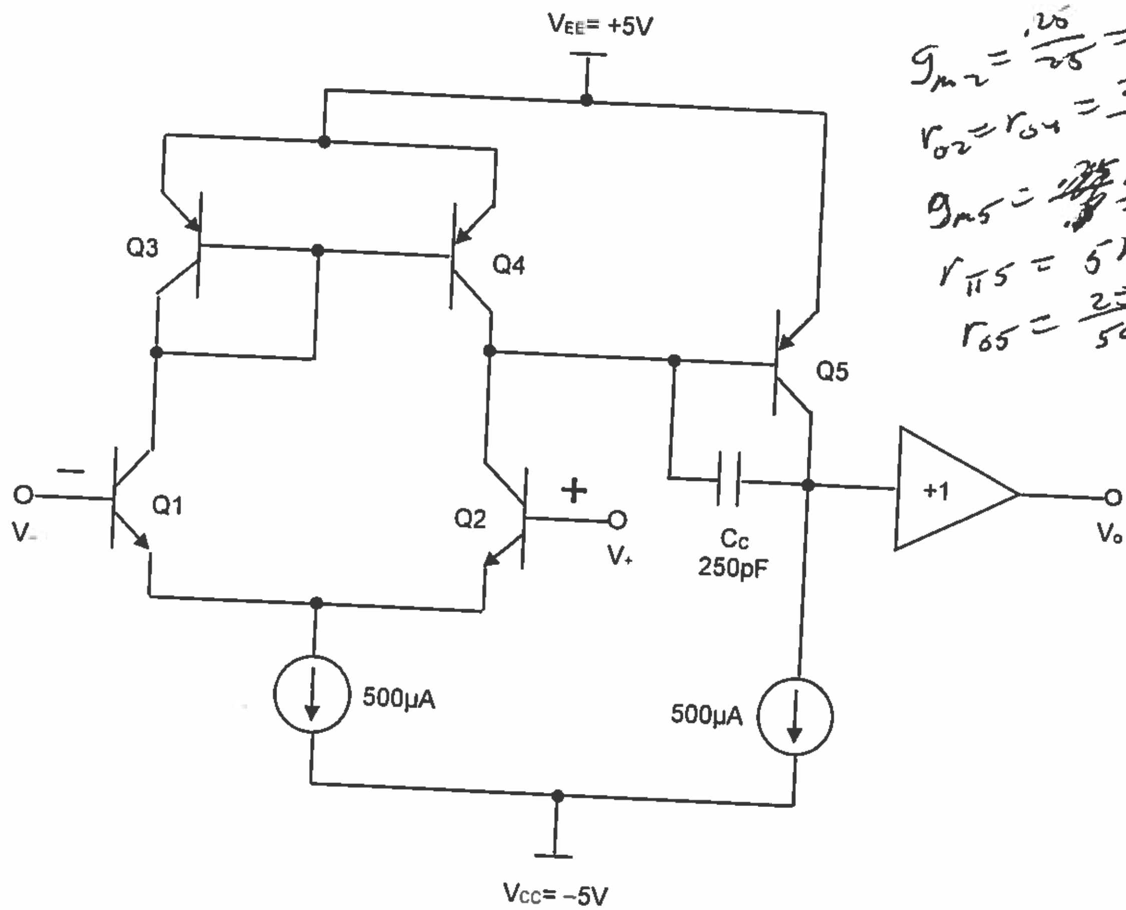
Problem 1 (20 points)

Consider the following open-loop opamp circuit. Assume the unity-gain output buffer is ***ideal***. Assume $\beta_n=\beta_p=100$, $V_{An}=V_{Ap}=250V$, and $V_T=25mV$. Please make reasonable approximations where appropriate.



$g_{m2} = \frac{.25}{25} = .01$

$r_{o2} = r_{o4} = \frac{250}{.25m} = 1M$

$g_{m5} = \frac{.5}{25} = .02$

$r_{\pi 5} = 5K$

$r_{o5} = \frac{250}{500\mu} = 500K$

a) Calculate the ω_t of the opamp. $\omega_t = \frac{g_{m2}}{C_c} = 40\,M\ rad/sec$

b) Calculate the SR of the opamp.

