Group No:

Experiment-04

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

CSE251 - Electronic Devices and Circuits Lab

Objective

1. To measure the drain current and drain voltage to plot the I-V characteristics curves of a MOSFET.
2. To implement a NAND gate and a Logical Function using MOSFETs and verify the truth tables.

Equipments

1. MOSFET (IRF 540) - $\times 3$
2. Resistance $(2.2k\Omega, 100k\Omega)$
3. DC power supply
4. Trainer Board
5. Digital Multimeter
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.

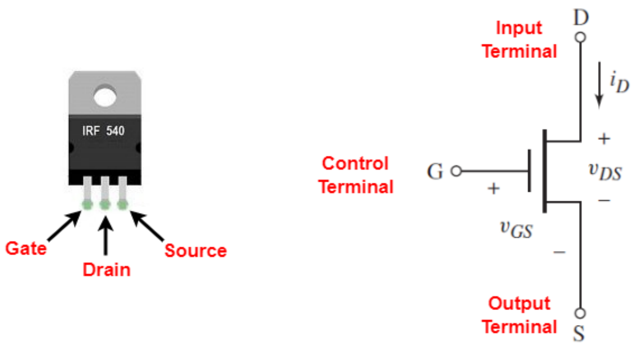


Figure 1: IC and Circuit Diagram of a MOSFET (NMOS)

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 this behavior which is shown in the following figure:

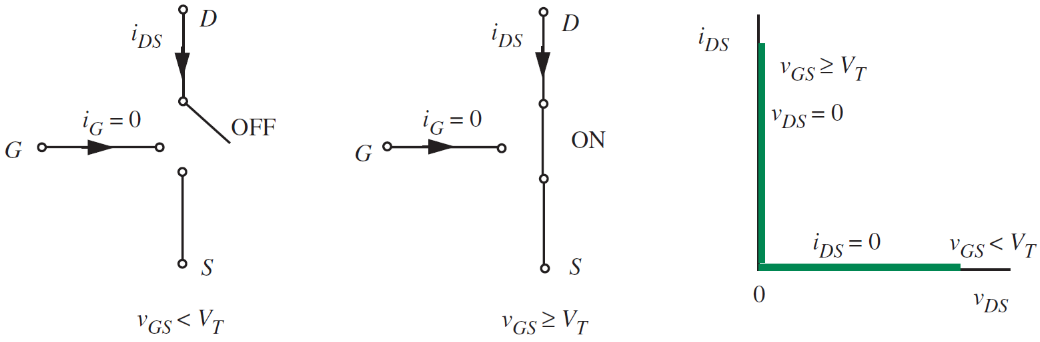


Figure 2: S-Model of MOSFET

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

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

MOSFET Switch Implementation of Logic Gates and Logical Functions

Switches can be used to build logic gates. As we can use MOSFETs as switches, logic gates can be built using MOSFETs. We can also implement various Logical Functions using MOSFET logic gates.

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.

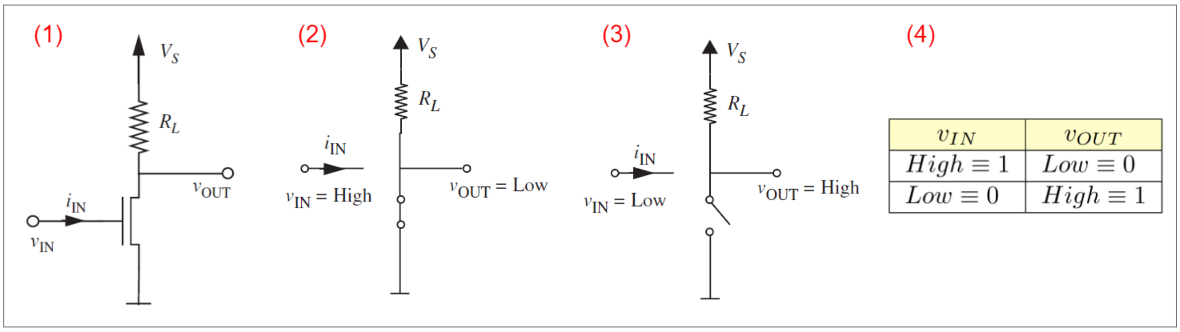


Figure 3: (1) MOSFET NOT Gate (2) When Input is '1' (3) When Input is '0' (4) Truth Table

