EE105
Microelectronic Devices and Circuits
Current Sources

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Load Impedance

- To achieve high gain (or low attenuation in the case of a source follower), it is very desirable to achieve high load impedance, $Z_L$
  - Unfortunately, using a simple resistor of high value has issues
    - What are these issues?
Issue: Headroom Limitations

- The bias current of the device is a direct function of $R_L$
  \[ I_d = \frac{V_{dd} - V_{ds}}{R_L} \]

- $V_{dd}$ is $< 3.6V$ for most modern CMOS processes
- $V_{ds}$ must be greater than $\Delta V$ to maintain device saturation

Large $R_L$ implies small $I_d$
(implies small $g_m$, poor frequency response, etc.)
Achieving High Gain

- Replacement of resistor load with a current source yields the highest possible DC gain out of the amplifier
  - Current source determines $I_d$ of device

- We can make current sources out of transistors
  - Generally smaller area than polysilicon resistors

What is the small signal gain of the above circuit?
Diode Connected Device

- How do we build current sources?
- Let’s start with a “diode connected” device
- A MOS device with gate and drain shorted operates like a diode (but not exponential)
Diode Connected -- SS Model

- We can derive the small-signal model by shorting out the hybrid-pi model
- Note that a Gm generator with it’s controlling terminals connected to the Gm is more simply a ...

?
The Integrated “Current Mirror”

- $M_1$ and $M_2$ have the same $V_{GS}$
- If we neglect CLM ($\lambda=0$), then the drain currents are equal
- Since $\lambda$ is small, the currents will nearly mirror one another even if $V_{out}$ is not equal to $V_{GS1}$
- We say that the current $I_{REF}$ is mirrored into $i_{OUT}$
- Notice that the mirror works for small and large signals!
Multiplication Ratio

\[ I_{IN} = k \frac{W_1}{L_1} (V_{GS1} - V_T)^2 \]

\[ I_{OUT} = k \frac{W_2}{L_2} (V_{GS2} - V_T)^2 \]

\[ V_{GS1} = V_{GS2} \]

\[ I_{OUT} = k \frac{W_2}{L_2} (V_{GS2} - V_T)^2 = I_{IN} \frac{W_2 / L_2}{W_1 / L_1} = NI_{IN} \]
Current Mirror as Current Source

- The output current of $M_2$ is only weakly dependent on $v_{OUT}$ due to high output resistance of FET
- $M2$ acts like a current source to the rest of the circuit
- For good current source behavior, what is the minimum $v_{OUT}$?
Small-Signal Resistance of $I$-Source
Improved Current Sources

Goal: increase $R_{o(out)}$

Approach: look at *amplifier* output resistance results ... to see topologies that boost resistance

![Circuit Diagram]

Looks like the output impedance of a common-source amplifier with source degeneration
Effect of Source Degeneration

- Equivalent resistance loading gate is dominated by the diode resistance ... assume this is a small impedance

- Output impedance is boosted by factor \((1 + g_m R_S)\)

\[
v_t = (i_t - g_m v_{gs}) r_o + v_{R_S}
\]

\[
v_{gs} \approx -v_{R_S}
\]

\[
v_{R_S} = i_t R_S
\]

\[
v_t = (i_t + g_m R_S i_t) r_o + i_t R_S
\]

\[
R_o = \frac{v_t}{i_t} \approx (1 + g_m R_S) r_o
\]
Improved Current Sources

How would you scale the output current?

\[ I_{IN} = k \frac{W}{L_1} (V_G - V_S - V_T)^2 \]

\[ V_S = I_{IN} R_S \]
Cascode (or Stacked) Current Source

Insight: \( V_{GS2} = \text{constant AND } V_{DS2} = \text{constant} \)

Small-Signal Resistance \( R_o \):

\[
R_o \approx (1 + g_m R_S) r_o
\]

\[
R_o \approx (1 + g_m r_o) r_o
\]

\[
R_o \approx g_m r_o^2 \gg r_o
\]
Drawback of Cascode $I$-Source

What is the minimum output voltage to keep all transistors in saturation?
Drawback of Cascode I-source

Minimum output voltage to keep both transistors in saturation:

\[ V_{OUT,MIN} = V_{DS4,MIN} + V_{DS2,MIN} \]

\[ V_{DS2,MIN} > V_{GS2} - V_{T0} = V_{DSAT2} \]

\[ V_{DSAT2} > V_{DSAT2} + V_{GS4} = V_{GS2} + V_{GS4} - V_{T0} \]

In EE140 you will learn circuit tricks to overcome this problem!
**Current Sinks and Sources**

*Sink*: output current goes to ground

*Source*: output current comes from voltage supply
Current Mirrors

_Idea:_ we only need one reference current to set up all the current sources and sinks needed for a multistage amplifier.
Example: Common-Drain Amplifier

\[ I_{DS} = \mu C_{ox} \frac{W}{L} \frac{1}{2} (V_{GS} - V_T)^2 \]
How does a REAL current source fit in to the small-signal model?
**CD Voltage Gain With Real I-Source**

![Circuit Diagram]

**Ideal I-Source**

\[
\frac{v_{out}}{R_L \parallel r_o} = g_m v_{gs}
\]

**Real I-Source**

\[
\frac{v_{out}}{R_L \parallel r_o} = g_m \left( v_{in} - v_{out} \right)
\]