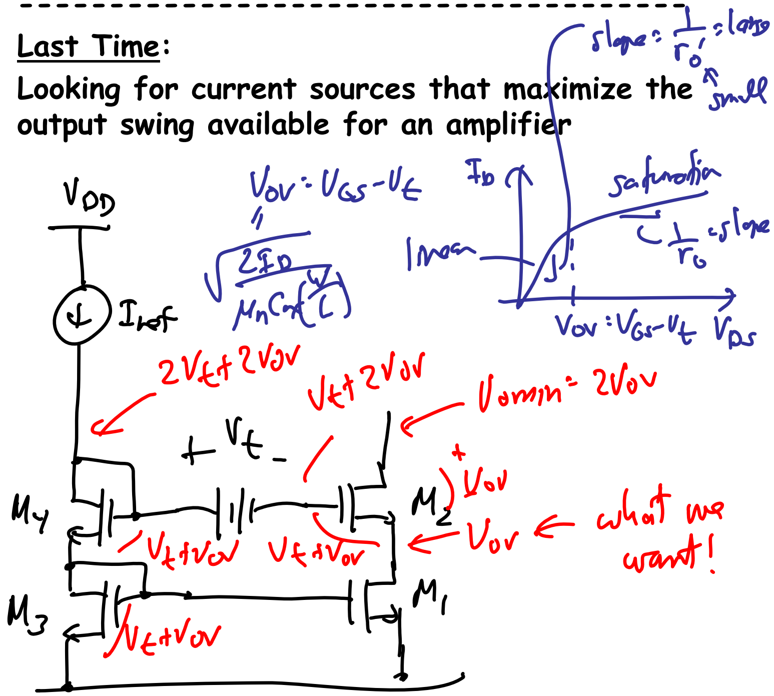
Lecture 10: High Swing Current Sources II

- **Announcements**:
  - This is the make-up lecture for yesterday's lecture
  - Reminder: Lab#2 starts next week
  - No Monday lab section next week due to holiday
  - Monday lab sections will start Lab#2 Monday the week after next
- **Lecture Topics**:
  - High Swing Current Sources (cont.)
  - Current Source Matching Considerations
  - Op Amp Review
- ------------------------------------
- **Last Time**:
- Looking for current sources that maximize the output swing available for an amplifier

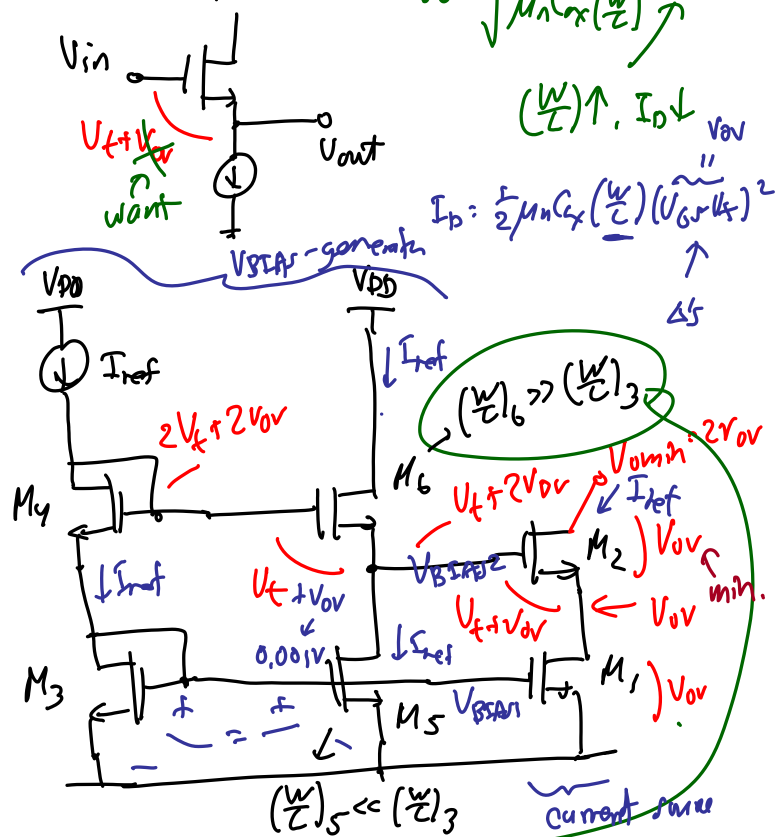


Problem: Not that easy to get an exact level shift.
↳ one way to do it:

$$V_{ov} = \sqrt{\frac{2I_D}{\mu_n C_{ox}(W/L)}} \rightarrow 0$$

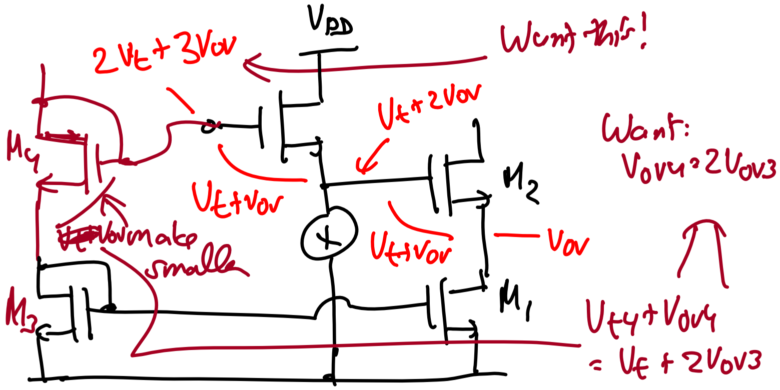
$(W/L)\uparrow,\ I_D\downarrow$

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

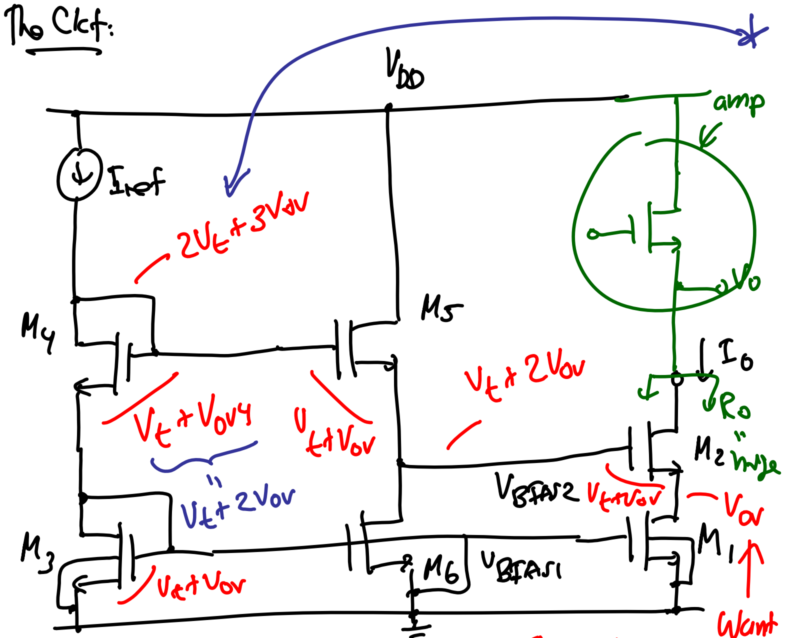


Problem: Don't like this.
↳ $(W/L)_6$ must be big to send $V_{ov} \approx 0$!
↳ if not → $V_{DS1} < V_{ov1}$ → I_{mean}! → Bad!

Another Option: just accept a $V_t + V_{ov}$ level shift.



The Ckt:



$V_{ov}=V_{ov3}$ a of any device whose $\left(\frac{W}{L}\right)=\left(\frac{W}{L}\right)_3$.

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

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

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

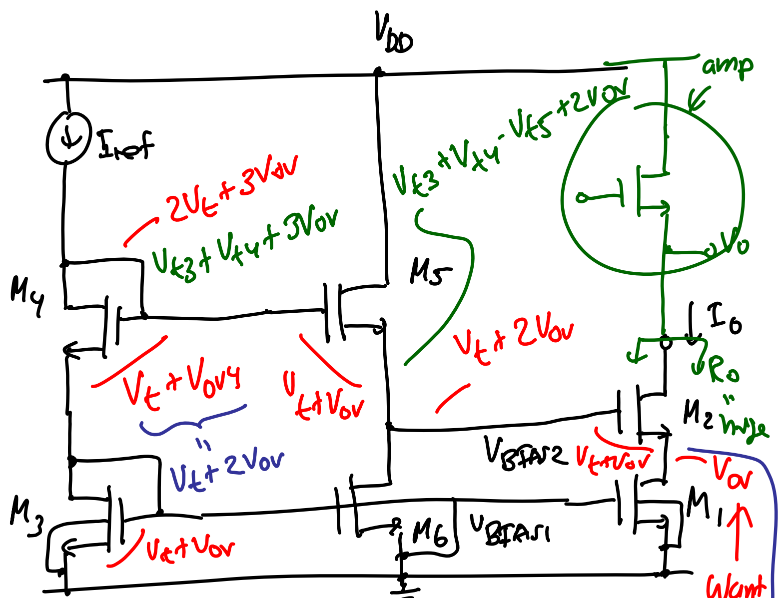
$$\cancel{\frac{1}{2}}\cancel{\mu_n C_{ox}}\left(\frac{W}{L}\right)_3 \cancel{(V_{ov3})^2}=\cancel{\frac{1}{2}}\cancel{\mu_n C_{ox}}\left(\frac{W}{L}\right)_4 \underbrace{(2V_{ov3})^2}_{4V_{ov3}^2}$$

