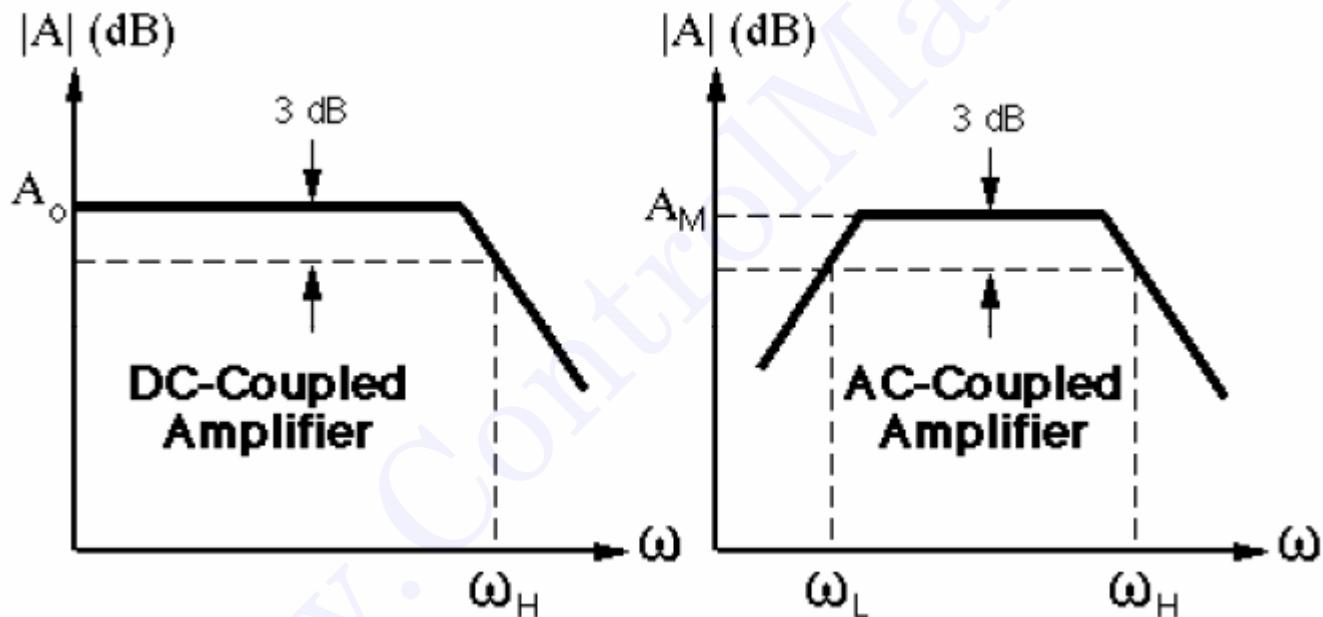




www.ControlMakers.ir

ac-coupled

dc-coupled



ac-coupled

$$A(S) = A_M F_L(S) F_H(S)$$

$$F_L(S) = \frac{(S + \omega_{Z1})(S + \omega_{Z2}) \cdots (S + \omega_{ZN})}{(S + \omega_{P1})(S + \omega_{P2}) \cdots (S + \omega_{PN})}$$

$$F_L(S) \approx \frac{S}{S + \omega_{p1}}$$

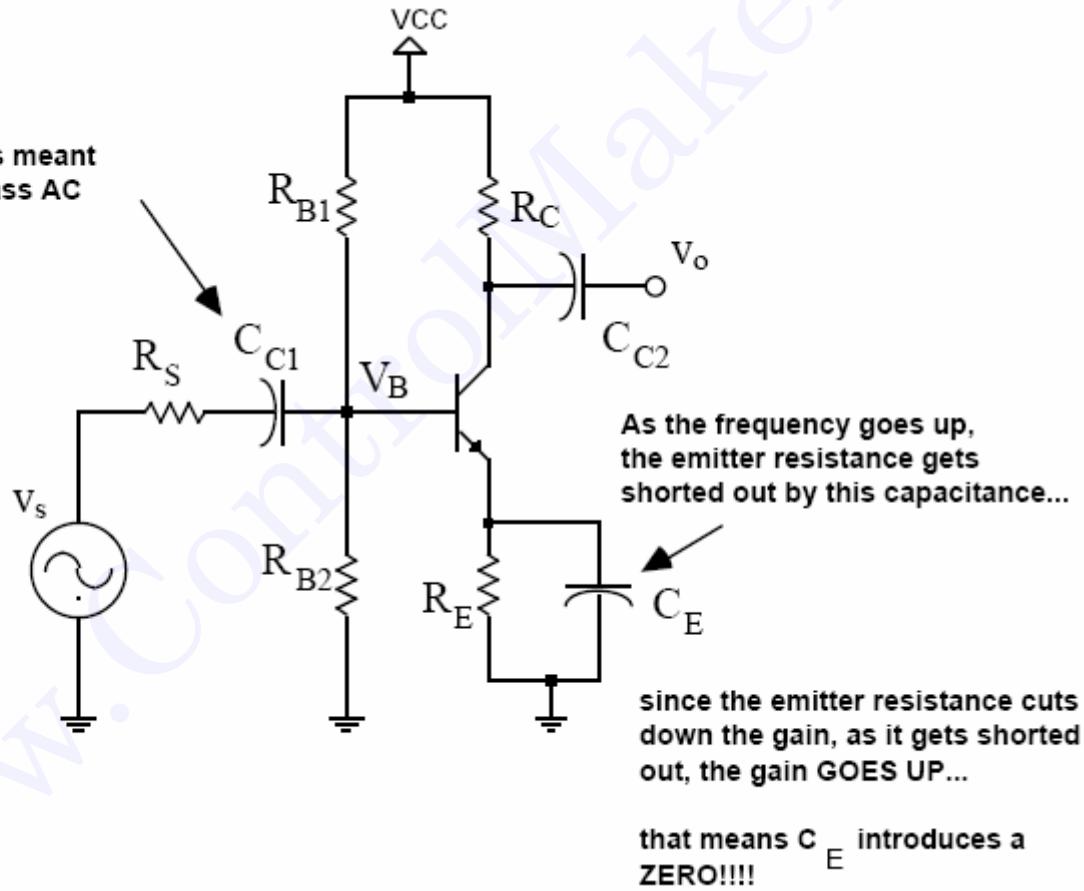
$$\omega_L \approx \sqrt{\sum_{n=1}^N \omega_{Pn}^2 - 2 \sum_{n=1}^N \omega_{Zn}^2}$$

