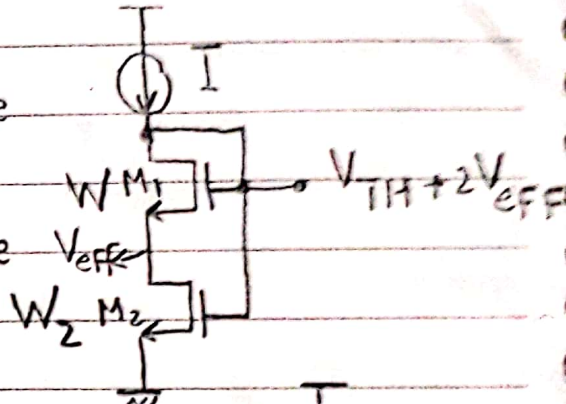
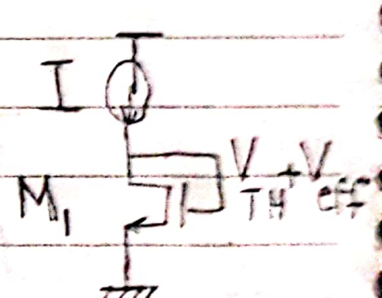
Problem Set: Advanced Current Mirrors

Problem 1:

The circuit shown is used to bias a low-voltage (high-swing) cascode current mirror. Show that $W_2 = \frac{1}{3}W$ to generate the required bias voltage $V_{Th} + 2V_{eff}$



Solution



→ M_2 is in triode region

$$\underset{\text{sat.}}{I_{M_1}} = \overset{\text{triode}}{I_{M_2}}$$

$$\frac{1}{2}\cancel{\mu_n C_{ox}}\frac{W}{\cancel{L}}(\cancel{V_{Th}}+V_{eff}-\cancel{V_{Th}})^2 = \cancel{\mu_n C_{ox}}\frac{W_2}{\cancel{L}}\left[(\cancel{V_{Th}}+2V_{eff}-\cancel{V_{Th}})V_{eff}-\frac{V_{eff}^2}{2}\right]$$

$$\frac{1}{2}W\cancel{V_{eff}^2} = \frac{3}{2}W_2\cancel{V_{eff}^2}$$

$$\boxed{W_2 = \frac{1}{3}W}$$

Problem 2:

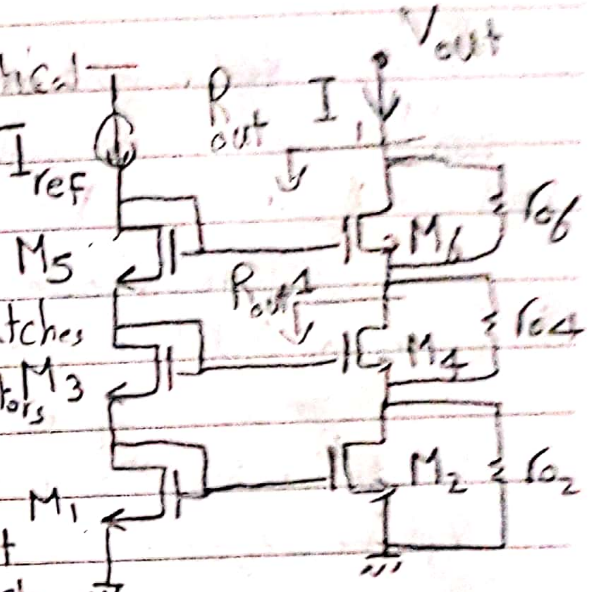
Assuming all transistors are identical

Find: A. R_{out}

B. Compliance Voltage of the current source

C. Assuming random mismatches between matched transistors (V_{os}) Find $\frac{\Delta I_1}{I_{ref}}$

(Consider only the most dominant mismatch



Solution

$\boxed{A}$ $R_{out_1} = g_{m4} r_{o4} r_{o2} + r_{o2} + r_{o4}$

$R_{out} = g_{m6} r_{o6} R_{out_1} + R_{out_1} + r_{o6}$

$\simeq g_{m6} r_{o6} g_{m4} r_{o4} r_{o2}$

$\boxed{B}$ $V_{Comp.} = 3V_{eff} + 3V_{Th} - V_{Th} = 3V_{eff} + 2V_{Th}$

$\boxed{C}$ Assuming V_{os_1} mismatch between M_1 & M_2

$I_{ref} = \frac{K_n}{2}(V_{GS_1} - V_{Th})^2$

$I_1 = \frac{K_n}{2}(V_{GS_1} + V_{os_1} - V_{Th})^2$

$= \frac{K_n}{2}\left[(V_{GS_1} - V_{Th})^2 + 2V_{os_1}V_{eff} + \cancel{V_{os}^2}\right]$

