Neuro-transmitter (EEG) Interface System

Final Report

ECE 445: Senior Design
Group #29

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I. Introduction

1.1 Purpose and Functions

The purpose of this project is to reduce the cost of and improve the efficiency of current Electroencephalography (EEG) systems. At the moment, low-cost EEG systems can run over $800 [1]. Our system costs under $500, and allows the end user to record brain activity without the presence of a laptop. The current market for EEG systems is in high demand both in neurological research and the medical industry. The devices on the market today require that one carries around a laptop in order to record data. Our product rids the necessity to carry a laptop or be near a desktop computer. Along with using a cheaper device design, our device is more mobile allowing researchers to have flexibility in their research and is less expensive thus creating a very viable product in the EEG market. Our device does not just replicate other similar devices on the market. Our device is a data logging system that will serve as a more economical alternative that adds convenience to traditional EEG systems.

The main functions of the device include the following. First, the device is capable of taking in 14 EEG sensors, where 12 of these sensors collect data and the other two are tied to together to represent a reference ground behind the ears of the patient. Second, the device has a 10,000 gain instrumentation amplifier that allows microvolt brain waves to be output as volts that are easily differentiated by an A/D converter in the Arduino. Third, the collected digitized data of the brain wave is time stamped and stored on an SD card by the Arduino. Finally, the device contains an impedance verification system that checks that the sensors are properly placed on the patient's head so as to ensure the data collected is accurate and acceptable.

1.2 Blocks Described

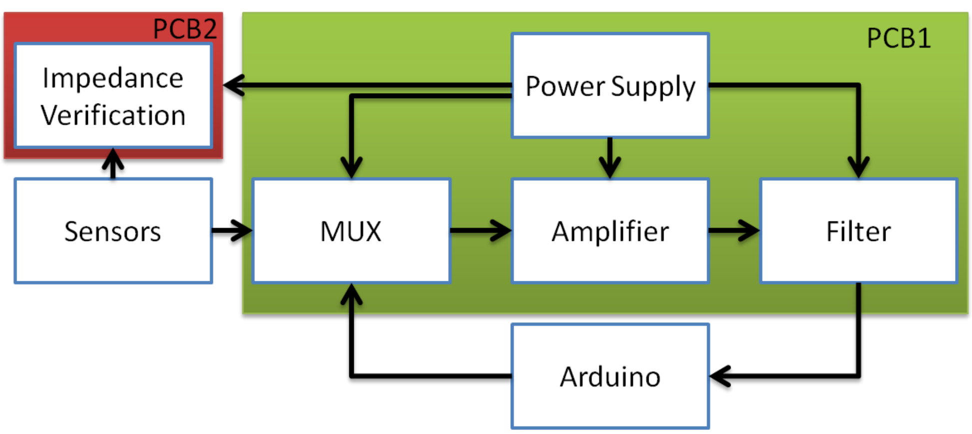

Figure 1: Overall Block Diagram.

Overall Physical and Functional Summary:

The large-scale block diagram describes the connection between the sensors in the EEG cap and our physical device strapped to the back of the patient. To ensure that the sensors are properly applied to the user, we have implemented an Impedance Verification in order to assure both the user and the researcher that the quality of the data being collected is accurate during data collection. The amplifier will take in the signals from the sensors and amplify them for the ADC on the Arduino to differentiate between the signal voltages. From the amplifier module, a filter module will remove the noise from each signal and leave the resulting data signal information that we need to store in the SD card. After filtering out the noise from each sensor, the individual sensor signals will be fed into the Arduino to store the data by signal. The ADC will convert the data with a resolution quality great enough to accurately differentiate between the different voltages that occur.

Impedance Verification:

The Impedance Verification monitors the impedance on each of the sensors one at a time versus the reference voltages behind the ears before the user begins data logging. The user puts on the sensor cap and applies all of the sensors with a saline solution to the best of their ability and then uses the impedance verification to make sure the sensors were properly applied. Proper application is essential to assuring accurate data. The system will have 4 parts: a user input, sensor selection, an amplifier, a comparator circuit. The current source supplies a small current (in the order of nA) that will be sent to the skin. The system reads the voltage over the sensor and compares those to known voltages that correspond to known impedances (20 kΩ and 30 kΩ). There are two warning light LEDs that display a relative impedance. The selected sensor number is displayed on two seven segment displays in decimal. The user has control which sensor he or she wants to view and can change them using the tactile push button provided that will up-count the sensor number. This provides a visual to notify the user if each sensor is correctly applied.

Sensors:

The sensors used are Ag-AgCl sensors with a large surface area for better electron conduction created by Grass Electrodes, the best on the market.

MUX:

The MUX block is a 16 to 1 Multiplexer (of which 12 are used) that passes the 12 sensors to the amplifier and filter circuitry. The MUX will count to 11 in binary and reset and continue at a specified sampling frequency. This makes it easier to collect data from all of the sensors at once without the problems of switching sensors in one at a time or designing multiple amplifiers and filters per sensor.

Power Supply:

The power supply provides power to the circuitry that is regulated at a consistent voltage, and protected from incorrect voltage polarity on the input. In addition, the power supply relies on batteries so it can be portable. Also a switched capacitor inverter was added to this module to provide the negative rail for other components that are dual supply.

Amplifier:

The amplifier module will take its inputs from the 13 sensors in the head cap, and will send its outputs to the Filter module. It will consist of an operational amplifier that will take in voltages between 20-200 micro-volts and output voltages from 0.2-2.00 voltages. It will primarily be composed of resistors and two cascaded operational amplifiers designed to give a 10,000 gain for the range of input voltages. The reason for cascading them is to ensure the slew rate is never exceeded in how fast the output voltages need to change relative to the input voltages. This amplification will be done to ensure the ADC can properly differentiate between the types of voltage values to convert. This will specifically be a non-inverting output.

Filter:

The filter model will consist of an 8th order Butterworth low pass filter circuit that will remove signals with frequencies above 50 Hz, while minimizing any reduction in the signal amplitude of those frequencies that are in the pass-band. It will take inputs from the amplifier module and send its outputs to the MUX module. It will primarily be resistors, capacitors, and operational amplifiers. The exact values of the resistors and capacitors will be determined using a filter design tool to give real world components to build the circuit.

Arduino:

The Arduino's Atmega328 processor handles the output from the filter and assigns it a timstamp before storing on the SD card. In order for proper signal reading, the port A2 takes the analog signal from the filter and converts it to a digital voltage that the end user Kyle Mathewson can read and interpret for graphing. Control of the 16x1 MUX is also managed by the Arduino processor, sending a particular 4-wire set (one for each bit) to the four SELECT bits on the MUX. This group of 4 signals count from 0 to 12, allowing each signal 0.1666 ms of time to run through the amplifier, filter, and SD card processing before the next signal is selected by the Arduino. The Arduino is powered by its one 9V battery supply, and does not draw from the general power supply seen in the block diagram. The signal data can be found in a file called DATALOG.CSV and is accessible in any excel style software. An important point to note is when data logging the end user MUST set the specific date and time that the user would like to start recording data.

