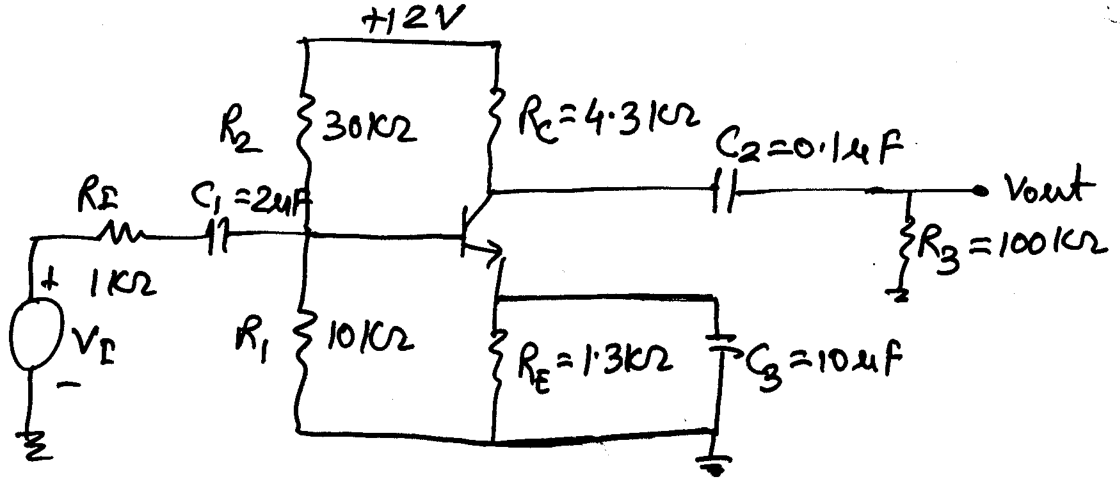
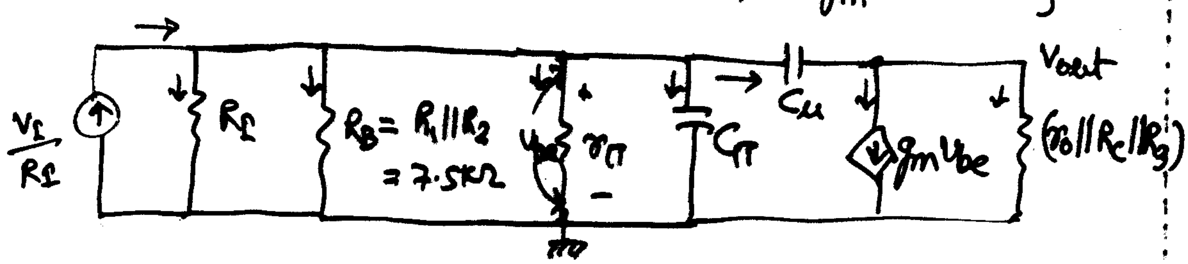
High Frequency Analysis of CE Amplifier



$I_C = 1.73\text{mA}$, $V_{CE} = 2.32V$, $\beta_o = 100$, $V_A = 75V$

$r_\pi = 1.45k\Omega$, $g_m = 69\text{mS}$, $r_o = 44.7k\Omega$

$C_\mu = 2pF$, $C_\pi = 10pF$ $\left\{\frac{2\pi f_T}{g_m} - C_\mu\right\}$



① Direct analysis

$G_I = \frac{1}{R_I}$; $G_B = \frac{1}{R_B}$

Nodal Equations

$$\frac{V_I}{R_I} = V_{be}\left\{G_I + G_B + \frac{1}{r_\pi} + sC_\pi\right\} + (V_{be} - V_{out})sC_\mu$$

$$\frac{V_I}{R_I} = V_{be}\left\{G_I + G_B + \frac{1}{r_\pi} + s(C_\pi + C_\mu)\right\} - V_{out}(sC_\mu) \quad \text{(1)}$$

