University of Waterloo

Electronic Devices
ECE 331

Introduction To Field-Effect Devices

Experiment #3

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1 Prelab

1. **As seen in Table 1 the MOSFETs with different channel cases have differing gate to source voltages (V_{GS}) vs drain to source voltages. (V_{DS}). We also know that $V_T = 2.5$ V**

V_{GS} (V)	V_{DS} (V)	Refers to graph
+2	0.0	A
+5	+5.0	E
-1	+7.0	A
+7	+1.0	C
+5	0.0	B
+5	+4.0	D
+7	+4.5	E
+7	+5.0	F
+3	0.0	B
+5	+2.5	B

Table 1: Different voltages applied to an n-channel MOSFET

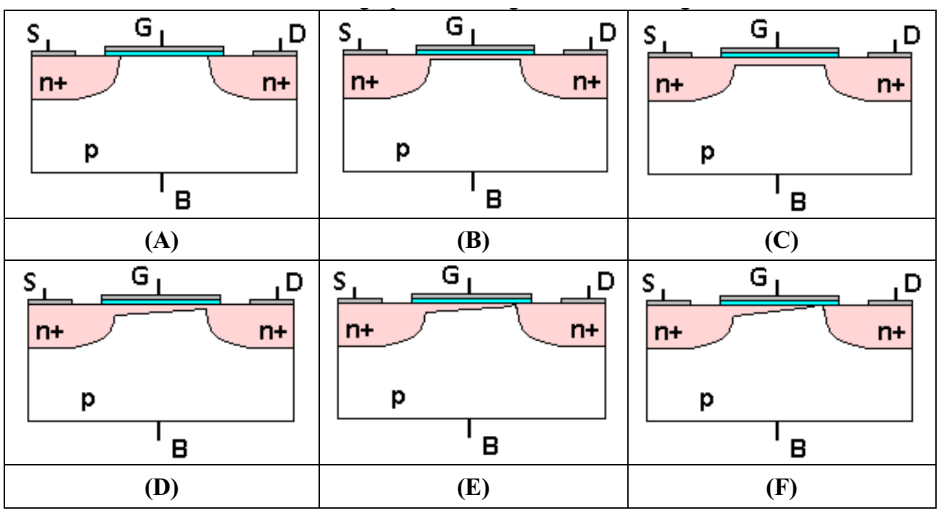
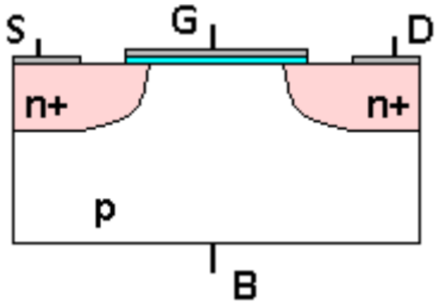


Figure 1: N-MOSFETs with different channel cases

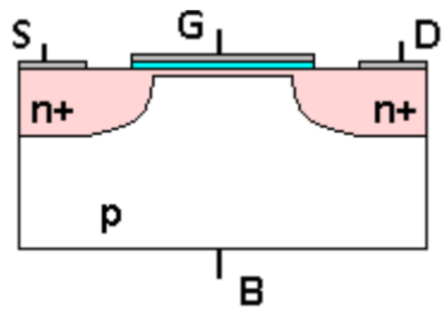
2. **Operation of a n-channel enhancement MOSFET**

An n-type enhancement MOSFET is normally off when the gate-source voltage is 0 ($V_{GS} = 0$). However, if a voltage is applied to its gate lead, the drain-source channel becomes less resistive. To turn on a N-Channel Enhancement-type MOSFET, you need to apply a sufficient positive voltage V_{DS} to the drain of the transistor as well as a sufficient positive voltage to the gate of the transistor. This allows a current to flow through the drain-source channel. With a sufficient positive voltage, V_{DS}, and sufficient positive voltage applied to the gate, the N-Channel Enhancement-type MOSFET is fully functional and is in the 'ON' operation.

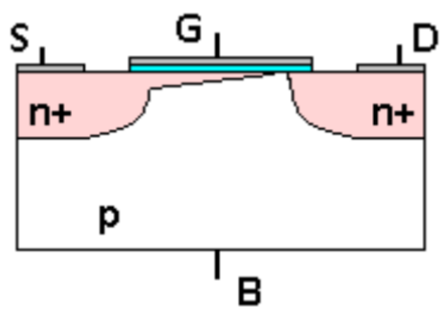
Conversely to turn off an N-channel Enhancement MOSFET, you can either cut off the bias positive voltage, V_{DS}, that powers the drain. Or you can turn off the positive voltage going to the gate of the transistor



(a) Below Threshold, $V_{GS} < V_T$ & $V_{DS} > 0$



(b) Above Threshold



(c) Above Threshold

Figure 2

2 In-Lab Data Collection

2.1 MOSFET Threshold Voltage

We first wish to find properties of the MOSFET, these results are found in Table 2.

By varying V_{GS} we can estimate V_T which is found to be: 1.58V

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}
0	2.86	7.09	6.0550	1.0108
0	3.60	8.15	6.0768	2.0041
0	4.22	9.13	6.0277	3.0031
0	4.76	10.17	6.0273	4.0049
0	5.27	11.21	6.0167	5.0176

Table 2: MOSFET characteristics at $V_{BB} = 0$

For each of V_{BB} = -2, -6, -10 we repeat the measurements, and these are shown in Tables below:

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}
-2	4.48	7.06	6.0200	1.0062
-2	5.18	8.07	6.0013	2.0049
-2	5.75	9.12	3.0004	6.0210
-2	6.27	10.21	4.0233	6.0476
-2	6.75	11.20	5.0190	6.0050

Table 3: MOSFET characteristics at V_{BB} = -2

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}
-6	6.64	7.05	6.0200	1.0014
-6	7.31	8.12	6.0434	2.0131
-6	7.86	9.12	6.0099	3.0064
-6	8.36	10.19	6.0380	4.0219
-6	8.81	11.22	6.0200	5.0171

Table 4: MOSFET characteristics at V_{BB} = -6

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}
-10	8.28	7.05	6.0195	1.0019
-10	8.93	8.14	6.0714	2.0046
-10	9.48	9.16	6.0354	3.0200
-10	9.96	10.19	6.0191	4.0268
-10	10.41	11.21	6.0154	5.0133

Table 5: MOSFET characteristics at V_{BB} = -10

2.2 Semiconductor Parameter Analyzer

See included for various data curves which are used to describe the MOSFET device.