II. Design

2.1 Impedance Monitoring System

The impedance monitoring system took on some redesigning throughout the semester. The original design included an on-off switch for the user input and the sensor number displayed in binary on LEDs. It also included comparators that compared voltage values in the order of µV. It was decided that binary LEDs would not suffice. A better design for a user interface would be to use two seven segment displays and display the current sensor number in decimal. An on-off switch for the user input was inefficient way to switch between sensors, so the switch was replaced with a tactile push button which had a better feel. The comparators used are not sensitive enough to detect small changes in µV so it was necessary to amplify the signals essentially adding more resolution, in order to more precisely detect the differences in voltages. A better design was to amplify the found voltages first from µV to V. The comparator can more precisely identify the voltage when in V as opposed to µV. With this change, a power supply inverter needed to be designed to provide -5.0 V to the amplifiers.

The Sensor Impedance Monitoring System monitors the impedance each sensor's impedance through the head to the reference sensors one at a time before the user begins data logging. The user will put on the sensor cap and apply all of the sensors to the best of their knowledge then user the impedance verification to make sure he or she applied the sensors correctly. The user has control of the changing rate of sensors and can change them using the button provided that will up-count the sensor number. The system checks if the sensor impedance is less than 20 kΩ and/or less than 30 kΩ. These numbers have been proven by empirical research that they can assure that the data collected is accurate. If either of the conditions are not met, warning LEDs appear. The system provides a visual to notify the user if sensors are incorrectly applied.

It is important that the sensors are properly applied (an acceptable impedance for the system is less than 20k ohm, but we will tolerate up to less than 30 kΩ) in order to ensure that our data collection is accurate. If a sensor is incorrectly applied, our voltage readings may be grossly attenuated and we may lose information. The user may check the sensors impedance when they need to. A proper exercise of electroencephalography research would be to read the impedances on the sensors first before data collecting.

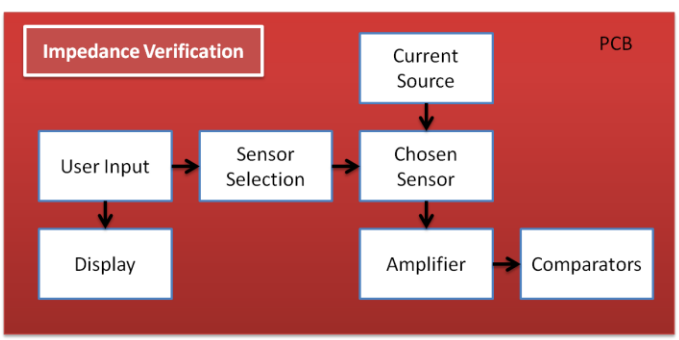

Figure 2: Impedance Verification Block Diagram.

The system was redesigned over the course of the semester. The final module contains subparts that work together to verify that each sensor is properly applied and the user is ready for data collection. The user has control of the speed of verification. By pressing a tactile push button, the user can step through each sensor and verify. The current sensor being verified is visible on two seven segment displays that make up the display. The seven segment displays are logic based in order to show the sensor number is displayed in decimal. See Appendix A for detailed schematics.

Logic design for counter circuit:

Counter start at zero and must count to 13 and reset. The K-maps included below show how I implemented the seven segment displays for first the most significant digit and then the least significant digit.

The sensor selection is a demuxing and muxing of sensors. It is innovative because in the past, the user needed to insert each sensor one at a time in order to check if the impedances were passable. This allows the user to not worry about checking each sensor one at a time. All the sensors are plugged in first before anything is checked. This novelty increases portability and adds to the ease of use of our product. Please see the attached schematics within the appendix.

The current source is constant at 25 nA. We use Ohm's Law in order to compare later on. The current source needs to be constant despite what impedance is inserted. The comparators will count on the constant current in order to compare voltages against. We have two comparators: one that determines whether or not the impedance is less than 20 kΩ and one that verifies if the impedance is less than 30 kΩ. The comparators are hardwired with a voltage that would correspond to 20 kΩ and 30 kΩ with a known constant current of 25 nA. To create a constant current we used a large current setting resistor in series with our sensor impedances:

$$V = IR$$
$$5V = 25nA * R\Omega$$
$$R = 200\ M\Omega$$

The last component included above is the amplifier. The original design did not include an amplification stage. The small voltages (uV) collected were too small for the comparators to handle. To give the comparators more resolution, the voltages collected were amplified by 5000 to the order of Volts. This also meant the inclusion of a power inverter to create -5.0V from +5.0V to power the amplifier. For the gain of the amplifier to be approximately 5000, we needed to choose R_g such that this was so:

$$Gain = 1+(50k\Omega)/R_g = 5000\ V/V$$
$$R_g = 10\Omega$$

After the voltages are amplified to respectable values, they are fed into the comparators and the conditions are tested. LEDs light up on the comparators when the conditions aren't met, serving as a warning to the user that the current sensor application doesn't meet the required standards for data collection.

To simulate the comparators, different values of resistances were inserted and tested. The simulations show the current setting resistor and the comparators comparing before amplification was included. The top comparator tests for less than 20 kΩ and the bottom comparators test for less than 30 kΩ. The reference voltages were calculated with Ohm's law with a known current of 25 nA. LEDs are lit if the conditions aren't met. See Appendix A for schematics that are used for this design.

2.2 Amplifier, Filter & Power Supply

The general design alternative for this set of modules comes down to the type of power supply we are using. Originally, we designed for a single supply that would be compatible with four D batteries. But during testing it was discovered the instrumentation amplifier used requires dual supply. We looked for other instrumentation amplifier chips that would still give us the desired high amount of gain-bandwidth ratio the INA128 gives while only needing a single supply voltage, but were unable to find such a device. Thus we found a switched capacitor inverter that would invert the input supply voltage and output a negative voltage that issued for a dual supply for the instrumentation amplifier. The amplifier and filter system themselves have no real alternatives beyond how they are implemented which will be discussed in their respective sections.

There was also a decision to make regarding whether the power supply would be with standard D batteries or with rechargeable D batteries. The reason for this design concern was that standard D batteries have 1.5 Volts starting out each and rechargeable batteries have 1.2 volts. Thus it would take six rechargeable batteries, but only four standard batteries to achieve the same results. For reasons of cost and ease of reuse for the costumer we designed for the rechargeable batteries.

Power Supply simulations / Circuits / Equations

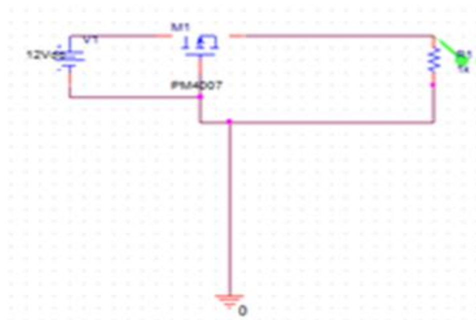

Figure 4: Reverse Polarity Protection Circuit.

