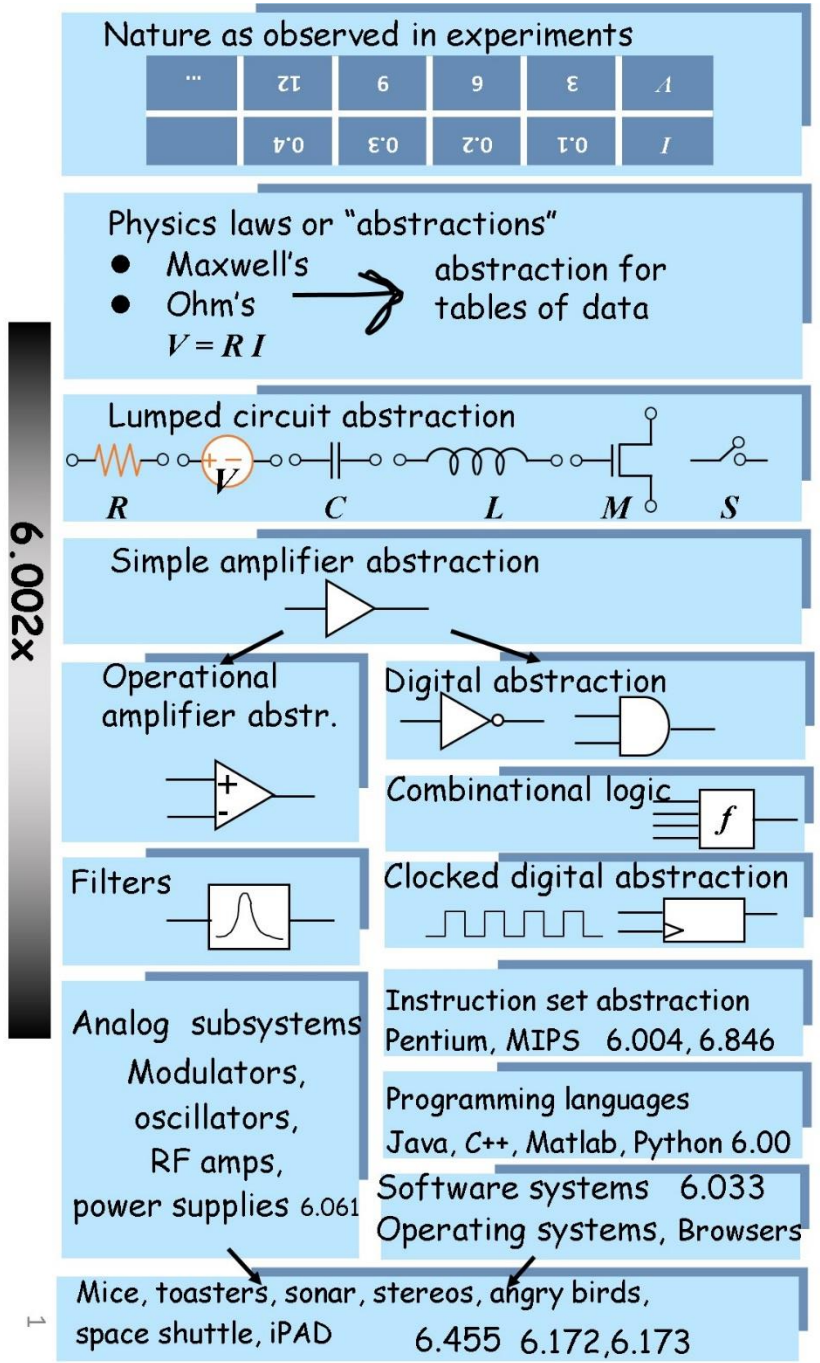
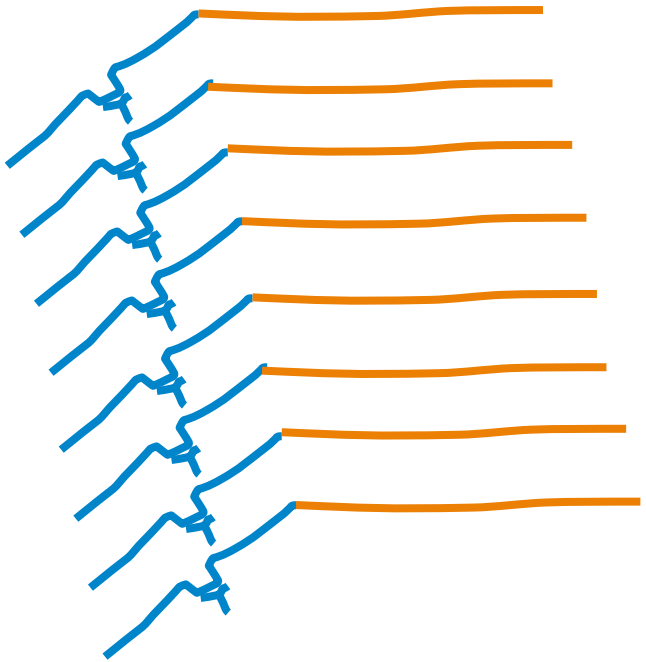

Nature as observed in experiments
V 3 6 9 12 ...
I 0.1 0.2 0.3 0.4
Physics laws or "abstractions"
Maxwell's
Ohm's
V = R I
abstraction for tables of data
Lumped circuit abstraction
R C L M S
Simple amplifier abstraction
Operational amplifier abstr.
Digital abstraction
Combinational logic
f
Filters
Clocked digital abstraction
Analog subsystems
Modulators, oscillators, RF amps, power supplies 6.061
Instruction set abstraction
Pentium, MIPS 6.004, 6.846
Programming languages
Java, C++, Matlab, Python 6.00
Software systems 6.033
Operating systems, Browsers
Mice, toasters, sonar, stereos, angry birds, space shuttle, iPAD
6.455 6.172,6.173
6.002x

