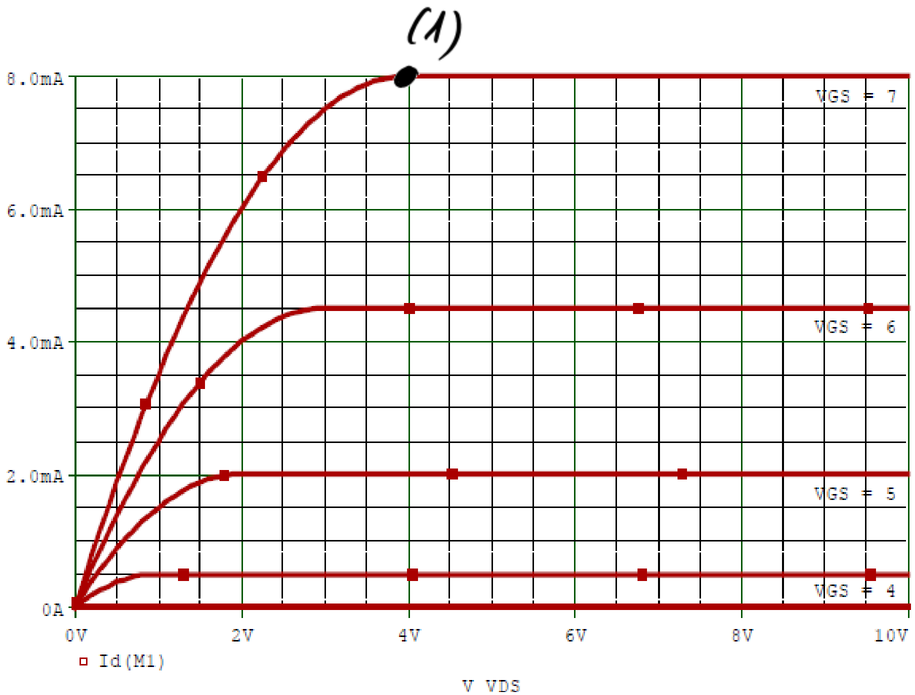
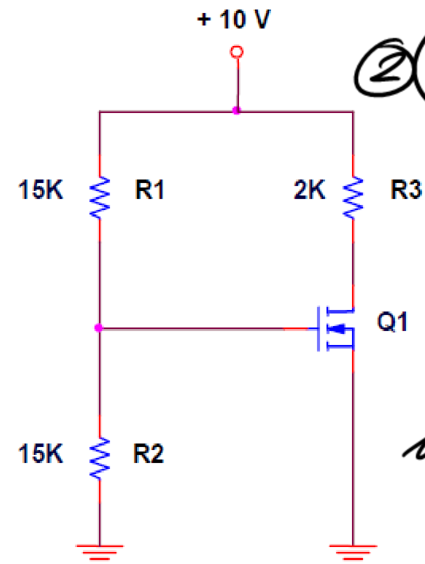
UNIT 2. MOSFETS: OPERATING POINT

3.6 The MOS transistor in the circuit of Figure B has a characteristic curve as shown in Figure A. Answer the following questions.





② V_T Easy way

ΔV_{GS} of curves: 1V

$\Rightarrow V_T = 3V$

More accurate: point (1) is in limit OHMIC–SAT:

$V_{DS} = V_{GS} - V_T \Rightarrow$

$V_T = V_{GS} - V_{DS} = 7 - 4 = 3V$

③ K Saturation

$I_{DS} = K(V_{GS} - V_T)^2 \Rightarrow$

$$K = \frac{I_{DS}}{(V_{GS}-V_T)^2} = \frac{8}{(7-3)^2} = 0.5\ \frac{mA}{V^2}$$

④ $V_{GS} = 10 \dfrac{R_2}{R_1+R_2} = 5V$

QUESTIONS	ANSWERS
1. Indicate the type of transistor:	n
2. V_T value	3 (Volts)
3. K value	0.5 (mA/V^2)
4. Obtain thevoltage V_{GS}in the circuit.	5V (Volts)
5. Obtain the current I_D.	(mA)
6. Obtain the voltage V_{DS}.	(Volts)
7. ¿What is the limit value of $R_3$to puttheMOSFET in the ohmic region?	(kΩ)

