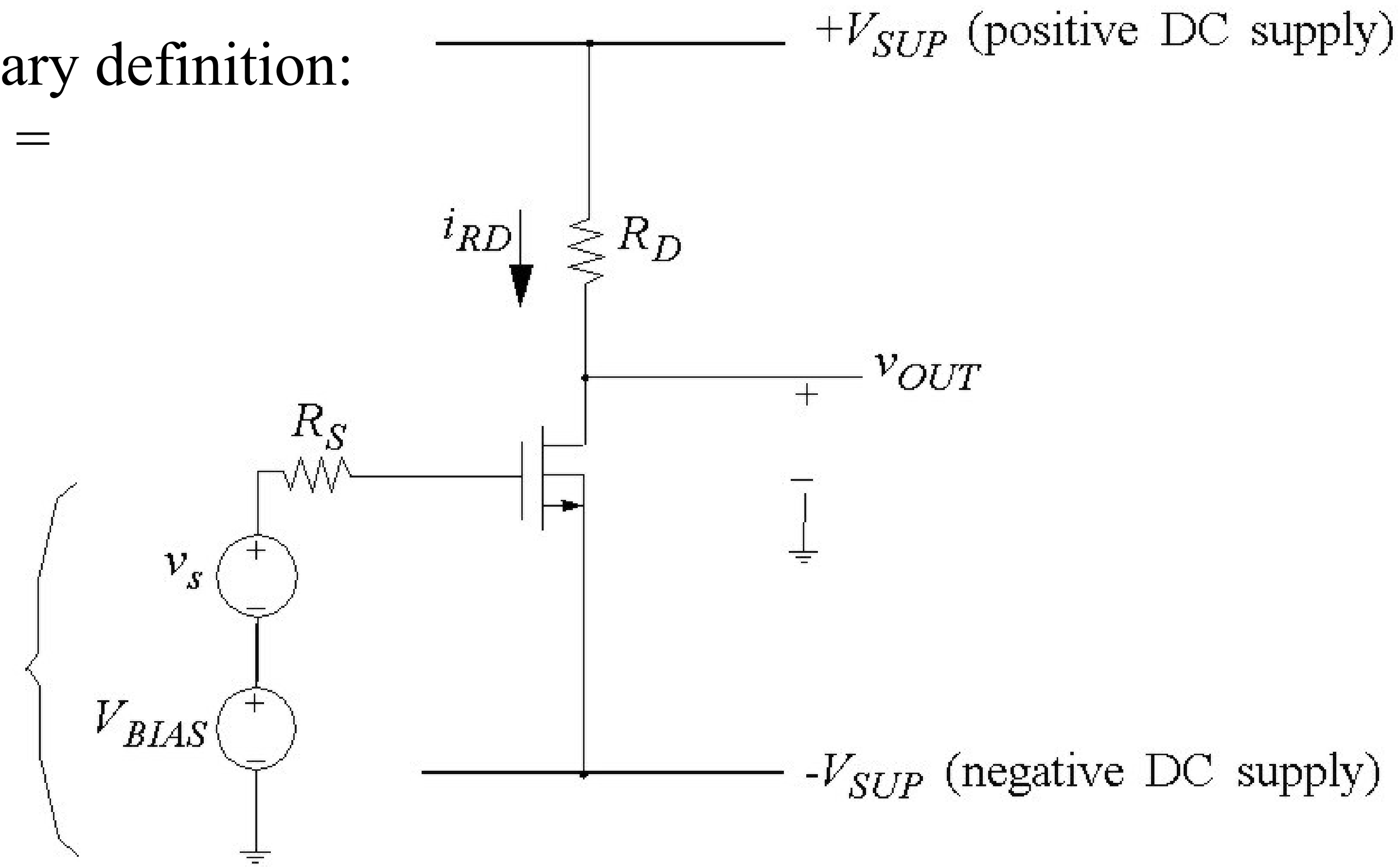
Lecture 22

- Last time:
  - Small-signal model of the npn bipolar transistor
- Today :
  - Introduction to amplifiers: a common-source MOS single-stage amplifier

An MOS Amplifier

Dictionary definition:
amplify =



Selecting the Output Bias Point

V_{BIAS} is selected so that V_{OUT} is centered between $+V_{SUP}$ and $-V_{SUP}$ (why?)

$V_{OUT} = 0$ V … **NOT** $v_{OUT} = 0$ V!

Constraint on the DC drain current:

$$I_{\mathrm{RD}} = (V_{\mathrm{SUP}} - V_{\mathrm{OUT}}) / R_{\mathrm{D}} = V_{\mathrm{SUP}} / R_{\mathrm{D}}$$

$I_{\mathrm{RD}} = I_{\mathrm{D}} = I_{D,SAT}$ … verify that MOSFET is saturated after finding V_{BIAS}

Finding the Input Bias Voltage

Hand calculation: neglect “fudge factor” in $I_{D,SAT}$

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

Typical numbers: $W = 40$ μm, $L = 2$ μm, $R_D = 25$ k Ω
$\mu_n C_{ox} = 100\ \mu\text{A/V}^2$, $V_{Tn} = 1$ V,
$V_{SUP} = 2.5$ V

$$I_{RD} = \frac{V_{SUP}}{R_D} = \quad I_{D,SAT} = 10 \cdot 100 \cdot (V_{GS} - 1)^2$$

Applying the Small-Signal Voltage

Approach 1. Just use v_{IN} in the equation for the total drain current i_D and find v_{OUT}

$$v_{IN} = V_{BIAS} + v_s \qquad v_{GS} = v_{IN} - (-V_{SUP}) = [V_{BIAS} + v_s + V_{SUP}]$$

$$v_s(t) = \hat{v}_s \cos(\omega t)$$

Result:

$$v_{OUT} = V_{SUP} - R_D i_D \cong V_{SUP} - R_D(\mu_n C_{ox})\left(\frac{W}{2L}\right)(V_{GS} + v_s - V_{Tn})^2$$

