# 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

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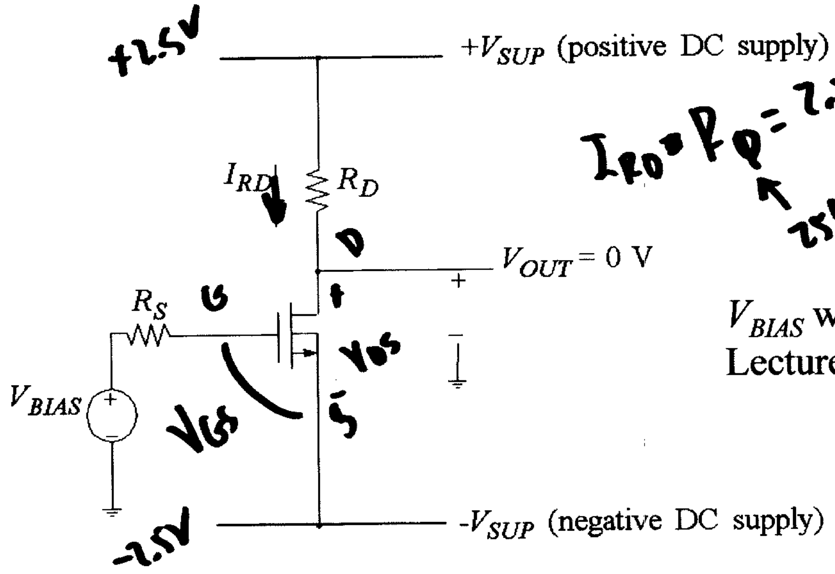
# Small-Signal Analysis

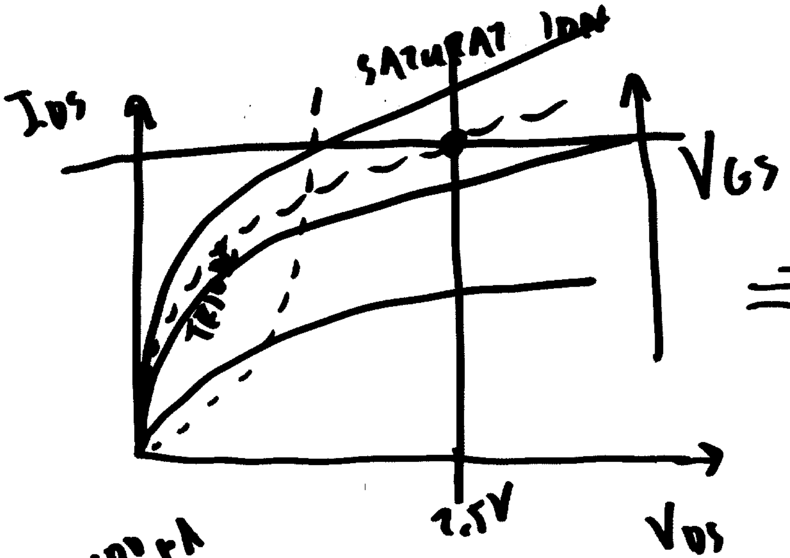
Problem 1. Find DC Bias – ignore small-signal source



