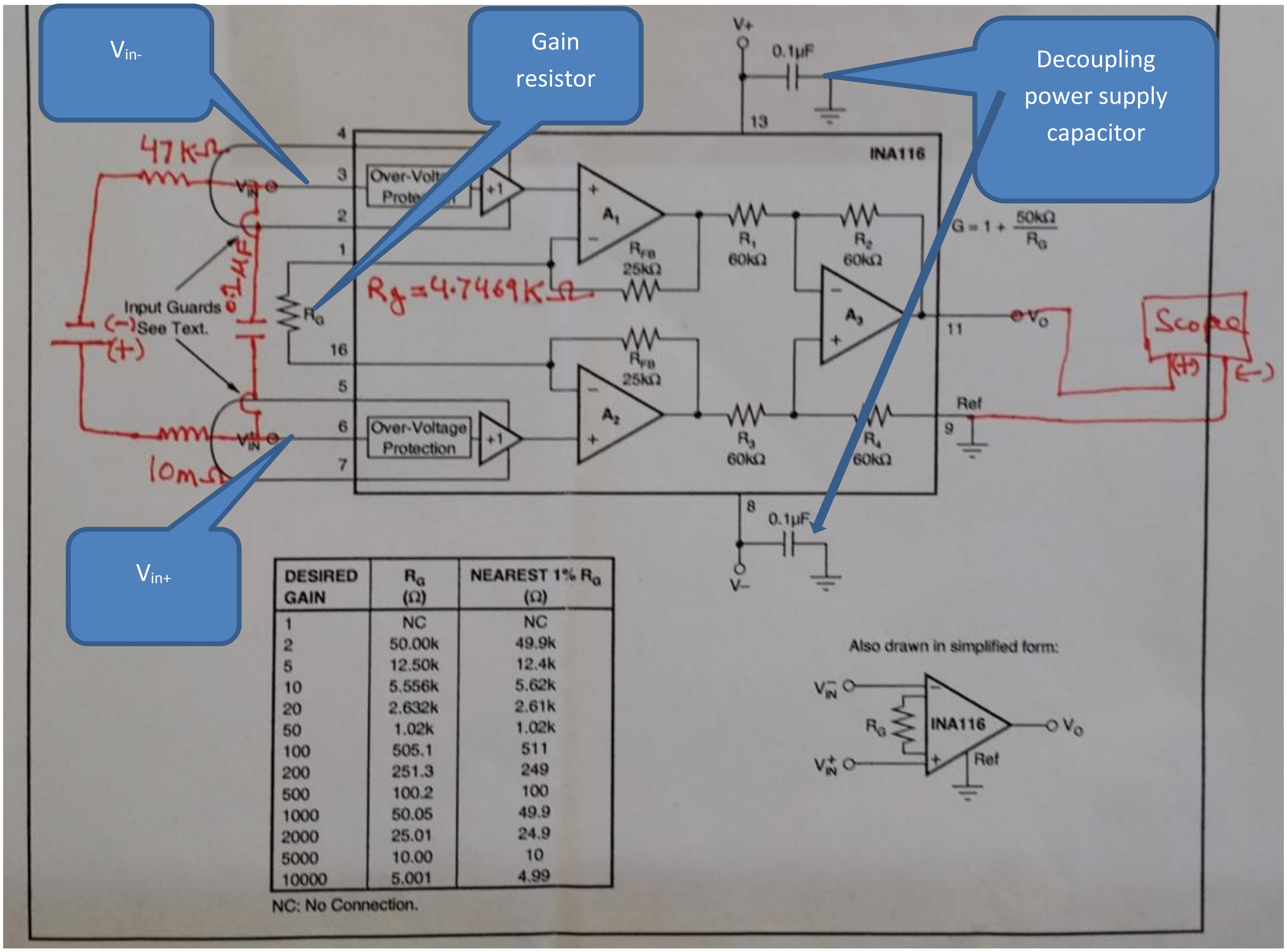
Prototype Testing Lab Results for INA116 Instrumentation Amplifier

This document provides an overview of our lab test results with INA116 Instrumentation Amplifier. Our goal is to obtain accurate pH measurement using an instrumental amplifier.

Figure 1 below shows the schematic of the circuit used to obtain results in Test-1, Test-2 & Test-3. We connected two resistors 10 MΩ in series with amplifier input (Pin 6) V_{in+} to simulate the ideal *pH* electrode and 47 kΩ in series with amplifier input (Pin 3) V_{in-} to simulate the ideal reference electrode. Decoupling 0.1μF capacitor were connected to both power rails (Pins 8 and 13) V_+/V_- to provide stability and minimize any ripple in the power supply. Also 0.1μF capacitor connects both amplifier inputs together to provide RFI protection.

Figure 1



DESIRED GAIN	RG (Ω)	NEAREST 1% RG (Ω)
1	NC	NC
2	50.00k	49.9k
5	12.50k	12.4k
10	5.556k	5.62k
20	2.632k	2.61k
50	1.02k	1.02k
100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9
2000	25.01	24.9
5000	10.00	10
10000	5.001	4.99

NC: No Connection.

Test 1

In order for us to confirm the proper operation of this INA chip, we set up the circuit as shown in the schematic above and set the differential input voltages to different values while observing the output in order to calculate our gain. Just for testing purposes, we chose a gain of 10 and as shown below in Table 1, the achieved gains were consistent while also being close to our desired gain. The figures below the table are the graphs of the approximate differential outputs on an oscilloscope based on the differential inputs.

$$\mathbf{Gain(Av)_{desired}} = 10\ \mathrm{V/V}$$

$$\mathbf{Gain(Av)_{\mathit{Formula}}} = 1 + \frac{50\ \mathrm{k\Omega}}{\mathrm{Rg}}$$

$$\mathbf{Rg_{required}} = 1 + \frac{50\mathrm{k\Omega}}{\mathrm{G(Av)}} = 5.555\ k\Omega$$

$$\mathbf{Rg_{Picked}} = 5.486\ k\Omega\ \pm 5\%\ \text{tolerance}$$

$$\mathbf{Gain(Av)_{\mathit{Calculated\ per\ Rg\ picked\ value}}} = 1 + \frac{50\ \mathrm{k\Omega}}{5.486\ \mathrm{k\Omega}} = 10.11\ \mathrm{V/V}$$

Table 1

Total Vin(mV) Measured	Total Vin(mV) Calculated	Differential Vout(Measured)	Gain (Av) Calculated
100.71	100.890208	1.02	10.128091
163.26	163.204748	1.65	10.106578
221.02	221.562809	2.24	10.134829
300.33	301.681503	3.05	10.155496
348.56	350.148368	3.54	10.156071
445.25	445.103858	4.5	10.106682

