ECE 3040 Microelectronic Circuits

Exam 3

November 22, 2015

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Print your name clearly and largely:

Solutions

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:

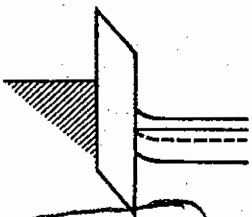
I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

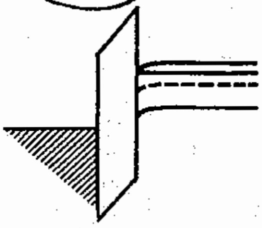
First 24% **Multiple Choice and True/False (Select the most correct answer)**

1.) (6-points total) For each MOS Capacitor, Circle the correct capacitor bias mode and what corresponding MOSFET Bias mode(s) could result

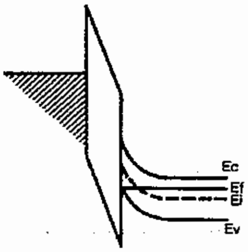
(A) Capacitor: Accumulation, [✓ Depletion], Inversion
MOSFET: [✓ Cutoff], Linear/triode, Saturation



(B) Capacitor: [✓ Accumulation], Depletion, Inversion
MOSFET: [✓ Cutoff], Linear/triode, Saturation



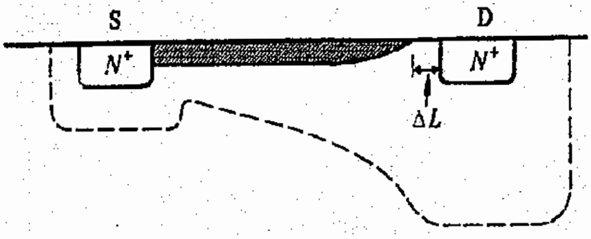
(C) Capacitor: Accumulation, Depletion, [✓ Inversion]
MOSFET: Cutoff, [✓ Linear/triode], [✓ Saturation]



2.) (3-points) True / [✓ False:] A MOSFET amplifier should be biased into linear/Triode mode.

3.) (3-points) True / [✓ False:] When a MOSFET channel is "pinched-off" the transistor is biased into linear/Triode mode.

4.) (3-points) [✓ True] / False: In the MOSFET transistor to the right, the voltage at the end of the channel (where the pinch off region begins) is always V_{DSAT}



5.) (3-points) [✓ True] / False: For a typical foundry process where you do not have control of the oxide thickness, your primary method of increasing the current of a MOSFET is to increase the W/L ratio.

6.) (3-points) [✓ True]/False: Modern MOSFETS sometimes use an oxide with a higher dielectric constant than SiO_2 has.

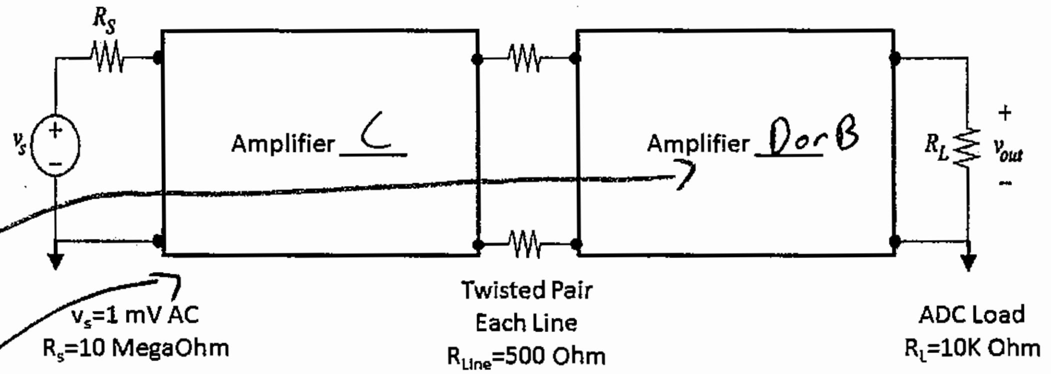
7.) (3-points) True/[✓ False:] Depletion mode MOSFETs cannot conduct drain current unless there is a gate voltage that creates the channel.

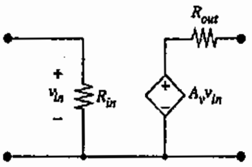
8.) (26-points) You work for a factory that needs to interface a chemical pH sensor with an analog to digital convertor (ADC) at a computer located ½ mile from the sensor. The sensor is connected to the ADC by a twisted pair wire. You must select an amplifier to use at the sensor and another one at the ADC. Using the sensor, twisted pair and ADC configurations below, ***select any two of amplifiers (A, B, C or D)*** from the 4 available below to insert in the two Amplifier boxes below which would result in the highest voltage signal at the ADC.

