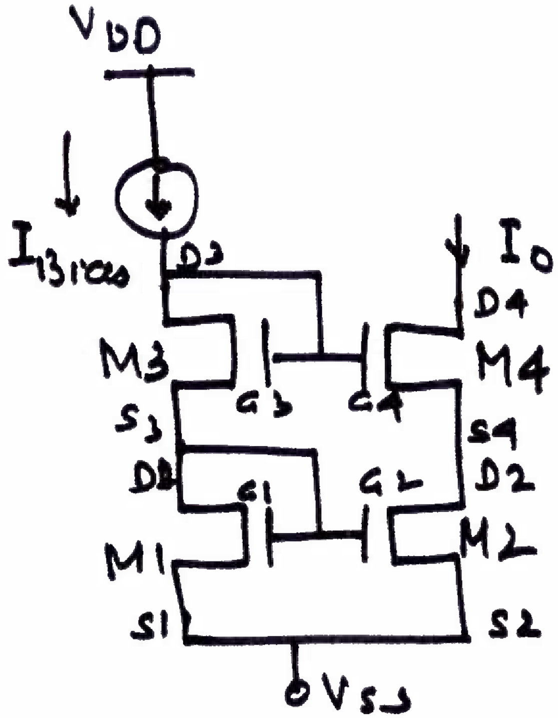
CASCODE CURRENT MIRROR



M2 & M4 form Cascode Stage leading to Higher Rout.

However we must ensure that M2 & M4 are in Saturation

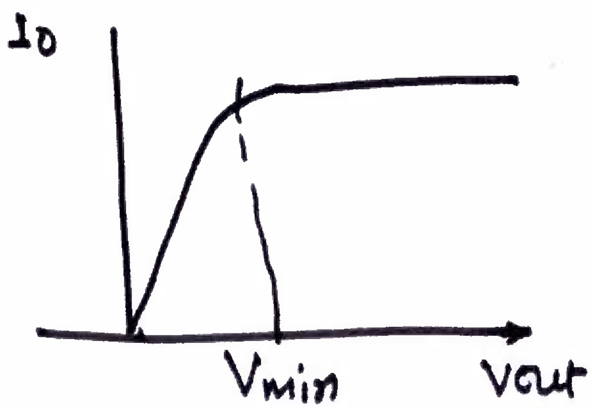
In current Source case, not only we need High Rout, but very small V_{min}

