Electrical and Electronics Circuits (4190.206A 002)

- HW #1 is due on Oct. 7 (Mon), 2019 3:15pm
- There will be a class on 10/9 (Wed) Hangul Day, (???)~~but the class attendance won't be checked~~(???), and video recording of the class will become available at ETL.
- Grades: 3 exams 30, 30, 30%   homework + attendance: 10% (If you cannot attend the class for official reason, please let me or TA know in advance. Note that your grade won't be affected until you are absent for more than three times.)

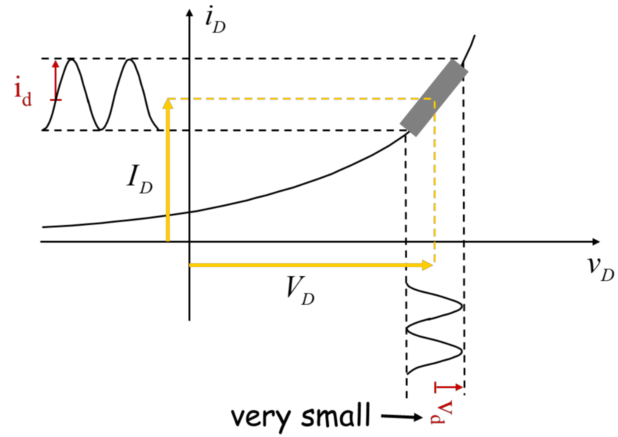
- Self-attendance check

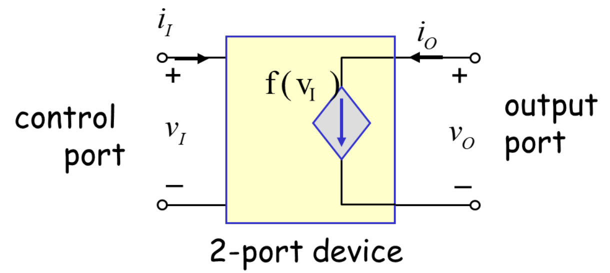
Review I

- SR (Switch Resistor) Model of MOSFET
- Analysis of nonlinear circuits
  - Distortion of the signal with demonstration
- Graphical analysis (with numerical root finding library)

- Incremental analysis
  - Find a small operation range where the system response is close to linear
  - Separate the signal into big signal (bias) and small signal

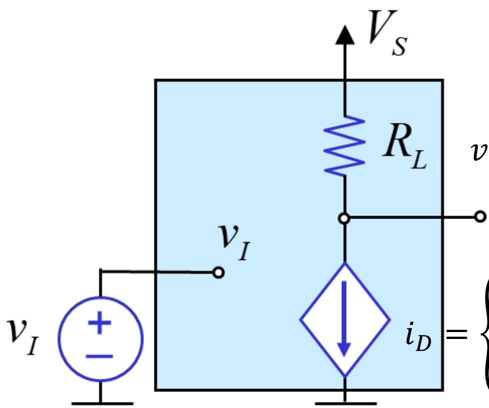
- Dependent sources
  - Voltage-controlled current source





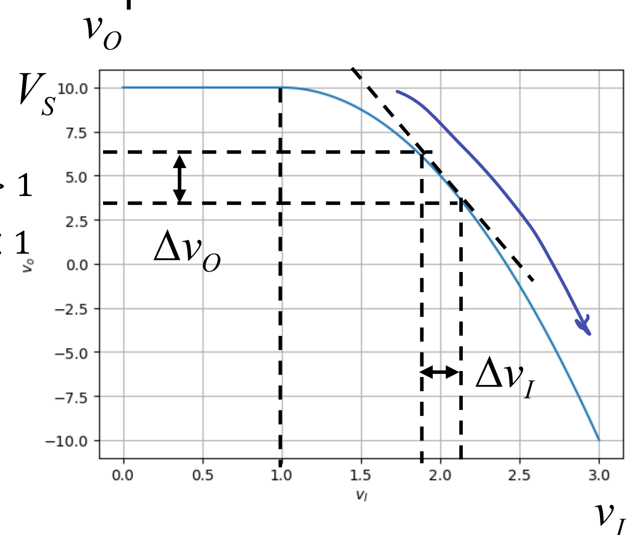
Review II

- Dependent source can be used as an amplifier



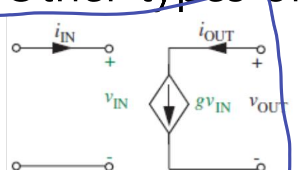
$$v_O = \begin{cases} V_S - \frac{K}{2}(v_I - 1)^2 R_L & \text{for } v_I > 1 \\ V_S & \text{for } v_I < 1 \end{cases}$$

$$i_D = \begin{cases} \frac{K}{2}(v_I - 1)^2 & \text{for } v_I > 1 \\ 0 & \text{for } v_I < 1 \end{cases}$$