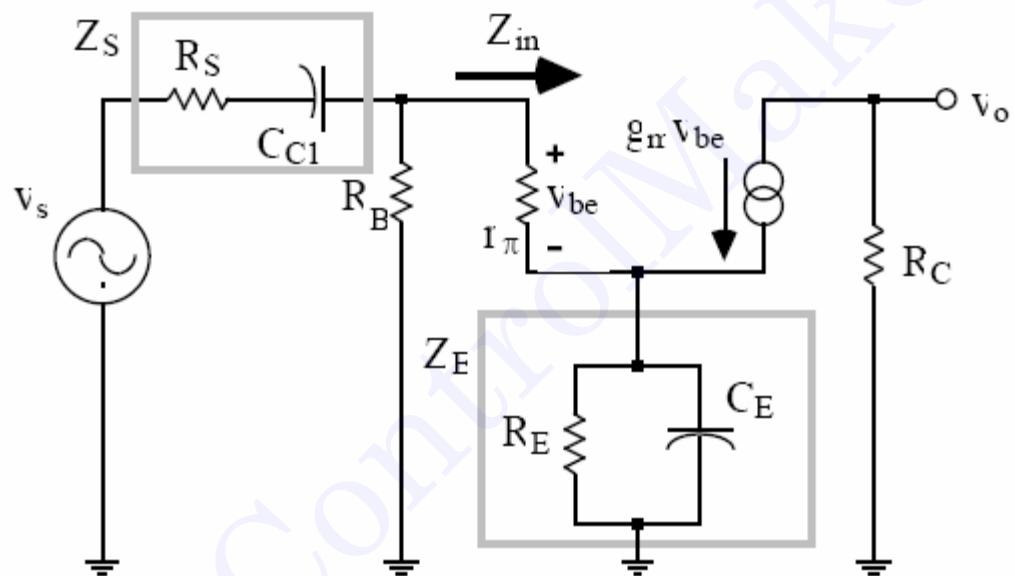
$$F_H(S) = \frac{\left(1 + \frac{S}{\omega_{Z1}}\right)\left(1 + \frac{S}{\omega_{Z2}}\right) \dots \left(1 + \frac{S}{\omega_{ZNH}}\right)}{\left(1 + \frac{S}{\omega_{P1}}\right)\left(1 + \frac{S}{\omega_{P2}}\right) \dots \left(1 + \frac{S}{\omega_{PNH}}\right)}$$

$$F_H(S) \approx \frac{1}{1 + \frac{S}{\omega_{p1}}}$$

$$\omega_H \approx \frac{1}{\sqrt{\sum_{n=1}^N \frac{1}{\omega_{p_n}^2} + 2 \sum_{n=1}^N \frac{1}{\omega_{Z_n}^2}}}$$

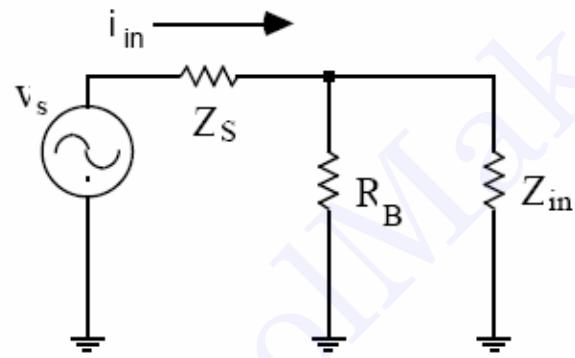
This capacitance is meant to block DC and pass AC





$$Z_S = \frac{1 + S R_S C_{C1}}{S C_{C1}}$$

$$Z_E = \frac{R_E}{1 + S R_E C_E}$$



$$i_{in} = \frac{V_s}{\left(1 + \frac{Z_{in}}{R_B}\right)Z_s + Z_{in}}$$

FROM HERE ON, ASSUME $R_B = \text{INFINITY}$ TO SIMPLIFY THINGS!

$$i_{in} = \frac{V_s}{Z_s + Z_{in}} = \frac{V_s}{Z_s + r_\pi + (\beta + 1)Z_E} = \frac{V_s}{\frac{1 + SR_S C_{C1}}{SC_{C1}} + r_\pi + \left[(\beta + 1) \frac{R_E}{1 + SR_E C_E} \right]}$$

()

$$\frac{i_{in}}{V_s} = \frac{(S C_{C1})(1 + S R_E C_E)}{1 + S \{C_{C1}[R_S + r_\pi + (\beta + 1) R_E] + R_E C_E\} + S^2 (R_S C_{C1} R_E C_E + r_\pi C_{C1} R_E C_E)}$$

a ZERO at $\omega = 0$ (because of C_{C1})

a ZERO at $\omega = \frac{1}{R_E C_E}$

()

$$\frac{V_o}{V_s} = \beta R_C i_{in}$$

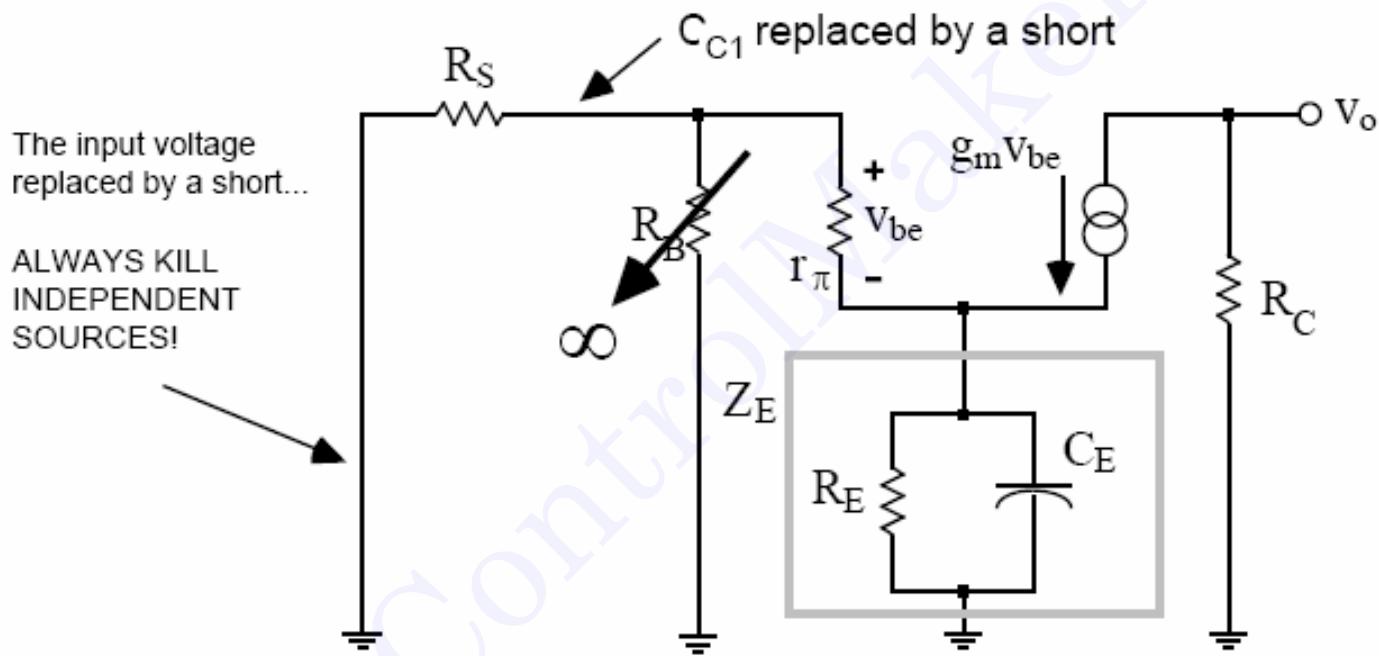
$$\frac{V_o}{V_s} = \frac{(\beta R_C C_{C1})(R_E C_E) S \left(S + \frac{1}{R_E C_E} \right)}{1 + S \left\{ C_{C1} [R_S + r_\pi + (\beta + 1) R_E] + R_E C_E \right\} + S^2 (R_S C_{C1} R_E C_E + r_\pi C_{C1} R_E C_E)}$$

()

$$\frac{V_o}{V_s} = \left(\frac{\beta R_C}{R_S + r_\pi} \right) \frac{s \left(s + \frac{1}{R_E C_E} \right)}{s^2 + s \left[\frac{1}{C_E \left(R_E \parallel \frac{R_S + r_\pi}{(\beta + 1)} \right)} + \frac{1}{C_{C1} (R_S + r_\pi)} \right] + \frac{1}{R_E C_E C_{C1} (R_S + r_\pi)}}$$

