Introduction to Microcircuits
Lab 2: Resistors and Diodes

Antonia Elsen, Ruby Spring

February 2015

1 Experiment 1: Diode-Connected Transistor Characteristics

1.1 Experimental Setup

- A current was swept logarithmically from 1nA to 10mA across a diode-connected transistor and the resulting voltage was measured. The resulting voltage-current characteristic is graphed in Fig. 1.
- Similarly, a voltage was swept logarithmically (see calculation below for values) to compare to the data obtained with the first setup.

To obtain the correct voltage range, we use the ideal Diode equation:

$$I = I_S * e^{\frac{V}{U_T}}$$

Solving for V yields:

$$V = U_T * ln\left(\frac{I}{I_S}\right)$$

Estimating I_s to be equal to 10^{-15}:

$$V = 10^{-15}A * ln\left(\frac{10^{-9}A}{0.025V}\right) = 0.345V$$

$$V = 10^{-15}A * ln\left(\frac{10^{-8}A}{0.025V}\right) = 0.748V$$

To account for potential error in the idealized equation, the voltage was actually swept from 0.25V to 1V. Later, graphs and linear regressions were done with data from V = 0.34V to V = 0.75V.

1.2 Results

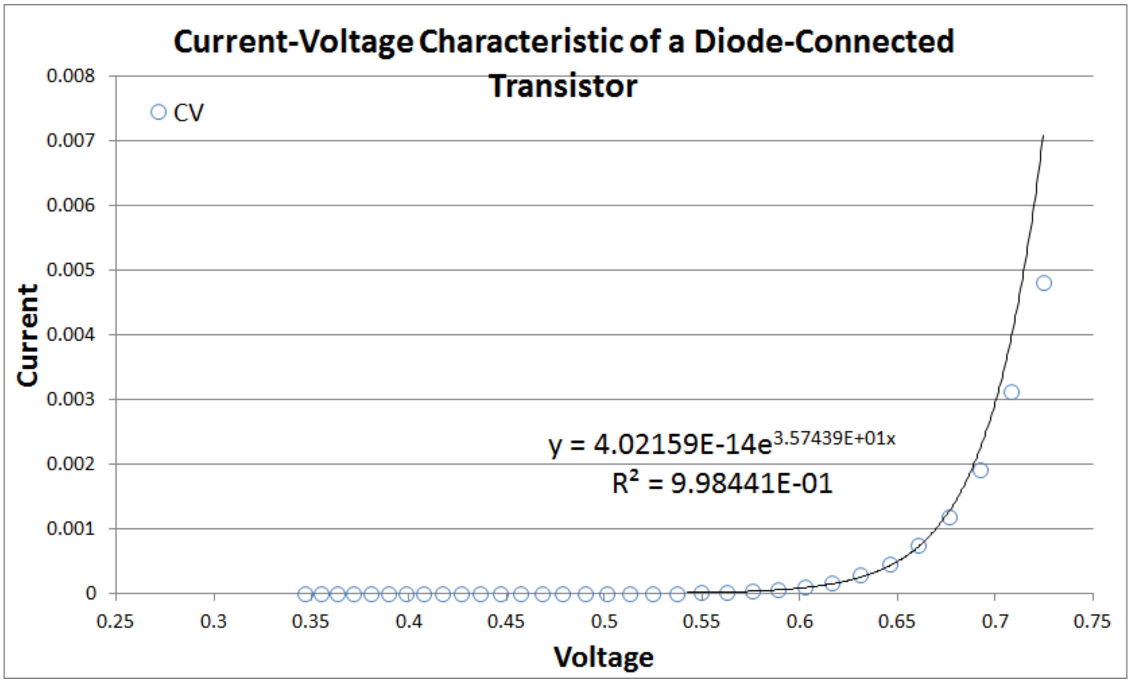

Figure 1: The IV characteristic of the diode-connected transistor with an exponential best-fit.

