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)
What is $V_{ov}$?

$$I_D = \frac{2}{\mu \kappa C \xi} (V_{GS} - V_T)^2$$

$$V_{ov} = \delta V = V_{MOS} = V_{GS} - V_T = \frac{2 I_D}{\mu \kappa C \xi} \cdot \delta V > V_{ov}$$

"Waddington voltage"

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

$$V_{ Thom; V_{ov}}$$

$\approx$ the output swing:

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

peak-to-peak

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

*Ex.: Cascode current source (load + cascode device)

- What is $V_{0,swing}$?

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

- $2V_{ov}$

- $2V_{ov} \cdot V_{omin}$

Best we can do...

- $V_{0,swing} = V_{DD} - V_{ov1} - V_{ov2} - V_{ov3} - V_{ov4} = V_{DD} - 4V_{ov}$

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

- How do we generate these?

- Answer: Make a $V_{bias}$ generator

  - Simplest way: replica bias (i.e., use a simple cascade)
**Simple Cascade $V_{BSA}-Generator$**

- $V_{DD}$
- $I_{ref}$
- $V_{BB}$
- $V_{T} + V_{on}$
- $2V_{T} + 2V_{on}$
- $V_{on}$
- $V_{VDD} - V_{on}$
- $V_{o}$
- $V_{min}$: $V_{T} + 2V_{on}$

**Problem:** Want $V_{min} = 2V_{on}$

**How can we get rid of $V_{T}$?**

**Need to level shift:**

- $V_{DD}$
- $I_{ref}$
- $V_{T}$
- $M_{1}$
- $M_{2}$
- $M_{3}$
- $M_{4}$
- $M_{5}$
- $M_{6}$

**All with same $\frac{W}{L}$'s**

**One way:** use a X-circuit:

- $V_{in}$
- $V_{out}$
- $V_{T} + V_{on}$
- $\sqrt{\frac{2I_{D}}{\mu_{n}C_{ox}L}}$
Another option just accept a $V_{OV}$ level shift via $M_6$ (use same clt.)

Need to design $M_y$ so that $V_{OV4} = 2V_{OV}$

$$I_{O3} = \frac{1}{2} \mu_n C_X (\frac{W}{L})_3 (V_{OV3})^2$$

$$I_{O4} = \frac{1}{2} \mu_n C_X (\frac{W}{L})_4 (2V_{OV3})^2$$

$$I_{D3} = I_{O4} + I_{red}$$

$$\frac{1}{2} \mu_n C_X (\frac{W}{L})_3 (V_{OV3})^2 = \frac{1}{2} \mu_n C_X (\frac{W}{L})_4 (2V_{OV3})^2$$

$$\left(\frac{W}{L}\right)_y = \frac{1}{4} \left(\frac{W}{L}\right)_3$$

... and $(\frac{W}{L})_1 = (\frac{W}{L})_2 = (\frac{W}{L})_3 = 2(\frac{W}{L})_6$
Problem: Body effect $M_4, M_6, M_2$ increase from $V_{E's}$

$V_{DD}$

$\downarrow$ $I_{REF}$

$V_O$ $V_{OUT}$ $V_{OUT}$

$V_{OUT} = V_{DD} - 2V_{DS} + 2V_{OV}$

$V_{GS4} = V_{E4} + V_{OV}$

$V_{GS6} = V_{E6} + 2V_{OV}$

$V_{GS6} = V_{E6}$

$V_{GS6} = V_{E6} + V_{OV}$

$V_{GS6} = V_{E6}$

$V_{E6} = V_{DD} - V_{DS} + 2V_{OV}$

Could be a problem if it makes $V_{DS1} < V_{OV}$ ($M_1 \rightarrow$ triode)

What exactly is the voltage here?

$V_{E6} - V_{D6} - V_{V2} + V_{OV}$

$(V_{E4} - V_{E6}) + (V_{E3} - V_{E4}) + V_{OV} < V_{OV}$

$(-) (-) (-)$

$M_1$ is not saturated!

BIG PROBLEM!

Solutions:

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

$V_{T1} = V_{S1} + \sqrt{\frac{V_{GS1}}{V_{TH}}}$

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

2. Bias $M_4$ so that $V_{GS4} = V_{E6} + 2V_{OV}$

$V_{GS4} = V_{E6} + V_{OV}$

$W/L = \frac{W}{L} = \frac{V_{GS4}}{V_{TH}}$

$W/L = \frac{V_{GS4}}{V_{TH}}$

$safety margin$!

$V_{MIN} = 3V_{OV}$

Not optimum, but safe -> $M_1$ stay in saturation
\[ I_{\text{out}} = \frac{1}{2} \mu C_{ox}(W/L)(V_{GS} - V_{T})^2 (1 + \lambda V_{DS}) \]

\[ \text{if } V_{DS1} \neq V_{DS3} \]

\[ I_0 = \frac{(1 + 2V_{DS1}) I_{\text{ref}}}{(1 + 2V_{DS3})} \rightarrow I_0 \neq I_{\text{ref}} \]

\[ \text{Solution: Use a different bias scheme.} \]

**Alternative Bias Scheme for Cascade**

```
\begin{center}
\begin{tikzpicture}
\node (VDD) at (0,0) {$V_{DD}$};
\node (M4) at (-1,-1) {$M_4$};
\node (M3) at (-1,-2) {$M_3$};
\node (VBIAS2) at (0,-1.5) {$V_{BIAS2}$};
\node (VBIAS1) at (0,-3) {$V_{BIAS1}$};
\draw (VDD) -- (M4);
\draw (M4) -- (VBIAS2);
\draw (M3) -- (VBIAS1);
\end{tikzpicture}
\end{center}
```