Physics 219_2018 - Nick Pun/Exp. 3 (Diodes and Transistors)/Exp 3 on Diodes and transistors

SIGNED by Nick Pun Nov 01, 2018 @02:01 PM PDT

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4.1 Measurement of the I-V characteristics of a diode

Resistor used: 9.80 +/- 0.01 kOhms

Variable Resistor: 10.070 +/- 0.001 kOhms

Measuring with middle position: cw = resistance goes down (to about 1.0034 kOhms)

ccw = resistance goes up (to about 11.0709 kOhms)

It should range from about 0-10 kOhms but there must be some internal resistance or some design flaw that is adding that extra 1 kOhm. We will not use resistances of more than 10 kOhms.

Varying voltage: cw = voltage goes up (to about 4.205 +/- 0.005 V)

ccw = voltage goes down (to 0.123 +/- 0.001 mV) which is pretty much 0 V

The current across the diode is going to be the same as the current across the resistor. Id = Ir = Vr /Rr

The voltage drop across the diode is just going to be the difference from the input voltage and voltage drop across the resistor. Vd = Vin - Vr

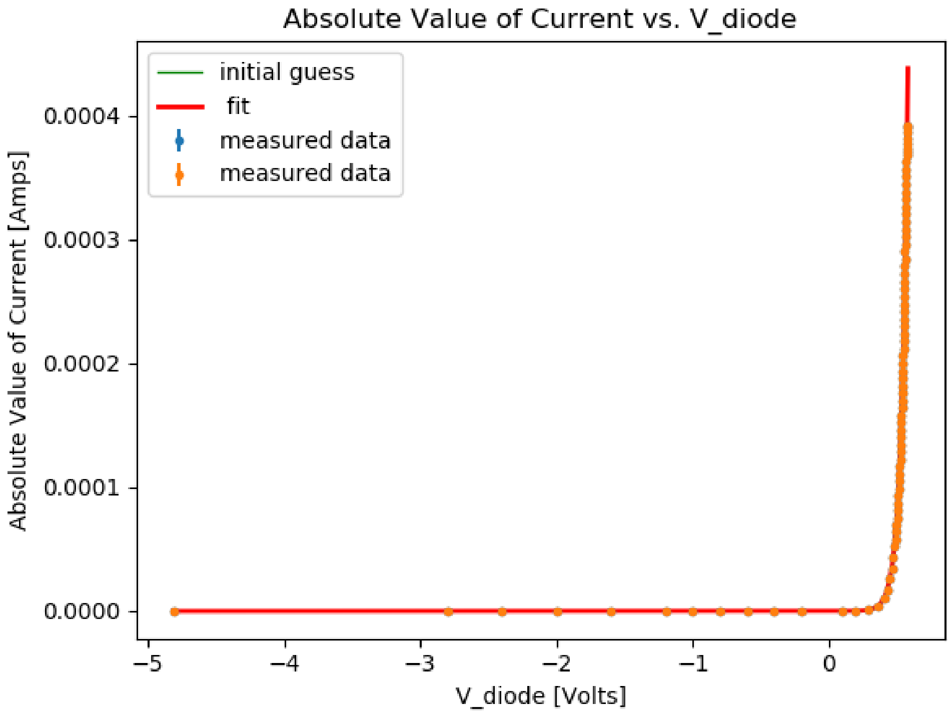
By testing the diode, we determined that the long end to short end of the diode = forward biased. The test was simple, for the long to short direction of the diode, we set Vin to about 4.2 and observed Vr to be about 3.6, which is what is expected when the diode is forward biased.

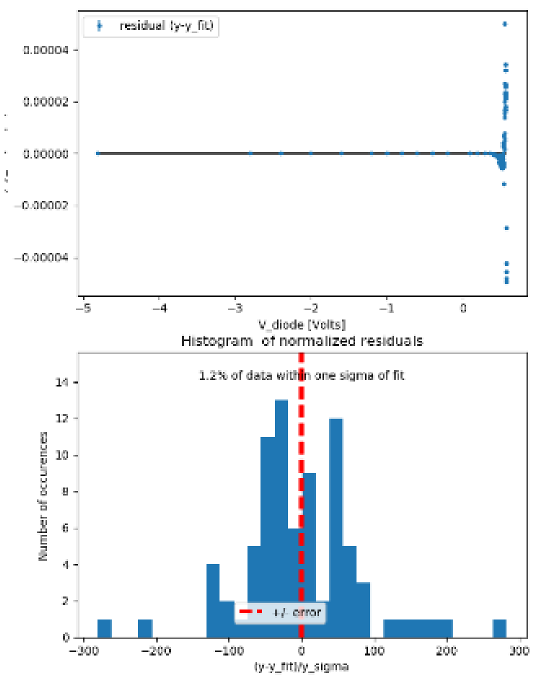
Accuracy on Vr on multi meter = 0.04% (according to manufacturer).

Plotting absolute value of current versus the voltage across the diode:

We won't need to take as many data points for the negative voltages because in this region, the change in absolute value of the current is very small for large changes of voltages. In fact, the change in absolute value of the current is almost negligible when compared to that in the region greater than 4 V.

guesses = (2.015e-9, 1.577e-4)





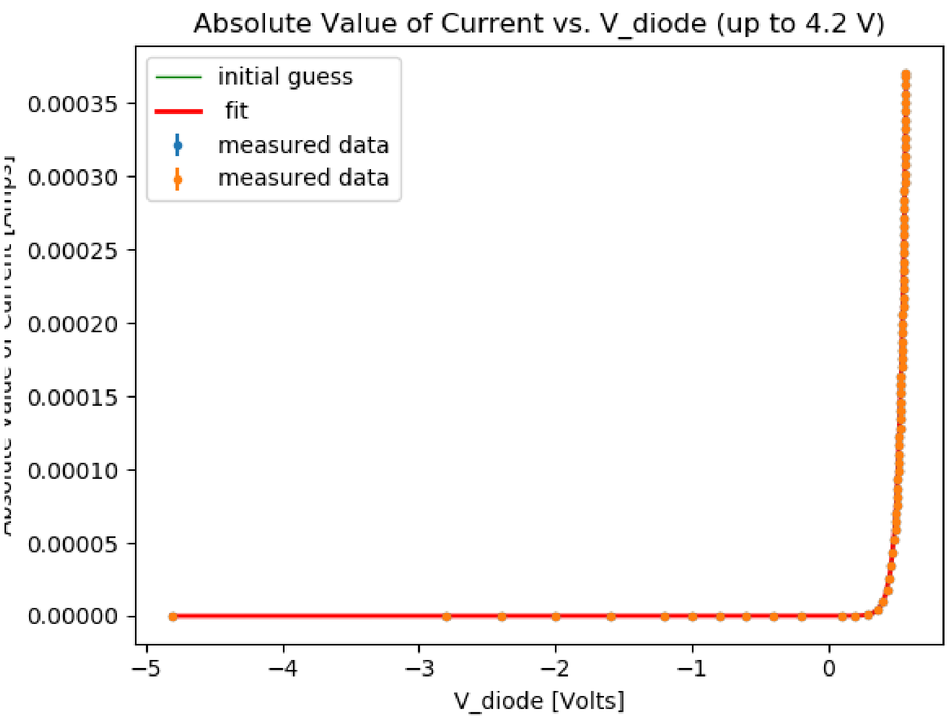
Goodness of fit - chi square measure:
Chi2 = 554573.7218424066, Chi2/dof = 7019.920529650716

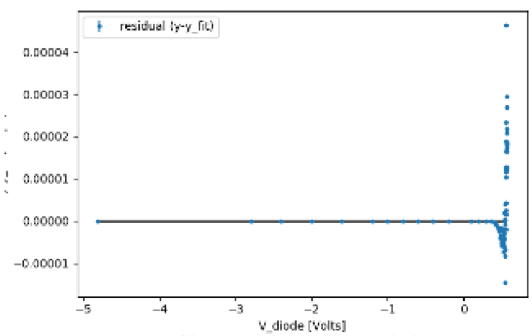
Fit parameters:
I0 = 2.015e-09 +/- 6.311e-13
k_B/e = 1.577e-04 +/- 4.768e-09

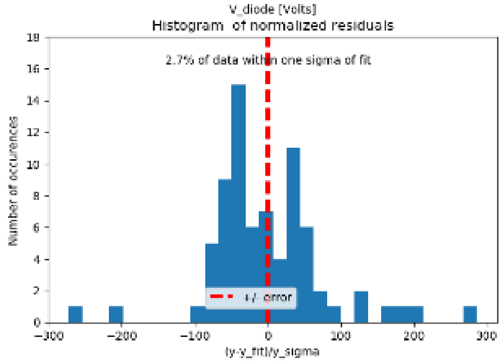
Residual information:
1.2% of data points agree with fit

This is a poor fit, because Chi^2/dof is extremely high. However, this is likely because the level of uncertainty of the DMM (0.04%) is very low. Furthermore, the data we took was not entirely consistent. We took data points from 0 V to 4.2 V in one day using one set of equipment but took the negative data points and data points from 4.2 V and higher on a second day using a different set of equipment (but keeping the same diode and resistors). It is clear that the data points from the second day are offset. The following is a refit of the data without the data points corresponding to 4.2 V and up.

guesses = (2.002e-9, 1.574e-4)







Goodness of fit - chi square measure:
Chi2 = 479679.46751428087, Chi2/dof = 6570.951609784669

Fit parameters:
I0 = 2.002e-09 +/- 6.322e-13
k_B/e = 1.574e-04 +/- 4.875e-09

Residual information:
2.7% of data points agree with fit

Without the positive data points from the second day, the fit clearly improved as the Chi^2/dof decreased by around 500. However, it is still extremely high and thus still a poor fit. This makes me more confident that the cause of the poor fitting is likely due to the low uncertainty in the DMM. We also used the less accurate DMM to measure the voltage across the diode, which could have effected measurements.

The fit appears to work well with data from the approximate range of voltage -5 V to 3.5 V. After this, the data drops below the fit line before climbing back up and above the fit line. This looks to me like the data should be fitted to an equation with a higher exponential power. My experimental value for the Boltzmann constant is about 2 times larger than the literature value. As such, there is disagreement between the values. My conclusion is that there are systematic errors that I am not taking into account or eliminating from my experiment. These could include the accuracy of the DMMs or state of the diode.

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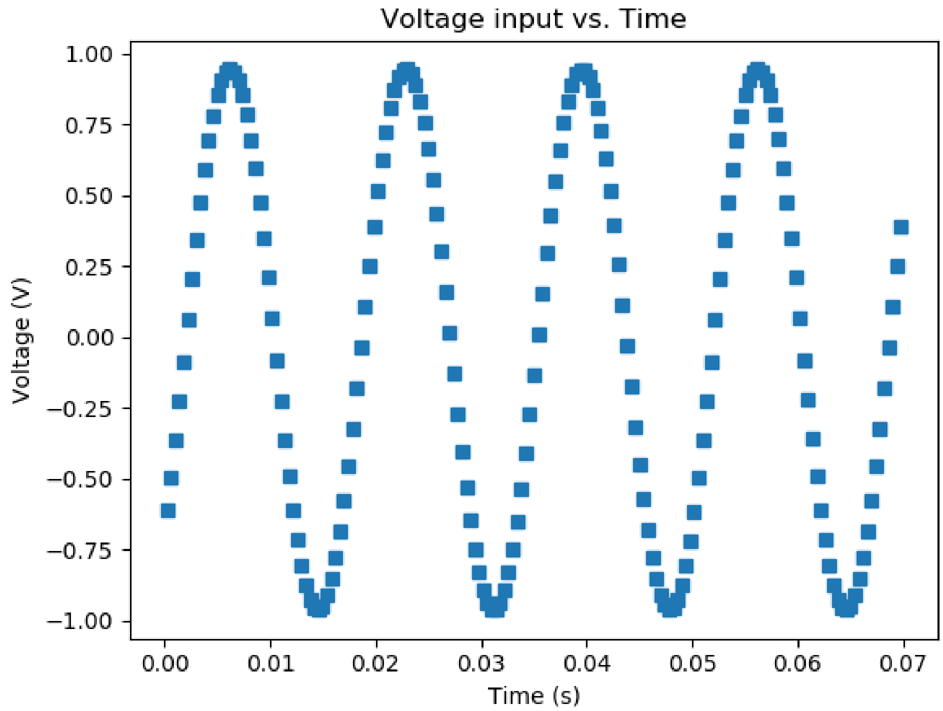
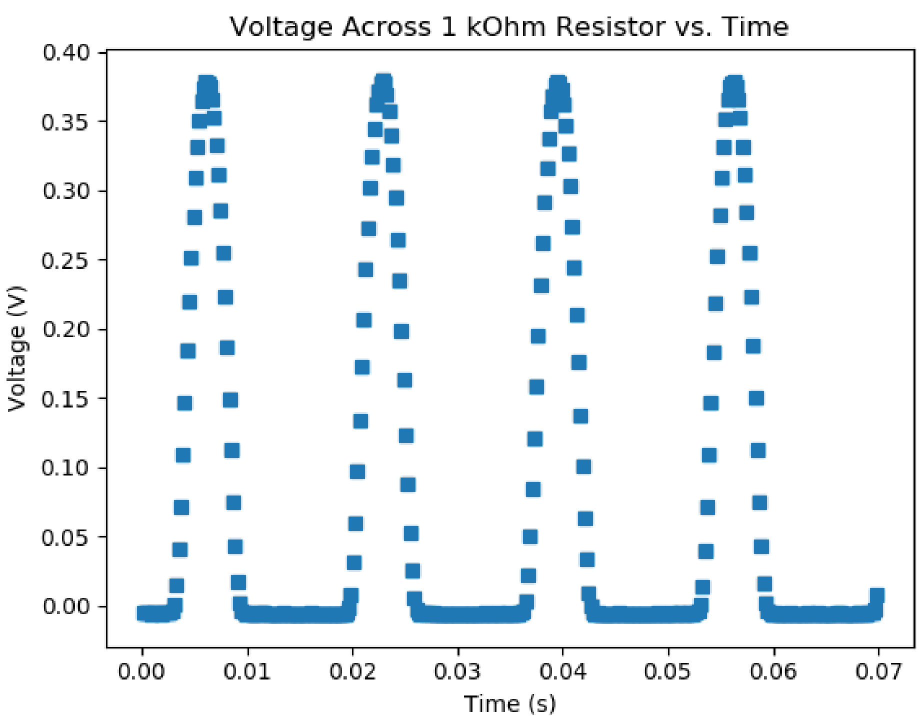
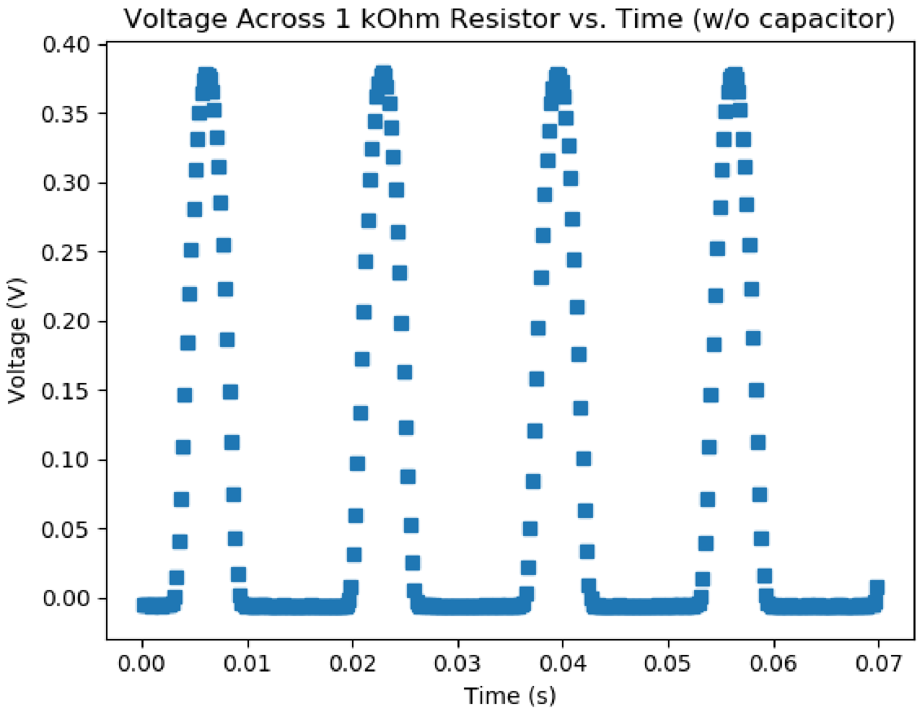
4.2 Diode as a Rectifier

