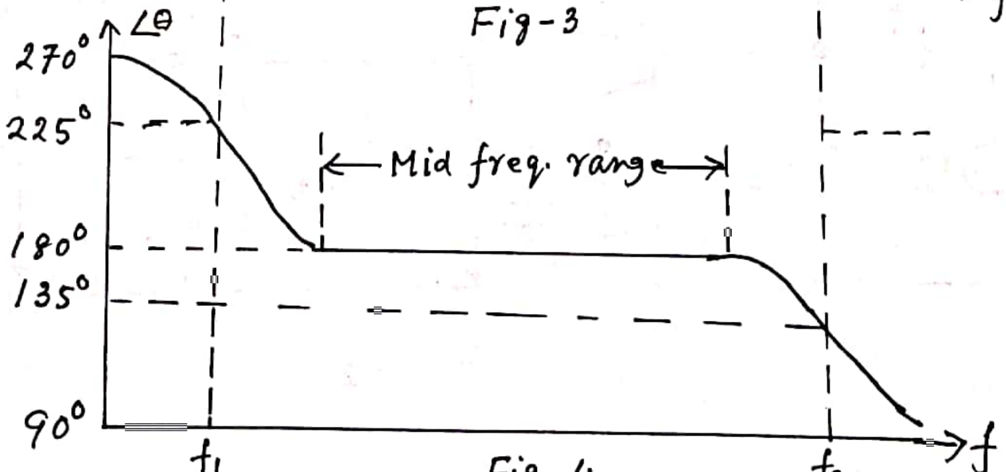

Fig-4

The decibel (dB):-

The telephone industries generally use a unit based on logarithms to the base 10, naming the unit bel for Alexander Graham Bell. The bel is defined as the logarithm of a power ratio i.e power gain

$$\text{No. of bells} = \log_{10}\left(\frac{P_2}{P_1}\right)$$

where P_2 = output power and P_1 = input power of a circuit.

The decibel denoted by dB, is defined by the relation

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

For the case of equal resistances at the input and output circuits

$$dB = 10 \log_{10}\left(\frac{v_2}{v_1}\right)^2 = 20 \log_{10}\left(\frac{v_2}{v_1}\right) = 20 \log_{10}\left(\frac{I_2}{I_1}\right)$$

$\boxed{\text{Problem 1}}$: The output voltage of an amplifier is 10V at 5 KHz and 7.07 V at 25 KHz. What is the decibel change in the output power level?

Soln: Let v_1 be the input voltage (standard voltage)

In first case the power gain at 5KHz is

$$dB = 20 \log_{10}\left(\frac{10}{v_1}\right)$$

In second case, power gain at 25KHz is

$$dB = 20 \log_{10}\left(\frac{7.07}{v_1}\right)$$

Therefore decibel change in power level

$$= 20\log_{10}\left(\frac{7.07}{v_1}\right) - 20\log_{10}\left(\frac{10}{v_1}\right)$$

$$= 20\left[\log_{10}7.07 - \cancel{\log_{10}v_1} - \log_{10}10 + \cancel{\log_{10}v_1}\right]$$

$$= 20\log_{10}\left(\frac{7.07}{10}\right) = 20\log_{10}(0.707)$$

$$= -3\ dB.$$

Frequency Response of R-C Coupled Amplifier :

The variation of voltage gain $|A_V|$ of an amplifier with frequency of input signal is shown in fig-3. The gain remains practically constant over a wide range of frequencies in the 'mid frequency range', but the gain decreases both in the low frequency range with decrease in frequency and in the high frequency range with increase in frequency. The frequency response is determined by the coupling capacitor C_o and various transistor junction capacitances. We calculate the voltage gain in different frequency ranges.

Mid-Frequency Range :-

The reactances offered by C_o and C_E are so small that they are a.c short circuited. The junction capacitances are so small that their reactances are very large. As they appear effectively in parallel with the associated resistances these reactances need not be considered in the mid-frequency range.

The approximate h-parameter equivalent circuit including input resistance of the next stage is shown in Fig-5. We assume the transistors are identical and R_1 and R_2 are large enough.