The power supply for our system takes a voltage input of 6 – 7.2 Vdc supplied by four D batteries. The power supply utilizes a PMOS transistor with the drain connected to Vin+, the gate connected to ground and the source connected to our load. The purpose of this PMOS transistor is to protect our circuit from a human failure or inserting the voltage source in backwards. When the voltage is correctly attached (correct polarity), the PMOS turns on and lets current flow through the circuit. When the voltage source is in reverse polarity, the PMOS turns off and the circuit in fact doesn't blow up like it would without the PMOS for protection. The novelty behind this is it protects the circuit from a possible human error in inserting the voltage source in reverse polarity because the PMOS will not conduct.

With a forward biased voltage source:

$V_{gs} = (V_g - V_s) = 0 - 6 = -6V$

-If Vgs is -4V or less the PMOS transistor will turn on thus conducting current.

With the reverse polarity voltage source:

(First assume MOSFET is turned on.)

$V_{gs} = (V_g - V_s) = 0 - (-12) = +12V$

Vgs must be -4V or less in order for the PMOS transistor to turn on which is not true here. The transistor must be off and therefore not conducting current. The circuit is safe.

Another important addition to our circuit is the inclusion of a low-dropout regulator. This component will take an input voltage from a source that can be characterized as unstable and make it stable. To be more precise, in our circuit our Vin from the 4 D batteries will be around 6V. The low-dropout regulator will take this value and stabilize it at a level it can hold for longer. The low-dropout regulator will keep our input voltage at a stable level of 5V +-10% = 4.5-5.5V. By doing this we will be dissipating less power in the regulator than you would if you used another type of regulator. This discussion continues in Appendix B under power supply.

Amplifier simulations / circuits / equations

See Appendix B under amplifier for the full discussion of the amplifier chosen and why.

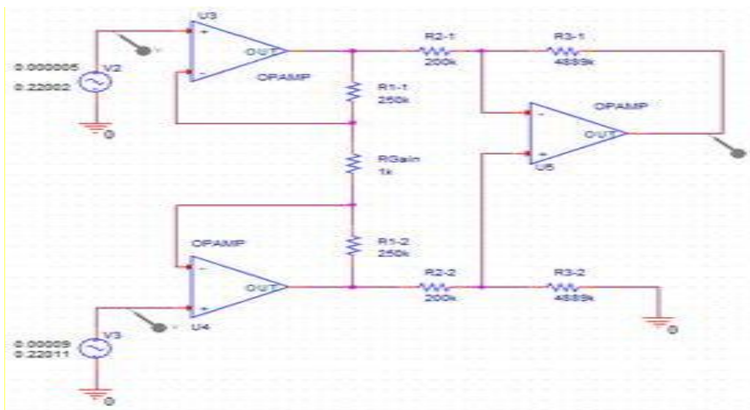

Figure 5: Circuitry of differential instrumentation amplifier.

The differential instrumentation amplifier works in two main ways. The first stage subtracts the bottom voltage from the top voltage, for convenience V2-V1. This voltage is then multiplied by a gain factor that results from finding the gain after the first two amplifiers. That being (1+2*R1/Rgain), since there are two R1 resistors used. Then this is feed into the next stage amplifier which is just an amplification stage which leads to R3/R2 as the gain. Thus the total gain equation is
(Vout)/(V2-V1) = (1 + (2*R1/Rgain))*(R3/R2)
(2*R1/Rgain)*(R3/R2) for the gain.

Now we need to mention the CMRR value which relates amplification of the signal to the amplification of the noise.
CMRR = 20 log(Ad/Acm)
where Ad is the differential gain, signal we want, and the Acm is the common mode gain, or the gain of both the noise and the signal we want. Thus the (2*R1/Rgain) corresponding to the Ad term should be larger than the (R3/R2) Acm term and together both of them need to be 10000 gain. Thus it was chosen to make Ad 250 and Acm 20 so total gain would be 10000 and the differential term would be 12.5 time bigger than the common mode gain giving a CMRR value of 21.9382. Thus the differential amplification removes the dc component, removes some noise, the high CMRR gives a greater amount of

amplification to the signal and not the noise, and gives the 10,000 gain that we want for the A/D converter to receive.
However an instrumentation amplifier chip exists INA128PA-ND that meets our needs.
It has a slew rate of 4 V/microsecond and has a bandwidth of 2 kHz at a gain of 10,000 which presents a very simplified solution to designing the circuitry. The schematic is below [2]. Though it's important to mention that for this amplifier to correctly operate a negative power supply became necessary and was added into the design for the power supply.

Filter Simulations / Circuits / Equations

See appendix B under filter for the full discussion of the filter design.

And thus gives the following circuitry:

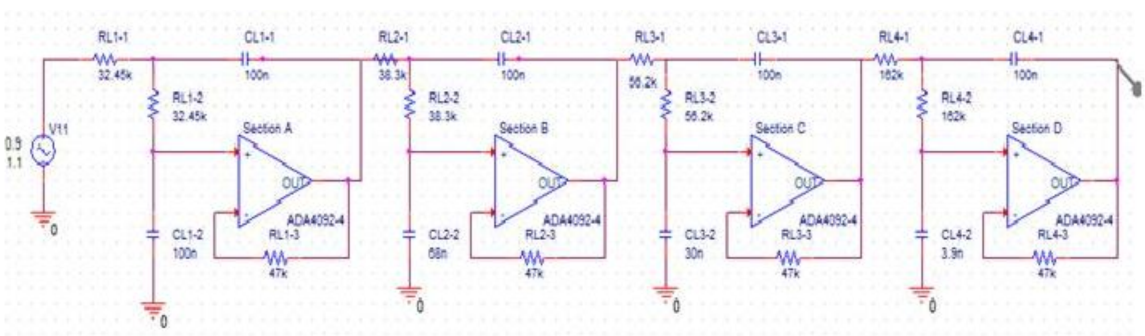

Figure 6: 8th order Butterworth Low-pass filter.

This schematic shows the exact chip we using ADA4092-4 and has the exact component values that are in use. The chip has 4 operational amplifiers, one for each stage used. The particular configuration used for each stage of the amplifier is the Sallen-Key configuration which minimizes the effect of the specific operational amplifier chosen on the overall quality of the filter used.

Amplifier Design

The output of the 16:1 MUX, which is comprised of the 12 sensors on the input to the MUX, is sent to the positive terminal of the instrumentation amplifier. One of the two sensors tied together to make the virtual ground for the systems is the input to the negative terminal of the instrumentation amplifier. Amplifier circuitry consists of an INA128 instrumentation amplifier. A resistor of five ohms sets the gain to 10,000 since 1+50k/Rg = Gain and thus an Rg of 5 ohms gives approximately 10,000 gain. The amplifier gets it rail power voltages from the power supply from the batteries for the positive rail and from the switch capacitor inverter for the negative rail. There are two 0.1 microfarad capacitors that are connected from the positive and negative rails respectively to ground to help reduce noise to the chip. The output of the amplifier is then sent to the filter module. Again the reason behind the 10,000 gain is to taken brainwaves that are 20-200 microvolts to 0.2-2 volts so there can be a high resolution of the signal at the A/D converter in the Arduino. Instrumentation design was chosen to allow a high CMR ratio and differential design allows the dc offset voltage of the sensors to be removed as well as any noise in the sensors that is common between the reference ground sensor and the data sensor being looked at.