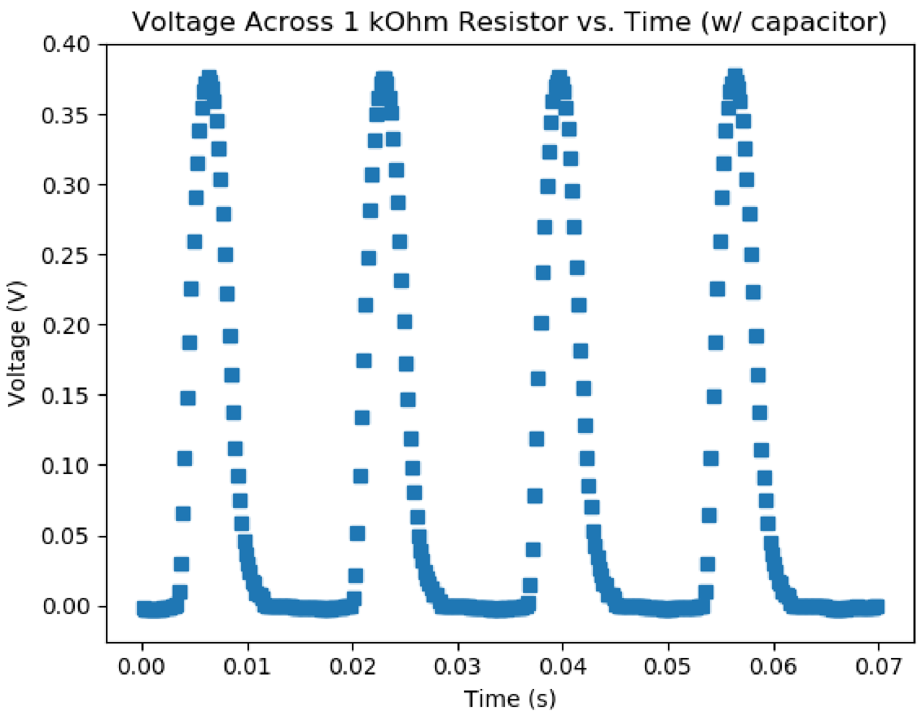
Here are plots of the initial input and output signals respectively. The input is a sin wave with amplitude of 1 V and frequency of 60 Hz. The output has the same frequency, but the amplitude has decreased and the bottom part of the signal is cut off such that these points flatten out at around 0 V. This makes sense by looking at the I-V characteristic of the diode: negative voltages across the diode creates results in almost zero current. Since the diode is in series with the resistor, the current out of the diode will be the same current going through the resistor. When the current out of the diode is 0, by V=IR, the voltage drop across the resistor is 0. For higher voltages across the diode, we see that there is a current allowed to pass through, and hence why we do see a positive non-zero voltage drop across the resistor corresponding to the positive voltages as a function of the voltage input.



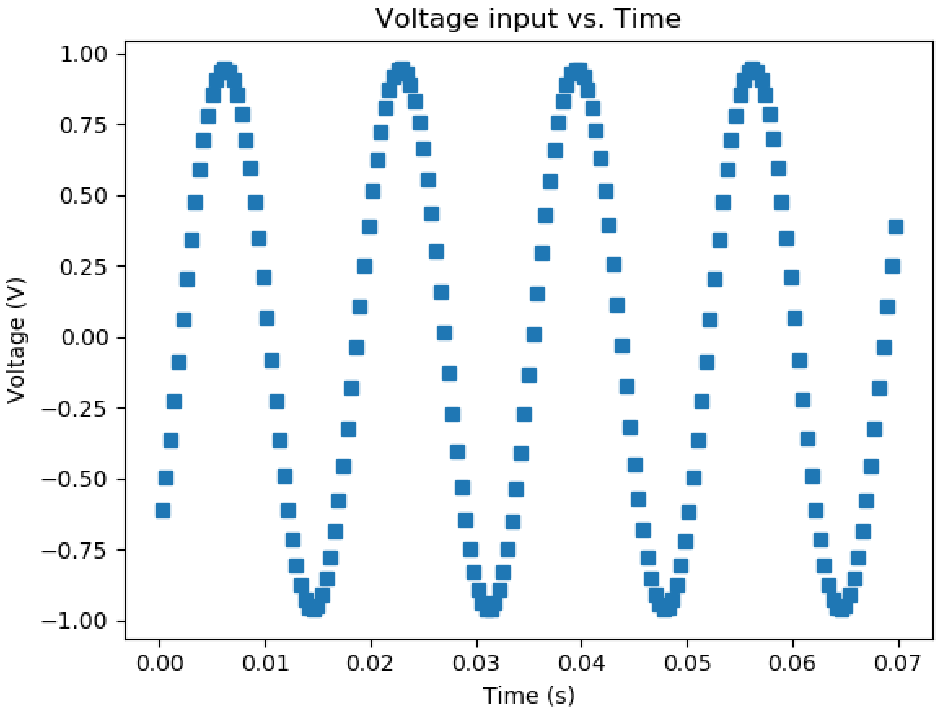


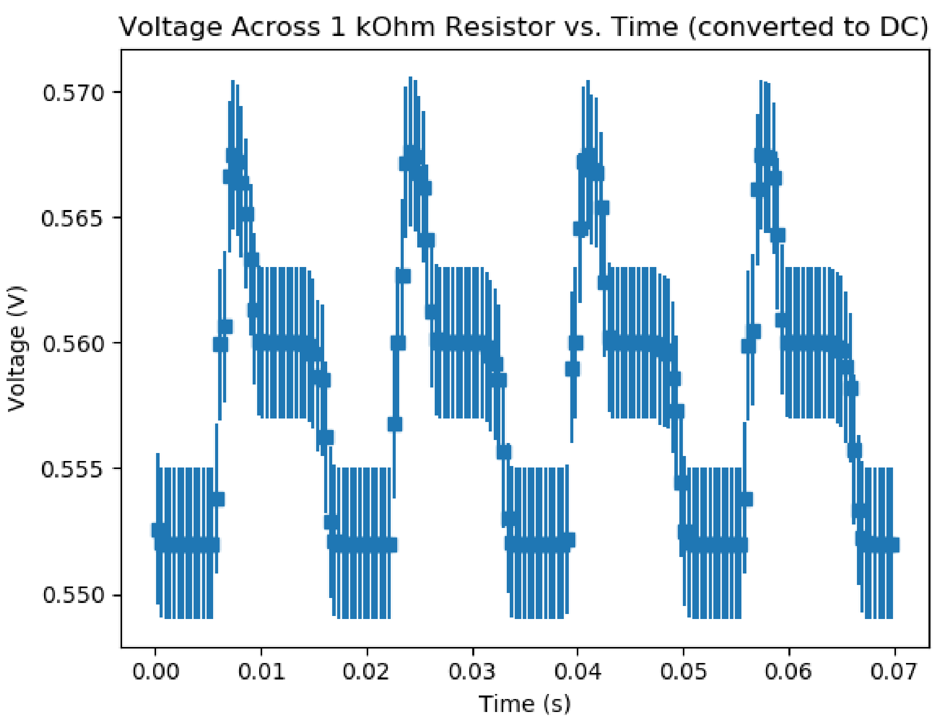
We then added a capacitor in parallel to the 1 kOhm resistor. Here are the plots with and without the capacitor respectively. It is clear that the cutoff and increasing part of each peak is unaffected. However, the decreasing part of each peak now decays slower and looks to be more of a function proportional to e^{-x}.





From the results above, we made an educated guess that the larger the resistor (or capacitor), the slower it will take for the decreasing part of each peak to reach the cutoff at the bottom. Therefore, a large enough resistor (or capacitor) will cause the decreasing part of each peak to take more time to drop than there exists between peaks, and hence create a DC signal. Algebraically, we need a resistor (or capacitor) large enough to satisfy tau = RC > 1/freq. For a 1 kOhm resistor and an input signal at 60 Hz, the C > 1/60000 = 17 μF. We substituted the capacitor for a 1 uF capacitor and the resulting output signal became similar to a DC signal (with minor peaks in the voltage to the degree of 10^{-2}). The following plots are of the voltage input and the resulting voltage with a 1 uF capacitor in parallel with the 1 kOhm resistor respectively. Here, we should have used a larger resistor instead of a larger capacitor, as we used the largest capacitor available in the lab, but it did not seem to be enough to completely flatten out the output voltage. This possibly could also be a result of some flaws in the equipment.





Some possible applications for rectifiers are in power supplies. Since household outlets are AC, experiments that require a DC signal cannot be done without a rectifier to convert the outlet's AC to DC. Similarly, personal devices such as phones and laptops needs to store power, and thus they need a DC input. Therefore, rectifiers are used in their chargers to convert the household outlet's AC to DC for the device to store the power.

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5.2 Current Amplification using a BJT

Resistors used:

R_{100} = 98.650 +/- 0.001 Ohm

R_{1k1} = 1.00463 +/- 0.00001 kOhm

R_{1k2} = 0.98540 +/- 0.00001 kOhm

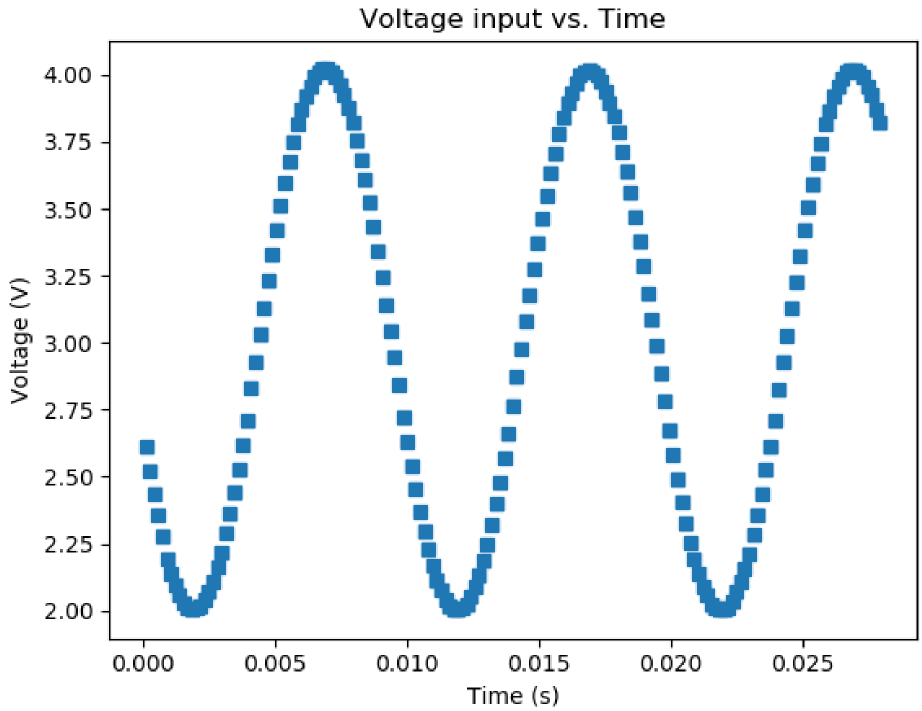
At V_offset = 0 V, we saw almost all of the bottom of the sinusoidal output signal cut off (cut off at approximately 520 mV from the top of the peaks).

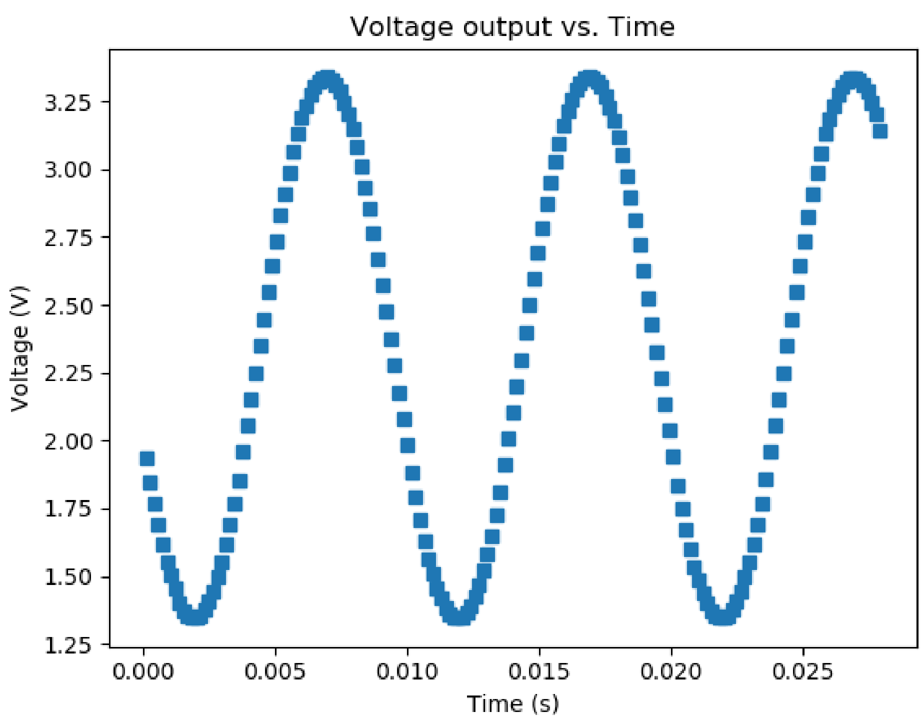
= 1.73, this is the lowest voltage where we can see the full (uncut) sinusoidal output wave. Lower voltages than this start to cut the wave off the bottom.

= 4.33, this is the highest voltage where we can see the full (uncut) sinusoidal output wave. Higher voltages than this start to cut the wave off the top.

Since the amplitude of the input voltage is 2 V, the range of voltages where the transistor is working properly should be 0.73 V - 5.33 V.

The following are plots of the input and output signals respectively. The input voltage amplitude is set at an offset such that there is no cutting of the output signal (4.33 V). The main difference between the two signals is that the output amplitude has been decreased. In this case, it has been decreased from 4.33 V to approximately 3.4 V.

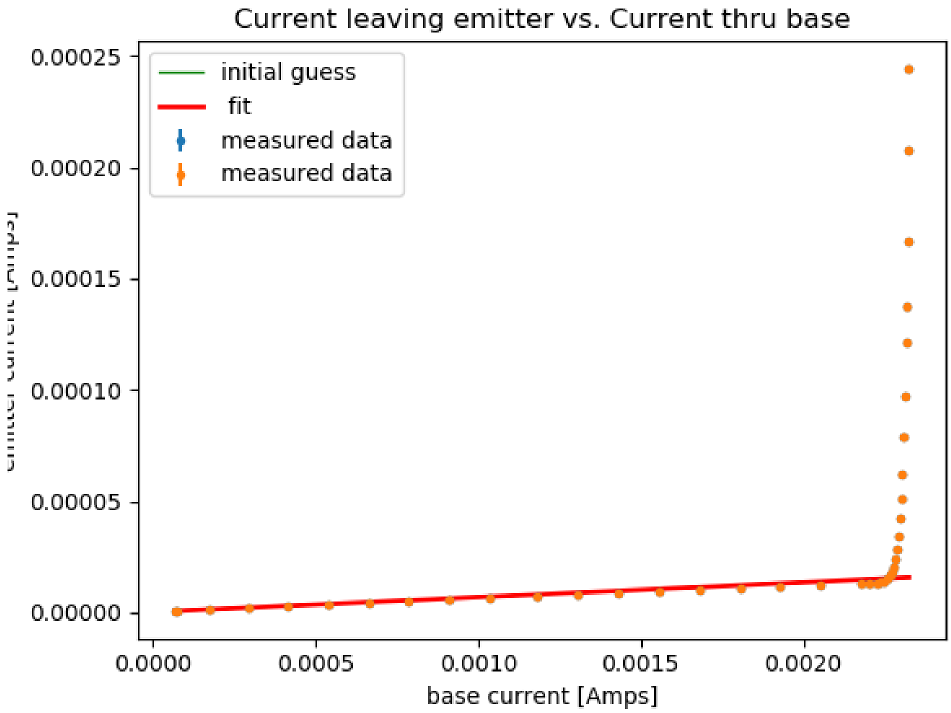


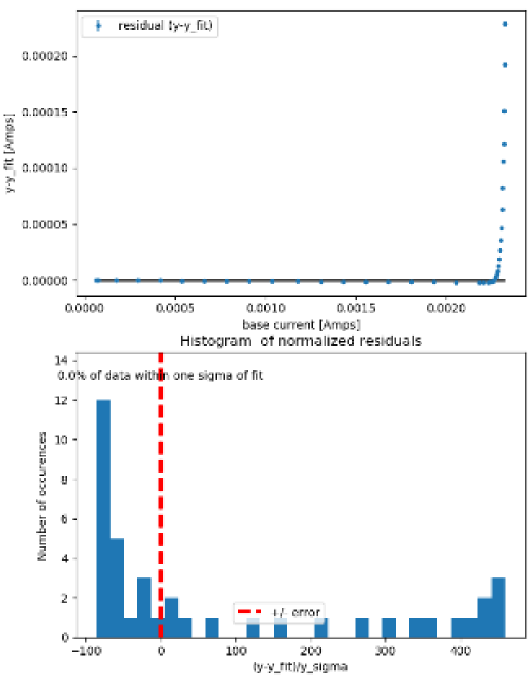


<u>Measuring the current gain:</u>

We set the input voltage amplitude to the lowest the function generator could set it at (1.4 mV, which is almost 0V). Now that the amplitude is nearly 0 V, the new range of V_offset where the transistor is working properly is 0.73 V - 5.33 V since the amplitude of the input voltage in the previous section was 2 V.

guesses = (6.682e-3, 1.424e-7)





Goodness of fit - chi square measure:
Chi2 = 1979160.4795934088, Chi2/dof = 52083.17051561602

Fit parameters:
gain = 6.682e-03 +/- 2.775e-06
y intercept = 1.424e-07 +/- 9.143e-10

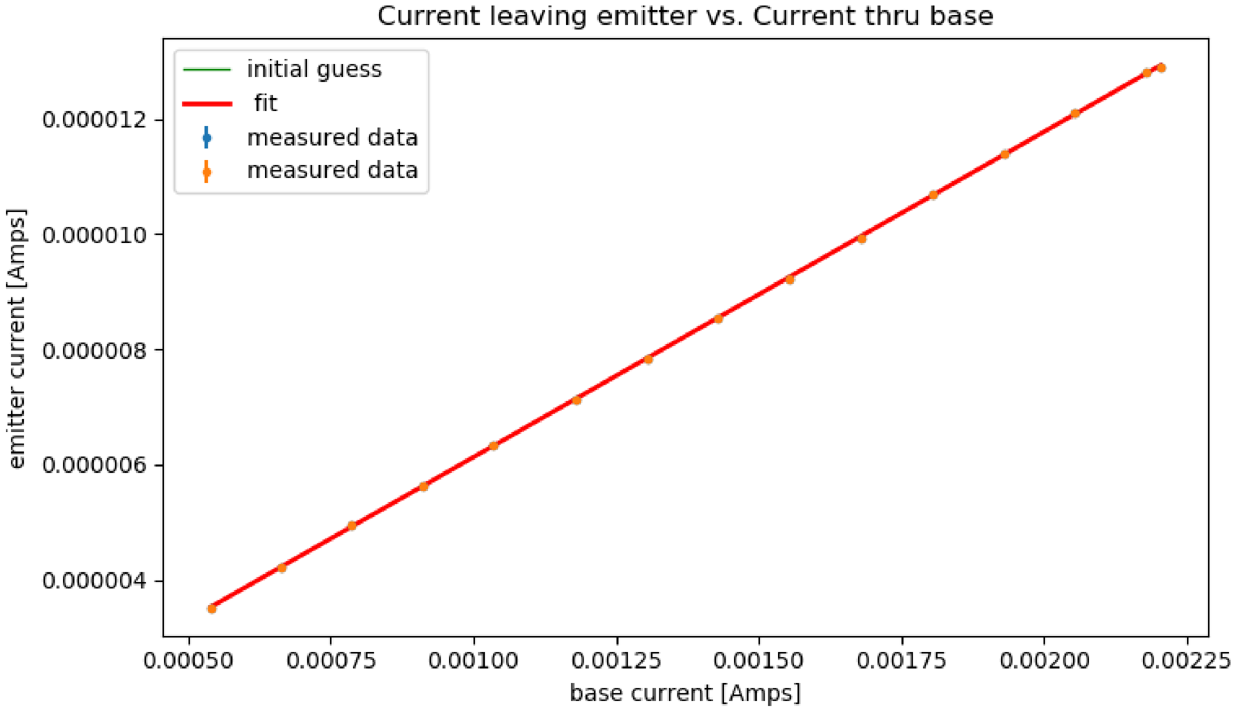
Residual information:
0.0% of data points agree with fit