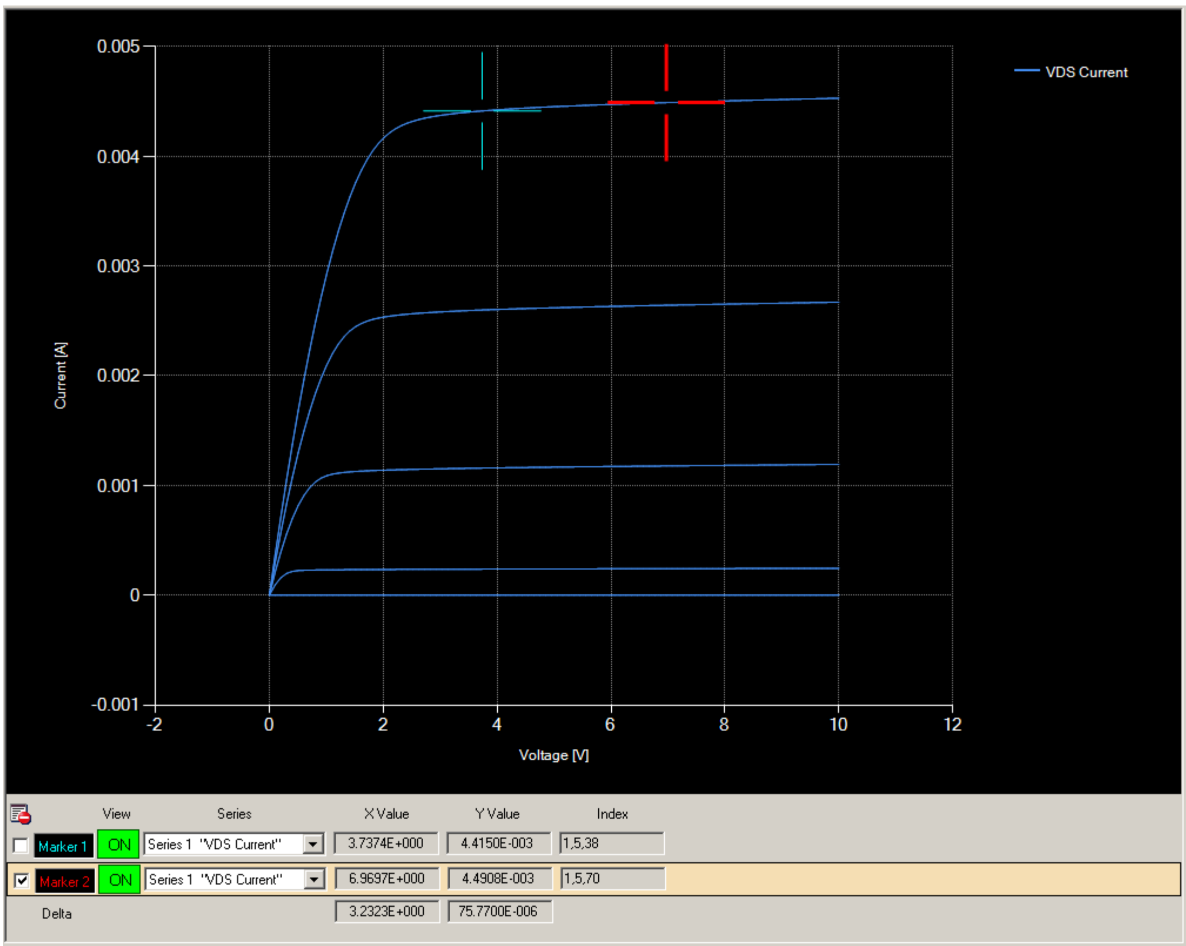


Figure 3: Drain-to-Source current vs Gate-to-Source voltage. The markers compare the highest V_{GS} to constant V_{GS} and are used to find the output resistance.

