1. A first-order RC filter that uses only MOS transistors is shown below. Assume that the AC input signal is small compared to the DC input bias voltage. What W/L ratio is needed for M1 to give a -3 dB frequency of 10 MHz? Ignore all junction and overlap capacitances.

\[ C = C_{gs}(m_2) = C_{ox} \cdot W \cdot L = 3.5 \text{ fF} / \mu m^2 \times 10 \mu m \times 10 \mu m \]

\[ = 350 \text{ fF} \]

\[ m_1 \text{ trade:} \]

\[ R_{on} = \frac{1}{\mu C_{ox} \frac{W}{L} (V_{gs} - V_r)} = \frac{1}{13 \times 10^5 \frac{W}{L} \left[5 - 2 - 1\right] V} \]

\[ = \frac{2.778 \mu m}{W} \]

\[ \text{want:} \frac{1}{2\pi R_{on} C} = 10 \text{ MHz} \Rightarrow R_{on} = 45.5 \text{ k}\Omega \]

\[ \Rightarrow \frac{W}{L} = 0.06 \]
2. Two capacitors \( C_1 \) and \( C_2 \) are needed with a very accurately defined ratio of \( C_1/C_2 = 2.6 \), with the constraint that the maximum area that can be used for \( C_2 \) is 25 \( \mu m^2 \). Draw a top view of the layout of the two capacitors. Show the dimensions of the capacitors on your drawing.

\[ C_1 \quad \text{unit} \]

\[ C_2 = \text{unit} = 5 \mu m \times 5 \mu m \]

\[ C_{1'} = \text{nonunit} \]

\( C_2 = \text{biggest unit cap possible} = 5 \mu m \times 5 \mu m \)

\( C_1 = 1 \text{unit} + 1 \text{non unit} \)

\( C_{1'} = \text{nonunit} \); area = \( wL = 1.6 (25 \mu m^2) = 40 \mu m \)

\[ \frac{\text{for \ area \ (C')}}{\text{area \ (unit)}} = \frac{\text{for \ area \ (unit)}}{w \cdot L} \]

\[ \frac{20 \mu m}{25 \mu m} \Rightarrow \frac{w + l}{4} = 16 \mu m \]

\[ w + l = w + \frac{40}{w} = 16 \Rightarrow w = 12.9 \mu m \]

\[ \frac{40}{w} = 3.1 \mu m \]
3. For the op amp shown below, assume DC biasing places the transistors in the saturation region. (Note: This op amp is slightly different than the standard folded-cascode op amp.)

\[ m_1 = m_2: \frac{W}{L} = \frac{100}{1} \]
\[ m_3 = m_4: \frac{W}{L} = \frac{100}{1} \]

\[ V_{\text{bias}} = -2V \]

\[ V_{\text{out}} \]
\[ C = 5pF \]

\[ V_{\text{id}} \]

\[ R_{\text{out}} = R_{\text{out}} \left(1 + \frac{m_3 R_2}{R_{\text{id}}}\right) = 900k \left[1 + \frac{(100 \mu A)}{100\mu A}\right] = 900k \Omega \]

\[ R_{\text{id}} = \frac{1}{0.02 \times 100 \mu A} = 500k \Omega \]

\[ m_3 \]

\[ m_4 \]

\[ V_{\text{out}} \]

\[ R_{\text{out}} = \left(0.01 \frac{\mu A}{100 \mu A}\right) = 1 \Omega \]

5. a) What is the low-frequency gain? \( v_{\text{out}}/v_{\text{id}} = \)

\[ A_v = \frac{1}{g_m R_{\text{out}}} = \frac{1}{((100 \mu A)/(900k \Omega))} = 522k \]

\[ g_m = \frac{1}{2\sqrt{2}(180 \mu A)(100\mu A)(100\mu A)} = 1100 \mu A/V \]

\[ R_{\text{out}} = \frac{1}{g_m R_{\text{out}}} = \frac{1}{(900k \Omega)(100\mu A)} = 1m \Omega \]

b) What is the positive output slew rate? \( SR^+ = \)

\[ \frac{\Delta V_{\text{out}}}{\Delta t} = \frac{100 \mu A}{50pF} = 2 \times 10^6 \frac{V}{s} \]
c) What is the dominant pole for this op amp? \( p_1 = \)

\[
p_1 = \frac{-1}{R_{SE}C_L} = \frac{-1}{(950 \text{ m}\Omega)(5 \text{ fF})} = -210 \frac{\text{rad}}{\text{s}}
\]

d) Estimate the frequency at which the magnitude of the voltage gain falls to one. Ignore the nondominant poles for this calculation. (This is the GBW.) \( f_u = 17.5 \text{ MHz} \)

\[
|A_v| |p_1| = 1 \cdot \omega_u
\]

\[
(522 \text{ kHz})(210 \frac{\text{ rad}}{\text{s}}) = \omega_u = 110 \text{ MHz} \frac{\text{ rad}}{\text{s}}
\]

\[
\frac{1}{2\pi f_u}
\]

e) Estimate the negative output swing limit.

