INDIAN INSTITUTE OF TECHNOLOGY BHUBANESWAR

Introduction to Electronics Laboratory

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MOSFET Characteristics

Introduction to Electronics Laboratory (EC2P001)

OBJECTIVES OF THE EXPERIMENT

- Study an NMOS transistor in the various regions of operation.
- Measure its drain-source characteristics.
- Measure its gate-source characteristics in the saturation region.
- Extract important information from the measurements like on-resistance, lambda and transconductance.

SIMULATION COMPONENTS REQUIRED:

- N-MOSFET Si7336ADP (X2)
- Voltage sources (X4)
- Connecting Wires

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BASIC INTRODUCTION TO MOSFET

MOSFET:
A metal–oxide–semiconductor field-effect transistor (MOSFET) is a field-effect transistor (FET with an insulated gate) where the voltage determines the conductivity of the device. It is used for **switching or amplifying signals**. The ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals. MOSFETs are now even more common than BJTs (bipolar junction transistors) in digital and analog circuits.

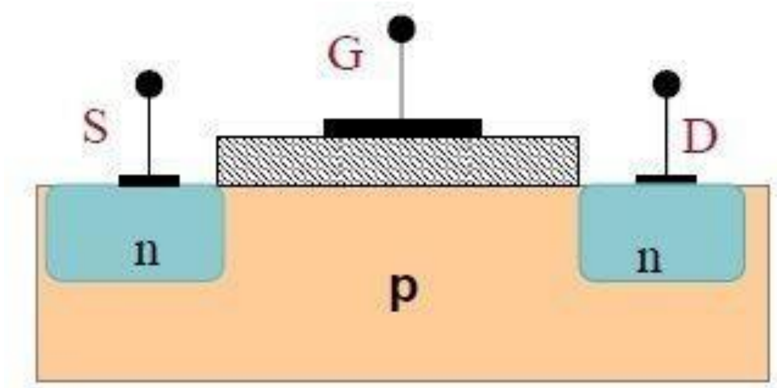

Figure 1: Structure of MOSFET

APPLICATIONS:
MOSFETs are particularly useful in **amplifiers** due to their input impedance being nearly infinite which allows the amplifier to capture almost all the incoming signal. **The main advantage is that it requires almost no input current to control the load current, when compared with bipolar transistors.** MOSFETs are available in two basic forms:

- ✓ **Depletion Type**
- ✓ **Enhancement Type**

STRUCTURE AND OPERATION:

It is a **four-terminal device with source(S), gate (G), drain (D) and body (B) terminals**. The body is frequently connected to the source terminal, reducing the terminals to three. **It works by varying the width of a channel along which charge carriers flow (electrons or holes).** The charge carriers enter the channel at source and exit via the drain. **The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain.** It is insulated from the channel near an extremely **thin layer of metal oxide.**

N-M OSFET:

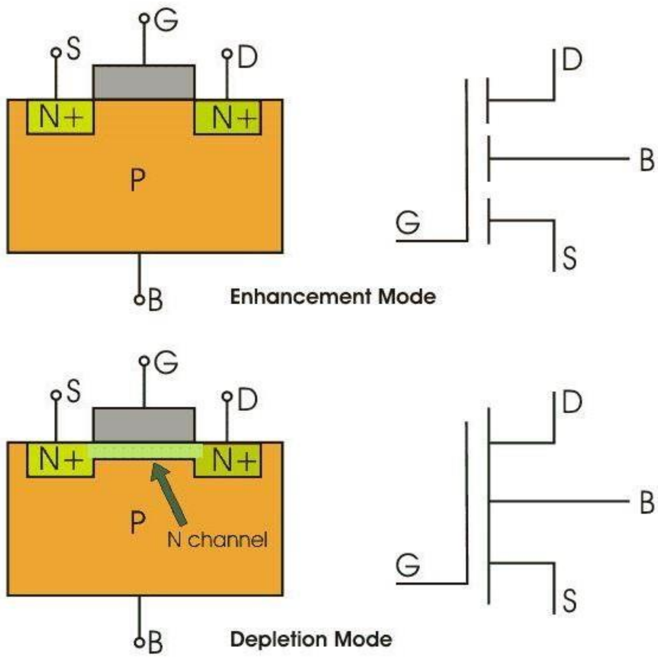

Figure 2: Working of a N-MOSFET

The drain and source are **heavily doped n+ region** and the substrate **are p-type**. The current flows due to the flow of negatively charged electrons, also known as **n-channel MOSFET.** When we apply the positive gate voltage the **holes present beneath the oxide layer experience repulsive force and the holes are pushed downwards in to the bound negative charges** which are associated with the acceptor atoms. The positive gate voltage **also attracts electrons from n+ source and drain region in to the channel thus an electron reach channel is formed.**

OUTPUT CHARACTERISTICS

CIRCUIT DIAGRAM:

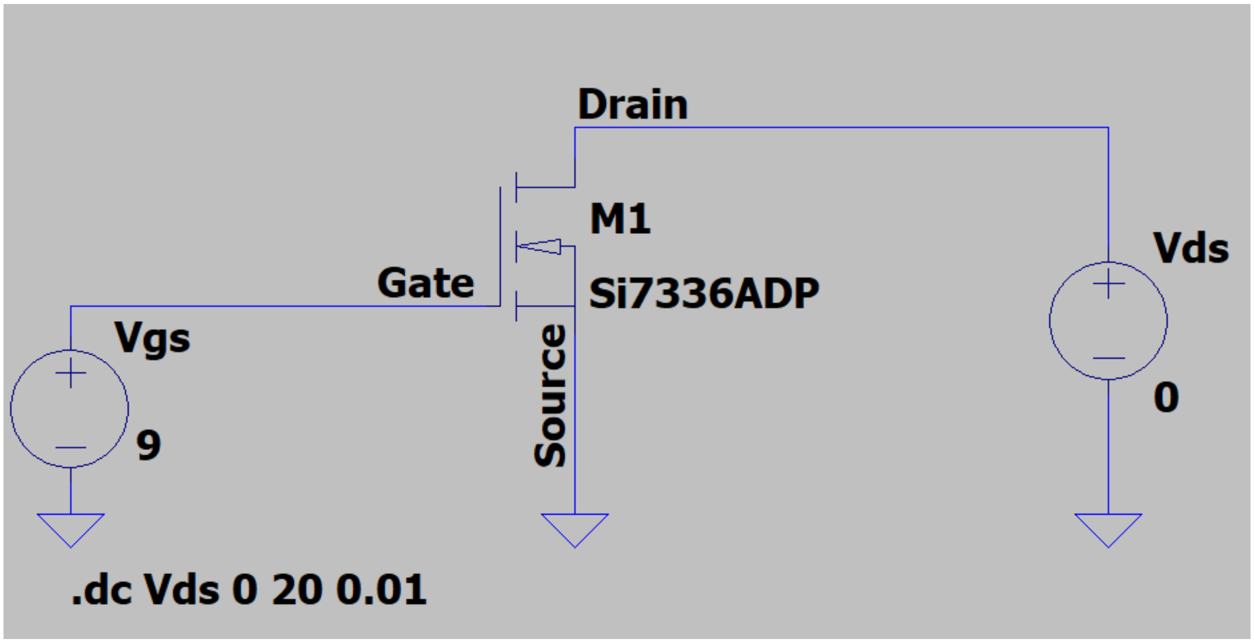

Figure 3: The circuit set-up for studying the output characteristics of the MOSFET with Vgs constant at 7V.

CIRCUIT SET-UP:

The circuit was set up using **Si73336ADP NMOSFET** in LTSpice. **DC Sweep** was used to study the characteristics. The voltage sources were set-up as shown to account for the gate-source and drain-source voltages. V_{DS} was varied and the output was studied. The specifications of the MOSFET is shown below **from SPICE Model** for reference.