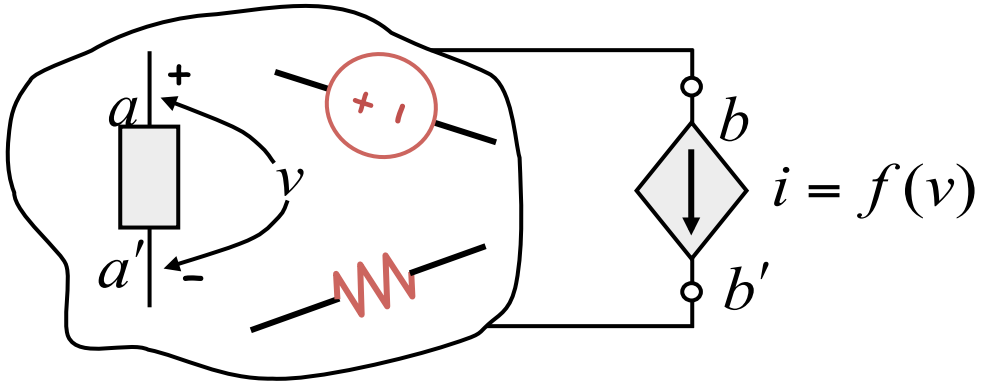
6.002x CIRCUITS AND ELECTRONICS

MOSFET SCS Model
MOSFET Amplifier



Review

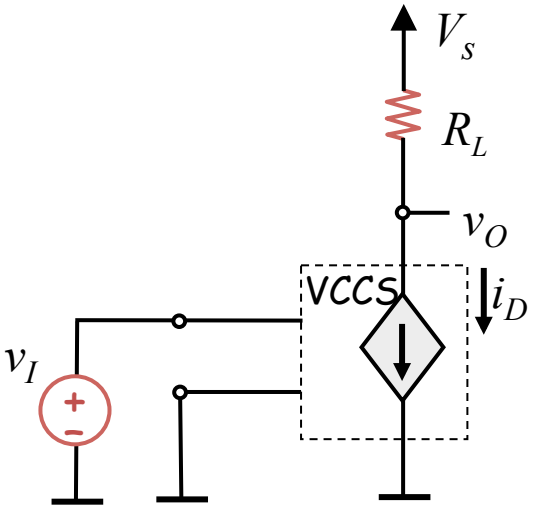
- Dependent source in a circuit



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

Review

Next, quick review of amp. **Reading:** Chapter 7.3-7.7



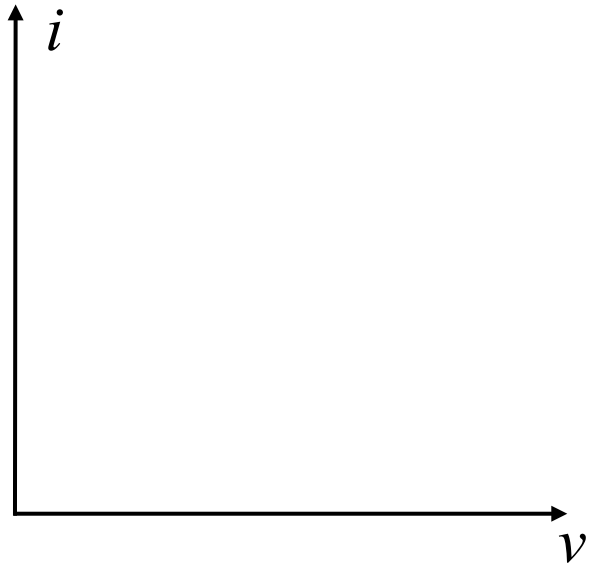
$$i_D = \frac{K}{2}(v_I - 1)^2 \quad for \quad v_I \geq 1V$$

$$= 0 \quad \text{otherwise}$$

$$v_O = V_S - i_D R_L$$

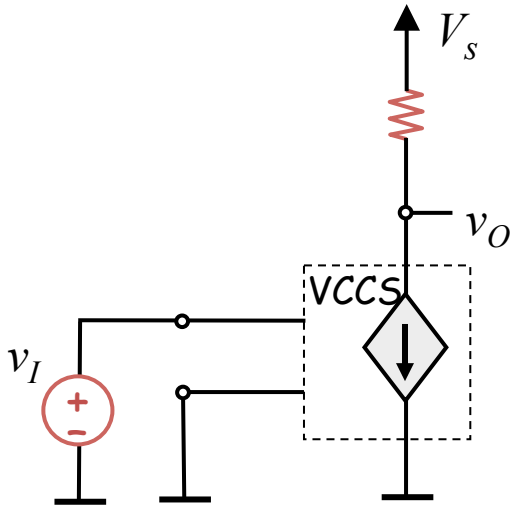
$$\frac{K}{2}(v_I - 1)^2$$

The i-v relation for a current source

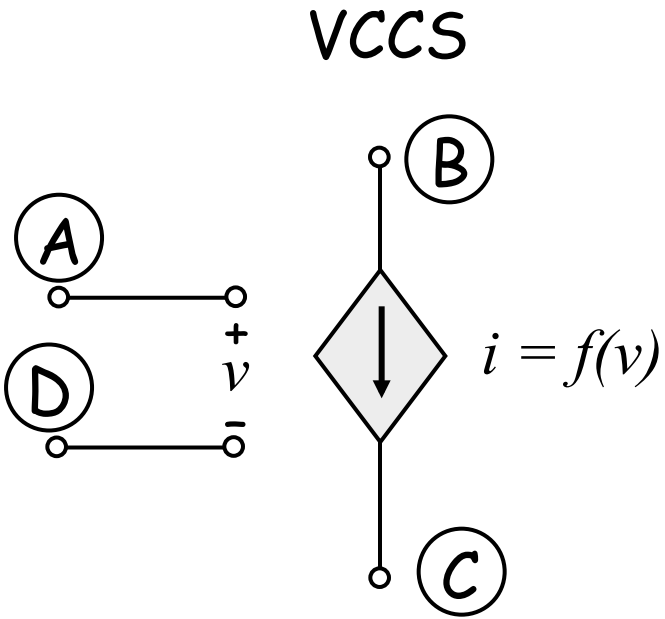


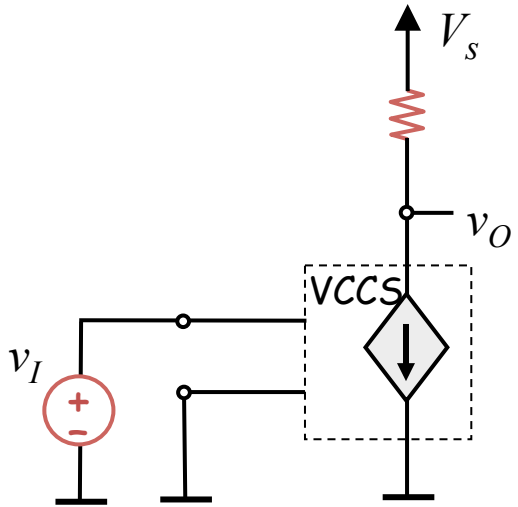
Hold the thought

Key device Needed



Key device Needed



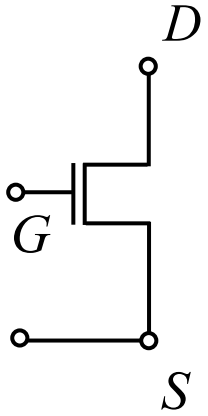


Let's look at our old friend, the MOSFET …

Our old friend, the MOSFET

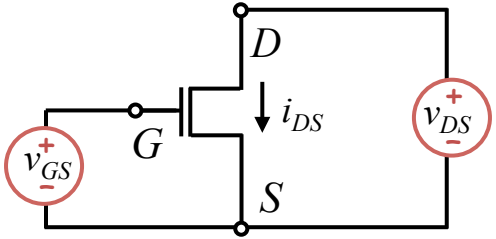
First, we sort of lied. The on-state behavior of the MOSFET is quite a bit more complex than either the ideal switch or the resistor model would have you believe.