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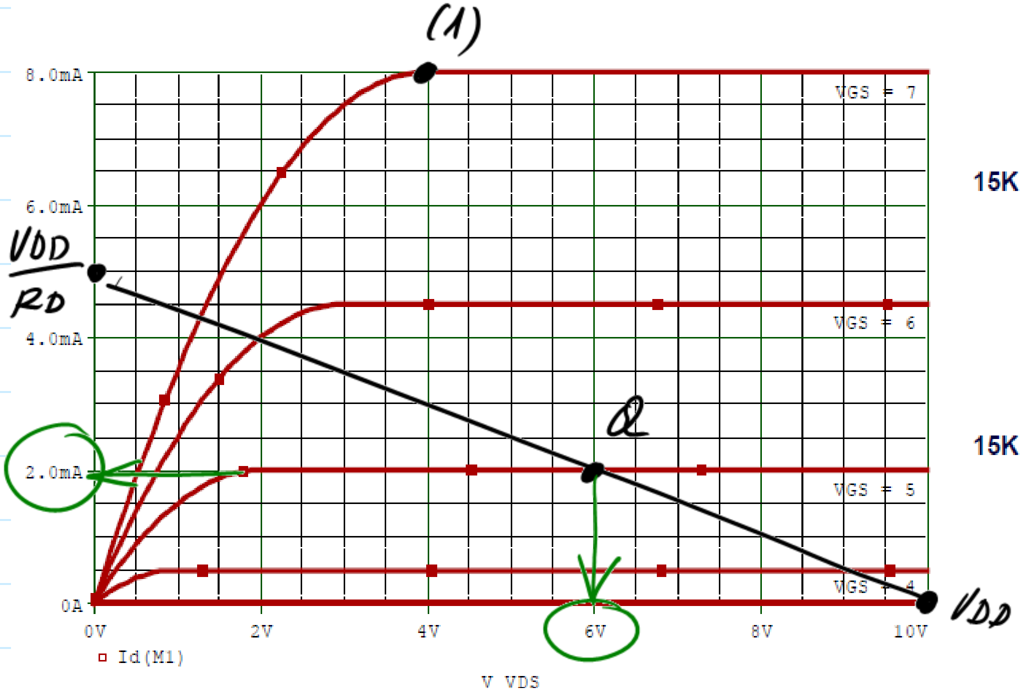
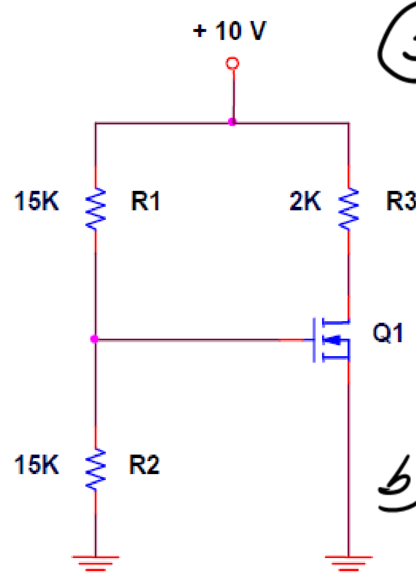




QUESTIONS	ANSWERS
1. Indicate the type of transistor:	n
2. V_T value	3 (Volts)
3. K value	0.5 (mA/V^2)
4. Obtain thevoltage V_{GS}in the circuit.	5 (Volts)
5. Obtain the current I_D.	2 (mA)
6. Obtain the voltage V_{DS}.	6 (Volts)
7. ¿What is the limit value of $R_3$to puttheMOSFET in the ohmic region?	4 (kΩ)

5) a) Load line:

X axis → $V_{DD} = 10V$

Y axis → $\frac{V_{DD}}{R_D} = 5mA$

Q point ($I_{DS} = 2mA$, $V_{DS} = 6V$)

b) analitically:

$V_{GS} = 5V > V_T \Rightarrow$ Q ON

assume sat ⇒

$I_{DS} = K(V_{GS} - V_T)^2 = 0.5(5-3)^2$

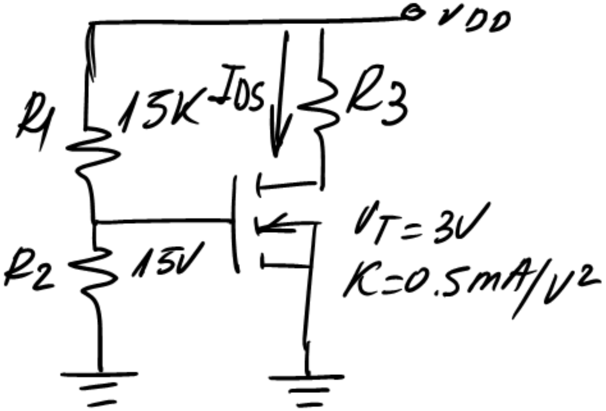
$I_{DS} = 2mA$

$V_{DS} = 10 - I_{DS} \cdot R_3 = 6V$

As $V_{DS} > V_G - V_T \Rightarrow$ Q1 SAT

and Q point is

Q ($V_{GS} = 5V$; $I_{DS} = 2mA$; $V_{DS} = 6V$)



