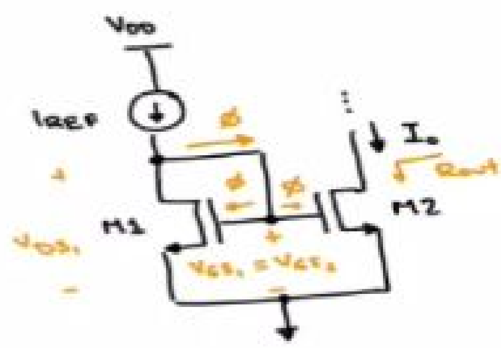
Basic MOSFET Current Mirror



$\equiv$

NOTE:
Assume transistors are matched:
$V_{t_1} = V_{t_2}$
$(\mu_n C_{ox})_1 = (\mu_n C_{ox})_2$

Two important parameters to determine performance of current source
- Accuracy (current transfer ratio : I_o / I_{REF})
- R_{out} (ideally $R_{out} = \infty$, I_o indep. of loading conditions)

M1 forced into saturation ($V_{DS_1} = V_{GS_1} > V_{GS_1} - V_t$)

$$I_{D1} = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)_1 (V_{GS} - V_t)^2 = I_{REF}$$

M2 has same V_{GS} as M1, and therefore, as long as $V_{DS_2} \geq V_{GS} - V_t$

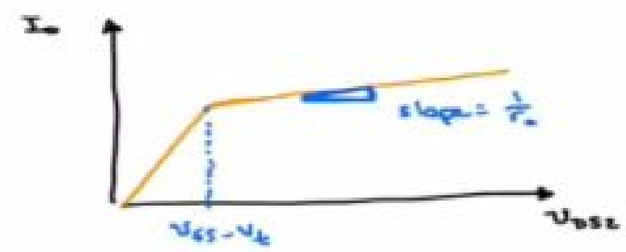
$$I_{D2} = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)_2 (V_{GS} - V_t)^2 = I_o$$

$$\frac{I_o}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1}$$

Note: More accurate than BJT mirror due to gate current = $\emptyset$

$$R_{out} = r_{o_2} = \frac{1}{\lambda V_{DS_2}} = \frac{V_A}{V_{DS}}$$

Effects of V_{DS} and r_o in I_o

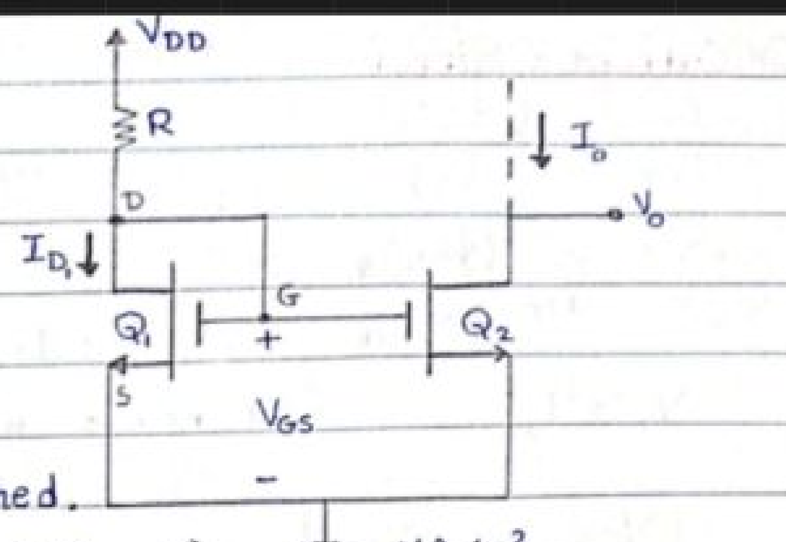


Modeling of finite r_o into I_o eq:

$$\frac{I_o}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1} \cdot \frac{(1 + \lambda V_{DS_2})}{(1 + \lambda V_{DS_1})}$$

EX (8.1) Page (536)

$V_{DD} = 3\text{ V}$
$I_{ref} = 100\ \mu A$
$I_{o\,nominal} = 100\ \mu A$



1. find R if Q_1, Q_2 are matched.
   $L = 1\ \mu m$, $W = 10\ \mu m$, $V_t = 0.7\text{ V}$, $k_n' = 200\ \mu A/V^2$
2. What is the lowest value of V_o? $V_{o\,min}$
3. $V_A' = 20\text{ V}/\mu m$, find the o/p resistance of the current source.
4. find the change in o/p current when $\Delta V_o = 1\text{ V}$.

