GENERAL ELECTRICAL ENGINEERING LAB

TRANSISTOR CHARACTERISTICS

Experiment 5

CH-120-B

Location: Jacobs University Bremen, Research 1

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Semester: 1

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Introduction

Explained in the simplest terms, a transistor is a device which controls the flow of electrons and hence, the electric current. When implemented in a circuit, these devices have two functions, i.e., they can either switch the direction of an electric current or amplify a current. This allows for more precise control of the electric current flowing through that circuit. Considering the structure of a transistor, it is made by placing two semi-conducting diodes 'back-to-back'. There are two types of transistors depending on the placement of the diodes (or P-N junctions) forming NPN or PNP type transistors. In a typical (bipolar) transistor, there are three terminals: the **emitter**, **base** and **collector**. When an electric current is applied at the central layer (**base**), electrons flow from the N-type side to the P-type side of the transistor. This small current applied acts as a switch which consequently allows a larger current to pass through, i.e., the transistor is acting as a switch and an amplifier at the same time in the circuit. A detailed drawing is given below.

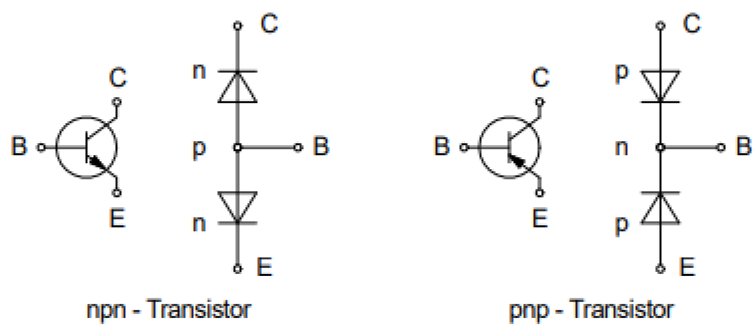


Fig. 1: A labelled Transistor (taken from lab manual)

A transistor can have different characteristics depending on its placement in the circuit. It can be forward bias, reverse bias or a current amplifier. During the experiment conducted, our focus is the **current amplification** characteristic.

Experimental Set-up and Results

Part 1: Input Characteristic

The following circuit was set up on the breadboard:

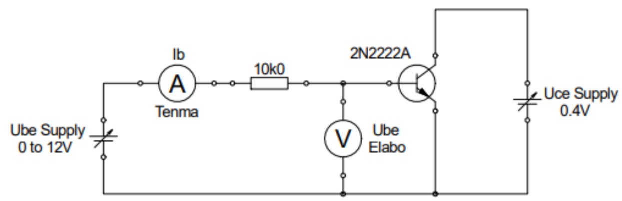


Fig. 2: Circuit to measure U_{BE} / I_{BE}

The Uce supply was set to 0.4V and the current was set using the Tenma ammeter to the following values consecutively: 0 µA, 5 µA, 10 µA, 20 µA, 40 µA, 60 µA, 80 µA, 100 µA 200 µA, 400 µA, 600 µA, 800 µA, 1000 µA.

Using the smallest possible range (µA in this case) on the Tenma multimeter, the set of I_{BE} from the ammeter and resulting U_{BE} from the voltmeter were recorded.

Current (µA)	U_{BE} (V)	Current I_{BE} (A)
0	0.0054	0
4.87	0.6298	0.00000487
9.53	0.6485	0.00000953
19.93	0.6693	0.00001993
40.41	0.6895	0.00004041
59.55	0.7011	0.00005955
81.07	0.7105	0.00008107
99.84	0.7169	0.00009984
200.49	0.7417	0.00020049
399.95	0.77	0.00039995
597.5	0.7856	0.0005975
798.5	0.7964	0.0007985
1003.9	0.8077	0.0010039

Table 1: Results for forward bias

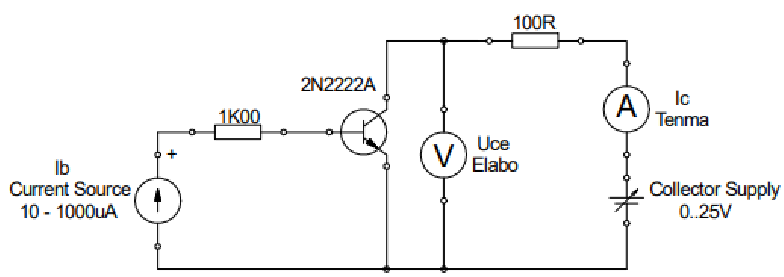
Next, U_{CE} was disconnected and the U_{BE} supply was reversed. The reverse current I_{BR} was then recorded as a function of U_{BE} .