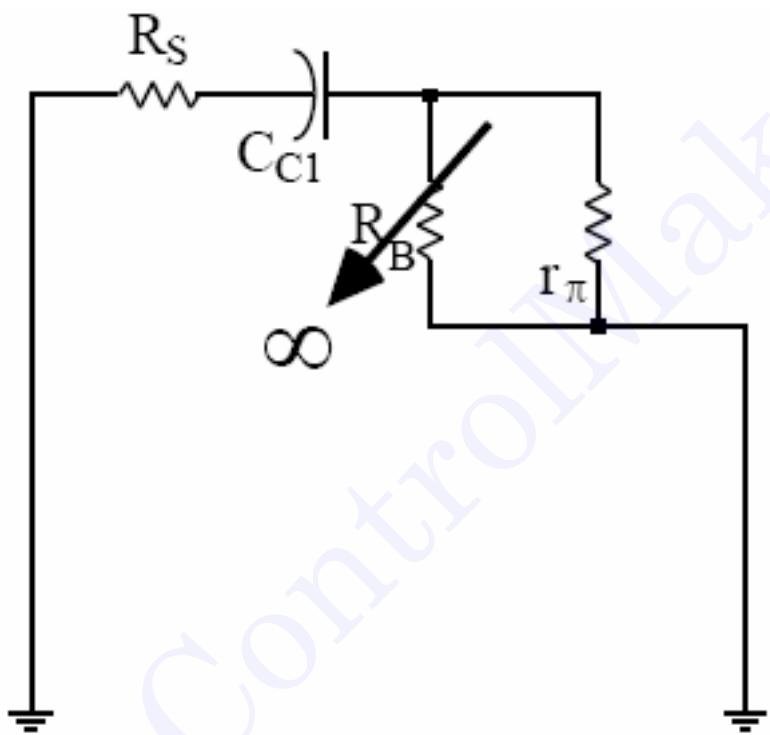
$$F_L(s) = \frac{s(s + \omega_{Z1})}{(s + \omega_{p1})(s + \omega_{p2})} = \frac{s(s + \omega_{Z1})}{s^2 + s(\omega_{p1} + \omega_{p2}) + \omega_{p1}\omega_{p2}}$$

$$\omega_L \approx \sum_i \frac{1}{C_i R_{iS}}$$

C_E 

$$R_{CES} = R_E \parallel \frac{R_S + r_\pi}{\beta + 1} = R_E \parallel \left(r_e + \frac{R_S}{\beta + 1} \right)$$

$$R_{CES} = R_E \parallel \frac{(R_S \parallel R_B) + r_\pi}{\beta + 1} = R_E \parallel \left(r_e + \frac{(R_S \parallel R_B)}{\beta + 1} \right)$$

C_{C1} 

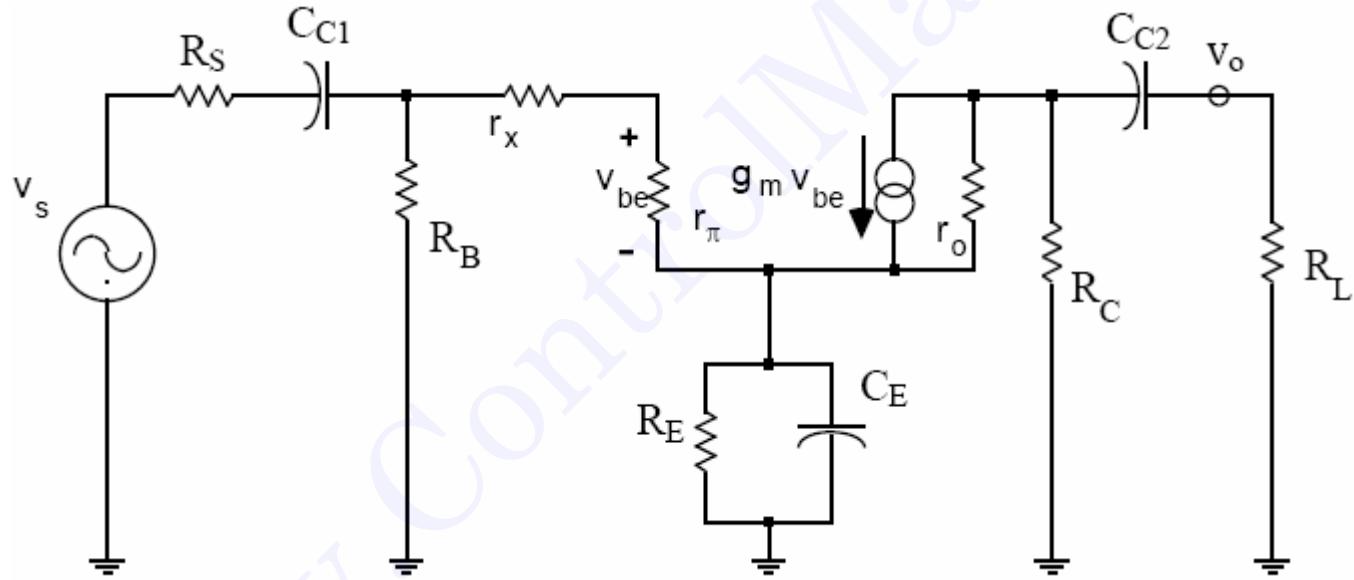
$$R_{C1S} = R_S + r_\pi$$

$$\omega_L \approx \sum_i \frac{1}{C_i R_{iS}}$$

$$\frac{V_o}{V_s} = \left(\frac{\beta R_C}{R_S + r_\pi} \right) \frac{s \left(s + \frac{1}{R_E C_E} \right)}{s^2 + s \left[\frac{1}{C_E \left(R_E \parallel \frac{R_S + r_\pi}{(\beta + 1)} \right)} + \frac{1}{C_{C1} (R_S + r_\pi)} \right] + \frac{1}{R_E C_E C_{C1} (R_S + r_\pi)}}$$

$$R_{ES} = R_E \parallel \frac{R_S + r_\pi}{\beta + 1}$$

$$R_{C1S} = R_s + r_\pi$$



$$\omega_L \approx \frac{1}{C_{C1}R_{C1S}} + \frac{1}{C_E R_{ES}} + \frac{1}{C_{C2}R_{C2}}$$

Where,

$$R_{C1S} = R_S + [R_B \parallel (r_x + r_\pi)] \quad (\text{INPUT})$$

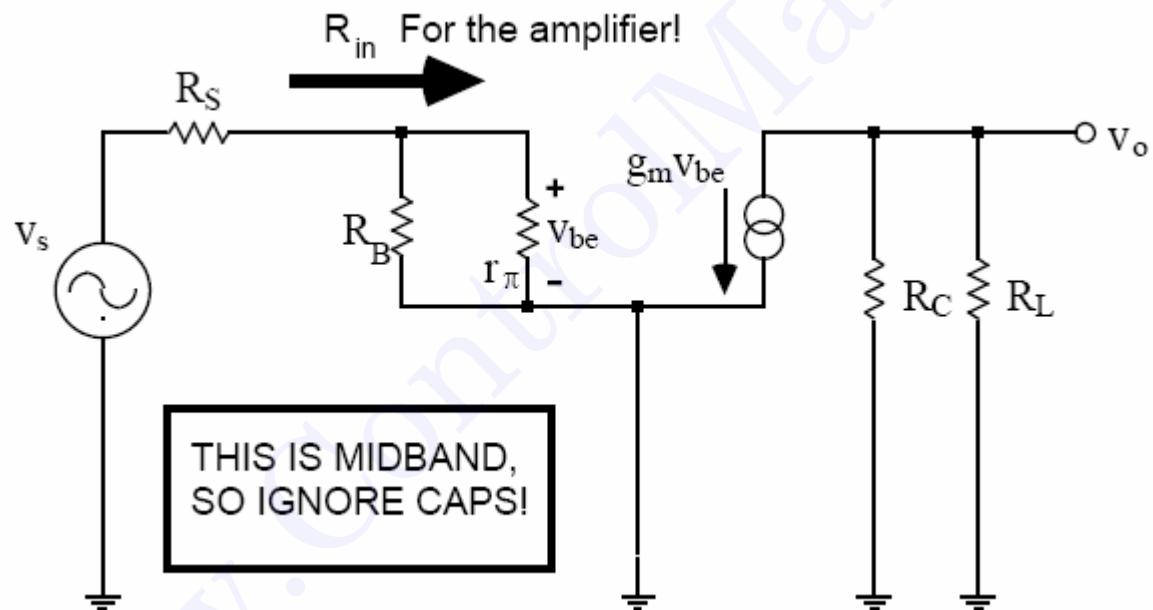
(remember that the other caps are shorts!)

