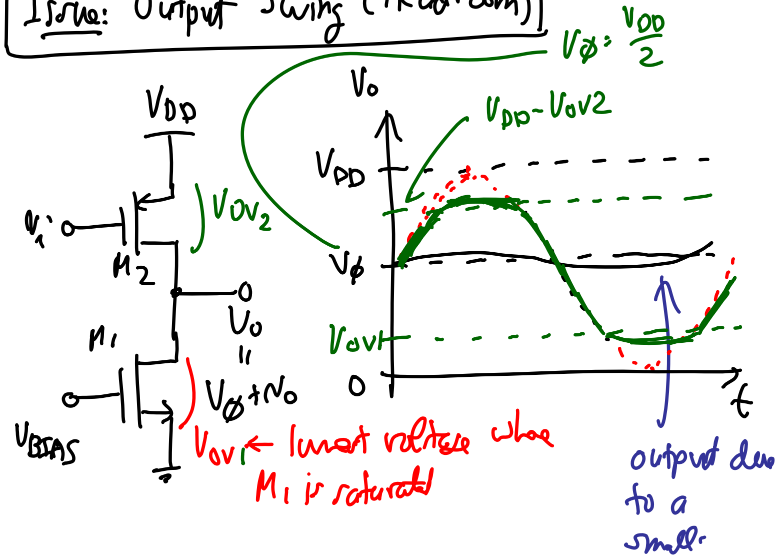
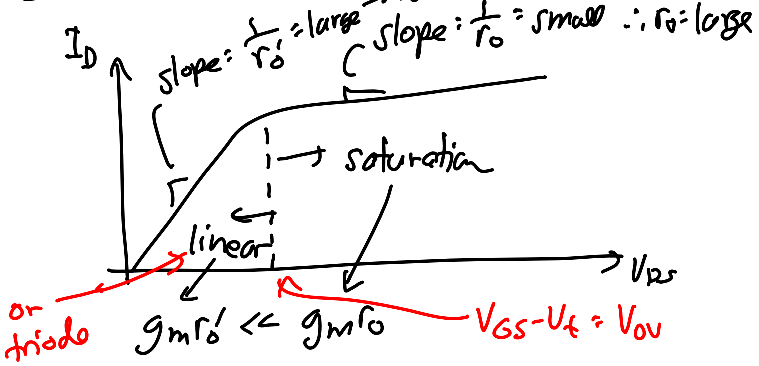
Lecture 10: High Swing Current Sources I

- **Announcements**:
  - ↳ HW#4 due tomorrow
  - ↳ HW#5 online soon
  - ↳ Lab#2 online
    - — This is a hardware lab, so you will need to use the lab to make measurements
    - — You are all being added to the access list for 353 Cory
  - ↳ Those taking 240A will soon get additional HW assignments to supplement the regular ones
- **Lecture Topics**:
  - ↳ Output Swing (Headroom)
  - ↳ High Swing Current Sources
- ------------------------------------
- **Last Time**:

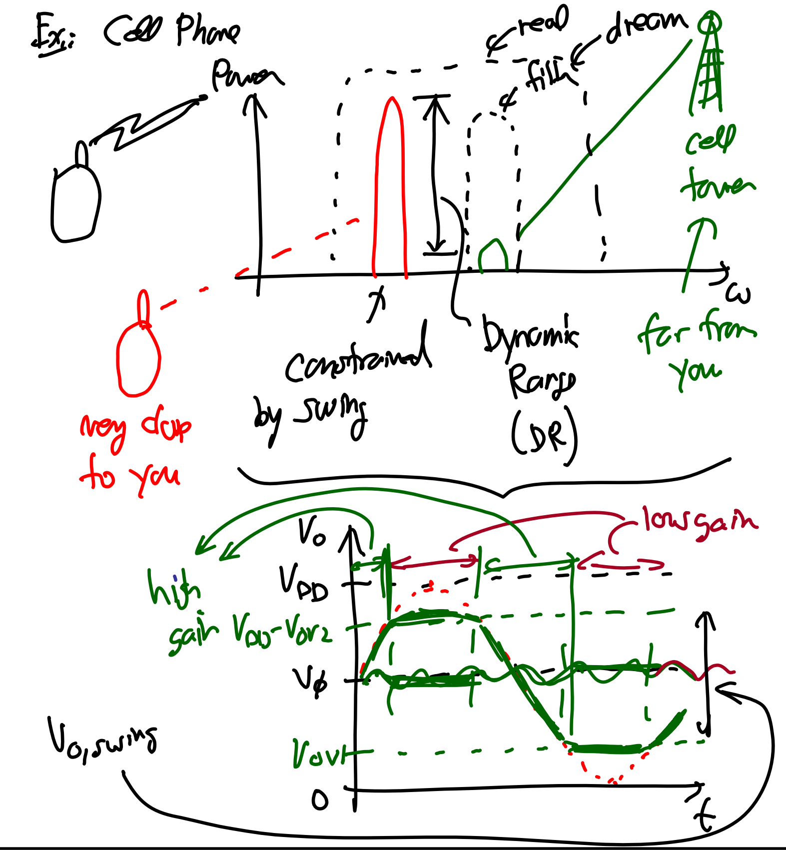
Issue: Output Swing (Headroom)



