

**Final Report for**

# **Virtual Multi-Channel Power Meter**

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**April 2019**

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## Background

In order to obtain a full picture of a power system, a power quality study of the system needs to be performed. A power quality study is used to gauge a power system's efficiency by measuring voltage and current. Though voltage and current measurements a power quality study reports the Apparent Power, True Power, Reactive Power; the phase relationship between the voltage and current (displacement power factor); harmonic content of the fundamental line frequency and multiples of the fundamental frequency; and total harmonic distortion of the current and voltage of a power system. Knowing the displacement power factor and harmonic distortion levels in a power system is important as it allows system operators to view any wasted energy in the system and address such issues as necessary.

A low displacement power factor (DPF) creates wasted energy known as reactive power. Displacement power factor less than 1 is common in AC induction motors. A certain level of reactive power is needed for a motor to operate, but high levels of reactive power does not contribute to the actual work being performed by the motor. A low DPF in a motor just contributes to a higher current draw from the source of the power system.

Harmonics are common in systems with non-linear loads such as power supplies and variable frequency drives. Such loads cause distortions in the AC current waveform. Distortions to the AC current waveform is the result of current conduction of input components in power supplies and variable frequency drives only occurring during specific times in a cycle, not over the whole cycle of an AC waveform, creating new frequencies in the system. Current distortion can cause voltage notching, resulting in more current being required to maintain a specific true power output. Harmonic content at high frequencies can also create resonances in a system, which can cause inductors and capacitors in the system to fail.

Power quality studies can be performed using a device known as a power quality analyzer, which is often called a power quality meter (PQM). An example of such a device is the Fluke 435 Series II Energy and Power Analyzer shown in Figure 1.



Figure 1: Fluke 435 Series II Energy and Power Analyzer

The Fluke 435 Series II Energy and Power Analyzer can be purchased for around \$8000 from a Fluke distributor. While this meter is on the less expensive side when compared with other power meters, it is not suitable for low current measurements found in laboratories.

Power quality meters designed for laboratory settings are available, however such a device can cost upwards of \$50,000. One example of a power quality meter designed for laboratory settings is the Hioki Power Analyzer PW6001, shown in Figure 2 below.



Figure 2: Hioki Power Analyzer PW6001

This device is capable of reading voltages as low as 6V and currents as low as 100mA. This device would make a fine addition to the Point Park University Power Lab; however, it is quite complex and rather expensive. The Hioki Power Analyzer PW6001 retails for around \$25,000, which does not include the accessory probes needed to measure current and voltage.

Due to the high cost of laboratory grade power quality meters, the Electrical Engineering department at Point Park University has proposed a senior design project to design and build a prototype PC based virtual power quality meter (PQM) with the following features:

- One voltage input channel rated for up to 600V (ac + dc)
- One current input channel rated for up to 20A (ac + dc)
- Accuracy of 0.1% of voltage and current measurements
- Detection of voltage and current harmonic content up to 1kHz
- Voltage input channel withstand rating of 1500V
- Current input channel withstand rating of 50A
- Isolation rating of 1500V between the input of voltage and the input current terminals

The goal of this project was to prove through delivery of a prototype PQM that the production of a low cost PQM is possible. If such a device is possible, future senior design classes will expand the device into a low-cost PC based virtual multi-channel PQM capable of displaying:

- Peak and RMS values of voltage and current in a 3-phase system
- Complex Power of a 3-phase system (volt-amperes)
- Real Power (Watts)
- Reactive Power (VARs)
- Power factor
- Phase angle between voltage and current
- Harmonic content through the 15<sup>th</sup> harmonic of a 60 HZ system

This document is written to report the first steps of the design of a low-cost PC based virtual multi-channel power quality meter. This document will describe the design process of the PQM; issues that arouse during the design; corrections to said issues; acceptance testing of PQM; the hardware and software being delivered; product documentation such as manuals, schematics, and software locations; a budget and timeline of project, and a project conclusion.

## Work

### Work Overview

The user interface for the PQM was designed using LabVIEW. LabVIEW is a programming software package by National Instruments that utilizes a block diagram approach to coding. Programming is completed on the back panel, which LabVIEW refers to as the block diagram. The user interface is displayed on a virtual front panel.

Voltage measurements required for analysis by the LabVIEW based PQM were acquired through use of a resistor divider network and fed into channel 0 of USB-1808X data acquisition module. Current measurements required for analysis by the LabVIEW based PQM were acquired through use of a shunt resistor and an instrumentation operational amplifier (OP Amp), and fed into channel 1 of USB-1808X data acquisition module. The USB-1808X data acquisition module (DAQ) used for this project was made by Measurement Computing.

The Measurement Computing USB-1808X, which was specified for use in this project by Dr. Keller, is a USB bus powered DAQ that contains 8 analog inputs, each with a  $\pm 10V$  rating with 18 bits of precision. The device is capable of sampling each channel simultaneously at a rate of up to 200k/s.

A complete description of the hardware and software used for this PQM can be found in the Hardware and Software Deliverables section of this report.

### Software Development

The first stage of this project was to attempt to acquire a single voltage signal in LabVIEW using the circuit shown in Figure 3 below and the example in Measurement Computing's ULx for NI LabVIEW Software Quick Start manual shown in Figure A1 in Appendix A. A link to the Measurement Computing's Software Quick Start manual can be found in Appendix C of this report. The load for this first test was a 1kOhm resistor.

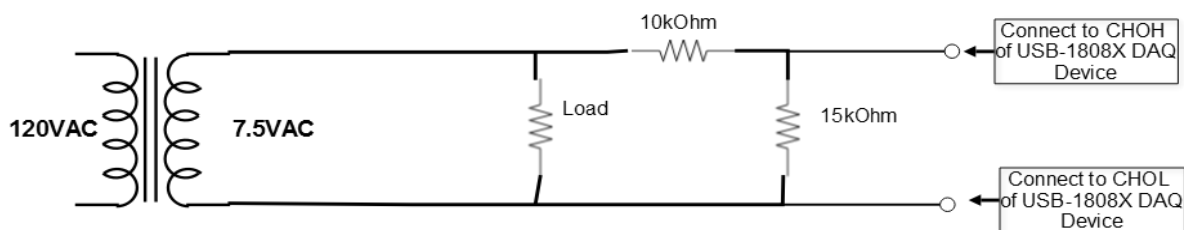


Figure 3 – PQM meter test circuit voltage only

To read a voltage signal, the physical channels input was configured to read channel 0 of the DAQ module, the sample rate was set to 100,000 samples per a second, and the number of samples to be acquired to was set to 10,000. Upon hitting the start button on the LabVIEW task bar, the program acquired 10,000 samples of a 4.5V<sub>RMS</sub> 60Hz signal at a rate of 100,000 samples per a second, and plotted the samples on a Waveform Graph. The result was approximately 6 cycles being displayed on the program's front panel. Note: In order to sample another few cycles to be viewed on the graph, the program run button had to be pressed again.

To have continuous data acquisition, a while loop was set around the code as shown in Figure 4 below. However, simply adding a while loop to the circuit was not the only necessary change required for the feature of continuous data acquisition.

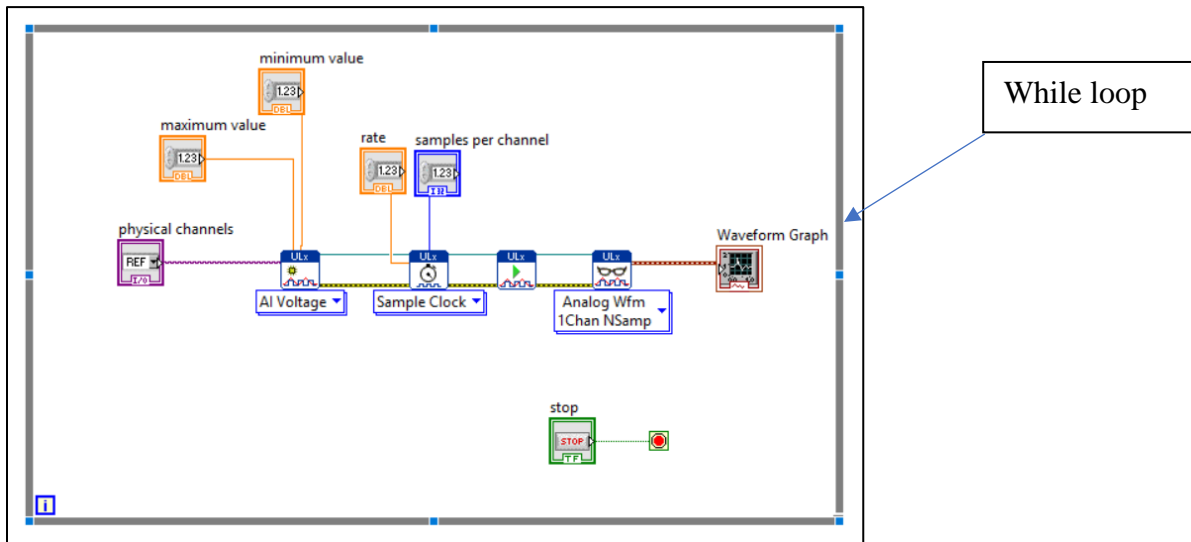


Figure 4 – Addition of a while loop

Just adding a while loop around the code presented an issue of the code starting the task over without realizing that the total number of samples had not yet been completely acquired. To correct this issue a delay time between loops had to be added. The code in Figure 5 shows the time delay being added. The time delay set was 167ms; this time was chosen because it takes 100ms to finish the data acquisition of 10,000 samples when the sample rate is set to 100,000 samples per a second. An addition 67ms was added as a buffer to allow the program enough time to plot the data onto a graph. Adding this change allowed for the appearance of a continuous signal being displayed on the waveform graph.