Figure 2

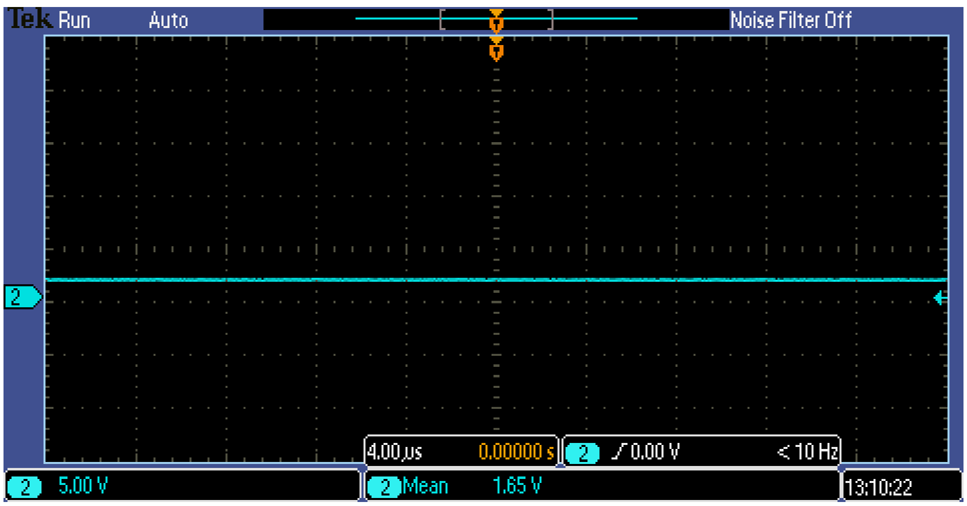


Figure 3

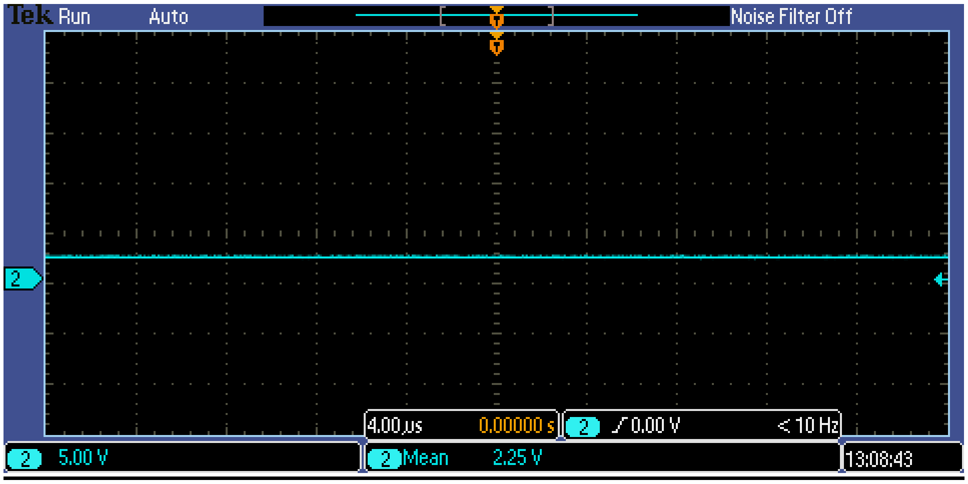


Figure 4

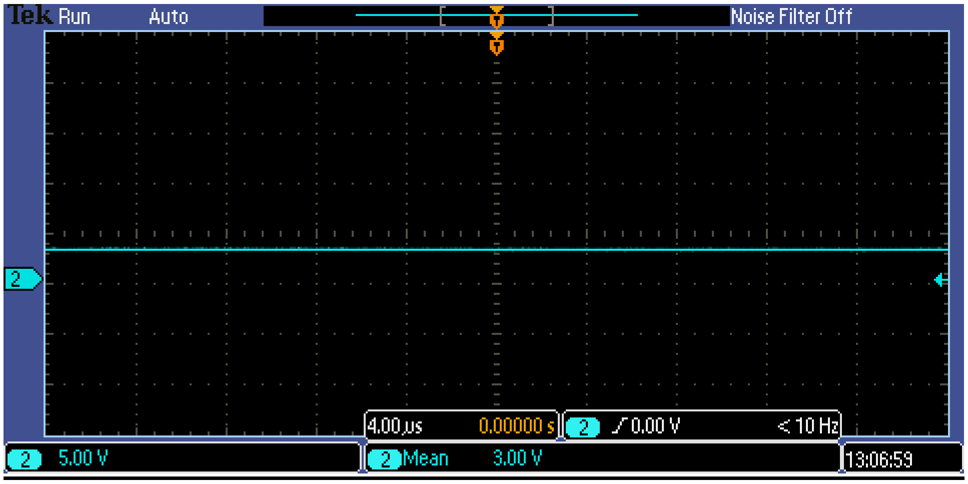


Figure 5

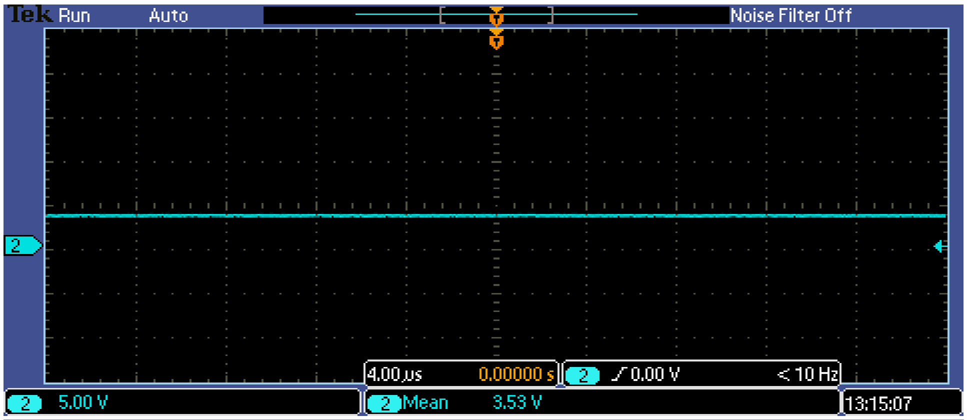
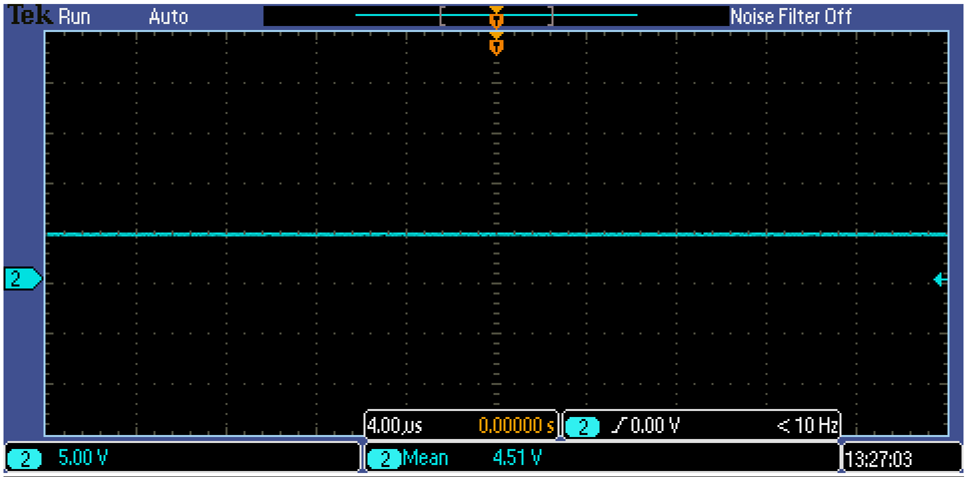


Figure 6



<u>Test 2</u>

$\mathbf{Gain(Av)_{desired}} = 11.51\ \text{v/v}$ **[NOTE: Gain value chosen per Dr. Hintz AD8222 Instrumental Amplifier prototype as its set to 11.51 V/V]**

$$\mathbf{Gain(Av)}_{\boldsymbol{Formula}} = 1 + \frac{50\ \text{k}\Omega}{\text{Rg}}$$

$$\mathbf{Rg_{required}} = 1 + \frac{50\text{k}\Omega}{\text{G(Av)}} = 4.757\ k\Omega$$

$$\mathbf{Rg_{Picked}} = 4.764\ k\Omega\ \pm 5\%\ \text{tolerance}$$

$$\mathbf{Gain(Av)}_{\boldsymbol{Calculated\ per\ Rg\ picked\ value}} = 1 + \frac{50\ \text{k}\Omega}{4.764\ \text{k}\Omega} = 11.49\ \text{V/V}$$

During our testing with the first INA116 chip we observed that our gain decreased as the input voltage increased. We want our gain to be constant as input voltage is varied therefore; we decided to switch that chip with another INA116 chip to verify if the chip is operational or not. Our test 3 results confirmed that INA116 chip used during test 2 was not working. We were able to obtain a constant gain output per variation in input voltage.

Table 2

Total Vin(mV) Measured	Total Vin(mV) Calculated	Differential Vout(Measured)	Gain (Av) Calculated
103.97	397.579948	4.6	44.243532
201.64	414.866033	4.8	23.804801
303.34	440.79516	5.1	16.812817
402.27	464.131374	5.37	13.349243
499.29	483.146067	5.59	11.195898
607.95	503.889369	5.83	9.5896044
802.17	553.15471	6.4	7.9783587

Test 3

$\mathbf{Gain(Av)_{desired}} = 11.51\ \mathrm{V/V}$ **[NOTE: Gain value chosen per Dr. Hintz AD8222 Instrumental Amplifier prototype as its set to 11.51 V/V]**

$$\mathbf{Gain(Av)}_{\boldsymbol{Formula}} = 1 + \frac{50\ \mathrm{k\Omega}}{\mathrm{Rg}}$$

$$\mathbf{Rg_{required}} = 1 + \frac{50\mathrm{k\Omega}}{\mathrm{G(Av)}} = 4.757\ k\Omega$$

$$\mathbf{Rg_{Picked}} = 4.764\ k\Omega\ \pm 5\%\ \text{tolerance}$$

$$\mathbf{Gain(Av)}_{\boldsymbol{Calculated\ per\ Rg\ picked\ value}} = 1 + \frac{50\ \mathrm{k\Omega}}{4.764\ \mathrm{k\Omega}} = 11.49\ \mathrm{V/V}$$

Table 3

Total Vin(mV) Measured	Total Vin(mV) Calculated	Differential Vout(Measured)	Gain (Av) Calculated
101.23	101.827676	1.17	11.557839
160.98	161.009574	1.85	11.492111
211.05	211.488251	2.43	11.513859
318.46	318.537859	3.66	11.492809
419.28	419.495213	4.82	11.495898
506.24	506.527415	5.82	11.496523
700.27	700.609225	8.05	11.495566
828.97	829.416884	9.53	11.496194

Below are the oscilloscope results based on the table above.