$$R_{ES} = R_E \parallel \left[\frac{r_x + r_\pi + (R_B \parallel R_S)}{\beta + 1} \right] \quad (\text{EMITTER})$$

(remember about dividing by $[\beta + 1]$ to reflect the input circuit impedances to the emitter circuit!)

$$R_{C2S} = R_L + (R_C \parallel r_o) \quad (\text{OUTPUT})$$

The zero introduced by C_E is at $\omega_{ZE} = \frac{1}{C_E R_E}$



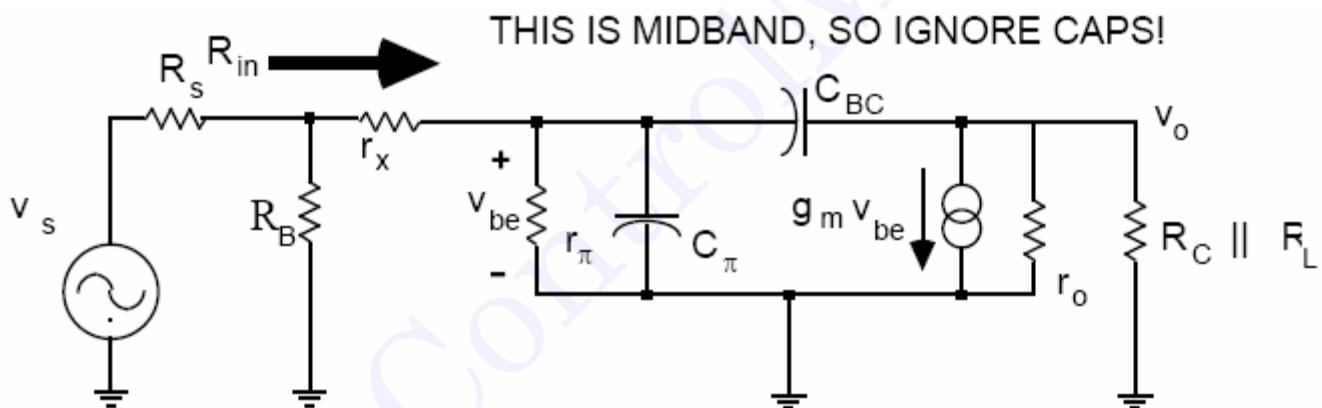
$$R_{in} = R_B \parallel r_\pi$$

$$R_B = R_{B1} \parallel R_{B2}$$

$$v_{be} = \left(\frac{R_{in}}{R_s + R_{in}} \right) V_s$$

$$V_o = - g_m v_{be} (R_C \parallel R_L)$$

$$A_v = \frac{V_o}{V_s} = \left(\frac{R_{in}}{R_s + R_{in}} \right) (-g_m) (R_C \parallel R_L)$$



$$R_{in} = R_B \parallel (r_x + r_\pi)$$

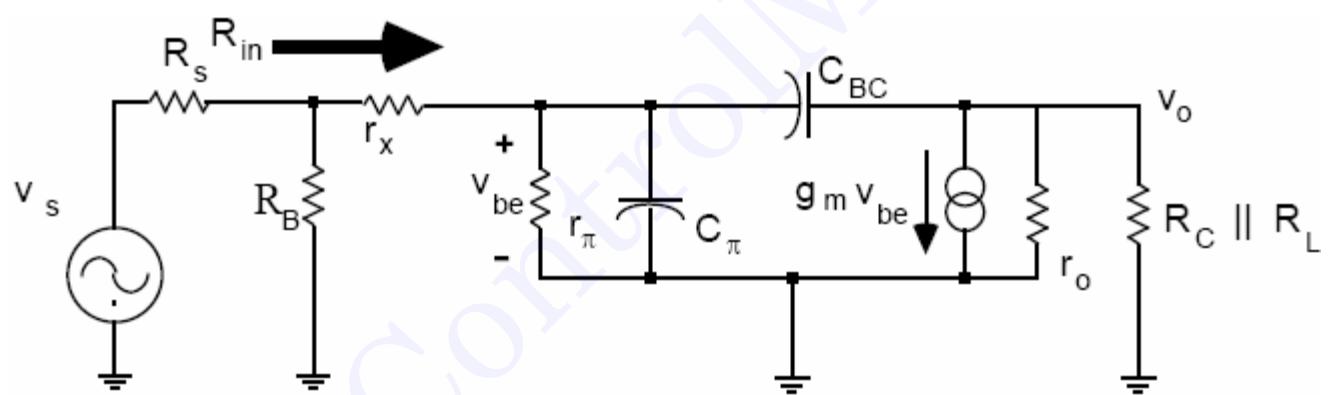
$$R_B = R_{B1} \parallel R_{B2}$$

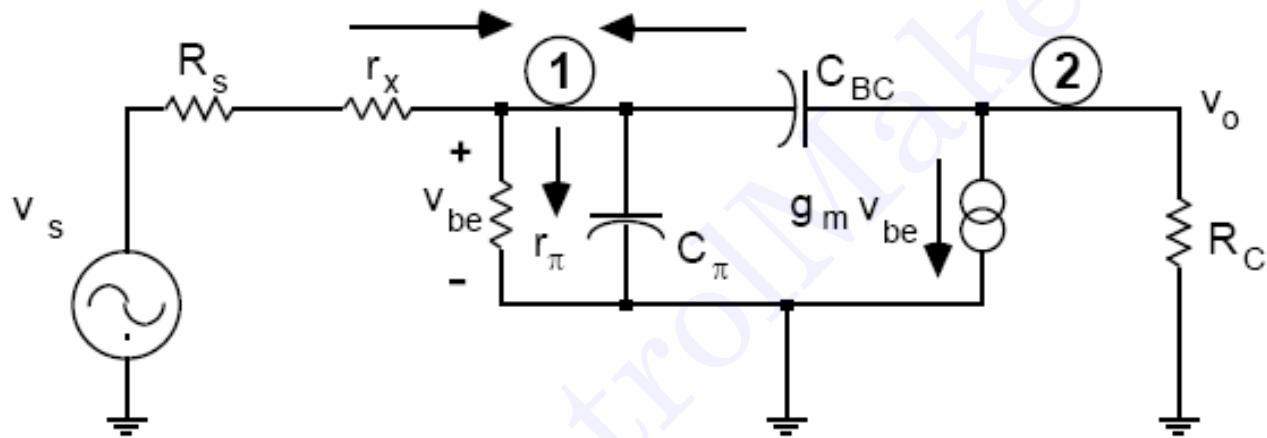
$$v_{be} = \left(\frac{R_{in}}{R_s + R_{in}} \right) \left(\frac{r_\pi}{r_\pi + r_x} \right) v_s$$

