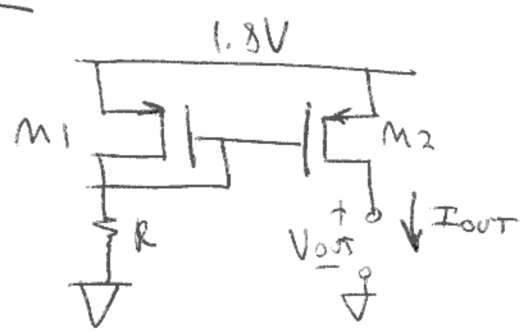
- ALSO TUNNELING @ GATE-DRAIN OVERLAP REGION TO BULK : GATE-INDUCED DRAIN LEAKAGE (GIDL)
- IMPACT IONIZATION CURRENTS : ELECTRON-HOLES PAIRS CREATED THAT PRODUCE A D-B CURRENT. DOES NOT HAPPEN IN LOW-VOLTAGE TECHNOLOGIES.

MORE ON CURRENT MIRRORS (INTRODUCE CURRENTS MIRRORS PAGE 2")

EXAMPLE : PROBLEM 5.1



$V_{th} = -0.4V$

$I_S = 1\mu A$

$n = 1.25$

$M1 = M2$

a) CALCULATE R FOR $I_{OUT} = [0.5 \to 50]\mu A$

b) " V_{OUT} MAX

c) $V_A = 5V$, CALCULATE ΔI FOR $V_{OUT} = 0$

d) $V_A = 0V$, " ΔI FOR $V_{th_2} = V_{th_1} \pm 10mV$

a)
$$I_{OUT} = I_{D2} \simeq I_S\, i_f \quad (\text{ASSUME } i_f \gg i_r)$$

$$\therefore \quad i_f = \frac{I_{OUT}}{I_S} = [0.5 \to 50]$$

$$\underbrace{\frac{V_P}{V_T}}_{V_S=0} = \mathcal{F}(i_f) = \sqrt{1+i_f} - 2 + \ln\left(\sqrt{1+i_f} - 1\right) = [-2.27, 6.96]$$

$$V_P = \frac{V_G - V_{th}}{n} \Rightarrow V_G = (V_{th} + nV_P) = [-0.33V, -0.63V]$$

$$R = \frac{1.8V + V_G}{I_{OUT}} = [2.94M\Omega, 23.4k\Omega]$$

b) $$V_{DSSAT} \cong V_T\left(\sqrt{1+i_f} + 3\right)$$

(USING $\zeta = 0.01$) FROM NOW ON $V_{DSSAT} \simeq V_T\left(\sqrt{1+i_f} + 3.6\right)$ $\zeta = 0.01$

$$V_{DSSAT} \simeq [-0.11V, -0.264V]$$

$$\therefore V_{OUT\,MAX} = [1.69V, 1.54V]$$

c) $$r_{ds} = \frac{V_A}{I_D}$$

$$\Delta I = \frac{\Delta V}{r_{ds}} = \frac{1.8V - |V_G|}{V_A} \times I_D$$

$$\Delta I = [0.15\mu A, 11.7\mu A]$$ ← NOT MUCH DIFFERENCE

30% 23%

d) $V_{G1} = V_{G2}$ BUT $V_{P1} \neq V_{P2}$

ASSUME $I_{D1} = [0.5 \rightarrow 50\mu A] \Rightarrow V_{G1} = [-0.33V, -0.63V]$

$\pm 10mV$

$$V_{P2} = \frac{V_{G1} - V_{th2}}{n} = V_{P1} \pm \frac{\Delta V_{th}}{n}$$

• 2 WAYS OF SOLVING THIS:

1. USE $$i_f = \mathcal{F}^{-1}\left(\frac{V_P}{V_T}\right)$$

2. USE LINEAR APPROXIMATION:

$$\frac{\Delta V_P}{V_T} \simeq \frac{d\mathcal{F}(i_f)}{di_f}\Delta i_f$$

@ $i_f = 0.5$ $i_f = 50$

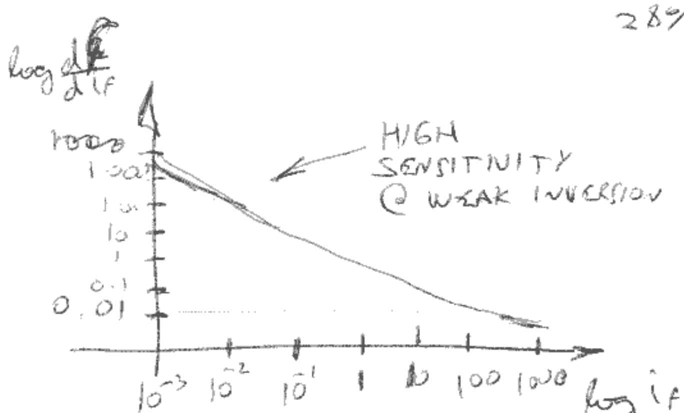
$$\frac{d\mathcal{F}}{di_f} = \frac{1}{2\sqrt{1+i_f}}\left[1 + \frac{1}{\sqrt{1+i_f} - 1}\right] = [2.22, 0.081]$$

$$= \frac{1}{2\left(\sqrt{1+i_f} - 1\right)}$$ VERY SIMPLE!

$$\Delta i_f = \frac{\Delta V_P}{V_T\left(\frac{dF}{di_f}\right)} = \left[\frac{0.0036}{V_T}, \frac{0.099}{V_T}\right]$$

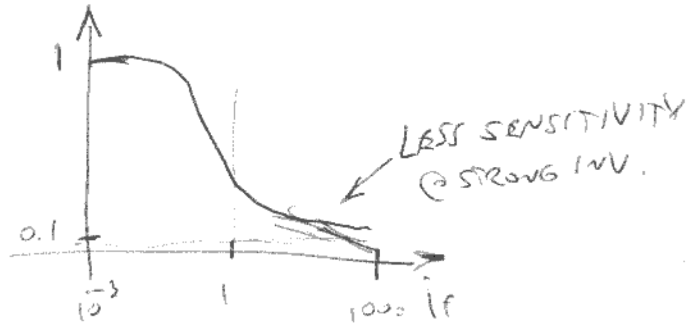
$$\Delta I_D = I_S \Delta i_f \simeq \left[0.14\mu A, 3.81\mu A\right]$$

28%   7.6% ← LESS EFFECT NEAR STRONG INVERSION

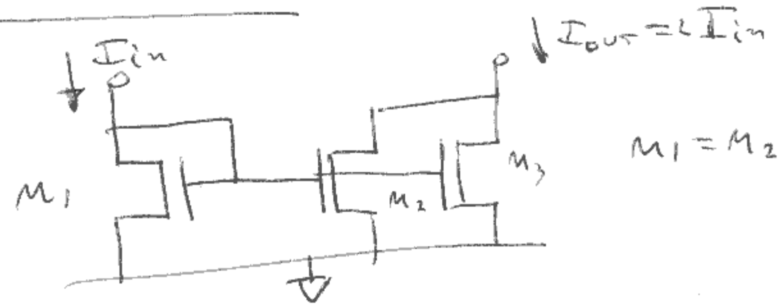


∴ MATCHING MORE DIFFICULT IN WEAK INVERSION.

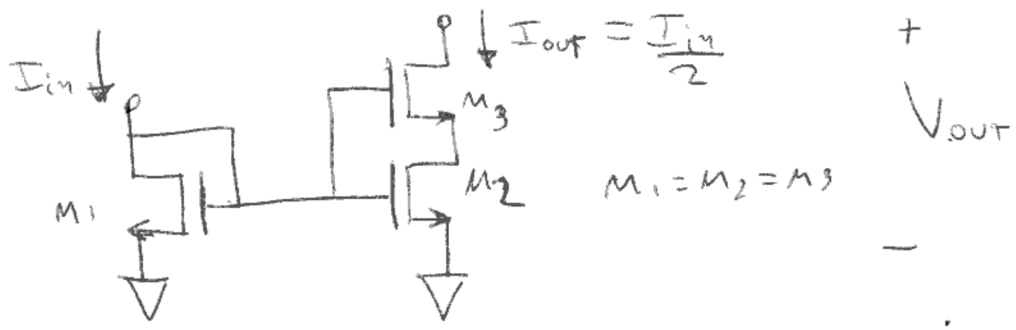
$$\frac{\Delta i_f}{i_f} = \frac{\Delta V_P}{V_T\, i_f\left(\frac{dF}{di_f}\right)} \propto \frac{1}{i_f \frac{dF}{di_f}}$$



CURRENT MIRROR GAIN



$M_1 = M_2 = M_3$



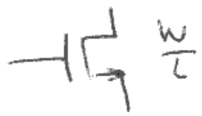
$M_1 = M_2 = M_3$

- $M_1 = M_2$ AND $V_{G1} = V_{G2} \Rightarrow i_{f1} = i_{f2}$
- $i_{r2} = i_{f3}$ SINCE $V_{D2} = V_{S3}$ AND $M_2 = M_3$ (M_2 TRIODE)
- ASSUMING V_{OUT} IS HIGH ENOUGH, $i_{r3} \approx 0$ (M_3 ACTIVE REGION)

$$\therefore i_{f3} = i_{f2} - i_{r2} = i_{f2} - i_{f3}$$

$$\therefore i_{f3} = \frac{i_{f2}}{2} = \frac{i_{f1}}{2} \Rightarrow I_{OUT} = \frac{I_{in}}{2}$$

- THE SAME WORKS FOR ANY NUMBER OF TRANSISTORS IN SERIES.

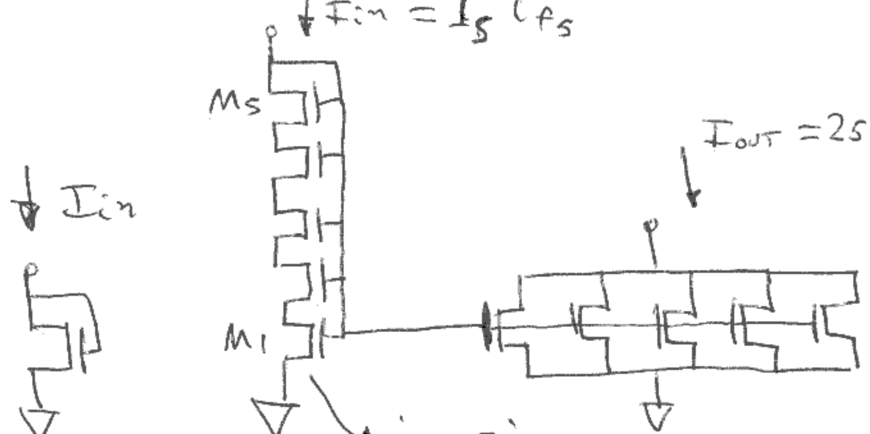


→ N TRANSISTORS IN // EQUIVALENT TO $N\frac{W}{L}$

N TRANSISTORS IN SERIES EQ. TO $\frac{W}{NL}$

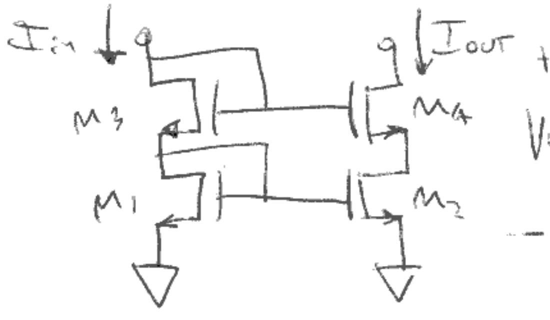
EXAMPLE: PROBLEM 5.4

IMPORTANT: TRANSISTORS ARE ALL EQUAL → GOOD MATCHING.



$I_{in} = I_S\, i_{f5}$ $\quad i_{f1} = 5 i_{f5}$ $\quad I_1 = I_{in} = I_S\,(\underbrace{5 i_{f5}}_{i_{f1}} - \underbrace{4 i_{f5}}_{= i_{r1}})$

CASCODE CURRENT MIRRORS: TO GET HIGH OUTPUT RESISTANCE



V_O, M_1 AND M_2 OPERATE ALMOST @ EXACT SAME OPERATING POINT

$\therefore$ SAME DRAIN CURRENTS