ABOUT THE MOSFET Si73336ADP:

R_{ON}	0.0024Ω	**MOSFET**	Si7336ADP
lambda	0.01	**Manufacturer**	Siliconix
V_{TN}	2.9V	**Ksubthres**	100m
Polarity	N-chan		

OUTPUT WAVEFORM:

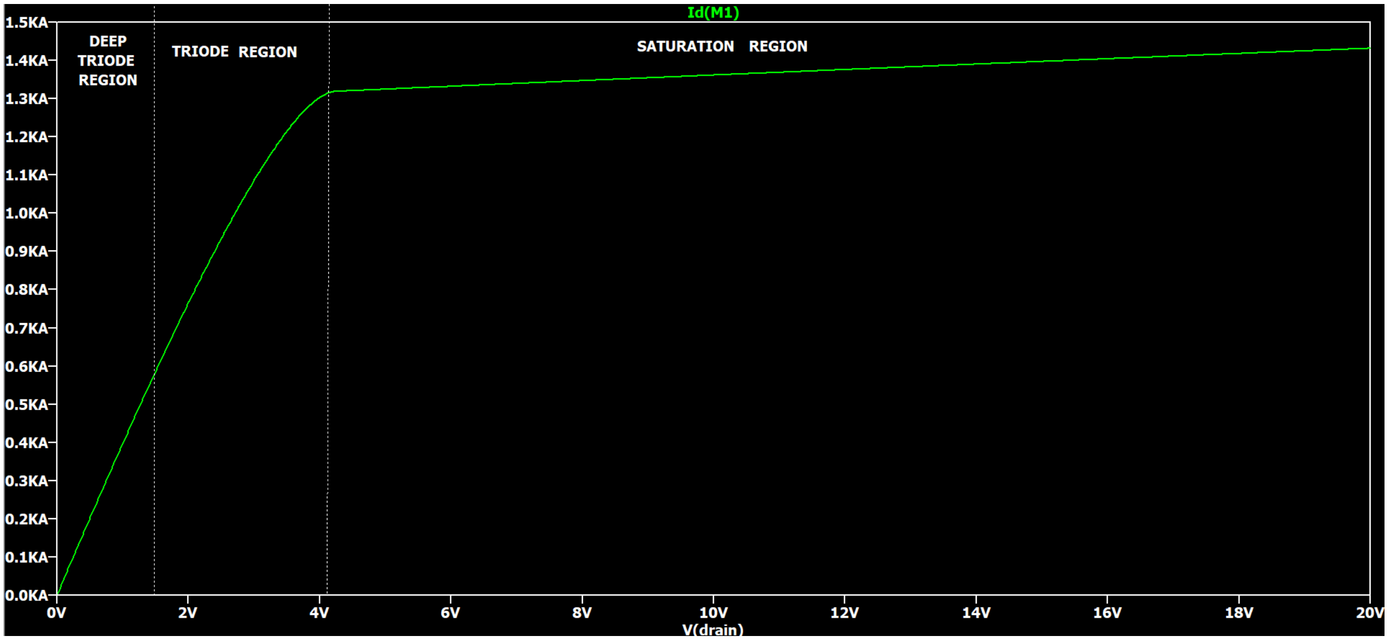

Figure 4: Output Graph of the Output Characteristics Circuit. Note that the three regions are marked and important parameters are found out later in the report.

OBTAINING RESULTS AND INTERPRETING THEM:

The ON-Resistance of the MOSFET can be calculated by taking the slope of the linear part of the deep triode region, where the slope should be almost constant:

$$R_{ON} = \left(\frac{V_{DS}}{I_D}\right) = \left[\mu C_{OX}\left(\frac{W}{L}\right)(V_{GS} - V_{TN})\right]^{-1}$$

$$\boldsymbol{R_{ON} = [405.011]^{-1} = 0.00247\Omega}$$

The linearity of the graph is lost at some higher values of V_{GS} as the **higher power terms are included**, so the triode region is governed by the following equation at higher values of drain-source voltage:

$$I_D = V_{DS} \times \mu C_{OX}\left(\frac{W}{L}\right)\left((V_{GS} - V_{TN})V_{DS} - \frac{{V_{DS}}^2}{2}\right)^1$$

