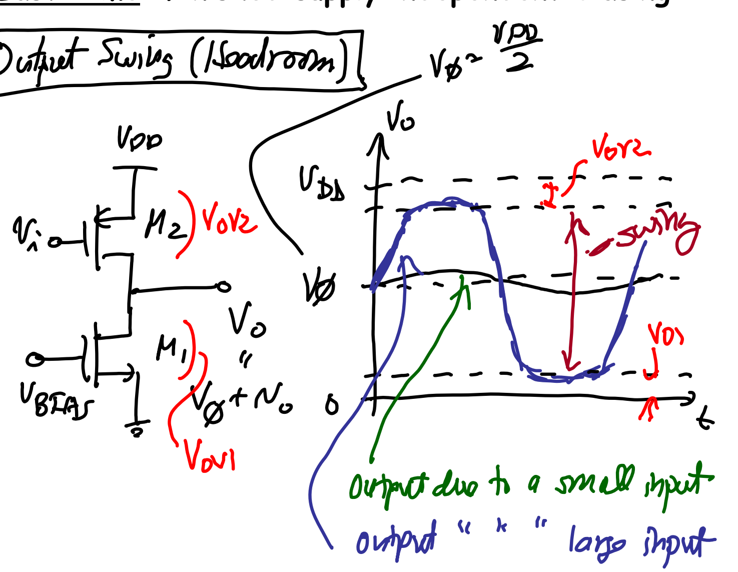
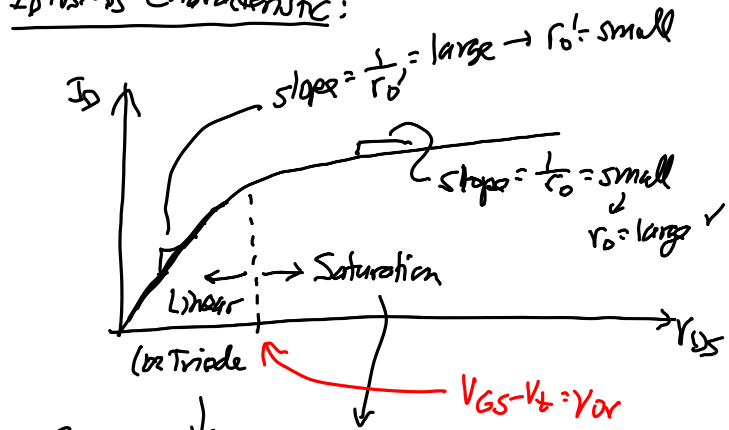
Lecture 11: High Swing Current Sources

- Announcements:
  - HW#5 online
  - Lab#1 reports are due on Oct. 5
    - Submit them in your lab section
  - Lab#2 is online
    - This is a hardware lab
    - You must show up to lab for Lab#2
  - Videos online in the lecture chart
- Lecture Topics:
  - Output Swing & Dynamic Range
  - High Swing Current Sources
- ------------------------------------
- Last Time: Finished supply independent biasing

Output Swing (Headroom)



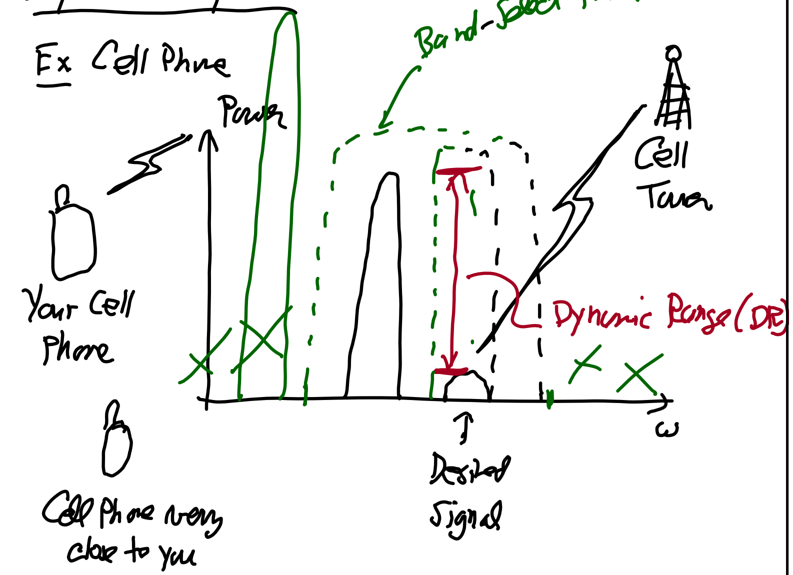
I_D vs. V_{DS} Characteristic:

