Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Spring 2020

Exam #3

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are **5** 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		50
2		50
Total		**100**

Name: SAM PALERMO

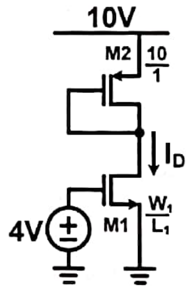
UIN:

Problem 1 (50 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 $W_1/L_1=10/1$. (15 points)
ii. The maximum W_1/L_1 such that the M1 transistor remains in saturation (15 points)

a)



For M1 Sat: $V_{DS1} \geq V_{GS1} - V_{TN} \Rightarrow V_{D1} \geq 4V - 1V = 3V$

$I_D = \frac{100\mu}{2}(10)(3V)^2 = 4.5mA$

$V_{D1} = 10V - \left(\sqrt{\frac{2(4.5mA)}{30\mu(10)}} + |-1V|\right) = 3.52V \Rightarrow M1\ Sat$

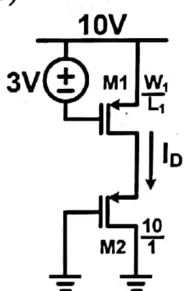
$Max\left(\frac{W}{L}\right)_1 = \frac{2I_D}{KP_N(V_{GS1}-V_{TN})^2}$ where $I_D = \frac{1}{2}KP_P\left(\frac{W}{L}\right)_2(V_{SG2}-|V_{TP}|)^2$ w/ $V_{SG2}=7V$

$= \frac{2\left(\frac{KP_P}{2}\right)\left(\frac{W}{L}\right)_2(V_{SG}-|V_{TP}|)^2}{KP_N(V_{GS1}-V_{TN})^2} = \frac{KP_P\left(\frac{W}{L}\right)_2(V_{SG2}-|V_{TP}|)^2}{KP_N(V_{GS1}-V_{TN})^2} = \frac{30\mu(10)(7-1)^2}{100\mu(4-1)^2} = 12$

$I_D(W_1/L_1=10/1) =$ 4.5mA

M1 Sat. Max $W_1/L_1 =$ 12

b)



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

$V_{SD1} \geq 3V - |-1V| = 2V \Rightarrow V_{D1} \leq 8V$

$I_D = \frac{30\mu}{2}(10)(2V)^2 = 600\mu A$

$V_{D1} = \sqrt{\frac{2(600\mu)}{30\mu(10)}} + |-1V| = 3V \Rightarrow M1\ Sat$

$Max\left(\frac{W}{L}\right)_1 = \frac{2I_D}{KP_P(V_{SG1}-|V_{TP}|)^2}$ where $I_D = \frac{1}{2}KP_P\left(\frac{W}{L}\right)_2(V_{SG2}-|V_{TP}|)^2$ w/ $V_{SG2}=8V$

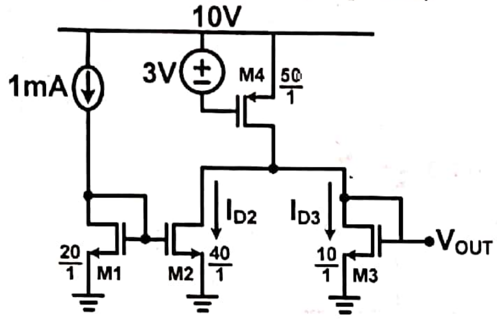
$= \frac{2\left(\frac{KP_P}{2}\right)\left(\frac{W}{L}\right)_2(V_{SG2}-|V_{TP}|)^2}{KP_P(V_{SG1}-|V_{TP}|)^2} = \frac{\left(\frac{W}{L}\right)_2(V_{SG2}-|V_{TP}|)^2}{(V_{SG1}-|V_{TP}|)^2}$

$= \frac{10(8-1)^2}{(3-1)^2} = 122.5$

$I_D(W_1/L_1=10/1) =$ 600μA

M1 Sat. Max $W_1/L_1 =$ 122.5

c) For the following circuit find the values for I_{D2}, I_{D3}, and V_{OUT}. Assume all transistors are operating in saturation. (20 points)



I_{D2} = 2mA

I_{D3} = 1mA

V_{OUT} = 2.41 V

From current mirror (M1/M2)

$$I_{D2} = 1mA\left(\frac{40/1}{20/1}\right) = 2mA$$

$$I_{D4} = \frac{1}{2}KP_P\left(\frac{W}{L}\right)_4\left(V_{SG4} - |V_{TP}|\right)^2 = \frac{30\mu}{2}(50)(3V - |-1V|)^2 = 3mA$$

