1. Textbook problem 4.14 (only compute the voltage gain and output resistance; no spice!)

4.12 Determine the unloaded voltage gain $v_o/v_i$ and output resistance for the circuit of Fig. 4.58. Check with SPICE and also use SPICE to plot out the large-signal $V_o/V_i$ transfer characteristic for $V_{sup} = 2.5 V$. Use SPICE to determine the CMRR if the current-source output resistance is 1 MΩ.

4.14 Repeat Problem 4.12 except replace $Q_1$ and $Q_2$ with $n$-channel MOS transistors $M_1$ and $M_2$. Also, replace $Q_3$ and $Q_4$ with $p$-channel MOS transistors $M_3$ and $M_4$. Assume $W_n = 50 \mu$m and $W_p = 100 \mu$m.

For all transistors, assume $L_{down} = 1 \mu$m and $X_d = 0$.

Use Table 2.3 for other parameters.

\[ A_v = G_m R_{out} \]
\[ G_m = 3 \mu \]
\[ R_{out} = R_{o2} || R_{o4} \]

\[ I_{d1} = I_{d2} = I_{d3} = I_{d4} = 50 \mu A \]
\[ L_{drag} = 1 \mu m \]
\[ V_{an} = \frac{L_{drag}}{0.08} = 12.5 \text{ V} \]
\[ V_{ap} = \frac{1}{0.08} = 25 \text{ V} \]
\[ R_{on} = \frac{V_{an}}{I_{d1}} = \frac{12.5}{50 \mu A} = 250 \Omega \]
\[ R_{op} = \frac{V_{ap}}{I_{d4}} = \frac{25}{50 \mu A} = 500 \Omega \]
\[ C_{ox} = \frac{3.9 \times 8.86 \times 10^{-6}}{150 \times 10^{-8}} = 2.3 \times 10^{-7} \text{ F/cm}^2 \]
\[ \mu_{n} L_{ox} = 5 \times 2.3 \times 10^{-7} = 126.5 \mu A/V \]
\[ G_m = \sqrt{2 \mu_{n} \frac{W}{L_{drag}}} I_{d1} \]
\[ = \sqrt{2 \times 126.5 \mu A \times \frac{50 \mu A}{1} \times 50 \mu A} = 79.5 \mu A/V \]
\[ R_{out} = R_{on} || R_{op} = 250 \Omega || 500 \Omega = 167 \Omega \]
\[ \Rightarrow A_v = G_m R_{out} = 79.5 \mu A \times 167 \Omega = 133 \]
2. Textbook problem #4.15 (only compute the voltage gain and output resistance; no spice!)

4.15 Repeat Problem 4.14, but now assuming that 2 kΩ resistors are inserted in series with the sources of \( M_3 \) and \( M_4 \). Ignore the body effect.

\[ V_{\text{out}} = \frac{L_{\text{down}}}{L_d} \]

\[ \text{(ignore } L_d) \]

\[ R_{\text{out}} = R_{\text{up}} \parallel R_{\text{dn}} \]
\[ = R_{\text{up}} [1 + \frac{R_{\text{dn}}}{2k}] \parallel R_2 \]

\[ m_{P_{\text{ox}}} = 250 \times 2.3 \times 10^{-7} = 57.5 \text{ mA/V} \]

\[ j_{ma} = \sqrt{2 m_{P_{\text{ox}}} \frac{W}{L_{\text{eff}}} \frac{I_{d+}}{I_{d+}}} \]
\[ = \sqrt{2 \times 57.5 \mu A \times \frac{100}{1} \times 50 \mu A} \]
\[ = 758 \text{ mA/V} \]

\[ \Rightarrow R_{\text{up}} = R_{\text{dn}} [1 + j_{ma} \times 2k] \]
\[ = 500k \times (1 + 0.758 \times 2) \]
\[ = 1.258 \text{ MΩ} \]

\[ R_{\text{out}} = 1.258 \text{ MΩ} / 250k = 208.5kΩ \]

\[ \Rightarrow AV = G_m R_{\text{out}} = 795 \mu A \times 208.5k = 165.7 \]
3. Textbook problem #4.17 (compute the voltage gain and output resistance)

4.16 Determine the unloaded voltage gain \( v_o/v_i \) and output resistance for the circuit of Fig. 4.59. Neglect \( r_i \). Verify with SPICE and also use SPICE to plot the large-signal \( V_o/V_i \) transfer characteristic for \( V_{sup} = 2.5 \text{V} \).

