1) 8.1

8.1 Referring to Fig. 8.1, \( V_{DD} = 1.3 \text{ V} \),
\[ I_0 = I_{IREF} = 100 \mu\text{A}, \quad L = 0.5 \mu\text{m}, \quad W = 5 \mu\text{m}, \quad V'_A = 5 \text{ V}/\mu\text{m}, \quad V_t = 0.4 \text{ V}, \quad k'_p = 500 \mu\text{A}/\text{V}^2 \]
\[ I_0 = I_D = \frac{1}{2} k'_p \left( \frac{W}{L} \right) V'_{ov}^2 \]
\[ V_{ov} = \sqrt{\frac{2 I_D}{k'_p \left( \frac{W}{L} \right)}} \]
\[ = \sqrt{\frac{2 \times 100 \mu\text{A}}{500 \mu\text{A}/\text{V}^2 \times 0.5}} = 0.2 \text{ V} \]
\[ V_{DS} = V_{GS} = V_t + V_{ov} = 0.4 + 0.2 = 0.6 \text{ V} \]
\[ R = \frac{V_{DD} - V_{GS}}{I_{REF}} = 1.8 - 0.6 \quad 0.1 \text{ mA} = 12 \text{ k}\Omega \]
The lowest \( V_O \) will be
\[ V_{DSS} = V_{ov} = 0.2 \text{ V} \]
\[ R_D = r_o = \frac{V_{in}}{I_D} = \frac{5 \text{ V}/\mu\text{m} \times 0.5 \mu\text{m}}{100 \mu\text{A}} = 25 \text{ k}\Omega \]
\[ \Delta I_D \approx \frac{\Delta V_D}{r_o} = \frac{0.5 \text{ V}}{25 \text{ k}\Omega} = 20 \mu\text{A} \]

2) 8.2

8.2 Refer to Fig. 8.1.
\[ \frac{\Delta I_o}{I_o} = 10\% \]
\[ \Delta I_o = 0.1 \times 150 = 15 \mu\text{A} \]
\[ \Delta V_o = 1.8 - 0.3 = 1.5 \text{ V} \]
\[ r_o = \frac{\Delta V_o}{\Delta I_o} = \frac{1.5 \text{ V}}{15 \mu\text{A}} = 100 \text{ k}\Omega \]
But
\[ r_o = \frac{V_A}{I_o} = \frac{V'_A L}{I_o} \]
\[ 100 = \frac{10 \times L}{0.15} \rightarrow L = 1.5 \mu\text{m} \]
\[ \Rightarrow V_A = 15 \text{ V} \]
\[ V_{ov} = V_{DSS} = 0.3 \text{ V} \]
\[ V_{GS} = V_t + V_{ov} = 0.5 + 0.3 = 0.8 \text{ V} \]
\[ I_0 = \frac{1}{2} k'_p \left( \frac{W}{L} \right) V_{ov} \left( 1 + \frac{V_{GS}}{V_A} \right) \]
\[ = \frac{1}{2} \times 400 \times \frac{W}{L} \times 0.69 \left( 1 + \frac{0.8}{15} \right) \]
\[ \Rightarrow \frac{W}{L} = 7.91 \]
\[ W = 7.91 \times 1.5 = 11.9 \mu\text{m} \]
\[ R = \frac{V_{DD} - V_{GS}}{I_{REF}} = \frac{1.8 - 0.8}{0.15} = 6.7 \text{ k}\Omega \]

3) 8.3

8.3

Set \( |V_{ov}| = V_{DD} - V_{Dmax} \)
\[ = 1.3 - 1.1 = 0.2 \text{ V} \]
\[ V_G = V_{DD} - |V_p| - |V_{ov}| \]
\[ = 1.3 - 0.4 - 0.2 = 0.7 \text{ V} \]
\[ R = \frac{V_G}{I_{D1}} = \frac{0.7 \text{ V}}{80 \mu\text{A}} = 8.75 \text{ k}\Omega \]
\[ I_D = \frac{1}{2} \mu_p C_{ov} \left( \frac{W}{L} \right) |V_{ov}|^2 \]
thus
\[ \frac{W}{L} = \frac{2 I_D}{\mu_p C_{ov} |V_{ov}|^2} = \frac{2 \times 80 \mu\text{A}}{80 \mu\text{A}/\text{V}^2 \times 0.2^2} = 50 \]
4) 8.5