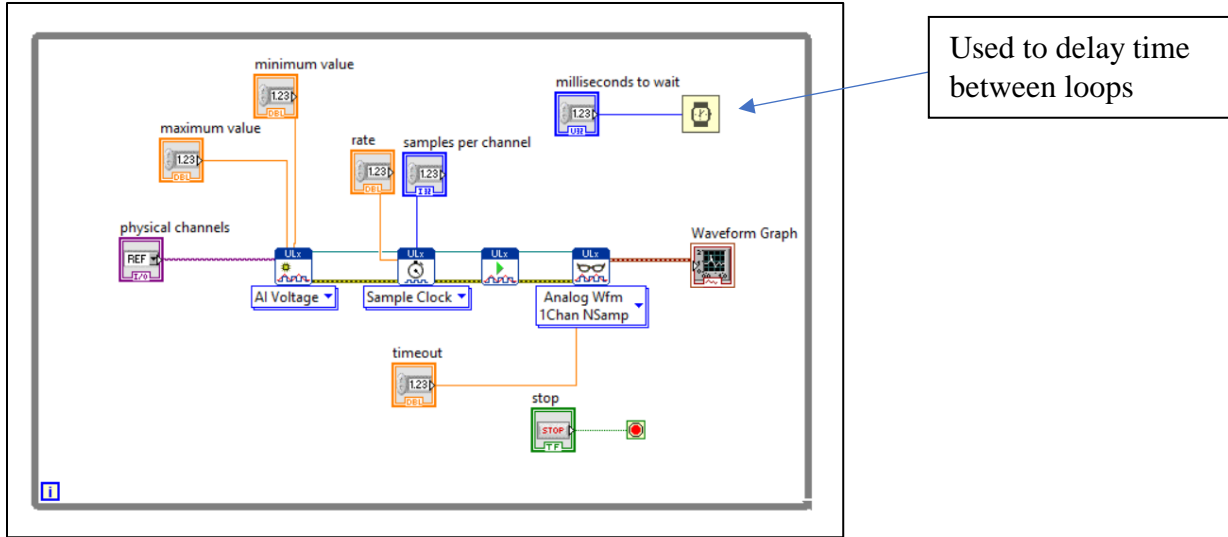


Figure 5 – Code required to add time delay between loops

Upon successfully reading a voltage signal, an attempt to measure both current and voltage was made, along with the attempt to measure the RMS values of the current and voltage and the phase difference between the two signals. The first attempt code can be found in Figure A2 in Appendix A of this report. The circuit in Figure 6 was constructed to measure both current and voltage, which are the required data sets for a power quality meter. This test circuit was used for the duration of the software development.

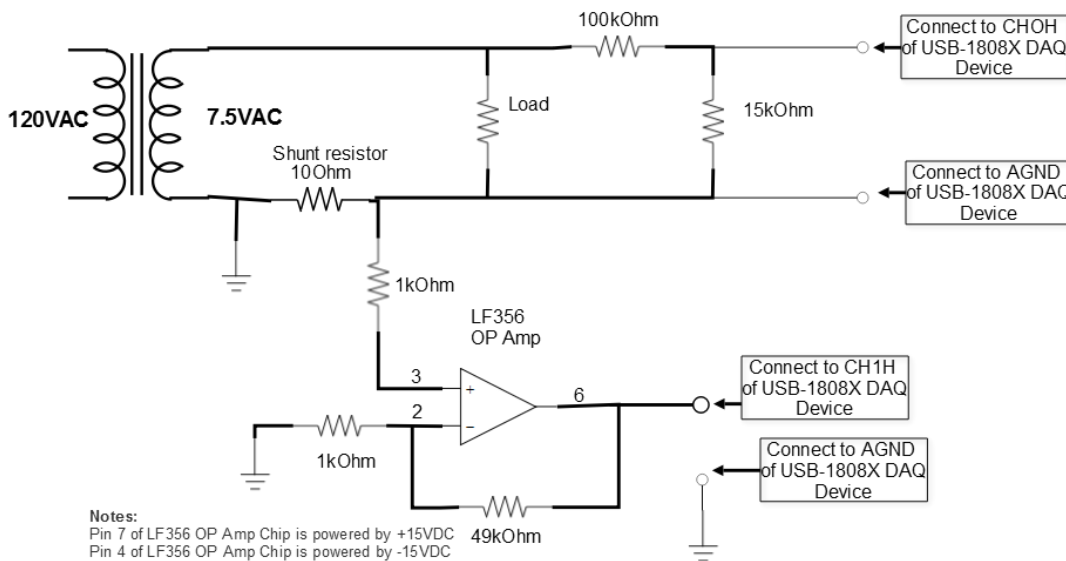


Figure 6 – PQM meter development test circuit

The initial test used a 1kOhm load resistor, which resulted in approximately 7.5mARMS flowing through the circuit, causing a 75mVRMS drop across the resistor. A non-inverting operational amplifier with a gain of 50 was used to increase the voltage representing current to 3.75VRMS, before feeding the voltage signal into DAQ module. Figure 7 shows the current and voltage

signals on the PQM wave graph for the first time. The signals appear to be out of phase, because as can be deduced from the code in Figure A2 in Appendix A, the signals were being acquired sequentially due to two tasks being performed to read the two signals. Note: The signals were not scaled to actual values. Scaling the voltage and current signals to actual values was not completed until later in the project through use of scalar multipliers and dividers.

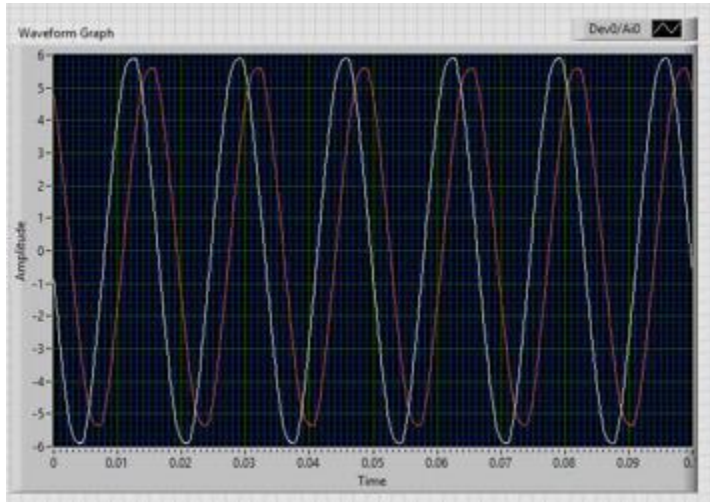


Figure 7 – Current and Voltage signals (not acquired simultaneously)

The code shown in Figure A3 located in appendix A corrects the issue of the current and voltage not being sampled simultaneously. Selecting the physical channels 0 and 1 of the DAQ module to be acquired by the LabVIEW program and setting the read ULx block in the software to Analog 1D Wfm NCann NSamp allowed the program to sample both the current and voltage signals simultaneously.

As shown in Figure A3 located in the appendix, the voltage and current RMS values and phase relationships are being measured using LabVIEW function blocks. The function blocks needed to complete these tasks were researched by scanning through the palettes in LabVIEW using LabVIEW's built in help feature for each function block. The help feature for each block describes the function of each block and provides examples of applications where the function block may be useful.

The RMS values of current and voltage were computed using the LabVIEW function block “Amplitude and Level Measurements”, which can be found under the Express/Signal Analysis palette in LabVIEW. The “Amplitude and Levels Measurements” function block can be configured to read Mean (DC), RMS, Positive peak, Negative peak, Peak to Peak, cycle average, and Cycle RMS. Setting the Amplitude and Levels Measurements function block to RMS takes the Root Mean Square of the whole data set acquired.

The phase difference between voltage and current was found using LabVIEW function block “Tone Measurements”, which can also be found under the Express/Signal Analysis palette in LabVIEW. The “Tone Measurements” block can be configured to read Amplitude, Frequency and Phase. To measure the phase of each of the voltage and current, each respective signal was



fed into its own Tone Measurements block configured for Phase detection. The voltage phase and current phase were referenced to the first data point taken during the data acquisition and the first zero crossing of said signal. The phase difference between the voltage and current was then calculated by subtracting the Current Phase from the Voltage Phase. In a later code revision, the phase difference between current and voltage was removed. The voltage phase was set to a base point of zero and the current phase being reported was corrected to show its difference from the voltage phase.

In code revision 3 shown in Figure A4 located in Appendix A, scalar dividers were used to calibrate the meter (multipliers would have worked as well), and the power meter was configured to report Apparent Power, Real Power, Reactive Power, and Power Factor. The method of calculating Real Power and Reactive was changed in the 4<sup>th</sup> revision of the code. As can be observed with code revision 3, the method of calculating True Power and Reactive Power is only valid if the voltage and current signals are purely sinusoidal. Any distortions in the sinewave would not have been considered by simply using trigonometry to calculate True Power and Reactive Power.

The 4<sup>th</sup> revision of the code for the PQM meter labeled Figure A5 in Appendix A, changed the method of calculating Real Power and Reactive Power to be compatible with signals that are not purely sinusoidal. Revision 4 calculates true power by taking the arithmetic mean of the sum of the instantaneous products of voltage and current, which is better described with the formula:

$$P = \frac{1}{N} \sum_{n=1}^N i(n\Delta t)v(n\Delta t)$$

Apparent power was calculated by multiplying  $V_{RMS}$  by  $I_{RMS}$ .

Power Factor was calculated by dividing Real Power by Apparent Power.

Reactive power was calculated using a Formula Node, which can be found under the Structures palette in LabVIEW. The Formula Node was populated with the formula:  $Q = \sqrt{S^2 - P^2}$

Before it was possible for Inputs S and P to be connected to the Formula Node, the data types of each had to be converting from a dynamic data type to a floating-point scalar by using LabVIEW function block “From DDT” configured to single scalar. The “From DDT” function block can be found under the Express\Signal Manipulation palette in LabVIEW.

The final version of the software code for the PQM is shown in figure A6 of Appendix A. In the final version of the software code, the phase detection of current and voltage was removed. Also, the final revision included a median filter used to provide a more accurate power reading by taking the median of last five calculated power ratings. The final change to the code was converting the power factor into phase difference between current and voltage.

The virtual front panel for the virtual power quality meter was configured to be intuitive by using tap control. Figure 8 below shows the first tab of the PQM virtual front panel.

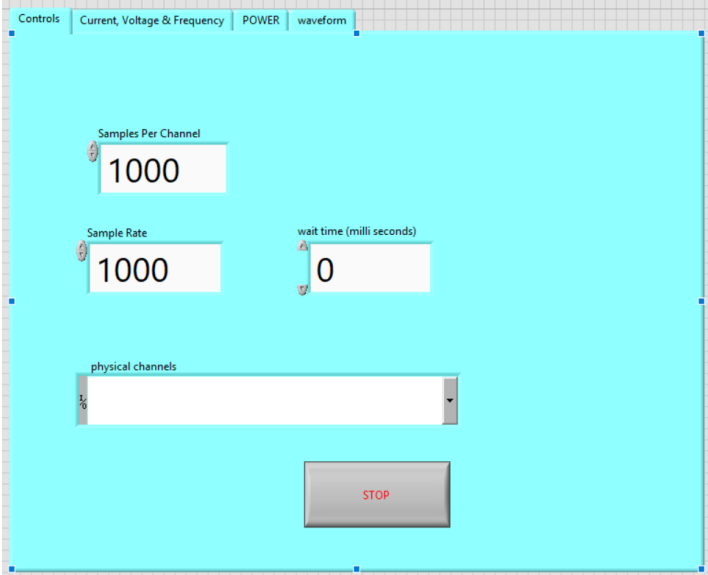


Figure 8 – Controls tab of PQM virtual front panel

The controls tab was configured for the user to select the physical channels that that will be acquired, the number of samples per a channel to be acquired, the rate at which each channel will be sampled, and the wait time between each acquisition of data. The PQM can also be stopped from the controls tab.

