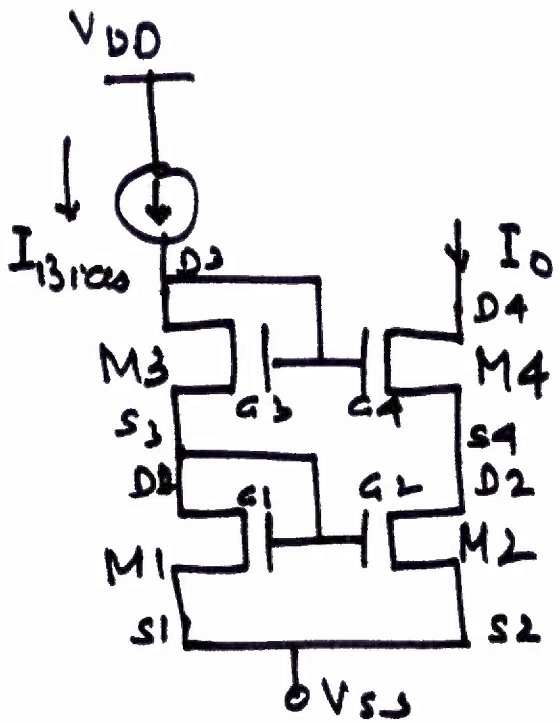
CASCODE CURRENT MIRROR

CDEEP
IIT Bombay

EE 618 L 14 / Slide 1



M2 & M4 form Cascode Stage leading to Higher Rout.

However we must ensure that M2 & M4 are in Saturation

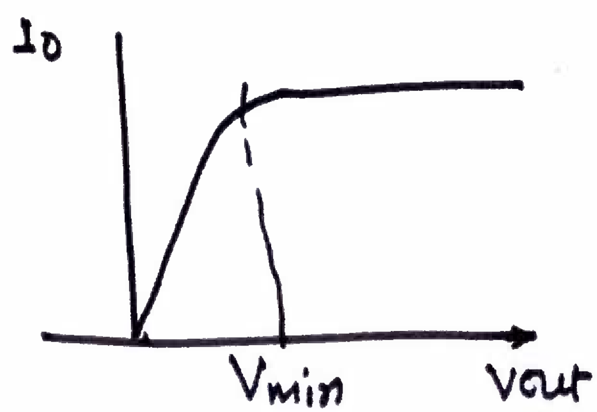
In current Source case, not only we need High Rout, but very small V_{min}

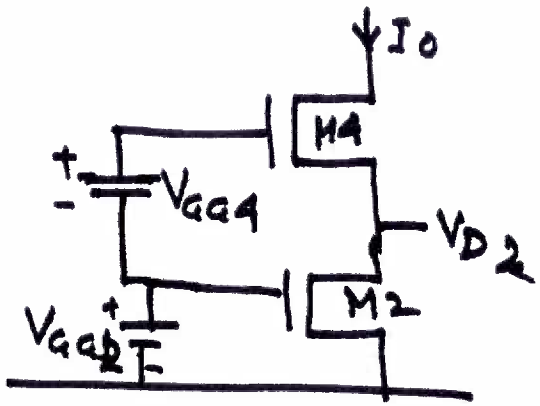
For a 5μ ($V_{DD} = 5V$) Process

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

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

V_{min} is drop across Current Source





If $V_{GS} = 1.2$ V

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

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

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

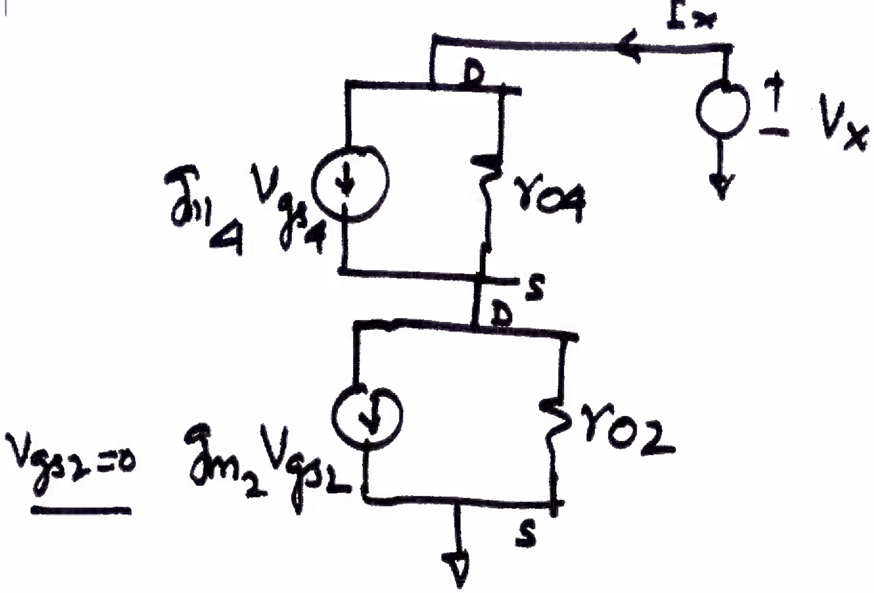
$\therefore V_{DS2} = V_{GG1} = V_{GG2} = 1.2$V

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 $= (2V_{OV} + V_T)$

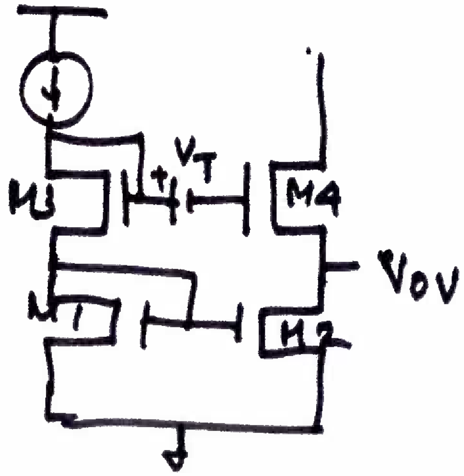
i.e. $V_{min} \geq 2V_{OV} + V_T$

Rout evaluation



$$R_{out} = r_{o_4}(1 + g_m r_{o2}) + r_{o2}$$
$$\cong r_{o4}(1 + g_m r_{o2})$$
$$\simeq g_{m_4} r_{o2} r_{o4} \quad \text{(Coscode Effect)}$$

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



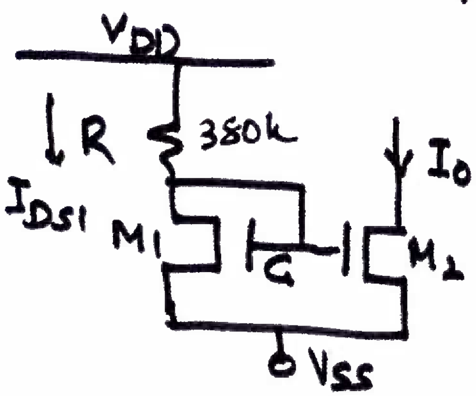
This gives $V_{G4} = 2V_{ov} + V_T$

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

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 $I_o = I_{DS1} = 10\,\mu A$

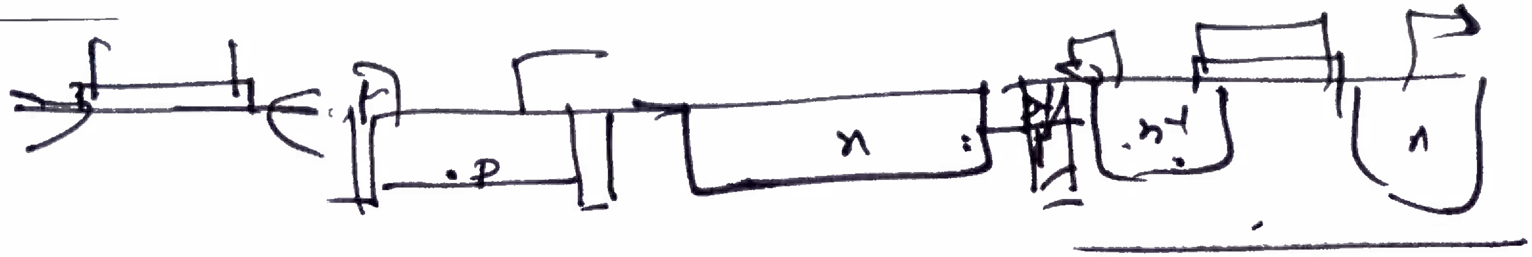
However $I_{DS1} = \dfrac{V_{DD} - V_{SS} - V_{GS}}{R}$

