R-C Coupled Amplifier

(Multi-stage amplifier)

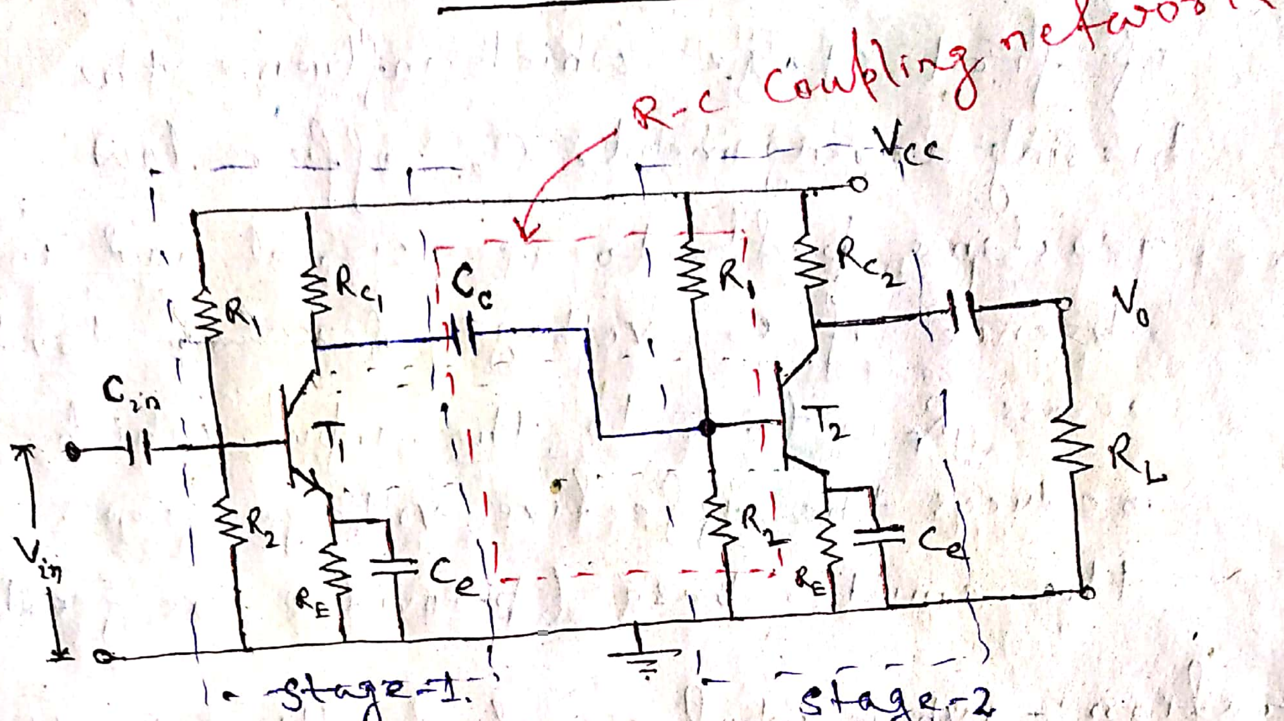

Fig-1

Above fig-1 shows two-stage R-C couple transistor amplifier in CE configuration consist of NPN-transistor. (R_1, R_2) and R_E form biasing and stabilization network respectively. Here, the signal to be amplify, is subjected to the base of first stage and amplified output signal developed across collector load R_c is coupled to the base of 2nd stage through coupling capacitor C_c (C_c and $R_1 \| R_2$ for R-C network) followed by shunt resistance ($R_1 \| R_2$) of 2nd stage.

Here, in the absence of input capacitor C_{in}, Source will become parallel to $(R_2 || R_1)$ of first stage which influence the biasing arrangement. C_e offers low reactance path to a.c signal and in absence of C_e, voltage ~~develop~~ droop across R_E, fed to the input which reduces the effective voltage across the emitter-base (provides -ve feedback).

Operation:- When input signal is applied to the base of first stage (stage-1), then due to transistor action, output signal appears across collector load R_c in amplified form. This amplified signal developed across R_c of Stage-1 is given to the next stage-2 through coupling capacitor C_c. Further, it is amplified and process can be extended so on for more number of stages. Thus, cascaded stage amplify the signal and thus, overall gain considerably increased. The phase of output signal is same as that of the input signal because, phase of signal is reversed twice by two transistors as they are in CE configuration. This configuration is called "cascading". Practically, the over-all gain is less than the product of individual gain.