Figure 7

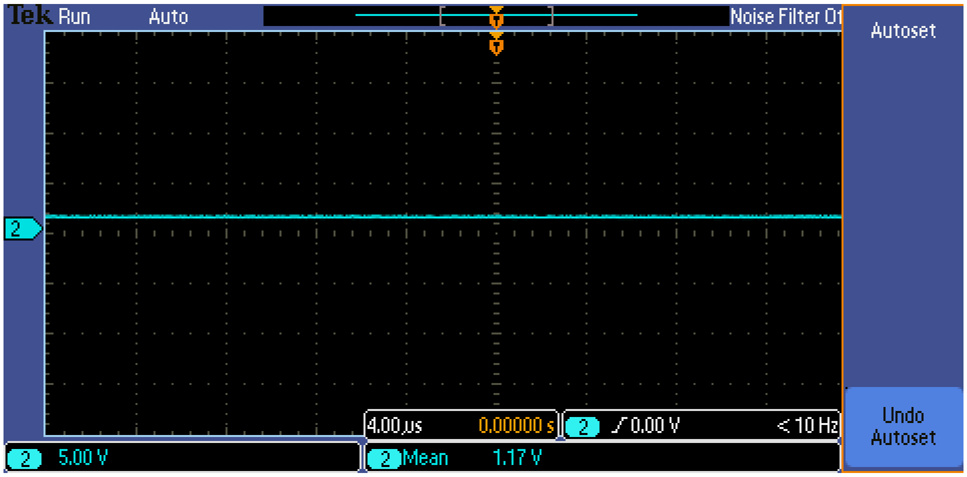


Figure 8

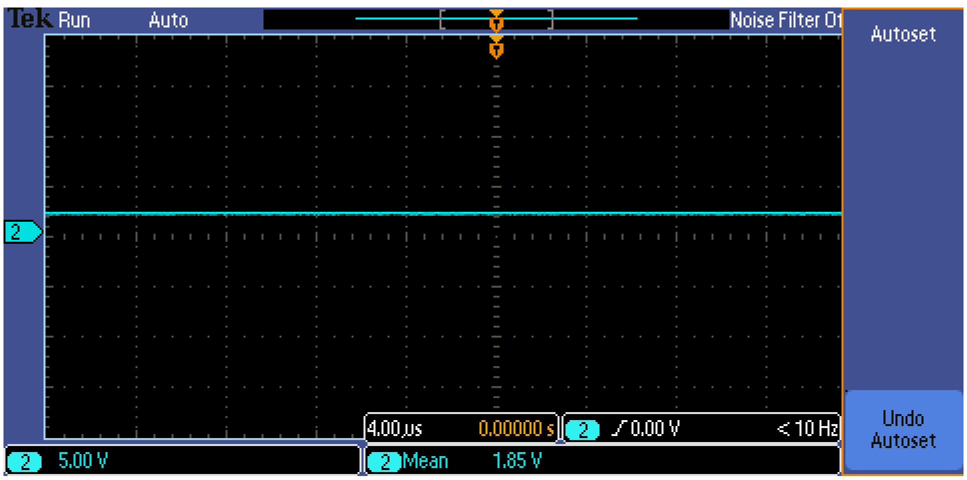


Figure 9

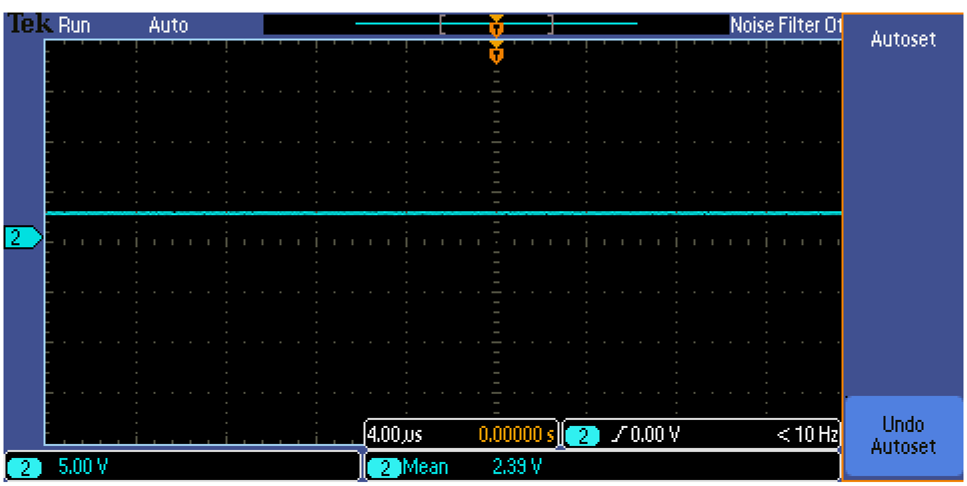


Figure 10

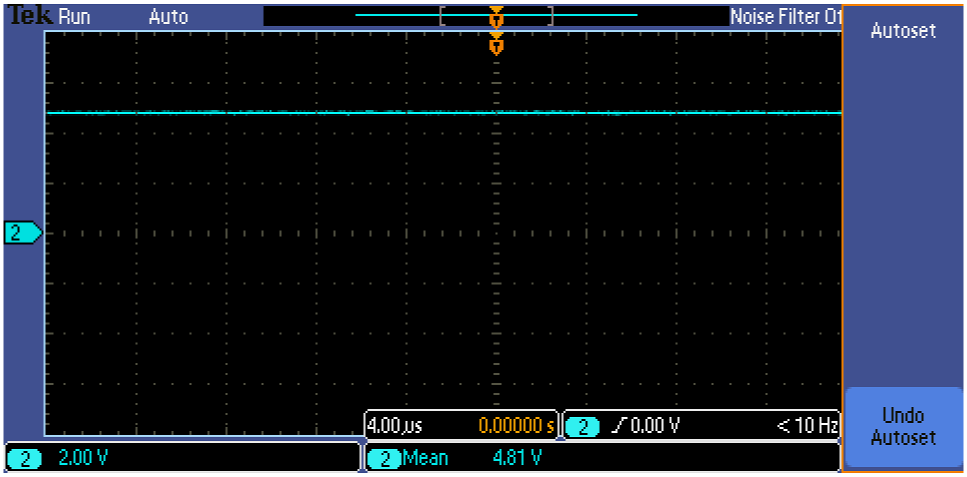


Figure 11

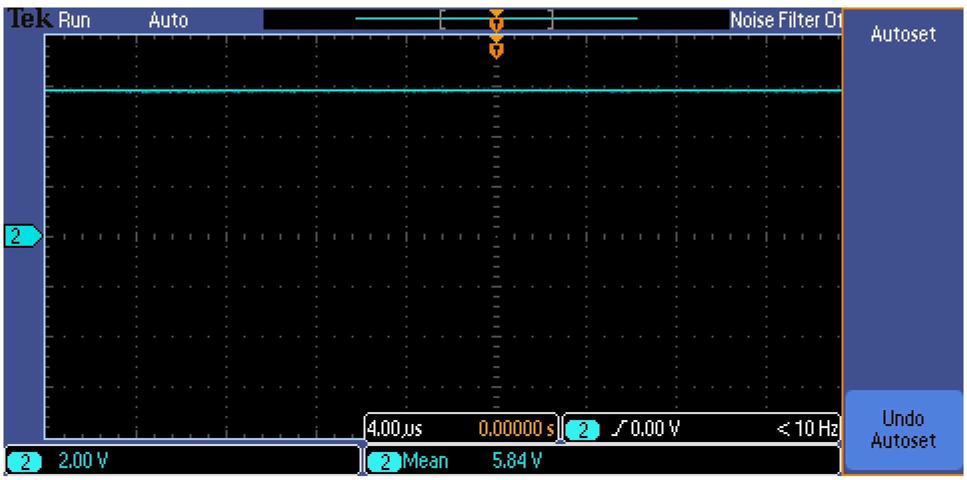


Figure 12

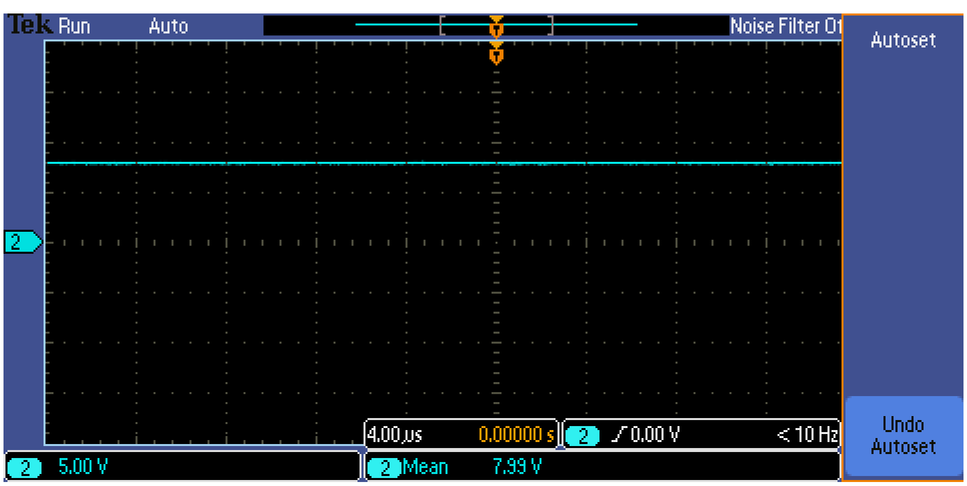
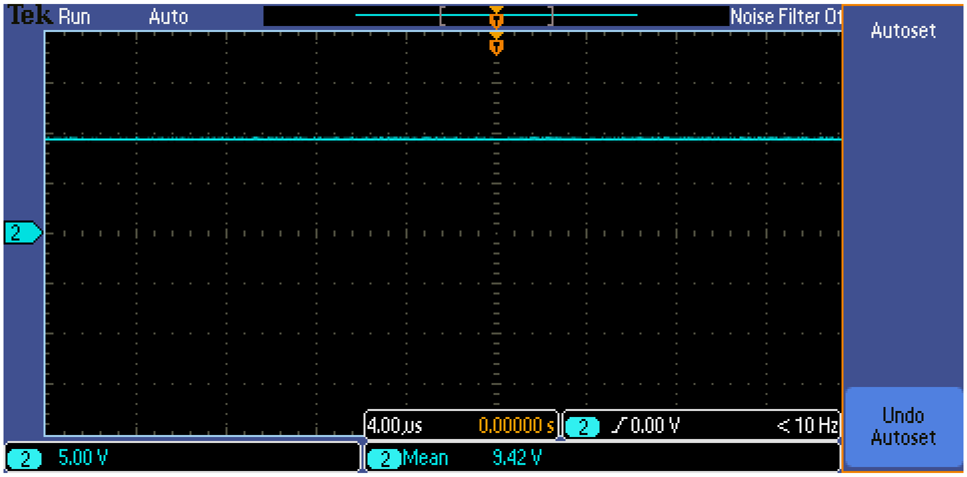


Figure 13



Test 4

In test 4, we used the *pH* probe from Dr Hintz's prototype as our differential input to the INA116 instrumentation amplifier through which we injected a series of buffer fluids (pH 4.0, 7.0, and 10.0). The result as shown in Table 4 was displayed on the oscilloscope in millivolts which corresponded to the pH value of the buffer solution. For this test, the amplifier was enclosed inside a faraday shielded box and we used a low tolerance resistor to set the gain

$\mathbf{Gain(Av)_{desired}} = 11.51\ \mathrm{V/V}$ **[NOTE: Gain value chosen per Dr. Hintz AD8222 Instrumental Amplifier prototype as its set to 11.51 V/V]**

$$\mathbf{Gain(Av)}_{\boldsymbol{Formula}} = 1 + \frac{50\ \mathrm{k\Omega}}{\mathrm{Rg}}$$

$$\mathbf{Rg_{required}} = 1 + \frac{50\mathrm{k\Omega}}{\mathrm{G(Av)}} = 4.757\ k\Omega$$

$$\mathbf{Rg_{Picked}} = 4.7469\ k\Omega\ \pm 0.1\%\ \text{tolerance}$$

$$\mathbf{Gain(Av)}_{\boldsymbol{Calculated\ per\ Rg\ picked\ value}} = 1 + \frac{50\ \mathrm{k\Omega}}{4.7469\mathrm{k\Omega}} = 11.53\ \mathrm{V/V}$$

***pH* measurement results shown below**

Table 4

pH	Voltage(V)	V_{out} (V)
4	0.117953166	1.36
7	-0.022896791	-0.264
10	-0.186470078	-2.15

