Name : Azmari Sultana

Id : 22201949

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Group : 03

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Experiment 04

Group No: 03

Experiment-04

Study of I-V Characteristics of MOSFET and Implementation of Logic Functions

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To observe and understand the I-V characteristics of MOSFET.
2. To implement a NAND gate and a Logic Function using MOSFETs and verify the truth tables.

Background Theory

Introduction to MOSFET

Three-terminal devices are far more useful than two-terminal ones (such as Diodes) because they can be used in a multitude of applications, ranging from signal amplification to digital logic and memory. The basic principle involved is the use of the voltage between two terminals to control the current flowing in the third terminal. In this way a three-terminal device can be used to realize a controlled source.

The control signal can be used to cause the current in the third terminal to change from zero to a large value, thus allowing the device to act as a switch. Switch is the basis for the realization of the logic inverter, which is a basic element of digital circuits.

There are two major types of three-terminal semiconductor devices: (i) MOSFET (Metal-Oxide Semiconductor Field-Effect Transistor) and (ii) BJT (Bipolar Junction Transistor). Although both of them offer unique features and areas of application, MOSFET has become by far the most widely used electronic device, especially in the design of integrated circuits (ICs).

There are two kinds of MOSFET: (i) NMOS and (ii) PMOS. In this experiment, we will study about the I-V characteristics of NMOS and design an NAND gate and a Boolean Logic Function using the NMOS transistor. The figure above shows the IC and the circuit diagram of a MOSFET (NMOS).

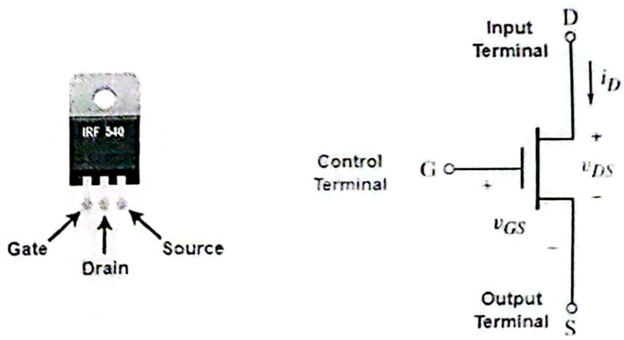


Figure 1: *NMOS IC (IRF540) and Circuit Diagram*

MOSFET as a Switch

MOSFET is a three-terminal device with a control terminal, an input terminal, and an output terminal. The control terminal of the MOSFET is called its gate G, the input terminal its drain D, and the output terminal its source S. MOSFET can act as a switch depending upon the applied voltage in the input terminal. A simple circuit model known as 'Switch Model' or 'S-Model' is used to model this behavior.

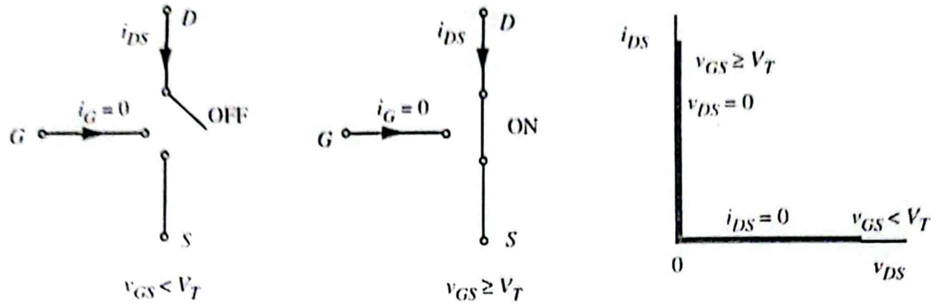


Figure 2: ***S-Model of MOSFET***

Note that the current $I_G = 0$. We can summarize the S-model of the MOSFET in algebraic form as:

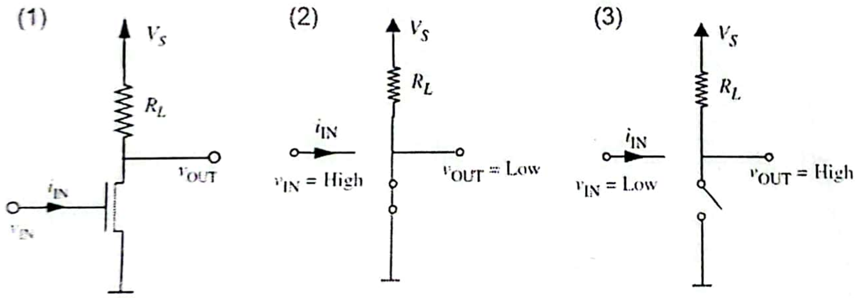
$$\text{when} \longrightarrow v_{GS} < V_T, \quad \text{then} \longrightarrow i_{DS} = 0 \quad \text{and} \quad \text{when} \longrightarrow v_{GS} \geq V_T, \quad \text{then} \longrightarrow v_{DS} = 0$$

MOSFET Switch Implementation of Logic Gates and Logic Functions

Switches can be used to build logic gates. As we can use MOSFET as a switch, logic gates can be built using MOSFETs. The following subsections discuss two logic gates, NOT gate and NAND gate, which are implemented using MOSFETs. We can also implement various Logic Functions using MOSFETs. To demonstrate this thing, a logic function will be implemented in Task-01.

NOT Gate/Inverter Using MOSFET

Consider the circuit shown in following figure, which comprises a MOSFET and a load resistor powered by a supply voltage V_S. This circuit acts as a NOT Gate/Inverter.



(4)

v_{IN}	v_{OUT}
$High \equiv 1$	$Low \equiv 0$
$Low \equiv 0$	$High \equiv 1$

Figure 3: ***(1) MOSFET NOT Gate (2) When Input is '1' (3) When Input is '0' (4) Truth Table***

NAND Gate Using MOSFET

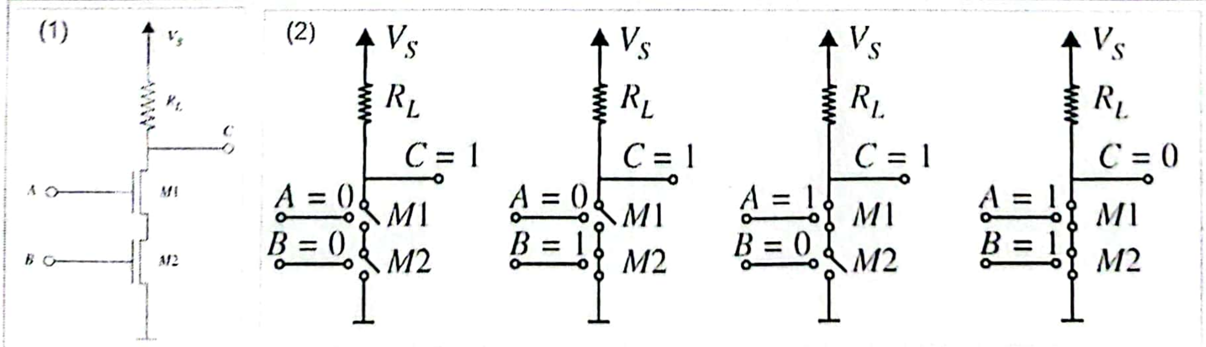


Figure 4: ***(1) MOSFET NAND Gate (2) Equivalent Circuits for Different Inputs***

Consider the circuit shown in the figure above, which comprises a two MOSFETs and a load resistor powered by a supply voltage V_S. This circuit acts as a NAND gate. NAND gate is a universal gate that can be used to implement any Logic Function.

Logic Function Using MOSFET

We can use combinations of MOSFETs to implement various logic funtions. The circuit shown in **Figure-5** implements $f = \overline{xy+z}$.

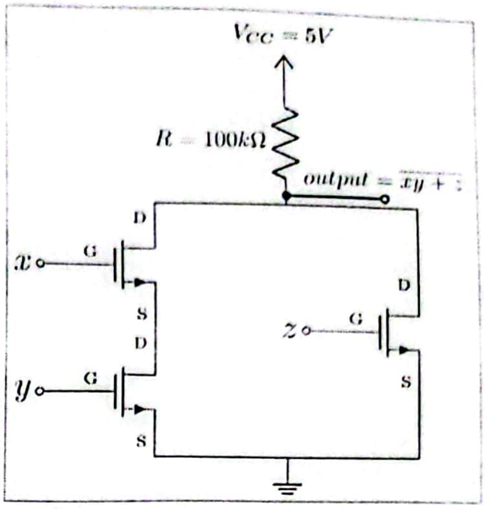


Figure 5: ***Logic Function using MOSFET***

I-V Characteristics of a MOSFET

The S-model of a MOSFET is a simplification of the actual I-V characteristics of a MOSFET which helps us understand the behavior of a MOSFET as a switch. But the actual I-V characteristics is very different from it.