I_D vs. V_{DS} Characteristic:



Ex: Cell Phone



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What is V_{ov}?

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

$$V_{ov} = \Delta V = V_{Dsat} = V_{GS}-V_t = \boxed{\sqrt{\frac{2I_D}{\mu_n C_{ox}\left(\frac{W}{L}\right)}} = V_{OV}}$$

"overdrive" voltage

The min. voltage that still keeps M_1 as a good current source (i.e., $R_o \approx$ large, M_1 saturated)

$V_{omin} = V_{ov}$

∴ the output swing:

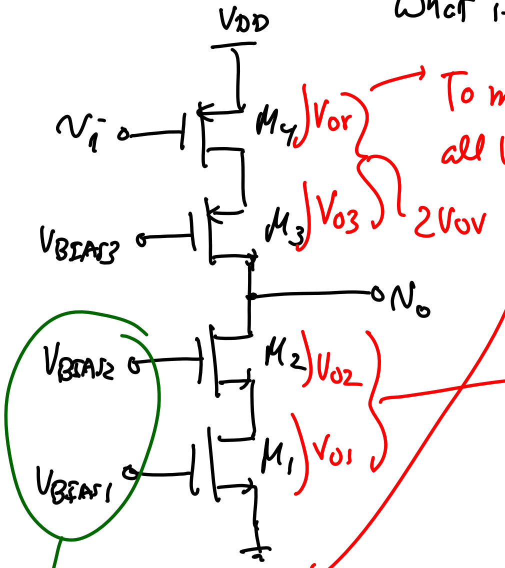
$$\boxed{V_{o,swing,pp} = V_{DD} - V_{ov1} - V_{ov2}}$$

↑ peak-to-peak

What about better current sources? (i.e., w/ higher R_o)

↳ Ex. Cascode current source load + cascode drive

What is $V_{o,swing}$?



To maintain high gain, all V_{DS}'s $\geq V_{ov}$

$2V_{ov} = V_{omin}$

Best we can do...

$$V_{o,swing} = V_{DD} - V_{ov1} - V_{ov2} - V_{ov3} - V_{ov4} = V_{DD} - 4V_{ov}$$

$$\approx 2 - 4(0.2) = 1.2V$$

How do we generate those?

↳ Answer: make a V_{BIAS}-generator

↳ simplest way: replica bias (i.e., use a simple cascode)

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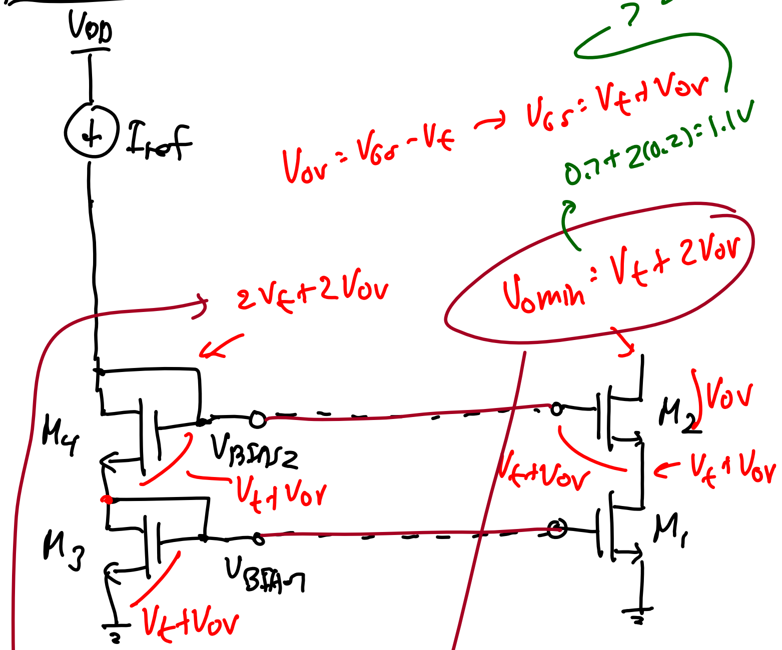
Simple Cascode V_{BIAS}-Generator



