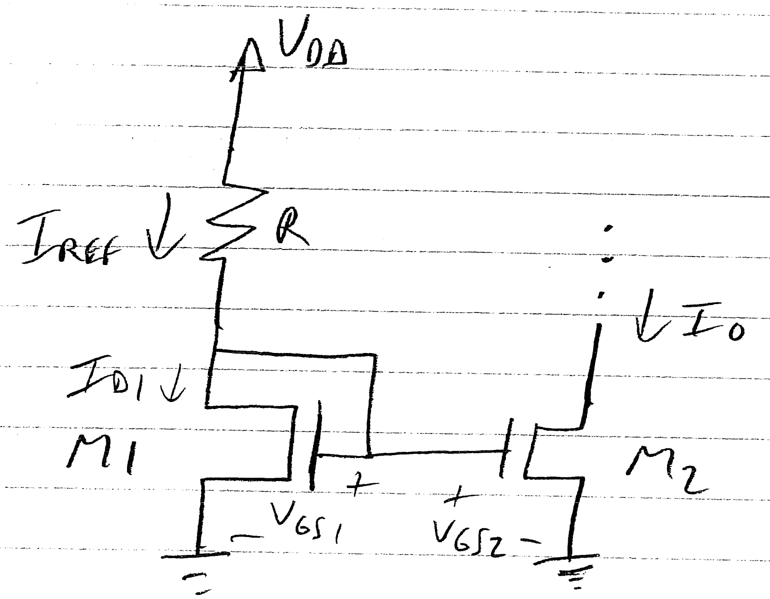
CURRENT MIRRORS

(CM1)



ASSUME

$\mu_N = \mu_{N1} = \mu_{N2}$

$C_{ox} = C_{ox1} = C_{ox2}$

$V_{tn} = V_{tn1} = V_{tn2}$

FOR M1 $\quad V_{DS} = V_{GS} \Rightarrow$ ACTIVE OR CUTOFF

NOT TRIODE

(SINCE $V_{DS} < V_{GS} - V_{tn}$ FOR TRIODE)

IF $I_{REF} \neq 0 \Rightarrow$ ACTIVE

$V_{OV1} = V_{GS1} - V_{tn1}$

$$I_{D1} = \frac{\mu_N C_{ox}}{2}\left(\frac{W}{L}\right)_1 V_{OV1}^2 \quad (1)$$

$$I_{D1} = I_{REF} = \frac{V_{DD} - V_{GS1}}{R}$$

FOR M2

$$I_O = I_{D2} = \frac{\mu_N C_{ox}}{2}\left(\frac{W}{L}\right)_2 V_{OV2}^2 \quad (2)$$

COMBINE ① & ②

$$\frac{I_{D2}}{I_{D1}} = \frac{(W/L)_2}{(W/L)_1}$$ CURRENT MIRROR.

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

VALID AS LONG AS M2 REMAINS ACTIVE

$\Rightarrow$ $V_o \geq V_{OV2}$ SINCE $V_{DS2} = V_o$

Ex GIVEN $I_{REF} = 40\,\mu A$

$\mu_n C_{ox} = 120\,\mu A/V^2$
$V_{tn} = 0.3\,V$
$L = 0.2\,\mu m$
$V_A' = 20\,V/\mu m$
$W_1 = 2\,\mu m$

- FIND W_2 SO THAT $I_{OUT} = 20\,\mu A$
- FIND OUTPUT IMPEDANCE OF CURRENT SOURCE
- FIND LOWEST POSSIBLE V_o (KEEPING M2 ACTIVE)
- FIND ΔI_{OUT} IF $\Delta V_o = +1V$.

(CM3)

$$40\mu A = I_{D_1} = \frac{\mu_n C_{ox}}{2}\left(\frac{W_1}{L}\right)(V_{ov_1})^2$$

$$40\mu A = \frac{(120e-6)}{2}\left(\frac{2}{0.2}\right)(V_{ov_1})^2$$

$$V_{ov_1} = \underline{\underline{0.258}} \quad \text{OR} \quad -0.258$$

✗ NOT POSSIBLE

$$\frac{I_{OUT}}{I_{REF}} = \frac{\left(\frac{W_2}{L}\right)}{\left(\frac{W_1}{L}\right)} = \frac{W_2}{W_1}$$

$$W_2 = \frac{I_{OUT}}{I_{REF}} W_1 = \frac{20\mu A}{40\mu A}(2\mu m)$$

$$W_2 = \underline{\underline{1\mu m}}$$

$$r_{o_2} = \frac{V_A}{I_{D_2}} = \frac{V_A' L}{I_{D2}} = \frac{(20)(0.2)}{20\mu A}$$

$$r_{o_2} = \underline{\underline{200\,k\Omega}}$$

SINCE $V_{GS_2} = V_{GS_1}$ & $V_{tn_1} = V_{tn_2}$

$$V_{ov_2} = V_{GS_2} - V_{tn_2} = V_{GS_1} - V_{tn_1} = V_{ov_1}$$

$$\text{MIN } V_o = V_{ov_2} = 0.258\text{ V} \simeq 0.25\text{ V}$$

CM4

$$\Delta I_{OUT} = \frac{\Delta V_o}{r_{o2}} = \frac{1V}{200k} = 5\,\mu A$$

SO A 1V CHANGE RESULTS IN

A 25% CHANGE IN I_{OUT}

- AT WHAT V_o DOES $I_{OUT} = 20\,\mu A$?