Solving for the Output Voltage v_{OUT}

$$v_{OUT} = V_{SUP} - \underbrace{R_D(\mu_n C_{ox})\left(\frac{W}{2L}\right)(V_{GS} - V_{Tn})^2}_{I_D}\left(1 + \frac{v_s}{(V_{GS} - V_{Tn})}\right)^2$$

$$v_{OUT} = V_{SUP} - \underbrace{R_D I_D}_{V_{SUP}}\left(1 + \frac{v_s}{(V_{GS} - V_{Tn})}\right)^2$$

Small-Signal Case

Linearize the output voltage for the s.s. case

Expand $(1 + x)^2 = 1 + 2x + x^2$ … last term can be dropped when $x << 1$

$$\left(1 + \frac{v_s}{V_{GS} - V_{Tn}}\right)^2 = 1 + \frac{2v_s}{V_{GS} - V_{Tn}} + \left(\frac{v_s}{V_{GS} - V_{Tn}}\right)^2$$

Linearized Output Voltage

For this case, the total output voltage is

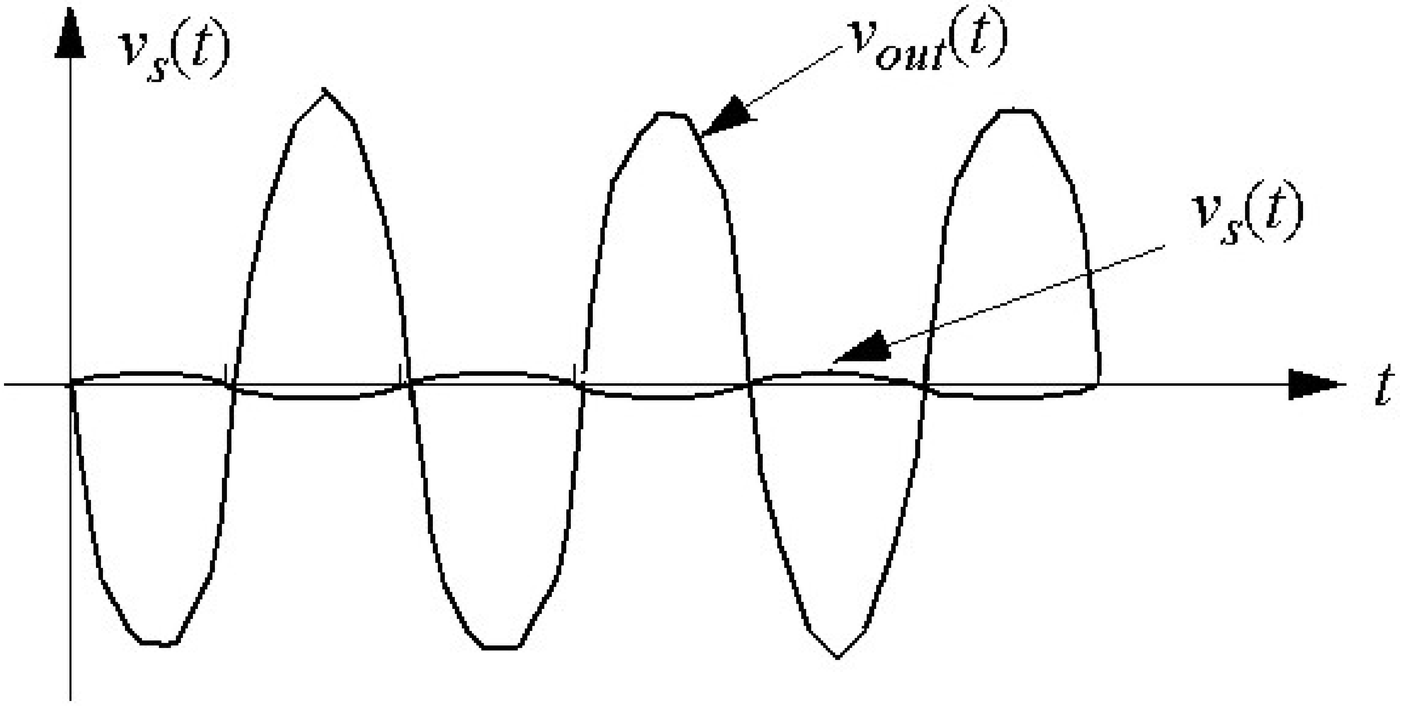
$$v_{OUT} \cong V_{SUP} - R_D I_D \left(1 + \frac{2 v_s}{(V_{GS} - V_{Tn})} \right) = \cancel{V_{SUP}} - \cancel{V_{SUP}} - \frac{2 R_D I_D v_s}{(V_{GS} - V_{Tn})}$$

The average output voltage $V_{OUT} = 0$ V so the total output voltage is the small-signal voltage in this special case:

$$v_{OUT} = v_{out} = -\left[\frac{}{(V_{GS} - V_{Tn})} \right] v_s = -\left[\frac{}{(V_{GS} - V_{Tn})} \right] v_s = A_v v_s$$

Plot of Output Waveform

Numbers: $2\, I_D R_D / (V_{GS} - V_{Tn}) = (2 \text{ x } 2.5) / 0.31 = 16.1$



Is there a Better Way?

What's missing: no inclusion of fudge factor term or of charge storage effects

Approach 2. Do problem in two steps.

1. DC voltages and currents (ignore small signals sources): set bias point of the MOSFET ... we had to do this to pick V_{BIAS} already

2. Substitute the small-signal model of the MOSFET and the small-signal models of the other circuit elements …