$$v_o = -g_m v_{be} (R_C \parallel R_L \parallel r_o)$$

$$A_v = \frac{V_o}{V_s} = \left(\frac{R_{in}}{R_s + R_{in}} \right) \left(\frac{r_\pi}{r_x + r_\pi} \right) (-g_m) (R_C \parallel R_L \parallel r_o)$$

$$A_v(S) = LF\text{gain}(S) \times MB\text{gain} \times HF\text{gain}(S)$$





$$\frac{v_s - v_{be}}{R_s} + (v_o - v_{be}) S C_{BC} = \left(\frac{1}{r_\pi} + S C_\pi \right) v_{be}$$

$$g_m v_{be} = - \frac{v_o}{R_C} - (v_o - v_{be}) S C_{BC}$$

$$V_o \gg V_{be}$$

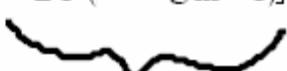
$$V_o \approx - \frac{g_m V_{be}}{\left(\frac{1}{R_C} + S C_{BC} \right)}$$

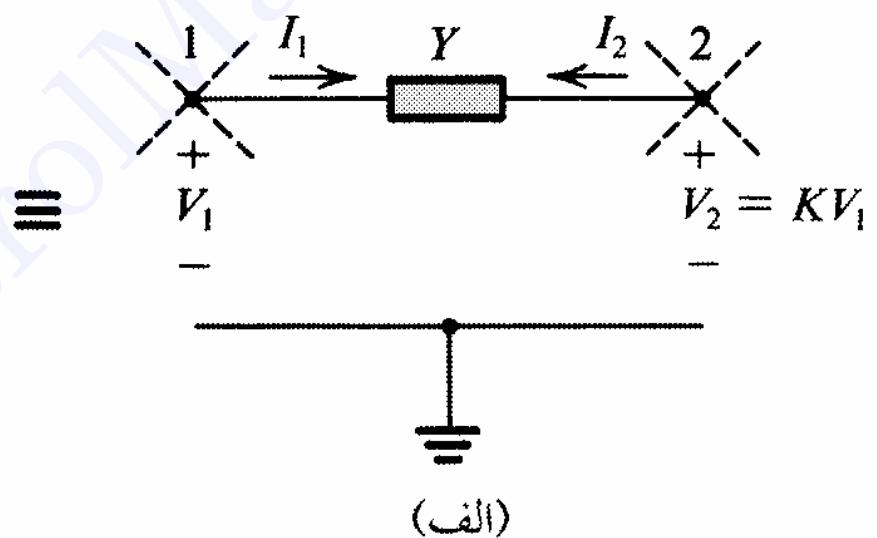
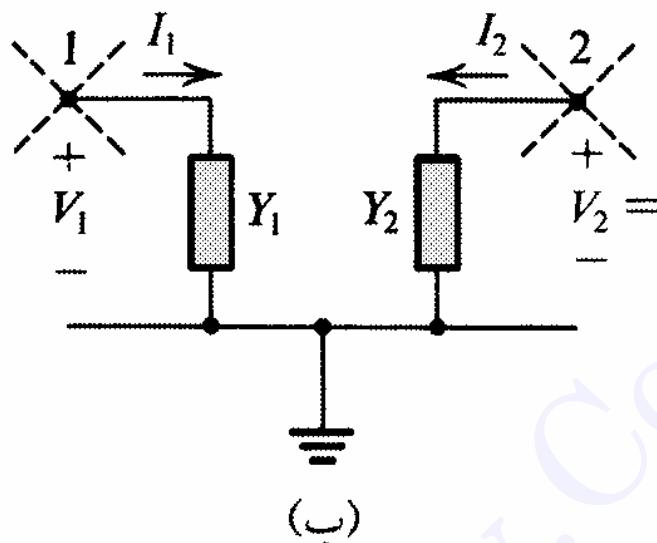
$$1/R_c \gg S C_{BC}$$

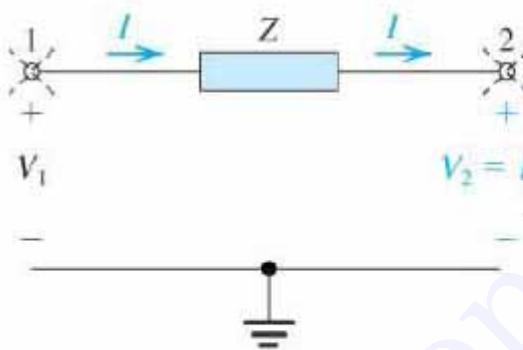
$$V_o \approx - g_m R_C V_{be}$$

The numerator is the DC gain.

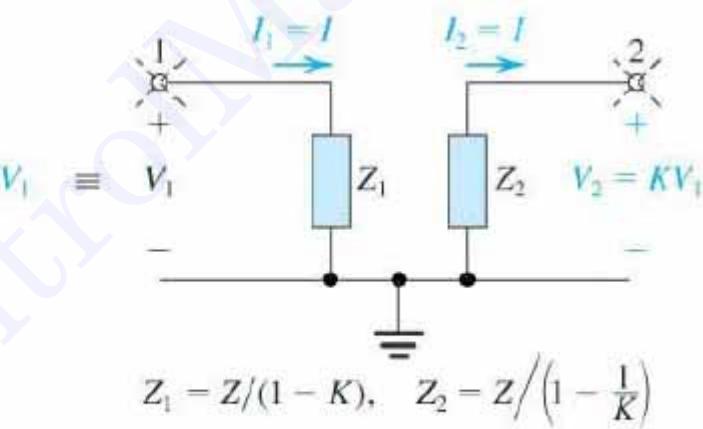
$$A_v = \frac{V_o}{V_s} \approx \frac{-g_m R_C \left(\frac{r_\pi}{r_\pi + R_s'} \right)}{1 + S(r_\pi \parallel R_s') [C_\pi + C_{BC}(1 + g_m R_C)]}$$


