UNIVERSITY OF CALIFORNIA

College of Engineering
Department of Electrical Engineering
and Computer Sciences

Professor Oldham — Spring 1999

EECS105 — Midterm 2

Thursday, 8 April 1999

Your name: ________________ _______________________
first last

Your discussion TA: ❒ Allan Chang ❒ Lily Tam

- This is a closed book exam, but you may use your 2 pages of notes.
- Please do all your work on the pages of this exam. Ask if you need extra paper.
- Full credit will be given only when you indicate the source of your answer, such as a table, graph, or calculation.
- Please write your name in the above space
- **SPECIAL NOTES:**

1. QUESTIONS: Because it is disturbing to others in the exam when we pass by to answer questions, we must ask you to please limit your questions. Re-read the exam question and be sure that the data or equation you need is not already provided.
2. GRAPHS AND FORMULAS PROVIDED: At the back of the exam are several pages of formulas, and data in the form of graphs. Please look for information here rather than asking a question.

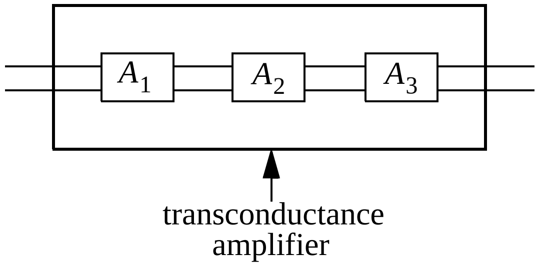
   ☐ Yes, I have looked these over. (Check box)

3. SOME PARTS OF THE EXAM ARE GRADED WITH NO PARTIAL CREDIT. They are noted. You may wish to double check your answers on those parts.
4. DEVICE PROPERTIES: Unless otherwise specified, assume n-channel transistors have $V_{tn} = 0.5$ V, $\mu C_{ox} = 50 \mu A/V^2$, and p-channel transistors have $V_{tp} = -0.5$ V, $\mu C_{ox} = 25 \mu A/V^2$. In small-signal calculations assume a lambda of 0.05 for both types. Assume bipolar transistors have beta of 100 and I_{ES} of 10-15 A (both npn and pnp transistors). In small-signal calculations assume the Early voltage is 20 V. You are to ignore lambda and Early voltage in biasing calculations.

	SCORE
Problem 1 (15 pts.)	
Problem 2 (15 pts.)	
Problem 3 (20 pts.)	
Problem 4 (25 pts.)	
Problem 5 (25 pts.)	
TOTAL (100 pts.)	

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?



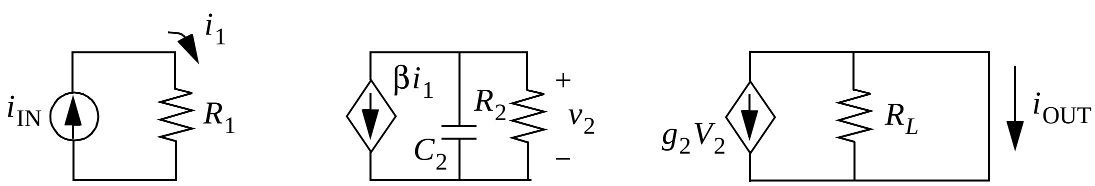
G_m = ____________

R_{in} = ____________

R_{out} = ____________

Problem 2 (15 points)

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



$$\mathbf{A}_1 \equiv \frac{\mathbf{I}_{out}}{\mathbf{I}_{in}} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

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


dB
log ω

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.

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

Problem 3 Worksheet

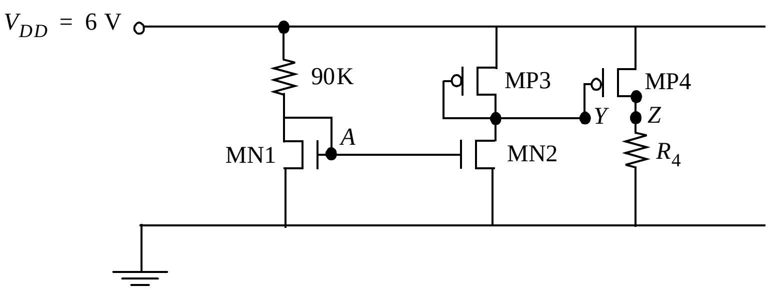
Problem 4   (25 points)

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.



$(W/L)_1$ = ___________

I_{D2} = ___________

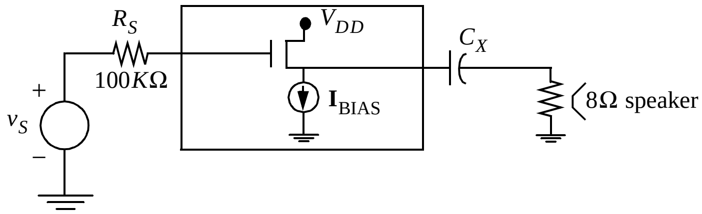
V_Y = ___________

R_4 = ___________

Problem 4 Worksheet

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.