Filter Design

The filter module takes the output of the amplifier as the input to the first of four serial Sallen-Key stages. At the heat of the filter is the ADA4092-4 which contains four operational amplifiers. Since there are four Sallen-Key stages the order will be 8^{th}. To determine the resistor and capacitor values used for each stage in order to have a low-pass Butterworth filter, a filter design tool was used provided by Analogue Devices. This allowed not only for the values for these components be found that optimize the filter response desired, but also allow for the resistor and capacitor values to be real world values whereby parts could be easily obtained and the filter easily put together. The output will go to the input of the Arduino. Again, the reason for choosing 50 Hz as the low pass point is because above this frequency no brain waves of interest exist and it would be a waste of SD store space to include them. Also at 60 Hz voltages from the surrounding power lines could add in interference to the signal and so this was another justification given for the frequency being the low pass point. Butterworth implementation was chosen since a flat pass band is necessary for accurate representation voltages of the brain waves signals at frequencies that are of interest. A Chebyshev type two filter was considered as an alternative to a Butterworth filter, but it was decided that a Butterworth filter would be easier to implement with the design tools available and a sharper transition band could occur by using 8 orders. And the Sallen-Key implementation of stages was implemented to have the least dependence of filter performance on the performance of the operational amplifier.

Power Supply Design

In our power supply block, we plan to start with a high voltage and step down by means of resistive elements between the blocks if needed. The overall power supply will consist of six rechargeable D batteries that at initial use will have 7.2 volts of power. This voltage will then be wired to a PMOSFET in such a way that the PMOSFET will be connected with the batteries going to the drain, the source going to the rest of the circuit, and the gate connected to ground(youtube, youtube). This setup will ensure the transistor will only be on when the voltage is attached the right way, and will be off otherwise. The reason for this and not a diode is a matter of safety to the research participant that will be wearing this. Diodes lose more power and thus generate more heat that could be hazardous. The PMOS on the other hand will generate far less heat and power loss and thus be safer and more efficient. The specific PMOS used is the FQP47P which has a 60 V limit and a +/-25 volt Vgs break down value.

From the PMOS, the power will go through a linear voltage regulator. The purpose for the linear voltage regulator is to ensure that even as the batteries lose volts before they no longer function, the voltage regulator will keep outputting a constant voltage of 5 volts. Thus the power supply to the rest of the system will not vary randomly and cause distortive effects. The specific chip used is the From the linear voltage regulator, the power will go to a switch that will be manually set to feed the power into either the data processing and logging circuitry, or feeding the power into the Sensor impedance verification circuitry.

Another component that needed to be added into the design of the power supply is the switched capacitor inverter that takes in power and outputs negative power to be used by the circuitry that requires dual supply. This is achieved with the LMC7660 chip, two polarized 10 micro farad capacitors, and a 10k resistor. The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two electrolytic capacitors. This device implementation was specifically chosen so that it would be easy to invert a 5 volt supply to approximately -5 volts without a great deal of additional components being used.

See Appendix B under design schematic section for a detailed design schematic.

2.3 Arduino

Design Procedure: Our overall design for processing the signal data on to the SD card focused on the processing rate limitations, the A/D conversion limitations of the Arduino, and the time at which each signal had to pass through the circuit before the MUX switched to the next signal. One noticeable design decision was going with a ready-made chip, the Arduino RTC module (see Appendix C-4). An alternative (and more error prone) solution would be to have an IC chip (DS 1307) connected to a 32.768 kHz Crystal chip at DS 1307's pin 1 and pin 2. A 5V power supply would be fed to pin 5 and a managed power would happen with pin 3(see Appendix C-3) . As one can see from this setup, we would need to alter the code to conform to the IC chip, requiring a special definition of write and read functions with the label I2C_WRITE and I2C_READ, in order to properly communicate with the IC chip DS 1307. However, the current schematic design of what we chose simplifies this and allows us to code a simple call "Write.read()". The RTC module does require that we define the address we are requesting, but we only have to code this once at the top of the code set with "Wire.requestFrom(DS1307_I2C_ADDRESS, 7)". The brief digression of code was used for the sake of justifying how we were able to simplify 184 lines of code to 151 lines. This will allow the non-coder easy readability, although a technical electrical engineer may find this level of abstraction limiting, since he/she cannot code directly on to the DS1307 IC chip.

Design Details MUX Counter/SD Card Frequency: We determined after studying source [4] that the maximum signal frequency that is released from the brain is 50 Hz. However, we cannot sample at this frequency without resulting in data that is aliased. We can avoid this issue by sampling twice the Nyquist rate. Also clarified in source [4] is that just sampling at twice the max frequency would not provide accurate data, so our group sampled at five times the Nyquist rate. With twelve signals being processed, we multiply the total sampling rate by twelve and get 6 kHz. This is the sampling rate allows the signal waveform to be rectified in the signal data recorded on to the SD card.

Baud Rate: In order to determine an appropriate baud rate for processing the signal data with its timestamp, we needed to determine a sampling rate that would accurately capture the sensor data entering the system. We found from section 2.2.1 that this appropriate sampling frequency is 6 kHz. However in order to process the data without error, we need to process at least twice the delay between signals. Converting frequency to ms (1/frequency=milliseconds), we get 0.166 ms. Therefore, our processing rate must be quicker than 0.08 ms. For the Arduino processing, we can set the baud rate to a couple of different numbers: 9600 bps or 115200 bps. As we can see, the 9600 bps is too small of a processing rate, so we are left with 115200 bps. We went with 115200 bps (as opposed to a smaller baud rate greater than 12000 bps) so as to leave enough overhead and have the smallest error rate for the adjusted CPU frequency of 2.0 MHz. Unfortunately we could not go above 115200 bps (limitation of the Arduino Atmega328 processor), so the optimized baud rate was 115200 bps, resulting in an error of 8.5% to the data processing.

III. Verification

For all detailed requirements, verifications, and results please see Appendix D.

3.1 Impedance Monitoring System

The impedance monitoring system verifications break down the subcomponents within the subsystem. There are four major parts within the subsystem: a user input, sensor selection, an amplifier, a comparator circuit. Each part is verified separately.

1. *User input:* The manual input switch must change the selected sensor. The user presses the tactile push button and verifies that it works properly by reading the seven segment and watching it increment. The input must also count correctly. It must start at zero and count to 13, then reset on the next count.

