1. A current is needed that is three times the reference current $I_1$: that is, $I_3/I_1 = 3$. Which of the two circuits shown will give a more accurate current ratio, assuming all transistors are saturated and have the same $V_{DS}$? Why?

(a) Circuit B is better.

(b) Why?

\[ A: \quad \frac{I_3}{I_1} = \frac{2W - 2W}{L - L} = 3 \]

\[ B: \quad \frac{I_3}{I_1} = \frac{3 \cdot \frac{W - 2W}{L - L}}{W - 2W} = 3 \]

Use unit devices for good matching.
2. An all-transistor sample-and-hold circuit is shown below. MC is being used as the sampling capacitor, and M1 is acting as the sampling switch. Assume both transistors have \( W = 20\mu m \) and \( L = 1\mu m \).

\[
\begin{align*}
V_{in} & \quad \downarrow \quad m1 \quad \downarrow \quad V_{o} \quad \downarrow \quad \phi \\
\downarrow \quad mc \quad \downarrow \quad \phi \\
\phi \quad \downarrow \quad 4V \\
\phi \quad \downarrow \quad 0V
\end{align*}
\]

(4) a) To give a large sampling capacitance, MC must operate in the triode region. For what range of \( V_o \) is MC triode? And what is the capacitor value when MC is triode?

\[
V_o \text{ range: } V_o > 1V \\
V_{ds} < V_{gs} - V_T \\
0 < V_o - V_T \\
\Rightarrow V_o > V_T = 1V
\]

\[
c = \frac{70 \ \text{fF}}{}
\]

\[
c = C_{gs} = \omega L \cdot C_{ox}
\]

\[
= 20 \times 1 \times 3.5 \ \text{fF}
\]

\[
= 70 \ \text{fF}
\]

(2) b) What is the range of \( V_{in} \) for which M1 will act as a switch?

\[
V_{in} \text{ range: } -1 < V_{in} < 3V
\]

M1 on : \( V_{\phi} - V_{in} > V_T \Rightarrow V_{in} < V_{\phi} - V_T = 4 - 1 = 3V \)

M1 off when \( V_{\phi} = 0 \) for \( V_{in} > -1 \) V
3. A new version of a two-stage opamp is shown below. Use \( W/L = 100 \) and \( I_D = 100\mu A \) for each transistor.

![Circuit Diagram]

(1) Label the + and - inputs of the op amp on the schematic. They are now labeled inA and inB.

(2) What is the low-frequency op-amp gain? \( \alpha = \frac{6.29 \times 10^5}{10.6} \)

\[
\alpha = g_{m2} \cdot (Y_{02} + Y_{04}) \cdot (g_{m6} + g_{m5}) \cdot (Y_{06} + Y_{05})
\]

\[
g_{m2} = g_{m5} = \sqrt{2} K_T \left( \frac{W}{L} \right) I_D = 1897 \ \text{mAM} \ \text{V}^{-1}
\]

\[
g_{m6} = \sqrt{2} K_P \left( \frac{W}{L} \right) I_D = 1095 \ \text{mAM} \ \text{V}^{-1}
\]

\[
Y_{02} = Y_{05} = \frac{1}{\lambda m I_D} = 5 \times 10^5 \ \Omega
\]

\[
Y_{04} = Y_{06} = \frac{1}{\lambda p I_D} = 10^6 \ \Omega
\]

\[
\alpha = 1897 \cdot (5 \times 10^5 \cdot 10^6) \cdot (1897 + 1095) \cdot (5 \times 10^5 \cdot 10^6) \times 10^{-12}
\]

\[
= 6.29 \times 10^5
\]
c) A design engineer is considering connecting a Miller compensation capacitor from the opamp output to the source of M7. Will this work? Why or why not?

No.

Source follower M7 blocks feedback current from Cc and feedforward current flows thru Cc \(\Rightarrow\) both bad!
4. A simplified, fully differential opamp is shown below. Assume common-mode feedback (not shown) is applied to control the CM output voltage. Assume all transistors are saturated, and all transistors have W/L = 100 and I_D = 100 \mu A.

