EXPERIMENT

Static characteristics of MOSFET in common source configuration

1 Objectives

To study characteristics of an n-channel Metal Oxide Semiconductor field effect Transistor (MOSFET) in Common-source configuration.

1.1 Circuit components/equipment

1. MOSFET (2N7000)
2. Bread board
3. Resistors (1 kΩ, 100 kΩ)
4. Digital Multimeter
5. Dual channel DC power supply (0 - 30 V)
6. Connecting wires

1.2 Theory

A Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) is a three-terminal semiconductor device in which the current flowing between the drain and source terminals is controlled by the voltage applied to the gate terminal. Since the gate is electrically insulated from the semiconductor channel by a thin layer of silicon dioxide (SiO_2), the MOSFET has an extremely high input impedance and requires negligible gate current. For this reason, it is also known as an Insulated Gate Field-Effect Transistor (IGFET). MOSFETs are widely used in digital integrated circuits, analog amplifiers, switching applications, power electronics, and voltage-controlled circuits due to their low power consumption, high switching speed, and ease of fabrication.

Types of MOSFET

Based on the type of charge carriers, MOSFETs are classified into:

- N-channel MOSFET (NMOS)
- P-channel MOSFET (PMOS)

Depending on the mode of operation, each type is further classified as:

- Enhancement-mode MOSFET
- Depletion-mode MOSFET

The 2N7000 used in this experiment is an Enhancement-mode N-channel MOSFET.

1.2.1 Enhancement-Type N-Channel MOSFET

An enhancement-mode NMOS consists of a p-type substrate into which two heavily doped n-type regions are formed. These regions act as the source (S) and drain (D) terminals. A thin insulating layer of silicon dioxide (SiO_2) is grown over the substrate, and a metal gate electrode is deposited on top of the oxide. Unlike a depletion-mode MOSFET, there is no conducting channel between the source and drain when the gate-to-source voltage is zero. Therefore, the device remains in the OFF state at $V_{GS} = 0$. When a positive voltage is applied between the gate and source, an electric field is established across the oxide layer. This field repels holes from the surface of the p-type substrate and attracts electrons toward the oxide-semiconductor interface. As the gate voltage increases, electrons accumulate beneath the gate and eventually form an inversion layer, creating an n-type conducting channel between the source and drain. The minimum gate-to-source voltage required to form this conducting channel is known as the threshold voltage (V_{TH}). Once $V_{GS} > V_{TH}$, the channel is established and drain current (I_D) begins to flow when a drain-to-source voltage (V_{DS}) is applied.

As the gate voltage increases beyond the threshold voltage, the channel becomes more conductive, reducing its resistance and allowing a larger drain current to flow. This is why the device is called an enhancement-mode MOSFET - the conductivity of the channel is enhanced by increasing the gate voltage.

1.2.2 Operation of the NMOS

The operation of an enhancement-mode NMOS can be divided into three regions.

1. **Cut-off region**: When $V_{GS} < V_{TH}$, inversion channel exists between the source and drain. Consequently, $I_D \approx 0$, and the MOSFET behaves like an open switch.

2. **Linear (Ohmic or Triode) Region**: When $V_{GS} > V_{TH}$, and $V_{DS} < V_{GS} - V_{TH}$, a conducting channel is formed between the source and drain. The MOSFET behaves like a voltage-controlled resistor, and the drain current increases approximately linearly with V_{DS}.

3. **Saturation Region**: As V_{DS} is increased further, $V_{DS} \geq V_{GS} - V_{TH}$, the channel becomes pinched off near the drain end. Beyond this point, the drain current becomes nearly independent of V_{DS} and is mainly controlled by the gate voltage. This region is widely used for amplifier applications.

1.2.3 Characteristics of a MOSFET

The electrical behaviour of a MOSFET is studied using the following characteristics:

1. **Input Characteristics**: Variation of gate current (I_{G}) with gate-to-source voltage (V_{GS}). Since the gate is insulated by the oxide layer, the gate current is practically zero, resulting in a very high input impedance.

