Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Spring 2024

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **6** pages in your exam
- You may use one double-sided page of notes and equations for the exam
- Good Luck!

Problem	Score	Max Score
1		30
2		35
3		35
Total		**100**

Name: SAM PALERMO

UIN: __________________________

Problem 1 (30 points)

For all the circuits below, use the following NMOS parameters

$KP_N=\mu_n C_{ox}=100\mu A/V^2$, $V_{TN}=1V$, $\lambda_N=0V^{-1}$

and the following PMOS parameters

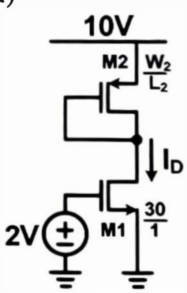
$KP_P=\mu_p C_{ox}=30\mu A/V^2$, $V_{TP}=-1V$, $\lambda_P=0V^{-1}$

For the following two circuits calculate

i. I_D with $W_2/L_2=10/1$. (10 points)

ii. The minimum W_2/L_2 such that the M1 transistor remains in saturation (10 points)

a)



M1 Sat: $V_{DS1} \geq V_{GS1} - V_{TN} = 2V - 1V = 1V$

$I_{D1} = \frac{1}{2}(100\mu A/V^2)\left(\frac{30}{1}\right)(2V-1V)^2 = 1.5mA$

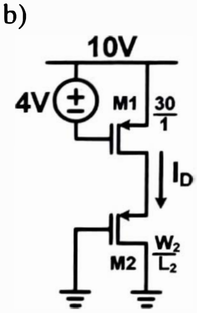
$V_{O1} = V_{DD} - V_{SG2} = 10V - \left(\sqrt{\frac{2(1.5m)}{(30\mu)(10)}} + |-1V|\right) = 5.84 \Rightarrow$ M1 Sat

$$\text{Min}\left(\frac{W}{L}\right)_2 = \frac{2I_D}{KP_p(V_{SG}-|V_{TP}|)^2} = \frac{2(1.5m)}{30\mu(9V-|-1V|)^2} = 1.56$$

I_D ($W_2/L_2=10/1$) = 1.5mA

M1 Sat. Min W_2/L_2 = 1.56

b)



M1 Sat $V_{SD1} \geq V_{SG1} - |V_{TP}| = 4V - |-1V| = 3V$

$I_{D1} = \frac{1}{2}(30\mu A/V^2)\left(\frac{30}{1}\right)(4V-|-1V|)^2 = 4.05mA$

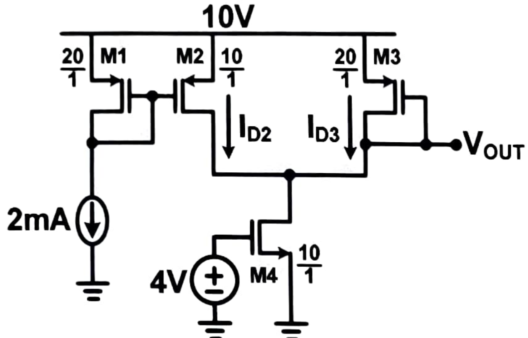
$V_{O1} = V_{SG2} = \sqrt{\frac{2(4.05mA)}{(30\mu)(10)}} + |-1V| = 6.20V \Rightarrow V_{SD1} = 3.8V$
$\Rightarrow$ M1 Sat

$$\text{Min}\left(\frac{W}{L}\right)_2 = \frac{2I_D}{KP_p(V_{SG}-|V_{TP}|)^2} = \frac{2(4.05mA)}{(30\mu)(7V-|-1V|)^2} = 7.5$$

I_D ($W_2/L_2=10/1$) = 4.05mA

M1 Sat. Min W_2/L_2 = 7.5

c) For the following circuit find the values for I_{D2}, I_{D3}, and V_{OUT}. Assume all transistors are operating in saturation. (10 points)



$$I_{D2} = I_{REF}\frac{(W/L)_2}{(W/L)_1} = 2mA\frac{(10)}{(20)} = 1mA$$

$$I_{D4} = \frac{1}{2}(100\mu)(10)(4V-1V)^2 = 4.5mA$$

$$I_{D3} = I_{D4} - I_{D2} = 4.5mA - 1mA = 3.5mA$$

$$V_{OUT} = V_{DD} - V_{SG3} = 10V - \left(\sqrt{\frac{2(3.5mA)}{(30\mu)(20)}} + |-1V|\right) = 5.58V$$

