Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474 – (Analog) VLSI Circuit Design

Fall 2010

Exam #1

Instructor: Sam Palermo

- Please write your name in the space provided below
- Please verify that there are 4 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: SAM PALERMO
Problem 1 (40 points)
For the layout below, assume that all the commonly labeled diffusion areas are connected with the appropriate metal layers. Assume that \( V_{G1}=V_{G2}=1.5V, V_X=V_Y=1V, V_Z=0.4V, V_{TO}=0.7V, \alpha=0 \), and that all Spice parameters are given (i.e. \( C_i, C_{jsw}, C_{ox}, C_{ov} \)). The dimensions are given in \( \mu m \), with all the poly gates having a length of 2\( \mu m \) and \( L_D=0.1\mu m \).

a) Draw the equivalent circuit. Combine all parallel transistors and give the total width and length of the equivalent transistors. (15 points)

b) What region(s) are the transistors operating in? (5 points)

c) For gate G1 only, calculate the gate area and give an expression of the total gate cap. (10 points)

d) For node X only, calculate the diffusion area and perimeter and give an expression of the total junction cap. Note for the perimeter terms, include the sides underneath the gate. (10 points)
Problem 2 (40 points)
For the transistor below, assume $V_{TO}=0.7V$, $\gamma=0.45V^{1/2}$, and $2\Phi_F=0.9V$.

\[
I_{DS} = \mu_n C_{OX} \frac{W}{L-2L_D} (V_{GS} - V_{Tn} - 0.5V_{DS}) V_{DS} \quad \text{(Triode)}
\]

\[
I_{DS} = \frac{1}{2} \mu_n C_{OX} \frac{W}{L-2L_D} (V_{GS} - V_{Tn}) (1 + \lambda V_{DS}) \quad \text{(Saturation)}
\]

\[
V_T = V_{TO} + \gamma \left( \sqrt{2\Phi_F} + V_{SB} - \sqrt{2\Phi_F} \right)
\]

a. Calculate $V_T$ and state the transistor's operation region. (10 points)

\[
V_T = 0.7V + 0.45V^{1/2} \left( \sqrt{0.9V + 0.5V} - \sqrt{0.9V} \right) = 0.806V
\]

\[
V_{GS} - V_T = 1.5V - 0.5V = 0.806V = 0.144V
\]

\[
V_{OS} = 0.6V - 0.5V = 0.1V \quad V_{OS} < V_{GS} - V_T
\]

Operation Region = **Triode**

b. Using the appropriate $I_{DS}$ equation above, derive and sketch the small-signal model of the transistor. Include expressions for the $g_m$, $g_o$, and $g_{mb}$. (20 points)

\[
g_m = \left. \frac{\delta I_{DS}}{\delta V_{GS}} \right|_Q = \mu_n C_{OX} \left[ V_{GS} - V_T - \frac{0.5V_{OS}}{2} \right]
\]

\[
g_o = \left. \frac{\delta I_{DS}}{\delta V_{DS}} \right|_Q = \mu_n C_{OX} \left[ V_{OS} - V_{T} - 0.5V_{OS} \right]
\]

\[
g_{mb} = \left. \frac{\delta I_{DS}}{\delta V_{SB}} \right|_Q = \mu_n C_{OX} \left[ V_{OS} - V_{T} - 0.5V_{OS} \right]
\]

\[
= \mu_n C_{OX} \left[ V_{OS} \left( -1 \right) \right] = \left[ V_{OS} + \gamma \left( -\sqrt{2\Phi_F} + V_{SB} - \sqrt{2\Phi_F} \right) \right] - 0.5V_{OS}
\]

\[
g_m = \left. \mu_n C_{OX} \left[ V_{OS} \left( -1 \right) \right] \right|_Q = \frac{g_m \gamma}{2 \sqrt{2\Phi_F} + V_{SB}} = \frac{g_m \gamma}{2 \sqrt{2\Phi_F} + V_{SB}}
\]

\[
g_m = \frac{\mu_n C_{OX} \left[ V_{OS} \left( -1 \right) \right]}{V_{OS} - V_{T} - 0.5V_{OS}} = \frac{0.1}{0.194 - 0.1}
\]

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\]

\[
I_D = \frac{\mu_n C_{OX} \left[ V_{OS} \left( -1 \right) \right]}{V_{OS} - V_{T} - 0.5V_{OS}} = \frac{0.1}{0.194 - 0.1}
\]

\[
\omega_T = 5.80 \quad \text{rad/s}
\]

Intrinsic Gain ($g_m/g_o$) = 1.06

Transconductance Efficiency ($g_m/I_D$) = 6.94

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Problem 3 (20 points)
Design a pair of 800Ω poly resistors and sketch a layout which matches these two 800Ω resistors. Assume that the poly $R_c=20\Omega/\square$, each (1μm x 1μm) contact has resistance of 10Ω, and fabrication tolerances limit unit resistor length, 4μm ≤ $L$ ≤ 20μm, and unit resistor width, 1μm ≤ $W$ ≤ 5μm. In the sketch clearly label the critical dimensions and use at least 2 layout matching techniques. Also, write specifically the 2 layout matching techniques that you are using.

Resistor Equation:

\[(2R_c + R_0 \frac{L}{W})F = 800\] where $F$=unit $R_s$

Setting $W$, $F$, and 2 contacts/unit $R$ and solving for $unitL$

\[\Rightarrow L = \left[ \frac{800}{F} - 2R_c \right] \frac{W}{R_c} \]

Using $W=1μm$, $F=4$

\[L = \left[ \frac{800}{4} - 2(10) \right] \frac{1μm}{20\Omega/μm^2} = 9μm\]

Some other nice solutions
\[\begin{array}{ccc}
(w = 1μm) & F & L \\
2 & 19μm \\
5 & 7μm \\
8 & 4μm \\
\end{array}\]

Layout Technique #1 = Interdigitized

Layout Technique #2 = Dummy $R_0$s on edges