Note: Use the device parameters given in class. $V_t = +0.5V$, $u_Cox=200\mu A/V2$, $u_Pox=100\mu A/V2$, $\lambda_0=0.02 \text{ } I/V$

1. (30pts) Design an amplifier with a low frequency gain of at least 100 and a unity gain frequency of 5 GHz with a 10pF load. Use an NMOS-input common-source amplifier with a PMOS current source load. You may use one resistor in your circuit, and assume a 5V supply, but all other devices must be FETs (no ideal voltage source, current sources, etc.). Try to minimize the size WIDTH of your transistors. All overdrive voltages ($V_{ov}$ or $V_{dsat}$) must be between 0.1 and 0.5 volts.
   - Calculate the values for $g_m$, $r_o$, $I_d$, and $V_{dsat}$ that you will use.
   - Draw a schematic of your design and clearly label all components ($R_1$, $W/L$, ...)
   - Fill in the table with the data about each of your FETs.

specs: Single stage NMOS CS amp
$|A_{o1}| \geq 100 \text{ } \text{V/V} \text{ } f_u = 5 \text{ } \text{GHz} \text{ } C_L=10 \text{pF}$

### Proposed design:

- **$V_{dd}=5V$**
- **For $M_2$, use 10 $M_3$ devices in parallel.**

Unity gain spec:

$$f_u = \frac{g_m}{2\pi C_L}$$

$$\Rightarrow g_m = 3.1415 \text{ } \text{S} < \text{pretty big!}$$

Gain spec:

$$|A_{o1}| = g_m r_o = g_m \left( \frac{r_o}{1+\lambda r_o} \right) = g_m \left( \frac{\lambda_0}{1+\lambda_0} \right)$$

$$\Rightarrow \lambda = 7 \lambda_0 \text{ (Thus } L_1=L_2). \text{ For } L_1=L_2=1\mu m, \lambda = 0.02 \text{ V}^{-1}$$

Then

$$|A_{o1}| = g_m \left( \frac{1}{\lambda r_o} \right) = \frac{I_{d1}}{V_{dsat1}} \text{ where } \frac{1}{V_{dsat1}} = \frac{1}{V_{dsat2}} \lambda \downarrow \text{ Note that you could assume } \lambda \text{ is constant here so you could have used } L=0.3$$

$$\Rightarrow V_{dsat1} = \frac{1}{|A_{o1}| \lambda} = 0.5 \text{ V}$$

$$I_{d1} = \frac{g_m V_{dsat1}}{2} = 78.5 \text{ mA} \Rightarrow \frac{V_{dsat1}}{I_{d1}} = \frac{2I_{d1}}{g_m V_{dsat1}} = 3140$$

Since $V_{dsat}$ must be 0.5V or less, choose $V_{dsat2} = 0.5 V$ to minimize $\frac{W}{L}$

$$\Rightarrow \left( \frac{W}{L} \right)_2 = 2 \left( \frac{W}{L} \right)_1 = 6980 \text{ (since } u_{Cox} = \frac{1}{2} u_{Pox})$$

For simplicity and power/area savings, choose $I_B = \frac{1}{10} I_{d1} = 7.85 \text{ mA}$

$$\Rightarrow \left( \frac{W}{L} \right)_3 = 698 \text{ mA} \Rightarrow R_B = \frac{V_B}{I_B} = \frac{V_{dd}-V_{dsat}}{I_B} = \frac{5V-1V}{7.85 \text{ mA}} = 510 \Omega$$