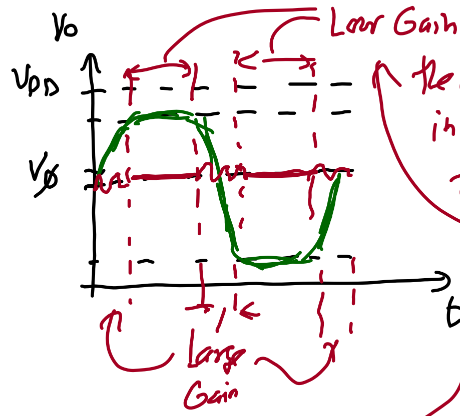


Gain: $g_m r_o' \ll g_m r_o$

↳ Much less gain in the triode region than in the saturation region.

Why is this important?





Low Gain → can't amplify the desired signal in this low gain time period

caused by the large interfering signal (blocker)

Large Gain

This is desensitization.

Dynamic Range (DR) = Largest Output Signal / minimum Signal

Largest Output Signal: determined by linearity (swing)

minimum Signal: determined by noise

What is V_{ov}?

$I_D = \frac{1}{2}\mu_n C_{ox}(V_{GS}-V_t)^2$, where $V_{GS}-V_t = V_{ov}$

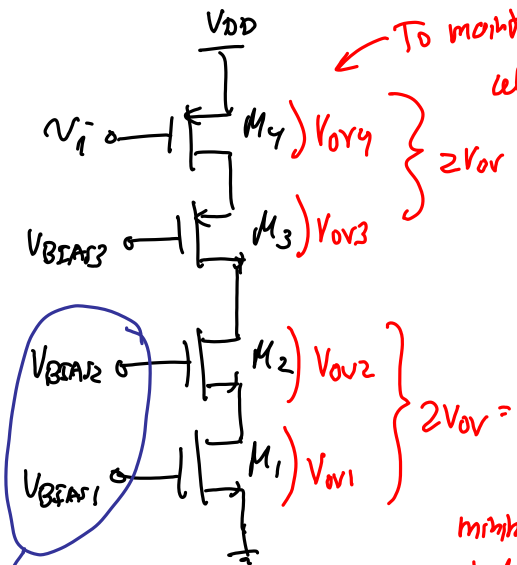
$V_{ov} = \Delta V = V_{Dsat} = V_{GS}-V_t = \sqrt{\frac{2I_D}{\mu_n C_{ox}(\frac{W}{L})}} = V_{ov}$

$\therefore V_{o\,swing} = V_{DD} - V_{ov1} - V_{ov2} = V_{DD} - 2V_{ov}$ ($V_{o\,swing}$: peak-to-peak)

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

Ex. Cascode Current Source Load & Cascode Drive

⇒ What is the $V_{o\,swing}$?