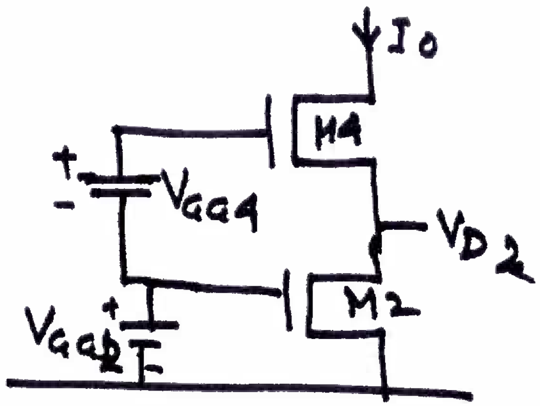
For a 5μ ($V_{DD} = 5V$) Process

$V_{Tn} \simeq 0.83 V$ & $V_{OV} = 0.37 V$

i.e. $V_{GS} = 1.2 V$

V_{min} is drop across Current Source





If $V_{GS} = 1.2\ V$

Then $V_{GG1} = V_{GG2} = 1.2$

and $V_{GG3} = V_{GG4} = 1.2 + 1.2$
$= 2.4V$

For M4 in Saturation

$V_{DS4} > V_{GS4} - V_T$ Now $V_{D2} = V_{S4}$

For M2 to saturate $V_{DS_2} \geq V_{GS_2} - V_T$

If we keep $V_{DS2} = V_{GS2}$, then M2 is always in Saturation

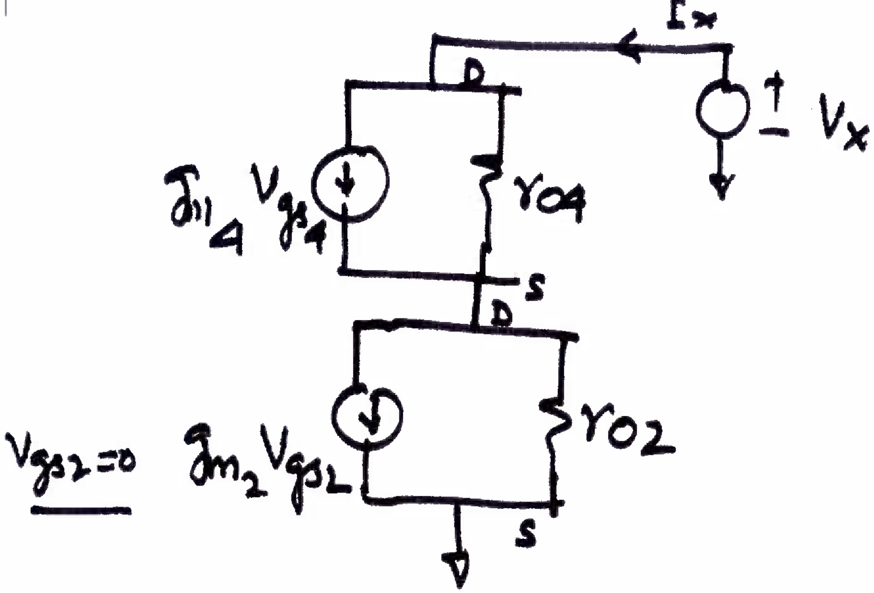
$\therefore V_{DS2} = V_{GG1} = V_{GG2} = 1.2V$

For M4 to be in saturation $V_{D4} - V_{D2} \geq V_{GG4} - V_{D2} - V_T$

or $V_{D4} \geq 2.4 - 0.83 = 1.57\ V = (2V_{ov} + V_T)$

i.e. $V_{min} \geq 2V_{ov} + V_T$

Rout evaluation

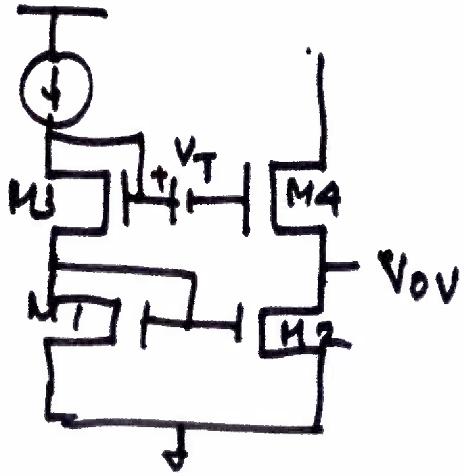


$$R_{out} = r_{o_4}(1 + g_m r_{o2}) + r_{o2}$$
$$\cong r_{o4}(1 + g_m r_{o2})$$
$$\simeq g_{m4} r_{o2} r_{o4} \quad \text{(Coscode Effect)}$$

To reduce V_{min}, we use additional Battery of V_T between Gates of M3 & M4.

This gives $V_{G4} = 2V_{ov} + V_T$

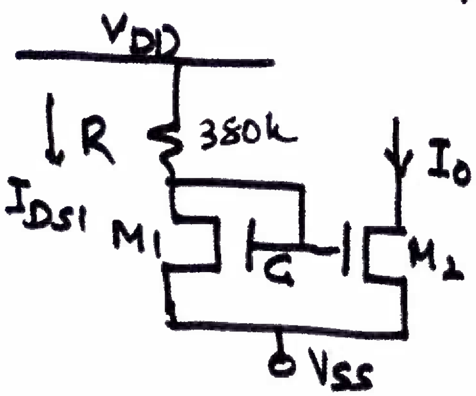
$$\therefore V_{Min} = 2V_{ov} + V_T - (V_{ov} + V_t)$$
$$= V_{ov}$$



Sensitivity Analysis

$$S_x^y = \lim_{\Delta x \to 0} \frac{\Delta y / y}{\Delta x / x} \quad \text{Definition}$$

(i) Sensitivity of Current Source wrt V_{DD} in a Simple Current Mirror (W/L are equal for M_1 & M_2)



