

MOSFET Amplifier

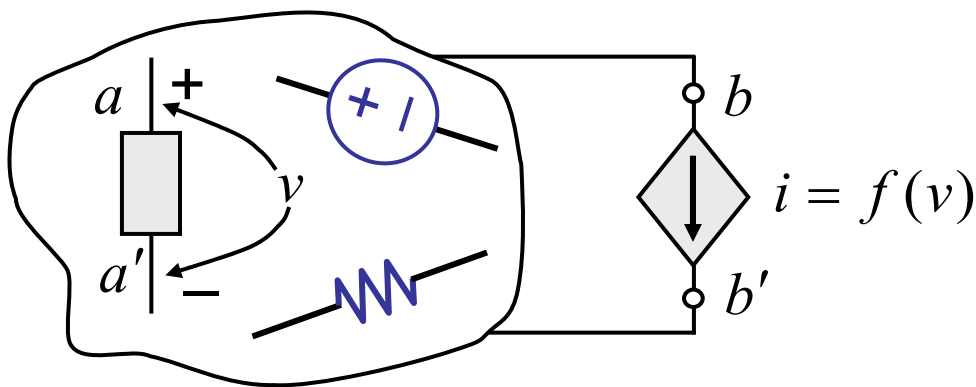
Large Signal Analysis

Review

- Amp constructed using dependent source



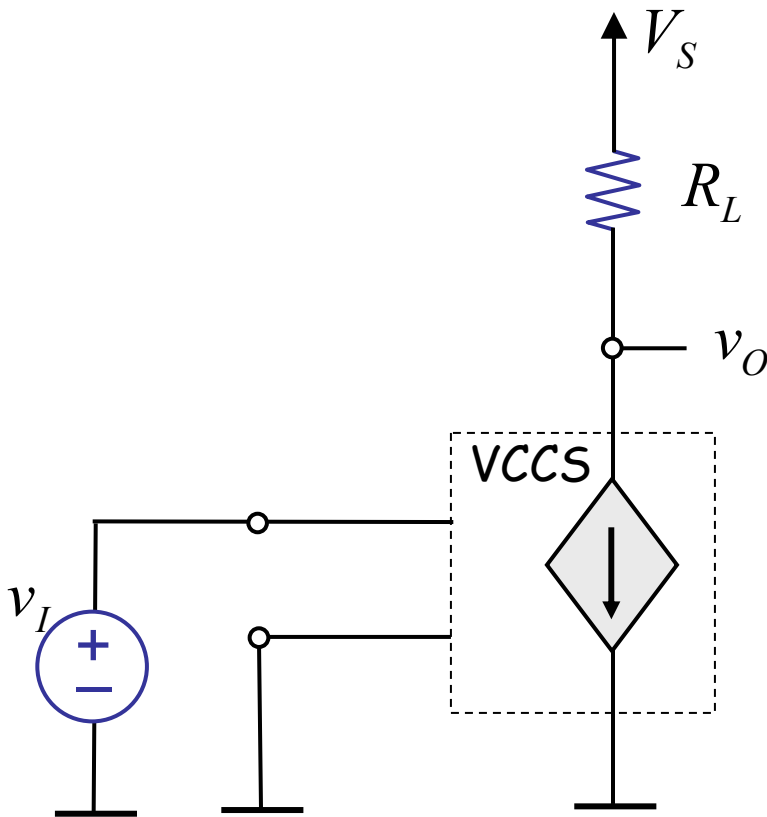
- Dependent source in a circuit



- Superposition with dependent sources:
one way \rightarrow leave all dependent sources in;
solve for one independent source at a
time [section 3.5.1 of the text]
- Next, quick review of amp ...

Reading: Chapter 7.3-7.7

Amp review



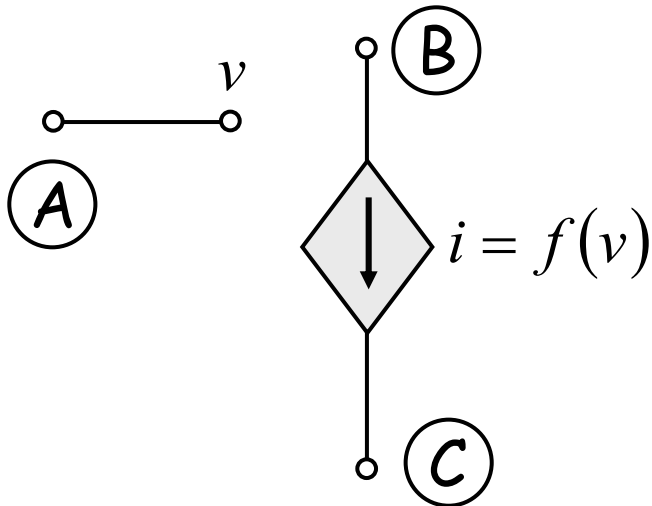
$$i_D = \frac{K}{2}(v_I - 1)^2$$

for $v_I \geq 1V$
 $= 0$ otherwise

$$v_O = V_S - i_D R_L$$

\nwarrow
 $\frac{K}{2}(v_I - 1)^2$

Key device Needed:



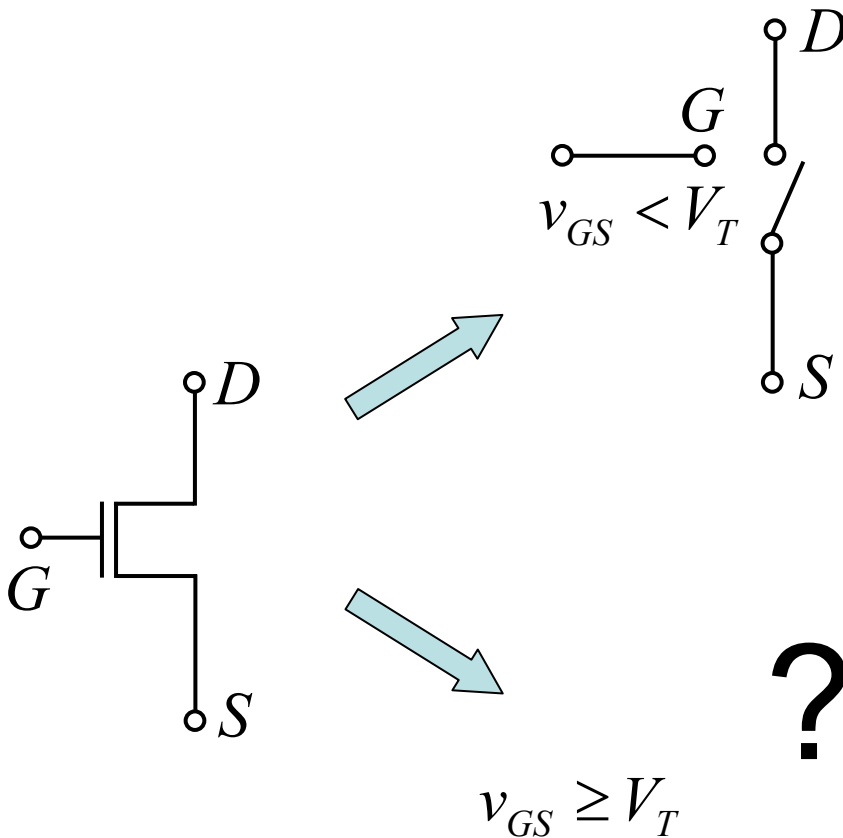
voltage controlled
current source

Let's look at our old friend, the MOSFET ...

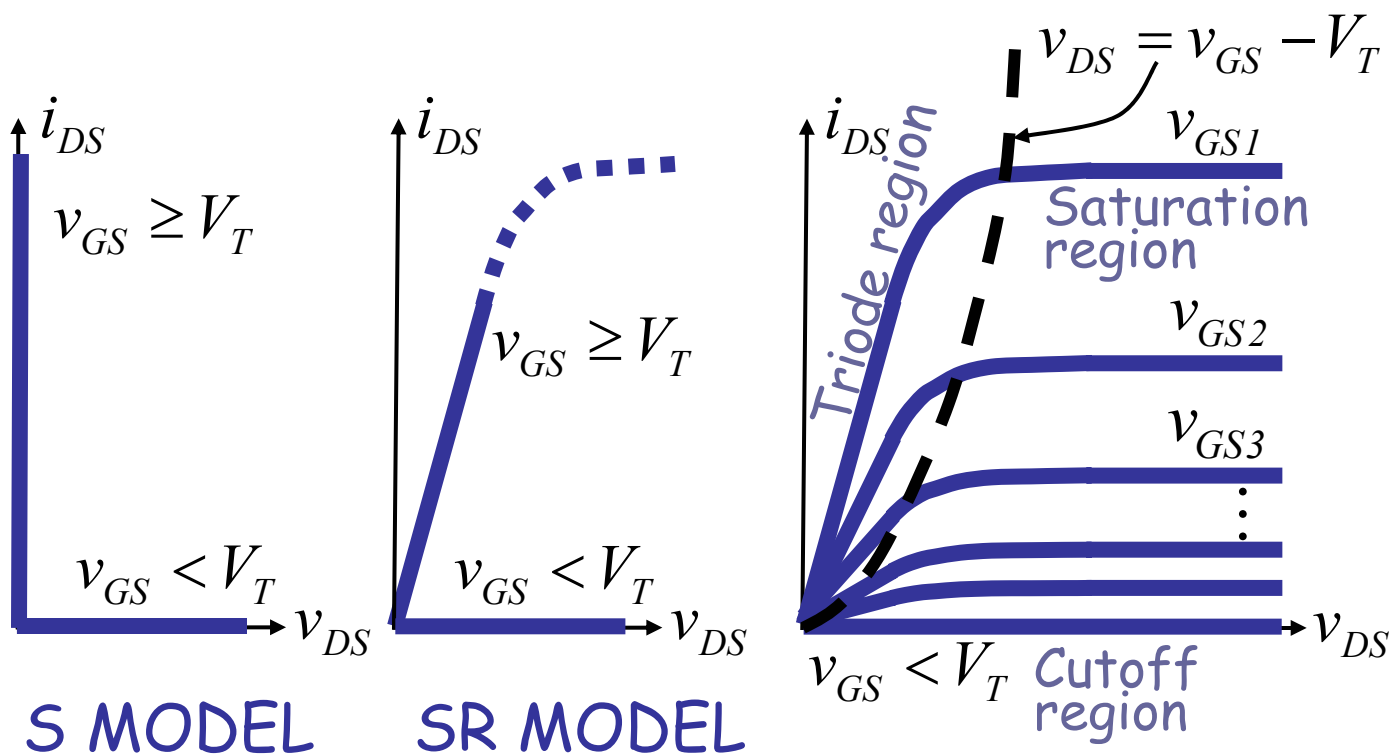
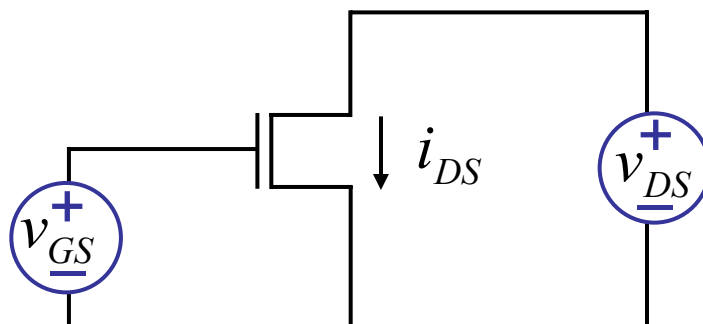
Key device Needed:

Our old friend, the MOSFET ...

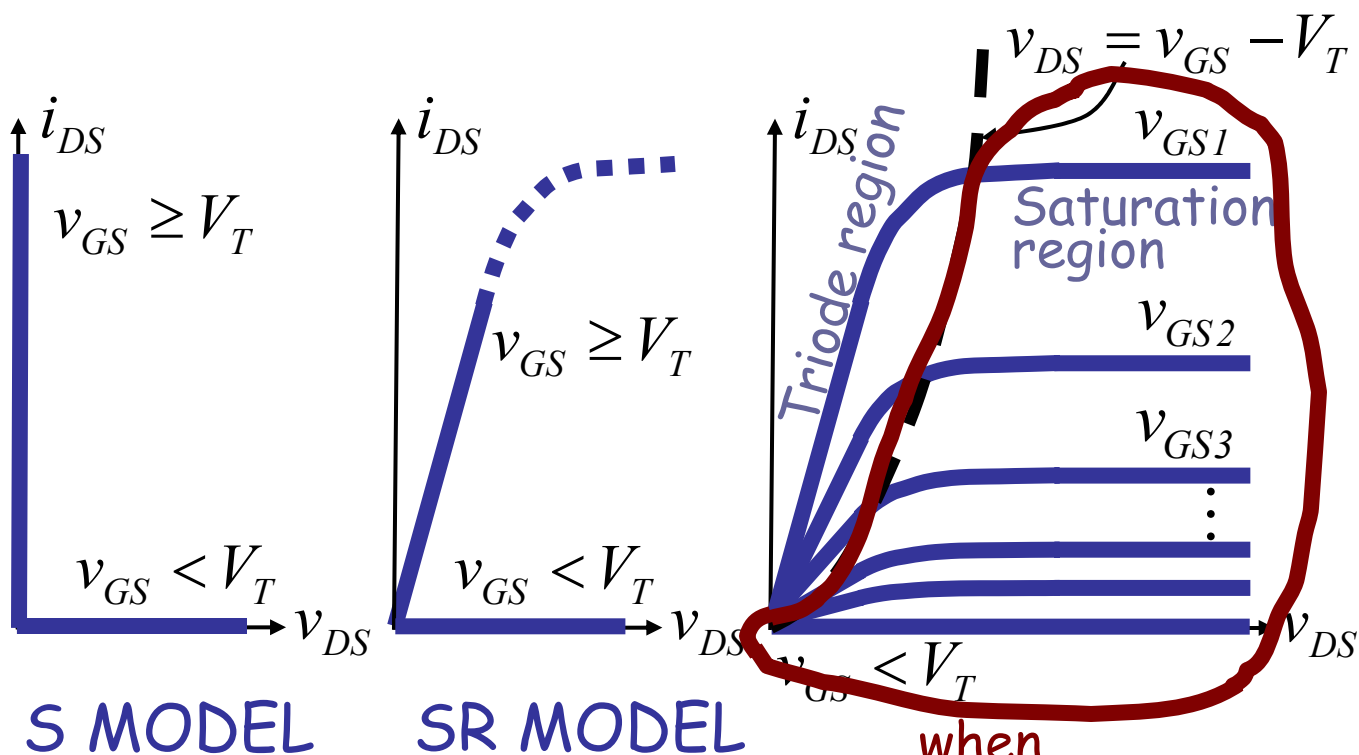
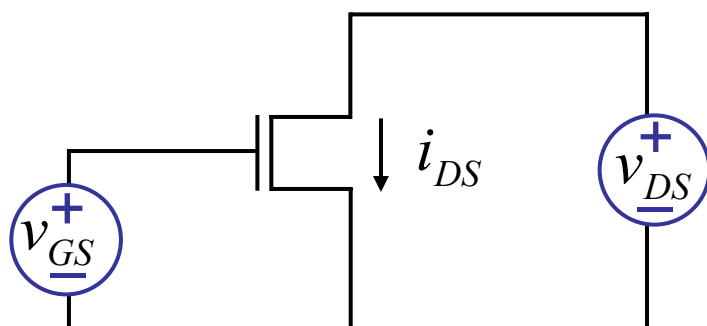
First, we sort of lied. The on-state behavior of the MOSFET is quite a bit more complex than either the ideal switch or the resistor model would have you believe.



Graphically



Graphically



when

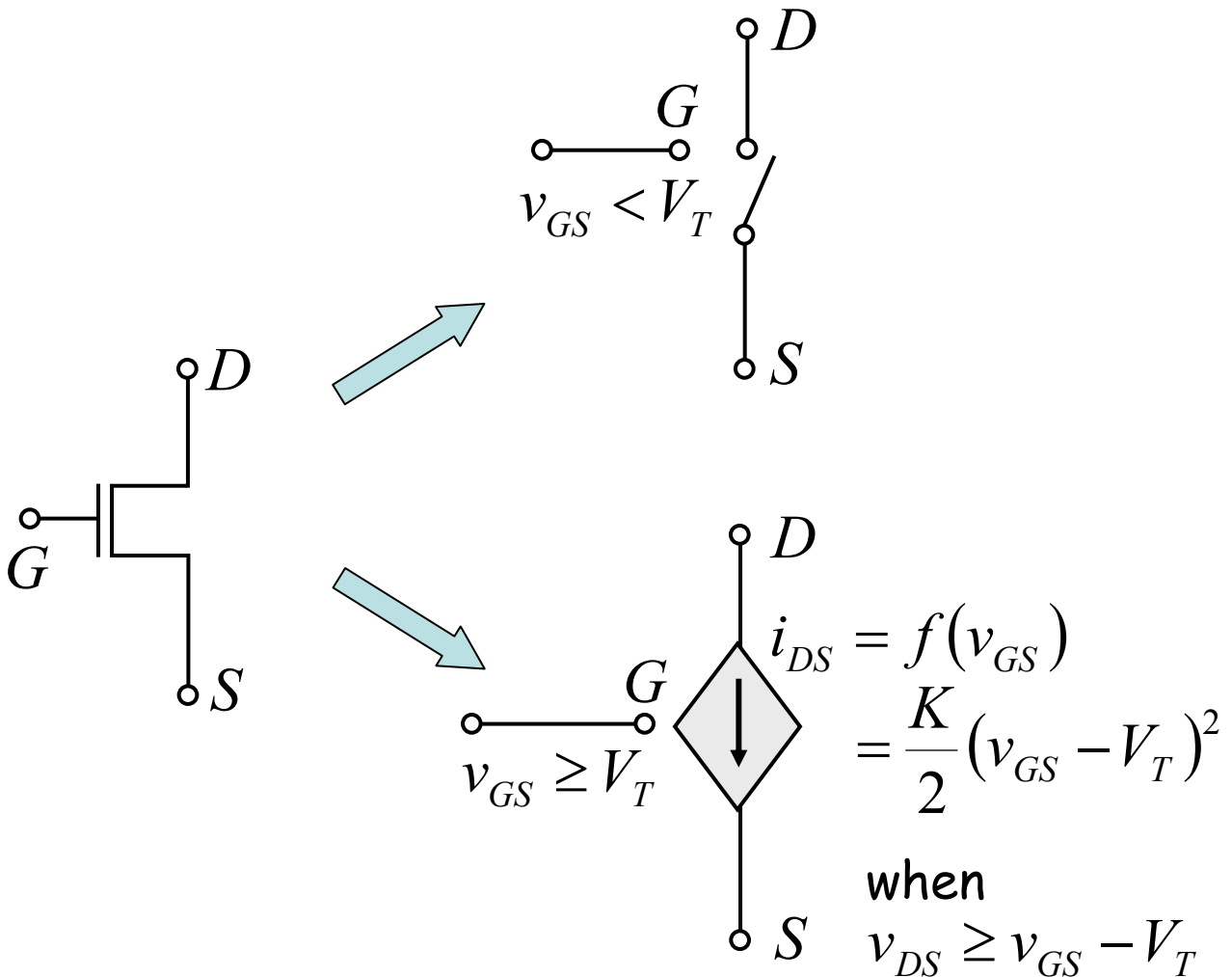
$$v_{DS} \geq v_{GS} - V_T$$

Notice that
MOSFET
behaves like a
current source

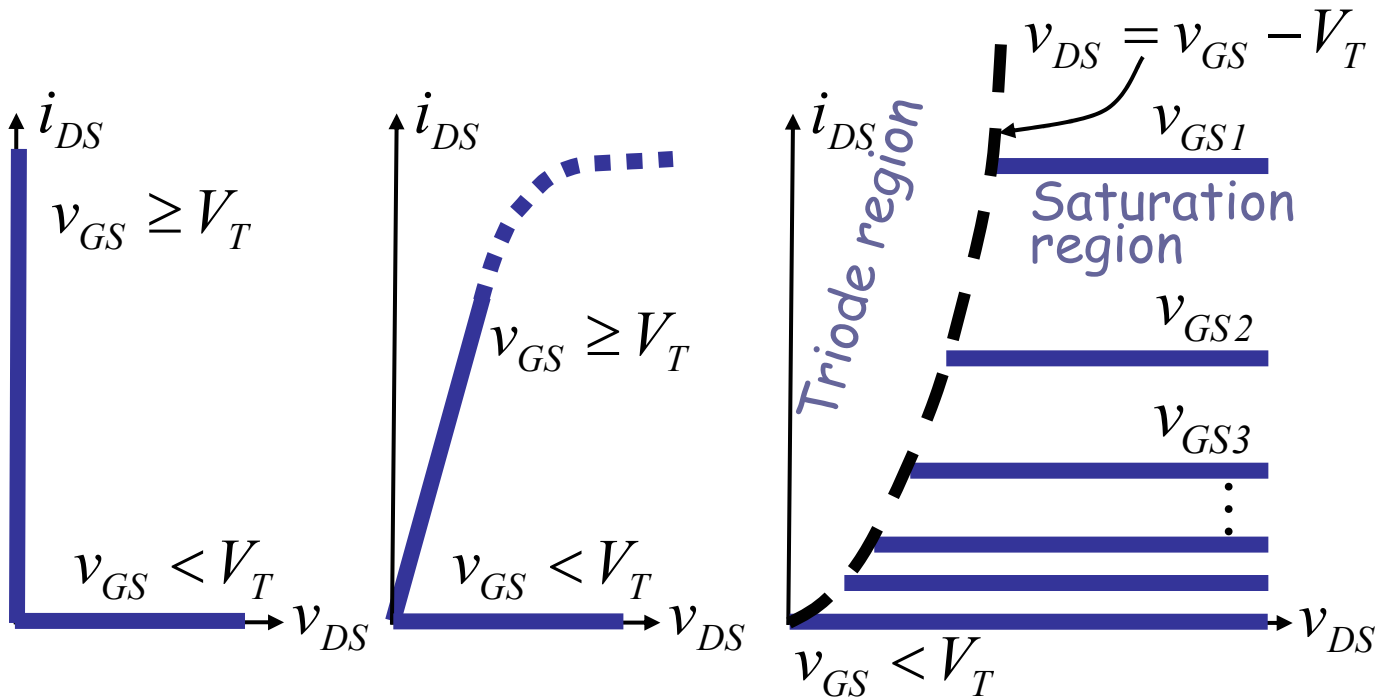
MOSFET SCS Model

When $v_{DS} \geq v_{GS} - V_T$

the MOSFET is in its saturation region, and the switch current source (SCS) model of the MOSFET is more accurate than the S or SR model



Reconciling the models...



S MODEL

for fun!

SR MODEL

for digital
designs

SCS MODEL

for analog
designs

When to use each model in 6.002?

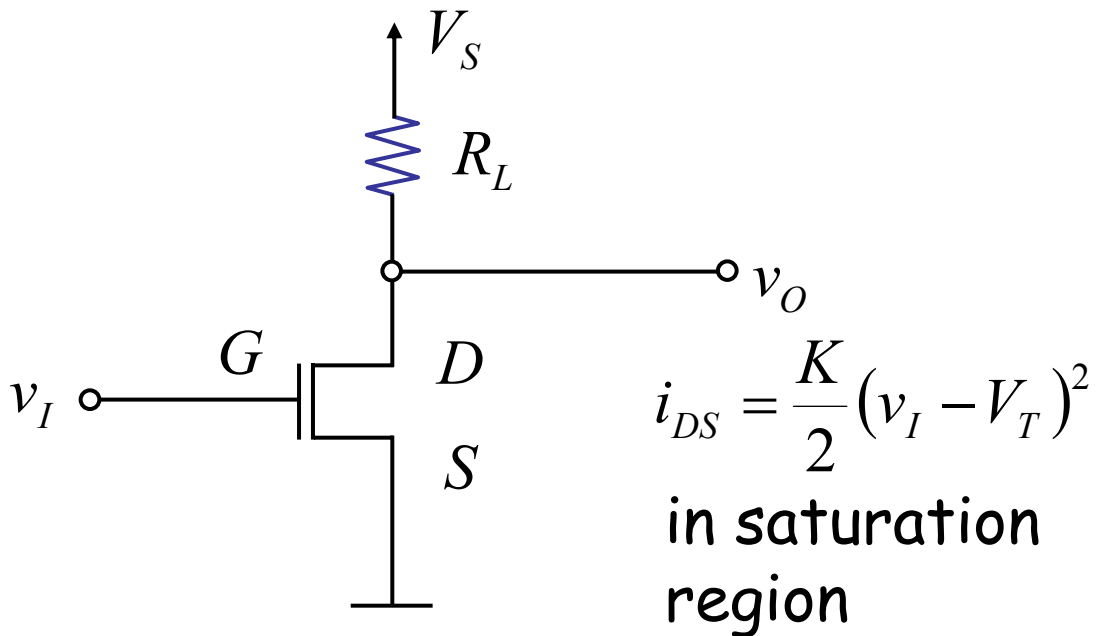
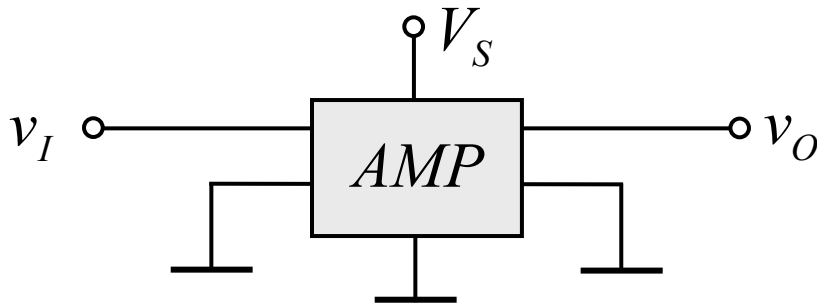
Note: alternatively (in more advanced courses)

$v_{DS} \geq v_{GS} - V_T$ use SCS model

$v_{DS} < v_{GS} - V_T$ use SR model

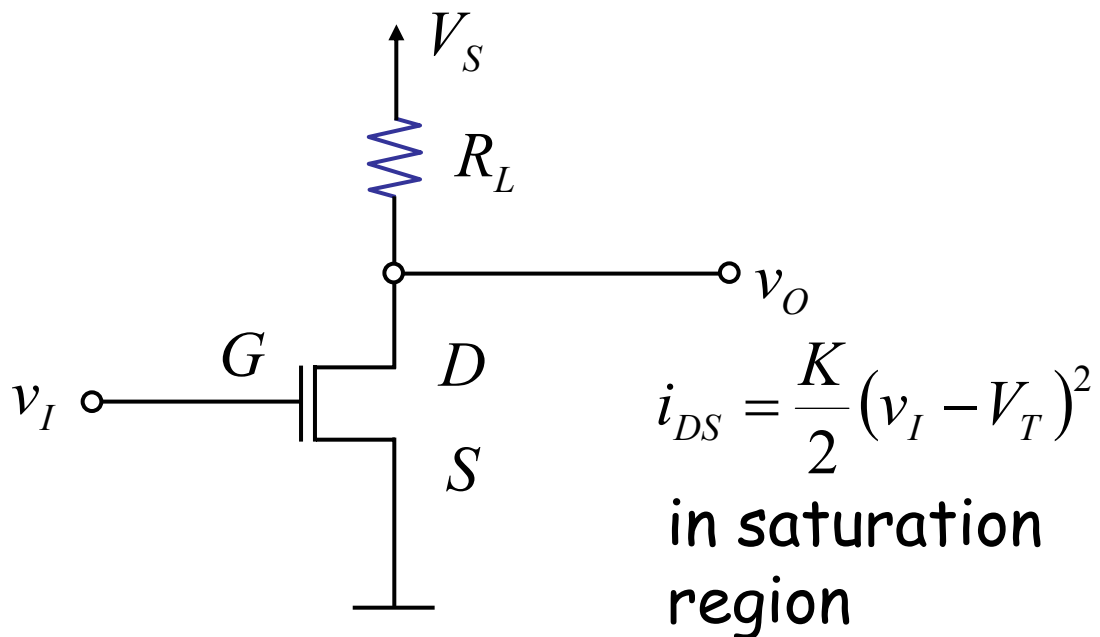
or, use SU Model (Section 7.8 of A&L)

Back to Amplifier



To ensure the MOSFET operates as a VCCS, we must operate it in its saturation region only. To do so, we promise to adhere to the "saturation discipline"

MOSFET Amplifier



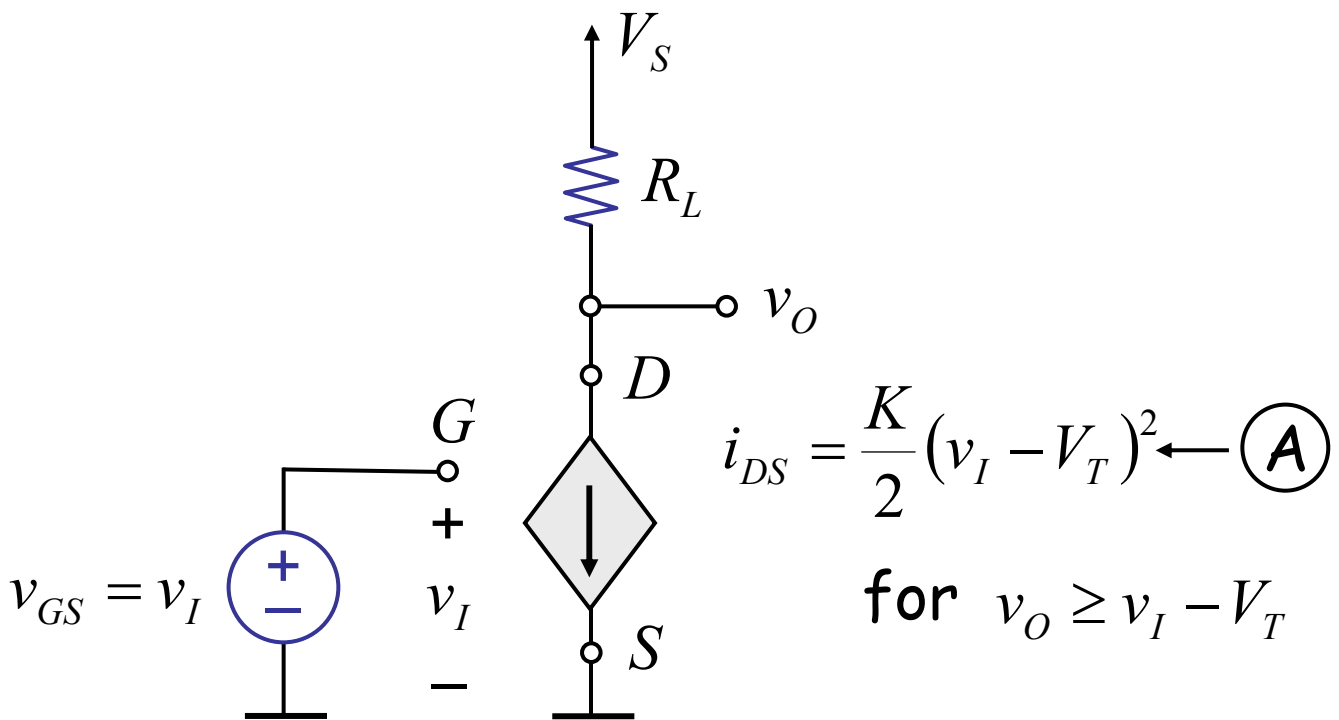
To ensure the MOSFET operates as a VCCS, we must operate it in its saturation region only. We promise to adhere to the “saturation discipline.”

In other words, we will operate the amp circuit such that

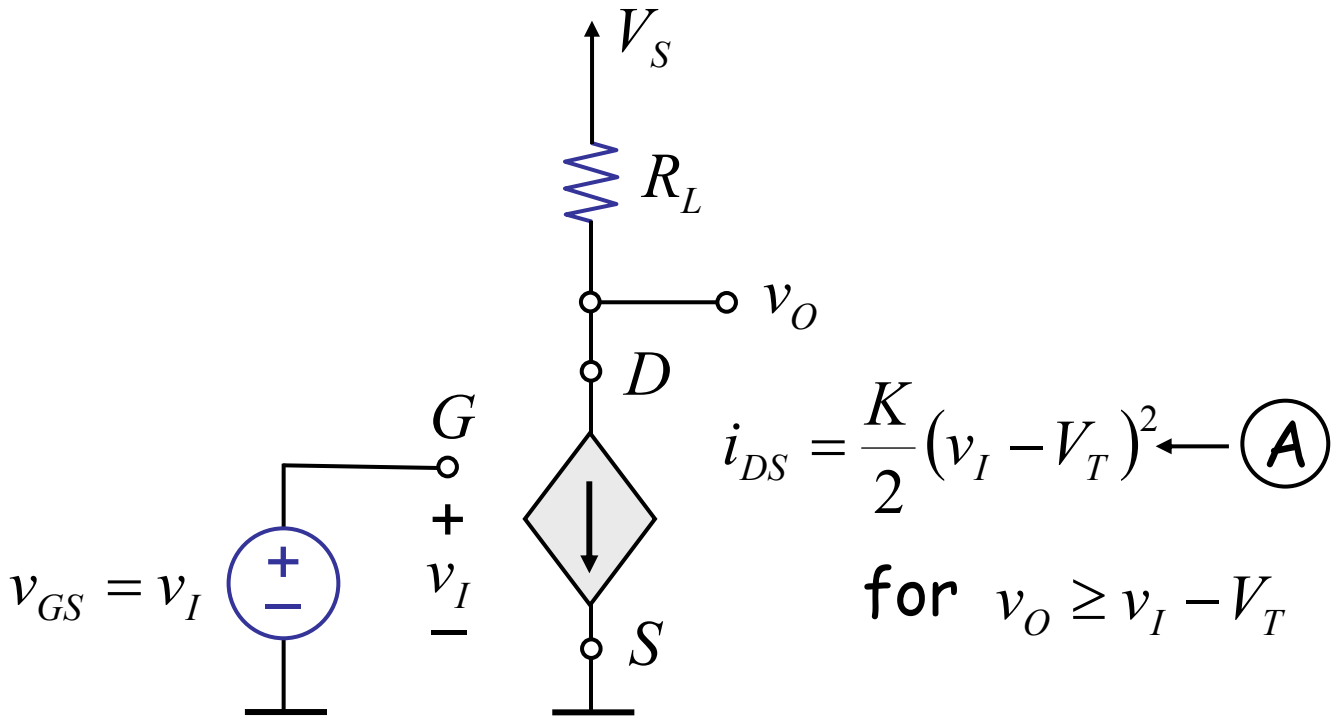
$$v_{GS} \geq V_T \text{ and } \begin{matrix} v_{DS} \geq v_{GS} - V_T \\ v_O \geq v_I - v_T \end{matrix} \text{ at all times.}$$

Let's analyze the circuit

First, replace the MOSFET with its SCS model.



Let's analyze the circuit



($v_O = v_{DS}$ in our example)

① Analytical method: $v_O \quad v_S \quad v_I$

$$v_O = V_S - i_{DS} R_L \quad \leftarrow \textcircled{B}$$

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

$v_O = V_S$ for $v_I < V_T$
 (MOSFET turns off)

② Graphical method v_O vs v_I

From ① : $i_{DS} = \frac{K}{2}(v_I - V_T)^2$,

for $v_O \geq v_I - V_T$
 \Downarrow

$$v_O \geq \sqrt{\frac{2i_{DS}}{K}}$$

$$\Downarrow$$

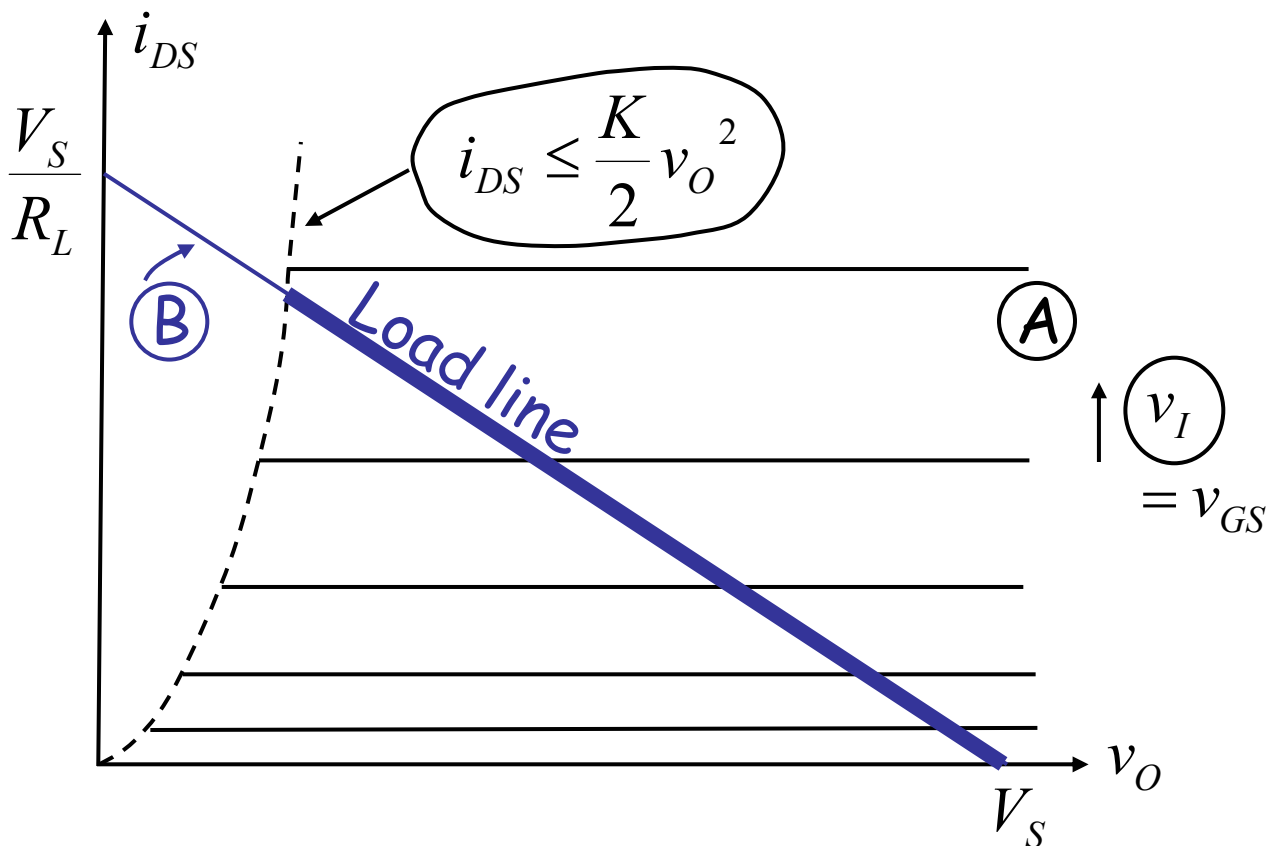
$$i_{DS} \leq \frac{K}{2} v_O^2$$

$$\textcircled{B} : i_{DS} = \frac{V_S}{R_L} - \frac{v_O}{R_L}$$

② Graphical method v_O vs v_I

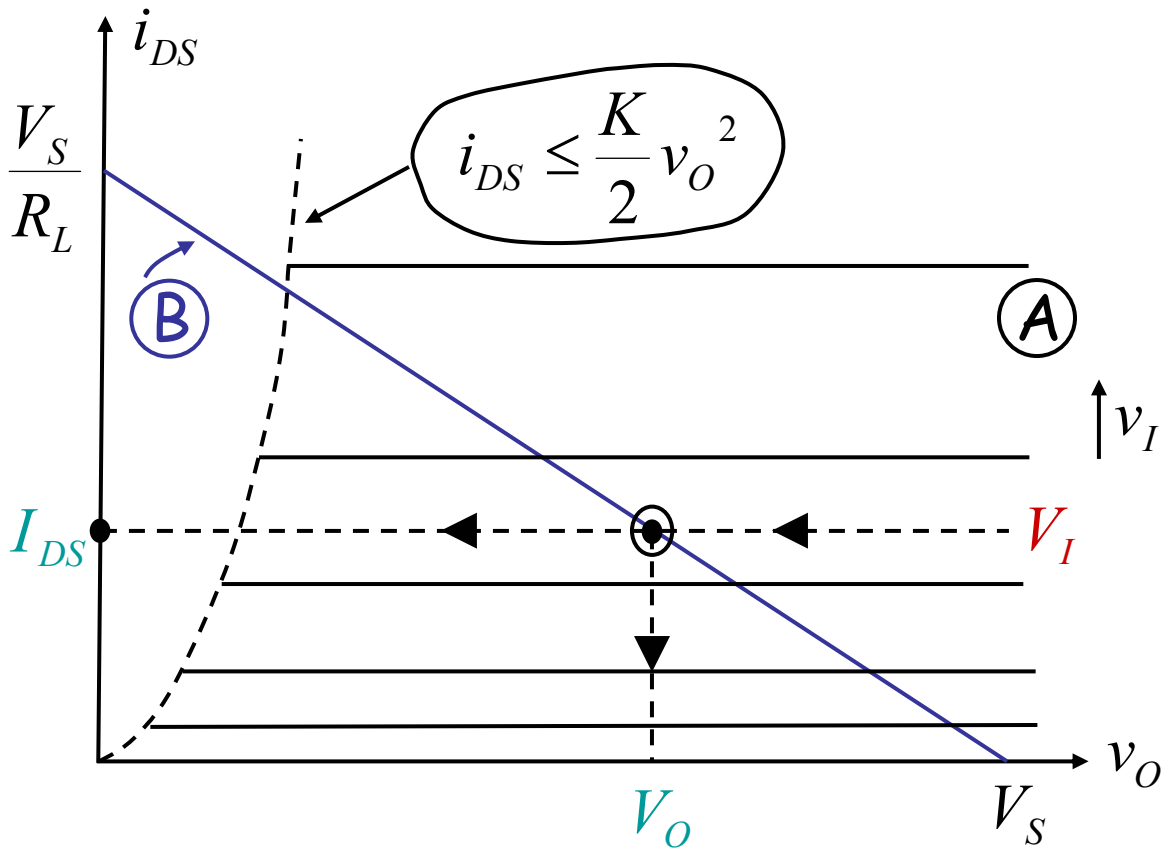
Ⓐ : $i_{DS} = \frac{K}{2}(v_I - V_T)^2$, for $i_{DS} \leq \frac{K}{2}v_O^2$

Ⓑ : $i_{DS} = \frac{V_S}{R_L} - \frac{v_O}{R_L}$



Constraints Ⓐ and Ⓑ must be met

② Graphical method v_O vs v_I



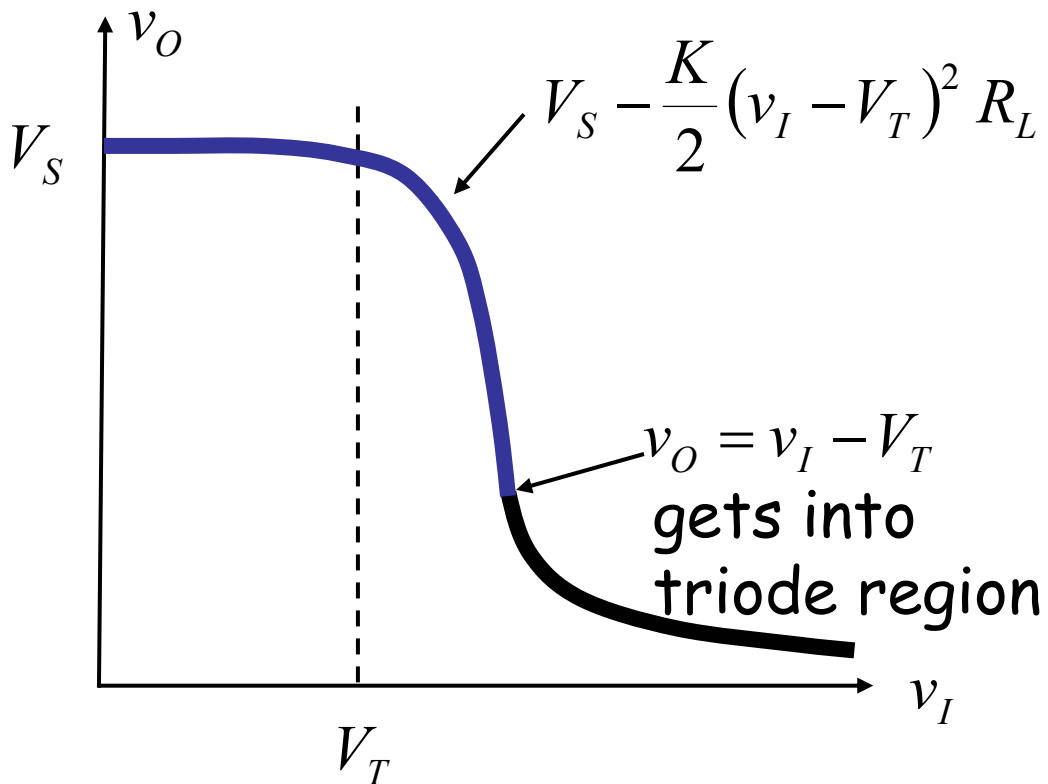
Constraints **(A)** and **(B)** must be met.
Then, given V_I , we can find V_O , I_{DS} .

Large Signal Analysis of Amplifier (under “saturation discipline”)

- ① v_O versus v_I
- ② Valid input operating range and valid output operating range

Large Signal Analysis

① v_O versus v_I

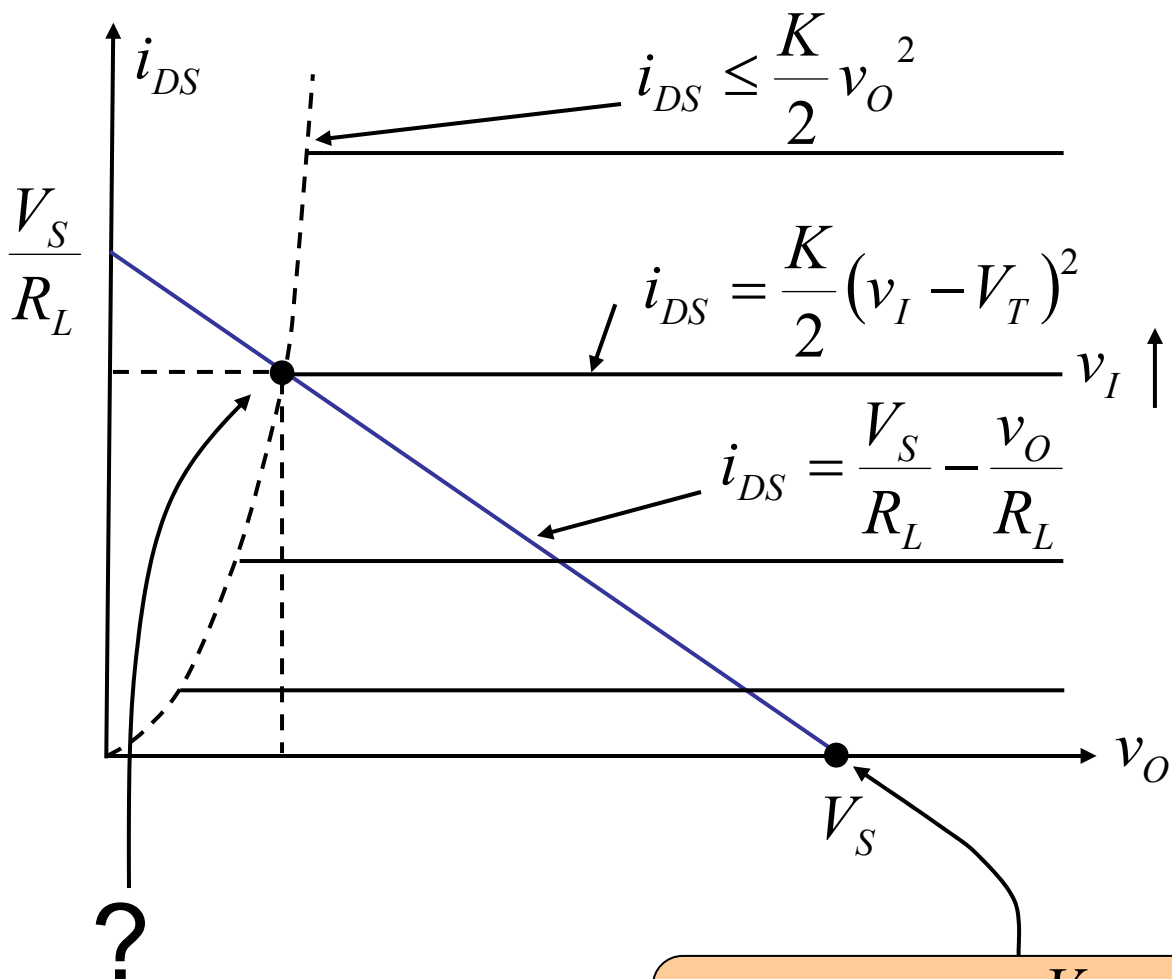


Large Signal Analysis

- ② What are valid operating ranges under the saturation discipline?

Our Constraints

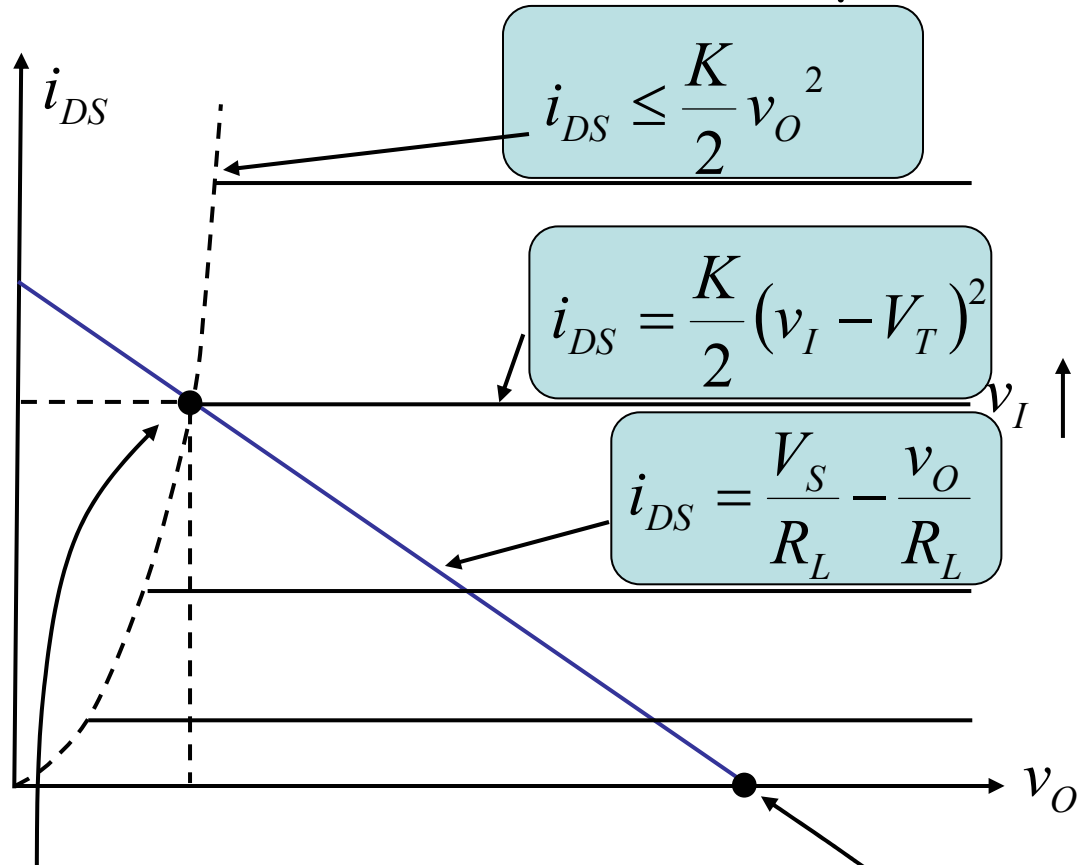
$$\begin{aligned} v_I &\geq V_T \\ v_O &\geq v_I - V_T \end{aligned} \longrightarrow i_{DS} \leq \frac{K}{2} v_O^2$$



$$\begin{aligned} v_I &= V_T \\ v_O &= V_S \text{ and } i_{DS} = 0 \end{aligned}$$

Large Signal Analysis

- ② What are valid operating ranges under the saturation discipline?



$$v_I = V_T + \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$

$$v_O = \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$

$$i_{DS} = \frac{V_S}{R_L} - \frac{v_O}{R_L}$$

$$v_I = V_T$$

$$v_O = V_S \text{ and } i_{DS} = 0$$

Large Signal Analysis Summary

① v_O versus v_I

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

② Valid operating ranges under the saturation discipline?

Valid input range:

$$v_I: V_T \text{ to } V_T + \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$

corresponding output range:

$$v_O: V_S \text{ to } \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$