C MILLER

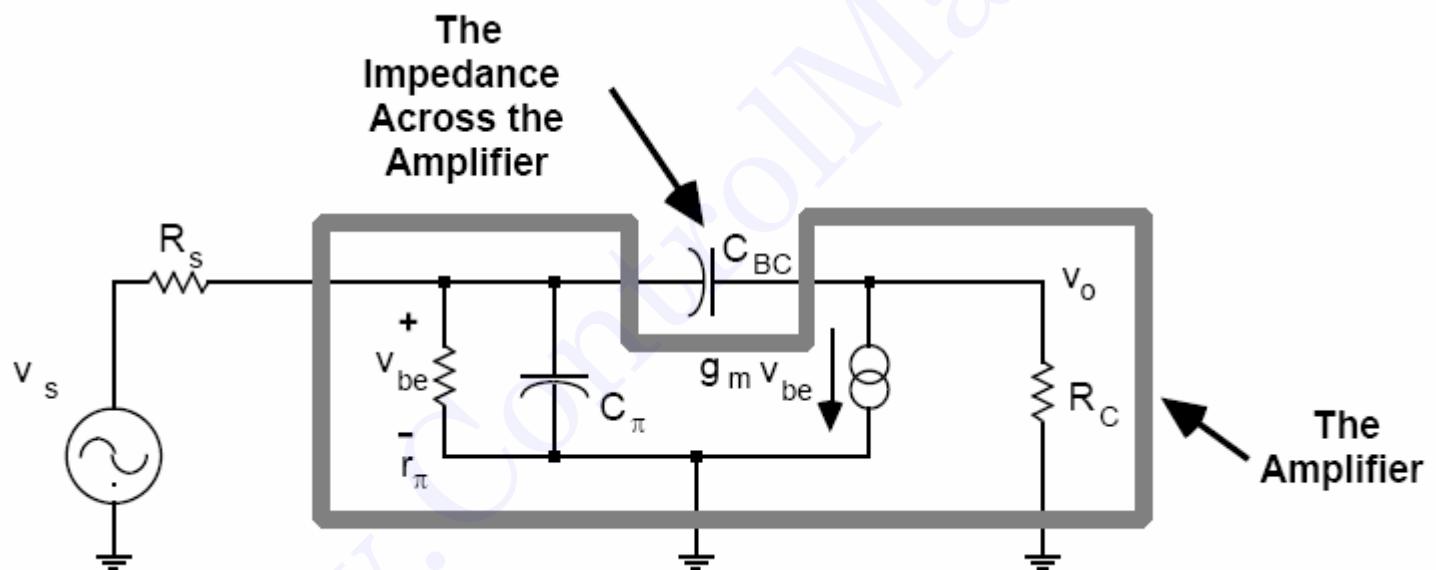


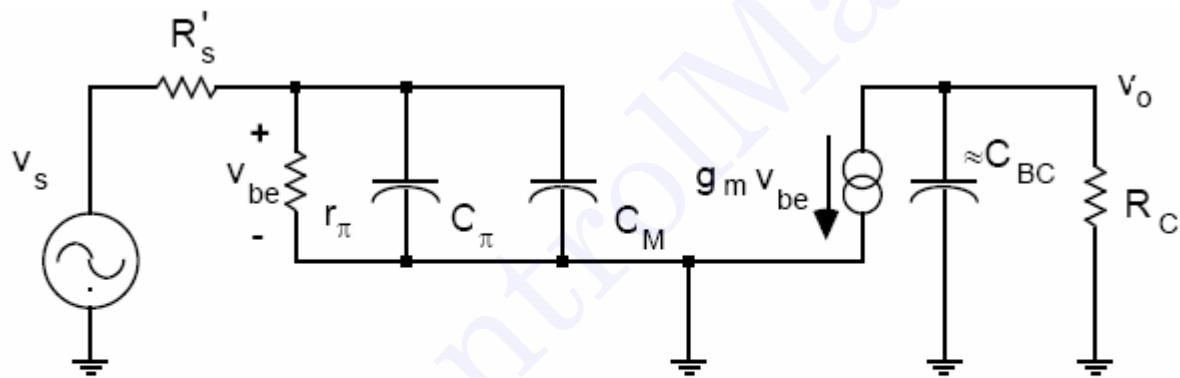


$$V_2 = KV_1$$



$$Z_1 = Z / (1 - K), \quad Z_2 = Z / \left(1 - \frac{1}{K}\right)$$





$$C_M = C_{BC}(1 + g_m R_C)$$

$$C_{out} = C_{BC} \frac{1 + g_m(R_C \parallel R_L \parallel r_o)}{g_m(R_C \parallel R_L \parallel r_o)}$$

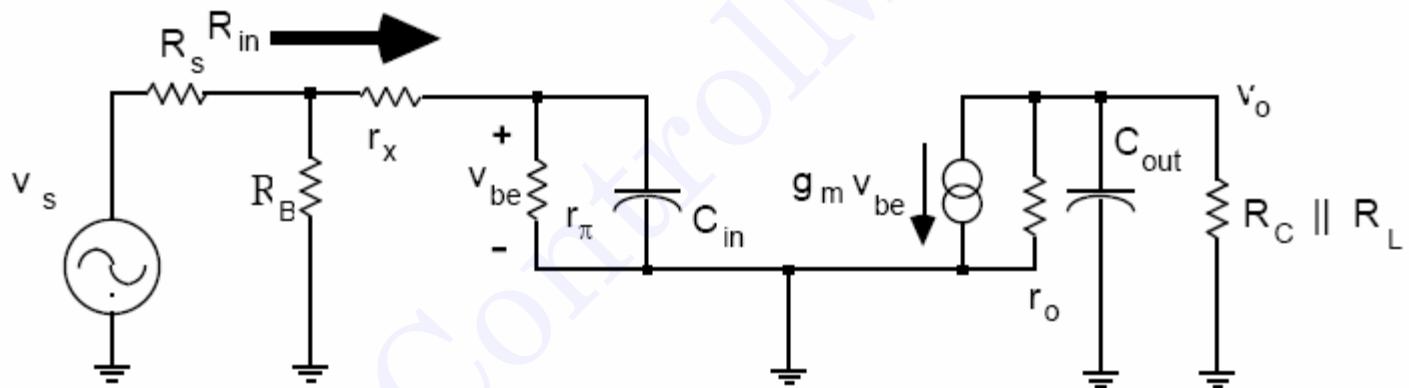
$$C_{in} = C_{\pi} + C_M = C_{\pi} + C_{BC}(1 - A_{VQ}) \quad \text{NOTE that S & S use } C_{\mu} \text{ instead of } C_{BC}$$

$$A_{VQ} = \frac{V_o}{V_{be}} = (-g_m)(R_C \parallel R_L \parallel r_o)$$

$$C_M = C_{BC}[1 + g_m(R_C \parallel R_L \parallel r_o)]$$

$$C_{out} = C_{BC} \frac{1 + g_m(R_C \parallel R_L \parallel r_o)}{g_m(R_C \parallel R_L \parallel r_o)}$$

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



The upper 3 dB frequency of the input circuit is often given by,

$$\omega_H = \frac{1}{R' C_{in}}$$

Where,

$$R' = r_\pi \parallel (r_x + R_B \parallel R_S)$$

and

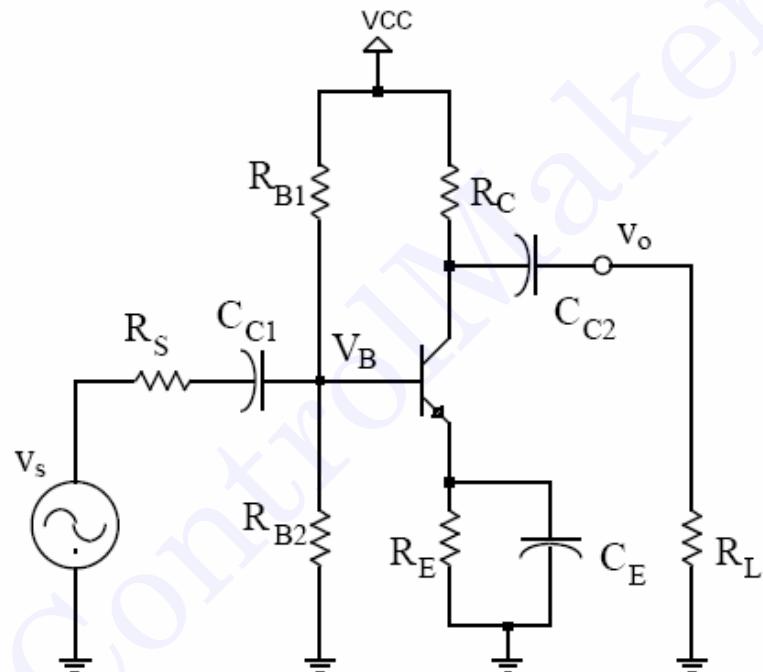
$$C_{in} = C_\pi + C_M = C_\pi + C_{BC} [1 + g_m (R_C \parallel R_L \parallel r_o)]$$

$$\omega_H \approx \frac{1}{\left[\sum_i C_i R_{io} \right]} = \frac{1}{C_{in} R' + C_{out} R_{out}} = \frac{1}{C_{in}(r_\pi \parallel [r_x + R_B \parallel R_S]) + C_{out}(r_o \parallel R_C \parallel R_L)}$$