RECALL $I_D = \left(\frac{\mu_n C_{ox}}{2}\right)\left(\frac{W}{L}\right)(V_{GS} - V_{tn})^2 (1 + \lambda V_{DS})$

SO I_D DEPENDS ON V_{GS} & V_{DS} & V_{tn}

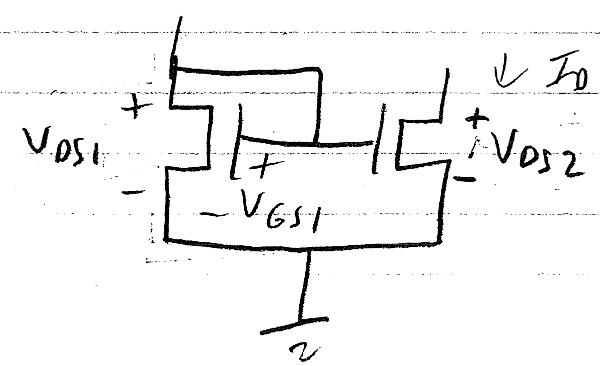
IF $V_{GS2} = V_{GS1}$, $V_{tn2} = V_{tn1}$

$V_{DS2} = V_{DS1}$, $L_2 = L_1$ (TO KEEP $\lambda_2 = \lambda_1$)

THEN $I_{D2} = \frac{W_2}{W_1} I_{D1}$

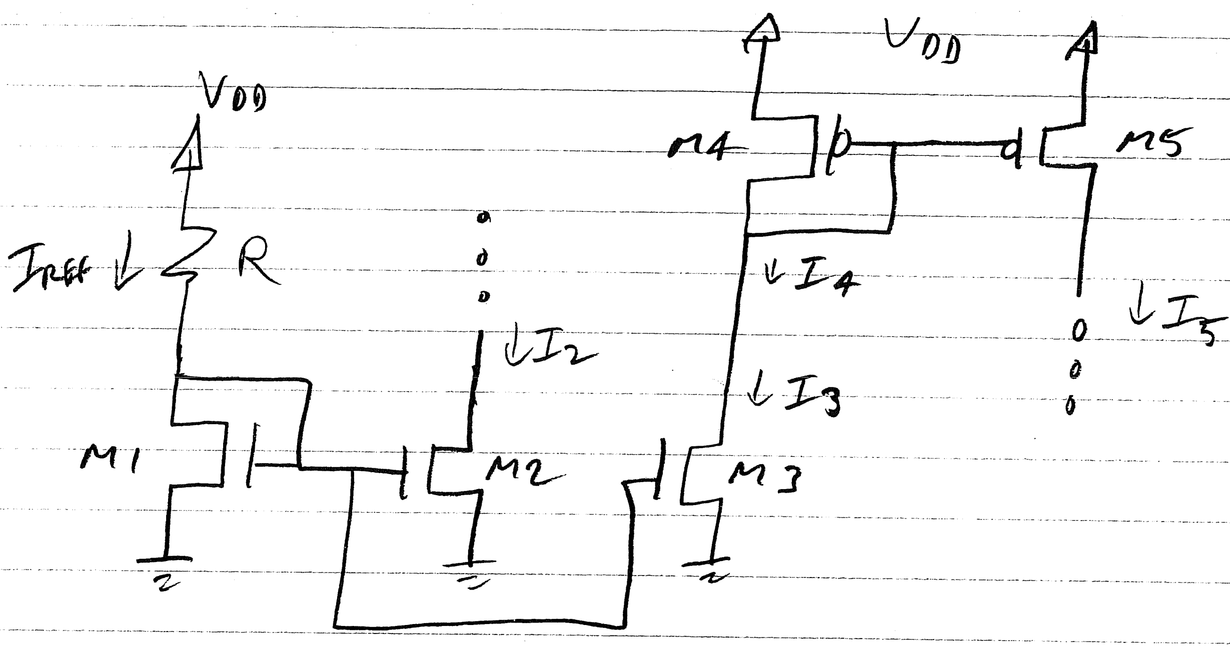
SO $I_{D2} = 20\,\mu A$ FOR $V_o = V_{GS1} = V_{ov} + V_{tn}$

