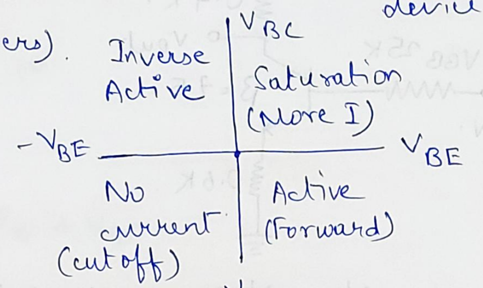
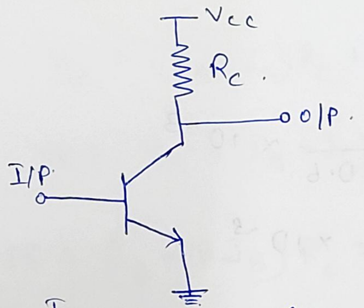
# Analog Electronics

## ① DC Analysis of BJT Amplifiers :-

BJT → current controlled device.

CE = Emitter Common. (Amplifiers).
CB = Base Common.
CC = Collector Common.



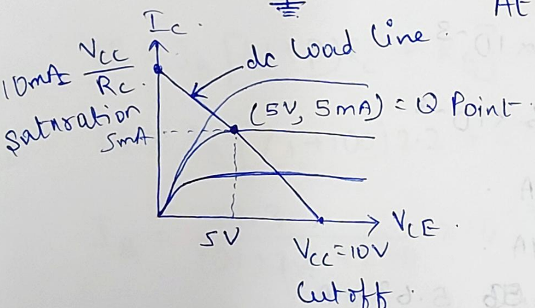




At Cutoff

$I_C = 0$, $V_{CE} = V_{CC}$.

At Saturation.

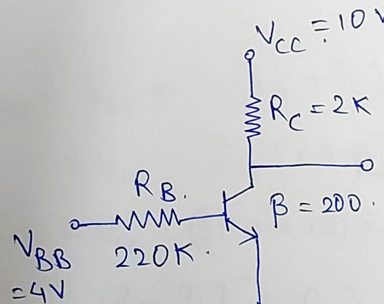
$V_{CE} = 0$; $I_C = \frac{V_{CC}}{R_C}$.




Cutoff = $I_C = 0 \Rightarrow V_{CE} = V_{CC}$ ✓

Sat = $V_{CE} = 0 \Rightarrow V_{CC} = I_C R_C$. $I_Q = \frac{V_{CC}}{R_C}$ ✓

Q)




Find ① $I_B$. ② $I_C$. ③ $I_E$. ④ $V_{CE}$. ⑤ Q Point. ⑥ Load line.

(o/p) $V_{CC} - I_C R_C - V_{CE} = 0$.

(I/p) $V_{BB} - I_B R_B - V_{BE} = 0$.

$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4 - 0.7}{220\ K} = \frac{3.3}{220}$ mA

$= 0.015$ mA.

$= 15\ \mu A$.

$I_C = \frac{V_{CC} - V_{CE}}{R_C}$.

$\beta = \frac{I_C}{I_B} \Rightarrow I_C = \beta I_B = 3$ mA.

$I_E = I_C + I_B = 3015\ \mu A = 3.015$ mA.

$V_{CEQ} = V_{CC} - I_{CQ} R_C$.

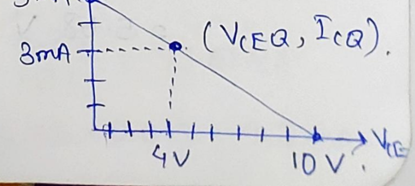
$V_{CE} = V_{CC} - I_C R_C$.
$= 10 - 6 = 4V$.

$V_{CE} = 10V$ (cutoff).

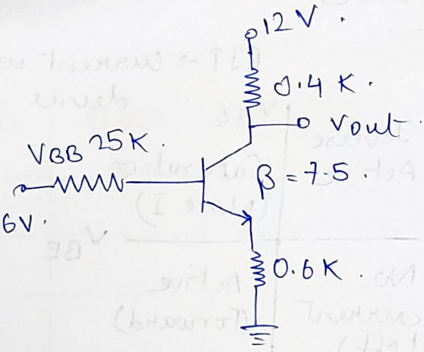
$V_{CC} = I_C R_C$.
$= 6V$ (saturation)

$I_C = \frac{V_{CC}}{R_C} = \frac{10}{2K}$.

$I_C = 5$ mA.



Q)




$$\begin{array}{r} 8.53 \\ 0.6 \\ \hline 510 \\ 00\times \\ \hline 5.10 \end{array}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B + (1+\beta)R_E} = \frac{6 - 0.7}{25 + (1+7.5)0.6} \times 10^{-3}$$

$$= \frac{5.3}{25 + 5.1} \times 10^{-3}$$

$$= \frac{5.3}{30.1} \times 10^{-3}$$

$$= 0.176 \times 10^{-3}$$

$$= 75\ \mu A$$

$$I_C = \beta I_B = 7.5(75) = 562.5\ \mu A$$

$$5.63\ mA$$

$$I_E = I_C + I_B = 5.71\ mA$$

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$V_{CC} - I_C R_C - V_{CE} - (1+\beta)R_E = 0$$

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

$$V_{CEQ} = 12 - (5.63 \times 0.4) - (5.71 \times 0.6)$$

$$= 12 - 2.252 - 3.426$$

$$= 6.322\ V$$

At cutoff $I_C = 0$

$$V_{CE} = V_{CC} = 12\ V$$

At saturation $V_{CE} = 0$

$$V_{CC} = I_C R_C + I_E R_E$$

$$= 2.252 + 3.426$$

$$= 5.68\ V$$

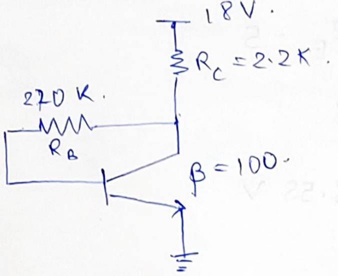
$$V_{CC} = I_C R_C + I_C\left(1 + \frac{1}{\beta}\right)R_E$$

$$= I_C\left(R_C + \left(1 + \frac{1}{\beta}\right)R_E\right)$$

$$I_C = \frac{12}{R_C + \left(1 + \frac{1}{75}\right)R_E}$$

$$= \frac{12}{0.4 + \frac{76}{75} \times 0.6} \times 10^{-3}$$

$$= \frac{12}{1.008} \times 10^{-3} = 12\ mA$$




$$V_{CC} = (I_B + I_C) R_C + I_B R_B + V_{BE}.$$

$$V_{CC} = (I_B + I_C). R_C + V_{CE}.$$

$$18 = (I_B + \beta I_B) R_C + I_B R_B + 0.7.$$

$$18 = I_B [(1+\beta) R_C + R_B] + 0.7.$$

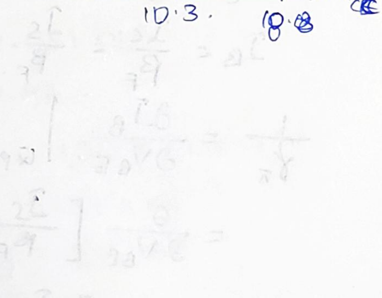
$$18 = I_B [(1+100) 2.2 + 270] \times 10^3 + 0.7.$$

$$I_B = \frac{17.3}{101 \times 2.2 + 270} \times 10^{-3} = \frac{17.3}{492.2} \times 10^{-3}$$

$$= 0.0351 \times 10^{-3} = 35.1 \mu A.$$

$$I_{CQ} = \beta I_B.$$
$$= 3.51 \text{ mA}$$

$$V_{CEQ} = V_{CC} - (I_B + I_C) R_C.$$
$$= V_{CC} - I_B [1 + \beta] R_C$$
$$= V_{CC} - (35.1 \times 101 \times 2.2) \times 10^{-3}.$$
$$= 18 - 7.7 = 10.3 \text{ V}.$$



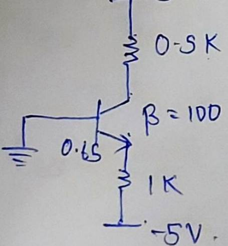

At cutoff $V_{CE} = 18V$.