We have $I_0 = I_{DS1} = 10\,\mu A$

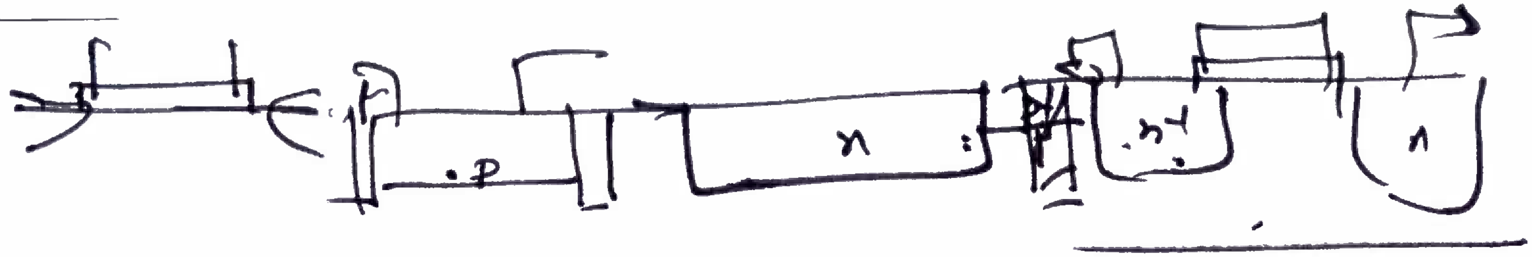
However $I_{DS1} = \dfrac{V_{DD} - V_{SS} - V_{GS}}{R}$

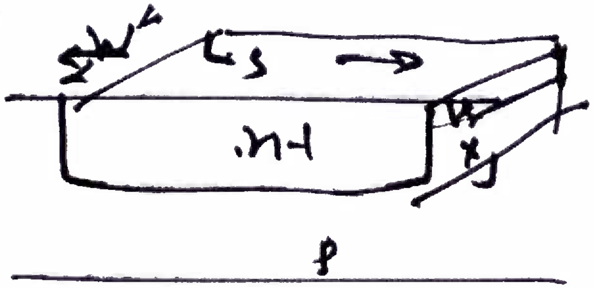
We need to find $S_{V_{DD}}^{I_0} = \lim_{\Delta V_{DD} \to 0} \dfrac{\Delta I_0 / I_0}{\Delta V_{DD} / V_{DD}}$

or $S_{V_{DD}}^{I_0} = \dfrac{V_{DD}}{I_0} \dfrac{\partial I_0}{\partial V_{DD}}$

But $\dfrac{\partial I_0}{\partial V_{DD}} = \dfrac{\partial I_{DS1}}{\partial V_{DD}} = \dfrac{1}{R}$ $\quad \therefore \quad S_{V_{DD}}^{I_0} = \dfrac{V_{DD}}{I_0 R} = \dfrac{2.5}{10^{-5} \times 380k} \simeq 0.66$

& $\dfrac{\Delta I_0}{I_0} = \dfrac{0.66 \times 0.2}{2.5}$ (If V_{DD} becomes $V_{DD} \pm 0.1V$) $\cong 5\%$.





$R_c = R_s \frac{L}{W}$

$\sigma = q \mu n^+$

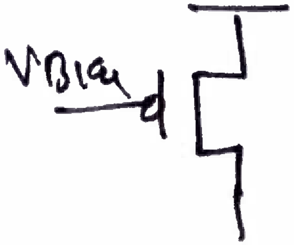
$R = \frac{\rho t}{A}$

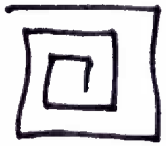
$A = W \cdot L_s$

$t = x_j$

$\rho = \frac{1}{q \mu_n n^+}$

$R_s = \frac{\rho}{t}$





1. $TC_f(R) = \frac{1}{R}\frac{dR}{dT} \simeq +2000 \text{ ppm}/^\circ C$

Where R is created from Diffused n^+ region

2. $TC_f(V_T) = -3000 \text{ ppm}/^\circ C$ for $V_T \simeq 0.8V$

Typically $\frac{\partial V_T}{\partial T} = -2.4 \text{ mV}/^\circ C$

3. For a MOSFET $\beta' = \mu C_{ox}$, $\therefore \beta'(T) = \beta'(0)\left(\frac{T}{T_0}\right)^{-3/2}$

This gives $\frac{1}{\beta'}\frac{\partial \beta'}{\partial T} \simeq -\frac{1.5}{T}$, T in $^\circ K$

or $TC_f(\beta') \simeq -\frac{1.5}{T} \rightarrow = \frac{1.5}{300} = \frac{1}{200} = \frac{10^6}{200} \text{ ppm}/^\circ C$

