

# ECE 3040 Microelectronic Circuits

*Exam 3*

*April 22, 2011*

*Dr. W. Alan Doolittle*

Print your name clearly and largely:

*Solutions*

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**Instructions:**

**DO NOT TAKE APART ANY PAGES OF THIS EXAM AND SHOW ALL WORK ON THE PROVIDED PAGES.** Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your two note sheets from the previous exams as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. **SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED.** Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

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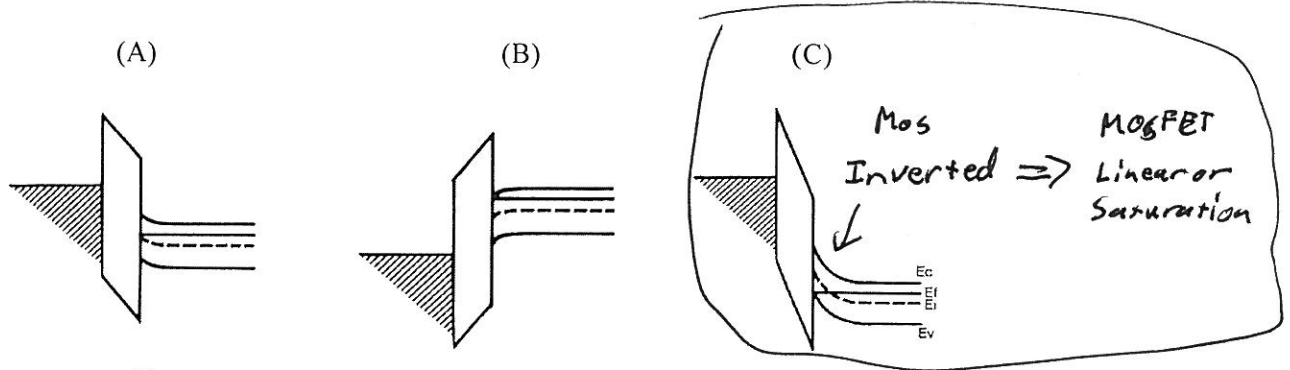
I DID NOT observe any ethical violations during this exam:

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I observed an ethical violation during this exam:

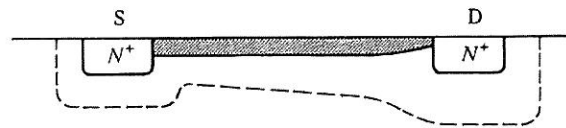
**First 24% Multiple Choice and True/False (Select the most correct answer)**

1.) (3-points total) Select the bias mode of the following MOS capacitor which could be used in a MOSFET biased in Saturation.

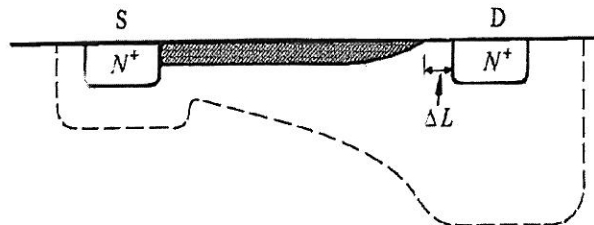


2.) (3-points) True / False: An enhancement mode MOSFET transistor has two competing electric fields – the Gate field is responsible for creating the channel while the drain’s electric field attempts to extract carriers from the channel.

3.) (3-points) True / False: The transistor to the right is biased in the linear/triode region and at low drain voltages the source-drain circuit acts like a resistor.



4.) (3-points) True / False: In the MOSFET transistor to the right, the source and drain have been inverted (converted to p-type) to allow channel current to flow.