The saturation region gives information about the **dependence of current on V_{DS}** at the saturation region of the MOSFET. **Ideally the current should saturate** and the channel gets pitched off at the drain end and V_{DS} doesn't affect current. But in reality, there is a **weak dependence given by a parameter lambda as:**

$$V_{DS} \times \left(\frac{1}{2}\right) \mu C_{OX} \left(\frac{W}{L}\right) ((V_{GS} - V_{TN})^2 (1 + \lambda V_{DS}))$$

This can be found by extrapolating the saturation region linear portion. As it is not possible in LTSpice to realize this, **we can assume that the portion is a linear line with equation y=mx +c.** From the cursors, we can say that for a given point (x_1, y_1):

$$c = y_1 - mx_1 = 1.32KA - (7.49)5.35V \approx 1.28KA$$

The intercept on x-axis is given as:

$$\lambda^{-1} = \frac{c}{m} \approx 170.89$$

$$\boldsymbol{\lambda \approx 0.00585}$$

The weak dependence is clearly visible in the small value of the parameter in the equation. Now before drawing conclusions on the different portions of the graph, we have a look at the **Transfer Characteristics** of the MOSFET to get an estimate of the threshold voltage and other parameters.

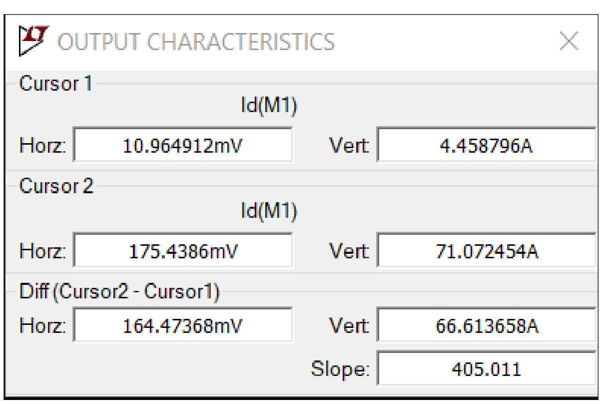

Figure 6: LTSpice cursors for the ON-resistance calculation showing a point in the deep triode region.

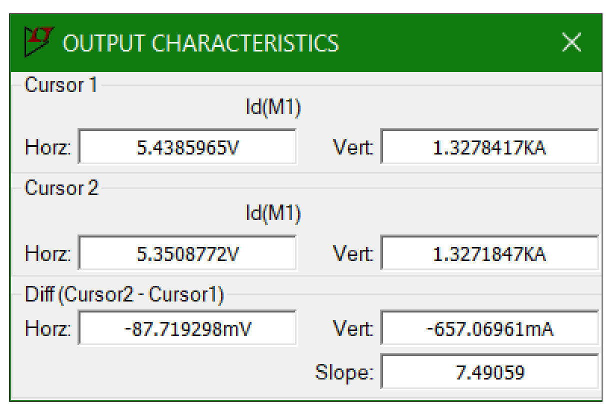

Figure 5: LTSpice cursors for the lambda calculation showing a point in saturation region.

TRANSFER CHARACTERISTICS

CIRCUIT DIAGRAM:

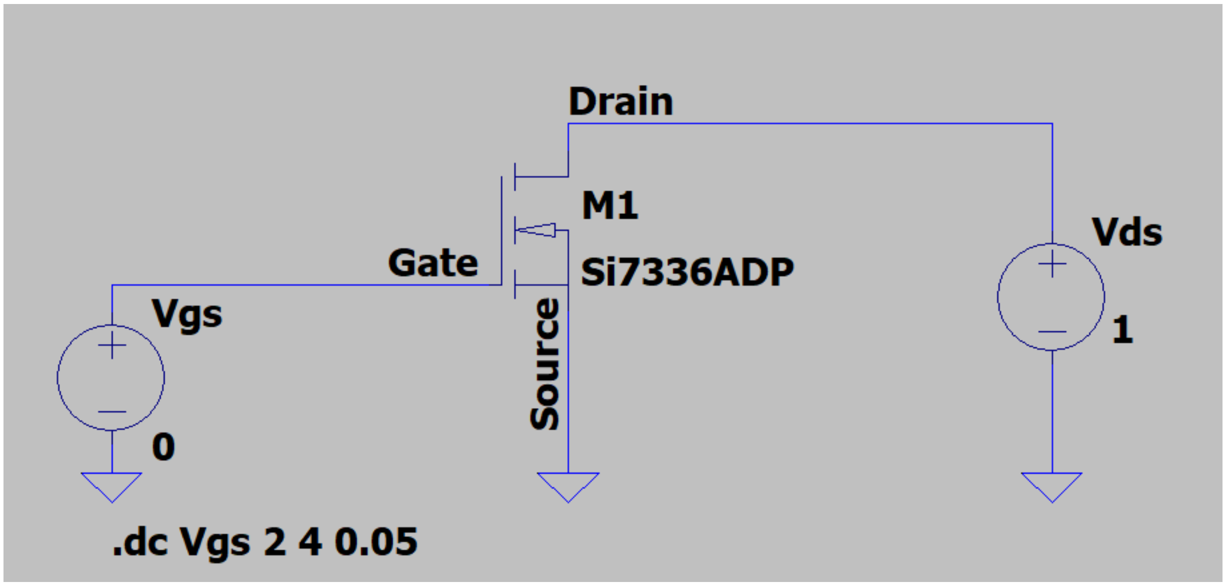

Figure 7: Circuit diagram to study the transfer characteristics of the MOSFET with Vds constant at 1V.

CIRCUIT SET-UP:

The circuit was set up using **Si73336ADP NMOSFET** in LTSpice. **DC Sweep** was used to study the characteristics. The voltage sources were set-up as shown to account for the gate-source and drain-source voltages. V_{GS} was varied and the output was studied. It was ensured that proper ranges for V_{GS} were taken to plot the output properly and clearly.

OUTPUT WAVEFORM:

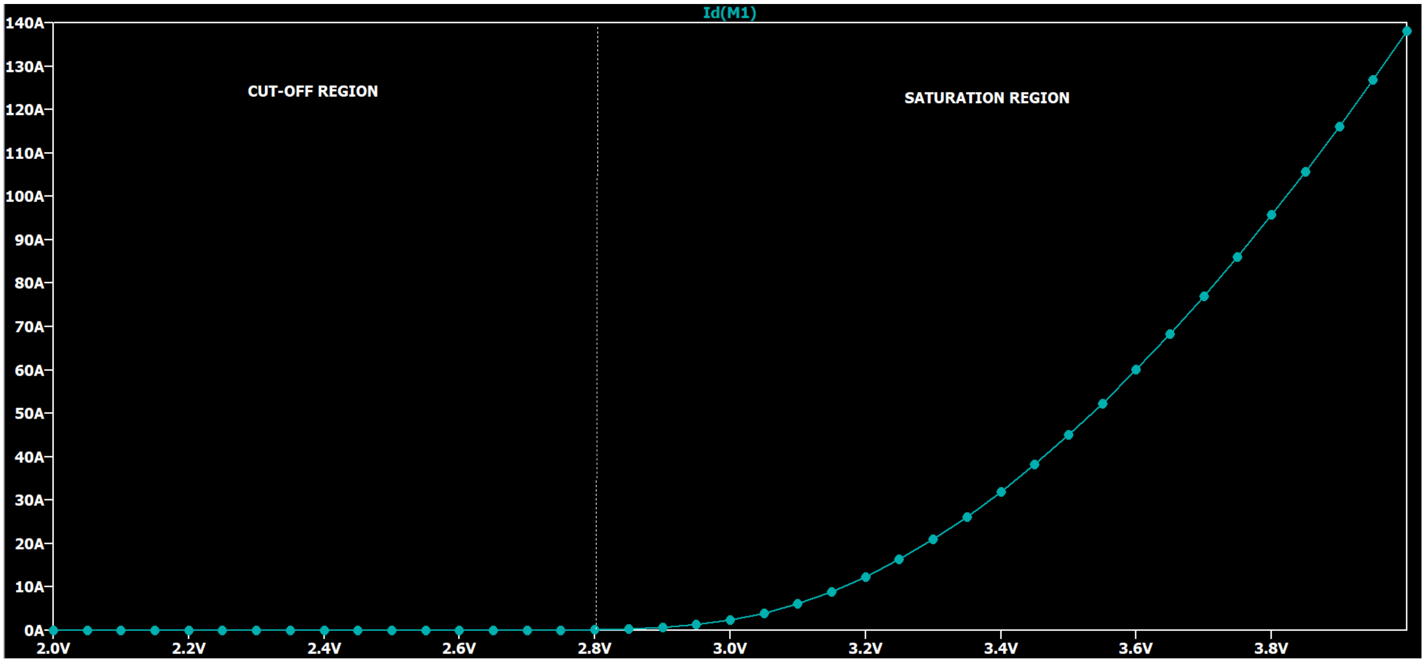

Figure 8: The graph for the Transfer Characteristics of the MOSFET. Note that the current before the marker is around nano-amperes and it starts shooting up at around 2.8V.

OBTAINING RESULTS AND INTERPRETING THEM:

The threshold voltage of the MOSFET can be calculated by looking at the point where the current starts to shoot up to appreciable values. From the graph, we can estimate that:

$$\boldsymbol{V_{TN} \approx 2.8V}$$

The transconductance can also be found here from the linear region of the graph after the threshold voltage. Using the cursors, we can say that:

$$\boldsymbol{g_m = \frac{\Delta I_D}{\Delta V_{DS}} = \frac{48.140044mV}{9.2137911A} \approx 191.396\Omega^{-1}}$$

Another parameter can be found out here, known as the subthreshold resistance, which is the inverse of slope of the graph before the threshold voltage. It can be calculated as:

$$\boldsymbol{SS = \left(\frac{\partial I_D}{\partial V_{DS}}\right)^{-1} \approx 0.00584023^{-1} \approx 171.23\Omega}$$

Also, the resistance of the linear region is:

$$\boldsymbol{r_{DS} \approx 191.396^{-1} \approx 0.00522\Omega}$$

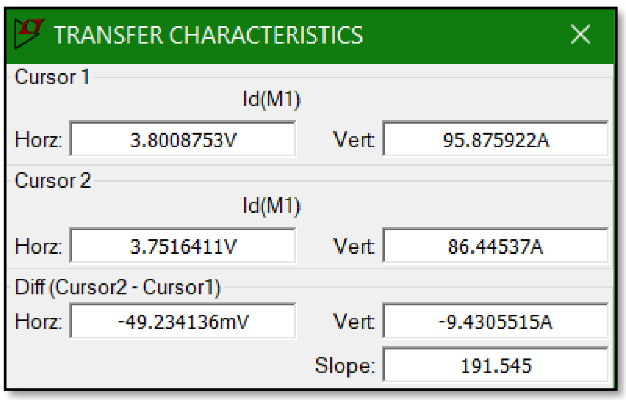

Figure 10: Cursor to calculate the transconductance in the saturation region.

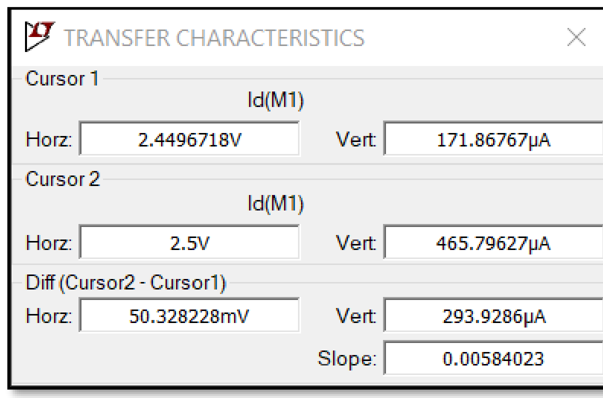

Figure 9: Cursor to calculate the subthreshold resistance

SUMMARISING THE PARAMETERS:

PARAMETER	VALUE
On-resistance	0.00247Ω
Lambda (λ)	$0.00585V^{-1}$
Threshold Voltage	$2.8V$
Transconductance	$191.396\Omega^{-1}$
Subthreshold resistance	171.23Ω

EXPERIMENTING WITH VALUE OF GATE-SOURCE VOLTAGE

Experiment for the Output Characteristics was conducted for a different value of **gate-source voltage** to check consistency in the parameters and observe changes, if any, in those values. The results of both sections are summarized in a tabular form in the summary along with the output graphs. The circuit diagram stays the same with only change in the V_{GS} value to **9V**.

