Lab 2: Resistors and Diodes

ENGR 2420 | Olin College

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October 7, 2020

Intro

In this lab, we were introduced to the behavior of a diode-connected transistor, a setup used when an extremely low reverse leakage current (current backflowing through the diode) is desired. We explore the current-voltage and voltage-current characteristics of the transistor, and extract values from our measured data. With equations derived in the prelab, we can create theoretical models of the transistor's behavior, extract values such as saturation current I_s, and thermal voltage U_T, and verify the identity of our transistor.

Methods & Materials

Experiment 1

(a) The circuit with a driving current.

(b) The circuit with a driving voltage.

Figure 1: The circuit schematic for Experiment 1, with both a driving current and driving voltage.

For the first experiment, we first plotted and theoretically-modeled relationships between data on the transistor's current and voltage response(s) that were given to us. Then, we made and used an LTSpice circuit identical to the one that produced the provided data to take experimental data, which we then plotted and fit theoretical curves to in the same manner as the given data.

The circuit form for both the provided and experimental data consists of a diode-connected transistor in two regimes: with a driving current (fig. 1a) and with a driving voltage (fig. 1b). Using both of these regimes, we visualized the voltage-current and current-voltage characteristics of the diode-connected transistor and extracted values for I_S and U_T. We then extracted the incremental resistance R_d of the diode-connected transistor from both the experimental and given data. The data was compared and various assessments on the efficacy and accuracy of the experiment were drawn.

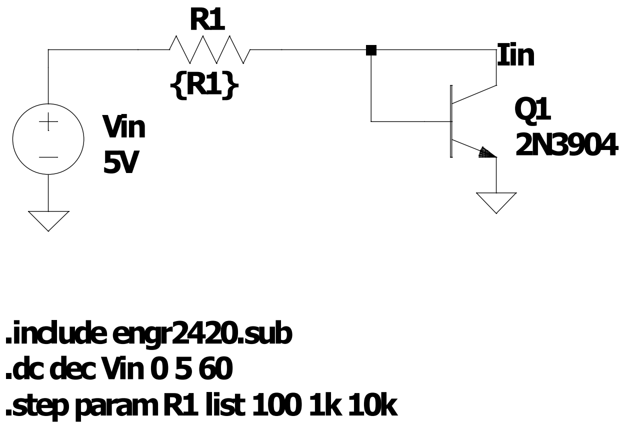

Figure 2: The circuit schematic for Experiment 2.

Experiment 2

The circuit setup for this experiment is similar to fig. 1b, except there is a resistor in series with the diode-connected transistor (fig. 2). We swept an applied input voltage into the circuit across three resistor values of different orders of magnitude and measured current into the circuit and voltage across the diode-connected transistor. Finally, we plotted different relations and extracted values of I_{on} and V_{on} which resulted in the transistor.

Data

Experiment 1

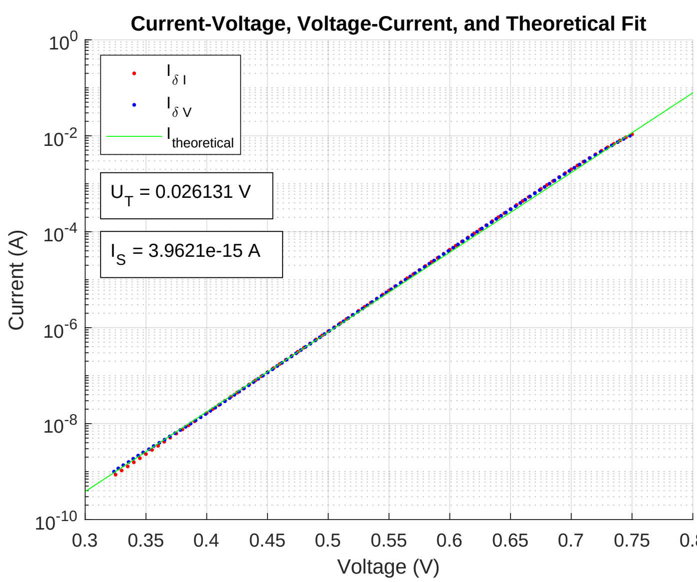

Figure 3: fig: Characteristics of transistor with driven current and driven voltage, along with a theoretical curve fit to the current-voltage response for given data.