2. *Sensor Selection:* Sensor selection refers to the DeMUXing and MUXing that is necessary to choose sensors one at a time. The MUXes must be wired correctly, verified by replacing the sensors with LEDs.

3. *Amplifier:* The amplifier needs to contain a gain of 5000 V/V with about a five percent error on each side. This will be verified by sending in a small signal and comparing it to the magnitude of the output using an oscilloscope. In order to make the amplifier function, a power inverter was included. The power inverter must be able to invert an input of +5.00 V and output -5.00 V, again with a factor of 5 percent error on each side. This will be verified with a voltmeter and a five volt power supply.

4. *Comparator Circuit:* Grouped with the comparator circuit is the constant current. The current through the sensors needs to stay constant at 20-25 nA despite inputting different impedances. This is verified by using an ammeter across the impedances.The comparator circuit needs to be able to verify input impedances are less than 20 kΩ and/or less than 30 kΩ. Impedances can be represented as resistors. One must insert resistors around those values and see if it correctly lights the warning LEDs.

Results: The sub-device functions as proposed. The user input through a tactile push button was verified and the counter circuit properly counted and reset as proposed. The selection circuit properly selected the wanted sensor and passed on its voltage (assumed proper current). The comparators properly determined where inputted impedances lie around 20 and 30 kΩ. The LEDs lit up if the comparing conditions did not verify.

3.2 Amplifier, Filter and Power Supply

The full verification and results for this subcomponent can be found in the associated table in the appendix. Here I will give a brief description of the verification procedure and the result that were obtained.

1. *Amplifier and Filter*: A sinusoidal waveform that has a peak to peak voltage of 0.002 from a function generator is voltage divided to 0.002 volts and put into an input of the Mux set to display a signal channel out. The output of the Mux goes to the amplifier. The output of the amplifier goes to the filter, and the output of the filter goes to the oscilloscope. The original input will also be show on the oscilloscope to show the frequency of the original signal is maintained in the output signal. Correct output will show a voltage of 2 volts peak to peak +/- 30% when the input frequency is below 50 Hz for 80% of these frequencies. (Those closer to 50 Hz will start to show more attenuation and that is acceptable for functionality.) When the input signal is changed to a frequency above 50 Hz the output signal will be attenuated. Thus this test will verify the amplifier can give 10,000 gain, the voltage values are consistent in the pass-band, and signals at frequencies above 50 Hz are attenuated. This test will also verify the Mux is working properly and that the negative power supply is working correctly since if either

of these two were implemented incorrectly the amplifier and filter operational amplifiers would not function properly.

Results:

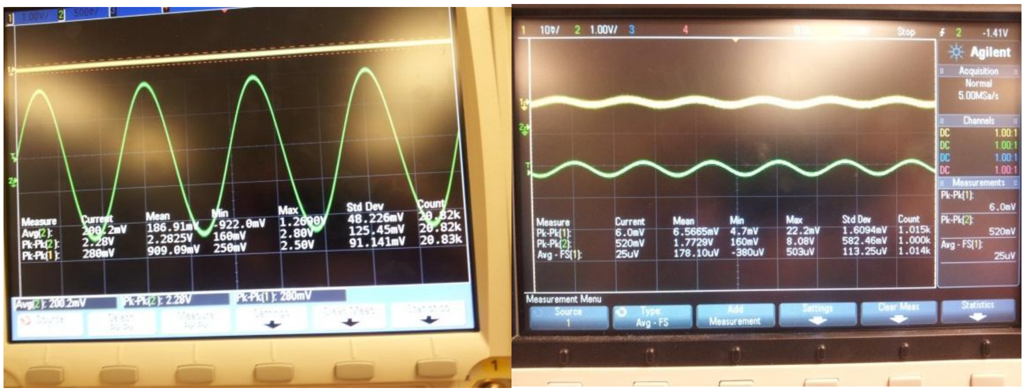

Figure 7: The images show 25 and 60 Hz inputs and outputs.

As scene in figure 7, the left image shows the output voltage has the 10,000 gain desired resulting in 2.28 volts that is within the tolerances specified. The input voltage peak to peak value is not correctly displayed due to resolution changes for the signal but the same input is correctly given in the next figure. The right image in figure 7 shows when the input signal is sent in at 60 Hz the output signal shows significant attenuation from 2.28-0.52 volts. Thus only 22.8% of the original signal peak to peak remains. Thus the verification indeed has passed.

2. *Power Supply*: To test the reverse polarity protection and the 5 volt voltage regulator, and 8 volt dc signal will be sent to the input of the reverse polarity protection P-MOSFET. The output of the MOSFET goes to the input of the linear voltage regulator, and the output goes to the oscilloscope. Thus the first test will be correct polarity to show an output voltage of 5 volts +/- 30%. The second test will show a reverse polarity showing close to zero volts output.

Results: The output of the linear regulator for an 8 volt input is an output of 4.82 volts. This is within the tolerances specified of 5 volts +/- 30% and thus the verification is met. The output of the linear regulator for an 8 volt input with reverse polarity is -0.088 volts. This is within the tolerances being close to zero volts or only 1.1% of the original negative input voltage.

3.3 Arduino

1. MUX LED Test: As seen in Appendix C-1, To test this we must set up four LEDs to verify that the Arduino is indeed sending the correct four signal sequence for each count to the MUX. To verify, we will do the following:

1) Arrange four LEDs vertically aligned with one end connected to ground and the other connected to a horizontal row that has a wire connected to one of the ports A2-A5.

2) Down-press the red LED button on the Arduino and watch the LEDs increment in a four bit binary count from 1 to 12.

One key equation employed is to convert from decimal to binary in four output signals from the Arduino. The equation looks like the following:
Let us assume that x is the decimal number.

LED0: (x mod 2)
LED1: x mod 2 || x mod 3 || x mod 6 || x mod 7 || x mod 10 || x mod 11
LED2: x mod 4 || x mod 5 || x mod 6 || x mod 7 || x mod 12
LED3: x mod 7 || x mod 8 || x mod 9 || x mod 10 || x mod 11 || x mod 12

This can be seen in the code included in Appendix A

2. MUX Counter Frequency Test: The MUX counter provided by code written to the Arduino has a delay of $1.66*10^1$ us. This frequency is based on the design decision for sampling rate of the data points. The ideal sampling rate is based on the following:

12 signals * (50 Hz max. sensor signal frequency) * 5 * 2 = 6 kHz

The factor of five is representative of sampling five times the Nyquist rate, stating that we need to sample at least twice the minimum sampling frequency of 0.1 kHz. Further explanation of how we select 0.1 kHz can be found in the design details. In order verify this test, we use the oscilloscope channel wires and link ground with the Arduino ground, while measuring the change in voltage over time. We measure the least significant rate, resulting in a 50% duty cycle. This test was uncertain due to irregular delay readings, and will be further tested for accuracy Appendix C-1.

