Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Fall 2022

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **6** pages in your 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

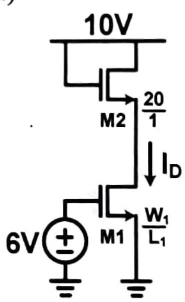
$KP_P=\mu_p C_{ox}=30\mu A/V^2$, $V_{TP}=-1V$, $\lambda_P=0V^{-1}$

For the following two circuits calculate

i. I_D with $W_1/L_1=10/1$. (10 points)

ii. The maximum W_1/L_1 such that the M1 transistor remains in saturation (10 points)

a)



i. $I_D = \frac{KP_N}{2}\left(\frac{W}{L}\right)_1 (V_{GS1}-V_{TN})^2 = \frac{100\mu}{2}(10)(6-1)^2 = 12.5mA$

Check Sat: $V_{DS1} \geq V_{GS1}-V_{TN} = 6V-1V=5V$

$V_{DS1} = V_{S2} = V_{DD} - V_{GS2} = V_{DD} - \left(\sqrt{\frac{2I_D}{KP_N \frac{W}{L_2}}} + V_{TN}\right) = 10V - \left(\sqrt{\frac{2(12.5m)}{100\mu(20)}} + 1\right)$

$= 5.46V \Rightarrow$ Sat.

ii. Max $\frac{W}{L}$ occurs with I_D that sets $V_{DS1}=5V$

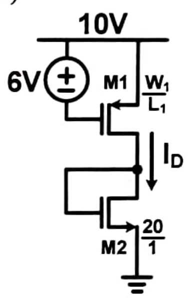
$I_D = \frac{KP_N}{2}\left(\frac{W}{L}\right)_2 (V_{GS2}-V_{TN})^2 = \frac{KP_N}{2}\left(\frac{W}{L}\right)_1 (V_{GS1}-V_{TN})^2$

$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 \frac{(V_{GS2}-V_{TN})^2}{(V_{GS1}-V_{TN})^2} = 20\frac{(5-1)^2}{(6-1)^2} = 12.8$

$I_D (W_1/L_1=10/1) =$ 12.5mA

M1 Sat. Max $W_1/L_1 =$ 12.8

b)



i. $I_D = \frac{KP_P}{2}\left(\frac{W}{L}\right)_1 (V_{SG1}-|V_{TP}|)^2$

$= \frac{30\mu}{2}(10)(6V-|-1V|)^2 = 3.75mA$

Check Sat: $V_{SD1} \geq V_{SG1}-|V_{TP}| = 6V-|-1V| = 5V$

$V_{SD1} = V_{DD} - V_{GS2} = V_{DD} - \left(\sqrt{\frac{2I_D}{KP_N\left(\frac{W}{L}\right)_2}} + V_{TN}\right) = 10V - \left(\sqrt{\frac{2(3.75mA)}{100\mu(20)}} + 1\right)$

$= 7.06V \Rightarrow$ Sat.

ii. Max $\frac{W}{L}$ occurs with I_D that sets $V_{SD1}=5V$

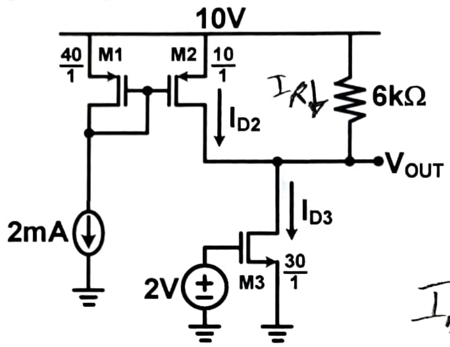
$I_D = \frac{KP_P}{2}\left(\frac{W}{L}\right)_1 (V_{SG1}-|V_{TP}|)^2 = \frac{KP_N}{2}\left(\frac{W}{L}\right)_2 (V_{GS2}-V_{TN})^2$

$\left(\frac{W}{L}\right)_1 = \frac{KP_N}{KP_P}\left(\frac{W}{L}\right)_2 \frac{(V_{GS2}-V_{TN})^2}{(V_{SG1}-|V_{TP}|)^2} = \frac{100\mu}{30\mu}(20)\frac{(5-1)^2}{(6-1)^2} = 42.7$

$I_D (W_1/L_1=10/1) =$ 3.75mA

M1 Sat. Max $W_1/L_1 =$ 42.7

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)