Current (μA)	U_{BE} (V)	Current I_{BR} (A)
0	-0.009	0.00000000
-4.93	-8.126	-0.00000493
-9.72	-8.127	-0.00000972
-20.39	-8.129	-0.00002039
-41.18	-8.13	-0.00004118
-60.44	-8.131	-0.00006044
-79.07	-8.132	-0.00007907
-100.43	-8.133	-0.00010043
-199.52	-8.135	-0.00019952
-400.8	-8.141	-0.00040080
-602.6	-8.149	-0.00060260
-805.8	-8.157	-0.00080580
-1001.5	-8.166	-0.00100150

Table 2: Results for reverse bias

Part 2: Output Characteristic

The next circuit was set up as shown in Fig. 3.



The constant current source is the small black box in the shelf of the workbench labeled *"Current μA"* . Plug it into one of the outputs of the DC-supply. Set the voltage to 20V. The output of the source is the BNC-plug at the bottom. Use the BNC to Cleps cable to connect it to the circuit. The red wire of the BNC-cable is the positive terminal and the black wire is the ground.

Fig. 3: Set-up for Part 2 of experiment (taken from Lab Manual)

For this part, I_B was set to 20µA and the collector supply was varied in a way that U_{CE} (read from Elabo) was changed from 0 V to 20 V in consecutive steps:

- from 0 V to 1 V every 0.2 V

- then 2.5 V, 5 V, 10 V, 15 V, and 20 V

The values of U_{CE} and I_{CE} had to be recorded quickly since the transistor heats up and will change its characteristics. (a smartphone camera was used to take a snapshot of the readings of the circuit at all the steps to get more accurate results and allow for faster data collection.) The whole experiment was done in such a way that $P_{CE} = U_{CE} * I_{CE} = 700$ mW was never exceeded.

- the first step was repeated for I_B = 40 µA, 60 µA, 80 µA, and 100 µA.
- I_{CE} was recorded for I_B = 100 µA, 200 µA, 300 µA, 400 µA and 500 µA with U_{CE} set to 1 V.

All results are recorded below in tables.

Steps	U_{cE} (V)	I_{cE} (A)	Power(W)
0	0.01	1.64E-04	1.64E-06
0.2	0.206	4.23E-03	8.72E-04
0.4	0.403	4.28E-03	1.72E-03
0.6	0.602	4.30E-03	2.59E-03
0.8	0.817	4.32E-03	3.53E-03
1	1.06	4.38E-03	4.64E-03
2.5	2.514	4.43E-03	1.11E-02
5	5.01	4.57E-03	2.29E-02
10	10.12	4.87E-03	4.93E-02
15	15.046	5.20E-03	7.83E-02
20	20.03	5.69E-03	1.14E-01

Table 3: Results for I_B= 20 µA

Step	U_{ce} (V)	I_{ce} (A)	Power(W)
0	0	9.70E-05	0.00E+00
0.2	0.19	9.30E-03	1.77E-03
0.4	0.38	9.43E-03	3.58E-03
0.6	0.61	9.35E-03	5.70E-03
0.8	0.8	9.33E-03	7.46E-03
1	1.02	9.33E-03	9.52E-03
2.5	2.51	9.49E-03	2.38E-02
5	5.01	9.85E-03	4.94E-02
10	10.01	1.08E-02	1.08E-01
15	15.08	1.21E-02	1.83E-01
20	20.1	1.37E-02	2.74E-01

Table 4: Results for I_B= 40 µA

STEP	U_{ce} (V)	I_{ce} (A)	Power(W)
0	0	2.20E-04	0.00E+00
0.2	0.21	1.29E-02	2.70E-03
0.4	0.4	1.31E-02	5.25E-03
0.6	0.62	1.32E-02	8.20E-03
0.8	0.79	1.33E-02	1.05E-02
1	1.05	1.35E-02	1.41E-02
2.5	2.49	1.39E-02	3.46E-02
5	5.12	1.49E-02	7.61E-02
10	10.05	1.70E-02	1.71E-01
15	15.08	1.98E-02	2.98E-01
20	20.02	2.29E-02	4.59E-01

Table 5: Results for I_B= 60 µA

STEP	U_{ce} (V)	I_{ce} (A)	Power(W)
0	0.161	0.00E+00	0.00E+00
0.2	0.19	1.69E-02	3.21E-03
0.4	0.4	1.75E-02	7.00E-03
0.6	0.59	1.76E-02	1.04E-02
0.8	0.78	1.78E-02	1.39E-02
1	1.01	1.80E-02	1.81E-02
2.5	2.55	1.88E-02	4.81E-02
5	5.21	2.03E-02	1.06E+02
10	10.02	2.38E-02	2.38E-01
15	14.99	2.80E-02	4.19E-01
20	20.28	3.24E-02	6.58E-01