$\because$ Q_1 & Q_2 are matched
$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2$ $\qquad$ $I_{o\,nominal} = I_{ref}$

$$I_{D_1} = I_{ref} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 V_{ov}^2$$

$$100\,\mu = \frac{1}{2} * 200\,\mu \left(\frac{10}{1}\right) V_{ov}^2 \qquad \boxed{V_{ov} = 0.316\text{ V}}$$

$$V_{DD} - \underbrace{V_{GS}}_{V_{ov} + V_t} = \underbrace{I_{ref}}_{I_{D_1}} R \qquad R = \frac{3 - (0.316 + 0.7)}{100\,\mu}$$

$$\boxed{R = 20\text{ K}\Omega}$$

$\because$ $V_{o\,min} = V_{ov}$ $\qquad$ $\boxed{V_{o\,min} = 0.316\text{ V}}$

$$\because r_{o_2} = \frac{V_A}{I_{o\,nominal}} \qquad V_A = V_A' L = 20 * 1 = 20\text{ V}$$

$$r_{o_2} = \frac{20}{100\,\mu} \qquad \boxed{r_{o_2} = 200\text{ K}\Omega}$$

$$\because \Delta I_o = \frac{\Delta V_o}{r_{o_2}} = \frac{1}{200\text{ K}} \qquad \boxed{\Delta I_o = 5\ \mu A}$$

Exercise (8.1) Page (536)

In Current source of Ex(8.1), require to reduce ΔI_o when $\Delta V_o = 1V$ to 1% of I_o.

- What should the dimensions of Q_1 & Q_2 be Changed to ?
  Q_1 & Q_2 are remain matched

$$I_{o\,nominal} = 100\,\mu A$$

$$\Delta V_o = 1V \longrightarrow \Delta I_o = 5\,\mu A$$

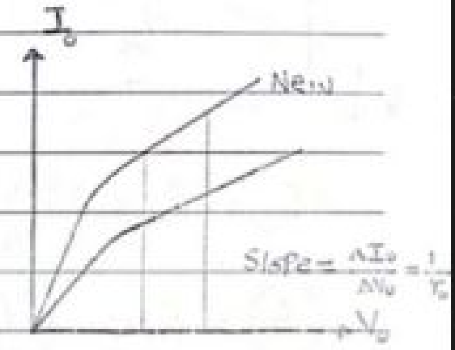
$$\Delta V_o = 1V \longrightarrow \Delta I_{o\,New} = 1\,\mu A$$

$\Delta I_o \downarrow 5$ times $\longrightarrow$ Slope $\downarrow 5$ time

$\therefore$ Slope$_{new}$ < Slope

$r_{o2\,new} > r_{o2}$

$$\boxed{r_{o2\,new} = 5\,r_{o2}}$$



$R \propto L$ $\quad R = \rho\frac{L}{A} \longleftarrow$ R هتزيد 5 أضعاف عن زيادة Length $\longleftarrow$

$$L_{new} = 5\,L$$

$$\frac{V_A' L_{new}}{I_{o\,nominal}} = \frac{5 V_A' L}{I_{o\,nominal}} \qquad L_{new} = 5L$$

