ECE 65: Components & Circuits Lab

Lecture 13

Metal Oxide Semiconductor Field Effect Transistor (MOSFET) introduction

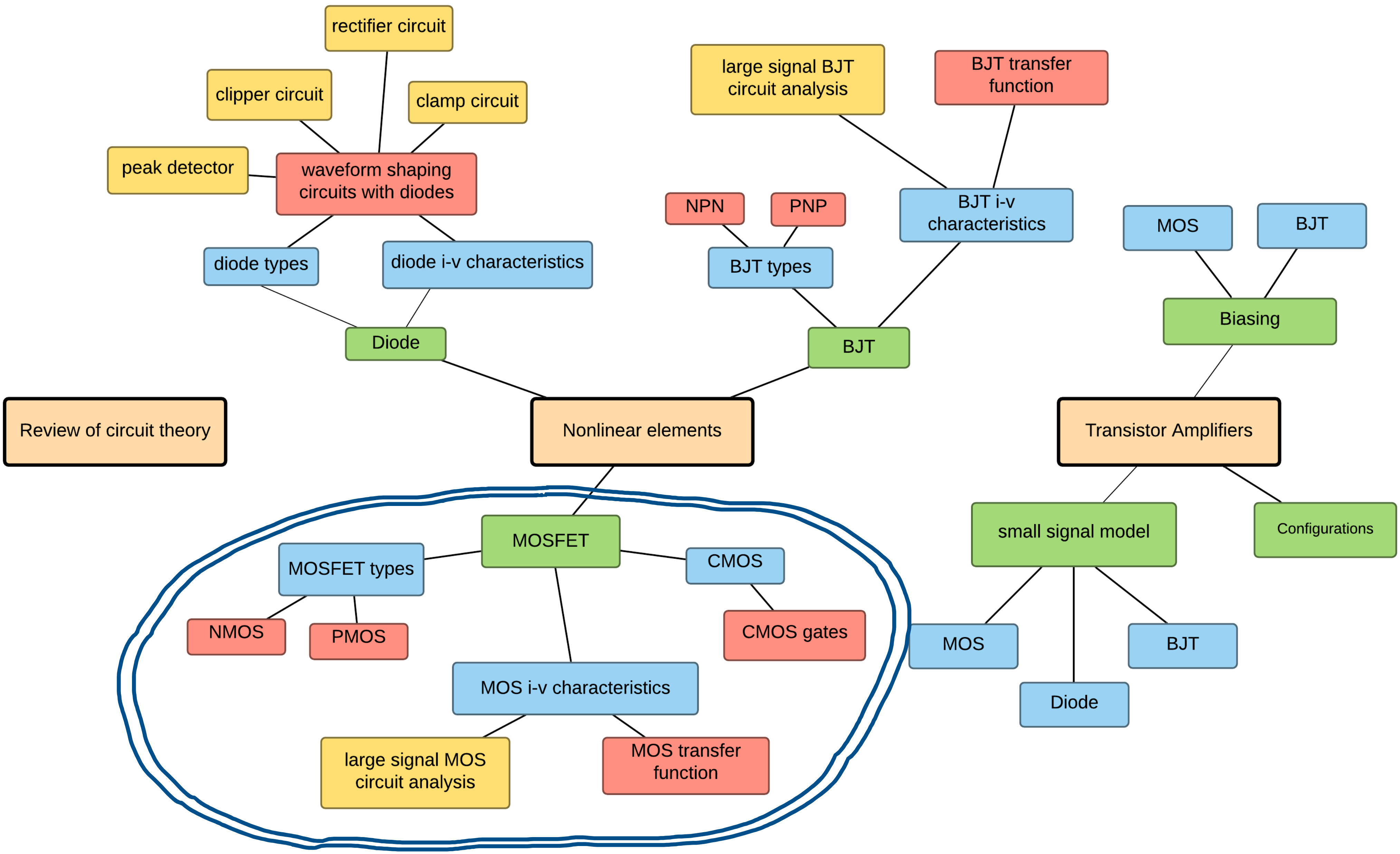
Reference notes: sections 4.1,4.2

Sedra & Smith (7th Ed): sections 5.1-5.3

Saharnaz Baghdadchi

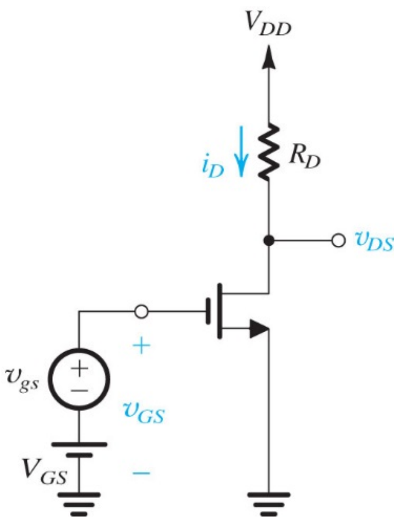
Course map

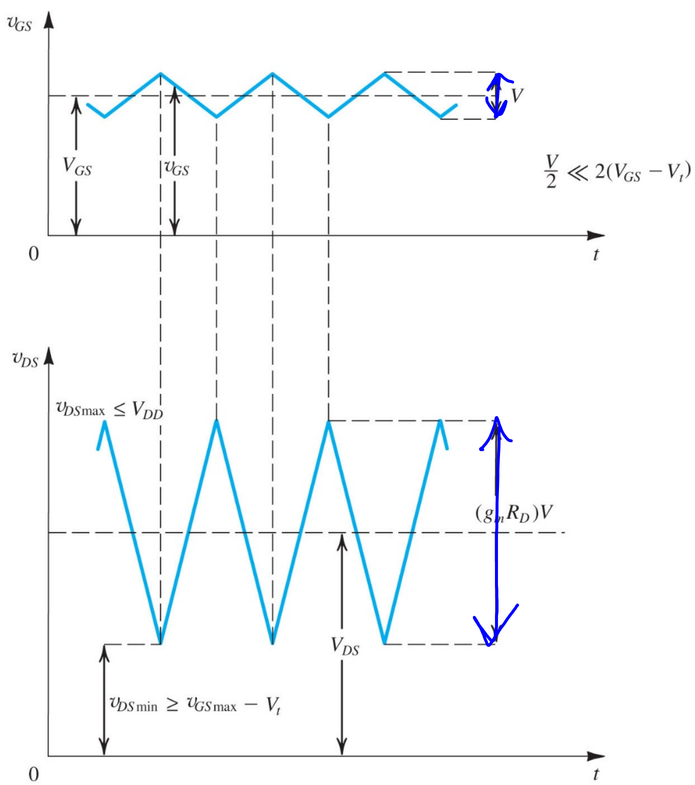
4. Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



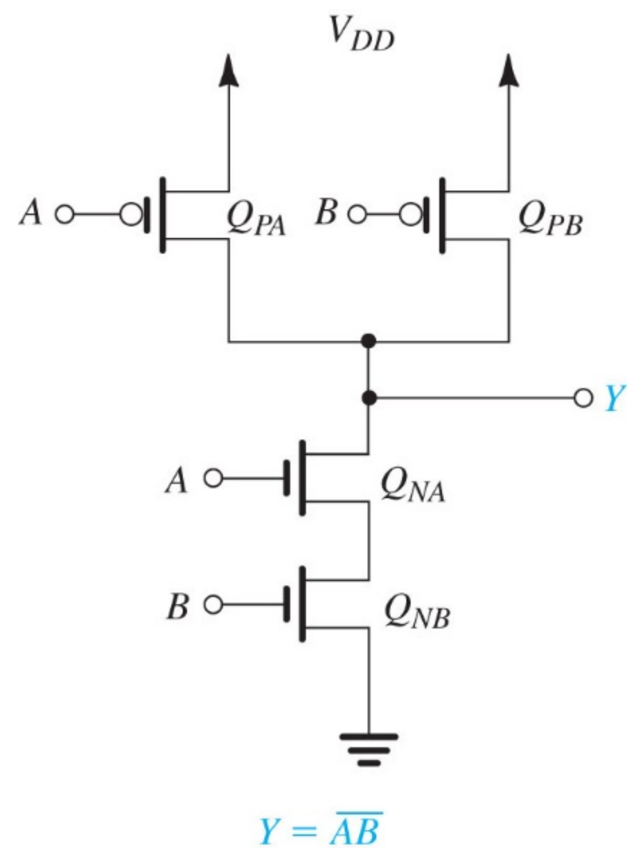
Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