Part a (10 points) - Write the letter of your amplifier selection in the blanks in the amplifier boxes below.

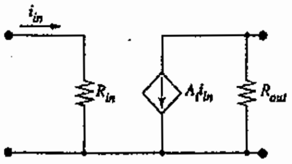
Part b (6 points) - Should a voltage or a current signal be transmitted along the twisted pair wires? Why? Prefer a current transmission to drive a twisted pair so that voltage drop in the lines is not a concern.

Part c (10 points) - What is the voltage of the signal v_{out} ? 89.1 mV or 886.8V

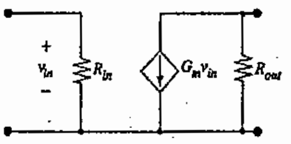




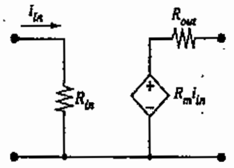
(Amplifier A)
A_v= 100 V/V
R_{in}=1K Ω
R_{out}=10K Ω



(Amplifier B)
A_i= 100 A/A
R_{in}=500 Ω
R_{out}=100K Ω



(Amplifier C)
G_m= 100 A/V
R_{in}=100 KΩ
R_{out}=100K Ω

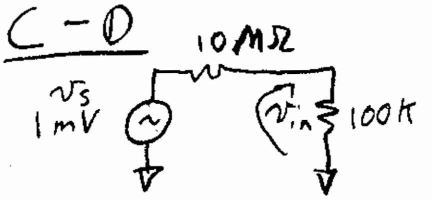


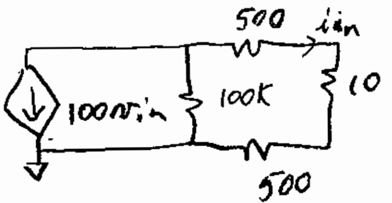
(Amplifier D)
R_m= 100 V/A
R_{in}=10 Ω
R_{out}=1K Ω

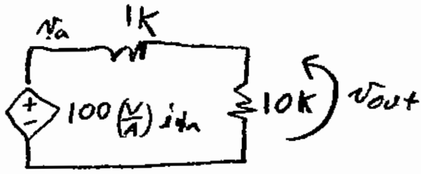
Input impedance: Want High input impedance due to high source Current output (see b above) ⟹ C

Output: Converts a current input to a voltage out ⟹ D or B

C − D





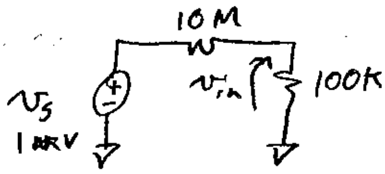


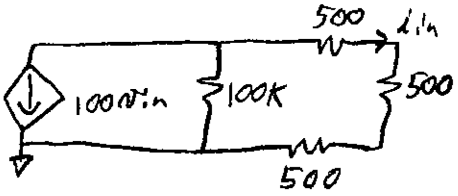
$$\frac{v_{out}}{v_s} = \left(\frac{v_{in}}{v_s}\right)\left(\frac{i_{in}}{v_{in}}\right)\left(\frac{v_a}{i_{in}}\right)\left(\frac{v_{out}}{v_a}\right) = \left(\frac{100K}{10M+100K}\right)\left(100 \frac{100K}{100K+1010}\right)(100)\left(\frac{10K}{10K+1}\right.$$

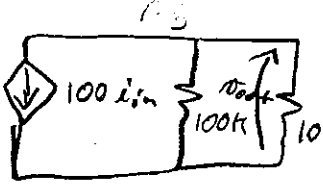
$= 89.1$ V/V

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

C - B solution (highest voltage)







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

$$= \left(\frac{100k}{10M + 100K}\right)\left(100\left(\frac{100k}{100K + 1.5K}\right)\right)\left(100\left(10K \| 100K\right)\right)$$