Circuit analysis :- by using h-parameter

Before the ckt analysis, following assumption are made —

i> h_{re} is so small that $h_{re}V_c$ can be neglected.

ii> $\frac{1}{h_{oe}}$ very large and can be neglected, and consider as open ckt.

iii> R_1 & R_2 are very large in comparision to h_{ie}

iv> Reactance offered by bypass-capacitor C_e to the a.c signal should be very low and combination of R_E & C_e considered as short circuit.

After employing all these assumption to the R-C coupled (cascaded config.) shown in fig-1, the h-parameter equivalent ckt is as shown in fig-2.

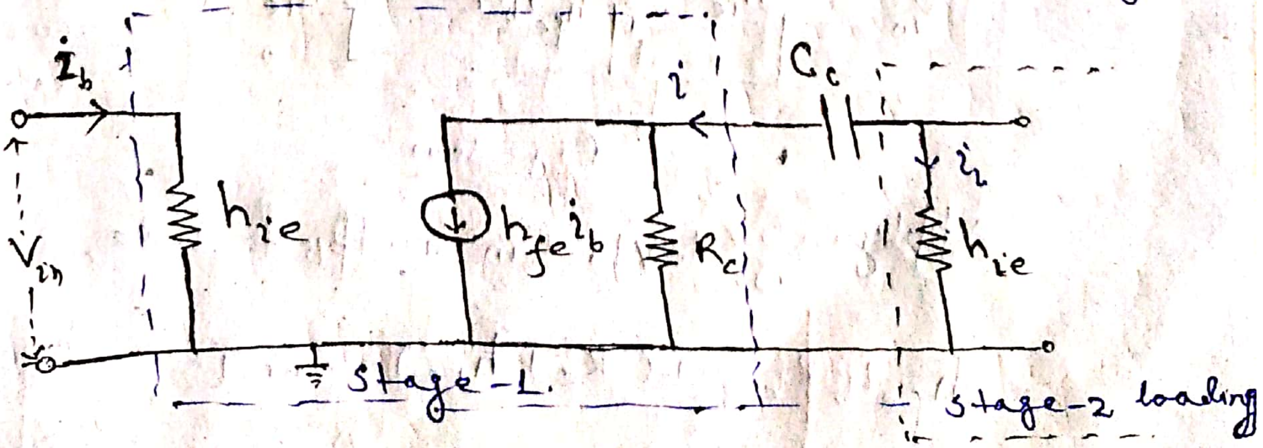

Fig-2

For, gain and frequency response analysis, our approach will be in accordance of following frequency ranges —

(a) Mid-frequency ~~resp~~ range

(b) Low-frequency range

(c) High frequency range.

(a) <u>Mid-frequency range</u> : In mid-frequency range, the reactance offered by C_c is so small, that it can be considered as short-circuit and then ckt model in fig-2 can be transformed as in fig-3(a),(b)

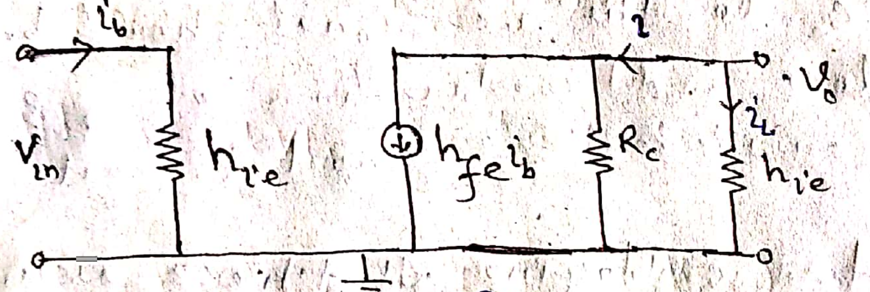

fig-3(a)

