ISim Lab9

Yoonyoung Cho

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1 Schematic

The full schematic of the receiver circuit is shown below:

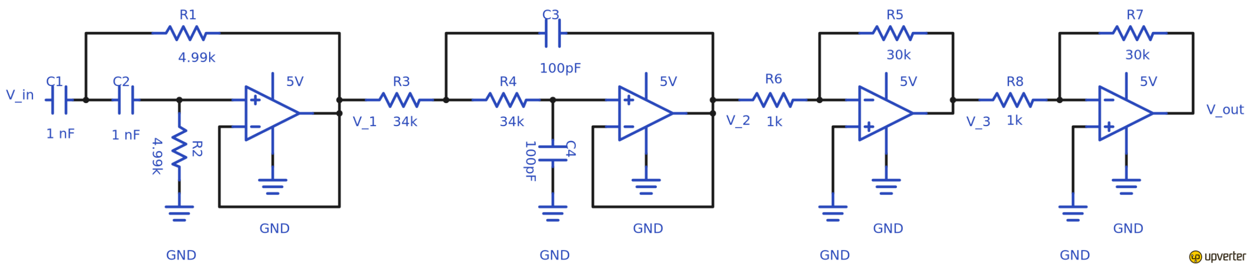


Figure 1: Full schematic of the receiver circuit.

In this circuit, V_{in} corresponds to the raw signal input from the receiver; V_{out} corresponds to the signal after going through a second order band-pass filter composed of two Sallen-Key filters. In order to keep the circuit simple, I did not utilize the amplification capability of the Sallen-Key filters; instead, signal amplification was isolated into a separate process.

2 Analysis

Relying on the fact that Op-Amps draw no current, it makes most sense to break down the parts into subsystems; furthermore, it would be convenient to treat a general case of the Sallen-Key topology, with impedence, that could be applied to both high-pass and low-pass filters. As the two amplifiers in the later stage of the process are identical, the analysis of the overall circuit would just involve two circuit structures.

2.1 Sallen-Key Topology

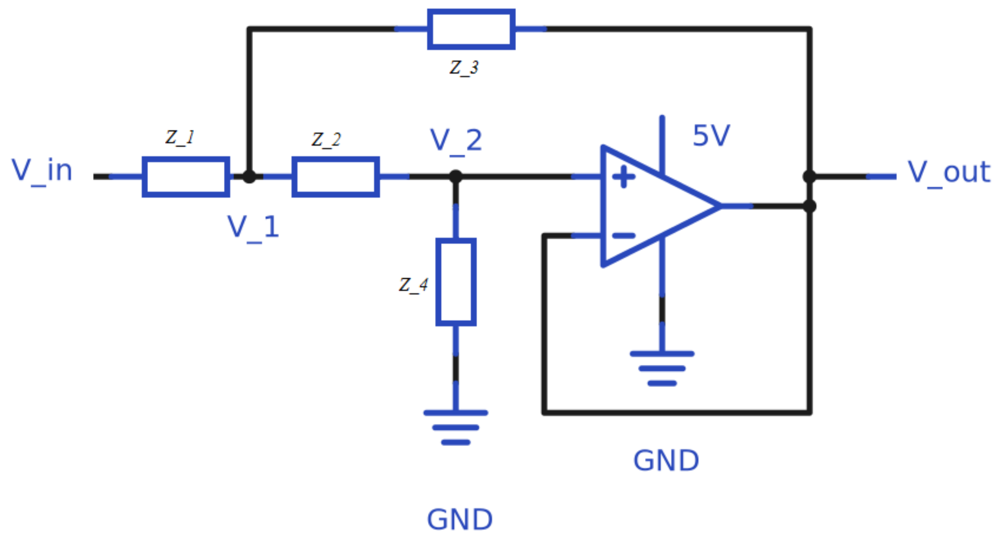


Figure 2: Generic Sallen-Key Topology.

Unlike previous labs, in this circuit the Gain-Bandwidth tradeoff has a significant impact upon; therefore, making a simple assumption that the positive and negative input voltage to the operational amplifiers are inappropriate. Thus, the Op-Amp would be bound to a more complex expression:

$$\frac{dV_{out}}{dt} = \omega_1(V_2 - V_{out})$$

in which ω_1 represents the characteristic frequency of the Op-amp. As well as the usual relationships:

$$\begin{aligned} I &= \frac{V_1 - V_{in}}{Z_1} \\ &= i_1 + i_2 \end{aligned}$$

$$\begin{aligned} i_1 &= \frac{V_{out} - V_1}{Z_3} \\ i_2 &= \frac{V_2 - V_1}{Z_2} \\ &= \frac{0 - V_2}{Z_4} \end{aligned}$$

The above equations conclude the overarching relationships in the circuit. Now, the analysis:

$$\begin{aligned} \frac{V_1}{Z_2} &= \frac{V_2}{Z_2} + \frac{V_2}{Z_4} \\ V_1 &= V_2\frac{Z_2 + Z_4}{Z_4} \\ V_2 &= V_1\frac{Z_4}{Z_2 + Z_4} \end{aligned}$$

$$
\begin{aligned}
\frac{V_1 - V_{in}}{Z_1} &= \frac{V_{out} - V_1}{Z_3} - \frac{V_1}{Z_2 + Z_4} \\
V_1(\frac{1}{Z_1} + \frac{1}{Z_3} + \frac{1}{Z_2 + Z_4}) &= \frac{V_{in}}{Z_1} + \frac{V_{out}}{Z_3} \\
Z_3V_1 + Z_1V_1 + \frac{Z_1Z_3V_1}{Z_2 + Z_4} &= Z_3V_{in} + Z_1V_{out} \\
V_1(Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2 + Z_4}) &= Z_3V_{in} + Z_1V_{out} \\
V_1 &= \frac{Z_3V_{in} + Z_1V_{out}}{Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2+Z_4}}
\end{aligned}
$$

$$
\begin{aligned}
\frac{dV_{out}}{dt} &= \omega_1(V_2 - V_{out}) \\
V_2 &= V_1\frac{Z_4}{Z_2 + Z_4} \\
\frac{dV_{out}}{dt} &= \omega_1(V_1\frac{Z_4}{Z_2 + Z_4} - V_{out}) \\
V_1 &= \frac{Z_3V_{in} + Z_1V_{out}}{Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2+Z_4}} \\
\frac{dV_{out}}{dt} &= \omega_1(\frac{Z_3V_{in} + Z_1V_{out}}{Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2+Z_4}}\frac{Z_4}{Z_2 + Z_4} - V_{out}) \\
\frac{dV_{out}}{dt} &= k_1V_{in} + k_2V_{out}
\end{aligned}
$$

Here k_1 and k_2 are simply placeholders for the complex expressions:

$$
\begin{aligned}
k_1 &= \omega_1Z_3(\frac{Z_4}{Z_2 + Z_4}\frac{1}{Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2+Z_4}}) \\
k_2 &= \omega_1(\frac{Z_4}{Z_2 + Z_4} * \frac{1}{Z_1 + Z_3 + \frac{Z_1Z_3}{Z_2+Z_4}}Z_1 - 1)
\end{aligned}
$$

$$
\begin{aligned}
V_{in} &= V_0e^{j\omega t} \\
V_{out} &= GV_0e^{j\omega t} \\
j\omega GV_0e^{j\omega t} &= k_1V_0e^{j\omega t} + k_2GV_0e^{j\omega t} \\
j\omega G &= k_1 + k_2G \\
G(j\omega - k_2) &= k_1 \\
G &= \frac{k_1}{j\omega - k_2}
\end{aligned}
$$

G represents the encoded Gain of V_{out} with respect to V_{in} (as well as the phase shift)

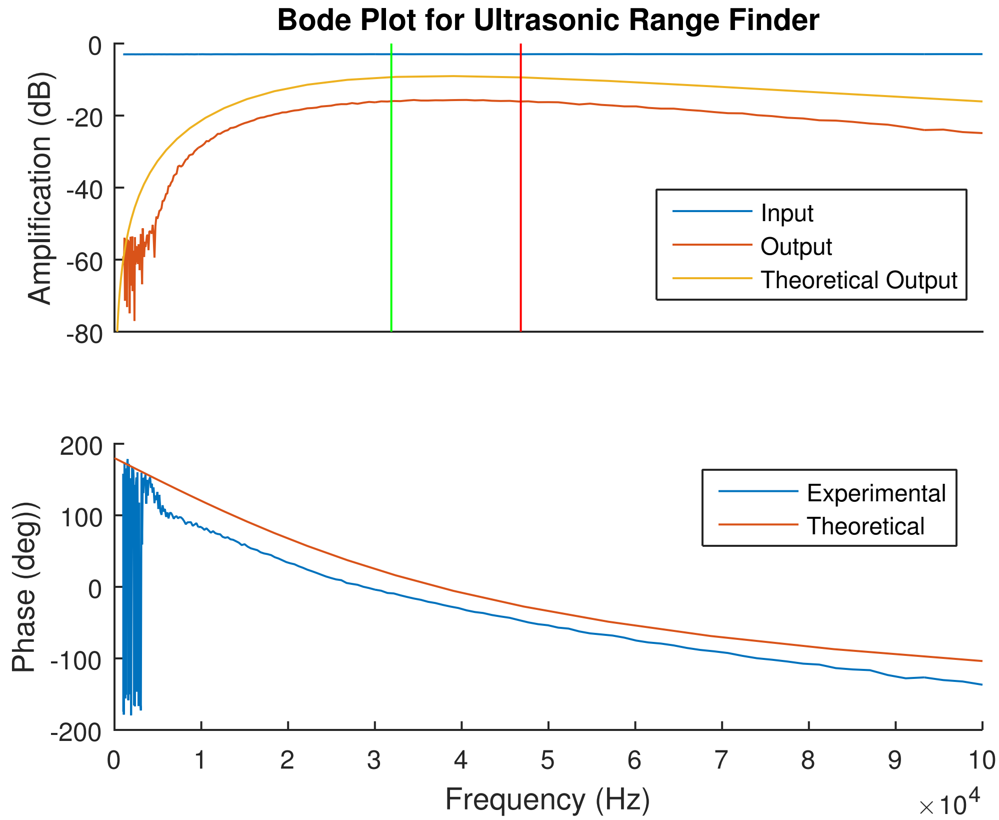


Figure 3: Bode plot, for the Band-pass filter only.

I couldn't get the plot to output reasonable data with the filters and amplifiers in conjunction; the parts were working fine in isolation, so I chose to present the results separately. As shown, the output is consistent with the theoretical output in trends, though with less intensity. As expected, the roll-off is much milder in the higher frequencies, in which the gain-bandwidth tradeoff reduces the overall magnitude, than in the lower frequencies.

2.2 Inverting Amplifier

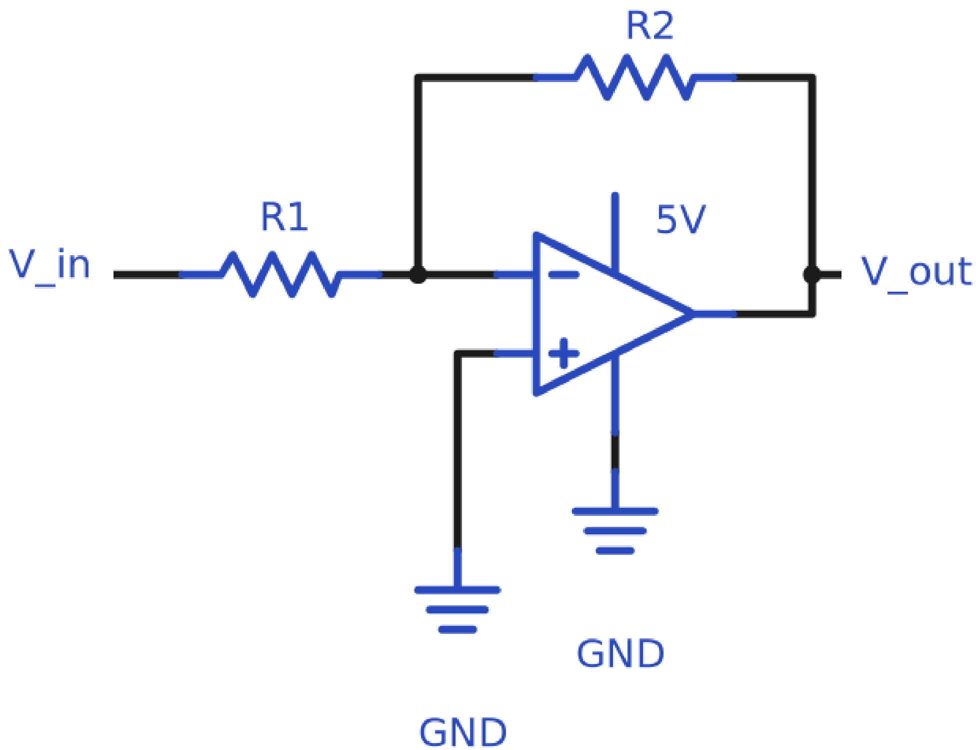


Figure 4: Inverting Amplifier Schematic.

Cutting to the chase, the relationships are as follows:

$$\frac{V_1 - V_{in}}{R_1} = \frac{V_{out} - V_1}{R_2}$$
$$\frac{dV_{out}}{dt} = -\omega_1 V_1$$

Henceforth, the analysis:

$$V_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V_{out}}{R_2} + \frac{V_{in}}{R_1}$$
$$(R_1 + R_2)V_1 = R_1 V_{out} + R_2 V_{in}$$
$$V_1 = \frac{R_1 V_{out} + R_2 V_{in}}{R_1 + R_2}$$

$$\frac{dV_{out}}{dt} = -\omega_1 \frac{R_1 V_{out} + R_2 V_{in}}{R_1 + R_2}$$
$$\frac{dV_{out}}{dt} = \frac{-\omega_1 R_1}{R_1 + R_2} V_{out} + \frac{-\omega_1 R_2}{R_1 + R_2} V_{in}$$

which is now of the form we had seen before:

$$\frac{dV_{out}}{dt} = k_1 V_{in} + k_2 V_{out}$$
$$k_1 = \frac{-\omega_1 R_2}{R_1 + R_2}$$
$$k_2 = \frac{-\omega_1 R_1}{R_1 + R_2}$$

thus,

$$G = \frac{k_1}{j\omega - k_2}$$

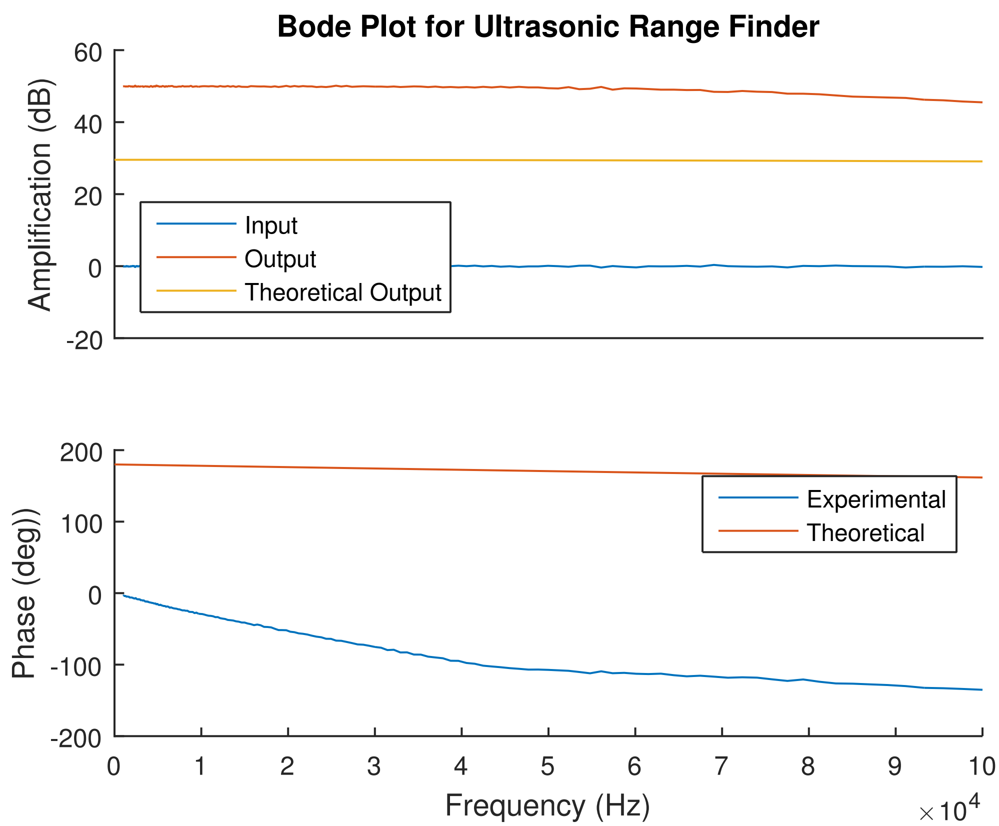
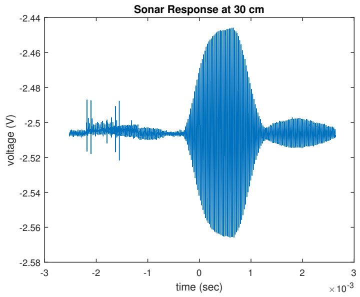


Figure 5: Bode plot, for the Amplifier only.

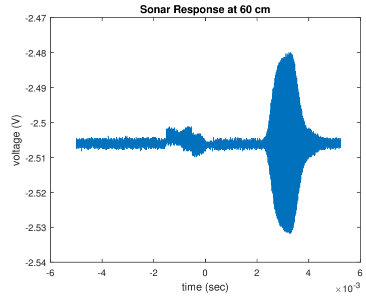
The theory as to the capped amplification of the amplifier was that the voltage emitted by the Analog Discovery was simply too big to be amplified 900 times; the discrepancy for the phase remains unclear, but is fortunately irrelevant to the signal reception in this circuit.

3 Comparison

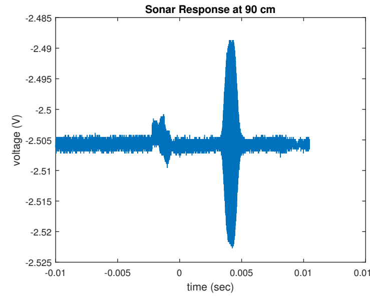
The measured sonar responses are as follows:



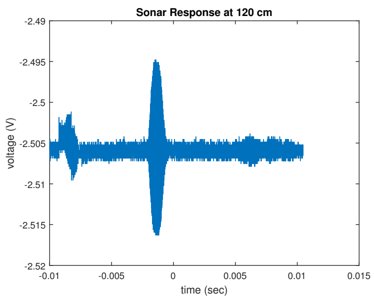
(a) 30 cm



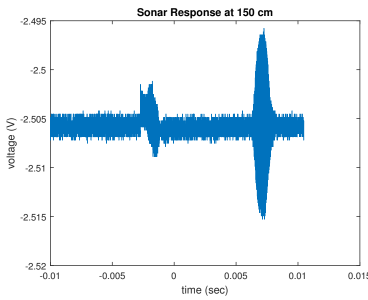
(b) 60 cm



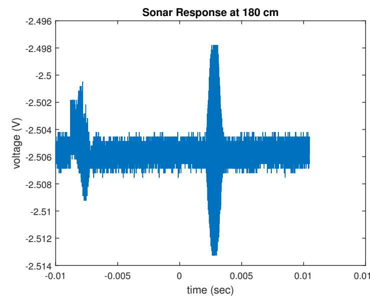
(c) 90 cm



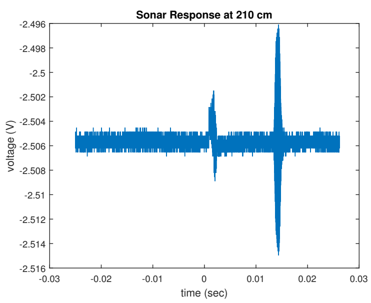
(d) 120 cm



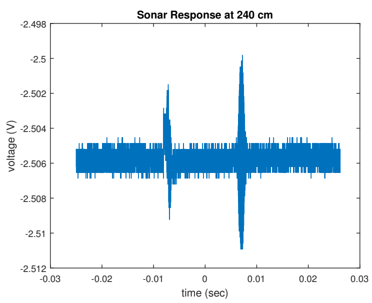
(e) 150 cm



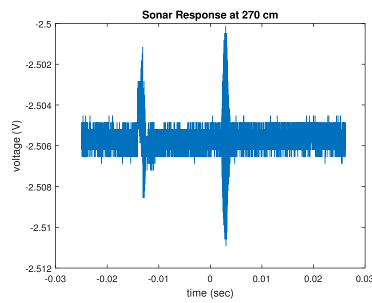
(f) 180 cm



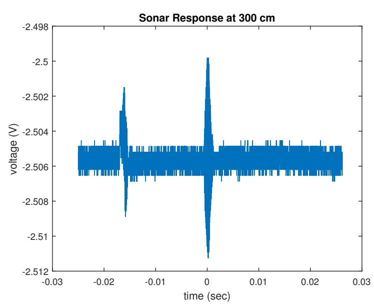
(g) 210 cm



(h) 240 cm



(i) 270 cm



(j) 300 cm

Figure 6: Measured sonar responses.

