ECSE 331: Electronics
Laboratory Report

Laboratory Experiment#5

MOSFETs And BJTs DC Characteristics

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Lab Section 6, Wed. 1:35-3:35PM

Submitted:

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Laboratory Experiement#5

MOSFETs and BJTs DC Characteristics

Abstract— The purpose of laboratory experiment number five, was to explore the functions and characteristics of MOSFETs and BJTs. In the first part of this laboratory, the I-V characteristics of the MOSFET was found and drawn for different gate voltages, then the transconductance g_m of the circuit was found. Then in the second part, the behavior of the MOSFET was studied at various temperatures. Then the same experiment was conducted on the BJT transistor: The I-V curve was drawn at various gate voltages, then the transconductance for the BJT was found and finally, the behavior f the BJT was studied at various temperatures. Experimental results showed that as the temperature of the transistors increased, I_{DS} also increased. So as the temperature increased the current conducted increased. In the introduction, the results will be discussed further.

I. INTRODUCTION

The goal of this laboratory was to test, and explore the behavior of the different transistors, draw their I-V diagrams using the NI Elvis-II test instrument. More specifically, the I-V curve for the MOSFET and BJT transistors were drawn using the data taken with the NI Elvis instrument. Then a resistor network was designed to find the DC operating point of the transistors. Finally, the effect of temperature on the operation of the transistors was tested and found. In the main body of this lab report the results for each of the circuits analyzed will be presented in a clear and concise manner.

II. MAIN BODY

We conducted several experiments with two kinds of transistors: The MOSFET and BJT. Their I-V curves were traced and the effects of temperature on their behaviors were found.

A. MOSFET i_D-v_{DS} Characteristics Using Curve Tracer
B. MOSFET Temperature Effects
C. BJT i_D-v_{DS} Characteristics Using Curve Tracer
D. BJT Temperature Effects

A. MOSFET i_D-v_{DS} Characteristics Using Curve Tracer

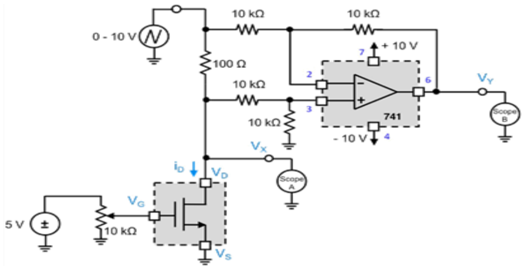


Fig1. Ciruit digram for I-V characteristic used in part A

I. The circuit diagram in figure 1 was constructed to measure V_{DS} and I_D and trace the I-V curve. This experiment was repeated multiple times with different gate voltages V_g. A sawtooth waveform going from 1v-10v was applied.

V_{in}	V_x=V_D	I_D= V_y/-100
0.5	510mV	0.29mA
1.5	1030mV	1.89mA
2.5	1050mV	4.74mA
2.7	1059mV	5.04mA
2.9	1059mV	5.20mA
2.95	1059mV	5.46mA
3	1059mV	5.46mA
3.5	1059mV	5.46mA
4	1059mV	5.46mA

Table 1: V_{DS} and I_D as a function of Vin when Vg=0

From the table 1, it can be seen that I_D is very small, close to around 0.29mA when V_D was around 510mA, but as the voltage at the drain was increased, the current increased to around 5.46mA, where it saturated. Ideally it should be 0, but very rarely, circuits and elements act as ideal elements.

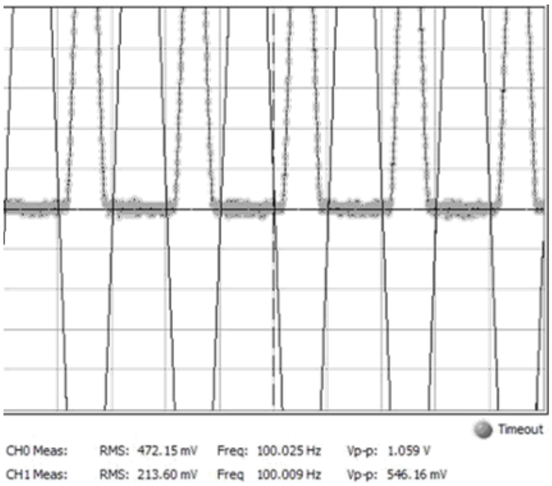


Fig2. Oscilloscope measurement when gate v=0V and Vin=3.5V

II. On the same circuit as in part I, the gate voltage Vg was increased to 1V, and the data collected, then Vg was increased to 2V and so on until the gate voltage had reached 5V, for each case 1-5V gate voltage the I-V curve was constructed using the data collected with the Oscilloscope. Below are the table of I_{DS} and V_D as Vin was varied.

V_{in}	V_x=V_D	I_D= $_{vy}$/-100
0.5	502mV	0.29mA
1.5	1030mV	1.89mA
2.5	1050mV	4.74mA
2.6	1059mV	5.04mA
2.65	1059mV	5.20mA
2.7	1059mV	5.46mA
2.8	1059mV	5.46mA
3	1059mV	5.46mA
3.2	1059mV	5.46mA
3.5	1059mV	5.46mA

Table 2 for V_D vs I_{DS} as Vin is varied for Vg= 1V

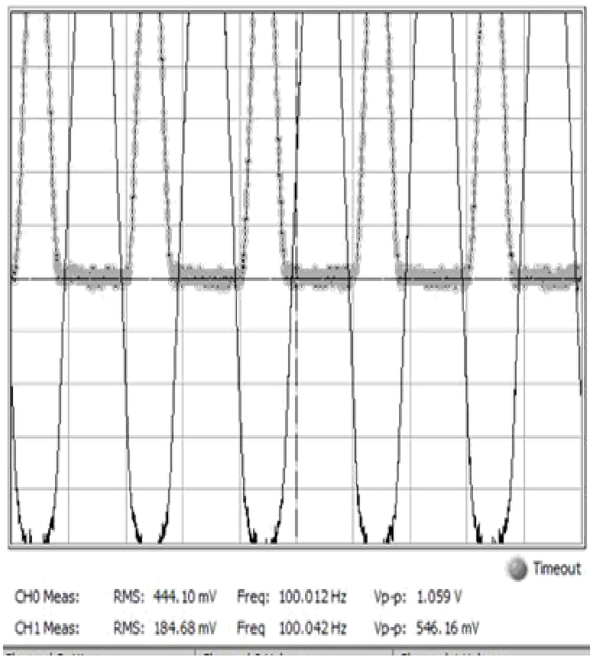


Fig3. Oscilloscope measurement when gate v=1V and Vin=2.8V

As we can see from the data in table 2, I_{DS} is around 0.29mA when the drain voltage is around 500mV, but as it increases, the current increase to a saturated value of about 5.46mA, just like the previous case where Vg=0v.Theoritically, the value should have been 0 because Vg was 1V and we know that $T_{hreshold}$=2v. For current to flow theoretically, we need to have a Vg larger than threshold.

When Vg is superior to 2V, we start to see the behavior of the MOSFET, if we plot the data of table 3, we see that the I-V curve in the first part consists of a linear function, where I_D increases as we increase Vin, then at a certain point, when Vin is more than 1.9V, so around the Threshold voltage, I_D saturates to a value of 7.05mA, as it can be seen in figure 4.

V_{in}	V_x=V_D	I_D= $_{vy}$/-100
0.5	162mV	2.47mA
0.75	265mV	3.44mA
1	380mV	4.32mA
1.7	664mV	6.55mA
1.8	664mV	6.89mA
1.85	668mV	7.01mA
1.9	670mV	7.05mA
2	680mV	7.05mA

Table 3 for V_D vs I_{DS} as Vin is varied for Vg= 2.5V

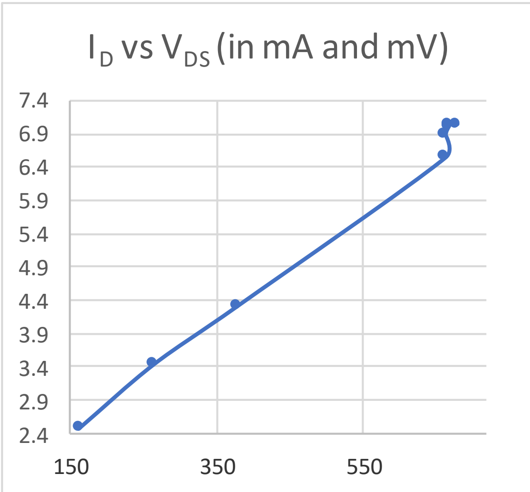


Figure 4: I-V curve when Vg=2.5V

In table table 4, I_{DS} vs V_{DS} can be seen as Vin is varied. As it can be seen in its corresponding I-V curve in figure 5, the current increases linearly until V_{DS} = 116mV when Vin= 1.6V, then it saturates at current value of around 10.7mA.

V_{in}	V_x=V_D	I_D= $_{vy}$/-100
1	112mV	6.38mA
1.5	116mV	9.53mA
1.6	116mV	10.0mA
1.75	120mV	10.7mA
2	120mV	10.7mA
3	141mV	10.7mA
4	153mV	10.7mA
5	182mV	10.7mA

Table 4 for V_D vs I_{DS} as Vin is varied for Vg= 3.7v

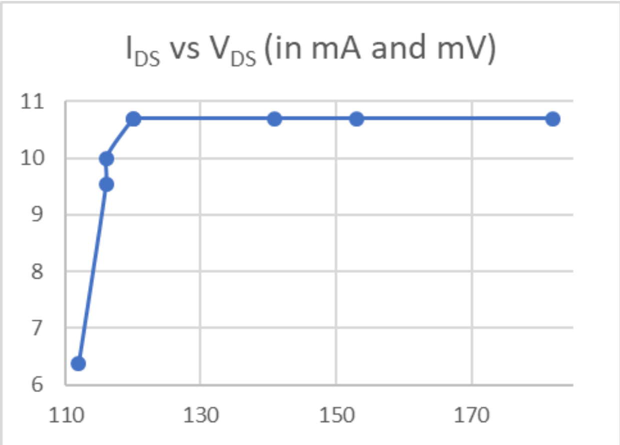


Figure 5: I-V curve when Vg=3.7V

We can clearly see from the graph in figure 5 that the current saturates to a value of 10.7mA when V_D reaches a value of 116mV (Vin= 1.85V).

