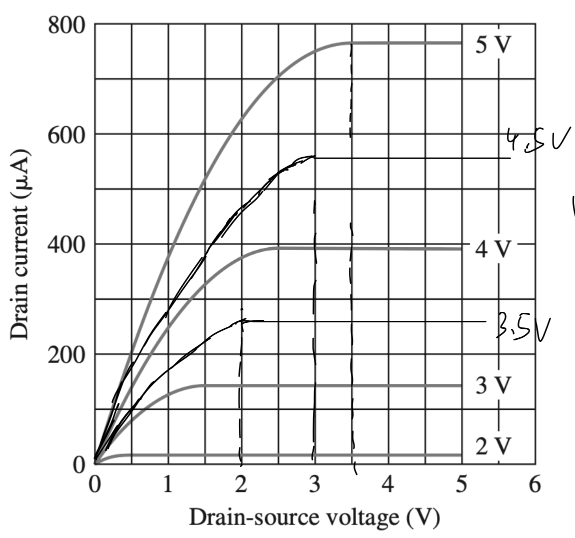
ECE3110J Electronic Circuit Homework 5
Due: **Jul 1st 11:59 a.m.**

Note.

1) Please use A4 size paper or page.
2) Please clearly state your final result for each question.
3) For questions asking for *plot*, you can either sketch or use computer software (Matlab, Python). But make sure to mark all the important values on the graph.

Christina, a talented young engineer, has recently joined Blue Tiger Electronics. Christina's demanding supervisor, Xuyang, is determined to outshine their rival company, Red Tiger Technologies, and secure a prestigious government contract that will ensure Blue Tiger's dominance in the industry. To achieve this, Xuyang assigns Christina a series of challenging tasks to demonstrate Blue Tiger's superior MOSFET technology.

Question 1. Saturation of the $I-V$ Characteristics
Xuyang shows a datasheet of an NMOS transistor but there is only one figure on it, as Fig. 1 shows. Christina knows that for any semiconductor component, one of the most important things is to learn the $I-V$ characteristics.



$V_{GS} - V_{th} = V_{DS}$

$V_{Th} = V_{GS} - V_{DS}$

$5V - 3.5V$

$4V - 2.5V$

$3V - 1.5V$

63×10^{-6}

FIGURE 1. $I-V$ curves

2.5

(1) She first determines the values of V_{TH} and k_n of this NMOS transistor.
(2) Then, she adds the $V_{GS} = 3.5V$ and $V_{GS} = 4.5V$ curves to Fig. 1.

(1). $V_{TH} = V_{GS} - V_{DS} = 5V - 3.5V = 1.5V$. $k_n = \mu_n C_{ox} \frac{W}{L}$.

$I_D = \frac{1}{2} k_n (V_{GS} - V_{Th})^2$ $\frac{1}{2} \cdot 2.5^2 \cdot k_n = 395 \times 10^{-6}$

$k_n = 1.26 \times 10^{-4}$.

(2).

Question 2. MOSFET DC Analysis I

Next, Xuyang assigns Christina the task of analyzing several simple circuits involving the MOSFET. For the circuits in Fig. 2, $V_{DD} = 3V$, $V_{TH} = 0.7V$ for NMOS, $V_{TH} = -0.8V$ for PMOS. She needs to sketch V_{out} as a function of V_{in} for each circuit as V_{in} varies from 0 to V_{DD}. Ignore body effect and channel length modulation.

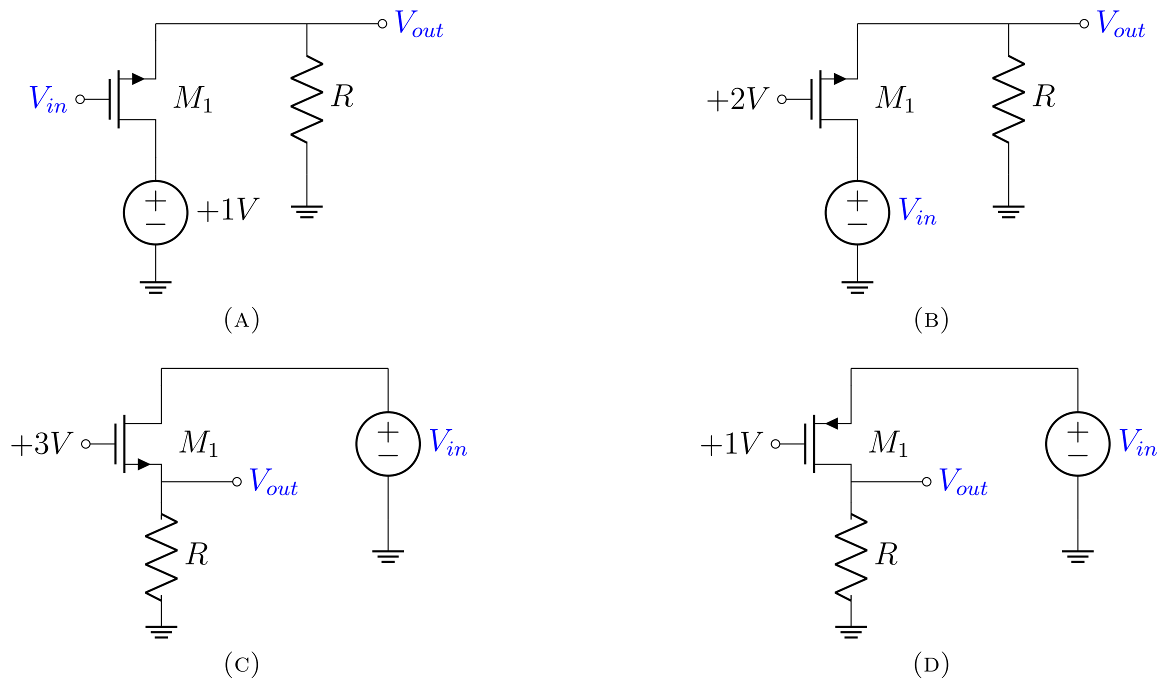
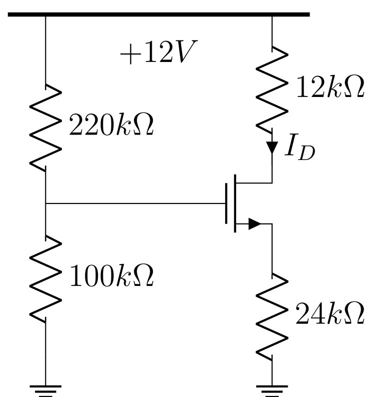


FIGURE 2. MOSFET circuits

Question 3. MOSFET DC Analysis II

Then, Xuyang assigns Christina the task of finding DC bias current I_D through the NMOS transistor in Fig. 3. $V_{TH} = 1V, \lambda = 0, k_n = \mu_n C_{ox}(W/L) = 500\mu A/V^2$.



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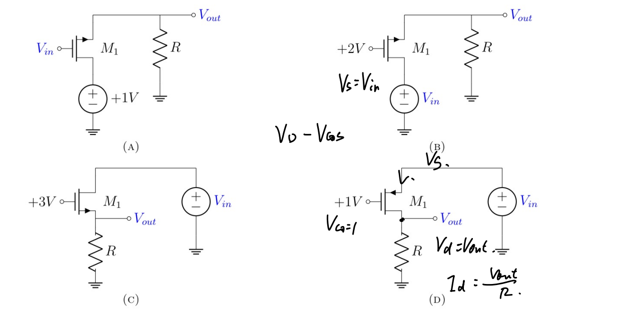
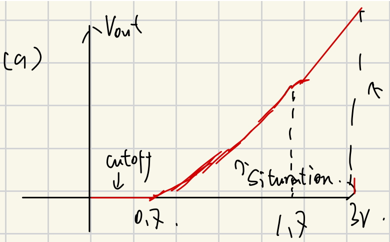


FIGURE 2. MOSFET circuits

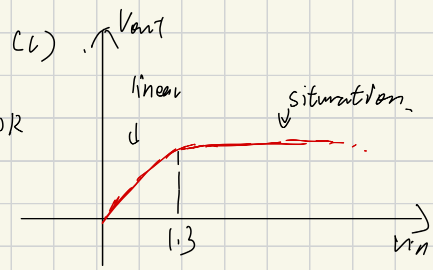
$V_{in} = \begin{cases} 0\text{-}2.3V & \text{linear, } V_s = I_D R_1 = kV_{DS} R_1 \\ 2.3V\text{-}3.0V, & \text{saturation } V_s = I_D R_1 = \frac{1}{2}k(V_G - V_S - 0.7)^2 R_1 \end{cases}$

(a)

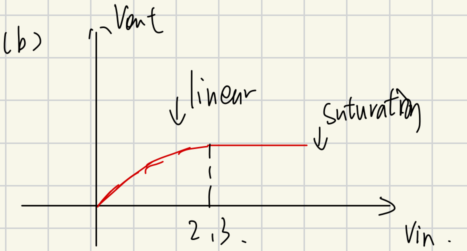


$V_{in} = \begin{cases} 0\text{-}0.7V. & \text{Cutoff } V_{out} = 0. \\ 0.7V\text{-}1.7V, & \text{saturation } V_s = I_D R_1 = \frac{1}{2}k(V_G - V_S - 0.7)^2 R \\ 1.7V\text{-}3V. & \text{linear } V_s = I_D R_1 = kR_1(V_{GS}). \end{cases}$

(c)

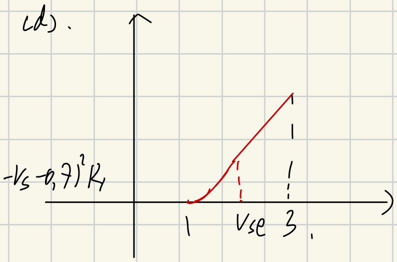


(b)



$V_{in} = \begin{cases} 0\text{-}1.3V & \text{linear } V_s = I_D R_1 = kV_{DS} R_1, \\ 1.3V\text{-}3V. & \text{saturation. } V_s = I_D R_1 = \frac{1}{2}k(V_G - V_S - 0.7)^2 R_1 \end{cases}$

(d).



$V_{in} \begin{cases} 0\text{-}1V & \text{cut off.} \\ 1V\text{-}V_{se}, & \text{saturation, } V_{out} = I_D R_1 = \frac{1}{2}k(V_S - V_G + V_{th})^2 R_1 \\ V_{se}\text{-}3V, & \text{linear, } V_{out} = I_D R_1 = kV_S R_1. \text{ linear.} \end{cases}$

Question 3. MOSFET DC Analysis II

Then, Xuyang assigns Christina the task of finding DC bias current I_D through the NMOS transistor in Fig. 3. $V_{TH} = 1V, \lambda = 0, k_n = \mu_n C_{ox}(W/L) = 500\mu A/V^2$.

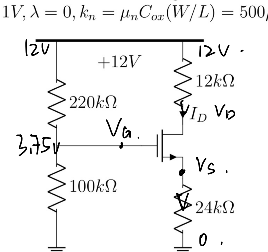


FIGURE 3. MOSFET circuit

$\begin{cases} I_D = \frac{V_S}{24\times10^3} \\ I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{Th})^2. \\ V_G = 3.75V. \end{cases}$

$\frac{1}{2} \cdot 500\times10^{-6}(3.75 - 1 - V_S)^2 = \frac{V_S}{24\times10^3}$.

$V_1 = 2.15V \qquad V_2 = 3.51V.$

Because $3.75 - 1 - V_S > 0.$

$V_S = 2.15V$

$I_D = \frac{2.15}{24\times10^3} = 0.09\times10^{-3} = 9\times10^{-5}$ A.

Question 4. MOSFET DC Analysis III

Finally, Xuyang assigns Christina the task of analyzing a complex circuit involving a combination of MOSFETs. For the circuit in Fig. 4, she needs to determine the labeled node voltages. The NMOS transistor has $V_{TH} = 0.9V$, $k_n = \mu_n C_{ox}(W/L) = 1.5mA/V^2$.

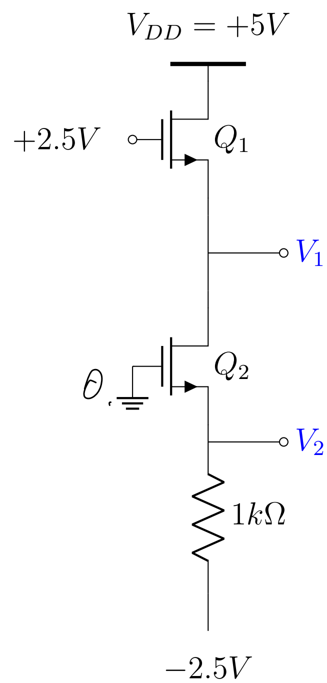


FIGURE 4. Two-MOSFET circuit

$$\begin{cases} \left(\frac{V_2+2.5}{10^3}\right) = \frac{1}{2}k_n\,(V_{GS_1} - V_{Th})^2. \\ \left(\frac{V_2+2.5}{10^3}\right) = \frac{1}{2}k_n\,(V_{GS_2} - V_{Th_2})^2. \end{cases}$$

$$\left(\frac{V_2+2.5}{10^3}\right) = \frac{1}{2}k_n\,(0 - V_2 - 0.9)^2.$$

$V_{21} = 1.37$. $V_{22} = -1.83$.

$0 - V_2 - 0.9 > 0$

$V_2 = -1.83V$.

$$\left(\frac{-1.83+2.5}{10^3}\right) = \frac{1}{2}k_n\,(2.5 - V_1 - 0.9)^2.$$

$V_1(1) = 0.65$ $V_1(2) = 2.54$

$2.5 - V_1 - 0.9 > 0$

$V_1 = 0.65V$.