$= 0.558$



ENSURE $L_2 = L_1$

SENDING BIAS CURRENTS AROUND A CHIP



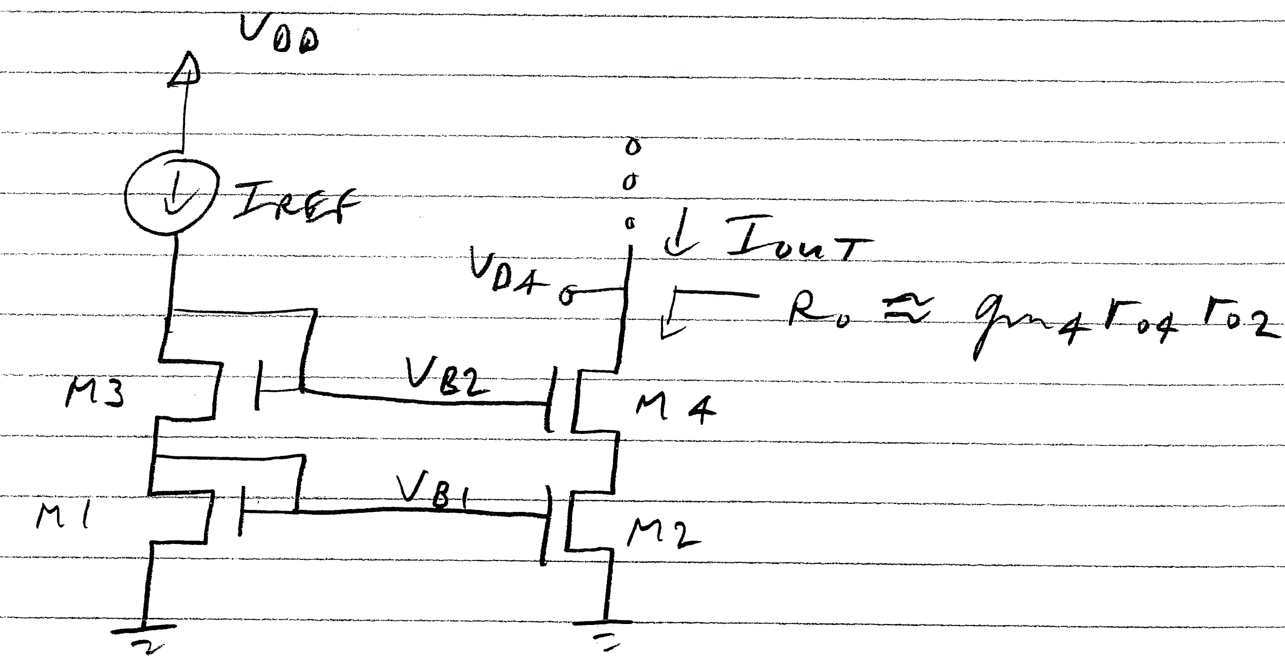
$$I_2 = \frac{(W/L)_2}{(W/L)_1} I_{REF}$$

$$I_3 = \frac{(W/L)_3}{(W/L)_1} I_{REF} = I_4$$

$$I_5 = \frac{(W/L)_5}{(W/L)_4} I_4 = \frac{(W/L)_3}{(W/L)_1} \frac{(W/L)_5}{(W/L)_4} I_{REF}$$

CASCODE MOS MIRROR

TO IMPROVE OUTPUT IMPEDANCE OF CURRENT MIRROR ⇒ CASCODE



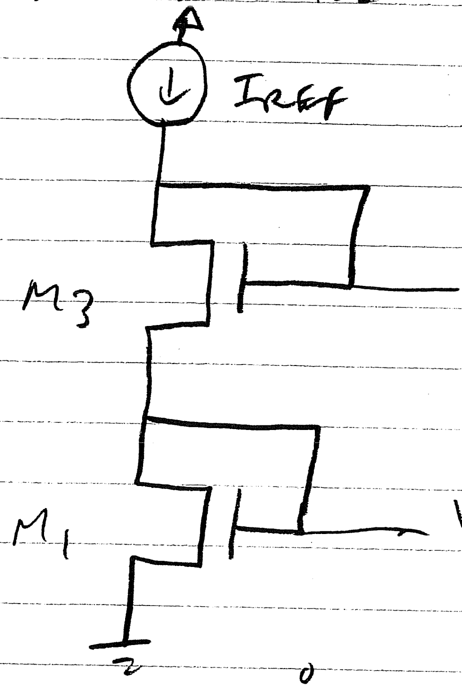
NORMALLY MATCH M1, M2
& M3, M4

$\Rightarrow L_2 = L_1$ & $L_4 = L_3$

$\Rightarrow \frac{W_2}{W_1} = \frac{W_4}{W_3}$ SO THAT

$$I_{OUT} = \frac{W_2}{W_1} I_{REF}$$

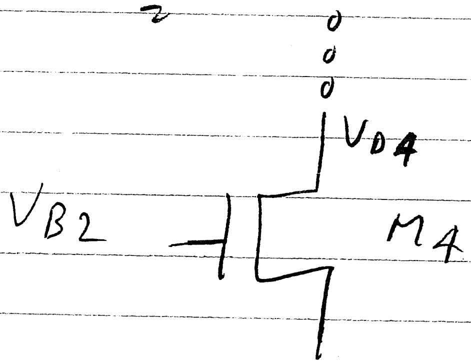
MIN VOLTAGE ON V_{D4} ?



