6.002x CIRCUITS AND ELECTRONICS

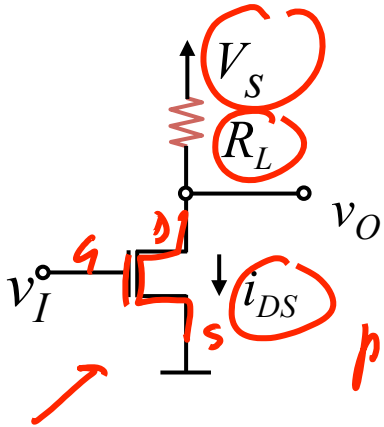
Amplifiers – Revisit Small Signal Trick



Reading: Amplifier small signal model -- Chapter 8 of A&L

Review

- MOSFET amp



- Saturation discipline — operate MOSFET only in saturation region
- Large signal analysis
  - 1. Find v_O vs v_I under saturation discipline.
  - 2. Valid v_I, v_O ranges under saturation discipline.

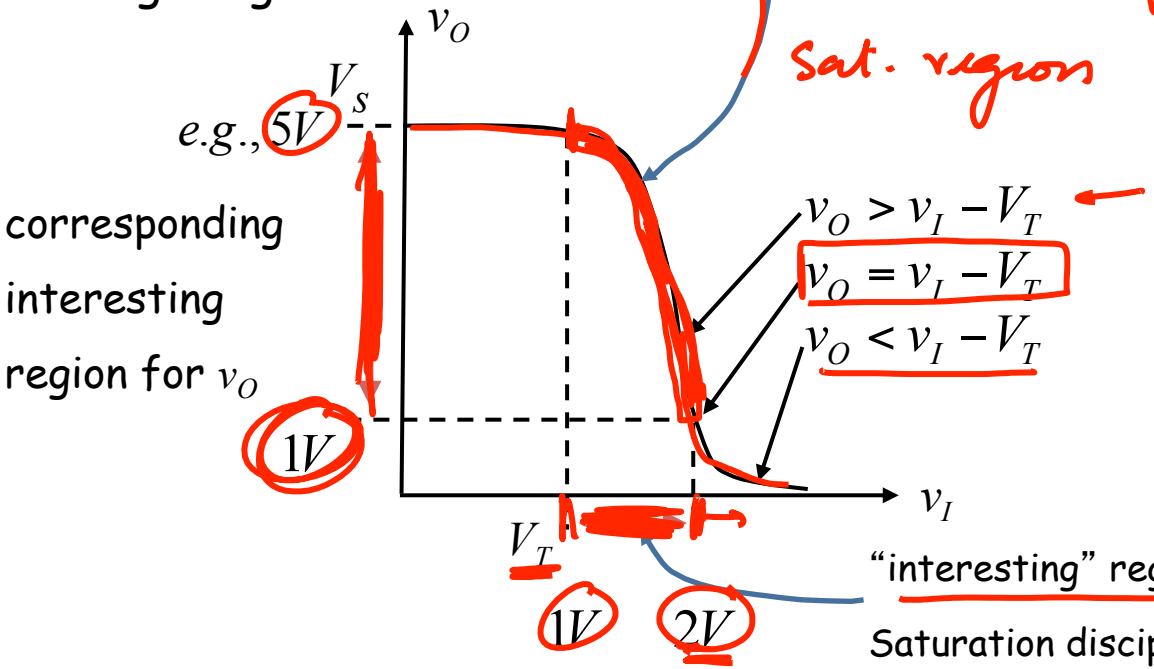


Review Large Signal Analysis Review

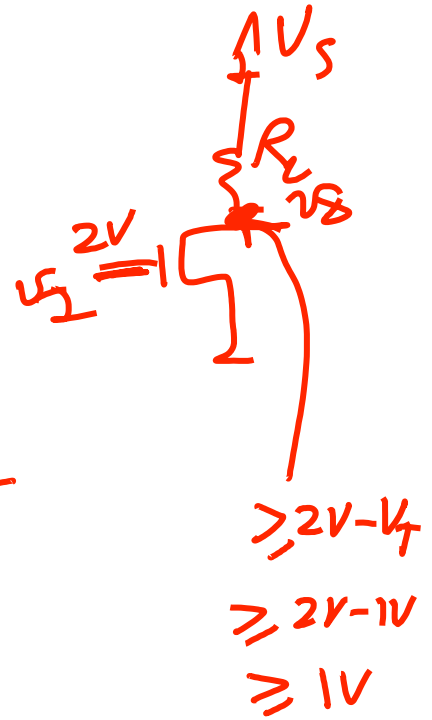
1. v_O vs v_I

$$v_O = V_S - \frac{K(v_I - V_T)^2}{2} R_L$$

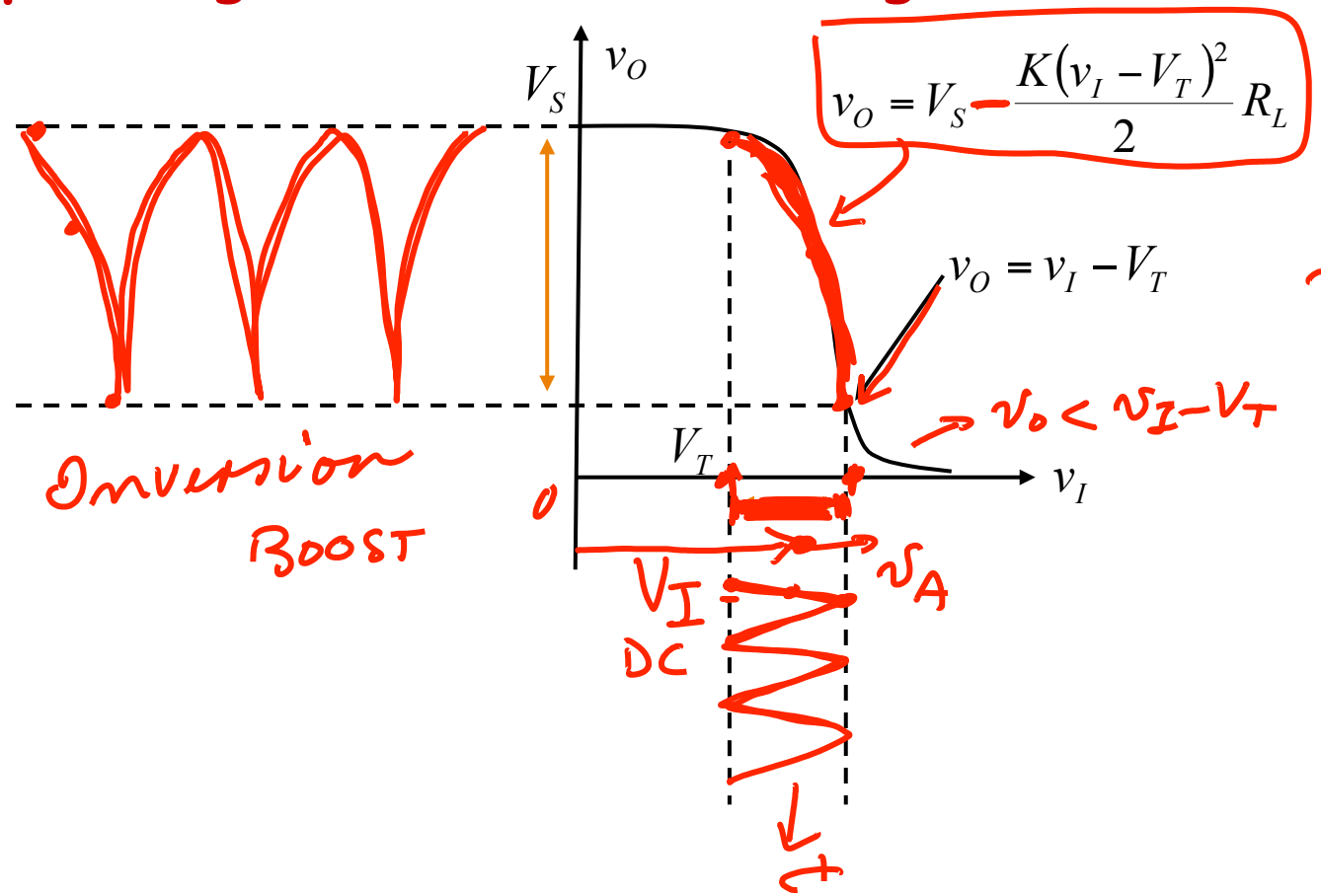
2. Valid operating ranges

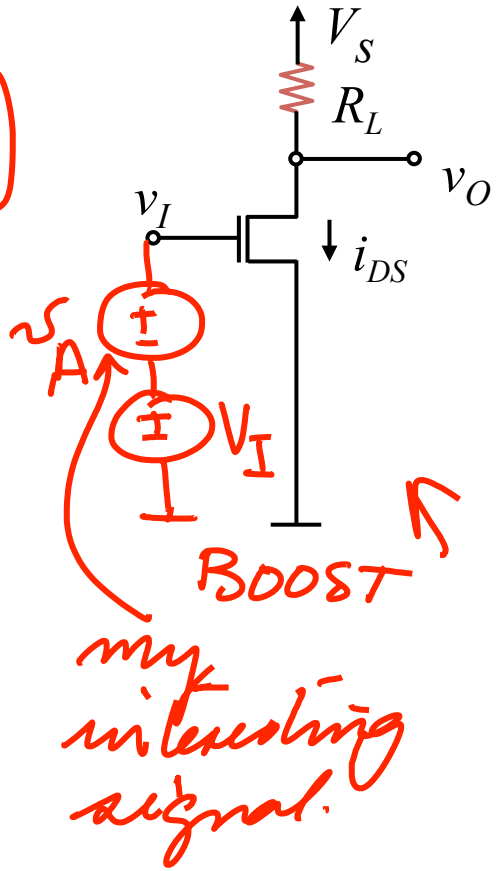


Sat. region