8.5 Referring to Fig. P8.5, we obtain

\[ V_{GS1} = V_{GS2} \text{ so that } \frac{I_{D2}}{I_{D1}} = \frac{(W/L)_2}{(W/L)_1} \text{ and } \]
\[ I_{D2} = I_{REF} \frac{(W/L)_2}{(W/L)_1} \]
\[ I_{D1} = I_{D2} \]

8.6 Refer to the circuit of Fig. P8.6. For \( Q_2 \) to operate properly (i.e., in the saturation mode) for drain voltages as high as \(+0.8\) V, and provided its width is the minimum possible, we use

\[ |V_{OV}| = 0.2 \text{ V} \]

Note that all three transistors \( Q_1 \), \( Q_2 \), and \( Q_3 \) will be operated at this value of overdrive voltage. For \( Q_1 \),

\[ I_{D1} = I_{REF} = 20 \mu\text{A} \]

\[ I_{D1} = \frac{1}{2} \mu p C_{ox} \left( \frac{W}{L} \right)_1 |V_{OV}|^2 \]

\[ 20 = \frac{1}{2} \times 100 \times \left( \frac{W}{L} \right)_1 \times 0.04 \]

\[ \Rightarrow \left( \frac{W}{L} \right)_1 = 10 \]

For \( L = 0.5 \mu\text{m} \),

\( W_1 = 5 \mu\text{m} \)

Now, for

\[ I_2 = 100 \mu\text{A} = 5I_{REF}, \text{ we have} \]

\[ \left( \frac{W}{L} \right)_2 = 5 \]

\[ \Rightarrow \left( \frac{W}{L} \right)_2 = 5 \times 10 = 50 \]

\( W_2 = 50 \times 0.5 = 25 \mu\text{m} \)

For

\[ I_3 = 40 \mu\text{A} = 2I_{REF}, \text{ we obtain} \]

\[ \left( \frac{W}{L} \right)_3 = 2 \]

\[ \Rightarrow \left( \frac{W}{L} \right)_3 = 20 \]

\( W_3 = 10 \mu\text{m} \)

We next consider \( Q_4 \) and \( Q_5 \). For \( Q_4 \) to operate in saturation with the drain voltage as low as \(-0.8\) V, and for it to have the minimum possible \( W/L \), we operate \( Q_5 \) at

\[ V_{OV} = 0.2 \text{ V} \]

This is the same overdrive voltage at which \( Q_4 \) will be operating. Thus, we can write for \( Q_4 \),

\[ I_4 = I_3 = 40 \mu\text{A} \]

and using

\[ I_{D4} = \frac{1}{2} \mu p C_{ox} \left( \frac{W}{L} \right)_4 |V_{OV}| \]

\[ 40 = \frac{1}{2} \times 400 \times \left( \frac{W}{L} \right)_4 \times 0.2^2 \]

\[ \Rightarrow \left( \frac{W}{L} \right)_4 = 5 \]

\( W_4 = 2.5 \mu\text{m} \)

Finally, since

\[ I_5 = 80 \mu\text{A} = 2I_{REF} \]

\[ \left( \frac{W}{L} \right)_5 = 2 \left( \frac{W}{L} \right)_4 \]

\[ \Rightarrow \left( \frac{W}{L} \right)_5 = 10 \]

\( W_5 = 5 \mu\text{m} \)

To find the value of \( R \), we use

\[ R = \frac{1}{I_{REF}} \left| V_{GS1} \right| \]

\[ = 0.5 + 0.2 = 0.7 \text{ V} \]

\[ R = \frac{0.3 \text{ V}}{0.02 \text{ mA}} = 15 \text{ k}\Omega \]

The output resistance of the current source \( Q_2 \) is

\[ r_{ds} = \frac{|V_{GS1}|}{I_2} = \frac{|V_{GS1}| \times L}{I_2} \]

\[ = \frac{5 \times 0.5}{0.1 \text{ mA}} = 25 \text{ k}\Omega \]

The output resistance of the current sink \( Q_5 \) is

\[ r_{ds} = \frac{V_{REF}}{I_5} = \frac{V_{GS} \times L}{I_5} \]

\[ = \frac{5 \times 0.5}{80} = 0.3125 \text{ k}\Omega \]