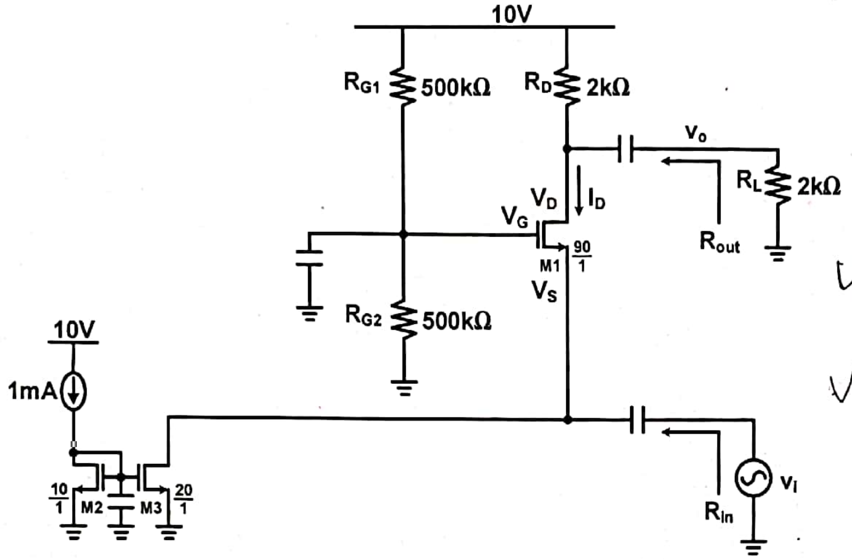
$$I_{D3} = I_{D4} - I_{D2} = 3mA - 2mA = 1mA$$

$$V_{OUT} = \sqrt{\frac{2I_{D3}}{KP_N\left(\frac{W}{L}\right)_3}} + V_{TN} = \sqrt{\frac{2(1mA)}{100\mu(10)}} + 1 = 2.41V$$

Problem 2 (50 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_D, V_G, V_S and the AC small-signal g_{m1}. (15 points)



From current mirror

$I_D = 1mA\left(\frac{20/1}{10/1}\right) = 2mA$

$V_G = 10V\left(\frac{500K}{500K+500K}\right) = 5V$

$V_D = 10V - 2mA(2k) = 6V$

$V_S = V_G - (V_{OD1} + V_{TN}) = 5V - \left(\sqrt{\frac{2(2m)}{100\mu(90)}} + 1\right) = 3.33V$

$g_{m1} = \sqrt{KP_N\left(\frac{W}{L}\right)_1 2I_D} = \sqrt{100\mu(90)(2)(2m)} = 6\,mA/V$

$I_D =$ 2mA

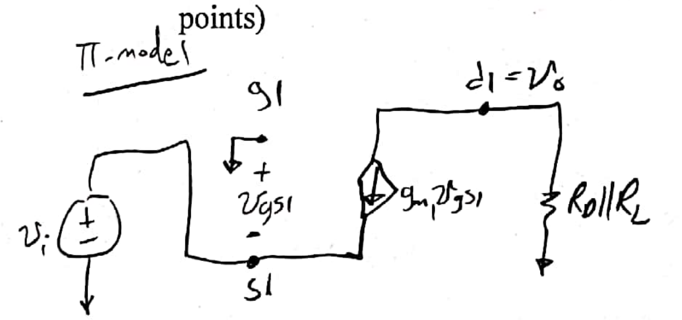
$V_D =$ 6V

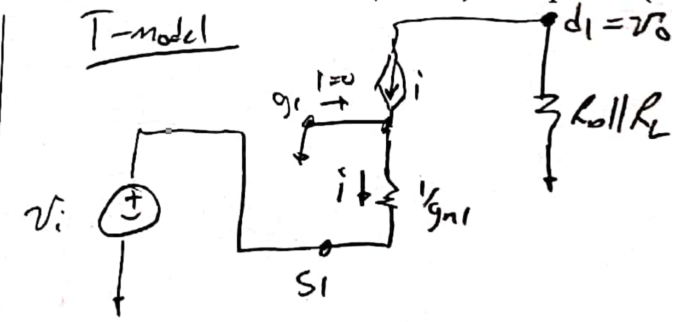
$V_G =$ 5V

$V_S =$ 3.33V

$g_{m1} =$ 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. (15 points)





c) Calculate small signal gain $A_v=v_o/v_i$, input resistance R_{in}, output resistance R_{out}. (20 points)

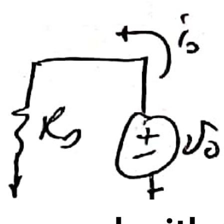
From π-model ∃ $v_{gs1} = -v_{in}$

$v_o = -g_{m1} v_{gs1}(R_o \| R_L) = g_{m1} v_{in}(R_o \| R_L)$

$A_v = \frac{v_o}{v_{in}} = g_{m1}(R_o \| R_L) = 6\,mA/V\,(2k \| 2k) = 6\,V/V$

$R_{in} = \frac{v_{in}}{i_{in}} = \frac{v_{in}}{-(-g_{m1} v_{in})} = \frac{1}{g_{m1}} = 167\Omega$

For Rout:



$A_v =$ 6 V/V

$R_{in} =$ 167 Ω

$R_{out} =$ 2 kΩ