The Current, Voltage & Frequency tab shown in Figure 9 displays the RMS values for Current and Voltage, along with the line frequency.

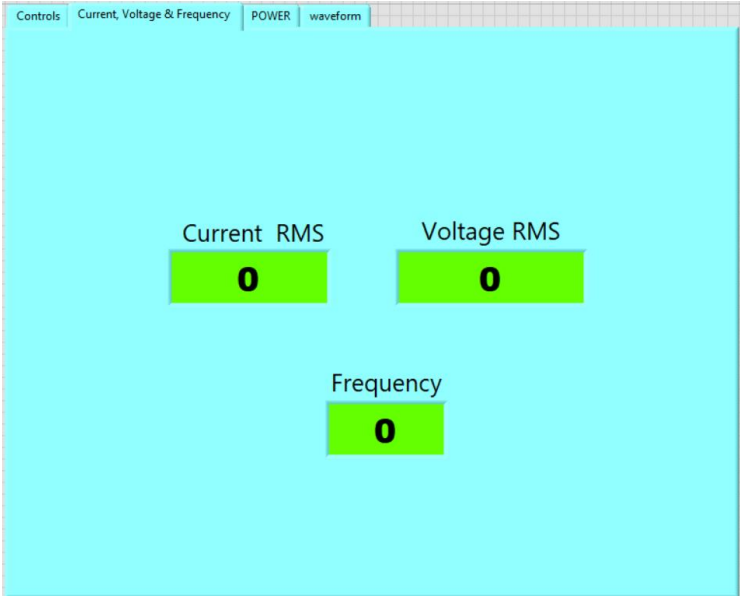


Figure 9 – Current, Voltage, & Frequency tab of PQM virtual front panel

Apparent Power (VA), True Power (Watts), Reactive Power (VARs), Power Factor (PF) and the phase difference (Theta) between current and voltage readouts were assigned to the tab labeled POWER, shown in Figure 10.

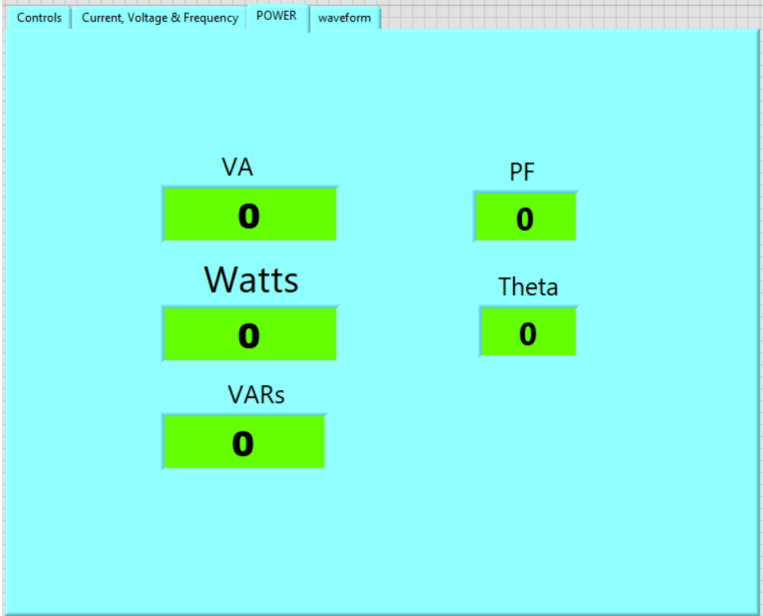


Figure 10 – POWER tab of PQM virtual front panel

The last tab, shown in Figure 11, of the PQM virtual front panel was configured for the waveform display of the voltage and current waveforms. From this tab, the user can view the current as leading or lagging the voltage.

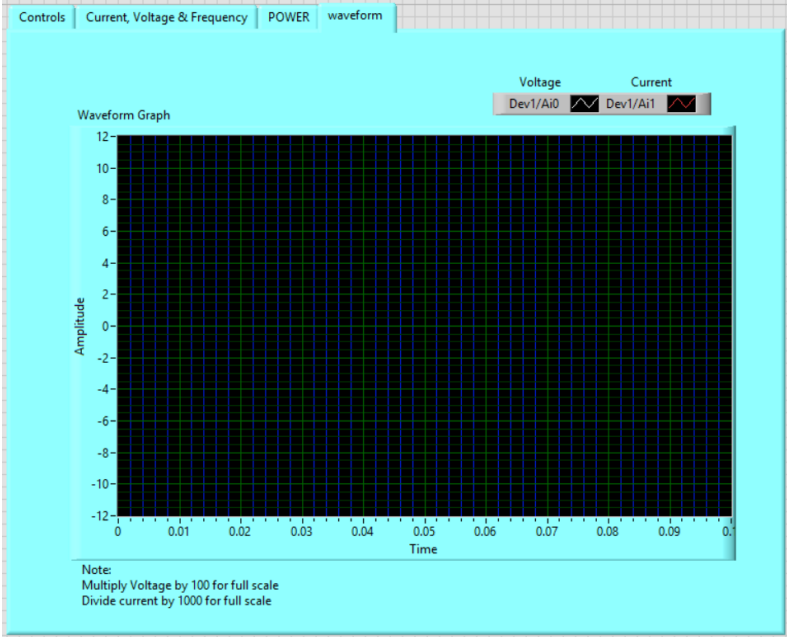


Figure 11 – waveform tab of PQM virtual front panel

When applicable the read outs were configured to display values in engineering notation.

## Hardware Development

As stated in the background section of this report, the objective of the project was to design a power meter capable of measuring voltages up to 600V and current up to 20A. However, voltages above 240V and currents above 3A were not available in the Power Lab. Due to available voltage and current levels in the Power Lab, the hardware was designed to operate on a single phase of a 3 phase AC system with a max line to line voltage of 300VAC.

The voltage divider network shown in Figure B1 in Appendix B of this report was used to bring the line voltage down to a safe level before feeding it through the isolation circuit which connects to channel 0 of the USB-1808X DAQ.

The USB-1808X DAQ has 8 analog inputs each rated for +/- 10V. To ensure that a voltage greater than +/-10V was never applied to the DAQ, the resistor divider network was designed for an output voltage of  $5V_{RMS}$  on a max voltage input of  $300V_{RMS}$ . A series of resistors were used to step down the voltage. This method was employed so that the voltage potential across any one of the step-down resistors was not greater than  $50V_{RMS}$  to avoid a flash over on the resistors. The max current through the resistor divider network would be 0.5mA, giving an estimated power dissipation of 150mW for the whole resistor divider circuit.

The output of the voltage divider circuit was fed into Texas Instrument ISO124 Isolation Amplifier chip that was used to provide galvanic isolation between the mains circuit and the DAQ module. The ISO124 chip was suggested to be used in this project by Dr. Keller Professor of Electrical Engineering at Point Park University. Dr. Keller also specified the use of Murata Power Solutions MEV1D0515DC DC-DC converter to isolate the input ISO124 chip supply power from the output ISO124 chip supply power.

During the development, directly connecting the resistor divider network to the ISO124 Isolation Amplifier created a slight loading effect on the resistor divider network because the ISO124 chip's low input impedance of 200kOhm. Knowing that a single OP amp has a high input impedance and low output impedance, a unity gain buffer, shown in the circuit in Figure B1 in Appendix B, was installed between the resistor divider network and the ISO124 chip input. A LF356 JFET OP Amp which was originally recommended by the project sponsor Mr. Michael Zaffuto for use in the software development circuit in Figure 6, was used for this unity gain buffer. The installation of this unity gain buffer prevented the loading of the ISO124 chip on the resistor divider network.

Current was measured by using of a shunt resistor in series with the source and the load. The shunt resistor was sized for a max voltage drop of 100mV when 5A of current flows through it, which required a 20mOhm resistor. The max watt loss of the resistor was calculated to be 500mW. The shunt resistor was installed into a plastic enclosure with banana connector on each end to make connecting the shunt resistor easy and safe. Figures 12 and 13 show the shunt resistor box. Figure B2 in Appendix B shows the current measuring circuit for transferring the voltage drop across the shunt resistor to channel 1 of the USB-1808X DAQ.



Figure 12 – Enclosed shunt resistor

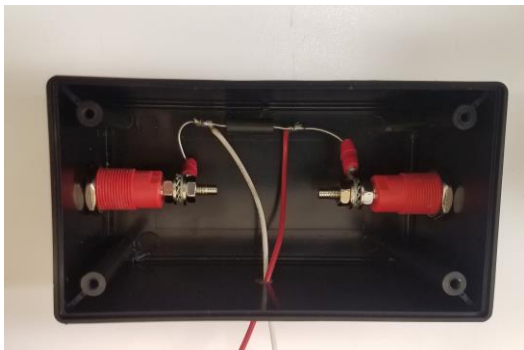


Figure 13 – Internal view of shunt resistor

When connecting the shunt into the circuit it was important to make sure that with the shunt resistor enclosure oriented as shown in Figure 12, the left side connector was connected to the hot side of the circuit and the right side was connected to the neutral side of the circuit. It was also important to have the red wire connected to V+IN pin 3 of the INA118 chip and the white wire connected to V-IN pin 2 of the INA118 chip in the current channel circuit in Figure B2 in Appendix B. Swapping any of these wires would result in an inversion of the current reading, which would make the current appear to be leading in an inductive circuit and lagging in a capacitive circuit.

A voltage drop across the shunt resistor was measured using a Texas Instrument 118P Precision Instrumentation Amplifier. The 118P chip was chosen for its low current draw of  $385\mu\text{A}$ , its high bandwidth of 70kHz at 100 Gain, and its easy of gain adjustment. The 118P chip has fixed internal resistance, and gain is adjusted by changing the resistance between pins 1 and 8 of the chip. A gain to the voltage drop of the shunt resistor was needed to increase the signal from a few millivolts to a few volts, so that the signal was less susceptible to noise.