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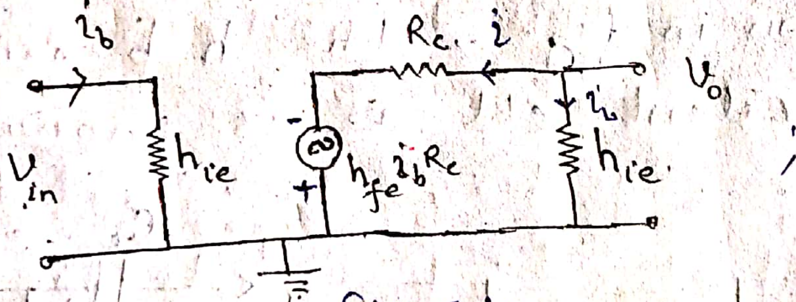

fig-3(b)

; Transform current source to voltage source

Applying KVL in output side,

$$h_{fe}i_bR_c = i(R_c + h_{ie}) \quad \text{or,} \quad i = \frac{h_{fe}R_ci_b}{R_c + h_{ie}}$$

$$\text{or,} \quad \frac{i}{i_b} = \frac{h_{fe}R_c}{R_c + h_{ie}}$$

$\therefore$ Current gain, $(A_i)_{mid} = \dfrac{i_L}{i_b}$

or $(A_i)_{mid} = \frac{-i}{i_b}$; $(\because i_L = -i)$

$$\therefore \boxed{(A_i)_{mid} = -\frac{h_{fe} R_c}{R_c + h_{ie}}} \text{———} (i)$$

Now,

<u>For voltage gain</u>

$V_o = i_L h_{ie}$ or, $V_o = -i h_{ie}$

or, $V_o = -\left(\frac{h_{fe} R_c i_b}{R_c + h_{ie}}\right) h_{ie}$

And, $V_i = i_b h_{ie}$

$$\therefore (A_v)_{mid} = \frac{V_o}{V_i} = \frac{-\left(\frac{h_{fe} R_c \cancel{i_b}}{R_c + h_{ie}}\right)\cancel{h_{ie}}}{\cancel{i_b}\cancel{h_{ie}}}$$

$$\Rightarrow \boxed{(A_v)_{mid} = -\frac{h_{fe} R_c}{R_c + h_{ie}}} \text{———} (ii)$$

clearly, gain is independent of freq. in mid-freq. range

(b) <u>Low-frequency range</u> :- In this frequency range the reactance offered by coupling capacitor C_c is comparable to load resistance. Hence, it largely affects the current amplification. Thus, now circuit include C_c as show in fig-4 (a), (b)

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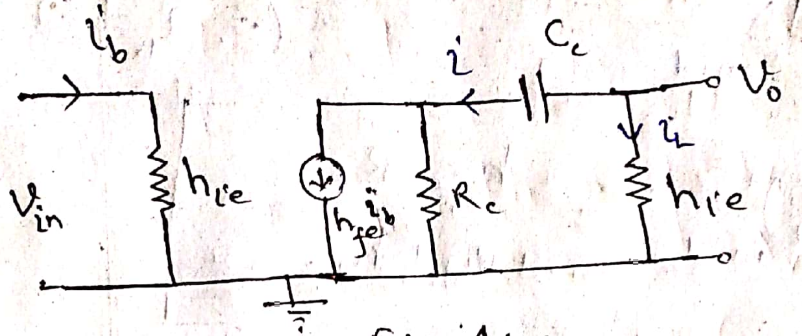

Fig - 4(a)

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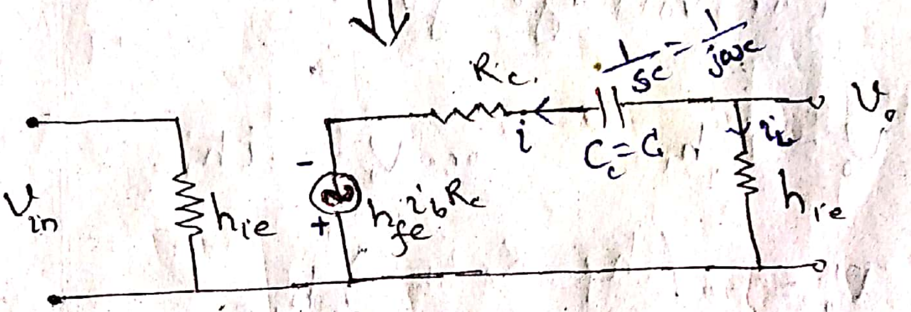

Let, $C_c = C$

Fig - 4(b)

