1. Equation sheet is on last page of test.

2. Unless otherwise stated, use transistor parameters on equation sheet.

3. Non-programmable calculator allowed; No other aids allowed

4. Grading indicated by [ ]. Attempt all questions since a blank answer will certainly get 0.

<table>
<thead>
<tr>
<th>Question</th>
<th>Mark</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
<td></td>
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<tr>
<td>4</td>
<td></td>
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<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Last Name: _____________________

First Name: ____________________

Student #: ____________________

(max grade = 36)
[6] **Question 1:** For the nmos circuit below, draw the small-signal T-model and derive expressions for $v_{o1}/v_i$ and $v_{o2}/v_i$ in terms of $R_D$, $R_S$ and $r_s = 1/g_m$. Assume $\lambda = 0$.

\[
\begin{align*}
\frac{v_{o1}}{v_i} &= \\
\frac{v_{o2}}{v_i} &= 
\end{align*}
\]
[6] **Question 2:** Consider the current mirror below. If the current mirror is designed for a current of $20\mu A$, find the voltages $V_{B1}$ and $V_{B2}$ such that $v_O$ can go as low as possible while the transistors remain in the active region. Find the minimum output voltage, $v_{O_{\text{min}}}$.

\[ V_{B1} = \]
\[ V_{B2} = \]
\[ v_{O_{\text{min}}} = \]
[6] **Question 3:** Find the small-signal gain, $\frac{v_o}{v_i}$ and output resistance $R_o$. (ignore $r_o$ when finding $i_{sc}$ but include $r_o$ when finding $R_o$).

$$V_{DD} = 5V \quad \text{all } L = 0.5 \mu m$$

$$W_1 = W_2 = 20 \mu m$$

$$W_3 = 4 \mu m$$

$v_i$ bias voltage is 1V

$R_o = \hspace{2cm} v_o = \hspace{2cm} v_i$
[6] **Question 4:** For the circuit below, all $V_{ov} = 200mV$ and all $I_D = 50\mu A$. The designer is concerned about noise on $V_{B1}$ and $V_{B2}$ bias lines. Find the gains $v_o/v_{i1}$ and $v_o/v_{i2}$.

(Include $r_{o1}$ when finding $i_{SC}$ for $v_o/v_{i2}$ otherwise ignore $r_o$ when finding $i_{SC}$)

$$V_{DD} \quad \text{all } L = 0.5\mu m$$

$$V_{B4} \quad M_4$$

$$V_{B3} \quad M_3$$

$$V_{B2} + v_{i2} \quad M_2$$

$$V_{B1} + v_{i1} \quad M_1$$

$$\begin{align*}
\frac{v_o}{v_{i1}} &= \\
\frac{v_o}{v_{i2}} &= 
\end{align*}$$
[6] Question 5: Consider the current mirror shown below. Using small-signal analysis, estimate the change in $I_o$ when there is a $V_{tn}$ mismatch of 5mV between $M_1$ and $M_3$. Ignore $r_o$.

$I_{ref} = 20 \mu A$

$\Delta I_o =$

\[ \Delta I_o = \]

\[
\begin{align*}
I_o & = 5mV \\
M_1 & = W_1 = W_2 = W_3 = 2 \mu m \\
M_2 & = \text{all } L = 0.5 \mu m \\
M_3 & = \text{all } L = 0.5 \mu m \\
\end{align*} \]
[6] **Question 6:** Consider the circuit below where \( v_{iCM} = 2V \).

\[ V_{DD} = 5V \]

- All \( L = 0.5 \mu m \)
- \( W_1 = W_2 = 5 \mu m \)
- \( W_3 = W_4 = W_5 = 20 \mu m \)

\( I_2 = 50 \mu A \)  
\( I_1 = 100 \mu A \)

a) What is the max and min for \( v_{op} \)?

\[ v_{op_{min}} = \]  
\[ v_{op_{max}} = \]

b) Find the gain, \( v_o/v_{id} \).

\[ v_o/v_{id} = \]
ECE331 Analog Electronics Equation Sheet

**MOS Transistor:** CMOS basic parameters. Channel length = 0.18\(\mu\)m

<table>
<thead>
<tr>
<th></th>
<th>(V_t) (V)</th>
<th>(\mu C_{ox}) ((\mu)A/V²)</th>
<th>(\lambda') ((\mu)m/V)</th>
<th>(C_{ox}) (F/(\mu)m²)</th>
<th>(t_{ox}) (nm)</th>
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<tr>
<td>NMOS</td>
<td>0.4</td>
<td>240</td>
<td>0.05</td>
<td>8.5</td>
<td>4</td>
</tr>
<tr>
<td>PMOS</td>
<td>-0.4</td>
<td>60</td>
<td>-0.05</td>
<td>8.5</td>
<td>4</td>
</tr>
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**Constants:**
\(k = 1.38 \times 10^{-23}\) J K\(^{-1}\); \(q = 1.602 \times 10^{-19}\) C; \(V_T = kT/q = 26\) mV at 300 °K;

\(e_0 = 8.854 \times 10^{-12}\) F/m; \(k_x = 3.9\); \(C_{ox} = (k_x e_0)/t_{ox}\)

**NMOS:**
\(k_n = \mu_n C_{ox} (W/L)\); \(V_{in} > 0\); \(v_{DS} \geq 0\); \(v_{DS} = V_{DS} - (V_{DS}^2/2))\)

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<tr>
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<th>(v_{DS} \leq v_{ov}) (or (v_{DS} \geq V_{in}))</th>
<th>(i_D = k_n (v_{ov} - v_{DS})^2/2)</th>
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<td>(v_{DD} \leq v_{ov})</td>
<td>(i_D = 0.5 k_n v_{ov}^2 (1 + \lambda v_{DS})); (g_m = k_n v_{ov} = 2 I_D/V_{ov} = \sqrt{2k_n I_D^*}; r_s = 1/g_m; r_o = L/(\vert V_{DD} \vert))</td>
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**PMOS:**
\(k_p = \mu_p C_{ox} (W/L)\); \(V_{in} \leq 0\); \(v_{SD} \geq 0\); \(v_{SD} = v_{SD} - (v_{SD}^2/2))\)

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**BJT:**
\(I_C = \beta I_B (1 + (V_{CE}/V_T)); g_m = \alpha/r_e = I_C/V_T; r_s = \beta/g_m; r_o = \vert V_A \vert/I_C\)

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**MOS Transistor:**

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**Diff Pair:**
\(A_d = g_m R_D; A_{CM} = -(R_{DS}/(2R_{SD}))((\Delta R_D)/R_D); A_{CM} = -(R_{DS}/(2R_{SD}))((\Delta g_m)/g_m)\)

\(V_{os} = \Delta V_t; V_{os} = (V_{ov}/2)((\Delta R_D)/R_D); V_{os} = (V_{ov}/2)((\Delta g_m)/g_m)\)