Lecture 23

• Last time:
  – Introduction to amplifiers: a common-source MOS stage

• Today:
  – Small-signal model for the entire common-source amplifier
  – Limits to model

Small-Signal Analysis

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

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

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

Transconductance

\[ g_m = \mu_n C_{ox} (W/L)(V_{GS} - V_{Th}) = \frac{2I_{D,SAT}}{V_{GS} - V_{Th}} \]
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 \( \lambda_n = 0.05 \text{ V}^{-1} \)

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

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

\[
\begin{array}{c}
\text{Input waveform: } v_{in}(t) \\
\text{Output waveform: } v_{out}(t)
\end{array}
\]

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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

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

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

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

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