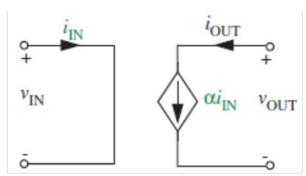


  - If $\mathrm{V} = 10\mathrm{V}, \mathrm{K} = 2\left(\frac{\mathrm{mA}}{\mathrm{V}^2}\right), \mathrm{R_L} = 5\mathrm{k\Omega}$,
  - amplification $\frac{\Delta \mathrm{v_O}}{\Delta \mathrm{v_I}} = -10$ around $\mathrm{v_I} = 2\mathrm{V}$.

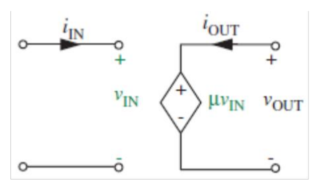
- Other types of controlled sources



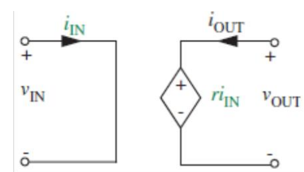
VCCS (voltage-controlled current source)



CCCS (current-controlled current source)



VCVS (voltage-controlled voltage source)



CCVS (current-controlled voltage source)

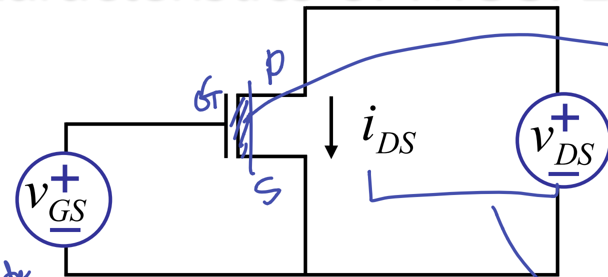
For the next two chapters

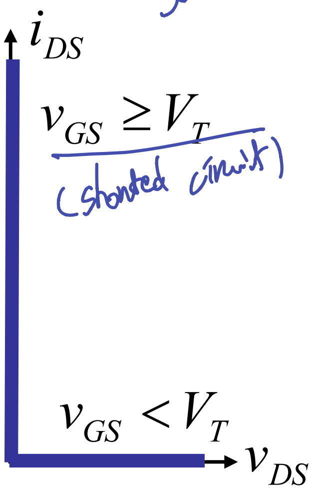
- Chap. 7 The MOSFET Amplifier
  - 7.3 Actual MOSFET Characteristics
  - 7.4 The Switch-Current Source (SCS) MOSFET Model
  - 7.5 The MOSFET Amplifier
  - 7.6 Large Signal Analysis of the MOSFET Amplifier
  - 7.7 Operating Point Selection
  - 7.8 Switch Unified (SU) MOSFET Model

- Chap. 8 The Small-Signal Model
  - 8.1 Overview of the Nonlinear MOSFET Amplifier
  - 8.2 The Small-Signal Model