To maintain high gain, all V_{DS}'s ≥ V_{ov}

V_{omin}: minimum voltage @ which we still have high gain

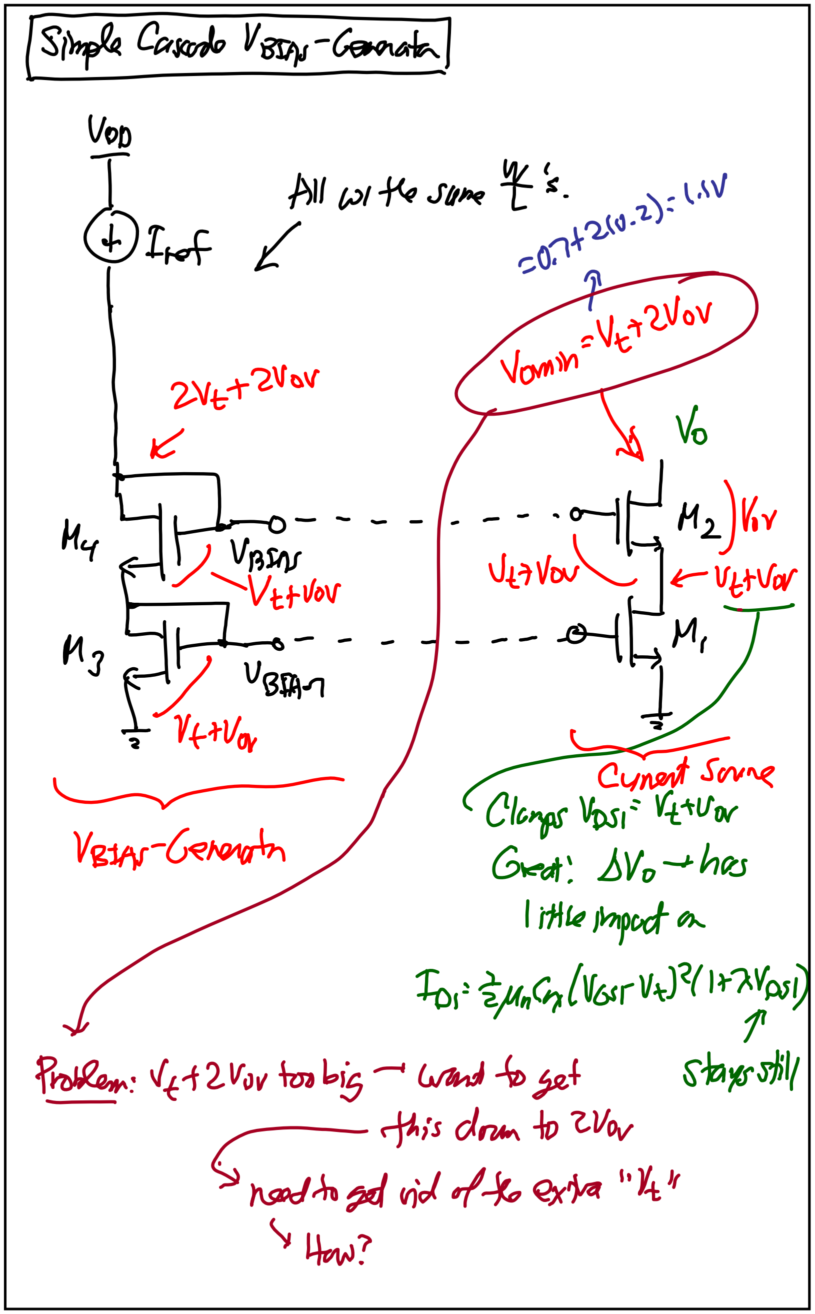
$V_{o\,swing} = V_{DD} - V_{ov1} - V_{ov2} - V_{ov3} - V_{ov4} = V_{DD} - 4V_{ov}$ (Best we can do)

