Texas A&M University
Department of Electrical and Computer Engineering

ECEN 474 – (Analog) VLSI Circuit Design

Fall 2012

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!

<table>
<thead>
<tr>
<th>Problem</th>
<th>Score</th>
<th>Max Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>40</td>
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<tr>
<td>2</td>
<td></td>
<td>40</td>
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<td>20</td>
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<td></td>
<td>100</td>
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</tbody>
</table>

Name: SAM PALERMO

UIN:
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 $V_X=1.5V$, $V_T=1V$, $V_Z=0.5V$, $V_{TH}=0.7V$, $\gamma=0$, and that all Spice parameters are given (i.e., $C_I$, $C_{jm}$, $C_{jx}$, $C_{ox}$, $C_{ov}$). 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 given the total width and length of the equivalent transistors. (15 points)

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

c) For node X only, give an expression and calculate the total gate cap. (10 points)

d) For node X only, give an expression and calculate 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 $V_{T0} = 0.7 \text{V}$, $\gamma = 0.45 \text{V}^{1/2}$, and $2\Phi_F = 0.9 \text{V}$.

$$I_{DS} = I_o \exp \left( \frac{(V_{GS} - V_{TH}) Q}{\xi kT} \right) \left( 1 - \exp \left( - \frac{V_{DS} Q}{kT} \right) \right) \quad \text{(Subthreshold)}$$

$$I_{DS} = \mu_n C_{ox} \frac{W}{L - 2L_D} (V_{GS} - V_{TH} - 0.5 V_{DS}) V_{DS} \quad \text{(Triode)}$$

$$I_{DS} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L - 2L_D} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS}) \quad \text{(Saturation)}$$

$$V_{TH} = V_{T0} + \gamma \left( \sqrt{2\Phi_F + V_{SB}} - \sqrt{2\Phi_F} \right)$$

$$V_{SB} = 0.6 \text{V}$$

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

$$V_T = 0.7 \text{V} + 0.45 \text{V}^{1/2} (0.9 \text{V} + 0.6 \text{V} - \sqrt{0.9 \text{V}}) = 0.824 \text{V}$$

$$V_{GS} = 1.4 \text{V} - 0.6 \text{V} = 0.8 \text{V}$$

$$V_{GS} < V_T \implies \text{Subthreshold}$$

$$V_{T} = 0.824 \text{V}$$

Operation Region = Subthreshold

b. Using the appropriate $I_{DS}$ equation above, derive and sketch the small-signal model of the transistor. Include expressions for the $g_m$, $g_0$, and $g_{mb}$. (30 points)

$$g_m = \frac{\Delta I_{DS}}{\Delta V_{GS}} \bigg|_{Q} = \frac{I_o Q}{\xi kT} \exp \left( \frac{(V_{GS} - V_{TH}) Q}{\xi kT} \right) \left( 1 - \exp \left( - \frac{V_{DS} Q}{kT} \right) \right)$$

$$g_0 = \frac{\Delta I_{DS}}{\Delta V_{GS}} \bigg|_{Q} = \frac{I_o Q}{kT} \exp \left( \frac{(V_{GS} - V_{TH}) Q}{kT} \right) \exp \left( - \frac{V_{DS} Q}{kT} \right)$$

$$g_{mb} = \frac{\Delta I_{DS}}{\Delta V_{GS}} \bigg|_{Q} = \frac{I_o Q}{kT} (-1) \exp \left( \frac{(V_{GS} - V_{TH}) Q}{kT} \right) \left( 1 - \exp \left( - \frac{V_{DS} Q}{kT} \right) \right) (-1) \left( \frac{Q}{2 \sqrt{2\Phi_F + V_{SB}}} \right)$$

$$= \frac{g_m}{2 \sqrt{2\Phi_F + V_{SB}}}$$
Problem 3 (20 points)
Sketch a layout that matches two capacitors of unit size 7.5 and 3.3. Assume that the unit capacitors are sized 10\(\mu\)m x 10\(\mu\)m. Make sure to give the non-unit capacitor(s) dimensions. 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. Note, if you use a common-centroid layout technique, it doesn’t have to have perfect center-of-mass matching, but it should be close.

Need to match \(\frac{\text{perimeter}}{\text{Area}}\) for all caps

\(C_1\) For 7.5 cap \(\Rightarrow\) 6 unit caps + 1 non-unit cap
\[ w/A_{\text{nu}} = 1.5 A_u \quad (k = 1.5) \]

\(C_2\) For 3.3 cap \(\Rightarrow\) 2 unit caps + 1 non-unit cap
\[ w/A_{\text{nu}} = 1.3 A_u \quad (k = 1.3) \]

\(C_1\):
\[ x_{\text{nu}_1} = x_u (k_1 - \sqrt{k_1^2 - 1}) \]
\[ = 10\mu (1.5 - \sqrt{1.5^2 - 1.5}) = 6.34\mu \]
\[ x_{\text{nu}_1} = \frac{k_1 x_u^2}{1.5(10\mu)^2} = \frac{1.5(10\mu)^2}{6.34\mu} = 23.7\mu \]

\(C_2\):
\[ y_{\text{nu}_2} = 10\mu (1.3 - \sqrt{1.3^2 - 1.3}) = 6.76\mu \]
\[ x_{\text{nu}_2} = \frac{1.3(10\mu)^2}{6.76\mu} = 19.2\mu \]

Layout Technique #1 = Dummies around entire perimeter
Layout Technique #2 = Common-centroid (Approximately)