As stated earlier, galvanic isolation (ground loop elimination) was provided through use of a Texas instrument ISO124 chip. The ISO124 chip was also used to provide isolation between the input of the voltage divider network and the input of the DAQ module so that if an overvoltage were to occur on the high side of the circuit, the transient would not travel to the DAQ module.

According to Texas Instruments the ISO124 chip provides continuous voltage isolation up to  $1500V_{RMS}$ . The ISO124 isolates the input and output of the circuit by transmitting the input signal digitally across a built-in 1pF capacitor. Additional information about the ISO124 can be found on the devices data sheet, which is linked in Appendix C of this report.

To test the full scale of the hardware and software, the circuit in Figure 14 was constructed. While it was not possible to measure the actual power factor using this circuit, the circuit did allow for testing the full scale of voltage and current readings.

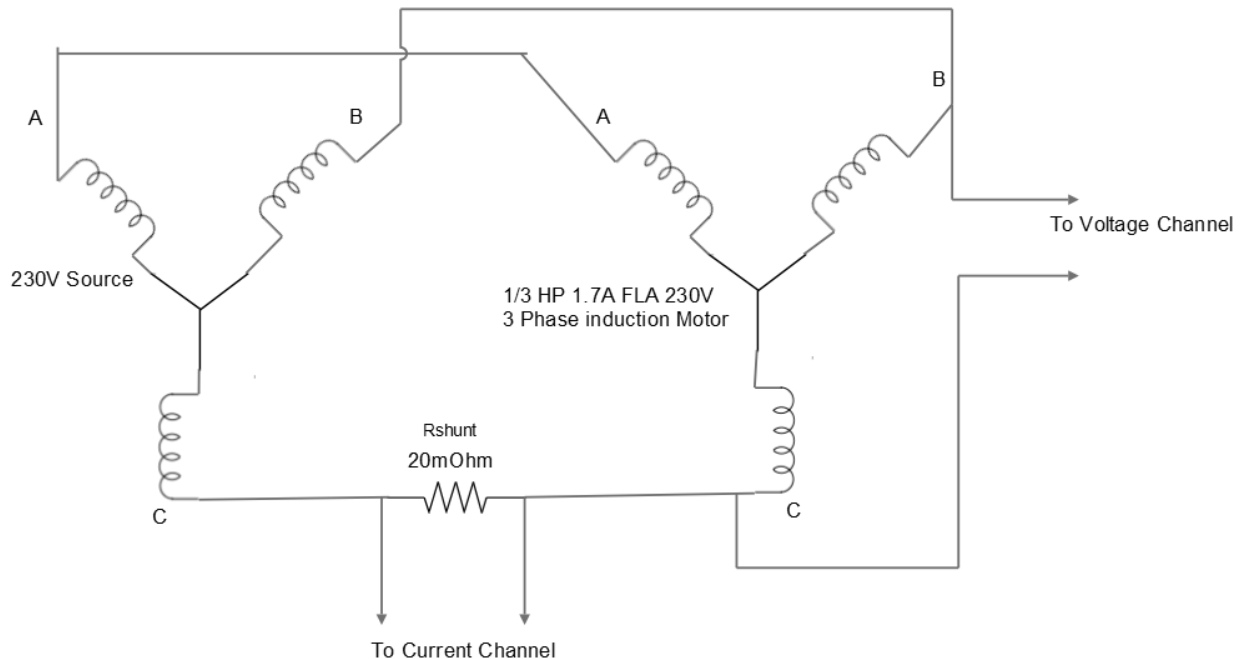


Figure 14 – PQM Full range test circuit

Before running the PQM software, the INA118 chip in the circuit in Figure B2 of Appendix B was configured for a gain of 50 by installing a 1kOhm resistor between pins 1 and 8 of the INA118 chip, the voltage calibration multiplier in the PQM program was set to 60, and current calibration divider was set to 1. A Fluke 189 meter was used to measure the actual line voltage and another Fluke 189 meter was used to measure the current to provide a comparison with the PQM. Upon running the PQM program, the voltage was slightly overshooting the voltage reading of the Fluke 189 meter. Due to only 5% accuracy resistors being used in the voltage divider circuit in Figure B1 of Appendix B, the voltage divider circuit was not exactly 1:60. Through trial and error, the voltage multiplier to bring the PQM meter to read within 1% of the Fluke 189 reading was found to be 51.2. The current divider was nearly accurate, but had to be adjusted to 1.03 to bring the meter within 1% of the Fluke 189 meter.

Testing of the PQM's full functionality was completed using the circuit in Figure 15. The circuit in Figure 15 was also used for the acceptance testing of the PQM.

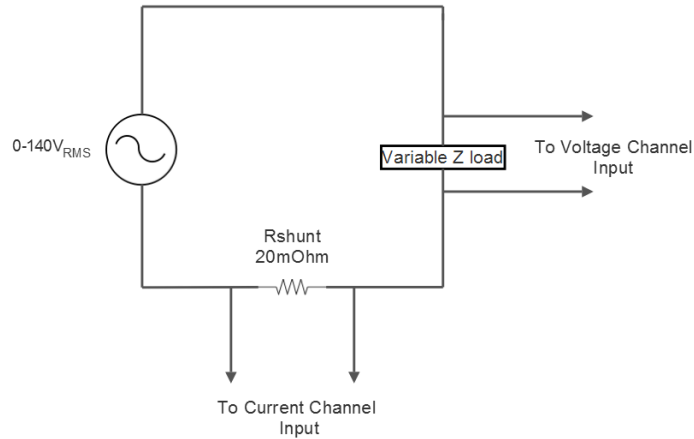


Figure 15 – Test circuit for full functionality of PQM

The variable Z load in the circuit of Figure 15 is shown in Figure 16.



Figure 16 – Variable Z load bank

By varying the voltage and the impedance of the circuit in Figure 15 the current of the circuit was varied between  $53\text{mA}_{\text{RMS}}$  and  $350\text{mA}_{\text{RMS}}$ , which resulted in voltage drops between  $1\text{mV}_{\text{RMS}}$  and  $7\text{mV}_{\text{RMS}}$  across the shunt resistor. Using a  $50\Omega$  5% resistor between pins 1 and 8 of the INA118 instrumentation amplifier in Figure B2 located in the Appendix, the voltage signal that the DAQ module read was between  $1\text{V}_{\text{RMS}}$  and  $7\text{V}_{\text{RMS}}$ .

Before testing the virtual power quality meter with the circuit in Figure 15, the software listing was adjusted with the following changes:

- current divisor for RMS current readout was set to 20
- voltage multiplier for RMS voltage readout was set to 51.2
- voltage multiplier for scope display was set to 0.512
- current divisor for scope display was set to 2

The current divisor of 20 was selected because the shunt resistor value multiplied by the instrumentation amplifier gain equals 20.

The circuit was tested with inductive-resistive loads, purely resistive loads, and capacitive-resistive loads. During the testing the PQM was configured to acquire 10,000 sample per a

channel at a rate of 100,000 samples per a second, every 167mS. The waveform chart was used to see that the PQM was able to show unity, current lagging voltage, and current leading voltage, which respectively is displayed in Figures 17, 18, and 19.

