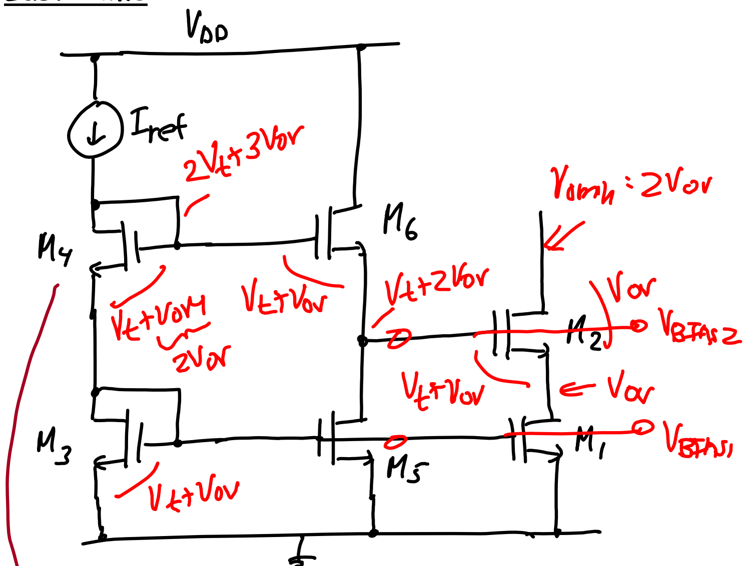
Lecture 12: Current Source Matching

- **Announcements:**
  - HW#5 due tomorrow
  - HW#6 online soon
  - 240A HW#1A online soon
- **Lecture Topics:**
  - High Swing Current Sources (cont.)
  - Current Source Matching Considerations
  - Op Amp Review
- ------------------------------------
- **Last Time:**



Need to design M_4 so that $V_{ov4} = 2V_{ov} = 2V_{ov3}$

$$I_{D3} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_3 (V_{ov3})^2$$

$$I_{D4} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_4 (V_{ov4})^2 = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_4 (2V_{ov3})^2$$

$I_{D3} = I_{D4} = I_{ref}$

$$\frac{1}{2}\cancel{\mu_n C_{ox}}\left(\frac{W}{L}\right)_3 (\cancel{V_{ov3}})^2 = \frac{1}{2}\cancel{\mu_n C_{ox}}\left(\frac{W}{L}\right)_4 (4\cancel{V_{ov3}^2})$$

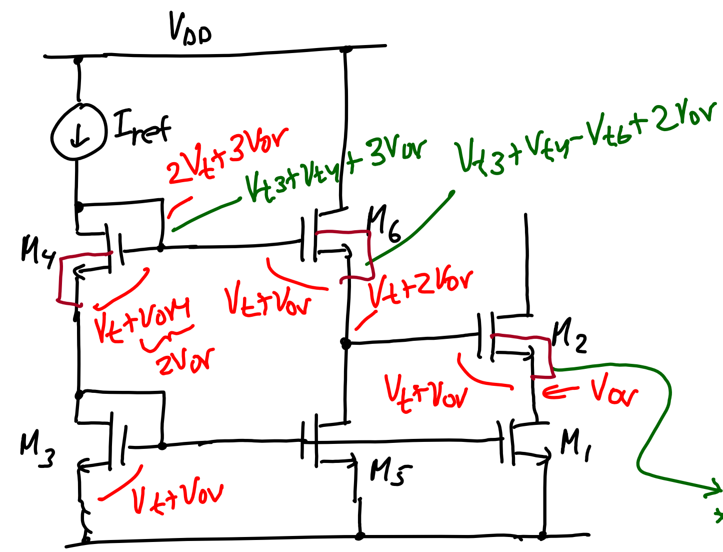
$$\left(\frac{W}{L}\right)_4 = \frac{1}{4}\left(\frac{W}{L}\right)_3 \ldots \text{ and } \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6$$

Problem: Body effect in M_4, M_6, M_2.

$$V_t = V_{t0} + \gamma\left(\sqrt{2|\phi_f| + |V_{SB}|} - \sqrt{2|\phi_f|}\right)$$

if $V_{SB} \neq 0 \rightarrow V_t > V_{t0}$

∴ V_t's of M_4, M_6, & M_2 increase.



$V_{t4} \stackrel{?}{=} V_{t6} \rightarrow V_{S4} = V_t + V_{ov}$, $V_{S6} = V_t + 2V_{ov}$ } $V_{S6} > V_{S4} \rightarrow \underbrace{V_{t6} > V_{t4}}$

Could make $V_{DS1} < V_{ov}$ (triode) ← problem!