Table 6: Results for I_B= 80 µA

STEP	U_{ce} (V)	I_{ce} (A)	Power(W)
0	0	2.33E-04	0.00E+00
0.2	0.2	2.10E-02	4.20E-03
0.4	0.42	2.19E-02	9.18E-03
0.6	0.61	2.21E-02	1.35E-02
0.8	0.79	2.23E-02	1.76E-02
1	1.02	2.25E-02	2.30E-02
2.5	2.52	2.39E-02	6.01E-02
5	5.03	2.66E-02	1.34E-01
10	10.03	3.30E-02	3.31E-01
15	15.05	3.98E-02	5.99E-01
20			

Table 7: Results for I_B= 100 µA

Note: No reading was taken for the 20V step when I_B was set to 100 µA as the power exceeded the maximum value of 700mW

Finally, I_{CE} was recorded for I_B = 100 µA, 200 µA, 300 µA, 400 µA, and 500 µA with U_{CE} set to 1 V. It was ensured that U_{CE} was adjusted every time after changing I_B.

I_B	I_{ce}
1.00E-04	2.27E-02
2.00E-04	4.55E-02
3.00E-04	6.88E-02
4.00E-04	9.18E-02
5.00E-04	1.13E-01

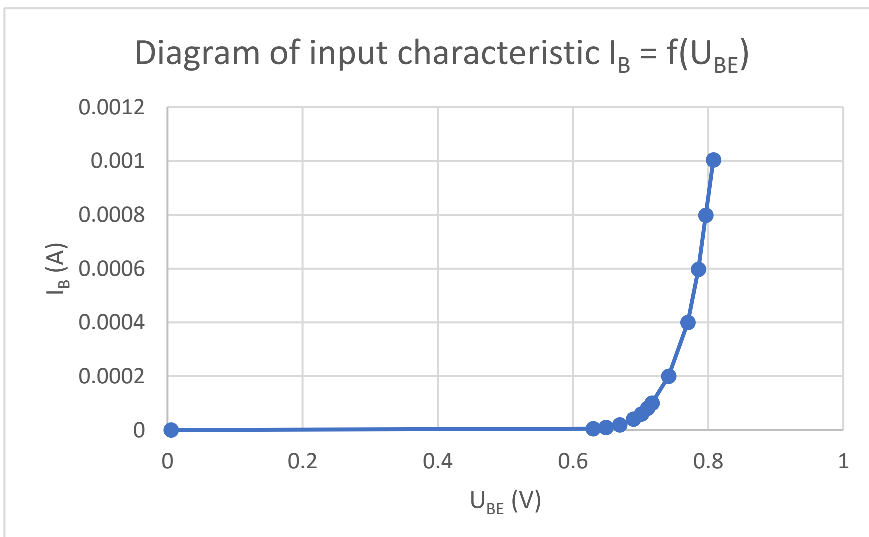
Table 8: Results for different I_B

Evaluation

PART 1: Input Characteristic

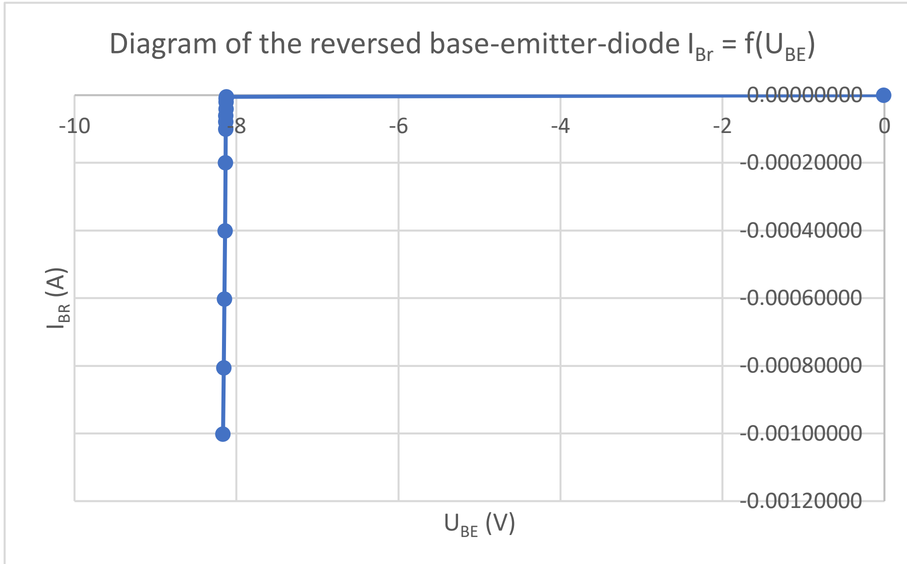
Forward Bias

U_{BE} (V)	Current I_{BE} (A)
0.0054	0
0.6298	0.00000487
0.6485	0.00000953
0.6693	0.00001993
0.6895	0.00004041
0.7011	0.00005955
0.7105	0.00008107
0.7169	0.00009984
0.7417	0.00020049
0.77	0.00039995
0.7856	0.0005975
0.7964	0.0007985
0.8077	0.0010039



