Communication Circuits Design – 2018-19, semester II

Lab 1 - Week 2

Student's Chinese name	郑长刚
Student's English name	Changgang Zheng
Student's UESTC ID#	2016200302027
Student's UoG ID#	2289258Z

I-V Characteristics of MOSFETs

The objective of this lab is to measure and plot the current-vs-voltage (I-V) operating curves of the Metal Oxide Semiconductor Field Effect Transistor (MOSFET).

Introduction

A metal-oxide-semiconductor field-effect transistor (MOSFET) is a three-terminal device that can be used as a switch (e.g. in digital circuits) or as an amplifier (e.g. in analog circuits). The three terminals are referred to as the Source, Gate, and Drain terminals. Current flow between the source and drain terminals is controlled by the voltage V_{GS} applied between the gate and source terminals. If the gate-to-source voltage V_{GS} is less than the threshold voltage value V_T, no current can flow between the source and the drain – i.e. the transistor is OFF; if $V_{GS} > V_T$, then current can flow between the source and the drain – i.e. the transistor is ON. The circuit symbol for an n-channel enhancement-mode ($V_T >$ 0 Volts) MOSFET is shown in Figure-1, along with the terminal current reference directions.

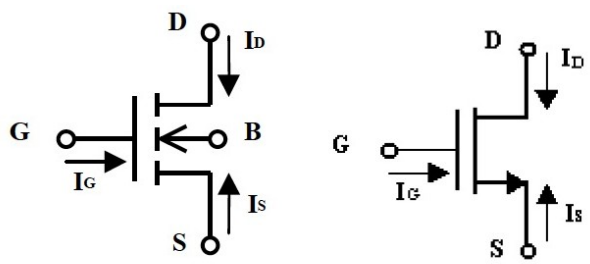


Figure-1: Circuit symbol for n-channel enhancement MOSFET

In the ON state, the current I_{DS} flowing from the drain to the source will depend on the potential difference V_{DS} between the drain and the source: I_{DS} increases with increasing drain-to-source voltage V_{DS} as long as the drain voltage is at least V_T below the gate voltage,
i.e. as long as $V_{GS} - V_T > V_{DS}$. When V_{DS} increases above $V_{GS} - V_T$, I_{DS} saturates at a constant value (i.e. it no longer increases with increasing V_{DS}.).

Practical Procedure

1. Build the circuit shown in the Fig. 2 below. In the circuit you will use a potentiometer (P_1) to vary the gate voltage. Use the following circuit with R_D=1 kΩ and the power boxes as a DC voltage supplies.

   When I built my circuit, finally I found it is hart to use RD = 1 kΩ in the question, so I change it to 0.1 kΩ in some questions.

2. First, the transfer characteristics, i.e. the dependence of the drain current (I_D) on the input voltage (V_{GS}), will be measured at a fixed drain bias V_{DS} = 5.0 V. Since the resistivity of the MOSFET changes as V_{GS} is changed, V_{DD} have to be adjusted for each point to keep V_{DS}=5.0 V. It is suitable to have V_{IN} =5 V to be able to vary V_{GS} with the potentiometer. Measure the points in the table below and plot the data as I_D vs V_{GS}. In this task V_{GS} is measured as a function of set I_D values instead of the other way around to avoid too high currents through the MOSFET.

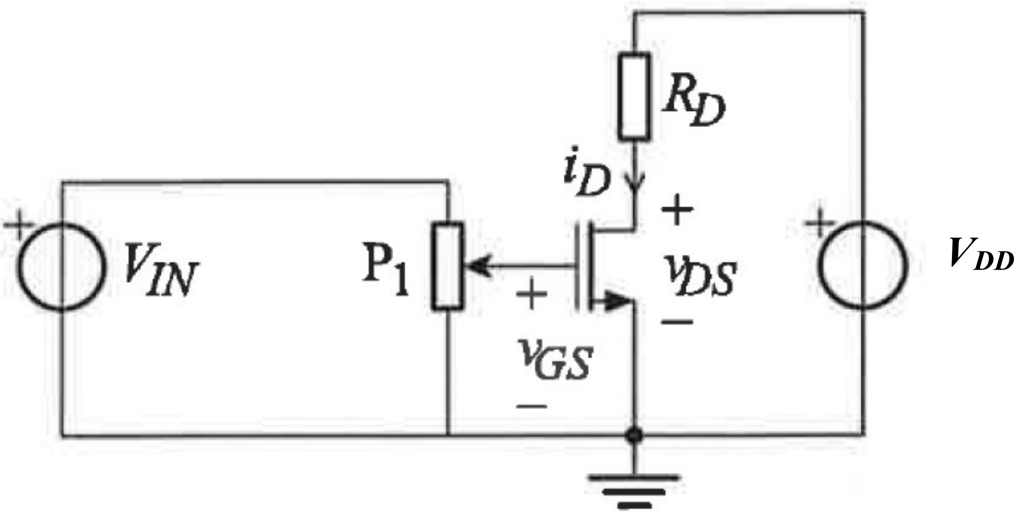


Figure-2: A simple circuit for obtaining the I-V characteristics of a MOSFET.

