Lecture 13

• Last time:
  – MOSFET voltage and current sources

• Today:
  – Digital-to-analog converter
  – Common source amplifier with current supply
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 $D_0D_1D_2D_3 = 0101$

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

$(W/L)_0 = (W/L)_{REF}
(W/L)_1 = 2W/L_0
(W/L)_2 = 2W/L_1
(W/L)_3 = 2W/L_2$

Output voltage is $v_{OUT} = V_{DD} - R_L (i_{D0} + i_{D2})$

$= V_{DD} - R_L (I_{REF} + 4 I_{REF})$

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

Problem 1. Find DC Bias – ignore small-signal source

\[ V_{BIAS} \] was found in Lecture 22

\[ V_{SUP} \] (positive DC supply)

\[ V_{OUT} = 0 \text{ V} \]

\[ V_{SUP} \] (negative DC supply)
Small-Signal Modeling

What are the small-signal models of the DC supplies?
Small-Signal Models of Ideal Supplies

Small-signal model:
Small-Signal Circuit for Amplifier
Voltage Gain

\[ v_{out} = -g_m v_s (R_D||r_o) \]

\[ A_v = -g_m (R_D||r_o) \]

Transconductance

\[ g_m = \mu_n C_{ox} \left( \frac{W}{L} \right) (V_{GS} - V_{Tn}) = \frac{2I_{D,SAT}}{V_{GS} - V_{Tn}} \]
Voltage Gain (Cont.)

Substitute transconductance:

\[ A_v = \left( - \frac{2I_{D,SAT}}{V_{GS} - V_{Tn}} \right) (R_D \parallel r_o) \]

Output resistance: typical value \( \lambda_n = 0.05 \, \text{V}^{-1} \)

\[ r_o = \left( \frac{1}{\lambda_n I_{D,SAT}} \right) = \left( \frac{1}{0.05 \cdot 0.1} \right) k\Omega = 200k\Omega \]

Voltage gain: \( A_v = -\left( \frac{2 \cdot 0.1}{0.31} \right) (25 \parallel 200) = -14.3 \)
Input and Output Waveforms

Input small-signal voltage amplitude: 25 mV
Output small-signal voltage amplitude: 14 x 25 mV = 350
What Limits the Output Amplitude?

1. $v_{OUT}(t)$ reaches $V_{SUP}$ or $-V_{SUP}$ … or

2. MOSFET leaves constant-current region and enters triode region

$$V_{DS} \leq V_{DS,SAT} = V_{GS} - V_{Tn} = 0.31V$$

$$v_{OUT,MIN} = -V_{SUP} + V_{DS,SAT} = -2.5V + 0.31V$$
Maximum Output Amplitude

\[ v_{out}(t) = -2.19 \text{ V} \cos(\omega t) \implies v_s(t) = 153 \text{ mV} \cos(\omega t) \]

How accurate is the small-signal (linear) model?

\[ \frac{v_s}{V_{GS} - V_{Th}} = \frac{0.15}{0.31} \approx 0.5 \]

Significant error in neglecting third term in expansion of \( i_D = i_D(v_{GS}) \)