$I_1 = I_{ref} + K_n V_{eff} V_{os_1}$

$I_1 = I_{ref} + g_m V_{os_1}$

$\therefore \frac{I_1 - I_{ref}}{I_{ref}} = \frac{g_m V_{os_1}}{I_{ref}} = \frac{2\cancel{I_{ref}}/V_{eff}\; V_{os_1}}{\cancel{I_{ref}}}$

$= \boxed{\frac{2V_{os_1}}{V_{eff}}}$

In general $\Delta I_{total} = \sqrt{(\Delta I_1)^2 + (\Delta I_2)^2 + (\Delta I_3)^2}$

Problem 3:

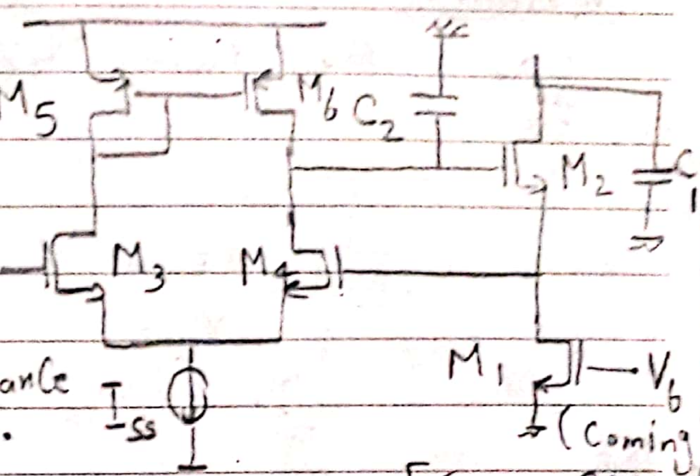
In the shown circuit (self regulated current source)

Find 1. R_{out} @ DC

2. Compliance Voltage V_c of the current source

3. V_c for optimum compliance

4. $Z_{out}(F)$



Assuming ideal I_{ss} (Can accept -ve Voltage on upper terminal)

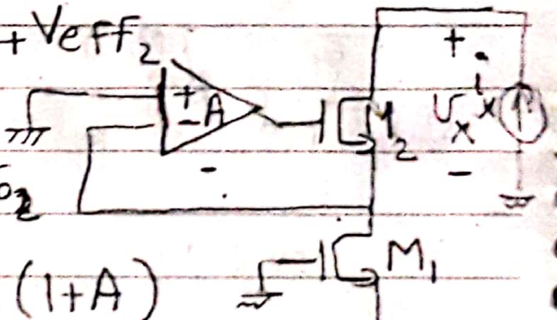
Solution

2. $V_{Comp.} = V_C + V_{eff_2}$

3. For optimum Compliance, $V_C = V_{eff_1}$

$\therefore V_{Comp.} = V_{eff_1} + V_{eff_2}$

1.

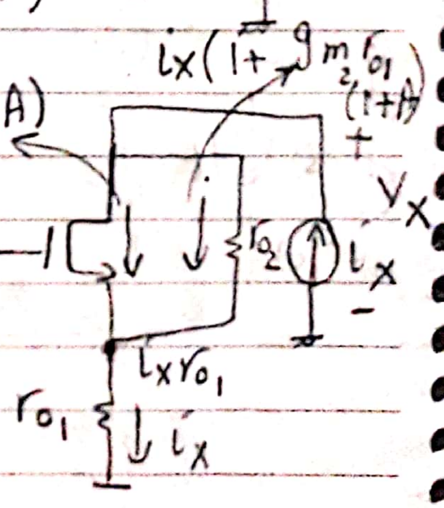


$$V_x = i_x r_{o_1} + i_x\left(1 + g_{m_2} r_{o_1}(1+A)\right) r_{o_2}$$

$$R_{out} = \frac{V_x}{i_x} = r_{o_1} + r_{o_2} + g_{m_2} r_{o_2} r_{o_1}(1+A)$$

$$R_{out} \simeq g_{m_2} r_{o_2} r_{o_1}(1+A)$$

$$A = g_{m_3}(r_{o_3} // r_{o_5})$$



4. $A(s) = g_{m_3}\left(\frac{1}{sC_2} // r_{o_3} // r_{o_5}\right)$

$$= g_{m_3} \cdot \frac{(r_{o_3} // r_{o_5}) * \frac{1}{sC_2}}{(r_{o_3} // r_{o_5}) + \frac{1}{sC_2}}$$