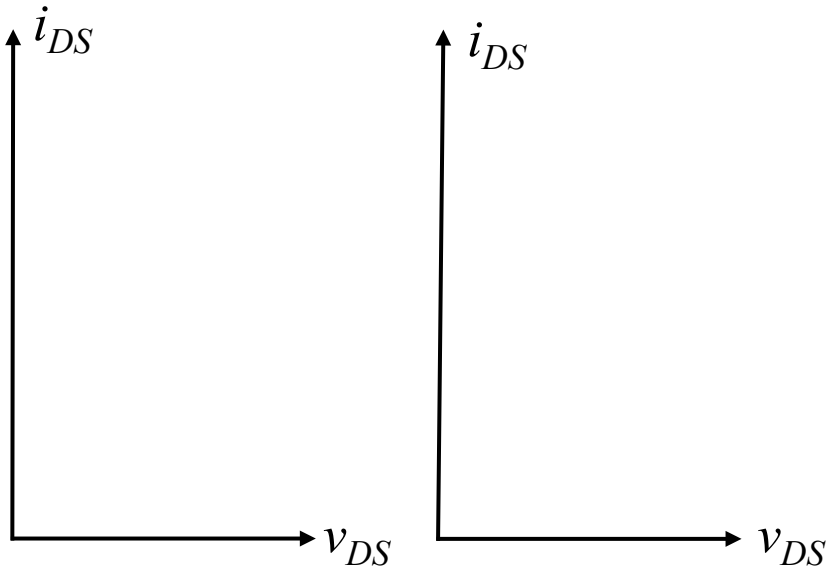
Let's Look at the MOSFET Behavior Graphically



