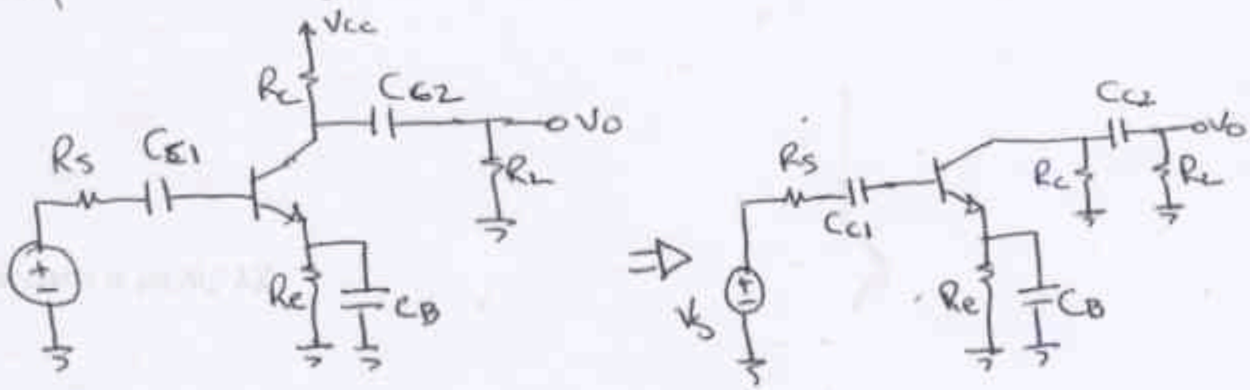
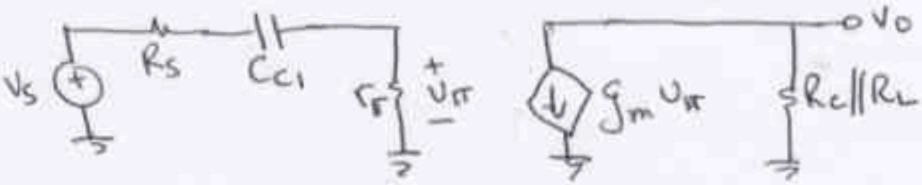
Amp. Freq. Resp. – low freq.



If C_{C2} & C_B are shorts, and $r_d = \infty$

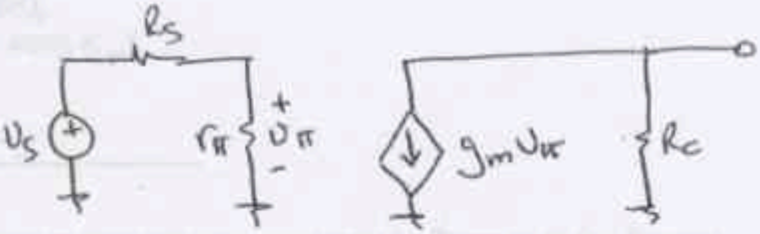


$$v_o = -g_m (R_C \| R_L)\, v_\pi \quad ; \quad v_\pi = \frac{r_\pi}{R_S + r_\pi} \, \frac{s\tau_{L1}}{s\tau_{L1}+1}\, V_S$$

$\tau_{L1} = C_{C1}(R_S + r_\pi)$ ← from Lect. 1

$$\frac{v_o}{v_s} = A = -\frac{r_\pi}{R_S + r_\pi}\, g_m (R_C \| R_L)\, \frac{s\tau_{L1}}{s\tau_{L1}+1}$$

To find the effect of C_{C2} (when C_{C1} and C_B are shorts)

