ECE 65: Components & Circuits Lab

Lecture 14

MOSFET transfer function

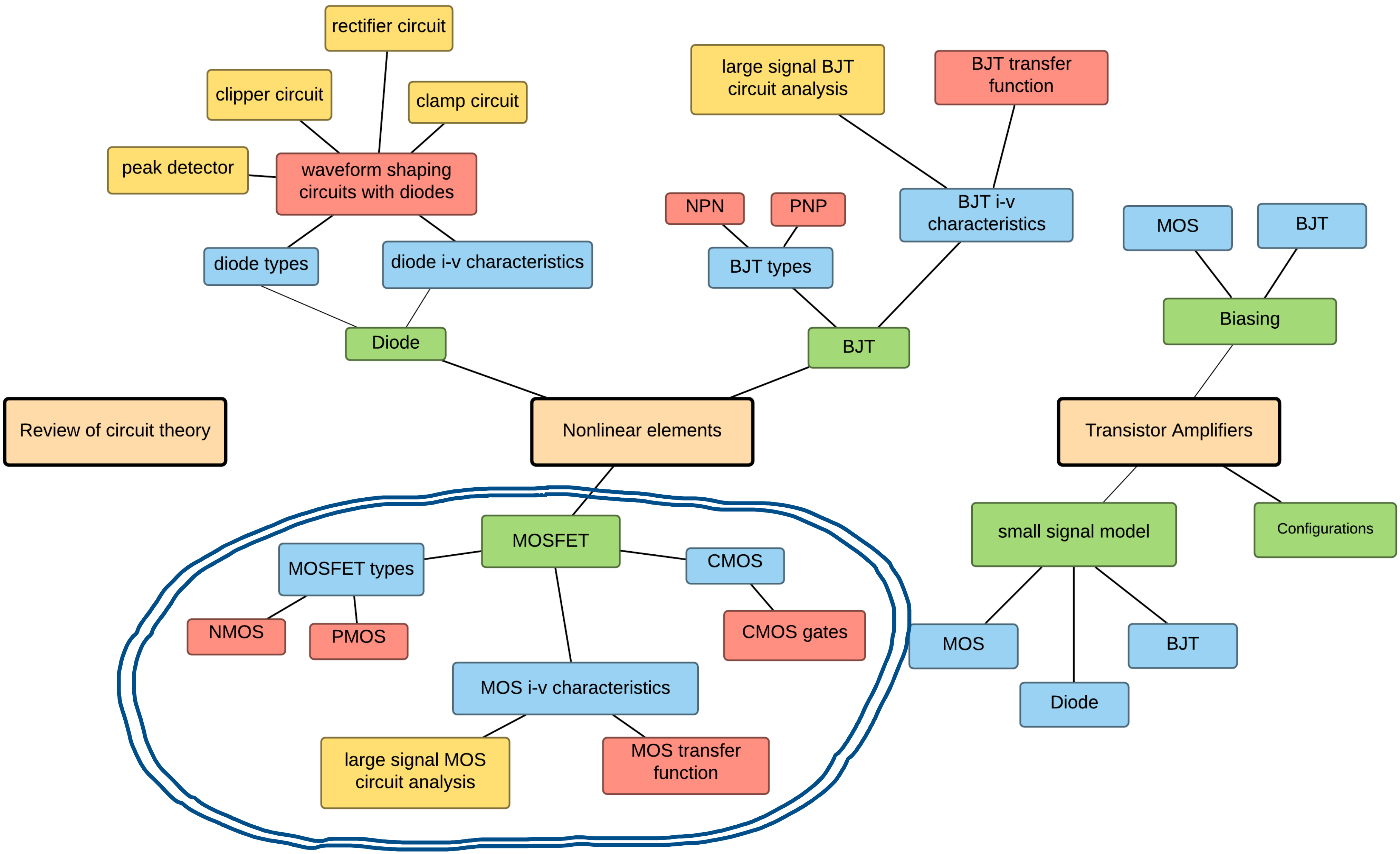
Reference notes: sections 4.2,4.3

Sedra & Smith (7th Ed): sections 5.3,7.1.3

Saharnaz Baghdadchi

Course map

4. Metal Oxide Semiconductor Field Effect Transistor (MOSFET)



NMOS Transfer Function

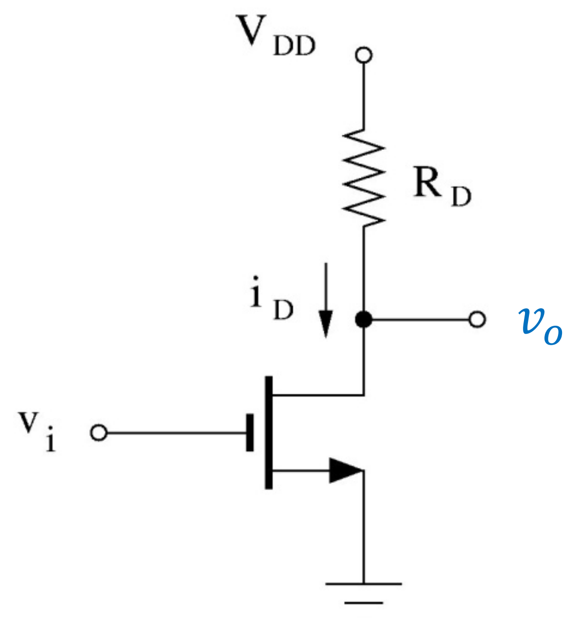
How does v_o change when v_i is changed from 0 to V_{DD}?

Circuit Equations:

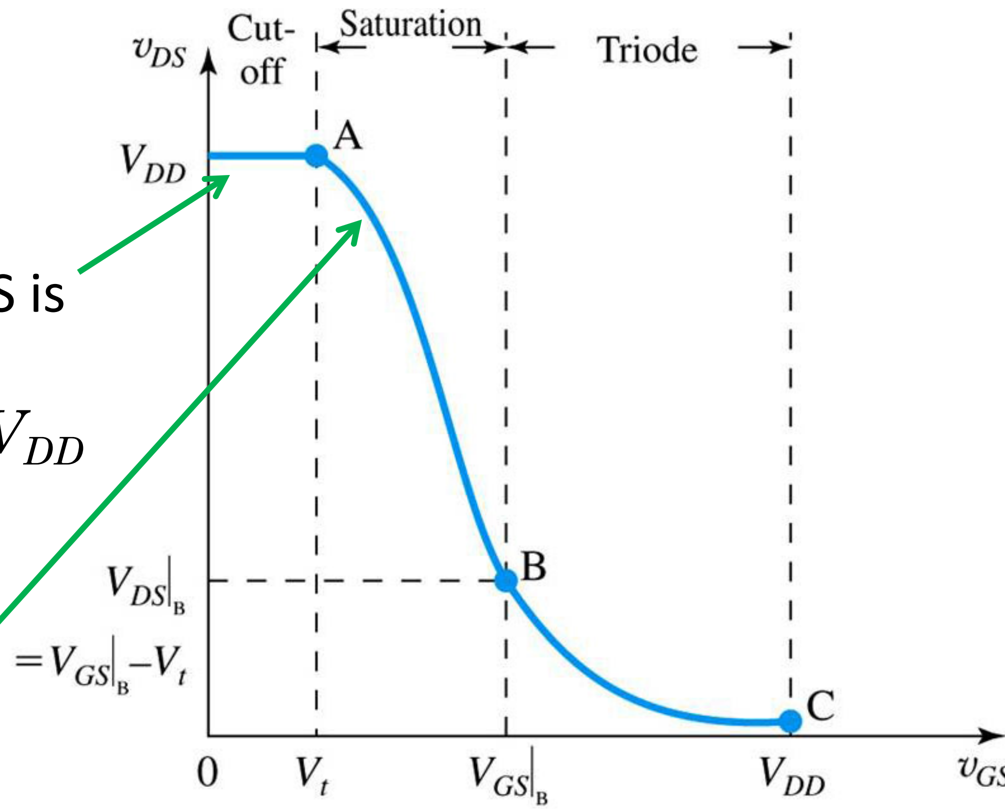
$$v_{GS} = v_i$$

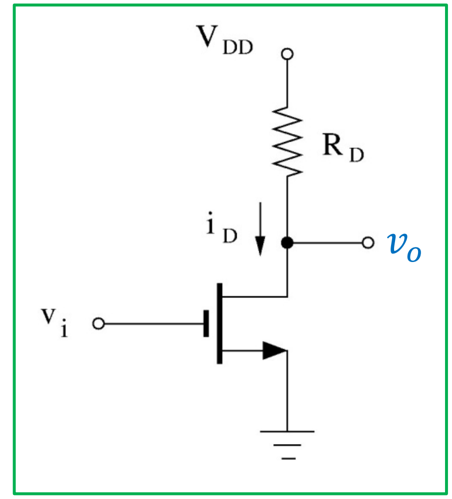
$$i_D = f\,(v_{GS}\ , v_{DS})$$

$$v_o = v_{DS} = V_{DD} - R_D\, i_D$$



NMOS Transfer Function





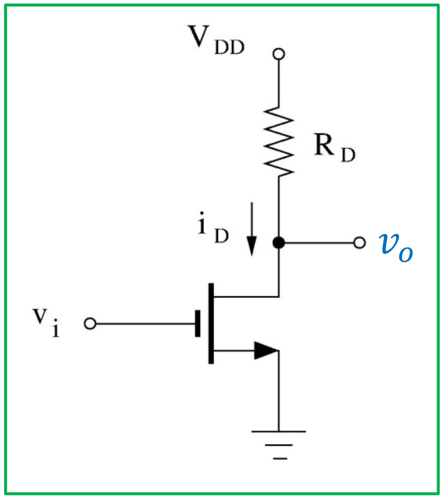
1) For $v_{GS} < V_t$, NMOS is in cutoff: $i_D = 0$ &