* What exactly is this voltage?

$V_{D1} = V_{t3} + V_{t4} - V_{t6} - V_{t2} + V_{ov}$

$= \underbrace{(V_{t4} - V_{t6})}_{(-)} + \underbrace{(V_{t3} - V_{t2})}_{(-)} + V_{ov} \Rightarrow V_{D1} < V_{ov}$

($M_1 \rightarrow$ triode)

M_1 not saturated!

Big Problem! → $R_o \downarrow$

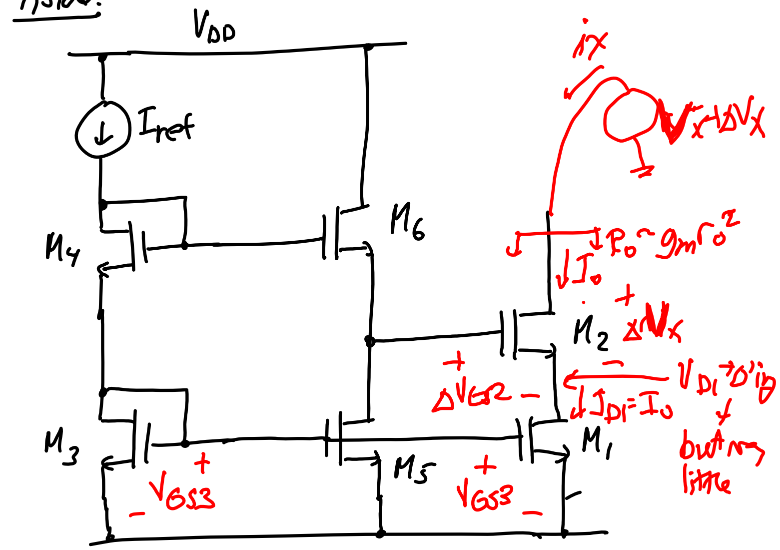
Solutions:

① Tie the wells of M_4, M_6 & M_2 to their sources.

$V_t = V_{t0} + \gamma\left(\cancel{\sqrt{2|\phi_F| + V_{SB}}} - \cancel{\sqrt{2|\phi_F|}}\right) \rightarrow V_{t0}$

Problem: too much die area consumed when giving these devices their own wells → Cost ↑

Aside:



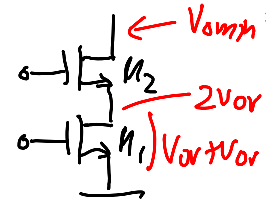
$I_o = I_{D1} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_t)^2 (1 + \lambda V_{DS1})$

high R_o → because M_2 shields M_1 from ΔV_X

② Bias M_4 so that $V_{GS4} \geq V_t + 2V_{ov}$

e.g., $V_{GS4} = V_t + 3V_{ov}$

$\left(\frac{W}{L}\right)_4 = \frac{1}{9}\left(\frac{W}{L}\right)_3$ ← safety margin!



← $V_{omin} = 3V_{ov}$ if all V_t's $= V_{t0}$

w/ V_t's $\neq V_{t0}$:

$2V_{ov} < V_{omin} < 3V_{ov}$

⇒ keeps M_1 saturated ✓

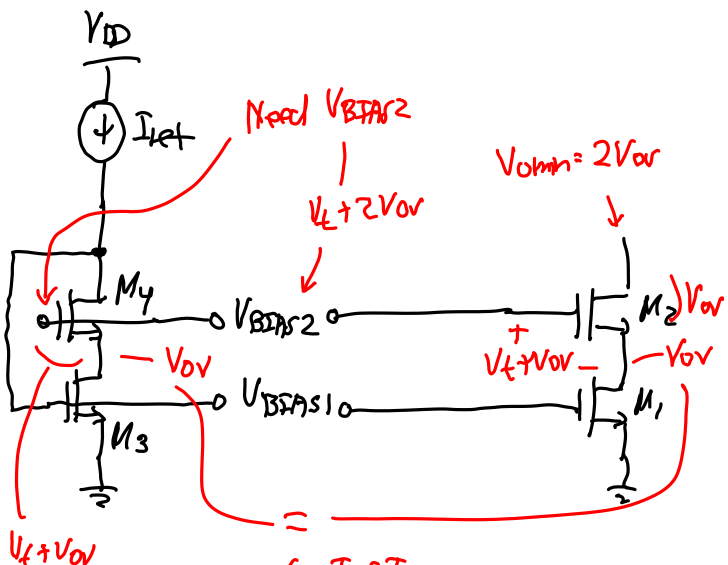
Issue: $I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_t)^2(1+\lambda V_{DS})$