Negative output swing limit =

can swing down until my ZEES briode (when \( V_{GB}(m4) = V_T = 1V \))

\[
V_o^- = -2V - V_{GB}(m4) = -2V - 1V = -3V
\]
4. A fully differential one-stage op amp with common-mode feedback is shown. The common-mode feedback is provided by M3 and M4. Assume all transistors are saturated, and assume M1 = M2, M3 = M4.

\[\text{\(V_o\)} \begin{array}{c}
\text{100\mu A} \\
\end{array}\]

\[\text{\(V_o\)} \begin{array}{c}
\text{100\mu A} \\
\end{array}\]

\[\text{\(m1=m2: \frac{w}{L}=100\)}\]

\[\text{\(m3=m4\)}\]

\[\text{\(-2.5V\)}\]

\[\text{\(2.5V\)}\]

\[\text{\(V_{gs}\)}\]

\(\text{\(I_{b3} = I_{b4} = 50 \mu A = \frac{1}{2} \left(180 \frac{mV}{V^2}\right) \frac{w}{L} (0 - (-2.5V) - 1V)^2\)}\]

\(\frac{w}{L} = 0.25\)

\[\text{\(v_{od}/v_{id} = \)}\]

\[\text{\(A_v = \frac{q_{m1} v_{os}}{q_{m1} v_{os}} = \sqrt{2(1.98 \frac{mV}{V})(100)(100\mu A)} \times \frac{1}{0.82V^{-1} \times 100\mu A}\)}\]

\(= 950\)
c) For this op amp, estimate the lower limit of the common-mode input voltage.

Lower CM input limit = ____________

\[ V_{in}^- (cm) = -2.5V + V_{DSAT} (m3) + V_e (m1) \]

\[ = -2.5V + \sqrt{\frac{2Id}{\mu COX_n \frac{W}{L_2}}} + \left( V_{TN} + \sqrt{\frac{2Ib}{\mu COX_n \frac{W}{L_1}}} \right) \]

\[ = 2.5V + 1.44V + (1V + 0.11)V \]

\[ = 0.1V \]
5. a) Find the frequency at which the magnitude of the return ratio equals 1 for the circuit below.

\[ \omega = \frac{g_m}{C} \; ; \; C = 2 \, \text{pF} \]

\[ \omega_u = \text{Frequency where } |RR| = 1 \]

\[ N_x = -\frac{1}{j\omega C} \, i_t \]

\[ i_r = g_m N_x \]

\[ i_r = -\frac{g_m}{j\omega C} \, i_t \]

\[ RR = -\frac{i_r}{i_t} = \frac{g_m}{j\omega C} \]

\[ |RR| = 1 = \frac{g_m}{\omega C} \]

\[ \omega = \frac{g_m}{C} \]

\[ C = 2 \, \text{pF} \]
5 (continued)

b) Use Blackman's impedance formula to compute the magnitude of the output impedance at the frequency computed in part (a).

\[ |Z_{out}| = \frac{\sqrt{2}}{g_m} \]

\[ \omega_1 g_m = 0: \quad Z_{out} \leftrightarrow 1 \quad \xi = (2pF \| 12pF) \]

\[ R_R (\text{out shorted}) = 0 \]

\[ R_R (\text{out open}) = \frac{g_m}{j\omega C} = \frac{1}{j} = -j \quad @ \omega' \]

\[ Z_{out} (\omega') = \frac{\frac{1}{j\omega'(1pF) (1 + 0)}}{1 - j} \]

\[ |Z_{out} (\omega')| = \frac{1}{\omega'(1pF)} \left| \frac{1}{1 - j} \right| \]

\[ = \frac{1}{g_m (1pF)} \cdot \frac{1}{\sqrt{2}} \]

\[ = \frac{2}{g_m \sqrt{2}} \quad \text{or} \quad \frac{\sqrt{2}}{g_m} \]

C = 2pF