At sat. $V_{CC} = I_C (1 + \frac{1}{\beta}) R_C$.

$$18 = I_C \left(\frac{101}{100}\right) 2.2 \times 10^3.$$

$$I_C = \frac{18}{2.22} \times 10^{-3} = 8.1 \text{ mA}.$$

Q)




$$0 = 0.65 + I_E R_E - 5.$$

$$I_E = \frac{5 - 0.65}{R_E} = 4.35 \text{ mA}.$$

$$I_B = \frac{I_E}{1+\beta} = \frac{4.35}{101} = 43.51 \mu A.$$

$$I_E - I_B = I_{CQ} \Rightarrow I_{CQ} = 4.35 - 0.043 = 4.3 \text{ mA}.$$

$$5 = I_C R_C + V_{CE} + I_E R_E - 5$$

$$10 = (4.3 \times 0.5) + V_{CE} + 4.3$$

$$V_{CEQ} = 10 - 4.3 - 2.15 = 3.55\ V.$$

At cutoff · $V_{CC} = 10\ V.$

At sat. $10 = I_C R_C + I_C\left(1 + \frac{1}{\beta}\right) R_E$

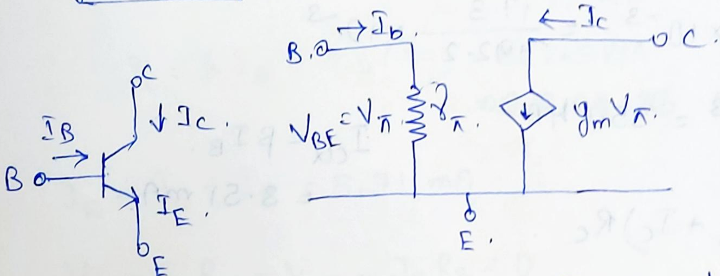
$$10 = I_C\left[R_C + \left(1 + \frac{1}{\beta}\right) R_E\right].$$

$$10 = I_C\left[2.2 + \frac{101}{100}\right]$$

$$I_C = \frac{10}{1.5} = 6.6$$

• Small Signal Equivalent ckt :-

Hybrid π Model :-




① Input Resistance.

$$\boxed{r_\pi = \frac{V_{BE}}{I_B} = \frac{V_T}{I_{BQ}} = \frac{\beta_F V_T}{I_{CQ}}}$$

$$I_C = I_S e^{(V_{BE}/V_T)}$$

$$I_B = \frac{I_C}{\beta_F} = \frac{I_S}{\beta_F} e^{(V_{BE}/V_T)}$$

$$\frac{1}{r_\pi} = \frac{\partial I_B}{\partial V_{BE}}\Big|_{Q\,pt.}$$

$$= \frac{\partial}{\partial V_{BE}}\left[\frac{I_S}{\beta_F} e^{(V_{BE}/V_T)}\right]$$

$$\Rightarrow \frac{1}{r_\pi} = \frac{1}{V_T}\left[\frac{I_S}{\beta_F} e^{(V_{BE}/V_T)}\right]$$

$$\Rightarrow \frac{1}{r_\pi} = \frac{I_{BQ}}{V_T}$$

$$\Rightarrow r_\pi = \frac{V_T}{I_{BQ}} = \frac{\beta_F V_T}{I_{CQ}}$$

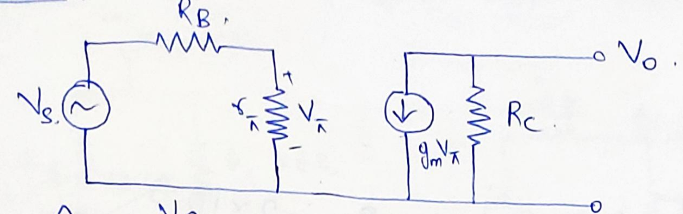
② Transconductance

$$g_m = \frac{\partial I_C}{\partial V_{BE}}$$

$$= \frac{I_{CQ}}{V_T}$$

$$\beta_F = \frac{\partial I_C}{\partial I_B}$$

$$\beta_F = g_m r_\pi$$



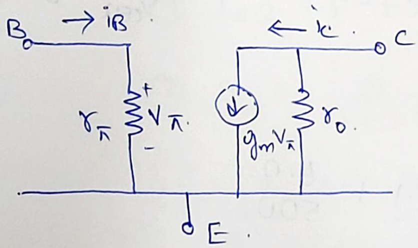

$$A_v = \frac{V_O}{V_S}, \quad V_O = V_{CE} = (-g_m V_{BE}) R_C$$
$$= -g_m V_\pi R_C$$

③ $V_\pi = V_{BE} = \left(\frac{r_\pi}{r_\pi + R_B}\right) V_s$

$$\therefore A_v = \frac{V_O}{V_S} = -g_m R_C \frac{r_\pi}{r_\pi + R_B}$$

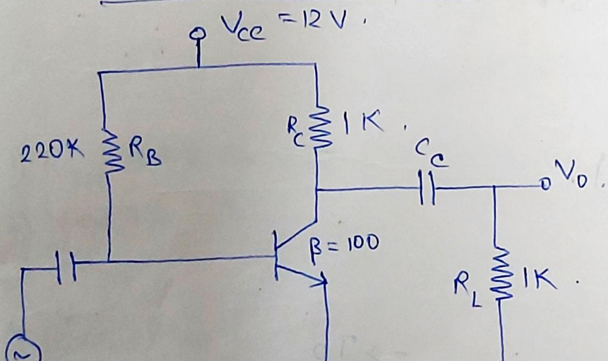
④ Output Resistance $r_o$.

$$r_o = \frac{\partial I_C}{\partial V_{CE}} = \frac{V_A}{I_{CQ}} \quad V_A = \text{Early voltage}$$




Hybrid π Model

- To determine AC & DC Load line:




$$V_{cc} = I_B R_B + V_{BE}$$
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$
$$= \frac{12 - 0.7}{220} \times 10^{-3}$$
$$= 0.051 \text{ mA}$$
$$= 51 \mu A$$
$$I_{CQ} = \beta I_B = 100 \times 51 \times 10^{-6}$$
$$= 51 \times 10^{-4}$$
$$I_{CQ} = 5.1 \text{ mA}$$

$$V_{CC} = I_C R_C + V_{CE}$$
$$V_{CEQ} = V_{CC} - I_C R_C$$
$$= 12 - (5.1 \times 1)$$
$$V_{CEQ} = 12 - 5.1 = 6.9 \text{ V}$$

$\therefore$ DC Load line

Cutoff point: $V_{CC} = V_{CE} = 12V$.

Saturation pt: $V_{CC} = I_C R_C$

$$I_C = \frac{V_{CC}}{R_C} = 12 \text{ mA}$$

AC Load Line

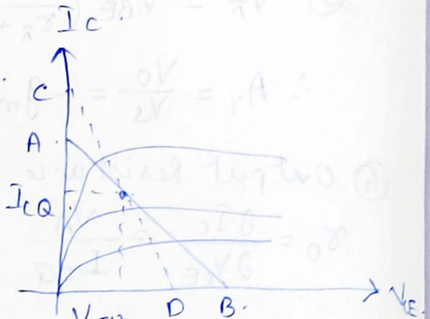
$R_{ac} = R_c || R_L$.

$R_{ac} = \frac{1}{R_c} + \frac{1}{R_L}$.

$\cancel{R_{ac} = \frac{R_C+R_L}{R_C R_L} = \frac{\frac{1}{10^{-6}}}{2\times10^{-3}} = 0.5\times10^{-3}} \quad \cancel{\frac{2\times10^{-3}}{10^{-6}} = 2K}$.

$\frac{1}{R_{ac}} = \frac{1}{R_C} + \frac{1}{R_L}$.

$R_{ac} = \frac{R_C R_L}{R_C + R_L} = 0.5\times10^{+3} = 500\ \Omega$.




$V_{CE(max)} = V_{CEQ} + I_{CQ} R_{ac}$
$= 6.9 + 5.1 \times 500 \times 10^{-3}$.
$= 6.9 + 5.1\times5\times10^{-1}$
$= 6.9 + 2.55$
$= 9.45$ V.

$i_{c(max)} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}} = 5.1 + \frac{6.9}{500}$
$= 5.1 + (0.0138)$ A
$= 5.1 + 13.8 = 18.9$ mA.

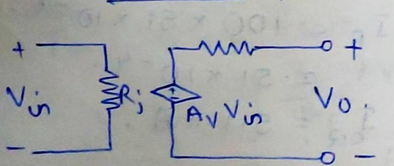
Max symmetrical swing.