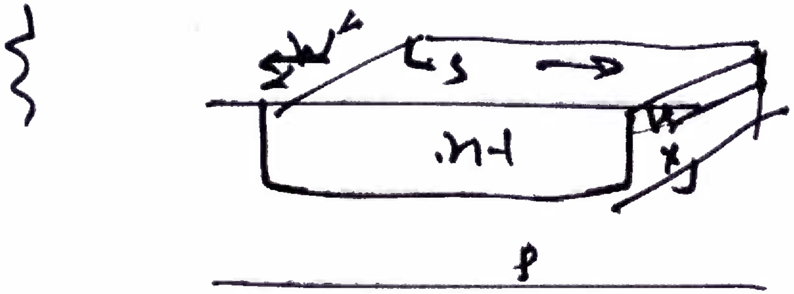
We need to find $S_{V_{DD}}^{I_o} = \lim_{\Delta V_{DD} \to 0} \dfrac{\Delta I_o / I_o}{\Delta V_{DD} / V_{DD}}$

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

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

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





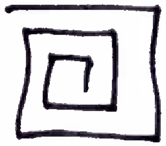
$A = W \cdot L_s$

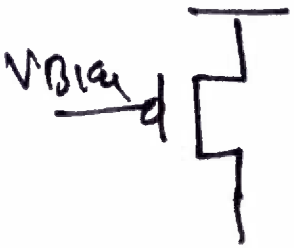
$t = x_j$

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

$\sigma = q \mu n^+$

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





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

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

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

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

CDEEP
IIT Bombay

(2) Temperature Sensitivity

$$TC_f(I_0) = \frac{1}{I_0}\frac{\partial I_0}{\partial T}$$

$$S_T^{I_0} = \lim_{\Delta T \to 0} \frac{\Delta I_0 / I_0}{\Delta T / T} = \frac{T}{I_0}\frac{\partial I_0}{\partial T} = T \cdot TC_f(I_0)$$

$TC_f(I_0) \Rightarrow$ evaluation

$$I_0 = I_{DS1} = \frac{V_{DD} - V_{GS} - V_{SS}}{R} \quad \text{for Simple Mirror}$$

$$\frac{\partial I_0}{\partial T} = \frac{\partial I_{DS1}}{\partial T} = -\frac{1}{R}\frac{\partial V_{GS}}{\partial T} + \frac{1}{R^2} V_{GS} \frac{\partial R}{\partial T}$$

$$\therefore \quad TC_f(I_0) = \frac{1}{I_0}\left[-\frac{1}{R}\frac{\partial V_T}{\partial T} - \frac{1}{R}\frac{\partial}{\partial T}\sqrt{\frac{2 I_0 R}{\beta}} + \frac{1}{R}\frac{\partial R}{\partial T}\right]$$

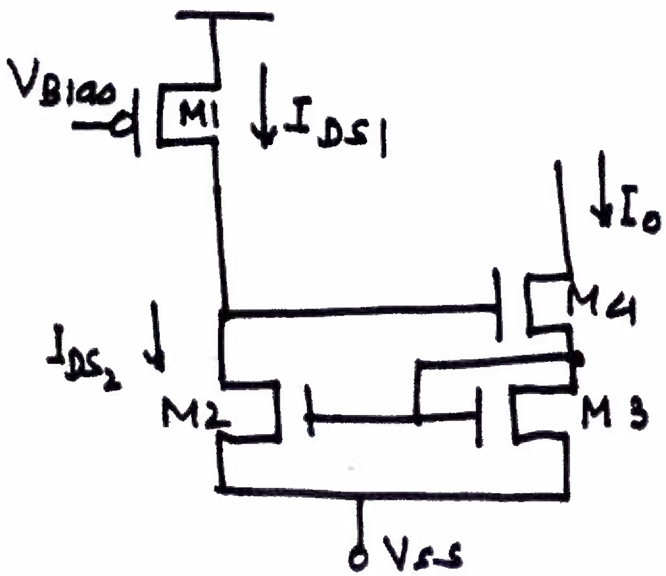
Typical value $\quad TC_f(I_0) = 0.17\ \%/^\circ C \quad \simeq$ [illegible]

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

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

1. Wilson Mirror 2. Regulated Cascode

Wilson Current Mirror:

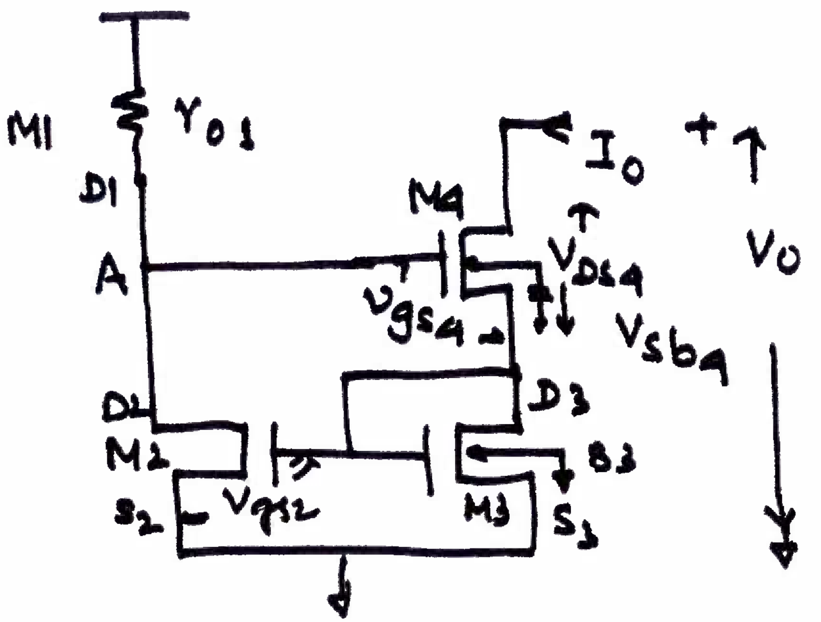


By using P-device with proper bias we can create stable & Reference Current I_{DS1}. V_{Bias} is normally taken from a 'Stable Band Gap reference'

This Current Mirror has

(i) I_o much stable than Simple case

(ii) Output Impedance is further improved.