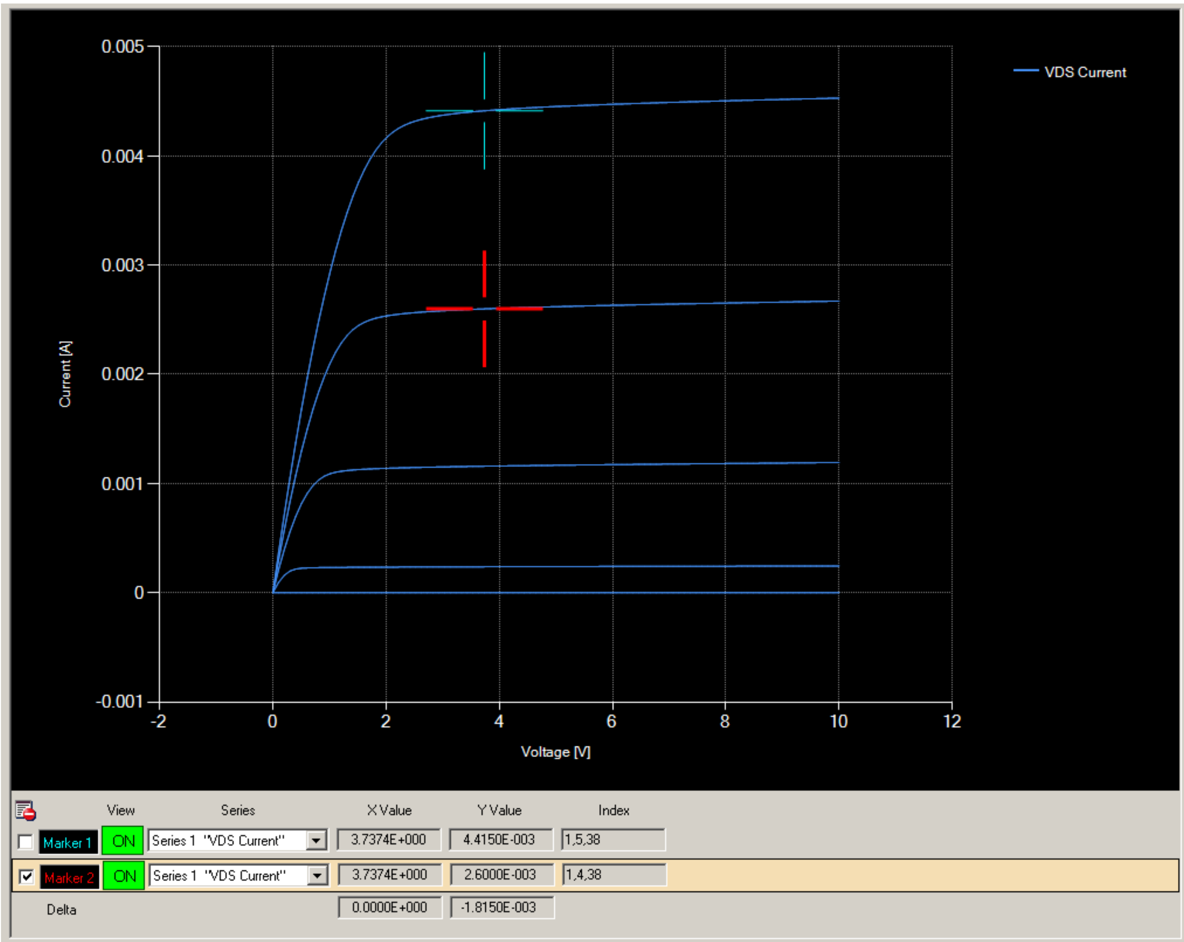


Figure 4: Drain-to-Source current vs Gate-to-Source voltage. The markers are used to find g_m, the MOSFET transconductance at saturation

3 Post Lab Data Analysis

3.1 MOSFET Threshold Voltage

The first part of this analysis was to determine the values of I_{DS} and $\sqrt{IDS}$ and put them into a table which is below.

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}	$\sqrt{I_{DS}}$
0	2.86	7.09	6.0550	1.0108	1.0054
0	3.60	8.15	6.0768	2.0041	1.4157
0	4.22	9.13	6.0277	3.0031	1.7329
0	4.76	10.17	6.0273	4.0049	2.0012
0	5.27	11.21	6.0167	5.0176	2.24

Table 6: MOSFET characteristics at $V_{BB} = 0$

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}	$\sqrt{I_{DS}}$
-2	4.48	7.06	6.0200	1.0062	1.0031
-2	5.18	8.07	6.0013	2.0049	1.4159
-2	5.75	9.12	6.0210	3.0004	1.7322
-2	6.27	10.21	6.0476	4.0233	2.0058
-2	6.75	11.20	6.0050	5.0190	2.2403

Table 7: MOSFET characteristics at V_{BB} = -2

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}	$\sqrt{I_{DS}}$
-6	6.64	7.05	6.0200	1.0014	1.0006
-6	7.31	8.12	6.0434	2.0131	1.4188
-6	7.86	9.12	6.0099	3.0064	1.7339
-6	8.36	10.19	6.0380	4.0219	2.0055
-6	8.81	11.22	6.0200	5.0171	2.2399

Table 8: MOSFET characteristics at V_{BB} = -6

From the data given we then plotted the values $\sqrt{I_{DS}}$ vs VGS and drew a line of best fit on each of the plot point. The line was then extrapolated to 0 for us to determine the threshold voltage V_T.

V_{BB} (V)	V_{GG} (V)	V_{DD} (V)	V_{DS} (V)	I_{DS}	$\sqrt{I_{DS}}$
-10	8.28	7.05	6.0195	1.0019	1.0009
-10	8.93	8.14	6.0714	2.0046	1.4158
-10	9.48	9.16	6.0354	3.0200	1.7378
-10	9.96	10.19	6.0191	4.0268	2.0067
-10	10.41	11.21	6.0154	5.0133	2.2349