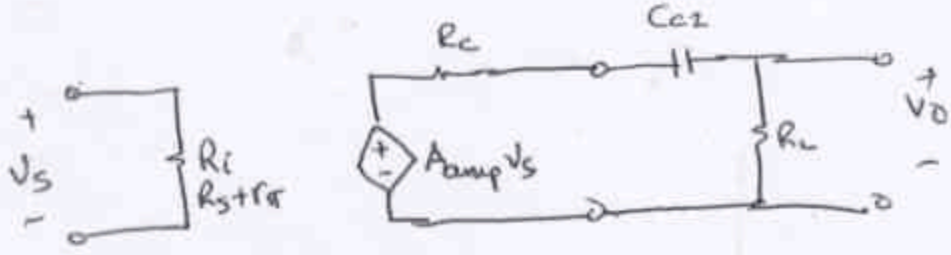


← amp. w/o the effect of C_{C2}/R_L

$$\frac{v_o}{v_s} = \underbrace{-\frac{r_\pi}{R_S + r_\pi}\, g_m R_C}_{A_{amp}} \quad ; \quad R_o = R_C$$

$$R_i = R_S + r_\pi$$

So we can represent the amp by a model



$$A_{amp} = -\frac{r_\pi}{R_s + r_\pi} g_m R_c = \left.\frac{V_o}{V_s}\right|_{OL}$$

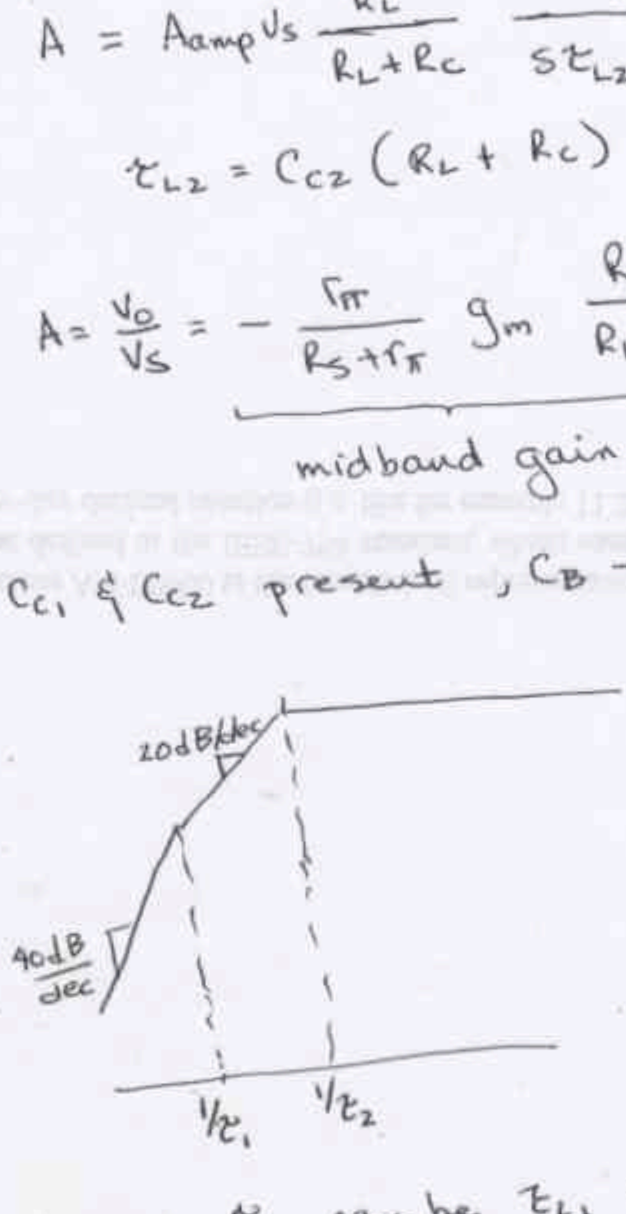
taking into account C_{c2} & R_L

$$A = A_{amp} V_s \frac{R_L}{R_L + R_c} \frac{s\tau_{L2}}{s\tau_{L2} + 1}$$

$$\tau_{L2} = C_{c2}(R_L + R_c) \quad \leftarrow \text{from lect. 1}$$

$$A = \frac{V_o}{V_s} = \underbrace{-\frac{r_\pi}{R_s + r_\pi} g_m \frac{R_c R_L}{R_L + R_c}}_{\text{midband gain}} \frac{s\tau_{L2}}{s\tau_{L2} + 1}$$

For C_{c1} & C_{c2} present, $C_B \rightarrow$ short, we have 2 poles



τ_1 can be τ_{L1} or τ_{L2} ← largest of either

$$\omega = 1/\tau$$

The smallest τ produces the largest ω. $\therefore$ if $\tau_{L2} \gg \tau_{L1}$,

$\omega_{L1} \gg \omega_{L2}$ and ω_{L1} determines the BW.