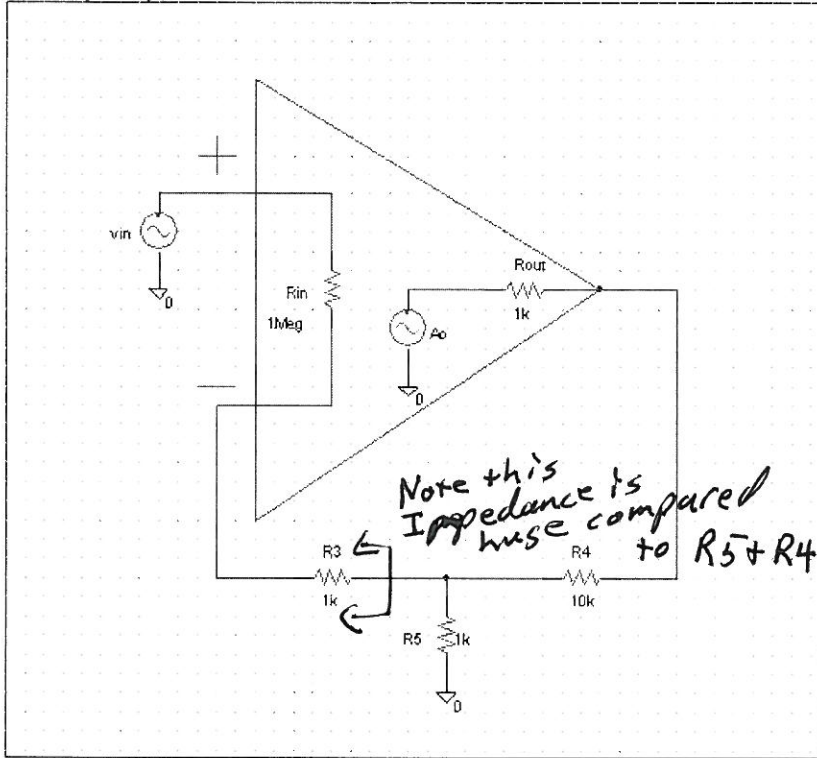
5.) (3-points) True / False: In the MOSFET from problem 4, since the channel is pinched off there is no current and thus the MOSFET is in cutoff.

6.) (3-points) True / False: A well designed current amplifier should have a very high output resistance.

7.) (3-points) True / False: While negative feedback is generally needed for an opamp to have stable amplification, POSITIVE feedback can be used to create an oscillator.

8.) (3-points) True / False: Since in a NMOS transistor, the source “sources electrons”, the source actually sinks (accepts) current coming from the drain.

9.) (26-points) For the non-ideal opamp below, the input resistance is 1 Megaohm, the output resistance is 1 K ohm and the open loop gain,  $A_o$ , is 40 dB at DC and has a gain bandwidth product (defined by a single pole) of 5 Hz. When used in the circuit below (with feedback as shown), determine the closed loop input and output resistance and sketch and label the Bode plot showing the voltage gain in all flat regions and the break frequencies (gain in dB vs Log of Frequency).



Open loop  
 DC gain = 40 dB  
 = 100 V/V

$$A_o = \frac{100}{\left(1 + \frac{5}{2\pi 5 \text{ Hz}}\right)}$$

↑  
 $\omega_B = 31.41 \text{ rad/s}$

$$= \frac{100}{1 + 0.5}$$

$L \rightarrow z = 0.05183$

$$\beta = \frac{R_5}{R_5 + R_4} = \frac{1}{11} = 0.09$$

$$(1 + \beta A_o) = \left(1 + \frac{1}{11} \frac{100}{\left(1 + \frac{5}{2\pi 5 \text{ Hz}}\right)}\right)$$