Figure-6 represents the actual I-V characteristics of a MOSFET. There are 3 operating regions in the I-V characteristics graph: **Cut-off, Triode, Saturation.** The first two are useful if we want to use MOSFET as a switch. On the other hand, if we want to use MOSFET as an amplifier, we must operate it in the saturation region.

MOSFET's operating region depends on the applied voltages at Gate, Drain, Source terminals which can be seen in the I-V characteristics graph.

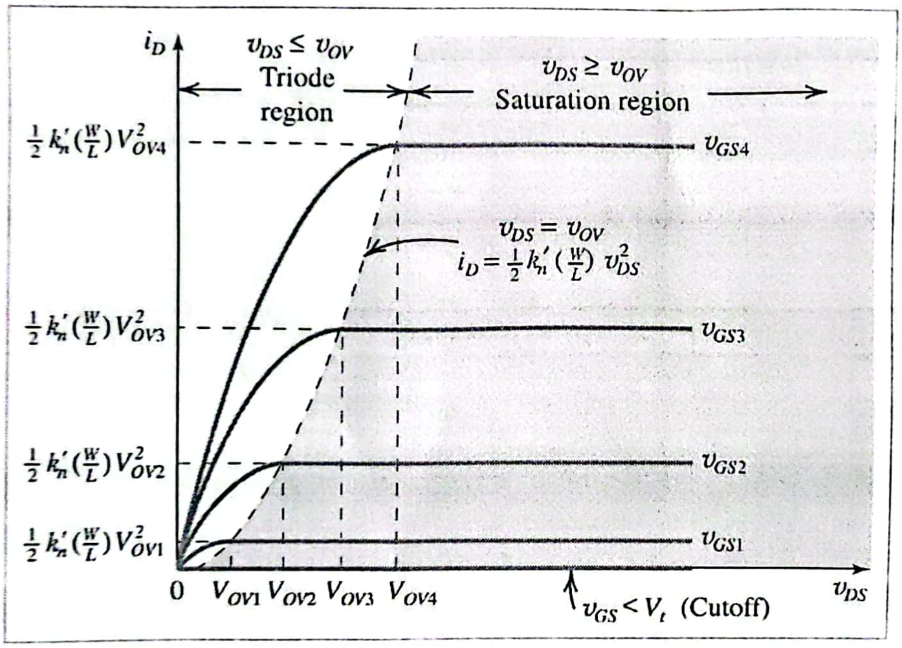


Figure 6: ***I-V Characteristics of a MOSFET***

In this graph

V_T = *Threshold Voltage*

v_{OV} = *Overdrive voltage*

L = *Channel Length*

W = *Channel Width*

k_n' = *Process Transconductance Parameter*

$v_{GS} = v_G - v_S$

$v_{DS} = v_D - v_S$

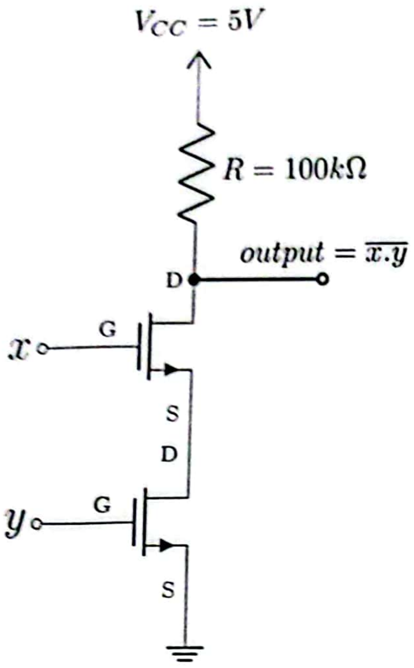
$v_{OV} = v_{GS} - V_T$

We can summarize the operating regions of as MOSFET as:

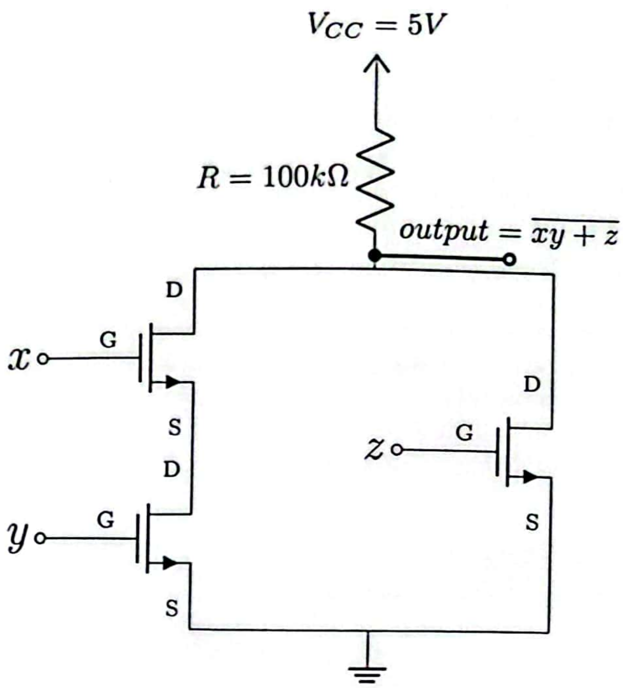
When	Operating Mode	Equation of Current
$v_{GS} < V_T$	Cutoff Mode	$i_D = 0$
$v_{GS} \geq V_T, v_{DS} \leq v_{OV}$	Triode Mode	$i_D = k_n'\,(W/L)\left(v_{OV} - \frac{1}{2}v_{DS}\right)v_{DS}$
$v_{GS} \geq V_T, v_{DS} > v_{OV}$	Saturation Mode	$i_D = \frac{1}{2}k_n'\,(W/L)\,v_{OV}^2$

The value of V_T is controlled during device fabrication and typically lies in the range of 0.3 V to 1 V. From the graph, we see that, for the same value of v_{DS}, i_{DS} increases if we increase v_{GS}. Also, for a lower value of v_{GS}, the MOSFET operates in Saturation for a lower value of v_{DS} and for higher value of v_{GS}, the MOSFET goes into Saturation for a higher value of v_{DS}.

Task-01: Logic Gate and Logic Function Implementation



Circuit-1
NAND Gate using MOSFET



Circuit-2
Logic Function, $f = \overline{xy + z}$ using MOSFET

Procedure

1. On a trainer board, setup the Circuit 1.
2. Connect the gate terminals (input x and y) to data switches. Those switches provide 5V approximately.
3. Keeping V_{CC} constant at 5V, at first turn off the data switches connected to the gate terminal. This implies you are now applying V_x= 0V, V_y= 0V. Measure the corresponding output voltage, V_{out} which should be approximately 5V which corresponds to boolean 1.
4. The boolean outputs can also be determined by the state of an LED. Connect V_{out} to one of the LEDs and check it. When the LED is ON, the boolean output is 1. Similarly, when the LED is OFF, the boolean output is 0.
5. Next, use the input voltage combinations of Data Table 1 and observe the state of LED again.
6. Verify the truth table of the NAND gate.
7. Now we will implement a Logic Function, f = $\overline{xy + z}$ using MOSFET. Circuit 2 in the figure shown above represents the Logic Function f = $\overline{xy + z}$. Setup Circuit 2 in a similar way to the procedure followed for Circuit 1.
8. Keeping V_{DD} constant at 5V, observe the state of the LED for different combinations of the inputs x, y and z as shown in Data Table 1.
9. Verify the truth table of the Logic Function, f = $\overline{xy + z}$.