Figure 14

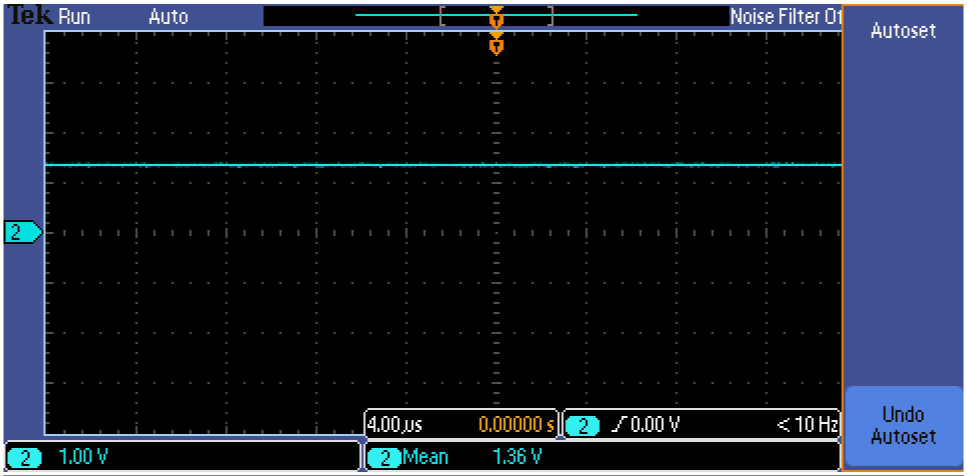


Figure 15

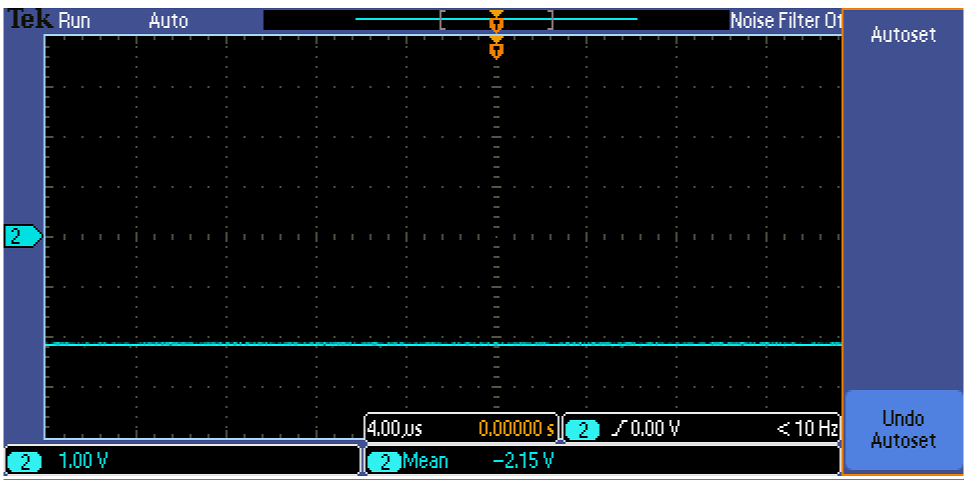
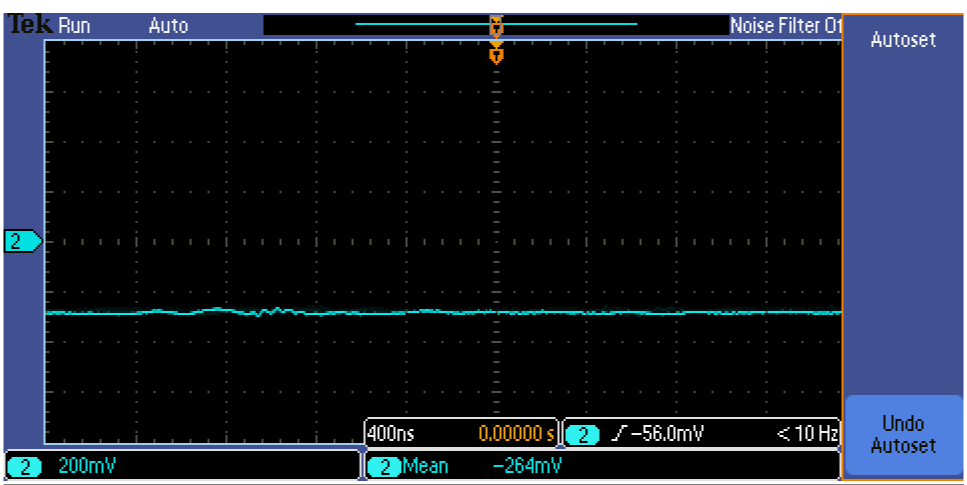


Figure 16



Test 5

In test 5, we were able to show the *pH* measurement capability of the INA116 instrumentation amplifier. We used the *pH* probe as our input to the amplifier through which we injected a series of buffer fluids (*pH* 4.0, 7.0, and 10.0). We then connected our instrumentation amplifier to the marine alkalinity measurement device prototype that Dr. Kenneth J. Hintz (Associate professor at George Mason University) built. The GUI (implemented by Dr. Hintz) displayed *pH* values and the voltage between the *pH* and reference electrodes which were read by analog-to-digital converter. The gain was set to 11.53 V/V similar to that of test 4 and the amplifier was enclosed within a faraday shielded box.

Figure 17 below shows the results of the *pH* 4 buffer solution. For this case, the output on the GUI shows a *pH* of 3.97 and 113 mV. In an ideal situation, we would obtain +177 mV at a *pH* of 4.

Figure 17

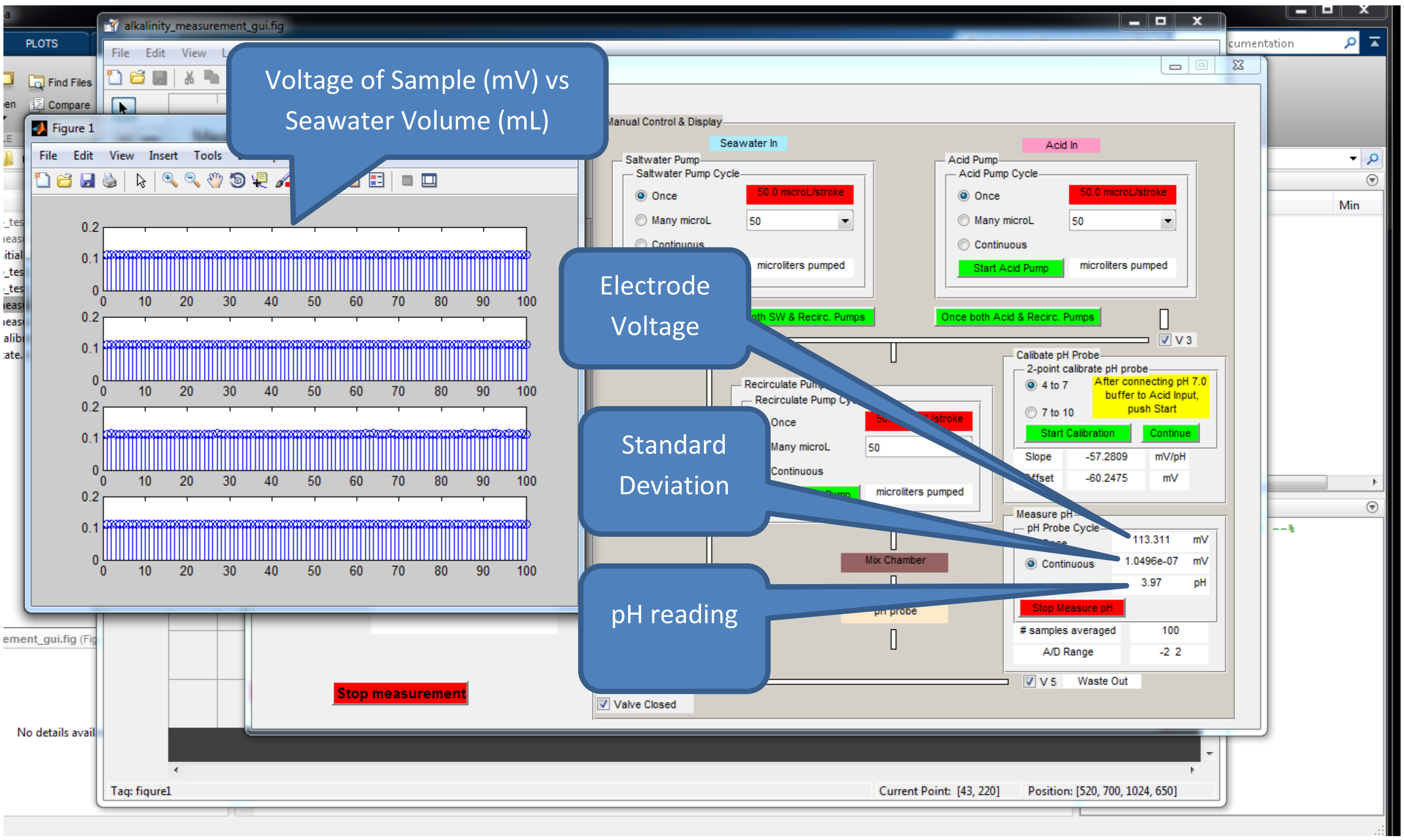


Figure 18 below shows the results of the *pH* 7 buffer solution. The output on the GUI shows 6.30 *pH* and -20 mV. In an ideal situation, we would obtain 0 mV at a *pH* 7. During the test, we noticed that the response time for the *pH* probe was slow. This can be due to the buffer solution contaminated with other solutions over time. More testing will be done with new *pH* probe and new *pH* buffer solutions to get more accurate results.

