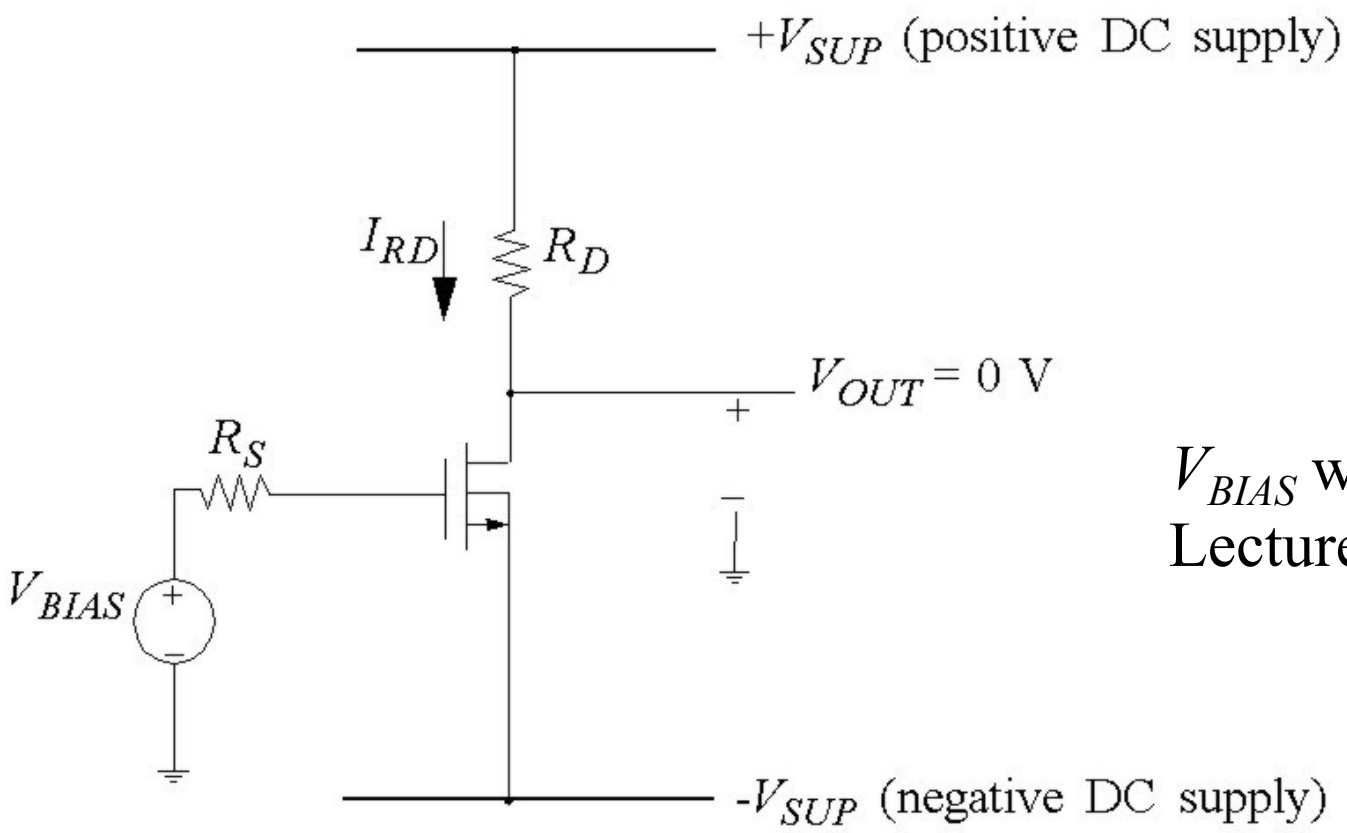
# Lecture 23

- Last time:
  - Introduction to amplifiers: a common-source MOS stage
- Today :
  - Small-signal model for the entire common-source amplifier
  - Limits to model