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.

A_M = ____________

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

A_M = ____________

Problem 5 Answer and Worksheet

a.

Small-signal Model

b.

c.

Appendix A:

Appendix B:

Appendix C: Formulas

(EQ 2.7) $$n_o \cdot p_o = n_i^2(T)$$

(EQ 2.34) $$v_{dn} = -\mu_n E$$

(EQ 2.55) $$J_n = J_n^{dr} + J_n^{diff} = qn\mu_n E + qD_n \frac{dn}{dx}$$

(EQ 2.56) $$J_p = J_p^{dr} + J_p^{diff} = qp\mu_p E - qD_p \frac{dp}{dx}$$

(EQ 2.67) $$R = \left(\frac{1}{qN_d \mu_n t}\right)\left(\frac{L}{W}\right) = R_\square \left(\frac{L}{W}\right) = R_\square N_\square$$

(EQ 3.1) $$\frac{dE}{dx} = \frac{\rho}{\varepsilon}$$

(EQ 3.4) $$E(x) = -\frac{d\phi(x)}{dx}$$

(EQ 3.56) $$X_{do} = x_{no} + x_{po} = \sqrt{\left(\frac{2\varepsilon_s \phi_B}{q}\right)\left(\frac{1}{N_a} + \frac{1}{N_d}\right)}$$

(EQ 3.88) $$V_{FB} = -(\phi_{n+} - \phi_p)$$

(EQ 3.89) $$Q_G(V_{GB} = V_{FB}) = 0$$

(EQ 3.95) $$V_{Tn} = V_{FB} - 2\phi_p + \frac{1}{C_{ox}}\sqrt{2q\varepsilon_s N_a(-2\phi_p)}$$

(EQ 4.18) $$V_{DS_{SAT}} = V_{GS} - V_{Tn}$$

(EQ 4.19) $$I_{D_{SAT}} = \left(\frac{W}{2L}\right)\mu_n C_{ox}(V_{GS} - V_{Tn})^2 = \left(\frac{W}{2L}\right)\mu_n C_{ox} V_{DS_{SAT}}^2$$

(EQ 4.59)
$$I_D = 0 \text{ A} \qquad (V_{GS} \le V_{Tn})$$
$$I_D = (W/L)\mu_n C_{ox}[V_{GS} - V_{Tn} - (V_{DS}/2)](1 + \lambda_n V_{DS})V_{DS} \qquad (V_{GS} \ge V_{Tn}, V_{DS} \le V_{GS} - V_{Tn})$$
$$I_{D_{SAT}} = (W/2L)\mu_n C_{ox}(V_{GS} - V_{Tn})^2(1 + \lambda_n V_{DS}) \qquad (V_{GS} \ge V_{Tn}, V_{DS} \ge V_{GS} - V_{Tn})$$

(EQ 4.60) $$V_{Tn} = V_{TOn} + \gamma_n(\sqrt{-V_{BS} - 2\phi_p} - \sqrt{-2\phi_p})$$

(EQ 4.67) $$g_m \cong \left(\frac{W}{L}\right)\mu_n C_{ox}(V_{GS} - V_{Tn}) = \sqrt{2\left(\frac{W}{L}\right)\mu_n C_{ox} I_D}$$

(EQ 6.10) $$\phi_B = V_{th}\ln\left(\frac{p_{po}}{p_{no}}\right) \text{ and } \phi_B = V_{th}\ln\left(\frac{n_{no}}{n_{po}}\right)$$

(EQ 6.22) $$p_n(x_n) = p_{no} \cdot e^{V_D/V_{th}} \text{ and } n_p(-x_p) = n_{po}e^{V_D/V_{th}}$$

(EQ 6.30) $$J = qn_i^2\left(\frac{D_p}{N_dW_n} + \frac{D_n}{N_aW_p}\right)(e^{V_D/V_{th}} - 1)$$

(EQ 6.31) $$I_D = qn_i^2A\left(\frac{D_p}{N_dW_n} + \frac{D_n}{N_aW_p}\right)(e^{V_D/V_{th}} - 1) = I_o(e^{V_D/V_{th}} - 1)$$

(EQ 6.48) $$C_j = \frac{C_{jo}}{\sqrt{1 - V_D/\phi_B}}$$

Appendix D: Values

$q = 1.6 \times 10^{-19}C$

$V_t = kT/q = 0.026 \text{ V}$

$\varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm}$

$\varepsilon_{\text{oxide}} = 3.9\varepsilon_0$

$\varepsilon_{Si} = 11.7\varepsilon_0$

Appendix E: SIA unit multipliers:

$M = 10^6$

$K = 10^3$

$m = 10^{-3}$

$\mu = 10^{-6}$

$n = 10^{-9}$

$p = 10^{-12}$

$f = 10^{-15}$