Amplifiers



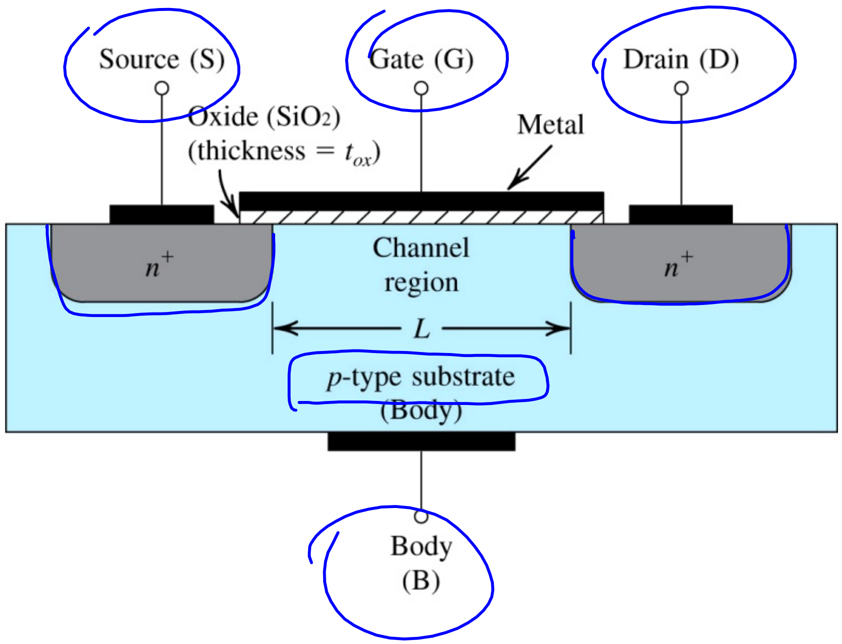


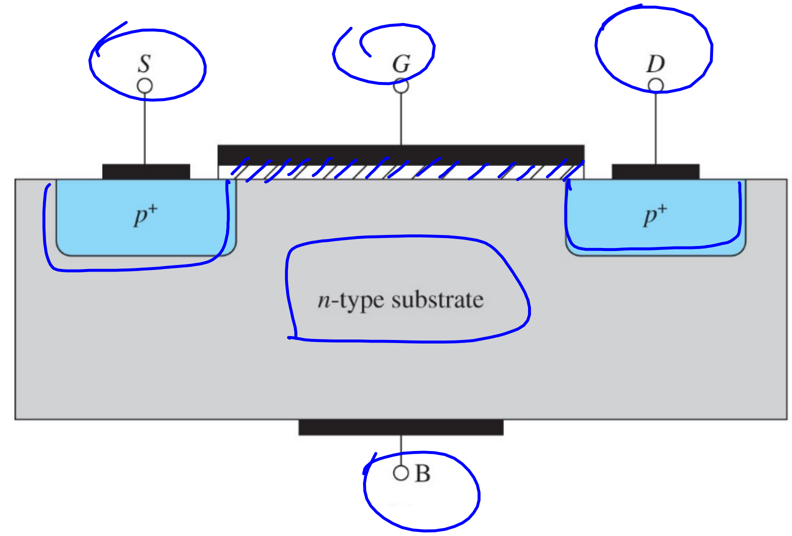
Digital Gates

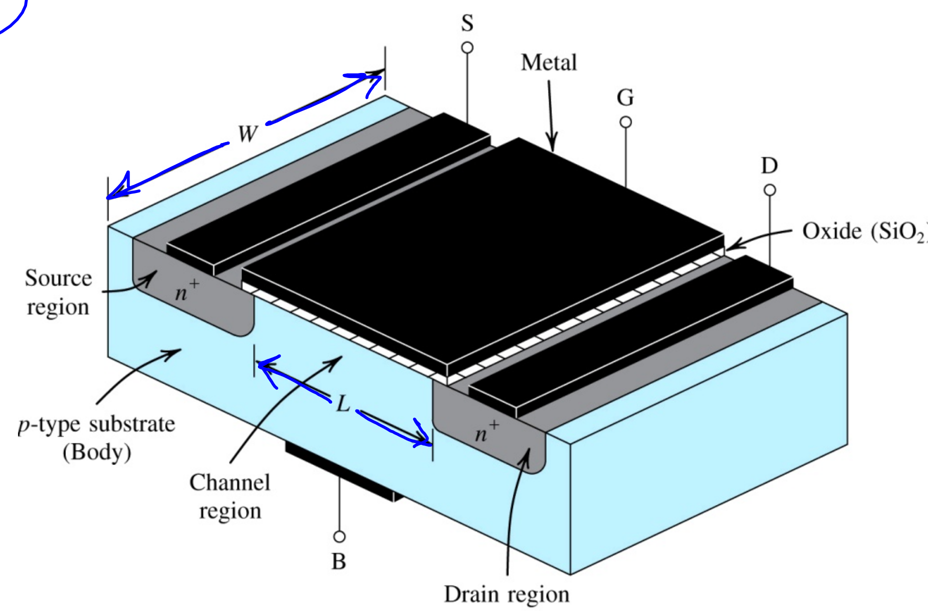


The structure of NMOS and PMOS

The thickness and capacitance of the oxide layer : t_{ox} , C_{ox}







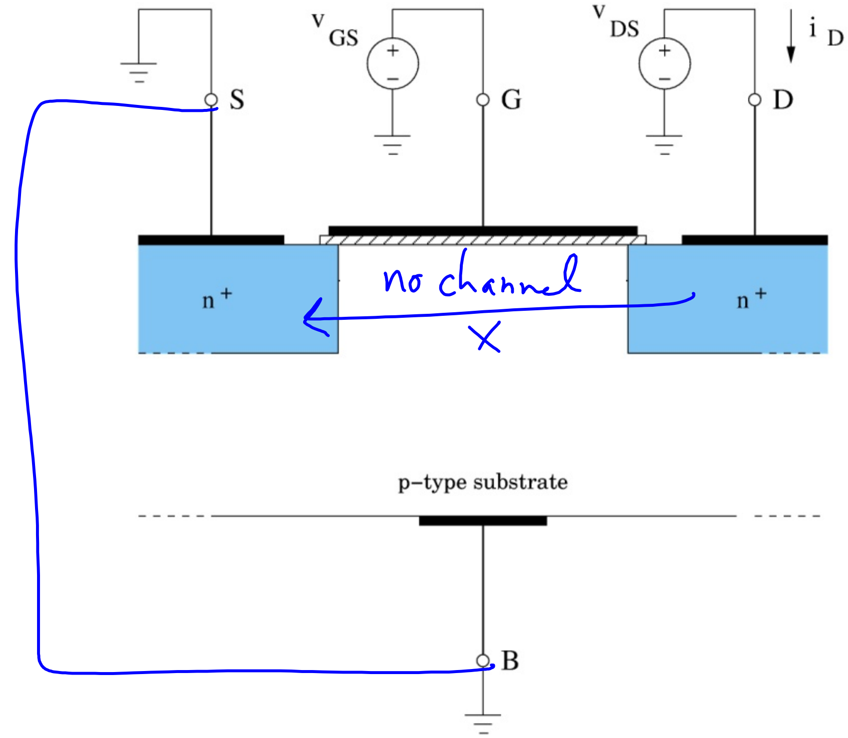
NMOS i-v Characteristics

Cut-off region

No inversion layer ($v_{GS} < V_{tn}$)

No current will flow.

In cut-off region, $V_{ov} < 0$.

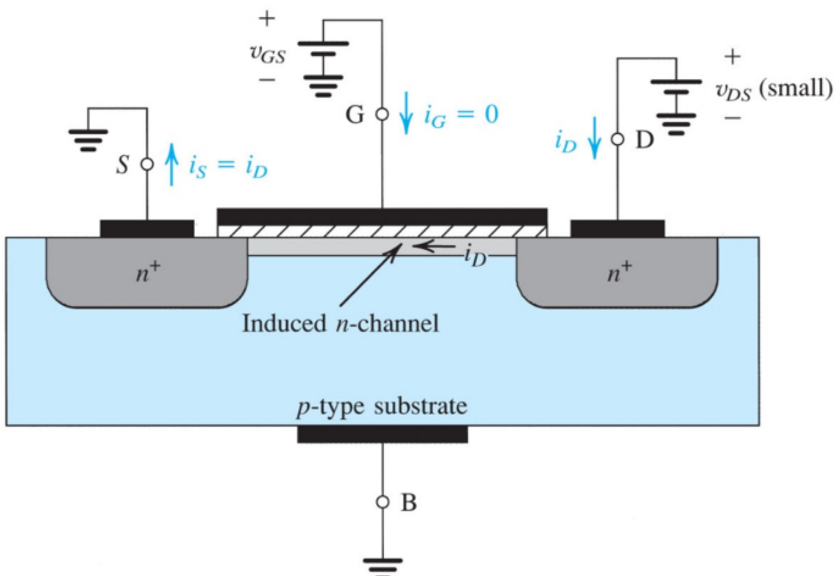


Overdrive Voltage: $V_{OV} = v_{GS} - V_{tn}$

NMOS i-v Characteristics

<ins>A channel is formed</ins> $(v_{GS} \geq V_{tn})$

If we apply a **<ins>small</ins>** $\boldsymbol{v_{DS}}$ between drain and source, current will flow in the channel.



$$i_D = \mu_n C_{ox} \frac{W}{L} (v_{GS} - V_{tn})\, v_{DS}$$

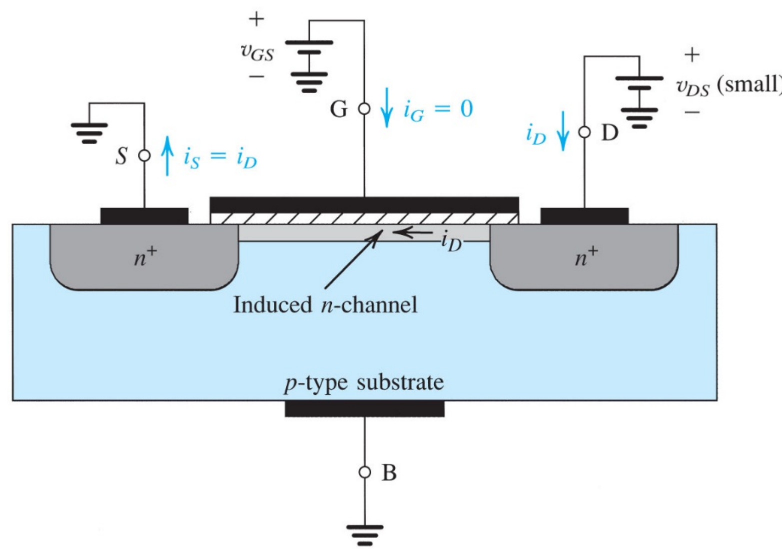
$$i_D = \mu_n C_{ox} \frac{W}{L} V_{OV}\, v_{DS}$$

μ_n is the mobility of electrons.

The values of μ_n, C_{ox} , and $\frac{W}{L}$ will be given to you.

NMOS i-v Characteristics

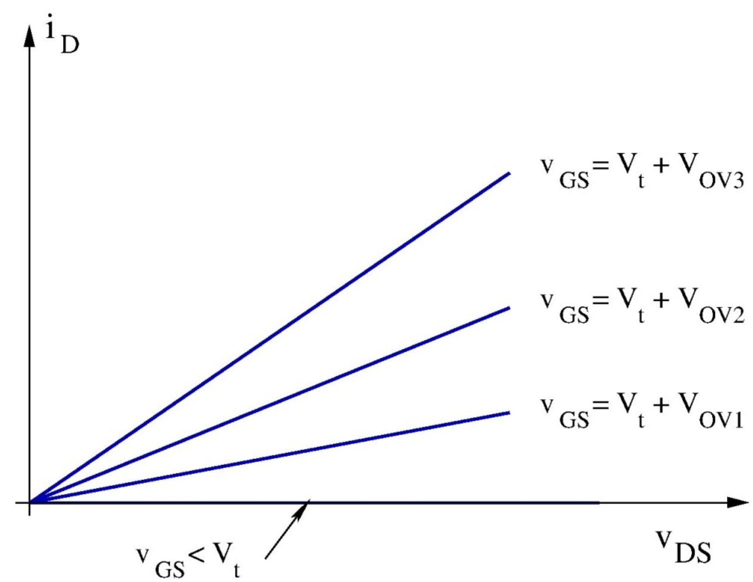
<u>A channel is formed</u> $(v_{GS} \geq V_{tn})$



$$i_D = \mu_n C_{ox} \frac{W}{L} (v_{GS} - V_{tn})\, v_{DS}$$

$$i_D = \mu_n C_{ox} \frac{W}{L} V_{OV}\, v_{DS}$$

For **<u>small</u>** $\boldsymbol{v_{DS}}$, MOSFET acts like a resistor with its conductivity controlled by V_{OV} (or v_{GS}).



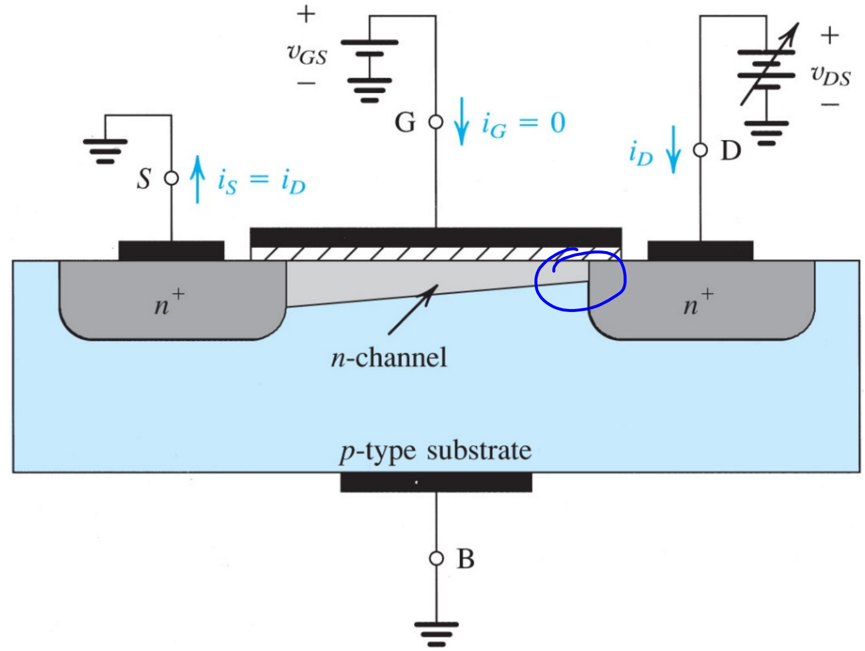
$$i_D = g_{DS}\, v_{DS}$$

Where $g_{DS} = \mu_n C_{ox} \frac{W}{L} V_{OV}$

NMOS i-v Characteristics

Triode region

As v_{DS} is increased, the channel becomes narrower near the drain.



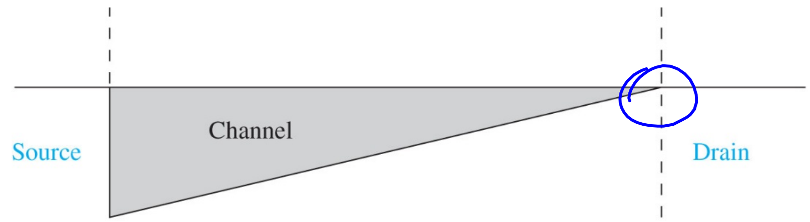
$$\boxed{i_D = \mu_n C_{ox} \frac{W}{L} (V_{OV}\ v_{DS} - 0.5 v_{DS}^2)}$$

For small v_{DS},

$$i_D = \mu_n C_{ox} \frac{W}{L} (V_{OV}\ v_{DS} - \cancel{0.5 v_{DS}^2}) \approx \mu_n C_{ox} \frac{W}{L} (v_{GS} - V_{tn})\, v_{DS}$$

NMOS i-v Characteristics

Saturation region

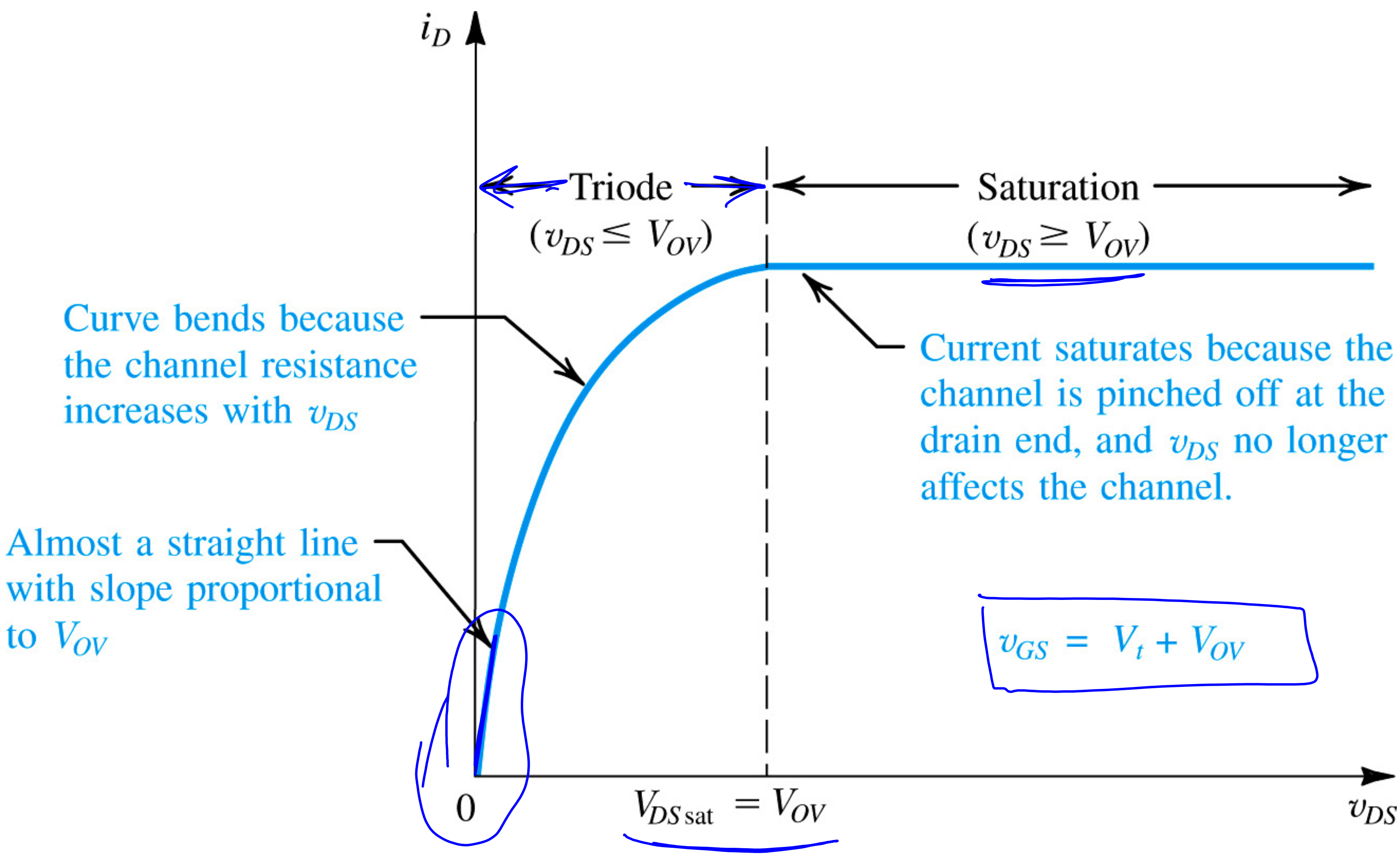


When v_{DS} is increased further such that $v_{DS} = V_{OV}$, the channel depth becomes zero at the drain (Channel "pinched off").

$$i_D = 0.5\,\mu_n C_{ox} \frac{W}{L}\, V_{OV}^2$$

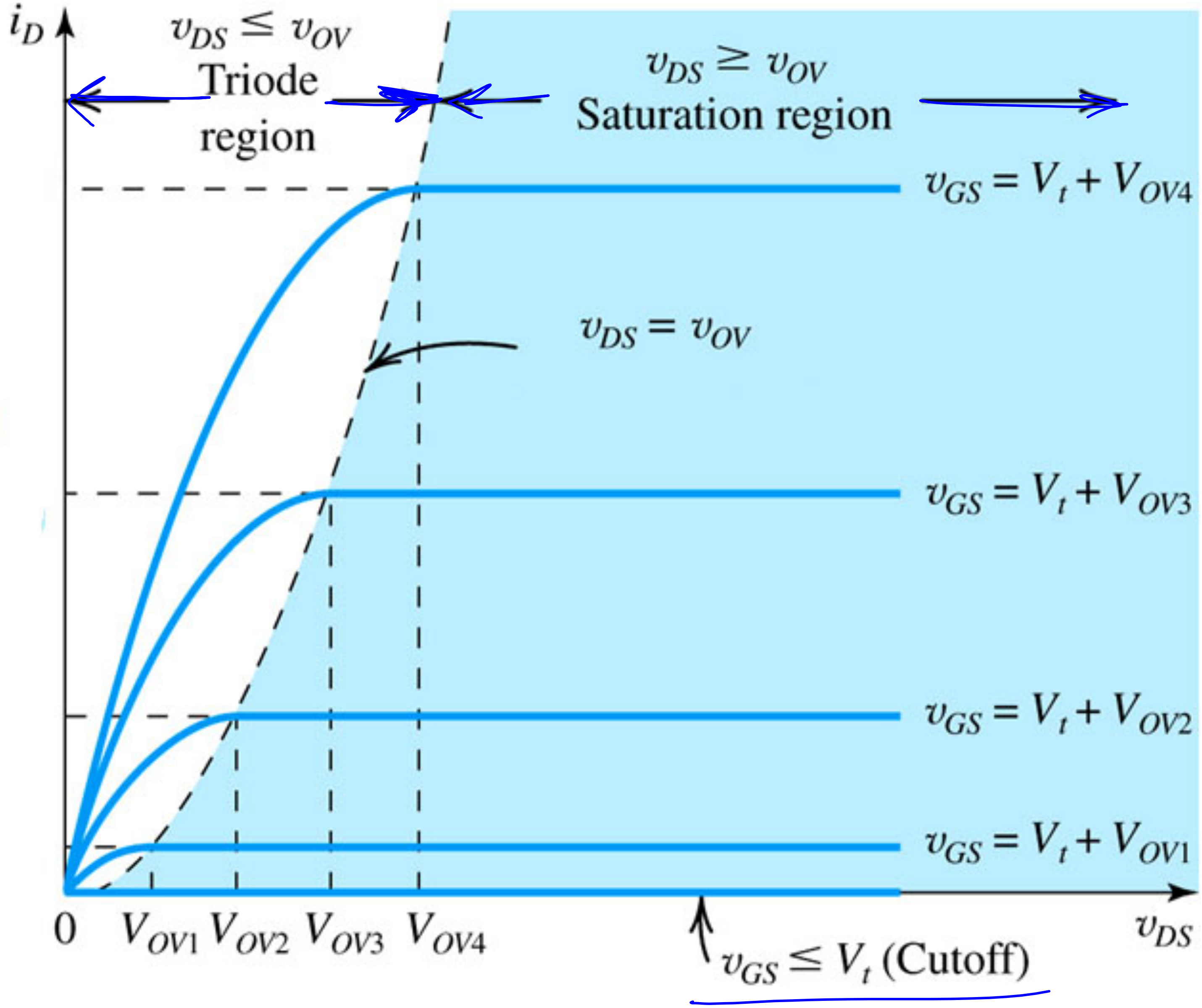
NMOS i-v Characteristics

For a given v_{GS} (or V_{OV})



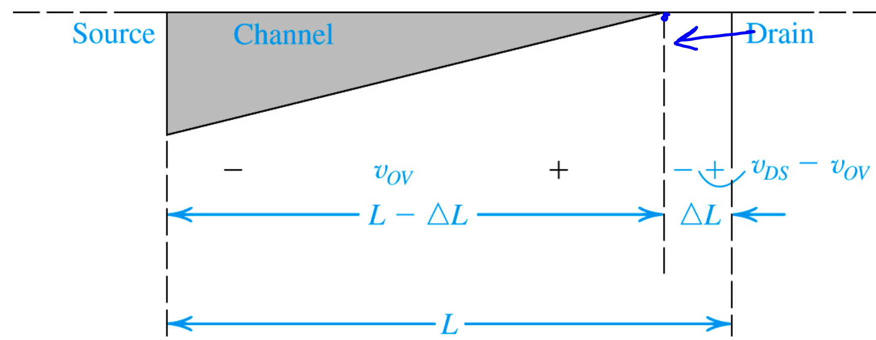
NMOS i-v Characteristics Plot

$v_{DS} = v_{OV}$ the edge of saturation



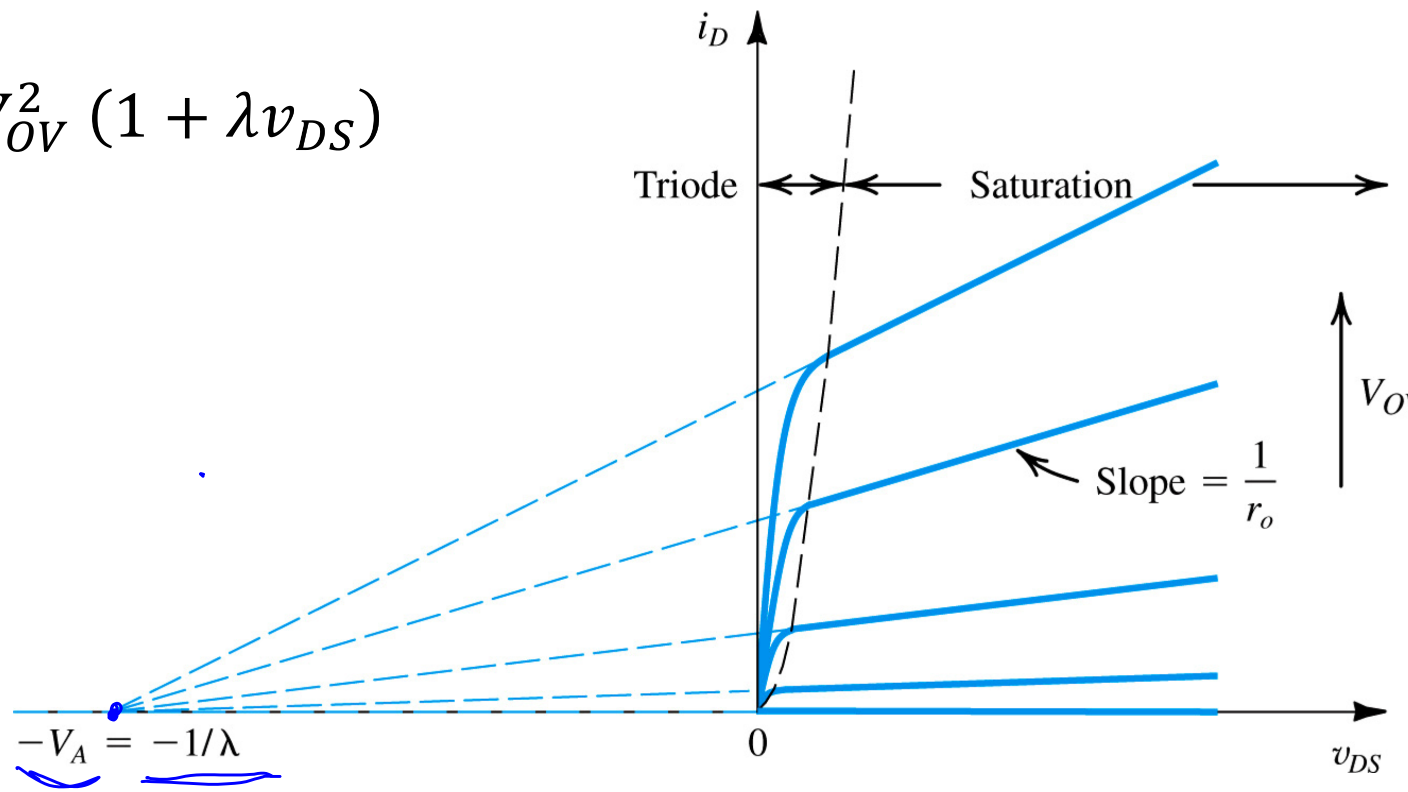
Channel-Length Modulation

As v_{DS} increases beyond V_{OV} , the pinch-off point moves “slightly” away from the drain: Channel- length Modulation

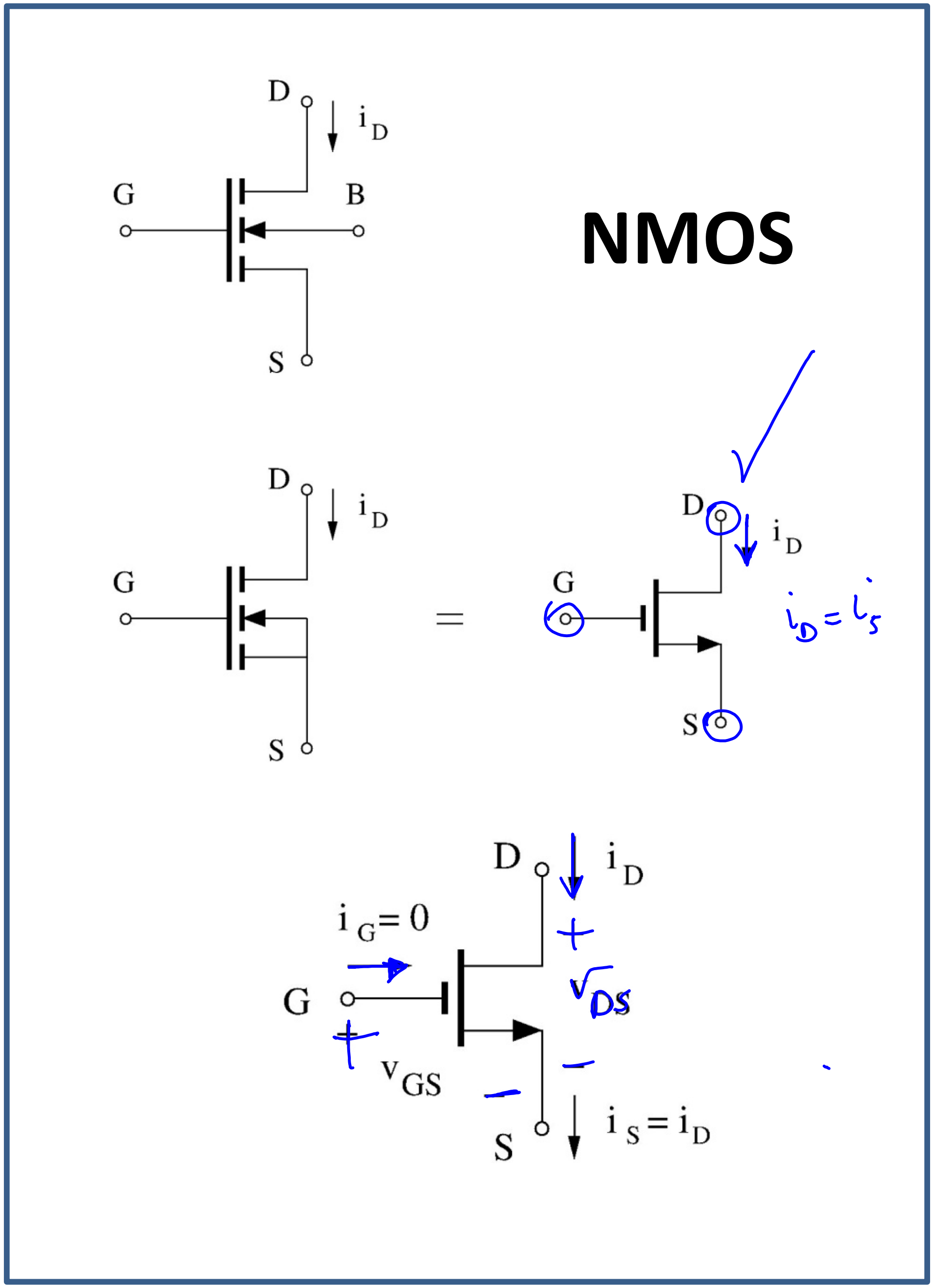


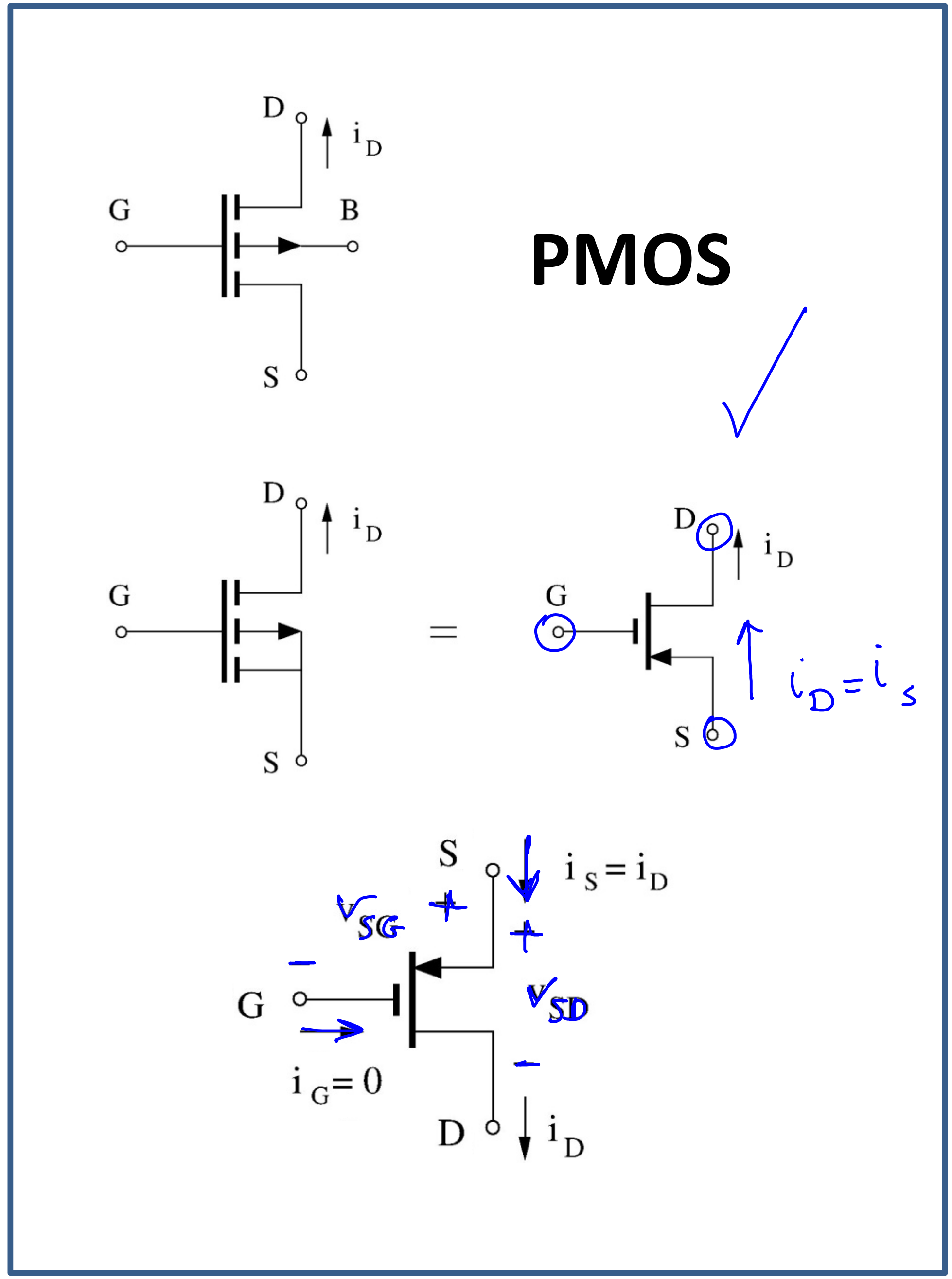
$$i_D = 0.5\, \mu_n C_{ox} \frac{W}{L} V_{OV}^2 \left(1 + \lambda v_{DS}\right)$$

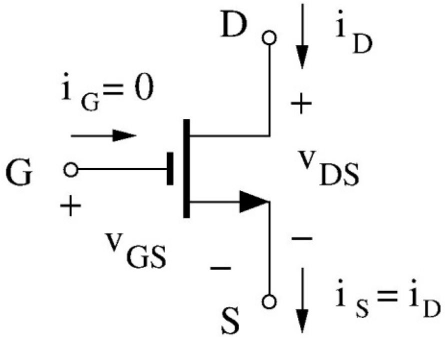
$$\lambda = \frac{1}{V_A}$$



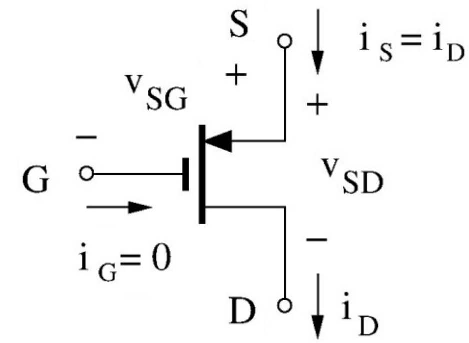
MOS Circuit symbols and conventions







MOS i-v Equations



NMOS $(V_{OV} = v_{GS} - V_{tn})$

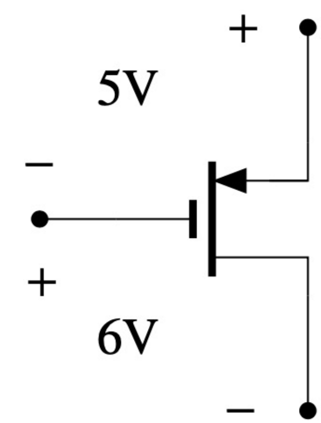
Cut– Off :	$V_{OV} < 0$	$i_D = 0$
Triode :	$V_{OV} \geq 0$ and $v_{DS} \leq V_{OV}$	$i_D = 0.5\, \mu_n C_{ox} \dfrac{W}{L} (2\, V_{OV} v_{DS} - v_{DS}^2)$
Saturation :	$V_{OV} \geq 0$ and $v_{DS} \geq V_{OV}$	$i_D = 0.5\, \mu_n C_{ox} \dfrac{W}{L}\, V_{OV}^2\, (1 + \lambda v_{DS})$

PMOS $(V_{OV} = v_{SG} - \lvert V_{tp} \rvert)$

Cut– Off :	$V_{OV} < 0$	$i_D = 0$
Triode :	$V_{OV} \geq 0$ and $v_{SD} \leq V_{OV}$	$i_D = 0.5\, \mu_p C_{ox} \dfrac{W}{L} (2\, V_{OV} v_{\mathrm{SD}} - v_{SD}^2)$
Saturation :	$V_{OV} \geq 0$ and $v_{SD} \geq V_{OV}$	$i_D = 0.5\, \mu_p C_{ox} \dfrac{W}{L}\, V_{OV}^2\, (1 + \lambda v_{SD})$

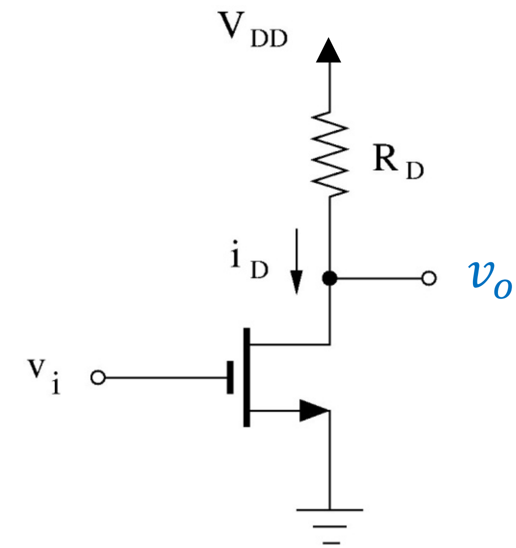
Lecture 13 reading quiz

For the MOSFET below, $v_{SG} = 5V, v_{GD} = 6V, \mu_n C_{ox}\left(\frac{W}{L}\right)_n = \mu_p C_{ox}\left(\frac{W}{L}\right)_p = 0.7\frac{mA}{V^2}$, $V_{tn} = |V_{tp}| = 2V$. Find the mode of operation of the MOSFET and the drain current i_D.