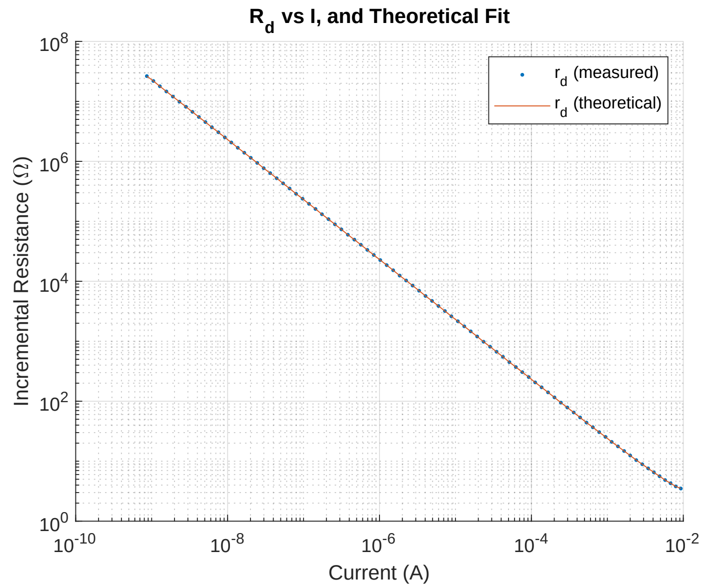

Figure 4: Extracted incremental resistance as a function of input current I with theoretical model for given data.

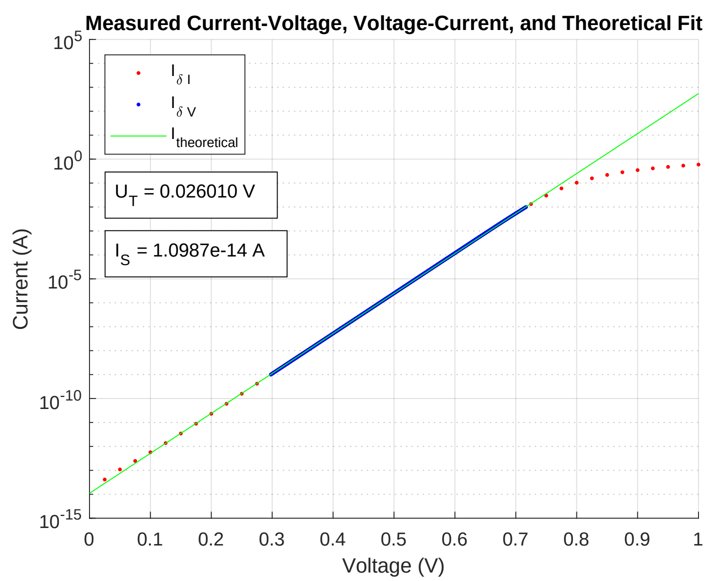

Figure 5: fig: Characteristics of transistor with driven current and driven voltage, along with a theoretical curve fit to the current-voltage response for measured data.

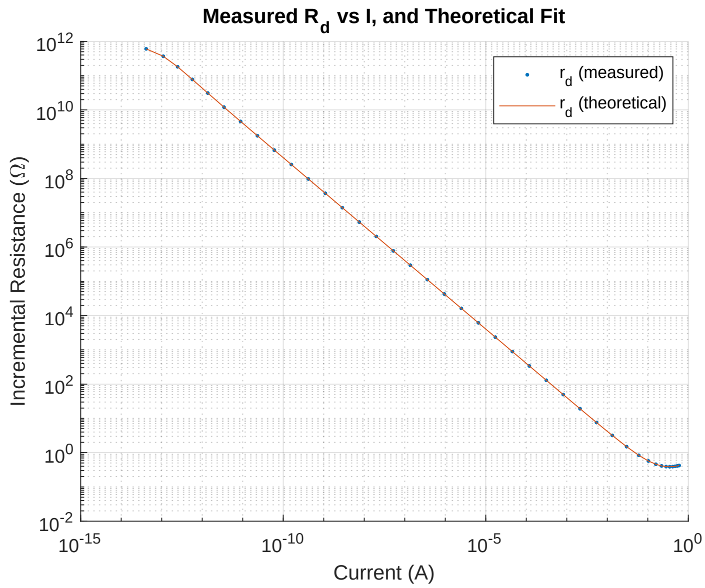

Figure 6: Extracted incremental resistance as a function of input current I with theoretical model for measured data.

Experiment 2

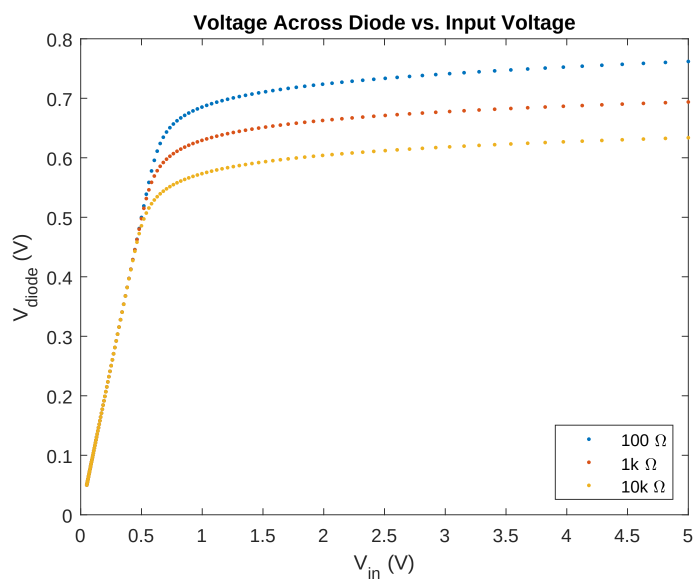

Figure 7: V_{diode} plotted across V_{in} for three resistor values.

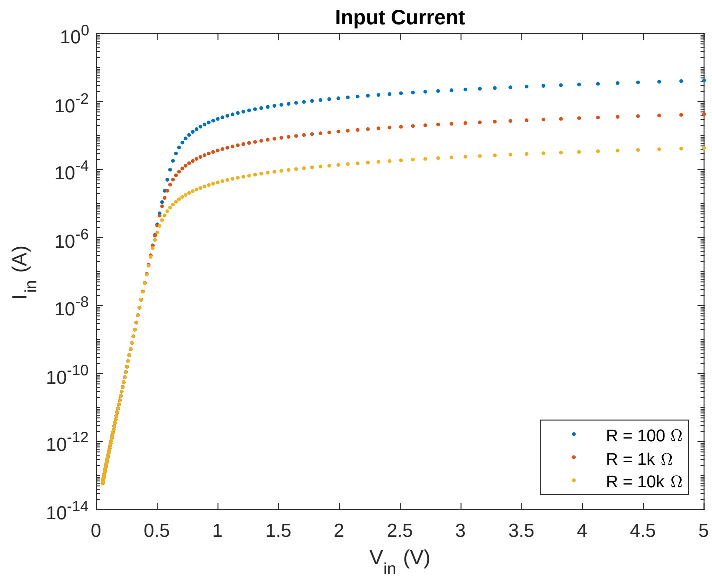

Figure 8: Input current across input voltage for three resistor values.

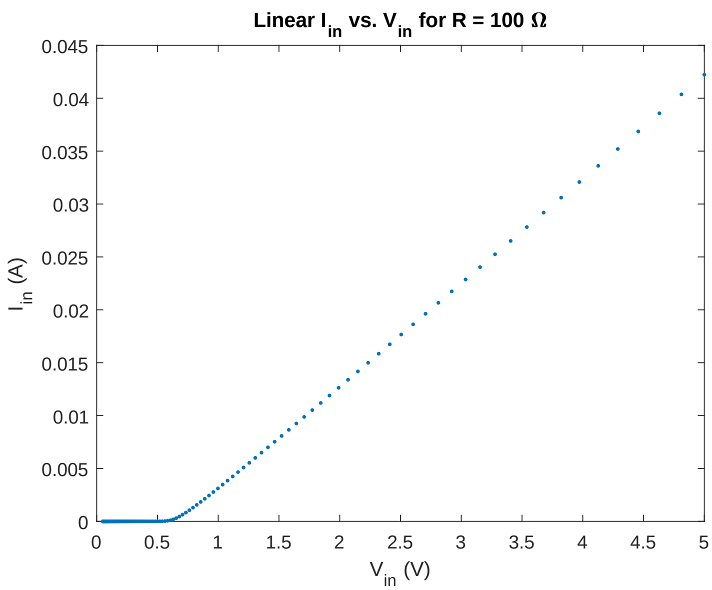

Figure 9: Input current plotted across input voltage for $R = 100\Omega$.

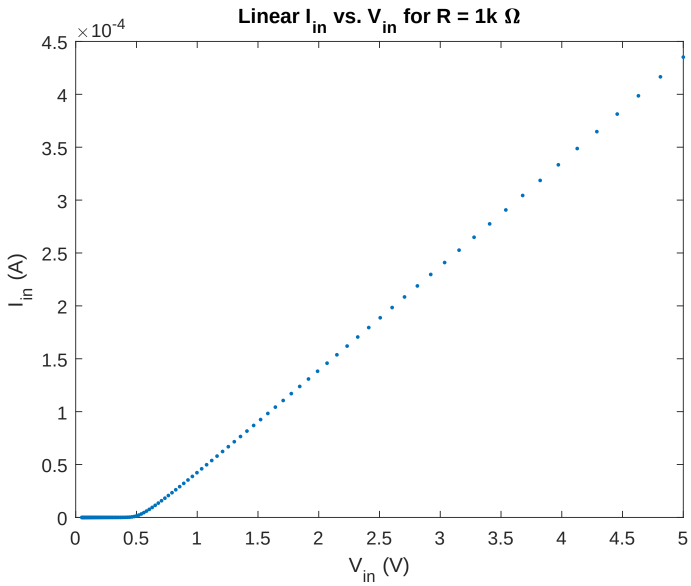

Figure 10: Input current plotted across input voltage for $R = 1k\Omega$.

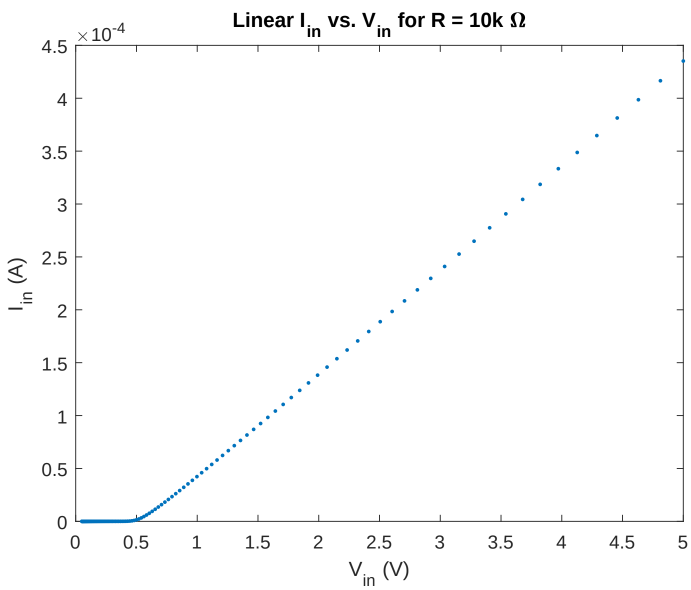

Figure 11: Input current plotted across input voltage for $R = 10k\Omega$.

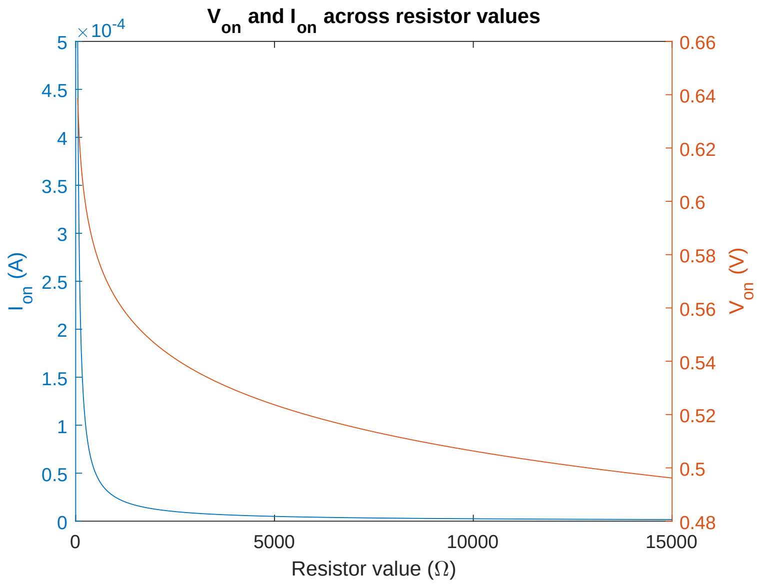

Figure 12: V_{on} and I_{on} plotted across resistor values. For $R = 100\Omega$, $V_{on} = 0.6215V$ and $I_{on} = 0.25mA$. For $R = 1k\Omega$, $V_{on} = 0.5639V$ and $I_{on} = 0.025mA$. For $R = 10k\Omega$, $V_{on} = 0.5063V$ and $I_{on} = 0.0025mA$.

Discussion

Experiment 1

For the current and voltage characteristic plots, there's no substantial difference in behavior over the range we measured, however as the data passes below the 10e-9 Amp range, the $I_{\delta I}$ drifts slightly below the current driven response and logarithmic theoretical curve. This could be due to the capacitance of the circuit and its components becoming more significant at extremely low currents, or perhaps the precision LTSpice is able to provide, even when its Absolute Current Tolerance is set to a lower value.

For the incremental resistance plots, we see that our theoretical data represents our measured data quite well. We could potentially improve the accuracy of the function by iterating over a smaller step size in LTSpice, but overall this representation works fine for both our measured and theoretical.

When comparing the overall given experimental data with the measured data from our own LTSpice simulations, we see that our simulations exhibit a higher value of I_S, although it is still in the acceptable range of a few fA. This could be due to a different characteristic of the transistor itself, or a difference in the LTSpice setup between the given data and our own simulation.

Experiment 2

Based on the prelab assignment, the circuit behaves qualitatively as we expected. There is a linear portion of the curve which gives way to a logarithmic portion, as seen in fig. 7.

From our earlier prelab analysis, these parameters vary with R inversely. Given the equation $I_{on} = \frac{U_T}{R}$, we expect that as R increases in value, I_{on} will decrease by an inverse proportion. In fig. 8, we see that higher impedance resistors result in the 'knee' of the curves and subsequent exponential characteristic response manifesting at a lower current. This confirms our expected behavior.

Conclusion

In doing this lab, we developed a greater understanding of the dynamics of a diode connected transistor, and now have a more solid basis for controlling the way it behaves to suit an application we desire.

Potential improvements to this lab would namely take the form of a higher resolution data capture, a more realistic experimental setup, and implementation of non-ideal conditions. Since we're simulating the behavior of everything in LTSpice, it's possible we're missing additional environmental factors such as capacitance, RF interference, part tolerances, or other environmental factors that would impact the way our circuit responds. Effectively, all we've done is simulate a circuit under ideal circumstances, visualize its behavior, and extract values from the data that we defined to begin with (i.e. I_s and U_T. This means that we're only really quantifying the precision of our simulation and theoretical setup, not the non-ideal behavior of a real-world circuit.