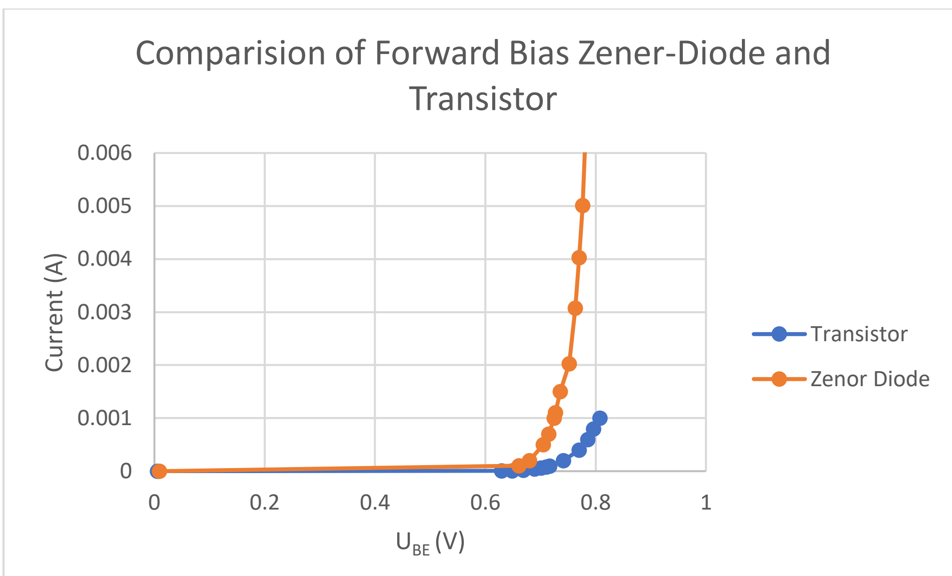
Reverse Bias

U_{BE} (V)	Current I_{BR} (A)
-0.009	0.00000000
-8.126	-0.00000493
-8.127	-0.00000972
-8.129	-0.00002039
-8.13	-0.00004118
-8.131	-0.00006044
-8.132	-0.00007907
-8.133	-0.00010043
-8.135	-0.00019952
-8.141	-0.00040080
-8.149	-0.00060260
-8.157	-0.00080580
-8.166	-0.00100150



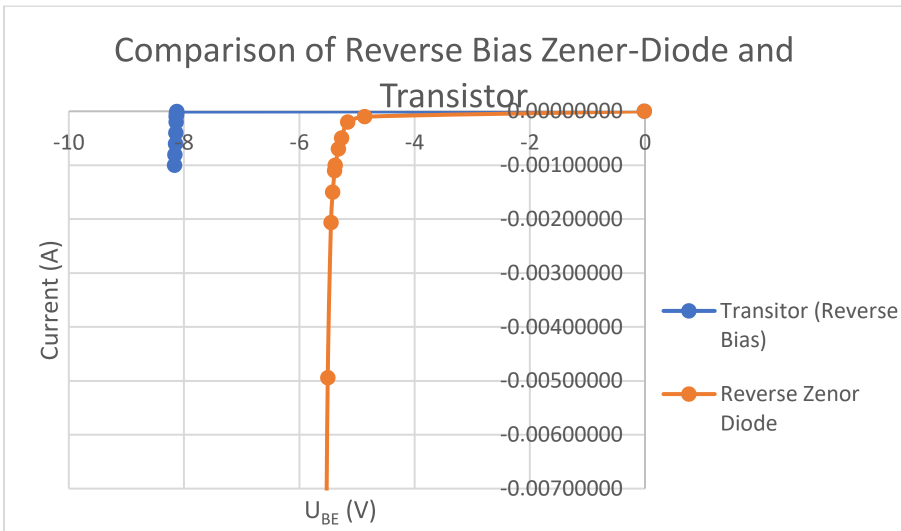
Comparison to the diode curves from the diode experiment

Forward Bias Comparison:



According to the chart, both the Zener-Diode and the transistor have similar forward bias characteristics. However, the transistor goes through forward bias at a higher voltage than the Zener-Diode. During forward bias, the Zener-Diode lets through a larger current over a small voltage variation when compared to the transistor. This conclusion can be reached by observing the much steeper gradient of the Zener-Diode. (some data collected for the Zener-diode has been ignored since it exceeds the y-axis scale here)