![Circuit Diagram]

\[ V_{od}/V_{id} = 2.077 \times 10^6 \]

\[ \frac{V_{od}}{V_{id}} = g_{m1} \left( \frac{V_{od}}{V_{m5}} \right) \cdot g_{m6} \cdot R_{o6} \left( 1 + g_{m8} \cdot R_{o6} \right) \]

\[ \approx g_{m1} \cdot g_{m8} \cdot R_{o6} \cdot R_{o8} \]

\[ = 2.077 \times 10^6 \]
b) What value of \( V_B \) will maximize the positive voltage swing at each output while keeping all transistors saturated?

\[
V_B = 1.14 \, V
\]

\[
V_B = V_{DD} - |V_{os5}| - |V_{os7}| - |V_T7|
\]

\[
|V_{os5}| = |V_{os7}| = \sqrt{\frac{2I_p}{M_i C_ox (W/L)}} = 0.18 \, V
\]

\[
V_B = 2.5 - 0.18 - 0.18 - 1 = 1.14 \, V
\]

c) Assume that the opamp is being used in a feedback circuit. To achieve acceptable phase margin in that feedback circuit, it is desired that the DM voltage gain of the opamp have -135 degrees of phase shift when the magnitude of the opamp gain equals 2. Assuming \( C_p = 0.1 \, \text{pF} \) and \( C_L \) are the only capacitors, what \( C_L \) is needed? Assume \( C_L \) sets the dominant pole.

\[
C_L = \frac{86 \, \text{fF}}{Z}
\]

\[
A_{V0} \cdot |P_1| = 2 \cdot |P_2|
\]

\[
A_{V0} = g_{m1} \cdot \left( \frac{1}{g_{m3}} \right) \cdot g_{m6} \cdot R_0
\]

\[
|P_1| = \frac{1}{R_0 \cdot C_L}, \quad |P_2| = \frac{g_{m3}}{C_p}
\]

\[
g_{m1} \cdot \left( \frac{1}{g_{m3}} \right) \cdot g_{m6} \cdot R_0 \cdot \frac{1}{R_0 \cdot C_L} = Z \cdot \frac{g_{m3}}{C_p}
\]

\[
\Rightarrow C_L = \frac{C_p}{Z} \cdot \frac{g_{m1}}{g_{m6}} = \frac{C_p}{Z} \cdot \sqrt{\frac{2 \cdot k_n (W/L) \cdot I_g}{2 \cdot k_p (W/L) \cdot I_g}} = \frac{C_p}{Z} \cdot \sqrt{\frac{k_n}{k_p}}
\]

\[
= \frac{C_p}{Z} \cdot \sqrt{3} = 86 \, \text{fF}
\]
d) Assume $C_L = 5 \text{ pF}$ (ignore your answer to part c). What is the positive output slew rate?

$$\text{SR}^+ = \frac{\text{d}v_{od}}{\text{d}t^+} = \frac{40 \times 10^6}{\text{V/s}}$$

$$\text{SR}^+ = \frac{2 \cdot I_P}{C_L} = \frac{2 \cdot 10^6 \times 10^{-6}}{5 \times 10^{-2}} = 40 \times 10^6 \text{ V/s}$$

---

e) What is upper limit of the common-mode input voltage?

$$V_{in(CM)}^+ = 2.32 \text{ V}$$

$$V_{in(CM)}^+ = V_{DD} - |V_{GS3}| + V_T1$$

$$= 2.5 - |V_{OH}| - |V_{T3}| + V_T1$$

$$= 2.32 \text{ V}$$
5. A feedback circuit is shown below. Assume the transistor is saturated. Do all return-ratio calculations with respect to the voltage-controlled voltage controlled source \( (1 \cdot V_x) \).

In this problem, \( \text{RR} \) stands for 'Return Ratio'.

\[
\text{a) What is the RR for } (1 \cdot V_x)? \text{ RR } = 948.5
\]

\[
\text{RR} = 1 - \frac{g_m}{1 + g_m R} \cdot V_0 \left( 1 + g_m R \right) = g_m V_0 = 948.5
\]
b) What is the closed loop gain $A_{CL} = \frac{v_o}{v_{in}} = \frac{1}{\phantom{0}}$?

$$A_{CL} = A_{v0} \cdot \frac{RR_{open}}{1 + RR_{open}}$$

$$A_{v0} = 1, \quad RR_{open} = g_m R_o$$

$$A_{CL} = 1 \cdot \frac{g_m R_o}{1 + g_m R_o} \approx 1$$

---

4) What is the closed-loop output resistance $R_o = 100 \, \text{k}\Omega$?

$$A = 0$$

$$Z_{out} = R_o = g_m R_o \cdot R$$

$A \neq 0$ & Output short

$$RR_{short} = - \frac{S_r}{S_t} = 0$$

$A \neq 0$ & Output open

$$RR_{open} = g_m R_o$$

$$R_{ocl} = Z_{out} \cdot \left( \frac{1 + RR_{short}}{1 + RR_{open}} \right)$$

$$= g_m R_o \cdot R \cdot \frac{1 + g_m R_o}{1 + g_m R_o}$$

$$\approx R = 100 \, \text{k}\Omega$$