$$(v_{be} - v_{out})\, sC_\mu = g_m v_{be} + v_{out}(g_o + G_C + G_3)$$

$$v_{be}\{-g_m + sC_\mu\} = v_{out}(g_o + G_C + G_3 + sC_\mu) \to (2)$$

$$\left(\frac{v_{out}}{v_I}\right) = \frac{(r_\pi \cdot G_2)(-g_m + sC_\mu)}{\left[\begin{array}{l} s^2(r_\pi C_\pi C_\mu) + s\left\{\begin{array}{l} C_\mu\{1 + r_\pi(g_m + g_o + G_C + G_3 + G_2 + G_B\} \\ + C_\pi\{r_\pi(g_o + G_C + G_3)\end{array}\right\} \\ + \{1 + r_\pi(G_2 + G_B)\}\{g_o + G_C + G_3\}\end{array}\right]}$$

$$= \left[\frac{(1.45)\overbrace{(-0.069 + s(2\times10^{-12}))}^{\text{zero }(z_1)}}{\underbrace{s^2(2.9\times10^{-20}) + s(2.09\times10^{-10})}_{\text{Second pole }(\omega_2)} \underbrace{\phantom{s(2.09\times10^{-10})}+ (7\times10^{-4})}_{\text{Dominant pole }(\omega_H)}}\right]$$

$$z_1 \Rightarrow \{-0.069 + s(2\times10^{-12})\} = 0 \Rightarrow z_1 = 34.5\times10^9 \text{ rad/sec}$$

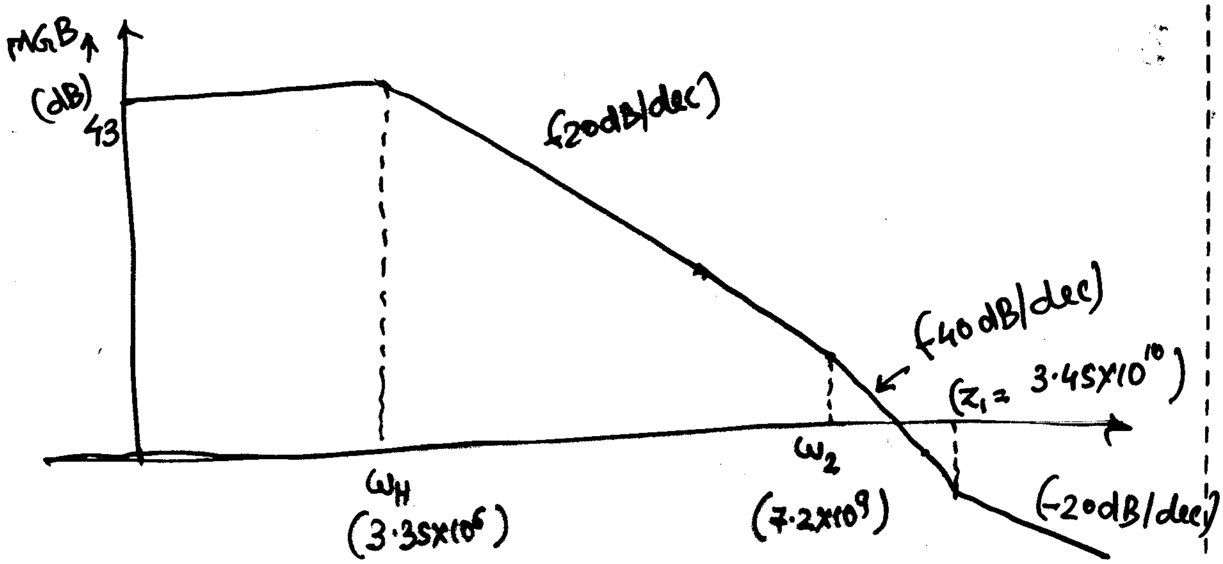
Dominant pole $(\omega_H) \Rightarrow$ $s(2.09\times10^{-10}) + (7\times10^{-4}) = 0$