NAND Gate Using MOSFET

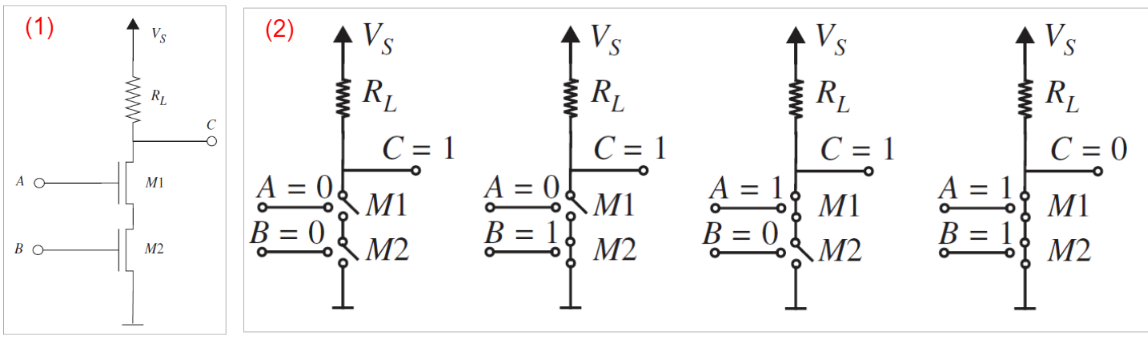


Figure 4: (1) MOSFET NAND Gate (2) Equivalent Circuits for Different Inputs (3) Truth Table

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 the MOSFET is to be utilized as a switch. On the other hand, if the MOSFET is to be used to design an amplifier, it must be operated 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.

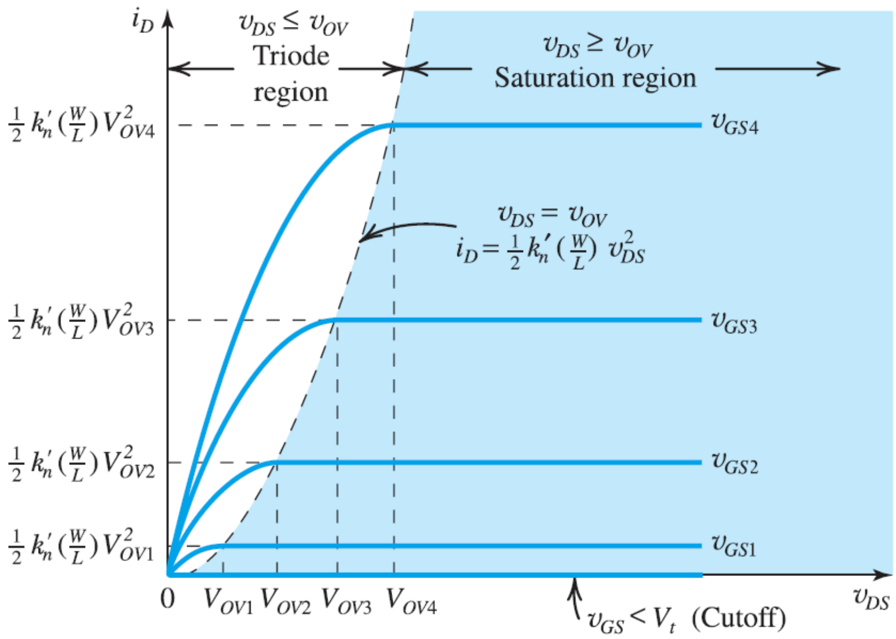


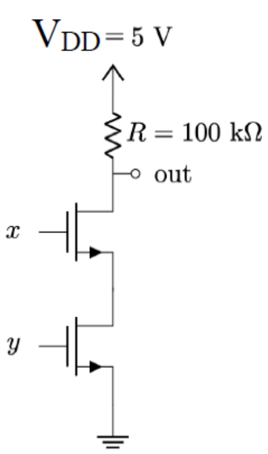
Figure 5: I-V Characteristics of a MOSFET

We can summarize the operating regions of the MOSFET as:

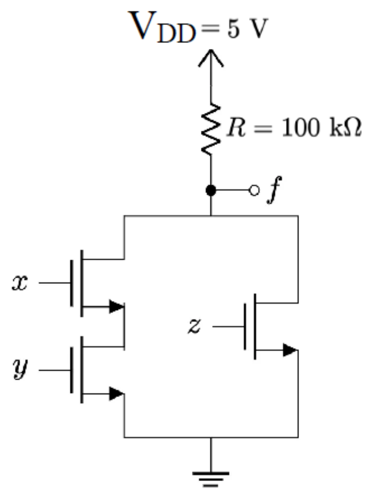
When	Operating Mode	Equation of Current
$v_{GS} < V_T$	Cutoff Mode	$i_D = 0$
$v_{GS} \geq V_T, v_{DS} \leq v_{OV}$	Triode Mode	$i_D = k_n'\,(W/L)\left(v_{OV} - \frac{1}{2}v_{DS}\right)v_{DS}$
$v_{GS} \geq V_T, v_{DS} > v_{OV}$	Saturation Mode	$i_D = \frac{1}{2}k_n'\,(W/L)\,v_{OV}^2$

here, $v_{GS} = v_G - v_S$, $v_{DS} = v_D - v_S$, V_T = ***Threshold Voltage, Overdrive voltage,*** $v_{OV} = v_{GS} - V_T$, k_n' = ***Process Transconductance Parameter,*** L = ***Channel Length,*** W = ***Channel Width.***
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 terminal (input) to any one of the data switches that provides a voltage of 5 V approximately.
3. Keeping V_{DD} constant at 5 V, 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 across drain and source (V_{out}). The output voltage can also be determined by the state of LED. If the LED is ON, then the output voltage V_{out} = 5 V. Similarly, when the LED turns OFF, the output voltage V_{out} corresponds to 0 V.
4. Next, use the input voltage combinations of Data Table 1 and observe the state of LED again.
5. Verify the truth table of the NAND gate.
6. 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.
7. Keeping V_{DD} constant at 5 V, observe the output voltage (state of LED) for different combinations of the inputs x, y and z as shown in Data Table 1.
8. 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

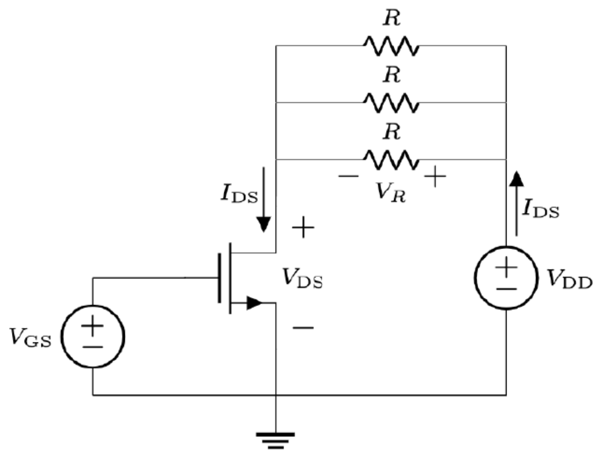
1. NAND Gate

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



Circuit 3: Circuit for measurement of IV characteristics (I_{DS} *vs* V_{DS}) of MOSFET

Procedure

1. For studying the IV characteristics of MOSFET, construct the Circuit 3, keeping R = 2.2 kΩ.
2. Now, keeping V_{GS} constant **exactly** at 2.9 V, increase V_{DD} from 0 V to 20 V and measure the corresponding voltage across the resistor V_R. Calculate the drain current, I_{DS} for each value of V_{DD} by using, $I_{DS} = \frac{V_R}{R}$. In addition to this, measure the drain-source voltage V_{DS}. Fill in the Data Table 2.
3. Repeat Step-2 for $V_{GS} = 2.85$ V and Fill in the Data Table 3.

Data Table 2: I-V Characteristics Data for $V_{GS} = 2.9$ V

Equivalent Resistance, R_{eq} = (using Multimeter)

V_{DD} (volt)	V_{DS} (volt)	V_R (volt)	$I_{DS} = V_R/R_{eq}$ (mA)

V_{DD} (volt)	V_{DS} (volt)	V_R (volt)	$I_{DS} = V_R/R_{eq}$ (mA)

Data Table 3: I-V Characteristics Data for $V_{GS} = 2.85$ V

Equivalent Resistance, R_{eq} = (using Multimeter)

V_{DD} (volt)	V_{DS} (volt)	V_R (volt)	$I_{DS} = V_R/R_{eq}$ (mA)

V_{DD} (volt)	V_{DS} (volt)	V_R (volt)	$I_{DS} = V_R/R_{eq}$ (mA)

