Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Spring 2021

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

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

and the following PMOS parameters

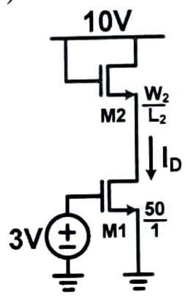
$KP_P=\mu_pC_{ox}=30\mu A/V^2$, $V_{TP}=-1V$, $\lambda_P=0V^{-1}$

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)



For M1 Sat: $V_{DS} \geq V_{GS1} - V_{TN}$

$V_{D1} \geq 3V - 1V = 2V$

$I_D = \frac{100\mu A/V^2}{2}(50)(3V-1V)^2 = 10mA$

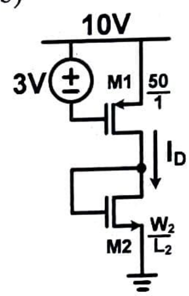
$V_{D1} = 10V - \left(\sqrt{\frac{2(10mA)}{100\mu(10)}} + 1V\right) = 4.53V \Rightarrow M1\ Sat$

For $V_{D1} = 2V \Rightarrow \frac{W}{L_2} = \frac{2I_D}{KP_N(V_{GS}-V_{TN})^2} = \frac{2(10mA)}{100\mu(8V-1V)^2} = 4.08$

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

M1 Sat. Min $W_2/L_2 =$ 4.08

b)



For M1 Sat: $V_{SD1} \geq V_{SG1} - |V_{TP}|$

$V_{SD1} \geq 3V - |-1V| = 2V$

$I_D = \frac{30\mu A/V^2}{2}(50)(3V-1V)^2 = 3mA$

$V_{D1} = V_{GS2} = \sqrt{\frac{2I_D}{KP_N\frac{W}{L}}} + V_{TN} = \sqrt{\frac{2(3mA)}{100\mu(10)}} + 1V = 3.45V$

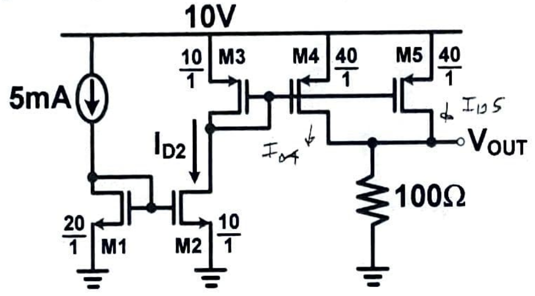
$\Rightarrow V_{SD1} = 10V - 3.45V = 6.55V \Rightarrow M1\ Sat$

For $V_{D1} = 8V \Rightarrow \frac{W}{L_2} = \frac{2I_D}{KP_N(V_{D1}-V_{TN})^2} = \frac{2(3mA)}{100\mu(9-1)^2} = 1.22$

$I_D (W_2/L_2=10/1) =$ 3mA

M1 Sat. Min $W_2/L_2 =$ 1.22

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



$I_{D2} =$ 2.5mA

$V_{OUT} =$ 2V

$I_{D2} = 5mA\left(\frac{10}{20}\right) = 2.5mA$

$I_{D4} = I_{D5} = 2.5mA\left(\frac{40}{10}\right) = 10mA$

$V_{OUT} = (I_{D4} + I_{D5})\,100\Omega$

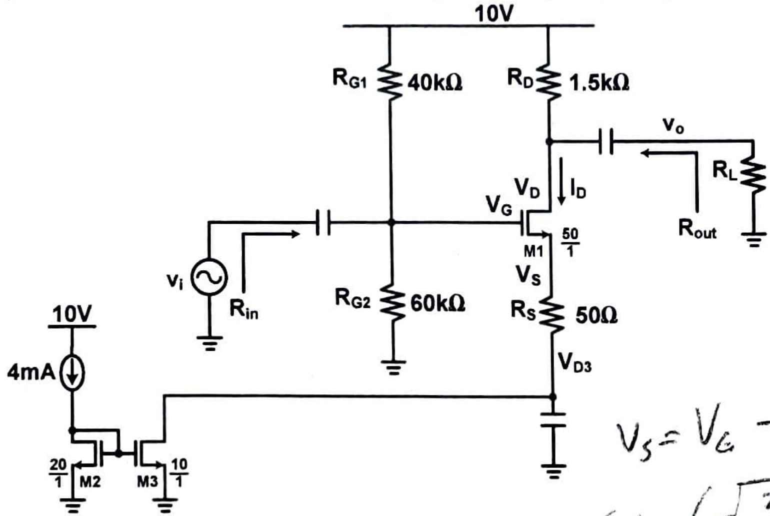
$= (20mA)(100\Omega) = 2V$

Problem 2 (35 points)

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

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

a) Calculate the DC values for I_D, V_D, V_G, V_S, V_{D3}, and the AC small-signal g_{m1}. (13 points)



$I_o = 4mA\left(\frac{10}{20}\right) = 2mA$

$V_o = V_{DD} - I_o R_D$
$= 10V - 2mA(1.5k\Omega) = 7V$

$V_G = 10V\left(\frac{60k}{60k+40k}\right) = 6V$

$V_S = V_G - \left(\sqrt{\frac{2I_o}{KP_N\frac{W}{L}}} + V_{TN}\right)$
$= 6V - \left(\sqrt{\frac{2(2m)}{100\mu(50)}} + 1V\right) = 4.11V$

$V_{D3} = V_S - I_o R_S = 4.11V - 2mA(50) = 4.01V$

$g_m = \sqrt{KP_N\frac{W}{L}2I_D} = \sqrt{100\mu(50)(2)(2mA)} = 4.47mA/V$

$I_D =$ 2 mA

$V_D =$ 7V

$V_G =$ 6V

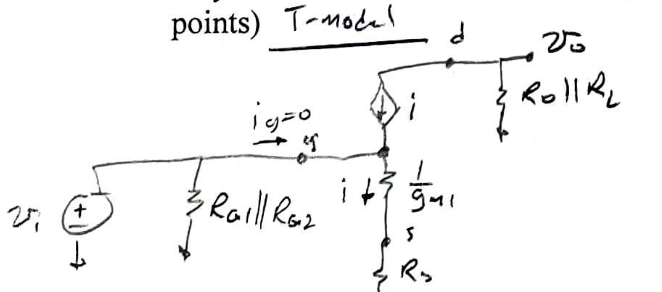
$V_S =$ 4.11V

$V_{D3} =$ 4.01V

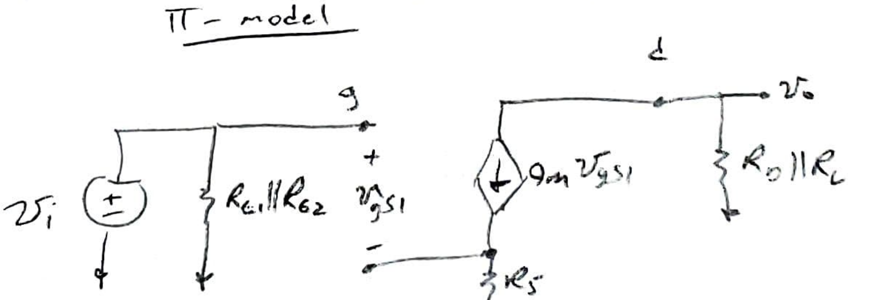
$g_{m1} =$ 4.47 mA/V

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)

T-model



π-model



c) Calculate small signal gain $A_v=v_o/v_i$, input resistance R_{in}, output resistance R_{out}. (12 points)

$v_o = -i(R_o \| R_L)$, $i = \frac{v_i}{\frac{1}{g_m} + R_s}$ $\Rightarrow A_v = \frac{-g_m(R_o\|R_L)}{1+g_mR_s}$

$= -\frac{(4.47mA/V)(1.5k\|5k)}{1+4.47mA/V(50)}$

$= -4.22 V/V$

$R_{in} = R_{G1}\|R_{G2} = 24k\Omega$

$R_{out} = R_D = 1.5k\Omega$

$A_v =$ −4.22 V/V

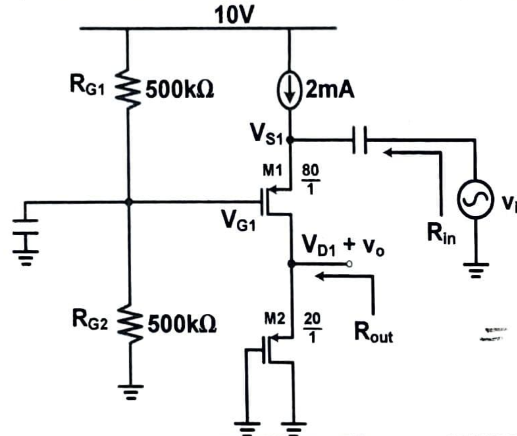
$R_{in} =$ 24kΩ

$R_{out} =$ 1.5kΩ

Problem 3 (35 points)

Assume for problem 3 that the PMOS transistors are all operating in saturation and have
$KP_P=\mu_p C_{ox}=30\mu A/V^2$, $V_{TP}=-1V$, $\lambda_P=0V^{-1}$

a) Calculate the DC values V_{D1}, V_{G1}, V_{S1} and AC small-signal values g_{m1} and g_{m2}. (10 points)



$$V_{D1} = \sqrt{\frac{2I_o}{KP_P \frac{W}{L}}} + |V_{TP}| = \sqrt{\frac{2(2mA)}{30\mu(20)}} + 1V = 3.58V$$

$$V_{G1} = 10V\left(\frac{500k}{500k+500k}\right) = 5V$$

$$V_{S1} = V_{G1} + \left(\sqrt{\frac{2I_D}{KP_P \frac{W}{L}}} + |V_{TP}|\right) = 5V + \left(\sqrt{\frac{2(2mA)}{30\mu(80)}} + 1V\right) = 7.29V$$

$$g_{m1} = \sqrt{KP_P \frac{W}{L_1} 2I_o} = \sqrt{30\mu(80)(2)(2mA)} = 3.1\,mA/V$$

$$g_{m2} = \sqrt{KP_P \frac{W}{L_2} 2I_o} = \sqrt{30\mu(20)(2)(2mA)} = 1.55\,mA/V$$

$V_{D1} =$ 3.58V

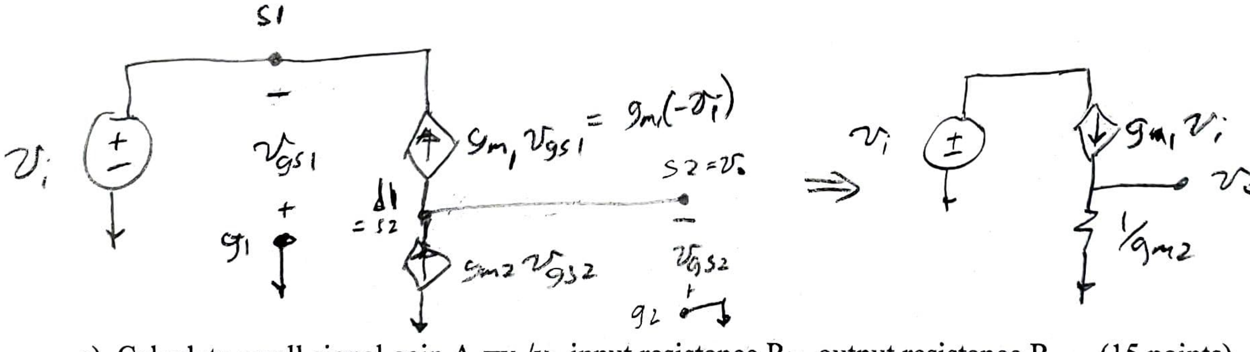
$V_{G1} =$ 5V

$V_{S1} =$ 7.29V

$g_{m1} =$ 3.1 mA/V

$g_{m2} =$ 1.55 mA/V

b) Sketch the circuit's small-signal model. Assume the capacitors act as AC shorts. (10 points)



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

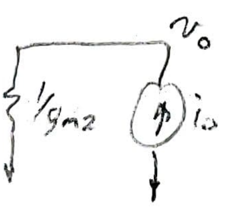
$$v_o = g_{m1} v_i \left(\frac{1}{g_{m2}}\right) \Rightarrow A_v = \frac{g_{m1}}{g_{m2}} = \frac{3.1\,mA/V}{1.55\,mA/V} = 2V/V$$

$A_v =$ 2 V/V

$$R_{in} = \frac{v_i}{-g_{m1}(-v_i)} = \frac{1}{g_{m1}} = \frac{1}{3.1\,mA/V} = 323\Omega$$

$R_{in} =$ 323Ω

R_{OUT}:



$$R_{OUT} = \frac{1}{g_{m2}} = \frac{1}{1.55\,mA/V} = 645\Omega$$

$R_{out} =$ 645Ω