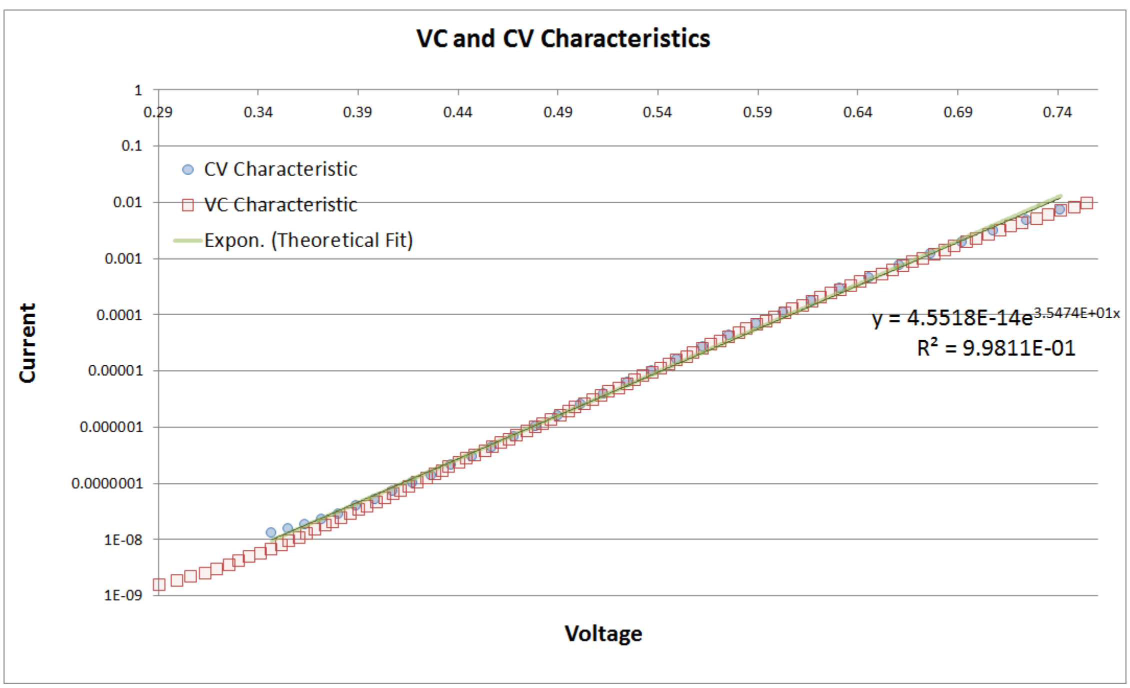

Figure 2: The semilog IV and VI characteristic of the diode-connected transisitor.

1.2.1 Incremental Resistance

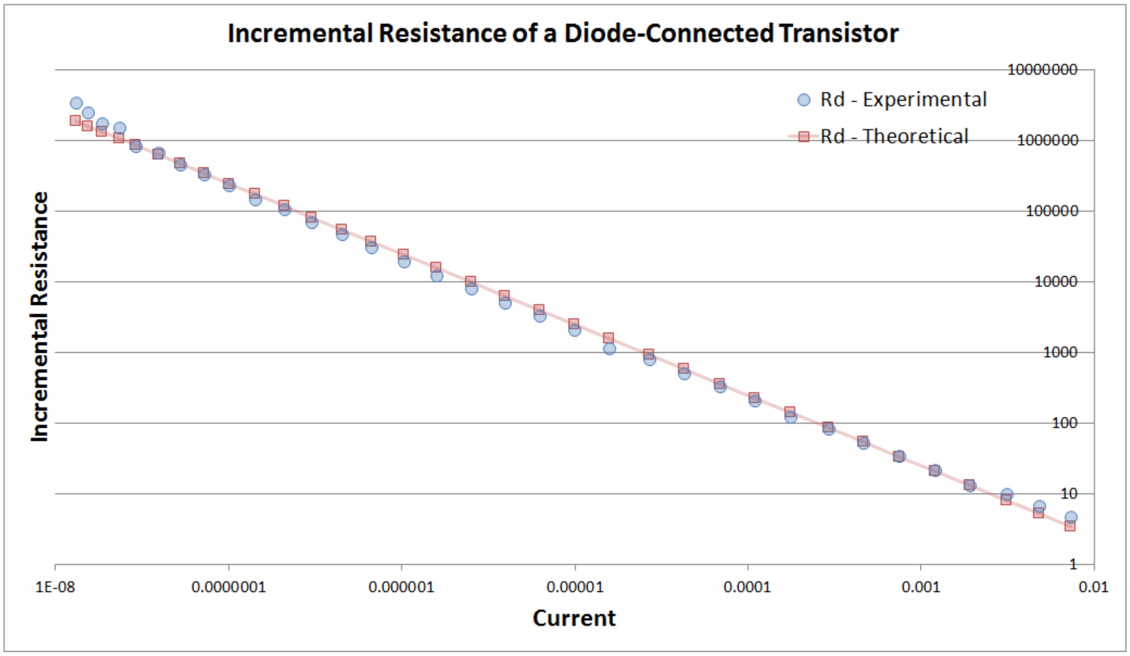

Figure 3: The experimental and theoretical incremental resistance of the diode-connected resistor.

1.3 Discussion

The saturation current was calculated based on the ideal diode equation, and the corresponding best-fit in Fig. 1, where

$$I = 4.02159 * 10^{-14} * e^{35.7439}$$

We see that:

$$I_s = 4.02159E - 14A$$

and

$$U_t = \frac{1}{35.7439V} = 0.027977V$$

The exponential best-fit in Fig. 1 has a R^2 value of 0.998, suggesting that our data fits quite well to these values for the saturation current and thermal voltage.

There are no substantial differences between the VC and CV characteristics. The two sets of data in Fig. 2 match very closely, such that it is difficult to see them on the same graph. These are the expected results. The R^2 of this graph is 0.998.

From Fig. 3, the experimental incremental resistance r_d was found using the equation:

$$r_d = \frac{\delta V}{\delta I}$$

where values for V and I were obtained from the current-driven data, and the calculation was done using MATLAB's "diff" built-in function. Theoretical incremental resistance was calculated using the equation:

$$r_d = \frac{U_T}{I}$$

where U_T was taken from the exponential best fit from Fig. 1 and I was taken from the current-driven data.These two theoretical and observed datasets are also very closely matched.

From this experiment we can infer that the current-voltage characteristic and the voltage-current characteristic of a diode-connected transistor is the same within an appropriate voltage range. This is the same prediction that we arrived at in the prelab.

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

2.1 Experimental Setup

Three resistors were chosen so that their values spanned at least two orders of magnitude. The following nominal values were used:

- $330\Omega \pm 5\%$.
- $1.07k\Omega \pm 1\%$.
- $12.7k\Omega \pm 1\%$.

Each resistors was placed in series with the diode-connected transistor. We then measured the current flowing through the series combination, and the voltage across the transistor to obtain the graphs in the results section.

2.2 Results

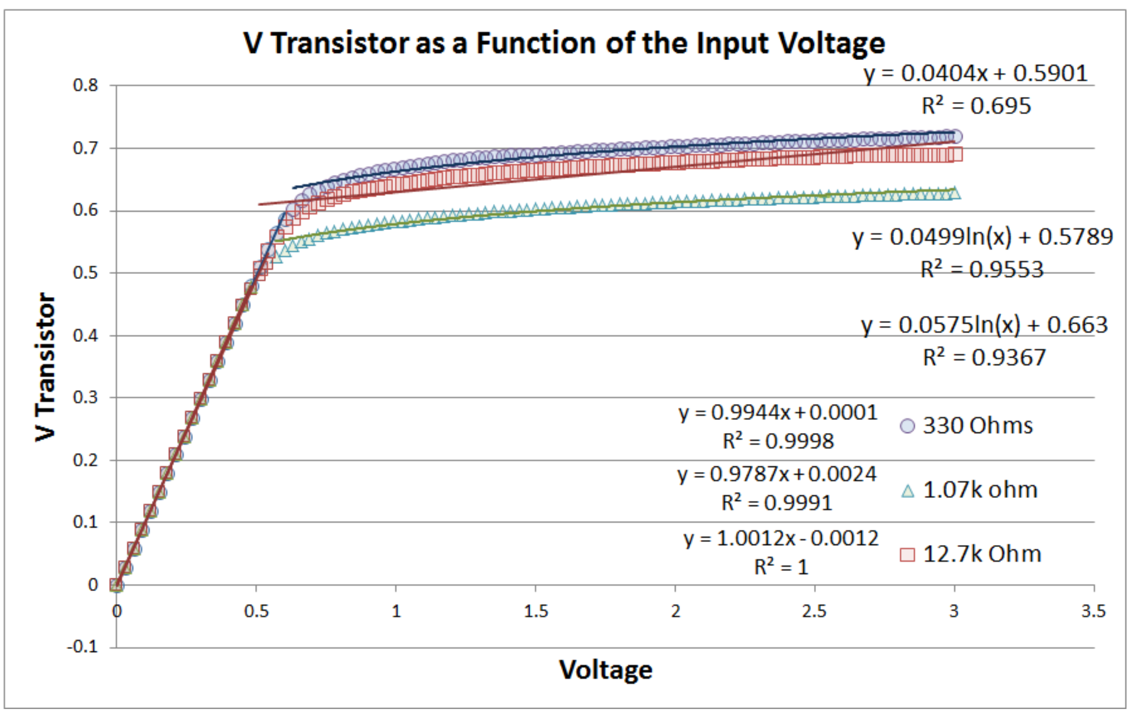

Figure 4: The Voltage drop across the diode-connected transistor as a function of the input voltage to the circuit.

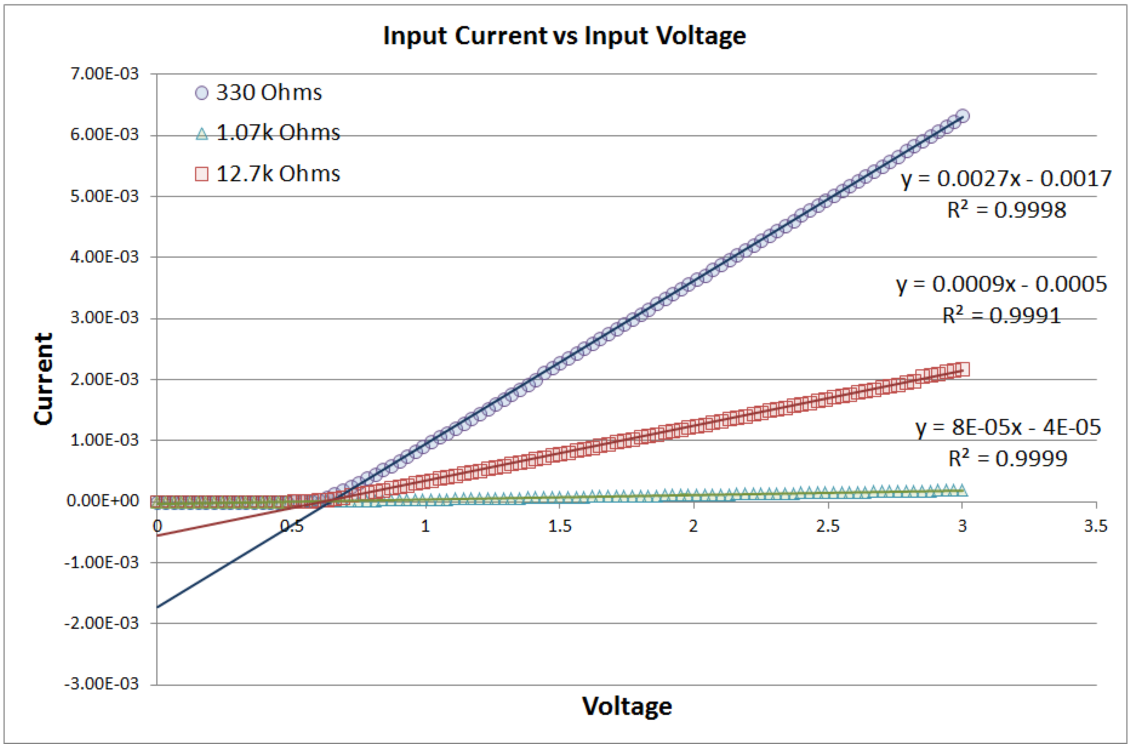

Figure 5: Linear plot of the current versus input voltage of the circuit.

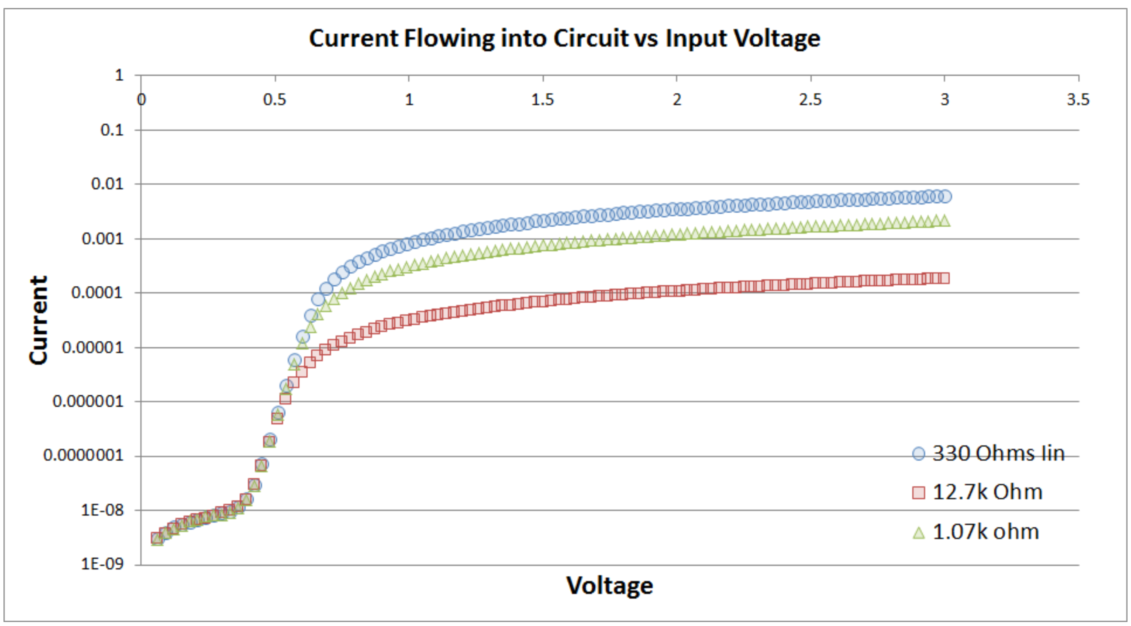

Figure 6: Semilog plot of the current versus input voltage of the circuit.

We can calculate I_{on} using the following equation:

$$I_{on} = \frac{U_T}{R}$$

Where U_T has a value of .027977V, obtained from experiment 1.

- for 330Ωs, $I_{on} = 8.4778 * 10^{-5}$A.
- for 1.07kΩs, $I_{on} = 2.614 * 10^{-5}$A.
- for 12.7kΩs, $I_{on} = 2.202 * 10^{-6}$A.

From there, we can calculate V_{on} using the following equation:

$$V_{on} = U_T * log\left(\frac{I_{on}}{I_s}\right)$$

- for 330Ωs, $V_{on} = 0.601$V.
- for 1.07kΩs, $V_{on} = 0.568$V.
- for 12.7kΩs, $V_{on} = 0.498$V.

We can plot these results to obtain the plots in Fig. 7 and Fig. 8 below:

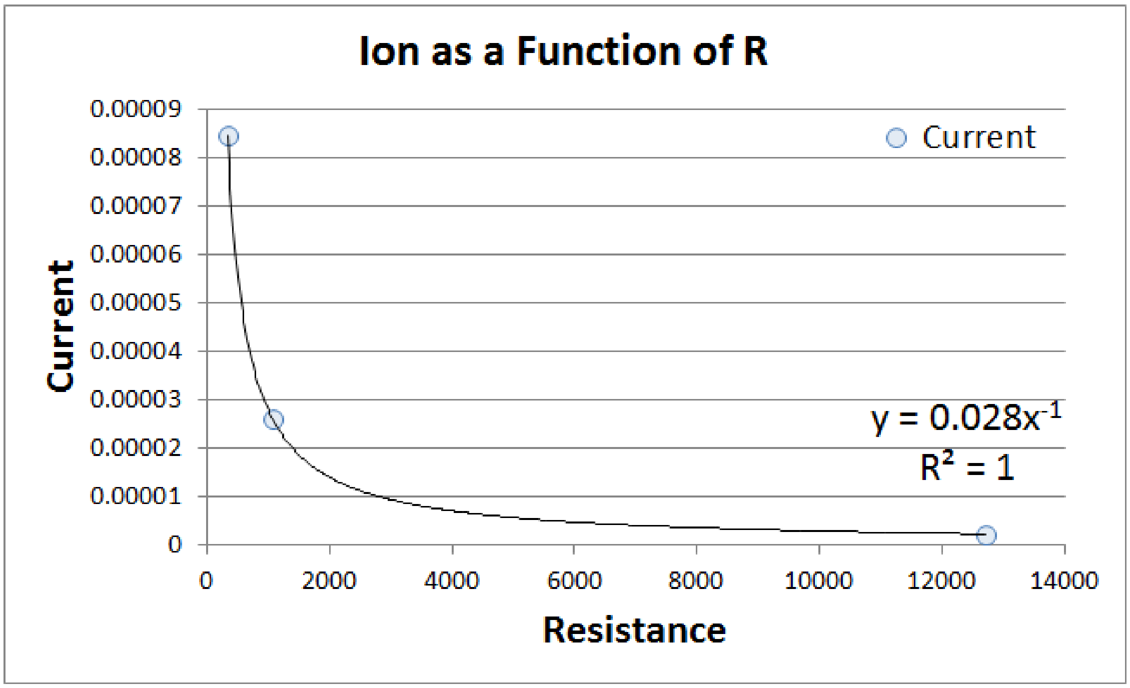

Figure 7: Plot of resistor values versus I_{on}.

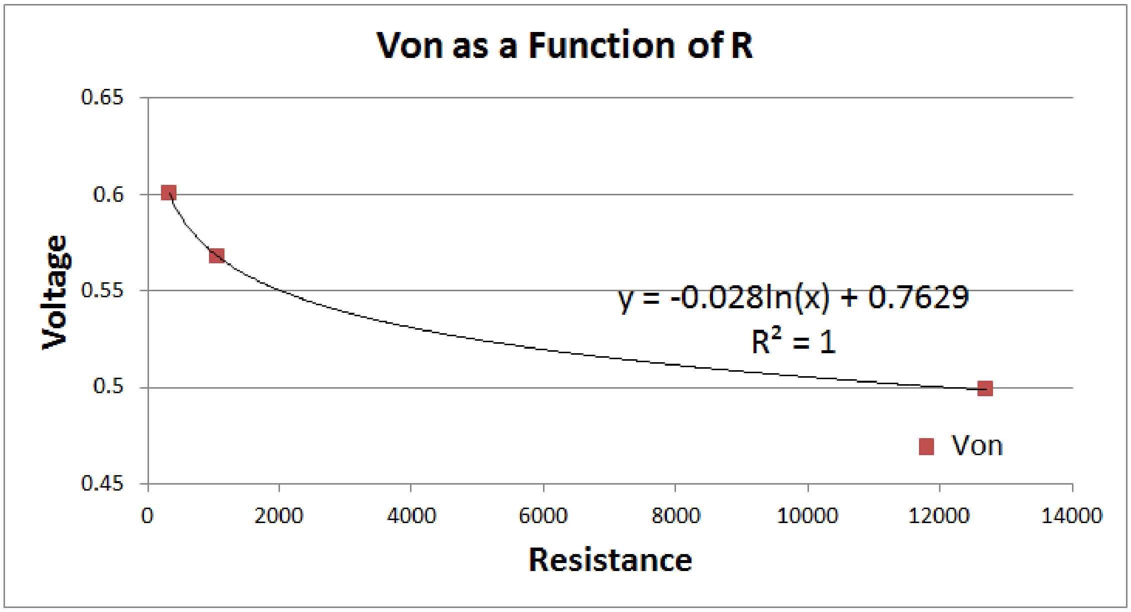

Figure 8: Plot of resistor values versus I_{on}.

2.3 Discussion

Fig. 4 exhibits the expected logarithmic/linear trends. While $V_{in} < V_{on}$, the VV characteristic of the transistor is linear and when $V_{in} > V_{on}$ the VV characteristic is logarithmic, just as predicted in the prelab.

The two IV characteristic plots in Fig. 5 and Fig. 6 were fitted using piece-wise functions for the distinctly linear and logarithmic regions, because the equation $V_{in} = IR + U_T ln\left(\frac{I}{I_s}\right)$ is not solvable for I, but $V_{in} = IR$ when $V_{in} < V_{on}$, and $V_{in} = U_T ln\left(\frac{I}{I_s}\right)$ when $V_{in} > V_{on}$.

Fig. 7 exhibits the expected behavior based on the equation $I_{on} = \frac{U_T}{R}$. Likewise, Fig. 8 exhibits the expected behavior based on the equation $V_{on} = U_T ln\left(\frac{I_{on}}{I_s}\right)$. From the best-fit equations in Fig. 7 and Fig. 8 we see that $U_T = 0.028$, which is consistent with the value for U_T obtained in experiment 1. Furthermore, the values of I_{on} and V_{on} calculated for these plots appears to be consistent with the transition point between the two distinct regions in Fig. 5 and Fig. 6.

3 Discussion

In this lab, we examined the CV characteristics, VC characteristics, and incremental resistance of a diode-connected transistor, as well as the CV characteristics and VVin characteristics of a resistor and diode in series. The theoretical equations and the data both demonstrate that the CV and VC characteristics of a diode-connected transistor are the same. They also demonstrated that a circuit comprised of a resistor and diode in series has two distinct regions of operation: when the diode is not ”on”, the circuit operates linearly, and when the diode is ”on”, the circuit operates logarithmically.