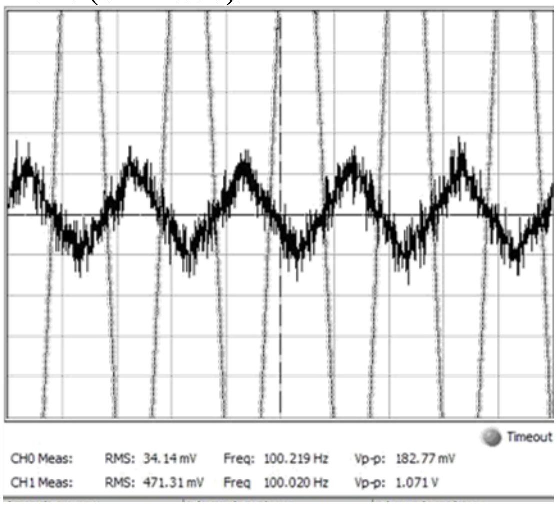


Fig6. Oscilloscope measurement when gate v=1V and Vin=2.8V

Finally, in the table and graph below are the data and I-V curve for the MOSFET when gate voltage Vg= 4.92V.

V_{in}	V_x=V_D	I_D= $_{Vy}$/-100
0.5	85mV	3.25mA
1	95mV	6.45mA
2	110mV	12.9mA
3	120mV	19.5mA
4	140mV	25.8mA
5	149mV	32.2mA
6	155mV	38.6mA
7	170mV	45.0mA
8	186mV	51.28mA
9	195mV	57.64mA
10	210mV	64.42mA

Table 5 for V_D vs I_{DS} as Vin is varied for Vg= 4.92v

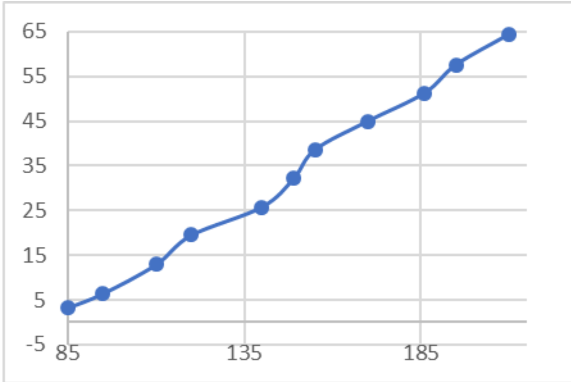
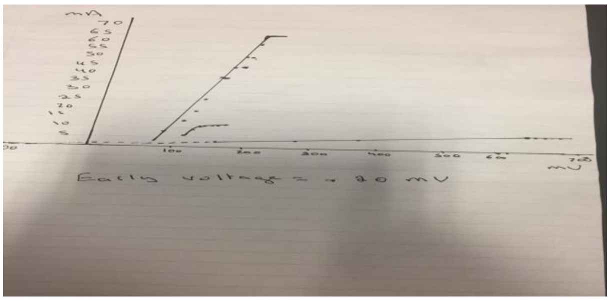


Figure 7: I-V curve when Vg=4.92V

III. According to the Manufacturers data sheet, the threshold voltage is around 2V. We know that theoretically for current to flow in a linear way $V_{DS} < V_{Gate} - T_{hreshold,}$ so at the point $V_{DS} = V_{Gatte} - T_{hreshold,}$ curve is no longer linear. From the graphs, we can easily find that point, and since we know $V_{Gate,}$ for each I-V curve, we can find the Threshold voltage.

When Vg= 2.5V, the saturation current is reached when V_{DS} =0.688V. Since we know $V_{DS} = V_{Gate} - V_{Treshold}$,$V_{Treshold}$ = 2.5-0.688v= 1.812V, which is very close to the value given by the data sheet. So the **Threshold voltage** found **experimentally** is **around 1.812V.**

IV. Figure 8 shows the combination of all the curve traces into a single plot, from it we get a general idea of its overall behavior. From the graph in figure 4 the Early voltage of our device was extrapolated **to be around 12V.**


Early voltage extrapolation

V. To find the transconductance $g_{m,}$ of our device the following formula was used:g_m= $\Delta i_D / \Delta v_{GS}$.
Using the circuit in figure 1, the following data were measured.
Vg1=3V, i_{D1}=37.81mV/-100, Vg2=3.1V and i_{D2}=33.61mV/-100
g_m= (((33.61-37.81)/-100) /1000) / (0.1)= **0.42*10^-3**