Graphically

Demo

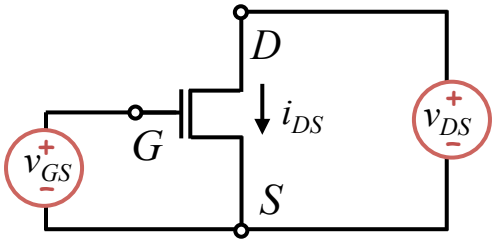


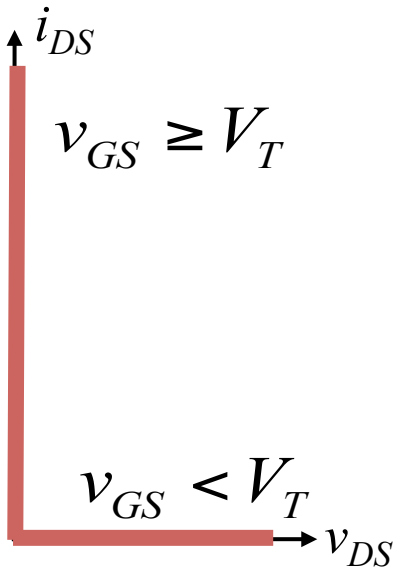


S MODEL SR MODEL

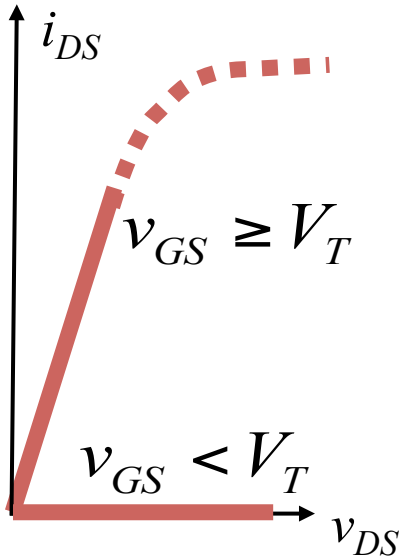
Graphically

Demo





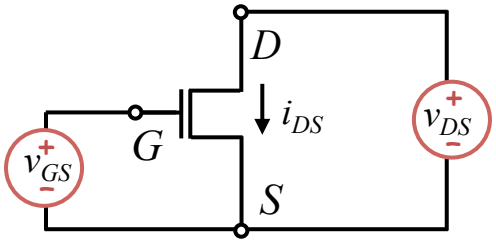
S MODEL

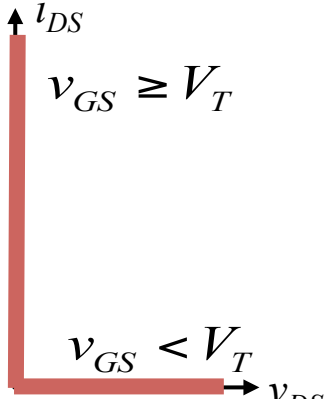


SR MODEL

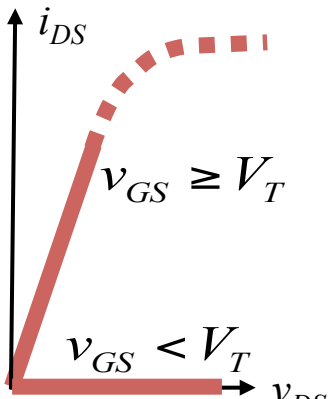


Graphically

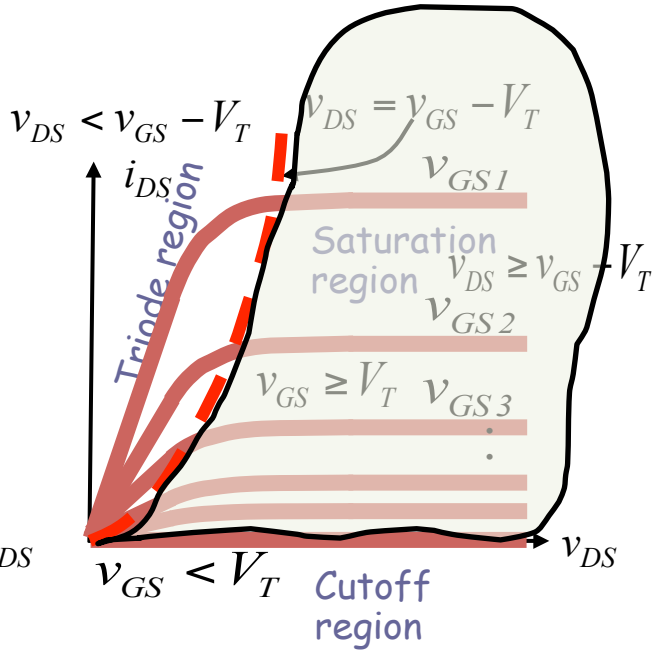




S MODEL



SR MODEL

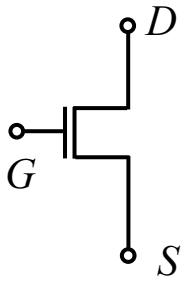


when
$v_{DS} \geq v_{GS} - V_T$

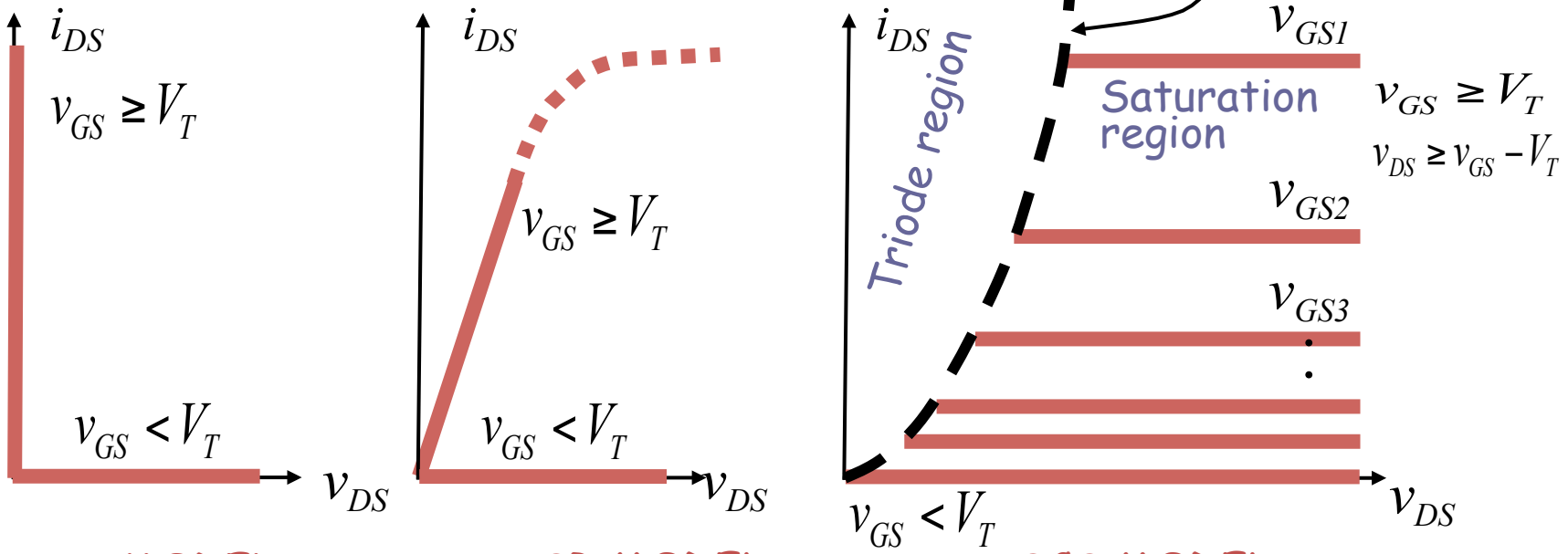
Notice that MOSFET behaves like a current source

MOSFET SCS Model

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



When to use which model



S MODEL

for fun!

SR MODEL

for digital designs

SCS MODEL

for analog designs

When to use each model in 6.002?

In More Advanced Courses…

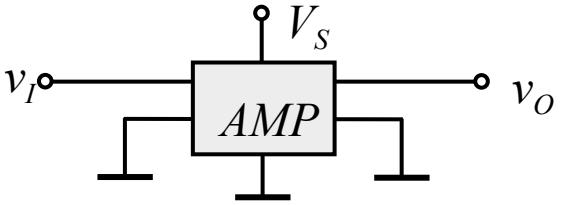
Note: alternatively (in more advanced courses)

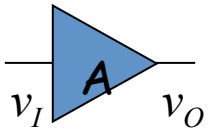
$v_{DS} \geq v_{GS} - V_T$ use SCS model

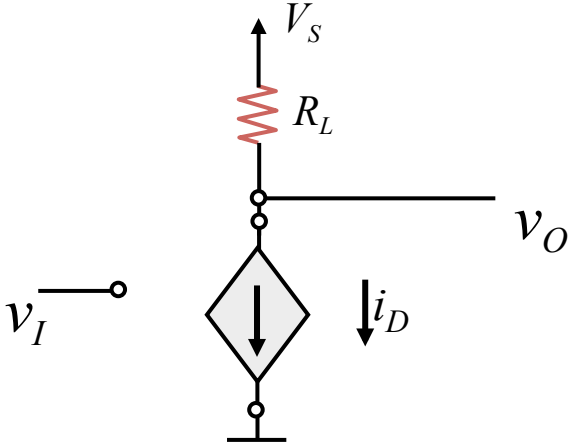
$v_{DS} < v_{GS} - V_T$ use SR model

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

Back to Amplifier





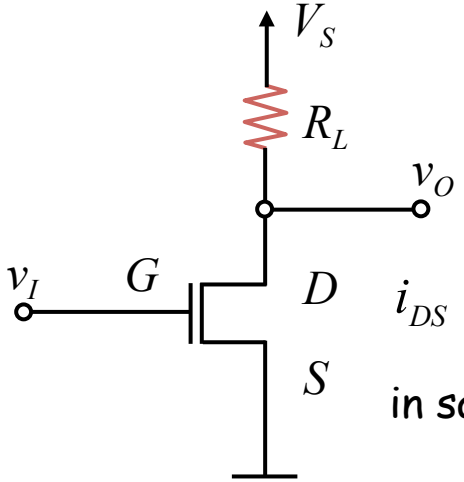


$$i_D = \frac{K}{2}(v_I - 1)^2$$

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

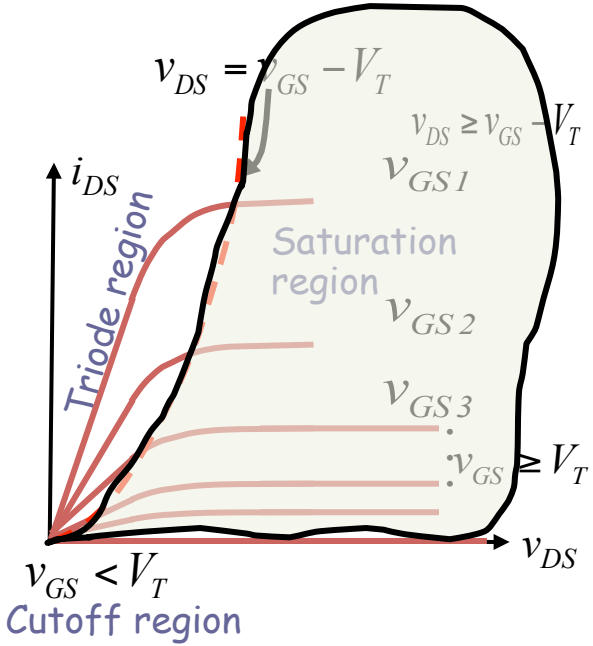
"saturation discipline"

MOSFET Amplifier



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

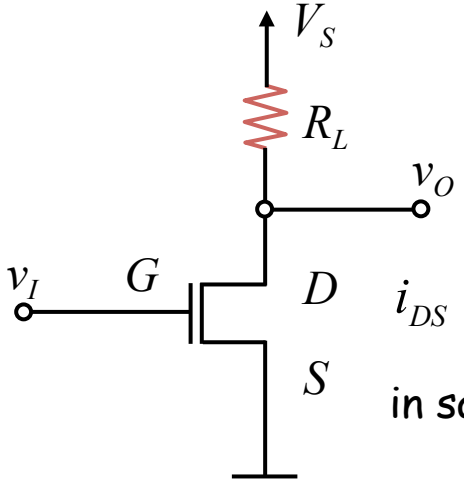
in saturation region



"Saturation discipline"