4.17 Repeat Problem 4.16 except replace the npn and pnp transistors with n-channel and p-channel MOS transistors, respectively. Assume \( W_n = 50 \text{ \mu m} \) and \( W_p = 100 \text{ \mu m} \). For all transistors, assume \( L_{dren} = 1 \text{ \mu m} \) and \( X_d = 0 \). Let \( I_{TAIL} = 100 \text{ \mu A} \). Ignore the body effect. Use Table 2.3 for other parameters.

\[
\begin{align*}
A_v &= Gm R_{out} \\
Gm &= gm_1 = gm_n \\
R_{out} &= R_{up} \parallel R_{dl} \\
&= (gm_6 R_{ob} R_{os}) \parallel (gm_4 R_{oa} R_{oe})
\end{align*}
\]

(All parameters are same as previous problems)

\[
\Rightarrow R_{out} = (758 \text{m} \times 500 \text{k} \times 500 \text{k}) \parallel (758 \text{m} \times 250 \text{k} \times 50 \text{k}) = 0.4 \text{ M} \Omega
\]

\[
\Rightarrow A_{v} = \frac{879.5 \text{m} \times 0.4 \text{ M}}{= 313.23}
\]

Figure 4.59 Cascode active-load circuit for Problem 4.16.
4. Textbook problem #6.11 (part a) only

6.11 Draw a two-stage op amp similar to the op amp in Fig. 6.16 except reverse the polarity of every transistor. For example, the resulting op amp should have an n-channel input pair. Calculate the following parameters: (a) low-frequency voltage gain, (b) output swing, (c) systematic input offset voltage assuming (6.66) is satisfied, (d) common-mode rejection ratio, (e) common-mode input range, and (f) low-frequency power-supply rejection ratio from both supplies.

\[
A_v = -\left( G_m \cdot R_{out1} \right) \left( G_m \cdot R_{out2} \right) \\
= -g_m \left( r_o + r_o \right) \cdot g_m \left( r_o + r_o \right)
\]

Figure 6.16 More detailed schematic diagram of a typical two-stage CMOS operational amplifier.
5. Textbook problem #6.15 (compute only the bias currents and voltage gain; ignore everything in the problem after: "...at the operating point.")

6.15 Calculate bias currents and the low-frequency small-signal voltage gain for the CMOS op amp of Fig. 6.58. Use the parameters given in Table 2.4, and assume that \( \frac{dX_d}{dV_{DS}} = 0.04 \mu m/V \) for all the transistors at the operating point.

**Calculate the input common-mode range assuming that the wells of \( M_1 \) and \( M_2 \) are connected to their common-source point. Calculate the low-frequency gain from each supply to the output. Check these calculations with SPICE simulations.**

\[
V_{DD} = 1.5 \text{ V}
\]

\[
\text{Left} = L_{down} = 0.4 \text{ cm}^2/V_s, \quad \text{Min} = 450, \quad \mu_p = 15 \text{ cm}^2/V_s
\]

\[
C_{ox} = 8 \times 10^{-9} \text{ cm}^2 = 8 \times 10^{-8} \text{ cm}^2
\]

\[
C_{ox} = \frac{E_{ox}}{E_{ox}} = \frac{3.9 \times 8.86 \times 10^{-14}}{8 \times 10^{-8}} = 0.432 \mu F/\text{cm}^2
\]

\[
M_{n} C_{ox} = 450 \times 0.432 \mu F = 194 \text{ mA/V}
\]

\[
M_{p} C_{ox} = 150 \times 0.432 \mu F = 64.8 \text{ mA/V}
\]

\[
V_{an} = \left( \frac{\text{Left}}{\frac{dX_d}{dV_{DS}}} \right) = \frac{0.4}{0.04} = 10 = V_{an}
\]

\[
\Gamma_{02} = \left( \frac{V_{a}}{I_{P2}} \right) = \frac{10}{100 \mu A} = 100 \Omega
\]

\[
\Gamma_{06} = \frac{10}{2 \cdot 100 \mu A} = 50 \text{ K}\Omega
\]

\[
J_{m1} = \sqrt{2 M_{p} C_{ox} \cdot \frac{150}{1} \times 100 \mu A}
\]

\[
= \sqrt{2 \times 64.8 \mu A \times 150 \times 100 \mu A} = 1394 \text{ mA/V}
\]

\[
J_{m6} = \sqrt{2 M_{n} C_{ox} \cdot \frac{100}{1} \times 100 \mu A}
\]

\[
= \sqrt{2 	imes 194 \mu A \times 100 \times 100 \mu A} = 2786 \text{ mA/V}
\]

\[
\Rightarrow A_{V} = -1394 \mu A \frac{100 \text{ K}}{2} \times 2786 \mu A \times \frac{50 \text{ K}}{2}
\]

\[
= -4855
\]