2. **Output Characteristics**: Variation of drain current (I_{D}) with drain-to-source voltage (V_{DS}) for different values of gate-to-source voltage (V_{GS}). These characteristics show the linear and saturation regions of operation.

3. **Transfer Characteristics**: Variation of drain current (I_{D}) with gate-to-source voltage (V_{GS}) at a fixed drain-to-source voltage (V_{DS}). The transfer characteristic is used to determine the threshold voltage and the transconductance of the MOSFET.

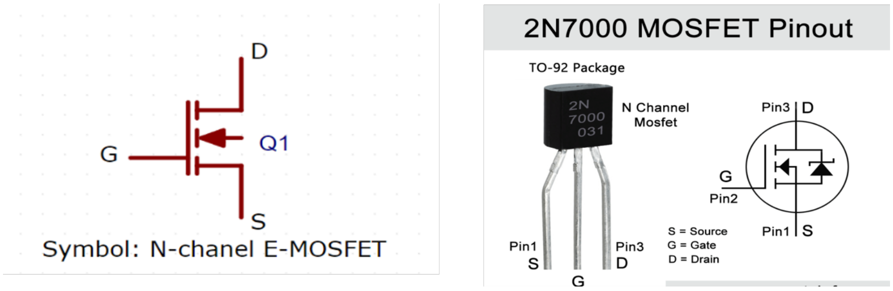

Figure 1: Symbol of a MOSFET and picture of 2N7000 MOSFET.

In a MOSFET, transfer characteristics plot the relation between the output drain current (I_{D}) and the input gate-to-source voltage (V_{GS}), while the drain current equations mathematically define how (I_{D}) flows across three distinct operating regions based on terminal voltages.

1. **In the Linear/Ohmic region**, ($V_{\mathrm{DS}} < V_{\mathrm{GS}} - V_{\mathrm{TH}}$):

$$I_{\mathrm{D}} = \mu_n C_{\mathrm{ox}} \frac{W}{L} \left[(V_{\mathrm{GS}} - V_{\mathrm{TH}}) V_{\mathrm{DS}} - \frac{V_{\mathrm{DS}}^2}{2} \right],$$

2. In the **Saturation region** ($V_{\mathrm{DS}} < V_{\mathrm{GS}} - V_{\mathrm{TH}}$):

$$I_{\mathrm{D}} = \frac{1}{2} \mu_n C_{\mathrm{ox}} \frac{W}{L} (V_{\mathrm{GS}} - V_{\mathrm{TH}})^2 (1 + \lambda V_{\mathrm{DS}}),$$

   where

   - μ_n = Electron mobility in the channel
   - C_{ox} = Gate oxide capacitance per unit area

- W = Channel width
- L = Channel length
- λ = Channel length modulation parameter

3. **Transconductance** g_m - Measure of the device's gain

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})$$

4. **Drain resistance** (r_D):