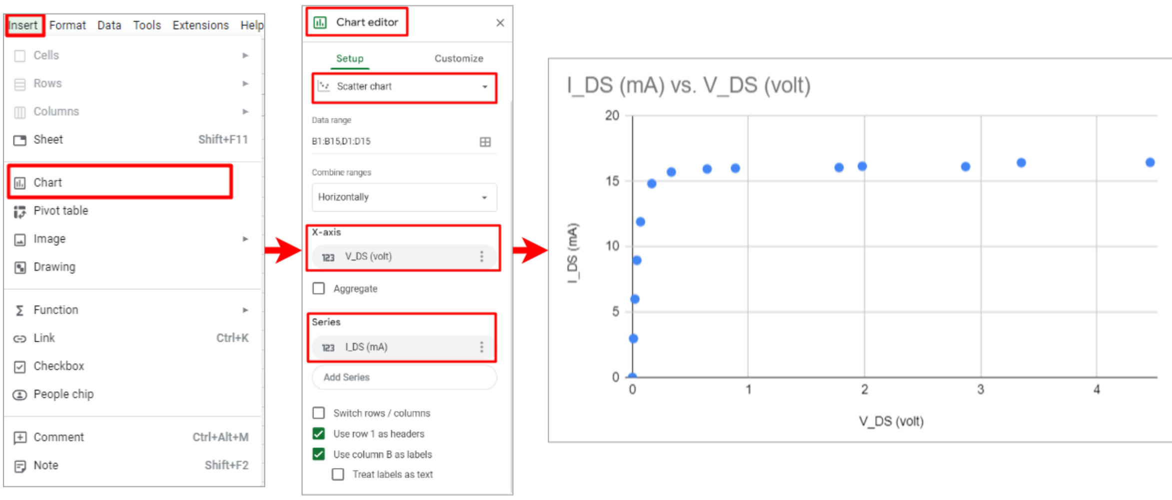
Task-03: Plotting Graphs on Excel (Home Task)

In this task, we will use the experimental data to plot the I-V characteristics of MOSFET.

1. Create a Google spreadsheet by visiting https://docs.google.com/spreadsheets
2. Fill in the spreadsheet with the data of Table 2 for $V_{GS} = 2.9$ V (refer to your labsheet). Select both the columns of V_{DS} and I_{DS} (to select a column, click on the column head, e.g., 'B'. Then hold CTRL while clicking the second column, e.g., 'D', to select both columns).

V_DD (volt)	V_DS (volt)	V_R (Volt)	I_DS (mA)
0	0	0	0
3	9.00E-03	2.942	2.971717172
6	2.15E-02	5.93	5.98989899
9	3.87E-02	8.87	8.95959596
12	6.97E-02	11.79	11.90909091
15	1.67E-01	14.68	14.82828283
16	3.35E-01	15.56	15.71717172
16.5	6.44E-01	15.79	15.94949495
17	8.87E-01	15.85	16.01010101
17.5	1.78E+00	15.9	16.06060606
18	1.98E+00	16	16.16161616
19	2.87E+00	15.97	16.13131313
20	3.35E+00	16.27	16.43434343
21	4.46E+00	16.29	16.45454545

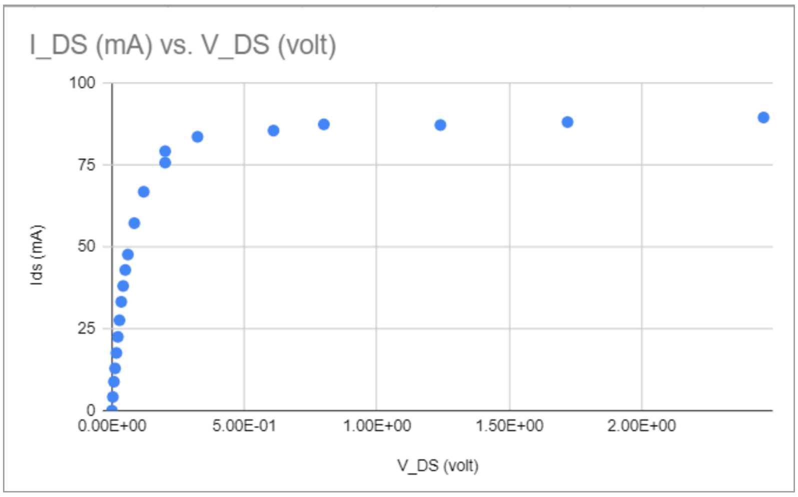
3. Select Insert → Chart.



4. A Chart Editor section should pop up at the right side of your screen. If it doesn't show up, then double click on the graph. Go the setup section in the chart editor and change the 'Chart type' to 'Scatter Chart' or 'Line Chart'. Keep V_{GS} on the x-axis, and the current I_D on the y-axis.