channel length ↓ ⇒ λ↑

If $V_{DS1} \neq V_{DS3}$

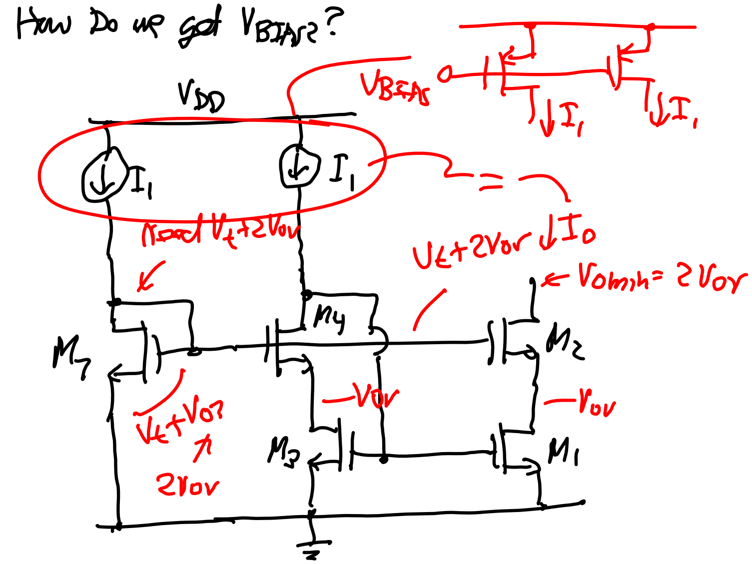
$I_o = \frac{(1+\lambda V_{DS1})}{(1+\lambda V_{DS3})} I_{ref} \rightarrow I_o \neq I_{ref}$

Solution: $\boxed{\text{Alternate Biasing Scheme for Cascode}}$



∴ $I_o = I_{ref}$

How do we get V_{BIAS2}?



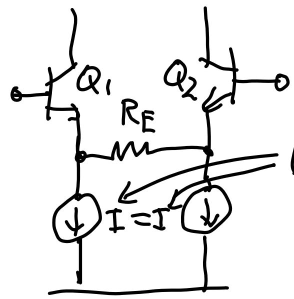
$I_{D7} = I_{D3}$

$\cancel{\tfrac{1}{2}\mu_n C_{ox}}\left(\frac{W}{L}\right)_7 (\overset{4}{\cancel{2}}\cancel{V_{ov}})^2 = \cancel{\tfrac{1}{2}\mu_n C_{ox}}\left(\frac{W}{L}\right)_3 (\cancel{V_{ov}})^2$

$\boxed{\left(\frac{W}{L}\right)_7 = \frac{1}{4}\left(\frac{W}{L}\right)_3,\ \left(\frac{W}{L}\right)_{rest} = \left(\frac{W}{L}\right)_3}$

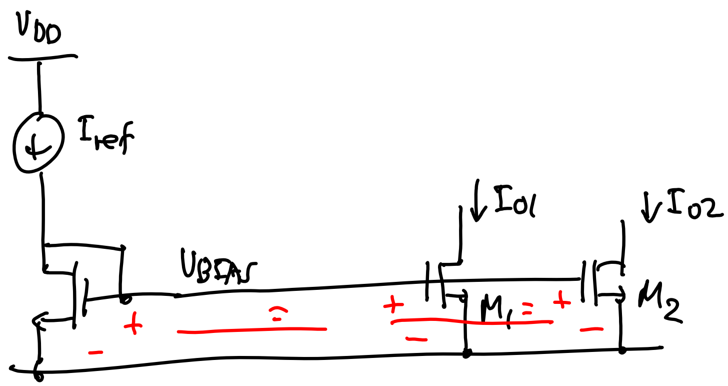
Note: Still must worry about Body effect!
↳ design defensively
↳ make $V_{DS7} > V_t + 2V_{ov}$
↑
$3V_{ov}$?

Current Source Matching Considerations



Need equal currents in this differential amplifier stage.
↳ want perfectly matched current sources!

Consider matching of Simple Current Source:



In MOS

$I_{O1}=I_{O2} \rightarrow I_{D1}=I_{D2}$

$I_{O1}=I_{D1}=\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1(V_{GS1}-V_{t1})^2$

$I_{O2}=I_{D2}=\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2(V_{GS2}-V_{t2})^2$

same

I_{O1} & I_{O2} will not be perfectly matched if

$\underbrace{(W/L)_1 \neq (W/L)_2 \;\&\; V_{t1}\neq V_{t2}}$

will always have this due to finite fabrication tolerances!

