Lab Report 2 by Jamie O'Brien, Sabrina Pereira, and Shyheim Russell

1. Introduction

In this lab, we dove into the characteristics of diode-connected transistors, specifically *npn* bipolar transistors. We wanted to see the qualitative behavior of this device and determine how the current-voltage relationship changes when connected in series to a resistor.

2. Experiment 1: Diode-Connected Transistor Characteristic

For this section, we built the circuits show in Figures 1 and 2 in order to measure the voltage-current characteristic by forcing a current into it and measuring the voltage resulting from this through an logarithmic sweep of the current from 1 nAmp to 10 mAmp, and to measure the current-voltage characteristic by measuring the resulting current values by sweeping through the same range of voltages found in the first step.

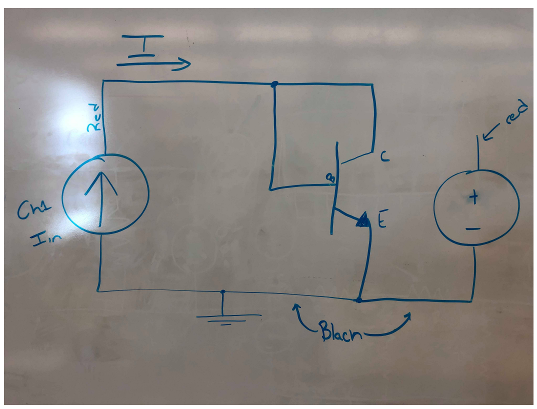

Figure 1: Experiment 1 Circuit Diagram for Voltage-Current Characteristic

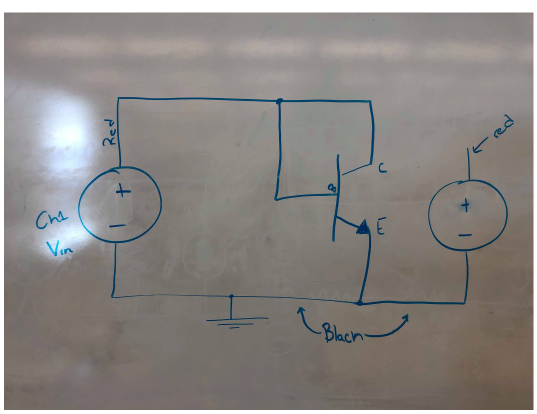

Figure 2: Experiment 1 Circuit Diagram for Current-Voltage Characteristics

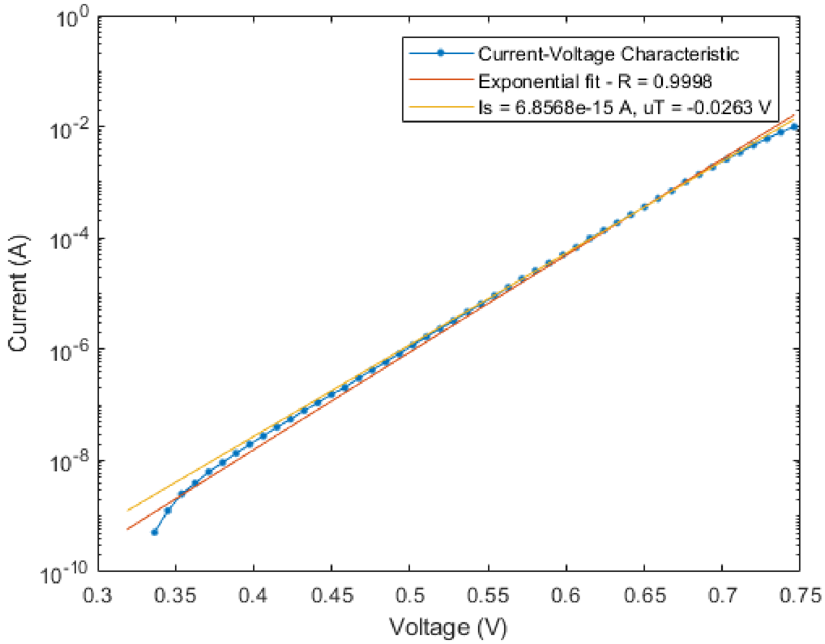

Figure 3: Experiment 1 Current-Voltage Characteristic, exponential fit with 99.98% accuracy, and theoretical comparison

As seen in Figure 3, the current-voltage characteristic is modeled by exponential model that fits the data with 99.98% accuracy with a saturation current of $Is = 6.8568 * 10^{-15} A$ and a thermal voltage of $u_T = -0.0263V$, as shown in Figure 3. We were able to extract I_s and u_T using the equation we learned from the prelab, $log(I) = m * V + b$, where $m = \frac{1}{u_T}$ and $b = log(I_s)$, which were the coefficients of the linear fit if we fit it to the semi-log plot of the current-voltage characteristic. Extracting the values in this manner allowed us to plug them into the ideal diode equation $I = I_s e^{V/u_T}$, which later allowed us to solve for the theoretical fit for the incremental diode resistance as seen in Figure 5.

Figure 4 shows the voltage-current characteristic and current-voltage characteristic plotted against the theoretical values that we calculated.

From this data, we see that each of these values map closely to one another as the diodes would have a similar relationship between the voltage and current, as we would expect given their relationship outlined in the ideal diode equation would not change for a current or voltage source.

Finally, we analyzed the incremental diode resistance, r_d, of our circuit. Given that $r_d = \frac{\delta V}{\delta I} = \frac{u_T}{I}$, we were able to solve for r_d both theoretically, $r_d = \frac{u_T}{I}$ and with our experimental data, $r_d = \frac{\delta V}{\delta I}$. These results are shown in Figure 5 where our theoretical calculations closely match our experimental data.

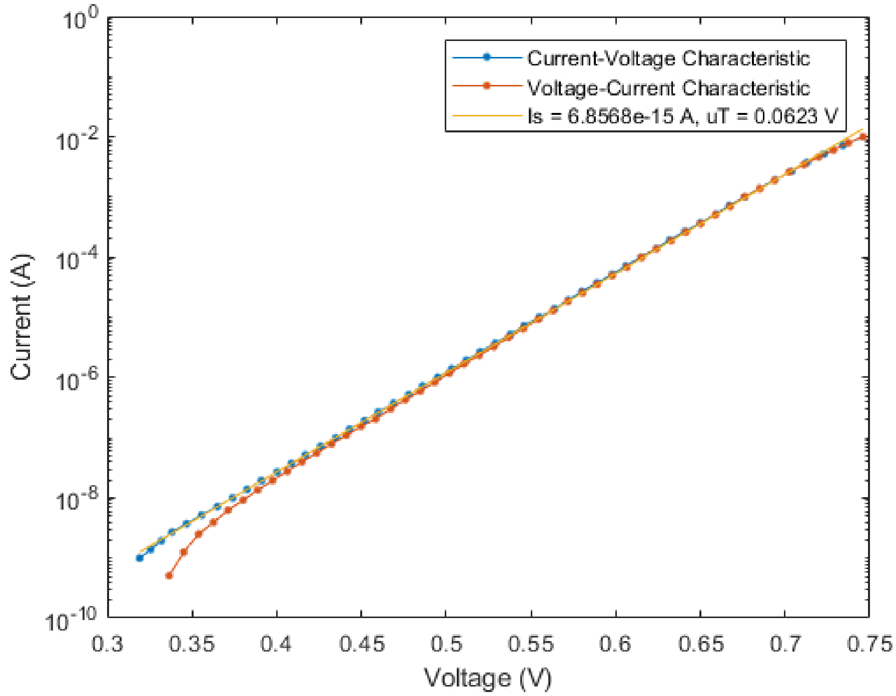

Figure 4: Experiment 1 Voltage-Current Characteristic, Current-Voltage Characteristic, and Theoretical Comparison

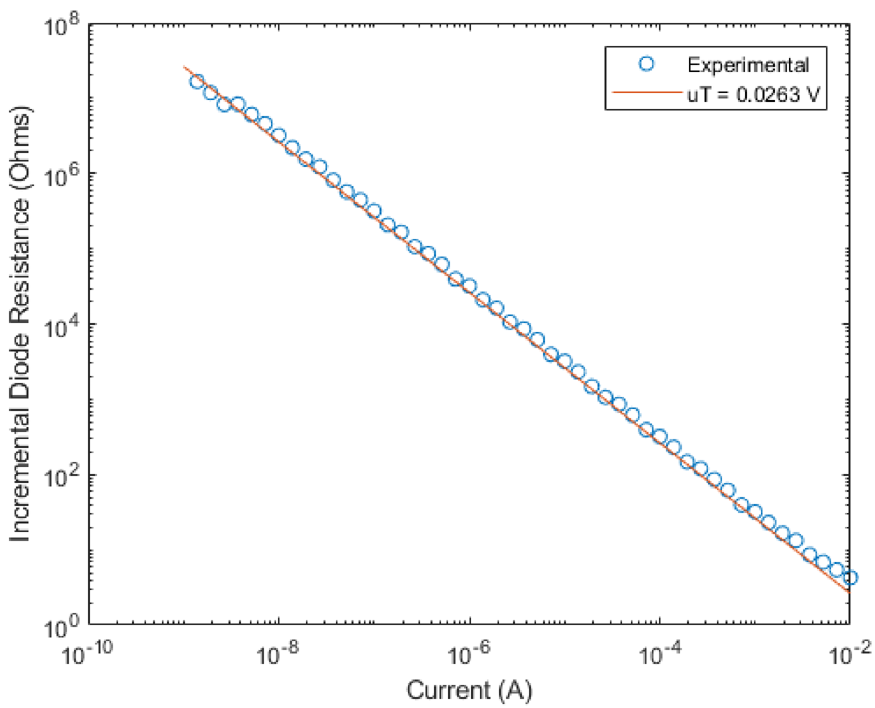

Figure 5: Experiment 1 Incremental Diode Resistance, r_d, vs. Current

3. Experiment 2: Characteristics of a Resistor and Diode in Series

In this experiment, we we used 100Ω, $1k\Omega$, $10k\Omega$ resistors to individually place in series with the diode and looked to see how the input current and the voltage across the transistor changes with respect to different applied input voltages. To do this, we swept from 0V to 1V as we measured both these values for each resistor value. We designed the circuit seen in Figure 6.

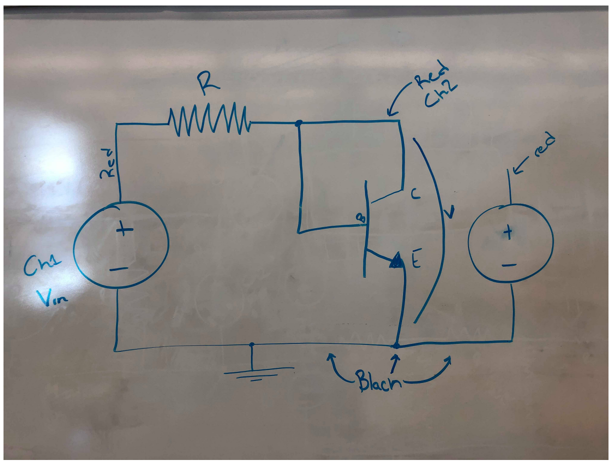

Figure 6: Experiment 2 Circuit Diagram for Current and Voltage Measurement

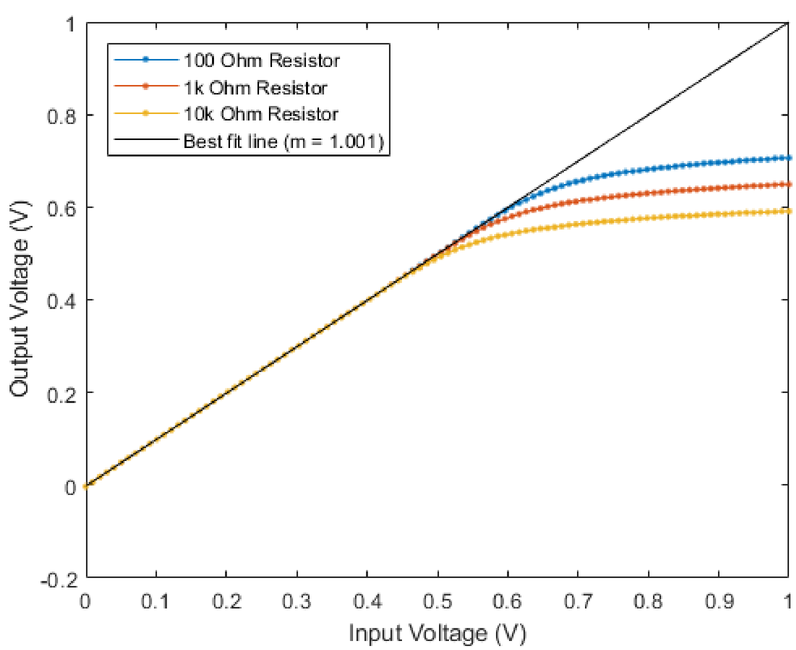

Figure 7: Experiment 2 V_{in} vs V_{out} for Each Resistor Value

As seen in Figure 7, all three curves have a linear portion to them until they reach their turn-on voltage V_{on}. The slope of the line of best fit to this linear segment is about 1, which indicates that effectively all of the change in the applied input voltage is reflected in the voltage across the transistor. We were surprised that the best-fit slope was slightly greater than 1 as that seems to defy KVL, so we assume this could mean that there was some noise in the circuit, human error in collecting the data, or perhaps an artifact of the linear regression performed.

We also created a semilog plot, plotting the values for measured current flowing into each different resistor's circuit as a function of the applied input voltage, as seen in Figure 8. Similar to before, we used the equation we learned from the prelab, $log(I) = m * V + b$, where $m = \frac{1}{u_T}$ and $b = log(I_s)$. The linear segment of these curves indicate the voltage range at which the Voltage-Current characteristic acts like that of a diode, so we can use linear regression to find a line of best fit. Here, we calculated the saturation current to be $Is = 4.167 * 10^{-15} A$ and a thermal voltage of $u_T = 0.0258V$, to be able to be used later on.

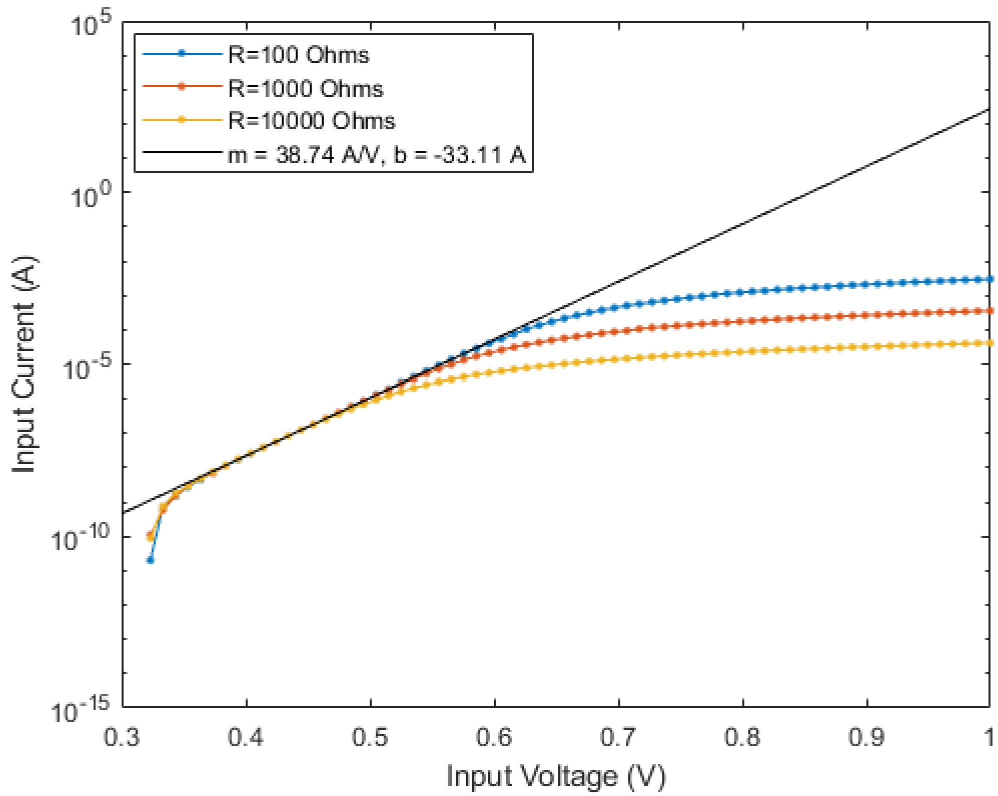

Figure 8: Current Vs. Voltage for each resistor value and line of best fit

Figures 9, 10, and 11 show the same data for each resistor value as V vs. I curves. In all cases, the circuit performed much like what we would expect based on our prelab assignment - on each of the curves, both the exponential behavior we would expect from a diode and the linear behavior we would expect from a resistor are present. We performed a regression on the line of best fit for the linear segment of each curve. The x-intercept of this best-fit line is a close approximate indicator for when the behavior of the curve begins to shift from exponential to linear - it is a good estimation for the turn-on voltage V_{on} for each of the circuits.

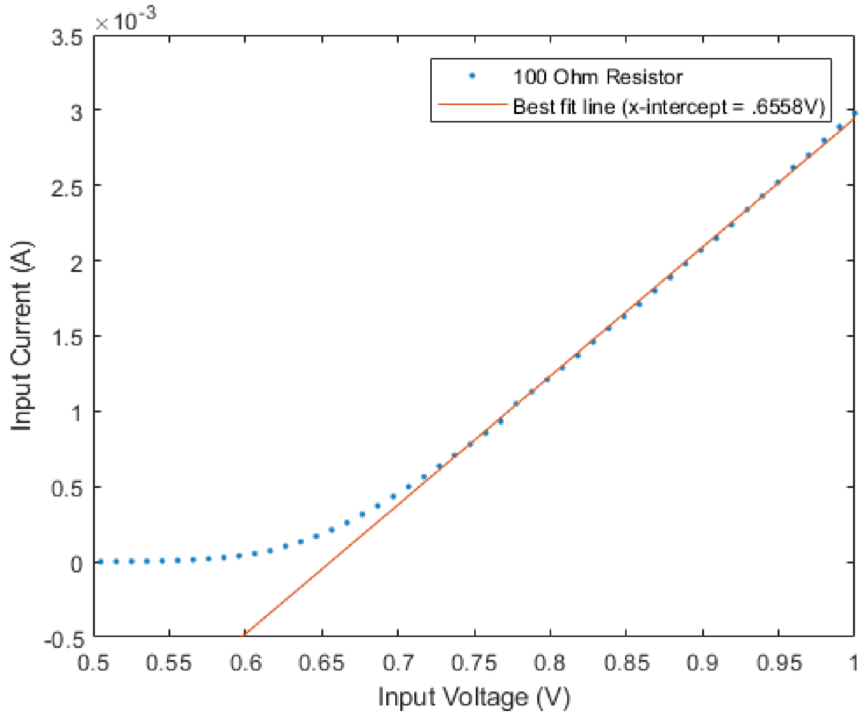

Figure 9: Experiment 2 100 Ω Resistor Data

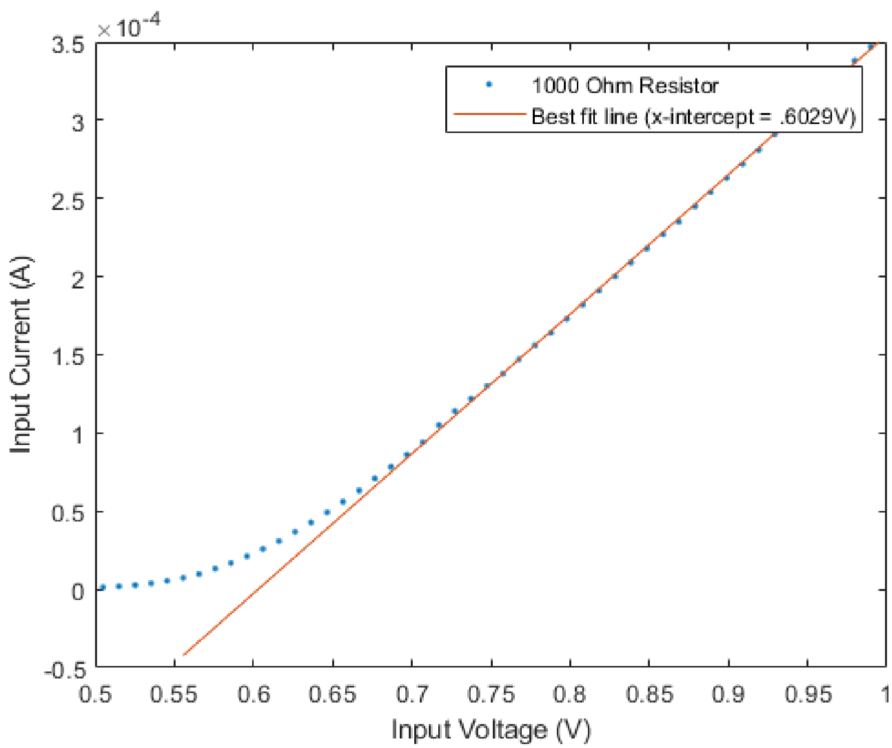

Figure 10: Experiment 2 1 kΩ Resistor Data

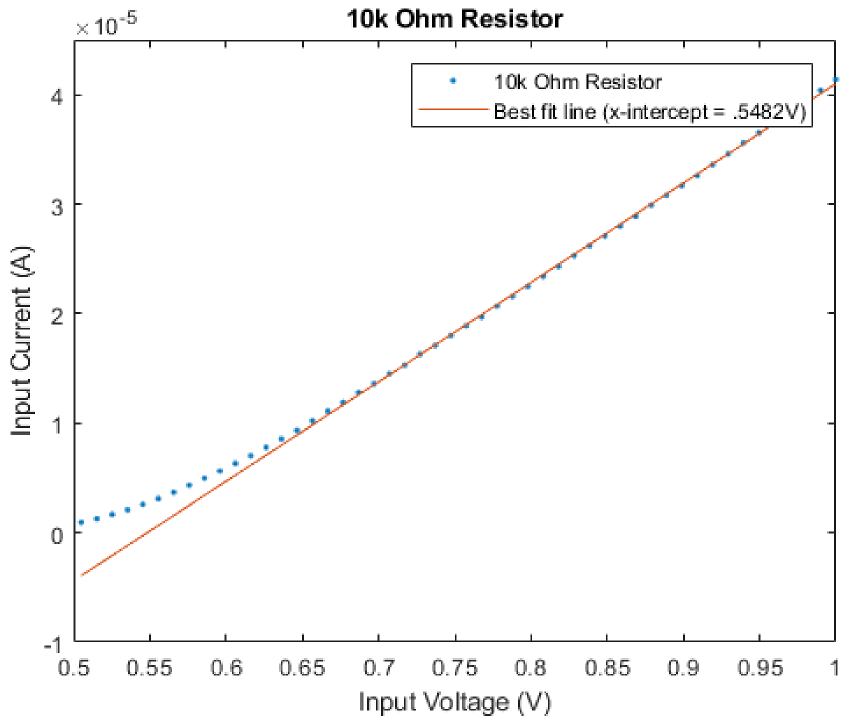

Figure 11: Experiment 2 10 kΩ Resistor Data

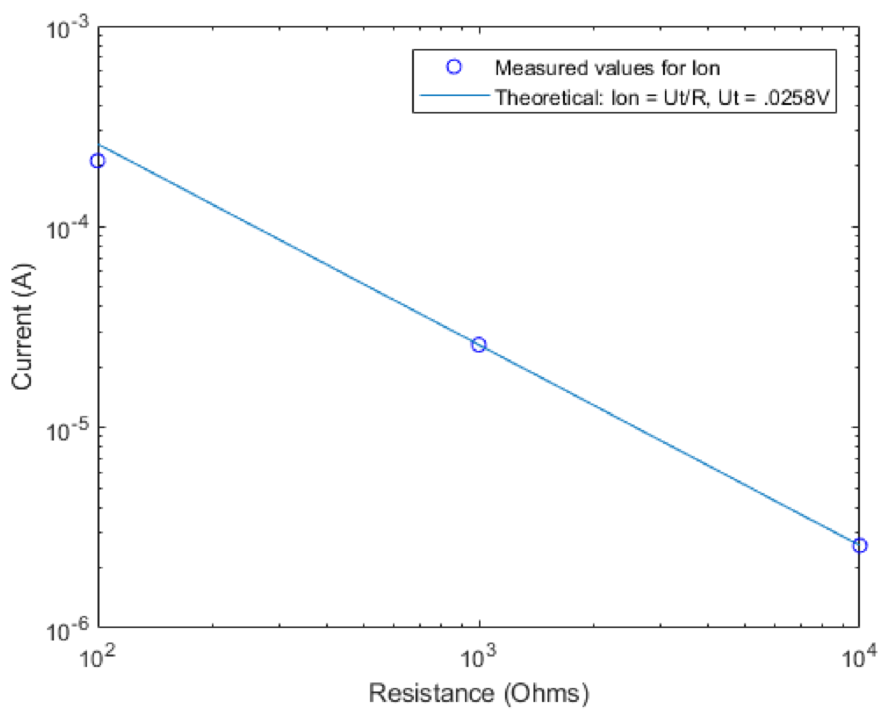

Figure 12: Experiment 2 R vs. I_{on}

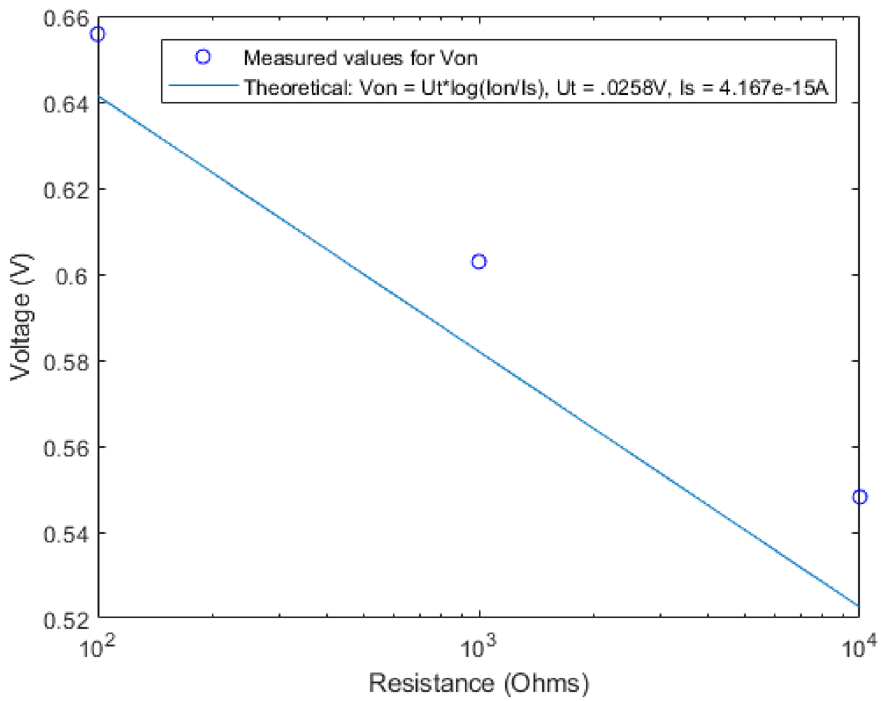

Figure 13: Experiment 2 R vs. V_{on}

With the extracted approximate values for the turn-on voltages per circuit with a different resistor, we created a R Vs. I_{on} log-log plot (Figure 12) and a R Vs. V_{on} semilog plot (Figure 13). We used the approximate values of V_{on} to locate the input current value of the circuit for that applied voltage, which gives us a good estimate for the value of I_{on}.

We plotted the theoretical values of I_{on} using the equation derived in the prelab, $I_{on} = u_T/R$. The theoretical values for V_{on} were found using the derived equation $V_{on} = u_T \log(I_{on}/I_s)$. The values are very closely matched to what we would expect from the prelab analysis in both cases.