$I_{RD} \cdot R_D = 2.5V \Rightarrow I_{RD} = 100\mu A$

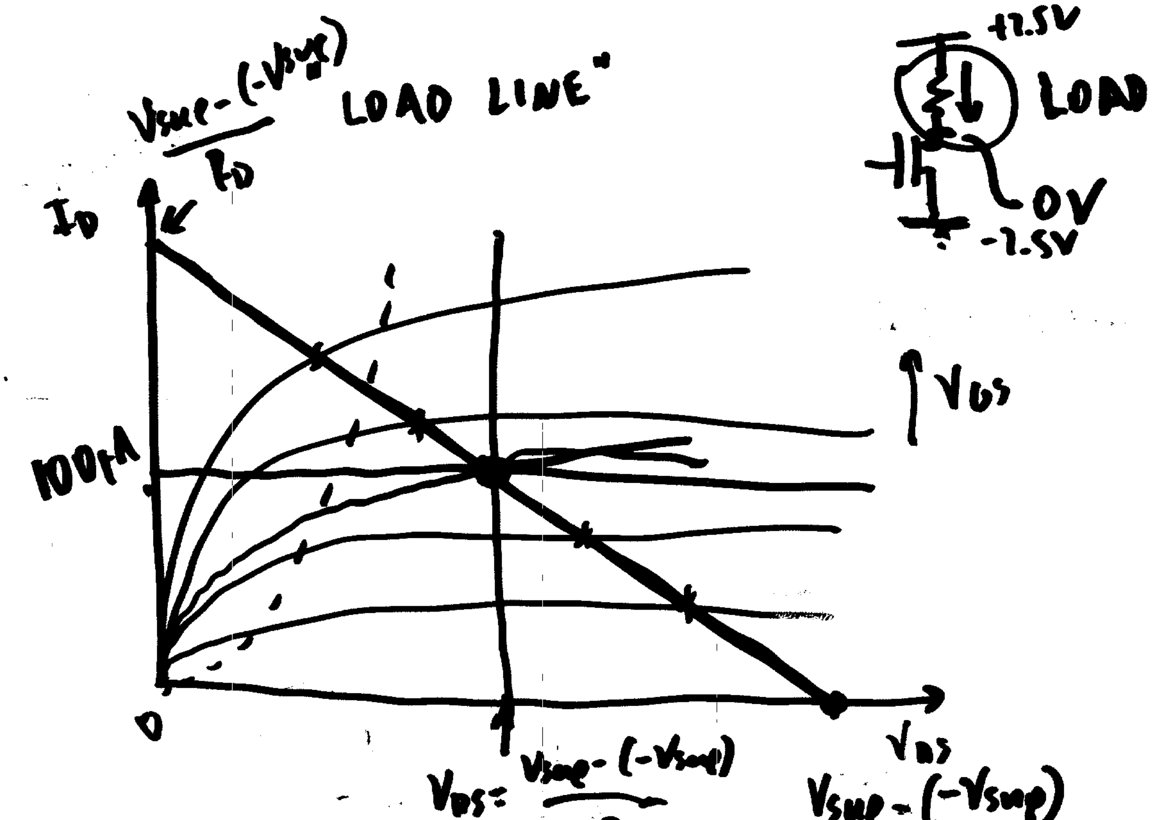
25kΩ

$V_{BIAS}$ was found in Lecture 22



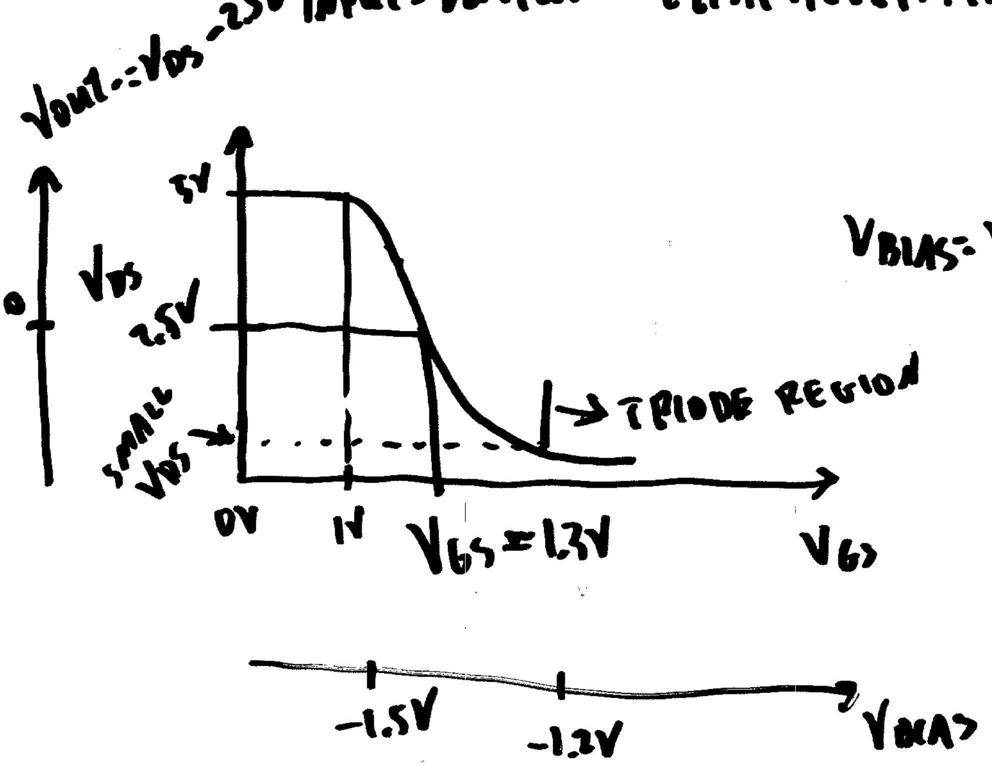
$$\overset{100\,\mu A}{I_{DS}} = \boxed{\frac{1}{2}\frac{W}{L}\mu_n C_{ox}}\left(V_{GS} - \underset{1V}{V_{tn}}\right)^2 \left(1+\lambda \overset{2.5V}{V_{DS}}\right)$$

$\Rightarrow V_{GS} \simeq 1.3V$



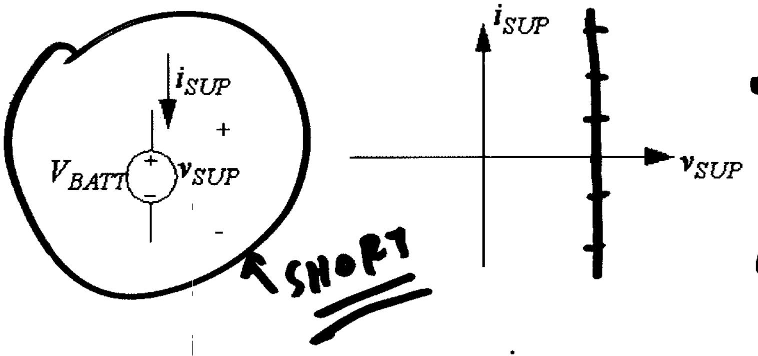
$V_{DS} = \frac{V_{sup} - (-V_{sup})}{2}$
(2.5V)

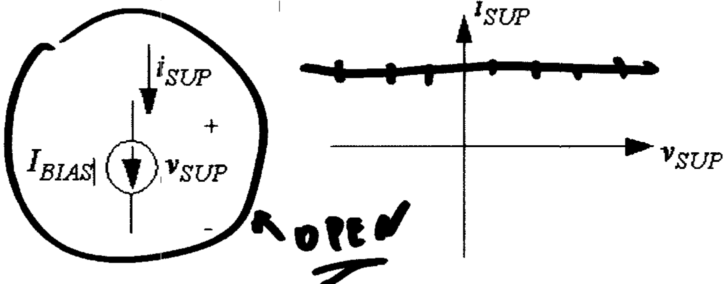
INPUT - OUTPUT CHARACTERISTIC



$V_{BIAS} = V_{GS} - 2.5V$

# Small-Signal Models of Ideal Supplies





Small-signal model:

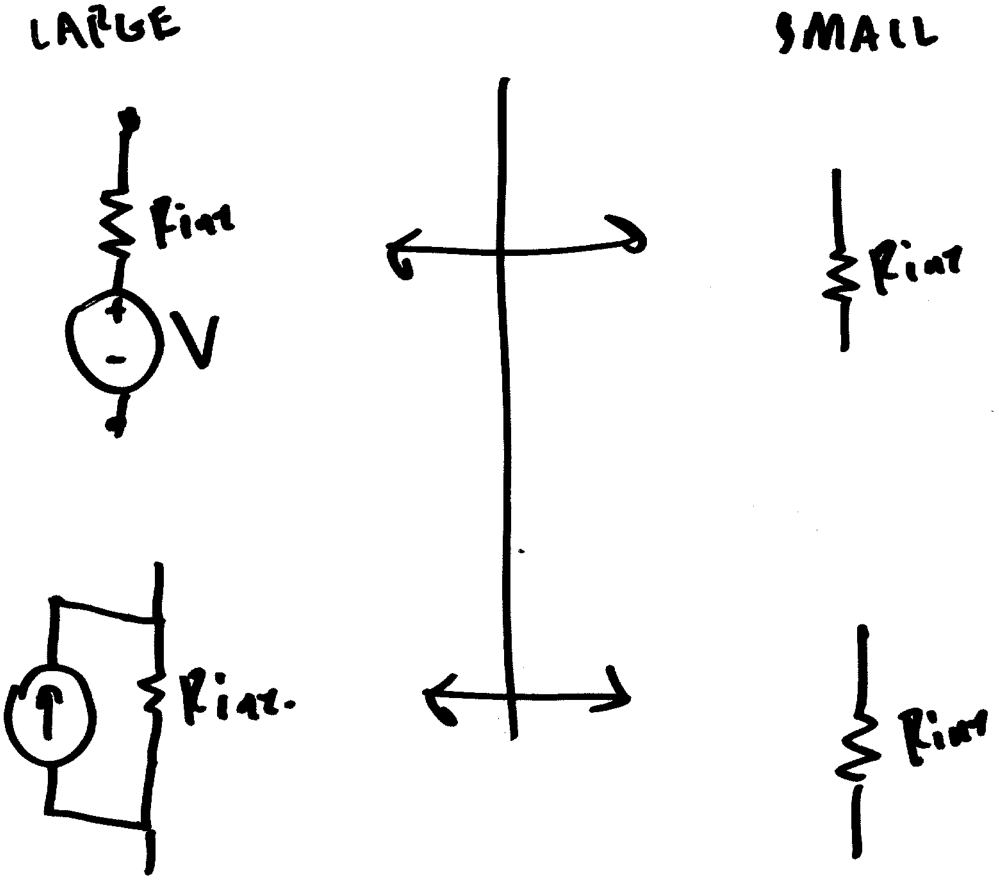
$r_{small signal} = \frac{\partial V_{sup}}{\partial i_{sup}}$