$= 5000 \text{ ppm}/^\circ C$

(2) Temperature Sensitivity

$$TC_f(I_o) = \frac{1}{I_o}\frac{\partial I_o}{\partial T}$$

$$S_T^{I_o} = \lim_{\Delta T \to 0} \frac{\Delta I_o / I_o}{\Delta T / T} = \frac{T}{I_o}\frac{\partial I_o}{\partial T} = T \cdot TC_f(I_o)$$

$TC_f(I_o) \Rightarrow$ evaluation

$$I_o = I_{DS1} = \frac{V_{DD} - V_{GS} - V_{SS}}{R} \quad \text{for Simple Mirror}$$

$$\frac{\partial I_o}{\partial T} = \frac{\partial I_{DS1}}{\partial T} = -\frac{1}{R}\frac{\partial V_{GS}}{\partial T} + \frac{1}{R^2} V_{GS} \frac{\partial R}{\partial T}$$

$$\therefore \quad TC_f(I_o) = \frac{1}{I_o}\left[-\frac{1}{R}\frac{\partial V_T}{\partial T} - \frac{1}{R}\frac{\partial}{\partial T}\sqrt{\frac{2 I_o R}{\beta}} + \frac{1}{R}\frac{\partial R}{\partial T} \right]$$

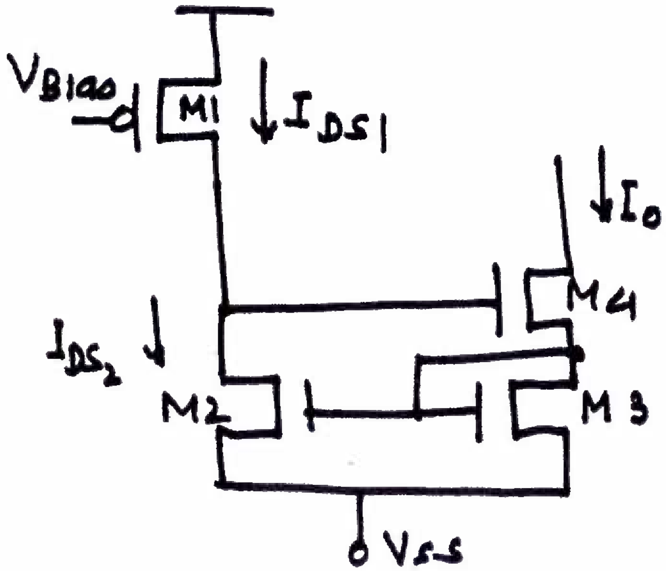
Typical value $\quad TC_f(I_o) = 0.17\ \%/^\circ C$ $\quad \approx$ [illegible] ppm/°C

$$= 1700\ \text{ppm}/^\circ C$$

Using -ve feedback, Simple current Mirror can further be improved. Two such circuits are

1. Wilson Mirror 2. Regulated Cascode

Wilson Current Mirror:

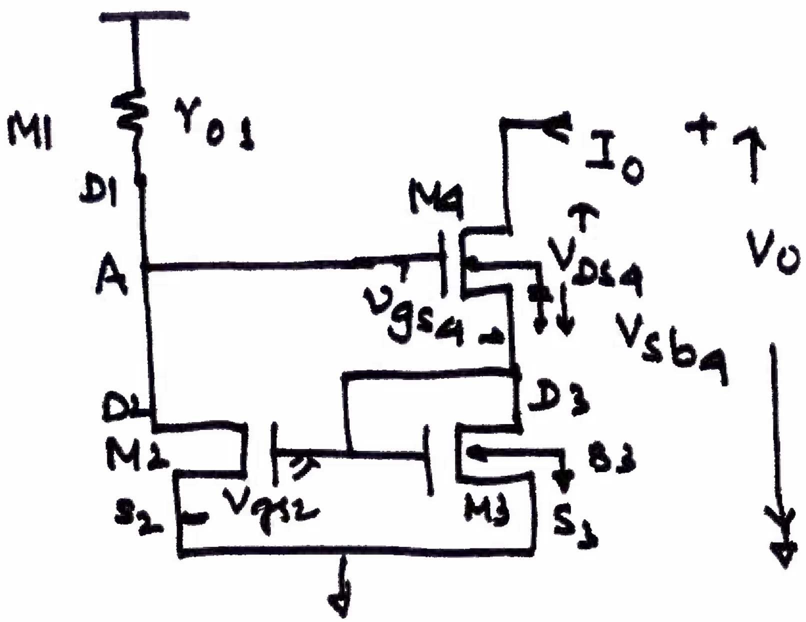


By using P-device with proper bias we can create stable & Reference Current I_{DS1}. V_{Bias} is normally taken from a 'Stable Band Gap reference'

This Current Mirror has

(i) I_o much stable than Simple case

(ii) Output Impedance is further improved.