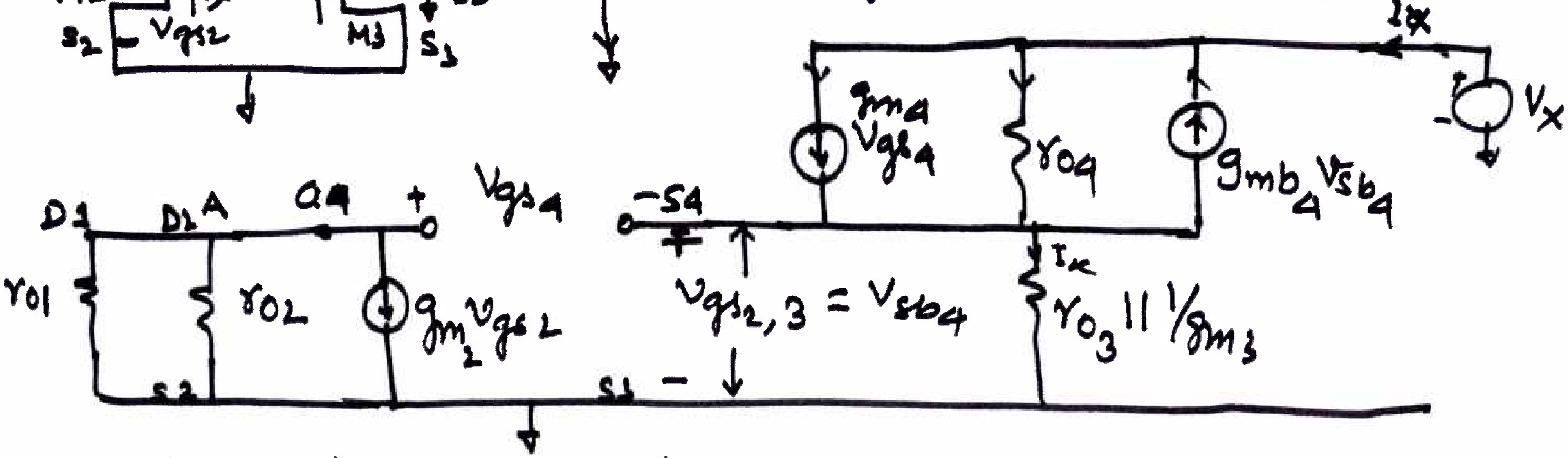
Vo increases

→ I_{DS4} increases

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

→ V_A decreases

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



$$v_{sb4} = V_{gs_2} = V_{gs_3} = I_x \left(r_{o3} \,\|\, 1/g_{m3} \right)$$

$$V_{gs4} = -g_{m2} V_{gs2} \left(r_{o1} \,\|\, r_{o2} \right) - V_{gs_2}$$

or

$$v_{gs4} = -\left[1 + g_{m2}(r_{o1} \| r_{o2})\right] v_{gs2}$$

$$= -\left[1 + g_{m2}(r_{o1} \| r_{o2})\right] v_{sb4}$$

$$\therefore v_{gs4} = -\left[1 + g_{m2}(r_{o1} \| r_{o2})\right] I_x\left(r_{o3} \| 1/g_{m3}\right) \quad \text{— (1)}$$

Further

$$I_x = g_{m4} v_{gs4} - g_{mb4} v_{sb4} + \frac{V_x - V_{gs2}}{r_{o4}} \quad \text{— (2)}$$

From (1) & (2)

$$R_{out} = \frac{V_x}{I_x} = r_{o4}\left[1 + g_{m4}\left(r_{o3} \| \frac{1}{g_{m3}}\right)\left(1 + g_{m2}(r_{o1} \| r_{o2})\right]\right.$$

$$\left. + g_{mb4}\left[\left(r_{o3} \| \frac{1}{g_{m3}}\right) + \frac{1}{r_{o4}}\left(r_{o3} \| \frac{1}{g_{m3}}\right) r_o\right] \quad r_o \; \cancel{r_{o?}}$$

Assume M3 & M4 Identical, then

$$g_{m3} = g_{m4}, \quad r_{03} \parallel \frac{1}{g_{m3}} = \frac{1}{g_{m3}} = \frac{1}{g_{m4}}$$

Further we see $r_o = r_{o1} = r_{o2} = r_{o4}$ can be assumed

$$\therefore R_{out} = r_o\left\{\left[1 + 1\cdot\left(1+\frac{g_{m2}r_o}{2}\right)\right] + \frac{g_{mb4}}{g_{m3}}r_o + \frac{1}{r_o g_{m3}}\right\}$$

$$R_{out} \simeq r_o + g_{m2}r_o^2 = r_o(1+g_{m2}r_o)$$

$\therefore$ Rout is Boosted due to Cascode configuration.

Next thing we wish to know $V_{min} = V_{omin}$

or $$V_{omin} = V_{GS3} + V_{DS4_{sat}}$$
$$= V_{GS3} + V_{GS4} - V_{T4}$$

$$V_{omin} = \sqrt{\frac{2I_o}{\beta_3}} + V_{T3} + \sqrt{\frac{2I_o}{\beta_4}}$$