OUTPUT WAVEFORM and CURSORS:

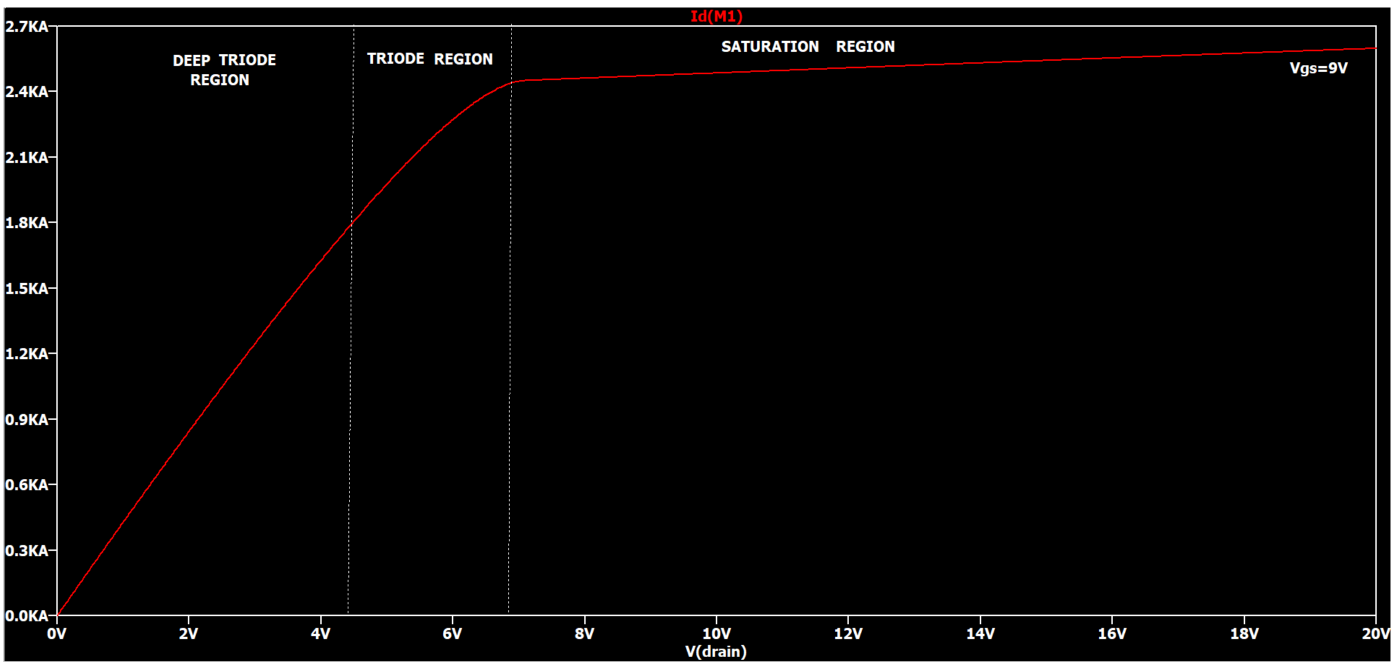

Figure 11: Output Graph of the Output Characteristics Circuit. Note that the three regions are marked and important parameters are found out later in the report.