$\Delta i_c = 2 I_{CQ}$.

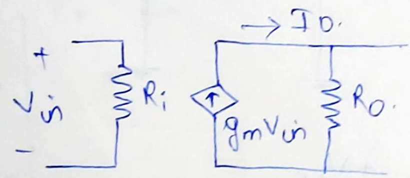
$\Delta V_{CE} = \Delta i_c (R_c || R_L)$.

Common Emitter Amplifier:

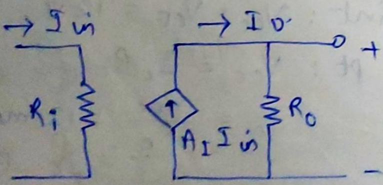
Two port Network



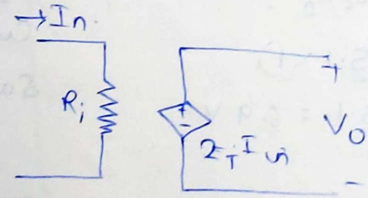

Voltage Amp.




Transconductance Amp.

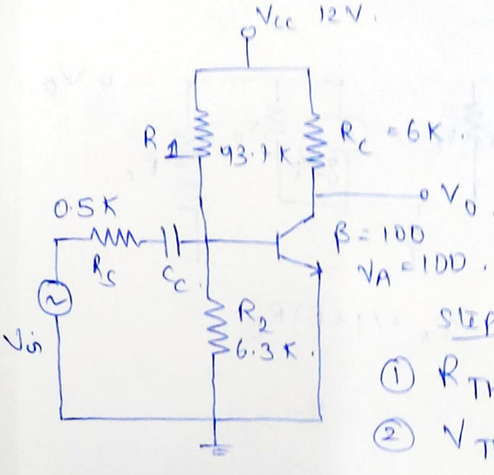


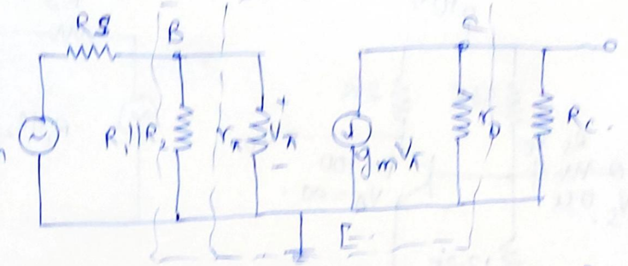

Current Amp.




Transimpedance Amp.

CE Amplifier   with bypass cap




Steps:

① $R_{TH}$ (Find) $= R_1 \| R_2$

② $V_{TH} = \dfrac{R_2}{R_1 + R_2} V_{CC}$

③ $I_{BQ} = \dfrac{V_{TH} - V_{BE}}{R_{TH}}$

④ $I_{CQ} = \beta I_{BQ}$

⑦ $g_m = \dfrac{I_{CQ}}{V_T}$

⑩ $V_\pi = \dfrac{V_s\,(r_\pi \| R_1 \| R_2)}{(R_1 \| R_2 \| r_\pi) + R_s}$

⑫ $R_i = R_1 \| R_2 \| r_\pi$

⑬ $R_o = r_o \| R_C$

⑤ $V_{CEQ} = V_{CC} - I_{CQ} R_C$ (without $R_E$)

$= V_{CC} - I_{CQ} R_C - I_{EQ} R_E$ (with $R_E$)

⑥ $r_\pi = \dfrac{V_T\, \beta}{I_{CQ}}$

⑧ $r_o = \dfrac{V_A}{I_{CQ}}$

⑨ $V_o = (-g_m V_\pi)(r_o \| R_C)$

⑪ $A_V = \dfrac{V_o}{V_S}$

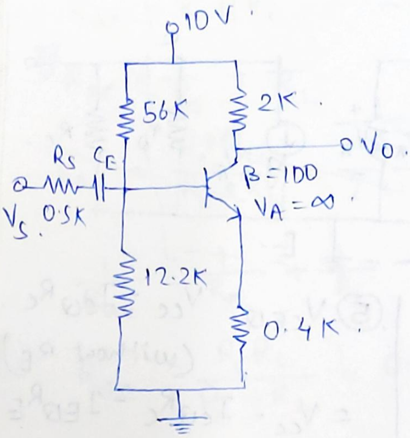
$= \dfrac{-g_m V_\pi (r_o \| R_C)}{V_S}$

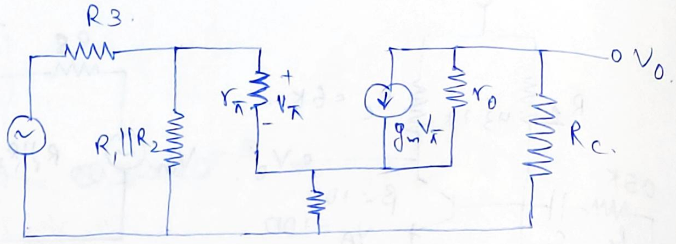
Substitute for $V_\pi$

$\therefore A_V = \dfrac{-g_m (r_\pi \| R_1 \| R_2)(r_o \| R_C)}{(R_1 \| R_2 \| r_\pi) + R_S}$

1) $R_{TH} = 5.9\,k\Omega$
2) $V_{TH} = 0.756$
3) $I_{BQ}$
4) $I_{CQ} = 0.9\,mA$
5) $V_{CEQ} = 6.3\,V$
6) $r_\pi = 2.79\,\Omega$
7) $g_m = 36.5\,mA/V$
8) $r_o = 105\,k\Omega$
9) $A_V = -163$
10) $R_i = 1.87\,k\Omega$
11) $R_o = 5.67\,k\Omega$

# CE Amplifier without bypass:



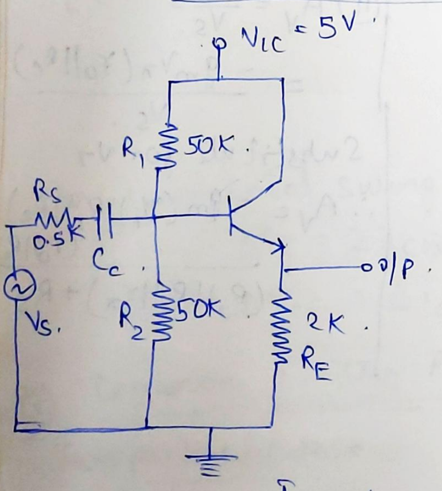



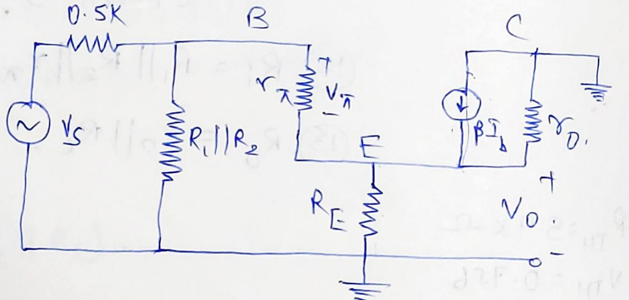

$r_\pi + (1+\beta) R_E$.

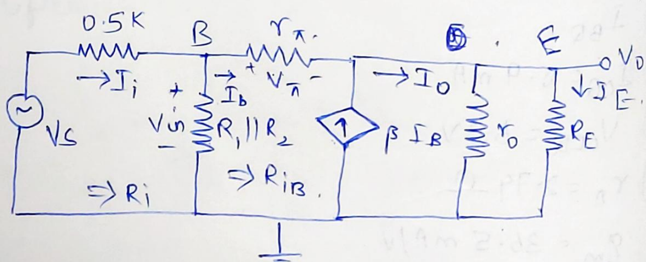
## Features of CE Amplifier:

1) Phase shift = 180°
2) Voltage Gain is high (without emitter)
3) Input & output impedance are moderate