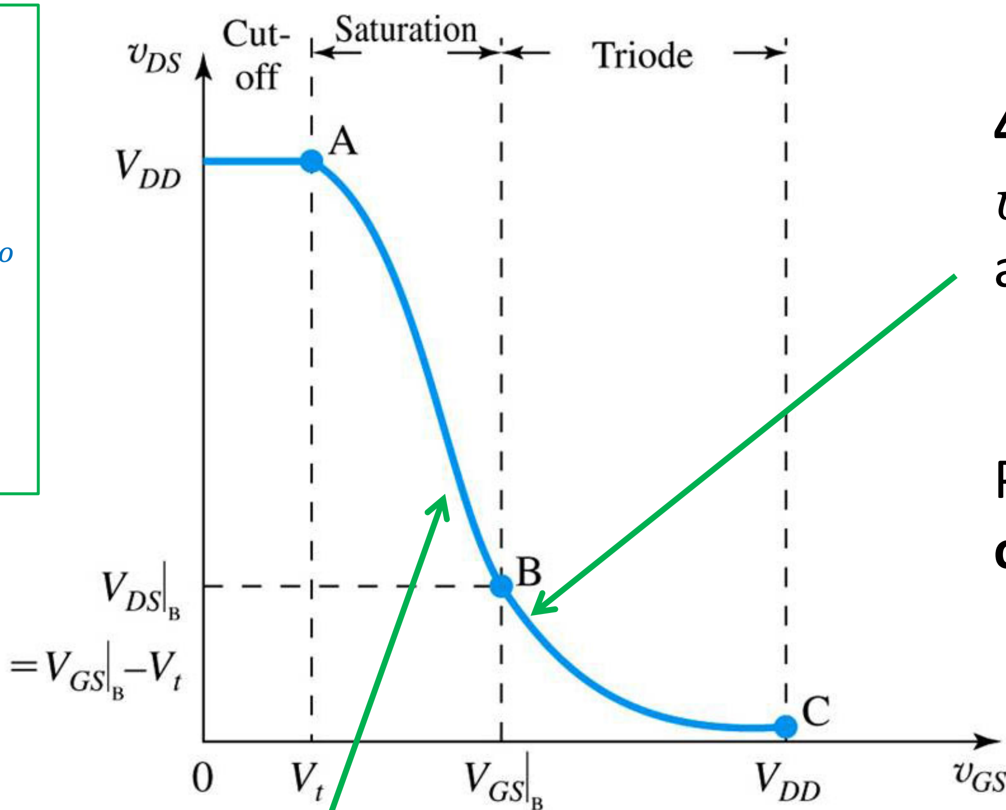
$v_{DS} = V_{DD} - R_D\, i_D = V_{DD}$

2) Just to the right of point A:

- $V_{OV} = v_{GS} - V_t$ is small, so i_D is small.
- $v_{DS} = V_{DD} - R_D\, i_D$ is close to V_{DD}
- Thus, $v_{DS} > V_{OV}$ and NMOS is in saturation.

NMOS Transfer Function