In order to emphasize the comparison, the data were all combined upon one plot with spaces in between:

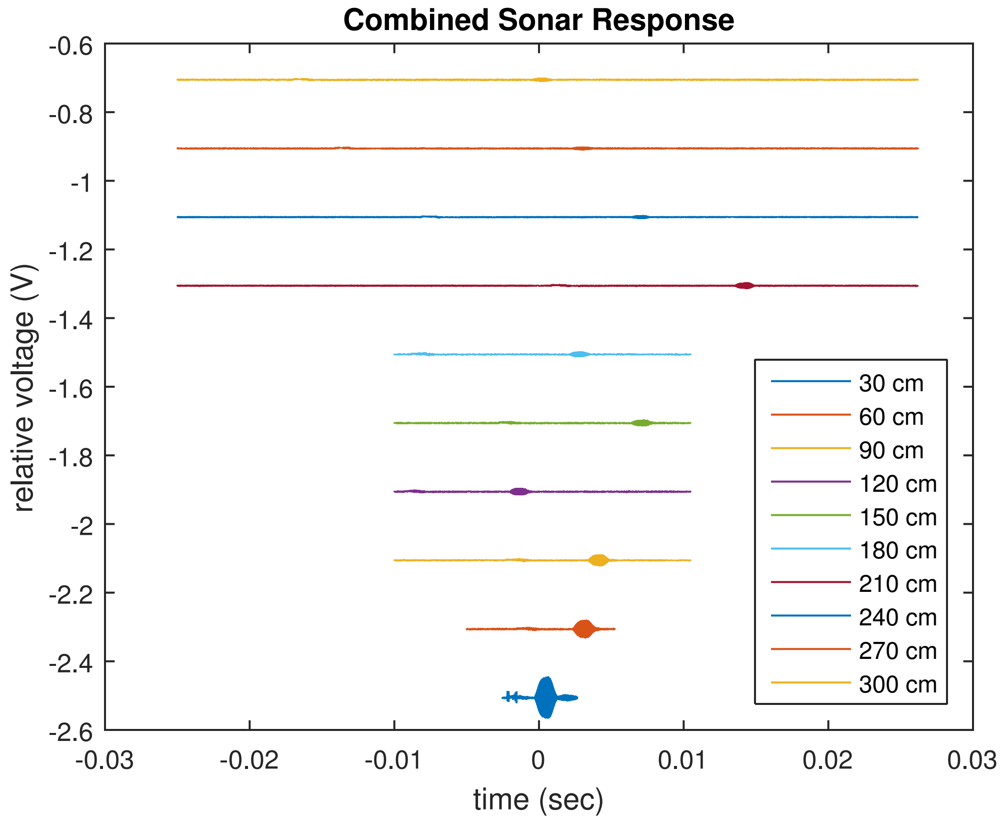


Figure 7: Combined Sonar Response.

The trend becomes more apparent in this display: the magnitude of the signal is significantly greater at closer range, and it takes less time to come back. After digitizing the signals(as it was very difficult to implement an automated process), I obtained the following result:

Table 1: Calculation of distance from the time interval of signals; Val was obtained by digitizing the data.

Dist(cm)	Val	time(sec)	time/2	dist(m)	dist(cm)
30	0.03358	0.002015	0.001007	0.342804	34.2804
60	0.065815	0.003949	0.001974	0.67189	67.18905
90	0.094694	0.005682	0.002841	0.966702	96.6702
120	0.120215	0.007213	0.003606	1.227237	122.7237
150	0.150437	0.009026	0.004513	1.535765	153.5765
180	0.181329	0.01088	0.00544	1.851136	185.1136
210	0.208865	0.012532	0.006266	2.132239	213.2239
240	0.238415	0.014305	0.007152	2.433911	243.3911
270	0.267293	0.016038	0.008019	2.728718	272.8718
300	0.274681	0.016481	0.00824	2.804134	280.4134

From this, I was able to validate my data, which concludes this lab.