Applying KVL in output side —

$$h_{fe} i_b R_c = i\left(R_c + \frac{1}{j\omega c} + h_{ie}\right)$$

or, $$\frac{i}{i_b} = \frac{h_{fe} R_c}{\left(R_c + h_{ie} - \frac{j}{\omega c}\right)}$$

∴ <u>Current gain</u>

$$(A_v)_\ell = \frac{i_L}{i_b} = \frac{-i}{i_b}$$

$$\Rightarrow \boxed{(A_v)_\ell = -\frac{h_{fe} R_c}{R_c + h_{ie} - \frac{j}{\omega c}}} \quad \text{— (iii)}$$

$$\therefore \quad |A_{v\ell}| = \frac{h_{fe} R_c}{\sqrt{(R_c + h_{ie})^2 + \left(\frac{1}{2\pi f c}\right)^2}} \quad \text{— (iv)}$$

It is clear, from eq^n (iv), that applied signal-frequency -'f' decreases in "low-freq-band", then $|(A_v)_l|$ ~~increases~~ also decreases and vice-versa. In other word, it functions as High-pass-filter.

Lower cut-off frequency

From eq^n (iv),
$$|(A_v)_l| = \frac{h_{fe} R_c}{\sqrt{(R_c + h_{ie})^2 + \left(\frac{1}{2\pi f c}\right)^2}}$$

or
$$|(A_v)_l| = \frac{h_{fe} R_c}{(R_c + h_{ie}) \sqrt{1 + \left\{\frac{1}{(R_c + h_{ie}) \cdot 2\pi f c}\right\}^2}}$$

or
$$|(A_v)_l| = \frac{\left(\frac{h_{fe} R_c}{R_c + h_{ie}}\right)}{\sqrt{1 + \left[\frac{1}{f} \cdot \left\{\frac{1}{2\pi (R_c + h_{ie}) c}\right\}\right]^2}} \quad \text{— (v)}$$

Replace $\left(\frac{h_{fe} R_c}{R_c + h_{ie}}\right)$ by $|(A_v)_{mid}|$ from eq (v)

$$\therefore |(A_v)_l| = \frac{|(A_v)_{mid}|}{\sqrt{1 + \left[\frac{1}{f} \cdot \left\{\frac{1}{2\pi (R_c + h_{ie}) c}\right\}\right]^2}}$$

or
$$\left|\frac{(A_v)_l}{(A_v)_{mid}}\right| = \frac{1}{\sqrt{1 + \left[\frac{1}{f} \left\{\frac{1}{2\pi (R_c + h_{ie}) c}\right\}\right]^2}}$$

By definition of 3-dB cut-off freq,

When, $f = f_1 = f_L$ then, $\left|\frac{(A_V)_L}{(A_V)_{mid}}\right| = \frac{1}{\sqrt{2}}$

$$\therefore \frac{1}{\sqrt{2}} = \frac{1}{\sqrt{1+\left[\frac{1}{f_L}\cdot\left\{\frac{1}{2\pi(R_c+h_{ie})C}\right\}\right]^2}}$$

$$\text{or } 2 = 1 + \left[\frac{1}{f_L}\cdot\frac{1}{2\pi C(R_c+h_{re})}\right]^2$$

$$\text{or } 1 = \left[\frac{1}{f_L\cdot 2\pi(R_c+h_{ie})C}\right]^2$$

$$\therefore \boxed{f_L = \frac{1}{2\pi(R_c+h_{ie})C}}$$

$$\boxed{\left|\frac{(A_V)_L}{(A_V)_{mid}}\right| = \frac{1}{\sqrt{1+\left(\frac{f_L}{f}\right)^2}}}$$

f increases, $\frac{1}{f}$ decreases

This is the transfer function of High-Pass-Filter. i.e in Low-freq. range, amplifier acts as High-Pass-Filter.