4) To the right of point B, $v_{DS} < V_{OV} = v_{GS} - V_t$ and NMOS enters triode.

Point B is called the **"Edge of Saturation"**

3) As v_{GS} increases:

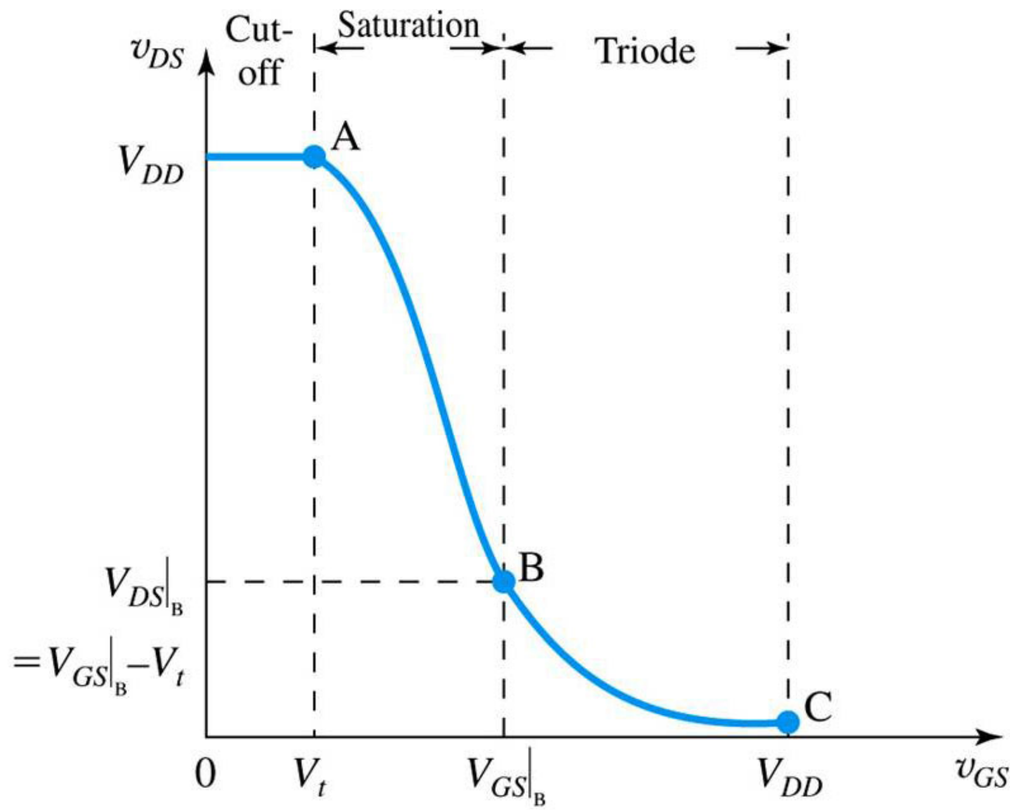
- $V_{OV} = v_{GS} - V_t$ and i_D become larger;
- $v_{DS} = V_{DD} - R_D\, i_D$ becomes smaller.
- At point B, $v_{DS} = V_{OV}$

