NAME ______________________________ NETID ____________

MIDTERM EXAM 2 - SOLUTIONS

(Closed book)

ECE 442

April 12, 2007

7:00 p.m. – 8:30 p.m.

Instructions: Write your name, and NetID where indicated. You are allowed to use one formula sheet ($8^{1/2} \times 11$) and a calculator. This examination consists of 4 problems. Each problem is worth 25 points. Show all work in order to receive partial credit.

Problem 1	Problem 2	Problem 3	Problem 4	Total

Formula Sheet

DIODE

$$I_D = I_S(e^{V_D/V_T} - 1)\text{, where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

BIPOLAR (NPN forward active $I_B > 0$, $V_{CE} > V_{CE,sat}$)

$$I_C = I_S e^{V_{BE}/V_T} \cdot \left(1 + \frac{V_{CE}}{V_A}\right) \cong I_S e^{V_{BE}/V_T} \text{ where } V_T = \frac{k_B T}{q} = 26\text{ mV}$$

$$I_C = \alpha I_E$$

$$I_C = \beta I_B \cdot \left(1 + \frac{V_{CE}}{V_A}\right) \cong \beta I_B$$

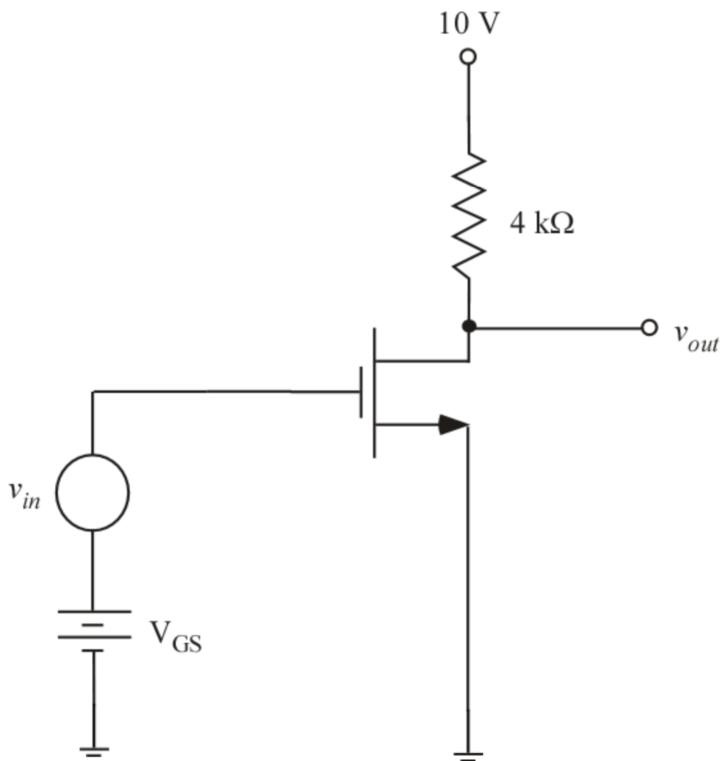
$$\alpha = \frac{\beta}{\beta + 1}$$

MOSFET (long channel model equations)
Define $V_{DSP} = V_{GS} - V_T$, where V_T is the threshold voltage