Data Table 1: Verification of the Truth Tables of Logic Gate and Logic Function

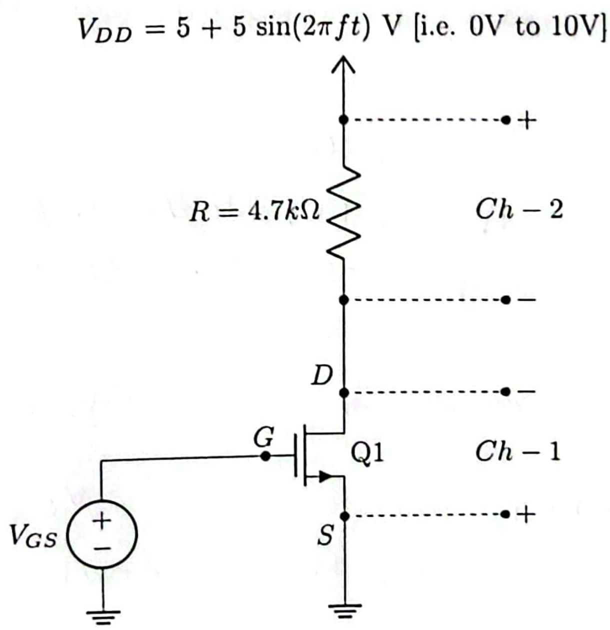
1. NAND Gate

Input Voltage, V_x (volt)	Input Voltage, V_y (volt)	State of LED (On/Off)	Boolean Output (0 or 1)
0V	0V	on	1
0V	5V	on	1
5V	0V	on	1
5V	5V	off	0

2. Logic Function, f = $\overline{xy + z}$

Input Voltage, V_x (volt)	Input Voltage, V_y (volt)	Input Voltage, V_z (volt)	State of LED (On/Off)	Boolean Output (0 or 1)
0V	0V	0V	on	1
0V	0V	5V	off	0
0V	5V	0V	on	1
0V	5V	5V	off	0
5V	0V	0V	on	1
5V	0V	5V	off	0
5V	5V	0V	off	0
5V	5V	5V	off	0

Task-02: I-V Characteristics of a MOSFET



Procedure

1. Construct the circuit shown above. Use a data switch and connect it to the Gate of the MOSFET which will provide necessary voltage for V_{GS}. Use the function generator for $V_{DD} = 5 + 5\sin(2\pi ft)$ V [i.e. an AC voltage that varies from 0V to 10V] and set $f = 50$ Hz.

2. Set the oscilloscope in X-Y mode. Invert the Channel-1.
3. Observe the plot in the oscilloscope when the data switch is ON and OFF. This plot shows the I-V characteristics of a MOSFET as a switch. Capture the plots using your mobile camera.
4. Now, disconnect the data switch from the gate of the MOSFET and connect the dc power supply to the gate terminal so that we can increase or decrease V_{GS}.
5. Rotate the voltage knob of the dc power supply slowly from 0V to 5V. You should observe the change in the I-V characteristics.
6. Use your mobile camera to capture the image of the I-V characteristics graphs for 3 different V_{GS}. Measure the values of V_{GS} of the captured images and write them in Data Table 2.

Data Table 2: Different Values of V_{GS} to observe the change in MOSFET I-V Characteristics

Values of V_{GS}	
1st Value	0
2nd Value	3.5
3rd Value	2.8

21/12/24

Signature of the lab faculty

Test Your Understanding

Answer the following questions:

1. We can use the MOSFET as a switch. Which operating regions do we need for this purpose and why? *[2 marks]*

Answer: The operating regions are cutoff region and saturation region.

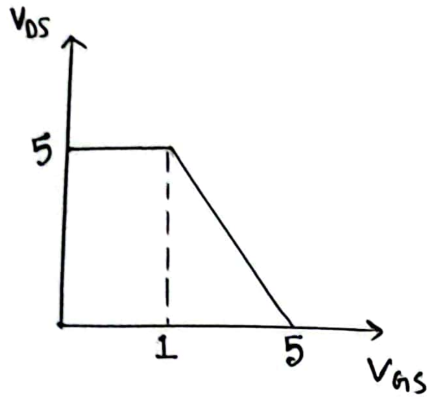
i) cutoff → if switch off

In this region, the MOSFET doesn't conduct and $V_{GS} < V_{th}$ ~~so~~ It acts like a open circuit. so the current $I_{DS} \cong 0$.