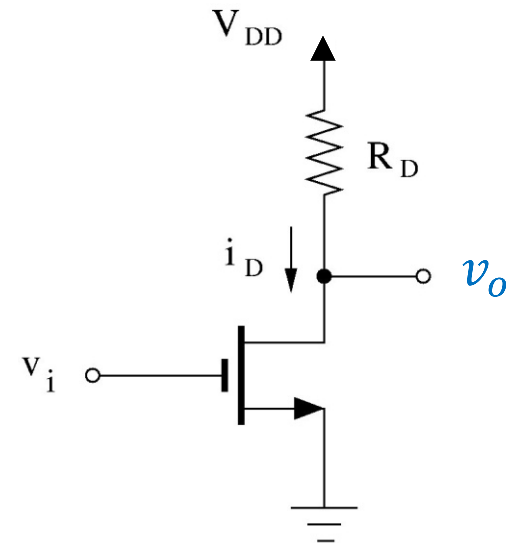


Example.

In the circuit below, $R_D = 1k$, and $V_{DD} = 12\ V$. Find v_o for $v_i = 0$ and $12V$. ($\mu_n C_{ox} \frac{W}{L} = 0.5\ \mathrm{mA/}V^2$, $V_{tn} = 2\ V$, and $\lambda = 0$)



Hints:



- Determine if the MOSFET is an N-channel or a P-channel MOSEF. The Arrow in the MOSFETs is always on the source. If the arrow points outside the gate, it is an NMOS.

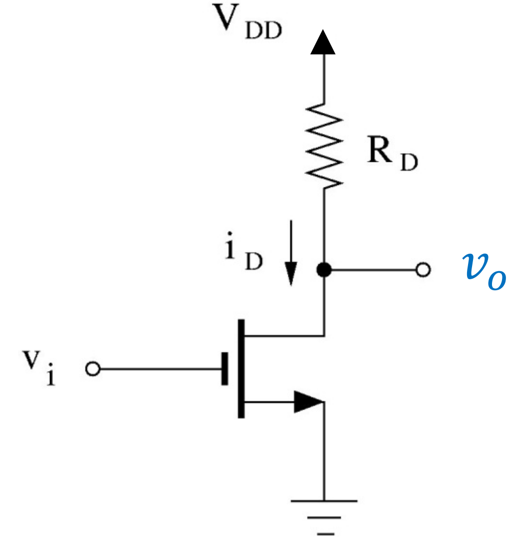
- Label V_{GS} and V_{DS}.

- Check if the MOSFET is ON or in Cut-off. You need to calculate V_{OV}. Use the definition of V_{OV}.

- If the MOSFET is in Cut-off, the drain current will be zero. You can write a KVL for the drain to source loop and find V_{DS}.

- If the MOSFET is ON, assume the saturation mode of operation. Write the drain current equation and identify the unknowns in that equation. Write a KVL for the drain to source loop and solve two equations concurrently to find the values of unknowns. You need to verify that V_{DS} is greater than V_{OV}.

- If the saturation assumption was incorrect, the MOSFET will be in triode mode. Write the drain current equation for the triode mode and identify the unknowns in that equation. Write a KVL for the drain to source loop and solve two equations concurrently to find the values of unknowns. You will be solving a quadratic equation that will give you two answers for V_{DS} or I_D or V_{OV}, depending on the parameter that you solve the equation for.
Note that because you know the MOSFET is ON, V_{OV} will be positive. Also note that V_{DS} cannot exceed the DC voltage source (V_{DD}) used to create the I_D current.

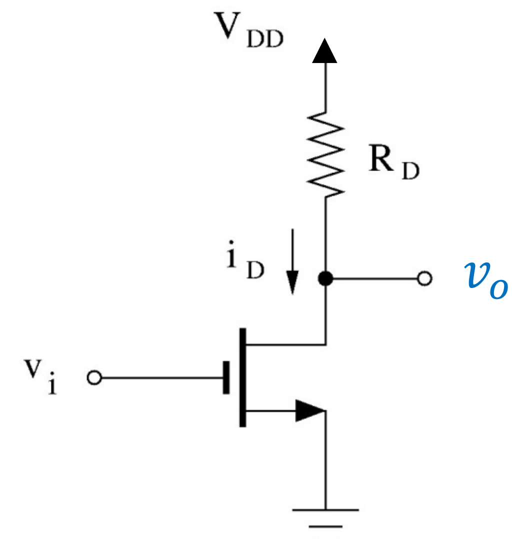


V_{DD}
R_D
i_D
v_o
v_i

Clicker question 1.

In the circuit below, $R_D = 1k$, and $V_{DD} = 12\,V$. Find v_o for $v_i = 6V$.

$(\mu_n C_{ox} \frac{W}{L} = 0.5\ \mathrm{mA}/V^2, V_{tn} = 2\,V$, and $\lambda = 0$)



A. $v_o = 6\,V$

B. $v_o = 8\,V$

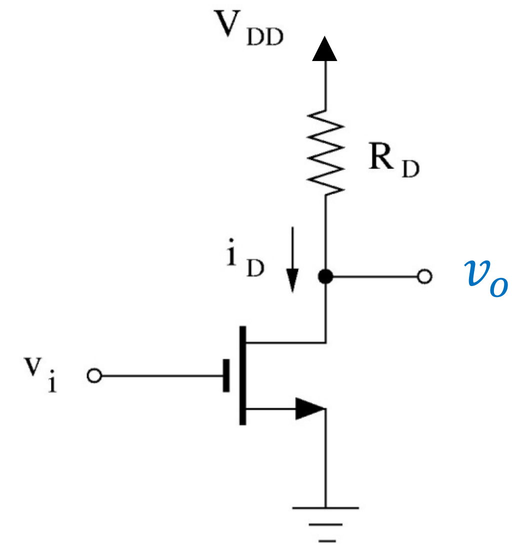
C. $v_o = 10\,V$

D. $v_o = 16\,V$

Clicker question 1.

In the circuit below, $R_D = 1k$, and $V_{DD} = 12\ V$. Find v_o for $v_i = 6V$.

($\mu_n C_{ox} \frac{W}{L} = 0.5\ \text{mA}/V^2, V_{tn} = 2\ V$, and $\lambda = 0$)



Discussion question 1:

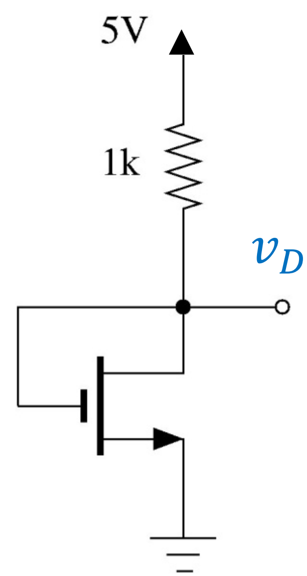
In the following circuit find V_D.

($\mu_n C_{ox} \frac{W}{L} = 0.5 \ \text{mA}/V^2$, $V_{tn} = 0.8\ V$, and $\lambda = 0$).

Is the NMOS in cut-off?

Is the NMOS in saturation?

Is the NMOS in triode?



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($\mu_n C_{ox}\frac{W}{L} = 0.5\ \mathrm{mA}/V^2$, $V_{tn} = 0.8\ V$, and $\lambda = 0$).