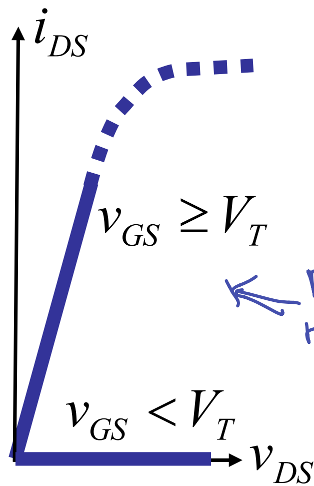
Full Characteristics of MOSFET Device

As width of this channel narrows

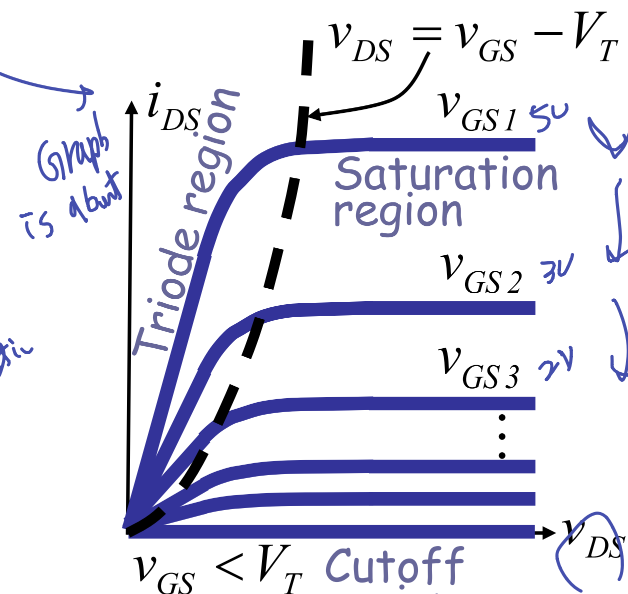




S MODEL



SR MODEL



위기를 1~5V 여도 i_{DS}가 일정

- Voltage-controlled current source?

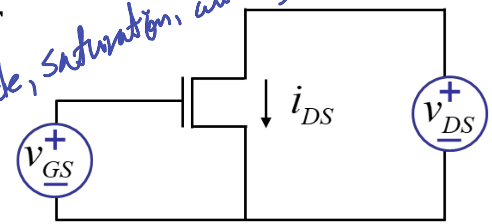
Full Characteristics of MOSFET Device

$$
i_{DS} = \begin{cases} K\left[(v_{GS} - V_T)v_{DS} - \dfrac{v_{DS}^2}{2}\right] & \text{for } v_{GS} \geq V_T \text{ and } v_{DS} < v_{GS} - V_T \\ \dfrac{K(v_{GS} - V_T)^2}{2} & \text{for } v_{GS} \geq V_T \text{ and } v_{DS} \geq v_{GS} - V_T \\ 0 & \text{for } v_{GS} < V_T \end{cases}
$$

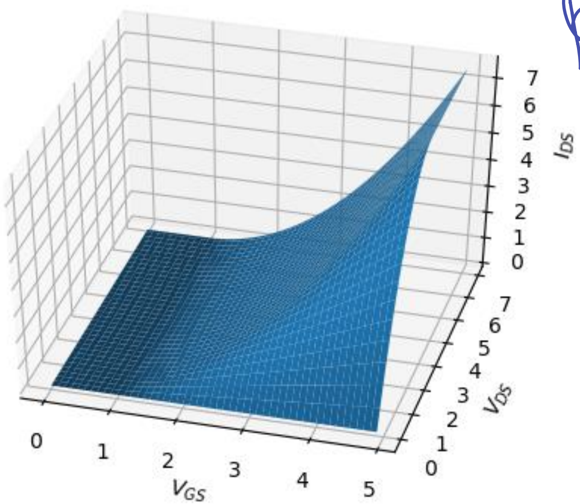
Eq. (7.75) in section 7.8 Switch Unified (SU) Model

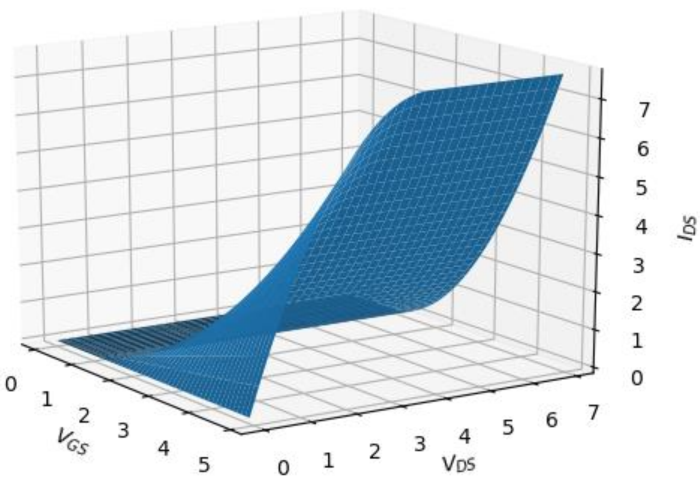
3 different region (triode, saturation, cut off)

point — used for the amplifier



3D plot of i_{DS} when V_T = 1V and K=1

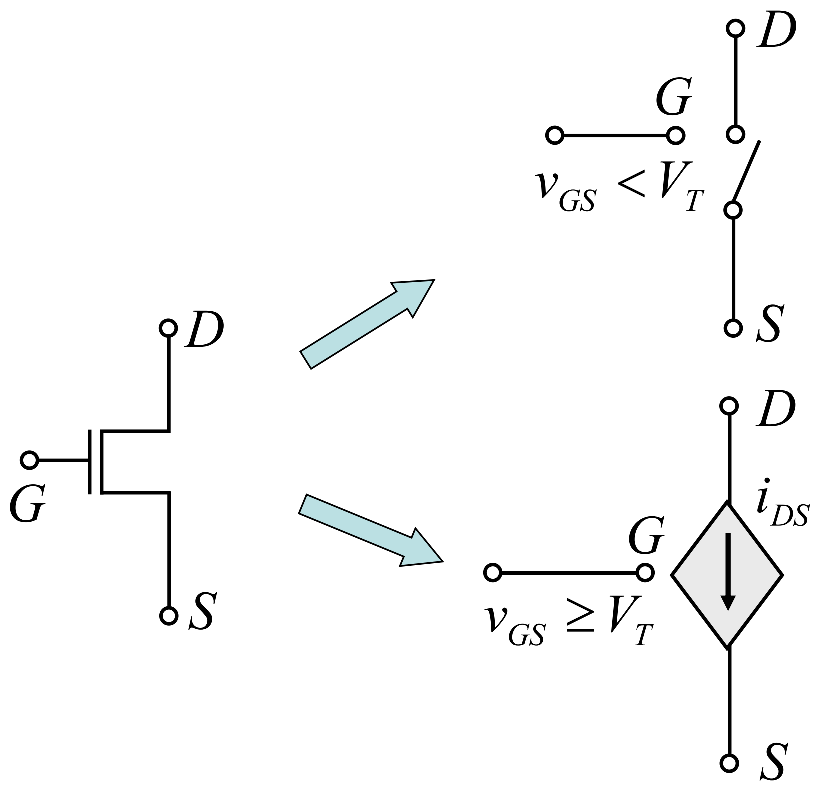




3D plot of i_{DS} when V_T = 1V and K=1 For interactive 3D plot, check “Lecture 11 - 3D plot of FET relation.ipynb”

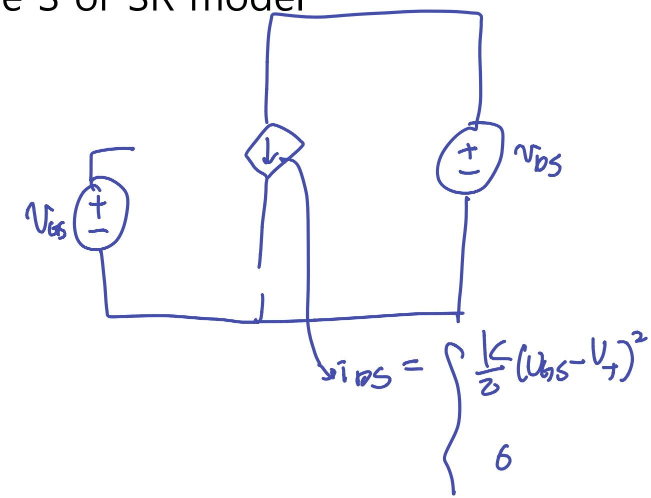
MOSFET SCS Model (Section 7.4)

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

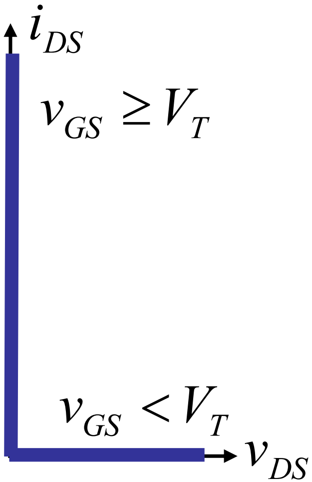


$$i_{DS} = f(v_{GS}) = \frac{K}{2}(v_{GS} - V_T)^2$$

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

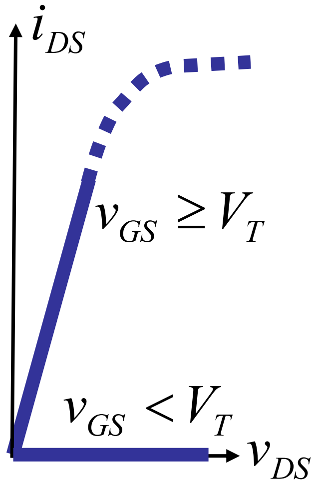


Which Model to Use?



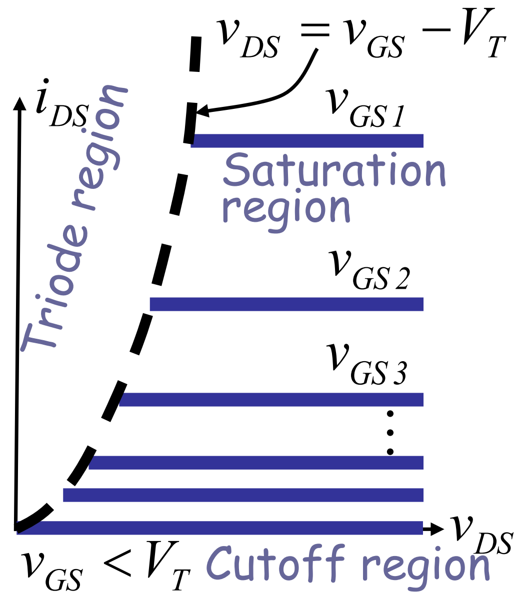
S MODEL

for quick digital analysis



SR MODEL

for digital designs



SCS MODEL

for analog designs

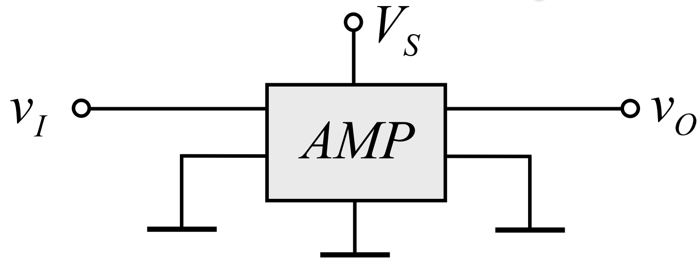
Note: alternatively

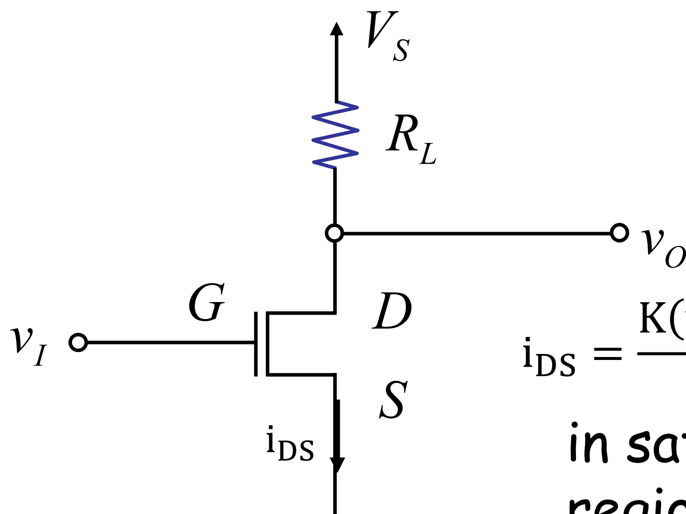
$v_{DS} \geq v_{GS} - V_T$ use SCS model

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

or, use SU Model (Section 7.8 of the textbook)

