ECE 3040 Microelectronic Circuits

Exam 3

November 27, 2023

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Print your name clearly and largely: Solution

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!

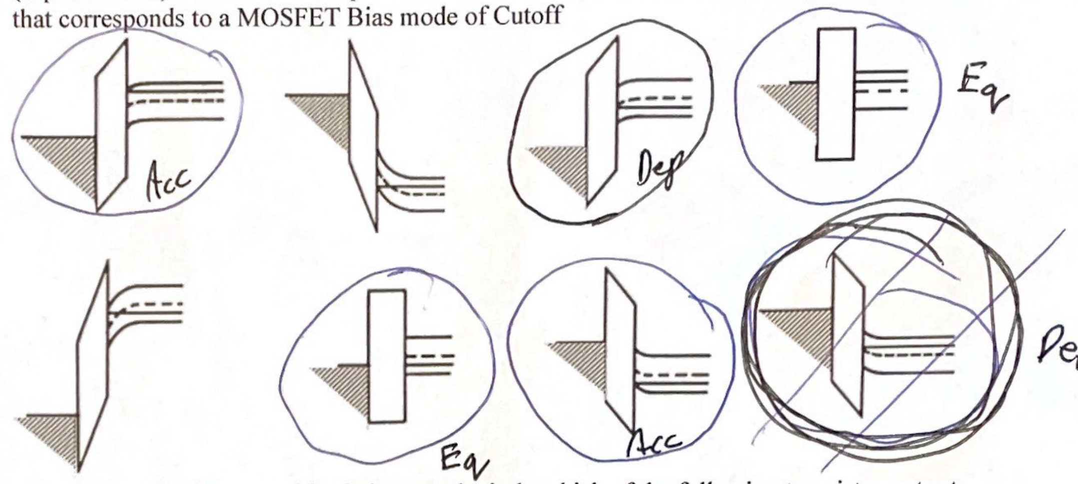
Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

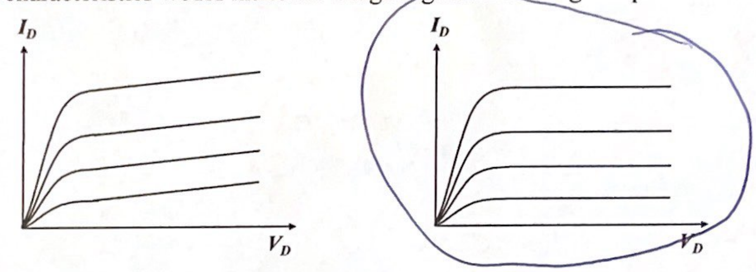
I observed an ethical violation during this exam:

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

1.) (6-points total) For the MOS Capacitors shown below, Circle the correct capacitor bias mode that corresponds to a MOSFET Bias mode of Cutoff



2.) (3-points): All other quantities being equal, circle which of the following transistor output characteristics would make for a higher gain in a voltage amplifier.



$r_o \to \infty$

3.) (3-points) True / False: When a MOSFET channel is "pinched-off", regardless of the length of the channel or the magnitude of the drain voltage V_{DS}, the end of the channel is at V_{DSAT}.

4.) (3-points) True / False: A PMOS enhancement mode transistor has a p-type drain.

5.) (3-points) True / False: A well designed current amplifier should have a very high input resistance.

6.) (3-points) True/False: A Common Drain amplifier has a high but positive gain.