Rule of thumb:

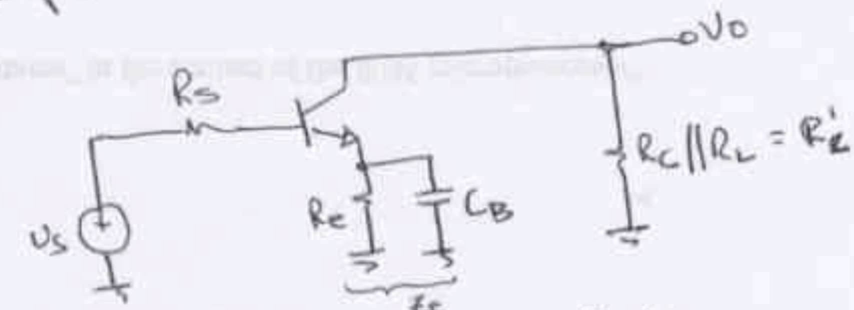
$\omega_{L1}, \omega_{L2}, \omega_{L3}, \omega_{L4}, \ldots, \omega_{Ln}$ ⇒ low-freq. poles

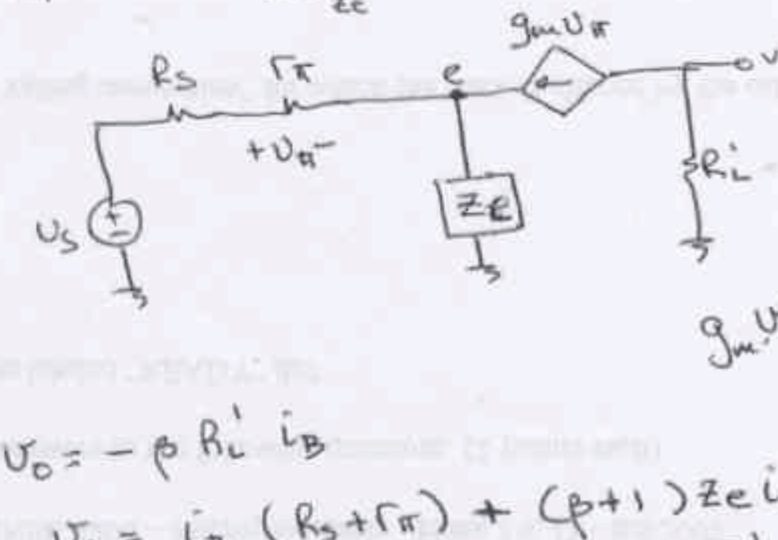
→ if $\omega_i \gg$ all other ω's by at least a decade, then $\omega_{BW} \simeq \omega_i$

else $\omega_{BW} \simeq \sum_{j=1}^{n} \omega_j$ ← add all of them to find an approx. bandwidth.

→ ω_i is the "dominant" low freq. pole

Bypass cap.