Table 9: MOSFET characteristics at V_{BB} = -10

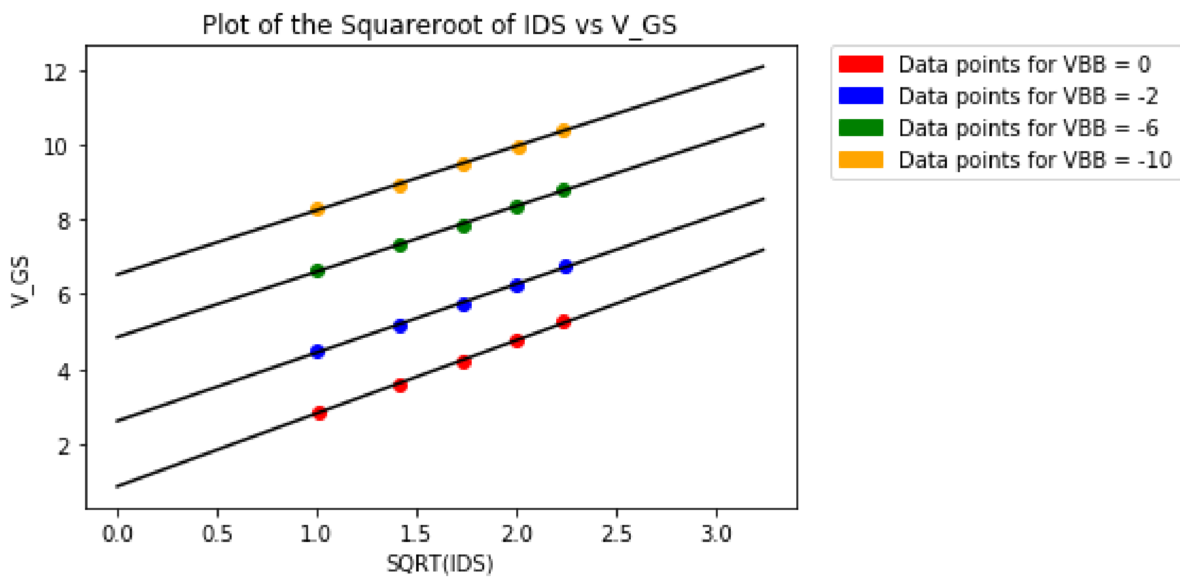


Figure 5: The plot of $\sqrt{I_{DS}}$ vs VGS

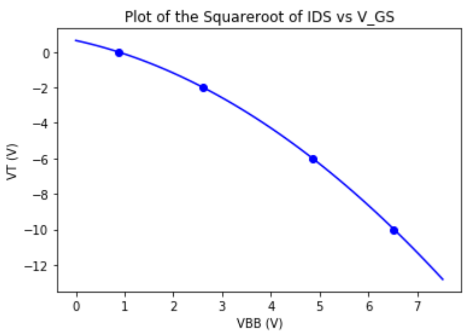
From the graphs we were able to determine the threshold voltage V_T for each V_{BS}.

V_T (V)	V_{BS} (V)
0.867	0
2.61	-2
4.85	-6
6.53	-10

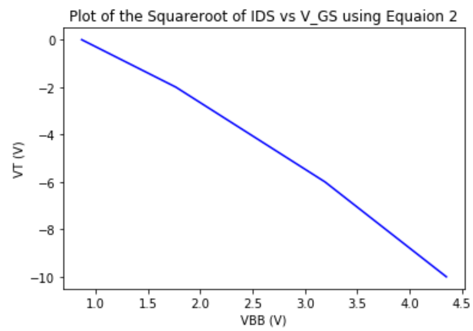
Table 10: Voltage Threshold at each V_{BB}

As we can see the value of V_t when $V_{BB} = 0$ is 0.867V, which is different to the value of V_T that we found in the previous part during the experiment which is 1.58V.From this data we then plotted V_T vs V_{BS}, and drew a curve through the points.

From the figure above we can see that the shape of the curve that we plotted with the data



(a) The plot of V_t vs VBS



(b) The plot of Equation 2

we obtained matched that of the shape of the curve that is created with equation 2 in the lab manual. The only difference would depend on the model parameters γ and ϕ.

$$I_{DS} = K(V_{GS} - V_T)^2 \tag{1}$$

Is equation 1, from this we know that $\sqrt{K}$ is the slope of the lines in Figure 5 we can see that the non-zero values of V_{BS} do not really effect the K parameter. The only thing that is effected is the threshold voltage V_T.

3.2 Semiconductor Parameter Analyzer

3.2.1 I_{DS} vs. V_{DS} Characteristics for various V_{GS}

First we will look at the MOSFET's three terminal characteristics:

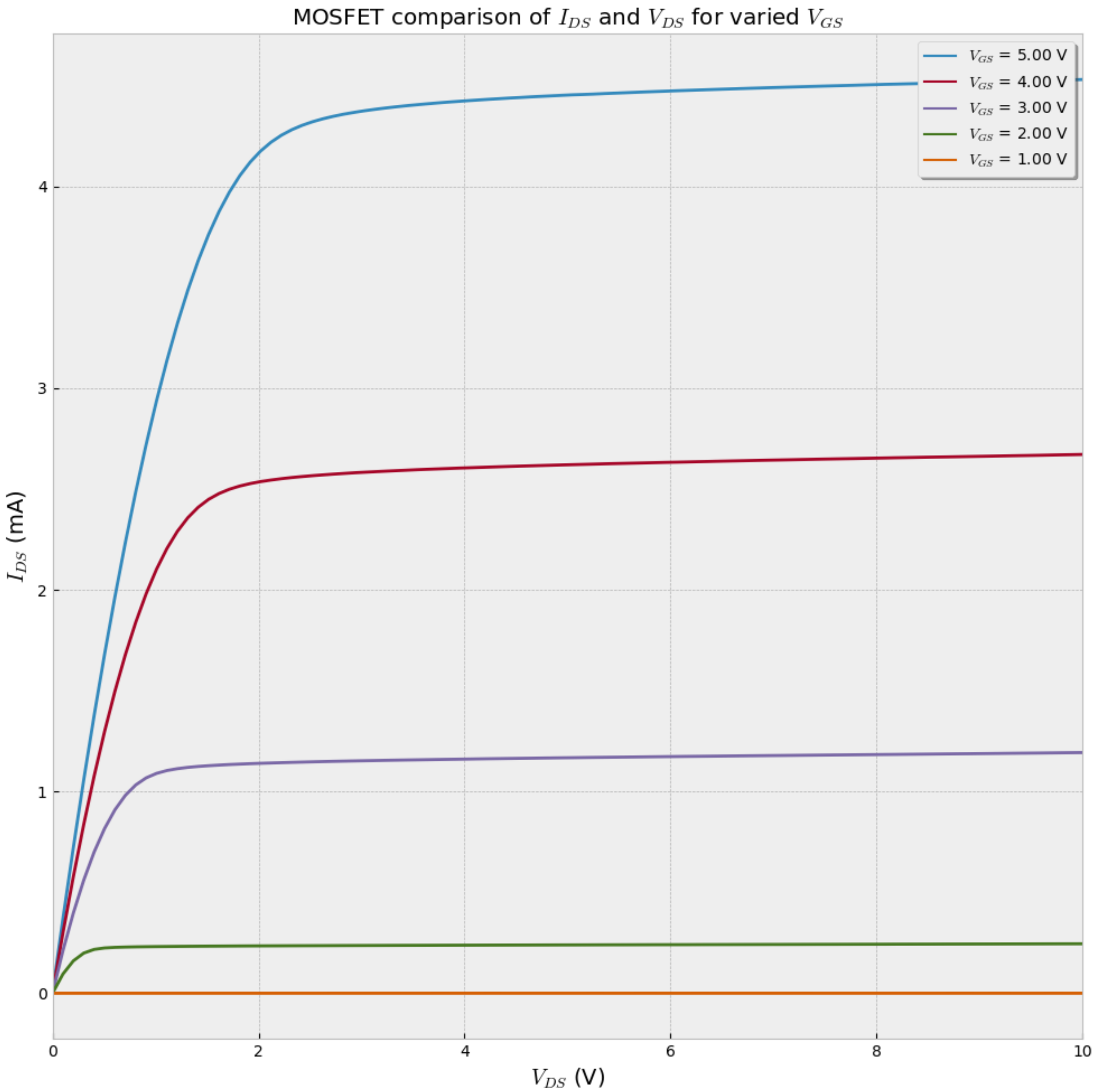


Figure 7: The characteristic graphs of I_{DS} vs. V_{DS} for several differing values of V_{GS}.

We also view these three terminal characteristics through the Agilent Software, which is shown here:

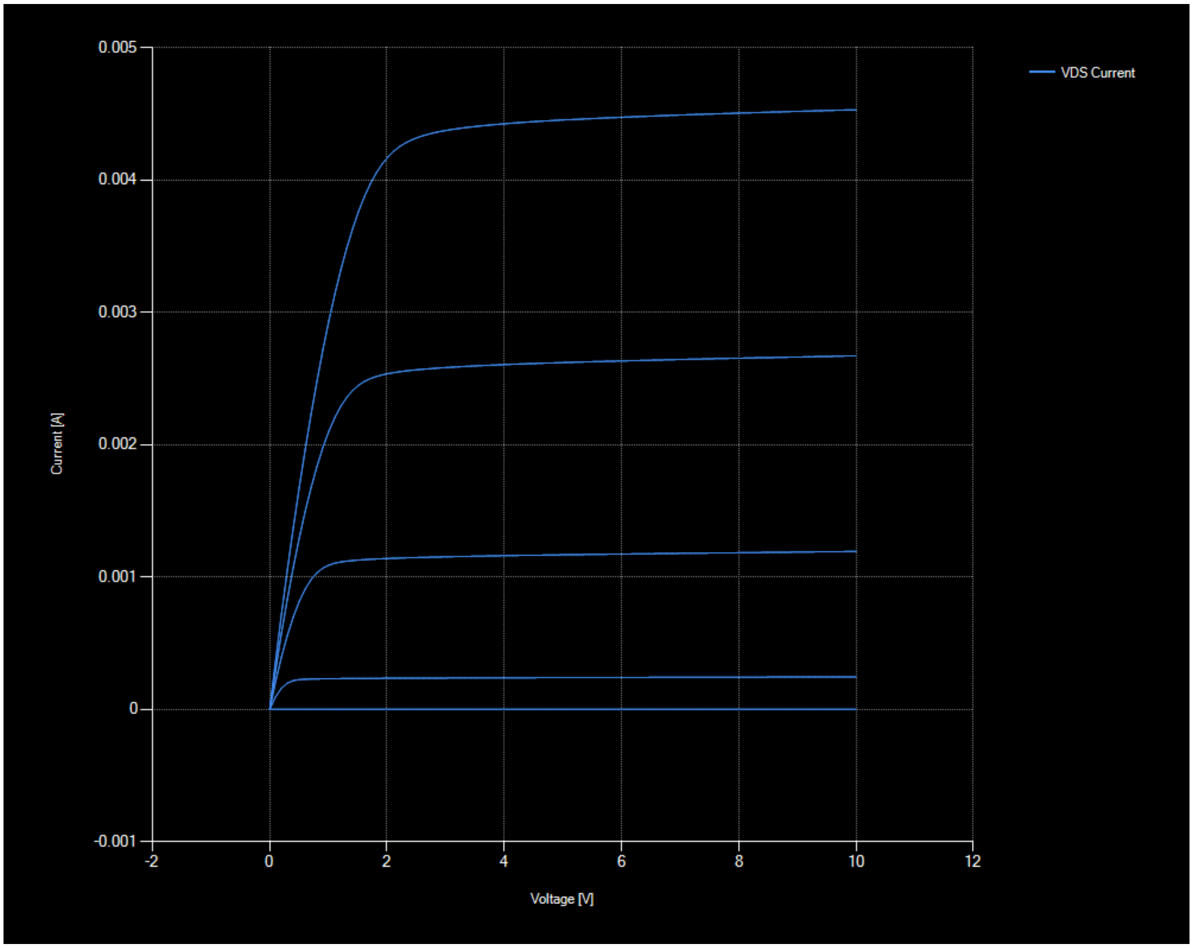


Figure 8: The characteristic graphs of I_{DS} vs. V_{DS} for several differing values of V_{GS}. Shown with in-lab software

From these graphs we can calculate two important characteristics, these are the MOSFET output resistance r_o and the trans conductance g_m.

We note that we can calculate the output resistance by taking two points along a single V_{GS} (The points taken are shown in Figure 3) through $r_o = (\frac{\partial I_{DS}}{\partial V_{DS}}|_{V_{GS}=constant})^{-1}$. We simply use the delta between the markers where $\Delta V_{DS} = 3.23\ V$ and $\Delta I_{DS} = 75.77\ \mu A$ where $V_{GS} = 5.00V$. Therefore $r_o = 42.63\ k\Omega$.