3dB

$$\omega_o = \frac{1}{r_\pi (C_\pi + C_{BC})} \quad (\text{the } 3\text{dB frequency for } \beta)$$

$$\omega_t \approx \frac{1}{\frac{1}{g_m} (C_\pi + C_{BC})}$$



- Following the example on page 530, Sedra & Smith (Exercises 7.14 - 7.19)

$$R_S = 4 \text{ k}\Omega \quad R_{B1} = 8 \text{ k}\Omega \quad R_{B2} = 4 \text{ k}\Omega \quad R_E = 3.3 \text{ k}\Omega \quad R_C = 6 \text{ k}\Omega \quad R_L = 4 \text{ k}\Omega$$

$$V_{CC} = 12 \text{ V} \quad I_E \approx 1 \text{ mA} \quad \beta_o = 100 \quad C_\pi = 13.9 \text{ pF} \quad C_\mu = 2 \text{ pF} \quad r_o = 100 \text{ k}\Omega$$
$$r_x = 50 \text{ }\Omega$$

$$C_{C1} = C_{C2} = 1 \text{ }\mu\text{F} \quad \text{and} \quad C_E = 10 \text{ }\mu\text{F}$$

$$A_V = \frac{V_o}{V_s} = \left(\frac{R_B || r_\pi}{R_S + R_B || r_\pi} \right) (-g_m)(R_C || R_L)$$

$$g_m = \frac{I_C}{V_T} \approx \frac{1 \text{ mA}}{25.9 \text{ mV}} = 0.039 \Omega^{-1}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{0.039 \Omega^{-1}} = 2.56 \text{ k}\Omega$$

$$R_B = R_{B1} || R_{B2} = 8 \text{ k}\Omega || 4 \text{ k}\Omega = 2.67 \text{ k}\Omega$$

$$R_{in} = R_B || r_\pi = 2.67 \text{ k}\Omega || 2.56 \text{ k}\Omega = 1.31 \text{ k}\Omega$$

$$A_V = \frac{V_o}{V_s} = \left(\frac{2.67 \text{ k}\Omega \parallel 2.56 \text{ k}\Omega}{4 \text{ k}\Omega + 2.67 \text{ k}\Omega \parallel 2.56 \text{ k}\Omega} \right) (-0.039 \text{ } \Omega^{-1}) (6 \text{ k}\Omega \parallel 4 \text{ k}\Omega)$$

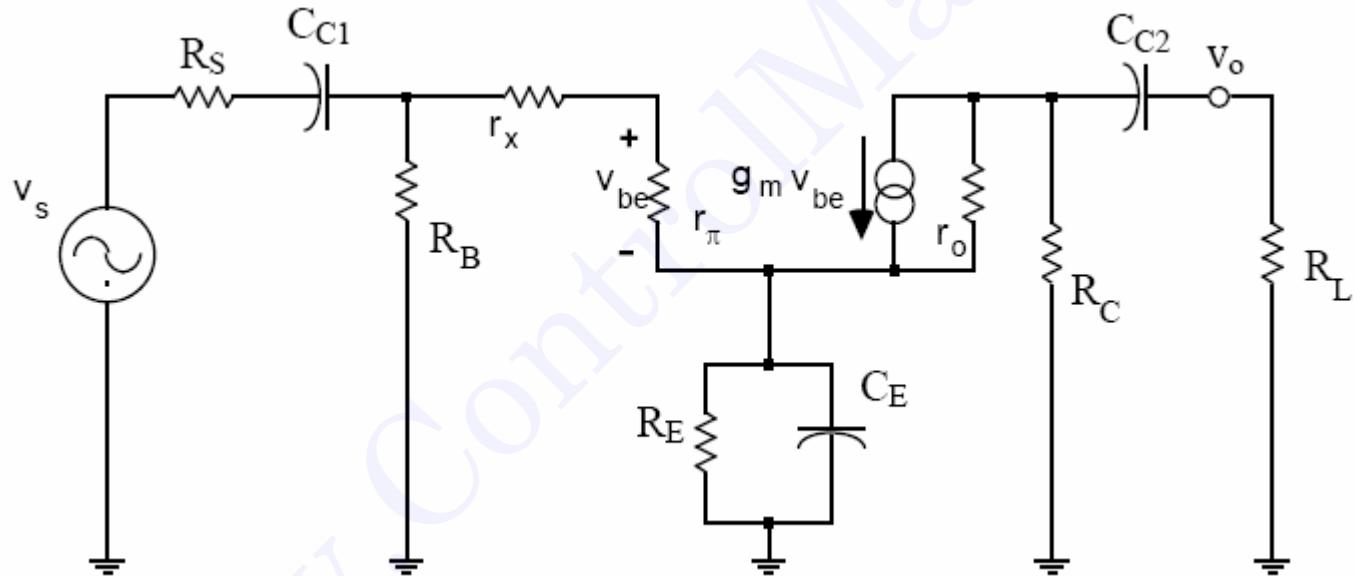
$$A_V = (0.247)(-0.039 \text{ } \Omega^{-1})(2.4 \text{ k}\Omega) = -23.1$$

$$R_{in} = R_B \parallel (r_x + r_\pi) = 2.67 \text{ k}\Omega \parallel (50 \text{ }\Omega + 2.56 \text{ k}\Omega) = 1.32 \text{ k}\Omega$$

$$A_v = \frac{V_o}{V_s} = \left(\frac{R_B \parallel (r_x + r_\pi)}{R_S + R_B \parallel (r_x + r_\pi)} \right) \left(\frac{r_\pi}{r_x + r_\pi} \right) (-g_m) (R_C \parallel R_L \parallel r_o)$$
$$= \left(\frac{1.32 \text{ k}\Omega}{4 \text{ k}\Omega + 1.32 \text{ k}\Omega} \right) \left(\frac{2.56 \text{ k}\Omega}{50 \text{ }\Omega + 2.56 \text{ k}\Omega} \right) (-0.037) (6 \text{ k}\Omega \parallel 4 \text{ k}\Omega \parallel 100 \text{ k}\Omega)$$

$$= (0.248)(0.981)(-0.039 \text{ } \Omega^{-1})(2.34 \text{ k}\Omega) = -22.2$$

$$A_v = (0.248)(0.981)(-0.039)(2.34 \text{ K}\Omega) = -22.2 \text{ V/V}$$



$$\omega_L \approx \frac{1}{C_{C1}R_{C1S}} + \frac{1}{C_E R_{ES}} + \frac{1}{C_{C2}R_{C2}}$$

$$R_{C1S} = R_S + [R_B \parallel (r_x + r_\pi)] = 4 \text{ k}\Omega + [2.67 \text{ k}\Omega \parallel (50 \text{ }\Omega + 2.56 \text{ k}\Omega)] = 5.32 \text{ k}\Omega$$

$$R_{ES} = R_E \parallel \left[\frac{r_x + r_\pi + (R_B \parallel R_S)}{\beta + 1} \right]$$

$$R_{ES} = 3.3 \text{ k}\Omega \parallel \left[\frac{50 \text{ }\Omega + 2.56 \text{ k}\Omega + (2.67 \text{ k}\Omega \parallel 4 \text{ k}\Omega)}{100 + 1} \right] = 41.2 \text{ }\Omega$$

$$R_{C2S} = R_L + (R_C \parallel r_o) = 4 \text{ k}\Omega + (6 \text{ k}\Omega \parallel 100 \text{ k}\Omega) = 9.66 \text{ k}\Omega$$

$$\omega_L \approx \frac{1}{C_{C1}R_{C1S}} + \frac{1}{C_E R_{ES}} + \frac{1}{C_{C2}R_{C2}}$$