- **Common collector BJT Configuration (Emitter Follower)** (used for impedance matching)




$$g_m V_{be} = \frac{I_c}{V_{be}} V_{BE}.$$

$$I_c = \beta I_b$$

$$V_{in} = \frac{R_i V_s}{R_i + R_s}.$$

$$R_i = R_1 || R_2 || R_{iB}.$$

$$A_V = \frac{V_O}{V_S} = \frac{[(1+\beta) I_B](r_o || R_E)}{\frac{V_{in}(R_i + R_s)}{R_i}}$$

$$\therefore A_V = \frac{R_i [(1+\beta) I_B](r_o || R_E)}{V_{in}(R_i + R_s)}$$

$$I_O = I_B + \beta I_B = (1+\beta) I_B. \quad \text{—(I)}$$

$$V_o = [(1+\beta) I_B](r_o || R_E) \quad \text{—(II)}$$

$$V_{in} = I_B r_\pi + \{(1+\beta) I_B\}(r_o || R_E)$$

$$V_{in} = I_B [r_\pi + (1+\beta)(r_o || R_E)]$$

$$\frac{V_{in}}{I_B} = R_{iB} = r_\pi + (1+\beta)(r_o || R_E) \quad \text{—(III)}$$

$$\therefore A_V = \frac{R_i\left[(1+\beta)\cancel{I_B}\right](r_o \| R_E)}{\cancel{I_B}\left[r_\pi + (1+\beta)(r_o\|R_E)\right](R_i + R_S)}$$

$$\therefore A_V = \frac{(1+\beta)(r_o\|R_E)}{r_\pi + (1+\beta)(r_o\|R_E)}\,\frac{R_i}{R_i + R_S} \quad \text{— (IV)}$$

$$r_\pi << (1+\beta)(r_o\|R_E)$$

$$R_i >> R_S.$$

$$\therefore A_V = \frac{(1+\beta)(r_o\|R_E)}{(1+\beta)(r_o\|R_E)}\,\frac{R_i}{R_i} \approx 1.$$

$$A_I = \frac{I_E}{I_i} \quad \text{— (V)}$$

$$I_B = I_i \frac{R_1\|R_2}{(R_1\|R_2) + R_{iB}} \quad \text{— (VI)}$$

$$I_o = (1+\beta) I_B.$$

$$I_E = I_o \frac{r_o}{r_o + R_E} = \frac{(1+\beta) I_B\, r_o}{r_o + R_E} \quad \text{— (VII)}$$

$$\therefore A_I = \frac{(1+\beta)\cancel{I_B}\, r_o}{r_o + R_E}\,\frac{R_1\|R_2}{\cancel{I_B}\left[(R_1\|R_2) + R_{iB}\right]}$$

$$\Rightarrow A_I = \frac{(1+\beta) r_o}{r_o + R_E}\,\frac{R_1\|R_2}{R_1\|R_2 + R_{iB}}$$

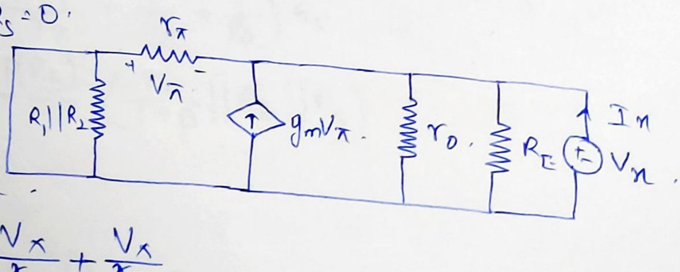
$$\Rightarrow A_I = \frac{r_o}{r_o + R_E}\,\frac{(1+\beta)(R_1\|R_2)}{(R_1\|R_2 + R_{iB})} \quad \text{— (VIII)}$$

$$R_1\|R_2 >> R_{iB} \;;\; r_o >> R_E.$$

$$\therefore \boxed{A_I = 1+\beta} \quad \text{— (IX)}$$

$R_S = 0.$

<u>To find o/p Imp.</u>




$V_\pi = -V_x.$

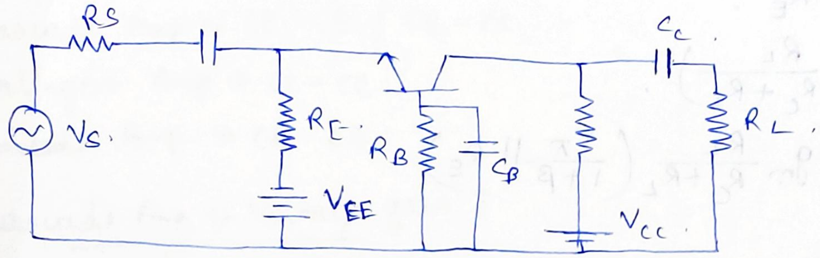
Apply KCL at o/p node.

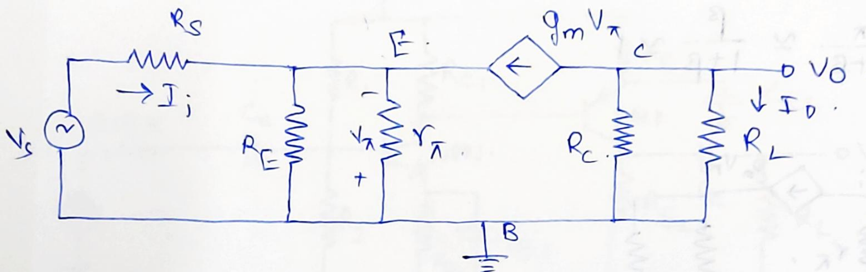
$$g_m V_\pi + I_x = \frac{V_x}{R_E} + \frac{V_x}{r_o} + \frac{V_x}{r_\pi}$$

$$\Rightarrow I_x = V_x\left[\frac{1}{R_E} + \frac{1}{r_o} + \frac{1}{r_\pi} + g_m\right] \quad \left[\because g_m = \frac{\beta}{r_\pi}\right]$$

$$\Rightarrow \frac{V_x}{I_x} = R_o = \frac{r_\pi}{1+\beta} \| R_E \| r_o \simeq \frac{1}{1+\beta} \quad \text{— (X)}$$

# Common Base Amp.




## Voltage Gain:

$$V_o = -g_m V_\pi (R_C \| R_L) \quad \text{— (I)}$$

Apply KCL at E.

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \left(\frac{V_s - (-V_\pi)}{R_s}\right) = 0 \quad \text{— (II)}$$

$$\beta = g_m r_\pi .$$

(II) can be.

$$V_\pi \left[\frac{1+\beta}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S}\right] = \frac{-V_s}{R_s}.$$

$$V_\pi = -\frac{V_s}{R_s}\left[\left(\frac{r_\pi}{1+\beta}\right) \| R_E \| R_s\right]$$

$$A_v = \frac{V_o}{V_s} = \frac{\cancel{-} g_m \cancel{V_\pi} (R_c \| R_L)}{\cancel{-} \cancel{V_\pi}\left(\frac{1+\beta}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S}\right) R_S}.$$

$$A_v = \frac{g_m (R_C \| R_L)}{R_S}\left(\frac{r_\pi}{1+\beta} \| R_E \| R_S\right)$$

## Current Gain

KCL at E.

$$I_i + \frac{V_\pi}{r_\pi} + g_m V_\pi + \frac{V_\pi}{R_E} = 0.$$

$$\Rightarrow I_i + \frac{V_\pi}{r_\pi} + \frac{\beta}{r_\pi} V_\pi + \frac{V_\pi}{R_E} = 0.$$

$$\Rightarrow I_i = -V_\pi \left[\frac{1+\beta}{r_\pi} + \frac{1}{R_E}\right]$$

$$V_\pi = \frac{I_i}{\frac{1+\beta}{r_\pi} + \frac{1}{R_E}}.$$

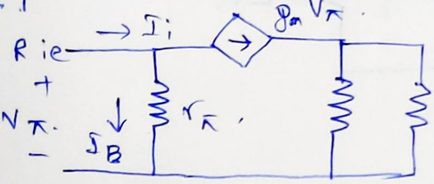
$$I_o = -g_m V_\pi \left(\frac{R_L}{R_C + R_L}\right).$$

$$A_i = \frac{I_o}{I_i} = g_m \frac{R_L}{R_C + R_L}\left(\frac{r_\pi}{1+\beta} \parallel R_E\right)$$

$R_E \simeq$ Infinity.

$$A_i = g_m \frac{r_\pi}{1+\beta} \simeq \frac{\beta}{1+\beta} \simeq 1$$

<u>I/O Imp.</u>

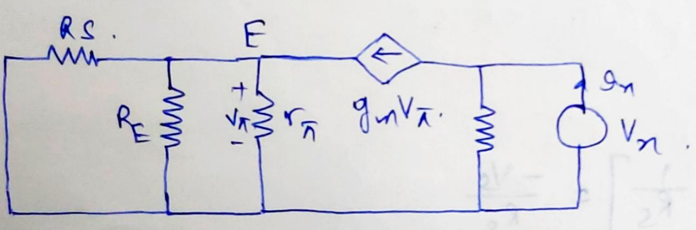



$$R_{ie} = \frac{V_\pi}{I_i}$$

$$I_i = I_b + g_m V_\pi = \frac{V_\pi}{r_\pi} + g_m V_\pi = V_\pi\left(\frac{1}{r_\pi} + g_m\right)$$

$$= V_\pi\left(\frac{1+\beta}{r_\pi}\right)$$

$$\therefore R_{ie} = \frac{V_\pi}{I_i} = \frac{r_\pi}{1+\beta} \downarrow$$




KCL at E.

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_\pi}{R_S} = 0.$$

$$V_\pi = 0 \quad \therefore \frac{V_x}{I_x} = R_C = R_O \uparrow$$

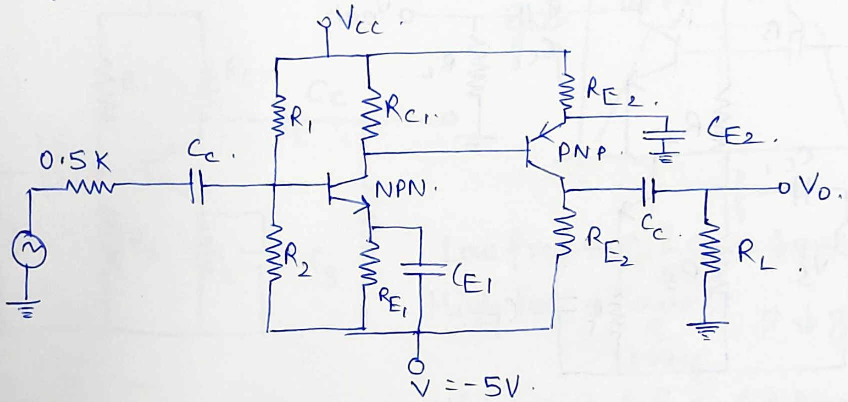
Multistage Amp:

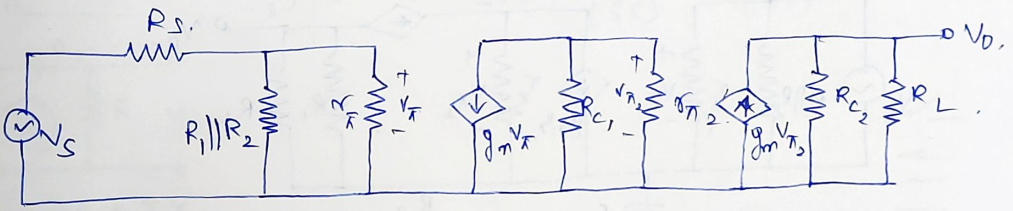
Cascade Amp → CE – CE / CE – CC.

Darlington Amp → CC – CC.

Cascode Amp → CE – CB

Cascade Amp ⇒ Voltage gain ↑




$$Av_1 = \frac{V_{O1}}{V_S} = -g_m (R_C \| r_{\pi 2}) \frac{R_i}{R_i + R_s}$$

$$Av_2 = \frac{V_{O2}}{V_{\pi_2}} = -g_{m_2} (R_C \| R_L)$$

$$A_V = \frac{V_O}{V_S} = Av_1 \cdot Av_2$$

$$A_V = g_{m_1} g_{m_2} (R_{C_1} \| r_{\pi 2}) \frac{R_i}{R_i + R_s} (R_{C_2} \| R_L)$$

$$V_{O1} = -g_{m_1} V_{\pi_1} (R_{C_1} \| r_{\pi_2})$$

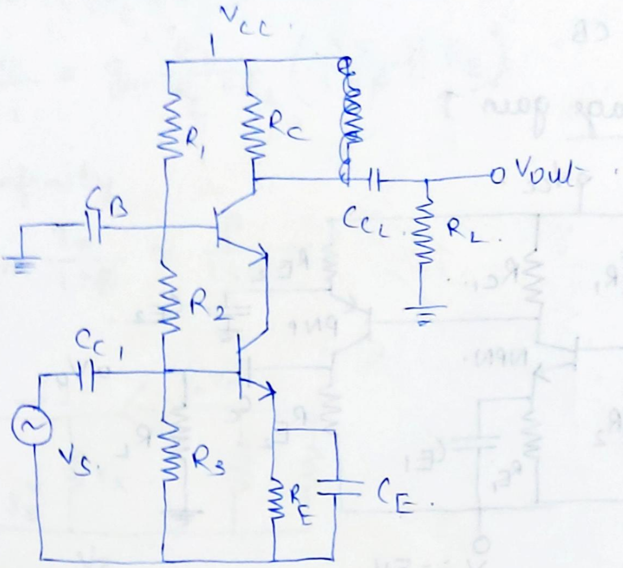
$$V_{O2} = +g_{m_2} V_{\pi_2} (R_{C_2} \| R_L)$$

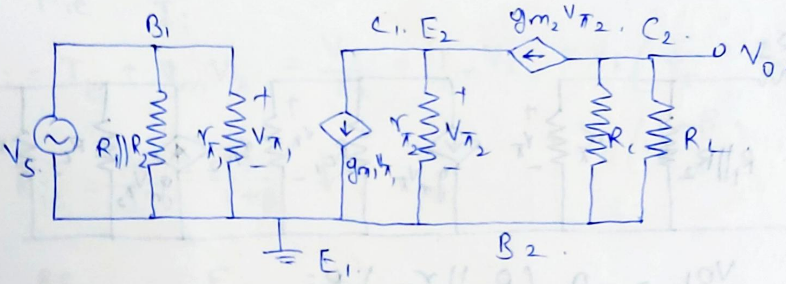
$$V_{in} = \frac{R_i}{R_i + R_s} V_s$$

Q) Determine $g_m$, $r_\pi$, $R_O$, $A_I$, $A_V$, $R_i$, $r_o$ for CB circuit which has $R_B = 100\,K\Omega$, $R_E = 10\,K\Omega$, $R_C = 10\,K\Omega$, $V_{CC} = V_{EE} = 10\,V$. $R_L = 1\,K\Omega$, $R_s = 1\,K\Omega$, $V_{BE} = 0.7\,V$, $\beta = 100$, $V_A = \infty$.

Q) Find $A_V$ (overall), $R_1 = 70\,K\Omega$, $R_2 = 6\,K\Omega$, $R_{C_1} = 5\,K\Omega$, $R_{E_1} = 0.2\,K$, $\beta = 125$. $R_{E2} = 1.5\,K\Omega$, $R_L = 10\,K\Omega$, $V_+ = 5V$, $V_- = 5V$, $r_o = \infty$

Cascode Amplifier :




I/P Impedance ⇒ CE ⇒ moderate

O/P Impedance ⇒ CB ⇒ high

KCL at $E_2$.

$$g_{m_1} V_{\pi_1} = \frac{V_{\pi_2}}{r_{\pi_2}} + g_{m_2} V_{\pi_2}$$

$$= \frac{V_{\pi_2}}{r_{\pi_2}} + \frac{\beta_2}{r_{\pi_2}} V_{\pi_2}$$

$$g_{m_1} V_{\pi_1} = V_{\pi_2} \left( \frac{1+\beta_2}{r_{\pi_2}} \right)$$

$$V_o = - g_{m_2} V_{\pi_2} (R_C \| R_L)$$

$$V_o = - g_{m_1} g_{m_2} V_{\pi_1} \left( \frac{r_{\pi_2}}{1+\beta_2} \right) (R_C \| R_L)$$

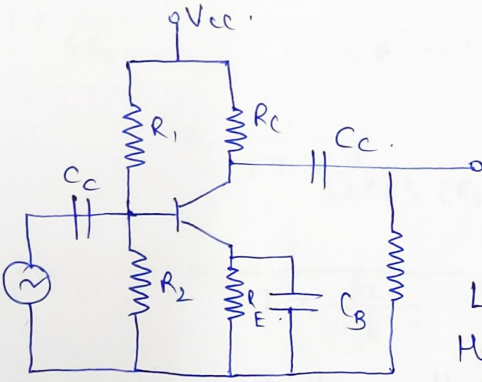
$$\therefore A_V = \frac{V_o}{V_s}$$

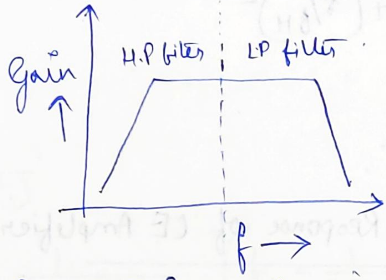
$$= - g_{m_1} g_{m_2} \left( \frac{r_{\pi_2}}{1+\beta_2} \right) (R_C \| R_L)$$