3. *SD Card Synchronization*: With our SD Card Synchronization, we need to process the incoming signals at the same rate that we cycle through the MUX. Therefore, we will have the same frequency of 6 kHz. In order to guarantee that the Arduino processor Atmega328 correctly processes the signal input on to the SD card, we want to set the baud rate that will compensate for the high sampling frequency. As explained in our Design Details section, we chose the baud rate with enough processing overhead, and decided on 115.2 kbps (kilobits per second). In order to confirm that the signals are being processed at this baud rate with date-timestamps, we print the signal values being stored to the Arduino Serial Monitor, which includes a baud rate of 115.2 kbps. The results as seen in the serial monitor in Appendix C-2, reflect two things: 1- that the analog-to-digital conversion from the Arduino is exactly 0.27V above what the desired output voltage is, and therefore each datapoint must be reduced by 0.27V. 2- the UTC (Universal Time Clock) to RTC (Real Time Clock) conversion is successfully being made by the RTC module and that the difference between constant input signal voltage values varies little (0.0-0.1V).

IV. Costs

4.1 Labor

Name	Hourly Rate	Total Hours Invested	Total = (Hourly Rate)*2.5*(Total Hours)
Kevin Armstrong	$35.00	150	$13,125
John Burton	$35.00	150	$13,125
Alex Lostumbo	$35.00	150	$13,125

4.2 Parts

Item	Quantity	Cost (USD)	Item	Quantity	Cost (USD)
D Batteries	6	$14.00	MOSFET(FQP47P06)	1	$2.26
LEDs	-	$10.00	LDO Voltage regulator(NCP7805TGOS)	1	$0.49
Resistors	-	$20.00	2 input ORs (SN74LS32N)	1	$1.20
MUXes (DG406DJZ)	3	$17.13	2 input NORs (SN74LS402)	1	$1.50
DeMUXes (29635175)	1	$1.39	Seven Segment Display Driver	1	$1.50
Battery casing	1	$4.23	Seven Segment Displays	2	$3.50
Amplifiers (INA128)	3	$21.75	PC Board	3	$60.00
Negative Power Supply (LMC7660IN)	1	$0.98	Operational Amplifier(OP497FPZ)	1	$12.22
Counter (74ALS161BN)	1	$4.00	Comparing Amplifiers (LM741CN)	2	$2.50
2 input ANDs (SN74LS09)	3	$6.00	3 input ANDs (SNLS4711)	1	$1.50
Capacitors	-	$20.00	Inverter (SN74LS04)	1	$1.50
Arduino Shield	1	$25.00	Arduino Uno	1	$40

4.3 Grand Total

Section	Total Cost(USD)
Labor	$39,375.00
Parts	$272.65
Total	$39,647.65

V. Conclusions

5.1 Executive Summary

Accomplishments: A significant accomplishment of this project is the impedance verification system which is fully able to detect sensor impedances and alerts the user if the impedance values are above the threshold at which accurate data collection can be assured. The system also allows any sensor to be checked by simply pushing a button the sensor number desired to be seen. The count numbers are in decimal so any user can tell what number they are looking at and thus what its corresponding impedance is.

In addition, we were successful in making a reliable power supply system that protects from reverse voltages, regulates voltages out, and includes a negative supply rail for those chips that are dual supply. We were able to also have a 10,000 gain amplifier working to amplify the microvolt brain wave signals, and a robust 8th order low-pass Butterworth filter that significantly attenuates signals with voltages above 50 Hz. We also have the Arduino accurately data logging the input it obtains from the filter and writing that data to an SD card that can be read at a later time.

Uncertainties: There are some uncertainties with regard to the final functioning project. There is some uncertainty as to if 50 Hz is the correct frequency at which the filter should be attenuating. The reason for this is that one sensor output through the amplifier and filter to the Arduino data collector works as intended, but when the Mux cycles through all twelve channels the output signal looks distorted. It would seem from the data that since there are 12 sensors and the Adruino is sampling at 500 Hz, 10 times high than max signal of interest sample rate, that the 50 Hz frequencies would appear as 500 Hz frequencies and so the low-pass frequency of the filter should be changed. This was something no one noticed until the final design test and is something that would need to be researched and addressed in future work.

There are also some uncertainties with the calculation of baud rate and how that is best optimized to the Arduino system we are using with the types of signals that we are looking at. In addition, the Counter for the MUX in the Arduino appears to function correctly, but with issues of all 12 sensors input being input causes distortion to the signal to the Arduino , the duty cycle of the MUX may not be sufficient for the signal delays used in the system. Thus both the delay and corresponding duty cycle of the Arduio for the counter of the MUX and the filter could be contributing to the problem and both need to be investigated more.

Future Work: There are some addition work that we would like to see done with the project that would make the design more robust and fully functioning as intended. The first is a comparator used on the power supply that will alert the user when the battery voltage drops so low that the linear voltage regulator is no longer regulating to 5 volts, but instead is acting like a resistor. This would help the user to ensure that the have enough power to have the device collect accurate data and not possibly damage any internal circuitry. Also, as mentioned previously, there are some question about 50 Hz being the desired frequency of the low-pass filter instead of a higher frequency. This would need to be researched more thoroughly and once a correct frequency was found I redesigned filter would need to be built and replace the current filter. This would most likely require only changing the resistor and capacitor values in the four stages but it would take time to make sure these changes will led to improved performance and that the new filter works reliably. In the same vein of things, more research in to baud rates and time delays would need to be looked at and optimized for the overall device to work optimally as intended.

Due to timing constraints from testing to get the instrumentation amplifier to work amplifier that is used in both the amplifier and the instrumentation verification system, we were unable to get these section onto printed circuit boards for the demo. We are in the process of creating the pcbs, and getting the components to work on them and hope to complete that soon. Naturally, once this is completed the housing for the entire device would be constructed.

In addition to creating an enclosure, one could expand upon the Ethernet part of the shield and possibly design a way to log data to a cloud system. The shield attached to the Arduino contains Ethernet features that can become wireless, allowing the user to record data both on an SD card for backup along with the possibility of logging the data to a cloud.

5.2 Ethical Considerations

We ensure that we continue to abide to the following standards from the IEEE Code of Ethics [2]:

1. *"to accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment."*

We are working toward creating a safe and affordable EEG that would be conducive with current health and safety standards. Our final device depends on the safety of the individual, since the data itself is useless without the individual trusting the device.

The impedance monitoring portion of the project contains a sensor to skin contact impedance reading system that sends current through the sensors applied to the heads of our users. Safety is crucial to a device that is interfacing with the human brain. Limitations on current are essential to the health of the user. There are serious consequences associated with ignoring the amount of current sent through the human body, which include pain, paralysis, and possible death. The health and safety of our users is of the utmost importance. The low linear voltage regulator and PMOSFET reverse polarity protector were also chosen specifically to reduce power dissipation of heat into the patient.

7. *"to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others."*

Ryan May and other instructors/professors are offering their wisdom to create the most efficient EEG that our group can produce with our limited budget. Kyle Mathewson, a post-doctoral student studying neuroscience at the Beckman Institute, serves as our group's point-of-contact in understanding how the EEG device properly functions. Working together as a team, we will critique each other's work to produce the best possible product. Honesty between our group members during peer critique is always the best policy.

