Today:
- High Swing Current Sources
- Current Source Matching Considerations

Last Time -

\[ V_{DD} \]
\[ V_{DS} \]
\[ V_{DS2} \]
\[ V_{GS1} \]
\[ V_{GS2} \]

\[ I_{ref} \]
\[ V_{DD} \]
\[ 2V_{DD} + 2V_{DD} \]

[Diagram showing MOSFETs and voltage relationships]

How can we generate this?

\[ V_{DS} = V_{DD} \]
\[ V_{DS2} \]
\[ V_{GS1} \]
\[ V_{GS2} \]

\[ V_{DS} = V_{DD} \]
\[ V_{DS2} \]
\[ V_{GS1} \]
\[ V_{GS2} \]

How can we generate these?
(While maximizing the swing on a headroom of the amplifier, use a current source as a load)

\[ V_{min} = V_{DD} + 2V_{DD} \]

[Diagram showing MOSFETs and voltage relationships]

MOS Cascade Current Source

- The simple way:

\[ V_{DD} \]
\[ 2V_{DD} + 2V_{DD} \]

[Diagram showing MOSFETs and voltage relationships]

Join: High Swing Cascade

- Basic idea: Level shift down to reduce the VDD of M2

\[ V_{DD} \]
\[ 2V_{DD} \]
\[ V_{DD} \]
\[ V_{DD} \]

[Diagram showing MOSFETs and voltage relationships]

This will give the optimum swing.
(M1 right at the edge of saturation)
Problem: It's not easy to get a $V_T$-level shift!

One way to do it:

\[ V_{in} = \sqrt{\frac{2I_o}{\mu n C_y(V_{DS})}} \]

\[ V_{out} = V_T + V_{in} \]

Can use large device w/ small current to get a $V_T$ level shift.

This is not a good solution; it's always best to avoid large devices!

But it is easy to get $V_T + V_{out}$.

To get this, must size $M_5$ accordingly:

\[ I_{DS} = \frac{1}{2} \mu n C_y \left( \frac{W}{L} \right)_3 (V_{DS})^2 \]

\[ I_{DS} = \frac{1}{2} \mu n C_y \left( \frac{W}{L} \right)_4 (2V_{out})^2 \]

\[ I_{DS} = I_{DS} + I_{ref} \]

\[ \frac{1}{2} \mu n C_y \left( \frac{W}{L} \right)_3 (V_{DS})^2 = \frac{1}{2} \mu n C_y \left( \frac{W}{L} \right)_4 (2V_{out})^2 \]

\[ \left( \frac{W}{L} \right)_4 = \frac{1}{4} \left( \frac{W}{L} \right)_3 \]

...and (\( \frac{W}{L} \))_3 (\( \frac{W}{L} \))_2 (\( \frac{W}{L} \))_1 = (\( \frac{W}{L} \))_4 (\( \frac{W}{L} \))_3

Problem: Body effect in $M_5$, $M_6$, $M_2$.

$V_T$ will increase their $V_T$s!
EE 140: Analog Integrated Circuits
Lecture 11: High Swing Current Sources

Solutions:
1. Tie the wells of $M_4, M_5, M_2$ to their sources — not practical.
2. Bias $M_4$ so that $V_{gs4} > V_t + 2V_T$, e.g., $V_{gs4} = V_{t} + 3V_T$
   make $M_4$ small so that $\frac{1}{2}(\frac{W}{L})_4$, $(\frac{W}{L})_4 = \frac{1}{2}(\frac{W}{L})_1$

Issue: $V_{gs1} = V_{ds2}$

Solution: Use an alternate biasing scheme.

Issues:
1. $I_{ref}$ not all that well-controlled.
2. Must still account for Body Effect.

So really read: $I_{R_b} = V_{ds4} + V_{ds6} - V_{bd}$

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Replace $R_0$ as a transistor level shift:

$V_{DD}$

$M_4$ $M_5$ $M_7$ $M_6$ $M_5$

$I_{ref} = \frac{V_{DD} - V_{GS1} - V_{GS2}}{R_{ref}}$

$V_{BSW2}$ $V_{BSW1}$

Current Source