Texas A&M University
Department of Electrical and Computer Engineering

ECEN 325 – Electronics

Summer 2018

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!

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Name: ____________________________

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Problem 1 (30 points)

For all the circuits below, use the following NMOS parameters

\[ K_{P_N} = \mu_n C_{ox} = 100 \mu A/V^2, \ V_{TN} = 1V, \ \lambda_n = 0V^{-1} \]

and the following PMOS parameters

\[ K_{P_F} = \mu_p C_{ox} = 30 \mu A/V^2, \ V_{TP} = -1V, \ \lambda_p = 0V^{-1} \]

For the following two circuits calculate

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

ii. The minimum \( W_3/L_3 \) such that the M1 transistor remains in saturation (10 points)

a) \[ \begin{align*}
\text{For M1 Sat:} & \quad V_{DS} \geq V_{GS1} - V_{TN} \\
& \quad V_{DS} \geq 2V - 1V = 1V \\
& \quad I_D = \frac{100 \mu A}{2} \left( \frac{30}{1} \right) (2V - 1V)^2 = 1.5mA \\
& \quad V_{D1} = 10V - \left( \sqrt{\frac{2(1.5mA)}{20\mu A \left( \frac{10}{1} \right)}} + 1V \right) = 5.84V \Rightarrow \text{M1 Sat} \\
& \quad \text{For } V_{D1} = 1V \Rightarrow \left( \frac{W}{L} \right)_2 = \frac{2(1.5mA)}{30\mu A \left( 6V \right)^2} = 1.56 \\
\end{align*} \]

\[ I_D (W_2/L_2=10/1) = 1.5mA \]

M1 Sat. Min \( W_3/L_3 = 1.56 \)

b) \[ \begin{align*}
\text{For M1 Sat:} & \quad V_{SD1} \geq V_{GS1} - |V_{TP}| \\
& \quad V_{SD1} \geq 4V - |1V| = 3V \\
& \quad I_D = \frac{30\mu A}{2} \left( \frac{30}{1} \right) (4V - 1V)^2 = 4.05mA \\
& \quad V_{D1} = \sqrt{\frac{2(4.05mA)}{20\mu A \left( \frac{10}{1} \right)}} + 1V = 6.20V \Rightarrow V_{SD1} = 3.8V \Rightarrow \text{M1 Sat} \\
& \quad \text{For } V_{D1} = 7V \Rightarrow \left( \frac{W}{L} \right)_2 = \frac{2(4.05mA)}{30\mu A \left( 6V \right)^2} = 7.5 \\
\end{align*} \]

\[ I_D (W_2/L_2=10/1) = 4.05mA \]

M1 Sat. Max \( W_3/L_3 = 7.5 \)
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)

![Circuit Diagram]

From current mirror ($M1/M2$)

$$I_{D2} = \frac{2mA}{(2\times1)} = 1mA$$

$$I_{D3} = 3.5mA$$

$$V_{OUT} = 5.58V$$

$$I_{D1} = \frac{1}{2} K p_{N} \left( \frac{W}{L} \right) \left( V_{GS} - V_{TH} \right)^{2} = \frac{1}{2} \left( \frac{100 \mu A}{\mu m} \right) \left( \frac{10}{2} \right) \left( 4V - 1V \right)^{2}$$

$$= 4.5mA$$

$$I_{D3} = I_{D1} - I_{D2} = 4.5mA - 1mA = 3.5mA$$

$$V_{OUT} = V_{DD} - V_{S63} = 10V - \left( \sqrt{\frac{2(3.5mA)}{30\mu m} \left( \frac{20}{1} \right)} + 1V \right) = 5.58V$$
Problem 2 (35 points)
Assume for problem 2 that the NMOS transistors are all operating in saturation and have
\[K_P = \mu_C C_{ox} = 100 \mu A/V^2, \quad V_{TN} = 1V, \quad \lambda_N = 0V^{-1}\]

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

\[
\begin{align*}
V_S &= V_D - (V_{OU1} + V_{TN}) = 4V - \left(\frac{2 \times (1mA)}{100 \mu A} + 1V\right) = 2.37V \\
I_D &= 10mA \\
V_G &= 4V \\
V_S &= 2.37V \\
g_{m1} &= \frac{31.6 mA/V}{V}
\end{align*}
\]

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 (\(\pi\) or T) is required. (10 points)

\[
\begin{align*}
T-model
\end{align*}
\]

\[
\begin{align*}
T-model
\end{align*}
\]

c) Calculate small signal gain \(A_v = V_o/V_i\), input resistance \(R_{in}\), output resistance \(R_{out}\). (15 points)

\[
\begin{align*}
A_V &= \frac{I_i \cdot g_m \cdot R_L}{R_L + \frac{1}{g_m}} \\
R_{in} &= R_{G1} || R_{G2} = 240k\Omega \\
A_v &= 0.612 \frac{V_o}{V_i} \\
R_{in} &= 240k\Omega \\
R_{out} &= 31.6 \Omega
\end{align*}
\]
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 \( A_v = \frac{v_o}{v_i} \), input resistance \( R_{in} \), and output resistance \( R_{out} \). (20 points)

\[
\begin{align*}
    v_o &= -\frac{1}{g_{m1}} i_1 \left( 1 + g_{m2} R_2 \right) \\
    i_1 &= -\frac{g_{m2} R_3^* R_2 - v_i}{1/g_{m1}} \\
    A_v &= g_{m1} R_1 \left( 1 + g_{m2} R_2 \right) \\
    R_{in} &= \frac{1}{g_{m1}(1+g_{m2} R_2)} \\
    R_{out} &= R_1
\end{align*}
\]