3. Set V_{DD} according to the table. Adjust the potentiometer until the indicated I_D is reached and measure V_{GS}.

Answer:

V_{DD} (V)	I_D (mA)	V_{GS} (V)
15.0	10.0	2.59
10.0	5.0	2.48
8.0	3.0	2.42
6.0	1.0	2.28
5.1	0.1	2.07
5.0	0.0	1.73

4. Plot the transfer characteristic I_D vs V_{GS} using the collected data in the Table-1.

Answer:

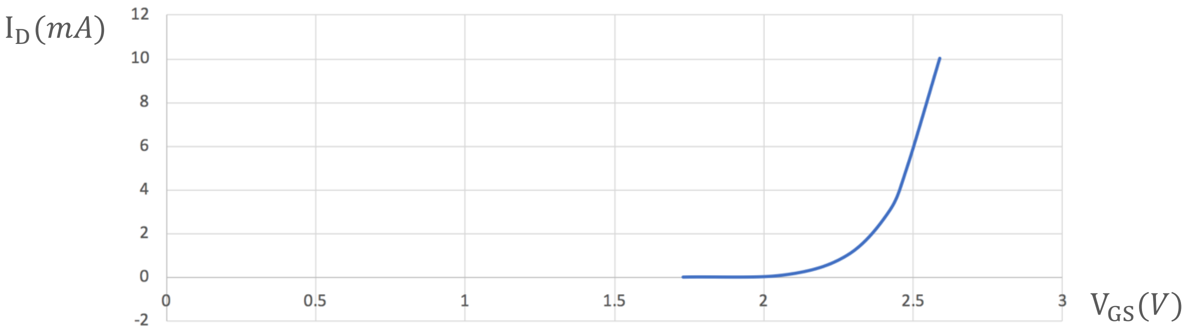


Figure-3: transfer characteristic I_D vs V_{GS} for a MOSFET

5. **Does I_D follow the expected long or short (velocity saturated) channel behavior ? Remember that I_D is proportional to V_{GS} for a velocity saturated MOSFET.**

Answer: The I_D follow the long channel behavior.

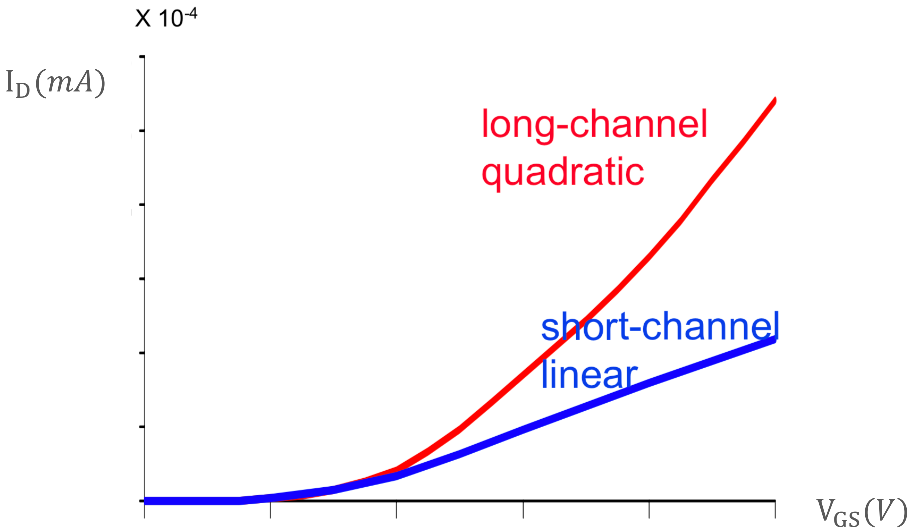


Figure-4: property for long/short channel [1]

From the above Figure-4, we can see that the long channel effect means voltage V_{GS} is quadratic to I_D. So, I plot the figure for I_D versus V_{GS}^2 shown as follow:

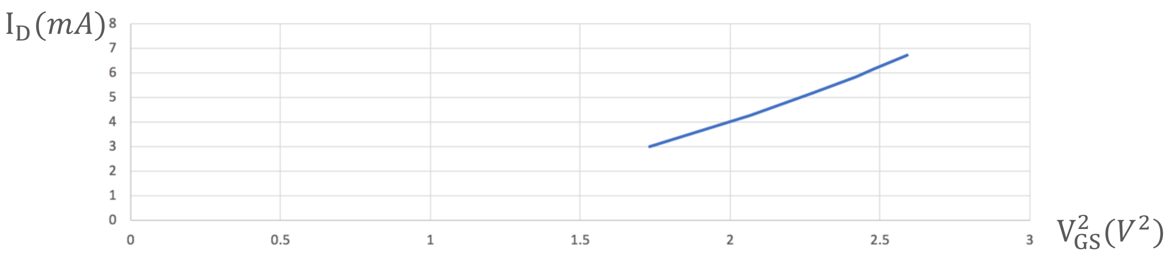


Figure-5: ID versus VGS2

From the Figure-5, we can see that the saturation between the I_D and V_{GS} square is linear dependent. Thus we can conclude that it follows the long channel effect.