$V_{B2} = V_{tn} + V_{ov1} + V_{tn} + V_{ov2}$

$= 2V_{tn} + V_{ov1} + V_{ov2}$

$V_{B1} = V_{tn} + V_{ov1}$



M4 ACTIVE UNTIL

$V_{D4} \leq V_{B2} - V_{tn}$

$$\text{MIN } V_{D4} = 2V_{tn} + V_{ov1} + V_{ov2} - V_{tn}$$

$$= V_{tn} + V_{ov1} + V_{ov2}$$

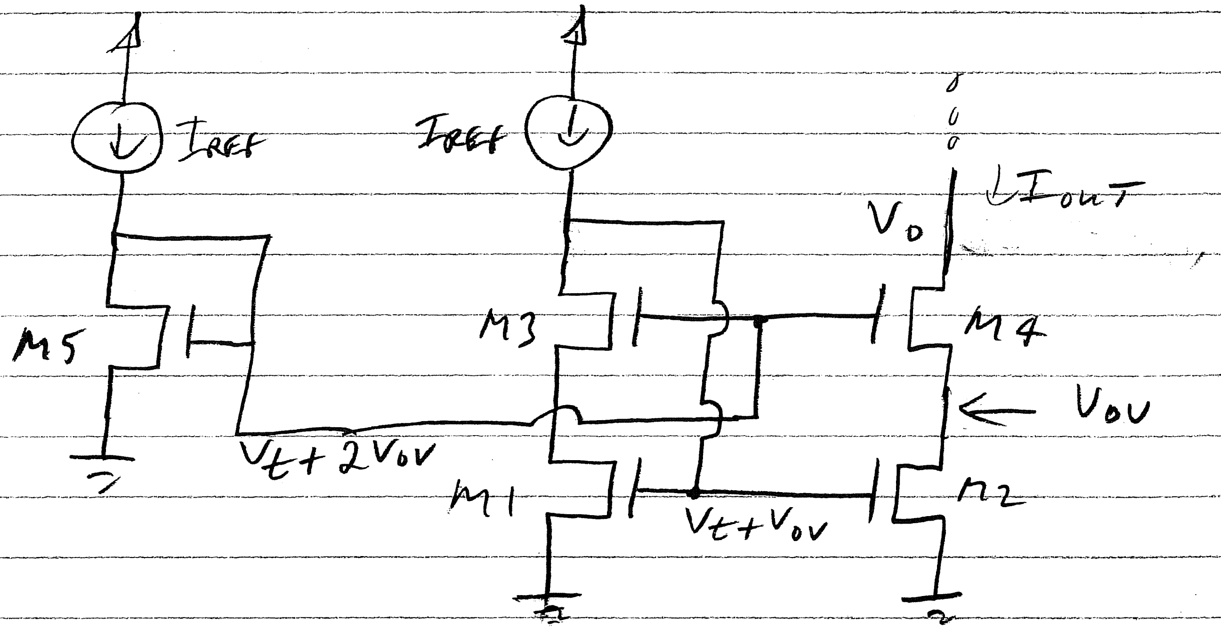
TYPICAL $V_{tn} \simeq 0.3\text{V}$

$V_{ov} \simeq 0.2\text{V}$

SO MIN $V_D \cong 0.7\text{V}$ NOT GREAT

WOULD LIKE TO LOWER VB2 SO M2 AT EDGE OF ACTIVE REGION

WIDE SWING CURRENT MIRROR



ASSUME ALL W/L EQUAL FOR $M_1 \rightarrow M4$

BUT $\left(\frac{W}{L}\right)_5 = \frac{1}{4}\left(\frac{W}{L}\right)_1$

DEFINE $V_{OV} \equiv V_{O1} = V_{OV2} = V_{OV3} = V_{OV4}$

CAN SHOW $V_{OV5} = 2V_{OV}$

SO MIN $V_O \approx 2V_{OV}$

(SINCE $V_{G4} = V_t + 2V_{OV}$)

GENERALLY $\left(\frac{W}{L}\right)_5 \lesssim \frac{1}{4}\left(\frac{W}{L}\right)_1$ SO THAT

M2 ENSURED IN ACTIVE