**American International University- Bangladesh**
**Faculty of Engineering (EEE)**
Analog Electronics Laboratory

**Title: Study of MOSFET Applications.**


## Abstract:

A MOSFET transistor is a three terminal semiconductor device in which, current flowing from the drain-source terminals, is controlled by the voltage on the gate terminal. In the cutoff and triode regions the MOSFET approximates the operation of a switch. In between these two regions lies the saturation region. In saturation the MOSFET makes a good amplifier. This experiment describes how MOSFET works as a switch and as a voltage amplifier. In addition, the effect of source-substrate voltage on threshold voltage will be observed.


## Introduction:

The most common transistor types are the Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) and the Bipolar Junction Transistors (BJT). BJTs based circuits dominated the electronics market in the 1960's and 1970's. Nowadays most electronic circuits, particularly integrated circuits (ICs), are made of MOSFETs. The BJTs are mainly used for specific applications like analog circuits (e.g. amplifiers), high-speed circuits or power electronics.

There are two main differences between BJTs and FETs. The first is that FETs are charge-controlled devices while BJTs are current controlled devices. The second difference is that the input impedance of the FETs is very high while that of BJT is relatively low. As for the FET transistors, there are two main types: the junction field effect transistor (JFET) and the metal oxide semiconductor field effect transistor (MOSFET). The power dissipation of a JFET is high in comparison to MOSFETs. Therefore, JFETs are less important if it comes to the realization of ICs, where transistors are densely packed. The power dissipation of a JFET based circuit would be simply too high. MOSFETs became the most popular field effect device in the 1980's.

The combination of n-type and p-type MOSFETs allow for the realization of the Complementary Metal Oxide Semiconductor (CMOS) technology, which is nowadays the most important technology in electronics. All microprocessors and memory products are based on CMOS technology. The very low power dissipation of CMOS circuits allows for the integration of millions of transistors on a single chip.

In this experiment, we will concentrate on the MOSFET transistor. We will investigate its applications as an amplifier and as a switch. The objective of experiment is --.

1. To understand the operation of the MOSFET as a switch.
2. To measure channel resistance during switch ‘ON’ and ‘OFF’ stage.
3. To illustrate amplification using a MOSFET
4. To measure the gain of the amplifier.

## Theory and Methodology:

It is important to note that the threshold voltage $V_{th}$ of MOSFETs can be controlled by the fabrication process and can be made either positive or negative for both types of MOSFETs. In the case of enhancement type transistors the channel is formed (induced) by the applied gate voltage and the threshold voltage is defined in the following way:

- Enhancement type NMOS: $V_{th} > 0$

- Enhancement type PMOS: $V_{th} < 0$

In the case of a depletion type transistor the channel is already physically implemented by doping the region so that already a drain current can flow for $V_{GS} = 0V$.

- Depletion Mode NMOS: $V_{th} < 0$
- Depletion Mode PMOS: $V_{th} > 0$

## Applications

## MOSFET as a Switch

Common application of MOSFETs is switches in analog and digital circuits. Switches in analog circuits can be used for example in data acquisition systems, where they serve as analog multiplexers, which allow the selection of one of several data inputs. In other applications, they may change gain of an operational amplifier or an attenuation ratio by switching different resistors, depending on the control voltage levels set usually by digital circuits. A simple example of a switching circuit based on an n-type enhancement transistor and a resistor is shown in figure 8. The voltage applied to the gate controls the conductance of the channel. A zero or low value of $V_{GS}$ the conductance is very low so that is the transistor acts like an open circuit and no current flows through the load resistor $R_L$. When $V_{GS}$ exceeds the threshold, the channel conductance becomes higher and the transistor acts like a closed switch. The channel resistance is not getting zero but the resistance is getting small so that the output voltage $V_{out}$ is getting small. Figure 8a shows an NMOS switching FET and its models for $V_{in} = 0$ (figure 8b) and $V_{in} = +5V$ (figure 8c). In each case, the FET is modeled as a mechanical switch.