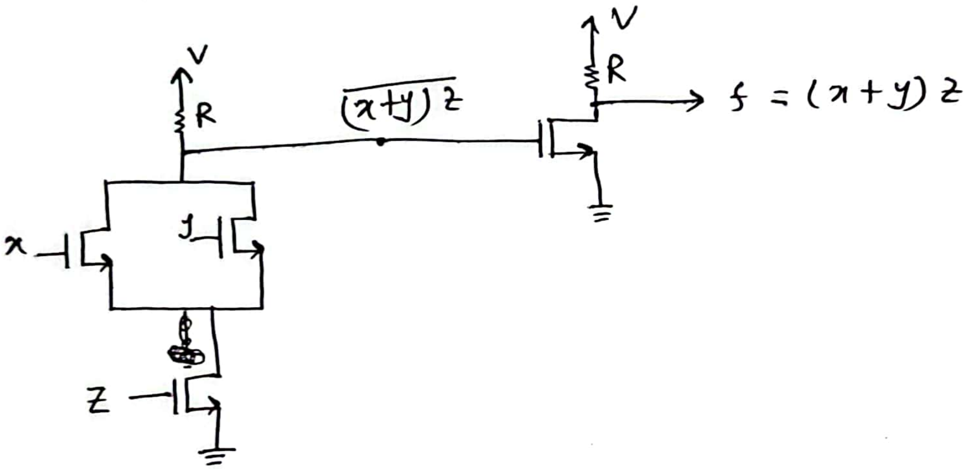
ii) Saturation region → if switch on

Here the MOSFET conducts fully. $V_{GS} > V_{th}$ and V_{DS} is large enough that the MOSFET reaches saturation. It acts like a close circuit with low resistance and here I_{DS} flows as per equation. $I_{DS} = k(V_{GS} - V_{th})^2$

2. Draw the VTC (V_{DS} vs V_{GS}) graph of a MOSFET inverter operating as a switch.
Answer: *[1 mark]*

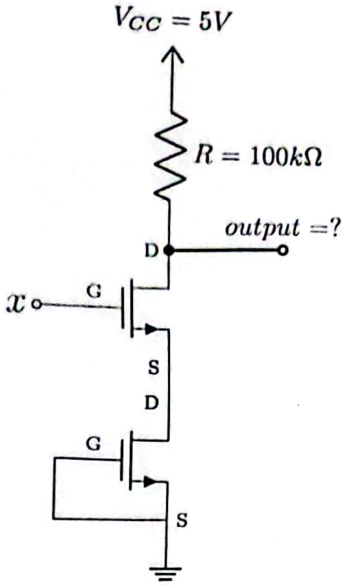


3. Draw a circuit using MOSFETs that implements the following logic function, $f = (x+y)z$
Answer: *[2 marks]*



4. When a MOSFET is in triode mode, does it display zero, finite or infinite resistance? Justify your answer.
Answer: *[2 marks]*

When a MOSFET is in triode mode, it display finite resistance. It allows current flow with a resistance determined by V_{GS} and V_{DS}. and it behaves like a voltage controlled resistor. There is a voltage drop VDS and a corresponding current IDS, So the resintance can't be zero. Because of the current flow through MOSFET, it can't be infinite.



5. What is the value of the output of the circuit above?
Answer: *[2 marks]*

No current will flow through the MOSFET, because gate terminal is grounded and output voltage will be 5V

$[V_{GS} = 0 < V_T]$

6. If $V_{DS} = 3V$, $V_{GS} = 3V$ and $V_T = 1V$, find the gate current, drain current and source current of a MOSFET given that $k = 0.5mA/V^2$.
Answer: *[1 mark]*