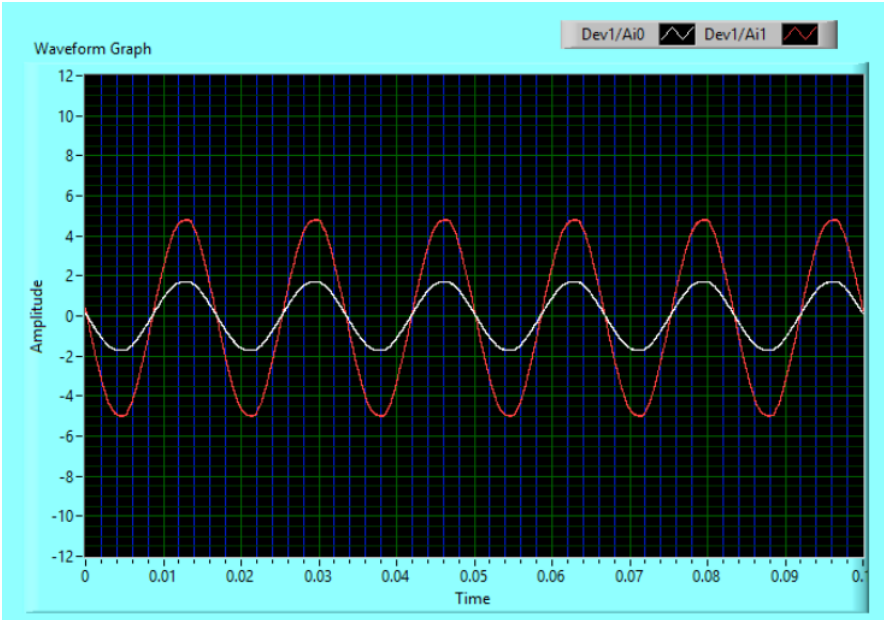


Figure 17 – Display of Unity

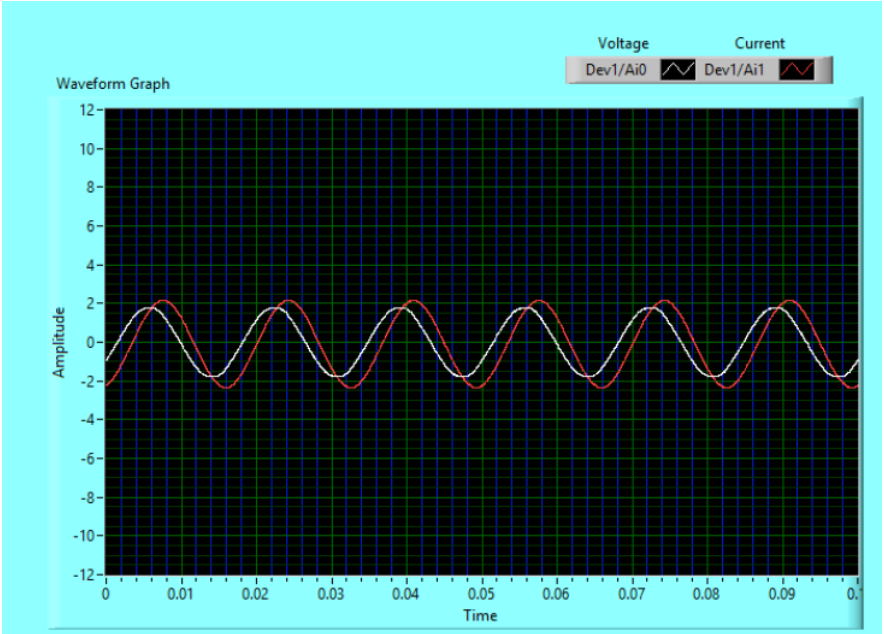


Figure 18 – Display of Current Lagging Voltage



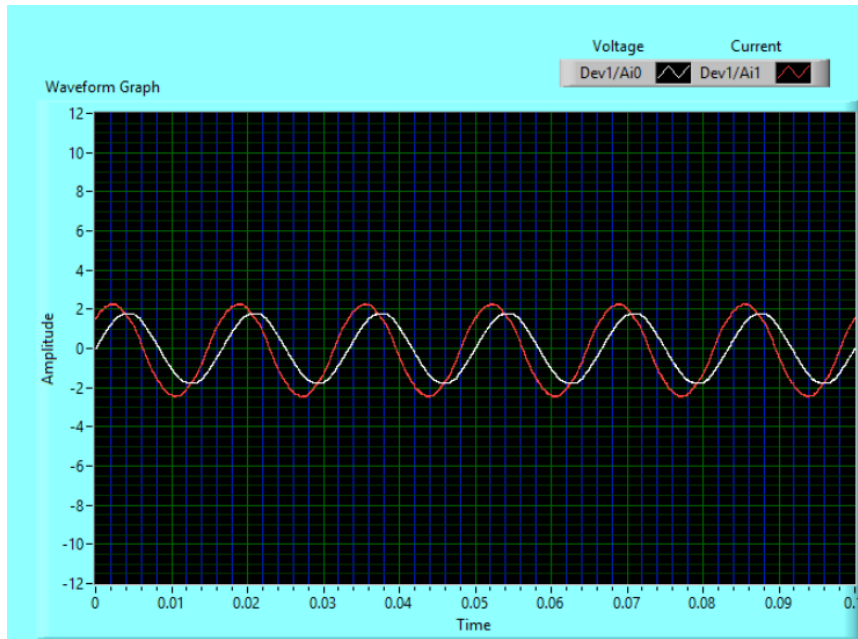


Figure 19 – Display of Current Leading Voltage

The PQM was calibrated for current readings for AC current ranging from 50m<sub>ARMS</sub> to 350m<sub>ARMS</sub> and AC voltage ranging from 0 to 300V<sub>RMS</sub> by comparing the current and voltage reads of the PQM to the voltage and current readings of Fluke 189 true RMS meters. Through trial and error, the voltage reading of the PQM was calibrated to be within 1% of the Fluke 189 true RMS meter by setting the voltage multiplier of the PQM software listing to 51.2. Through trial and error, the current reading of the PQM was calibrated to be within 1% of a Fluke 189 true RMS meter by setting the current divider of the PQM software listing to 19.5.

### Tasks not complete

Time did not permit for the PQM to be thoroughly tested on a DC system due to issues that arose during hardware development. The PQM likely will not have an issue operating on DC circuits. During the voltage channel development, a D battery was placed at the input of the voltage channel circuit. The PQM read the battery DC voltage with no problem. However, the current channel was not tested for DC current.

During the initial testing of the voltage and current channel hardware mated together, a small DC offset of a few millivolts was detected at the current channel input circuit with the gain of the instrumentation amplifier used in the current channel set to 50. This small DC offset was ignored at first. However, as the gain of the instrumentation amplifier was increased, the DC offset also increased. Tracking down the root cause of the DC offset proved to be quite time consuming. The root cause of the DC offset was eventually found, after probing around the circuit for a few lab sessions, to be a defective DC-DC converter.

## Acceptance Testing

The PQM was validated on the single-phase AC circuit shown in Figure 15, which has a voltage supply capable of being varied from 0-140V<sub>RMS</sub> and a variable impedance load. The voltage readings of the PQM were validated between 26V<sub>RMS</sub> and 127V<sub>RMS</sub>. The current reading of the PQM were validated between 52.44mA and 353.22mA. The power factor reading of the PQM was tested for cases of unity, leading and lagging power factor.

The following devices were used to measure the accuracy of the PQM:

- Qty 2 – Fluke 189 True RMS Digital Multimeters
- Qty 1 - Tektronix Oscilloscope TDS 3014B

The validation of the PQM was performed on April, 11, 2019.

The apparent power reading accuracy of the PQM varied from 0.26% to 1.75%.

The true power reading accuracy of the PQM varied from 0.28% to 3.07%

The reactive power reading accuracy of the PQM varied from 0.1% to 3.57%.

The power factor reading accuracy of the PQM varied from no difference to 2.7%.

The voltage reading accuracy of the PQM was within 0.25% accuracy for readings above 70V.

The current reading accuracy of the PQM was within 1% accuracy for readings above 140mA.

A full report of the procedures and results of the PQM validation testing can be found in the validation report being supplied with this report.

## Project Hardware and Software Deliverables

Hardware being delivered is as follows:

- Voltage Measuring Circuit in Figure B1 installed on trainer breadboard
- Current Measuring Circuit in Figure B2 installed on trainer breadboard
- A 20mOhm shunt resistor installed in an enclosed box with banana style connectors

Software being delivered is a LabVIEW file titled Power Quality Meter Program Final. The file is located on a USB flash drive provided with this report.

The software being delivered works with a single-phase circuit and reports the following:

- Voltage in RMS
- Current in RMS
- Power Factor
- Apparent Power, True Power, and Reactive Power
- A graphical display of the current and voltage waveforms

## Project Documentation Deliverables

Included with this report are the following:

- A wiring schematic for the voltage measuring circuit (Figure B1 in Appendix B)
- A wiring schematic for the current measuring circuit (Figure B2 in Appendix B)
- A final software code block diagram (Figure A6 in Appendix A)
- Validation Testing report of Power Quality Meter (attached with report)
- A listing of links for component data sheets of all hardware components (located Appendix C)
- A user manual for running and calibrating the Power Quality Meter (attached with report)

## Budget and Timeline

### Budget

The estimated component cost not including the Measurement Computing USB-1808X DAQ module, which was already owned by the University, was \$1082.00. The cost was drastically over estimated, as the true material cost for development was \$152.04. The table below shows a breakdown of material used for this development project. The USB-1808X and LabVIEW was already owned by the University.

qty	part	description	unit price	extended price
2	ISO124P-ND	ISOLATION OPAMP	\$20.43	\$40.86
2	MEV1D0515DC	DC -DC Converter	\$6.69	\$13.38
10	capacitors	1uF	\$1.00	\$10.00
1	13FPRO20E-ND	RES 0.02 OHM 3W 1% FOUR TERMINAL AXIAL	7.96	7.96
1	13FR020E-ND	RES 0.02 OHM 3W 1% TWO TERMINAL AXIAL	\$2.40	\$2.40
5	LF356N/NOPB-ND	IC OPAMP JFET 5MHZ 8DIP	\$0.83	\$4.15
3	INA118P-ND	Instrumentation OP AMP	\$11.67	\$35.01
2	377-1167-ND	BOX ABS BLACK 4.11"L X 2.23"W	\$4.50	\$9.00
4	314-1218-ND	banana jack	\$5.07	\$20.28
10	WM18274CT-ND	CONN RING CIRC 18-22AWG #8 CRIMP	\$0.40	\$4.00
1	misc parts	connection wires resistors	\$5.00	\$5.00
			Total	\$152.04

## Timeline

The software of the PQM was developed first. Software development ran until the end of February. Hardware development was not started until the software development was complete. Hardware development was completed towards the end of March. The software and hardware were combined for full testing of the PQM at the end of March. Some issues arose during the full testing of the PQM, but were corrected in the middle of April. The project was completed on April 11, 2019, which was two weeks past the planned completion date.

## Conclusion

The goal of this project was to develop a low-cost virtual power quality meter to operate on a single-phase AC system, and a DC system. A power quality meter to operate on a single-phase AC system with a voltage range of 0-300V<sub>RMS</sub> and 100mA<sub>RMS</sub> to 5A<sub>RMS</sub> was developed. The power quality meter developed reports the RMS values for current and voltage, line frequency, apparent power, true power, reactive power, power factor, phase angle between current and voltage, and a waveform graph for displaying current and voltage. The meter was fully tested for a single-phase AC system; however, it was not tested for a DC system.

The accuracy of the meter's ability to report current and voltage was found to be within 1% for current ranging from 140mA<sub>RMS</sub> to 1.6A<sub>RMS</sub> and voltage ranging from 70V<sub>RMS</sub> to 208V<sub>RMS</sub>. For voltages and currents below these values the meter's accuracy was found to be within 5%.

The reason for this low accuracy below these current and voltage ranges listed is likely due to high resistance connections. The prototype boards used had resistances of around 20ohms between connection points. Gator to Gator clips used in the circuit also likely had high resistance connections. High resistance connections result in signal losses. Future designs with a focus on lower resistance connections and signal amplification when needed will likely make the meter perform more accurately with lower voltages and currents. Also, proper shielding around the meter input circuits would also help to prevent surrounding noise from degrading signals being acquired.

Time did not allow for the circuit to be tested on a DC system. Issues arose during the hardware development that prevented this testing from occurring. As stated previously, during the hardware and software implementation a high DC offset was detected in the current channel circuit output. Tracing the root cause of this problem took several lab sessions. The root cause was eventually traced to a defective DC to DC convert chip in the current channel circuit.

Overall the project's goals were accomplished. The lessons learned from this project were that things do not always go according to plan and that all individuals involved in a project development need to be fully involved and collaborate with one another for a project to be successful. Designs will not always work as expected. Deadlines will get pushed back due to mistakes made and other unanticipated events. However, the effort of all members of a team contributes to a project's success.