$SR = \frac{I_{Q1}}{C_c} = 2V/\mu s$

c) Calculate the A_0 of the opamp.

$A_0 = g_{m2}\left[r_{o2} \| r_{o4} \| r_{\pi 5}\right] g_{m5}\, r_{o5}$

$= 500K\ V/V$

d) Calculate the ω_H of the opamp.

$\omega_H = \frac{\omega_t}{A_0} = 80\ rad/sec$

Problem 2 (20 points)

Consider the following 2nd-order Transfer Function T(s):

$\omega_n = 10^6$

$\zeta = .2$

$$T(s) = \frac{1000}{10^{-12}s^2 + 4\times10^{-7}s + 1}$$

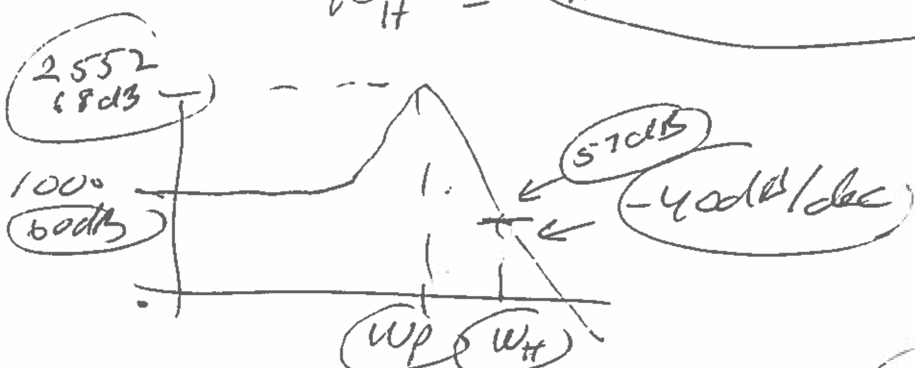
a) Using the "Calculator Sheet", calculate M_p, ω_p, and ω_h. Sketch and label the Bode Magnitude Plot.

b) Using the "Calculator Sheet", calculate t_r, t_p and P_o. Sketch and label the Step Response, $v_o(t)$, if $v_i(t)$ is a 0-to-1mV step.

a.) $M_p = 2.552$

$\omega_p = 9.59 \times 10^5$ rad/sec

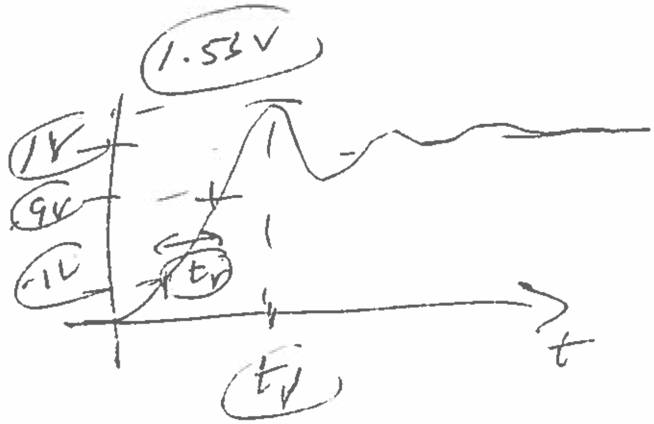
$\omega_H = 1.51 \times 10^6$ rad/sec



b.) $t_r = .46\ \mu s$

$t_p = 3.2\ \mu s$

$P_o = 1.53$



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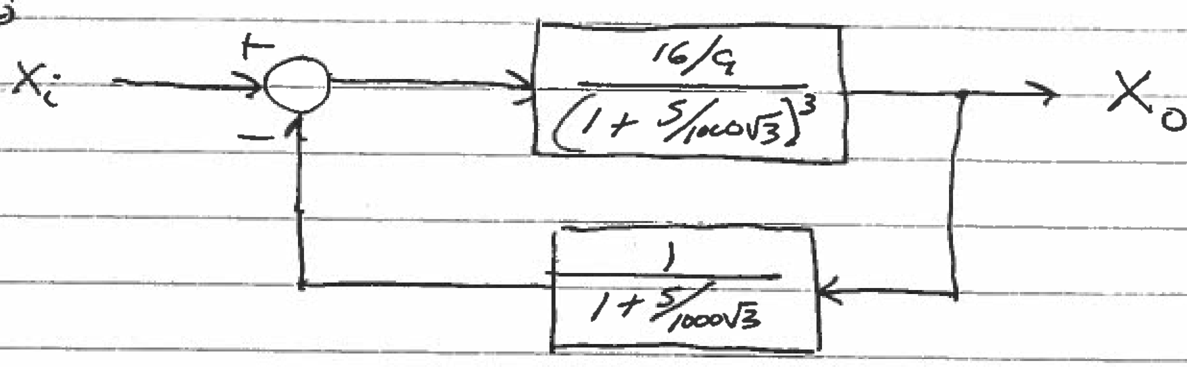


a.) $LG(s) = A(s)\beta(s) = \dfrac{16/9}{\left(1+ s/1000\sqrt{3}\right)^4}$

b.) $PM = 180^\circ - \left| \measuredangle LG(j\omega_1) \right|$

$$\measuredangle LG(j\omega_1) = -4 \tan^{-1} \frac{\omega_1}{1000\sqrt{3}}$$

$$\left| LG(j\omega_1) \right| = 1 = \frac{16/9}{\left[1 + \left(\frac{\omega_1}{1000\sqrt{3}}\right)^2\right]^2}$$

$$1 = \frac{4/3}{1 + \frac{\omega_1^2}{3\times10^6}}$$

$$\frac{\omega_1^2}{3\times10^6} = \frac{1}{3} \Rightarrow \boxed{\omega_1 = 1000\ \text{rad/sec}}$$

$$\measuredangle LG(j\omega_1) = -4\tan^{-1}\frac{1000}{1000\sqrt{3}} = -4\tan^{-1}\frac{1}{\sqrt{3}}$$

$$= (-4)(30^\circ) = -120^\circ$$

$$PM = 180^\circ - |-120^\circ| = 60^\circ$$

c.) $GM = 20 \log \left[\frac{1}{|LG(j\omega_{180})|} \right]$

$$|LG(j\omega_{180})| = \frac{16/9}{\left[1 + \left(\frac{\omega_{180}}{\sqrt{3} \times 10^3}\right)^2\right]^2}$$

$$\measuredangle LG(j\omega_{180}) = -180^\circ = -4 \tan^{-1} \frac{\omega_{180}}{\sqrt{3} \times 10^3}$$

$$\therefore \; 45^\circ = \tan^{-1} \frac{\omega_{180}}{\sqrt{3} \times 10^3}$$

$$\Rightarrow \boxed{\omega_{180} = \sqrt{3} \times 10^3 \text{ rad/sec}}$$

$$\therefore \; |LG(j\omega_{180})| = \frac{16/9}{(1+1)^2} = \frac{\frac{16}{9}}{4}$$

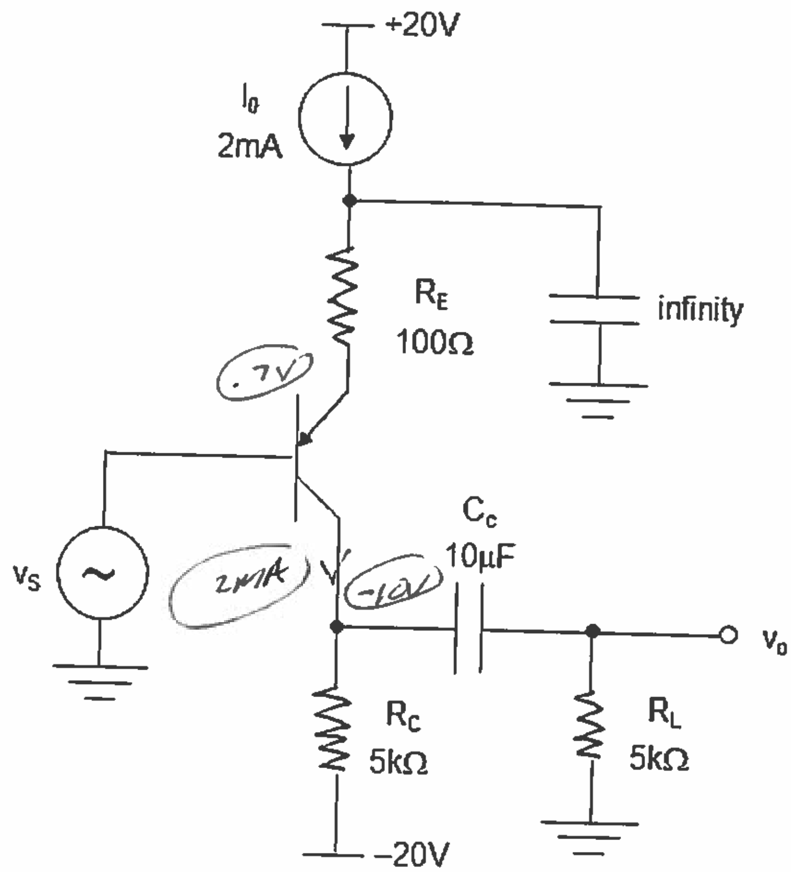
$$= .444$$

$$\therefore \; GM = 20 \log \left[\frac{1}{4/9} \right]$$

$$\boxed{GM = 7.04 \text{ dB}}$$

Problem 4 (20 points)

Consider the following simple BJT CE Amplifier with Emitter Degeneracy. Assume β=200, $V_{BE\text{-}on}$=0.7V, C_π=400pF, C_μ=40pF, V_T=25mV and r_o=infinity. Please make reasonable approximations where appropriate.



a) DC Analysis: Calculate I_C, V_E, and V_C (Remember, please make reasonable approximations).

b) Sketch and label the full SS AC model.

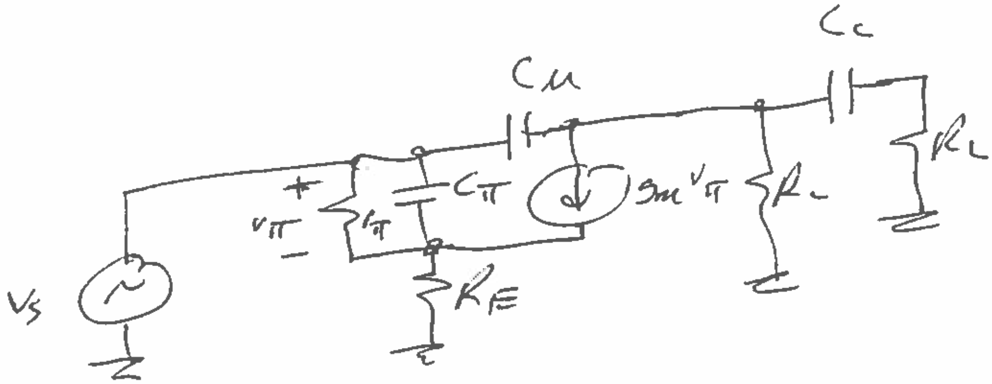
c) Calculate A_M exactly. What happens to A_M if β goes to infinity?

d) Calculate ω_L using SCTC's.

e)_ Calculate ω_H using OCTC's. (Hint: You may assume that $\tau_{C\pi}$=0)

f) Determine T(s) and sketch and label the Bode Magnitude Plot for T(s). (Note: Please express T(s) in its correct, simplified format).

b)



$$g_m = \frac{I_c}{V_T} = \frac{2}{25} = .08$$

$$r_\pi = \frac{\beta}{g_m} = \frac{200}{.08} = 2.5K$$

c.) $A_m = \frac{V_o}{V_s} \Rightarrow$

$$V_o = -g_m V_\pi \left[R_c \| R_L\right]$$

$$\frac{V_\pi}{r_\pi} + g_m V_\pi = \frac{V_s - V_\pi}{R_E}$$

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

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

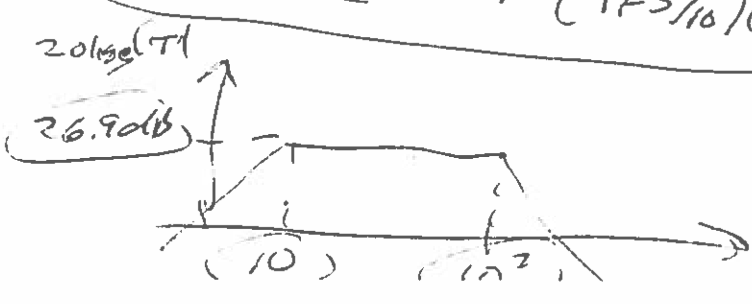
$$A_m = \frac{V_o}{V_s} = -\frac{\beta\left[R_c \| R_L\right]}{R_E\left(1+\beta+\frac{r_\pi}{R_E}\right)} = -22.1 \text{ V/V}$$

$A_m \rightarrow -25$ as $\beta \rightarrow \infty$

d.) $\omega_L = \sum \frac{1}{\tau_{i,s.s}} = \frac{1}{\tau_{C_c}} = \frac{1}{(R_c + R_L) C_c} = 10 \text{ rad/sec}$

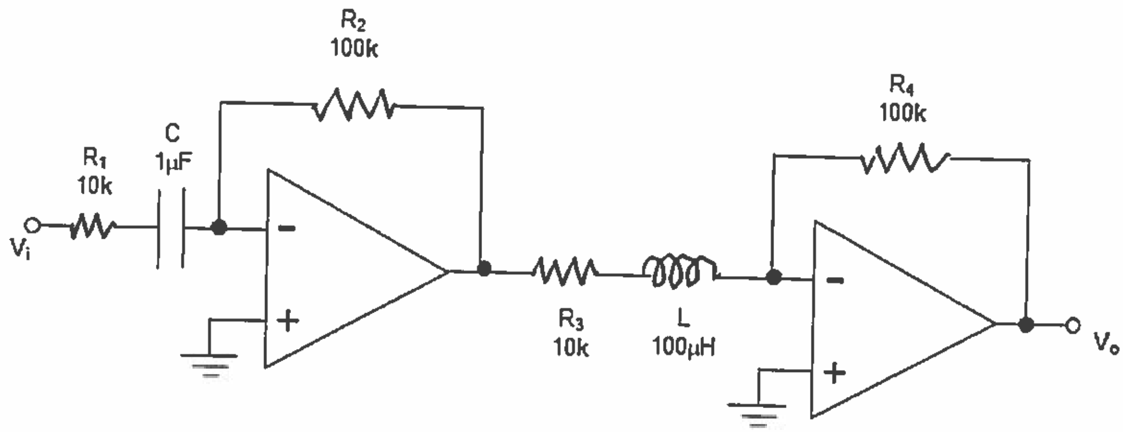
e.) $\omega_H = \frac{1}{\sum \tau_{i,o's}} = \frac{1}{\cancel{\tau_\pi} + \tau_{C_\mu}} = \frac{1}{(R_c \| R_L) C_\mu} = 10^7 \text{ rad/sec}$

f.) $T(s) = (-22.1)\frac{s/10}{(1+s/10)(1+s/10^7)}$



Problem 5 (20 points)

Consider the following active filter comprised of two cascaded opamp amplifier circuits. Assume the opamps are ***ideal***.



a) Calculate the overall transfer function, $T(s)=V_o/V_i(s)$. (Hint: This is a BPF. Please express T(s) in its correct, simplified format).

b) Calculate the input impedance, R_{in}, of this active filter at midband frequencies.

c) Calculate the output impedance, R_{out}, of this active filter.

d) Sketch and label both the Bode Magnitude and Phase Plots for T(s).

a.) $T_1(s) = \dfrac{-R_2}{R_1 + \frac{1}{Cs}} = -\dfrac{R_2}{R_1}\left[\dfrac{R_1Cs}{1+R_1Cs}\right]$

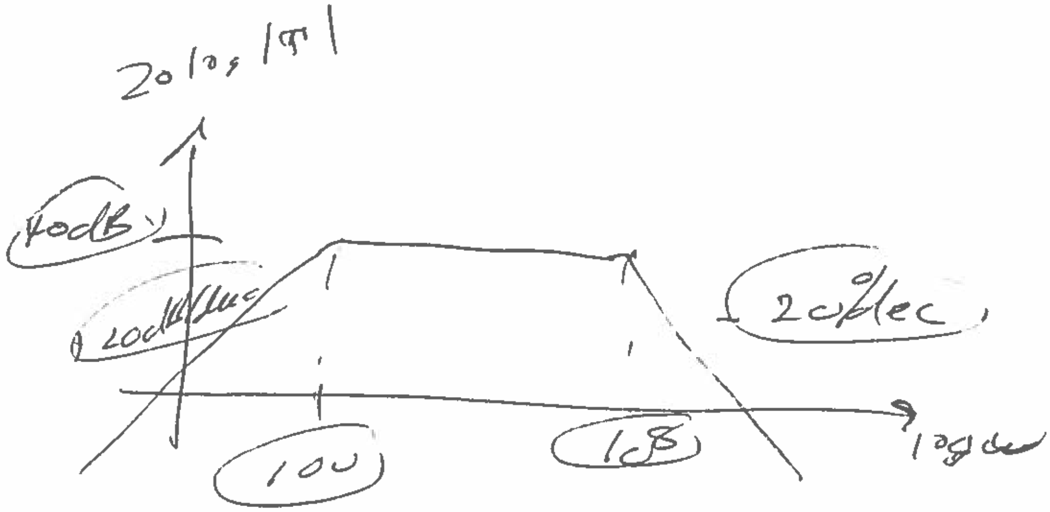
$T_2(s) = \dfrac{-R_4}{R_3 + sL} = -\dfrac{R_4}{R_3}\left[\dfrac{1}{1+s\frac{L}{R_3}}\right]$

$T(s) = \left[\dfrac{R_2R_4}{R_1R_3}\right]\left[\dfrac{R_1Cs}{(1+R_1Cs)(1+sL/R_3)}\right]$

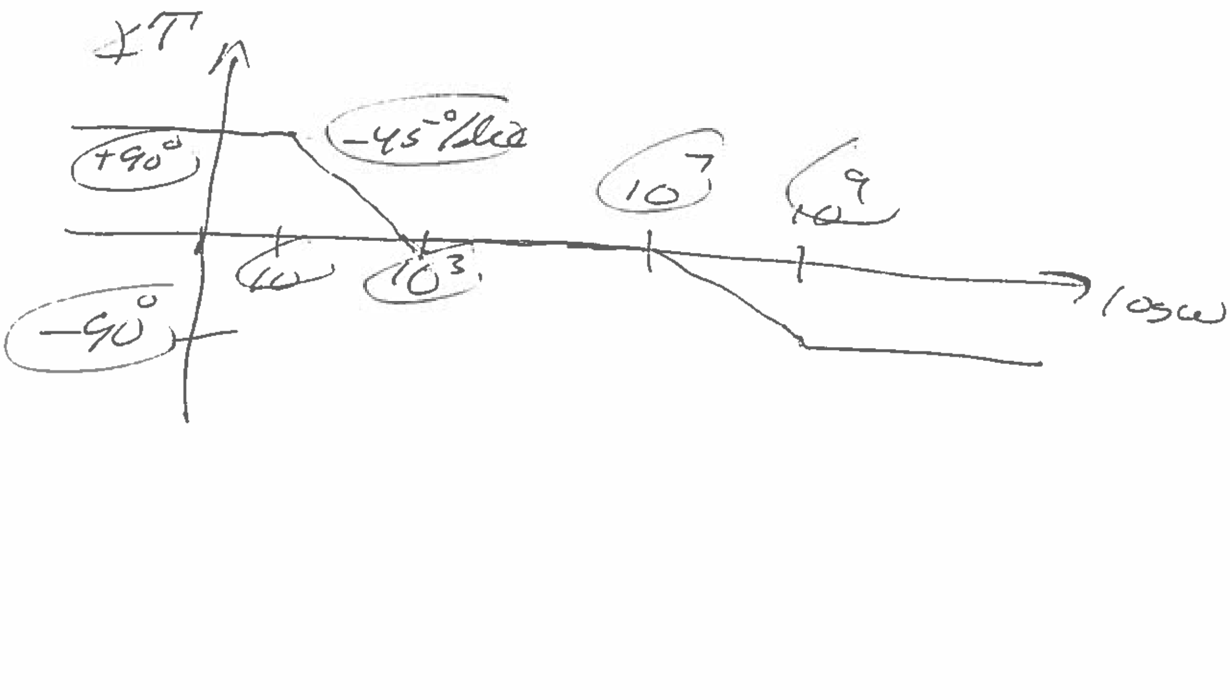
$$\boxed{T(s) = 100\left[\frac{s/100}{(1+s/100)(1+s/10^8)}\right]}$$