From Current Mirror

$$I_{D2} = I_{D1} \frac{(W/L)_2}{(W/L)_1} = 2mA\left(\frac{10}{40}\right) = 500\mu A$$

$$I_{D3} = \frac{KP_N}{2}\left(\frac{W}{L}\right)_3 (V_{GS3} - V_{TN})^2 = \frac{100\mu}{2}(30)(2-1)^2 = 1.5mA$$

$I_{D2} =$ 500µA

$I_{D3} =$ 1.5mA

$V_{OUT} =$ 4V

$$I_R = I_{D3} - I_{D2} = 1.5mA - 0.5mA = 1mA$$

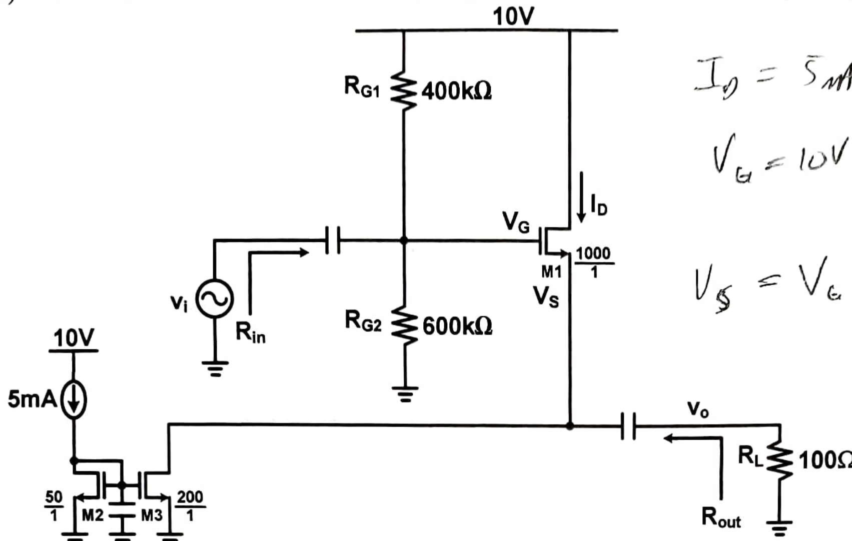
$$V_{OUT} = VDD - I_R R = 10V - 1mA(6k\Omega) = 4V$$

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)



$I_D = 5mA\left(\frac{200}{50}\right) = 20mA$

$V_G = 10V\left(\frac{600K}{400K+600K}\right) = 6V$

$V_S = V_G - \left(\sqrt{\frac{2I_D}{KP_N\left(\frac{W}{L}\right)_1}} + V_{TN}\right)$

$= 6V - \left(\sqrt{\frac{2(20m)}{100\mu(1000)}} + 1\right)$

$= 4.37V$

$g_{m1} = \sqrt{KP_N\left(\frac{W}{L}\right)_1 2I_D} = \sqrt{(100\mu)(1000)(2)(20mA)}$

$= 63.2\ mA/V$

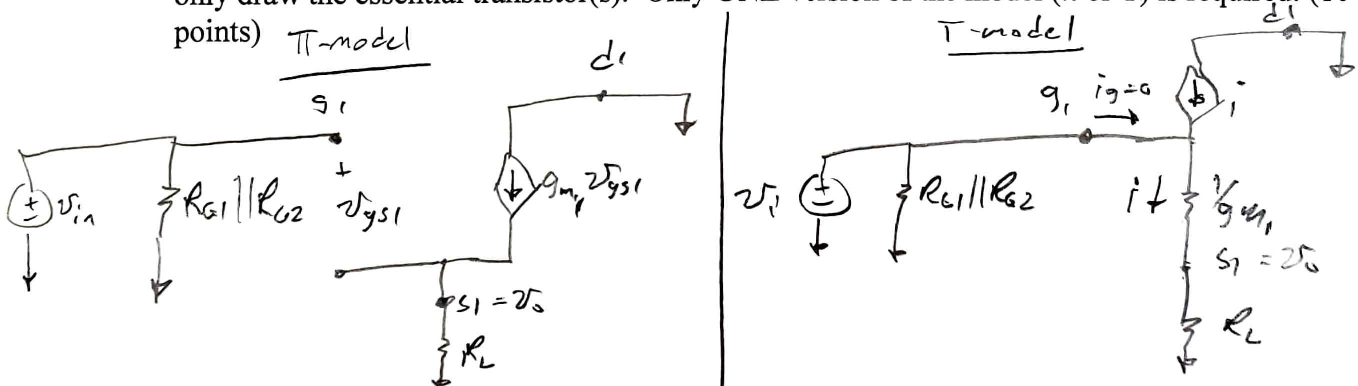
$I_D =$ 20mA

$V_G =$ 6V

$V_S =$ 4.37V

$g_{m1} =$ 63.2 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)