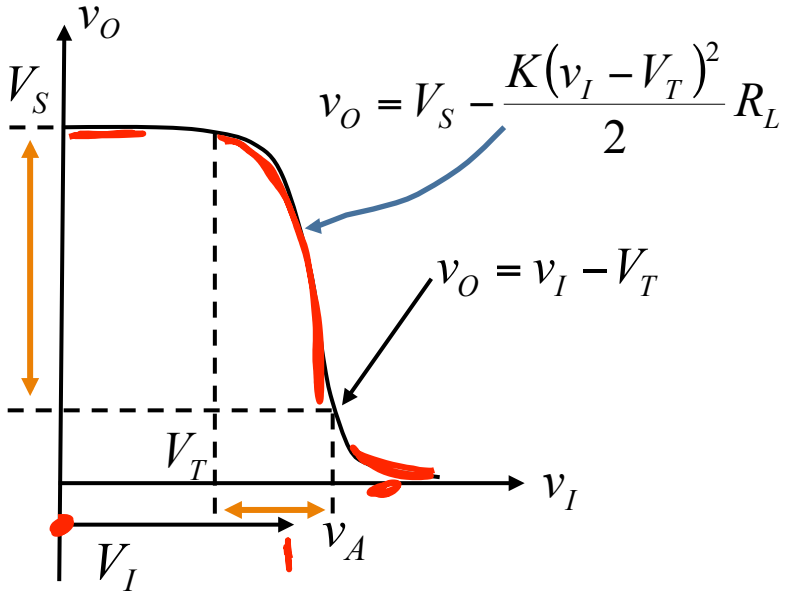


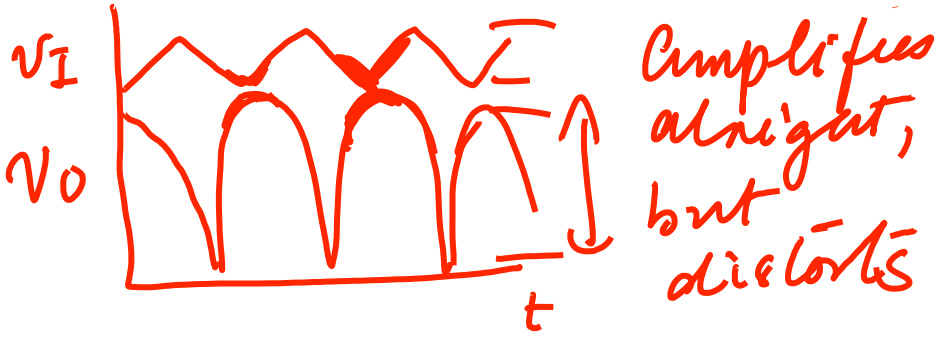
Operating in the saturation region

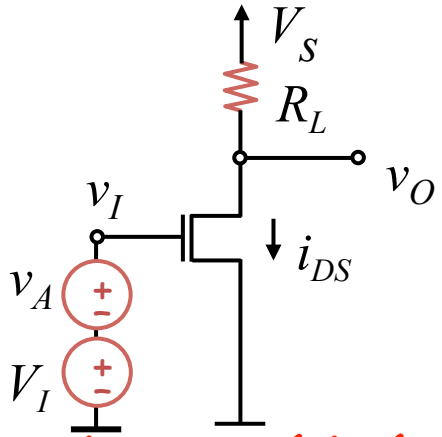




But…







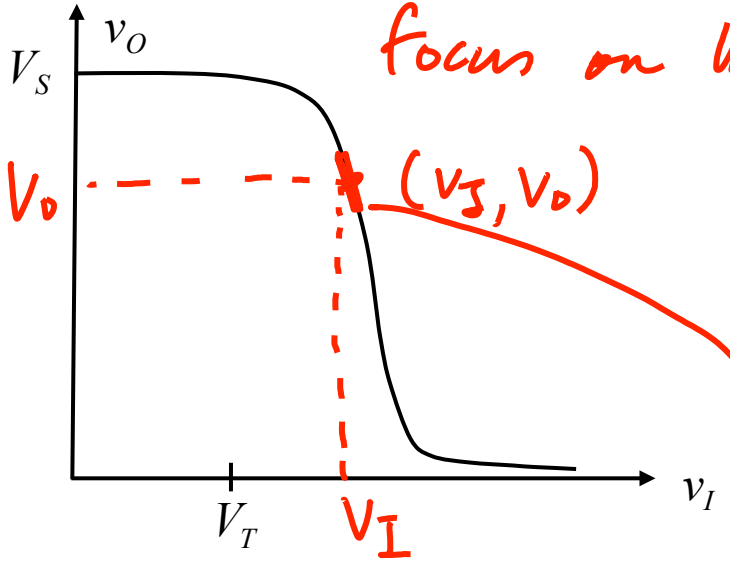
- apply large offset
- apply offset
- apply no offset

Demo

Amp is nonlinear … ☹

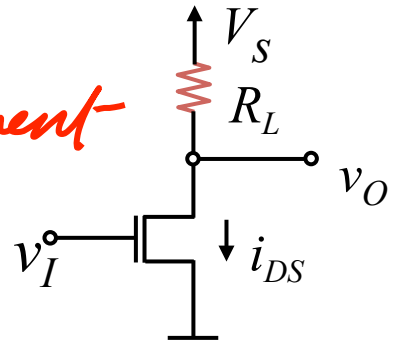
How do we get a linear amplifier?