$= 0\Omega$

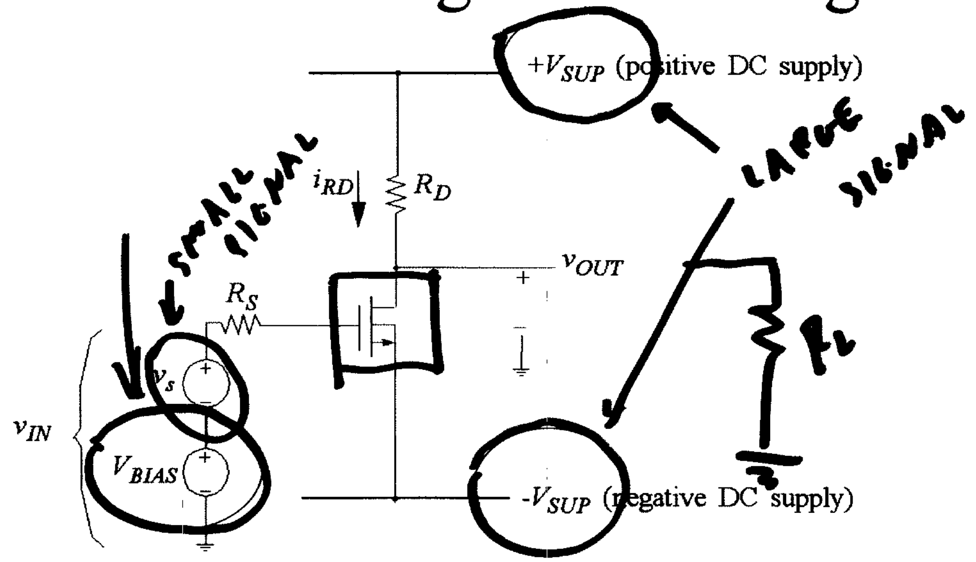
$g_{small} = \frac{\partial i_{sup}}{\partial V_{sup}} = \infty$