$$= 1 + \frac{(100/11)}{1 + 5/\omega_B} = 1 + 9.09 \frac{1}{(1 + 5/\omega_B)}$$

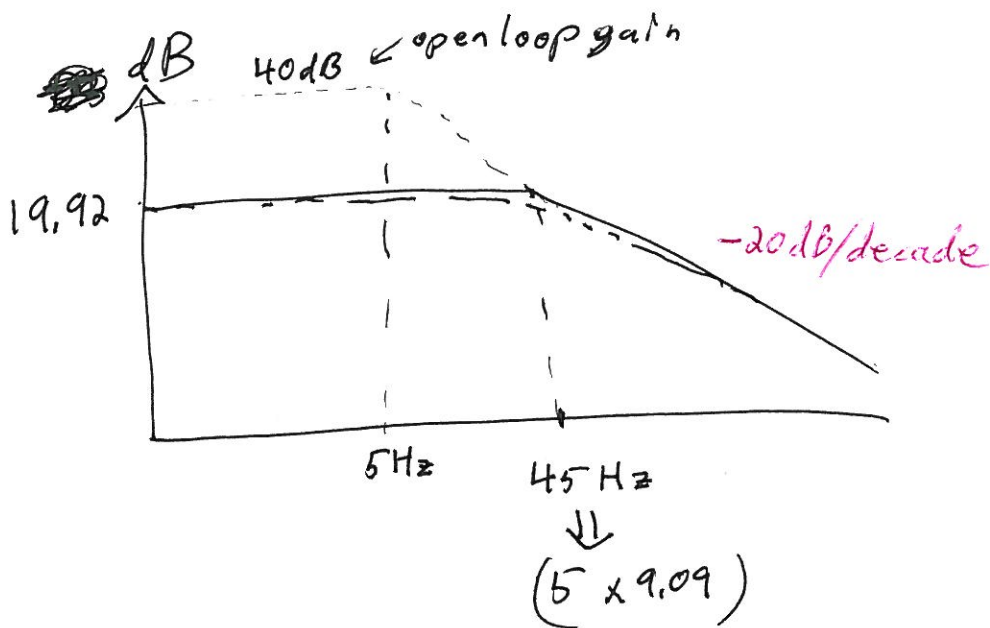
$$R_{in \text{ closed loop}} = 1 \text{ Meg} \left(1 + \frac{100/11}{1 + 5/\omega_B}\right) = 10.09 \text{ Meg} @ \text{DC}$$

$$R_{out \text{ closed loop}} = \frac{1 \text{ k}}{\left(1 + \frac{100/11}{1 + 5/\omega_B}\right)} = 99.09 \Omega @ \text{DC}$$

$$A_{v \text{ closed loop}} = \frac{100}{1 + 5/\omega_B} \cdot \frac{1}{1 + \beta A_{open}} = \frac{100}{1 + \frac{5}{\omega_B} + 100/11}$$

Extra work can be done here, but clearly indicate with problem you are solving.

$$\begin{aligned}
 &= \frac{100}{\frac{111}{h} + \frac{s}{\omega_B}} \\
 &= \frac{100}{\frac{111}{11} \left(1 + \frac{11s}{100\omega_B}\right)} \\
 &= \frac{1100}{111} \left(\frac{1}{1 + \frac{s}{\omega_B \frac{100}{11}}}\right) \\
 &= 9.909 \left(\frac{1}{1 + \frac{s}{(2\pi 5\text{Hz}) 9.09}}\right)
 \end{aligned}$$

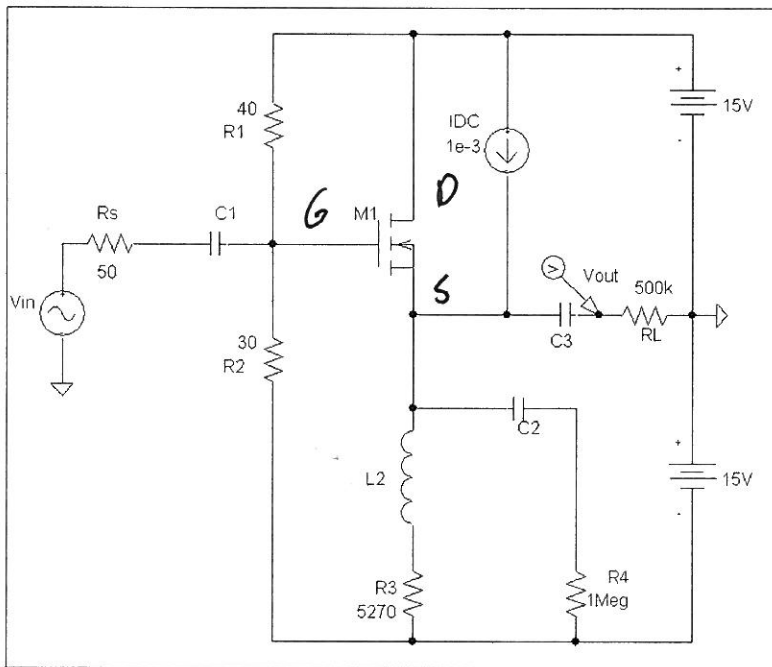


Note: I did not ask for the open loop gain.