$g_{m_2} r_{\pi_2} = \beta_2$ ; $\frac{g_{m_2} r_{\pi_2}}{1+\beta_2} = \frac{\beta_2}{1+\beta_2} \simeq 1$

$\therefore A_V = -g_{m_1}(R_C \| R_L)$. ($A_V$ of $CE_1$)

## Frequency Response of an Amp :-



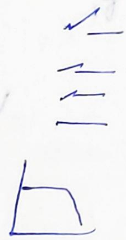





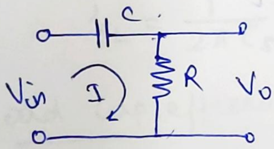
Low freq ⇒ $C_C$ & $C_B$ (OC) ⇒ ↓gain  E||B||C

High freq ⇒ Parasitic & Stray (SC) ⇒ ↓gain  E||C

Mid freq ⇒ $C_C$ & $C_B$ (SC) & Internal (OC) ⇒ Const.



### High Pass Filter




$V_{in} = IR + IX_C$

$= IR + \frac{I}{2\pi f C}$

$V_{out} = IR$

$A_v = \frac{R}{R+\frac{1}{2\pi f C}} = \frac{RSC}{RSC+1} = \frac{1}{1+\frac{1}{RSC}} = \frac{1}{1+\frac{1}{j2\pi f RC}}$  $1 - j 2\pi f R_C$

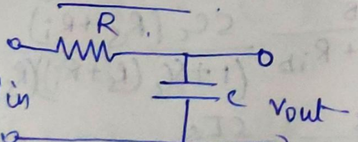
$= \frac{1}{1-j\frac{f_L}{f}}$ $\left[f_L = \frac{1}{2\pi RC}\right]$  $f_1 = \frac{1}{2\pi RC}$

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

At $f = f_L$,

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

### Low Pass Filter




$V_{out} = IX_C = \frac{I}{SC}$

$V_{in} = IR + \frac{I}{SC}$

$A_V = \frac{I/SC}{IR + I/SC} = \frac{\frac{1}{SC}}{R+\frac{1}{SC}} = \frac{1}{RSC+1}$

$$= \frac{1}{1+jR2\pi fC}$$

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

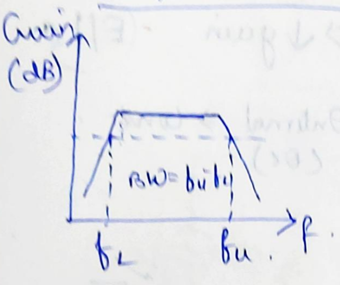
$$|A_v| = \frac{1}{\sqrt{1+(f/f_H)^2}}$$

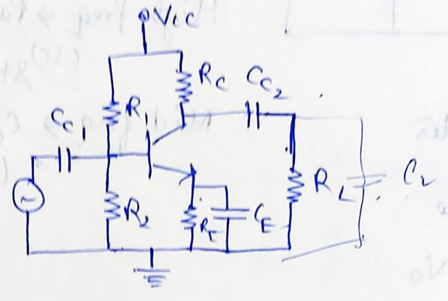
At $f = f_H$.

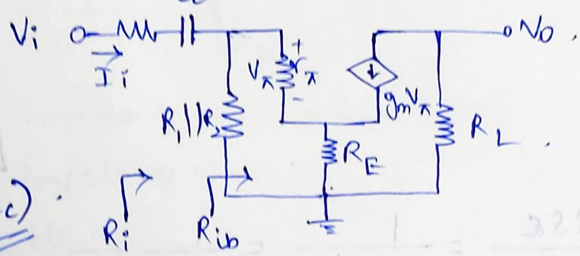
$$|A_v| = \frac{1}{\sqrt{2}}.$$

- Frequency Response of CE Amplifier:-

Coupling capacitor effects:




(I/P $C_C$).

$$I_i = \frac{V_i}{R_S + \frac{1}{SC_c} + R_i}$$

$$I_b = \frac{R_B}{R_B + R_{iB}} I_i$$

$$V_\pi = I_b r_\pi.$$

$$R_i = R_B || r_\pi + (1+\beta) R_E.$$

$$R_B = R_1 || R_2.$$

Resistance Reflection Rule

$$R_{ib} = \frac{V_\pi}{I_b} = r_\pi + (1+\beta) R_E.$$

$$V_O = -g_m V_\pi R_C.$$

$$V_O = -g_m R_C (I_B r_\pi)$$

$$= -g_m R_C r_\pi \frac{R_B}{R_B + R_{ib}} I_i$$

$$= -g_m R_C r_\pi \frac{R_B}{R_B + R_{iB}} \cdot \frac{V_i}{R_S + \frac{1}{SC_c} + R_i}$$

$$A_V = \frac{V_O}{V_i} = -g_m R_C r_\pi \frac{R_B}{R_B + R_{ib}} \frac{SC_c (R_S + R_i)}{(1 + SC_c (R_S + R_i))(R_S + R_i)}$$

$$= \frac{-g_m R_C r_\pi}{R_S + R_i} \frac{R_B}{R_B + R_{ib}} \frac{S\tau_S}{1 + S\tau_S}.$$

$$\therefore A_v(s) = \frac{-g_m R_C}{R_i + R_S} r_\pi \frac{R_B}{R_B + R_{ib}} \frac{1}{1+\frac{1}{s\tau_s}}$$

$$|A_v(s)| = 20\log\left(\frac{g_m R_S}{R_i + R_S} r_\pi \frac{R_B}{R_B + R_{ib}}\right)$$

$$\frac{1}{1+\frac{1}{s\tau_s}} = \frac{1}{1+\frac{1}{j\omega C_c(R_s + R_i)}}$$

$$= \frac{1}{1+\frac{1}{j2\pi f C_c(R_s + R_i)}}$$

$$= \frac{1}{1+\frac{f_L}{jf}} = \frac{1}{1-\frac{jf_L}{f}} \quad \left[f_L = \frac{1}{2\pi C_c(R_s + R_i)}\right]$$

O/p coupling capacitance effect

$$\tau_s = (R_S + R_L) C_{C_2}.$$

$$f_L = \frac{1}{2\pi\tau_s}.$$

Load cap effects

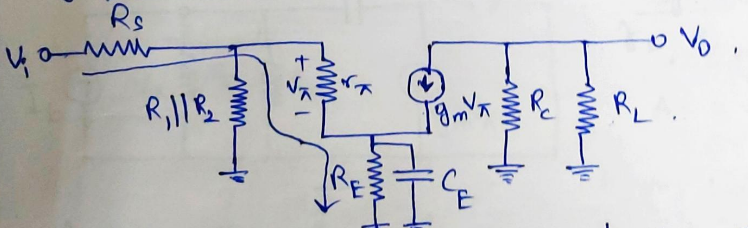
$$\tau_p = (R_C \| R_L)$$

$$A_v = \frac{g_m(R_C \| R_L)}{1 + g_m R_s}\left(\frac{1}{1+\frac{1}{s\tau}}\right)$$

$$A_{v(max)} = \frac{g_m(R_C \| R_L)}{1 + g_m R_s}.$$

▲ Effect in Frequency Response :-

Bypass capacitor:




$$I_b = \frac{V_i}{R_S + r_\pi + (1+\beta)(R_E \| \frac{1}{sC_E})}$$

$$V_\pi = I_b r_\pi$$

$$V_o = -g_m V_\pi (R_C \| R_L)$$

$$\therefore V_o = -g_m I_b r_\pi (R_C \| R_L)$$

$$V_o = -g_m r_\pi (R_C \| R_L) \frac{V_i}{R_S + r_\pi + (1+\beta)(R_E \| \frac{1}{sC_E})}$$

$$A_v = \frac{V_o}{V_i}$$

$$= \frac{-g_m r_\pi (R_C \| R_L)}{R_S + r_\pi + (1+\beta)\left(\frac{R_E \cdot 1/sC_E}{R_E + 1/sC_E}\right)}$$

$$= \frac{-g_m r_\pi (R_c || R_L)}{R_s + r_\pi + (1+\beta)\frac{R_E}{1+sR_E C_E}}$$

$$= \frac{-g_m r_\pi (R_c || R_L)(1 + sR_E C_E)}{(R_s + r_\pi)(1 + sR_E C_E) + (1+\beta)R_E}$$