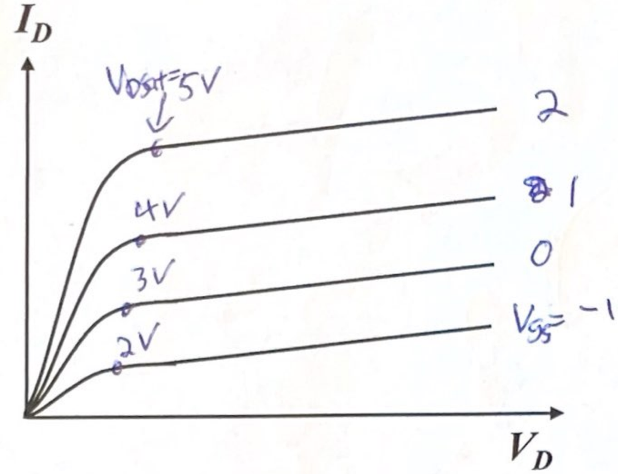
7.) (3-points) True/False: In a saturated MOSFET because the channel is pinched off, the carriers reaching the pinch off region accumulate because they have nowhere else they can move to.

no small signal model for a switch. Small signal model is only for saturation

8.) (3-points) True/False: The full SPICE small signal model of a MOSFET predicts a loss of gain at higher frequencies when using the transistor as a switch in the on (conducting) state.

9.) (3-points) True/False: The depletion region surrounding a saturated MOSFET provides a degree of electrical isolation when multiple MOSFETs are used in an integrated circuit.

10.)(20-points Total) To acquire the depletion mode NMOS MOSFET transistor characteristics shown below, the gate voltage is stepped in 1 V steps from -1 to 2 V. The threshold voltage is -3V.



$V_{Dsat} = V_{GS} - V_{TH}$

a) (5-points) On the graph above, identify the location and numerically label the four values of V_{DSAT} .

b) (5-points) Determine what the numeric value of the voltage is ACROSS the pinch off region for the largest V_{GS} and a V_{DS} of 10 V.

For $V_{GS} = 2V$, $V_{Dsat} = 5V$

$$\boxed{V_D - V_{Dsat} = 10 - 5V = 5V}$$

c) (5-points) Describe what the slope of the linear region represents for a switch.

$R_{on} = \frac{V_D}{I_D}$

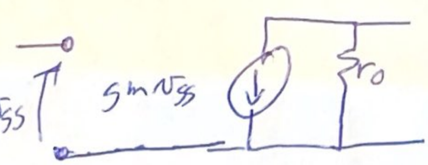
Conduction Resistance of the switch

d) (5-points) Describe what the slope of the saturation region represents for the small signal model used in an amplifier.

Slope $\xrightarrow{1/slope}$ r_{out}

$\downarrow$

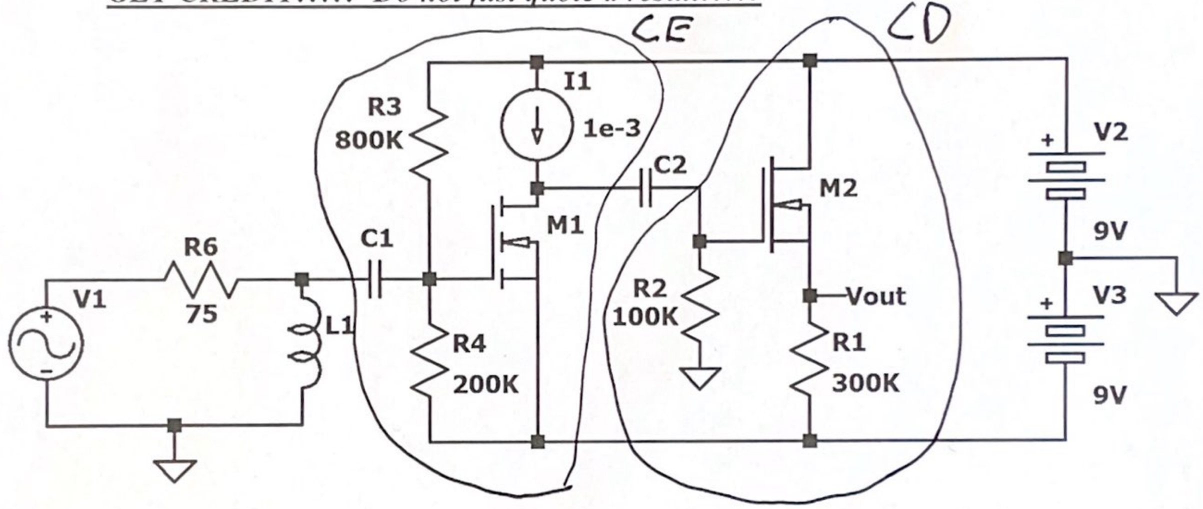
$\lambda \xrightarrow{1/\lambda}$



Pulling all the concepts together for a useful purpose:

<u>*11) (50-points)*</u> Given the following 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. ***<u>SHOW ALL WORK TO GET CREDIT!!!!! Do not just quote a result!!!!!</u>***



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

M2: For NMOS Depletion Transistors:
K_n'=15 uA/V^2 V_T= -2.0V λ=0.0 V^{-1} Length (L)=10 um Width (W)=10 um

M1: **For NMOS Enhancement Transistors:**
K_n'=12.5 uA/V^2 V_T= +1.0V λ=0.1 V^{-1} Length (L)=1 um Width (W)=10 um

For PMOS Depletion Transistors:
K_p'=40 uA/V^2 V_T= +3.0V λ=0.0 V^{-1} Length (L)=10 um Width (W)=10 um

For PMOS Enhancement Transistors:
K_p'=5 uA/V^2 V_T= -1.75V λ=0.1 V^{-1} Length (L)=1 um Width (W)=10 um

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

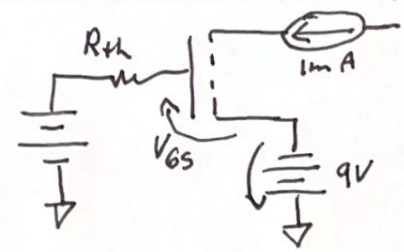
DC Solution

M1:

↑

Enhancement

$V_{th} = +1V$



.... Does not matter

$$V_{th} = 9\left(\frac{200K}{200K+900K}\right) - 9\left(\frac{800K}{800K+200K}\right)$$

$V_{th} = -5.4V$

$R_{th} \rightarrow$ Does not matter since no I_G flows but ....

$R_{th} = 75 \| 800K \| 200K \cong 75\Omega$

$\boxed{V_{GS}} = V_G - V_S = -5.4 - (-9)V = \boxed{3.6V}$

↳ $V_{TH} = 1V$, M1 is on!

$$\boxed{I_{DS} = 1mA} \left(\frac{10um}{1um}\right)\left(\frac{12.5uA/V^2}{2}\right)(\underset{V_{GS}}{3.6} - \underset{V_{th}}{1})^2(1 + \underset{\lambda}{0.1}V_{DS})$$

$\boxed{V_{DS} = 13.7V}$

Check saturation:

$V_{DS} > V_{GS} - V_{TH}$

$13.7 > 3.6 - 1$

$13.7 > 2.6$ ✓

M2: $V_G = 0V$ $V_D = 9V$ $V_S = -9 + R_1 I_{DS}$

$V_{th} = -2V$

Depletion

$$* \; I_{DS} = \left(\frac{10um}{10um}\right)\left(\frac{15e{-6}\ A/V^2}{2}\right)(V_{GS} - V_T)^2(1 + \lambda V_{DS})$$

$\lambda \to \varnothing$

$V_{GS} = 0V - (-9 + R_1 I_{DS}) = 9 - R_1 I_{DS}$ we could substitute this in * for V_{GS} but instead...