$$* \quad \boxed{\left(\frac{W}{L}\right)_4=\frac{1}{4}\left(\frac{W}{L}\right)_3} \leftarrow \text{ignoring Body Effect}$$

... 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_5, & M_2

↳ will increase their V_t's!



Want this.

$V_{ov} = V_{ov3}$ or of any device whose $\left(\frac{W}{L}\right) = \left(\frac{W}{L}\right)_3$.

$V_{t4} \stackrel{?}{=} V_{t5}$ — $\left.\begin{array}{l} V_{S4} = V_t + V_{ov} \\ V_{S5} = V_t + 2V_{ov} \end{array}\right\} V_{t5} > V_{t4}$

$V_t = V_{t0} + \gamma\sqrt{V_{SB}}$

This could a problem since need to make sure that $V_{DS1} \geq V_{ov}$

What actually is the voltage @ this node?

$V_{t3} + V_{t4} - V_{t5} - V_{t2} + V_{ov}$

$\underbrace{(V_{t4} - V_{t5})}_{(-)} + \underbrace{(V_{t3} - V_{t2})}_{(-)} + V_{ov} < V_{ov}$ $\therefore M_1$ is not saturated!

$\left.\begin{array}{l} V_{S3} = 0V \\ V_{S2} = V_{ov} \end{array}\right\} V_{t3} < V_{t2}$

$V_{t3} + V_{t4} - V_{t5} - V_{t2} + V_{ov}$

$\underbrace{(V_{t4} - V_{t5})}_{(-)} + \underbrace{(V_{t3} - V_{t2})}_{(-)} + V_{ov} < V_{ov}$ $\therefore M_1$ is not saturated!

Big Problem!

linear! → r_o = small

R_o = small → bad current source!

Solutions:

1. Tie the wells of M_4, M_5, M_2 to their sources.
2. Bias M_4 so that $V_{GS4} > V_t + 2V_{ov}$

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

$$\boxed{\left(\frac{W}{L}\right)_4 = \frac{1}{9}\left(\frac{W}{L}\right)_3}$$

Safety margin against Body effect

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

$\lambda \uparrow$ as channel length $\downarrow$

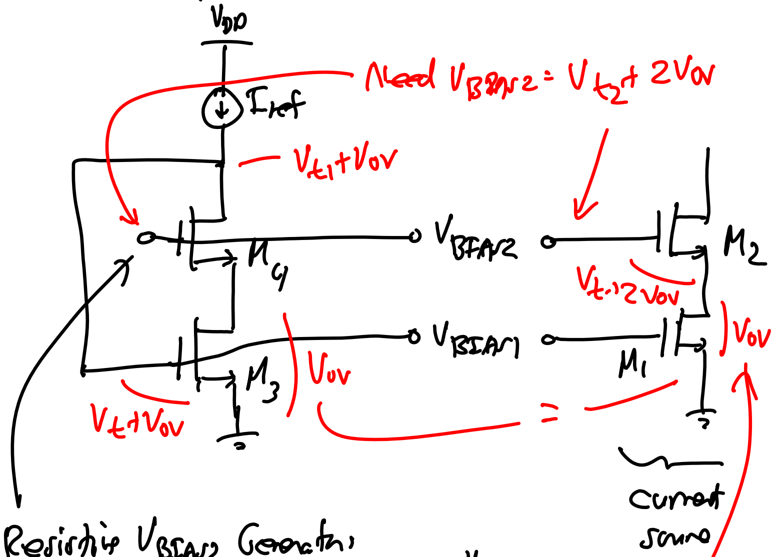
If $V_{DS1} \neq V_{DS3}$

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

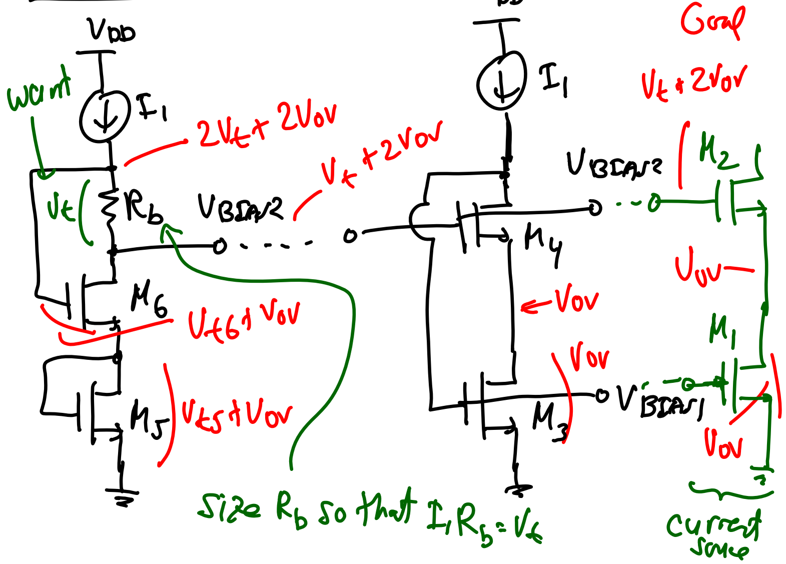
Solution: Use alternate biasing scheme.

Alternate Biasing Scheme for Cascode

⇒ want only V_{ov} across M_3 to make it's $V_{DS3} = V_{DS1}$:



Resistive V_{BIAS2} Generator:

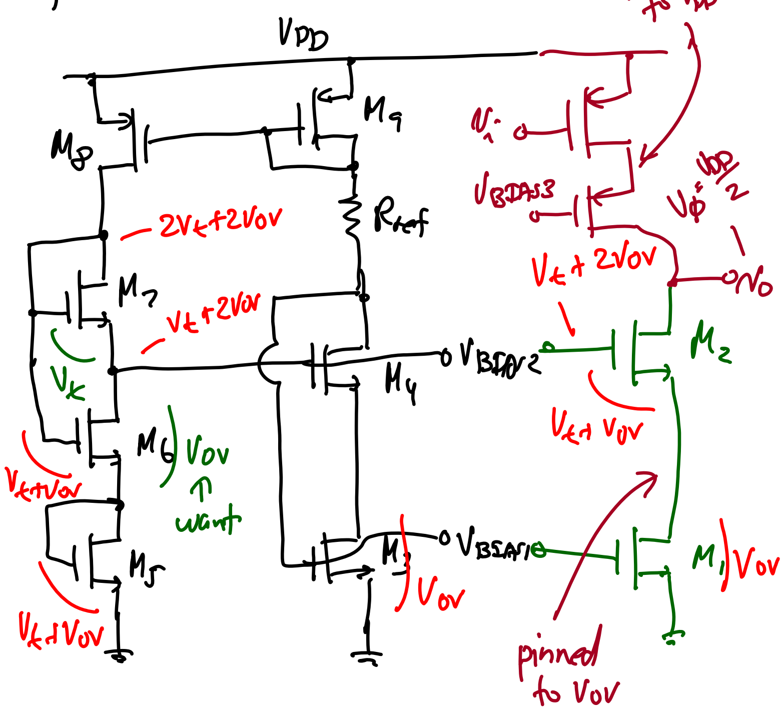


Issues:

1. I_1R_b not all that well-controlled.
2. Resistor = area consumption.
3. Body effect complicates things:
   ↳ really need: $I_1R_b = V_{t5} + V_{t6} - V_{t4}$

↓

Replace R_b w/ a transistor level shift:



Design:

Approach 1: Want $V_{GS7} = V_{t}$, so must make $\left(\frac{W}{L}\right)_7$ = large,
so that:

$$V_{OV7} = \sqrt{\frac{2I_D}{\mu_n C_{ox} \left(\frac{W}{L}\right)_7}} \rightarrow 0, \text{ then}$$

Problem: too much chip area!

Solution

Approach 2: → recognize that devices in the V_{BIAS}-generator don't all need to be saturated → some can be linear!