We then calculate transconductance g_m, where this is defined as $g_m = \frac{\partial I_{DS}}{\partial V_{GS}}|_{V_{DS}=constant}$. The points taken are shown in Figure 4, where the deltas $\Delta V_{GS} = 1.00\ V$ and $\Delta I_{DS} = 1.815\ mA$ where $V_{DS} = 3.73V$. Therefore $g_m = 1.815\ mS$.

To find the early voltage, the saturation portion of the curves are fitted with a linear function and then the x intercept should be the value of the early voltage. The fitting is completed here, with the fit shown in Figure 9. Then the intercepts are found in Figure 10. We see that there is large variation in the values of early voltage, leading to an experimentally found value of $V_E = -250 \pm 50V$.

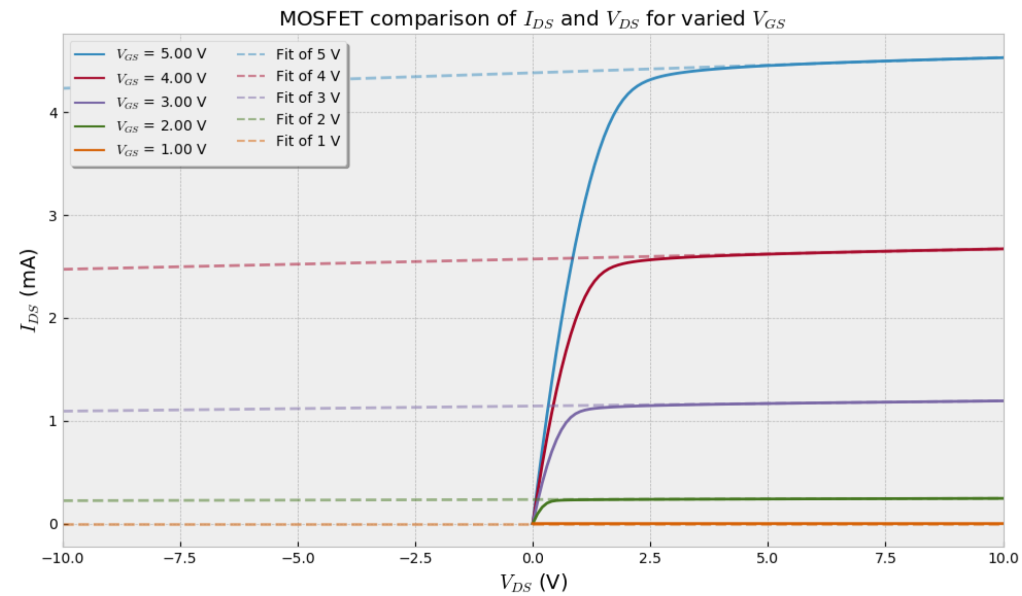


Figure 9: The characteristic graph with linear fit of saturation portion of curve to show quality of fit.

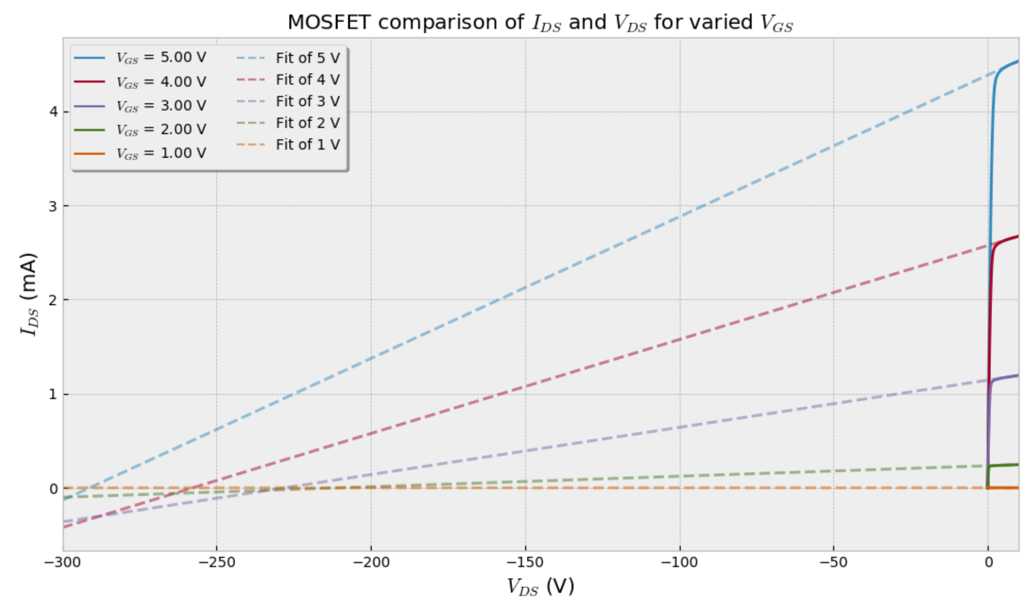


Figure 10: The characteristic graph with linear fit to show the Early Voltage

To estimate the threshold voltage we graph the value of I_{DS} vs. V_{GS}. this is shown in Figure 11. Due to the low number of V_{GS} points which are taken, the determination of V_T is a rough approximation. We approximate that it is 1V. This agrees with the found estimated value found during data collection and during part 1, A higher number of V_{GS} points taken would allow for a more accurate approximation.