NMOS Functional circuits

Transition from cut-off to triode can be used to build NMOS switch circuits.

- Voltage at point C (see graph) depends on NMOS parameters and the circuit (in BJT $v_o = V_{sat}$)!

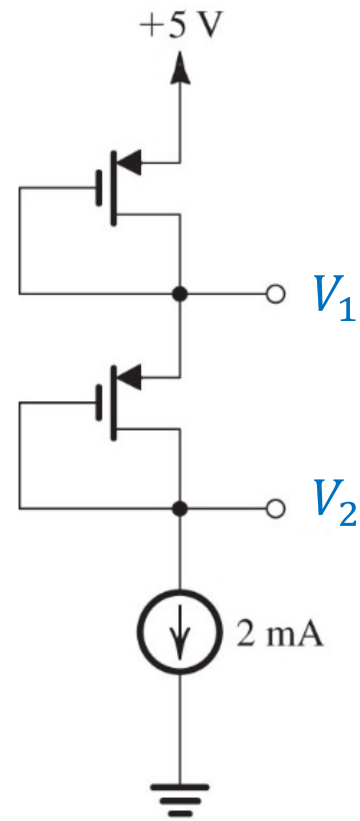
We can also build NMOS logic gates similar to a BJT. But there are much better gates based on CMOS technology!



Lecture 14 reading quiz

The transistors in the below circuit are characterized by $|V_t| = 0.5\ V$

k_p= $4\ mA/V^2$, $\lambda = 0$. Find the labeled node voltages.



Both transistors are in saturation because $V_{GD1} = V_{GD2} = 0$

$$i_{D1} = 0.5\ k_p(V_{SG1} - |V_t|)^2$$

$$i_{D1} = i_{D2} \rightarrow V_{SG1} = V_{SG2} \rightarrow V_{OV1} = V_{OV2}$$

$$i_D = 2\ mA = 0.5\ k_p V_{OV}^2 \rightarrow V_{OV} = 1\ V$$

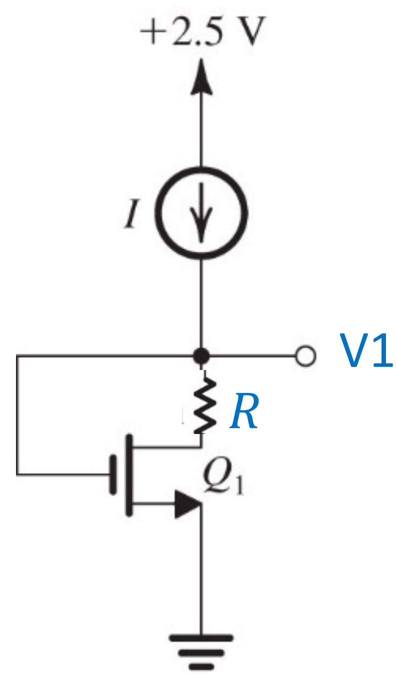
$$V_{OV} = V_{SG} - |V_t| \rightarrow V_{SG} = 1.5\ V$$

$$V_{SG1} = V_{SD1} = 5 - V_1 = 1.5\ V \rightarrow V_1 = 3.5\ V$$

$$V_{SG2} = V_{SD2} = V_1 - V_2 = 1.5\ V \rightarrow V_2 = 2\ V$$

Discussion question 1.