$$r_D = \frac{\partial V_{DS}}{\partial I_D} = \frac{1}{\lambda I_D}$$

1.2.4 Procedure

1. Set up the circuit on breadboard as per the circuit diagram in figure 2.

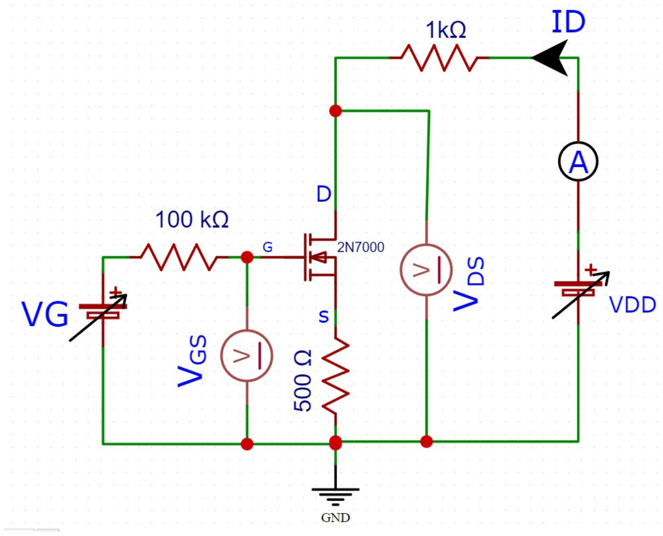

Figure 2: Circuit diagram of N-channel E-MOSFET

2. Connect the drain and gate terminals of the MOSFET to their respective DC power supplies through appropriate resistors.
3. Set the drain-to-source voltage (V_{DS}) to a constant value (e.g., 5 V).
4. Start with gate-to-source voltage (V_{GS}) at 0 V.
5. Gradually increase V_{GS} in steps of 0.2 V and record the corresponding drain current (I_D).
6. Continue until V_{GS} reaches about 5 V or as recommended for your specific MOSFET.
7. Repeat the experiment for different constant values of V_{DS} (e.g., 3 V, 5 V, 7 V).
8. Plot the transfer characteristics (I_D vs. V_{GS}) for each V_{DS} value.

Table 1: Part A: Transfer characteristics (I_D vs. V_{GS} and V_{DS} = constant).

V_{GS} (V)	I_D (mA) for V_{DS} = 3 V	I_D (mA) for V_{DS} = 5 V	I_D (mA) for V_{DS} = 7 V
0.0			
0.2			
0.4			
0.6			
...			
0.0			

Table 2: Part B: Output characteristics (I_D vs. V_{DS} and V_{GS} = constant).

V_{DS} (V)	I_D (mA) for V_{GS} = 2 V	I_D (mA) for V_{GS} = 3 V	I_D (mA) for V_{GS} = 4 V
0.0			
0.5			
1.0			
...			
10.0			

1.2.5 Observations

The observations have to be tabulated as given in tables 1 and 2.

1.2.6 Calculations

1. From Transfer Characteristics:

   (a) Threshold Voltage (V_{TH}):
   Plot $\sqrt{I_D}$ vs. V_{GS}. The x-intercept of the linear portion of this graph gives the threshold voltage V_{TH}.

   (b) Transconductance (g_m):
   Calculate the slope of the I_D vs. V_{GS} curve in the linear region.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

2. From Output Characteristics:

   (a) Drain Resistance (r_D):
   Calculate the slope of the I_D vs V_{DS} curve in the saturation region.

$$r_D = \frac{\Delta V_{DS}}{\Delta I_D}$$

1.2.7 Result

Based on the experimental observations and calculations, the following parameters of the N-channel MOSFET were determined:

1. Threshold Voltage (V_{TH}) = ______ V.
2. Transconductance (g_m) = ______ mS.
3. Drain Resistance (r_D) = ______ kΩ.

1.2.8 Graph

1. Plot the graph of Transfer Characteristics (I_D vs. V_{GS} and V_{DS} = constant) using the observation table 1.
2. Plot the graph of Output Characteristics (I_D vs. V_{DS} and V_{GS} = constant) using the observation table 2.

1.2.9 Error analysis

Find the errors and report them together with the experimentally calculated values of

1. Threshold Voltage (V_{TH}) = ______ V.
2. Transconductance (g_m) = ______ mS.
3. Drain Resistance (r_D) = ______ kΩ.

1.2.10 Precautions

1. Never exceed the maximum ratings of the MOSFET as specified in its datasheet 10 V.
2. Make sure all connections are proper and tight before applying power.
3. Start with lower voltage values and gradually increase to avoid damaging the device.
4. Switch off the power supply before making any changes to the circuit.
5. Double-check the pinout of the MOSFET before making connections.
6. Avoid touching the terminals of the MOSFET with bare hands during operation.
7. Allow the MOSFET to cool down if it gets heated during the experiment.
8. Keep the measuring instruments in appropriate ranges to avoid damage and obtain accurate readings.