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Experiment-05

Study of MOSFET I-V Characteristics and Implementation of Logic Gates Using MOSFETs

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To implement a NAND gate and a Logical Function using MOSFETs and verify the truth tables.

2. To observe and understand the IV characteristics of a MOSFET.

Equipments

1. MOSFET (IRF 540) - $\times 3$

2. Resistance $(4.7k\Omega, 100k\Omega)$

3. DC power supply

4. Oscilloscope

5. Trainer Board

6. Breadboard

7. Chords and Wire

Background Theory

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 IV characteristics of NMOS and design a NOT gate and a NAND gate using the NMOS transistor.
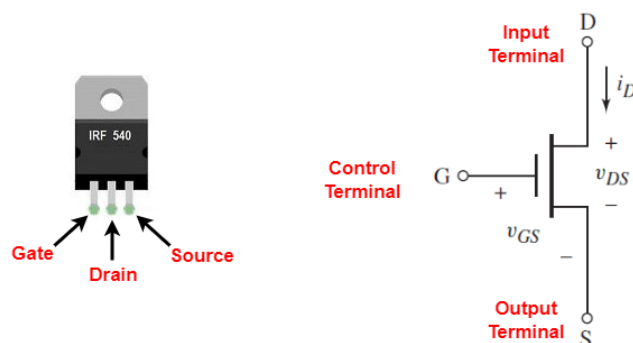

Figure 1: IC and Circuit Diagram of a MOSFET (NMOS)

The figure above shows the IC and the circuit diagram of a MOSFET.

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.
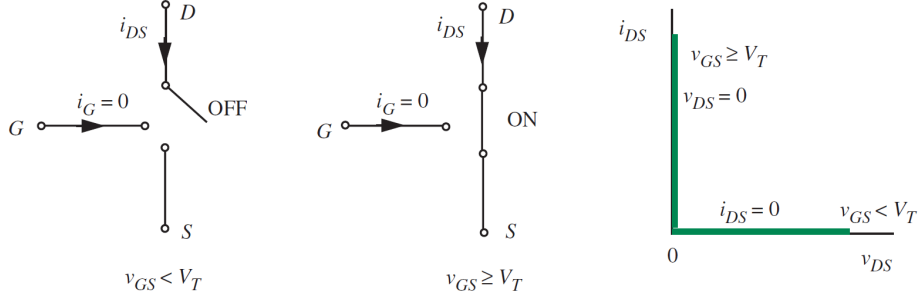

Figure 2: S-Model of MOSFET

We can summarize the S-model of the MOSFET in algebraic form as:

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

MOSFET Switch Implementation of Logic Gates and Logical 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 Logical Functions using MOSFETs. To demonstrate this thing, a logical 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.
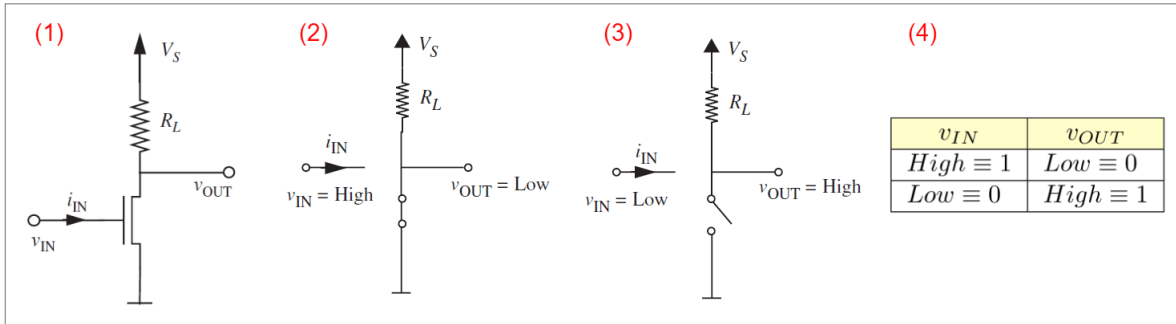

Figure 3: (1) MOSFET NOT Gate (2) When Input is '1' (3) When Input is '0' (4) Truth Table
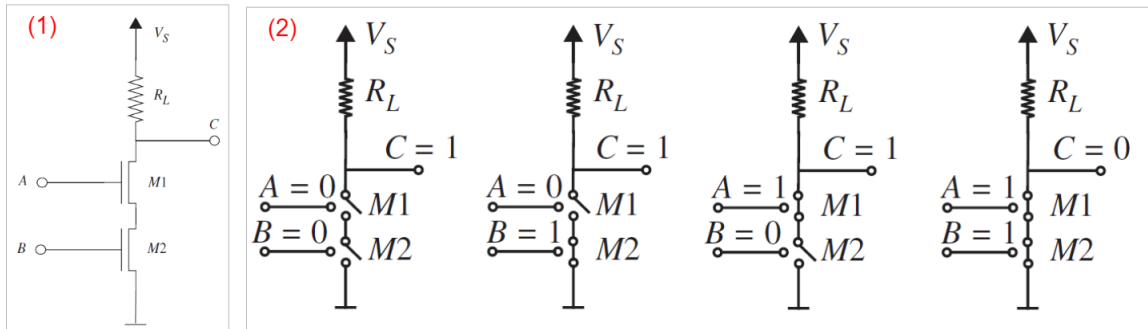
NAND Gate Using MOSFET

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 logical function.