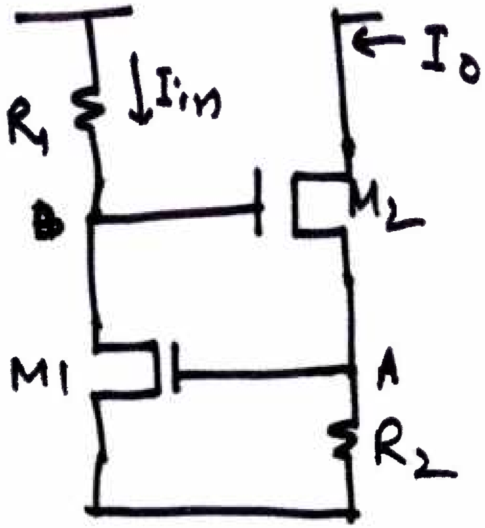
If $\beta_3 = \beta_4$, then

$$V_{omin} = 2\sqrt{\frac{2I_o}{\beta'(W/L)}} + V_T$$

or $V_{omin} \propto \sqrt{2I_o}$

CDEEP
IIT Bombay

(iv) V_T reference CS



This is good stable source

If $I_o \uparrow$, $I_{DS_2} = I_{R2}$ also increase. Drop across R_2 increases ($V_A = I_o \cdot R_2$) increases V_{GS1} of M1. Hence I_{DS_1} increase with increase of I_o.

Since I_{in} is good current source, Hence increase in I_{DS1} causes V_B to reduce. But $V_B = V_{G2}$. Thus reduction in V_{G2} reduces V_{GS_2} which in turn reduces I_o. Thus Negative Feeback leads to '<u>Stability</u>'

Clearly $I_0 = I_{DS2} = I_{R2}$

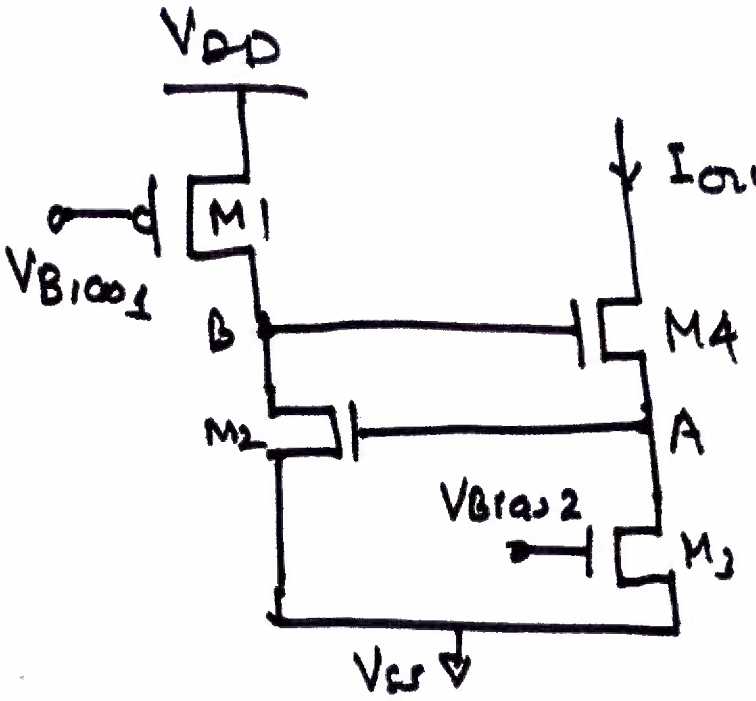
$$\therefore \; I_0 = \frac{V_A}{R_2} = \frac{V_{GS1}}{R_2}$$

$$\text{or} \quad I_0 = \frac{V_{OV} + V_T}{R_2}$$

$$I_0 = \frac{V_T + \sqrt{\dfrac{2 I_{in}}{\beta' (W/L)}}}{R_2}$$

Thus I_0 is function of V_T, which is relatively fixed value.

A Better version of V_T reference CS, is Regulated Cascode CS.



If we have larger (W/L) for M2, then

V_{ov} $(= V_{GS_2} - V_T)$ is $<< V_T$

$$\therefore\ I_0 \simeq \frac{V_T}{R_2}$$

However if we do Small Signal Analysis

$$R_{out} \simeq g_m r_o^2 \left\{ 1 + \frac{1}{2} g_m r_o \right\} \simeq \frac{1}{2} g_m^2 r_o^3$$