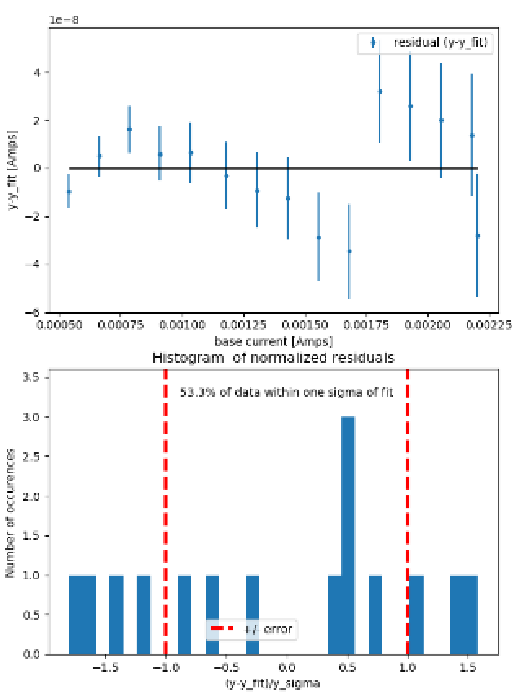
The fit function appears to fit well with the data for the range of base currents up until about 0.0023 A. Before this point, the data appears to follow a linear function. After this point, the data no longer appears to be a linear function, and hence the data fitting cannot compute viable fit parameters.

The data points skew upwards, and thus causes the fitted function to have a larger slope than the linear portion of the data. This causes all of the data points to fall off the fitted line and hence why 0% of the data fit within 1 sigma of the fit. This is why Chi^2/dof is extremely high.

By fitting using only the linear portion of the data, we get a much better linear fit.

guesses = (5.643e-3, 4.848e-7)





Goodness of fit - chi square measure:
Chi2 = 17.51156343754127, Chi2/dof = 1.3470433413493283

Fit parameters:
gain = 5.643e-03 +/- 7.267e-06

y intercept = 4.848e-07 +/- 7.976e-09

Residual information:
53.3% of data points agree with fit

This is a much better fit because Chi^2/dof is low (around 1).

5.3 Voltage Amplification using a BJT

Resistors used:

R_{10k1} = 9.832 +/- 0.001 kOhm

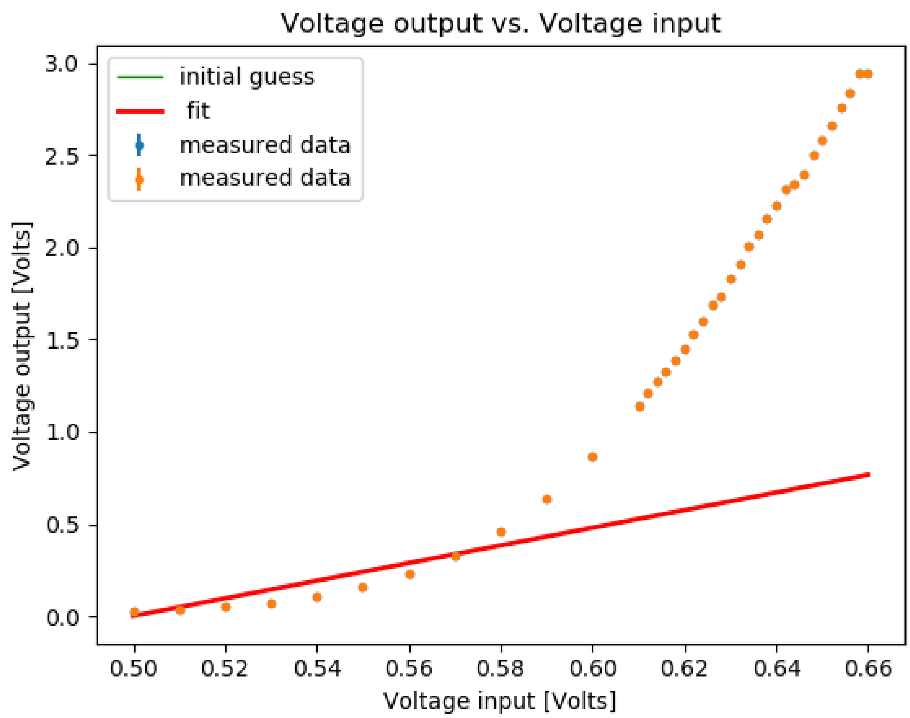
R_{10k1} = 9.853 +/- 0.001 kOhm

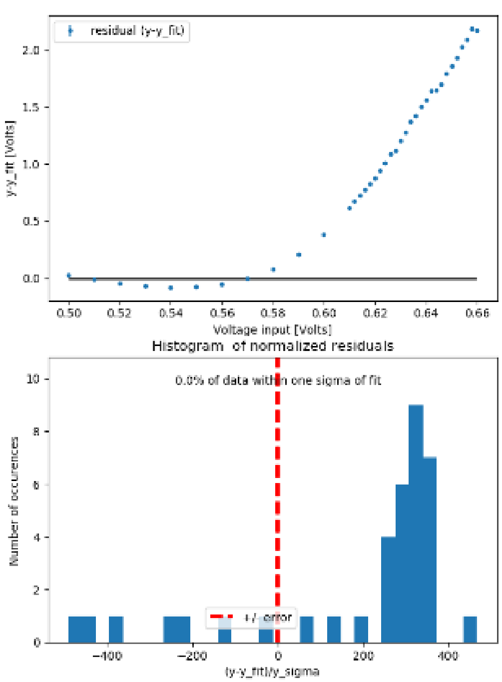
The V_offset range where the output signal is undistorted is approximately 0.5 V - 0.660 V (V greater than 0.660 V starts to get cut off at the bottom)

The V_offset range where the output signal is larger than the input signal is approximately 0.59 V - 0.660 V

Both of these are within the given range of 0.5 V - 1.5V

guesses = (4.78, -2.389)