Pulling all the concepts together for a useful purpose:

**10) (50-points)** Given the following Clemson designed Radio Frequency amplifier circuit, (a) Identify the configuration of the stage (common \_\_\_\_). (b) What is the AC voltage gain,  $v_{out}/v_{in}$ ? You may assume all capacitors have infinite capacitance and all inductors have infinite inductance. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances.

Grading will be based as such: part a=5 points, part b=18 points for DC solution (gate, source and drain voltages along with drain currents), 12 points for the conversion to the small signal model and 15 points for small signal analysis. **SHOW ALL WORK TO GET CREDIT!!!!**



a) Common Drain

Use the following parameters (note that  $K$ ,  $V_T$  and  $\lambda$  vary with transistor type):

For NMOS Depletion Transistors:

$$K_n' = 20 \mu\text{A}/\text{V}^2 \quad V_T = -4.0\text{V} \quad \lambda = 0.15 \text{V}^{-1} \quad \text{Length (L)} = 0.18 \mu\text{m} \quad \text{Width (W)} = 10 \mu\text{m}$$

For NMOS Enhancement Transistors:

$$K_n' = 30 \mu\text{A}/\text{V}^2 \quad V_T = +1.5\text{V} \quad \lambda = 0.0 \text{V}^{-1} \quad \text{Length (L)} = 0.18 \mu\text{m} \quad \text{Width (W)} = 18 \mu\text{m}$$

For PMOS Depletion Transistors:

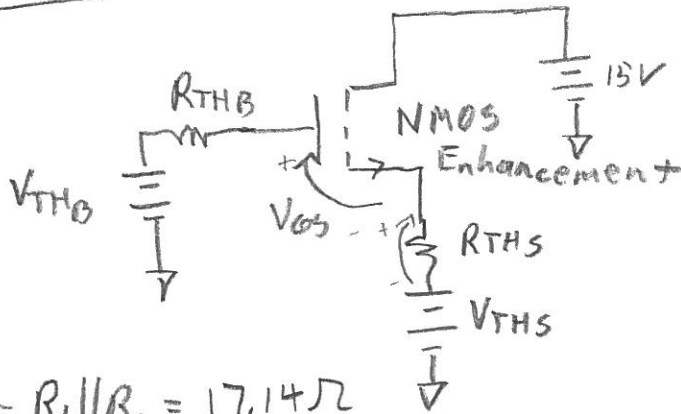
$$K_p' = 40 \mu\text{A}/\text{V}^2 \quad V_T = +3.0\text{V} \quad \lambda = 0.0 \text{V}^{-1} \quad \text{Length (L)} = 0.36 \mu\text{m} \quad \text{Width (W)} = 10 \mu\text{m}$$

For PMOS Enhancement Transistors:

$$K_p' = 50 \mu\text{A}/\text{V}^2 \quad V_T = -0.75\text{V} \quad \lambda = 0.1 \text{V}^{-1} \quad \text{Length (L)} = 0.36 \mu\text{m} \quad \text{Width (W)} = 5 \mu\text{m}$$

Extra work can be done here, but clearly indicate with problem you are solving.

DC:



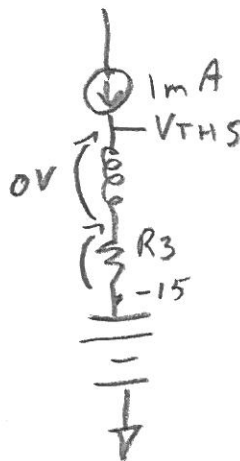
$$R_{THB} = R_1 || R_2 = 17.14 \Omega$$

$$V_{THB} = 15 \left( \frac{30}{30+40} \right) - 15 \left( \frac{40}{30+40} \right) = -2.1428 \text{ V}$$

Used superposition

$$R_{THS} = 5270 \Omega$$

$V_{THS}$ :



$$V_{THS} = -15 + R_3(1\text{mA}) = -9.73 \text{ V}$$

Don't Forget

Assume Linear:

$$I_{DS} = \frac{\mu_n}{2} \left( \frac{W}{L} \right) (V_{GS} - V_T)^2$$

$$I_{DS} = \frac{1}{2} (30e-6) (100) (V_{GS} - 1.5)^2$$

and

$$V_{TAB} = V_{THS} + I_{DS} R_{THS} + V_{GS}$$

Extra work can be done here, but clearly indicate with problem you are solving.

$$V_{THS} + I_{DS} R_{THS} + V_{GS} = V_{THB}$$

$$I_{DS} = \frac{V_{THB} - V_{GS} - V_{THS}}{R_{THS}}$$

$$= \frac{-2.1428 - (-9.73) - V_{GS}}{5270}$$

$$\rightarrow = \frac{+7.587 - V_{GS}}{5270} = 0.00144 - 0.00019V_{GS}$$

$$\therefore I_{DS} = 0.00144 - 0.00019V_{DS} = (1.5e-3)(V_{GS}^2 - 3V_{GS} - 2.25)$$

$$0 = 1.5e-3 V_{GS}^2 - 0.00431 V_{GS} - 0.00481$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$I_{DS} = 1mA$$

$$\rightarrow V_{GS} = 2.316 V \text{ or } 0.5569 V < V_{TH} = 1.5V$$

$$15V = V_{DS} + I_{DS} R_{THS} + V_{THS}$$

$$= V_{DS} + 1mA (5270) - 9.73V$$

$$V_{DS} = 19.46 V$$

$$19.46 = V_{DS} > V_{GS} - V_T = 2.316 - 1.5 = 0.816 V$$

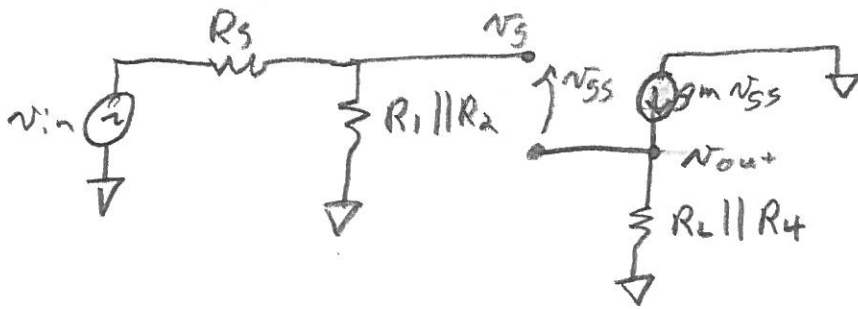
Assumption Verified

Extra work can be done here, but clearly indicate with problem you are solving.

$$g_m = \frac{I_{D5}}{\left(\frac{V_{GS} - V_{TH}}{2}\right)} \quad r_o = \frac{I_{D5}}{\frac{1}{\lambda} + V_{DS}}$$

$$= \frac{1 \text{ mA}}{\frac{0.816}{2}} \quad = \frac{1}{\frac{1}{0} + \dots} = \infty$$

$$g_m = 0.002451 \text{ S}$$



$$\textcircled{1} \quad \frac{v_s}{v_{in}} = \frac{R_1 \parallel R_2}{R_s + R_1 \parallel R_2}$$

$$\textcircled{2} \quad v_s = v_{ss} + v_{out}$$

$$= v_{ss} + g_m v_{ss} (R_L \parallel R_4)$$

$$\textcircled{3} \quad \frac{v_{out}}{v_{ss}} = -g_m (R_L \parallel R_4)$$

$$A_v = \left(\frac{v_s}{v_{in}}\right) \left(\frac{v_{ss}}{v_s}\right) \left(\frac{v_{out}}{v_{ss}}\right)$$

$$= \left(\frac{R_1 \parallel R_2}{R_s + R_1 \parallel R_2}\right) \left(\frac{1}{1 + g_m (R_L \parallel R_4)}\right) \left(g_m (R_L \parallel R_4)\right)$$

$$= \left(\frac{17.14}{50 + 17.14}\right) \left(\frac{1}{1 + 0.002451 (333 \text{ k})}\right) 0.002451 (333 \text{ k})$$

$$A_v = 0.255 \text{ V/V}$$