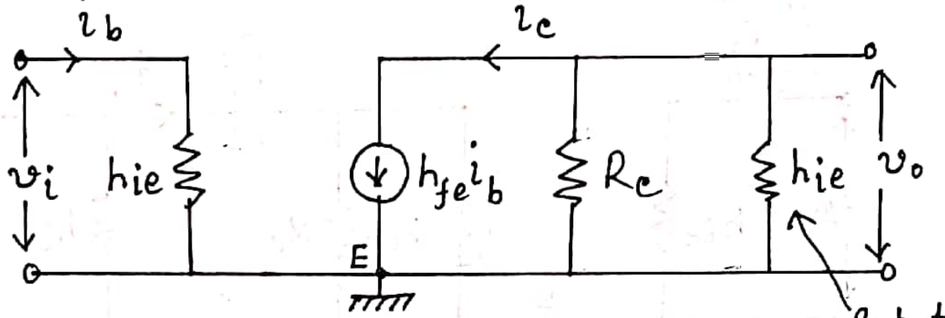

Fig-5

The output voltage

$$v_o = -h_{fe} i_b \cdot (R_c \| h_{ie})$$

$$= -h_{fe} i_b \cdot \frac{R_c h_{ie}}{R_c + h_{ie}} \quad \text{- - - - (1)}$$

The input voltage

$$v_i = h_{ie} i_b \quad \text{- - - - - - (2)}$$

Therefore the voltage gain in mid-frequency range

$$A_{VM} = \frac{v_o}{v_i} = -\frac{h_{fe} R_c}{R_c + h_{ie}} \quad \text{- - - - (3)}$$

A_{VM} is independent of the frequency of the input signal.

Low Frequency Range :-

In the low frequency range, the effect of various junction capacitors and C_E (by-pass capacitor) remains negligible while the reactance of C_o (Coupling capacitor) becomes appreciable. The a.c drop across C_o causes reduction of voltage gain. The approximate h-parameter a.c equivalent circuit in the low frequency range is shown in Fig-6

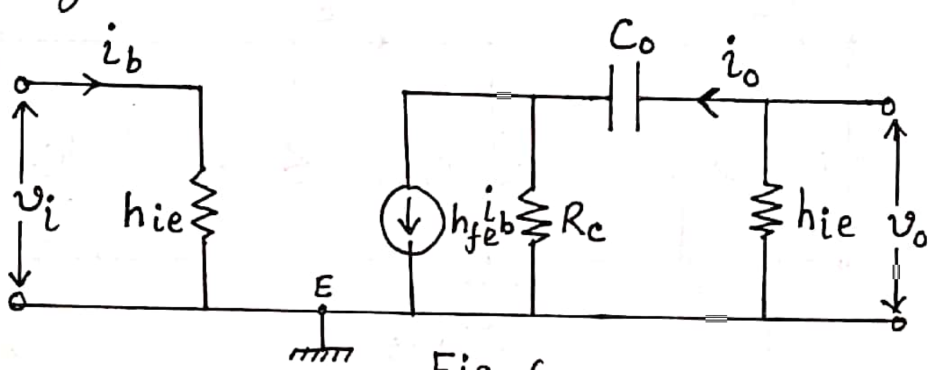

Fig-6

It is assumed that the transistors are identical and $R_1 \| R_2 \gg hie$. The output voltage is

$$v_o = -i_o h_{ie} = -\frac{(h_{fe} i_b) R_c}{R_c + h_{ie} + \frac{1}{j\omega C_o}} \cdot h_{ie} \quad \text{---(4)}$$

The input voltage $v_i = h_{ie} i_b$ ----(5)

Therefore the voltage gain at low frequency range

$$A_{VL} = \frac{v_o}{v_i} = -\frac{h_{fe} R_c}{h_{ie} + R_c - \frac{j}{\omega C_o}}$$

$$= -\frac{h_{fe} R_c}{(h_{ie} + R_c)\left[1 - \frac{j}{\omega C_o (h_{ie} + R_c)}\right]}$$

$$\Rightarrow A_{VL} = -\frac{\left(\frac{h_{fe} R_c}{h_{ie} + R_c}\right)}{1 - \frac{j}{\omega C_o (h_{ie} + R_c)}}$$

$$\Rightarrow A_{VL} = \frac{A_{VM}}{1 - j\left(\frac{\omega_1}{\omega}\right)} = \frac{A_{VM}}{1 - j\left(\frac{2\pi f_1}{2\pi f}\right)} \quad \text{[using (3)]}$$

$$\therefore A_{VL} = \frac{A_{VM}}{1 - j\left(\frac{f_1}{f}\right)} \text{ - - - - - - - - - (6)}$$

where $\omega_1 = \frac{1}{C_o (h_{ie} + R_c)}$

$$\therefore f_1 = \frac{1}{2\pi C_o (h_{ie} + R_c)} \text{ - - - - - - - - (7)}$$

and $f = \frac{\omega}{2\pi}$ is the frequency of the input signal.