NMOS	PMOS
Triode Region (Linear) $V_{GS} > V_T$ & $V_{DS} < V_{DSP}$, $I_D = \frac{W}{L} \cdot k' \left((V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right)$	Triode Region (Linear) $V_{GS} < V_T$ & $V_{DS} > V_{DSP}$, $I_D = \frac{W}{L} \cdot k' \left((V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right)$
Active Region (Saturation) $V_{GS} > V_T$ & $V_{DS} \geq V_{DSP}$, $I_D = \frac{W}{L} \cdot \frac{k'}{2} \cdot (V_{GS} - V_T)^2 \cdot [1 + \lambda \cdot V_{DS}]$	Active Region (Saturation) $V_{GS} < V_T$ & $V_{DS} \leq V_{DSP}$, $I_D = \frac{W}{L} \cdot \frac{k'}{2} \cdot (V_{GS} - V_T)^2 \cdot [1 - \lambda \cdot V_{DS}]$
Body Effect $V_T = V_{To} + \gamma \cdot \left(\sqrt{\lvert V_{SB} \rvert + 2\phi_F} - \sqrt{2\phi_F} \right)$ $V_{GS} \leq V_T$, $I_D = 0$	Body Effect $V_T = V_{To} - \gamma \cdot \left(\sqrt{\lvert V_{SB} \rvert + 2\phi_F} - \sqrt{2\phi_F} \right)$ $V_{GS} \geq V_T$, $I_D = 0$

PROBLEM 1 [25 points]

For the amplifier shown $\mu WC_{ox}/2L$ = 3 mA/V^2, λ =0.02/V, and V_T = 1.0 V.



(a) Calculate V_{DSQ} when V_{GSQ} = 1.5 V (15 pts).

$$I_D = \frac{\mu C_{ox} W}{2L}\left(V_{GS}-V_T\right)^2\left[1+\lambda V_{DSQ}\right]$$

$$1+\lambda V_{DSQ} = \frac{I_D}{\frac{k_n W}{2L}\left(V_{GS}-V_T\right)^2}$$

$$V_{DSQ} = \frac{1}{\lambda}\left[\frac{I_D}{\frac{k_n W}{2L}\left(V_{GS}-V_T\right)^2}-1\right] = \frac{1}{0.02}\left[\frac{I_D}{3\left(1.5-1\right)^2}-1\right] = 66I_D - 50$$

$$V_{DSQ} = V_{DD} - R_D I_D = 10 - 4I_D$$

PROBLEM 1 (continued)

$$66I_D - 50 = 10 - 4I_D$$

$$70I_D = 60$$

$$I_D = 6/7 = 0.857\ mA$$

$$V_{DSQ} = V_{DD} - R_D I_D = 10 - 4 \times 0.857 = 6.57\ V$$

(b) Calculate the midband voltage gain for the stage (10 pts).

$$r_{ds} = \frac{1}{\lambda \frac{k_n W}{2L}\left(V_{GS} - V_T\right)^2} = \frac{1}{0.02 \times 3 \times 0.25} = 66.66\ \text{k}\Omega$$

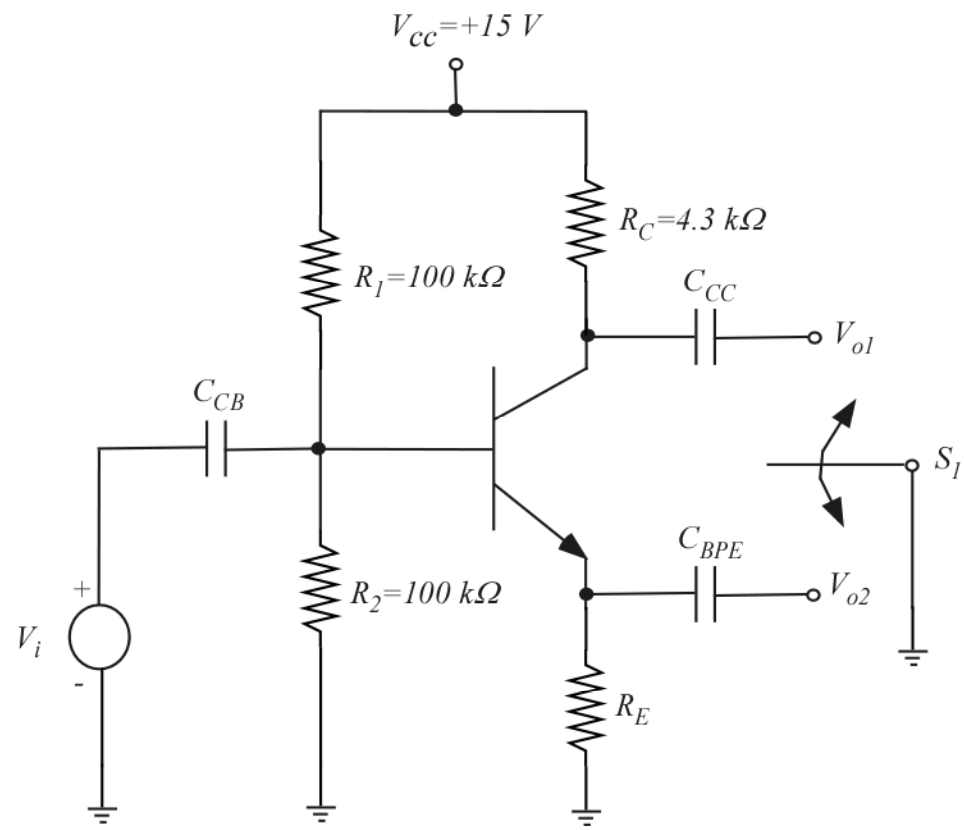
$$R_L = R_D \,||\, r_{ds} = 4 \,||\, 66.66 = 3.77\ \text{k}\Omega$$