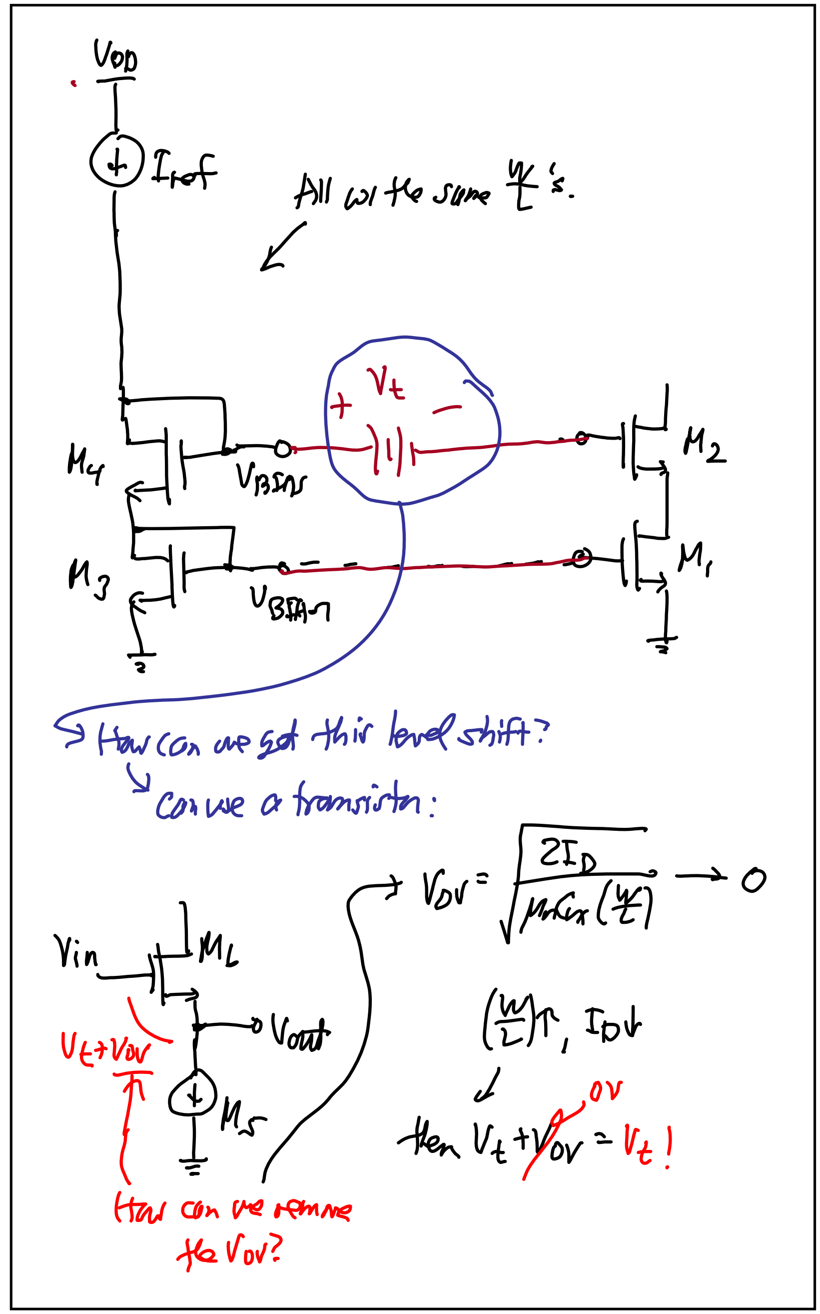
$\approx 2 - 4(0.2) = 1.$

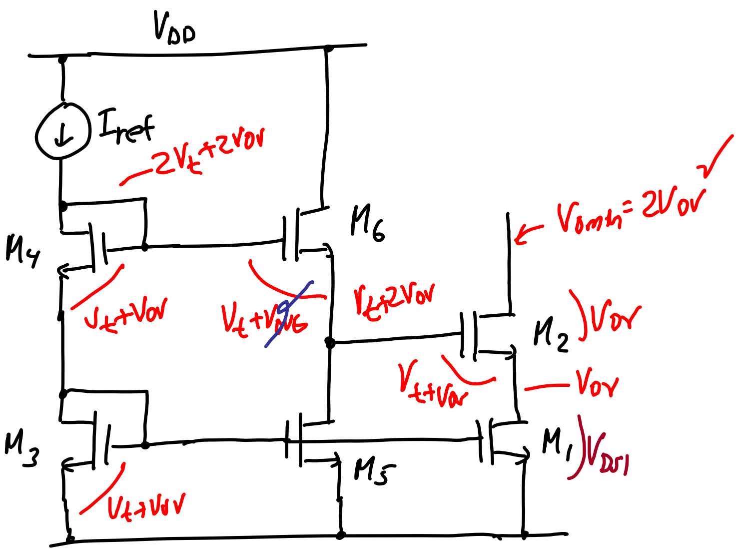
How do we generate these?

Answer: make an appropriate V_{BIAS}-generator

↳ simplest way: replica bias → use a simple cascode of diodes


Simple Cascode V_{BIAS}-Generator
V_{DD}
I_{ref}
All w/ the same $\frac{W}{L}$'s.
$= 0.7 + 2(0.2) = 1.1V$
$V_{omin} = V_t + 2V_{ov}$
$2V_t + 2V_{ov}$
V_o
M_4
V_{BIAS}
$V_t + V_{ov}$
M_2
V_{ov}
$V_t + V_{ov}$
$V_t + V_{ov}$
M_3
V_{BIAS}
M_1
$V_t + V_{ov}$
V_{BIAS}-Generator
Current Source
Clamps $V_{DS1} = V_t + V_{ov}$
Great! $\Delta V_o \rightarrow$ has little impact on
$I_{D1} = \frac{1}{2}\mu_n C_{ox}(V_{GS} - V_t)^2(1 + \lambda V_{DS1})$
Stays still
Problem: $V_t + 2V_{ov}$ too big → want to get this down to $2V_{ov}$
need to get rid of the extra "V_t"
How?