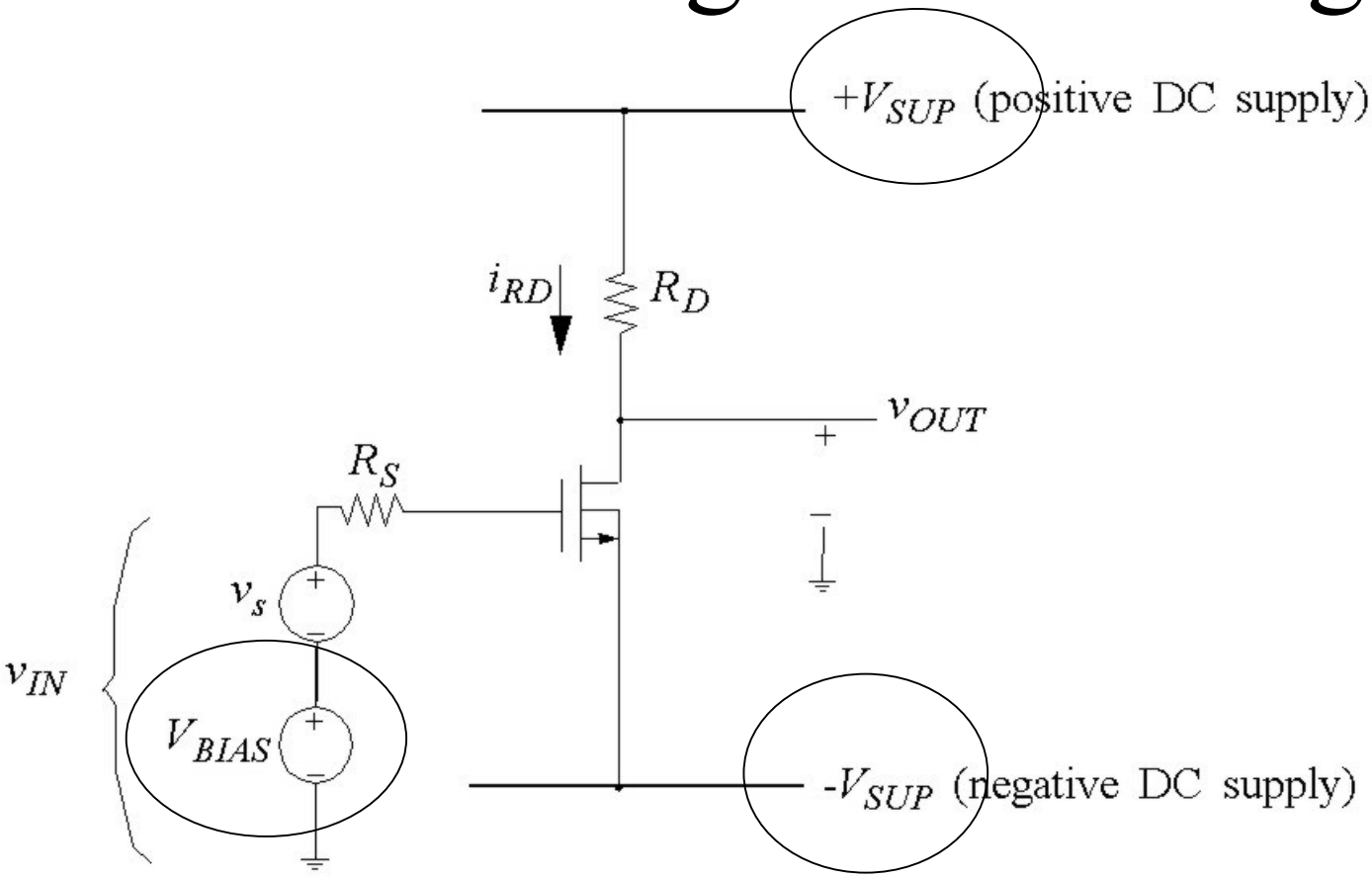
# Small-Signal Analysis

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




$V_{BIAS}$ was found in Lecture 22

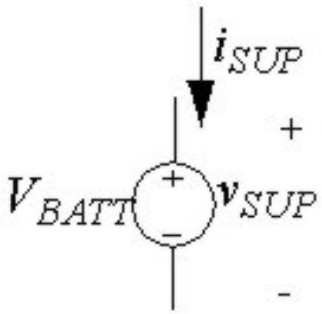
# Small-Signal Modeling

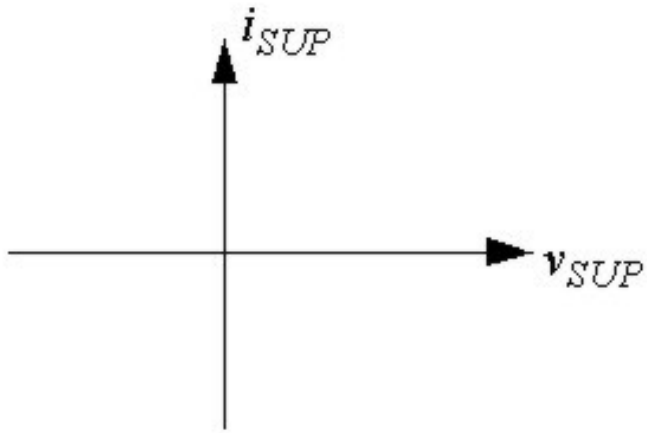


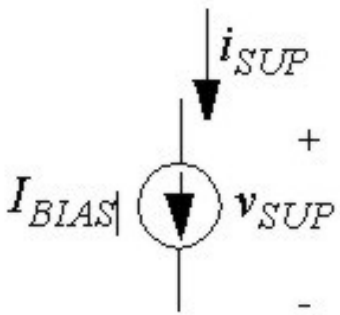

What are the small-signal models of the DC supplies?