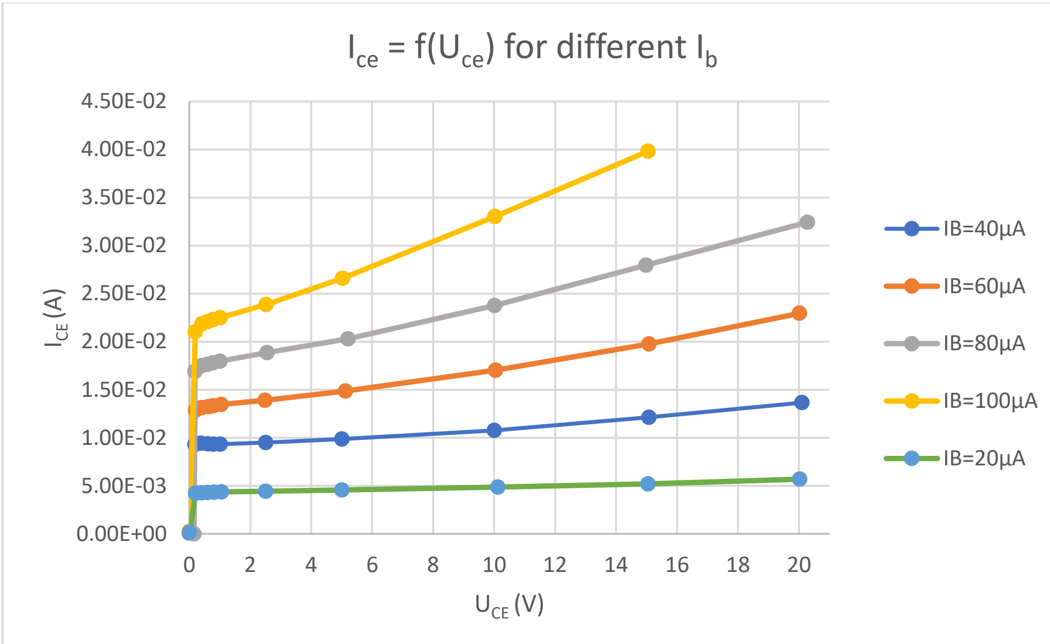
Reverse Bias Comparison:



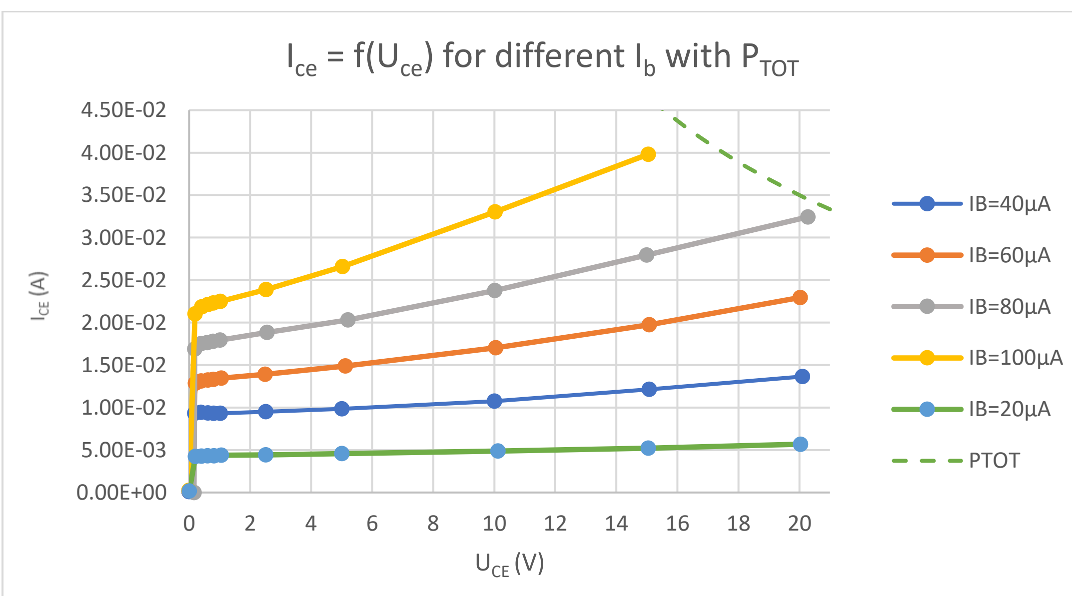
According to this graph, the transistor in reverse bias has a greater negative breakdown voltage than the Zener-Diode in reverse bias. Once again, by analyzing the steepness of the graphs, it is obvious that the transistor in reverse bias (which is has the steeper gradient) conducts a larger current over a small voltage variation. (some data collected for the Zener-diode in reverse bias has been ignored since it exceeds the y-axis scale here)

The differences observed in the characteristics of these two devices is very likely due to the structural difference between them (diodes have a single P-N junction while transistors have two), although the difference in circuit set up could also be a factor.