From (6) we can write

$$\left|\frac{A_{VL}}{A_{VM}}\right| = \frac{1}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}} \text{ - - - - - - - - (8)}$$

Equation (8) clearly shows that the voltage gain of the amplifier at low frequency range decreases with decrease in the frequency of the input signal. At $f = f_1$, $|A_{VL}| = \frac{1}{\sqrt{2}} |A_{VM}|$ and the power delivered to the load is reduced by a factor $\frac{1}{2}$. For this f_1 is called <u>lower half power frequency or lower 3dB frequency.</u>

Scanned with CamScanner

High Frequency Range:-

At high frequencies The capacitors C_o and C_E may be assumed to be virtually a.c short circuited and Their effects are neglected. But The effect of C_{be} and C_{bc} can not be neglected as They tend to shunt The load resistance. The effective a.c load becomes smaller and hence The voltage gain decreases with increase of frequency. The approximate h-parameter a.c equivalent circuit for high frequency range is shown in Fig-7.

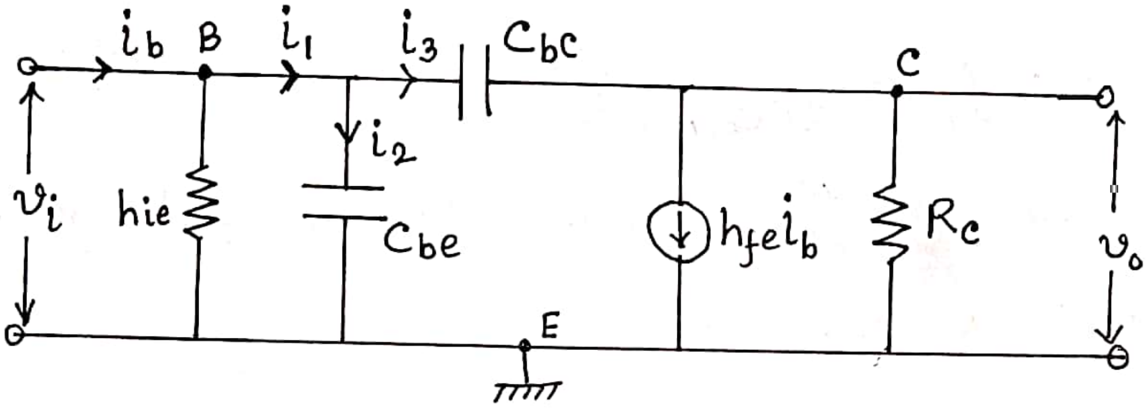

Fig-7

From This Fig-7 we can write

$$i_1 = i_2 + i_3 = \frac{v_i}{\frac{1}{j\omega C_{be}}} + \frac{v_i - v_o}{\frac{1}{j\omega C_{bc}}}$$

$$= j\omega C_{be} v_i + j\omega C_{bc} v_i \left(1 - \frac{v_o}{v_i}\right)$$

$$= j\omega v_i \left[C_{be} + C_{bc}\left(1 - \frac{v_o}{v_i}\right)\right] \quad \text{---(9)}$$

Now using the approximate relation

$$\frac{v_o}{v_i} \approx -\frac{h_{fe} R_c}{h_{ie}}$$, the equation (9) becomes

$$i_1 = v_i\, j\omega \left[C_{be} + \left(1 + \frac{h_{fe} R_c}{h_{ie}}\right) C_{bc} \right]$$

$$\Rightarrow \quad i_1 = \frac{v_i}{\dfrac{1}{j\omega\left[C_{be} + \left(1 + \dfrac{h_{fe} R_c}{h_{ie}}\right) C_{bc}\right]}} = \frac{v_i}{\dfrac{1}{j\omega C_d}} \quad \text{--- (10)}$$

where $C_d = C_{be} + \left(1 + \frac{h_{fe} R_c}{h_{ie}}\right) C_{bc}$ ----- (11)

The eqn. (10) indicates that C_{be} and C_{bc} are in effect equivalent to a single capacitor C_d connected across the input resistance h_{ie}. The eqn. (11) shows that base-collector junction capacitor C_{bc} which provides feedback from output to the input, has the effect of a larger capacitance at the input. This amplification of capacitance is known as <u>Miller effect</u>.

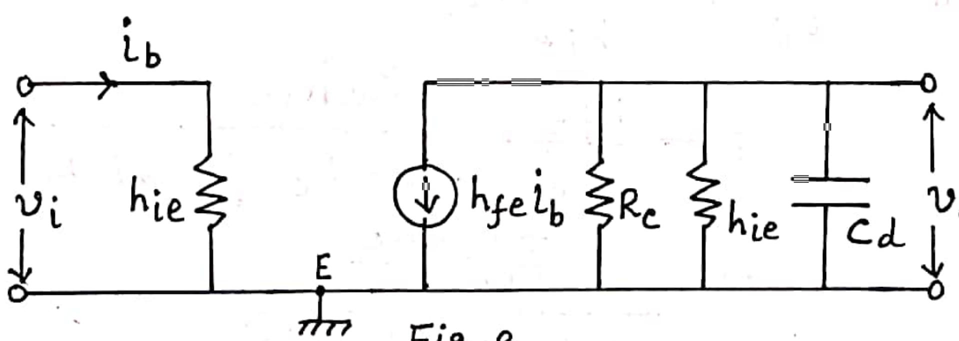

Fig-8

Scanned with CamScanner

we assume $R_1 \| R_2 >> h_{ie}$. The h-parameter a-c equivalent circuit is shown in Fig-8