$V_{GS} = 5V$

7 limit OHMIC — SAT

a) $V_{DS} = V_{GS} - V_T = 5 - 3 = 2V$

b) $I_{DS} = K\,(V_{GS} - V_T)^2 = 0.5(5-3)^2 = 2mA$

From output loop:

$V_{DD} = R_3 I_{DS} + V_{DS} \Rightarrow R_3 = \dfrac{V_{DD} - V_{DS}}{I_{DS}}$

$$R_3 = \frac{10-2}{2} = 4K$$

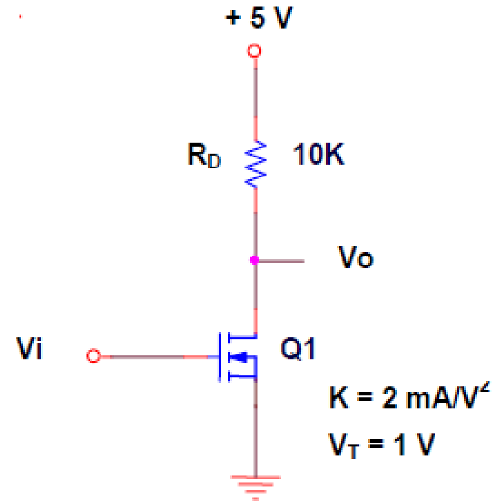
$R_3 > 4K \Rightarrow$ Ohmic

$R_3 < 4K \Rightarrow$ Saturation

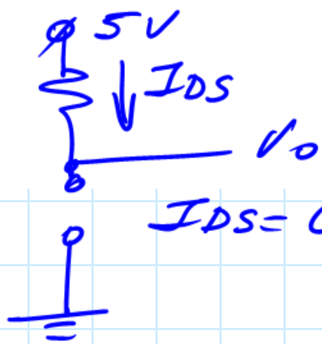
UNIT 2. MOSFETS: OPERATING POINT

5.1 Indicate the output voltage levels of the logic inverter of figure if Vi is a square wave with values from 0V to 5V. Use the approximate expression for the ohmic region of transistor: $I_{DS} \approx 2K(V_{GS}-V_T)V_{DS}$.

[A] 5 V y 1 V
[B] 5 V y 0.03 V
[C] 5 V y 0.5 V
[D] 2.5 V y 0.5 V



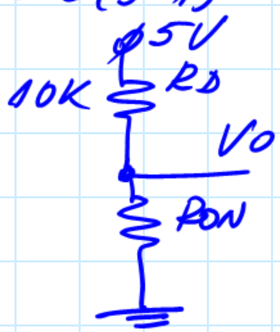
a) $V_i = 0V < V_T \Rightarrow Q_1$ OFF $\Rightarrow$



$I_{DS} = 0 \Rightarrow V_o = 5V$

b) $V_i = 5 > V_T \Rightarrow Q_1$ ON; assume OHMIC $\Rightarrow R_{ON} = \frac{1}{2K(V_{GS}-V_T)}$

$R_{ON} = \frac{1}{2 \cdot 2(5-1)} = 0.0625K$



$\boxed{V_o = 5\frac{R_{ON}}{R_D+R_{ON}}} = 0.031V = V_{DS}$

as $V_{DS} = 0.031 < V_{GS} - V_T = 4V \Rightarrow Q_1$ is in ohmic (linear) region

UNIT 2. MOSFETS: OPERATING POINT

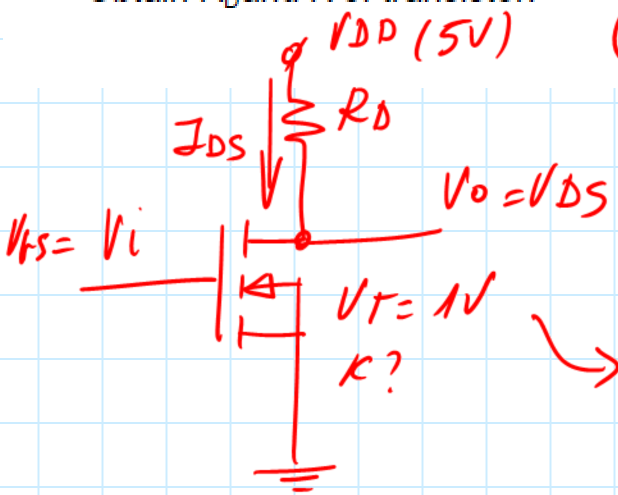
(5.8) Design a NMOS inverter with a pull-up resistor R_D, with the following requirements:

- Static power consumption when the output is low = 0.10 mW
- V_{OL} = 0.5V
- $V_{OH} = V_{DD}$ = 5V
- Transistor: V_T = 1V

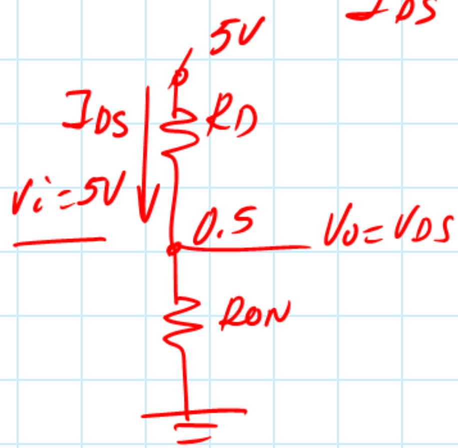
$P_L = V_{DD} \cdot I_{DS}$; $I_{DS} = \frac{P_L}{V_{DD}} = \frac{0.1}{5} = 0.02mA$

Obtain R_D and K of transistor.

② $V_{DD} - I_{DS}R_D - V_{DS} = 0 \Rightarrow$



$R_D = \frac{V_{DD} - V_{DS}}{I_{DS}} = \frac{5-0.5}{0.02} = \underline{\underline{225K}}$



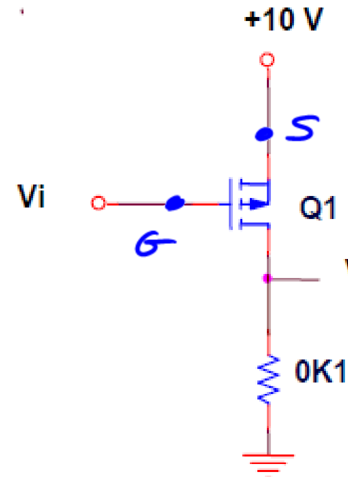
$R_{ON} = \frac{V_o}{I_{DS}} = \frac{0.5}{0.02} = \underline{\underline{25K}}$

$R_{ON} = \frac{1}{2K(V_{GS} - V_T)}$

$K = \frac{1}{2R_{ON}(V_{GS} - V_T)} = \frac{1}{2 \cdot 25(5-1)}$

$= 5 \cdot 10^{-3}\, mA/V^2 = \underline{\underline{5\, \mu A/V^2}}$

(5.7) Given the switch of the figure, with a control input Vi which is a square wave varyingbetween 0 and V_{DD}, answer the following questions:



$V_G = 0 \Rightarrow$

$V_{GS} = -10V < -V_T \Rightarrow$

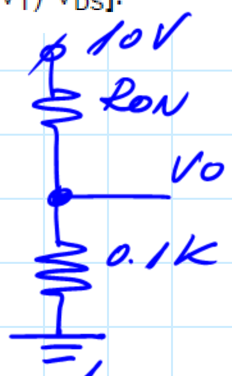
Q_1 ON

[A] Considering the transistor as a voltage-controlled variable resistor, calculate its resistance value when closed, so that the value of the output voltage is 0.01 V.

[B] If V_T of transistor is 2 V, find the value of K of the transistor. To do so, consider that in the ohmic region (also called linear region) the current value I_{DS} can be approximated by the following expression:

$$I_{SD} \approx K\,[2\,(V_{GS}+V_T)\,V_{DS}].$$

[A]



$$V_o = 10\,\frac{0.1}{0.1+R_{ON}} = 0.01$$

$$0.01(0.1+R_{ON}) = 1 \Rightarrow R_{ON} = 99.9K$$

[B] $R_{ON} = \left|\dfrac{1}{2K(V_{GS}+V_T)}\right|$; $K = \left|\dfrac{1}{2R_{ON}(V_{GS}+V_T)}\right| = \left|\dfrac{1}{2\cdot 99.9(-10+2)}\right|$

$$K = 0.625\ \mu A/V^2$$