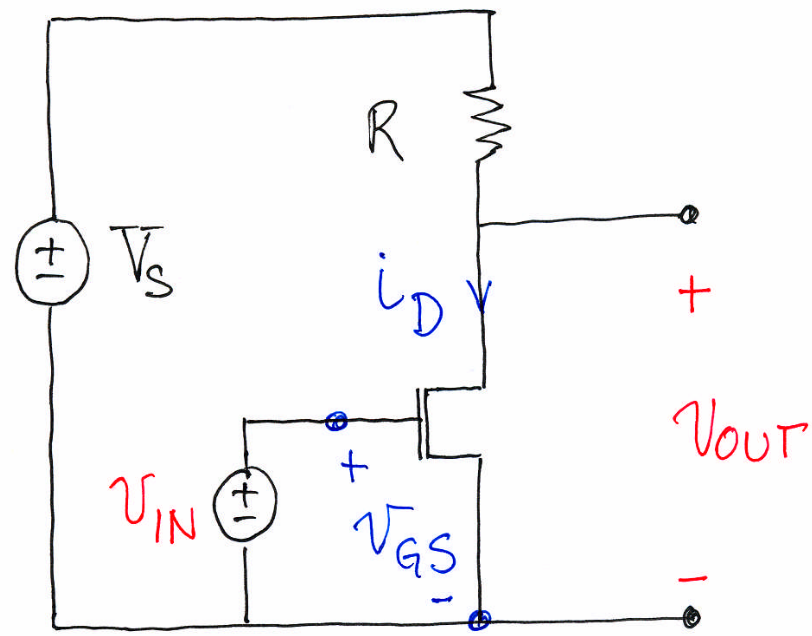
6.002 - Lecture 8

Biasing & Small Signals

- Need For Biasing
- Small-Signal Analysis
- Simple Biasing Methods
- Also
  - Loading
  - Thevenin Equivalents
  - More MOSFET Amplifiers

MOSFET Amplifier Review



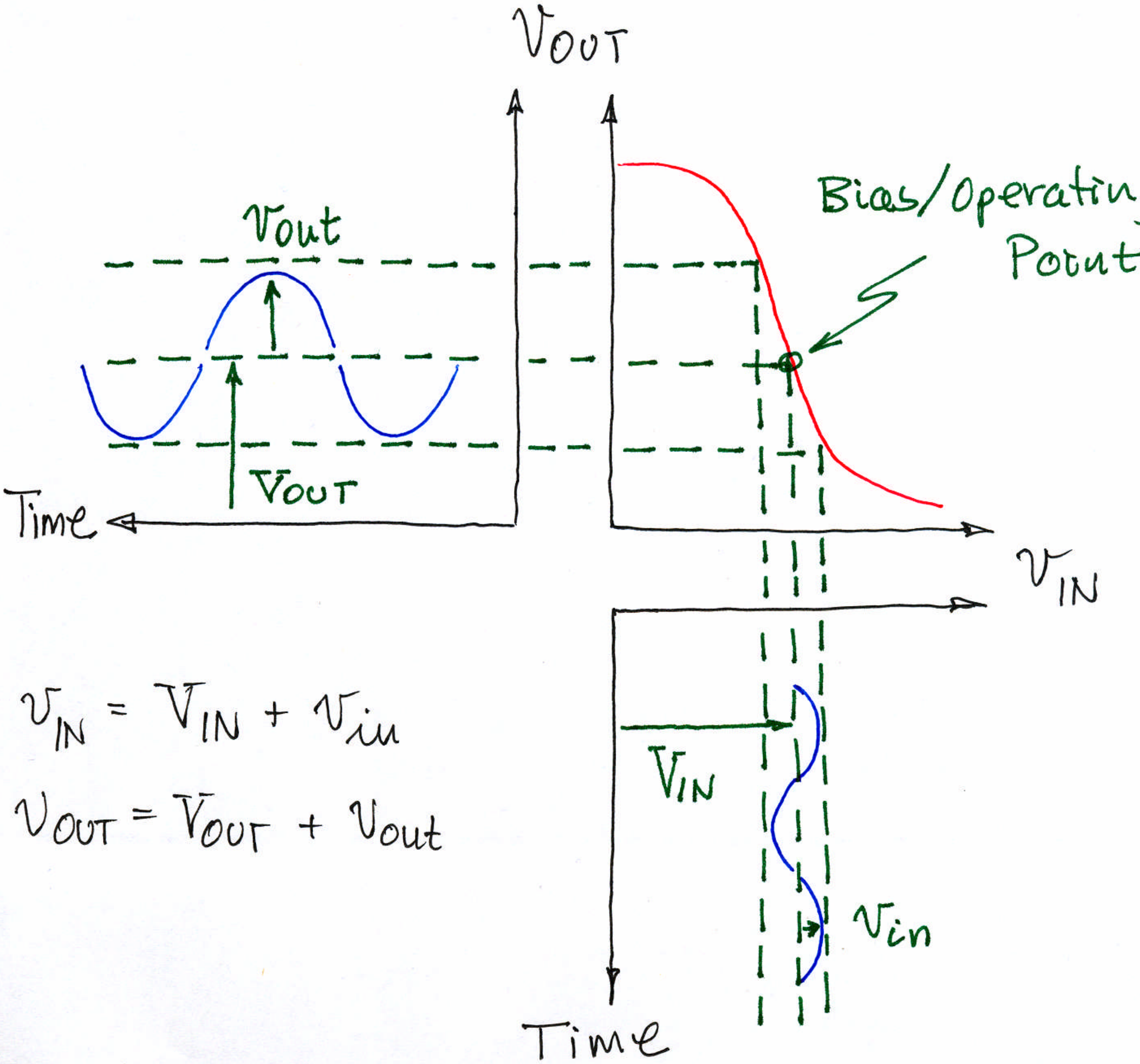
MOSFET (Saturation): $i_D = \frac{K}{2}(v_{GS} - V_T)^2$