I_{D2} = 1mA

I_{D3} = 3.5mA

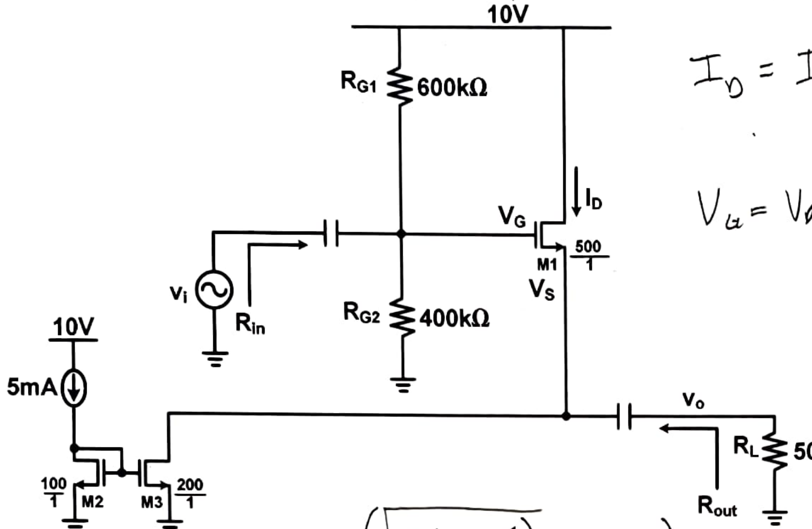
V_{OUT} = 5.58V

Problem 2 (35 points)

Assume for problem 2 that the NMOS transistors are all operating in saturation and have

$KP_N=\mu_n C_{ox}=100\mu A/V^2$, $V_{TN}=1V$, $\lambda_N=0V^{-1}$

a) Calculate the DC values for I_D, V_G, V_S and the AC small-signal g_{m1}. (10 points)



$$I_D = I_{REF}\frac{(W/L)_3}{(W/L)_2} = 5mA\,\frac{200}{100} = 10mA$$

$$V_G = V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} = 10V\left(\frac{400k}{600k+400k}\right) = 4V$$

$$V_S = V_G - V_{GS} = 4V - \left(\sqrt{\frac{2(10mA)}{100\mu(500)}} + 1V\right) = 2.37V$$

$$g_{m1} = \sqrt{KP_N \frac{W}{L_1} 2I_D} = \sqrt{(100\mu)(500)(2)(10mA)} = 31.6\,mA/V$$

$I_D =$ 10 mA

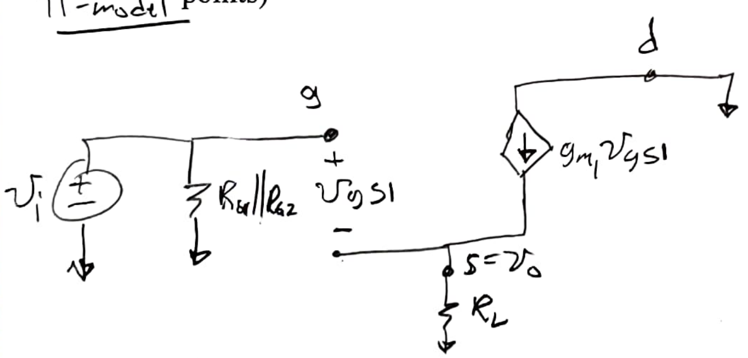
$V_G =$ 4V

$V_S =$ 2.37V

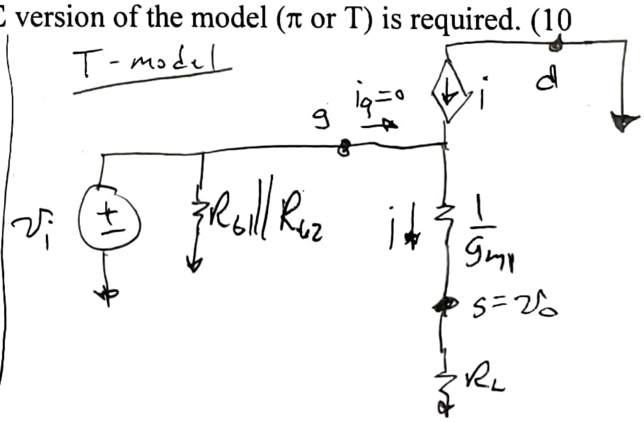
$g_{m1} =$ 31.6 mA/V

b) Sketch the small-signal model of the circuit. Assume that the capacitors act as AC shorts and only draw the essential transistor(s). Only **ONE** version of the model (π or T) is required. (10 points)