b.) $R_{in} = R_1 = 10K$

c.) $R_{out} = 0$



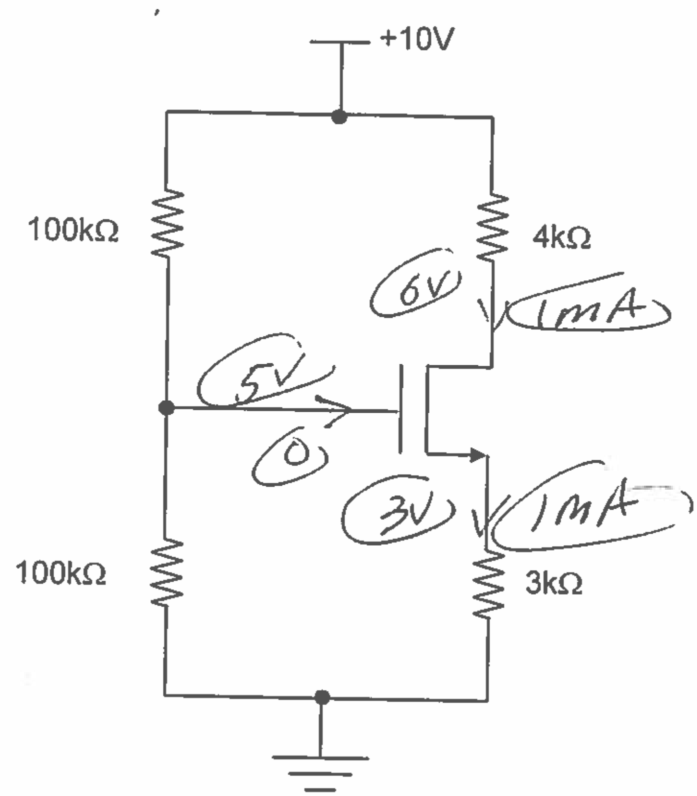
20 log |T|
40dB
20dB/dec
20dB/dec
100
10^8
log ω



∡T
+90°
-45°/dec
10^7
10^9
10
10^3
-90°
log ω

Optional Extra Credit Problem (10 points, no partial credit)

Consider the following MOSFET circuit. For the nFET, assume V_{tn}=+1V and $K_n=\mu_n C_{ox} W/2L$=1mA/V². Calculate I_G, ~~I_S, I_D, V_G~~, V_S ~~and V_D~~.



~~Check: $I_D = I_S = K_n[V_{GS} - V_{tn}]^2 = 10^{-3}[(5-3)-1]^2 = 1mA$~~

$$I_D = K_n[V_{GS} - V_{tn}]^2 = 10^{-3}[5 - V_S - 1]^2$$

$$= 10^{-3}[4 - V_S]^2 = \frac{V_S}{3K}$$

$$3[16 - 8V_S + V_S^2] = V_S$$

$$3V_S^2 - 25V_S + 48 = 0$$

$$V_S = \frac{25 \pm \sqrt{25^2 - (12)48}}{6} = \frac{25 \pm 7}{6} = 3V, \; 5.33V$$