In the below MOSFET circuit, find the node voltage V1. How large a resistor can be inserted in series with the drain while maintaining saturation? $V_t = 0.5\ V$, $I = 0.1\ mA$, $V_{GS} = 1\ V$



Before adding the resistor,

$$V_{GS} = V_{DS} = V_1 = 1\ V$$

For the MOSFET to stay in saturation, $V_{DS} \geq V_{OV}$

$$V_{DS} \geq V_{GS} - V_t$$

After adding the resistor, $V_{GS} = \mathrm{I}\times\mathrm{R} + V_{DS}$

$$V_{DS} \geq \mathrm{I}\times\mathrm{R} + V_{DS} - V_t \quad \rightarrow \quad \mathrm{I}\times\mathrm{R} \leq V_t \quad \rightarrow \quad \mathrm{R} \leq \left(\frac{0.5\ \mathrm{V}}{0.1\ mA}\right)$$

$$\mathrm{R} \leq 5\ \mathrm{k\Omega}$$

Discussion question 2.

Design the following MOSFET circuit so that the transistor operates in saturation with $I_D = 0.5\ mA$ and $V_D = +3\ V$. Let PMOS have $V_{tp} = -1\ V$, k_p= $1\ mA/V^2$, $\lambda = 0$.

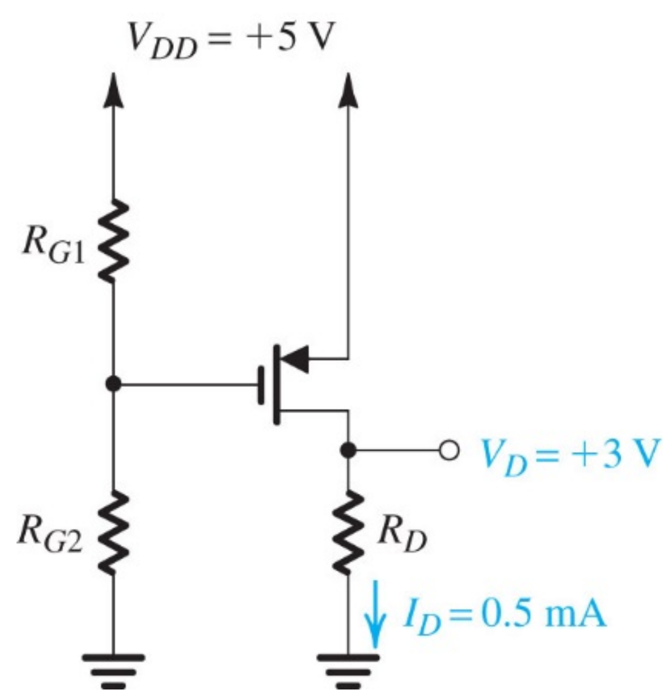
$$\boxed{I_D = 0.5\ k_p (V_{OV})^2}$$

$$0.5\ mA = 0.5\times\left(\frac{1mA}{V^2}\right)\times(V_{OV})^2$$

$$|V_{OV}| = 1\ V \quad \rightarrow V_{SG} = 1 + 1 \rightarrow V_{SG} = 2\ V$$

$$V_{SG} = V_S - V_G = 5 - V_G = 2\ V$$

$$V_G = 3\ V \quad \rightarrow \quad \frac{R_{G2}}{R_{G2} + R_{G1}} V_{DD} = V_G = 3\ V$$



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$$\frac{R_{G2}}{R_{G2}+R_{G1}} V_{DD} = V_G = 3\ V$$

One possible selection is

$R_{G2} = 3\ M\Omega$ and $R_{G1} = 2\ M\Omega$

$$R_D = \frac{V_D}{I_D} \rightarrow R_D = 6\ k\Omega$$