$$= (0.0099)(98.522)(909,090)$$

$$= 886,786.67 \text{ V/V}$$

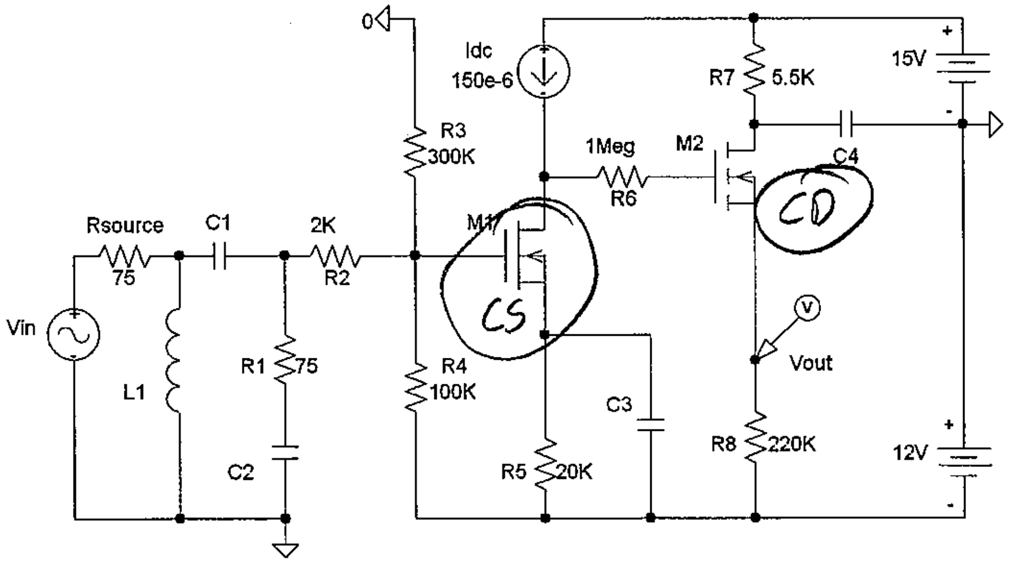
$$v_{out} = 1mV\left(\frac{v_{out}}{v_s}\right)$$

$$v_{out} = 886.8 V$$

Pulling all the concepts together for a useful purpose:

__*10) (50-points)*__ Given the following amplifier circuit, (a) Identify the configuration of each stage (example - 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!!!!!*__



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

For NMOS Depletion Transistors:
K_n'=1 uA/V^2 **V_T= -1.0V** **λ=0.1 V^{-1}** Length (L)=1 um Width (W)=100 um

For NMOS Enhancement Transistors:
K_n'=50 uA/V^2 **V_T= +1.0V** **λ=0.0 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'=50 uA/V^2 **V_T= -1.75V** **λ=0.1 V^{-1}** Length (L)=10 um Width (W)=10 um

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

DC Solution:

M1:

$$I_{DS} = 150\mu A = \frac{1}{2}\left(\overset{1\mu A/V^2}{\overset{\downarrow}{K_n'}}\right)\left(\overset{100}{\overset{\downarrow}{\frac{W}{L}}}\right)\left(V_{GS}-\overset{-1}{\overset{\downarrow}{V_T}}\right)^2\left(1+\overset{0.1\,V^{-1}}{\overset{\downarrow}{\lambda}} V_{DS}\right)$$

$$V_G = -12\left(\frac{R_3}{R_3+R_4}\right) = -9\,V$$

$$V_S = -12 + 150\mu A\,(20k) = -9\,V$$

$$\boxed{V_{GS} = 0}$$

$$\boxed{I_{DS} = 150\mu A} = (50\mu A/V^2)(-1)^2(1+0.1\,V_{DS})$$

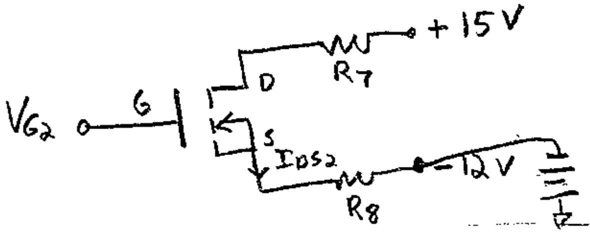
$$\boxed{V_{DS} = 20V} > (\underset{\overset{\uparrow}{0}}{V_{GS}} - \underset{\overset{\uparrow}{-1}}{V_T})$$

$$\boxed{\text{Saturation confirmed}}$$

M2:

$$V_{D1} = V_{G2} = -12V + (\overset{I_{DC}}{\overset{\downarrow}{150\mu A}})\overset{R_4}{\overset{\downarrow}{20K}} + \overset{20V}{\overset{\downarrow}{V_{DS_1}}}$$

$$= +11\,V$$



$$V_{GS_2} = V_G - V_S = 11V - (I_{DS_2} R_8) + 12V$$

$$(1) \qquad V_{GS2} = 23 - R_8 I_{DS2}$$

$$-12V + I_{DS2}R_8 + V_{DS_2} + I_{DS2}R_7 = 15V$$

$$(2) \quad V_{DS2} = 27V - I_{DS2}(R_8+R_7)$$

$$I_{DS_2} = \frac{1}{2}\left(\underset{\overset{\uparrow}{10}}{\frac{W}{L}}\right)\left(\underset{\overset{\uparrow}{50\mu A/V^2}}{K_n'}\right)\left((23 - I_{DS2}R_8) - \underset{\overset{\uparrow}{1}}{V_T}\right)^2 \cancel{\left(1+\underset{\overset{\uparrow}{0}}{\lambda} V_{DS2}\right)} \rightarrow 1$$