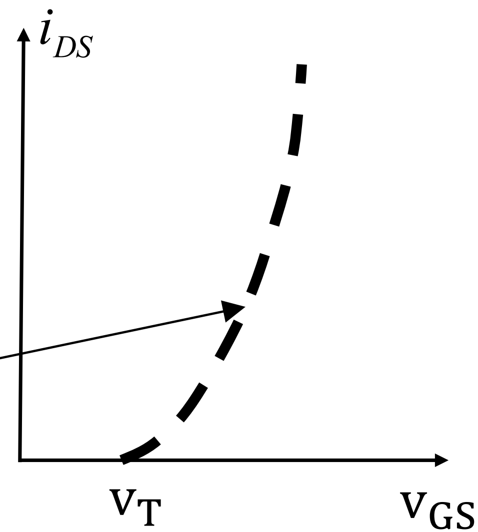
Constraint for Analysis as Amplifier





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

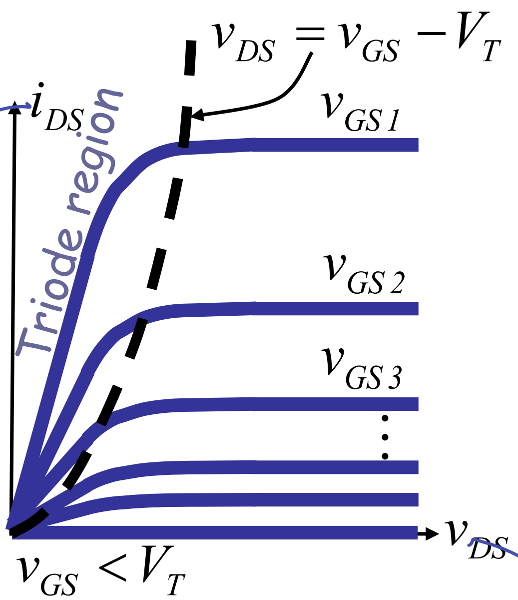
in saturation region



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"

Side note: analog multiplier

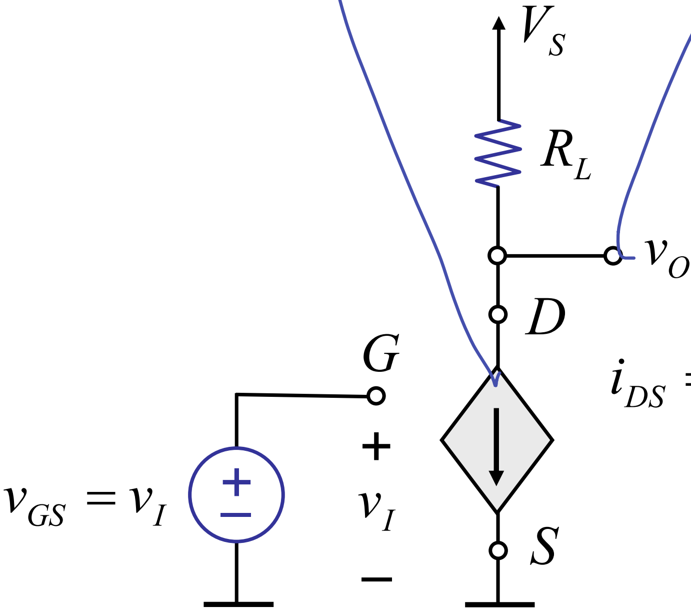
- Any application for triode region in analog circuit?
  - Within small region of v_{GS} and v_{DS}, this can be used as an analog multiplier with proper DC bias setting
  - $i_{DS} = K\left[(v_{GS} - V_T)v_{DS} - \frac{v_{DS}^2}{2}\right]$
  - In communication, multiplication of two signals is frequently required and such device is called as a mixer
- Typically more general analog multipliers are implemented by combining op-amps and diodes.



Control X 그게
양계의 관찰.

Analysis of the Simple Amplifier Circuit

- Replace the MOSFET with its SCS model.