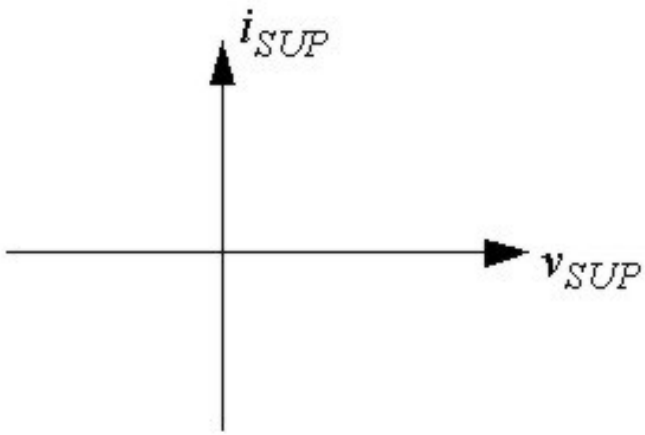
# Small-Signal Models of Ideal Supplies

Small-signal model:

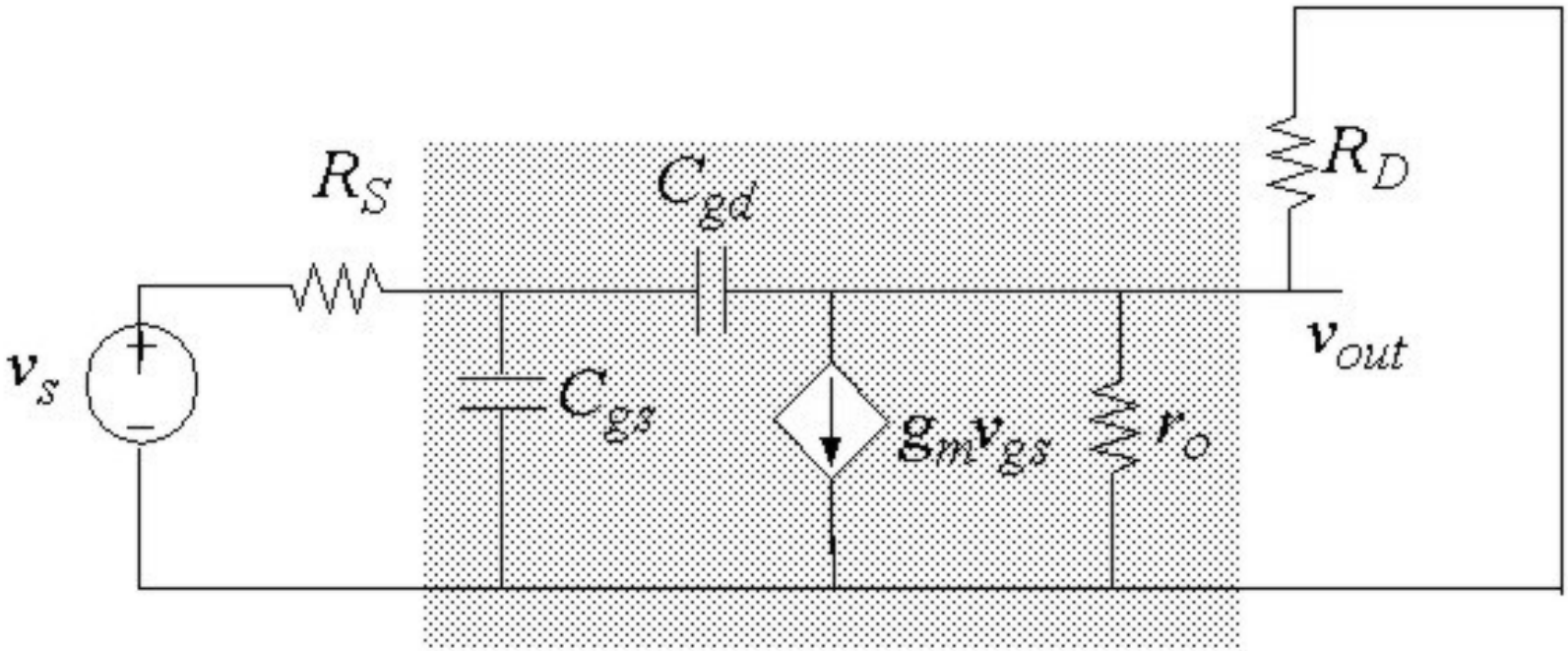


# Small-Signal Circuit for Amplifier



# Low-Frequency Voltage Gain

Consider first $\omega \rightarrow 0$ case … capacitors are open-circuits

$$v_{out} = -g_m v_s (R_D || r_o)$$

$$A_v = -g_m (R_D || r_o)$$

Transconductance

$$g_m = \mu_n C_{ox} (W/L)(V_{GS} - V_{Tn}) = \frac{2I_{D,SAT}}{V_{GS} - V_{Tn}}$$