$$= g_{m_3} \cdot (r_{o_3} // r_{o_5}) \frac{1}{1 + sC_2(r_{o_3} // r_{o_5})}$$

$$Z_{out}(s) \simeq \left[g_{m_2} r_{o_2} r_{o_1}(1 + A(s))\right] // \frac{1}{sC_1}$$

Problem (4):

For the Wilson current mirror shown:

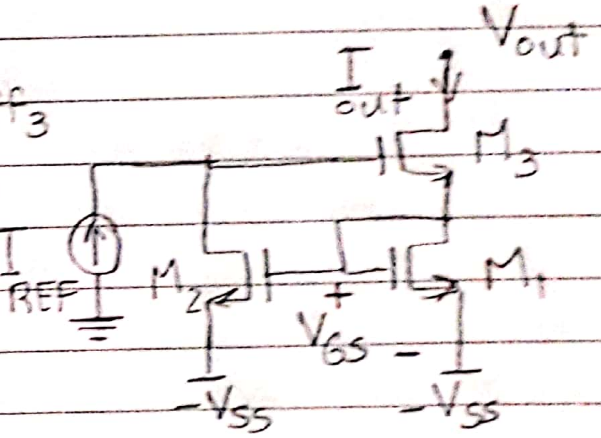
1) Find an expression for $V_{Compliance}$ and R_{out}
2) Does the current mirror suffer from systematic offset? Explain

Solution

1) $V_{Compliance} = V_{GS_1} + V_{eff_3}$

$= 2V_{GS} - V_{th}$

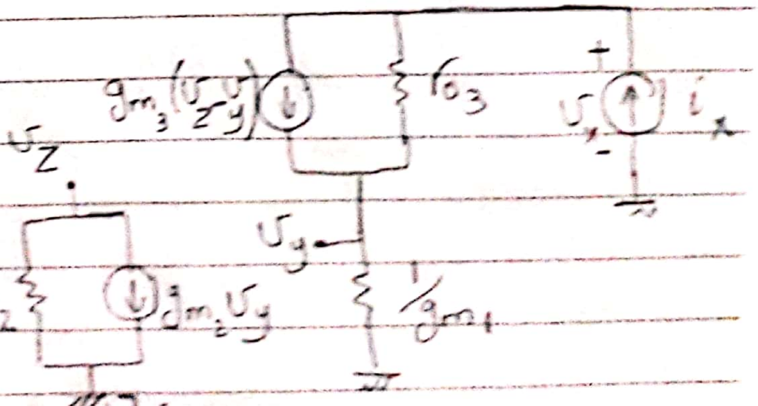
(if M_1 and M_3 have the same V_{GS})



R_{out}:

$$v_y = \frac{i_x}{g_{m_1}}$$

$$v_z = -g_{m_2} r_{o_2} v_y = \frac{-g_{m_2} r_{o_2}}{g_{m_1}} i_x$$



$$v_x = v_y + \left[i_x - g_{m_3}(v_z - v_y)\right] r_{o_3}$$

$$= \frac{i_x}{g_{m_1}} + \left[1 + \frac{g_{m_3}}{g_{m_1}}(g_{m_2} r_{o_2} + 1)\right] i_x r_{o_3}$$

$$R_{out} = \frac{v_x}{i_x} \simeq \frac{g_{m_3}}{g_{m_1}} g_{m_2} r_{o_2} r_{o_3}$$

2) Yes, $V_{DS_1} \neq V_{DS_2}$.

$V_{DS_1} = V_{GS_1}$

$V_{DS_2} = V_{GS_1} + V_{GS_3}$ $\longrightarrow$ $I_{out} = \frac{W_1}{W_2} I_{REF} \frac{(1 + \lambda V_{GS_1})}{\left[1 + \lambda(V_{GS_1} + V_{GS_3})\right]}$