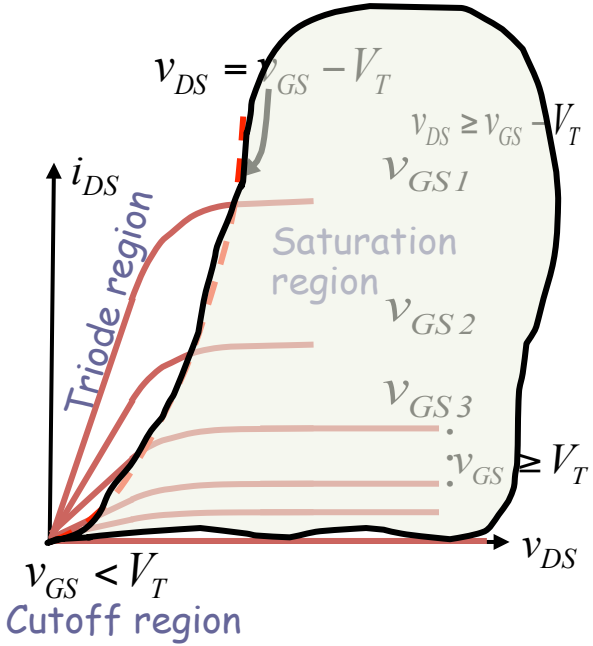
In other words, we will operate the amp circuit such that:

MOSFET Amplifier



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

in saturation region

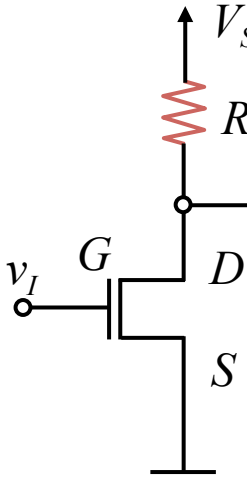


"Saturation discipline"

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

Let's analyze the circuit

First, replace the MOSFET with its SCS model



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

in saturation region

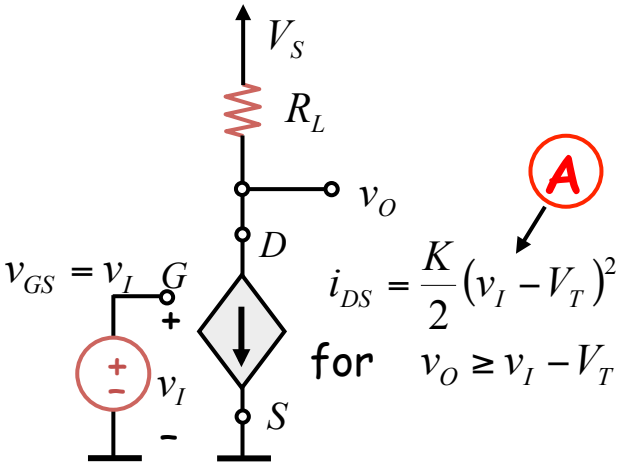
Two methods:

1. Analytical
2. Graphical

Let's analyze the circuit

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

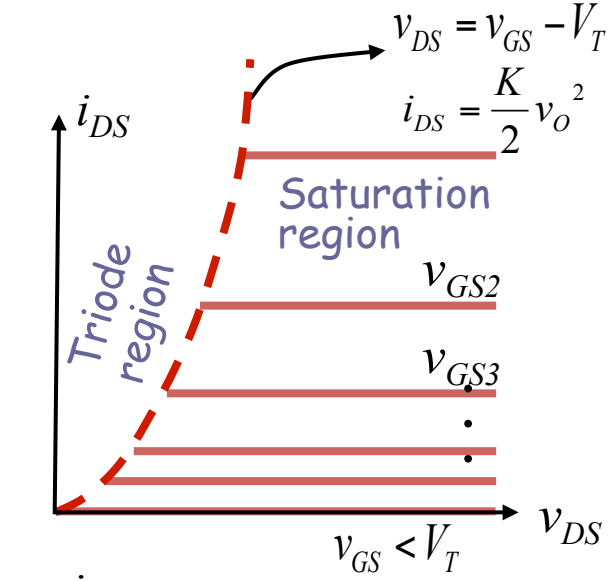
1 Analytical method: v_O vs v_I

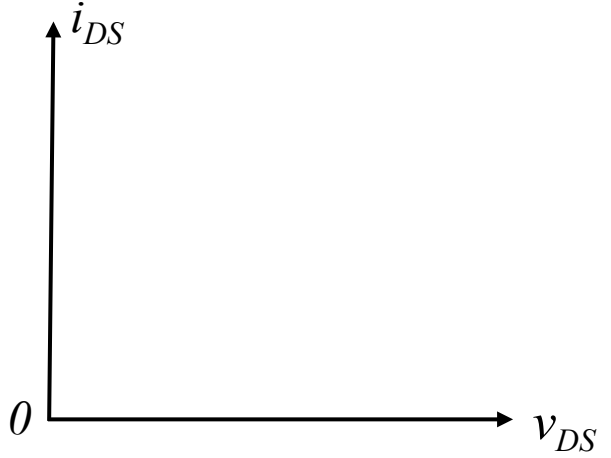


② Graphical method

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

From (B) : $v_O = V_S - i_{DS}R_L$



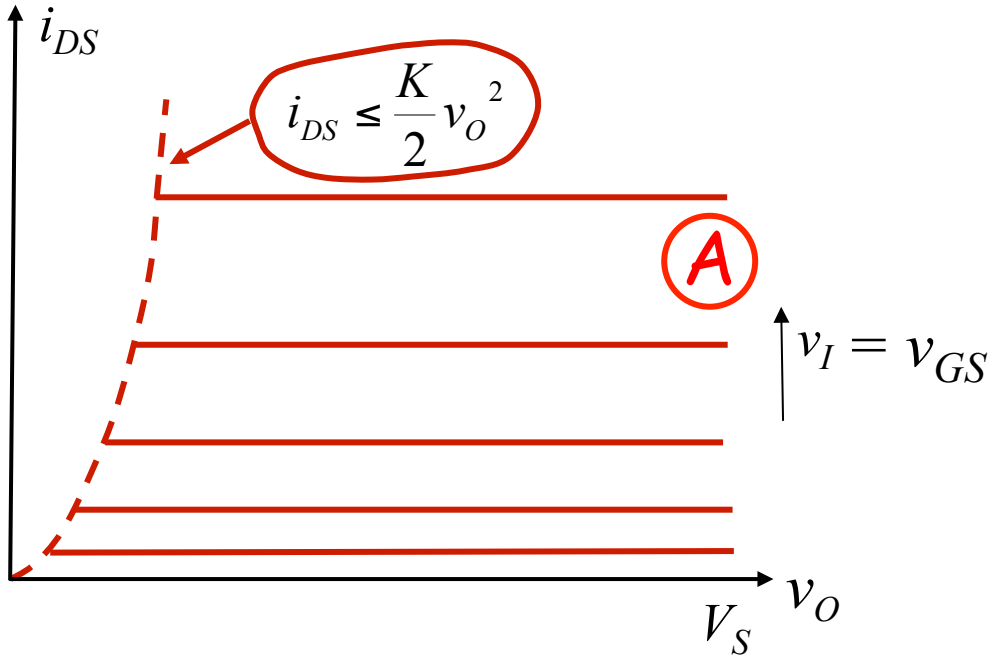


② Graphical method v_O vs v_I

Remember, superimpose "loadline due to rest of circuit (B)" over device relation (A)