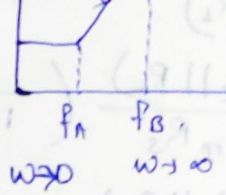
$$= \frac{-g_m r_\pi (R_c || R_L)(1 + sR_E C_E)}{R_s + r_\pi + (1+\beta)R_E + (R_s + r_\pi) s R_E C_E}$$

$$= \frac{-g_m r_\pi (R_c || R_L)}{R_s + r_\pi + (1+\beta)R_E} \frac{(1 + sR_E C_E)}{\left(1 + \frac{sR_E (R_s + r_\pi) C_E}{R_s + r_\pi + (1+\beta)R_E}\right)}$$

$$= \frac{-g_m r_\pi (R_c || R_L)}{R_s + r_\pi + (1+\beta)R_E} \frac{1 + s\tau_A}{1 + s\tau_B}$$

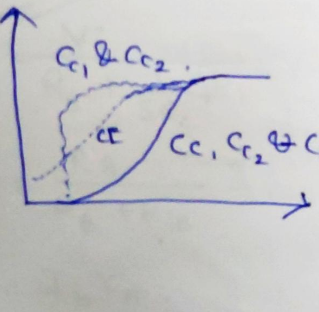
when $\omega \to 0$ $C_E$ is open cirwit.

$$\therefore A_v(s) = \frac{g_m r_\pi (R_c || R_L)}{R_s + r_\pi + (1+\beta)R_E}$$

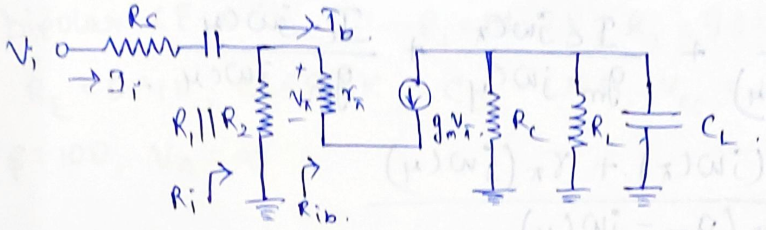



$\omega \to \infty$

$$A_v(s) = \frac{g_m r_\pi (R_c || R_L)}{R_s + r_\pi}$$



## Midband Gain :-




$$I_i = \frac{V_i}{R_s + R_1 || R_2 || R_{ib}}$$

$$I_b = \frac{R_1 || R_2 \; I_i}{(R_1 || R_2) + R_{ib}}$$

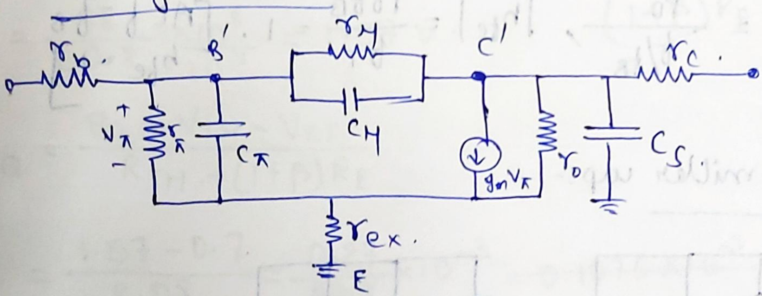
$$V_\pi = I_b \cdot r_\pi$$

$$V_0 = -g_m V_\pi (R_C || R_L)$$

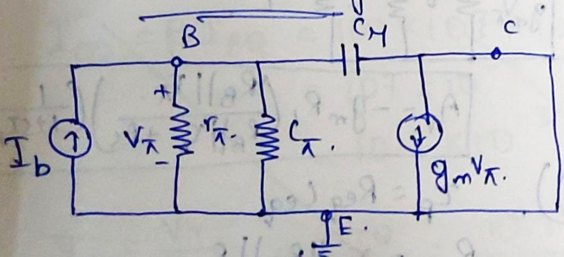
$$V_0 = -g_m r_\pi \frac{(R_1 || R_2)}{(R_1 || R_2) + R_i} \frac{V_i}{(R_s + R_1 || R_2 || R_{ib})}$$

$$A_V = \frac{V_0}{V_i} = -g_m r_\pi \frac{(R_1 || R_2)}{(R_1 || R_2) + R_i} \frac{1}{(R_s + R_1 || R_2 || R_{ib})}$$

## Expanded hybrid π Model :-




## Short circuit I gain :-




Neglecting.

$r_b, r_c, r_{ex}, r_\mu$ & $C_s, r_o$.

$$A_i = \frac{I_c}{I_b}$$

Apply KCL at B.

$$I_b = \frac{V_\pi}{r_\pi} + \frac{V_\pi}{1/j\omega C_\pi} + \frac{V_\pi}{1/j\omega C_\mu} \quad \text{— (I)}$$

Applying KCL at C.

$$\frac{V_\pi}{1/j\omega C_\mu} + I_c = g_m V_\pi$$

$$\therefore V_\pi = \frac{I_c}{g_m - j\omega C_\mu} \quad \text{— (II)}$$

Subctituting $I_c$ on $V_\pi$ in $I_b$.

$$I_b = \frac{I_c}{r_\pi(g_m - j\omega C_\mu)} + \frac{I_c\, j\omega C_\pi}{g_m - j\omega C_\mu} + \frac{I_c\, j\omega C_\mu}{g_m - j\omega C_\mu}$$

$$\Rightarrow \frac{I_b}{I_c} = \frac{1 + r_\pi(j\omega C_\pi) + r_\pi(j\omega C_\mu)}{r_\pi(g_m - j\omega C_\mu)}$$

$$\Rightarrow \frac{I_c}{I_b} = \frac{r_\pi(g_m - j\omega C_\mu)}{1 + r_\pi(j\omega C_\pi) + r_\pi(j\omega C_\mu)}$$

$$\Rightarrow A_i = \frac{g_m - j\omega C_\mu}{\frac{1}{r_\pi} + j\omega(C_\pi + C_\mu)}$$

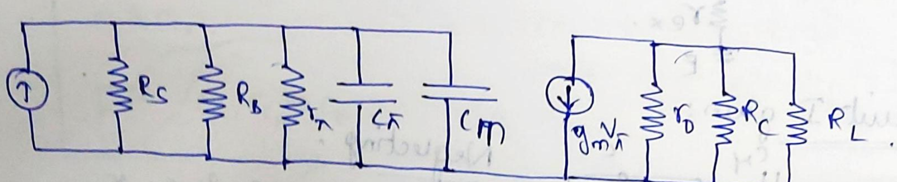
$$\Rightarrow A_i = \frac{g_m - j\omega C_\mu}{1 + j\omega r_\pi(C_\pi + C_\mu)}$$

$$= \frac{\beta_0}{1 + j\omega r_\pi(C_\pi + C_\mu)}$$

$$= \frac{\beta_0}{1 + f/f_\beta}$$

$$|h_{fe}| = \frac{\beta_0}{\sqrt{1 + (f/f_\beta)^2}} = \frac{\beta_0}{f/f_\beta}, \quad |h_{fe}| = \frac{\beta_0 f_\beta}{f_T} = 1. \quad \begin{bmatrix} \text{At } f = f_\beta \\ h_{fe} = 1 \end{bmatrix}$$

Miller effect and miller cap:-




$$C_m = C_\mu(1 + A_v)$$

$$C_m = C_\mu(1 + (-g_m(R_C \| R_L)))$$

Total i/p capacitance $= C_\pi + C_m$

$$\boxed{A_V = -g_m R_L \left(\frac{R_B \| r_\pi}{R_B \| r_\pi + R_S}\right)\left(\frac{1}{1 + s\tau_p}\right)}$$

$\tau_p = R_{eq} C_{eq}$

$R_{eq} = r_\pi \| R_B \| R_S$

$C_{eq} = C_m + C_\pi$

$$\therefore f_H = \frac{1}{2\pi R_{eq} C_{eq}}$$

Q) Calculate the corner frequency and max gain of bipolar CE with $C_C$. $R_1 = 51.2K$, $R_2 = 9.6K$, $R_C = 2K$, $R_E = 0.4K$, $R_S = 0.1K$, $C_C = 1\mu F$, $V_{CC} = 10V$, $V_{BE} = 0.7V$, $\beta = 100$, $V_A = \infty$.