$V_{ov} = V_{GS} - V_t \rightarrow V_{GS} = V_t + V_{ov}$

$\frac{2V}{2}$? ✗

$V_{omin} = V_t + 2V_{ov}$

$0.7 + 2(0.2) = 1.1V$

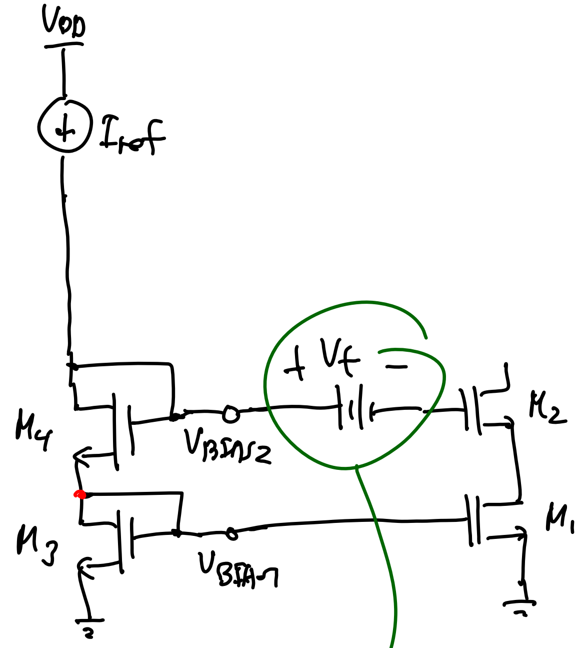
All w/ same $\left(\frac{W}{L}\right)$'s.

Problem! Want $V_{omin} = 2V_{ov}$

How can we get rid of V_t?

recognize that this voltage is too high!

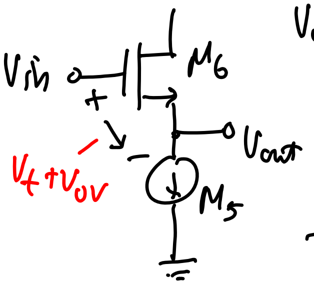
Need to level shift:



All w/ same $\left(\frac{W}{L}\right)$'s

How can we best get this level shift?

One way: use a Xsistor:

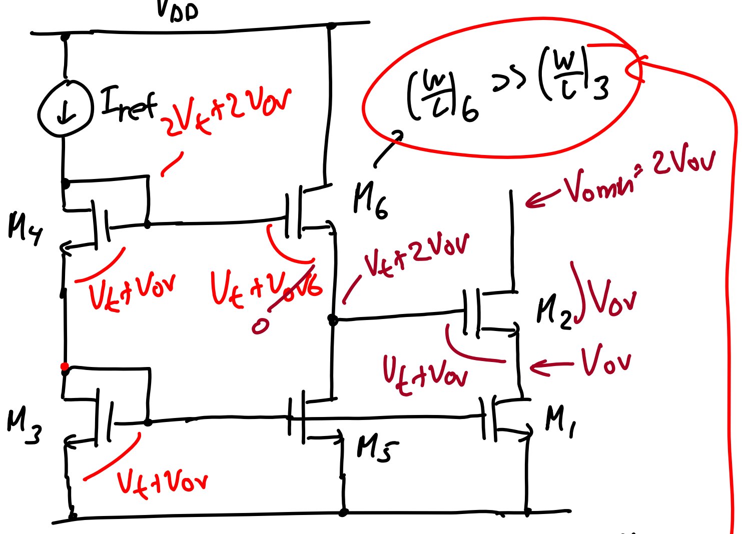


$V_{ov} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\left(\frac{W}{L}\right)}} \longrightarrow 0$

$\left(\frac{W}{L}\right)\uparrow,\ I_D\downarrow$

then $V_t + \cancel{V_{ov}} \cong V_t$! ✓

The Actual Ckt:



All $(\frac{W}{L})$'s the same as $\left(\frac{W}{L}\right)_3$, except $\left(\frac{W}{L}\right)_6$.