Need to quantify their impact → How much mismatch caused by

Define average & mismatch quantities:

Average:

$I_D=\frac{1}{2}\left[I_{D1}+I_{D2}\right]$

$\frac{W}{L}=\frac{1}{2}\left[\left(\frac{W}{L}\right)_1+\left(\frac{W}{L}\right)_2\right]$

$V_t=\frac{1}{2}\left[V_{t1}+V_{t2}\right]$

Mismatch:

$\Delta I_D=I_{D1}-I_{D2}$

$\Delta\left(\frac{W}{L}\right)=\left(\frac{W}{L}\right)_1-\left(\frac{W}{L}\right)_2$

$\Delta V_t=V_{t1}-V_{t2}$

$\frac{\Delta I_D}{I_D} \triangleq$ fractional current mismatch

$\frac{\Delta(W/L)}{(W/L)} \triangleq$ " $\left(\frac{W}{L}\right)$ "

$\frac{\Delta V_t}{V_t} \triangleq$ " V_t "

$\Rightarrow$ want $\frac{\Delta I_D}{I_D}=f\left(\frac{\Delta(W/L)}{(W/L)},\frac{\Delta V_t}{V_t}\right)$

Rearranging:

$$I_{D1} = I_D + \frac{\Delta I_D}{2} \qquad \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right) + \frac{\Delta(W/L)}{2} \qquad V_{t1} = V_t + \frac{\Delta V_t}{2}$$

$$I_{D2} = I_D - \frac{\Delta I_D}{2} \qquad \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right) - \frac{\Delta(W/L)}{2} \qquad V_{t2} = V_t - \frac{\Delta V_t}{2}$$

Plug these into the current equation:

$$I_{D1} = \cancel{I_D} + \frac{\Delta I_D}{2} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (\overset{V_{GS}}{V_{GS1}} - V_{t1})^2$$

$$= \frac{1}{2}\mu_n C_{ox}\left[\left(\frac{W}{L}\right) + \frac{\Delta(W/L)}{2}\right]\Big(\underbrace{V_{GS} - V_t}_{V_{ov}} - \frac{\Delta V_t}{2}\Big)^2 \quad \text{neg.}$$

$$= \frac{1}{2}\mu_n C_{ox}\left[\left(\frac{W}{L}\right) + \frac{\Delta(W/L)}{2}\right]\left(V_{ov}^2 - 2V_{ov}\frac{\Delta V_t}{2} + \cancel{\frac{(\Delta V_t)^2}{4}}\right)$$

$$= \frac{1}{2}\mu_n C_{ox}\left[\left(\frac{W}{L}\right)V_{ov}^2 + \frac{\Delta(W/L)}{2}V_{ov}^2 - \left(\frac{W}{L}\right)V_{ov}\Delta V_t - \cancel{\frac{\Delta(W/L)}{2}V_{ov}\Delta V_t}\right] \quad \text{neg!}$$

$$= \underbrace{\cancel{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)V_{ov}^2}}_{I_D} + \frac{1}{2}\mu_n C_{ox}V_{ov}^2\left[\frac{\Delta(W/L)}{2} - \frac{(W/L)}{V_{ov}}\Delta V_t\right]$$

$$\frac{\Delta I_D}{2} = \overbrace{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)V_{ov}^2}^{I_D}\left[\frac{1}{2}\frac{\Delta(W/L)}{(W/L)} - \frac{\Delta V_t}{V_{ov}}\right]$$

$$\therefore \boxed{\frac{\Delta I_D}{I_D} = \frac{\Delta(W/L)}{(W/L)} - \frac{\Delta V_t}{(V_{ov}/2)}}$$

$$\boxed{\frac{\Delta I_D}{I_D} = \frac{\Delta(W/L)}{(W/L)} + \frac{\Delta V_t}{(V_{ov}/2)}}$$

(−) means nothing → always take worst case, so can replace (−) w/ (+)

Fractional Current Mismatch

Geometry-Based Component → Indep of Bias

$V_{ov}\uparrow$ → to minimize this component

Today Ckts: Driven by power saving for digital.

$V_{DD}\downarrow \rightarrow V_{ov}\downarrow \rightarrow \frac{\Delta I_D}{I_D}\uparrow$ X Bad!

To Combat this: $\underbrace{\left(\frac{W}{L}\right)\uparrow \rightarrow \frac{\Delta(W/L)}{(W/L)}\downarrow \rightarrow \frac{\Delta I_D}{I_D}\downarrow}$ ✓

@ the expense of die area = cost!

Chip Size With Time: