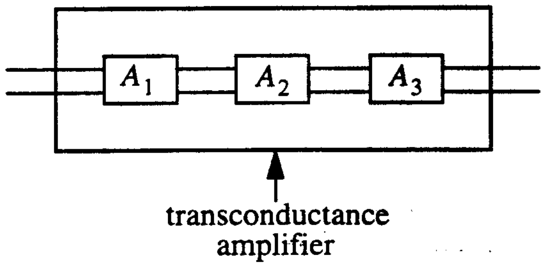
Problem 1 (15 pts., NO Partial Credit)

You buy three voltage amplifiers with the following specifications: $R_{in} = 10^5$, $R_{out} = 10^5$, $A = 10$. You hook them up in series (i.e., output 1 = input 2, etc.), and place them in a black box. You are going to sell this box as a transconductance amplifier. What are the specifications of the transconductance amplifier?



$$\frac{V_{OUT}}{V_1} = A_1 A_2 A_3 \times \frac{R_{i2}}{R_{o1}+R_{i2}} \times \frac{R_{i3}}{R_{o2}+R_{i3}}$$

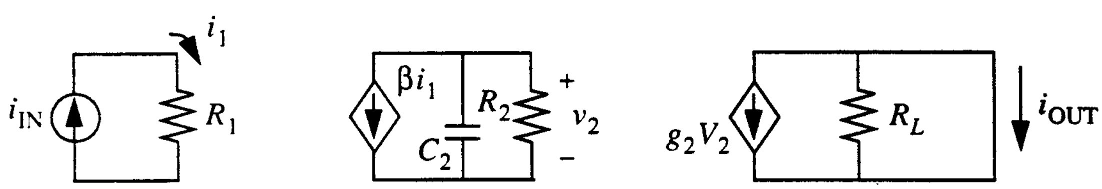
G_m = -2.5×10^{-3} S

R_{in} = 10^5 Ω

R_{out} = 10^5 Ω

Problem 2 (15 points)

a. Find the phasor representing the ratio of short-circuit output current to input current for the following circuit:

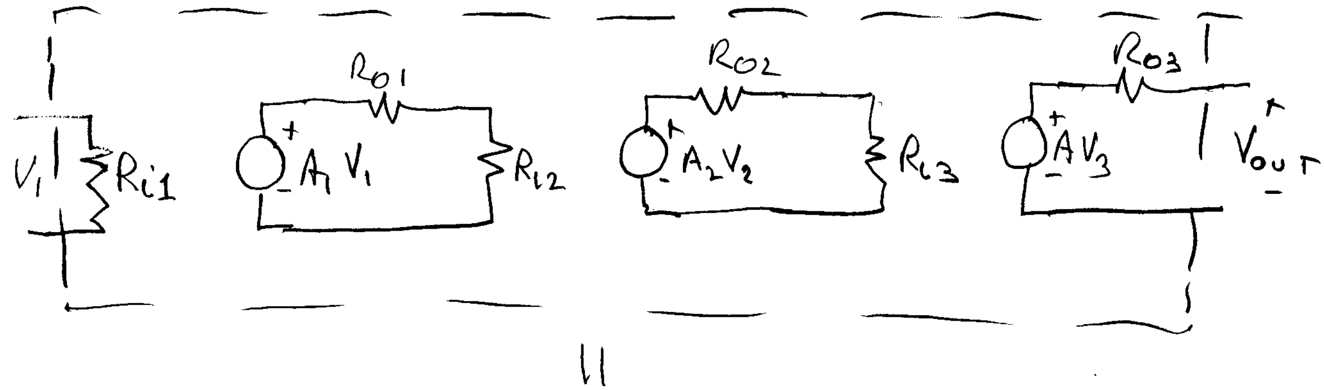


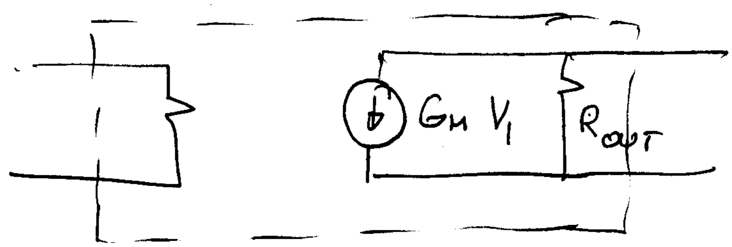
$$\tilde{I}_{OUT} = -g_2 \bar{V}_2 = -g_2 \left(-\beta \tilde{I}_1 \times \frac{\frac{1}{j\omega C_2}}{\frac{1}{j\omega C_2}+R_2}\right) R_2$$

$$\mathbf{A}_1 \equiv \frac{\mathbf{I}_{out}}{\mathbf{I}_{in}} = \beta g_2 \frac{R_2}{1 + j\omega R_2 C_2}$$

b. What is the general shape of the frequency response? Sketch magnitude vs frequency on dB scale provided on pg. 2.

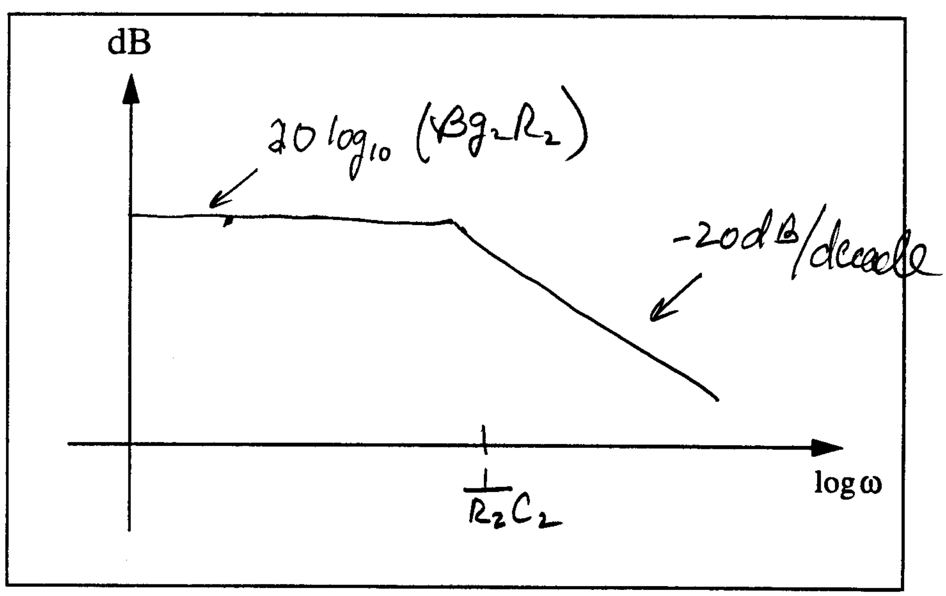
SINGLE POLE LOW-PASS





$$\frac{V_{OUT}}{V_1} = -G_M R_{OUT}$$

$$G_M = \underbrace{-A_1 A_2 A_3}_{-10^3} \; \underbrace{\frac{R_{i2}}{R_{o1}+R_{i2}} \times \frac{R_{i3}}{R_{i3}+R_{o2}}}_{\frac{1}{4}} \times \underbrace{\frac{1}{R_{o3}}}_{10^{-5}}$$



Problem 3 (20 points)

Sketch the Bode plot on the graphs provided for the following function. Please show your work. (Neatness and clarity are important.) Only straight-line approximations are wanted.

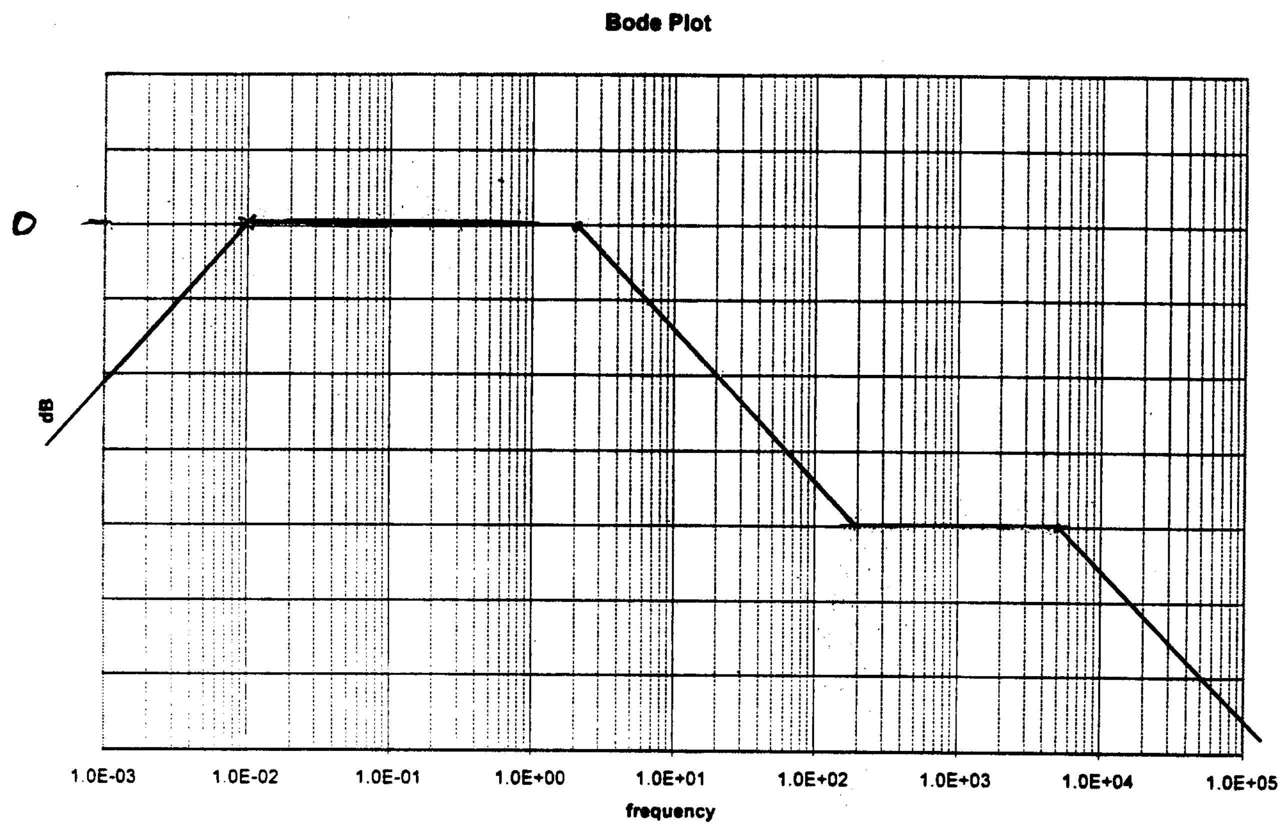
$$\mathbf{F} = \frac{200j\omega \times \left(1 + \frac{j\omega}{200}\right)}{(2 + j\omega)(1 + 100j\omega)(1 + 0.0002j\omega)}$$

$$= \frac{\left(\frac{j\omega}{.01}\right)\left(1 + \frac{j\omega}{200}\right)}{\left(1 + \frac{j\omega}{2}\right)\left(1 + \frac{j\omega}{.01}\right)\left(1 + \frac{j\omega}{5\times 10^3}\right)}$$

