Lab 3: Resistors and Bipolar Transistors

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Experiment 1: Bipolar Transistor Characteristics

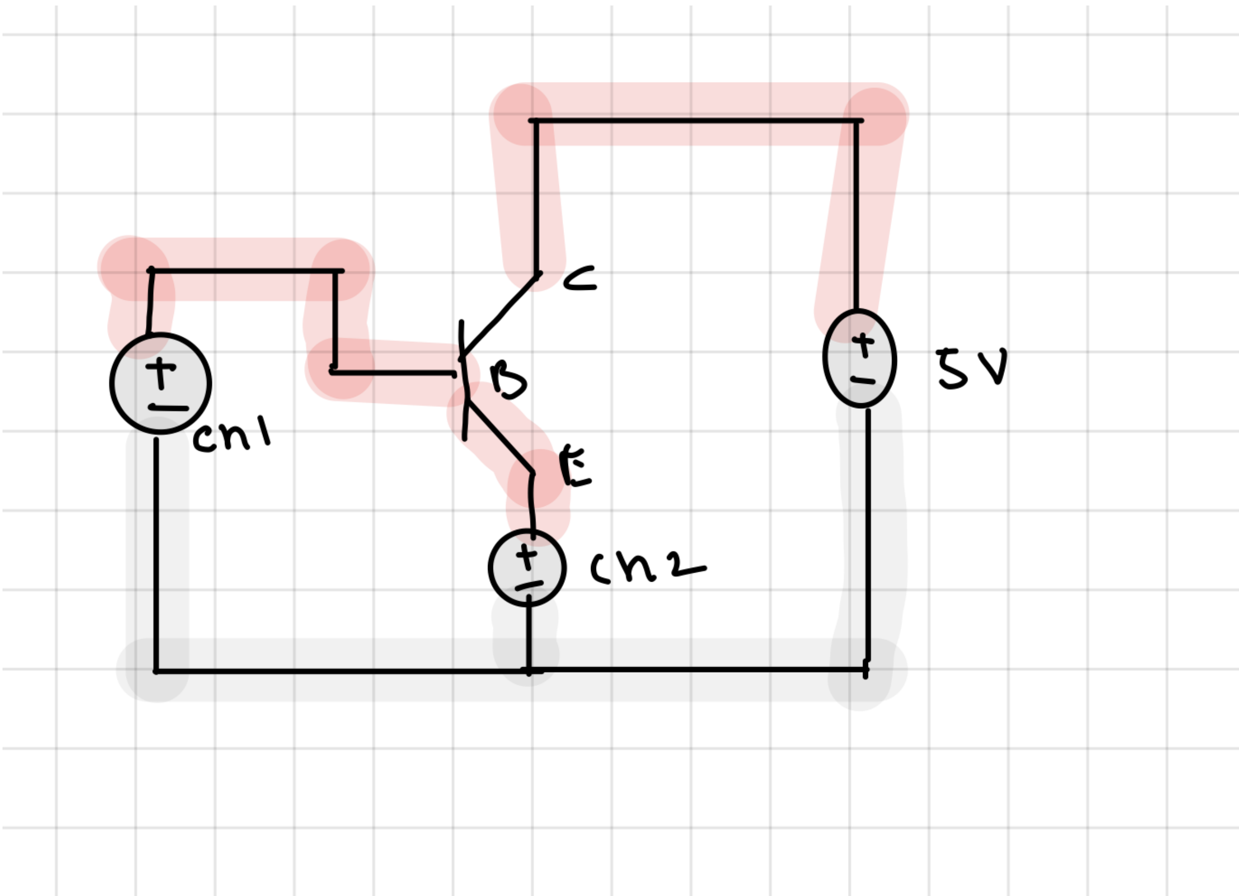

Figure 0: Circuit Diagram of Experiment 1

We let channel 1 supply the base voltage and channel 2 measure the emitter current since we are not able to measure the collector current directly.

We then plotted the collector current vs the base voltage we supplied (sweeping a range of values as shown in figure 1).

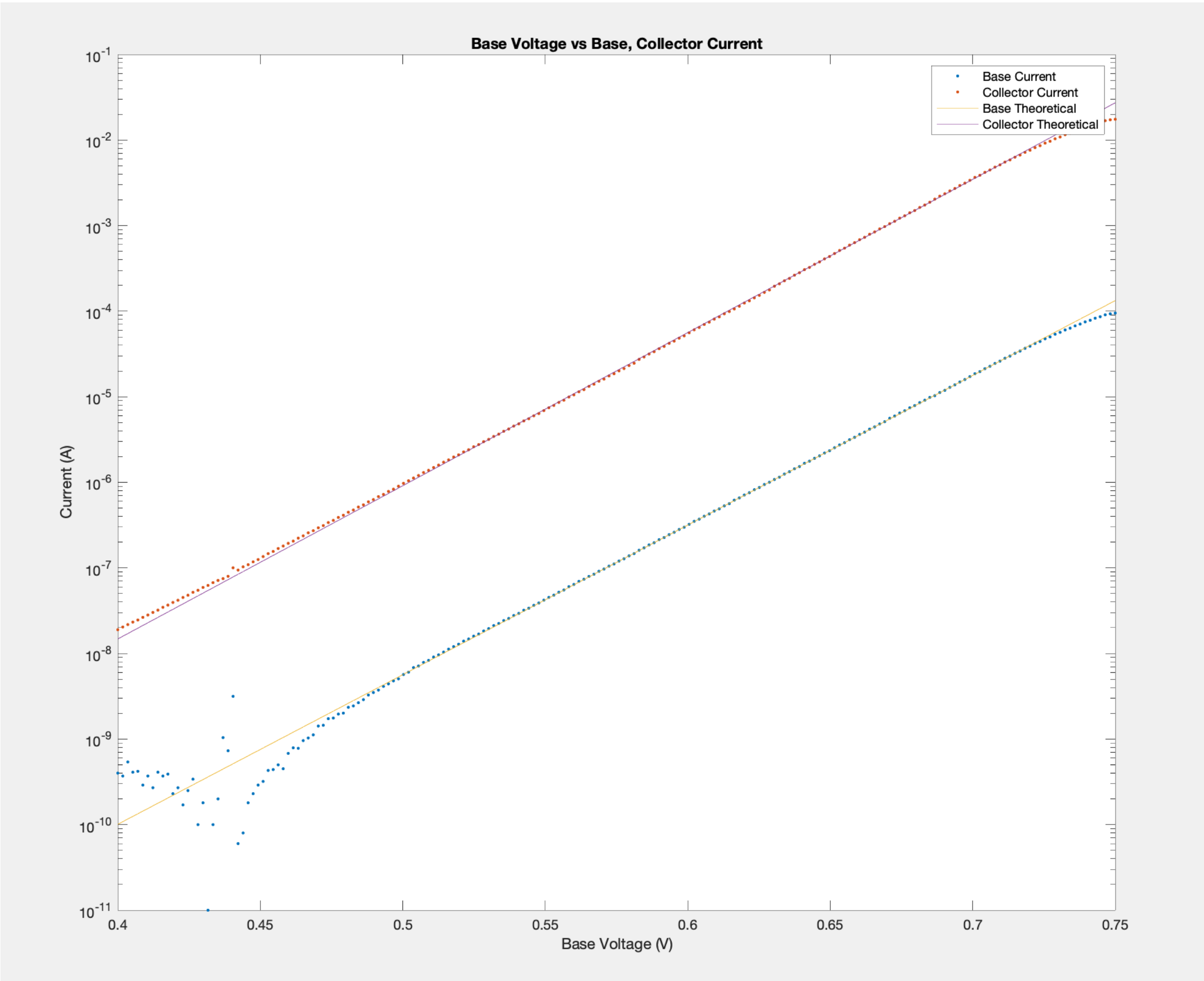

Figure 1: A semilog plot showing the base current and collector current with their theoretical linear fits.

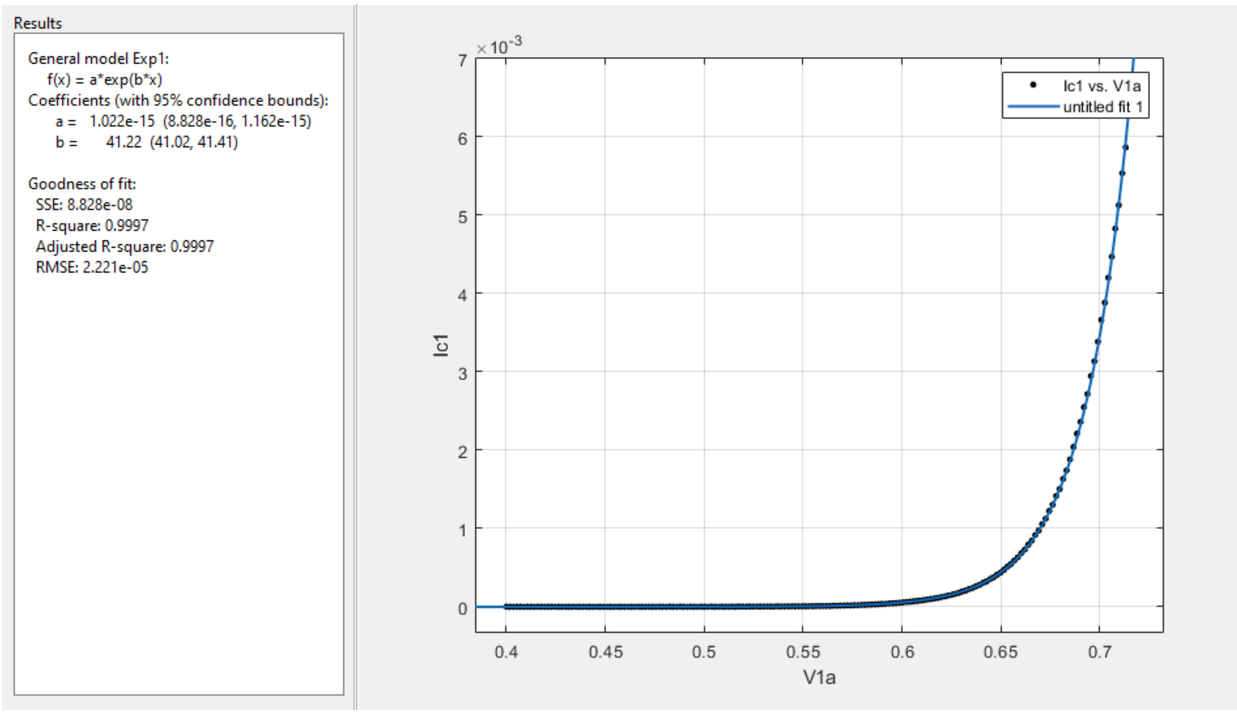

Figure 2: Extracted values from the curve fit for the base current.

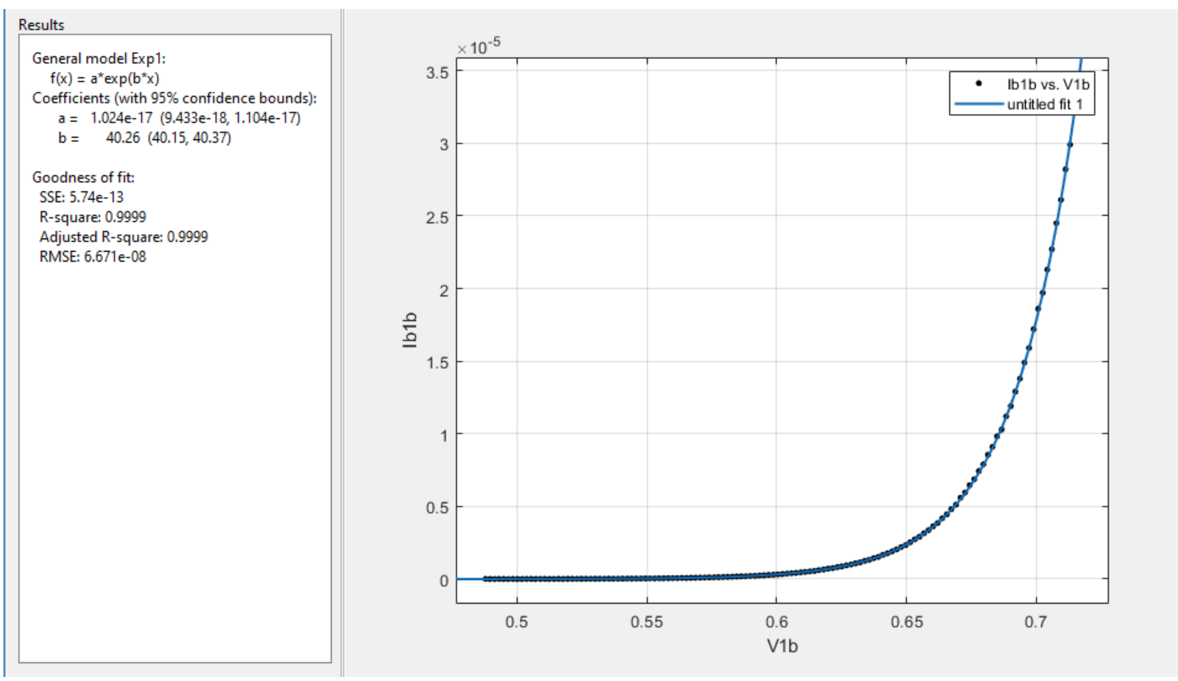

Figure 3: Extracted values from the curve fit for the collector current.

As it can be seen in figure 3, the collector current does follow an exponential relationship with the base voltage. This is proven with the R-square value of 0.999.

Using the following equation, we can say that a is the saturation current in figure 2 and 3.

$$I = I_s \cdot e^{V/U_T} = a \cdot e^{b \cdot x}$$

From this, we know that the saturation current for the base is 1.022e-15 A and the saturation current for the collector is 1.024e-17. Using the following formula, we can say that beta is 100.

$$I_c = \frac{I_b}{\beta}$$

$$\beta = \frac{1.022 \times 10^{-15}}{1.024 \times 10^{-17}} \approx 100$$

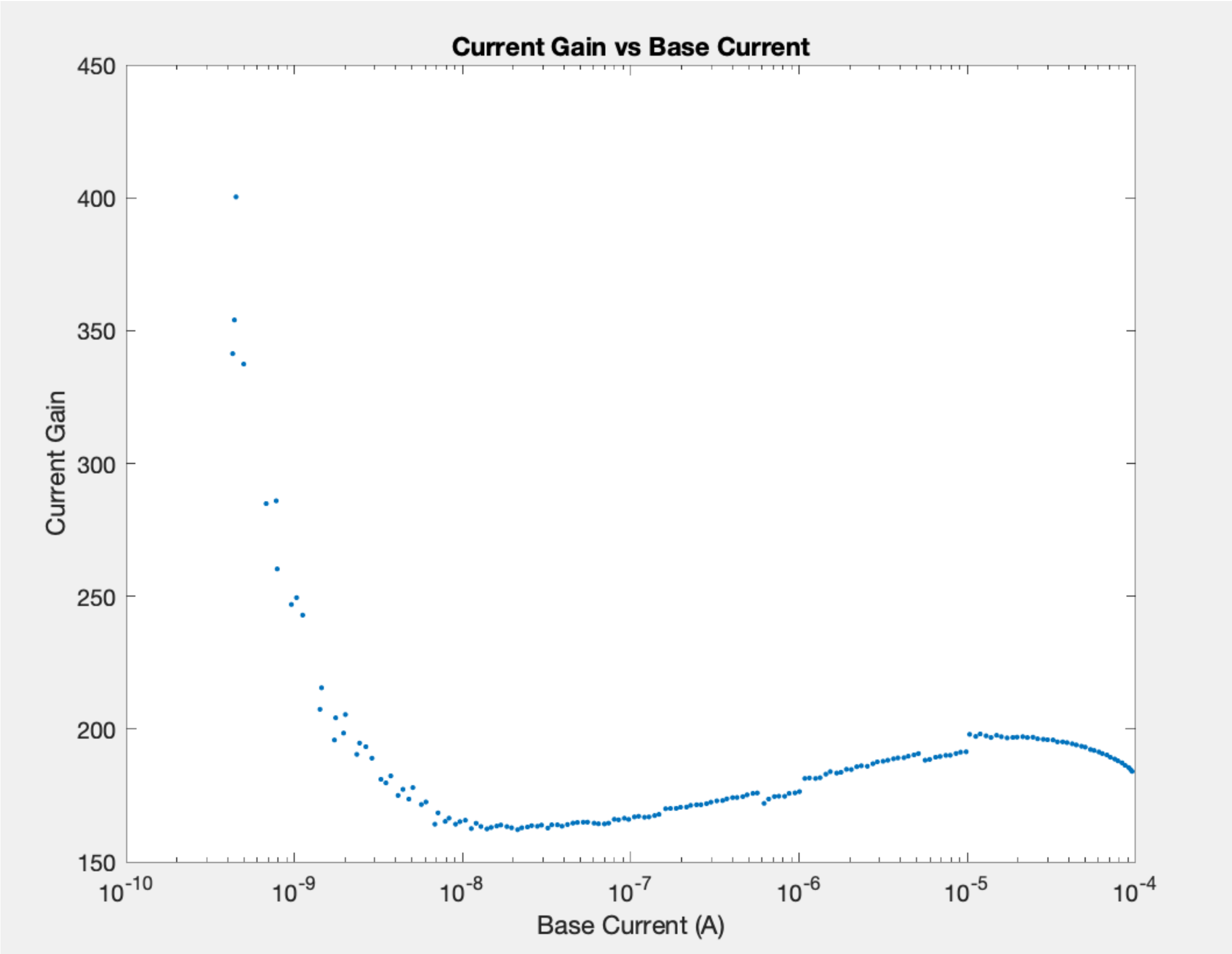

Figure 4: A plot of the current gain against base current.

In figure 4, we can see that the current gain in fact does not level off around our calculated current gain of 100. This is most likely because we got different Ut values when we curve fitted the collector current vs voltage. This could have been caused by the fact that the SMU can't directly measure collector current.

At higher base currents the current gain is more constant than at lower base currents. This could be due to the fact that small current cause artifacts.

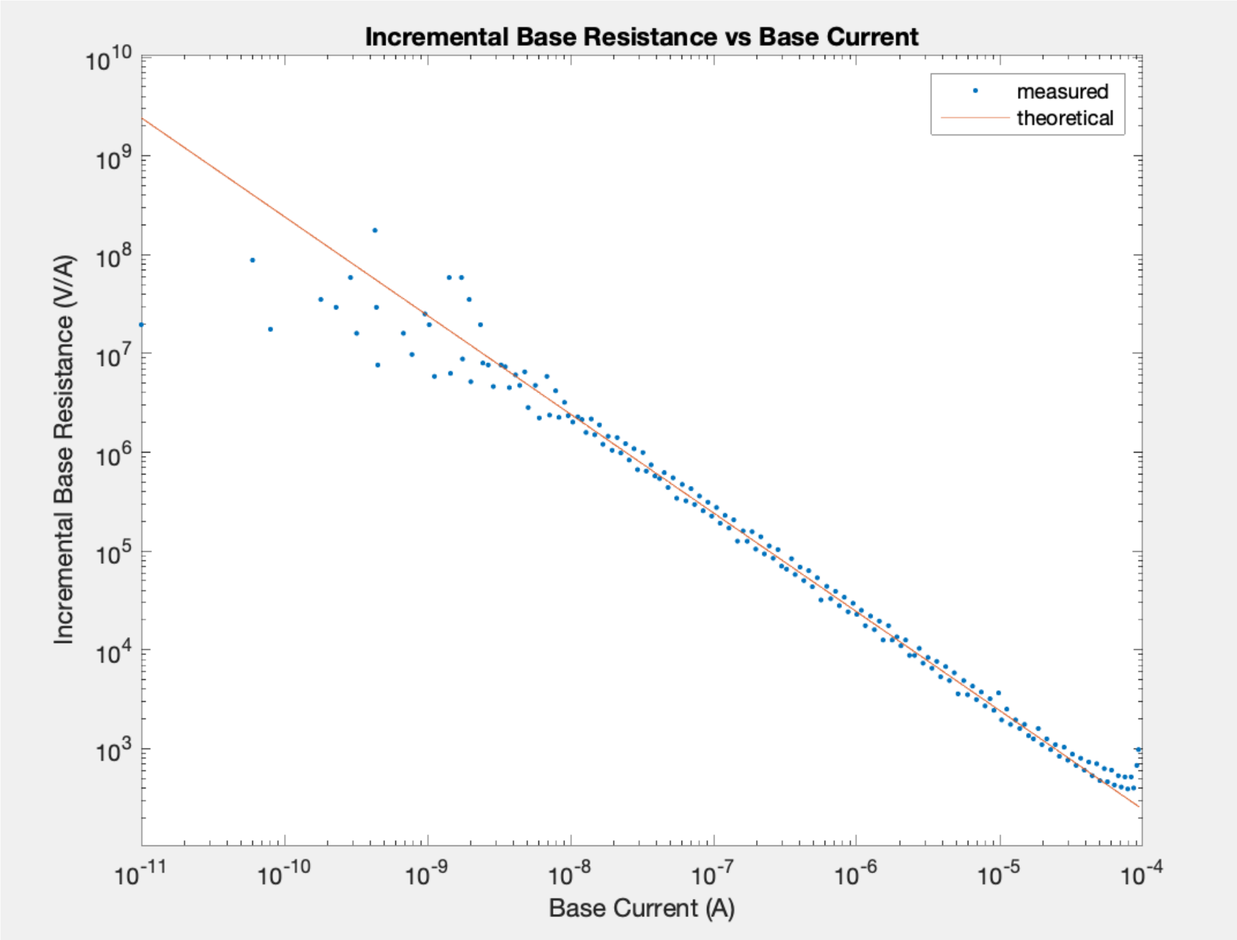

Figure 5: Measured incremental base resistance at many different base current values and the theoretical linear fit for them.

As seen in figure 5, the theoretical fit matches the data at higher current values much better than it does at lower current values. This is seen throughout our various plots including the plot of the current gain against the base current. This could be due to the fact that lower current values tend to have a higher error.

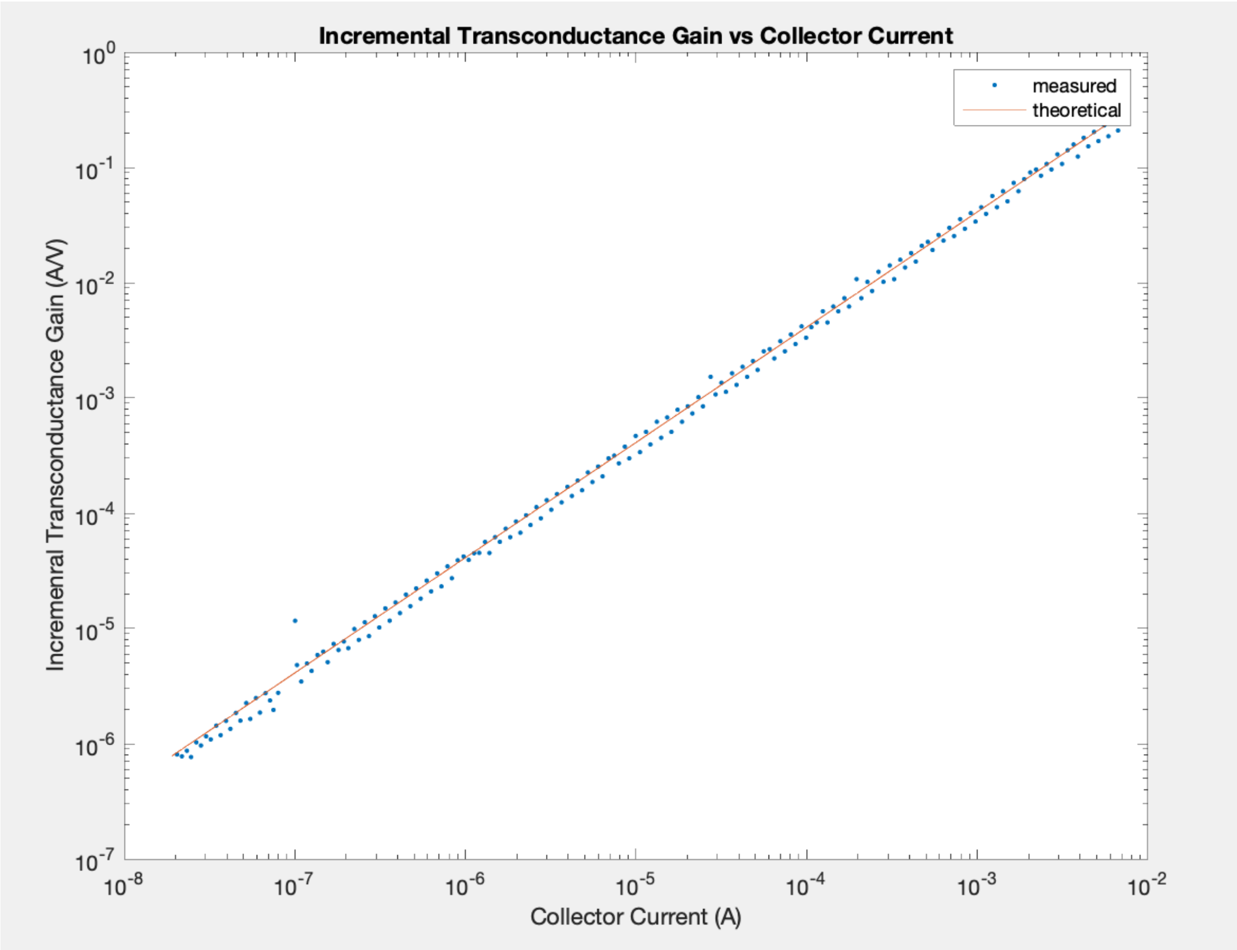

Figure 6: The incremental transconductance gain plotted against the collector current. The theoretical fit is included.

The measured incremental transconductance gain was calculated by taking the derivative of the collector current and dividing that by the derivative of the base voltage. This is also shown in the equation below.

$$G_{m_{measured}} = \frac{dI_c}{dV_B}$$

The theoretical incremental transconductance gain was calculated by the following formula where Ut is was found by the exponential fits of the collector current against the base voltage. The inverse of b is Ut.

$$G_{m_{theoretical}} = \frac{I_c}{U_T}$$

Experiment 2: Emitter-Degenerated Bipolar Characteristics

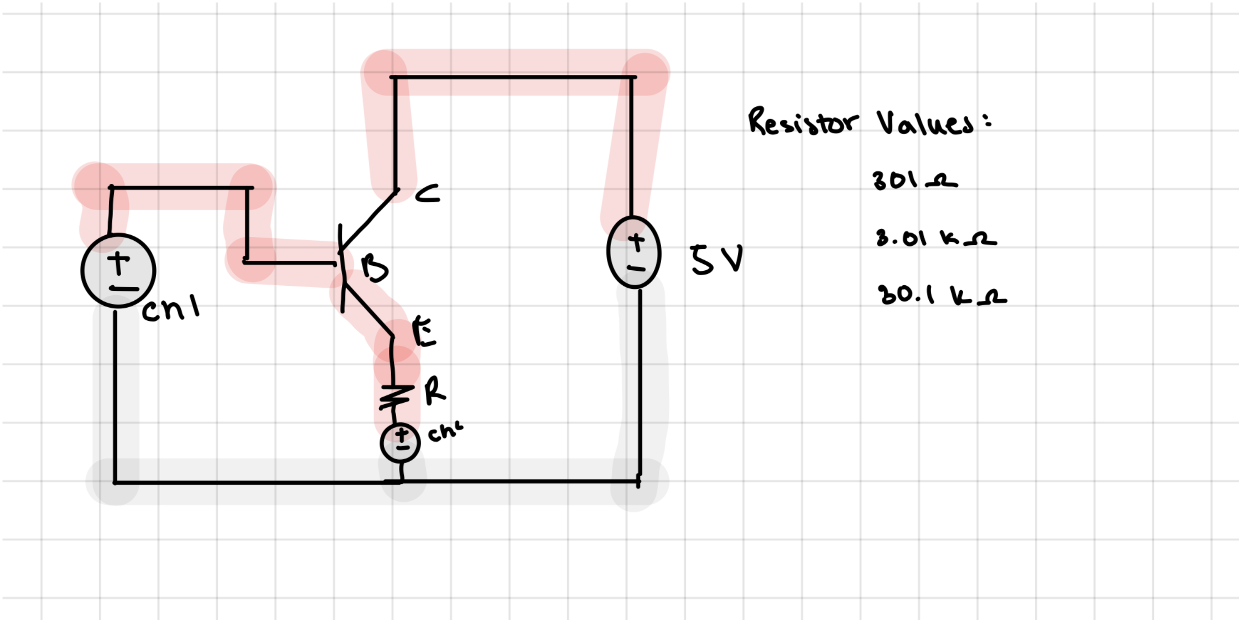

Figure 7: Circuit diagram of experiment 2

In this experiment, we added an extra resistive component in series with the current measuring channel 2. channel 1 still sweep through a range of voltage value to supply to the base. We switched this resistive component between three values: 301 ohms, 3.01 kOhms, and 30.1 kOhms.

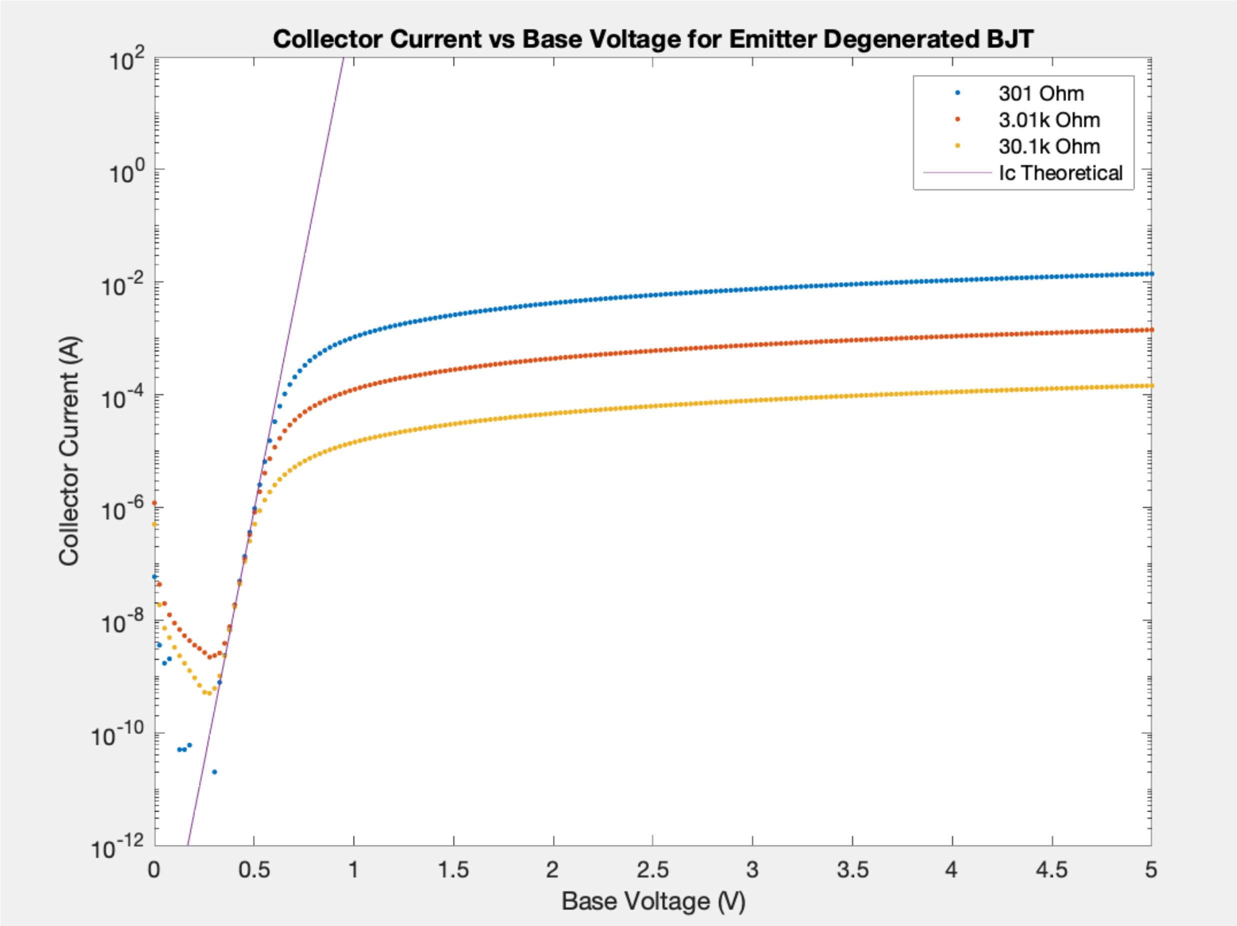

Figure 8: A plot of the collector current against a swept base voltage.

In figure 8, we can see how different resistances change the IV characteristic of the emitter degenerated BJT. A theoretical fit is applied along the linear saturation region.

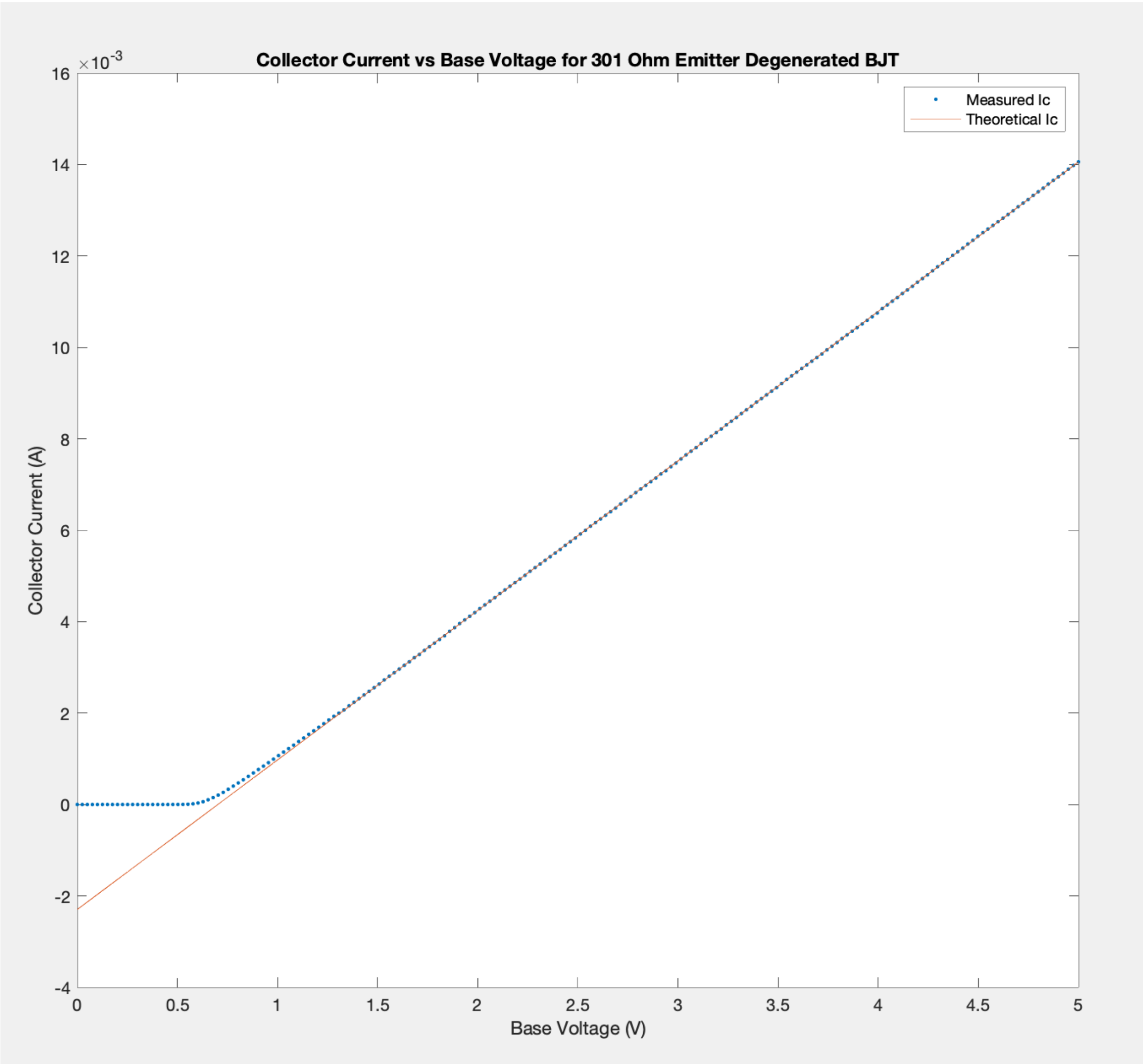

Figure 9: Collector current against swept base voltages for the circuit with a 301 Ohm resistor

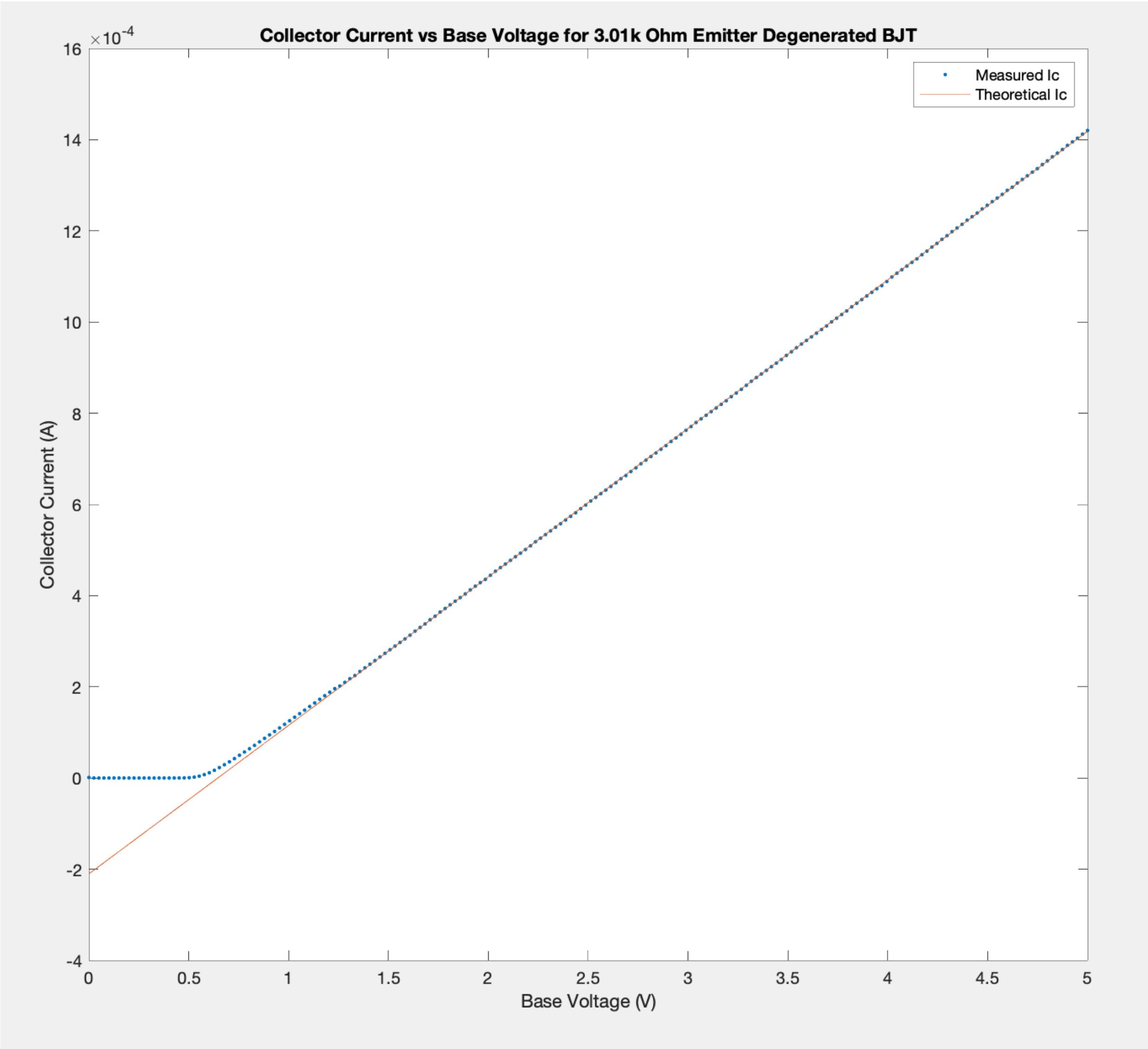

Figure 10: Collector current against swept base voltages for the circuit with a 3.01 kOhm resistor

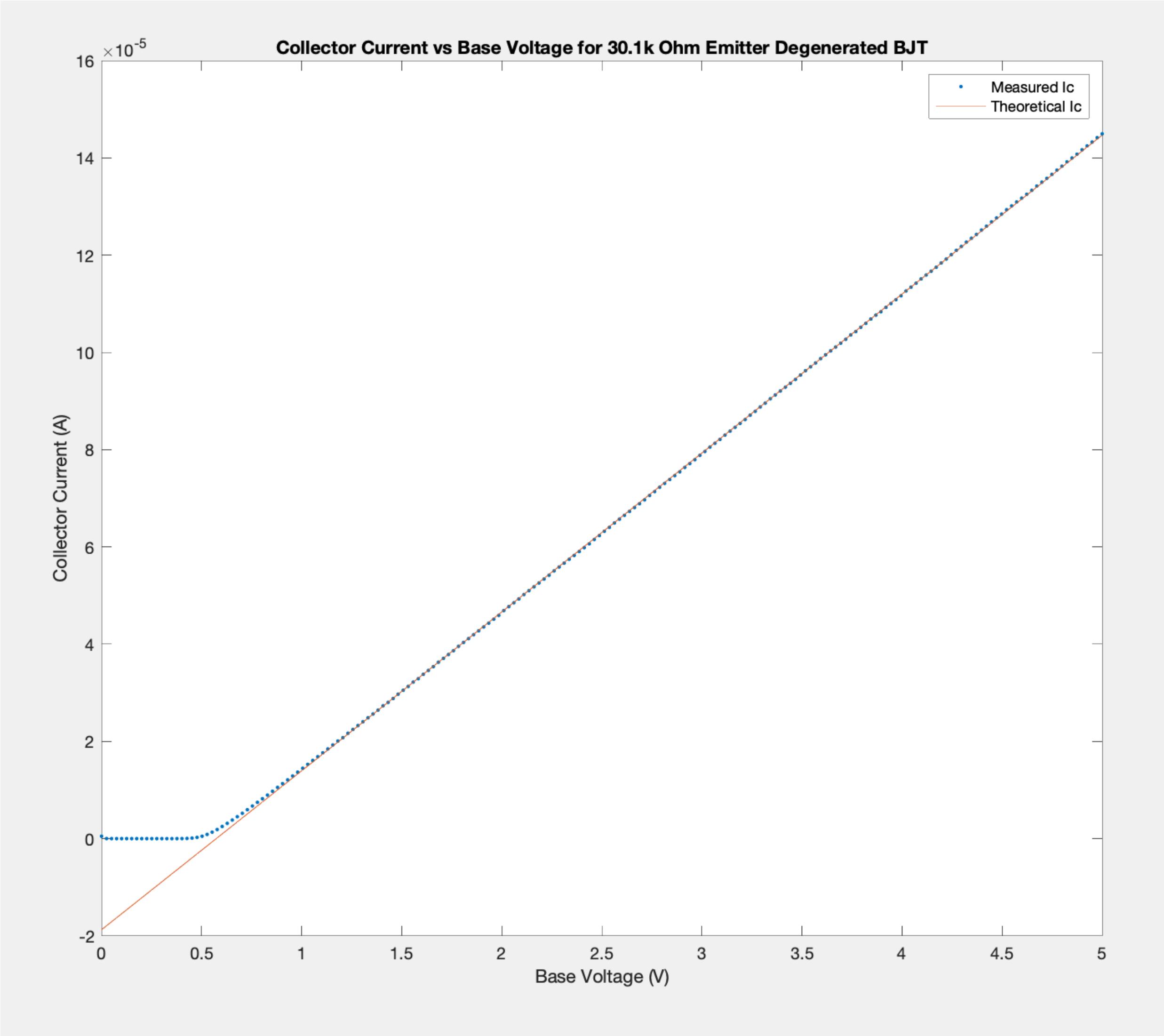

Figure 11: Collector current against swept base voltages for the circuit with a 30.1 kOhm resistor

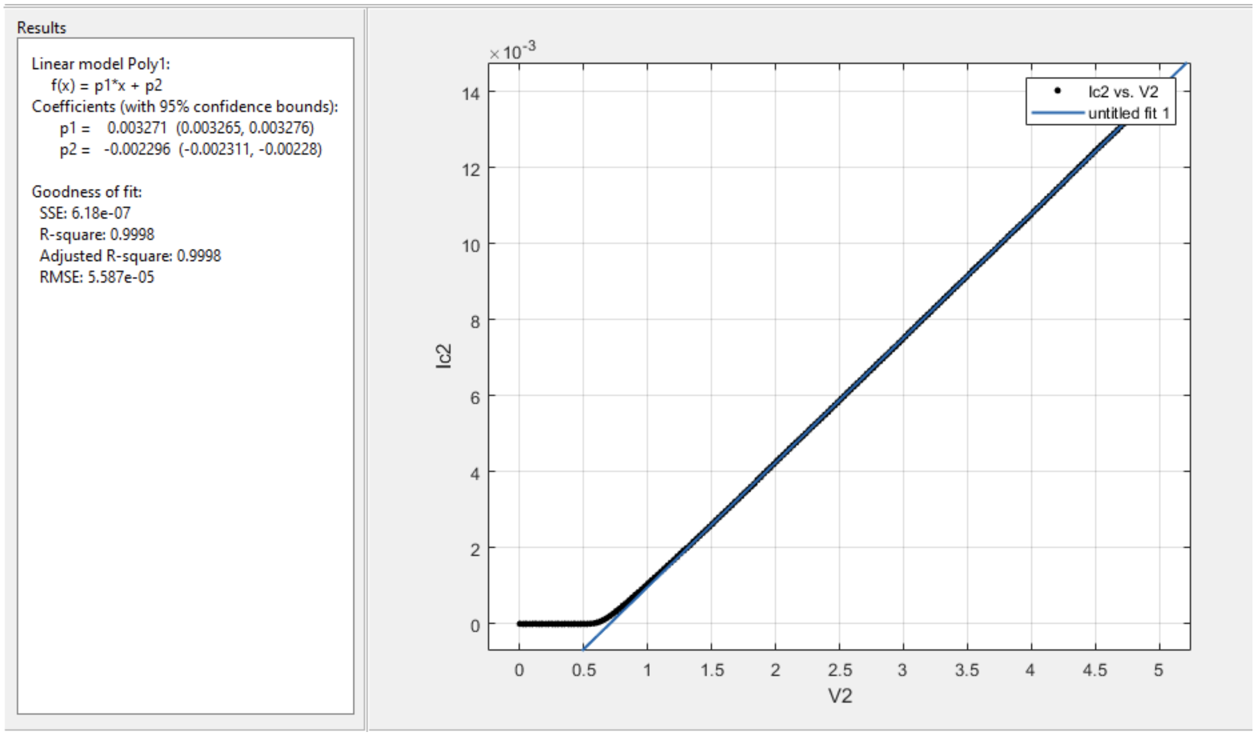

Figure 12: Linear fit values of the collector current against swept base voltages for the circuit with a 301 Ohm resistor

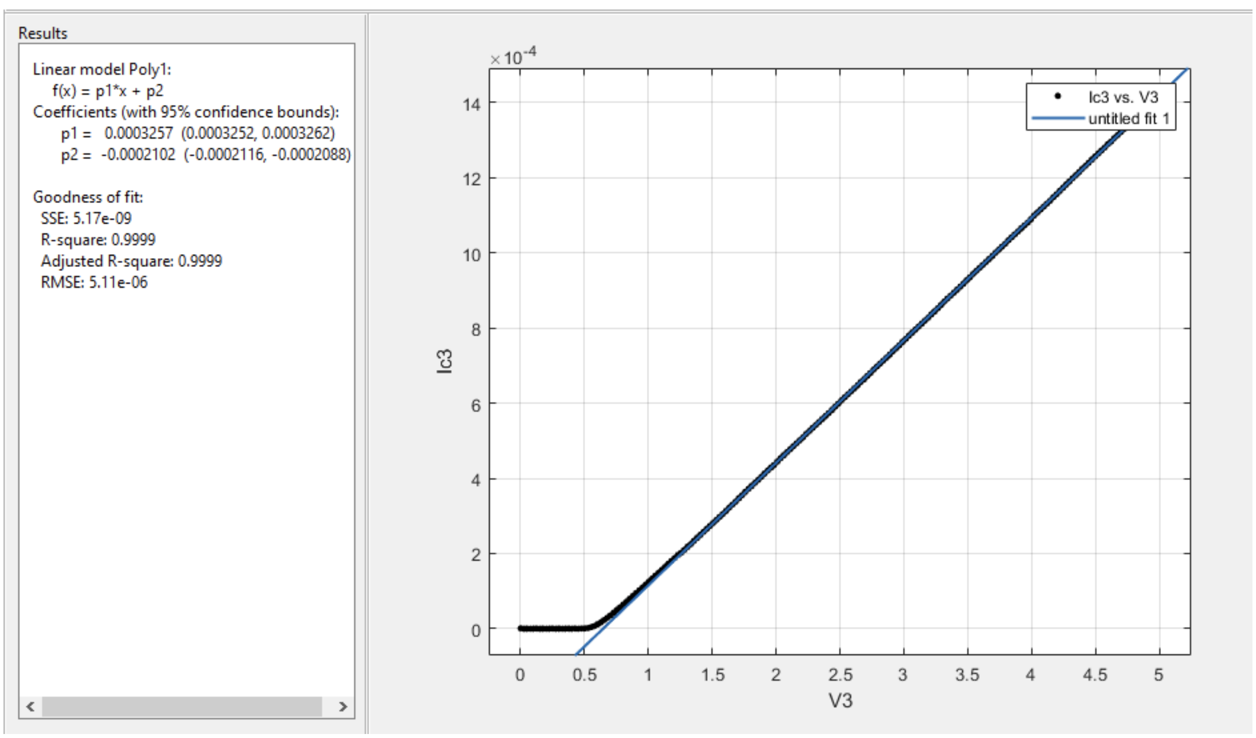

Figure 13: Linear fit values of the collector current against swept base voltages for the circuit with a 3.01 kOhm resistor

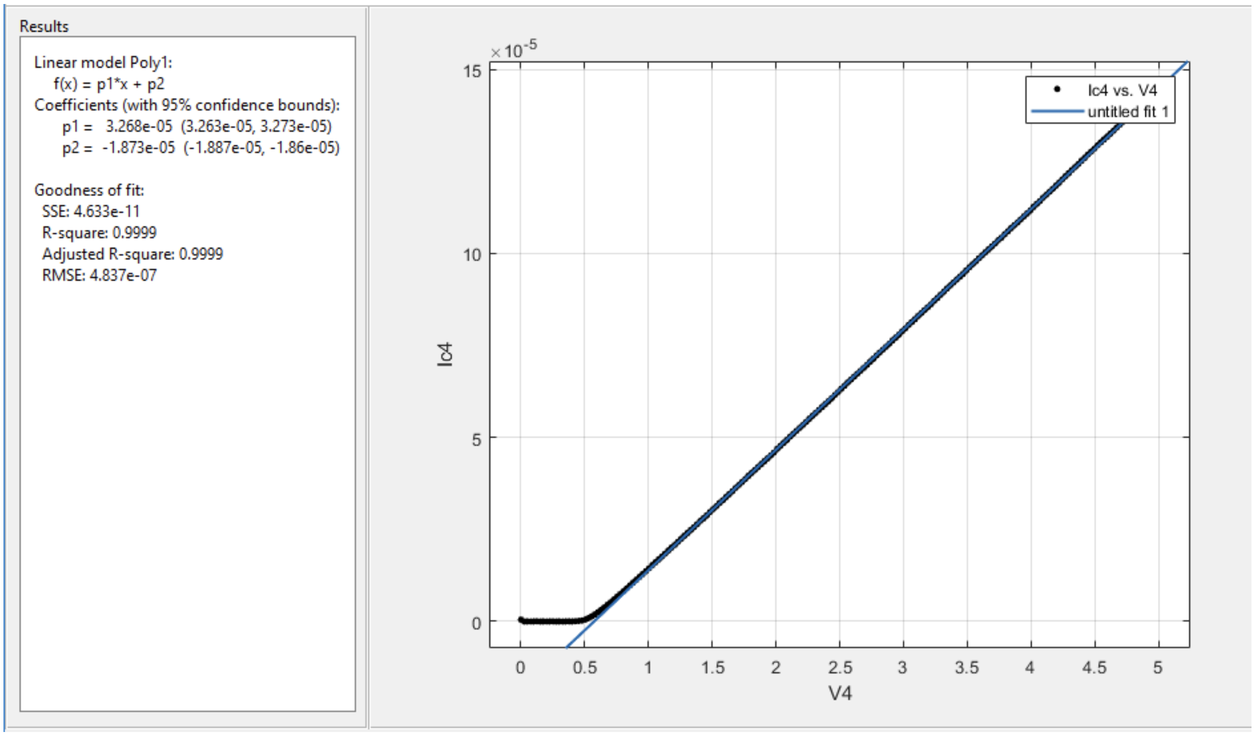

Figure 14: Linear fit values of collector current against swept base voltages for the circuit with a 30.1 kOhm resistor

The linear fit parameters fall in line with the resistor values. The resistor values change by a magnitude of 10 between each other. It can also be seen that the slope and y intercept of the lines fitted to the IV characteristics of the circuits at different resistor values also follow a similar trend. The slopes seem to decrease by an order of 10 with each 10x increase in resistance and so do the y intercepts.

The incremental base resistance can be found by the following equation.

$$R_b = \beta \cdot R \cdot (1 + \frac{U_T}{\beta \cdot I_b \cdot R})$$

We can say that beta is 170 from figure 4 and Ut is 1/40.26 from figure 3.

To find the measured incremental base resistance we take the derivative of the base voltage divided by the derivative of the base current.

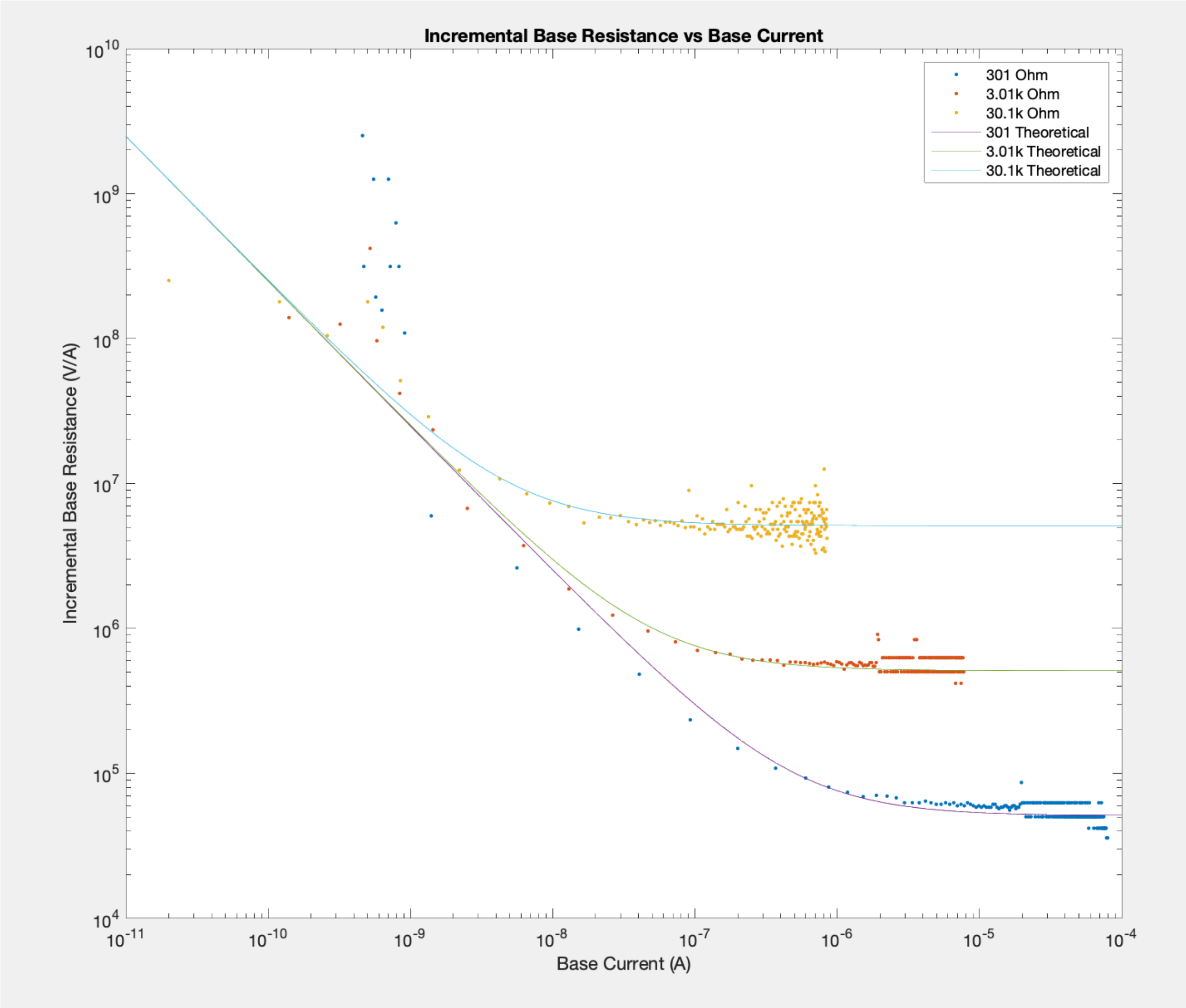

Figure 15: A plot of the extracted incremental base resistance values against the base current for the three resistor values.

The theoretical fits match the data relatively well, with a much better fit at higher base current values. This can be due to the fact that lower current values lead to higher error with this SMU.

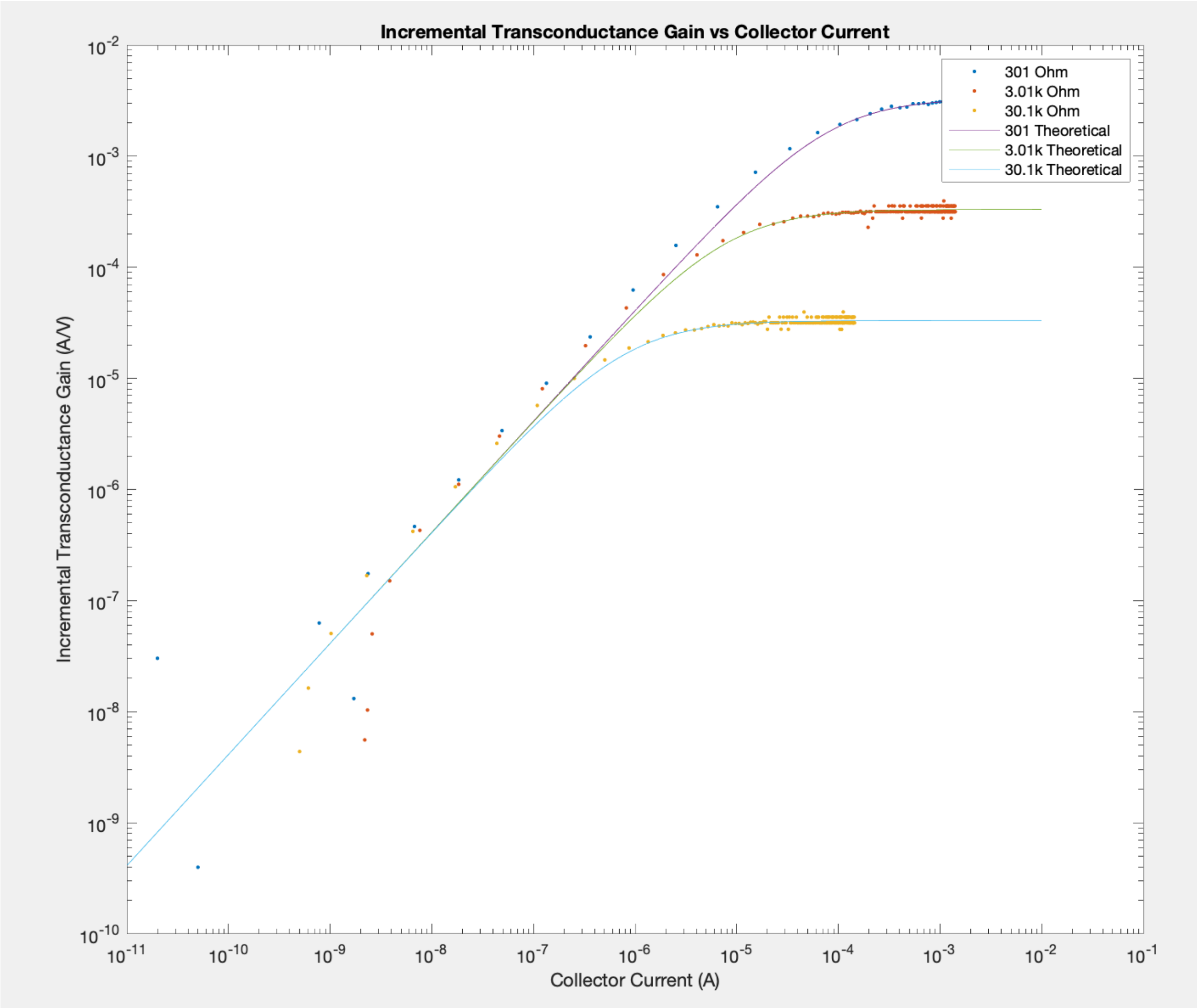

Figure 16: Incremental transconductance gain at different resistor values against the collector current.

The measured incremental transconductance gain can be found by the following equation, where Ut is 1/40.226 which was found in figure 3.

$$G_{m_{measured}} = \frac{I_c}{U_T}$$

The theoretical incremental transconductance gain can be calculated using the following equation.

$$G_{m_{theoretical}} \approx \frac{1}{R} \cdot \frac{1}{1 + \frac{U_T}{I_C \cdot R}}$$

The theoretical fits generally match the data. The fit is much better at higher current values which has been repeatedly shown through this experiment. Lower current values lead to higher error.

Experiment 3: Follower Voltage Transfer Characteristics

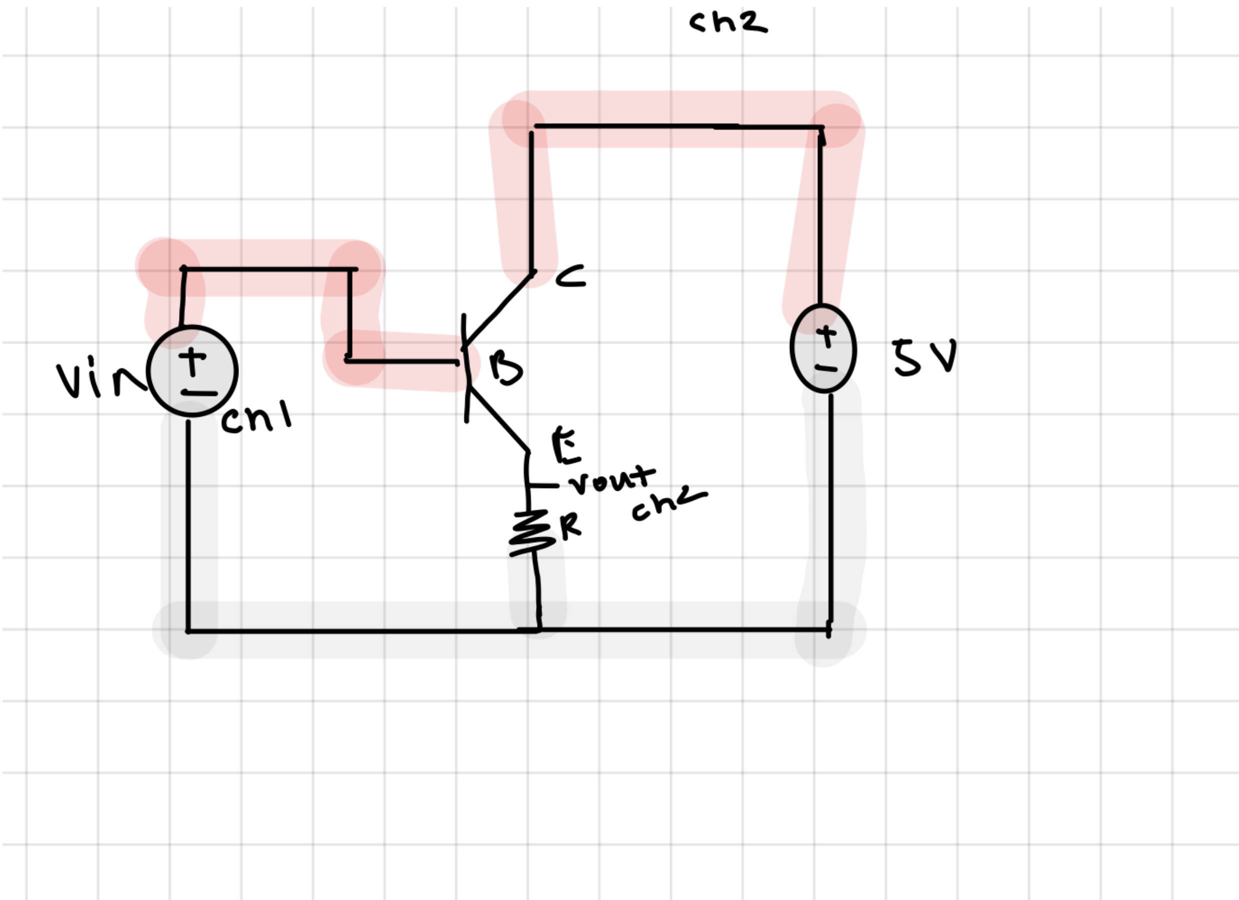

Figure 17: Schematic of experiment 3 set up.

In this experiment, we supplied a series of voltages using channel 1 to the base of the BJT and then measured the emitter follower's output voltage using channel 2. The resistor value we used here was 30.1 kOhms which was the greatest resistor value we used in experiment 2.

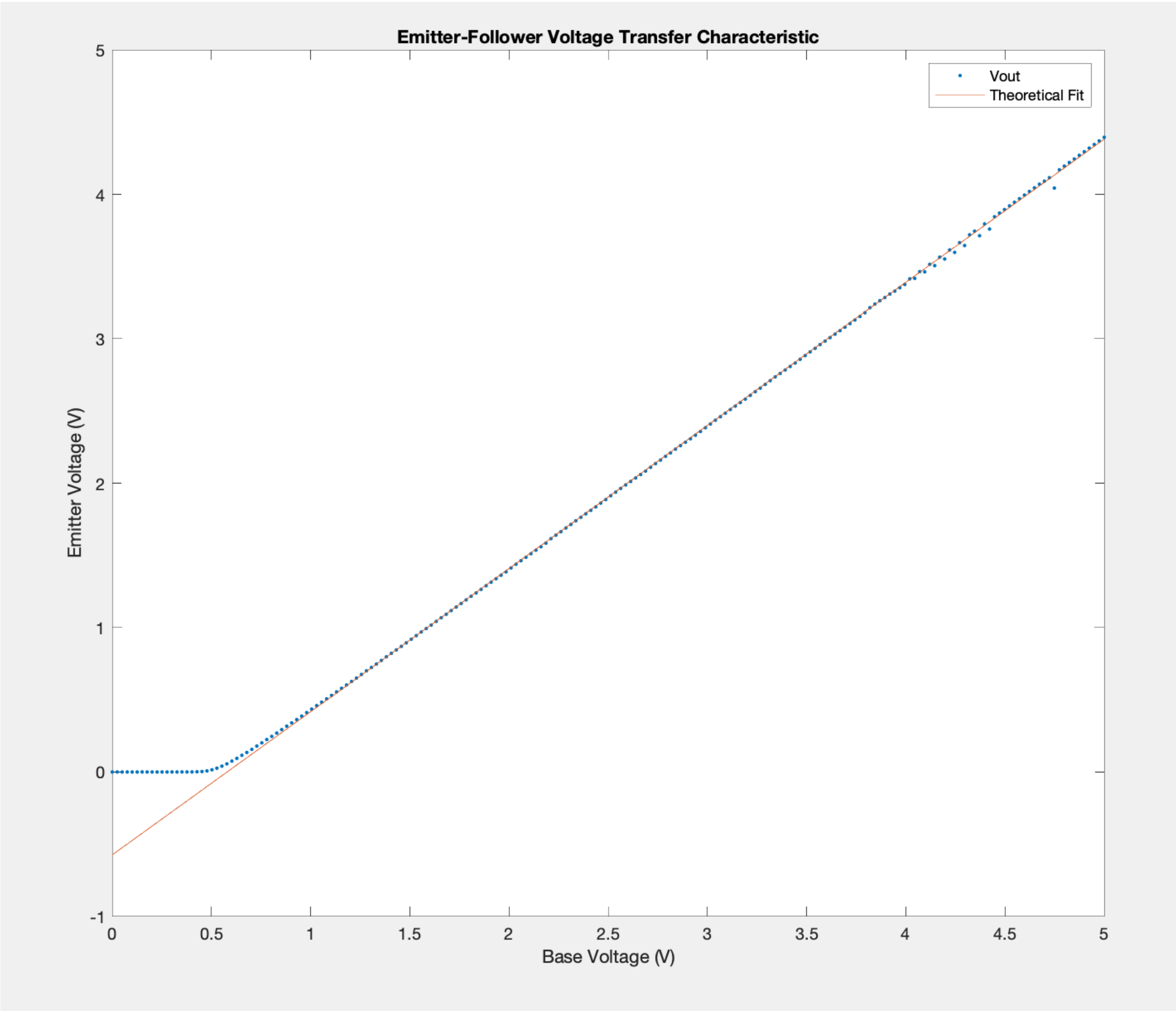

Figure 18: The emitter voltage against the base voltages that are being swept.

The voltage transfer characteristic of this circuit at a resistor value of 30.1 kOhms is shown in figure 18.

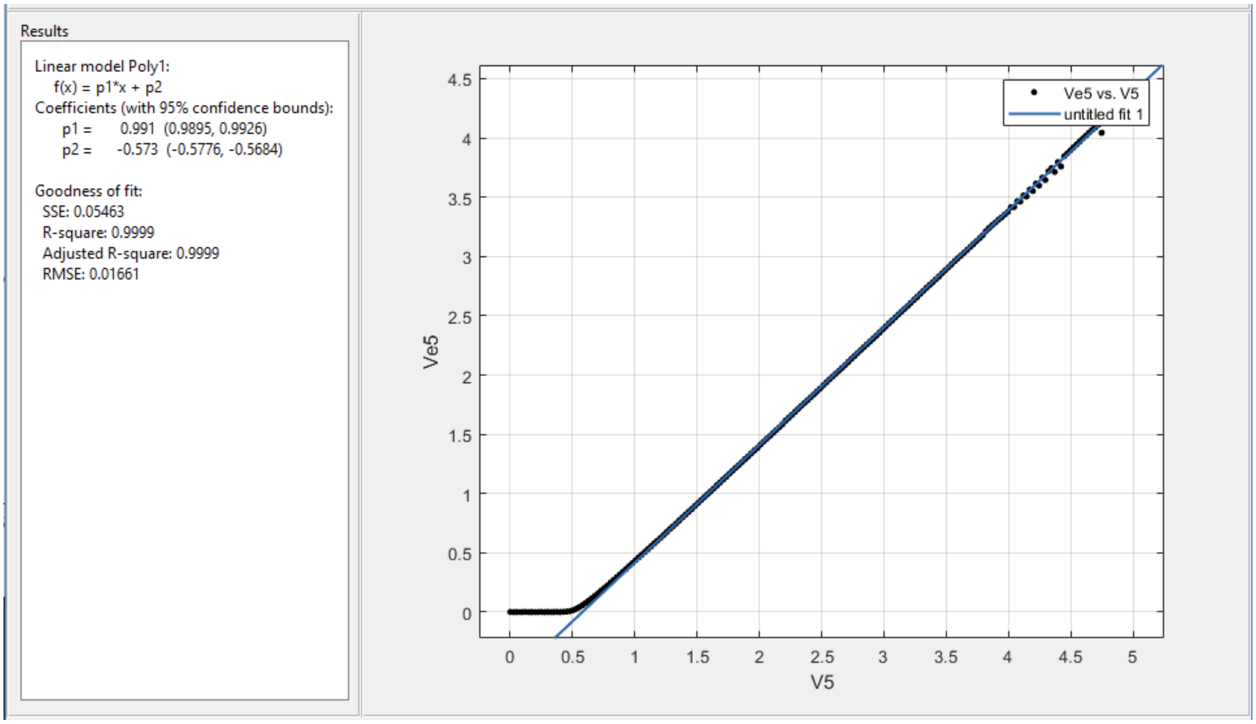

Figure 19: The linear fit coefficients of the emitter voltage vs base voltage VTC.

The incremental voltage gain of the emitter follower is 0.991. This is found through the linear fit shown in figure 19.

The difference between the Vin and Vout of this circuit is -0.573 which is given by the y-intercept found in figure 19. The fit intersects the x axis at the turn on voltage. This voltage difference is determined by the value of the resistor placed in series.

Experiment 4: Inverter Voltage Transfer Characteristics

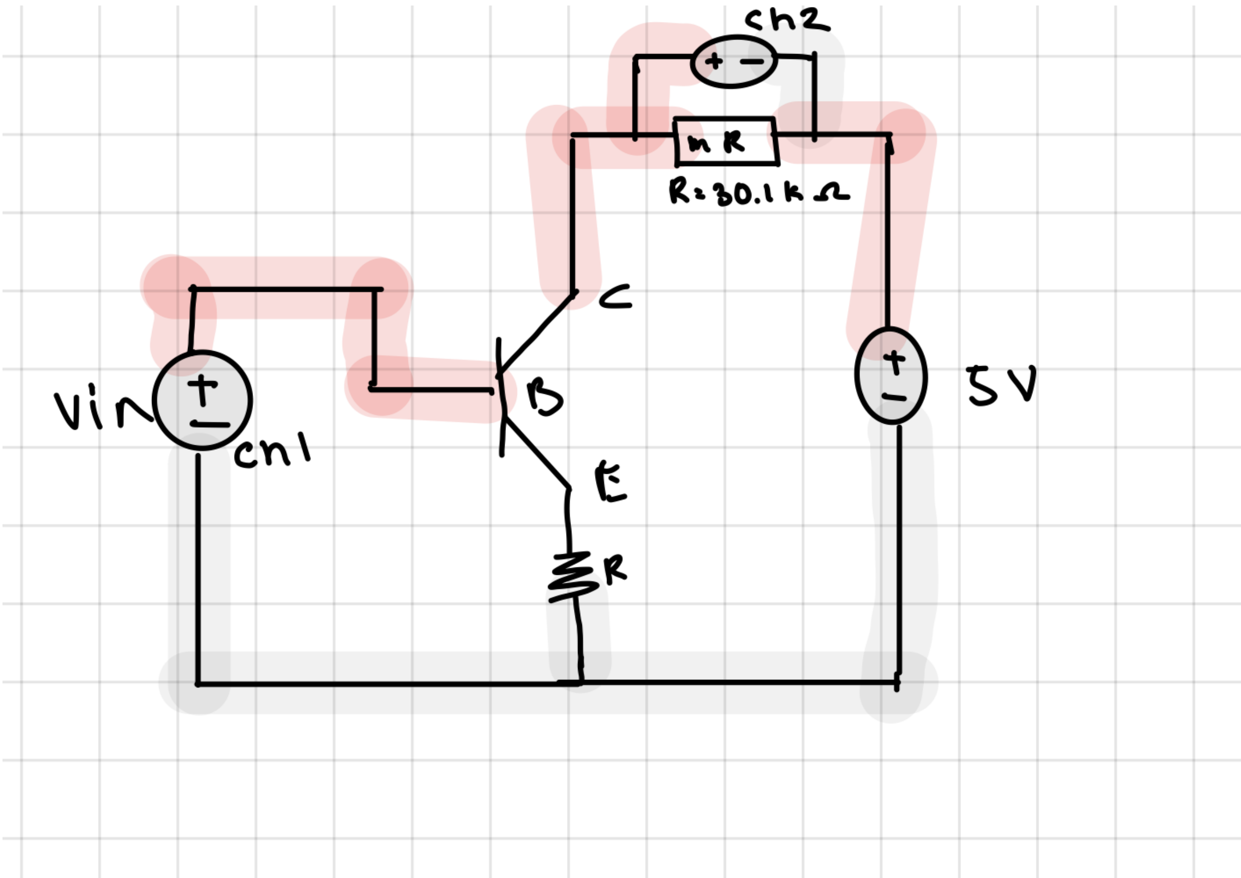

Figure 20: Schematic for experiment 4

In this experiment, we used channel 1 to supply a series of voltages to the base of the BJT and measure the output voltage thus allowing us to show the voltage transfer characteristic at different collector resistor values. The resistor values we used are shown below.

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Resistor Values
30.1 kOhms
60.4 kOhms
90.9 kOhms
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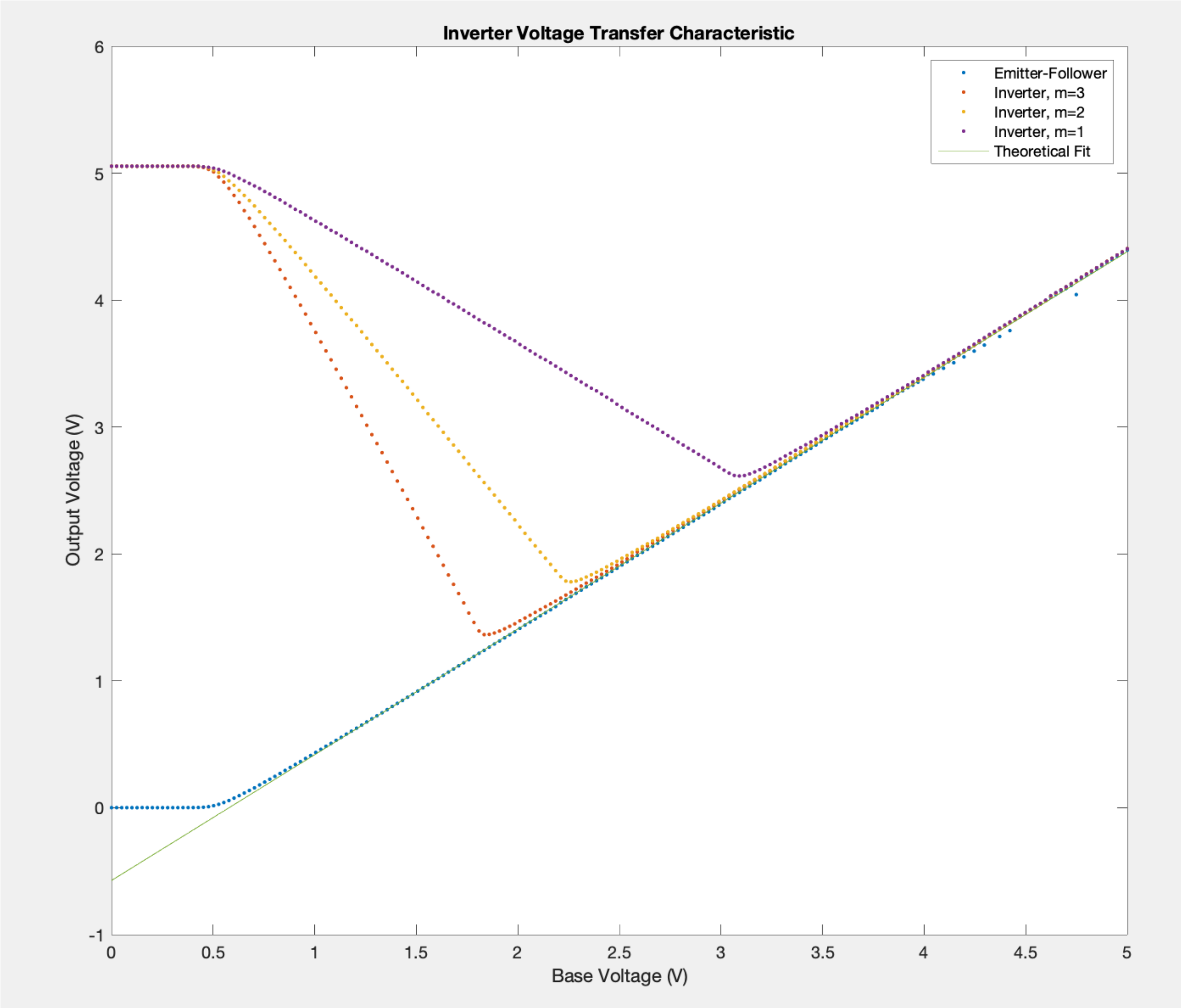

Figure 21: Voltage transfer characteristic of the experiment 4 circuit

The incremental voltage gain if both are 30.1 kOhms is 1, 2 if the top resistor is 60.4 kOhms, and 3 if the top resistor is 90.9 kOhms. This voltage gain is determined by the ratio of the two resistors in this circuit.