$I_{DS} = \dfrac{9 - V_{GS}}{R_1}$ Substitute this into *

$$\frac{9 - V_{GS}}{R_1} = (7.5e{-6}\ A/V^2)(V_{GS}^2 - 2V_{GS}V_{th} + V_{th}^2)$$

$$0 = 7.5e{-6}\, V_{GS}^2 + \left(\frac{1}{R_1} - (7.5e{-6})(2)V_{th}\right)V_{GS} + \left((7.5e{-6})V_t^2 - \frac{9}{R_1}\right)$$

$0 = 7.5e{-6}\, V_{GS}^2 + 3.33e{-5}\, V_{GS} + 0$

$V_{GS}((7.5e{-6})V_{GS} - (3.33e{-5})) = 0$

$\boxed{V_{GS} = 0}$ or $V_{GS} = -4.44V$ ← M2 would be cutoff

$\boxed{I_{DS}}$ from $* = \dfrac{15e{-6}}{2}(0 - 2)^2 = \boxed{30uA}$

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

DC: Continued: $V_{DS} = 9-(-9+30\mu A(300K))$

$$\boxed{V_{DS} = 9V}$$

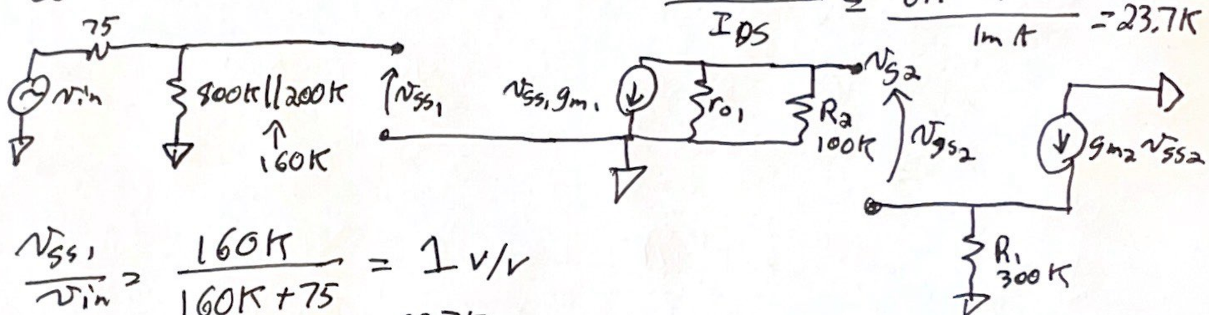
Check saturation:

$$V_{DS} > V_{GS} - V_{Tn}$$
$$9 > 0-(-2)$$
$$9 > 2$$

Conversion to small signal model:

$$g_{m2} = \frac{2I_{DS_2}}{V_{GS_2}-V_{T_2}} = \frac{2(30\mu A)}{0-(-2)} = 30e\text{-}5\ \mho \qquad g_{m1} = \frac{2I_{DS_1}}{V_{GS_1}-V_{T_1}} = \frac{2mA}{3.6-1} = 0.000769\ \mho$$

$$r_{o2} = \infty \qquad r_{o1} = \frac{1/\lambda + V_{DS}}{I_{DS}} = \frac{\frac{1}{0.1}+13.7V}{1mA} = 23.7K$$



1) $\dfrac{v_{gs1}}{v_{in}} = \dfrac{160K}{160K+75} = 1\ V/V$

2) $\dfrac{v_{g2}}{v_{gs1}} = -g_{m1}(\overset{23.7K}{r_{o1}}\|100K) = -14.7\ V/V$

3) $v_{g2} = v_{gs2} + R_1 g_{m2} v_{gs2} = v_{gs2}(1 + \overset{300K}{R_1}\,\overset{30\mu\mho}{g_{m2}})$

$$\frac{v_{gs2}}{v_{g2}} = \frac{1}{1+(300K)3e\text{-}5} = 0.1$$

4) $\dfrac{v_{out}}{v_{gs2}} = g_{m2} R_1 = 9\ V/V$

$$\frac{v_{out}}{v_{in}} = \underbrace{\left(\frac{v_{gs1}}{v_{in}}\right)}_{1}\underbrace{\left(\frac{v_{g2}}{v_{gs1}}\right)}_{2}\underbrace{\left(\frac{v_{gs2}}{v_{g2}}\right)}_{3}\underbrace{\left(\frac{v_{out}}{v_{gs2}}\right)}_{4}$$

$$\boxed{\frac{v_{out}}{v_{in}} = -13.3\ V/V}$$