Part 2: Output Characteristic

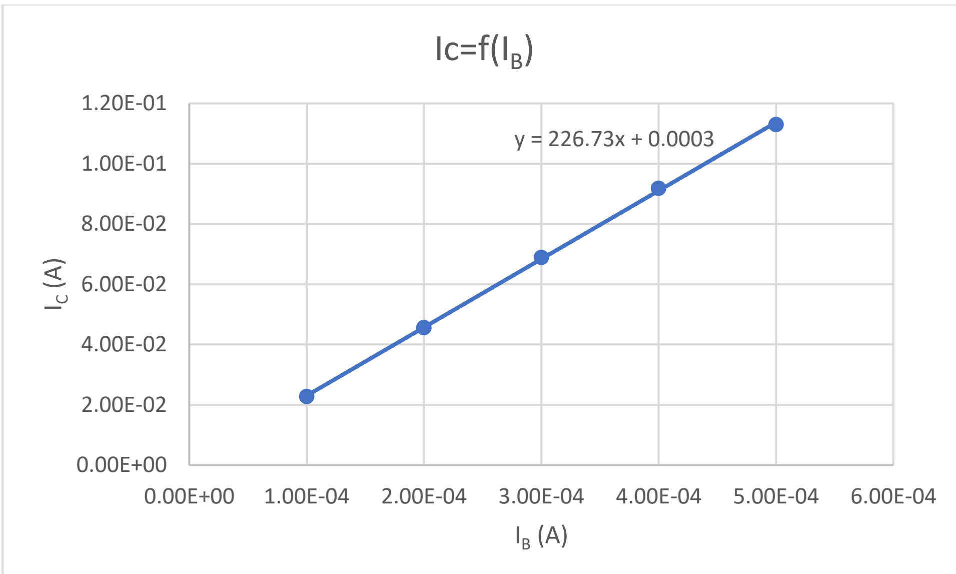


Since the maximum power dissipation for the **2N2222** is P_{TOT} = 700 mW, the line for P_{TOT} is included in the graph as shown below.



According to the graph, it is clear that the limit was NOT exceeded at any point during the experiment. However, if the value at 20V U_{CE} was taken into account for when I_B= 100 µA, it would have clearly exceeded the maximum power dissipation of the particular diode.

When U_{CE} =1V (constant), the following graph could be plotted on excel for I_C=f(I_B). Analyzing the straight trendline plotted, it was found that the equation of the graph is y = 226.73x + 0.0003.



Current Amplification for this experiment can be found using the following formula:

$$Current\ Amplification = \frac{I_C}{I_B}$$

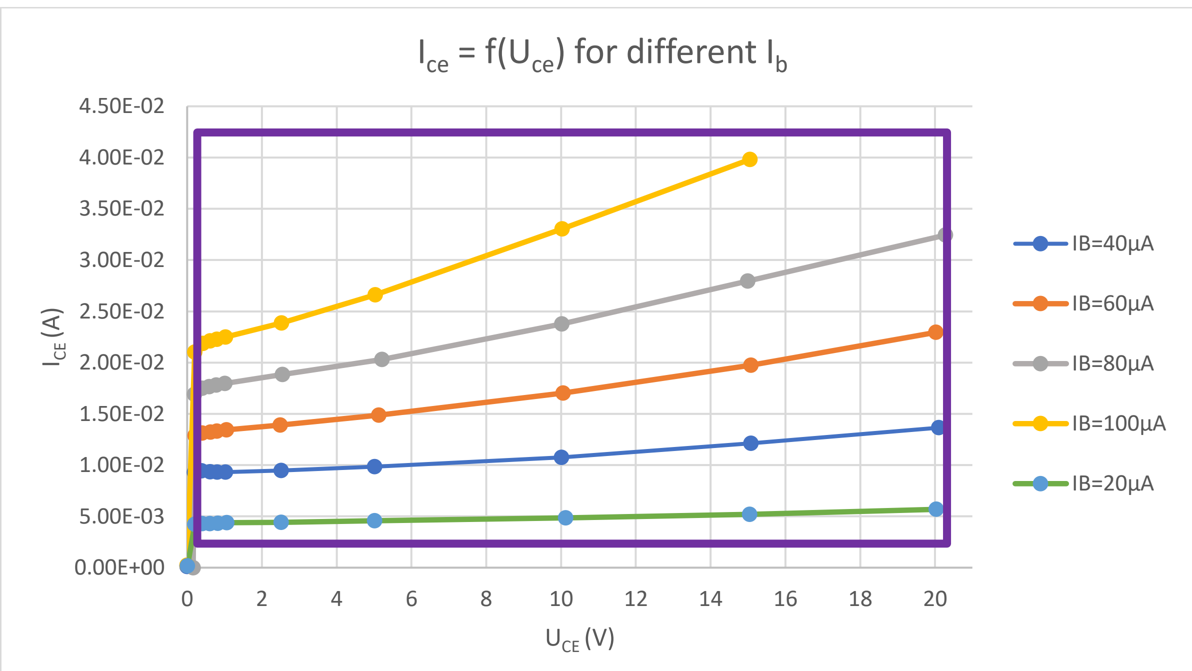
An example calculation when IC =22.693 mA and IB = 0.100mA:

$$Current\ Amplification = \frac{22.693}{0.100} = 226.93$$

Other values obtained are given below:

I_B	I_C	Current Amplification
1.00E-04	2.27E-02	226.93
2.00E-04	4.55E-02	227.7
3.00E-04	6.88E-02	229.367
4.00E-04	9.18E-02	229.45
5.00E-04	1.13E-01	225.88

The Area for which linear operation is possible is indicated by the purple box in the diagram below:



Conclusion

Throughout this experiment, the characteristics of a transistor were our main points of focus. This involved exploring the forward and reverse bias characteristics. These characteristics were then compared to those of a Zener-Diode used in the previous experiment. From the analysis of both sets of results, the conclusion drawn was that while both showed similar characteristics, there were some differences which were observed through the gradient of the graphs. The transistor conducted a large amount of current within a small voltage variation than a diode.

For the next part where the use of a transistor as an amplifier were shown:

> -For an NPN transistor, the emitter current was the sum of the collector current and the base current ($I_E = I_C + I_B$). The amplification of the current is I_C/I_B.

During this evaluation, the area in which a transistor could perform linear operations was also covered. This is an important property of transistor amplification since nonlinear amplification causes distortion. Hence, linear amplification is preferred.

The threshold power of transistors was also explored since the transistor we used (2N2222) could not go beyond 700 mW. However, since the power was always kept below this limit and since all high-power measurements were done quickly and recorded, there was no damage to the transistor used.

The only major error source was that if the measurements were not taken fast enough, the values would be erroneous due to heating of the transistor, but this was also avoided by taking pictures of the results instead of reading them off the instruments.

References

[Lab Manual (jacobs-university.de)]

