Assignment 4

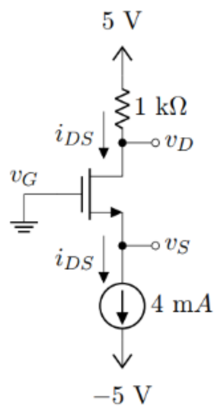
BRAC University

Semester: Fall 2022
Course No: CSE251
Course Title: Electronic Devices and Circuits

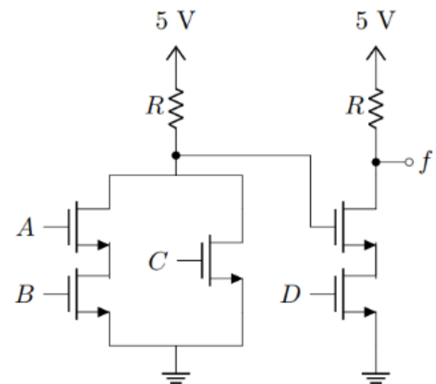
Full Marks: 10×4×2.5=100 [Bonus: 15]
Deadline: **15 December 2022**

Note: The formulas for a MOSFET are given in Ques 2.

1.



Circuit 1



Circuit 2

Part a: Refer to the **Circuit 1** above. For the MOSFET, $V_T = 1$ V and $k = k_n' \frac{W}{L} = 4\ \text{m}A/V^2$.

(a) **Identify** the value of the gate voltage v_G and the drain-source current i_{DS}. [0.5+0.5]

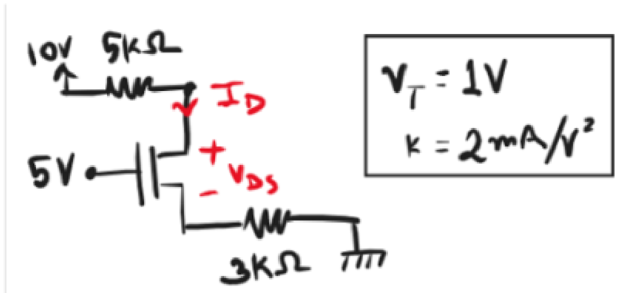
(b) **Calculate** the value of the drain voltage v_D using the 1 kΩ resistor. [1]

(c) **Analyze** the circuit to find v_S. Here, **use** the Method of Assumed State. You must **validate** your assumptions. [Hint: assume $v_S = x$] [3+2]

Part b: **Analyze** the **Circuit 2** above to find f in terms of *boolean* inputs A, B, C, and D. [3]

2.

Analyze the following circuit to find the values of I_D and V_{DS} **using** the Method of Assumed State. You must **validate** your assumptions.
Hint: Use I_D as unknown x. Use Ohm's law to represent V_D and V_S in terms of x.



For MOSFET

$$k = k_n' \frac{W}{L}$$

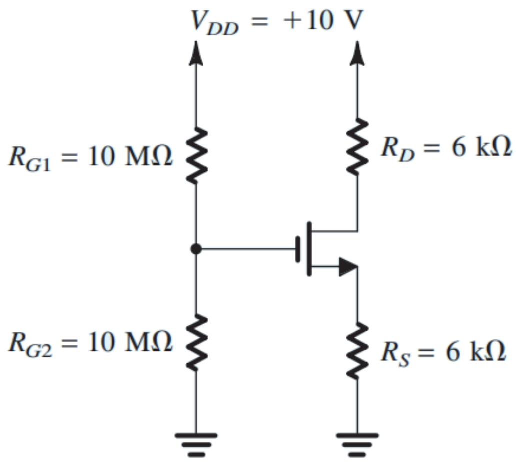
$$I_D = 0, \text{ if } V_{GS} < V_T$$

$$I_D = k\left[(V_{GS} - V_T)\,V_{DS} - \frac{1}{2}V_{DS}^2\right], \text{ if } V_{GS} \geq V_T \text{ and } V_{DS} < (V_{GS} - V_T)$$

$$I_D = \frac{1}{2}k\,(V_{GS} - V_T)^2, \text{ if } V_{GS} \geq V_T \text{ and } V_{DS} \geq (V_{GS} - V_T)$$

3. Consider an NMOS transistor fabricated with L = 0.18 μm and W = 2 μm. The process technology is specified to have k_n'=387 μA/V^2, and V_t = 0.5 V.
Find V_{GS} and V_{DS} that result in the MOSFET operating at the edge of the saturation region with I_{DS} = 150 μA. **[7+3]**

4. Analyze the circuit shown in the following Figure to determine the voltages at all nodes and the currents through all branches. Let V_T = 1 V and $k_n'(W/L)$ = 1 mA/V^2. **[10]** *[Hints: current at the gate terminal is zero for a MOSFET]*.



BONUS: An NMOS transistor is operating at the edge of saturation with an overdrive voltage V_{OV} and a drain current I_D. If V_{OV} is doubled, and we must maintain operation at the edge of saturation, what should V_{DS} be changed to? **Find** the value of drain current results. Does changing V_{OV} change the process parameter k? **[0.5+3+1.5]**

1.