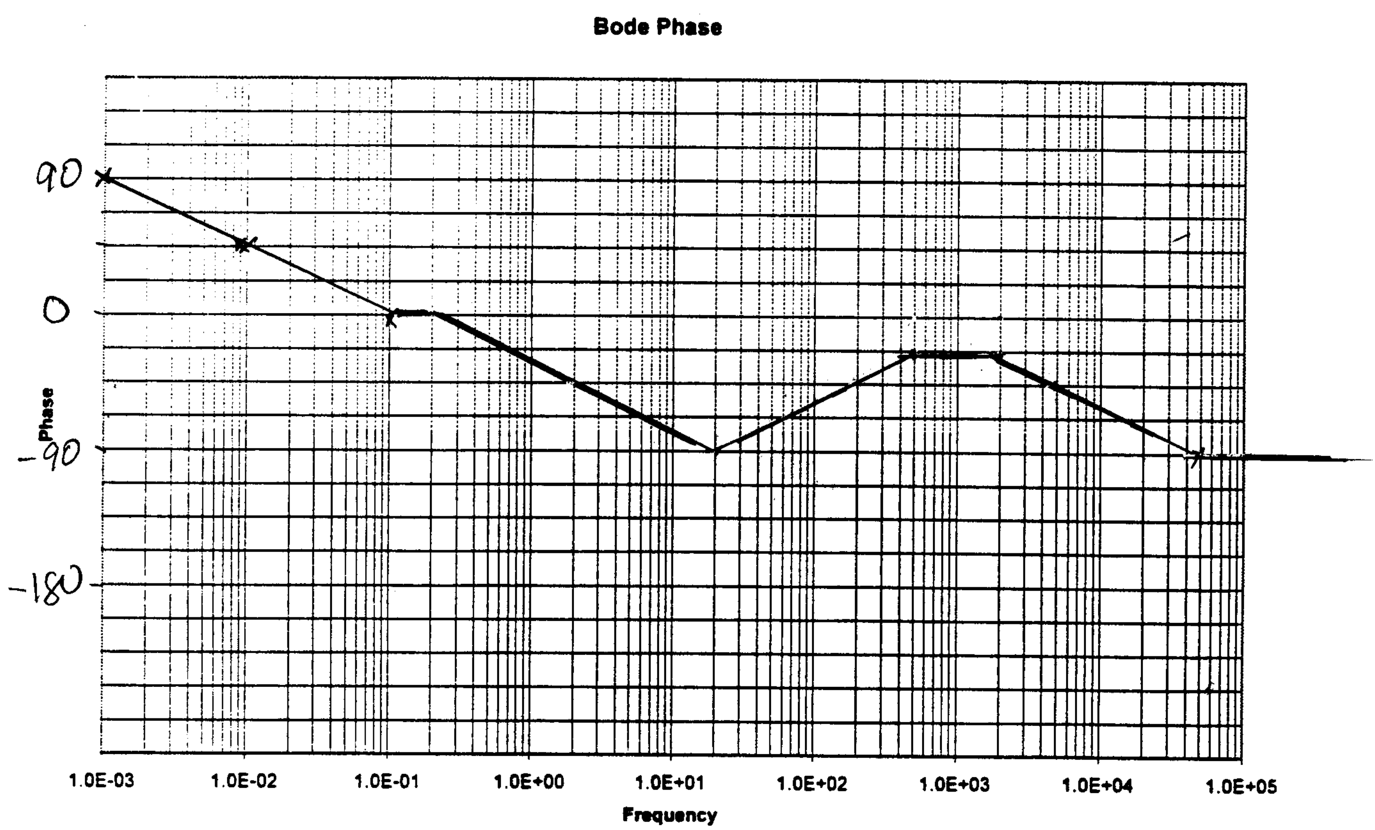
$|F| = 0$ dB @ $\omega = .01$

FOR $\omega << .01$, $\phi = 90°$, $|F| = -20$ dB/decade

FOR $\omega > .01$ ADD PHASE & dB CONTRIBUTIONS:



Bode Plot
0
dB
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
frequency



Bode Phase
90
0
-90
-180
Phase
1.0E-03
1.0E-02
1.0E-01
1.0E+00
1.0E+01
1.0E+02
1.0E+03
1.0E+04
1.0E+05
Frequency

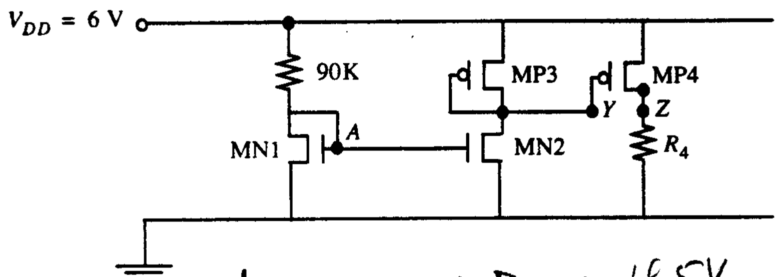
Problem 4 (25 points)

In the circuit below, the reference node A is at a potential of 1.5 V. The W/L ratios for the n-channel devices are chosen as: $(W/L)_2 = 2(W/L)_1$. For the p-channel devices $(W/L)_4 = 10(W/L)_3$. Also, $\left(\frac{W}{L}\right)_3 = 4\left(\frac{W}{L}\right)_1$.

a. Find W/L for n-channel device MN1 (to produce the required 1.5 V at node A).

b. Find the drain current of MN2 and the node voltage V_Y.

c. Find the value of R_4 needed to produce a voltage of 3 V at node Z.



$V_A = 1{,}5 \Rightarrow I_{D1} = \frac{4{,}5V}{90K} = 50\mu A$

$(W/L)_1 =$ 2

$50\mu A = \underbrace{\mu C_{ox}}_{50} \frac{W}{2L} \underbrace{(V_{GS} - V_T)^2}_{1} \Rightarrow \frac{W}{L}\Big|_{①} = 2$

$\frac{W}{L}\Big|_2 = 2\,\frac{W}{L}\Big|_1 \Rightarrow 100\mu A$

$I_{D2} =$ 100μA

$100\mu A = \underset{\uparrow\ 25}{\mu C_{ox}|_p}\ \underset{\uparrow\ 4}{\frac{W}{2L}\Big|_3} \underbrace{(V_{GS} - V_T)^2}_{1} \Rightarrow |V_{GS}|_{③} = 1{,}5V$

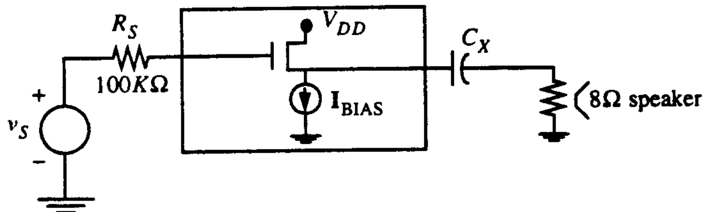
$V_Y =$ 4,5V

$I_{D4} = I_{D3} \times 10 = 1mA$

$R_4 =$ 3K

Problem 5 (25 points)

a) You are given one "power nMOS" transistor and need to construct a transistor circuit to drive an 8 ohm speaker through a coupling capacitor C_X. (The "power nMOS" transistor has a 1V threshold, a W/L of 10^4, and $\mu C_{ox} = 50\mu A/V^2$. The source is connected to the body internally.) Your circuit should have a voltage gain of about 0.5 at higher frequencies (that is, at frequencies high enough that the impedance of C_X is negligible). (Note that C_X must be quite large to have a good low frequency response.) The bias current source you have available is essentially ideal (i.e., infinite parallel resistance). You choose the circuit below.



a) Draw the small-signal model for this amplifier in the box opposite, ignoring all internal device capacitances and parasitic resistances.

EITHER DEVICE S-S MODEL OK

OR CORRECT AMP MODEL OK

b) Solve for the "mid-band" gain A_M (formula in terms of circuit and device parameters). The mid-band gain is a real quantity. It is the gain at frequencies high enough that coupling capacitors act as shorts, yet the frequency is low enough that capacitors to ground are negligible.

FOR S-S MODEL $v_{OUT} = g_m(v_g - v_o)\, r_o \| R_L$

ie $v_o = v_g \dfrac{g_m\, r_o \| R_L}{1 + g_m\, r_o \| R_L}$

$A_M = \dfrac{g_m\, r_o \| R_L}{1 + g_m\, R_L \| r_o}$

c) Find the mid-band gain of the circuit A_M at a bias current of $I_{BIAS} = 10$ mA.

@ 10mA $r_o = \dfrac{1}{\lambda I} = 2K$ $\quad V_{GS} - V_T = 0.2V$

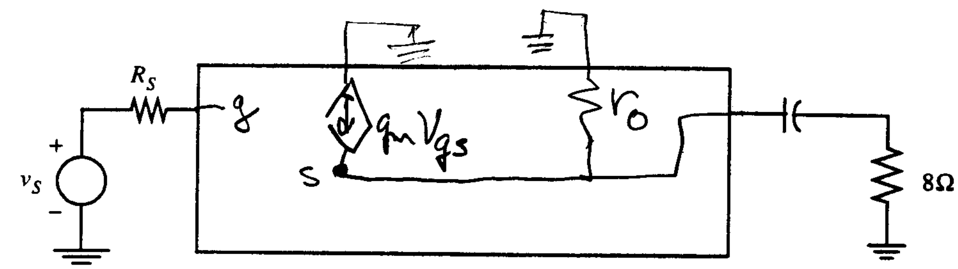
$g_m = \dfrac{2I_D}{V_{GS} - V_T} = 0.1$

$r_o \| R_L \cong R_L$

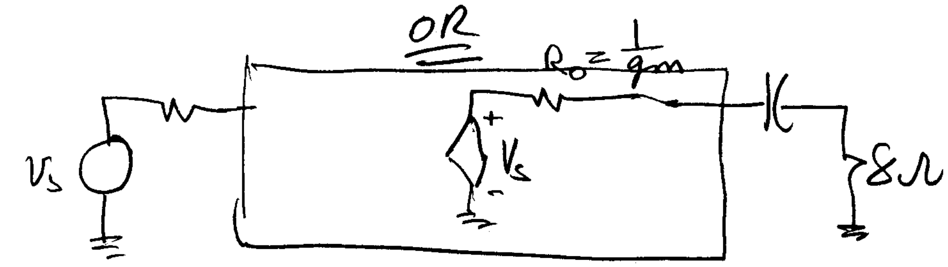
$A_M = \underline{0.44}$

Problem 5 Answer and Worksheet

a.



Small-signal Model



b.

c. $I_D = \mu C_{ox} \frac{W}{2L} (V_{GS} - V_T)^2 \Rightarrow V_{GS} - V_T = 0.2$