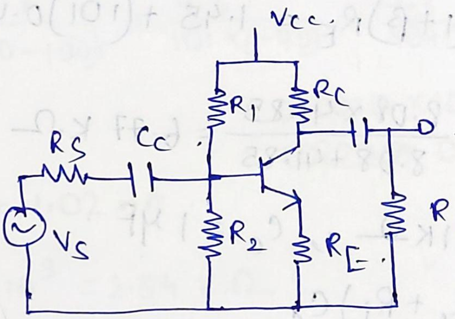
$I_{CQ}$, $g_m$, $r_\pi$, $R_i = R_1 \| R_2 \| r_\pi + (1+\beta)R_E$, $\tau_S = (R_S + R_i)C_C$,

$f_L = \dfrac{1}{2\pi \tau_S}$, $|A_v| = \dfrac{g_m r_\pi R_C}{R_S + R_i}$, $\dfrac{R_B}{R_B + R_{iB}}$.

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$$= \frac{(51.2 \cdot 9.6) \times 10^6}{51.2 + 9.6}$$

$$= 8.08\ K\Omega$$




$$V_{TH} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$= \frac{9.6 \times 10 \times 10^3}{(51.2 + 9.6) \times 10^3}$$

$$= \frac{96}{60.8} \frac{\times 10^3}{10^3} = 1.57\ V$$

$(1+\beta)R_E = 0.4 \times 101 = 40.4$

$$I_{BQ} = \frac{V_{TH} - V_{BE}}{R_{TH} + (1+\beta)R_E}$$

$$= \frac{1.57 - 0.7}{8.08 + 40.4} = \frac{0.87}{48.48} \times 10^{-3} \ \cancel{= 0.1076 \times 10^{-3} = 107\ \mu A} =$$

$0.0179 \times 10^{-3} = 17.9\ \mu A$

$I_{CQ} = \beta I_{BQ} = 100 \times 107 \times 10^{-6}$
$= 107 \times 10^{-4}$
$= 10.7 \times 10^{-3} = 10.7\ mA$.

$\dfrac{1}{g_m} = \dfrac{V_T}{I_{CQ}} = \dfrac{I_{CQ}}{V_T} = \dfrac{10.7 \times 10^{-3}}{0.026} = 411.53 \times 10^{-3}$
$= 0.41$.

$R_1 \| R_2 = 8.08\ K\Omega$.

$r_\pi = \dfrac{\beta V_T}{I_{CQ}} = \dfrac{100 \times 0.026}{10.7} \times 10^3 = \dfrac{2.6}{10.7}\ K\Omega = 0.24\ K\Omega$

$$\cancel{r_\pi + (1+\beta)R_E = 0.24 + (101)0.4}$$

$$I_{CQ} = \beta I_{BQ} = 100\,(17.9) \times 10^{-6}$$
$$= 17.9 \times 10^{-4}$$
$$= 1.79 \text{ mA}.$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.79 \times 10^{-3}}{0.026} = 68.84 \times 10^{-3} = 0.068.$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 \times 0.026 \times 10^3}{1.79} = 1.45 \text{ k}\Omega.$$

$$r_\pi + (1+\beta)R_E = 1.45 + (101)0.4 = 41.85 \text{ K}\Omega.$$

$$R_i = \frac{8.08 \times 41.85}{8.08 + 41.85} = 6.77 \text{ K}\Omega.$$

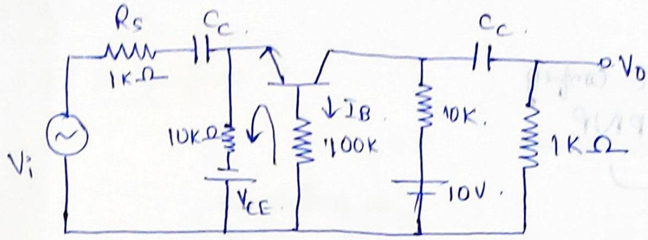
$R_S = 0.1 \text{K}\Omega$, $C_C = 1\,\mu F$.

$$\tau_s = (R_s + R_i)\,C_c$$
$$= (0.1 + 6.77) \times 1 \times 10^{-3}.$$
$$= 6.87 \times 10^{-3}$$

$$f_L = \frac{1}{2\pi \tau_s} = \frac{10^3}{2 \times 3.14 \times 6.87} = \frac{1}{43.14} \times 10^3 = 0.0231 \times 10^3.$$
$$= 23 \text{ Hz}.$$

$$|A_v| = \frac{0.068 \times 1.45 \times 2 \times 10^6}{6.87 \times 10^3} \cdot \frac{8.08 \times 10^3}{(8.08 + 41.85) \times 10^3}$$

$$= 0.028 \times 10^3 \times 0.162 = 0.0045 \times 10^3 = 4.5.$$




$$I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

$$\Rightarrow V_{EE} - V_{BE} = I_E R_E - I_B R_B$$

$$= I_B(1+\beta)(R_E - R_B)$$

$$I_B = \frac{V_{EE} - V_{BE}}{(1+\beta)(R_E - R_B)} = \frac{10 - 0.7}{101(10-100)} = \frac{9.3}{101 \times (-90)} = \frac{9.3}{9090} \times 10^{-3}$$

$$= 0.0010 \times 10^{-3}$$

$$= \cancel{0.00204} \; 0.0102 \text{ mA}$$

$$I_{CQ} = \beta I_{BQ} = 100(0.0102) = 1.02 \text{ mA}.$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{100 \times 0.026}{1.02} \times 10^3 = 2.54 \text{ K}\Omega.$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{1.02 \times 10^{-3}}{0.026} = 39 \text{ mmho}.$$

$$A_I = \frac{g_m R_L}{R_C + R_L}\left(\frac{r_\pi}{1+\beta} \| R_E\right).$$

$$\frac{r_\pi}{1+\beta} = \frac{2.54 \times 10^3}{101} = 0.025 \times 10^3.$$

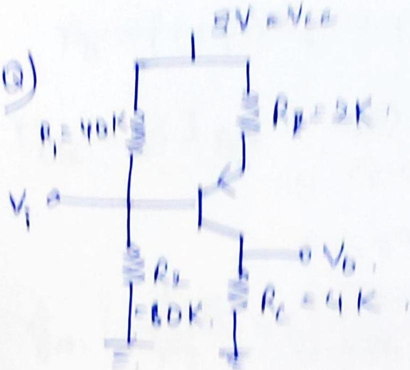
$$\frac{r_\pi}{1+\beta} \| R_E = \frac{0.025 \times 10^3 \times 10 \times \cancel{10^3}}{10.025 \times \cancel{10^3}} = 0.0249 \times 10^3.$$

$$= 24.9.$$

$$A_I = \frac{39 \times \cancel{10^{-3}} \times 1 \times \cancel{10^3}}{(10+1) \times \cancel{10^3}} \times 0.0249 \times \cancel{10^3} = 0.089.$$

$$= \frac{\dfrac{39 \times 10^{-3} \times 1 \times \cancel{10^3}}{(10+1) \times \cancel{10^3}}}{\left(\dfrac{101}{2.54} + \dfrac{1}{10}\right) \times 10^{-3}} = \frac{3.54 \times 10^{-3}}{39.86 \times 10^{-3}} = 0.089.$$

Q)




CE config
PNP

Quiscent parameters, small signal voltage gain, Transistor parameters, are $V_{BE} = 0.7V$, $\beta = 80$, $V_A = \infty$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = 24\,K\Omega$$

$$V_{TH} = \frac{R_2 V_{CC}}{R_1 + R_2} = 8V.$$

$$V_+ = (1+\beta) I_B R_E + V_{BE} + I_B R_{TH} + V_{TH}$$

$$\frac{V_+ - V_{BE} - V_{TH}}{R_{TH} + (1+\beta) R_E} = I_B$$

$$\Rightarrow I_{BQ} = \frac{V_+ - V_{BE} - V_{TH}}{R_{TH} + (1+\beta) R_E}.$$

$$I_{CQ} = \beta I_{BQ}.$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}.$$

$$g_m = \frac{I_{CQ}}{V_T}.$$