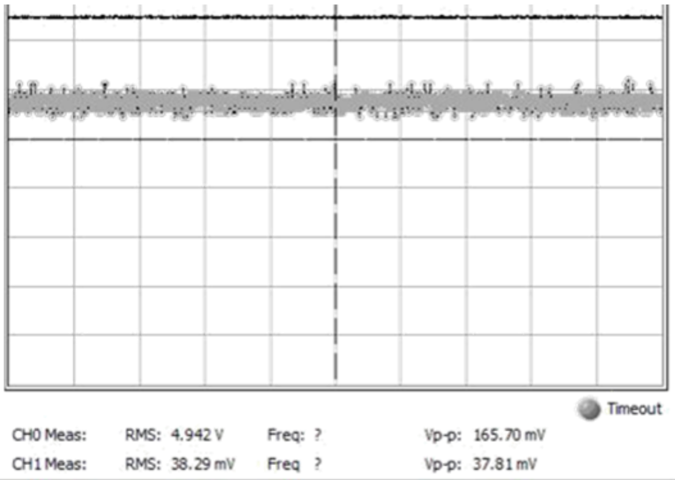


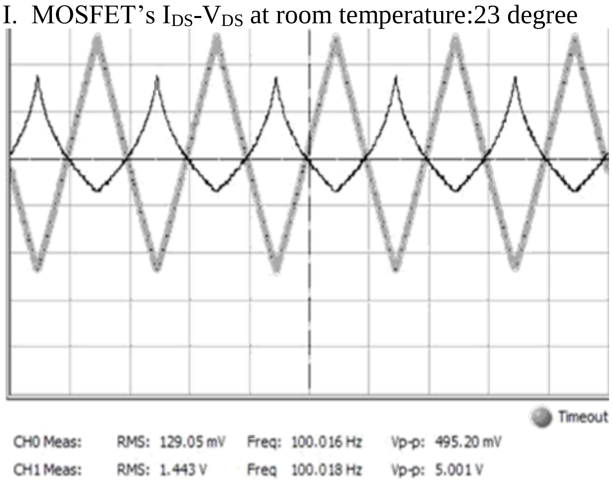
Fig6. Oscilloscope measurement when gate v=3 and Vy=37.81

VI. Equivalent small signal model of MOSFET for low-frequency operation.

B. MOSFET Temperature effects

The MOSFET's I_{DS}-V_{DS} curve was measured using the circuit in figure 1 with the MOSFET being at different temperatures, theoretically for higher temperature there will be more holes and electrons at the interface of the metal gate and the substrate. Thus, a larger current can be conducted. Therefor, theoretically for higher temperatures the current conducted at a certain V_{DS} will be larger than for a lower temperature.

I. MOSFET's I_{DS}-V_{DS} at room temperature:23 degree



V_{DS} vs V_y for MOSFET at 23 degrees (Vin=8V)

Using the circuit in figure 1 with the MOSFET being at 23 degrees, we observe get the following data as written in table 6 and graph of I_{DS} vs V_{DS} figure 8.

V_{in}	V_{DS}	I_{DS}
1	54mV	6.42mA
2	100mV	12.76 mA
3	145 mV	18.90 mA
4	200 mV	21.41 mA
5	257 mV	31.79 mA
6	319 mV	37.70mA
7	400 mV	44.00 mA
8	495 mV	50.00 mA
9	660 mV	55.50 mA
10	949 mV	60.18 mA

Table 6. V_{DS} vs I_{DS} when at 23 degrees Vg=3v

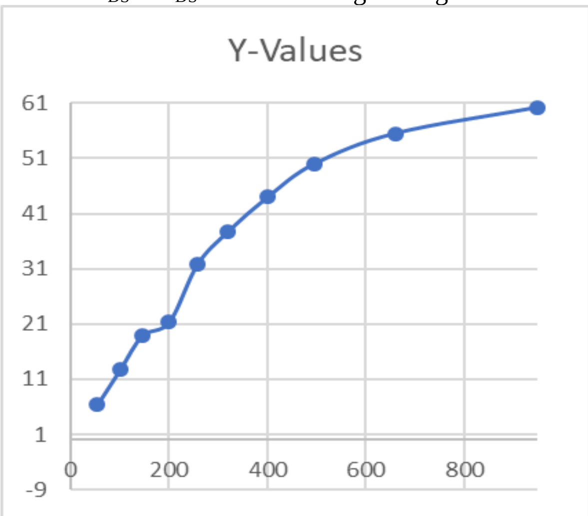


Fig3. I-V Characteristic at 23 degrees

II. MOSFET's I_{DS}-V_{DS} at -5 degrees:

Using the circuit in figure 1 with the MOSFET being at -5 degrees, we observe get the following data as written in table 7 and graph of I_{DS} vs V_{DS} figure 8.

V_{in}	V_{DS}	I_{DS}
1	83mV	6.20mA
2	170 mV	12.00 mA
3	270 mV	18.20mA
4	400 mV	24.10mA
5	660 mV	28.80 mA
6	1050 mV	33.00mA
7	1210 mV	36.87 mA
9	2460 mV	43.60 mA
10	2700 mV	49.00 mA

Table 7. V_{DS} vs I_{DS} when at -5 degrees Vg=3v

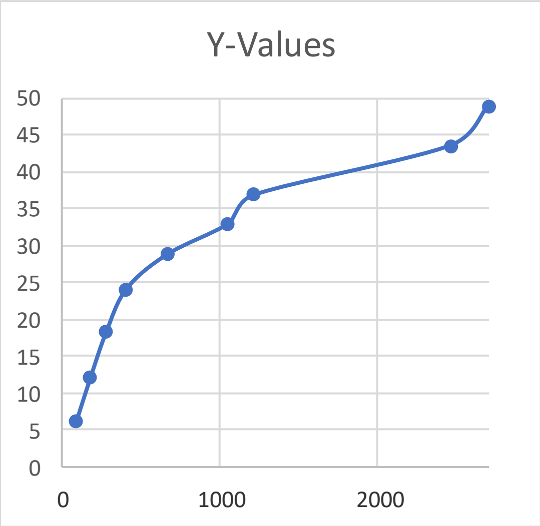
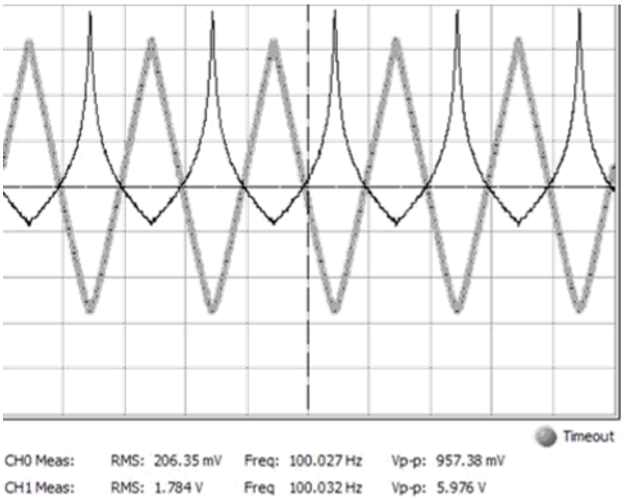


Fig4. I-V characteristic at -5 degrees C

III. MOSFET's I-V curve at 60 degrees:



V_{DS} vs V_y for MOSFET at 60 degrees (Vin=10V)

Using the circuit in figure 1 with the MOSFET being at 60 degrees, we observe get the following data as written in table 8 and graph of I_{DS} vs V_{DS} figure 8.

V_{in}	V_{DS}	I_{DS}
1	49.00mV	6.42mA
2	95.5 0mV	12.70 mA
3	140.00 mV	19.00 mA
4	190.00 mV	25.40 mA
5	240.00 mV	31.79 mA
6	307.00 mV	37.70 mA
7	379.00 mV	42.65 mA
8	486.00 mV	50.10 mA
9	652.00 mV	55.20 mA
10	957.00 mV	60.10 mA

Table 8. V_{DS} vs I_{DS} when at -5 degrees Vg=3v

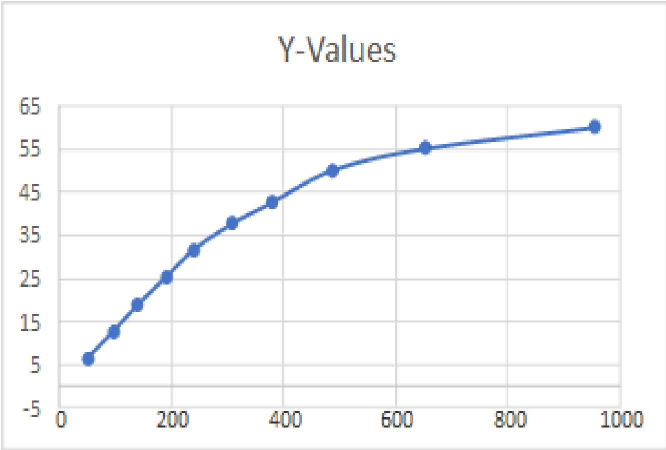


Fig5. I-V characteristics at 60 degree C

IV. As was explained earlier, from theory, we know that the MOSFETS behavior changes with temperature, as temperature increases the I-V curve shifts to the left, so the barrier voltage is lowered and when the temperature is decreased, the curve shift to the right, which means the barrier voltage is increased. This follows from the fact that as the temperature increases, we have more thermally generated holes and free electrons, this will decrease the voltage barrier at the PN junction. Which causes the MOSFET to conduct more current at lower voltages!

By comparing the three graphs, we see that for 23 degrees and 60 degrees the values and the graph are very similar, while for -5 degrees, for a given value of V_{DS}, I_{DS} is smaller. That is explained by the fact that at lower temperatures, there are less free electrons and holes available to conduct current.

V. To reduce change in MOSFET behavior as a function of time, keep the devices temperature constant.

C. BJT I_{DS} -V_{DS} Characteristics

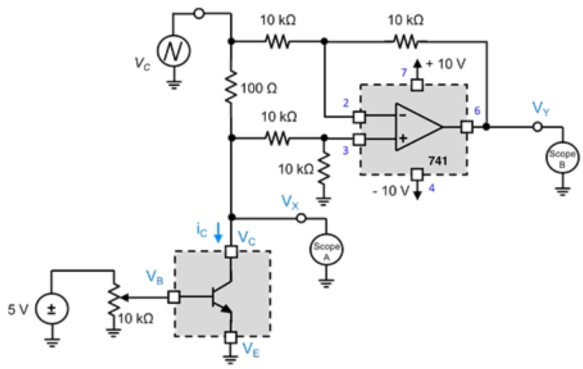


Fig6. Circuit diagram to find I_{DS} vs V_{DS} for the BJT

To analyze the behavior of I-V characteristic of the BJT, we build circuit in figure X and plot the curve for different values of Vin. Similarly, to part A, our input signal is a sawtooth waveform that varies from 0 to 10v.

I. When the gate voltage is at 0, it is less than the threshold voltage needed to generate a current, so as a result I_{DS} is 0v irrespective of the V_{DS}.

V_{in}	V_{DS}	I_{DS}
1	0	0
…..	0	0
10	0	0

Table 9. BJT when Vg=0v

When the gate voltage is at 0.2V, we start to get some current in the channel.

V_{DS}	I_{DS}
2v	0.077mA
3v	0.12 mA
6.98v	0.28 mA
7.96v	0.28 mA
9.42v	0.33mA

Table 10. BJT when Vg=0.2v

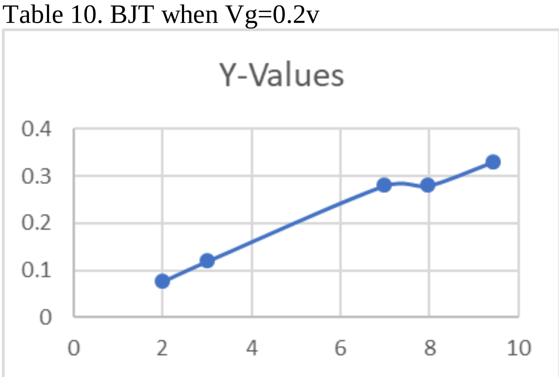


Fig7. Ids vs Vds when Vg=0.2v

When Vg=0.4v

Vin for BJT vg= 0.4V	Vd	Ids (mv)
	3.89v	0.077mA
	6.98v	0.245 mA
	7.96v	0.245 mA

Table 11. BJT When Vg=0.4v

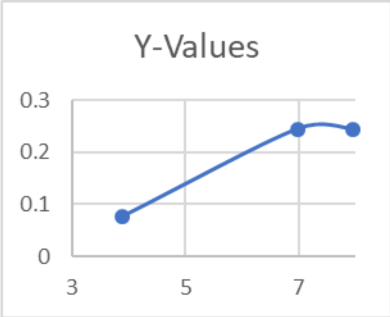


Fig 8. Ids vs Vds when Vg=0.4v

When Vg=0.65v

Vin for BJT vg= 0.65V	Vd	Ids (mv)
	2.26v	1.12mA
	5v	1.25 mA
	6.33v	1.33 mA
	7.96v	1.37 mA

Table 12. BJT When Vg=0.65V

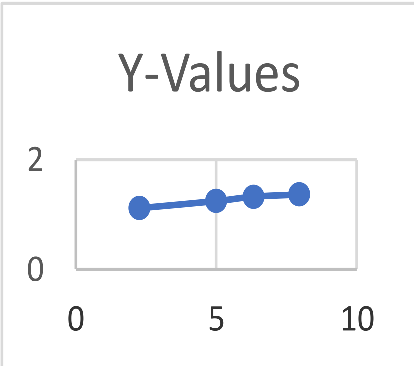


Fig 9. Ids vs Vds when Vg=0.65v

When Vg=0.71v

V_{DS}	I_{DS}
2.1	3.06mA
3.56	3.10mA
4.7	2.97 mA
6.49	3.23 mA
7.63	3.14 mA
8.77	3.26 mA

Table 13 BJT When Vg=0.71V

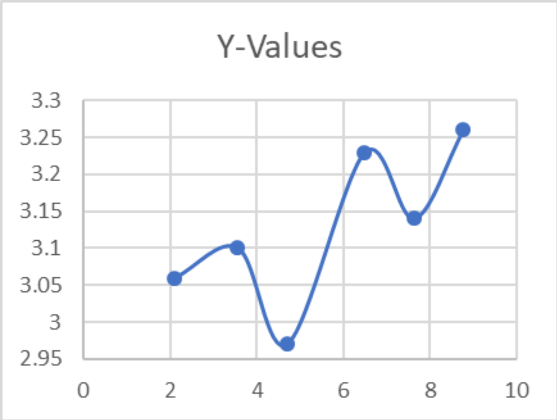
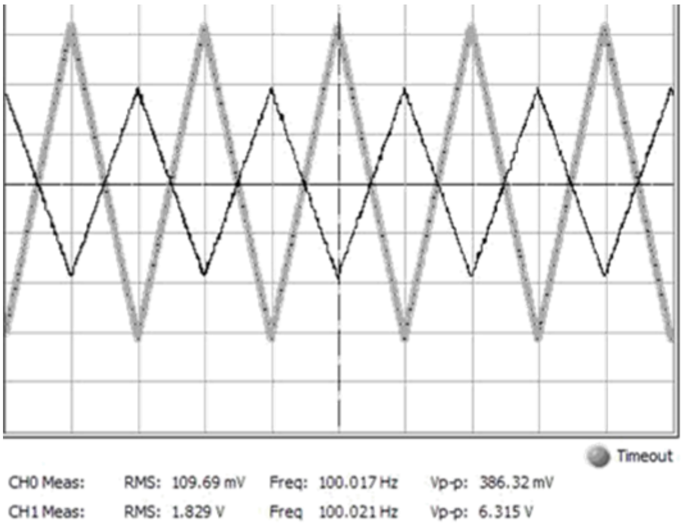