Small Signal Trick



focus on this line segment

(V_I, V_0)

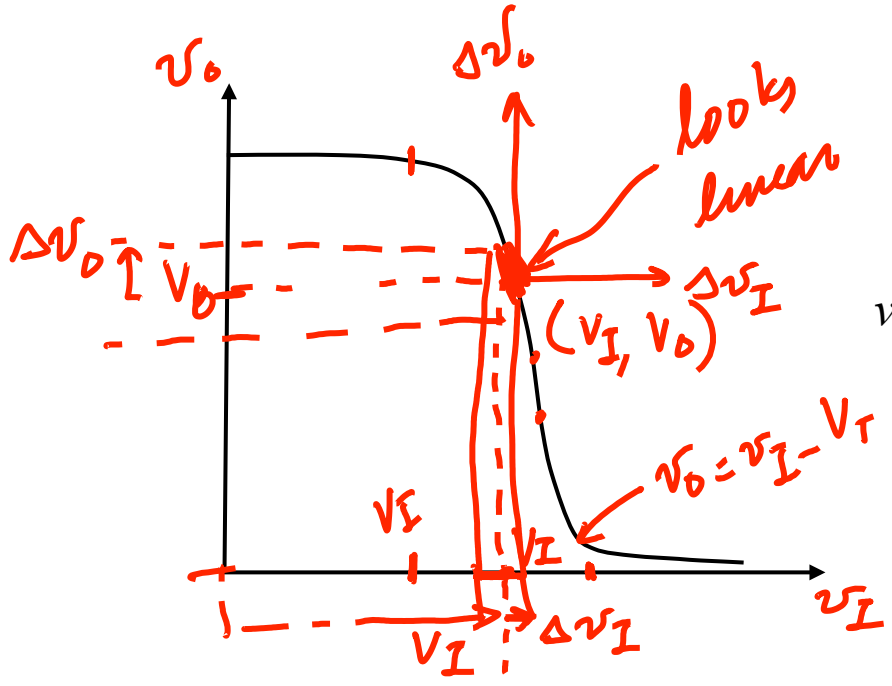


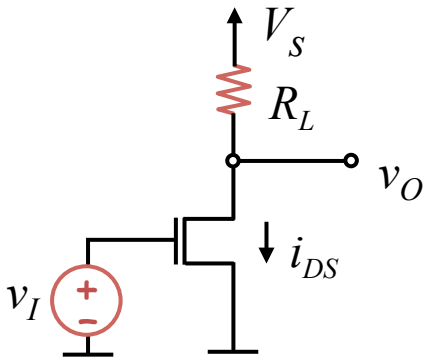


Insight:
Observe v_I vs v_O about zone
point (V_I, V_0) .. looks more or less linear!

Small Signal Trick

Remember
"Boost and Shrink"

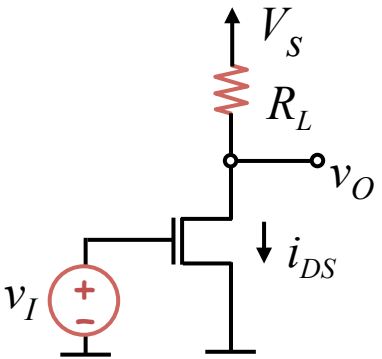


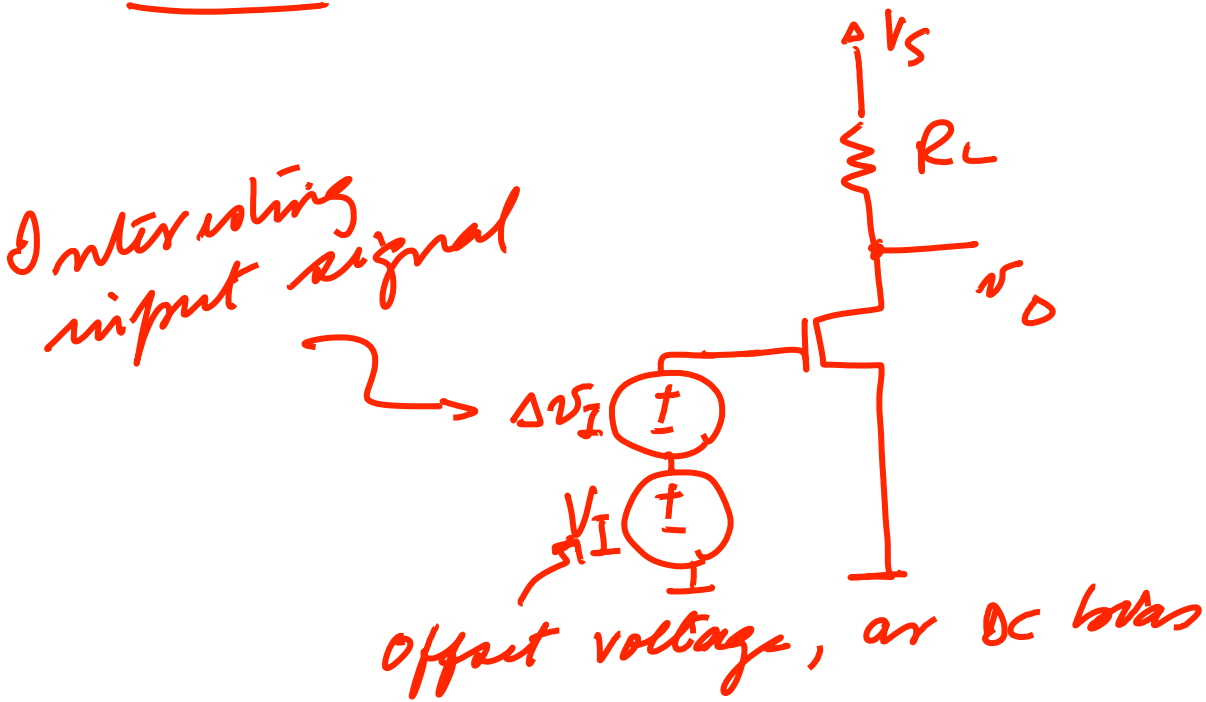


- Operate amp at V_I, V_O → DC "bias"
  (possible choice: midpoint of valid input operating range)
- Superimpose small signal of interest on top of V_I
- Response to small signal seems to be approximately linear

Boost – Use DC Bias

We use a DC bias V_I to "boost" interesting input signal above V_T (and in fact, well above V_T)





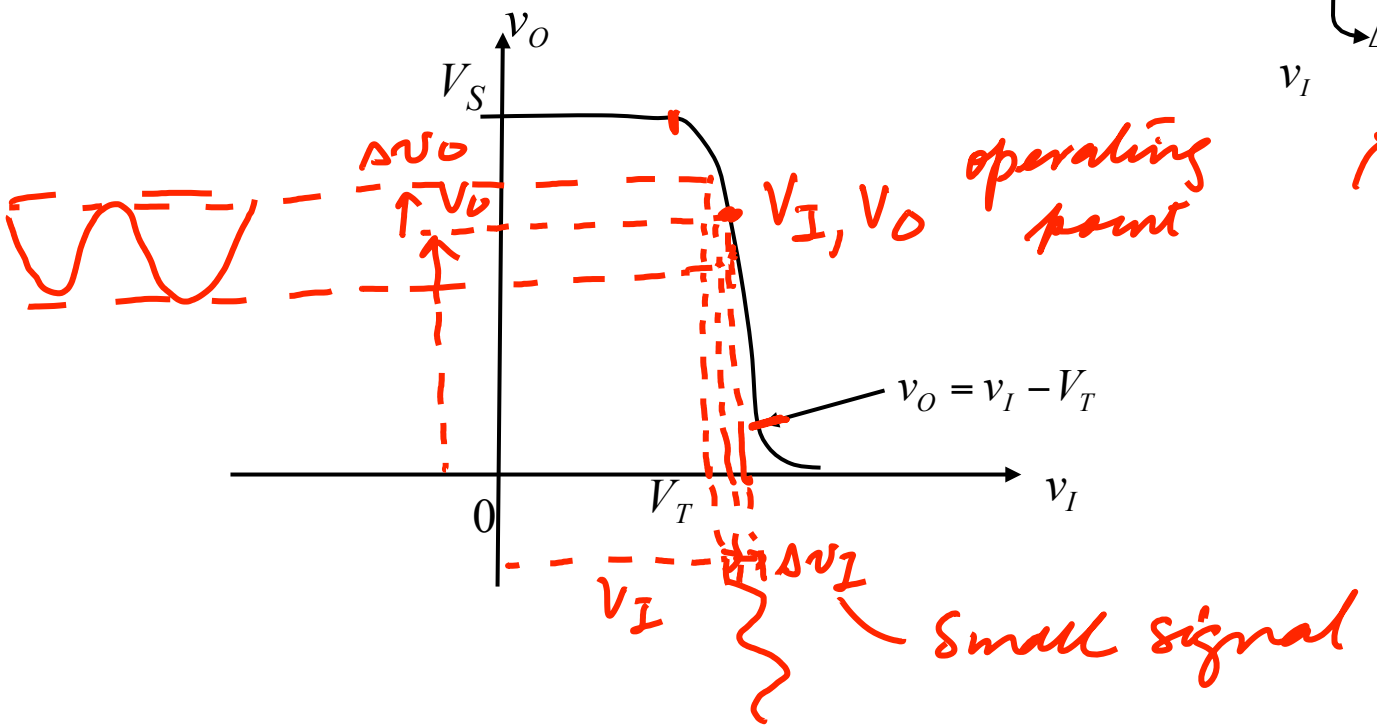
Small Signal Method

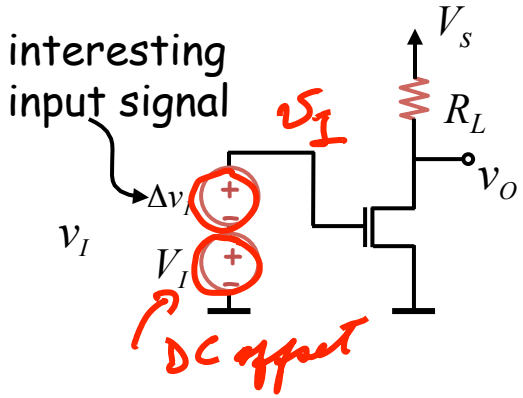
Let's look at this in more detail —

- I graphically
- II mathematically
- III from a circuit viewpoint

In the next sequence

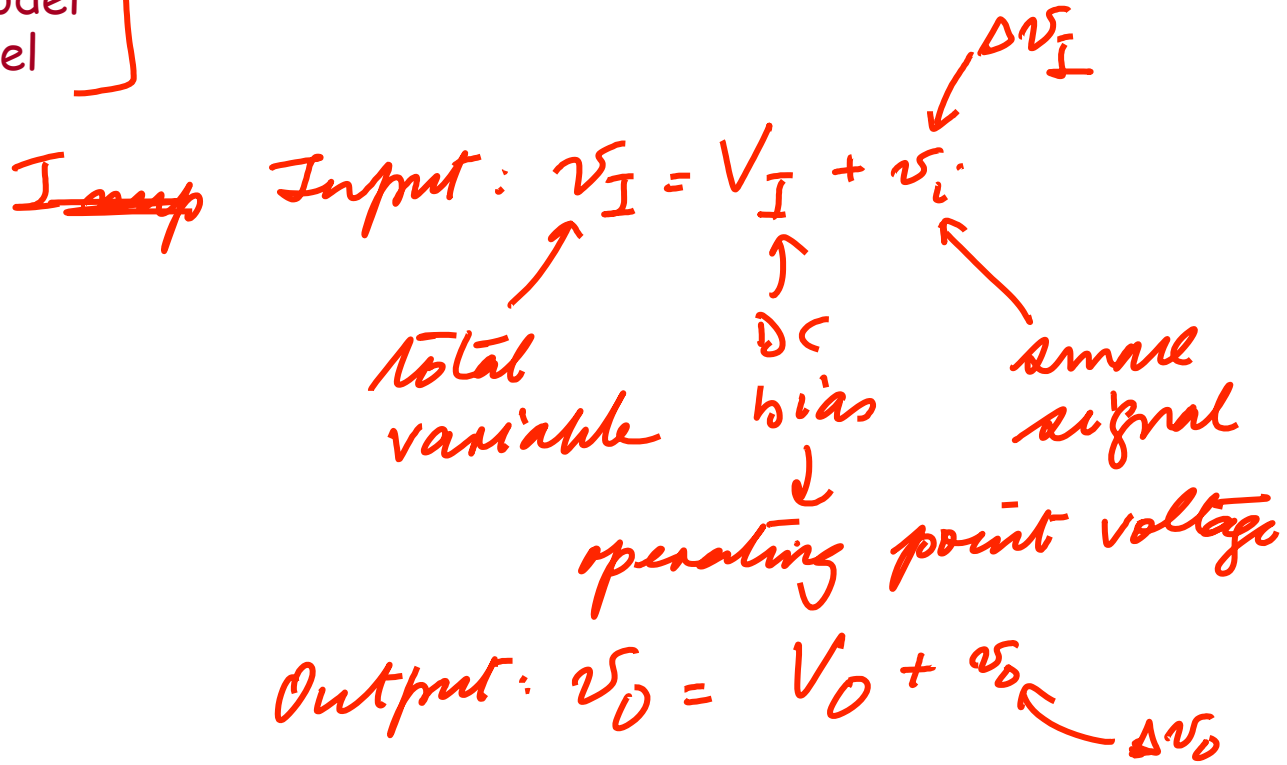
I Graphically





Recall Small Signal Model Notation

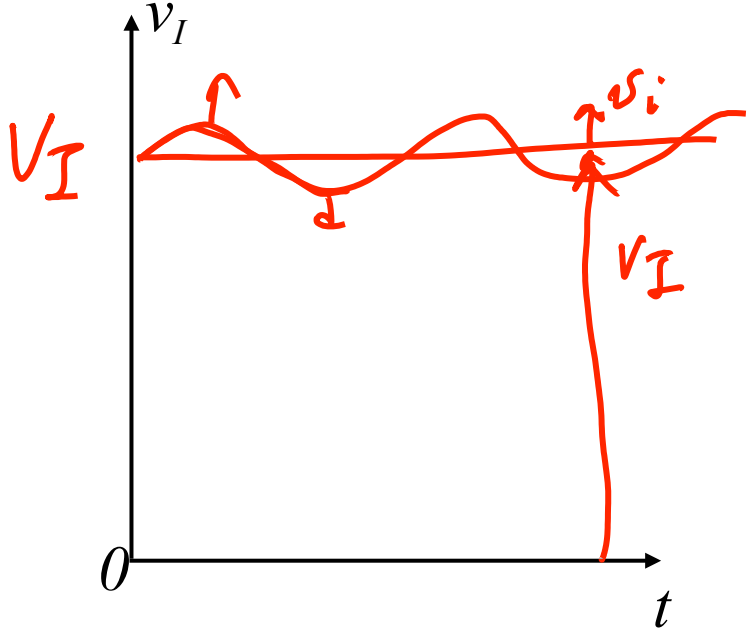
aka incremental model
aka linearized model

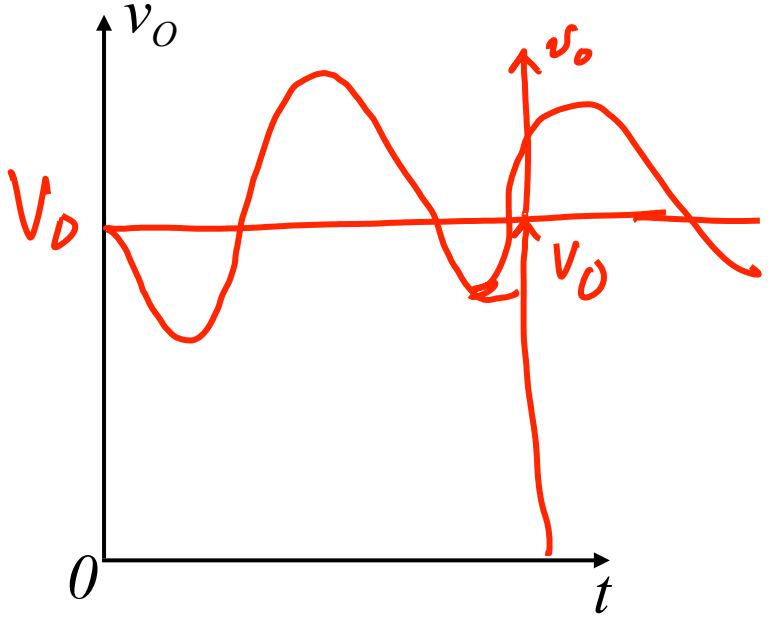


Small Signal Model

Input: $v_I = V_I + v_i$

Output: $v_O = V_O + v_o$





II Mathematically

$$v_O = V_S - \frac{R_L K}{2}(v_I - V_T)^2$$

Bias point Equation

$$V_O = V_S - \frac{R_L K}{2}(V_I - V_T)^2 \longrightarrow *$$

... watch my fingers!

substituting $v_I = V_I + v_i$, $v_i \ll V_I$

$$v_O = V_S - \frac{R_L K}{2}([V_I + v_i] - V_T)^2$$

$$= V_S - \frac{R_L K}{2}([V_I - V_T] + v_i)^2$$

$$v_O = V_O + v_o = V_S - \frac{R_L K}{2}([V_I - V_T]^2 + 2[V_I - V_T]v_i + v_i^2)$$

$$v_o = \text{“}A\text{”} v_i$$

?

II Mathematically

$$v_O = V_S - \frac{R_L K}{2}(v_I - V_T)^2$$

Bias point Equation

$$V_O = V_S - \frac{R_L K}{2}(V_I - V_T)^2 \quad \longrightarrow *$$

… watch my fingers!

substituting $v_I = V_I + v_i$, $v_i \ll V_I$

$$v_O = V_S - \frac{R_L K}{2}\left([V_I + v_i] - V_T\right)^2$$

$$= V_S - \frac{R_L K}{2}\left([V_I - V_T] + v_i\right)^2$$

neglect higher order terms in v_i

$$V_O + v_o = V_S - \frac{R_L K}{2}\left([V_I - V_T]^2 + 2[V_I - V_T]v_i + v_i^2\right)$$

From *

$$v_o = A\, v_i$$

$$v_o = -\frac{R_L K}{2}\left(2[V_I - V_T]v_i\right)$$

$$v_o = -R_L K (V_I - V_T) v_i = -g_m R_L v_i$$

$K(V_I - V_T) = g_m$

We will see why this is called transconductance in the next sequence

Transconductance related to MOSFET parameters and V_I

Mathematically

$$v_o = -R_L \underbrace{K\left(V_I - V_T\right)}_{g_m} v_i$$

g_m related to V_I

$v_o = -g_m R_L v_i$

For a given DC operating point voltage V_I,

$V_I - V_T$ is constant, so

$v_o = -A v_i$

↳ constant w.r.t. v_i

In other words, our circuit behaves like a linear amplifier for small signals

Another way

$$v_O = V_S - \frac{R_L K}{2}(v_I - V_T)^2$$

$v_o = \frac{d}{dv_I}(\quad)\Big|_{v_I = V_I} \cdot v_i$

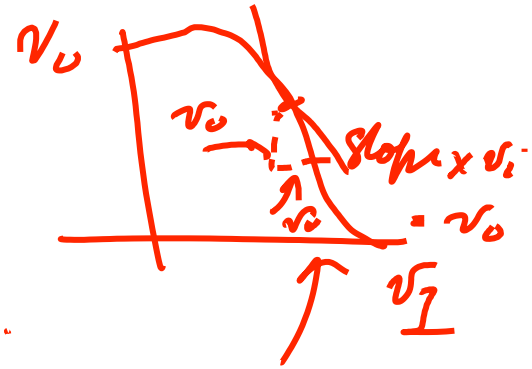
slope at V_I

$v_o = -\frac{R_L K}{2} \cdot 2 \cdot (v_I - V_T)\Big|_{v_I = V_I} \cdot v_i$

$= -R_L K (V_I - V_T) \cdot v_i$

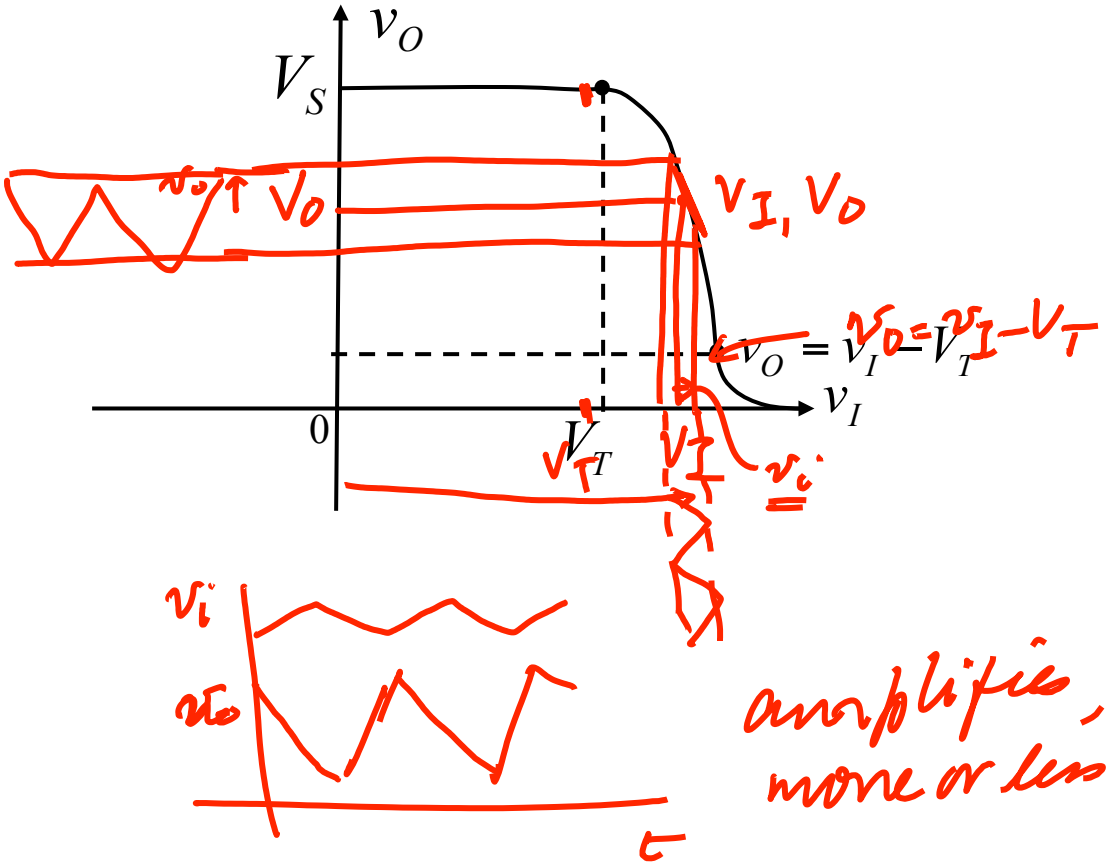
g_m

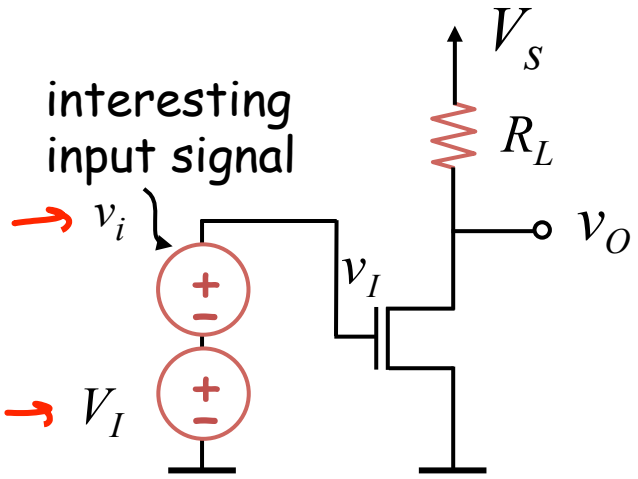
amp gain $A = g_m R_L$, so that $v_o = -A v_i$



Also, see Figure 8.9 in the text for a graphical interpretation of this result

Small Signal Demo





Demo