$$I_{DS_2} = (250\mu A/V^2)(22 - I_{DS_2}R_8)^2$$

$$= (250\mu A/V^2)(484 - 44 I_{DS_2}R_8 + R_8^2(I_{DS2})^2)$$

$$= (\quad '' \quad)(484 - 9.68e6\, I_{DS_2} + 4.84e10\, I_{DS}^2)$$

$$1.21e7(I_{DS_2})^2 - 2421\, I_{DS_2} + 0.121 = 0$$

$$\boxed{\begin{aligned} I_{DS_2} &= 97.16\mu A \\ V_{GS2} &= 1.62\,V \\ V &= 5.09\,V \end{aligned}}$$

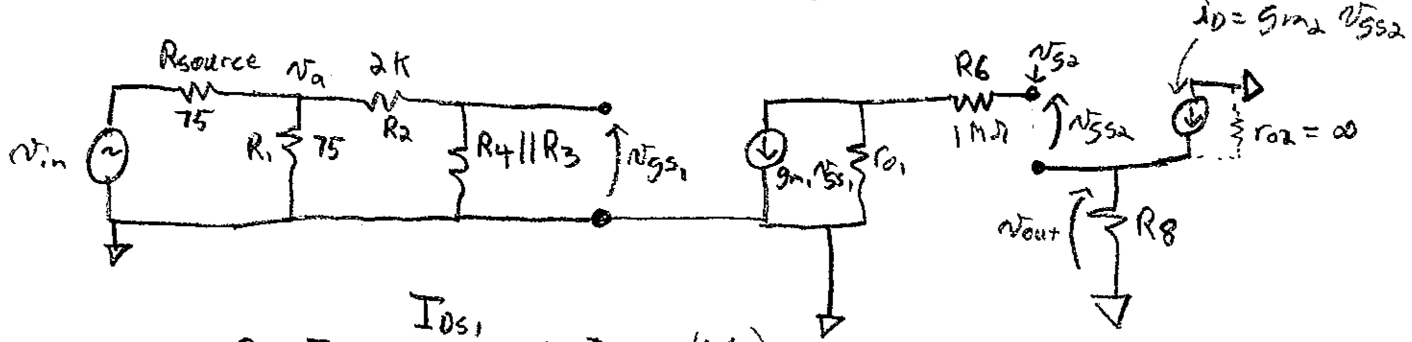
or 102.9 μA

or 0.362 < $V_T \Longrightarrow$ not possible

or

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

Conversion to Small signal Model



$$g_{m_1} = \frac{I_{DS_1}}{\left(\frac{V_{GS_1}-V_T}{2}\right)} = 3e\text{-}4 \, (A/V)$$

$$g_{m_2} = 3.13e-4 \text{ A/V}$$

$$r_{o_1} = \left[\frac{I_{DS_1}}{\frac{1}{\lambda}+V_{DS}}\right]^{-1} = 200 \text{ k}\Omega$$

$$r_{o_2} = \infty$$

1) $v_a = v_{in} \dfrac{R_1 \| (R_2 + R_4 \| R_3)}{R_{source} + R_1 \| (R_2 + R_4 \| R_3)} = v_{in}(0.4997)$

2) $v_{g_2} = -g_{m_1} v_{gs_1} r_{o_1} = -60 \, v_{gs_1}$

3) $v_{s_2} = v_{gs_2} + g_{m_2} v_{gs_2} R_8 = v_{gs_2}(1 + 68.86)$

4) $v_{out} = g_{m_2} R_8 v_{gs_2} = 68.86 \, v_{gs_2}$

5) $v_{gs_1} = v_a \dfrac{R_4 \| R_3}{R_2 + R_4 \| R_3} = v_a \left(\frac{75}{77}\right)$

2) + 3) $\Rightarrow$ $-60 \, v_{gs_1} = v_{gs_2}(69.86)$

$$A_v = \overset{\textcircled{1}}{\left(\frac{v_a}{v_{in}}\right)} \overset{\textcircled{5}}{\left(\frac{v_{gs_1}}{v_a}\right)} \overset{\textcircled{2+3}}{\left(\frac{v_{gs_2}}{v_{gs_1}}\right)} \overset{\textcircled{4}}{\left(\frac{v_{out}}{v_{gs_2}}\right)}$$

$$\left(\frac{75}{77}\right)(0.4997)\left(\frac{-60}{69.86}\right)(68.86)$$

$$\boxed{A_v = -28.78 \text{ V/V}}$$