$g_{small sig} = \frac{\partial i_{sup}}{\partial V_{sup}} = 0 S$

$r_{ss} = \infty\Omega$

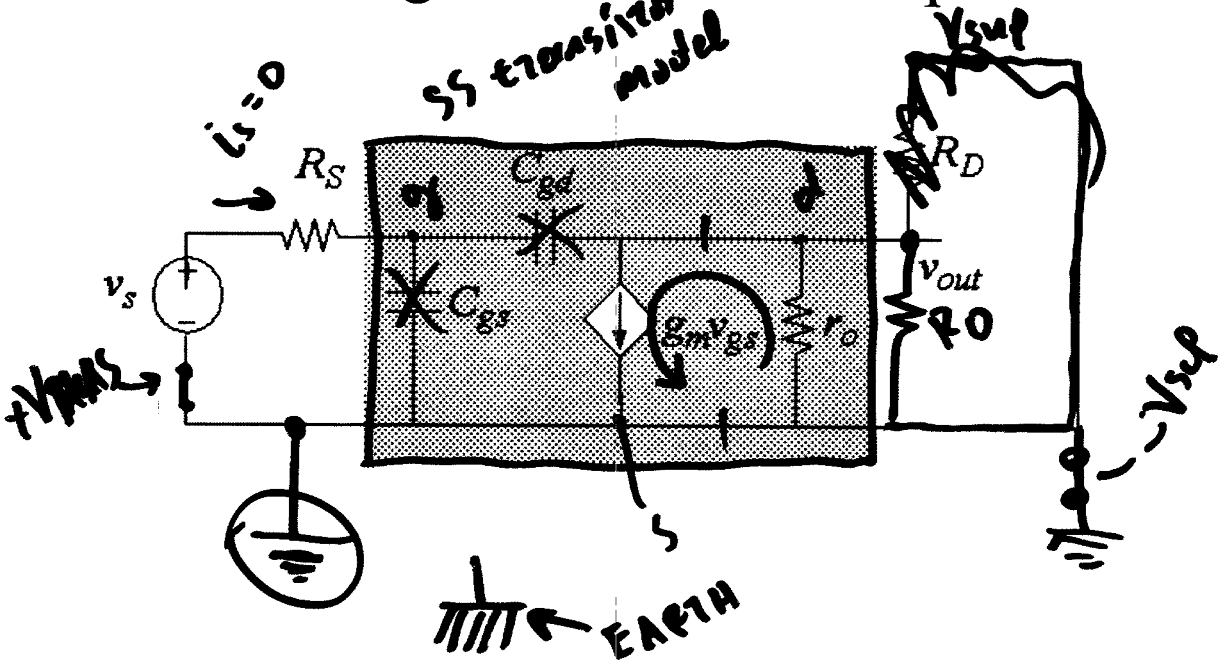


# Small-Signal Modeling



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

# Small-Signal Circuit for Amplifier



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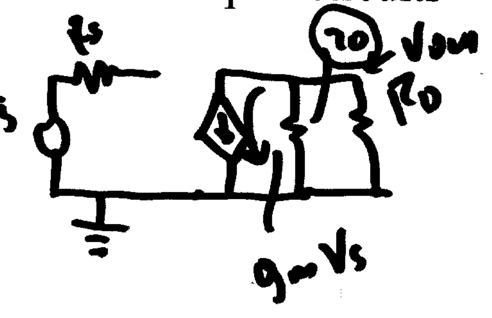
# Low-Frequency Voltage Gain

Consider first ω → 0 case... capacitors are open-circuits

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

$$A_v = \underline{-g_m}(R_D||r_o)$$

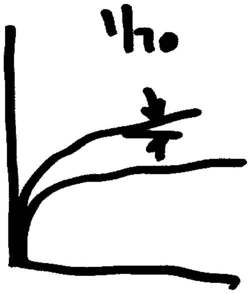


Transconductance

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

ignore(1+λVDS)

# 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 $\boxed{\lambda_n = 0.05 \text{ V}^{-1}}$

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

Voltage gain: $A_v = -\left( \frac{2 \cdot 0.1}{0.31} \right) (\underline{25} \| \cancel{200}\,7) = \underline{-14.3}$

-16.1

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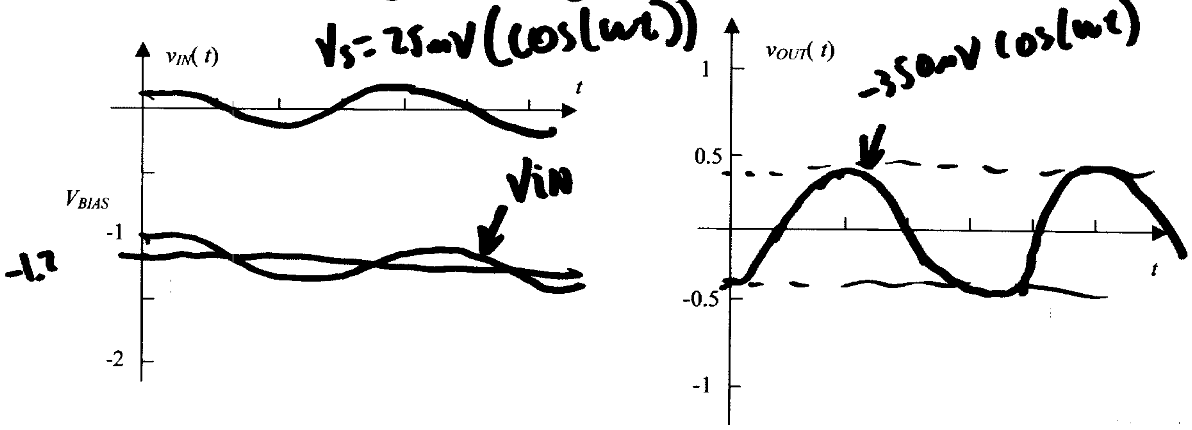
# Input and Output Waveforms

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

$$V_{DS} \le V_{DS,SAT} = \overset{1.31V}{V_{GS}} - V_{Tn} = \boxed{0.31V}$$

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

-2.19V

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# Maximum Output Amplitude

✓ max input

$v_{out}(t)$= -2.19 V cos(ω$t$) → $v_s(t)$ = $\underline{153}$ mV cos(ω$t$)

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 $i_D = i_D(v_{GS})$