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.

\[ \frac{\omega}{L} = \frac{10\mu m}{10\mu m} \]

\[ C = C_{gs}(m2) = C_{ox}. W \cdot L = 3.5 fF / \mu m \times 10 \mu m \times 10 \mu m \]

\[ = 350 fF \]

\[ R_{sw} = \frac{1}{\mu C_{ox} \frac{W}{L}(V_{GS} - V_{T})} = \frac{1}{128 \times \frac{W}{L} \frac{V}{V_{T}}[5 - 2 - 1]} \]

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

\[ \text{Want:} \quad \frac{1}{2\pi f_{sw}C} = 10\text{MHz} \quad \Rightarrow \quad R_{sw} = 45.5 k\Omega \]

\[ \omega = 0.061 \]
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.

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

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

\[ C'_1 = \text{nonunit} \]

\[ C'_2 = \text{nonunit} \quad \text{area} = w \times L = 1.6 \left( 25 \, \mu m^2 \right) = 40 \, \mu m^2 \]

\[ \text{want \ } \frac{\text{for} \ (C'_1)}{\text{area}} = \frac{\text{per} \ (\text{unit})}{w \times L} \]

\[ \frac{2w + 2L}{w \times L} = \frac{20 \, \mu m}{25 \, \mu m} \Rightarrow w + L = \frac{40}{25} (40) \frac{1}{2} = 16 \, \mu m \]

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

\[ L = \frac{40}{w} = 3.1 \, \mu m \]
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.)

\[
\begin{align*}
  m_1 = m_2: \frac{W}{L} &= \frac{100}{1} \\
  m_3 = m_4: \frac{W}{L} &= \frac{100}{1}
\end{align*}
\]

\[
\begin{align*}
  V_{\text{bias}} &= -2 \text{V} \\
  V_{\text{out}} &= \frac{5}{100 \mu \text{A}} \\
  V_{\text{id}} &= -5 \text{V}
\end{align*}
\]

\[\text{a) What is the low-frequency gain? } V_{\text{out}}/V_{\text{id}} = \frac{1}{2} g_m R_{\text{out}} = \frac{1}{2} \left( \frac{100 \mu \text{A}}{\text{V}} \right) (950 \text{m} \Omega) = 522 \text{k} \]

\[g_m = \frac{1}{2} \left( \frac{10 \mu \text{A}}{\text{V}} \right) (100) (100 \mu \text{A}) = 1100 \frac{\mu \text{A}}{\text{V}} \]

\[R_{\text{out}} = R_{\text{out}} \left( 1 + \frac{g_m R_2}{g_m} \right) = 900k \left[ 1 + \left( \frac{100 \mu \text{A}}{\text{V}} \right) \text{mA} \right] = 950 \text{m} \Omega \]

\[R_{\text{in}} = \frac{1}{g_m} = 0.02 \text{M} \Omega \]

\[\frac{g_m}{g_m} = \frac{1}{2} \left( \frac{13 \mu \text{A}}{\text{V}} \right) (100) (100 \mu \text{A}) = 1900 \frac{\mu \text{A}}{\text{V}} \]

\[V_{\text{out}} = \left( 0.01 \frac{\mu \text{A}}{\text{V}} \right) (100 \mu \text{A}) = 1 \text{m} \text{A} \]

\[\text{b) What is the positive output slew rate? } \text{SR}^+ = \frac{100 \mu \text{A}}{50 \text{F}} = 2 \times 10^6 \text{V/s} \]
c) What is the dominant pole for this op amp? $p_1 =$

\[ p_1 = \frac{-1}{R_{\text{out}} C_L} = \frac{-1}{(950 \text{mF})(5 \text{F})} = -210 \frac{\text{rad}}{\text{s}} \]

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.) $f_u = \frac{17.5 \text{MHz}}{2}$

\[ 0.9 \cdot |s_1| = 1 \cdot \omega_u \]

\[ 52.22 \times 210 \frac{\text{rad}}{\text{s}} = \omega_u = 110 \text{ Mrad} \frac{\text{s}}{\text{s}} \]

\[ 11 = \frac{2\pi f_u}{2\pi f_u} \]

\[ e) \text{ Estimate the negative output swing limit.} \]

Negative output swing limit =

\[ V_0^{\text{swing down}} = V_0^{\text{peaked at } V_T} = V_T = 1 \text{V} \]

\[ V_0^{\text{swing down}} = -2 \text{V} - V_{GB}(m4) = -2 \text{V} - (-1 \text{V}) = -3 \text{V} \]
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 $M1 = M2$, $M3 = M4$.

![Circuit Diagram]

$m1 = m2: \frac{w}{L} = 100$

$m3 = m4$

a) What should $W/L$ be for $M3$ and $M4$ so that the common-mode output voltage is $0V$?

\[ W/L = \frac{V_{GS}}{V_{DS}} \]

\[ \omega_{acc} = I_{DQ} = 50 \mu A = \frac{1}{2} (180 \mu A) \frac{W}{L} (0 - (-2.5V) - 1V)^2 \]

\[ \frac{W}{L} = 0.25 \]

b) What is the differential-mode (DM) voltage gain?

\[ \frac{V_{OD}}{V_{ID}} = \]

\[ Q_{V} = Q_{M1} V_{DS} = \sqrt{2(180 \mu A)(100)(100 \mu A)} \times \frac{1}{0.02 V^{-1}, 100 \mu A} \]

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

Lower CM input limit =

\[ V_{\text{in}}^{-}(\text{CM}) = -2.5V + V_{\text{DSAT}}(m3) + V_{\text{GS}}(m1) \]

\[ = -2.5V + \sqrt{\frac{2Ib_3}{\mu COXn WC_3}} + \left( V_{TN} + \sqrt{\frac{2Ib_1}{\mu COXn WC_1}} \right) \]

\[ = -2.5V + 1.49V + (1V + 0.11)V \]

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

\[ \omega_n = \text{Frequency where } |RR| = 1 : \quad 0.5 \frac{G \text{ rad}}{\text{sec}} \left( 79.6 \text{ MHz} \right) \]

\[ C = 2 \text{pF} \]

\[ \begin{align*}
N_x &= -\frac{1}{j\omega C} i_t \\
N_x &= -j\frac{g_m N_x}{\omega C} \\
\end{align*} \]

\[ i_r = g_m N_x \]

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

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

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

\[ \omega = \frac{g_m}{C} = \frac{1 \text{ mA}}{2 \text{pF}} = 0.5 \times 10^9 \frac{\text{rad}}{\text{sec}} \]
b) Use Blackman's impedance formula to compute the magnitude of the output impedance at the frequency computed in part (a).

\[ |Z_{\text{out}}| = \quad \text{_____} \]

\[ \omega \text{)} \quad g_m = 0 : \quad Z_{\text{out}} \leftrightarrow 1_p F = (2pF \parallel 12pF) \]

\[ R_{R}(\text{out shorted}) = 0 \]
\[ R_{R}(\text{out open}) = \frac{g_m}{j \omega C} = \frac{1}{j} = -j \theta \omega \]

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

\[ |Z_{\text{out}}(\omega')| = \frac{\omega' (1pF)}{|1 - j|} = \frac{2k\mu}{\sqrt{2}} = 1.4k\mu \]