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

for $v_O \geq v_I - V_T$

Analysis of the Simple Amplifier Circuit

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

Analytical method: $v_O \quad vs \quad v_I$

$$v_O = V_S - i_{DS} R_L \longleftarrow \text{B}$$

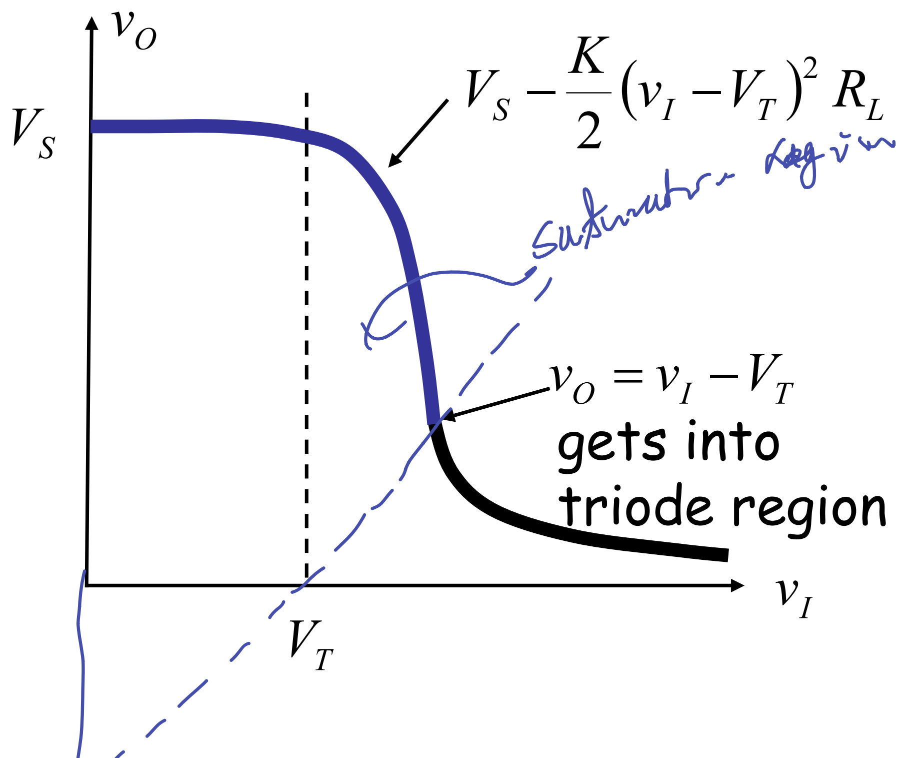
or $$v_O = V_S - \frac{K}{2}(v_I - V_T)^2 R_L$$ for $v_I \geq V_T$, $v_O \geq v_I - V_T$

$$v_O = V_S$$ for $v_I < V_T$

(MOSFET turns off)