6. **Now the output characteristics, i.e. the dependence of the drain current (I_D) on the drain voltage (V_{DS}), will be measured at a fixed gate bias. Adjust V_{DD} to 10 V and adjust the potentiometer so that you obtain I_{DS} = 5 mA with V_{DS}= 5 V. Keep this setting of the potentiometer (controlling V_{GS}) throughout the measurement while varying V_{DD} to obtain the V_{DS} values in the table. Fill out I_D in the table and plot the data in the diagram as I_D vs V_{GS}.**

Answer: The data is in the following table and the plot is shown in Figure-4

V_{DS} (V)	I_D (mA)
0	0
0.2	4.702
1.0	5.012
3.0	5.012
5.0	5.012
10.0	5.012

Plot of the data in the diagram as I_D vs V_{GS}:

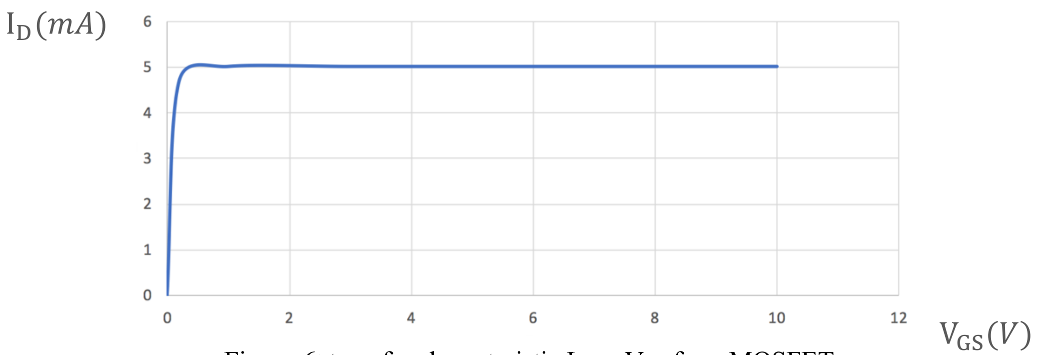


Figure-6: transfer characteristic I_D vs V_{GS} for a MOSFET

1. **Does I_D saturate? If not, what is the reason.**

   Answer: Yes, It does. From the Figure-6, the I_D rise with the increase of the V_{GS}, which is then maintaining 5V after I_G is 1 V. According to this, we can find that the I_D did not increase with the rising of the V_{GS}, which means it is saturated.

2. **Now set V_{GS} to 4 V and measure V_{DS} and I_D as V_{DS} is varied from 0 to 10 V. Repeat this experiment with V_{GS} equal to 6 V, 8 V and 10 V. Plot the I-V characteristics of this MOSFET. The horizontal axis should be V_{DS} and the vertical axis I_D. The various V_{GS} values generate a family of curves.**

   Answer:

V_{GS} (V) = 4 V		V_{GS} (V) = 6 V		V_{GS} (V) = 8V		V_{GS} (V) = 10V	
V_{DS} (V)	I_D (mA)	V_{DS} (V)	I_D (mA)	V_{DS} (V)	I_D (mA)	V_{DS} (V)	I_D (mA)
0	0	0	0	0	0	0	0
1	67.3	1	164.2	1	259.8	1	355.9
2	87.5	2	281.5	2	471.5	2	664.2

3	87.5	3	347.3	3	637.2	3	921.5
4	87.5	4	347.9	4	753.5	4	1138
5	87.5	5	368.4	5	821.2	5	1302
6	87.5	6	368.4	6	841.1	6	1419
7	87.5	7	368.4	7	841.1	7	1488
8	87.5	8	368.4	8	841.1	8	1507
9	87.5	9	368.4	9	841.1	9	1507
10	87.5	10	368.4	10	841.1	10	1507

3. Identify and explain the operating regions of the I-V curve generated for the transistor.

Answer:

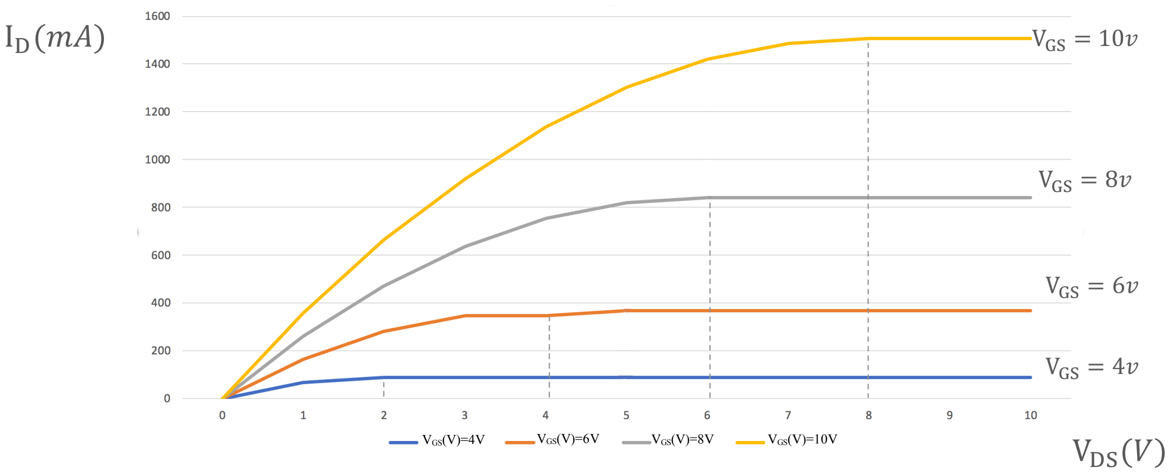
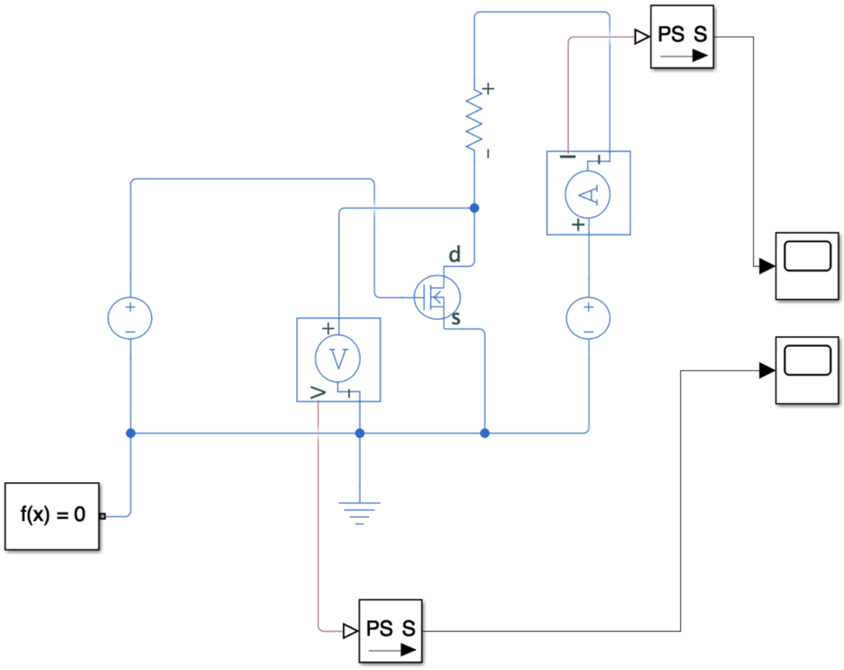


Figure-7: transfer characteristic I_D vs V_{GS} for a MOSFET

VGS(V)	Ohmic Region	Operating Region	Breakdown Region
4	$0V < V_{DS} < 2V$	$V_{DS} \geq 2V$	—
6	$0V < V_{DS} < 4V$	$V_{DS} \geq 4V$	—
8	$0V < V_{DS} < 6V$	$V_{DS} \geq 6V$	—
10	$0V < V_{DS} < 8V$	$V_{DS} \geq 8V$	—

Ohmic region, where current and voltage are related by Ohm's law. [2]
Active (or constant-current) region, where current is essentially independent of V_{DS}. [2]

The operating region is the active region, where the I_D is proportional to the V_{GS}. This property ensures that it can be used as the amplifier.



Note: the experimental condition cannot allow me to do this experiment totally in reality (burn the circuit and cannot generate such high voltage, so we just simulate it)

References

[1] course power pint, Communication Circuits Design Academic year 2018 to 2019 Semester 2 Week 1 Lecture 1.5: Field-Effect Transistor (FET) ,Francesco Fioranelli, Wasim Ahmad, Faisal Tariq .

[2] COMP 103 Lecture 04: MOS Transistor short channel and scaling effects Reading: Section 3.3 up to page107, Sec 3.5 [All lecture notes are adapted from Mary Jane Irwin, Penn State, which were adapted from Rabaey's Digital Integrated Circuits, ©2002, J. Rabaey et al.]