Fig 10. Ids vs Vds when Vg=0.71v



Oscilloscope reading for BJT V_{DS} vs V_y when Vin=10v

When Vg =0.75v

V_{DS}	I_{DS}
1.12	4.60 mA
3.08	4.60 mA
4.38	4.76 mA
5.19	4.93 mA
6.33	4.85 mA
7.31	4.93 mA
7.96	4.93 mA
8.45	5.02mA
9.26	5.1mA

Table 14 BJT when Vg=0.75

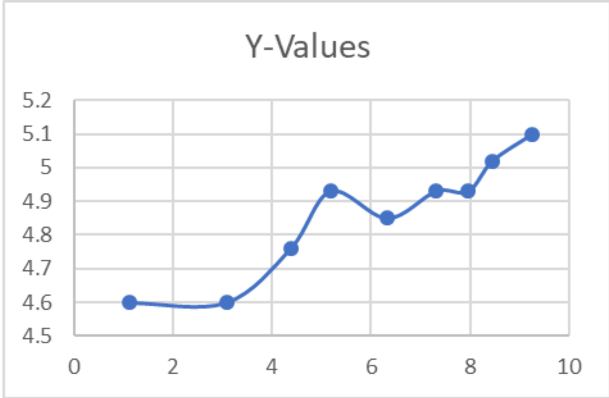


Fig 11. Ids vs Vds when Vg=0.75v

II. As it can be seen from the graphs and tables, at low gate voltages, the value of I_{DS} is very small, in the range of around 0.077mA to around 1.37mA. When the gate voltage is increased to around 0.71V, we see that the current starts to increase to around 3.26mA. Finally, for a gate voltage of 0.75, we see that the current I_{DS} goes from 4.6mA to up to 5mA for values of V_{DS} going from 1.12v to 8.45v.

III. The early voltage was extrapolated to be around 15 volts using the multiple graphs from figures 7-10.

IV. Computing the Transconductance of the device.

G_m= (((125.3-293)/100) / (4.71-4.81))/1000= 0.168.

VI. Small signal model of BJT at low frequency:

D. Temperature Effect on I-V curve of BJT

Using the same circuit diagram, the I-V curve of the BTJ was measured at various temperatures. Theoretically, at lower temperatures the current Ids is going to be lower and vice versa.

I. I-V curve when BJT temperature is 22 degrees
Graph of I-V characteristic is in figure 10.

V_{DS}	I_{DS}
2.1	3.06mA
3.56	3.10mA
4.7	2.97 mA
6.49	3.23 mA
7.63	3.14 mA
8.77	3.26 mA

Table 15 Ids and Vds for BJT when at 22 degrees

II. When BJT temperature is -14 degree Celsius

Vds in v	Ids in mA
0.797	0.077
2.43	0.035
4.22	0.161
5.03	0.202
5.68	0.282
6.49	0.246
8.45	0.287
9.10	0.311
9.91	0.287

Table 16 Ids and Vds for BJT when at -14 degrees

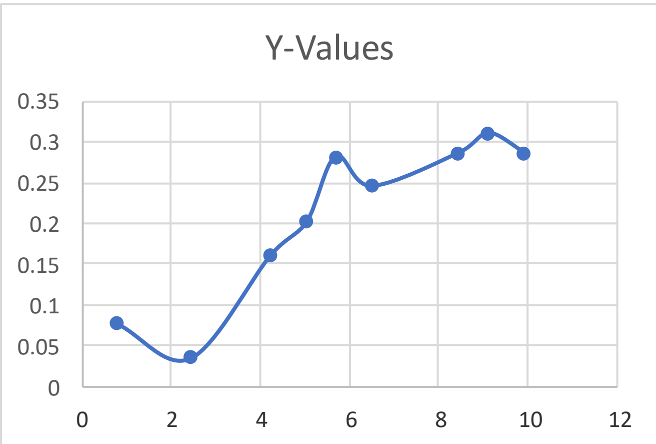


Fig 12. Ids vs Vds for BJT at -14 degrees

III. When BJT temperature 40 degrees

Vds in v	Ids in mA
1.64	6.61
2.89	6.78
4.54	6.87
5.79	6.95
6.20	7.03
6.53	6.78
7.28	7.20
8.85	7.28

