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!

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Name: Sam Palermo

UIN:
Problem 1 (30 points)
For all the circuits below, use the following NMOS parameters
\[ K_{PM} = \mu n C_{ox} = 100 \mu A/V^2, \quad V_{TN} = 1V, \quad \lambda_n = 0V^{-1} \]
and the following PMOS parameters
\[ K_{P} = \mu p C_{ox} = 30 \mu A/V^2, \quad V_{TP} = -1V, \quad \lambda_p = 0V^{-1} \]

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) \[ \begin{align*}
I_D &= \frac{K_{PM}}{2} \left( \frac{W_1}{L_1} \right) \left( V_{GS1} - V_{TN} \right)^2 \\
&= \frac{100 \mu A}{2} \left( \frac{10}{1} \right) (6 - 1)^2 = 12.5 mA
\end{align*} \]
Check Sat: \( V_{GS1} \geq V_{GS1} - V_{TN} = 6V - 1V = 5V \)

b) \[ \begin{align*}
I_D &= \frac{K_{PM}}{2} \left( \frac{W_1}{L_1} \right) \left( V_{GS1} - V_{TN} \right)^2
\end{align*} \]

Id (W/L=10/1) = 12.5 mA

M1 Sat. Max W/L = 12, 8
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:

$$I_{D2} = I_{D1} \frac{(V_{L2})}{(V_{L1})} = 2\text{mA} \left(\frac{10}{40}\right) = 500\mu\text{A}$$

$$I_{D3} = \frac{K_{PN}}{2}(\frac{V}{L})_{3}(V_{os2} - V_{TN})^{2} = \frac{1000}{2}(30)(2-1) = 1.5\text{mA}$$

$$I_{D2} = 500\mu\text{A}$$

$$I_{D3} = 1.5\text{mA}$$

$$V_{OUT} = V_{DD} - I_{R}R = 10\text{V} - 1\text{mA}(6\text{K}) = 4\text{V}$$
Problem 2 (35 points)
Assume for problem 2 that the NMOS transistors are all operating in saturation and have

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

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

\[ I_D = 5mA \left( \frac{200}{50} \right) = 20mA \]
\[ V_G = 10V \left( \frac{600K}{100K + 600K} \right) = 6V \]
\[ V_S = V_G - \left( \frac{2TC_0}{K_{m1}^2} + V_{TN} \right) = 6V - \left( \frac{2C_0}{10\mu (1000)} + 1 \right) = 4.37V \]

\[ I_D = 20mA \]
\[ V_G = 6V \]
\[ V_S = 4.37V \]
\[ g_{m1} = 63.2 mA/V \]

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

\[ \frac{\delta m_1}{1 + \delta m_1^2} = \frac{1}{2} \cdot \frac{K_{PN}}{I_D} \]

\[ 2I_D = 1 + (1000)(1000)(2)(20mA) \]
\[ = 63.2 mA/V \]

\[ \delta m_1 = 1 \]
\[ I_D = 20mA \]
\[ V_G = 6V \]
\[ V_S = 4.37V \]
\[ g_{m1} = 63.2 mA/V \]

\[ V_{in} \]
\[ I_{in} \]
\[ R_{in} \]
\[ V_{out} \]
\[ R_{out} \]

\[ A_v = \frac{g_{m1}R_L}{1 + g_{m1}R_L} = \frac{(63.2 mA)(100)}{1 + (63.2 mA)(100)} = 0.863 \]
\[ R_{in} = R_L = 400K \parallel 600K = 240K \]
\[ R_{out} = \frac{1}{g_{m1}} = \frac{1}{63.2 mA} = 15.9 \]

\[ A_v = 0.863 \]
\[ R_{in} = 240K \]
\[ R_{out} = 15.9 \]
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 $r_0=\infty$.

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)

\[ V_o = \frac{V_o - 2V_i}{R_F} + g_mV_i - g_m2V_i = 0 \]
\[ V_o \left( \frac{1}{R_F} \right) = V_i \left( \frac{1}{R_F} - g_m - g_m2 \right) \]
\[ A_v = \frac{V_o}{V_i} = 1 - (g_m + g_m2)R_F \]
\[ A_v = 1 - (g_m + g_m2)R_F \]
\[ R_{in} = \frac{1}{g_m + g_m2} \]
\[ R_{out} = R_F \]