Large Signal Analysis

- Piecewise analysis for v_O vs v_I



Graphical Method

- Constraint for saturation region

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

for $v_O \geq v_I - V_T$

$$\Downarrow$$

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

$$\Downarrow$$

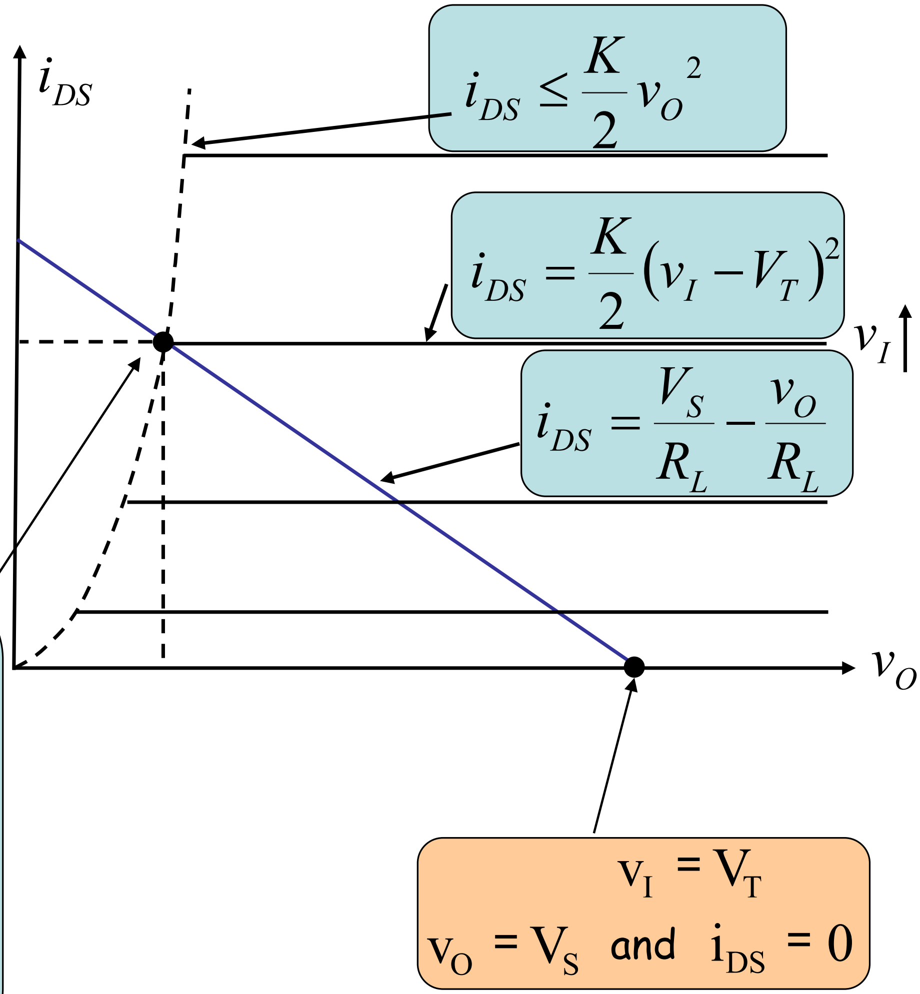
$$i_{DS} \leq \frac{K}{2} v_O{}^2$$

Load relation

B : $i_{DS} = \frac{V_S}{R_L} - \frac{V_0}{R_L}$

Graphical Analysis

- Only interested in the saturation region



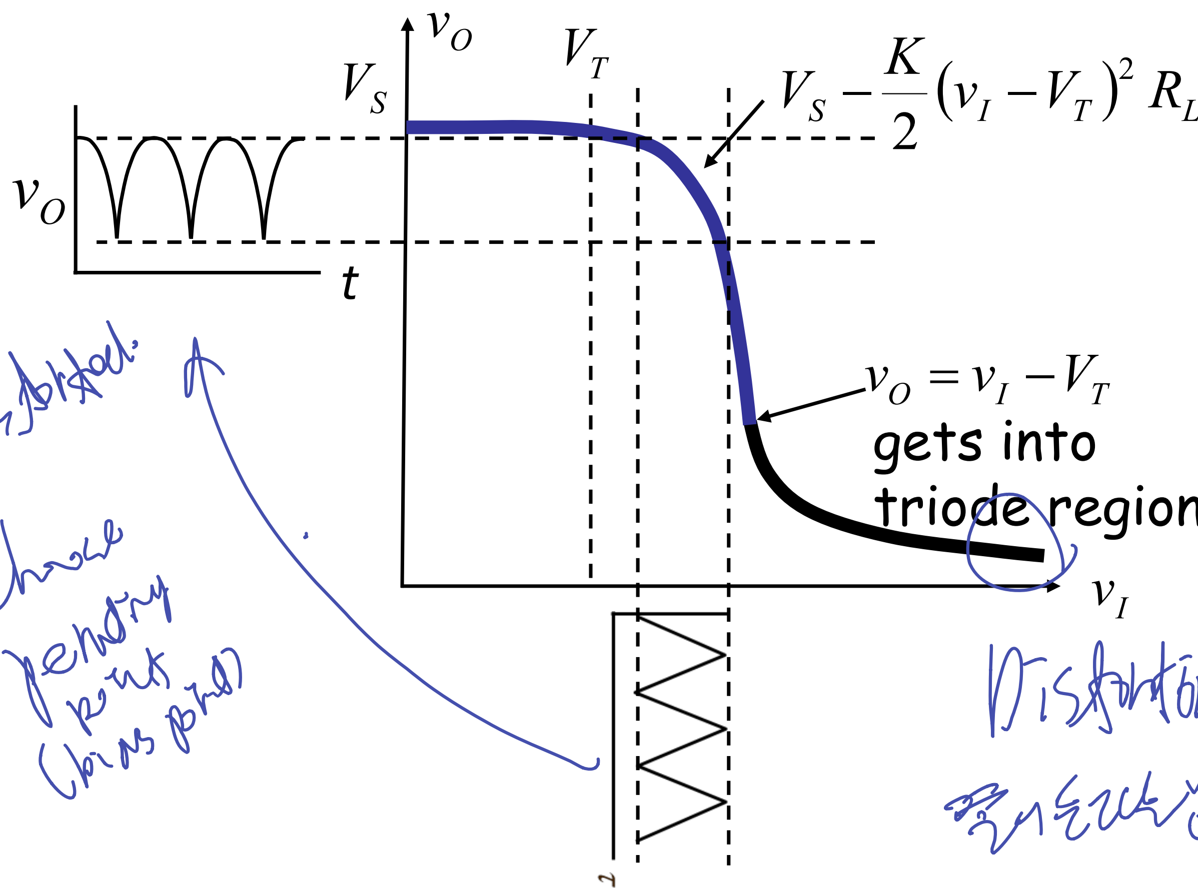
$$v_O = \frac{-1+\sqrt{1+2KR_L V_S}}{KR_L}$$

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

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

Large Signal Analysis

- Piecewise analysis for v_O vs v_I



Distorted.

① change operating point (bias point)

Distortion이 줄어들었는가.