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

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

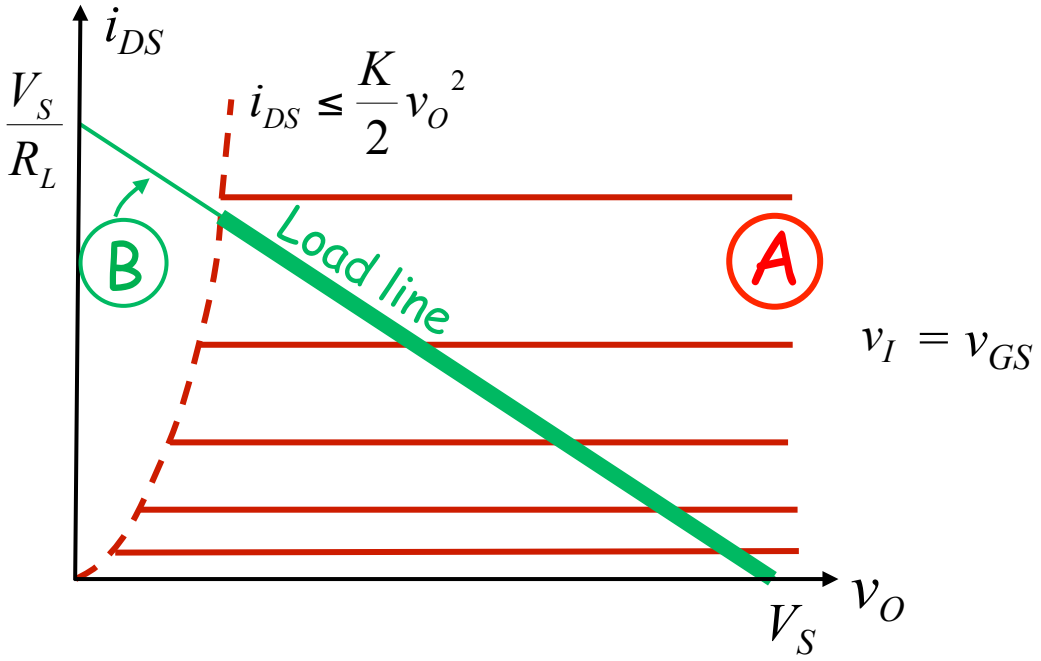


Constraints (A) and (B) must be met

② Graphical method v_O vs v_I

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

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



Constraints Ⓐ and Ⓑ 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

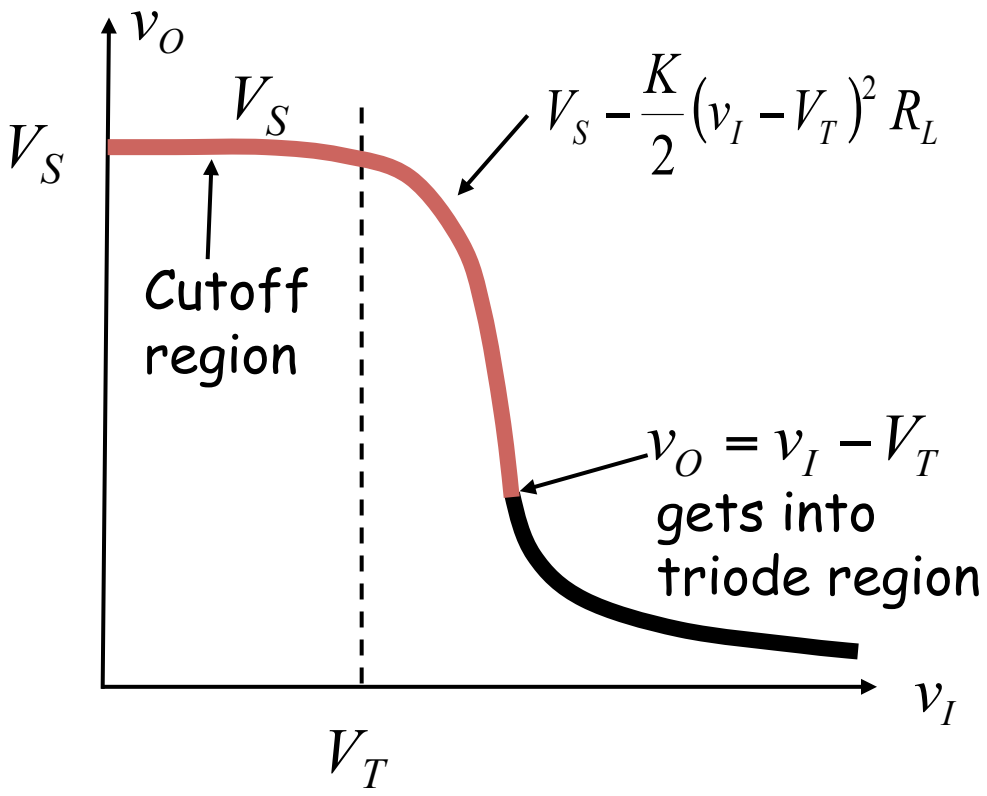
② Valid input operating range and valid output operating range (to guarantee saturation region operation)