$i_G = 0 A$

$i_D = i_S = k(V_{GS} - V_T)^2$

$= 0.5(3-1)^2$

$= 2 mA$

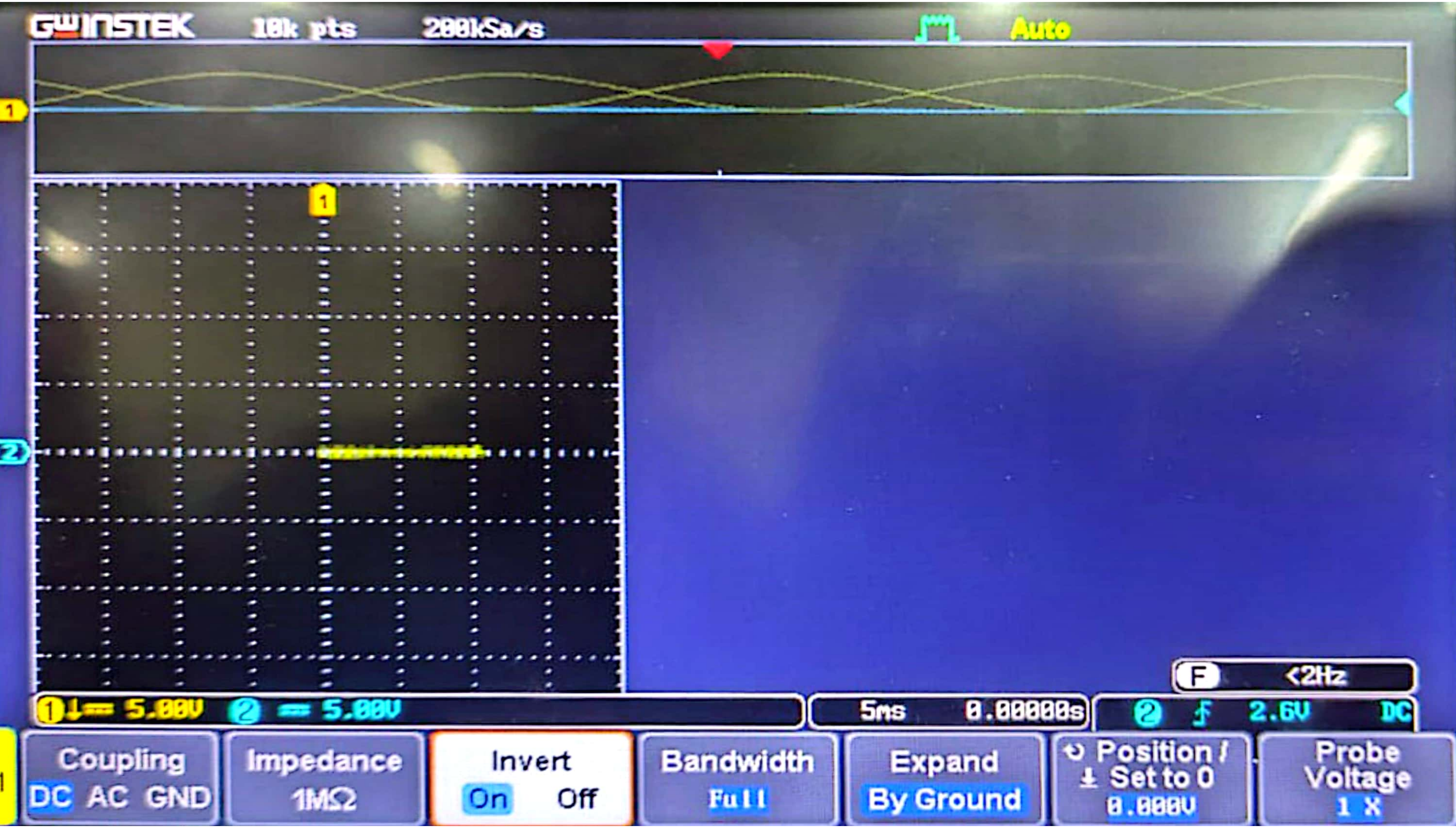
$\therefore i_G = 0A$

$i_D = 2mA$

$i_S = 2mA$

Discussion

In this experiment, to implement logic gates, we used MOSFETS. It is divided into three region - cutoff, triode and saturation. Using the MOSFET in series connection replicates AND gate and in parallel connection, it represents OR gate through which we implemented some logic function. When $V_{GS} > V_T$, then the MOSFETs act as ON switch by letting current flow. Again when $V_{GS} < V_T$, then the MOSFET act as ~~ON~~ OFF switch that represents open circuit where current doesnot flow. We also saw the I-V characteristics of MOSFET and how it overcomes the V_T in the graph.



GW INSTEK
10k pts
200kSa/s
Auto
1 = 5.00V
2 = 5.00V
5ms
0.00000s
F
<2Hz
2
2.6V
DC
Coupling
DC AC GND
Impedance
1MΩ
Invert
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Bandwidth
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Expand
By Ground
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0.000V
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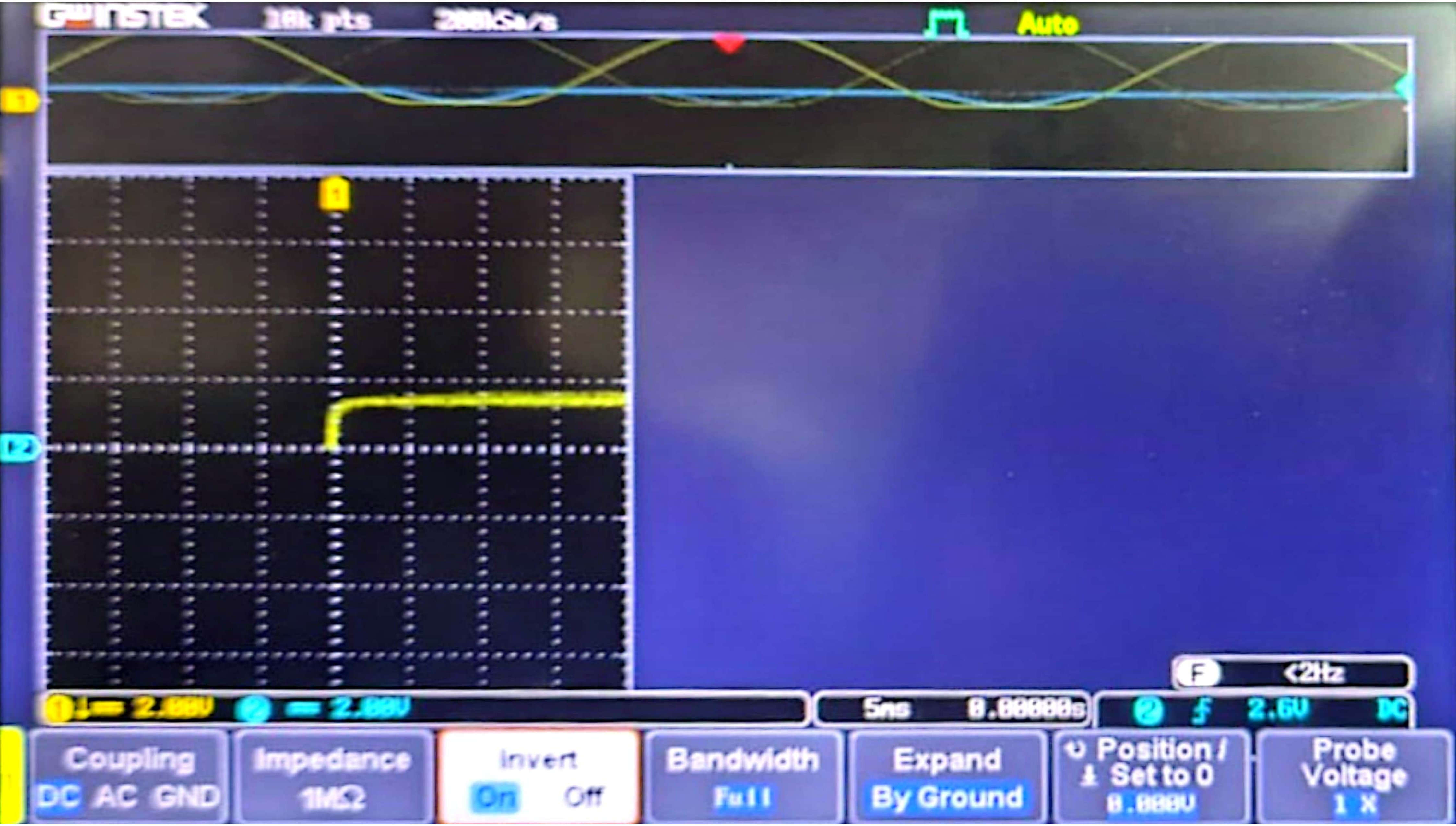
Auto
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