Figure 18

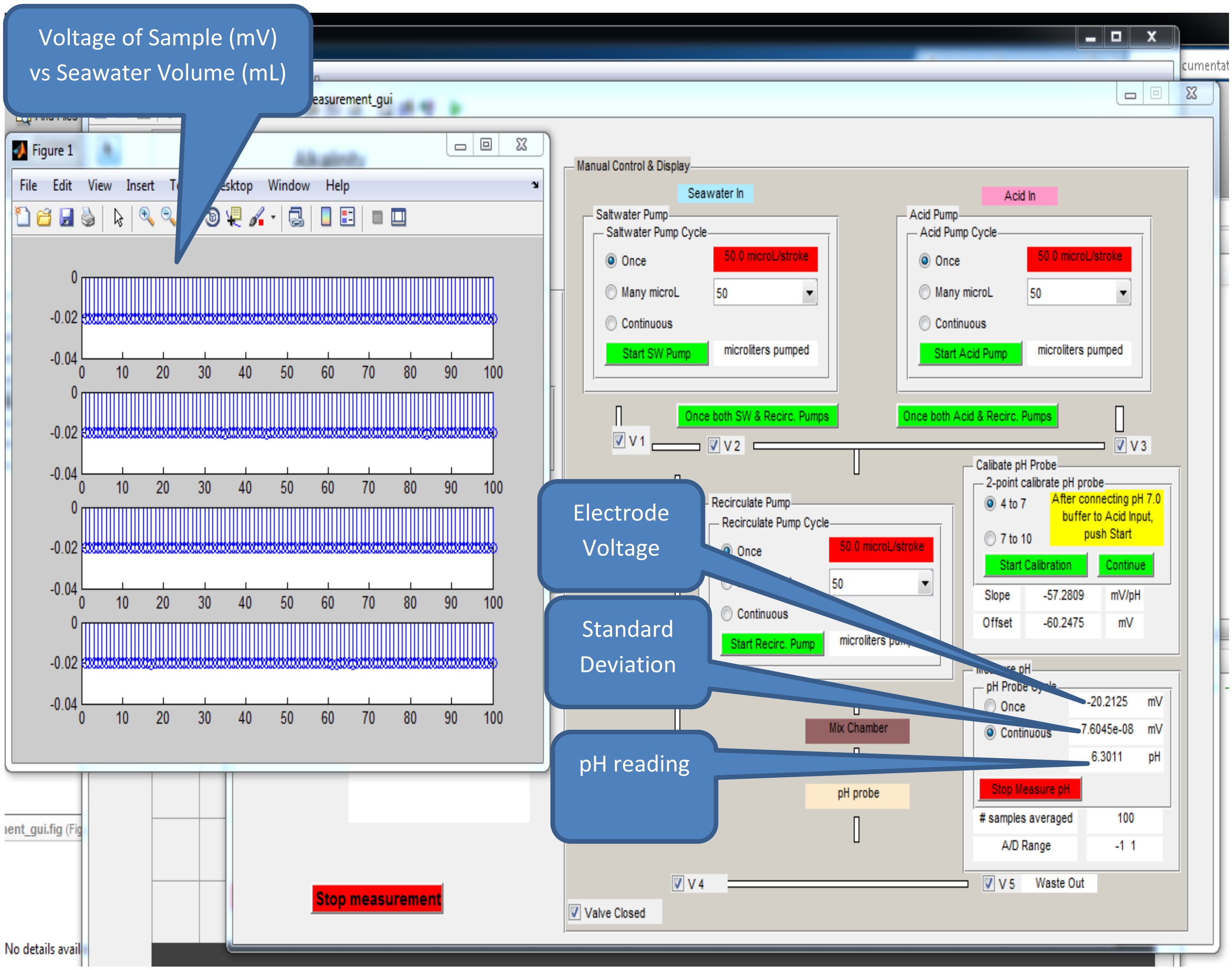
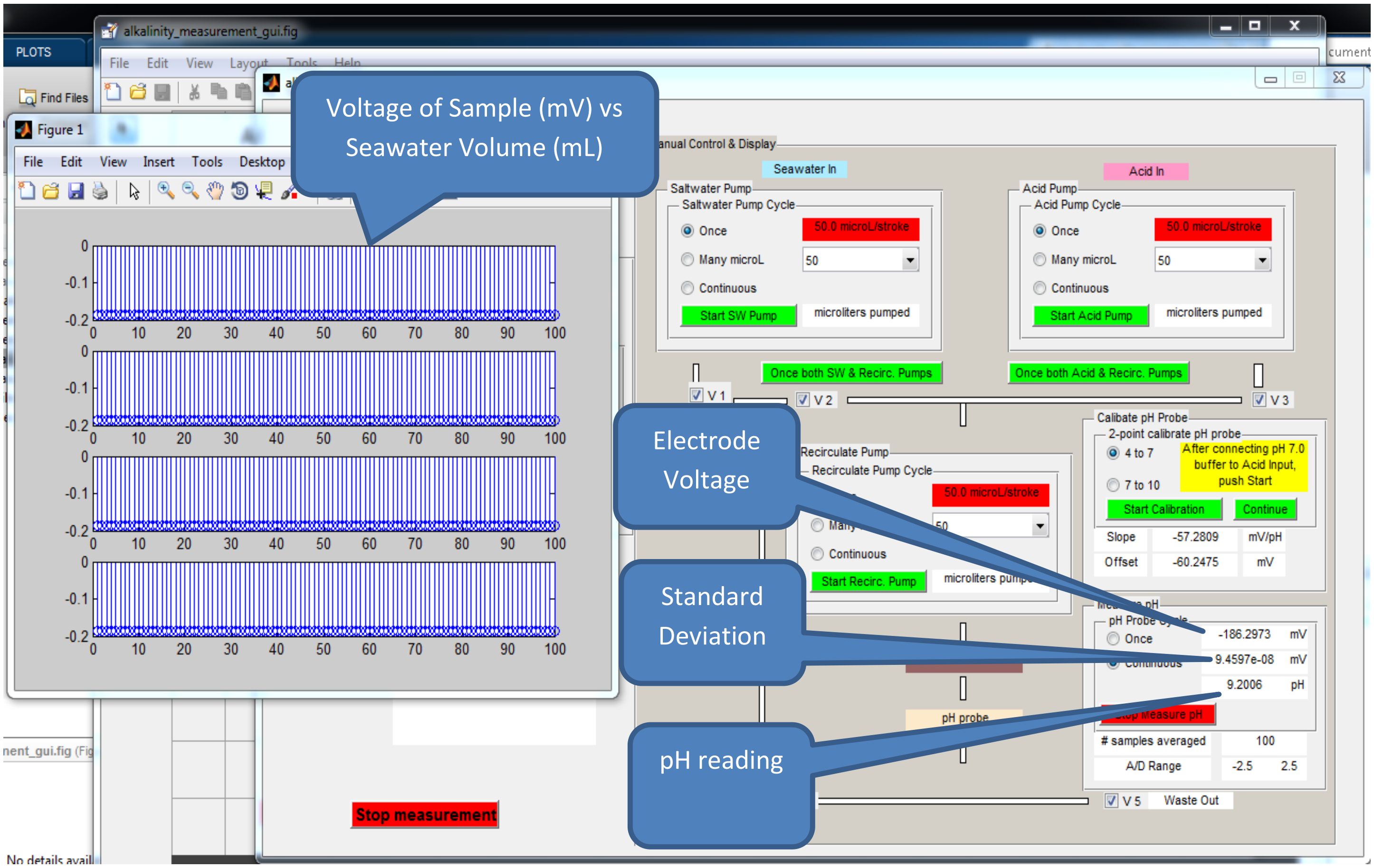


Figure 19 below shows the results of the *pH* 10 buffer solution. The display on the GUI shows a *pH* of 9.2 and -186.29 mV. In an ideal situation we would obtain -177.48 mV at a *pH* of 10. During the test we noticed that the response time for the *pH* probe was slow as in the *pH* 7 buffer test. It's possible that the buffer solution got contaminated with other solutions over time. More testing will be done with new pH probe and new pH buffer solutions to get more accurate results.

INA116 Instrumentation Amplifier Test

Figure 19



Implementation of faraday box

As shown below, we will be using this faraday box with shielded cables during our testing of the amplifier to block any static or non-static electric fields by channeling electric charge buildup on the aluminum foil to the ground. This will protect the internal components such as amplifier and signal conductor in the wire from external electrical noise and prevent RF signals from leaking into the signal.

Parts used:

1. Pre-galvanized steel box enclosure
2. Aluminum Foil Tape
3. Breadboard
4. Twinaxial 22-Guage stranded shielded cables
5. Heat shrink