5. Create another table with the data of Table 3 for $V_{GS} = 2.85$ V (refer to your labsheet). Select columns of V_{DS} and I_{DS} ($V_{DS} = x$-axis, $I_D = y$-axis).

6. Repeat the same procedure and plot another line chart. Your graph should look like the following one. Notice that, for the same value of V_{DS}, I_{DS} has higher value for higher value of V_{GS}.

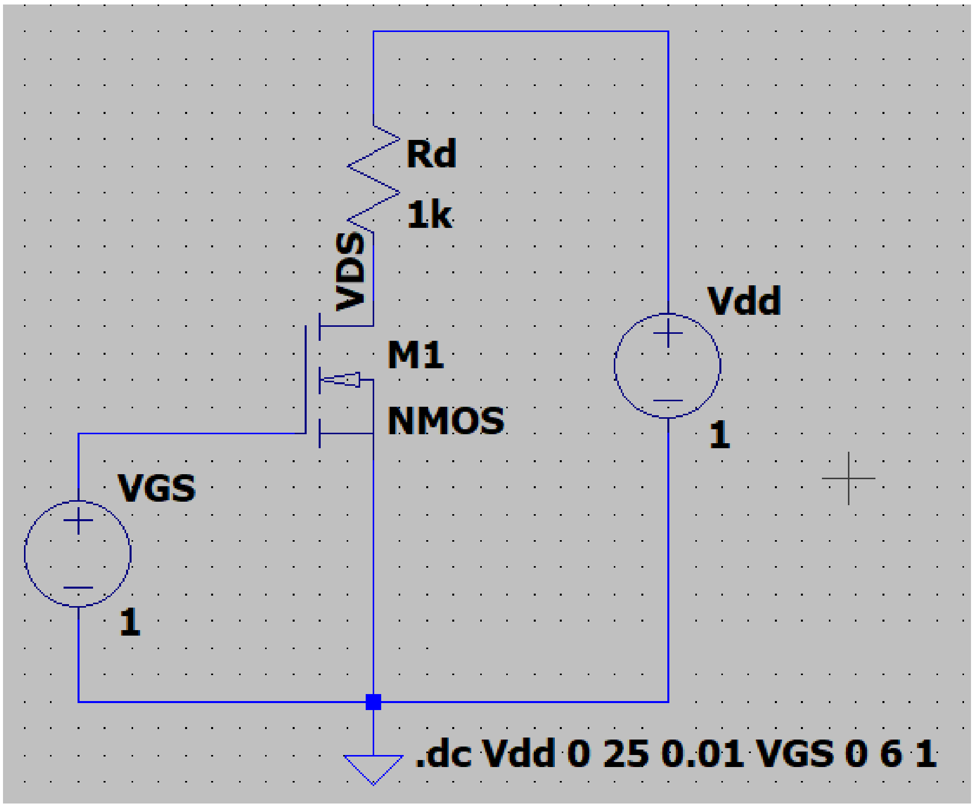


Note: This is a sample data collected from a simulation. Your data may not match with this one.

Task-04: Simulation (Home Task)

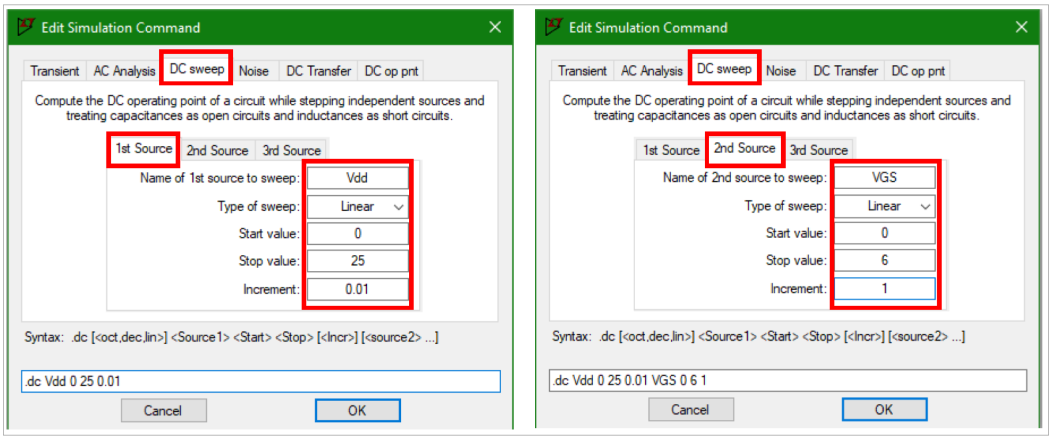
In this task, we will simulate the I-V characteristics of a MOSFET in LTspice. We will also observe the change in I-V characteristics for different values of V_{GS}.