9. *"to avoid injuring others, their property, reputation, or employment by false or malicious action."*

Focusing on safety, we want to make certain that our product does not harm anyone involved. We must constantly reiterate that the safety of our subjects will be the primary goal throughout this process. We also plan on ensuring the safety of the sensor cap we plan on using, which is in fact, not our personal property. Other items borrowed during the semester, including our kits, devices in the labs, and power supplies, will be taken care of. They are not ours and we promise to act in a responsible fashion.

VI. Resources (Citations)

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[2] IEEE, "Code of Ethics," IEEE, [Online]. Available: http://www.ieee.org/about/ethics_code/index.html. [Accessed 22 October 2012].

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[11] Atmel, "8-Bit Microcontroller with 4/8/16/32K Bytes In-System Programmable Flash," [Online]. Available: www.atmel.com. [Accessed 10 November 2012].

VII. Appendix A: Impedance Design

These are schematics that are used for the impedance verification design.

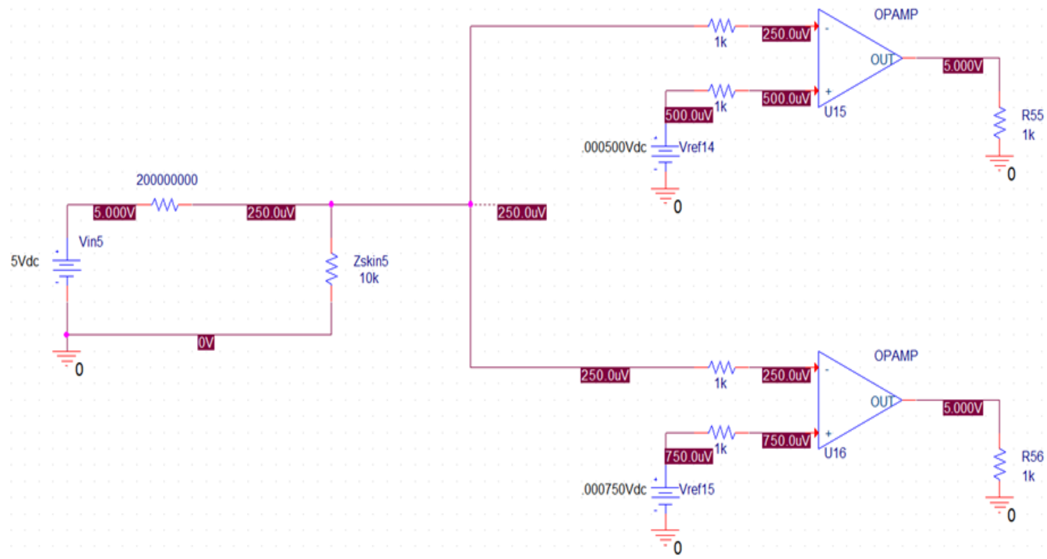

Figure A-1: Simulation of impedance verification with input 10 kohm.

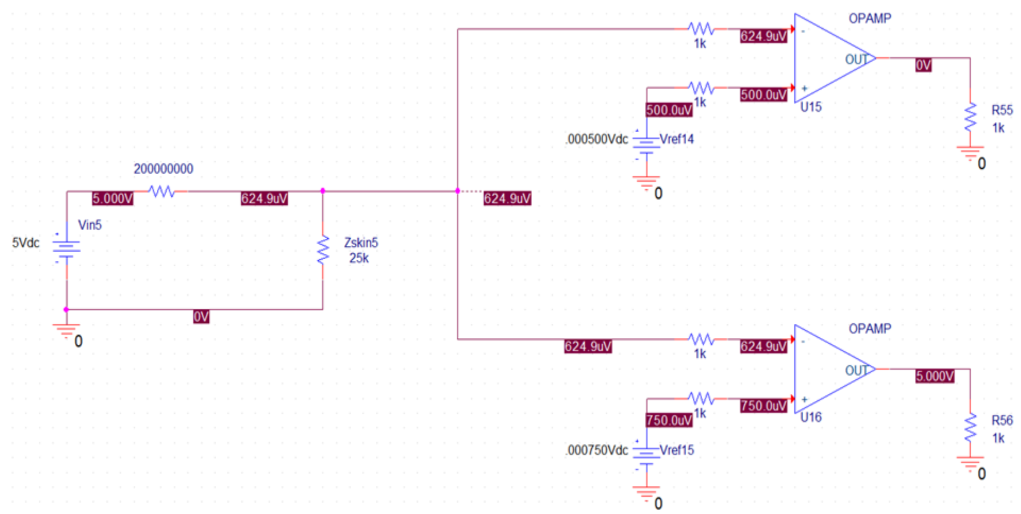

Figure A-2: Simulation of impedance verification with input 25 kohm.

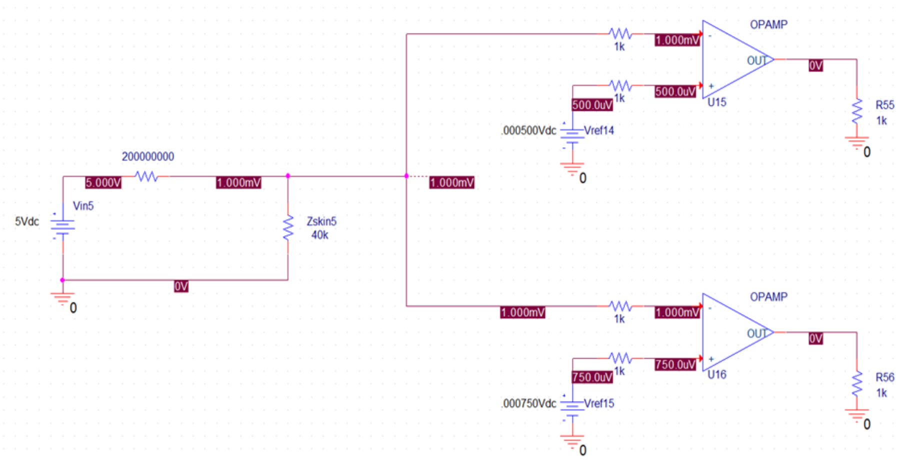

Figure A-3: Simulation of impedance verification with input 40 kohm.