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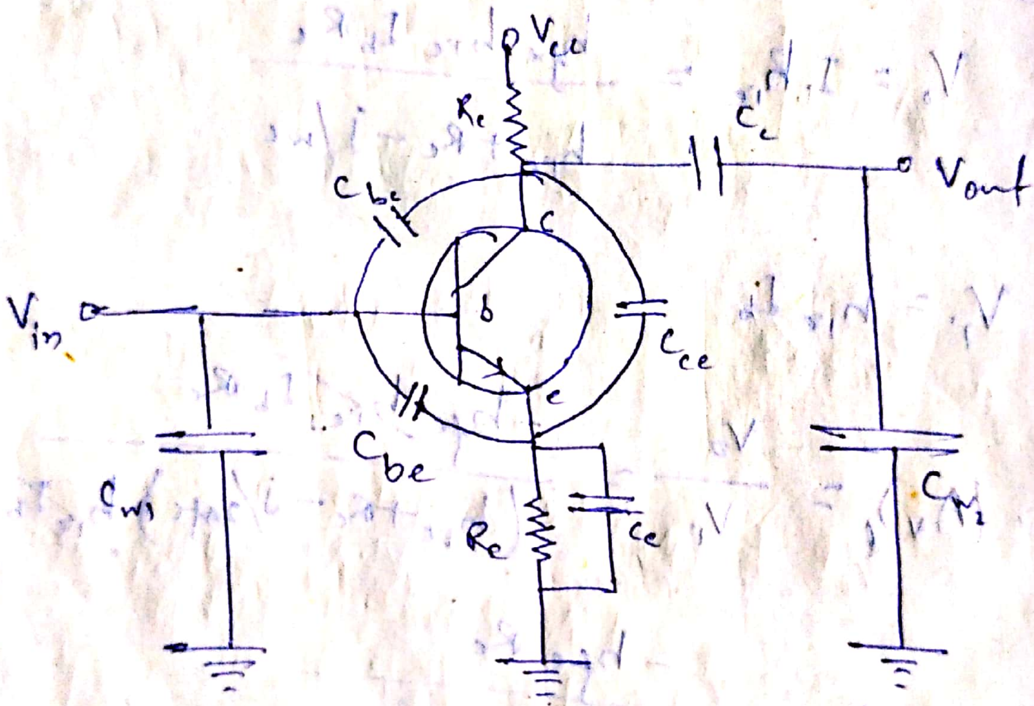
(c) High frequency Region :- At high frequency, the reactance offered by Coupling capacitor is very small and it is treated as short ckt. But, at high frequency the inter-electrode capacitance or junction capacitance of transistor come into play vital role. These capacitance are shown in figure by dotted line.



Here,

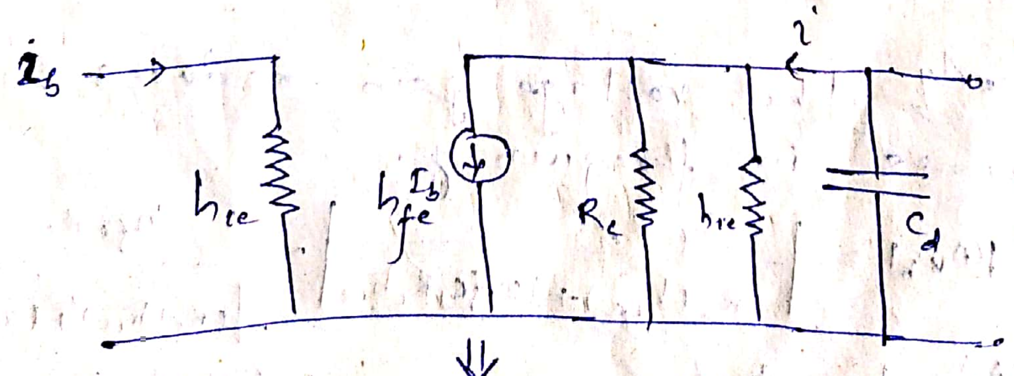
the capacitance betn forward biased base-emitter junctn which is called diffusion capacitance i.e. $C_{be} = C_{\pi}$, is much greater than the capacitance betn reversed bias collector-base junctn which is called transition capacitance i.e. $C_{bc} = C_{\mu} = C_T$

i.e. $C_{\pi} > C_{\mu}$.

But, here the capacitance betn collector-base junctn is more important

Because of high frequency, through this capacitor feedback takes place from output to the input. Since output is in ~~out~~ out-off phase with input, gain reduces. This effect is called Miller effect.