$g_m v_\pi = \beta i_B$

$v_o = -\beta R_L' i_B$

$v_s = i_B(R_s + r_\pi) + \underbrace{(\beta+1) Z_e i_B}_{\text{KCL at } e}$ ← KVL on input loop

$$i_B = \frac{v_S}{R_S + r_\pi + (\beta+1) Z_e}$$

$$v_o = - \frac{\beta R_L'}{R_S + r_\pi + (\beta+1) Z_e} v_S$$

$$Z_e = \frac{R_e \, {}^{1}\!/_{sC_B}}{R_e + {}^{1}\!/_{sC_B}} = \frac{R_e}{sC_B R_e + 1}$$

$$\frac{v_o}{v_S} = - \frac{\beta R_L'}{R_S + r_\pi + \dfrac{(\beta+1) R_e}{s C_B R_e + 1}}$$

$$= - \frac{\beta R_L' \, (s C_B R_e + 1)}{s C_B R_e (R_S + r_\pi) + R_S + r_\pi + (\beta+1) R_e}$$

$$= \underbrace{- \frac{\beta R_L'}{R_S + r_\pi + (\beta+1 R_e)}}_{\text{midband gain}} \; \frac{s C_B R_e + 1}{1 + s C_B \dfrac{R_e (R_S + r_\pi)}{R_S + r_\pi + (\beta+1) R_e}}$$

$$C_B \frac{R_e (R_S + r_\pi)}{R_S + r_\pi + (\beta+1) R_e} = C_B \frac{R_e \dfrac{R_S + r_\pi}{\beta+1}}{R_e + \dfrac{R_S + r_\pi}{\beta+1}}$$

$$\frac{R_S + r_\pi}{\beta+1} \leftarrow$$ equivalent resistance "looking" into emitter

$$\frac{v_o}{v_S} = A_{dc} \frac{s\tau_z + 1}{s\tau_p + 1}$$

$\leftarrow$ zero at $\omega_z = \dfrac{1}{C_B R_e}$

pole at $C_B R_{eq.}$

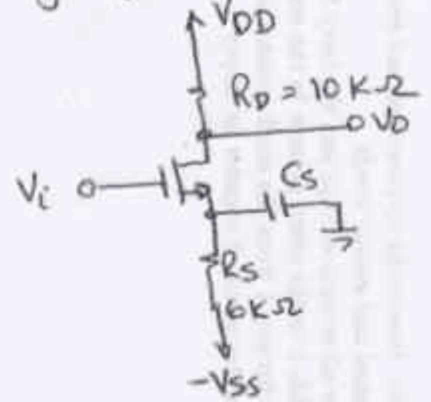
$$R_{eq.} = R_e \, || \, \frac{R_S + r_\pi}{\beta+1}$$

Notice that ω_p is alwas larger than ω_z.

$\omega_p \rightarrow$ can be found from C_B & the equivalent resistance "seen" by C_B $\rightarrow$ "open-circuit t.c."

$A_{dc} \rightarrow$ gain when C_B is an open circuit.

Ejemplo



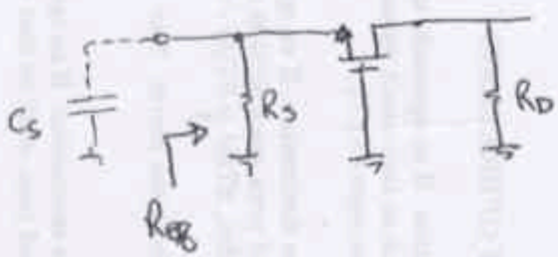
$I_D = 1mA$; $g_m = 1 mA/V$, $r_o = \infty$

Find:
a) midband gain A_{MB}
b) value of C_S that places the low-freq. pole at 10HZ
c) freq. of zero due to bypass for this value of C_S
d) $A_v(s)$

(a) $A_{MB} = -g_m R_D = -(1mA/V)(10K\Omega) = \boxed{-10\ V/V}$

(b) find the "R_{eq}" from terminals of C_S.

For A.C.