$$\boxed{L_{new} = 5(1)\,\mu m = 5\,\mu m}$$

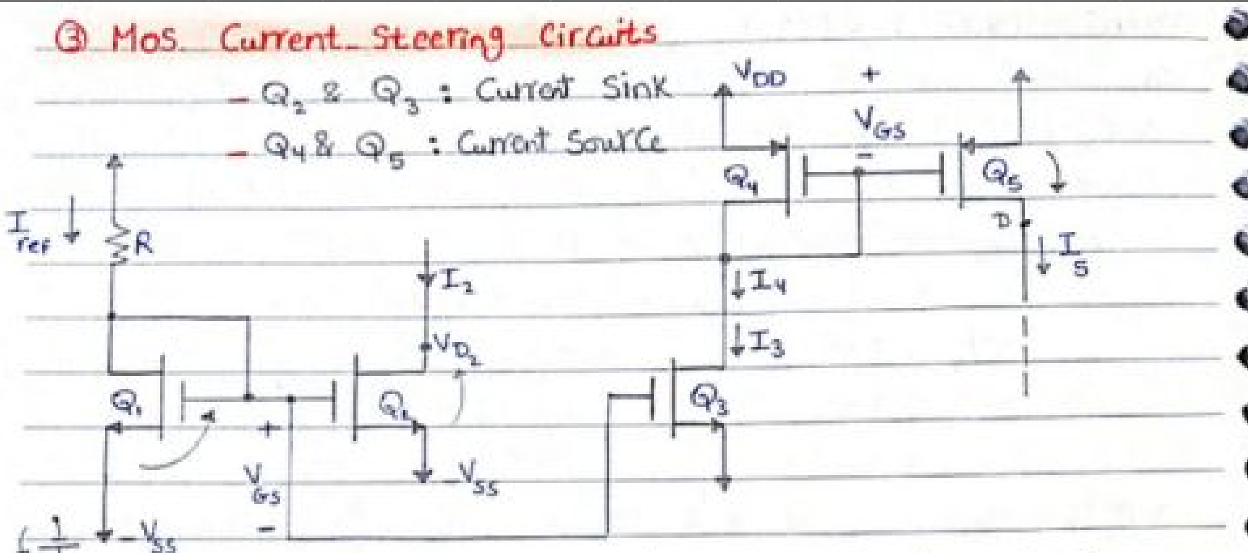
I_{ref} ثابتة في الحالتين فلازم W تتغير زي ما غيرت L $\longleftarrow$

$$I_{ref} = I_{D_1} = \frac{1}{2}k_n'\left(\frac{W}{L}\right)V_{ov}^2 \qquad W \propto L$$

$$\boxed{W_{new} = 5\,W = 5\,(10)\,\mu m = 50\,\mu m}$$

③ MOS Current Steering Circuits

- Q_2 & Q_3 : Current Sink
- Q_4 & Q_5 : Current Source



* Each MOS should be in saturation

$$I_2 = I_{ref}\frac{(W/L)_2}{(W/L)_1} \qquad Q_1\ \&\ Q_2\ \&\ Q_3 \longrightarrow \text{NMOS}$$

$$I_3 = I_{ref}\frac{(W/L)_3}{(W/L)_1} \qquad Q_4\ \&\ Q_5 \longrightarrow \text{PMOS}$$

$V_{D2,3}$

$$V_{DS_2} \geq V_{ov_2} \qquad V_{DS_2} \geq V_{GS_2} - V_{tn}$$

$$\because V_{DS_2} = V_{D_2} - V_{S_2} = V_{D_2} - (-V_{SS}) = V_{D_2} + V_{SS}$$

$$\therefore V_{D_2} \geq -V_{SS} + V_{GS_2} - V_{tn}$$

$$\boxed{V_{D2} \geq -V_{SS} + V_{ov_1}} \quad \text{for Current Sink}$$

$$I_5 = I_4\frac{(W/L)_5}{(W/L)_4}$$

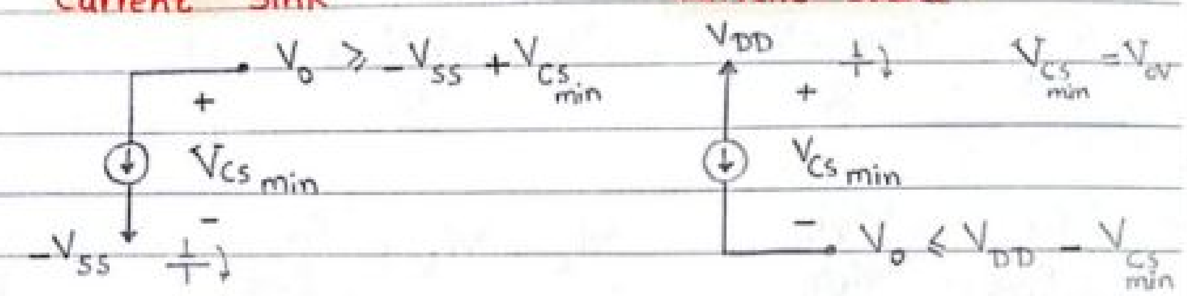
$$V_{DS_5} \leq \underset{(-ve)}{V_{GS_5}} - \underset{(-ve)}{V_{tp}} \qquad \because V_{DS_5} = V_{D_5} - V_{DD}$$