Now the input voltage

$$v_i = h_{ie} i_b \quad \text{-------------(12)}$$

The output voltage

$$v_o = -h_{fe} i_b \cdot Z \quad \text{----------(13)}$$

where

$$\frac{1}{Z} = \frac{1}{R_c} + \frac{1}{h_{ie}} + \frac{1}{\frac{1}{j\omega C_d}}$$

$$= \frac{1}{R_c} + \frac{1}{h_{ie}} + j\omega C_d$$

$$= \frac{h_{ie} + R_c + j\omega C_d R_c h_{ie}}{R_c h_{ie}}$$

$$\therefore Z = \frac{R_c h_{ie}}{h_{ie} + R_c + j\omega C_d R_c h_{ie}}$$

Hence the high frequency voltage gain

$$A_{VH} = \frac{v_o}{v_i} = -\frac{h_{fe}}{h_{ie}} \cdot Z$$

$$= -\frac{h_{fe}}{\cancel{h_{ie}}} \cdot \frac{R_c \cancel{h_{ie}}}{h_{ie} + R_c + j\omega C_d R_c h_{ie}}$$

$$= \frac{\dfrac{-h_{fe} R_c}{(h_{ie} + R_c)}}{1 + j\omega\left(\dfrac{C_d R_c h_{ie}}{h_{ie} + R_c}\right)}$$

Scanned with CamScanner

$$\therefore A_{VH} = \frac{A_{VM}}{1+j\left(\frac{\omega}{\omega_2}\right)} = \frac{A_{VM}}{1+j\left(f/f_2\right)} \quad \text{-----}(14)$$

where $\frac{1}{\omega_2} = \frac{C_d R_c h_{ie}}{h_{ie}+R_c}$

$$\Rightarrow \omega_2 = \frac{h_{ie}+R_c}{C_d\,(h_{ie}R_c)}$$

$$\therefore f_2 = \frac{1}{2\pi C_d}\cdot\left(\frac{h_{ie}+R_c}{h_{ie}R_c}\right) \quad \text{------}(15)$$

From (14)

$$\left|\frac{A_{VH}}{A_{VM}}\right| = \frac{1}{\sqrt{1+\left(f/f_2\right)^2}} \quad \text{---------}(16)$$

The equation (16) shows that the voltage gain decreases in the high frequency range with increase in the frequency f of the input signal. At $f=f_2$; the voltage gain $|A_{VH}|$ reduces to $\frac{1}{\sqrt{2}}$ of its mid-frequency value and the power is reduced by a factor of $\frac{1}{2}$. For this f_2 is called upper half power frequency or upper 3 dB frequency.

Bandwidth (B.W) and Gain - B.W Product :-

Bandwidth (B.W) $= f_2 - f_1$

where f_2 and f_1 are the upper and lower half-power frequencies of R-C Coupled transistor amplifier. Under normal operation $f_2 >> f_1$. Therefore, B.W becomes

$$B.W \approx f_2 = \frac{1}{2\pi C_d (R_c \| h_{ie})} \quad \text{---} (1)$$

The product of B.W and gain (mid-frequency) of the amplifier is called gain-B.W product. For two stage R-C Coupled amplifier, the mid-frequency voltage gain of the first stage is given by

$$A_{VM1} = -\frac{h_{fe}}{h_{ie}} (R_c \| h_{ie}) \quad \text{----} (2)$$

and that of the second stage is given by

$$A_{VM2} = -\frac{h_{fe}}{h_{ie}} \cdot R_c \quad \text{----} (3)$$

The over-all voltage gain is

$$A_{VM} = A_{VM1} \times A_{VM2} = \left(\frac{h_{fe}}{h_{ie}}\right)^2 (R_c \| h_{ie}) \cdot R_c \quad \text{--} (4)$$

The gain-B.W product $= A_{VM} \times B.W$

$$= \frac{R_c}{2\pi C_d} \left(\frac{h_{fe}}{h_{ie}}\right)^2 = \text{Constant.}$$

$$\therefore \boxed{A_{VM} \propto \frac{1}{B.W}}$$

Scanned with CamScanner