$R_{eq} = R_S \| 1/g_m$

$= 6K\Omega \| 1K\Omega$

$= 6/7\ K\Omega = 0.857 K\Omega$

$$C_S \frac{6000}{7} = \frac{1}{\omega_L} = \frac{1}{2\pi(10HZ)} = \frac{1}{20\pi}$$

$$C_S = \frac{7}{12\,0000\pi} = \frac{7}{1.2\times10^5\,\pi} = \frac{7}{.12\pi}\ \mu F$$

$$\boxed{C_S = 18.6\ \mu F}$$

(c) $\omega_z = \dfrac{1}{18.6\mu F \times 6K\Omega} = 8.97\ rps \approx 9\ rps \Rightarrow f_z = \dfrac{\omega_z}{2\pi} = \boxed{1.4\ HZ}$

(d) $\quad A_v(s) = \frac{V_o}{V_i} = A_{dc} \; \frac{s/9 + 1}{s/20\pi + 1}$

$$A_{dc} = \frac{-g_m R_d}{1 + g_m R_s} = \frac{-(1mA/v)(10K)}{1 + (1mA/v)(6K)}$$

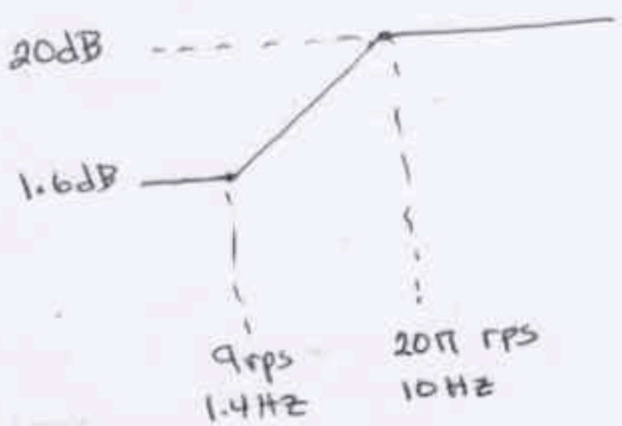
$$= -\frac{10}{7} \; v/v \;\Rightarrow\; \sim 1.6\,dB$$

$$\boxed{A_v(s) = -\frac{10}{7} \; \frac{s/9 + 1}{s/20\pi + 1}}$$

$\rightarrow$ to find A_{MB} let $s \to \infty$

$$A_{MB} = -\frac{10}{7} \; \frac{20\pi}{9} = \underline{-9.97 \, v/v}$$

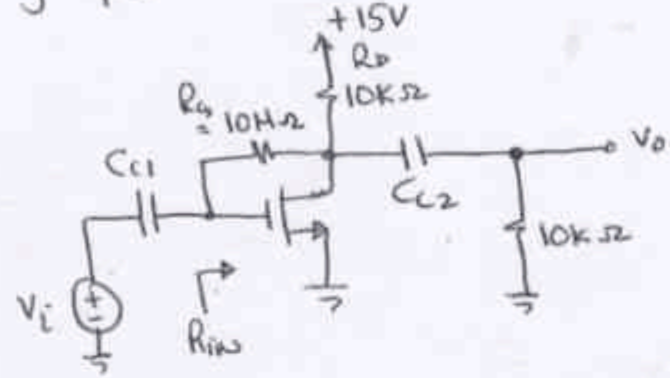
this is the gain when C_B is a short



$\leftarrow$ bode plot of gain (mag.)

$$\phi = -180^\circ + \tan^{-1}(\omega/9) - \tan^{-1}(\omega/20\pi)$$

Ejemplo:



Given $I_D = 1.06\,mA$

$g_m = 0.725\,^{mA}/_{V}$

$r_o = 47K\Omega$

$A_{MB} = -3.3\,V/V$

$R_{IN} = 2.33M\Omega$

select values for C_{C1} and C_{C2} so that the low-freq. response is dominated by a pole at 10 Hz with the other pole at least a decade lower.

ANS. using the S.C.T.C. method.