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. The following figure represents the actual I-V characteristics of a MOSFET. There are 3 operating regions in the I-V characteristics graph: **Cutoff, 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.
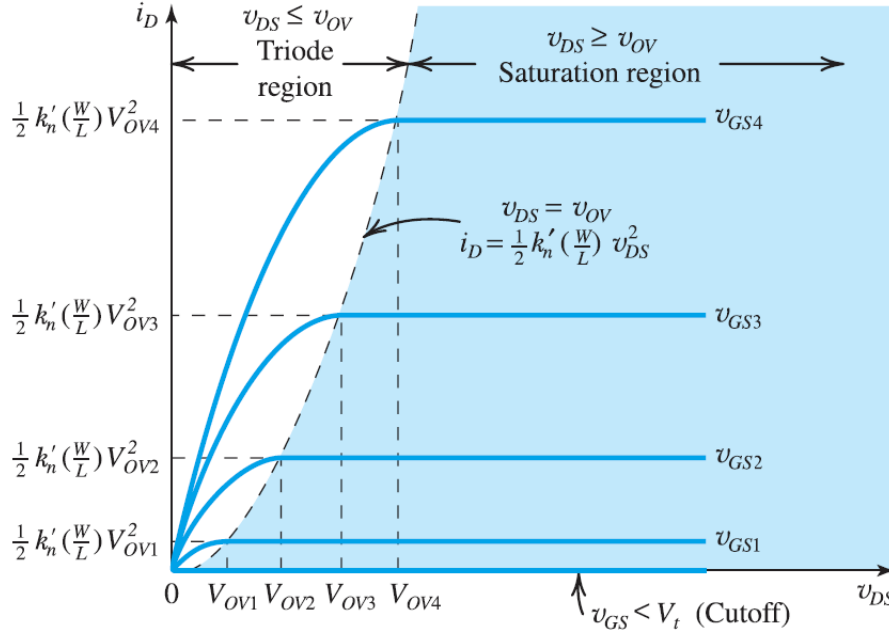

Figure 5: I-V Characteristics of a MOSFET

We can summarize the operating regions of as MOSFET as:

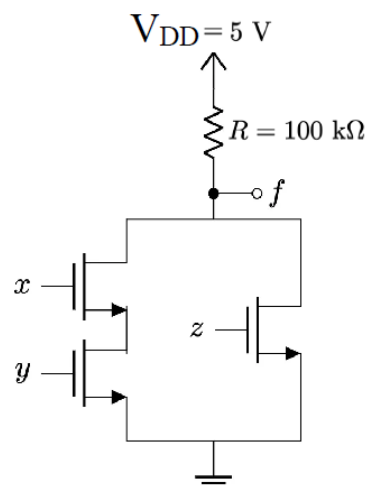| When	Operating Mode	Equation of Current
$v_{GS} < V_T$	Cutoff Mode	$i_D = 0$
$v_{GS} \geq V_T, v_{DS} \leq v_{OV}$	Triode Mode	$i_D = k'_n \left(W/L \right) \left(v_{OV} - \frac{1}{2} v_{DS} \right) v_{DS}$
$v_{GS} \geq V_T, v_{DS} > v_{OV}$	Saturation Mode	$i_D = \frac{1}{2} k'_n \left(W/L \right)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

here, V_T = **Threshold Voltage**, v_{OV} = **Overdrive voltage**
L = **Channel Length**, W = **Channel Width**
k'_n = **Process Transconductance Parameter**
$v_{GS} = v_G - v_S$, $v_{DS} = v_D - v_S$, $v_{OV} = v_{GS} - V_T$

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 Logical Function Implementation using MOSFET
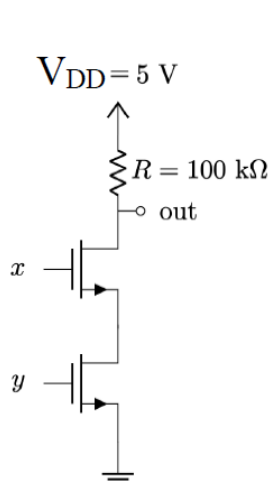
Circuit 1: NAND gate using MOSFET   **Circuit 2: Logical Function f = $\overline{xy+z}$ using MOSFET**

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_{DD} 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 Logical Function, $f = \overline{xy + z}$ using MOSFET. Circuit 2 in the figure shown above represents the Logical 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 Logical Fuction, $f = \overline{xy + z}$.

Data Table 1: Verification of The Truth Tables of Logic Gate and Logical Function
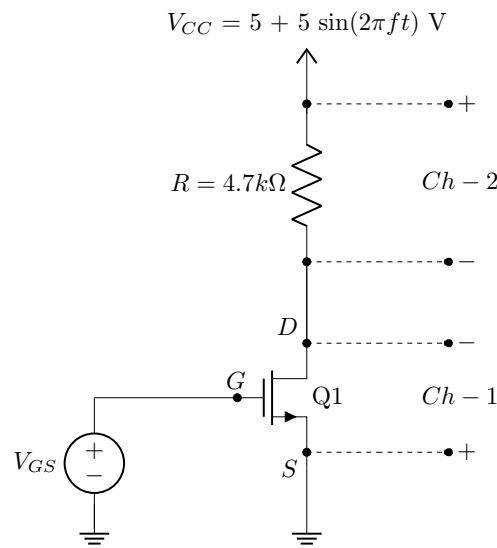
1. NAND Gate

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

2. Logical 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		
0V	0V	5V		
0V	5V	0V		
0V	5V	5V		
5V	0V	0V		
5V	0V	5V		
5V	5V	0V		
5V	5V	5V		

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_{CC}. For V_{CC}, set $f = 5$ 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 IV 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 it so that we can increase or decrease V_{GS}.

5. Rotate the knob of the dc power supply slowly from 0V to 5V. You should observe the change in the IV characteristics. Capture the plots for different V_{GS} using your mobile camera.

Task-03: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]

2. Attach the Signed data sheet

3. Attach the captured photos and describe them properly.

4. Add a brief Discussion regarding the experiment.