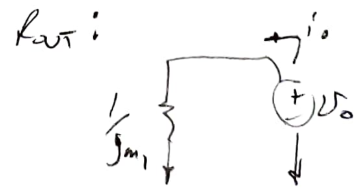
c) Calculate small signal gain $A_v=v_o/v_i$, input resistance R_{in}, output resistance R_{out}. (15 points)

$A_V = \frac{g_m R_L}{1+g_m R_L} = \frac{(63.2\ mA/V)(100)}{1+(63.2\ mA/V)(100)} = 0.863\ V/V$

$R_{in} = R_G = 400K \| 600K = 240K\Omega$

$R_{OUT} = \frac{1}{g_{m1}} = \frac{1}{63.2\ mA/V} = 15.8\Omega$

R_{OUT}:



$A_v =$ 0.863 V/V

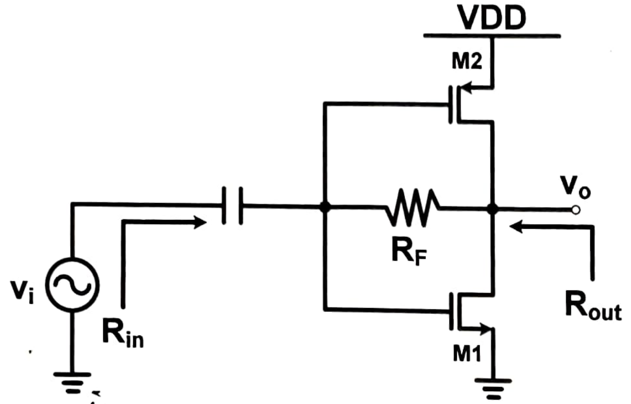
$R_{in} =$ 240KΩ

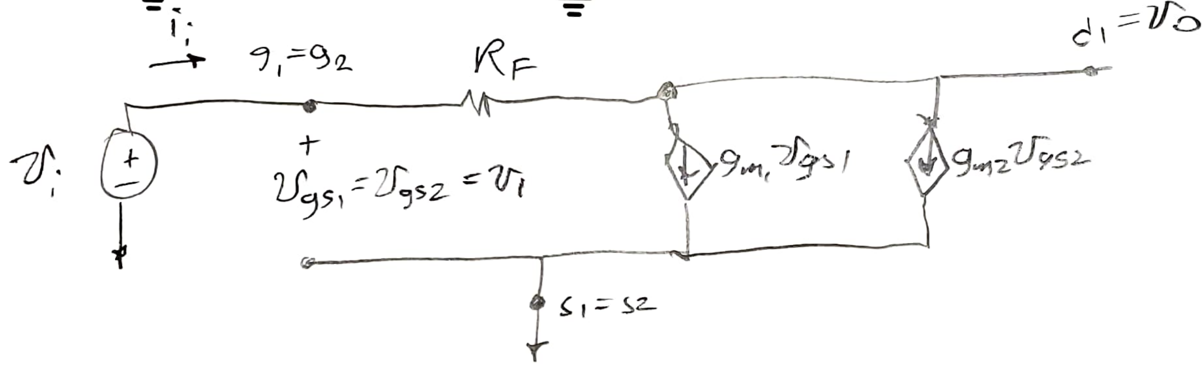
$R_{out} =$ 15.8Ω

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)





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)

KCL at v_o: $\frac{v_o - v_i}{R_F} + g_{m1} v_i + g_{m2} v_i = 0$

$$v_o \left(\frac{1}{R_F}\right) = v_i \left(\frac{1}{R_F} - g_{m1} - g_{m2}\right)$$

$$A_v = \frac{v_o}{v_i} = 1 - (g_{m1} + g_{m2}) R_F$$

R_{in}: $i_i = (g_{m1} + g_{m2}) v_i$

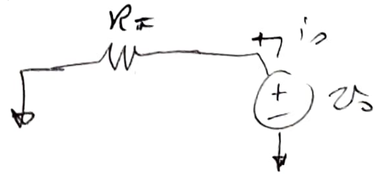
$$\frac{v_i}{i_i} = \frac{1}{g_{m1} + g_{m2}}$$

$A_v = 1 - (g_{m1} + g_{m2}) R_F$

$R_{in} = \frac{1}{g_{m1} + g_{m2}}$

$R_{out} = R_F$

R_{OUT}:



$R_{OUT} = R_F$