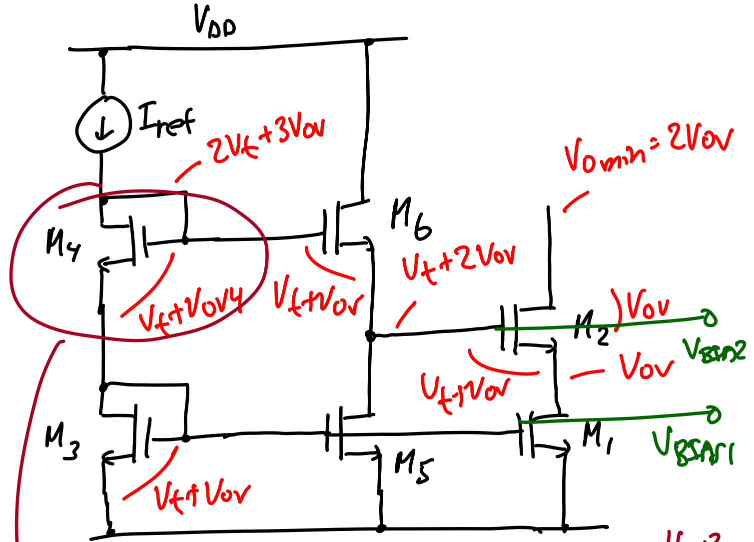
Problem: Don't like this

↘ $\left(\frac{W}{L}\right)_6$ must be big to send $V_{ov6} \to 0$ V

↘ if $(W/L)_6$ not big → $V_{GS6} = V_t + \underline{V_{ov6}}$
finite

$V_{DS1} = V_{ov} - V_{ov6}$ → not saturated ✗

Another Option: just accept a V_t+V_{ov} level shift via M_6 (use same ckt.)



V_{ov3} //

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

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

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

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

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

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

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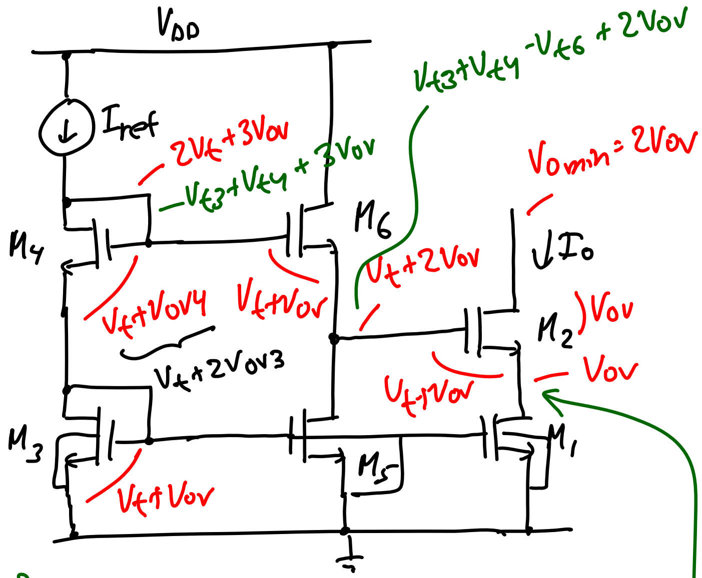
Lecture 10w: High Swing Current Sources I

Problem: Body effect M_4, M_6, M_2 → increases their V_t's



$V_{t4} \overset{?}{=} V_{t6}$ → $V_{S4} = V_t + V_{ov}$, $V_{S6} = V_t + 2V_{ov}$ } $V_{t6} > V_{t4}$

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

Could be a problem if it makes $V_{DS1} < V_{ov}$

(M_1 → triode)

What exactly is the voltage here?

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

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

∴ M_1 is not saturated!

BIG PROBLEM!

Solutions:

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

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

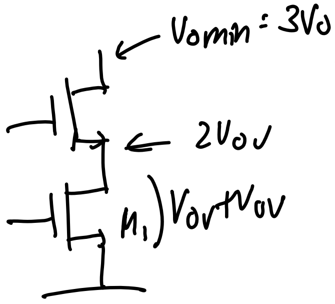
But don't want to do this → too much die area consumed → cost↑

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

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!



Not optimum, but safe → M_1 stays in saturation

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

↑ λ↑ as channel length↓

↓

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

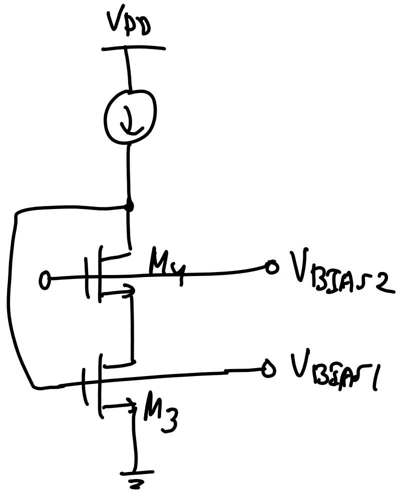
↓

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

↓

Solution: Use alternative biasing scheme.

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



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