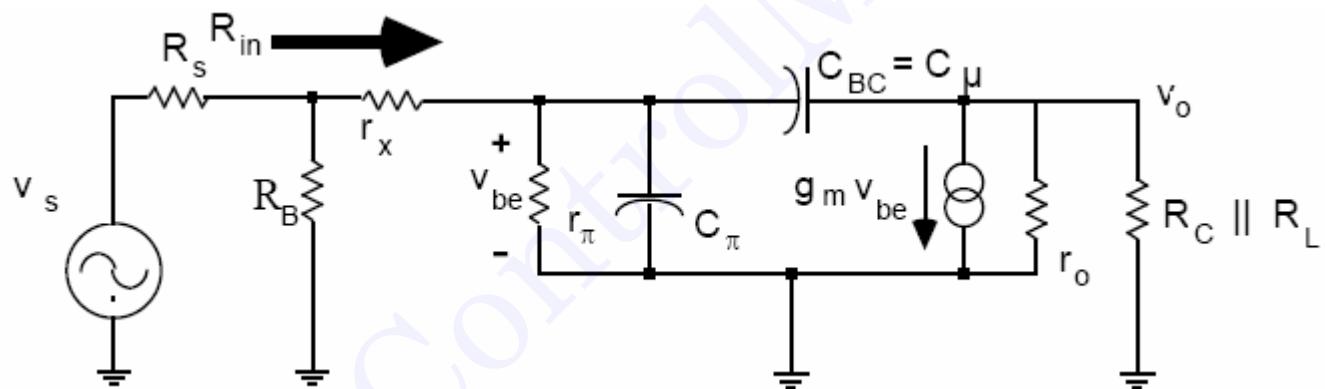
$$\omega_L \approx \frac{1}{(1 \times 10^{-6})(5.32 \text{ K})} + \frac{1}{(10 \times 10^{-6})(41.2)} + \frac{1}{(1 \times 10^{-6})(9.66 \text{ K})}$$

$$\omega_L \approx 188.0 + 2,427 + 103.5 = 2,719 \text{ Radians} \quad \rightarrow \quad f_L \approx 432.7 \text{ Hz}$$

$$\omega_{ZE} = \frac{1}{C_E R_E} = \frac{1}{10 \times 10^{-6} \times 3.3 \text{ K}\Omega} \rightarrow f_{ZE} = 4.8 \text{ Hz}$$

What components control the low cut off frequency?

Can you "design" it?



$$C_M = C_{BC} [1 + g_m (R_C \parallel R_L \parallel r_o)] \quad (\text{note dependence on load resistance!})$$

$$C_M = 2 \times 10^{-12} [1 + (0.039) (6 \text{ K}\Omega \parallel 4 \text{ K}\Omega \parallel 100 \text{ K}\Omega)] = 184.8 \text{ pF}$$

$$C_{in} = C_{\pi} + C_M = 198.7 \text{ pF}$$

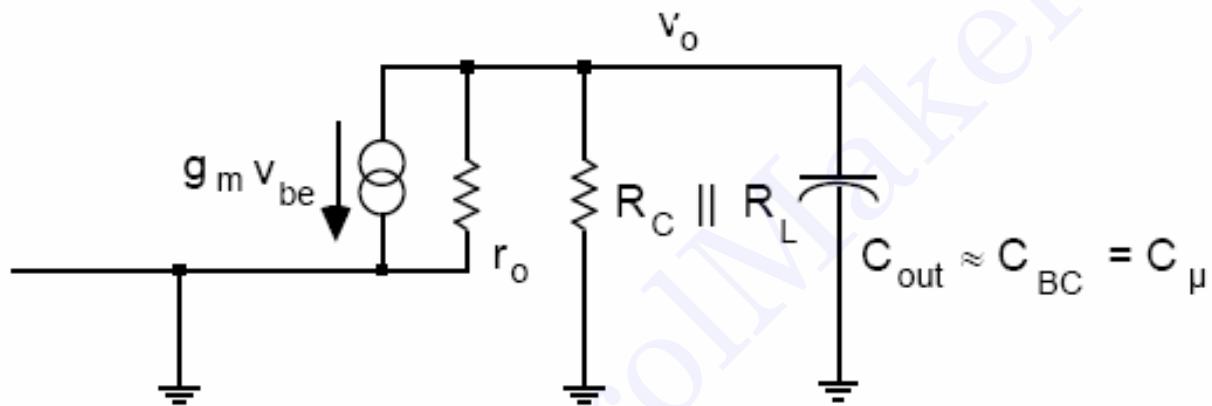
$$\omega_H = \frac{1}{R' C_{in}}$$

$$R' = r_{\pi} \parallel (r_x + R_B \parallel R_s) = 2.56 \text{ K}\Omega \parallel (50 \Omega + 2.67 \text{ K}\Omega \parallel 4 \text{ K}\Omega) = 1.00 \text{ K}\Omega$$

$$\therefore \omega_H = \frac{1}{(1.00 \text{ K})(199 \times 10^{-12})} = 5.025 \times 10^6 \text{ Radians} \rightarrow f_H = 800 \text{ KHz}$$

$$C_{out} = C_{BC} \frac{1 + g_m (R_C \parallel R_L \parallel r_o)}{g_m (R_C \parallel R_L \parallel r_o)} = (2 \times 10^{-12}) \frac{1 + (0.039 \Omega^{-1})(6 k\Omega \parallel 4 k\Omega \parallel 100 k\Omega)}{(0.039 \Omega^{-1})(6 k\Omega \parallel 4 k\Omega \parallel 100 k\Omega)}$$

$$C_{out} = (2 \times 10^{-12})(1.01) = 2.02 \times 10^{-12}$$



$$R'_\text{out} = r_o \parallel R_L \parallel R_C = 100\text{K}\Omega \parallel 4\text{K}\Omega \parallel 6\text{K}\Omega = 2.34 \text{ K}\Omega$$

$$\omega_{\text{out}} = \frac{1}{R'_\text{out} C_{BC}} = \frac{1}{2.34 \text{ K}\Omega \cdot 2 \text{ pF}} = 214 \times 10^6 \text{ Radians} = 34 \text{ MHz}$$

(800KHz)

$$\omega_H \approx \frac{1}{\left[\sum_i C_i R_{io} \right]} = \frac{1}{C_{in} R' + C_{out} R_{out}} = \frac{1}{C_{in} (r_\pi \parallel [r_x + R_B \parallel R_S]) + C_{out} (r_o \parallel R_C \parallel R_L)}$$

- If a dominant pole exists

$$F_H(s) \equiv \frac{1}{1 + s/w_{P1}}$$

- If not, use the cond. $|F(w_H)| = \frac{1}{2}$ to derive

$$w_H \equiv 1/\sqrt{\left(\frac{1}{w_{P1}^2} + \frac{1}{w_{P2}^2} + \cdots + \frac{1}{w_{Pn}^2} \right) - \left(\frac{1}{w_{Z1}^2} + \frac{1}{w_{Z2}^2} + \cdots + \frac{1}{w_{Zn}^2} \right)}$$

- Open-circuit time constants

$$w_H \equiv \frac{1}{\sum_i C_i R_{io}}$$

R_{io} : resistance seen by C_i when all other Cs are open-circuit
and all sources equal zeros