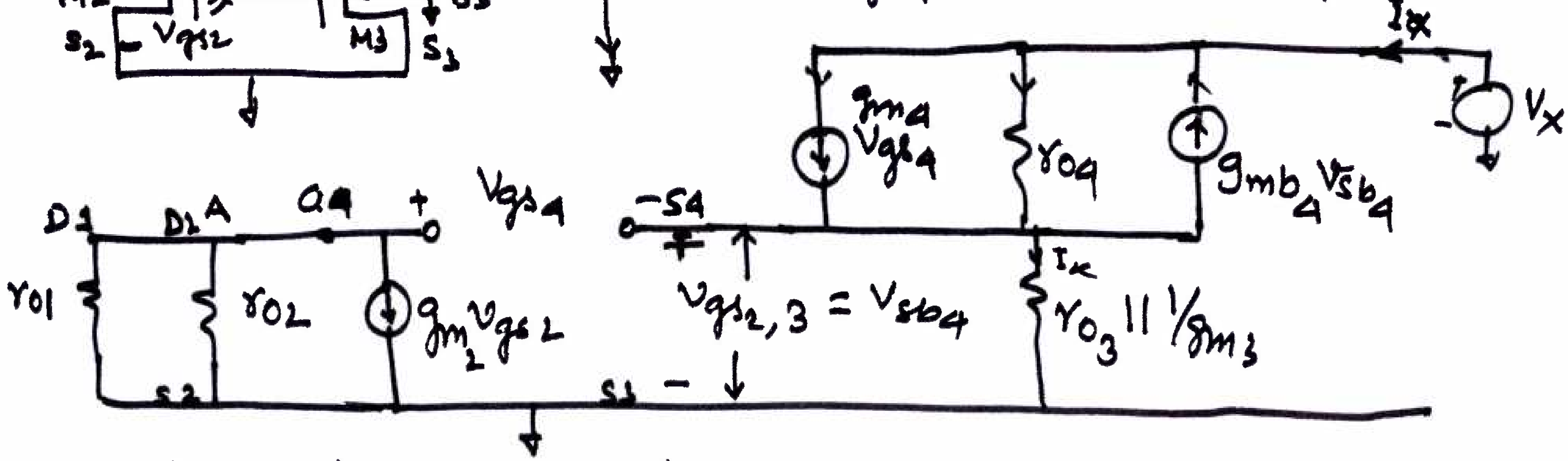
V_o increases

→ I_{DS4} increases

→ $I_{DS4} = I_{DS3}$ & hence increase of I_{DS4} increases I_{DS2}.

→ V_A decreases

→ V_{gs4} decreases → $I_{DS4}\downarrow$.



$$v_{sb4} = V_{gs2} = V_{gs3} = I_x (r_{o3} \| 1/g_{m3})$$

$$V_{gs4} = -g_{m2} V_{gs2} (r_{o1} \| r_{o2}) - V_{gs2}$$

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or

$$v_{gs_4} = -\left[1 + g_{m_2}(r_{o_1} \| r_{o_2})\right] v_{gs_2}$$

$$= -\left[1 + g_{m_2}(r_{o_1} \| r_{o_2})\right] v_{sb_4}$$

$$\therefore v_{gs_4} = -\left[1 + g_{m_2}(r_{o_1} \| r_{o_2})\right] I_x \left(r_{o_3} \| 1/g_{m_3}\right) \quad \text{— (1)}$$

Further

$$I_x = g_{m_4} v_{gs_4} - g_{mb_4} v_{sb_4} + \frac{V_x - V_{gs_2}}{r_{o_4}} \quad \text{— (2)}$$

From (1) & (2)

$$R_{out} = \frac{V_x}{I_x} = r_{o_4}\left[1 + g_{m_4}\left(r_{o_3} \| \frac{1}{g_{m_3}}\right)\left(1 + g_{m_2}(r_{o_1} \| r_{o_2})\right)\right]$$

$$+ g_{mb_4}\left[\left(r_{o_3} \| \frac{1}{g_{m_3}}\right) + \frac{1}{r_{o_4}}\left(r_{o_3} \| \frac{1}{g_{m_3}}\right) r_o\right]$$