$$g_m = \sqrt{4\frac{k_n W}{2L} I_D} = \sqrt{4 \times 3 \times 0.857} = 3.20\ \text{mA/V}$$

$$A_{MB} = -g_m R_L = -3.20 \times 3.77 = -12.07\ \text{V/V}$$

PROBLEM 2 [25 points]

For the circuit shown, assume that β is very large. Also C_μ = 1 pF and ω_T = 5 GHz. It is desired to have a dc collector current of 1 mA. Use V_{BEON} = 0.7 V and assume that all coupling and bypass capacitors are midband short circuits.



(a) Determine the proper value for R_E

$$V_B \simeq \frac{V_{CC}}{2} = 7.5V$$

$$V_E = V_B - 0.7 = 6.8V$$

PROBLEM 2 (continued)

$$I_C \approx I_E = 1\,mA$$

$$R_E = \frac{V_E}{I_E} = \frac{6.8}{1} = 6.8\,k\Omega$$

R_E = ____6.8 kΩ__________

(b) The switch S_1 is set in the off position (as shown in the figure) and the output is collected at V_{o1}. What is the midband voltage gain?

This is a common-emitter configuration with external emitter resistance.

$$r_e = \frac{V_T}{I_E} = \frac{25}{1} = 25\Omega$$

The midband gain is:

$$A_{MB} = \frac{-\beta R_C}{R_E(\beta+1) + r_e(\beta+1)} = \frac{-\alpha R_C}{R_E + r_e} = \frac{-4.3}{6.8 + 0.025} = -0.63$$

A_{MB} = ____-0.63__________

(c) The switch S_1 is now connected to V_{o1} and the output is collected at V_{o2}. What is the midband voltage gain?

This is the emitter follower configuration. The midband gain is:

$$A_{MB} = \frac{R_E}{R_E + r_e} = \frac{6.8}{6.8 + 0.025} = 0.996$$

A_{MB} = __0.996____________

PROBLEM 2 (continued)

(d) Next, the switch S_1 is connected to V_{o2} and the output is collected at V_{o1}. What is the midband voltage gain?

This is the standard common-emitter configuration. The transconductance is:

$$g_m = \frac{I_C}{V_T} = \frac{1}{25} = 40mA/V$$

The midband gain is:

$$A_{MB} = -g_m R_C = -40 \times 4.3 = -172$$

A_{MB} = _____-172_________

(e) Determine the upper 3dB corner frequency for the common-emitter configuration of this amplifier.