<table>
<thead>
<tr>
<th>Transistor</th>
<th>$W$</th>
<th>$L$</th>
<th>$V_{dsat}$</th>
<th>$g_m$</th>
<th>$r_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_1$</td>
<td>3140\mu m</td>
<td>1\mu m</td>
<td>0.5V</td>
<td>0.314S</td>
<td>637\Omega</td>
</tr>
<tr>
<td>$M_2$</td>
<td>6980\mu m</td>
<td>1\mu m</td>
<td>0.5V</td>
<td>0.314S</td>
<td>637\Omega</td>
</tr>
<tr>
<td>$M_3$</td>
<td>698\mu m</td>
<td>1\mu m</td>
<td>0.5V</td>
<td>31.4mS</td>
<td>637\Omega</td>
</tr>
<tr>
<td>$R_B$</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>510\Omega</td>
</tr>
</tbody>
</table>

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2. (25pts) For the amplifier shown below,
- Circle and label all differential pairs, current mirrors, gain stages.
- Label the input(s) and the output(s)
- Which devices make up the bias network:

\[ R_j, M6, M4, M5 \]

- Which transistors are in the signal path:

\[ M1AB, M3AB, M2 \]
3) (30pts) For the amplifier below assume that $g_m = 500 \text{microS}$, $R_{o1} = 100\text{kOhm}$, $R_{o2} = 200\text{kOhm}$, $C_{x2} = 1\text{pF}$, $C_{C} = 0.1\text{pF}$. In the top plot draw the magnitude of the impedance $Z_{eq}(\omega)$ seen looking into the capacitor at node $V_{i2}$, and in the lower plot draw the magnitude of the first stage gain, $v_{i1}$ to $v_{i2}$, and the total gain, $v_{i1}$ to $v_{o2}$. LABEL AXES, poles, and magnitudes CLEARLY!
4. (15 points)
A. You have a single stage MOS amplifier with a low frequency gain of 100, a pole frequency of 5MHz, and an output capacitance of 1pF. Calculate the unity gain frequency, the transconductance \( g_m \), and the output resistance \( R_o \).

See plot below which is a general single pole amp system AC response.

Given: \( \mid A_{\text{vol}} \mid \mid g_m \mid R_o \mid = 100 \), \( \omega_p = \frac{1}{R_o C_L} = 2\pi \times 5 \text{ MHz} \), \( C_L = 1 \text{ pF} \)

From plot: \( \Rightarrow R_o = \frac{1}{\omega_p C_L} = 31.8 \text{ k}\Omega \) \( \Rightarrow g_m = \frac{\mid A_{\text{vol}} \mid}{R_o} = 3.14 \text{ mS} \)

\[ \omega_u = \frac{g_m}{C_L} = 3.14 \text{ G rad/s} \Rightarrow f_u = 500 \text{ MHz} \]

B. You need to design a single-stage amplifier with a gain of 5 at 10^9 rad/sec, and a DC gain of 50. Calculate the unity gain frequency, the pole frequency, and the gain at 10^7 rad/sec and 10^{10} rad/sec.

Given: \( \mid A_{\text{vol}} \mid = g_m R_o = 50 \), \( A_{\text{vol}}(10^9 \text{ rad/s}) = 5 \)

From plot: Gain- Bandwidth = constant for single pole amp

\[ \Rightarrow \omega_u = 5 \times 10^9 \text{ rad/s} \Rightarrow f_u = 795.8 \text{ MHz} \]

\[ \omega_p = \frac{\text{GBW}}{A_{\text{vol}}} = 10^8 \text{ rad/s} \]

C. You have a single-stage amplifier with an output resistance of 10^4 Ohms, a transconductance of 10mS, and a unity gain frequency of 10^9 rad/sec. What is the DC gain, the pole frequency, and the output capacitance?

Given: \( R_o = 10^4 \Omega \), \( \omega_u = 10^9 \text{ rad/s} \)

From plot: \( \Rightarrow \mid A_{\text{vol}} \mid = g_m R_o = 10^5 \text{ V/V} \)

\[ \omega_u = \frac{g_m}{C_L} = 10^9 \text{ rad/s} \]

\[ \omega_p = \frac{1}{R_o C_L} = 10^4 \text{ rad/s} \Rightarrow f_p = 1.59 \text{ kHz} \]