https://www.build-electronic-circuits.com/how-transistors-work/

Appendix

Data collected from Ohm's Law Lab, done on: Dec 3, 2020

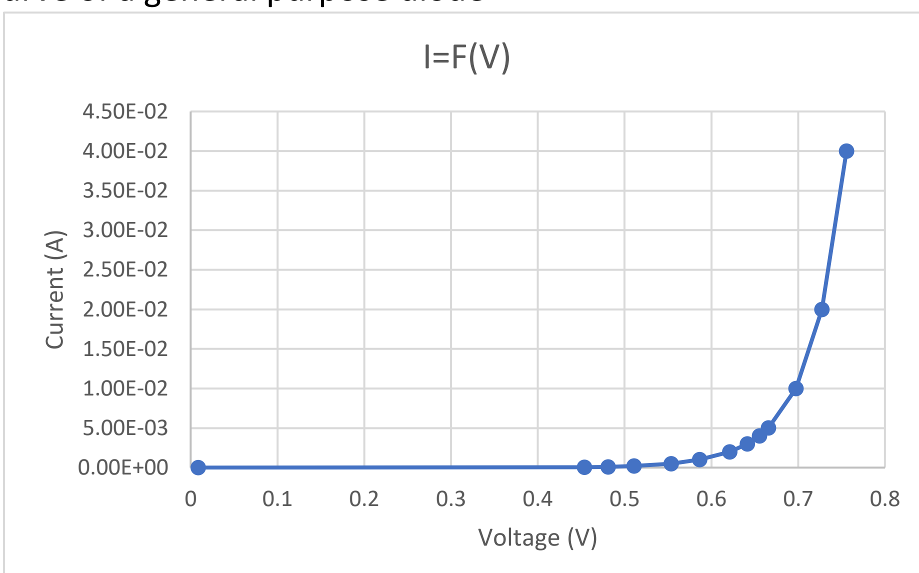
PART 1: Determine Anode and Cathode

- Ring points to positive (Reverse Bias)
  V=12.067V
  A=1.11µA

- Ring points to negative (Forward Bias)
  V=0.7268V
  A= 20.079mA

Part 2: Forward V-I-Curve of a general purpose diode

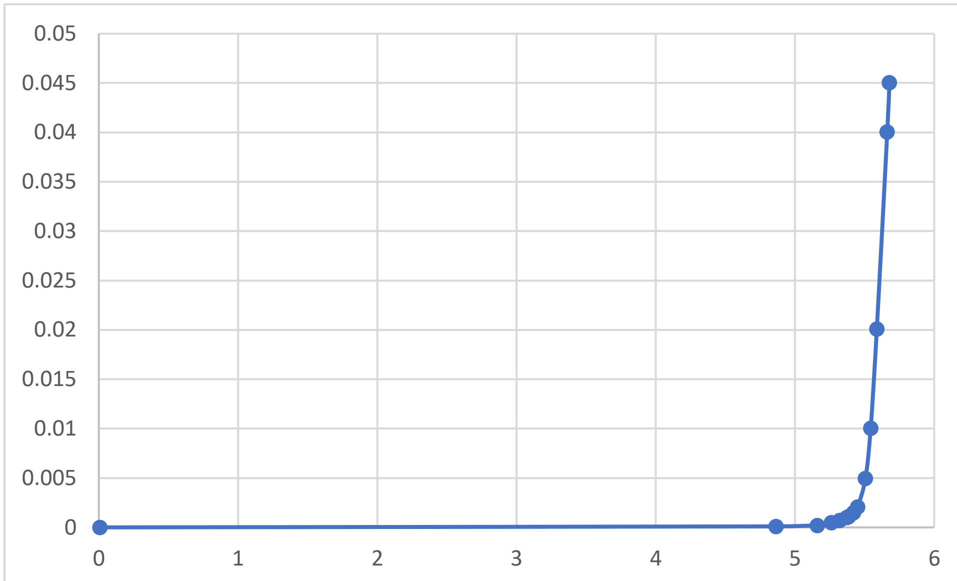
V	A
0.0087	0.00E+00
0.4536	5.06E-05
0.4811	1.01E-04
0.5111	2.01E-04
0.5537	5.05E-04
0.5866	1.00E-03
0.6212	2.01E-03
0.6415	3.00E-03
0.6553	4.00E-03
0.6657	5.02E-03
0.6975	1.00E-02
0.7272	2.00E-02
0.7557	4.00E-02



Part 3: Reverse and Forward Characteristic of a Z-Diode

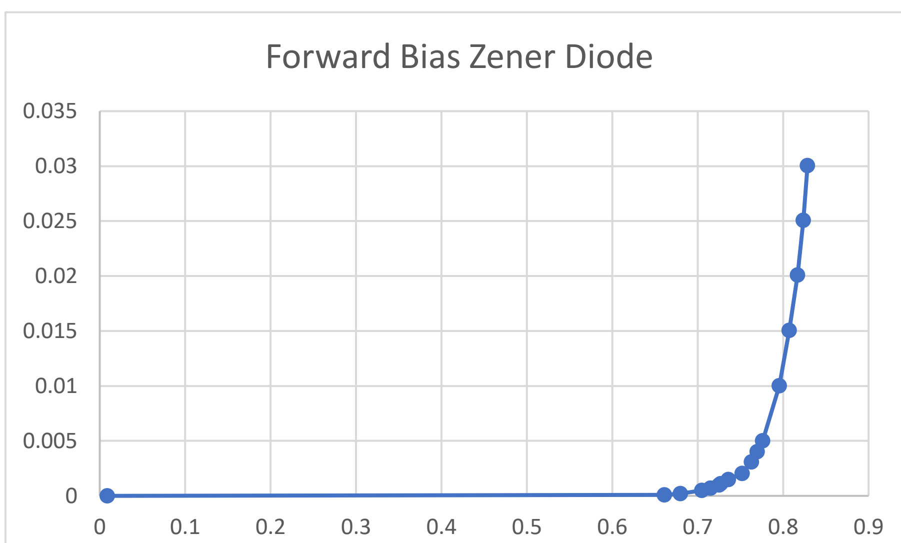
Reverse Zener Diode

v	A
VOLTAGE	CURRENT
0.0088	0
4.865	1.01E-04
5.16	2.02E-04
5.263	5.00E-04
5.321	6.99E-04
5.373	1.00E-03
5.385	1.10E-03
5.42	1.50E-03
5.45	2.07E-03
5.506	4.94E-03
5.544	1.01E-02
5.588	2.01E-02
5.663	4.00E-02
5.679	4.50E-02



Forward Bias Zener Diode

V	A
0.0088	0
0.661	0.000102
0.68	0.000201
0.705	0.000499
0.715	0.000699
0.725	0.001002
0.727	0.001101
0.736	0.0015
0.752	2.03E-03
0.763	3.08E-03
0.7699	4.03E-03
0.7762	5.01E-03
0.7955	1.00E-02
0.8073	1.51E-02



0.8168	2.01E-02
0.8236	2.51E-02
0.8286	3.01E-02

Part 4: A Zener Shunt Regulator

Iz=1mA, R- 855 Ω		
Load (Ohms)	I (Amps	V(Volt
56	1.63E-02	0.917
560	1.11E-02	5.414
5600	1.10E-02	5.54
No RL	1.10E-02	5.546

Iz=10mA, R= 470Ω		
56	2.81E-02	1.58
560	1.99E-02	5.54
5600	1.98E-02	5.58
No RL	1.98E-02	5.583