We have:

$$f_{3dB} = \frac{1}{2\pi R_{in} C_{in}}$$

First, we must calculate C_{in}

$$C_\pi + C_\mu = \frac{g_m}{\omega_T} \Rightarrow C_\pi = \frac{g_m}{\omega_T} - C_\mu = \frac{40 \times 10^{-3}}{5 \times 10^{+9}} - 1 = 7\,pF$$

$$C_{in} = C_\pi + C_\mu (1 + g_m R_C) = 7 + 173 = 180\,pF$$

Next, we must calculate R_{in} which is the resistance seen in parallel with C_{in}.

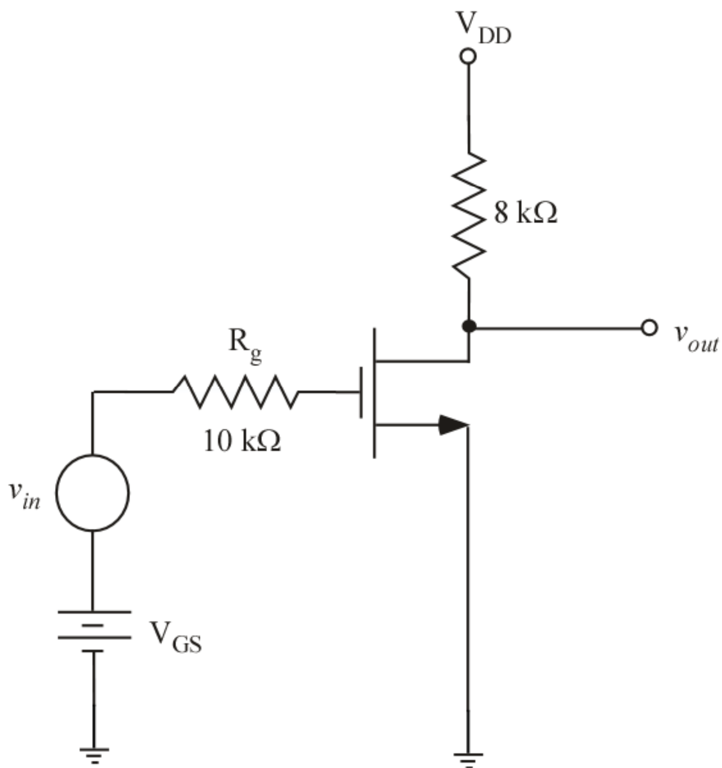
$$R_{in} = r_\pi \,||\, \left(r_x + R_1 \,||\, R_2 \right) ||\, R_g$$

Since R_g (internal generator impedance) is 0 (not given), $f_{3dB} = \frac{1}{2\pi R_{in} C_{in}} = \infty$ or undetermined

f_{3dB} = __undetermined______

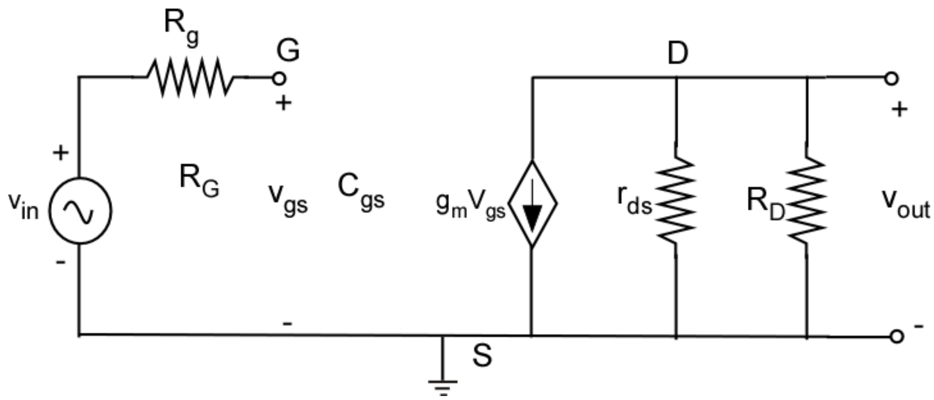
PROBLEM 3 [25 points]

Consider the MOSFET circuit shown below, with g_m=3 mA/V and r_{ds}=63 kΩ. Assume that C_{gs}=1 pF and C_{gd}=0.1 pF.



