Announcements

- Homework 6 due next Tuesday
- Lab 4 this week
- Reading: Chapters 9.4, 8 (MOS only)
- Midterm 1 next week
  - October 13, 6:30-8pm, Sibley
- Review session on Tuesday
  - October 11, 6:30-8pm, 277 Cory

Lecture Material

- Last lecture
  - MOSFET small-signal model
- This lecture
  - MOS current sources
  - Generalized two-port models

Application of Current Mirrors: Digital-to-Analog Converter

Digital input: word $D_0D_1D_2D_3 \rightarrow$ voltages are either $V_{DD}$ or 0 V.
Transistors $M_0, M_1, M_2, M_3$ have binary-weighted $(W/L)$ ratios

Example

Input word $D_0D_1D_2D_3 = 0101$

$I_{REF} = 100 \, \mu A$

$(W/L)_0 = 0$

$(W/L)_1 = 2(W/L)_0$

$(W/L)_2 = 2(W/L)_1$

$(W/L)_3 = 2(W/L)_2$

Output voltage is $v_{OUT} = V_{DD} - R_L (i_{D0} + 4 i_{REF})$

Sources of error: fab imprecision, channel-length modulation, …

Generalized Amplifier
Amplifier Terminology

- **Sources**: Signal, its source resistance, and bias voltage or current
- **Load**: Use resistor/current source or in Chap. 8, but could be a general impedance
- **Port**: A pair of terminals across which a voltage and an associated current are defined

- Source, Load: “one port”
- Amplifier: “two port”

One-Port Models (EECS 40)

- A terminal pair across which a voltage and associated current are defined

Small-Signal Two-Port Models

- General case: four variables, \( v_{in}, i_{in}, v_{out}, i_{out} \):
  - Two independent, two dependent
- Four choices (Math 54):
  1. \( i_{in} = f(v_{in}, v_{out}) \) \( i_{out} = f(v_{in}, v_{out}) \)
  2. \( v_{in} = f(i_{in}, v_{out}) \) \( i_{out} = f(i_{in}, v_{out}) \)
  3. \( v_{in} = f(i_{in}, i_{out}) \) \( v_{out} = f(v_{in}, i_{out}) \)
  4. \( i_{in} = f(v_{in}, i_{out}) \) \( v_{out} = f(v_{in}, i_{out}) \)

Small-Signal Two-Port Models

- We assume that input port is linear and that the amplifier is unilateral:
  - Output depends on input but input is independent of output.
  - Output port: depends linearly on the current and voltage at the input and output ports
  - Unilateral assumption is good as long as “overlap” capacitance is small (MOS)

Math 54 Perspective

- Can write linear system of equations for either \( i_{in} \) or \( v_{out} \) in terms of two of \( i_{in}, v_{in}, i_{out}, v_{out} \); possibilities are
  - \( i_{out} = \alpha_1 v_{in} + \alpha_2 v_{out} \)
  - \( i_{out} = \alpha_3 i_{in} + \alpha_4 v_{out} \)
  - \( v_{out} = \alpha_5 v_{in} + \alpha_6 i_{out} \)
  - \( v_{out} = \alpha_7 i_{in} + \alpha_8 i_{out} \)

What is physical meaning of \( \alpha_1 \)? of \( \alpha_2 \)?

EE Perspective

- Four amplifier types: determined by the output signal and the input signal ... both of which we select (usually obvious)
  - Voltage Amp (\( V \rightarrow V \))
  - Current Amp (\( I \rightarrow I \))
  - Transconductance Amp (\( V \rightarrow I \))
  - Transresistance Amp (\( I \rightarrow V \))

- Need methods to find the 6 \( \alpha \) parameters for the four models and equivalent circuits for unilateral two ports
Two-Port Small-Signal Amplifiers

Voltage Amplifier

Current Amplifier

Transconductance Amplifier

Transresistance Amplifier

Input Resistance $R_{in}$

Output Resistance $R_{out}$

Finding the Voltage Gain $A_v$

Finding the Current Gain $A_i$
Finding the Transresistance $R_m$

$$R_m = \left[ \frac{v_{out}}{i_{in}} \right] \bigg|_{R_2 \to \infty, R_1 \to \infty}$$

Finding the Transconductance $G_m$

$$G_m = \left[ \frac{v_{out}}{i_{in}} \right] \bigg|_{R_2 = 0, R_1 = 0}$$

Common-Source Amplifier (again)

How to isolate DC level?

DC Bias

Neglect all AC signals

Choose $I_{B\text{LOAD}} = \frac{W}{L}$

Load-Line Analysis to find $Q$

$$V_{DD} - V_{out} = I_{D} R_D$$

Small-Signal Analysis
Two-Port Parameters:

Find $R_{in}$, $R_{out}$, $G_{m}$

$G_{m}$ in $R$ = $\infty$

$G_{m}$ = $g_{m}$

$R_{out}$ = $r_{o} \parallel R_{L}$

Two-Port CS Model

Reattach source and load one-ports: