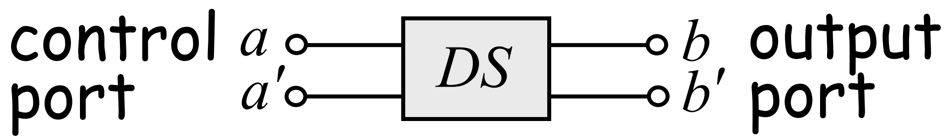
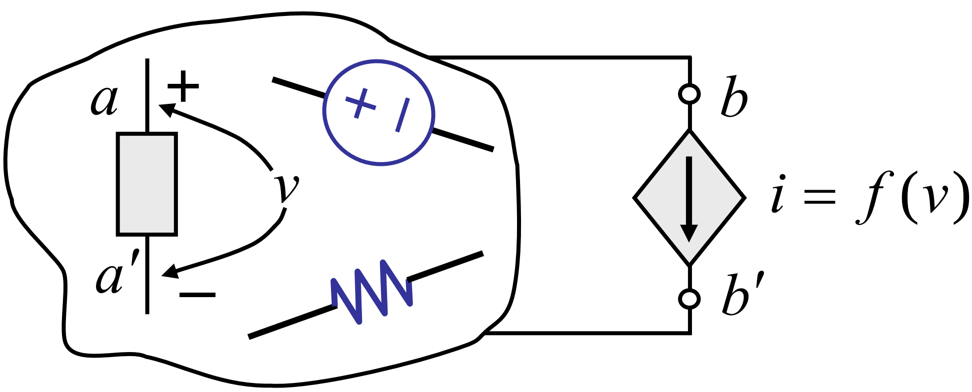
MOSFET Amplifier Large Signal Analysis

Review

- Amp constructed using dependent source



- Dependent source in a circuit

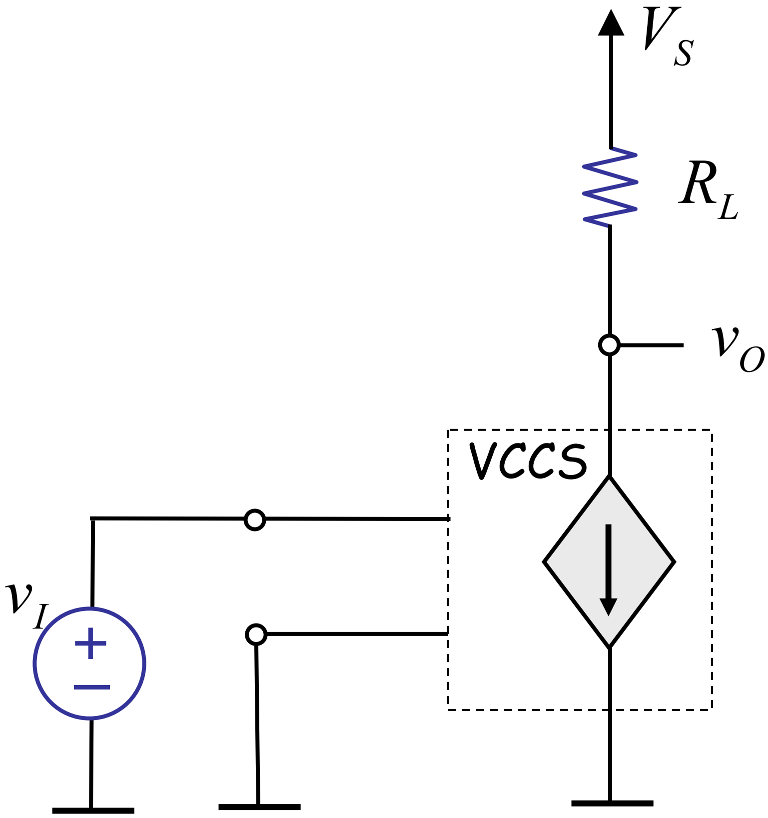


- Superposition with dependent sources:
one way → leave all dependent sources in; solve for one independent source at a time [section 3.5.1 of the text]

- Next, quick review of amp …

Reading: Chapter 7.3-7.7

Amp review



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

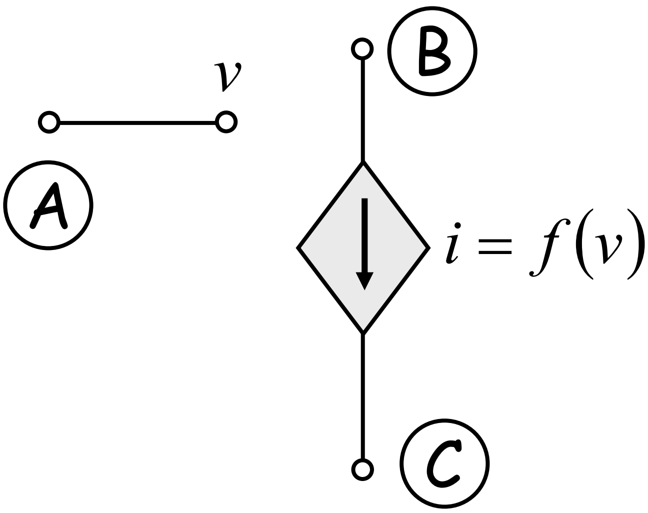
for $v_I \geq 1V$

$= 0$ otherwise

$$v_O = V_S - i_D R_L$$

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

Key device Needed:



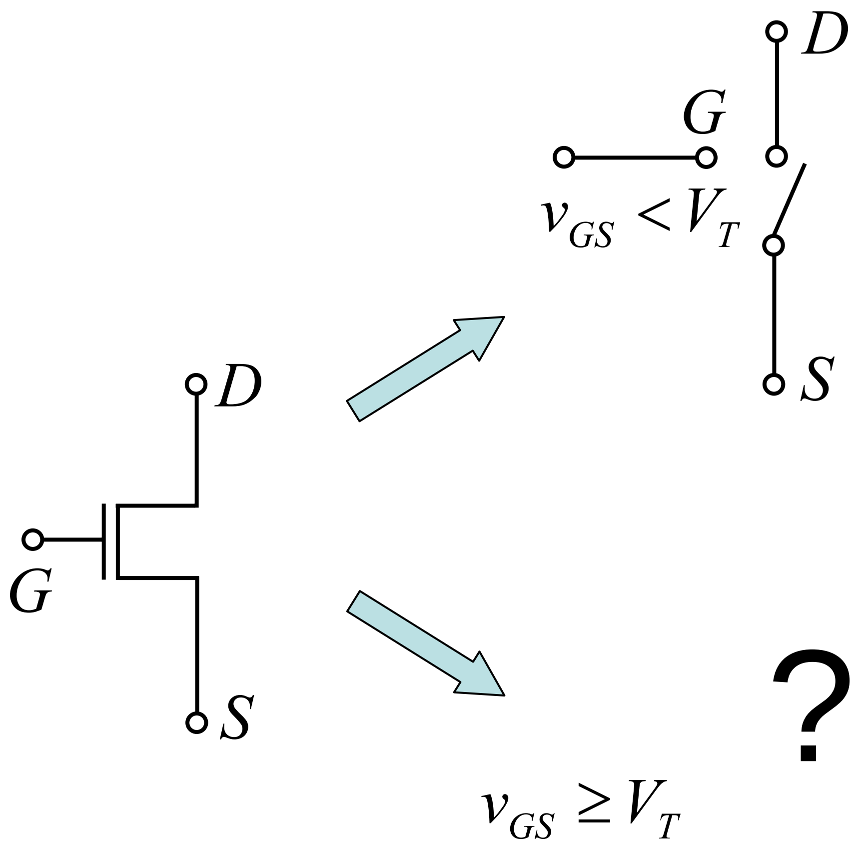
voltage controlled
current source

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

Key device Needed:

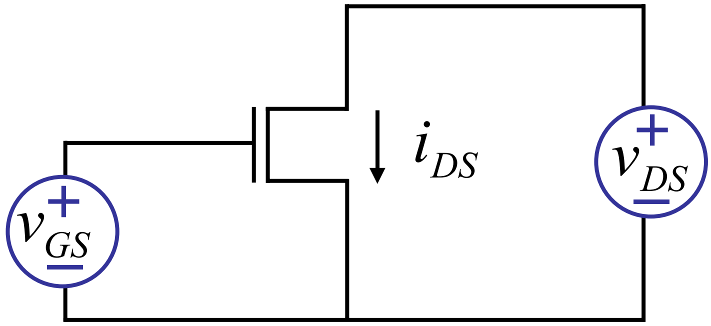
Our old friend, the MOSFET …

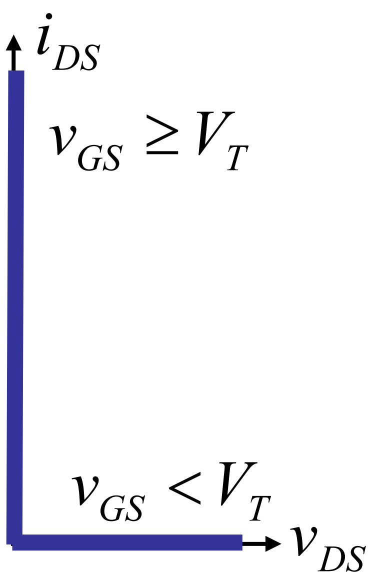
First, we sort of lied. The on-state behavior of the MOSFET is quite a bit more complex than either the ideal switch or the resistor model would have you believe.



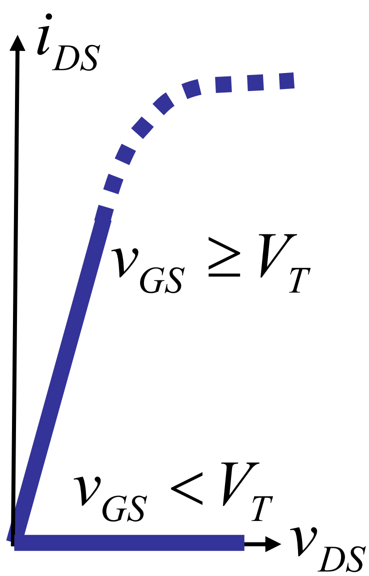
Graphically

Demo

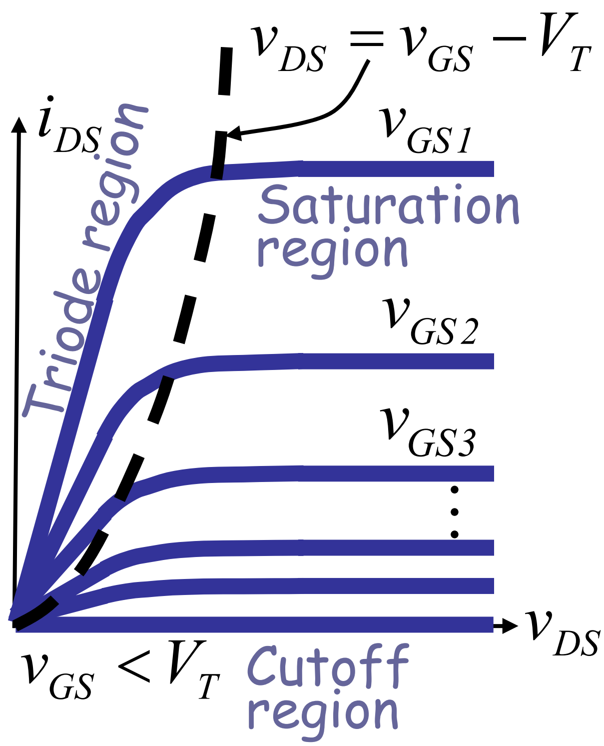




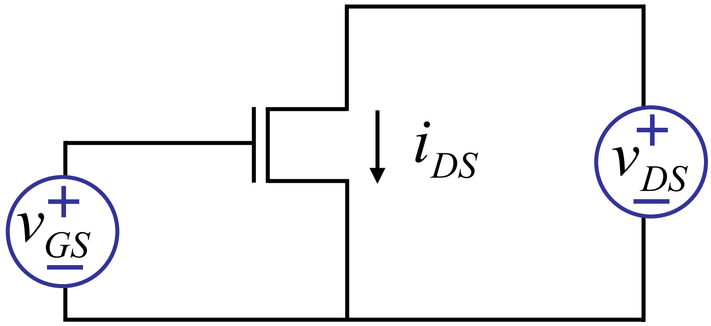
S MODEL

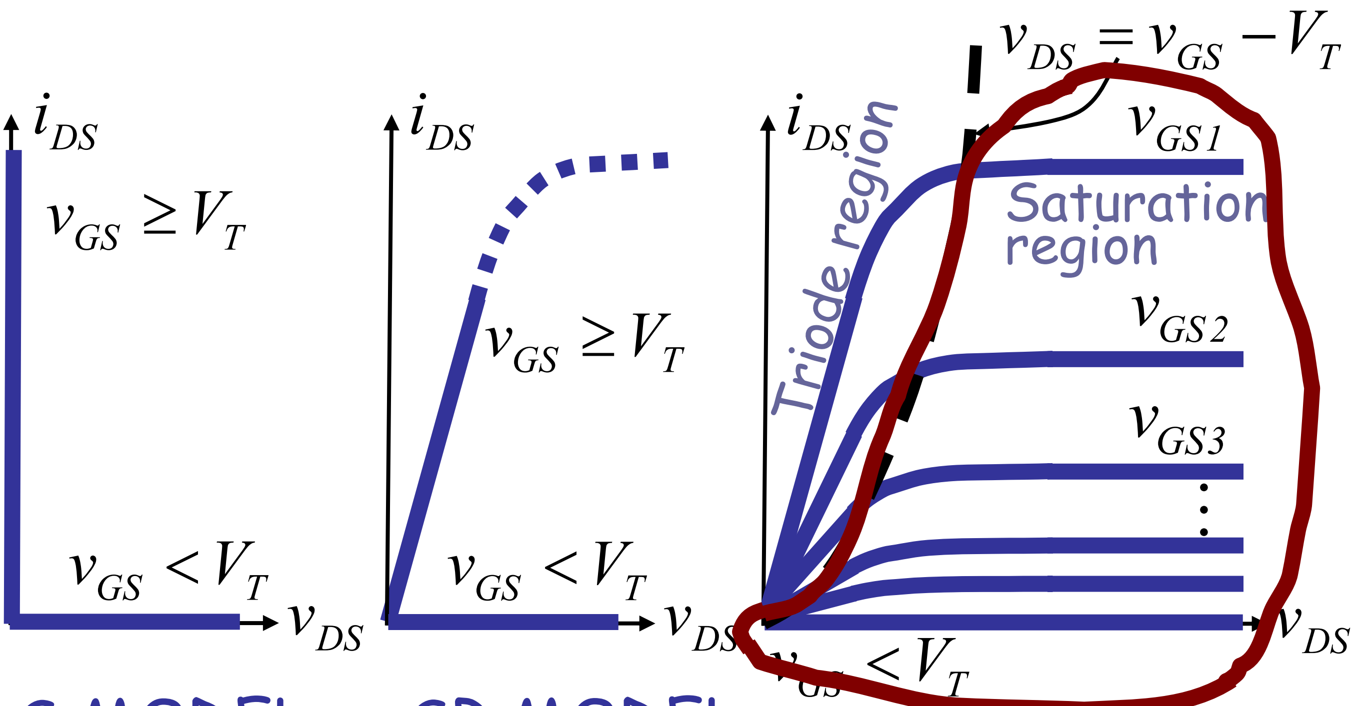


SR MODEL



Graphically





S MODEL   SR MODEL

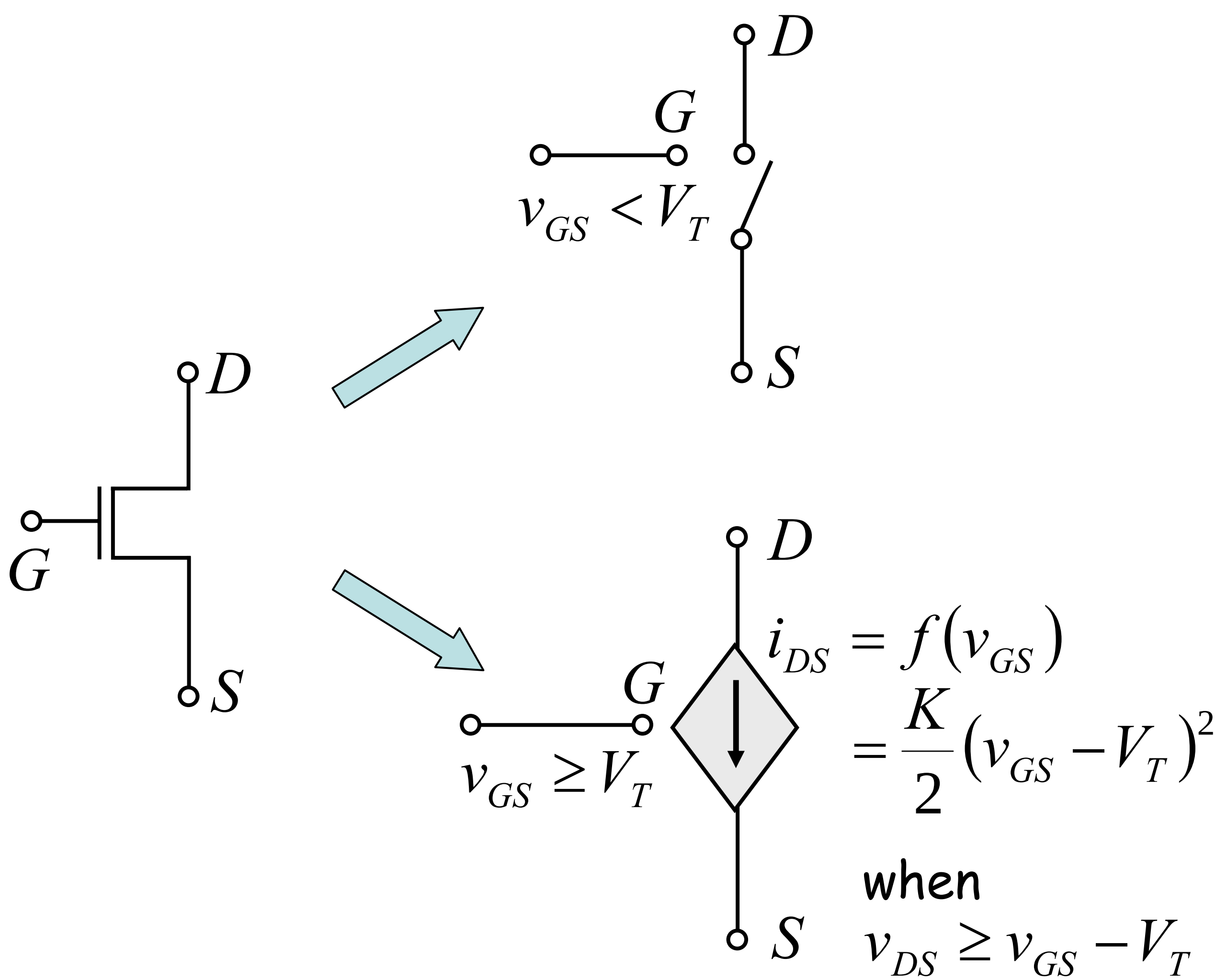
when
$v_{DS} \geq v_{GS} - V_T$

Notice that MOSFET behaves like a current source

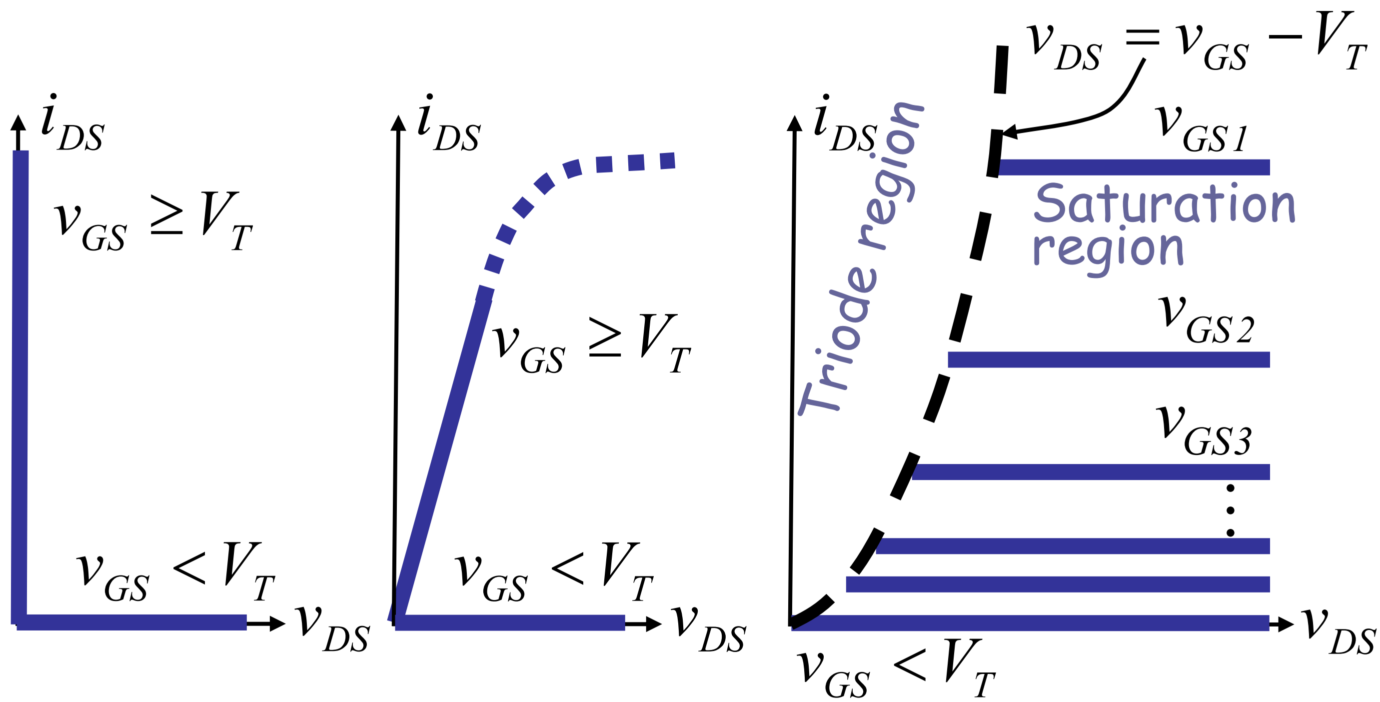
MOSFET SCS Model

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?

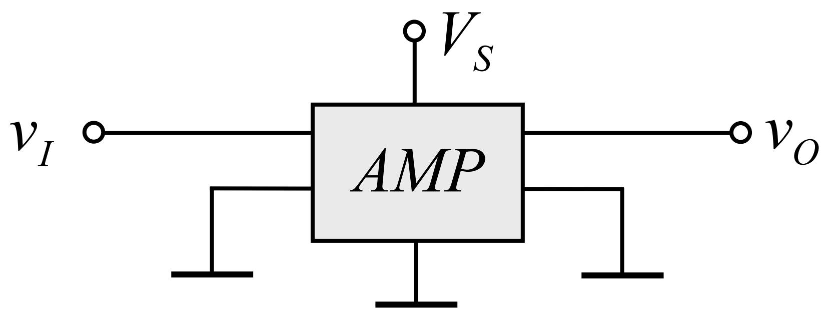
Note: alternatively (in more advanced courses)

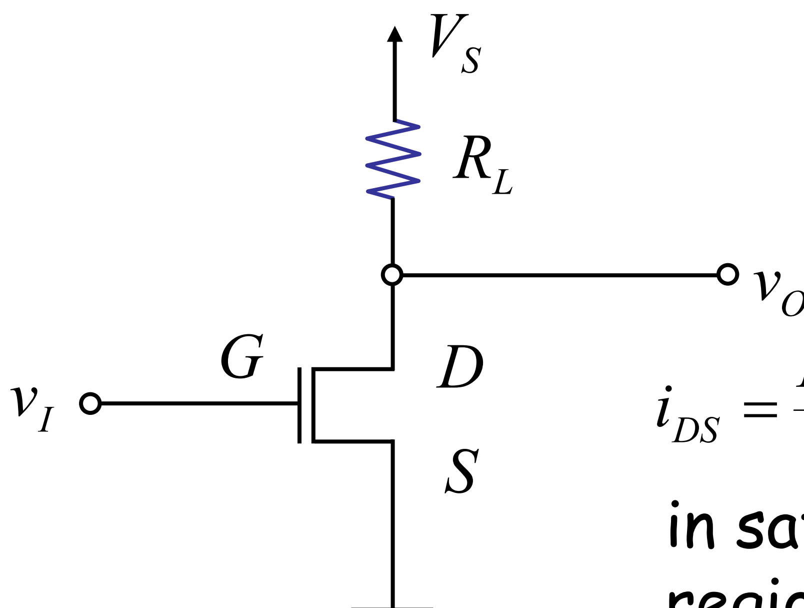
$v_{DS} \geq v_{GS} - V_T$ use SCS model

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

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

Back to Amplifier



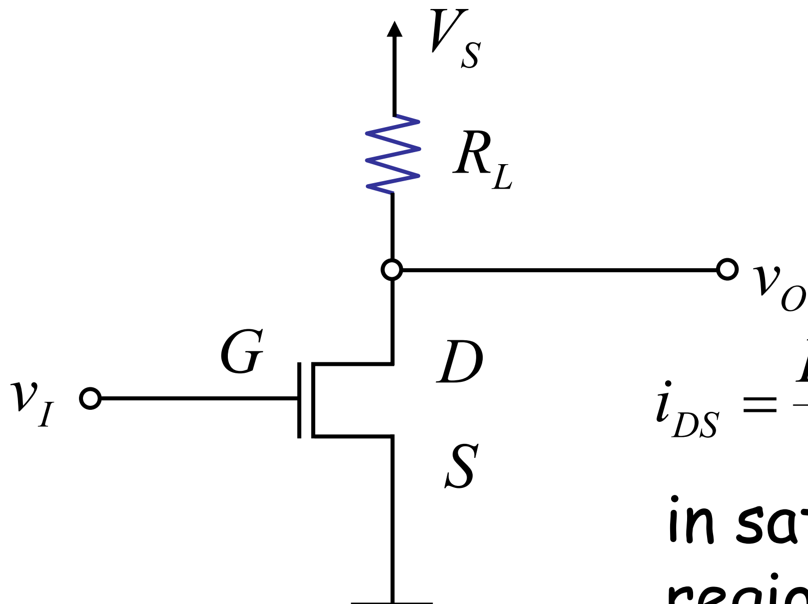


$$i_{DS} = \frac{K}{2}(v_I - V_T)^2$$

in saturation region

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



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

in saturation region

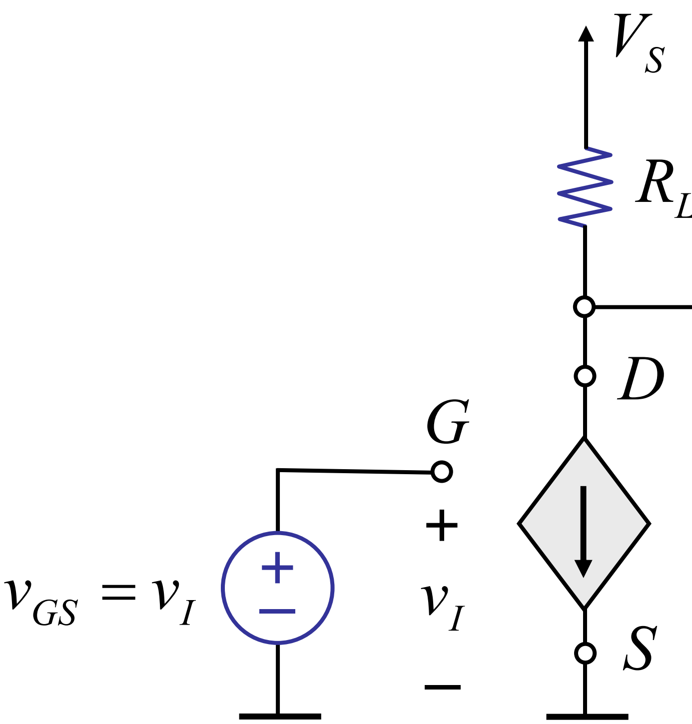
To ensure the MOSFET operates as a VCCS, we must operate it in its saturation region only. We promise to adhere to the "saturation discipline."

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

$v_{GS} \geq V_T$ and $v_{DS} \geq v_{GS} - V_T$, i.e. $v_O \geq v_I - v_T$ at all times.

Let's analyze the circuit

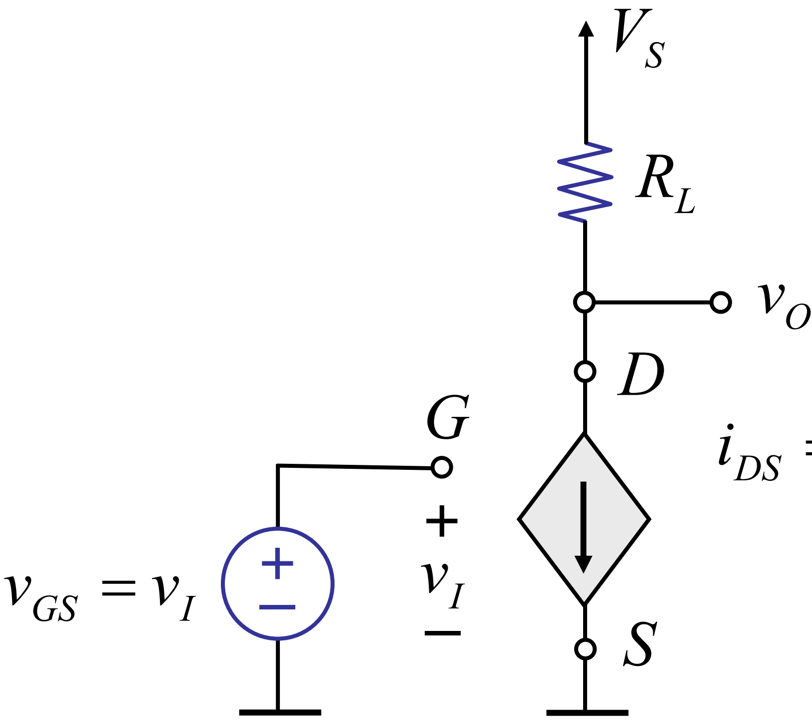
First, replace the MOSFET with its SCS model.



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2 \leftarrow \text{(A)}$$

for $v_O \geq v_I - V_T$

Let's analyze the circuit



$$i_{DS} = \frac{K}{2}(v_I - V_T)^2 \leftarrow \text{(A)}$$

for $v_O \geq v_I - V_T$

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

(1) Analytical method: v_O vs v_I

$$v_O = V_S - i_{DS} R_L \leftarrow \text{(B)}$$

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 Ⓐ : $i_{DS} = \frac{K}{2}\left(v_I - V_T\right)^2$,

for $v_O \geq v_I - V_T$

$$\Downarrow$$

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

$$\Downarrow$$

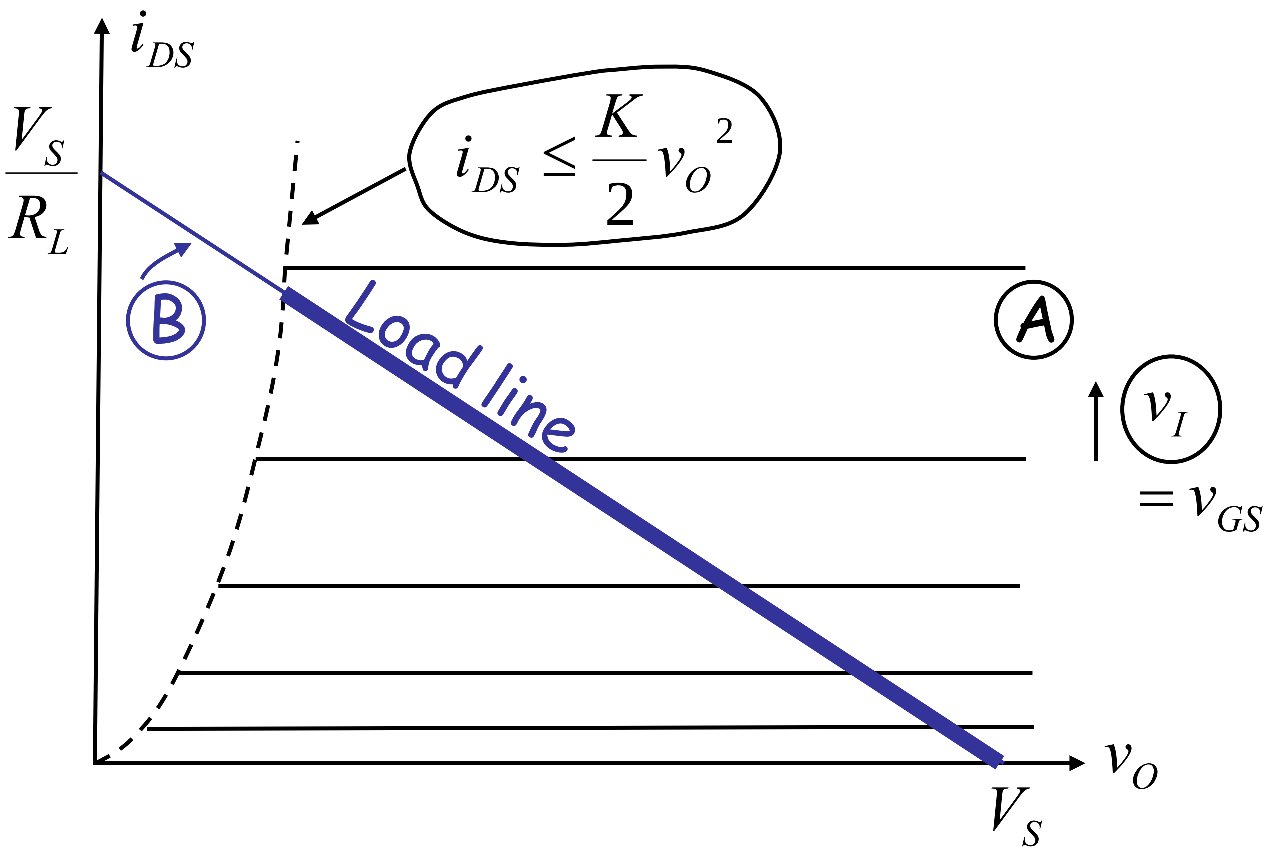
$$i_{DS} \leq \frac{K}{2} {v_O}^2$$

Ⓑ : $i_{DS} = \frac{V_S}{R_L} - \frac{v_0}{R_L}$

② Graphical method v_O vs v_I

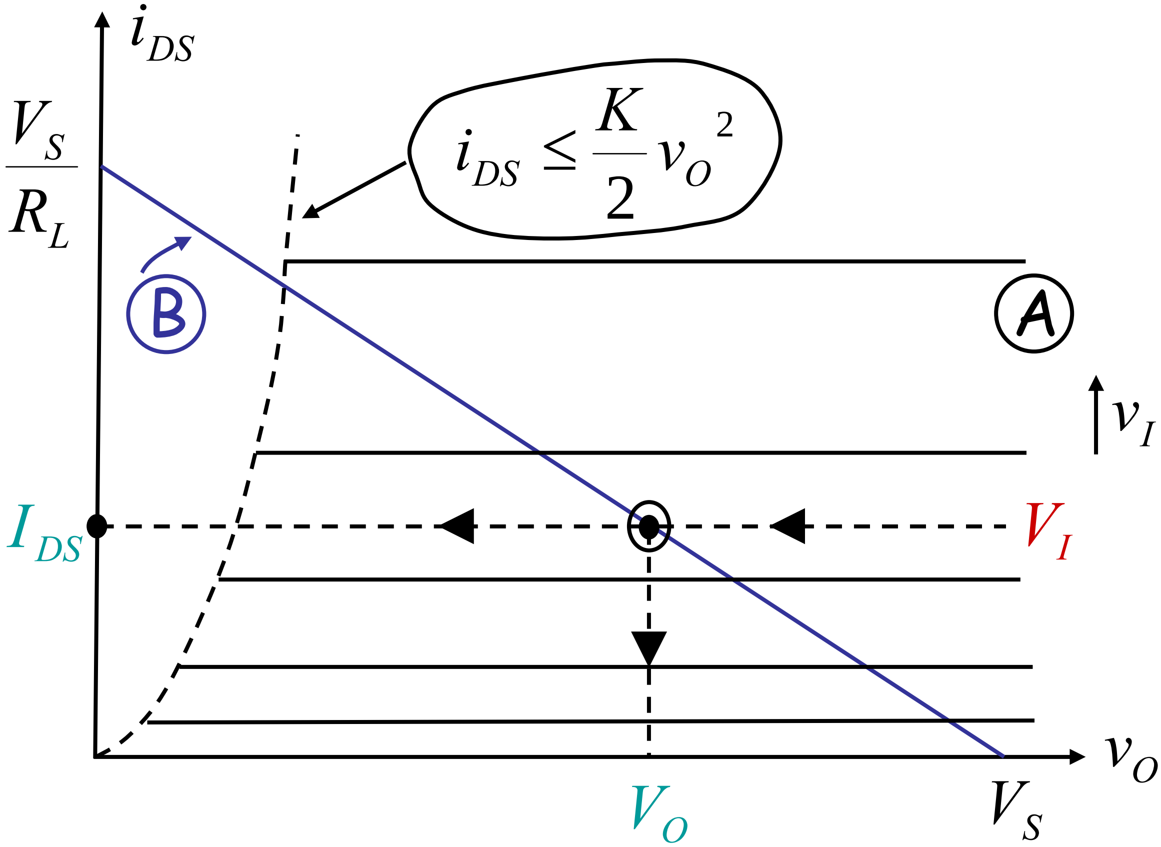
Ⓐ : $i_{DS} = \frac{K}{2}(v_I - V_T)^2$, for $i_{DS} \leq \frac{K}{2} v_O{}^2$

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



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} .

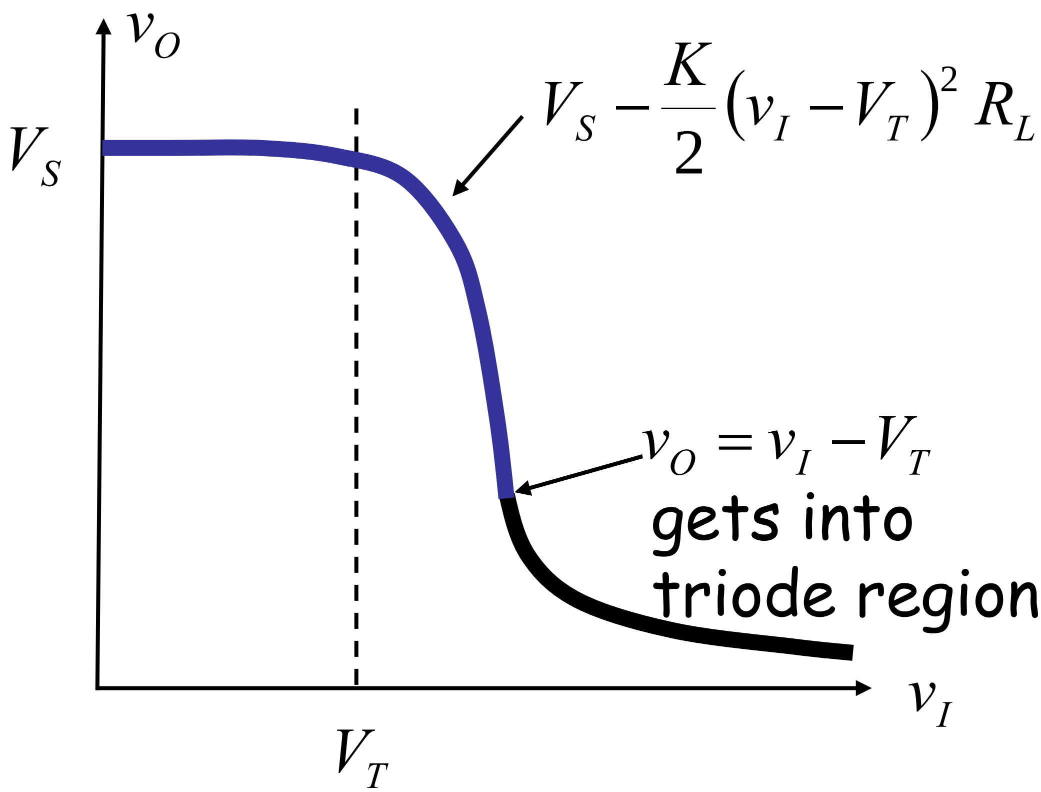
Large Signal Analysis of Amplifier (under “saturation discipline”)

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



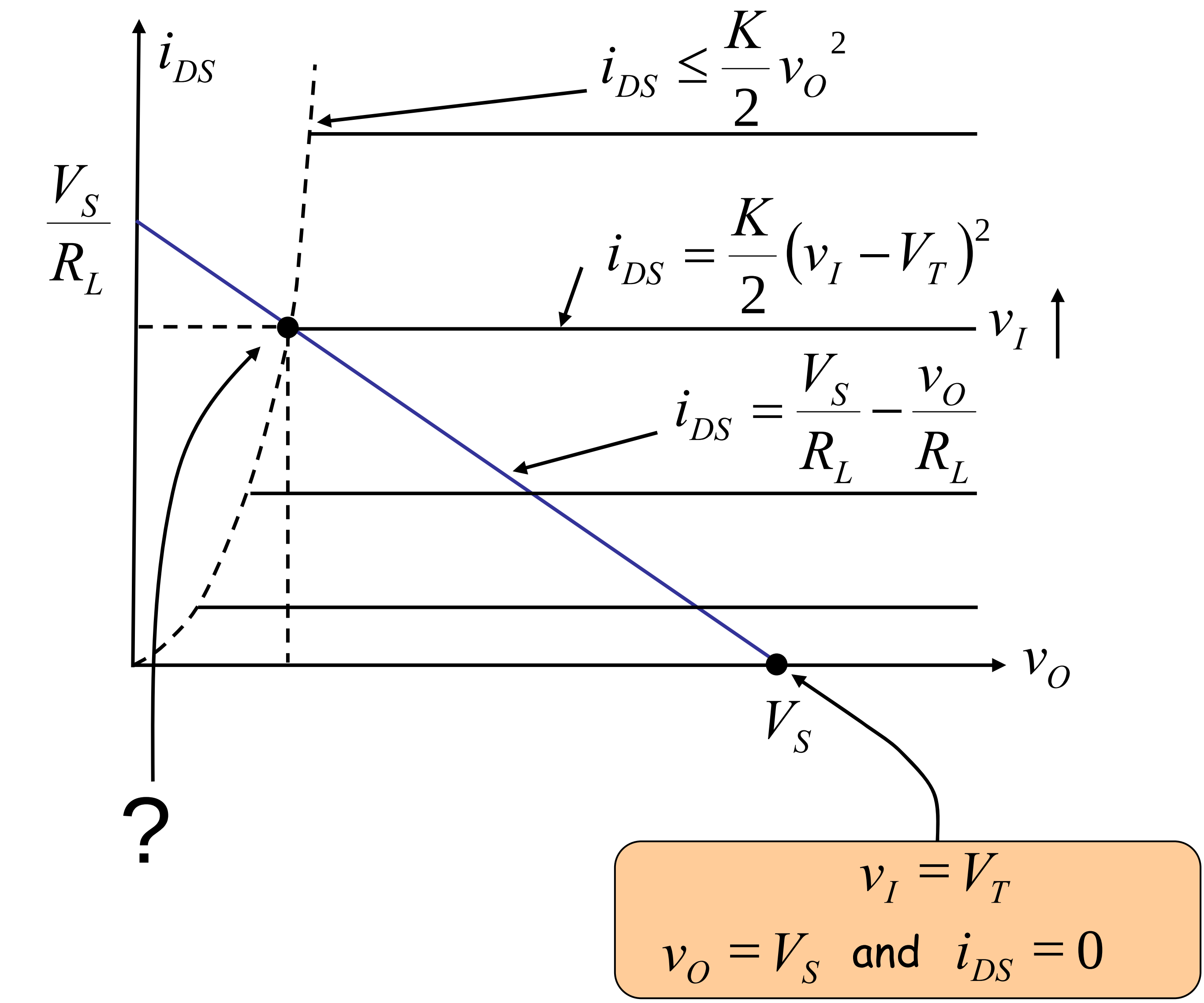
Large Signal Analysis

② What are valid operating ranges under the saturation discipline?

Our Constraints

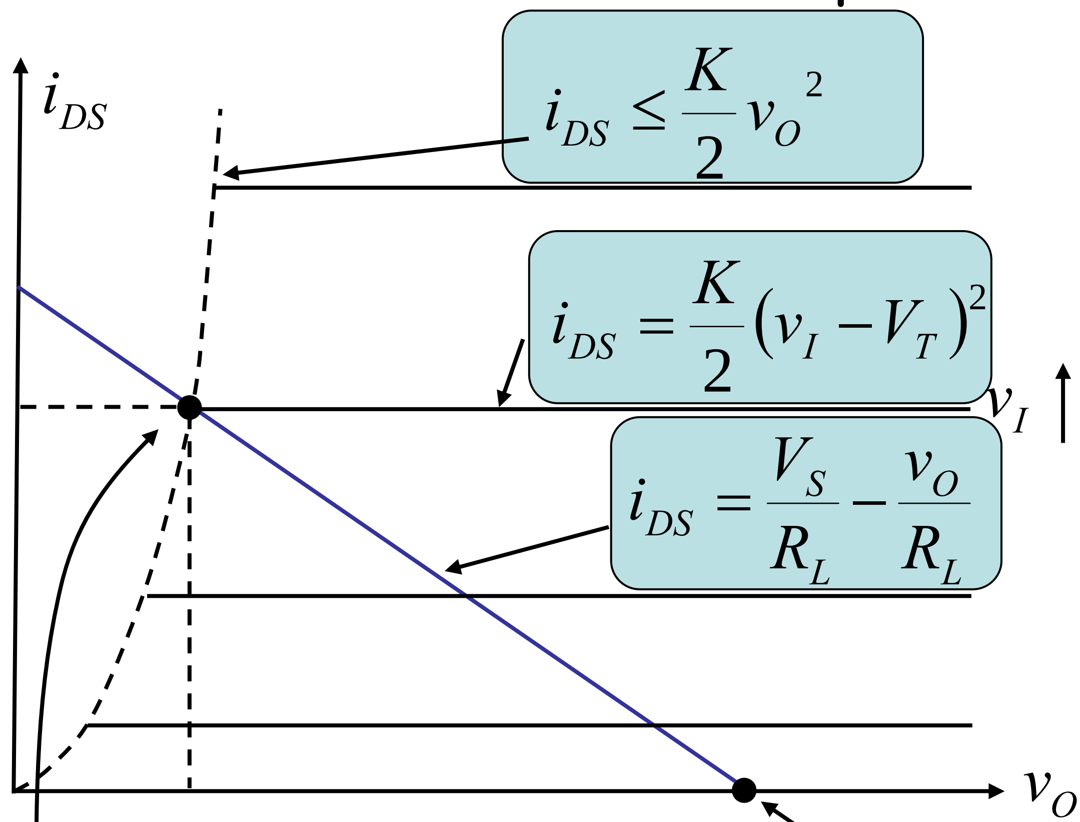
$v_I \geq V_T$

$v_O \geq v_I - V_T$ → $i_{DS} \leq \frac{K}{2} v_O^{\ 2}$



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:

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

corresponding output range:

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