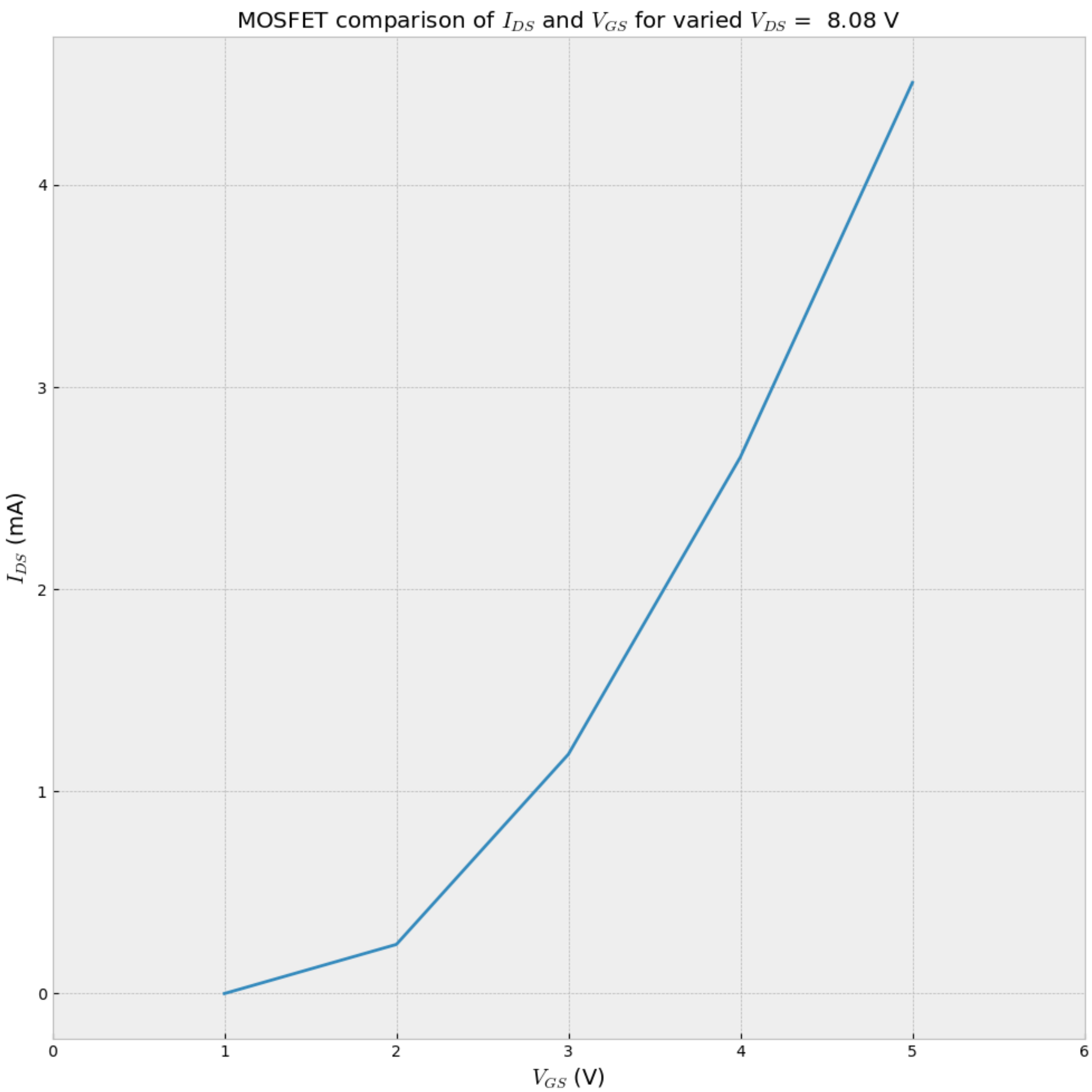


Figure 11: The characteristic graph of I_{DS} vs. V_{GS} used for determining the threshold voltage

Finally for this characteristic graph we show the condition $V_{DS} = V_{GS} - V_T$ which designates the two regions of the graph. These regions correspond to the triode region and the saturation region.