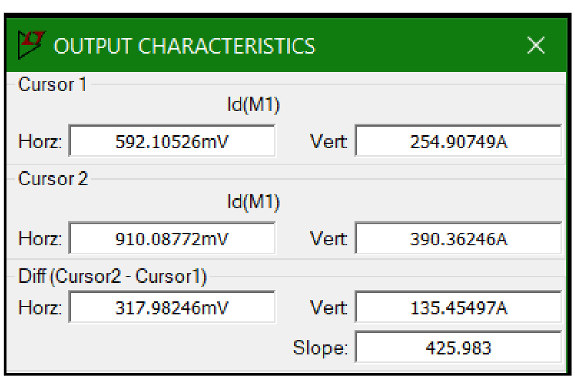

Figure 13: Cursors to determine the ON-resistance in the deep-triode region

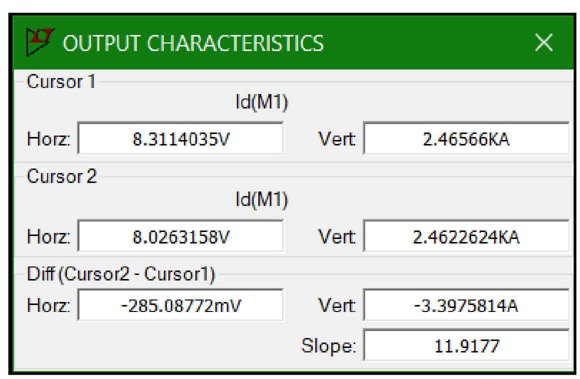

Figure 12: Cursors to determine the value of lambda in the saturation region.

CONCLUSION AND DISCUSSION

- The output characteristics and transfer characteristics were successfully studied using LTSpice. The input characteristics was not studied under this experiment as **the I_G is always zero**, so its not of any importance to us.
- After studying the graph below, we can now come-up with the **conditions imposed for the various regions** of the MOSFET as follows:

CUT-OFF REGION	$V_{GS} < V_{TN}$
SATURATION REGION	$V_{DS} < V_{GS} - V_{TN}$
TRIODE REGION	$V_{DS} \geq V_{GS} - V_{TN}$

- The output characteristics was done for **two values of gate-source voltages** and is summarized below:

Gate-Source Voltage	R_{ON}	λ
7V	0.0024Ω	$0.00585\ V^{-1}$
9V	0.0023Ω	$0.00503\ V^{-1}$

- There is a very small variation in the values above so we can say that these parameters are constant and characterize a MOSFET. **The ON resistance is very low** as required from a transistor and the value of **lambda is very low implying very weak dependance.**
- The various calculations, observations and conditions derived from the graph is tabulated and included in the report. **Errors in the calculations and deviation from the designed parameter values were within the experimental limits.**
- These could have arisen due to the factor **that no resistances were used in input or output branches leading to very high current values which practically can destroy a transistor** but as a simulation, it could be used to study the characteristics.

- **'A MOSFET can also be termed as a unipolar transistor'. Give your views for or against this statement.**

ANS: Unipolar means having **single polarity**. In the field of electronics there are two types of polarities i.e. electron or negative polarity and hole or positive polarity. It is considered that **electrons are negative charge carriers and holes are positive charge carriers**

As we know there are two types of transistors. One of them is BJT (Bipolar Junction Transistor) and other one is FET (Field Effect Transistor). **In the case of BJT, as its name indicates there are both types of charge carriers i.e. electrons and holes**. Hence it is called bipolar. In the case of FET there is only **one type of charge carrier i.e. either electron or hole**. FETs are classified into two types namely JFET (Junction Field Effect Transistor) and MOSFET (Metal Oxide Semiconductor Field Effect Transistor). As there is only one type of charge carrier in either of JFETs or MOSFETs hence it is called unipolar.

- **SS is a key metric for any switching device. Why?**

ANS: As we can see from the experimented values, there is a large difference in the current as well as the resistances in the cut-off and saturation region which is the bass for making MOSFET work as a switch. **This large ratio ensures that the function of switch is proper**. In cut-off, the current is in nano to micro scale while it rises to amperes in the saturation region. **The difference in the resistances of the two regions can be seen as:**

$$\frac{\boldsymbol{SS}}{\boldsymbol{r_{DS}}} \approx \frac{\mathbf{171.23\Omega}}{\mathbf{0.00522\Omega}} \approx \mathbf{32802.7}(\boldsymbol{very\ high})$$