Lecture 10: High Swing Current Sources

Announcements:
- Monday Labs: due to holiday next week, shift to the following Monday
- Monday Lab#1's are due in the 140 Box on Tuesday next week (per Travis's email)

Lecture Topics:
- Output Swing (Headroom) (cont.)
- High Swing Current Sources
- Current Source Matching Considerations

Last Time:

Issue: Output Swing (Headroom)

\[ V_{DD} \]
\[ V_{IN} \]
\[ V_{DS} \]
\[ V_{GS} \]
\[ V_{TH} \]
\[ V_{SAT} \]

What's the minimum voltage for which \( M_1 \) still behaves as a good current source.

"large \( R_o \) need \( M_1 \) saturated!"

\[ \text{Small } V_{TH} \text{ for which } M_1 \text{ still behaves as a good current source.} \]

\[ I_D = \frac{1}{2} \mu C_{ox} \left( \frac{W}{L} \right) (V_{GS} - V_{TH})^2 \]

\[ V_{BOD} = V_{DD} - V_{TH} - V_{GS} - V_{TH} = V_{DD} \left( 2C_D \right) \]

\[ V_{GS} = V_{TH} + V_{DD} \]

\( \text{for long-channel devices} \)

\( \text{for short-channel it's different} \)
The min. voltage that still keeps $I_{m}$ as a good current source:

$$V_{\text{min}} = V_{\text{sat}} = V_{\text{OV}}$$

The output swing is:

$$V_{\text{swing,pp}} = V_{\text{DD}} - V_{\text{sat1}} - V_{\text{sat2}} = V_{\text{DD}} - 2V_{\text{OV}}$$

*Peak-to-peak*

**Dynamic Range**: $\frac{V_{\text{max}}}{V_{\text{min}}}$

- Determined by Output Swing
- Determined by Node

What about a OCL using a buffer current source, like a cascode current source?

In most analog circuits, we want to avoid non-linearities. Linear.

$$V_{\text{min}} = 2V_{\text{OV}}$$

How can we guarantee this?

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**MOS Cascade Current Source**

- The simple way:

\[ V_{on} \]

- This is one \( V_t \) higher than it needs to be:

\[ V_{on} = V_t + 2V_t \]

\[ V_{dd} = V_t + 2V_t \]

- Assume:

\[ V_{GS} = V_t + V_t \]

\[ V_{VO} = V_{GF} - V_t \]

- \( V_{off} \):

\[ M_1 : M_2 : M_3 = M_2 \]

**Problem 4: Shrinking!**

(for simple cascade current source)

\[ V_{on} = V_t + 2V_t \]

\[ V_{onm} = V_t + 2V_t \]

\[ V_{onm} = 0.7V + 2(0.3V) = 1.8V \]

- This is a lot in a 2V supply technology — not permissible in a \( V_{dd} = 1.1 \)V technology.

- Solution: **High Swing Cascade** (VSSA - generator)

- Basic Idea: level-shift down to move the \( V_{gs2} \) of \( M_2 \) to \( V_t \).
Problem: Not the best solution due to need for a large device!

Better option: just accept a \( V_{dd} + V_{th} \) level shift:

\[
V_{th} = 2I_{th}/(\mu C_{ox}(W/L)) \rightarrow V_{th} \rightarrow 0?
\]

Use large device + small current \( I_{th} \) for \( V_{th} \) level shift

Need a level-shift:

\[
V_{dd} \quad \Rightarrow \quad I_{ref} \quad \Rightarrow \quad 2V_{dd} + 2V_{th} \quad \Rightarrow \quad V_{dd} + 2V_{th} \quad \Rightarrow \quad \text{what we want!}
\]
To get this, must size $M_4$ accordingly:

$$I_{D3} = \frac{1}{2} \mu_n C_ox \left(\frac{W}{L}\right)_3 (V_{ch3})^2$$

$$I_{D4} = \frac{1}{2} \mu_n C_ox \left(\frac{W}{L}\right)_4 (2V_{ch3})^2$$

$$V_{ch3} = 2V_{ch4}$$

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

$$\frac{1}{2} \mu_n C_ox \left(\frac{W}{L}\right)_3 (V_{ch3})^2 \quad \frac{1}{2} \mu_n C_ox \left(\frac{W}{L}\right)_4 (2V_{ch3})^2$$

... and $(W/L)_3, (W/L)_2, (W/L)_1, (W/L)_6$

Problems: body effect in $M_4, M_5, M_2$.

We will increase their $V_t$'s!

**Solution:**

1. Tie the wells of $M_4, M_5, M_2$ to their sources, making all $V_t$'s the same.

   - Not practical to take up area to give each device its own well.

   - $M_1$ is not saturated! 😱
2. Bias $M_y$ so that $V_{os,y} > V_t + 2V_{os}$,

    (e.g., $V_{os,y} = V_t + 3V_{os}$

    make $M_y$ smaller than $\frac{1}{y}(\frac{W}{L})_T$

    $(W/L)_y = \frac{1}{9} (W/L)_T$

Issue: $V_{in} \neq V_{pd3} \rightarrow I_o = \frac{(1+\lambda V_{ps3})}{(1+\lambda V_{ps})} I_{ref}$

$\downarrow$

$I_o \neq I_{ref}$

Solution: next hint.