# Voltage Gain (Cont.)

Substitute transconductance:

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

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

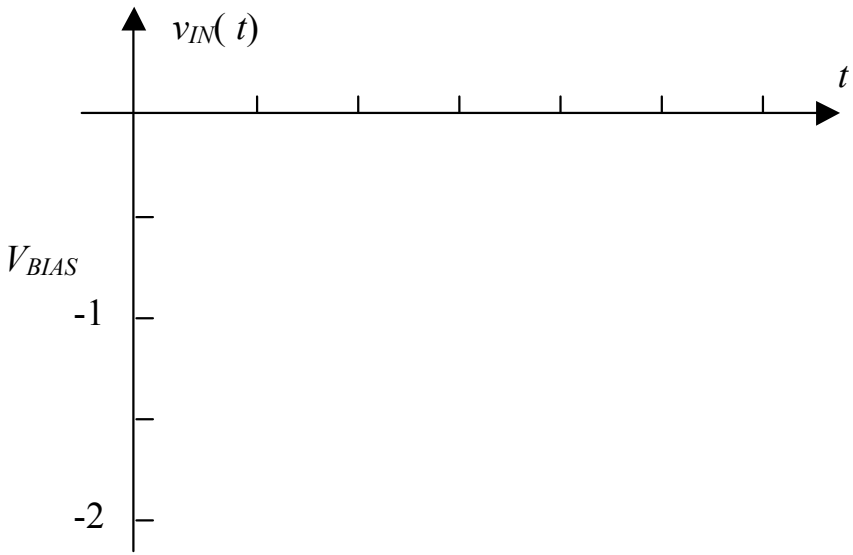
$$r_o = \left( \frac{1}{\lambda_n I_{D,SAT}} \right) = \left( \frac{1}{0.05 \cdot 0.1} \right) k\Omega = 200 k\Omega$$

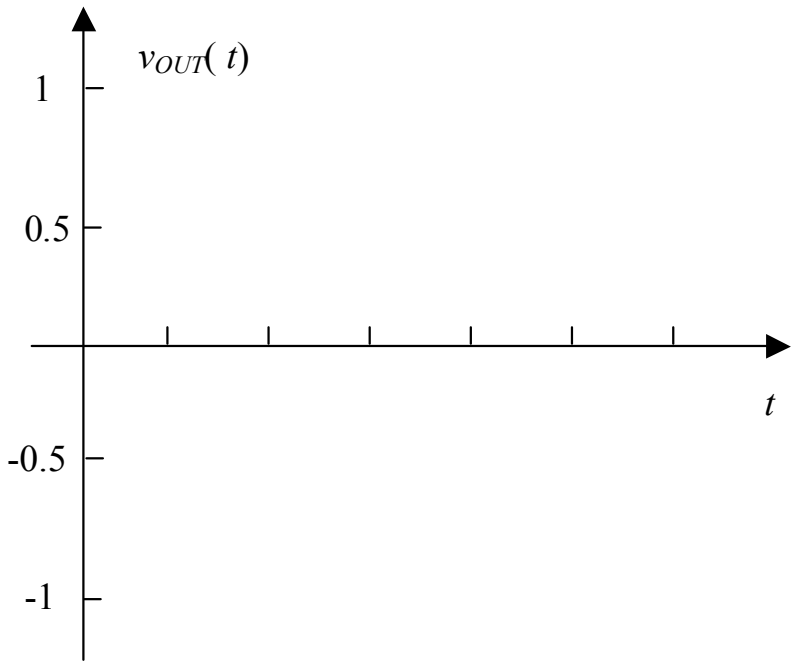
Voltage gain: $$A_v = -\left( \frac{2 \cdot 0.1}{0.31} \right) (25 \| 200) = -14.3$$

# 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

$v_{out}(t) = -2.19\ \text{V}\cos(\omega t) \rightarrow v_s(t) = 153\ \text{mV}\cos(\omega t)$

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 $i_D = i_D(v_{GS})$