(a) Draw the midband equivalent circuit

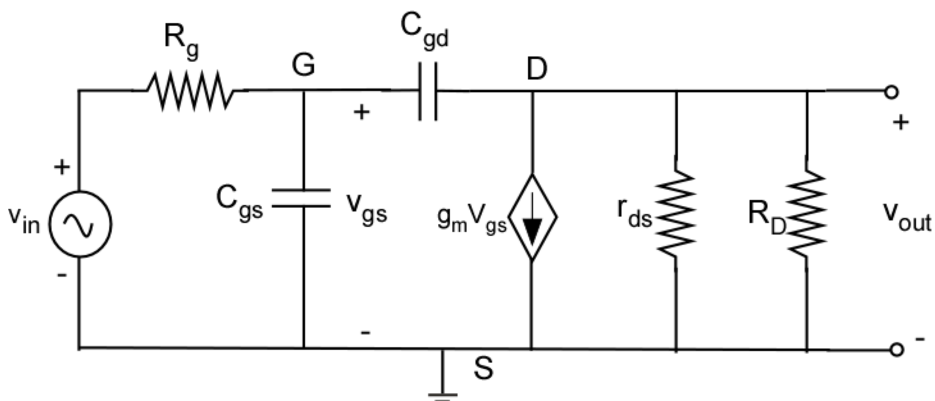
PROBLEM 3 (continued)



(b) Calculate the midband voltage gain

$$A_{MB} = -g_m\left(r_{ds} \parallel R_D\right) = -3\times 7.1 = -21.3\, V/V$$

(c) Draw the high-frequency equivalent circuit



PROBLEM 3 (continued)

(d) Calculate the upper corner frequency

Calculate the Miller capacitance:

$$C_M = \left(1 + \left|A_{gd}\right|\right) C_{gd} = 22.3 \times 0.1 = 2.23\ pF$$

from which we get:

$$f_{inh} = \frac{1}{2\pi R_g \left(C_{gs} + C_M\right)} = \frac{1}{2\pi \times 10^{+4} \times 3.23 \times 10^{-12}} = 4.93\ MHz$$

The upper corner frequency due to the output loop is approximately

$$f_{outh} = \frac{1}{2\pi C_{gs} \left(r_{ds} \parallel R_D\right)} = \frac{1}{2\pi \times 10^{-13} \times 7{,}100} = 224\ MHz$$

Since f_{outh} is much greater than f_{inh}, the upper corner frequency is:

$$f_{high} = f_{inh} = 4.93\ MHz$$

(e) Calculate the unity current-gain frequency point f_T

$$f_T = \frac{g_m}{2\pi \left(C_{gs} + C_{gd}\right)} = \frac{3 \times 10^{-3}}{2\pi \times (1 + 0.1) \times 10^{-12}} = 434\ MHz$$

PROBLEM 4 [25 points]

For the opamp circuit shown, determine the values of:

(a) $v_1 \Rightarrow v_1 = 0$ since it is a virtual ground

(b) $i_1 \Rightarrow i_1 = \frac{1V - v_1}{1k\Omega} = \frac{1-0}{1} = 1 \text{ mA}$

(c) $i_2 \Rightarrow i_1 = i_2 = 1 \text{ mA}$

(d) $v_o \Rightarrow v_o = v_1 - R_2 i_2 = 0 - 10 \times 1 = -10 \text{ V}$

(e) $i_L \Rightarrow i_L = \frac{v_o}{1k\Omega} = -10 \text{ mA}$

(f) $i_o \Rightarrow i_o = i_L - i_2 = -10 \ -1 = -11 \text{ mA}$