Figure 20

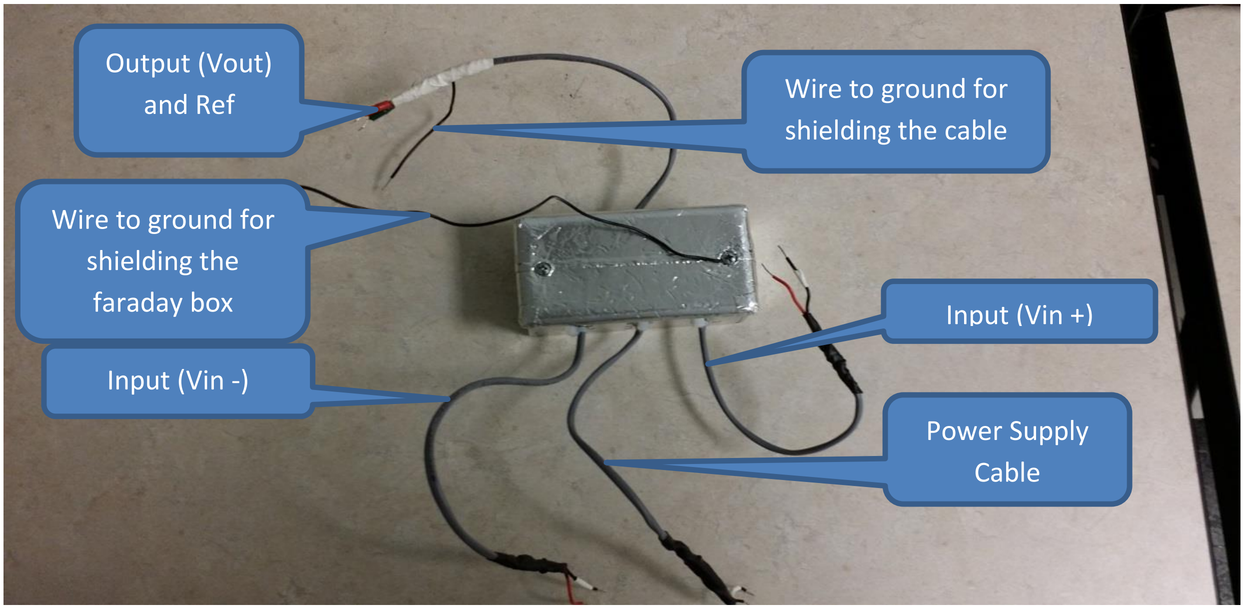


Figure 21

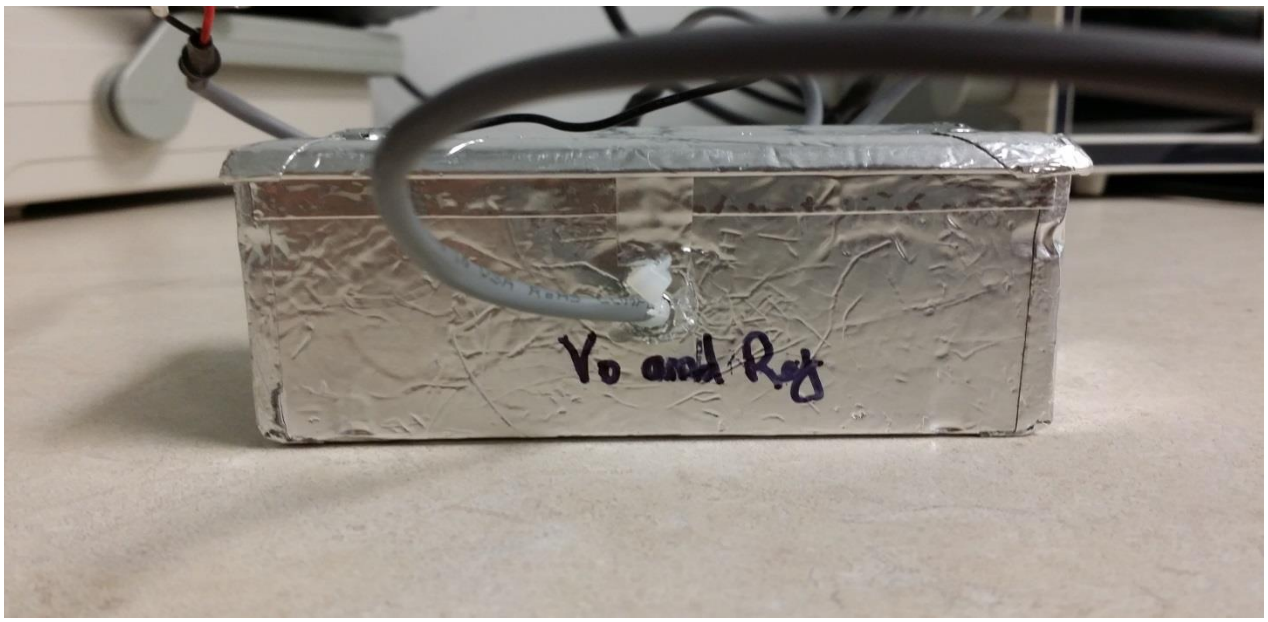


Figure 22

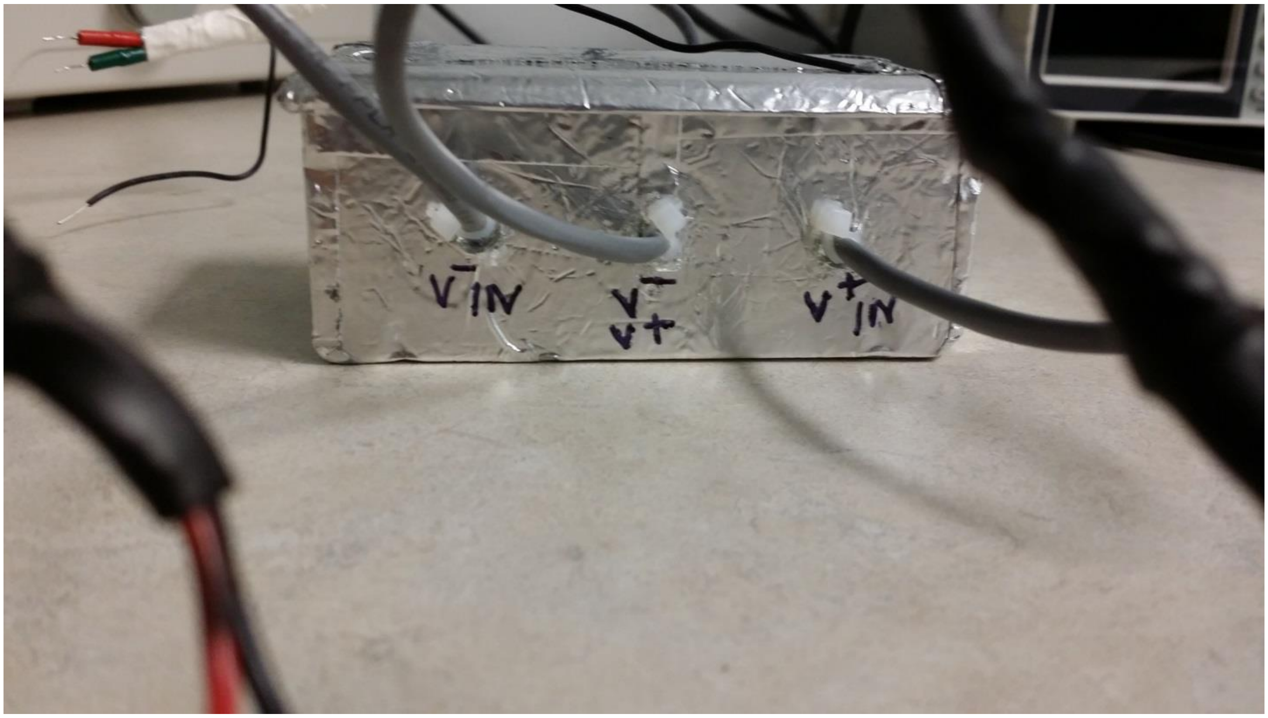
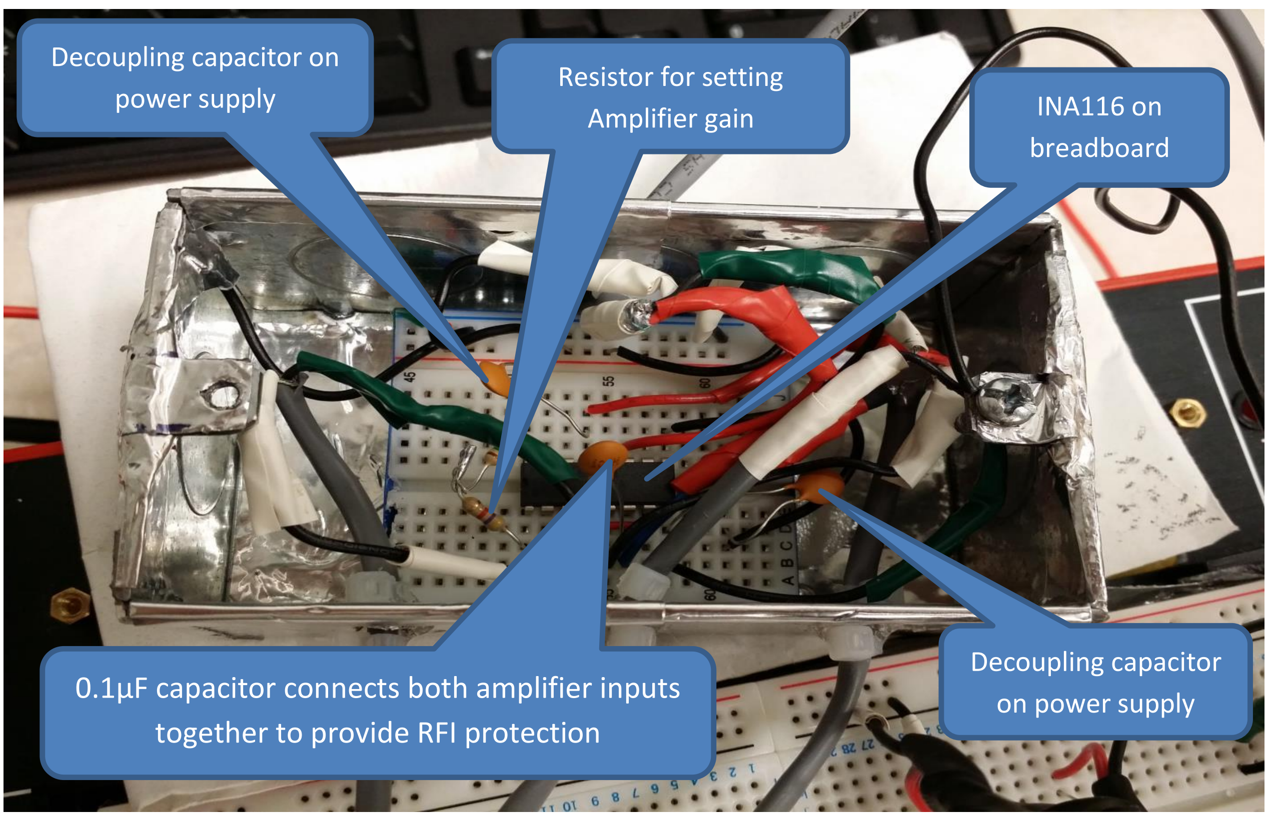