$v_{GS} \leftarrow v_{IN}$

Amplifier: $v_{OUT} = V_S - R\underbrace{\frac{K}{2}(v_{IN} - V_T)^2}_{i_D}$

Biasing & Small Signals

Biasing and small-signals are used to avoid distortion by nonlinearities. (What if a large signal is desired?)

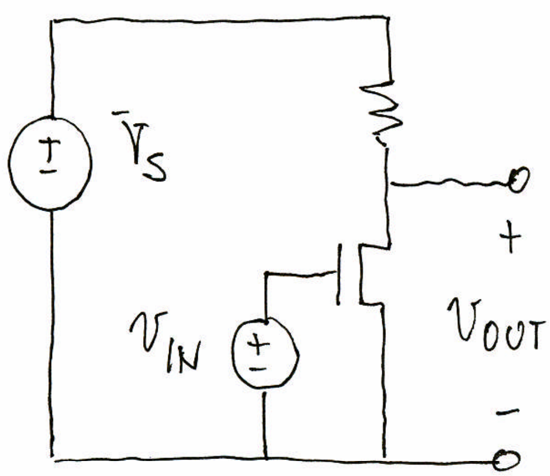


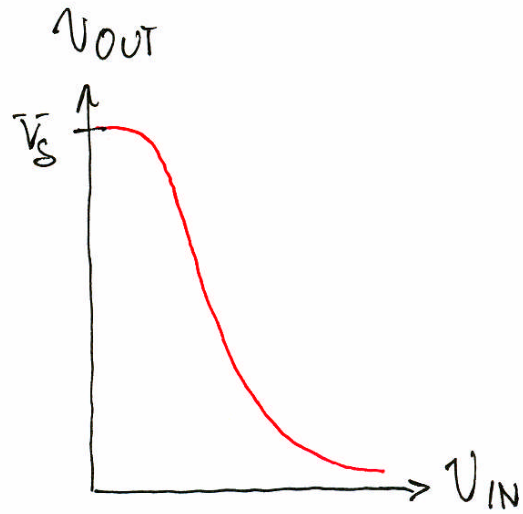
$v_{IN} = V_{IN} + v_{in}$

$v_{OUT} = V_{OUT} + v_{out}$

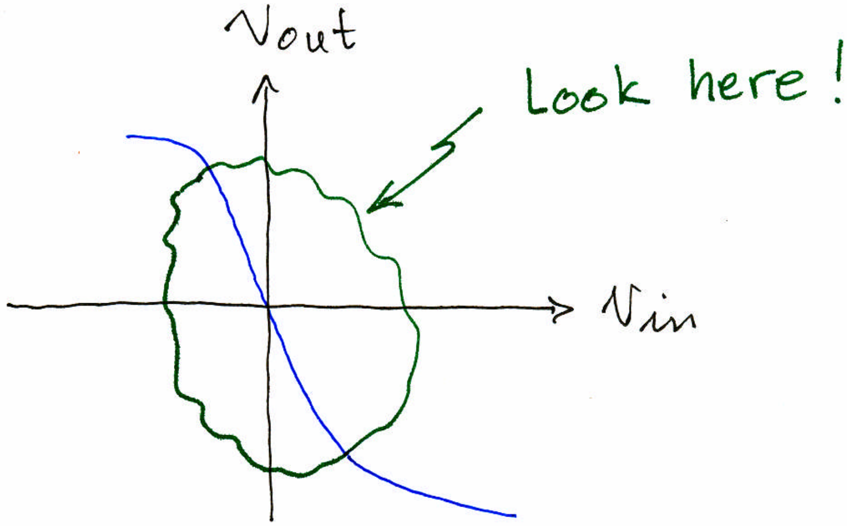
Where is the amplifier?