Large Signal Analysis



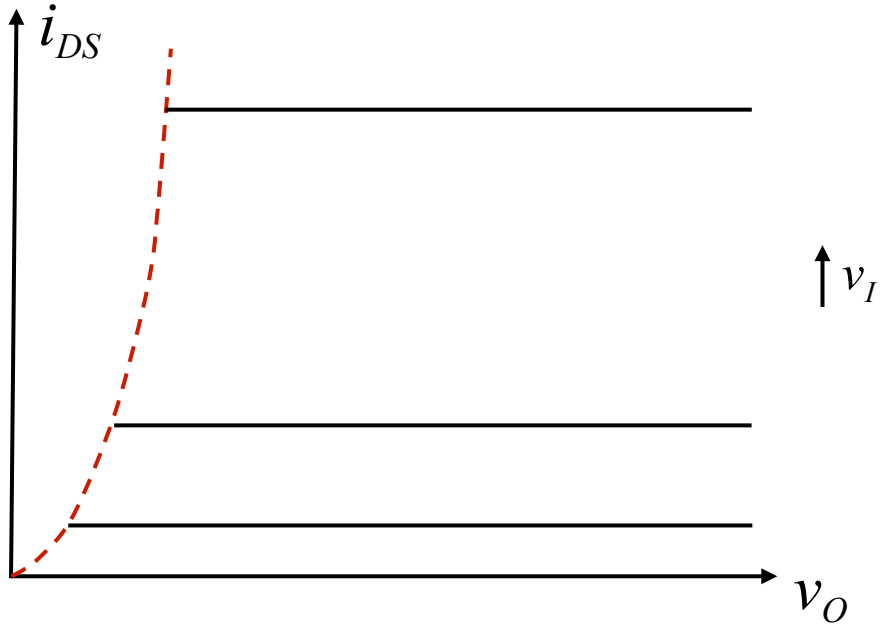
① v_O versus v_I

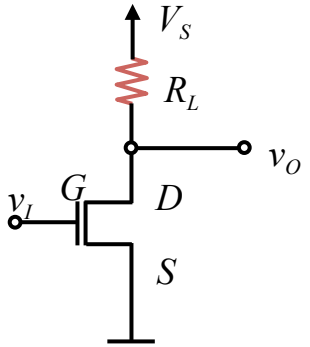
A Curious Aside



Large Signal Analysis

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

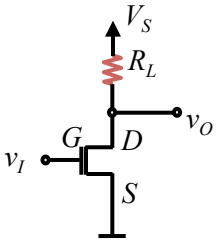


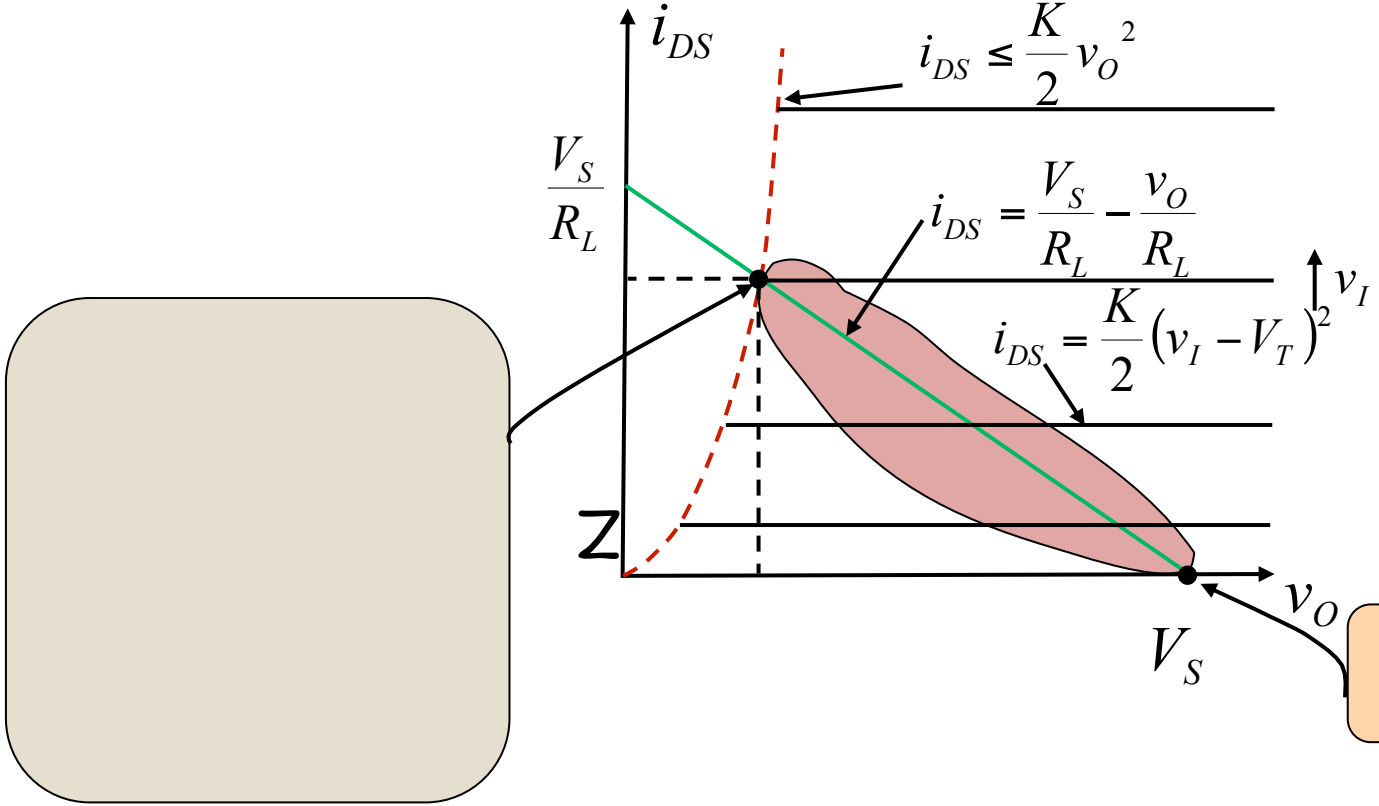


Our Constraints

Large Signal Analysis

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





Our Constraints

$v_I \ge V_T$

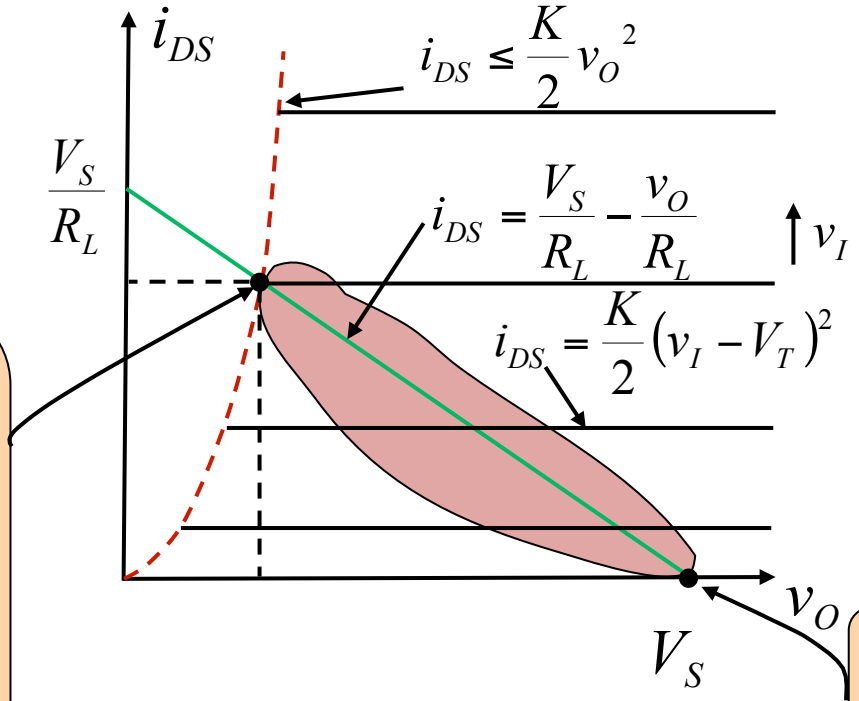
$v_O \ge v_I - V_T$

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

$v_I = V_T$
$v_O = V_S$ and $i_{DS} = 0$

Large Signal Analysis

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



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