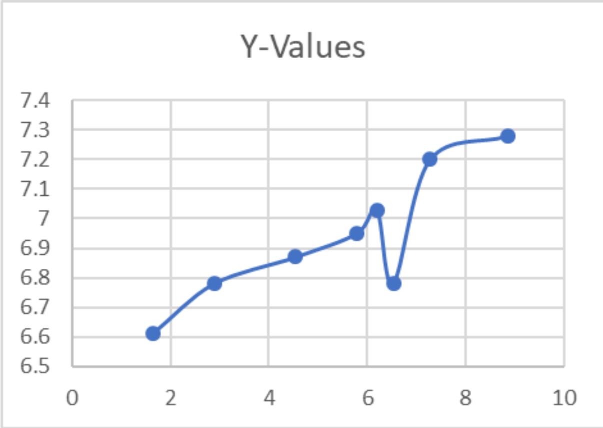


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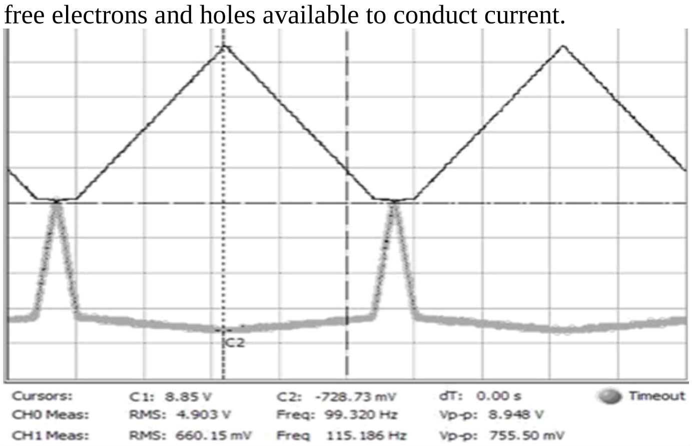
Fig13. I_{DS} vs D_{DS} for BJT at 40 degrees

IV. As it can be seen from tables 15, 16 and 17 and graphs in figure 10, 12 and 13, as we increase the temperature, the current for a certain drain voltage increases, as we decrease the temperature, the current decreases. So the temperature has a strong effect on the operations of the BJT transistor. Everything comes back to the physics of the components. As the temperature increases, there are more free holes and electrons to carry the charges, as a result the I_{DS} V_{DS} curve shifts up as we increase the temperature.

As was explained earlier, from theory, we know that the BJT's behavior changes with temperature, as temperature increases the I-V curve shifts to the left, so the barrier voltage is lowered and when the temperature is decreased, the curve shift to the right, which means the barrier voltage is increased. This follows from the fact that as the temperature increases, we have more thermally generated holes and free electrons, this will decrease the voltage barrier at the PN junction. Which causes the BJT to conduct more current at lower voltages!

By comparing the three graphs, we see that for 22 degrees and 40 degrees the values and the graph are very similar, while for -14 degrees, for a given value of V_{DS}, I_{DS} is smaller. That is explained by the fact that at lower temperatures, there are less free electrons and holes available to conduct current.



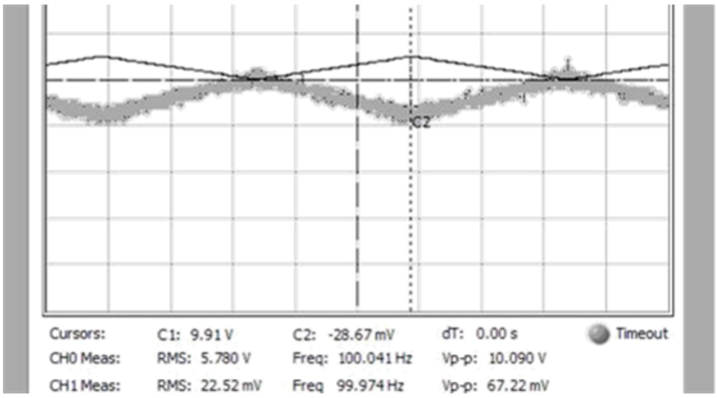
BJT Vds Vs Yy when at 60 degrees

CONCLUSION

To conclude, this lab was very helpful and eye opening because various circuits were built using MOSFETS and BJTs, and their behavior were observed under different conditions and in different circuits, and this created a contrast with everything learnt in the classroom. We saw in this lab that a MOSFETs and BJTs are heavily influenced by temperature, and we saw that for different values of Vds, the transistors behave differently. When Vds is less than Vgs-Vth, then the MOSFET functions in the triode region, if Vds is more than the overdrive voltage, then it is saturated and the current Ids is thus saturated.

We saw how the I-V characteristic curve of the diode changes as the temperature changes, theory predicted that as the temperature increased, the diode I-V curve would shift left by 2mV and if the temperature decreased, it would shift to the right by 2mV. Experimental data showed that it does shift to the left when temperature increases, and that the I-V curve shifts to the right when temperature decreases, but it did not shift to the left and right by exactly 2mV, it was more pronounced.

In this lab, the experiments overall confirmed what was learned in class, various circuits were built and the usefulness of the MOSEFT and BJT transistors were demonstrated.



BJT Vds Vs Yy when at -14 degrees