For C_{C1}, $R_{eq} \cong R_{IN} = 2.33M\Omega$

For C_{C2}, $R_{eq} = 10K\Omega + 10K\Omega \| 10M\Omega \| 47K\Omega$

$= 10K\Omega + 8.24K\Omega$

$= 18.24K\Omega \simeq 18.2K\Omega$

let $\tau_2 = \frac{1}{20\pi} = C_{C2}(18K\Omega) \Rightarrow \boxed{C_{C2} = 0.87\mu F}$

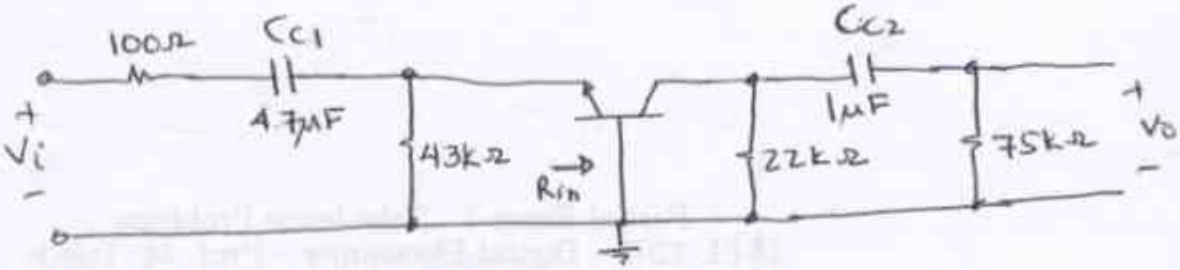
$\tau_1 = \frac{1}{2\pi} = C_{C1}(2.33M\Omega)$

$\Rightarrow \boxed{C_{C1} = 68\,nF}$

Notice that if $\tau_2 = 1/2\pi$ and $\tau_1 = 1/20\pi$

$C_{C2} = 8.7\mu F$ & $C_{C1} = 6.80\,nF$ $\Rightarrow$ bigger C_{C2} caps. so less convenient.

Ejemplo



Given: $I_C = 0.1\,mA$; $\beta_0 = 100$; $r_0 = \infty$

Find: midband gain and low-freq. poles

midband gain

$$A_{MB} = \frac{V_o}{V_e}\,\frac{V_e}{V_i}$$

$$\frac{V_o}{V_e} = +g_m R_L' = \left(\frac{I_C}{V_T}\right)(22k\Omega \| 75k\Omega)$$

$$= \frac{.1\,mA}{.025\,V}\,(22\|75) \times 1000 = 68\ V/V$$

$$\frac{V_e}{V_i} = \frac{43k\|R_{in}}{100 + 43k\|R_{in}} \ ; \quad R_{IN} = \frac{r_\pi}{\beta+1} = \frac{100}{101}\,\frac{25\,mV}{.1\,mA} \cong 250\Omega$$

$$43k\|R_{in} \cong 250\Omega$$

$$\frac{V_e}{V_i} = \frac{25}{35}$$

$$A_{MB} = \frac{25}{35}\,68\ V/V \cong \boxed{49\ V/V}$$

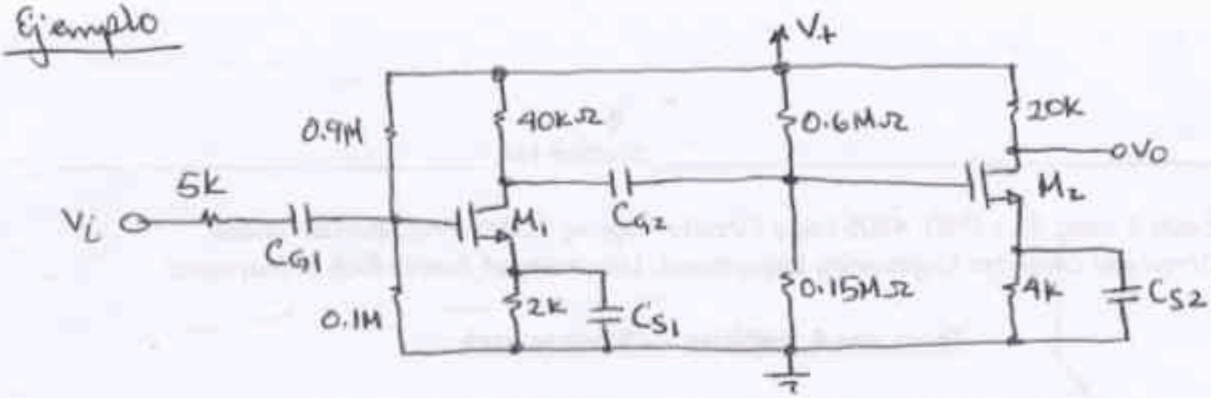
due to C_{C1} $\omega_1 \rightarrow$ $\tau_1 = (4.7\mu F)(350\Omega) = 1645 \times 10^{-6}\,s$ ← dominant