V_{DD}
I_{ref}
All w/ the same $\frac{W}{L}$'s.
V_t
+
−
M_4
V_{BIAS}
M_2
M_3
V_{BIAS}
M_1
How can we get this level shift?
Can use a transistor:
$V_{ov} = \sqrt{\frac{2I_D}{\mu_n C_{ox}(\frac{W}{L})}} \rightarrow 0$
V_{in}
M_L
V_{out}
$V_t + V_{ov}$
M_S
$(\frac{W}{L})\uparrow$, $I_D\downarrow$
then $V_t + V_{ov} = V_t$!
0V
How can we remove the V_{ov}?



All (W/L)'s the same as $(W/L)_3$, except $(W/L)_6$.

Problem.

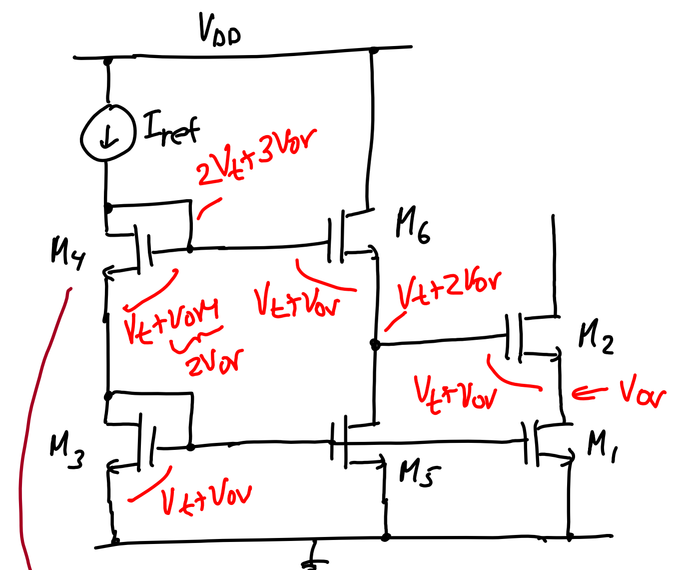
① $(W/L)_6$ must be big to send $V_{ov6} \to 0V$

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

$V_{DS1} = V_{ov1} - V_{ov6} < V_{ov1}$

↑ M_1 not saturated! (big problem)

Another Option: Just accept a $V_t + V_{ov}$ level shift from the gate to source of M_6. (use the same ckt.)



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

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

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

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

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

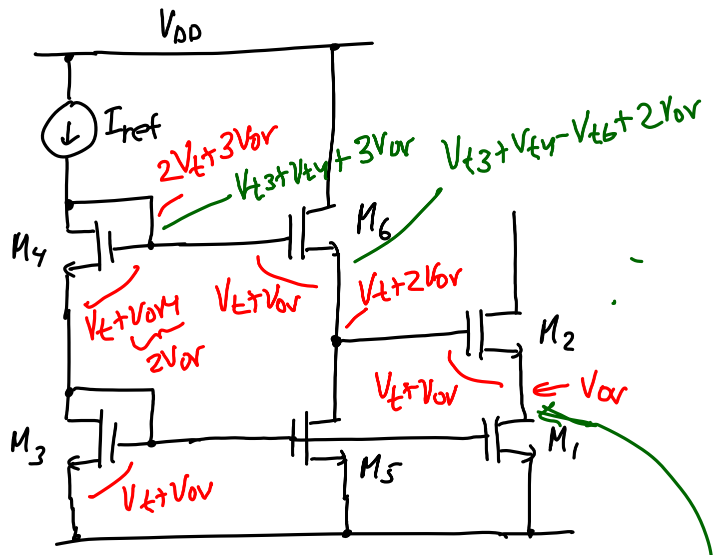
$\left(\frac{W}{L}\right)_4 = \frac{1}{4}\left(\frac{W}{L}\right)_3$ ... and $\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_5 = \left(\frac{W}{L}\right)_6$

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

$\therefore$ V_t's of M_4, M_6, & M_2 increase.



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

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

What exactly is this voltage?