1. Open a new schematic and build the following circuit. We used an N-channel MOSFET in the hardware part. To insert an N-channel MOSFET in LTspice, type ‘nmos’ in the Select Component Symbol window.



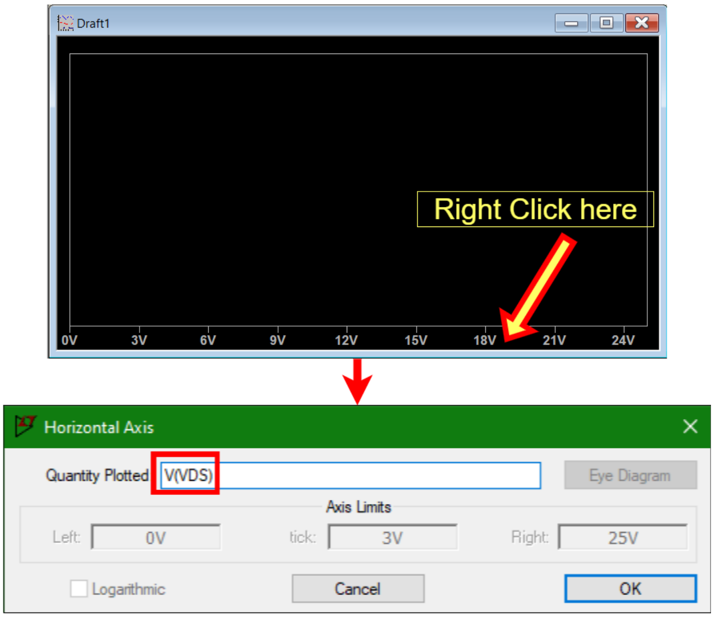
2. Rename the components as shown in the figure. Set ‘Rd’ as 1 kΩ. Set the two voltages, VGS and Vdd to any dc value for now (you may use 1V). We will sweep the two sources later. Label the drain node of the MOSFET as ‘VDS’ using Label Net which can be seen in the figure above.

3. Go to the Edit Simulation Command window. In the ‘DC sweep’ tab, set the properties to sweep VGS and Vdd as shown in the figure below.

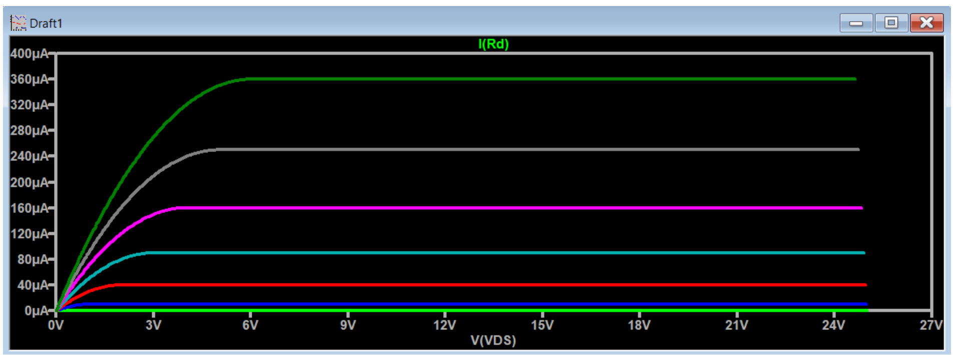


4. Run the simulation.

5. Note that, ‘Vdd’ is plotted along the horizontal axis. Right click to the horizontal axis and change the horizontal attribute to ‘VDS’ as shown in the following figure.



6. Plot the current through the resistor (which equals to the drain current through the MOSFET i.e. I_{DS}). You should get a plot like the following one. The graph corresponds to the theoretical understanding of the I-V characteristics of MOSFET.



Task-05: Report

1. Cover page [include course code, course title, name, student ID, group, semester, date of performance, date of submission]
2. Draw the Circuit Diagrams
3. Add the Signed data sheet
4. Attach the graphs of I_{DS} vs. V_{DS} for $V_{GS} = 2.9V$ and $V_{GS} = 2.85V$ using Google Sheets (i.e. Task-03)
5. Attach the graph that was generated in the simulation part (i.e. Task-04)
6. Discussion