Phys219_2017 - Ryan Kaufmann/Exp. 3 (Diodes and Transistors)/Exp 3 on Diodes and transistors

SIGNED by Ryan Kaufmann Nov 06, 2017 @12:01 PM PST

Ryan Kaufmann Nov 05, 2017 @01:57 PM PST

Experiment 3: Semiconductor Diodes and Transistors

Partner: Eric Brock

Ryan Kaufmann Nov 05, 2017 @01:57 PM PST

3.2 Objectives

Ryan Kaufmann Nov 05, 2017 @02:43 PM PST

In this lab, we are going to go into another direction from the few experiments. Instead of looking at the behavior of a simple circuit, we want to observe the behavior of the properties of components made from semiconductors, namely diodes and bipolar junction transistors. In this lab, we want to see some of the uses for these components.

Ryan Kaufmann Nov 05, 2017 @01:58 PM PST

3.3 Introduction

Ryan Kaufmann Nov 05, 2017 @06:19 PM PST

Both transistors and diodes are made from semiconducting metals. Because of the properties of these metals, for a certain range of voltages, the diode only lets current flow one way. The bipolar junction transistor or BJT works in a similar way, and we can even imagine it to be a series of diodes. However, the diode acts differently if we move outside of its range. If it is too far below, it pushes the diode to let current through itself. If it is too far above, it saturates the diode and lets only a portion of the current through. BJTs have a second interesting feature. If used in the right conditions, it can amplify or depreciate an input current or voltage.

In this lab, we are going to observe a couple of these features. Namely, we want to observe the behavior between current and voltage across the diode and then an application for the diode. We want to confirm the following equation for the current across a diode:

Ryan Kaufmann Nov 05, 2017 @07:02 PM PST

$$I = I_0[e^{\frac{eV}{k_B T}} - 1]$$

Ryan Kaufmann Nov 05, 2017 @06:20 PM PST

Then we will observe both the current and voltage amplification of the BJT. Specifically if the gain formulas follow the forms: $G=I_E/I_B$ and $G=V_{out}/V_{in}$

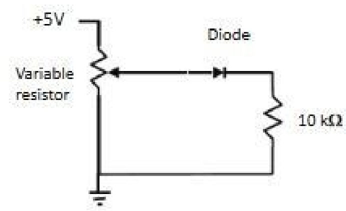
Ryan Kaufmann Nov 05, 2017 @01:59 PM PST

3.4.1 I-V Characteristics of Diodes

Ryan Kaufmann Nov 05, 2017 @04:06 PM PST

For our first section, we want to observe the I-V behavior of our diode circuit, which we set up like so:

Ryan Kaufmann Nov 05, 2017 @04:06 PM PST



I-VCircuitDiagram.jpg(11.3 KB)

Ryan Kaufmann Nov 05, 2017 @08:10 PM PST

We input 5V from the power supply. Then after find a proper resistor and diode, we create the above circuit with the variable resistor on the breadboard. The resistor had a measurement of 9843.9 kiloOhms, which we got using the HP digital multi-meter.

To measure the voltage across the diode, we will measure the voltage before the diode and the voltage after the diode, or rather the voltage between the point after the variable resistor and ground (Vin) and the voltage drop across the 10 kOhm resistor (Vr). Then we can adjust Vin using the variable resistor and simply calculate the voltage across the diode by subtracting Vr from Vin. We could then calculate the current by calculating the current across the resistors. We got the following data:

Ryan Kaufmann Nov 05, 2017 @05:25 PM PST

CSV

I-VCurve.csv(1.7 KB)

Ryan Kaufmann Nov 05, 2017 @05:51 PM PST

We then used the Python script Curvefitdiode to fit the data to a model and calculate our desired values. After one try we received a plot that was less than desirable. Firstly, our residuals showed a clear pattern and most were above 0. Otherwise the chi-squared we received was not so good either. We received a chi-squared of 4.211, which is above the mark we set for good fits. from this we get the following plots and data:

Ryan Kaufmann Nov 05, 2017 @06:17 PM PST

$$I_0 = 2.407 \pm 0.06429 nanoAmps$$

$$\frac{k_B}{e} = 0.0001564 \pm 0.0000003599 \frac{V}{K}$$

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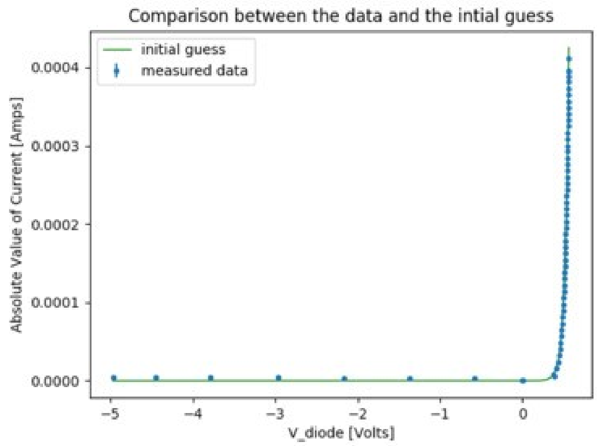
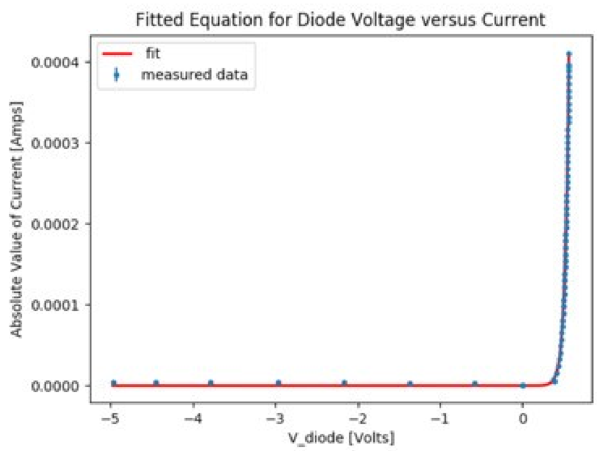


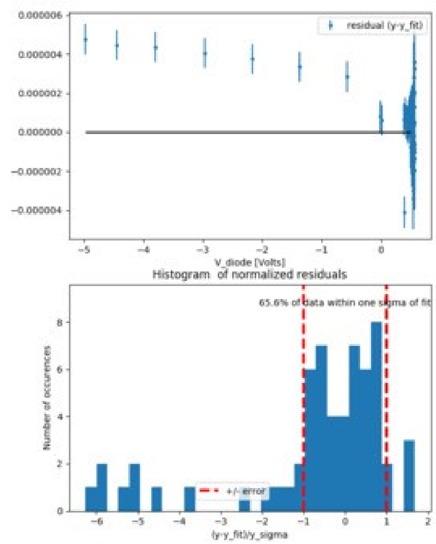
I-VCurveInitial.png(30.3 KB)

Ryan Kaufmann Nov 05, 2017 @06:00 PM PST



I-VCurveFitted.png(29.9 KB)

Ryan Kaufmann Nov 05, 2017 @06:00 PM PST



I-VCurveResids.png(42.5 KB)

Ryan Kaufmann Nov 05, 2017 @06:14 PM PST

We thought we could do better than the last plot however, since the residuals were so high above the 0 line. Thus, we added in an offset to the values. We hoped to get better values. Our residuals were slightly better but they still showed a pattern. However, they no longer were high above zero. Furthermore, our chi-squared was better at 2.224. It still isn't the best, but we don't believe we could get a better fit. Thus, we get the following parameters and graphs:

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$$I_0 = 1.944 \pm 0.06568 nanoAmps$$

$$\frac{k_B}{e} = 0.0001537 \pm 0.0000004320 \frac{V}{K}$$

$$I_{offset} = 2.532 \pm 0.2135 microAmps$$

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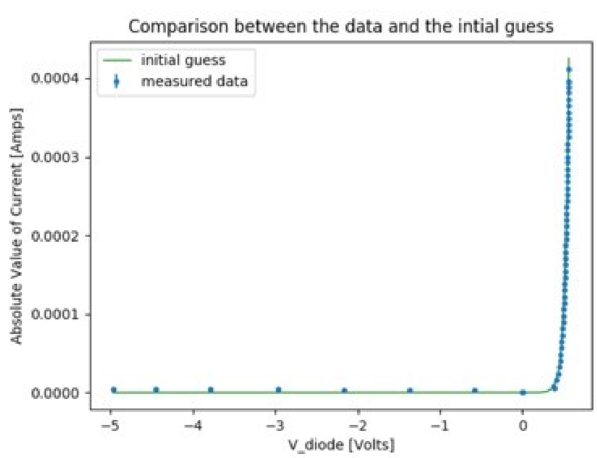
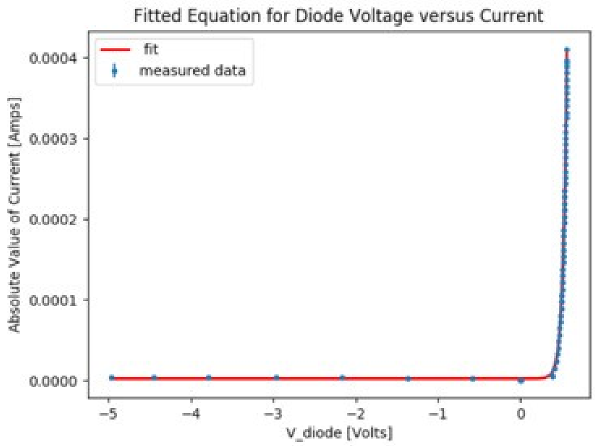


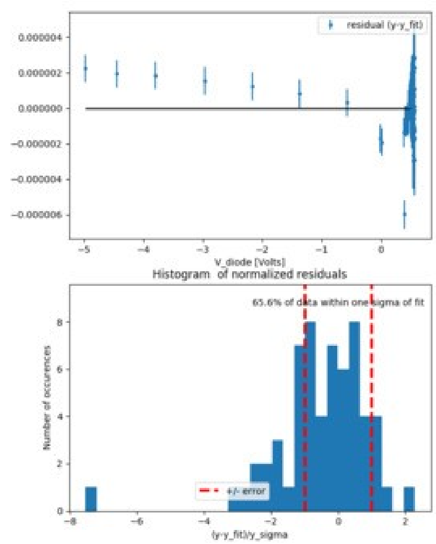
I-VOffsetInitial.png(30.3 KB)

Ryan Kaufmann Nov 05, 2017 @06:18 PM PST



I-VOffsetFitted.png(30 KB)

Ryan Kaufmann Nov 05, 2017 @06:18 PM PST



I-VOffsetResids.png(42.2 KB)

Ryan Kaufmann Nov 06, 2017 @12:01 PM PST

For the most part, our data seems to agree pretty well with the curve we had fitted the theoretical equation we looked at in the prelab. However, when we go below zero, there is a bit more deviation. The data seems to get farther and father away from the expected low values. Furthermore, the data doesn't perfectly fit the bend in the graph we expected. From our fit, we believe that our data fits best for voltages greater than zero. We can only conclude that it fits well with voltages up to about 0.55 Volts.

We can also compare our value of the boltzmann constant to the actual value of the boltzmann constant. The boltzmann constant is about 8.6e-5 electron Volts per Kelvin. However, the boltzmann constant we measured is about 1.5e-4 electron Volts per Kelvin, almost a factor of 2 greater, considerably higher than our uncertainty and thus a fantastically high T-score. There are several things that could affect this measurement. One is that our diode was not at the temperature that we predicted (300K) especially after all the data collection we did. There may be other factors that we haven't considered either that affects the diode.

Ryan Kaufmann Nov 05, 2017 @02:00 PM PST

3.4.2 Diodes as Rectifiers

Ryan Kaufmann Nov 05, 2017 @08:14 PM PST

We then switch gears and see some of the application of a diode. We remove the 5V power supply from the circuit and plug in an AC voltage from the function generator. We set the generator to out a 60Hz sinusoidal voltage with an amplitude of 1Volt. Then we set up our circuit, switching out our 10kOhm resistor for a 1kOhm resistor and removing the variable resistor. Thus our circuit is as follows:

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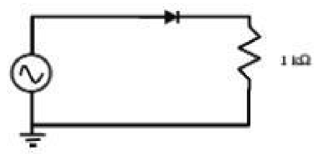
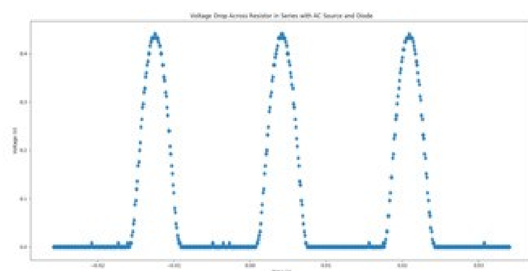


RectifierCircuitDiagram.jpg(10 KB)

Ryan Kaufmann Nov 05, 2017 @08:37 PM PST

We then set up our oscilloscope to measure the behavior of the voltage drop across the resistor. We found that the voltage drop across the resistor only showed if the AC voltage was outputing a positive voltage. Otherwise the voltage drop was zero. Thus, we got these repeating peaks across the oscilloscope as so:

Ryan Kaufmann Nov 05, 2017 @08:37 PM PST

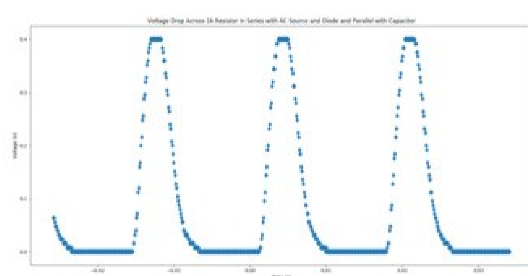


ACDiodeR.png(48.3 KB)

Ryan Kaufmann Nov 05, 2017 @09:10 PM PST

We then wondered what would happen if a capacitor was placed in parallel with the resistor. We believed that the capacitor would partially charge and then discharge when the AC circuit was outputing a negative voltage. Thus there would be some current through the resistor when the AC circuit outputs a negative voltage. We put a 1 microFarad capacitor in parallel with the resistor and received the following plot:

Ryan Kaufmann Nov 05, 2017 @09:12 PM PST

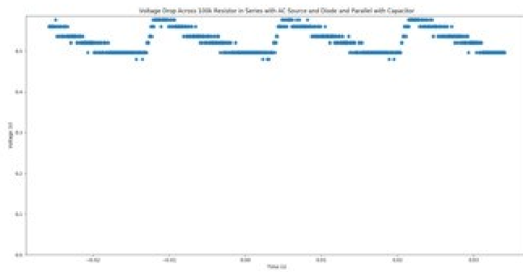


ACDiodeRC1k.png(51.2 KB)

Ryan Kaufmann Nov 05, 2017 @09:22 PM PST

Notice the exponential 'flick' at the end of each curve now, where there was none before. So the next thing we tried to observe was a system where we could simulate a DC circuit. In order to do this, we need a DC circuit with a very large time constant compared to the period of the AC input voltage. This would cause the voltage across the resistor to be large for a longer time. So we tried a 100 kiloOhm resistor, and we received the following graph:

Ryan Kaufmann Nov 05, 2017 @09:30 PM PST

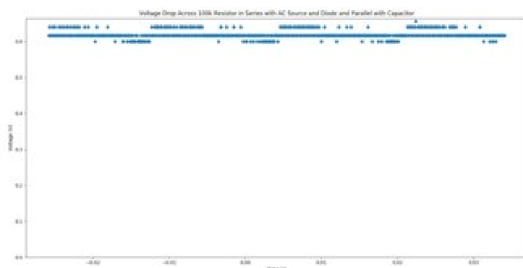


ACDiodeRC100k.png(38.4 KB)

Ryan Kaufmann Nov 05, 2017 @09:49 PM PST

With this resistor we got a drop of about 20%. However, we thought that we could do better. We aimed for a drop of 5%. In order to achieve this, we replaced the 100 kiloOhm with a MegaOhm resistor. Then we get the following plot:

Ryan Kaufmann Nov 05, 2017 @09:51 PM PST



ACDiodeRC1M.png(37.3 KB)

Ryan Kaufmann Nov 05, 2017 @10:14 PM PST

From the graph, we can see that the voltage drop across the resistor never goes down more that 5% of its max value. We can believe that if we made a time constant high enough, we can recreate a DC circuit. Thus we've effectively made an AC-DC converter. This is especially usefully in house, where the majority of appliances need a DC input but the voltage delivered to the house is AC. In fact, laptop computers have it built in to their chargers.

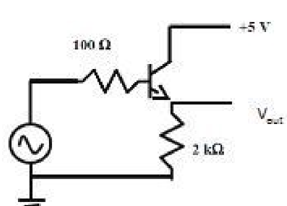
Ryan Kaufmann Nov 05, 2017 @02:01 PM PST

3.5.1 Current Amplification in a BJT

Ryan Kaufmann Nov 05, 2017 @11:31 PM PST

Now that we have gotten a good grasp on how diodes work both in theory and in practice, let us move on to a circuit component that is more complicated. In the next two sections we will be observing the behavior of the bipolar junction transistor. The first of these behaviors we want to observe is how to amplify current using a BJT. We thus set up the following circuit to test for the current amplification:

Ryan Kaufmann Nov 05, 2017 @10:41 PM PST



BJTCurrentAmplification.jpg(11.3 KB)

Ryan Kaufmann Nov 05, 2017 @11:31 PM PST

We set up our generator to first have an output of 1kHz sinusoidal with a DC offset of 2.7V. Note the large DC offset. This is so that we always get a good sinusoidal output and the transistor is always forward biased. We then set up the HP Digital multi-meter to measure the voltages across both resistors, alternating in between the measurements. As we noted above, there are point where the voltage is too high or too low for the transistor to be forward biased and it doesn't work anymore. For us, this seems to be around 0.6Volts and 7V.

We then began to take data to see if we can calculate the gain of the transistor. We begin by varying the voltage amplitude of the AC circuit, starting with 2V and ending with 3.3V, in 0.1V intervals. From the values the HP DMM gave us over each of the resistors, we got the following data:

Ryan Kaufmann Nov 05, 2017 @11:32 PM PST

IB-IECurve.csv(450 Bytes)

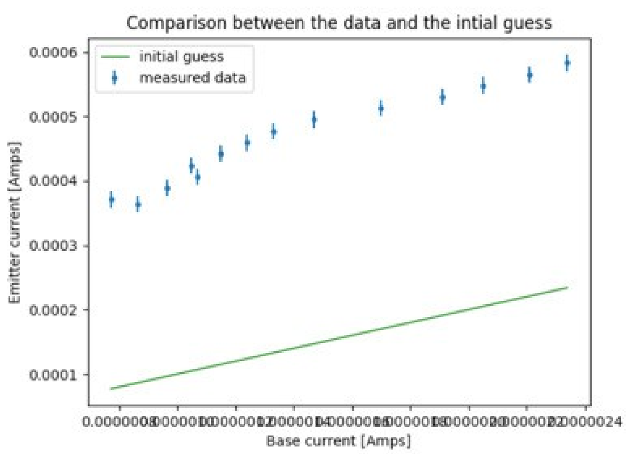
Ryan Kaufmann Nov 05, 2017 @11:47 PM PST

This data provided a fair fit for the model. However, there are some bad parts about our fit. Firstly, our residuals show a very clear pattern that suggests that this fit is not exactly linear. However, we expected this since the linearity of the transistor is very limited and restricted to small voltages. Furthermore, our chi-squared wasn't the most favorable either, having a value of 1.466, but it wasn't the worst. We got the following numbers and graphs:

Ryan Kaufmann Nov 05, 2017 @11:48 PM PST

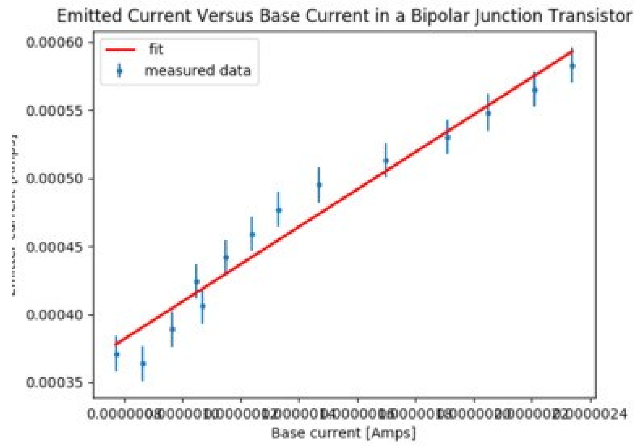
$$Gain_I = 137.2 \pm 6.936$$

Ryan Kaufmann Nov 05, 2017 @11:48 PM PST



BJTCurrentInitial.png(32.2 KB)

Ryan Kaufmann Nov 05, 2017 @11:48 PM PST



BJTCurrentFitted.png(36.3 KB)

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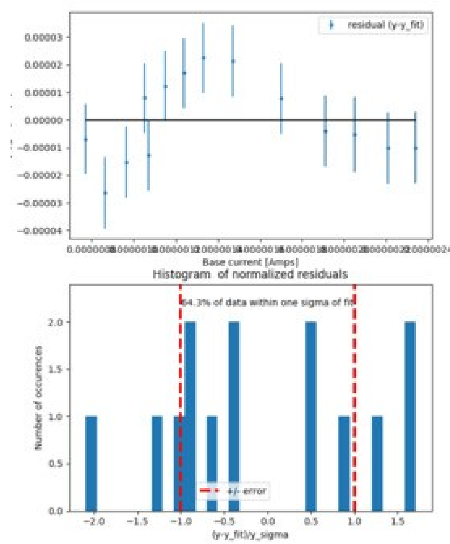


BJTCurrentResids.png(46.1 KB)

Ryan Kaufmann Nov 05, 2017 @11:51 PM PST

This value is fairly close to the value we assumed the gain to be, approximately 100. However, when taking the uncertainty into account, it may be much further. There maybe something else that we aren't taking into account that may be affecting the transistor. For example, once again, the temperature may affect the performance of the transistor. Whatever the reason, it can be checked with furthering testing.

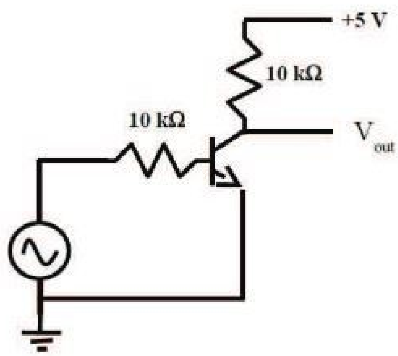
Ryan Kaufmann Nov 05, 2017 @02:01 PM PST

3.5.2 Voltage Amplification in a BJT

Ryan Kaufmann Nov 06, 2017 @08:31 AM PST

For the last part of the lab, we want to use the BJT to create and observe voltage amplification. To observe this, we must slightly adjust our circuit. Thus we create the following circuit:

Ryan Kaufmann Nov 06, 2017 @09:04 AM PST



BJTVoltageAmplification.jpg(13.9 KB)

Ryan Kaufmann Nov 06, 2017 @09:35 AM PST

Once again we set up our function generator to output at a frequency of 1kHz, with a DC offset of 3V. We also changed our voltage to output at a changeable RMS voltage instead of peak-to-peak voltage. This is so that we can compare the function generator's reading with that of our measured Vout, since the DMM read the RMS voltage.

Once again we vary the amplitude of the function generator between 0.1V and 1.6V RMS. In this section, we only have to worry about hitting above the linearity of the transistor. We thus received the following data from the oscilloscope and DMM:

Ryan Kaufmann Nov 06, 2017 @09:36 AM PST

VC-VBCurve.csv(457 Bytes)

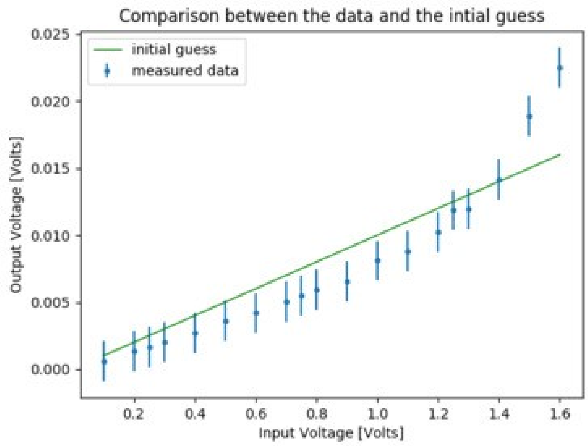
Ryan Kaufmann Nov 06, 2017 @10:37 AM PST

At first, the fit doesn't seem the best for the data. There are segments of the data that don't seem to fit well. We seem to have reached the point where the voltage fail to follow the linearity of the transistor. Our residuals show a pattern in it as well, suggesting that the fit isn't exactly linear. Our chi-squared was 1.800. We thus got the following graphs and values:

Ryan Kaufmann Nov 06, 2017 @10:39 AM PST

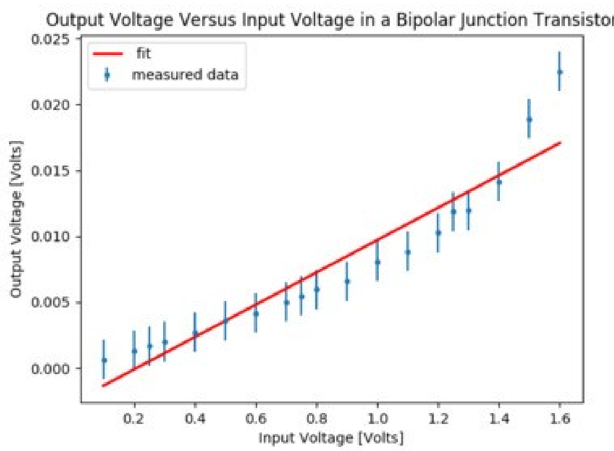
$$G_V = 0.01227 \pm 0.0007571$$

Ryan Kaufmann Nov 06, 2017 @10:38 AM PST



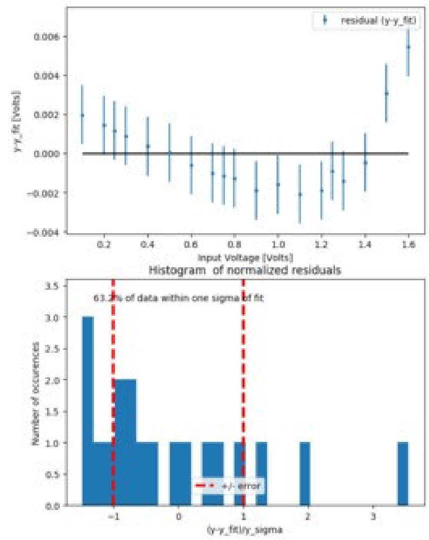
BJTVoltageInitialExp.png(33.2 KB)

Ryan Kaufmann Nov 06, 2017 @10:38 AM PST



BJTVoltageFittedExp.png(35.2 KB)

Ryan Kaufmann Nov 06, 2017 @10:38 AM PST



BJTVoltageResidsExp.png(44.1 KB)

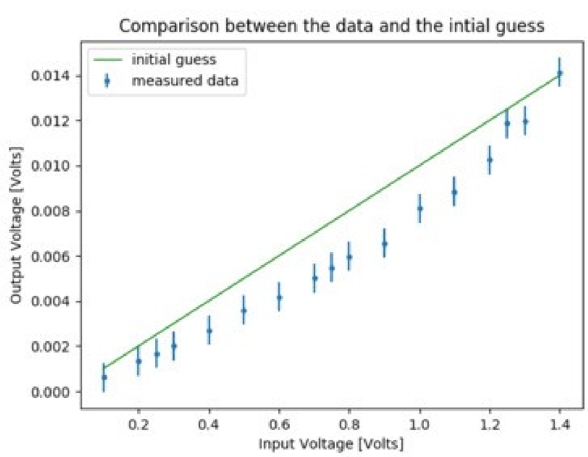
Ryan Kaufmann Nov 06, 2017 @10:55 AM PST

In order to improve this graph, we decided to exclude the data where the exponential behavior appeared. We judged this to be about Vin>=1.5V. Thus we replotted the data and got a slightly better fit. This time our chi-squared is 1.306, which is slightly better. However, there is still a slight curve pattern in the residuals still. Our second round gives us the following graphs and values:

Ryan Kaufmann Nov 06, 2017 @11:23 AM PST

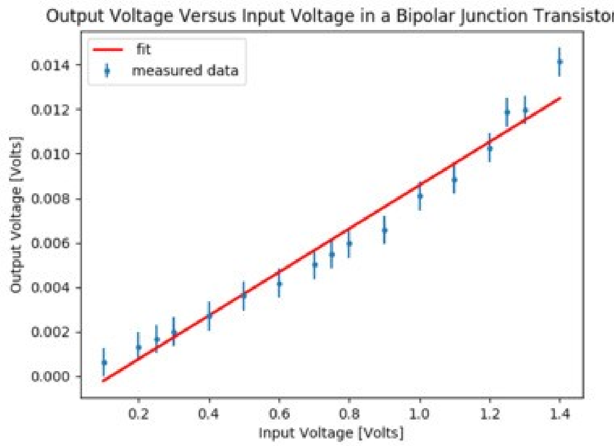
$$G = 0.009776 \pm 0.0003902$$

Ryan Kaufmann Nov 06, 2017 @10:59 AM PST



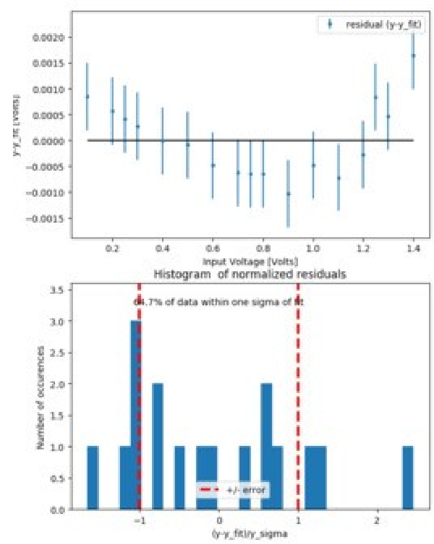
BJTVoltageInitialLin.png(36.2 KB)

Ryan Kaufmann Nov 06, 2017 @10:59 AM PST



BJTVoltageFittedLin.png(37.4 KB)

Ryan Kaufmann Nov 06, 2017 @10:59 AM PST



BJTVoltageResidsLin.png(46.1 KB)

Ryan Kaufmann Nov 06, 2017 @11:18 AM PST

Which is slightly better. In this equation, our gain seems much lower than we originally anticipated. In fact, our gain is the inverse of the 100 that we predicted. This maybe because the theory was wrong for the gain or because of some other influence.

Furthermore, we estimated a gain of 1000 (or 0.001, if our prediction about the theory is correct) if we replaced the the collector resistor with 100kOhm instead of the 10kOhm. We believed that since the transistor has a constant gain in current, the voltage gain would be defined by the ratio of the resistors in the system. Thus since our resistors has a ratio of 10 times, our gain is ten times more.

Ryan Kaufmann Nov 05, 2017 @02:02 PM PST

3.6 Conclusion

Ryan Kaufmann Nov 06, 2017 @12:00 PM PST

Our values are as follows:

Variable	Value	Uncertainty
k_B/e	0.0001537 V/K	0.0000004320 V/K
I_0	1.944 nA	0.06568 nA
G_I	137.2	6.936
G_V	0.009776	0.0003902

In this lab, we explored the operations of diodes and transistors. We saw how the diodes only move current in one way, up to a certain point, and how well it fits with the data. Then we applied this to use diodes as a rectifier, or a AC-DC converter. Finally we looked at the voltage and current amplification behavior of the bipolar junction transistor.