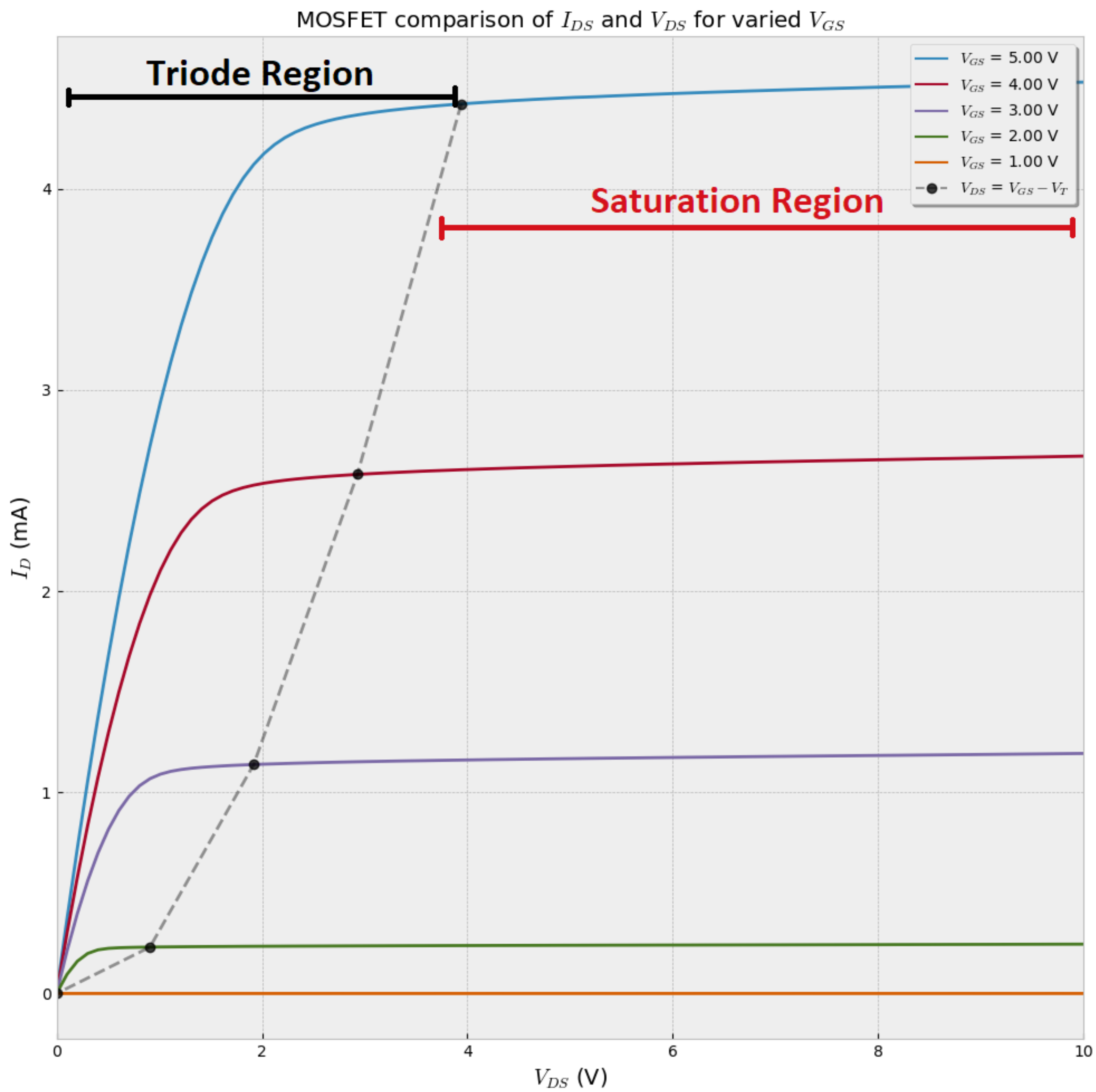


Figure 12: The characteristic graph of I_{DS} vs. V_{DS} with the condition $V_{DS} = V_{GS} - V_T$ inputted and shown on graph

3.2.2 I_{DS} vs. V_{DS} Characteristics for various V_{GS} for small V_{DS}

Here we take a look at the characteristic graph of I_{DS} vs. V_{DS} but for small positive and negative values of V_{DS}. This is shown in Figure 13.

We also wish to determine if the MOSFET is behaving as a voltage controlled resistor. We note that a voltage controlled resistor will essentially behave as a passive resistor, except that a third terminal will be able to change the resistance of the device. We note that resistors are linear and in Figure 13 we see that the slope of the curve and hence the resistance is controlled by the Gate Voltage. However we also note that the lines are not perfectly linear. These non-linear regions are evidence of distortion in the resistor. We conclude that the MOSFET can be used as a voltage controlled resistor, but care must be taken to avoid distortion effects.

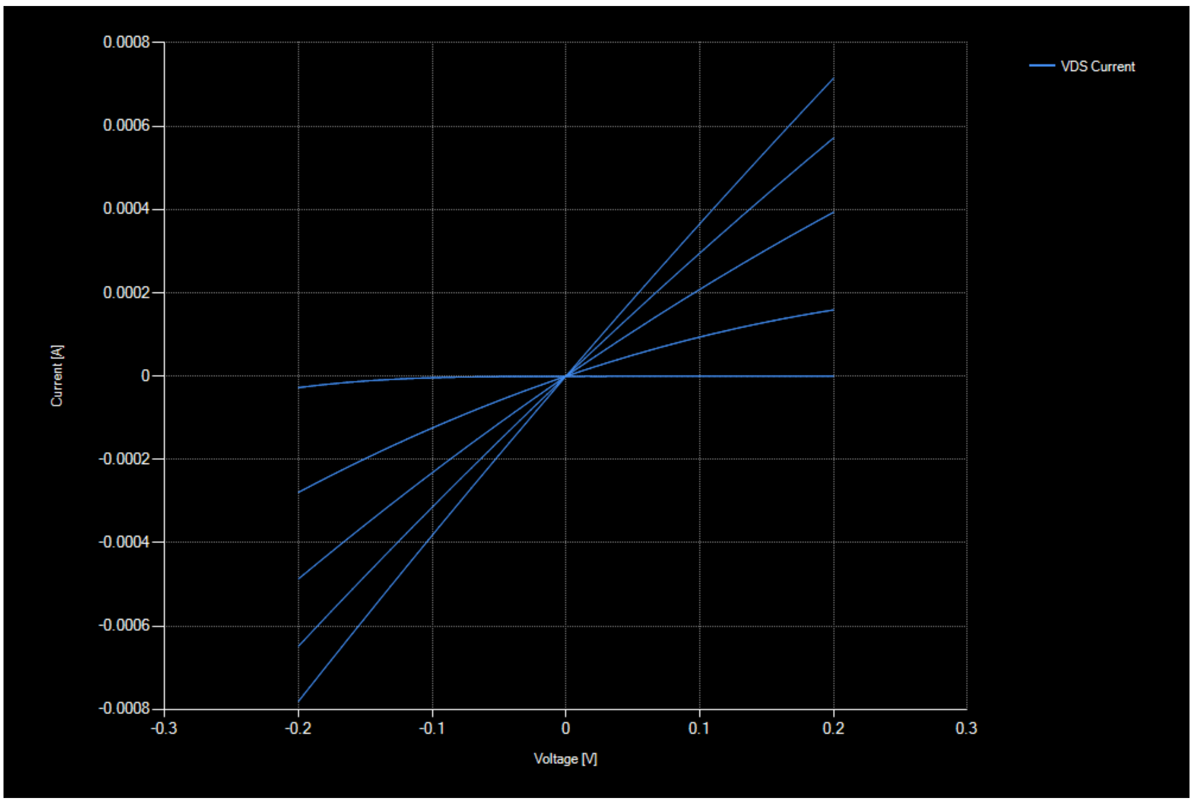


Figure 13: The characteristic graph of I_{DS} vs. V_{DS} with small V_{DS}