Our Constraints

$$v_I \ge V_T$$

$$v_O \ge v_I - V_T$$

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

$v_I = V_T$
$v_O = V_S$ and $i_{DS} = 0$

Large Signal Analysis Summary

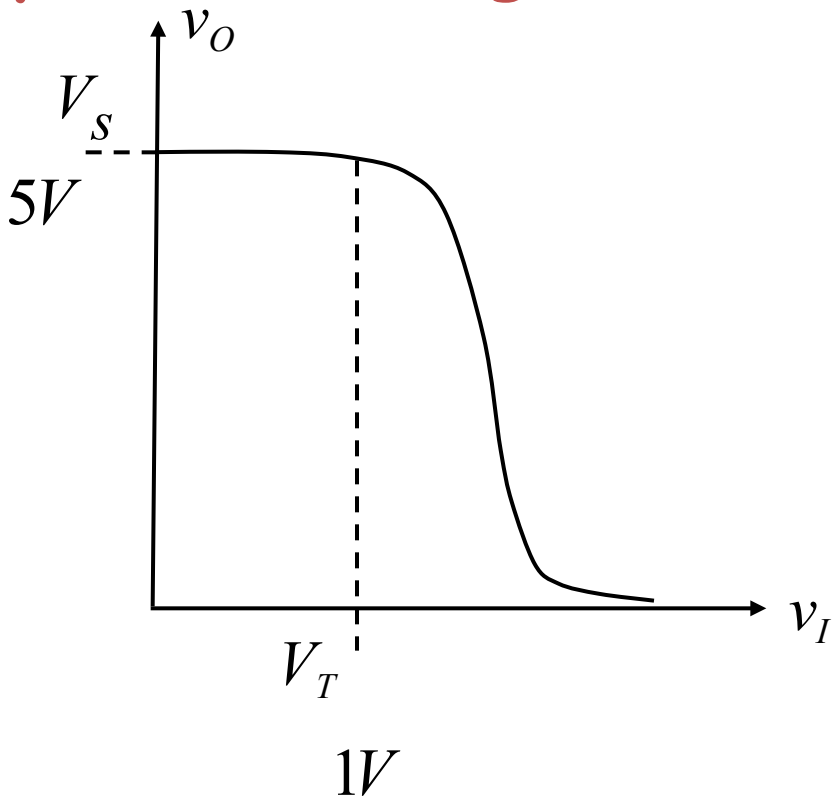
1. v_O versus v_I

2. Valid operating ranges under the saturation discipline?
   Valid input range:

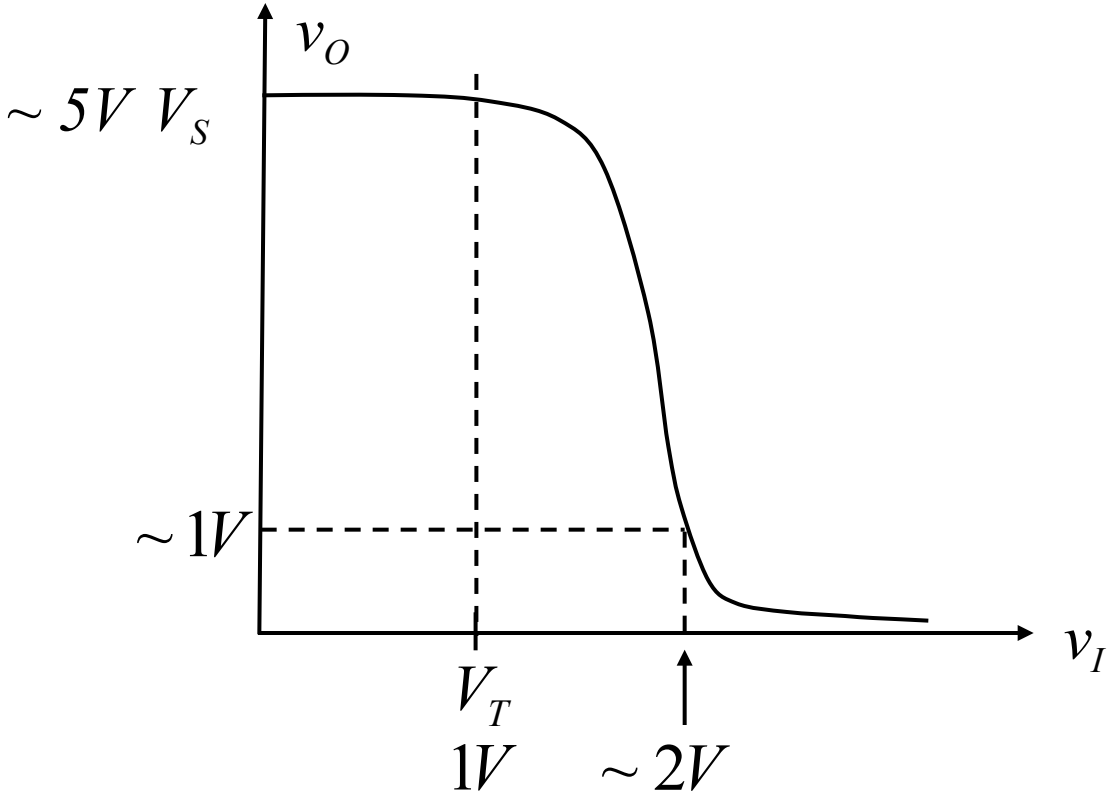
   Corresponding output range:

We will look at another way of obtaining (2) shortly

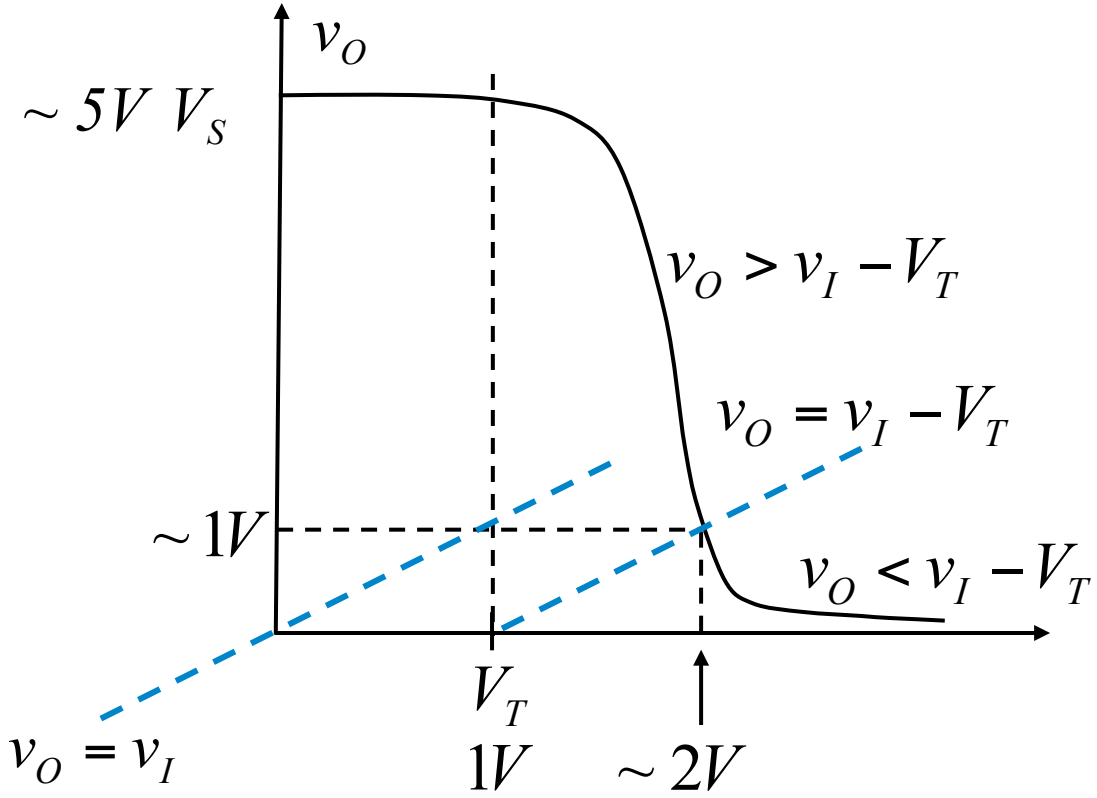
Another Way of Obtaining (2) Valid Op Range



Another Way of Obtaining (2) Valid Op Range



Another Way of Obtaining (2) Valid Op Range



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

$$v_O = v_I - V_T$$