Goodness of fit - chi square measure:
Chi2 = 3883642.760401509, Chi2/dof = 110961.2217257574

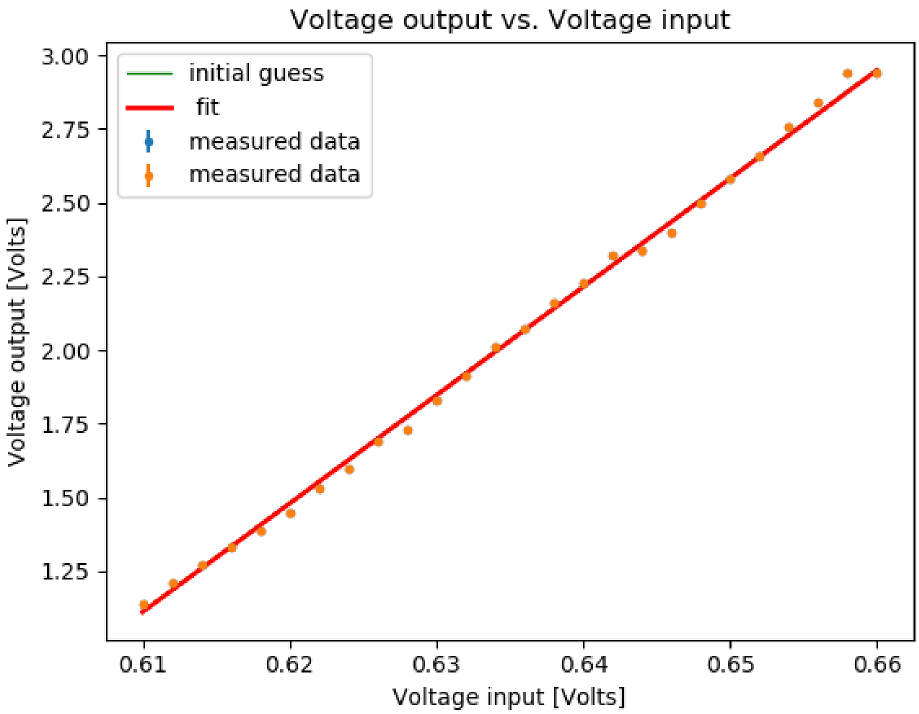
Fit parameters:
gain = 4.780e+00 +/- 2.457e-03
y intercept = -2.389e+00 +/- 1.251e-03

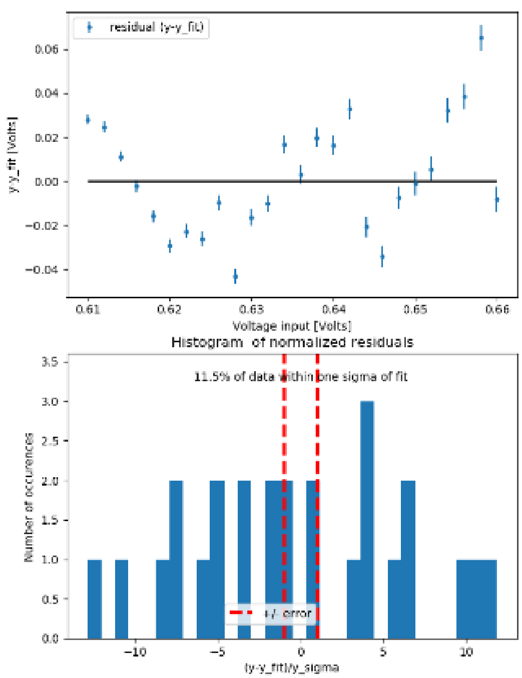
Residual information:
0.0% of data points agree with fit

This appears to be a bad fit as the data before V_input = 0.6 V doesn't seem to follow a linear function, hence why Chi^2/dof is extremely high.

The data after V_input = 0.6 V appears as if it may follow a linear function, which would make sense as this is the region where there actually is a voltage gain. The following is a refit using only those data points.

guesses = (3.673e1, -2.129e1)





Goodness of fit - chi square measure:
Chi2 = 1099.4881200666186, Chi2/dof = 45.81200500277578

Fit parameters:
gain = 3.673e+01 +/- 5.062e-02
y intercept = -2.129e+01 +/- 3.173e-02

Residual information:
11.5% of data points agree with fit

Clearly, this fit is much better than before as Chi^2/dof is nearly 111000 less than the earlier fit. However, it is still higher than what we should be looking for (around 1). I believe this is because the uncertainty of the DMM is small and thus the y-sigma is small, which causes only 11.5% of the data to fit within the fit. There could also be other flaws in the equipment.

From the two fits above, it is clear that the limitations on the linear response of the amplifier (the range over which the output is proportional to the input) is approximately V_input = 0.6 V - 0.66 V.

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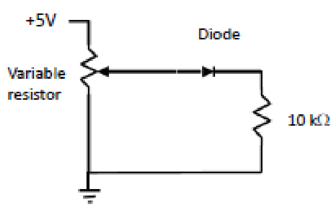
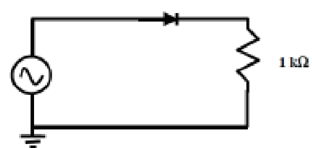
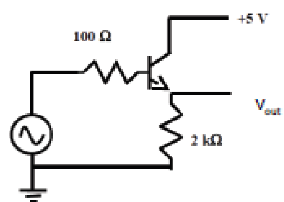
6. Conclusion

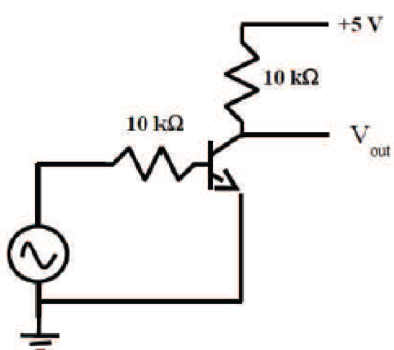
Both the results on the diode and transistor have a large degree of uncertainty surrounding them. In both of the tests, the diode and transistor each work well for a certain range of input parameters but deviate away from the fit in other ranges. Eqn 1 describes the IV characteristics well for the diode but only for the linear portion of the data. The upper voltages did not fit as well. From diode rectification, I learned that diodes can be a very useful tool for converting a radical input signal to a steady, storable signal. The current gain from the transistor experiment was 5.643e-03 +/- 7.267e-06 and the voltage gain was 3.673e+01 +/- 5.062e-02. We are confident in out value for the current gain as the Chi^2/dof for it is low, but we are not as confident in pour value for the voltage gain as its Chi^2/dof is high. In both these transistor circuits, the condition required for the amplifiers to remain linear ad undistorted is that the range of the input must be narrowed. For the current, the range is about 0 A - 0.0023 A. For the voltage, the range is about 0.6 V - 0.66 V.