Is this an amplifier?





The amplifier behavior is more apparent from this viewpoint.



Biasing & Small-Signal Questions

- How should V_{IN} be introduced?
- How should V_{OUT} be removed?
- How should V_{IN} and V_{OUT} be managed in multi-stage amplifiers?
- How does one carry out a small-signal analysis?

Small-Signal Analysis (Expansion)

Bias: $V_{OUT} = V_S - \frac{RK}{2}(V_{IN} - V_T)^2$

Off Bias: $v_{OUT} = V_{OUT} + v_{out}$

$$= V_S - \frac{RK}{2}(v_{IN} - V_T)^2$$

$$= V_S - \frac{RK}{2}(V_{IN} + v_{in} - V_T)^2$$

$$= V_S - \frac{RK}{2}(V_{IN} - V_T)^2 \quad \text{Bias}$$

$$- RK(V_{IN} - V_T)\, v_{in} \quad \text{Linear}$$

$$- \frac{RK}{2} v_{in}^2 \quad \text{Quadratic}$$

Linearized Small Signals: $v_{out} = \underbrace{-RK(V_{IN} - V_T)}_{\text{Small-Signal V Gain}}\, v_{in}$

Accurate if $V_{IN} - V_T \gg \frac{v_{in}}{2}$

Small-Signal Analysis (Differentiation)

$$v_{OUT} = V_S - \frac{RK}{2}(v_{IN} - V_T)^2$$

$$V_{OUT} + v_{out} \approx v_{OUT}\Big|_{V_{IN}} + \frac{dv_{OUT}}{dv_{IN}}\Big|_{V_{IN}} \cdot v_{in}$$

$$= V_{OUT} - RK(V_{IN} - V_T)\, v_{in}$$

$$v_{out} \approx \underbrace{-RK(V_{IN} - V_T)}_{\text{Small-Signal Voltage Gain}}\, v_{in}$$

Numerical Example

- SS Gain $= -RK(V_{IN} - V_T)$

- $I_D = \frac{K}{2}(V_{IN} - V_T)^2 \Rightarrow V_{IN} - V_T = \sqrt{\frac{2I_D}{K}}$

  $\Rightarrow$ SS Gain $= -R\sqrt{2KI_D}$

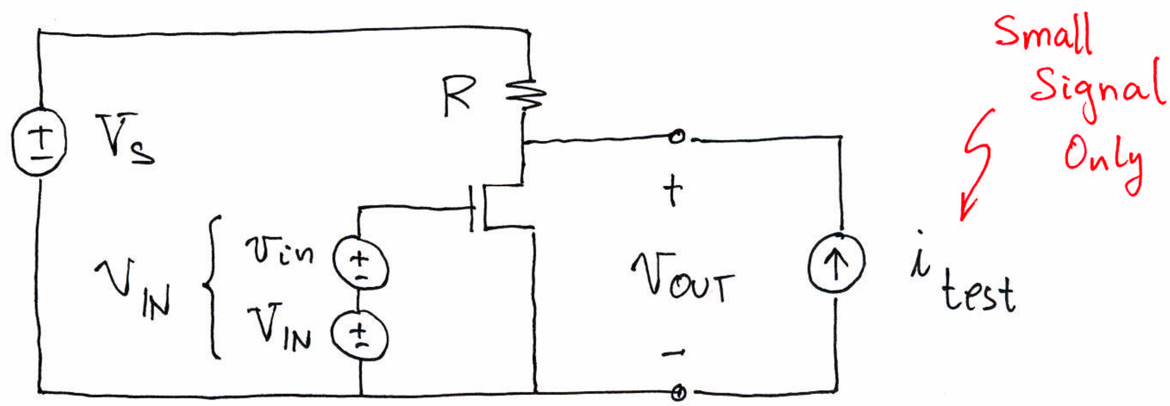
- Bias point with $V_{OUT} = \frac{V_S}{2} \Rightarrow$