π-model



T-model



c) Calculate small signal gain $A_v=v_o/v_i$, input resistance R_{in}, output resistance R_{out}. (15 points)

$$v_o = v_i\left(\frac{R_L}{\frac{1}{g_m}+R_L}\right) = \frac{g_m R_L}{1+g_m R_L} = \frac{(31.6m)(50)}{1+(31.6m)(50)} = 0.612\,V/V$$

$$R_{in} = R_{G1}||R_{G2} = 400k||600k = 240K$$

$$R_{OUT} = \frac{1}{g_m} = \frac{1}{31.6\,mA/V} = 31.6\Omega$$

$A_v =$ 0.612 V/V

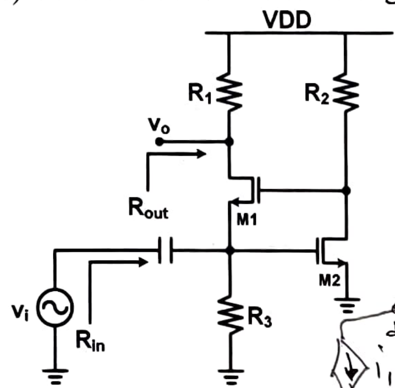
$R_{in} =$ 240K

$R_{out} =$ 31.6Ω

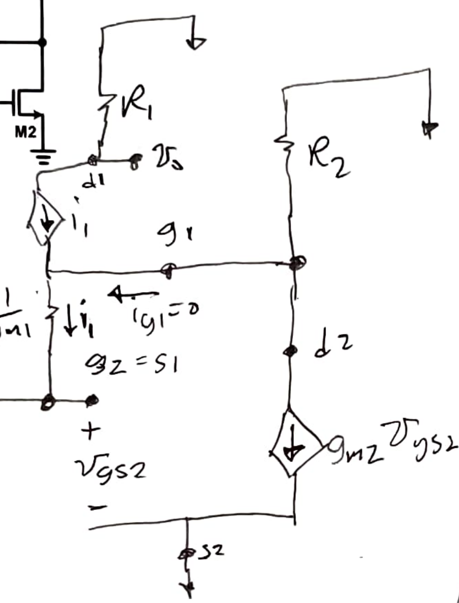
Problem 3 (35 points)

This problem involves the small signal analysis of the circuit below. Assume that the transistors are all operating in saturation and have $r_o=\infty$.

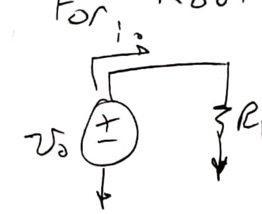
a) Sketch the circuit's small-signal model. Assume the capacitors act as AC shorts. (15 points)



M1: T-model, M2: T-model



For R_{OUT}



$R_{OUT} = R_1$

b) Derive expressions for the small signal gain $A_v=v_o/v_i$, input resistance R_{in}, and output resistance R_{out}. (20 points)

$$v_o = -i_1 R_1$$

$$i_1 = \frac{-g_{m2} v_i R_2 - v_i}{1/g_{m1}} \Rightarrow v_o = +v_i\left[g_{m1} g_{m2} R_2 + g_{m1}\right] R_1$$

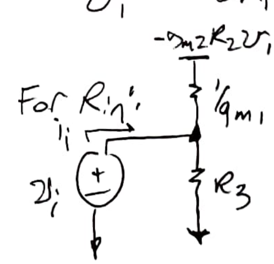
$$\frac{v_o}{v_i} = g_{m1} R_1 \left[1 + g_{m2} R_2\right]$$

$A_v = g_{m1} R_1 \left[1 + g_{m2} R_2\right]$

$R_{in} = R_3 \,||\, \left(\frac{1}{g_{m1}(1+g_{m2}R_2)}\right)$

$R_{out} = R_1$

For R_{in}:



$$i_i = \frac{v_i}{R_3} + \frac{v_i + g_{m2}R_2 v_i}{1/g_{m1}}$$

$$R_{in} = \frac{v_i}{i_i} = \frac{1}{\frac{1}{R_3} + g_{m1}(1+g_{m2}R_2)}$$

$$= R_3 \,||\, \left(\frac{1}{g_{m1}(1+g_{m2}R_2)}\right)$$