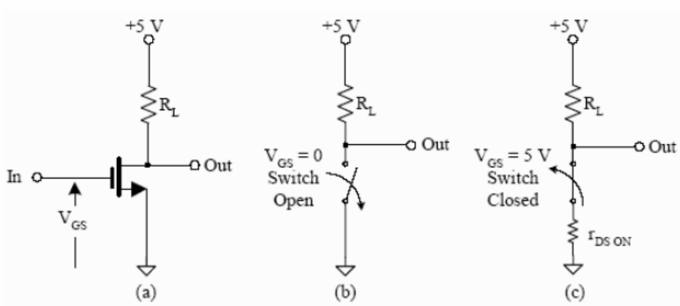
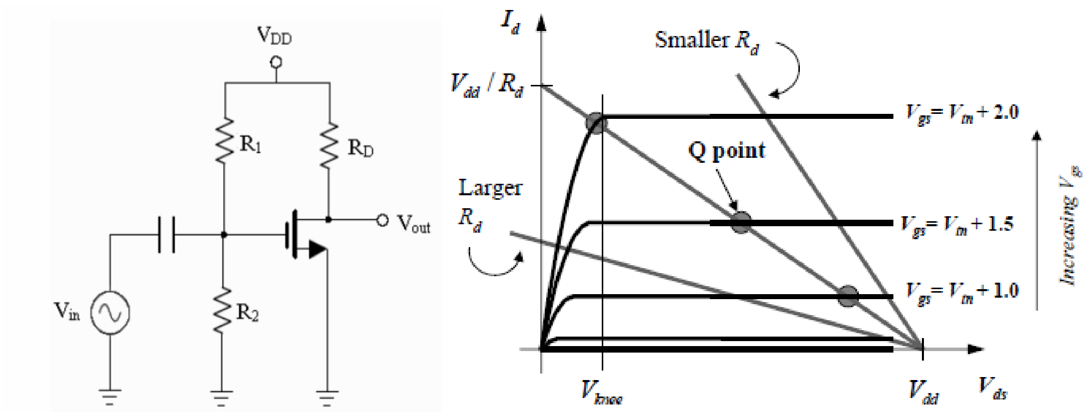



Figure 1: An NMOS transistor switch

## MOSFET as an Amplifier

MOSFET can be used in several applications including amplifiers, logic circuits, memories, and power electronics applications. A MOSFET amplifier circuit is shown in figure 7. The MOSFET is used as a common source voltage amplifier. The voltage divider based on two resistors $R_1$ and $R_2$ is used to define the Q-point or the operating point of the gate-to-source voltage $V_{GSQ}$. The Q-point on the input side will then define the Q-point of the drain-to- source voltage $V_{DSQ}$ on the output side. The operating point of the MOSFET circuit can be graphically extracted from the graph in figure 7. In this amplifier circuit, cut-off occurs when $i_D$=0. Subsequently, the output voltage reaches its maximum value Vout = $V_{DD}$. On the other hand, if the input voltage increases, the output voltage swings along the line to reach the Vout = $V_{DSmin} = V_{GS} – V_{th}$, the pinch-off value. As an amplifier operates in the saturation region, the Q-point of the drain-to-source voltage has to be in the range between $V_{DSmin}$ and $V_{DSmax}$..




(a) (b)

Figure 2: A common-source amplifier and determination of Q point.

## Pre-Lab Homework:

1. Explain the differences between an enhancement and depletion type MOSFET.

2. Explain the differences between an NMOS and PMOS transistor.

Students must install PSpice/LTSpice/ Psim software and MUST present the simulation results using transistors to the instructor before the start of the experiment.

## Apparatus:

(1) Resistors: 470 Ohms 1 pc , 500kΩ POT 2 pcs, 100kΩ 1pc
(2) NMOS
(3) Connecting wires.
(4) Trainer Board

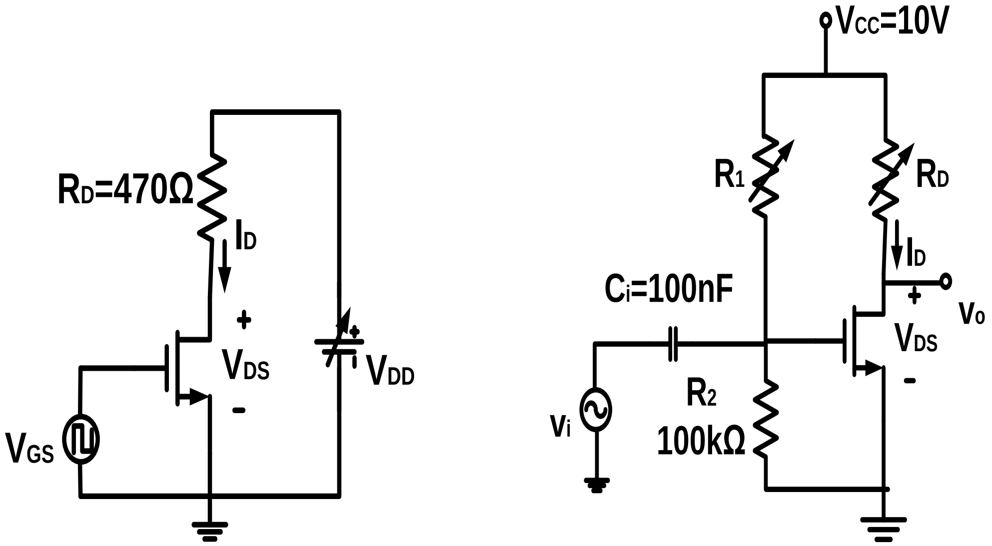
## Precautions:

Have your instructor check all your connections after you are done setting up the circuit and make sure that you apply only enough voltage (within $V_{DD}$) to turn on the transistors and/or chip, otherwise it may get damaged.

## Simulation:

**The given circuits student needs to simulate at home using a convenient software (Multisim is recommended). The output of the simulation should be attached with the lab report.**

## Experimental Circuits:




(a) (b)

Figure 3: (a) MOSFET as a switch and (b) MOSFET as an amplifier.

## Experimental Procedure:

***Problem 1: MOSFET as a Switch***

1. Implement the circuit given in figure 3(a). Use a rectangular input voltage with $10V_{p\text{-}p}$ at 1 kHz. With this arrangement MOSFET will work as a switch. At negative half cycle MOSFET is in the cut-off region (the switch is opened between D and S) and at positive half cycle MOSFET is in the triode region (switch closed ~ short circuit).
2. Observe the input and output waveforms simultaneously.
3. Now replace $V_{GS}$ with a DC voltage of 5V and measure $I_D$ and $V_{DS}$ using multimeter.
4. Calculate the "on" resistance of this MOSFET, where $R_{ON}=V_{DS}/I_D$.
5. Turn $V_{GS}=0$ and again measure $I_D$ and $V_{DS}$.
6. Find $R_{off}$ where where $R_{ON}=V_{DS}/I_D$.
7. Comment on the quality of this device as a switch. (Ideally, $R_{on} = 0\Omega$ and $R_{off} \rightarrow \alpha$).

***Problem 2: MOSFET as Amplifier***

Goal of the problem is to design and realize an amplifier circuit using a MOSFET.

1. Determine $V_{th}$ of the given MOSFET according to experiment no.6
2. Construct the circuit as shown in figure 3(b).
3. Consider $V_{GS}$ = 2.7V, $V_{DS}$=5V, $K_n$=72.2 mA/$V^2$, $V_{th}$ =use measured value and now calculate $I_D$, $R_D$ and $R_1$ using following equations.

$$I_D = \frac{1}{2} K_n \ (V_{GS} - V_t)^2$$

$$R_D = \frac{V_{CC} - V_{DS}}{I_D}$$
$$V_{GS} = \frac{R_2}{R_1 + R_2} \times V_{CC}$$

And

$$R_1 = \frac{R_2 V_{CC}}{V_{GS}} - R_2$$

4. Now assemble the circuit and apply a sinusoidal input signal with amplitude of 100mV and a frequency of 1 KHz to the input of the circuit. (use $R_2$=100K, $c_1$=100nF, $V_{DD}$=10V )
5. Observe the input and the output signals simultaneously.
6. Calculate the gain of the amplifier, , $A_V = \frac{v_o}{v_i}$

**Results and Discussion:**

Students will summarize the experiment and discuss it as a whole. Interpret the data/findings and determine the extent to which the experiment was successful in complying with the goal that was initially set. Discuss any mistake you might have made while conducting the investigation and describe ways the study could have been improved.

**Report:**

1. Draw input output waveforms during the MOSFET switch operation.
2. Draw input output waveforms during the MOSFET Amplifier operation
3. Explain phase relationship for both the cases.

**Reference(s):**


1. A.S. Sedra, K.C. Smith, Microelectronic Circuits, Oxford University Press (1998).
2. J. Keown, ORCAD PSpice and Circuit Analysis, Prentice Hall Press (2001).
3. P. Horowitz, W. Hill, The Art of Electronics, Cambridge University Press (1989).
4. David Comer & Donald Comer, "Fundamentals of Electronic Circuit Design".