$$\hookrightarrow \omega_H = 3.35\times10^6 \text{ rad/sec}$$

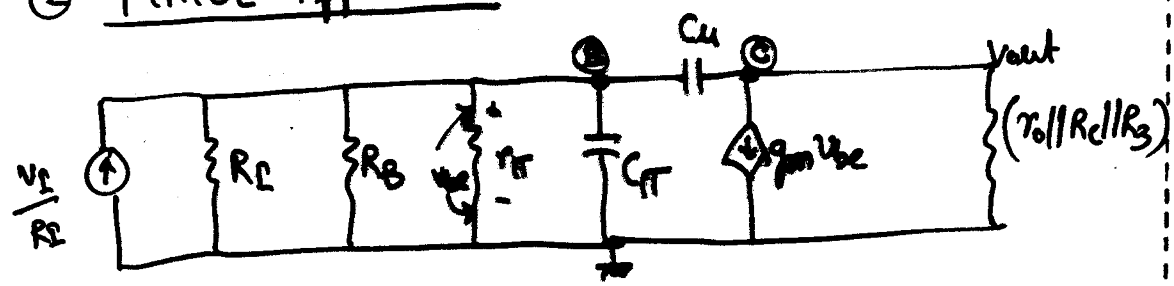
Second pole $(\omega_2) \Rightarrow$ $\{s^2(2.9\times10^{-20}) + s(2.09\times10^{-10})\} = 0$

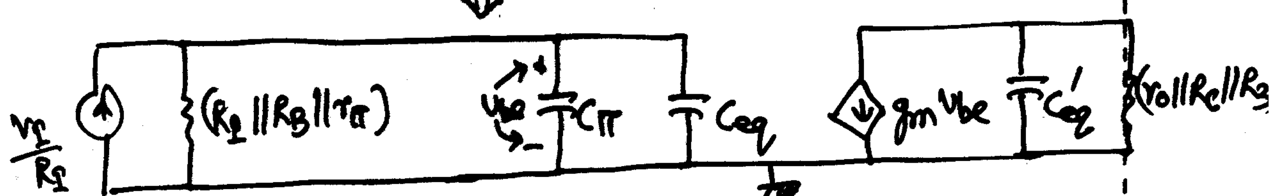
$$\cancel{s=0}\ ;\quad s = \omega_2 = 7.2\times10^9 \text{ rad/sec}$$

Bode plot



② Miller Approach





$$C_{eq} = C_\mu(1+K) \; ; \quad |K| = \left|\left(\frac{V_{out}}{V_{be}}\right)\right|$$

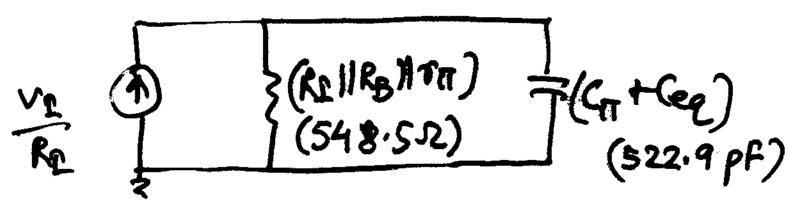
$$\underbrace{V_{out} = -g_m(r_o||R_c||R_3)\,v_{be}} \quad \text{if } \frac{1}{\omega_H C_\mu} >> (r_o||R_c||R_3)$$

$$K = \frac{V_{out}}{v_{be}} = -g_m(r_o||R_c||R_3) = -260.4 \text{ V/V}$$

$$C_{eq} = C_\mu\left(1 + g_m(r_o \| R_c \| R_3)\right) = (2pF)(1+260.4)$$
$$= 522.9\,pF$$