# Appendix A - Development Code

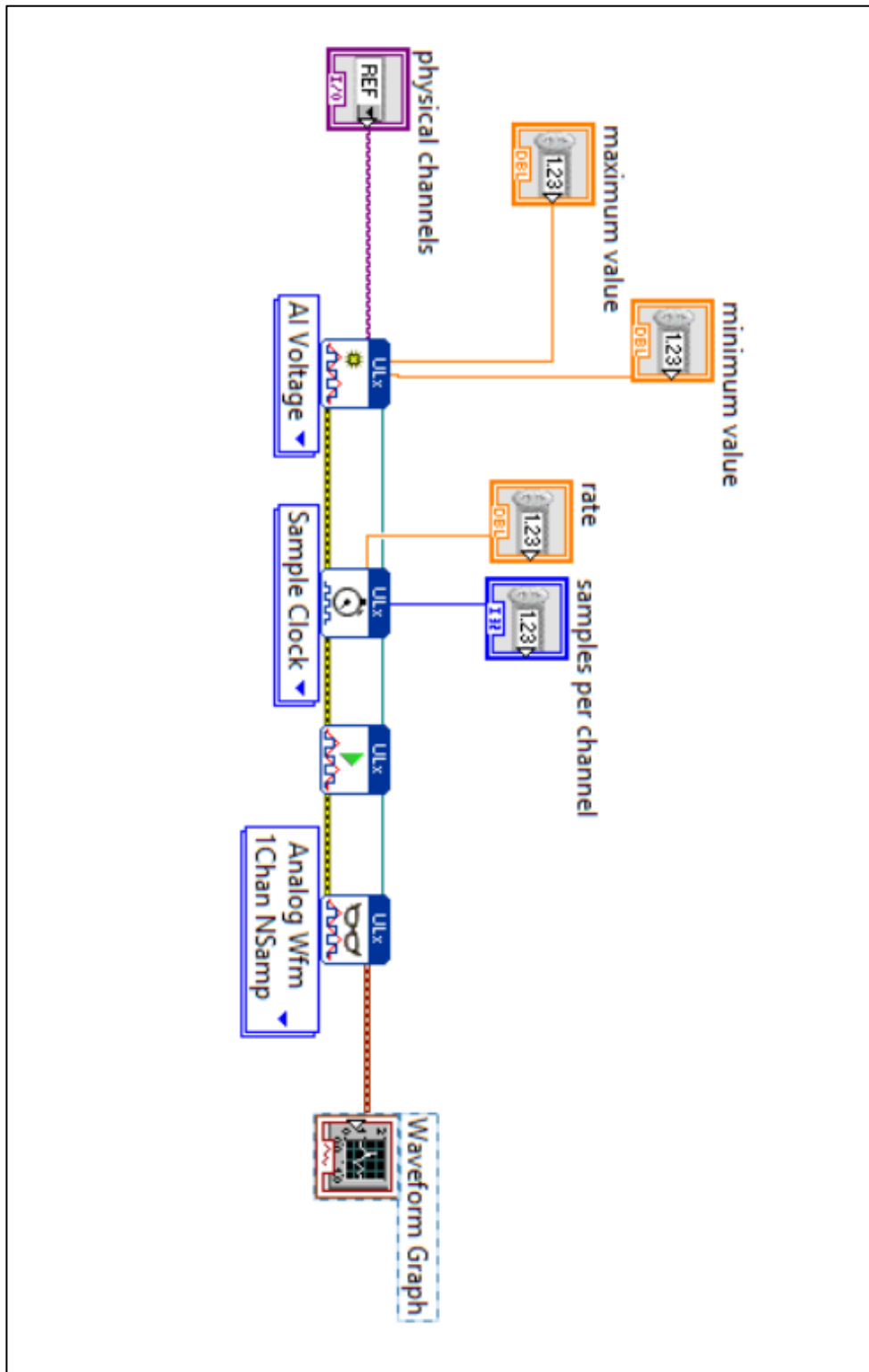


Figure A1 – Block diagram code for acquiring a single channel signal

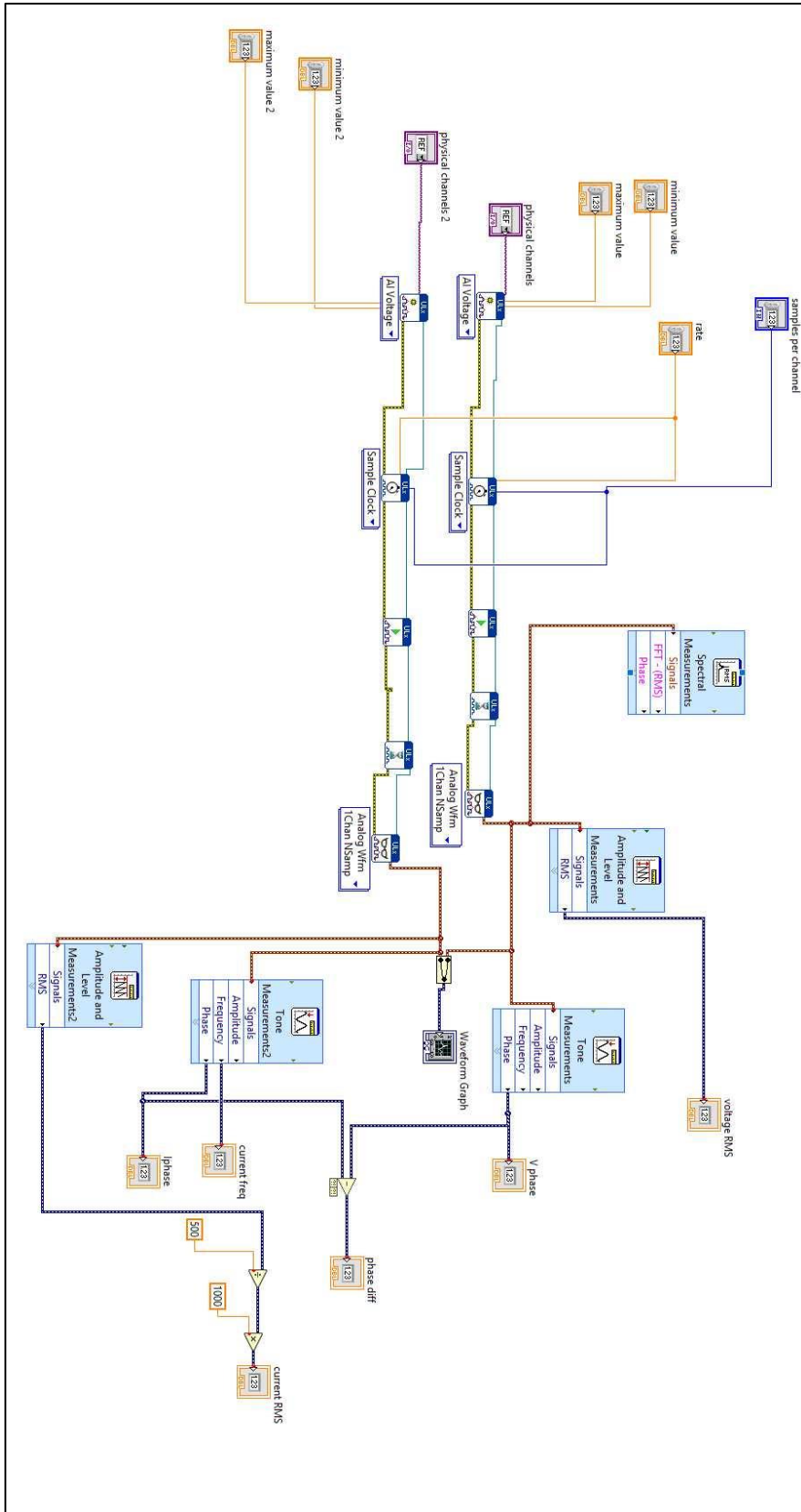


Figure A2 – First attempt code for acquiring voltage and current

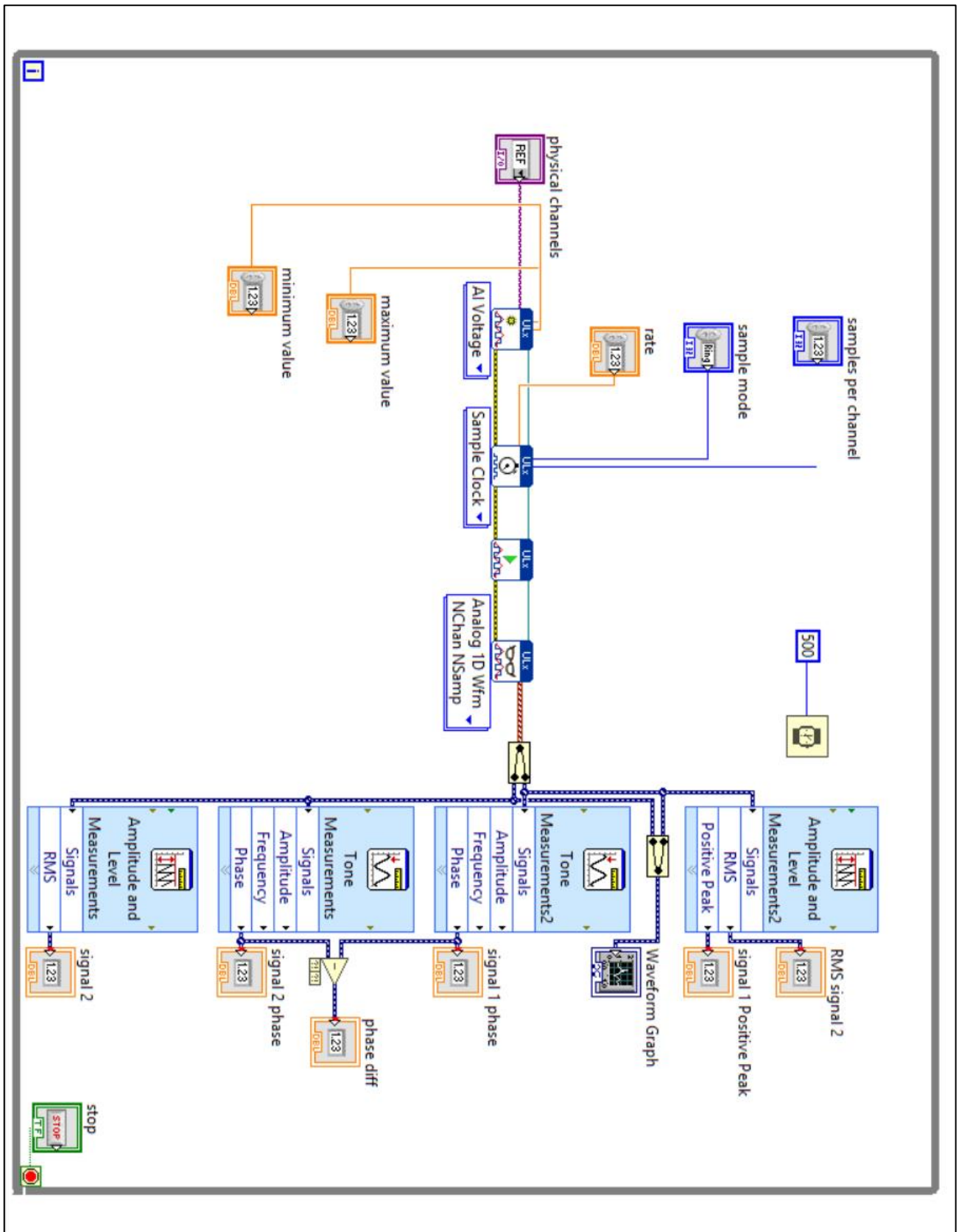


Figure A3 - Corrected Code for measuring current and voltage

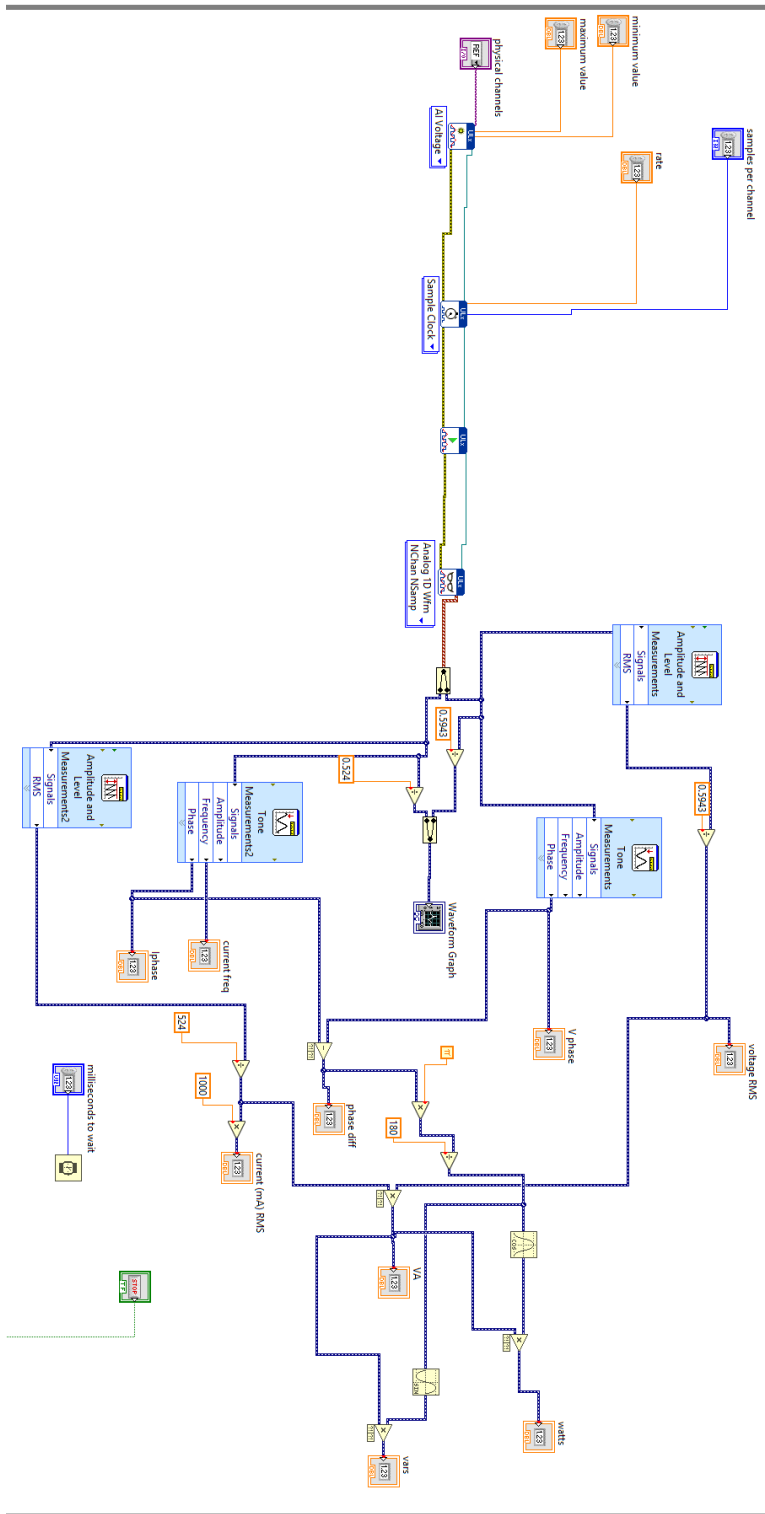


Figure A4 – 3<sup>rd</sup> Rev to Code



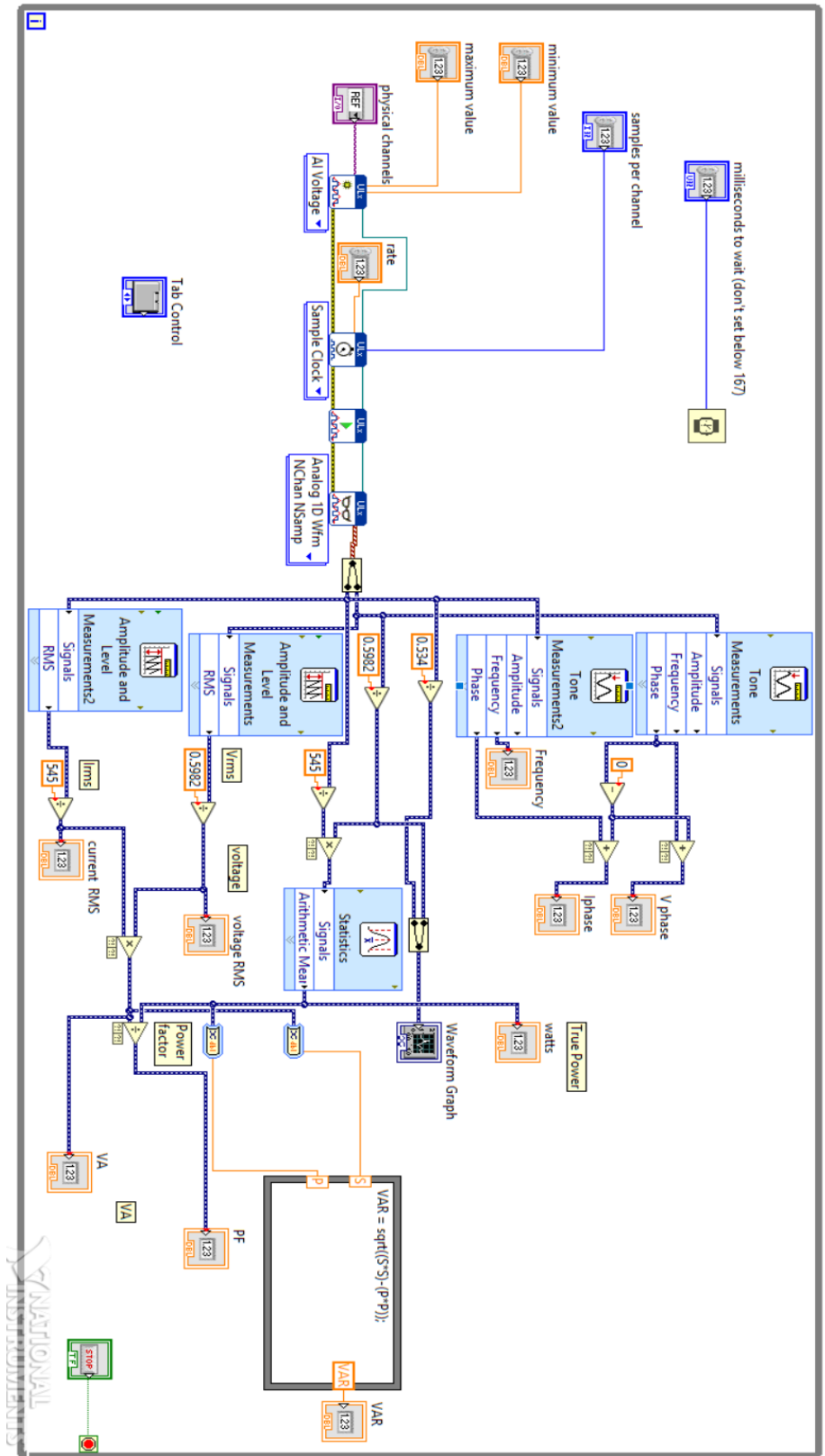


Figure A5 – 4<sup>th</sup> Rev to Code

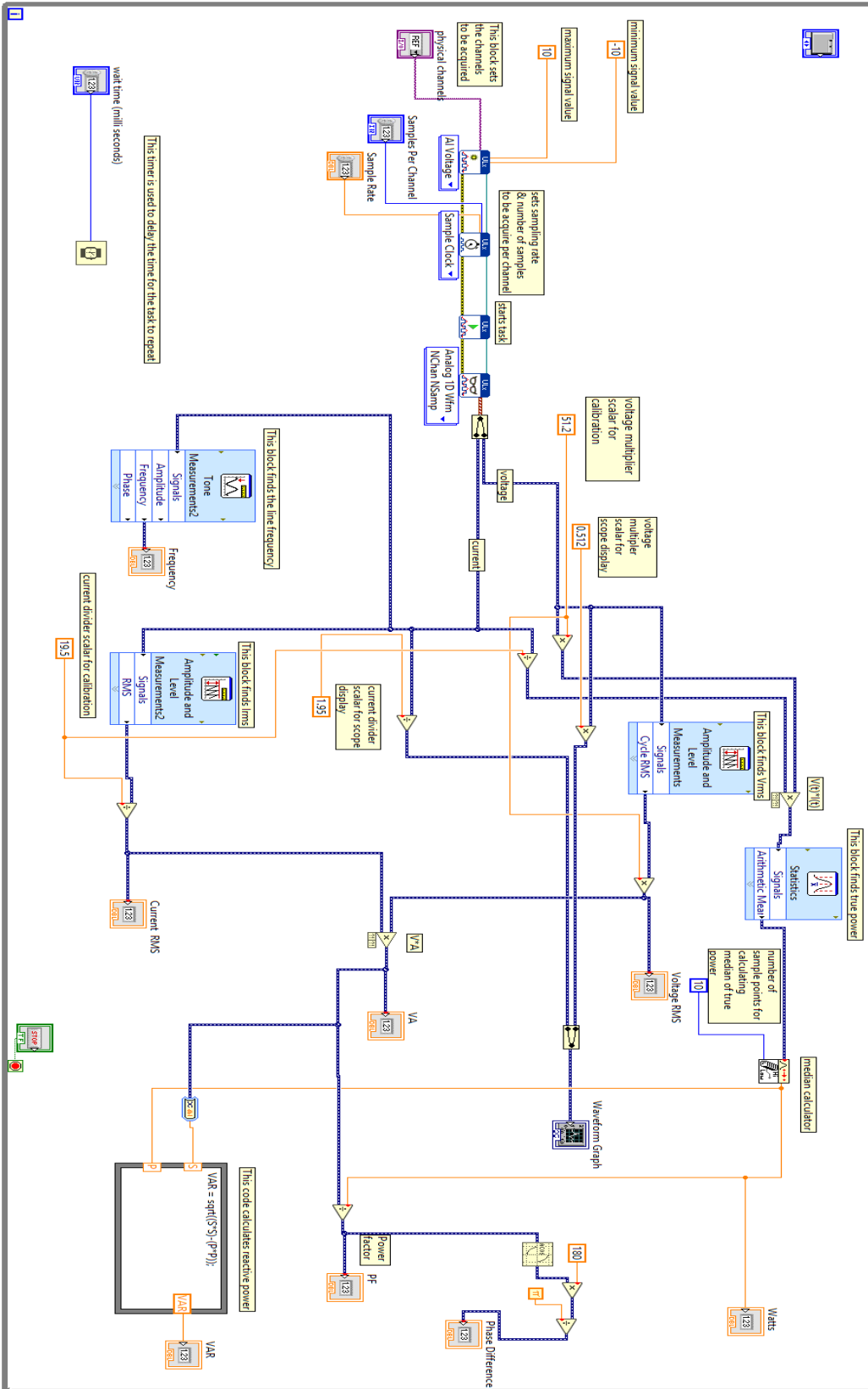


Figure A6 – Finalized software listing

# Appendix B - Hardware Wiring Diagrams

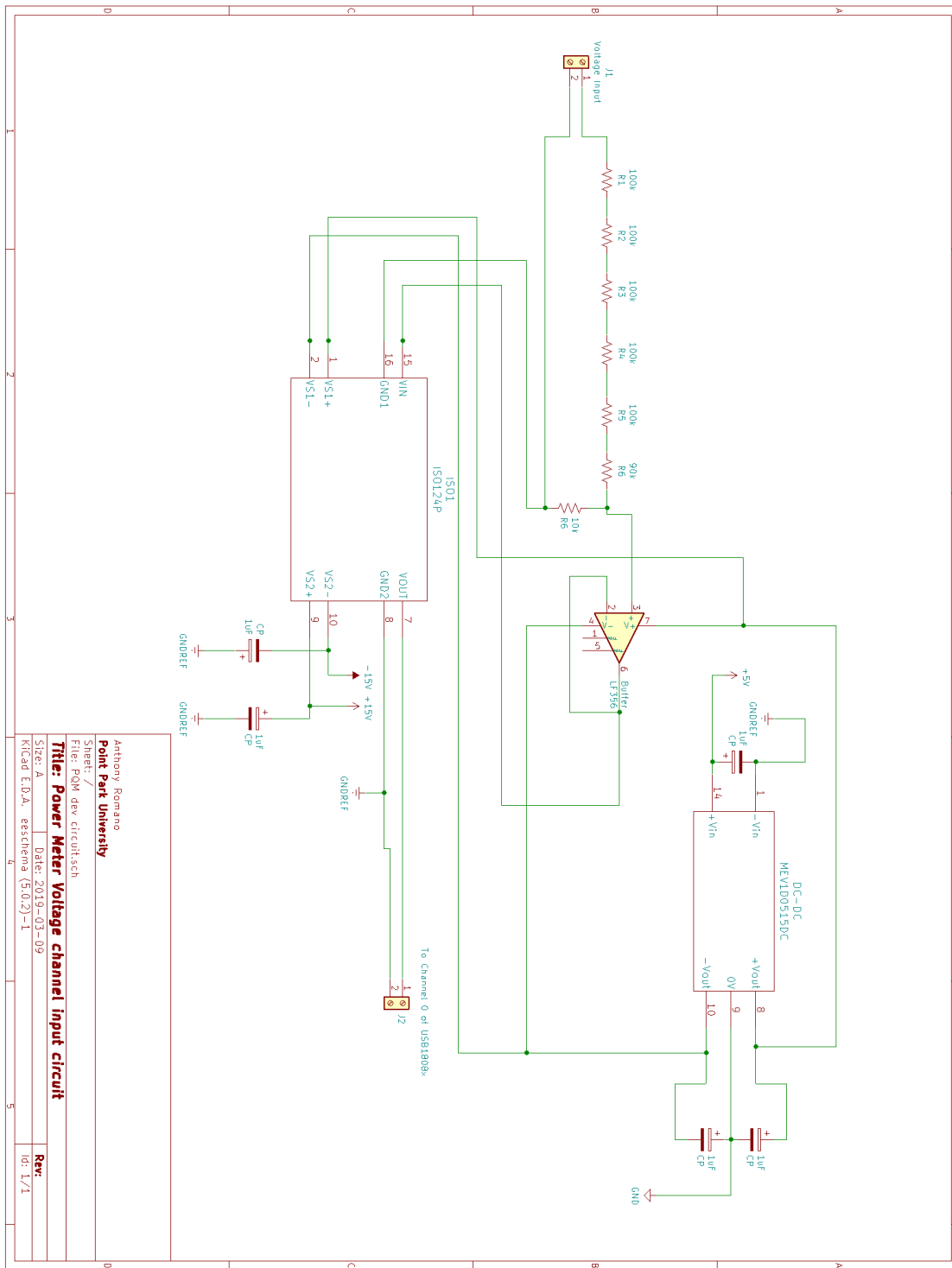


Figure B1 – Voltage Measuring Input Channel Circuit

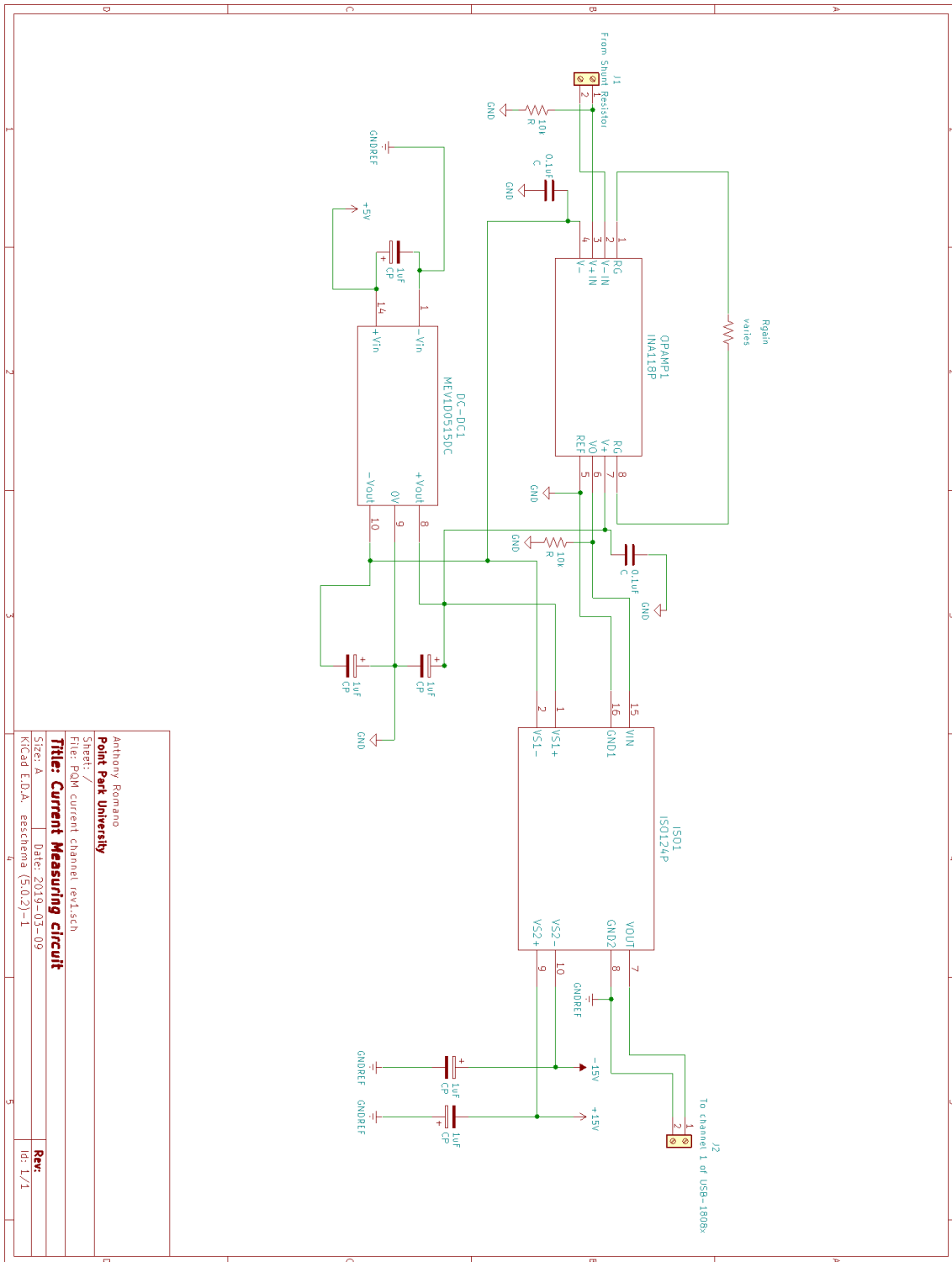


Figure B2 – Current Measuring Input Channel Circuit

## **Appendix C - Components Data Sheets**

USB-1808x DAQ Hardware manual

<https://www.mccdaq.com/pdfs/manuals/USB-1808X.pdf>

Measurement Computing ULx for NI LabVIEW Software Quick Starter

<https://www.mccdaq.com/PDFs/manuals/QS%20ULx%20for%20NI%20LabVIEW.pdf>

Texas Instruments ISO124 Isolation Amplifier Data sheet

<http://www.ti.com/lit/ds/symlink/iso124.pdf>

Muratra Power Solutions MEV1D0515DC DC-DC Converter Data Sheet

[https://power.murata.com/datasheet?/data/power/ncl/kdc\\_mev.pdf](https://power.murata.com/datasheet?/data/power/ncl/kdc_mev.pdf)

Texas Instruments LF356 JFET Operational Amplifier Data sheet

<http://www.ti.com/lit/ds/symlink/lf356.pdf>

Texas Instruments INA118 Low Power Instrumentation Amplifier Data Sheet

<http://www.ti.com/lit/ds/symlink/ina118.pdf>

Ohmite Shunt Resistor 13FR020E Data Sheet

[https://www.ohmite.com/assets/docs/res\\_10.pdf?r=false](https://www.ohmite.com/assets/docs/res_10.pdf?r=false)