due to C_{C2} $\omega_2 \rightarrow$ $\tau_2 = (1\mu F)(97k\Omega) = 97 \times 10^{-3}\,s$

$$\omega_1 = \frac{1}{1645} \times 10^6\ rps = 607.9\ rps \cong \underline{98\,Hz}$$

$$\omega_2 = \frac{1000}{97}\ rps = 10.3\ rps \cong 1.64\,Hz$$

Ejemplo



$$g_1 = g_2 = 2\,\text{mA/V}\ ,\ r_{d1} = r_{d2} = 40\text{k}\Omega$$

$$C_{G1} = C_{G2} = 1\mu F\ ,\ C_{S1} = C_{S2} = 100\mu F$$

Find: midband gain ; low-freq. poles and zeroes

$$A_{MB} = \frac{V_o}{V_i} = \frac{V_o}{V_{G2}} \cdot \frac{V_{G2}}{V_{D1}} \cdot \frac{V_{D1}}{V_{G1}} \cdot \frac{V_{G1}}{V_i}$$

$$\frac{V_o}{V_{G2}} = -(g_{m2})(20\text{K}) = -2\frac{\text{mA}}{\text{V}} \times 20\text{k}\Omega = \underline{-40\ \text{V/V}}$$

$$\frac{V_{D1}}{V_{G1}} = -g_{m1} R_{d1}' \ ;\ R_{d1}' = 40\text{k} \,\|\, 150\text{k} \,\|\, 600\text{k} \,\|\, 40\text{k} \overset{\vee}{=} 17\text{K}\Omega$$

$$\frac{V_{D1}}{V_{G1}} = -2\frac{\text{mA}}{\text{V}}(17\text{K}\Omega) \cong \underline{-34\ \text{V/V}}$$

$\dfrac{V_{G2}}{V_{D1}} = 1$ since we account for loading when finding V_{D1}/V_{G1}

$$\frac{V_{G1}}{V_i} = \frac{900\|100}{5 + 900\|100} = \frac{90}{95}$$

$$A_{MB} = -40 \times (-34) \times 90/95 = \boxed{+1288\ \text{V/V}} \Rightarrow \underline{62.2\text{dB}}$$

$\tau_{CG1} = (1\mu F)(5K + 100K \| 900K) = (1\mu F)(90K) = 90 ms$

$\tau_{CG2} = (1\mu F)(600K \| 150K + 40K \| 40K)$

$= (1\mu F)(120K + 20K) = 140 ms$

$\tau_{CS1} = (100\mu F)(2K \| \frac{1}{g_{s1}}) = 100\mu F (2K \| 500\Omega) = \underline{40 ms}$

pole due to CS1

$\tau_{CS2} = (100\mu F)(4K \| \frac{1}{g_{s2}}) = 100\mu F (4K \| 500\Omega) = \underline{44.4 ms}$

pole due to CS2

<u>zeros</u> @ $\tau_{CS1_z} = (100\mu F)(2K) = 200 ms$

$\tau_{CS2_z} = (100\mu F)(4K) = 400 ms$

<u>Frequencies</u>

poles at 25 rps, 22.5 rps, 11 rps, 7.1 rps

zeros at 5 rps, 2.5 rps

Approximate low freq. -3dB point is

$f_L = \sum \text{poles} - \sum \text{zeros}$

$\cong \frac{58 \text{ rps}}{2\pi} = \boxed{9.3 \text{ Hz}}$