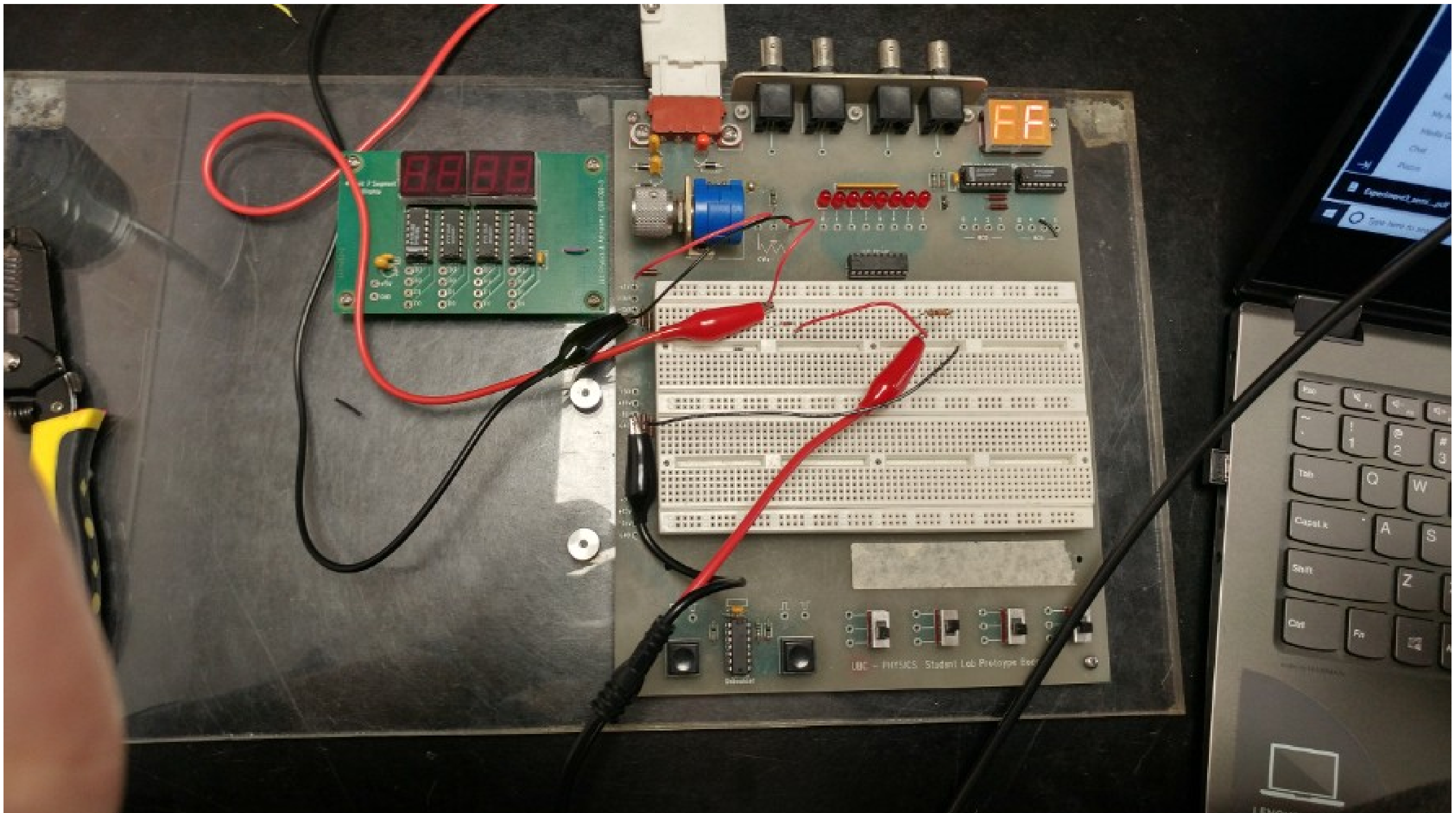
Here are pictures of our circuits and their circuit diagrams:

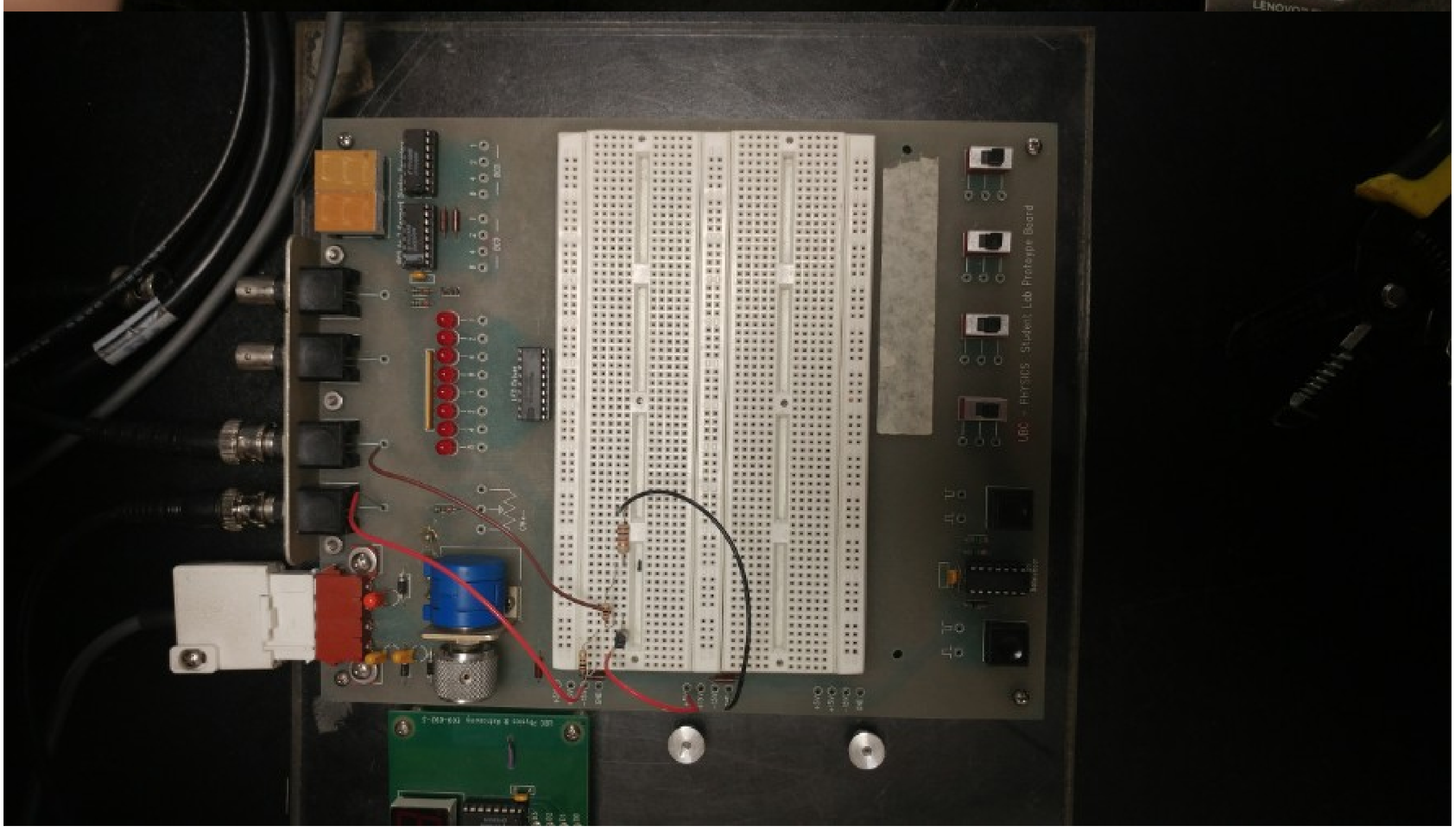








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