It can be shown that C_{be} and C_{bc} can be replaced by a single capacitor C_d across the input resistance h_{ie}. The value of shunt capacitance C_d in the input ckt of first stage is very small because it depends upon the output impedance. But, the value of C_d in the output of first stage is increased by stray capacitance of connecting wire. Thus, the capacitive reactance $\frac{1}{\omega C_d}$ will have appreciable shunting effect across R_2 and h_{ie}. And, thus, the ~~ckt~~ equivalent ckt can be modified as below —



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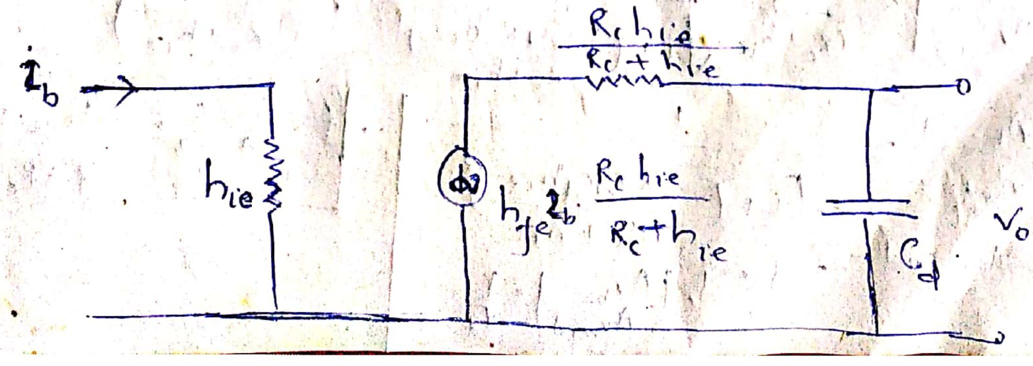

By KVL —

$$h_{fe} I_b \cdot \frac{R_c h_{ie}}{R_c + h_{ie}} = I\left(\frac{R_c h_{ie}}{R_c + h_{ie}} + X_{cd}\right)$$

$$= I\left(\frac{R_c h_{ie}}{R_c + h_{ie}} + \frac{1}{j\omega C_d}\right).$$

$$\text{or, } I/I_b = \frac{h_{fe} R_c h_{ie}}{(R_c + h_{ie})\left[\frac{R_c h_{ie}}{R_c + h_{ie}} + \frac{1}{j\omega C_d}\right]}; \text{ or, } I = \left(\frac{h_{fe} R_c h_{ie}}{R_c h_{ie} + \frac{R_c + h_{ie}}{j\omega C_d}}\right) I_b$$

$$\therefore (A_i)_h = \frac{I_L}{I_b} = \frac{-I}{I_b}$$

$$\text{or, } (A_i)_h = \frac{-h_{fe} h_{ie} R_c}{\left(R_c h_{ie} + \frac{R_c + h_{ie}}{j\omega C_d}\right)} \quad \text{——— (1)}$$

Now,

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

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

$$\therefore (A_v)_h = \frac{-h_{fe} R_c}{R_c h_{ie} j\omega C_d + R_c + h_{ie}}$$

Clearly the voltage gain reduces with increase in frequency.

$$\text{Now, } |(A_v)_h| = \left|\frac{h_{fe} R_c}{(R_c + h_{ie}) + j 2\pi f C_d R_c h_{ie}}\right| = \frac{h_{fe} R_c}{\sqrt{(R_c + h_{ie})^2 + (2\pi C_d R_c h_{ie})^2}}$$

$$\text{or, } \left|\frac{(A_v)_h}{(A_v)_{mid}}\right| = \frac{h_{fe} R_c}{(R_c + h_{ie})\sqrt{1 + \left(\frac{2\pi f C_d R_c h_{ie}}{R_c + h_{ie}}\right)^2}} \div \left(\frac{h_{fe} R_c}{R_c + h_{ie}}\right)$$

$$\text{or, } \left|\frac{(A_v)_h}{(A_v)_{mid}}\right| = \frac{1}{\sqrt{1 + \left(\frac{2\pi R_c f C_d h_{ie}}{R_c + h_{ie}}\right)^2}}$$

For upper 3-dB cut-off freq, $\left|\frac{A_{v_h}}{A_{v_{mid}}}\right| = \frac{1}{\sqrt{2}}$

$$\therefore \boxed{f = f_H = f_2 = \frac{h_{ie} + R_c}{2\pi R_c C_d h_{ie}}}$$

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