Part-a

a) $V_G = 0, \quad i_{DS} = 4\,mA$

b) $V_D = 5 - 4 i_{DS} = 5 - 4 \times 1 = 5 - 4 = 1\,V$

c) Let, ... saturation

$i_{DS} = \frac{1}{2} K \left(V_{GS} - V_T\right)^2$

$\Rightarrow 4 = \frac{1}{2} \times 4 \times \left(V_{GS} - 1\right)^2$

$\Rightarrow \left(V_{GS} - 1\right)^2 = 2 \qquad \therefore V_{ov} = 1.414\,V$

$\therefore V_{GS} = 1 + \sqrt{2} > V_T \qquad \Rightarrow V_G - V_S = 1 + \sqrt{2}$

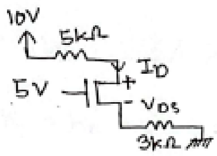
$\therefore V_S = -2.414\,V$

Here, $V_{DS} = 1 + 2.414 = 3.414 > V_{ov}$

$\therefore$ assumption is correct.

Part-b

$f = \overline{\overline{AB + C}\,D}$



Here,

For 5kΩ, $I_D = \frac{10 - V_D}{5}$

$\therefore V_D = 10 - 5I_D = 10 - 5x$

again, for 3kΩ,

$I_D = \frac{V_S - 0}{3}$

$\therefore V_S = 3I_D = 3x$

So, $V_{GS} = V_G - V_S = 5 - 3x$

$V_{OV} = V_{GS} - V_T = 5 - 3x - 1 = 4 - 3x$

$V_{DS} = V_D - V_S = (10 - 5x) - 3x = 10 - 8x$

2.

Let's assume this is in saturation region.

$\therefore I_D = \frac{k}{2} V_{ov}^2$

$\Rightarrow x = \frac{2}{2}(4 - 3x)^2$

$\Rightarrow x = 16 - 24x + 9x^2$

$\Rightarrow 9x^2 - 25x + 16 = 0$

$\therefore x = 1.78$

$x = 1$

We have to take the smaller x.

$\therefore V_{GS} = 5 - 3x = 5 - 3 = 2$

$V_{ov} = (5 - 3 \times 1) - 1 = 1$

$V_{DS} = 10 - 8 \times 1 = 2$

$\therefore V_{GS} \geqslant V_T$

and $V_{DS} \geqslant V_{OV}$

$\therefore$ The assumption is correct.

This is in saturation region. (Ans)

3.

and the transistor transconductance parameter k_n,

$$k_n = k_n'\left(\frac{W}{L}\right)$$

$$= 387\left(\frac{2}{0.18}\right) = 4.3 \text{ mA/V}^2$$

(a) With the transistor operating in saturation,

$$I_D = \frac{1}{2}k_n V_{OV}^2$$

Thus,

$$100 = \frac{1}{2} \times 4.3 \times 10^3 \times V_{OV}^2$$

which results in

$$V_{OV} = 0.22 \text{ V}$$

Thus,

$$V_{GS} = V_{tn} + V_{OV} = 0.5 + 0.22 = 0.72 \text{ V}$$

and since operation is at the edge of saturation,

$$V_{DS} = V_{OV} = 0.22 \text{ V}$$

4.

Since the gate current is zero, the voltage at the gate is simply determined by the voltage divider formed by the two 10-MΩ resistors,

$$V_G = V_{DD}\frac{R_{G2}}{R_{G2}+R_{G1}} = 10\times\frac{10}{10+10} = +5\text{ V}$$

With this positive voltage at the gate, the NMOS transistor will be turned on. We do not know, however, whether the transistor will be operating in the saturation region or in the triode region. We shall assume saturation-region operation, solve the problem, and then check the validity of our assumption. Obviously, if our assumption turns out not to be valid, we will have to solve the problem again for triode-region operation.

Refer to Fig. 5.24(b). Since the voltage at the gate is 5 V and the voltage at the source is $I_D\ (\text{mA})\times 6\ (\text{k}\Omega) = 6I_D$, we have

$$V_{GS} = 5 - 6I_D$$

Thus, I_D is given by

$$I_D = \frac{1}{2}k_n'\frac{W}{L}(V_{GS}-V_{tn})^2$$

$$= \frac{1}{2}\times 1\times(5-6I_D-1)^2$$

which results in the following quadratic equation in I_D:

$$18I_D^2 - 25I_D + 8 = 0$$

This equation yields two values for I_D: 0.89 mA and 0.5 mA. The first value results in a source voltage of $6\times 0.89 = 5.34\text{ V}$, which is greater than the gate voltage and does not make physical sense as it would imply that the NMOS transistor is cut off. Thus,

$$I_D = 0.5\text{ mA}$$

$$V_S = 0.5\times 6 = +3\text{ V}$$

$$V_{GS} = 5-3 = 2\text{ V}$$

$$V_D = 10-6\times 0.5 = +7\text{ V}$$

Since $V_D > V_G - V_{tn}$, the transistor is operating in saturation, as initially assumed.

BONUS:

Bonus:

We know,
at the edge of saturation region,

$$V_{DS} = V_{OV}$$

if V_{OV} is doubled,

$$V_{DS} = 2V_{OV}$$

here, $\frac{V_{DS}(new)}{V_{OV}(old)} = \frac{2\cancel{V_{OV}}}{\cancel{V_{OV}}} = 2$

$$\therefore V_{DS}(new) = 2 \cdot V_{OV}(old)$$

now, In the saturation region,

$$\frac{I_{DS}(new)}{I_{DS}(old)} = \frac{\frac{K}{2}[2V_{OV}]^2}{\frac{K}{2}[V_{OV}]^2}$$

$$\Rightarrow \frac{I_{DS}(new)}{I_{DS}(old)} = \frac{4\cancel{V_{OV}^2}}{\cancel{V_{OV}^2}}$$

$$\therefore I_{DS}(new) = 4 I_{DS}(old)$$

And changing V_{OV} does not change the process parameter K. (Ans:)