Lecture 22 - Multistage Amplifiers (II)

DC Voltage and Current Sources

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Reading assignment:

Howe and Sodini, Ch. 9, §§9.4
Key questions

- How does one synthesize voltage and current sources?
- How can this be done in an economic way?
1. DC voltage sources

- Features of voltage source:
  - A well controlled voltage
  - Voltage does not depend on current drawn from source (low internal resistance).

I-V characteristics of voltage source:

Equivalent circuit model of voltage source:

\[ V_s \]

\[ R_S \]

Matching with small want.
Consider MOSFET in “diode configuration”:

\[
\begin{align*}
\text{I-V characteristics:} \\
I_D &= \frac{W}{2L} \mu C_{ox} (V_{GS} - V_T)^2 = \frac{W}{2L} \mu C_{ox} (V_{DS} - V_T)^2
\end{align*}
\]

Beyond threshold, MOSFET looks like “diode” with quadratic I-V characteristics.
How does one synthesize a voltage source with this?

Assume a current source is available.

\[ V_{GS} = V_{DS} \text{ takes value needed to sink current:} \]

\[ I_D = I_{REF} + i_{OUT} = \frac{W}{2L} \mu C_{ox} (v_{OUT} - V_T)^2 \]

Then:

\[ i_{OUT} = \frac{W}{2L} \mu C_{ox} (v_{OUT} - V_T)^2 - I_{REF} \]

Solving for \( v_{OUT} \):

\[ v_{OUT} = V_T + \frac{I_{REF} + i_{OUT}}{\frac{W}{2L} \mu C_{ox}} \]
$v_{OUT}$ is function of $I_{REF}$ and $W/L$ of MOSFET:

- $I_{REF} \uparrow \Rightarrow v_{OUT} \uparrow$
- $W/L \uparrow \Rightarrow v_{OUT} \downarrow$

\[ i_{OUT} \quad i_{OUT} \quad i_{OUT} \]

\[ v_{OUT} \quad v_{OUT} \quad v_{OUT} \]

\[ -I_{REF1} \quad -I_{REF2} \quad -I_{REF} \]

\[ V_T \quad V_T \quad V_T \]

\[ \square \text{Small-signal view of voltage source:} \]

\[ R_{out} = \frac{1}{g_m / / r_o} \approx \frac{1}{g_m} \]

$R_{out}$ is small (good!).

("current can change a lot w/ voltage changing too much")
PMOS voltage source:

Same operation and characteristics as NMOS voltage source.

PMOS needs to be bigger to attain same $R_{out}$. 
2. DC current sources and sinks

- Features of current source:
  
  - A well controlled current,
  
  - supplied current does not depend on voltage across (high internal resistance)

I-V characteristics of current source:

Equivalent circuit model of current source:
Connect voltage source to another MOSFET:

\[ I_{OUT} \approx \frac{1}{2} \left( \frac{W}{L} \right)_2 \mu C_{ox} (V_{REF} - V_T)^2 \]

\[ I_{REF} \approx \frac{1}{2} \left( \frac{W}{L} \right)_1 \mu C_{ox} (V_{REF} - V_T)^2 \]

Then:

\[ I_{OUT} = I_{REF} \frac{\left( \frac{W}{L} \right)_2}{\left( \frac{W}{L} \right)_1} \]

\( I_{OUT} \) scales with \( I_{REF} \) by \( W/L \) ratios of two MOSFETs (current mirror circuit).

Well ”matched” transistors important.

(same \( V_T, t_{ox} \), etc.)
• Small-signal view of current source:

\[ R_{out} = r_{o2} \]

I-V characteristics of NMOS current source:
- PMOS current source

- NMOS current source *sinks* current to ground.

- PMOS current source *sources* current from positive supply.

PMOS current mirror:

![PMOS current mirror diagram]

\( V_{DD} \)

\( M_1 \)

\( M_2 \)

\( I_{REF} \)

\( i_{OUT} \)
Multiple current sources

Since there is no DC gate current in MOSFET, can tie up multiple current mirrors to single current source:

\[ I_{OUTn} = I_{REF} \left( \frac{W}{L} \right)^n \]

Similar idea with NMOS current sinks:
\( \square \) Multiple current sources and sinks

Often, in a given circuit, we need current sources and sinks. Can build them all out of a single current source:

\[
I_{OUT1} = I_{REF} \left( \frac{W}{L} \right)_1 \left( \frac{W}{L} \right)_R
\]

\[
I_{OUT2} = I_{REF} \left( \frac{W}{L} \right)_2 \left( \frac{W}{L} \right)_R
\]

\[
I_{OUT4} = I_{OUT1} \left( \frac{W}{L} \right)_4 = I_{REF} \left( \frac{W}{L} \right)_4 \left( \frac{W}{L} \right)_1 \left( \frac{W}{L} \right)_3 \left( \frac{W}{L} \right)_R
\]
Generating $I_{REF}$:

Simple circuit:

\[ I_{REF} = \frac{V_{DD} - V_{OUT}}{R} \]

\[ V_{OUT} = V_T + \sqrt{\frac{I_{REF}}{2L\mu C_{ox}}} \]

For large $W/L$, $V_{OUT} \to V_T$:

\[ I_{REF} \approx \frac{V_{DD} - V_T}{R} \]

- Advantages:
  - $I_{REF}$ set by value of resistor.

- Disadvantages:
  - $V_{DD}$ also affects $I_{REF}$.
  - $V_T$ and $R$ are function of temperature $\Rightarrow I_{REF}(T)$.

In real world, more sophisticated circuits used to generate $I_{REF}$ that are $V_{DD}$ and $T$ independent.
□ Can now understand more complex circuits.

Examples:

![Circuit Diagram]

Amp stages:

What does it do?
Can now understand more complex circuits.

Examples:

Amp stages:  

What does it do?  

CD  

voltage buffer
Amp stages:

What does it do?
Amp stages:

What does it do?

transconductance amp.
Amp stages:

What does it do?
Amp stages: CE

What does it do? transconductance amp.
Amp stages:

What does it do?
Amp stages: CS + CD

What does it do? Voltage amp.
Amp stages:

What does it do?
Amp stages: \( CC + CE \)

What does it do? Voltage amp. for signal source with high \( R_s \)
Key conclusions

- Voltage source easily synthesized from current source using MOSFET in diode configuration.
- Current source easily synthesized from current source using current mirror circuit.
- Multiple current sources and sinks with different magnitudes of current can be synthesized from a single current source.
- Voltage and current sources rely on availability of well ”matched” transistors in IC technology.