  $RI_D = \frac{V_S}{2} \Rightarrow I_D = \frac{V_S}{2R} \Rightarrow$

  SS Gain $= -\sqrt{RKV_S}$

- $$\left.\begin{aligned} V &= 5\ \mathrm{V} \\ K &\approx 0.14\ \mathrm{A/V^2} \\ R &= 100\ \Omega \end{aligned}\right\} \Rightarrow \text{SS Gain} \approx -8.4$$

Small-Signal Thevenin Equivalent



$$v_{OUT} = V_S - R\left(\frac{K}{2}(v_{IN} - V_T)^2 - i_{test}\right) \equiv v_{OUT}(v_{IN}, i_{test})$$

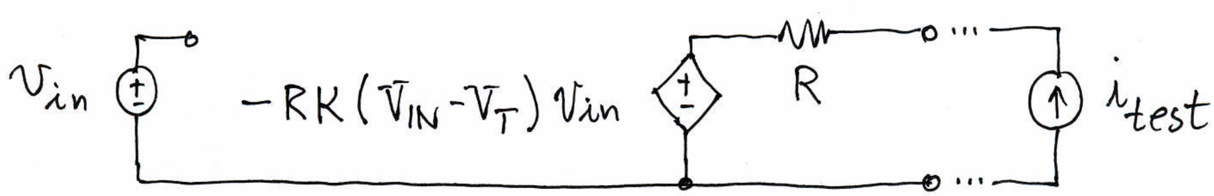
$$V_{OUT} + v_{out} = v_{OUT}(V_{IN} + v_{in}, i_{test})$$

$$\approx v_{OUT}(V_{IN}, 0)$$

$$+ \frac{\partial v_{OUT}}{\partial v_{IN}}(V_{IN}, 0)\, v_{in} + \frac{\partial v_{OUT}}{\partial i_{test}}(V_{IN}, 0)\, i_{test}$$

$$= V_{OUT} - RK(V_{IN} - V_T)\, v_{in} + R\, i_{test}$$

$$v_{out} \approx -RK(V_{IN} - V_T)\, v_{in} + R\, i_{test}$$



Difficulties

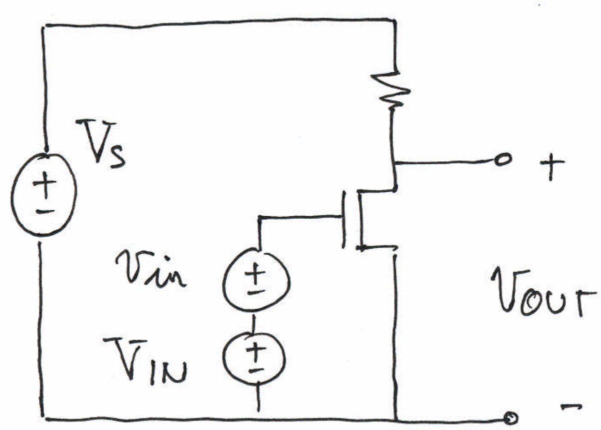
- Expansion and differentiation require a complete non-linear analysis just to begin.

- The expanded or differentiated small-signal analysis must be evaluated at a bias point which also requires a nonlinear derivation.

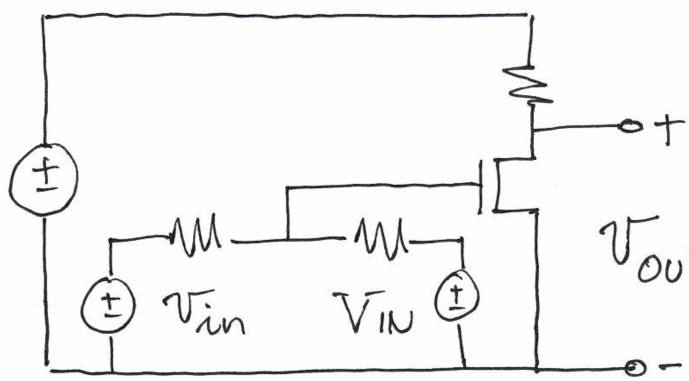
- Small-signal analysis seems hard for large/complex amplifiers. Why bother?

Is there a better way? Yes, small-signal circuit models.