$$C_\pi = 10\,pF$$

$$(C_\pi + C_{eq}) = 532.9\,pF$$



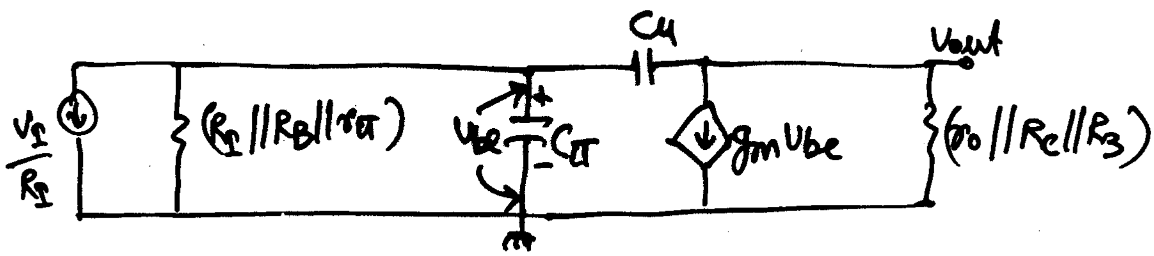
$$\omega_H = \frac{1}{(548.5\Omega)(522.9\,pF)} = 3.42 \times 10^6 \text{ rad/sec}$$

$$\frac{1}{\omega_H C_\mu} = 146.1\,k\Omega$$

$$(r_o \| R_c \| R_3) = 3.77\,k\Omega$$

$$\boxed{\frac{1}{\omega_H C_\mu} \gg (r_o \| R_c \| R_3)}$$

③ <u>open circuit Time constant</u>

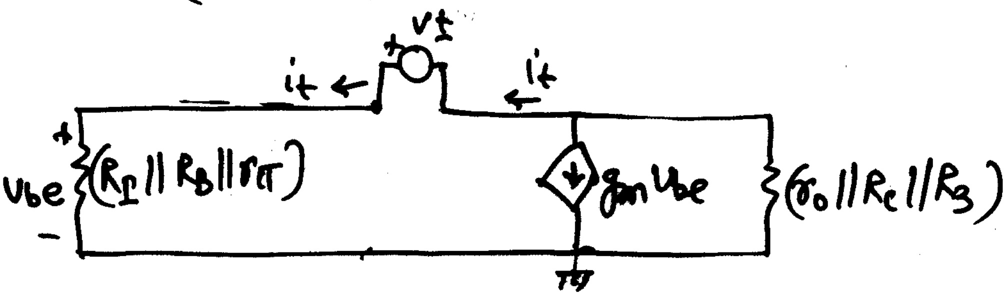


$$\omega_H = \frac{1}{\sum_i R_{io} C_i}$$

$$\omega_H = \frac{1}{(R_{C\pi o})(C_\pi) + (R_{C\mu o})(C_\mu)}$$

$C_\pi \Rightarrow \quad (R_{C\pi o}) = (R_L \| R_B \| r_\pi) = (548.5\,\Omega)$

$C_\mu \Rightarrow \quad (R_{C\mu o}) = ??$



$$v_{be} = i_t\,(R_L \| R_B \| r_\pi)$$

$$i_t = -g_m v_{be} - \frac{(v_{be} - v_t)}{(r_o \| R_C \| R_3)}$$

$$R_{C\mu o} = \frac{v_t}{i_t} = \left[(r_o \| R_C \| R_3) + (R_L \| R_B \| r_\pi)\left(1 + g_m (r_o \| R_C \| R_3)\right)\right]$$

$$= \left[\,3775 + (548.5)(1 + 260.48)\,\right]$$

$$R_{C\mu o} = 147.2\,k\Omega$$

$$\omega_H = \frac{1}{(R_{C\pi o})(C_\pi) + (R_{C\mu o})(C_\mu)}$$

$$= \frac{1}{(548.55)(10p) + (147.2K)(2p)}$$

$$\omega_H = 3.33 \times 10^6 \text{ rad/sec}$$