$$V_{D_5} - V_{DD} \leq V_{GS_5} - V_{tp}$$

$$V_{D_5} \leq V_{DD} + V_{GS_5} - V_{tp} \qquad V_{D_5} \leq V_{DD} + \underset{(-ve)}{V_{ov}}$$

$$\boxed{V_{D5} \leq V_{DD} - |V_{ov_5}|} \quad \text{for Current Source}$$

Current Sink $\qquad\qquad$ Current Source



Exercise (8.2) **Page (539)** **Very Important**

$V_{DD} = V_{SS} = 1.5\ V$ $\quad V_{tn} = 0.6\ V$ $\quad V_{tp} = -0.6\ V$ $\quad L = 1\ \mu m$

$k_n' = 200\ \mu A/V^2$ $\quad k_p' = 80\ \mu A/V^2$ $\quad \lambda = 0$

$I_{ref} = 10\ \mu A$ $\quad I_2 = 60\ \mu A$ $\quad I_3 = 20\ \mu A$ $\quad I_5 = 80\ \mu A$

→ the voltage at the drain of Q_2 must be allowed to go down to within 0.2 V of the negative supply.

→ the voltage at the drain of Q_5 must be allowed to go up to within 0.2 V of the positive supply.

find the widths of all transistors

[1] $-$ve supply $\longrightarrow -V_{SS}$ $\quad Q_2 \longrightarrow$ Sink $\quad V_{ov_1} = 0.2\ V$

$V_{D_2} \geq -V_{SS} + V_{ov_1}$ $\quad V_{D_2} \geq -1.5 + 0.2$

$$\boxed{V_{D_2} \geq -1.3\ V}$$

[2] $+$ve supply $\longrightarrow V_{DD}$ $\quad Q_5 \longrightarrow$ Source $\quad |V_{ov_5}| = 0.2\ V$

$V_{D_5} \leq V_{DD} - |V_{ov_5}|$ $\quad V_{D_5} \leq 1.5 - 0.2$

$$\boxed{V_{D_5} \leq 1.3\ V}$$

$$I_{ref} = I_{D_1} = \frac{1}{2} k_n' \frac{W_1}{L} (V_{ov_1})^2$$

$$10\ \mu A = \frac{1}{2} (200\ \mu) \frac{W_1}{1} (0.2)^2$$

$$\boxed{W_1 = 2.5\ \mu m}$$

$$I_{D_1} = \frac{V_{DD} - V_G}{R} = \frac{V_{DD} - (V_{GS} - V_{SS})}{R}$$

$$\frac{I_2}{I_{ref}} = \frac{W_2/L}{W_1/L} \qquad W_2 = W_1 * \frac{I_2}{I_{ref}} = 2.5 * \frac{60}{10}$$

$$\boxed{W_2 = 15\ \mu m}$$

$$\frac{I_3}{I_{ref}} = \frac{W_3/L}{W_1/L} \qquad W_3 = W_1 * \frac{I_3}{I_{ref}} = 2.5 * \frac{20}{10}$$

$$\boxed{W_3 = 5\ \mu m}$$

* from the diff. in the Current

$10\ \mu m \xrightarrow[6]{} 60\ \mu m$

* L : Const

* W ↑ 6 مرات $\quad \boxed{W_2 = 6 W_1}$

$\boxed{W_3 = 2 W_1}$ $\quad$ وهكذا في W_3

← هنا ميفعش أقول $I_4 = I_3$ يبقى $W_3 = W_4$ ×××

لأن W_3 بتاعة NMos ، W_4 بتاعة PMos وكمان K_n' & K_p' مختلفين

$$I_4 = \frac{1}{2} k_p' \frac{W_4}{L} V_{ov_5}^2$$

$$20\ \mu = \frac{1}{2} (80\ \mu) \frac{W_4}{1} (0.2)^2$$

$$\boxed{W_4 = 12.5\ \mu m}$$

$$\frac{I_5}{I_{ref}} = \frac{W_5/L}{W_4/L} \qquad W_5 = W_4 * \frac{I_5}{I_4} = 12.5 * \frac{80}{20}$$

$I_4 \leftarrow I_{ref}$

$$\boxed{W_5 = 4 W_4 = 50\ \mu m}$$