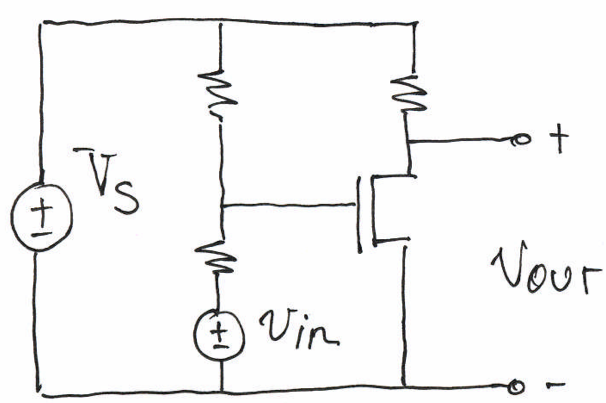
Simple Input Biasing Methods



- Split V_{IN} into $V_{in} + V_{IN}$
- Requires two sources, one of which floats



- Superposition eliminates floating source
- Input bias and attenuation
- Two sources

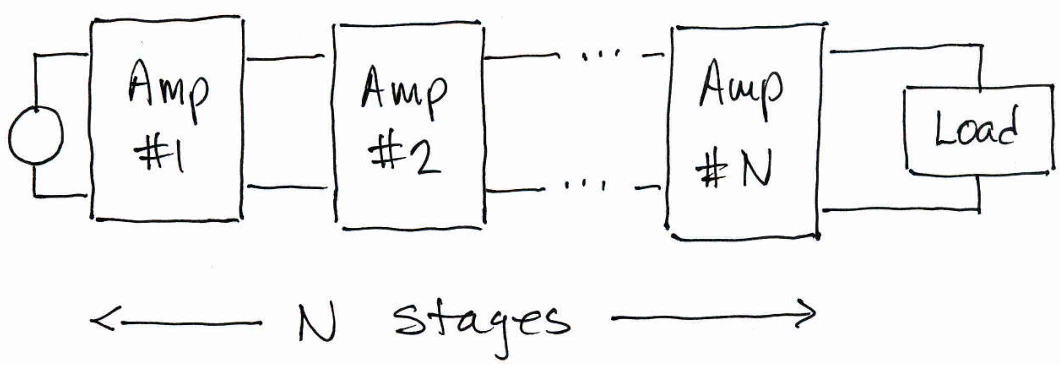


- V_S replaces V_{IN}
- Input bias and attenuation

Loading

Amplifiers ultimately drive loads.

One way to analyze a complex amplifier is to break it into smaller cascaded amplifier stages. Each stage loads the previous stage.

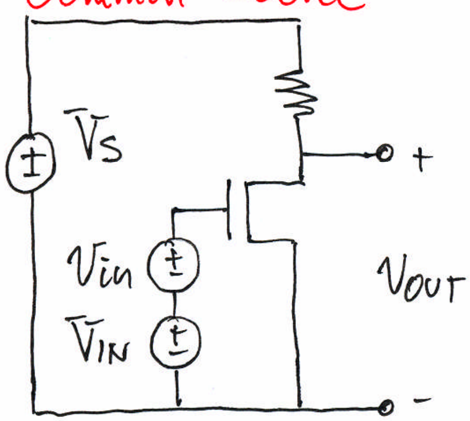


Loading must be considered during the analysis of each stage. Small-signal circuit models help.

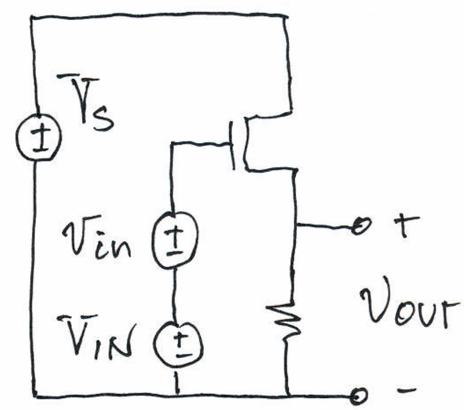
Single MOSFET Amplifiers

		Output	
		Drain	Source
Input	Gate	Common Source	Common Drain Source Follower
	Source	Common Gate	Wire

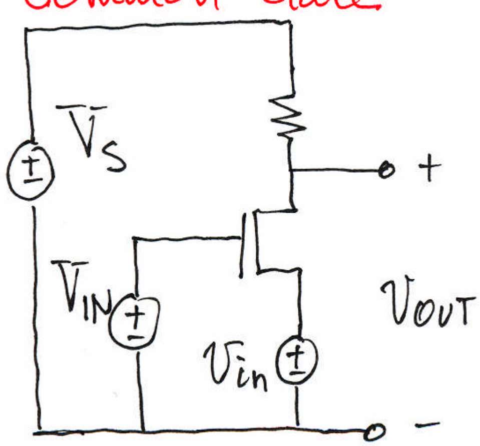
Common Source



Source Follower



Common Gate



These amplifiers can have very different properties.