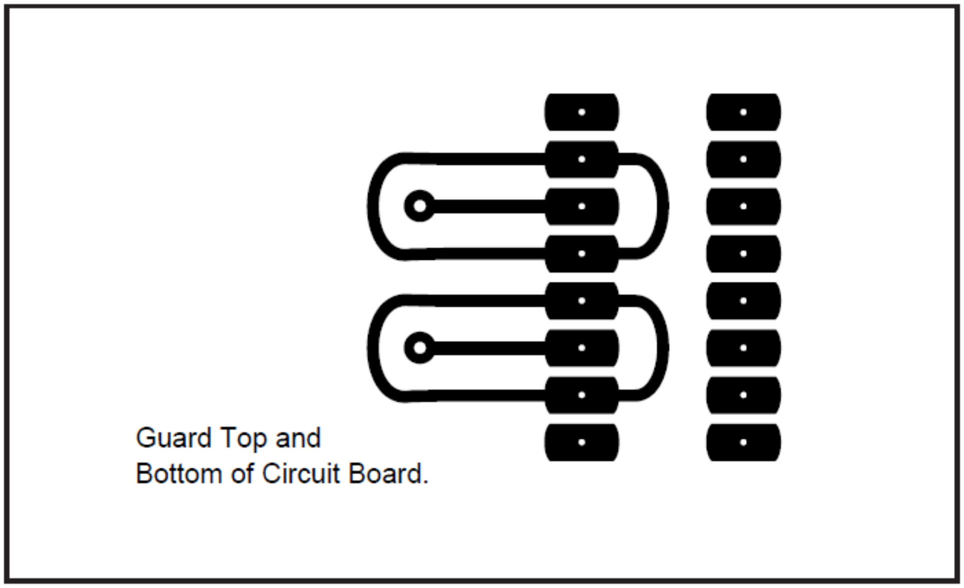
Figure 23



<u>Pending Task</u>

1. Design of PCB board for INA116 Instrumental Amplifier
    a. Our testing was done with INA116 chip placed on a breadboard. Per data sheet instructions on page 8, Figure 24 below shows PCB board layout for input guard pins. The data sheet states "*Careful circuit board layout and assembly techniques are required to achieve the exceptionally low input bias current performance of the INA116. Guard terminals adjacent to both inputs make it easy to properly guard the critical input terminal layout. Since traces are not required to run between device pins, this layout is easily accomplished, even with the surface mount package. The guards should completely encircle their respective input connections. Both sides of the circuit board should be guarded, even if only one side has an input terminal conductor. Route any time varying signals away from the input terminals. Solder mask should not cover the input and guard traces since this can increase leakage*".

Figure 24



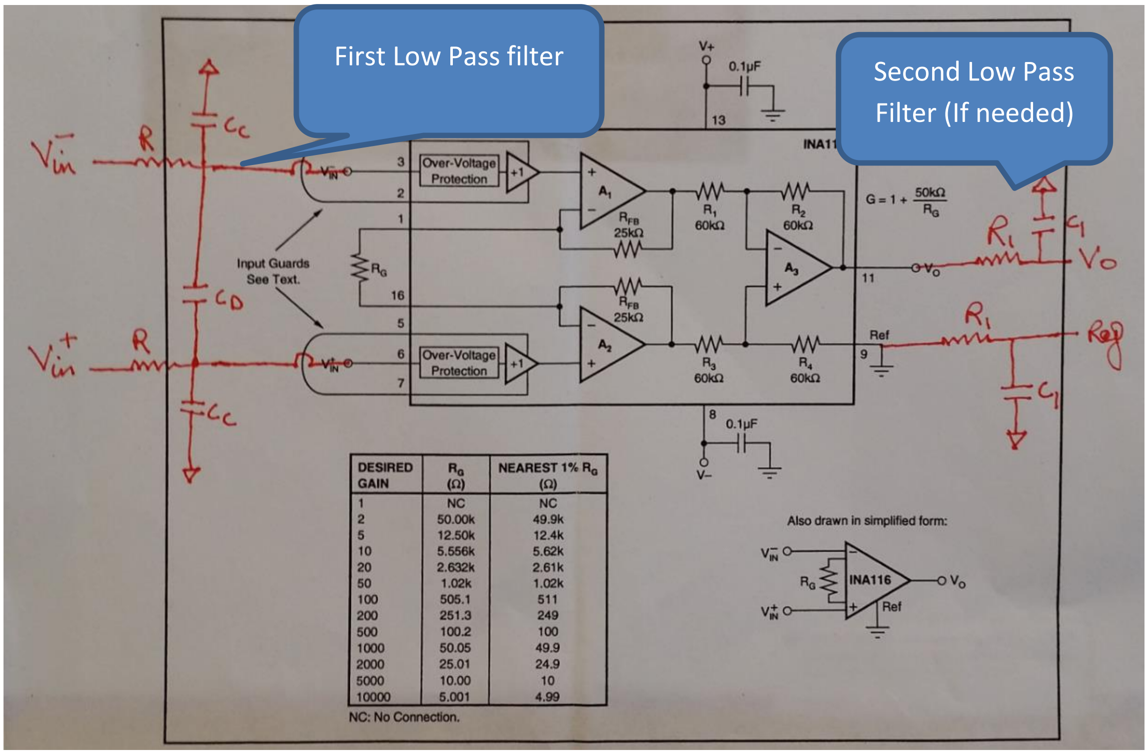
2. More testing with the new pH probe (Figure 25) and Buffer solutions (Figure 26)

Figure 25

Figure 26

3. Implementation of Calibration procedure in GUI
4. Implementation/testing of RFI and Antialiasing Filter as shown in Figure 27 below

Figure 27



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2	50.00k	49.9k
5	12.50k	12.4k
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100	505.1	511
200	251.3	249
500	100.2	100
1000	50.05	49.9
2000	25.01	24.9
5000	10.00	10
10000	5.001	4.99

NC: No Connection.

$$\textbf{LP Filter}_{Diff} = \frac{1}{2\pi R(2C_D + C_C)}$$

Note: $C_D \geq C_C$

RF rectification can cause some problems in an amplifier due to strong RF signal. Sometimes the disturbances can appear as a small DC offset voltages in the signal. By using the first low pass filter at the input stage we will be able to filter out very high frequencies. In our design we are only dealing with a 1 Hz input frequency so our filter will be designed with a cutoff frequency of 2 Hz. A second low pass filter will be implemented if necessary.

5. Implementation of new Faraday box using aluminum enclosure as shown in Figure 28 below

Figure 28