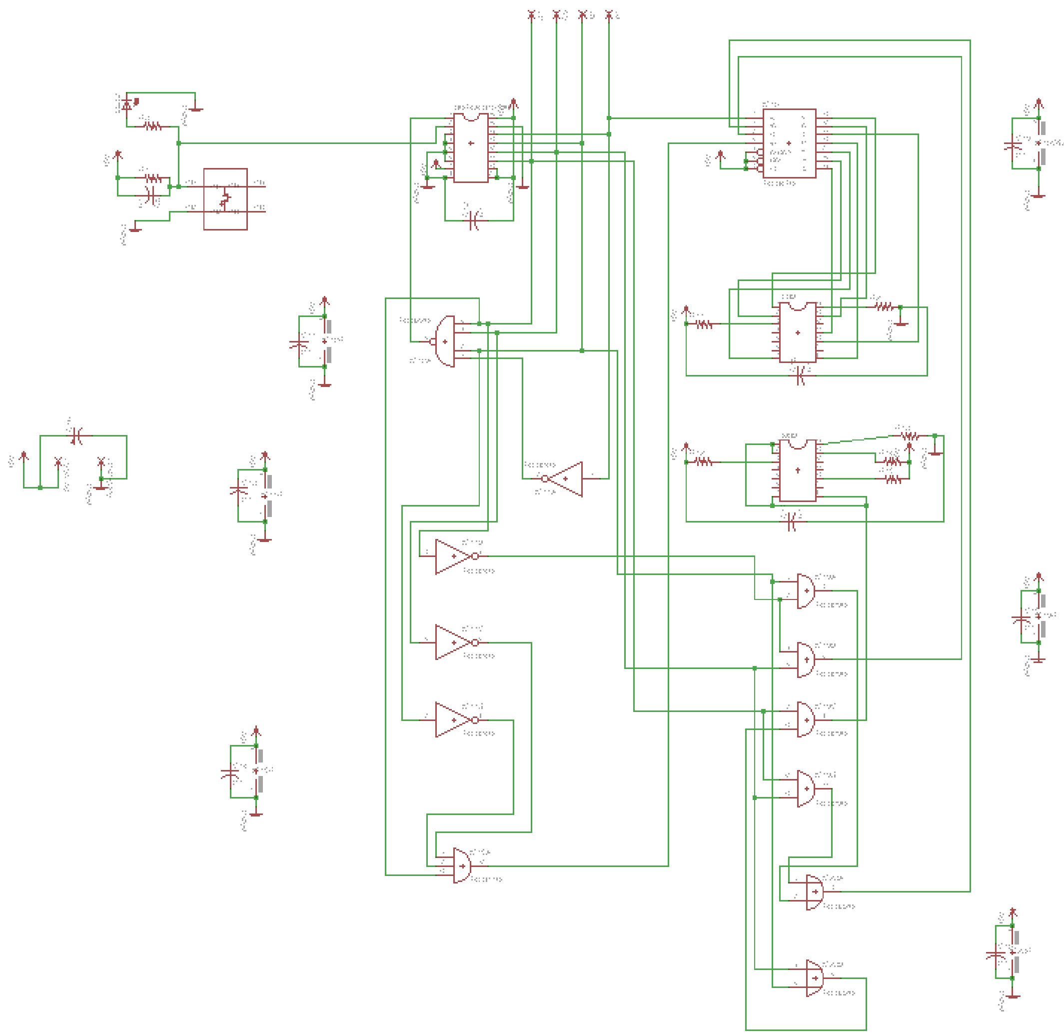

Figure A-4: Design schematic of counter system within impedance verification.

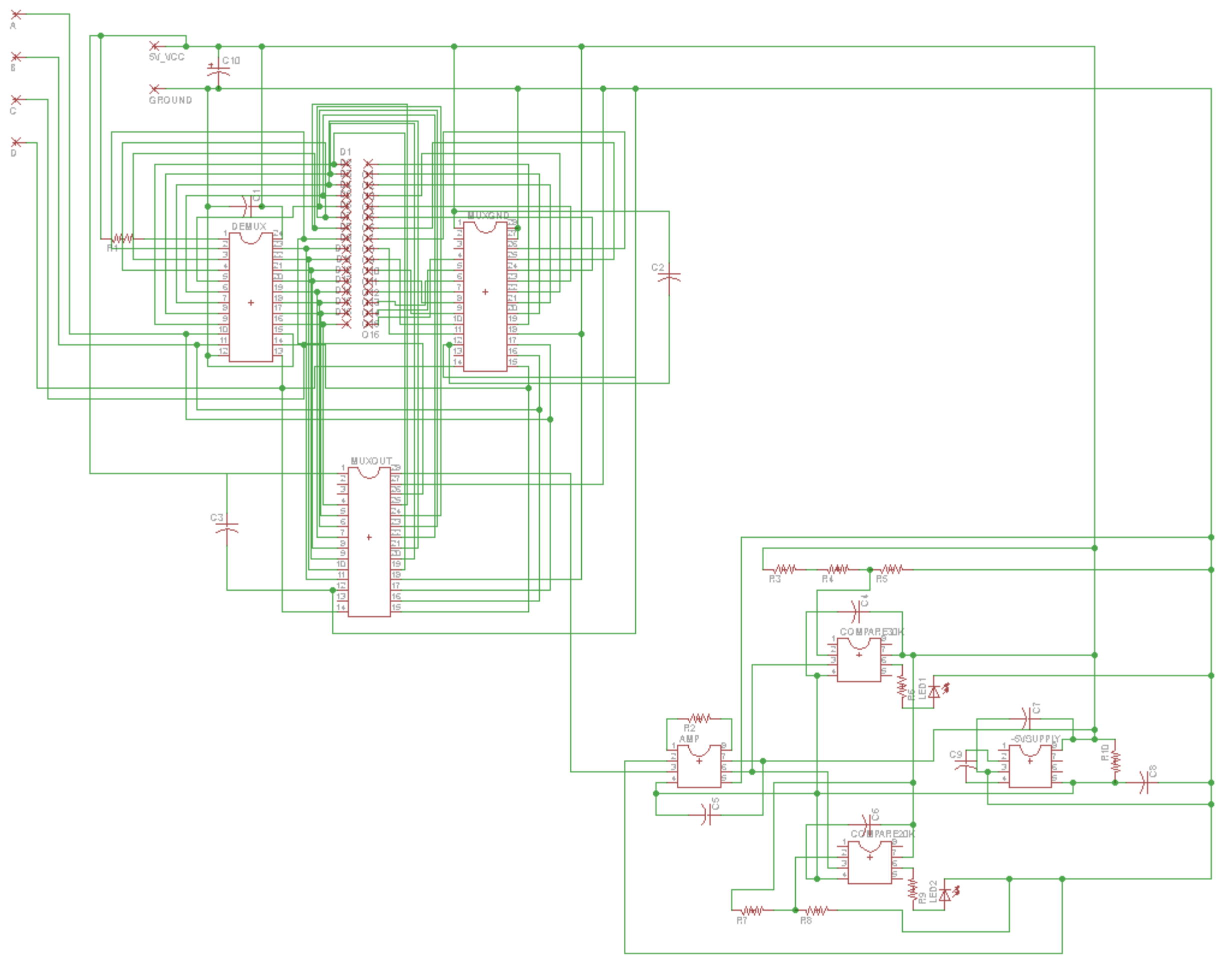

Figure 3: Design schematic of sensor selection, amplifying, and comparing within impedance verification.

VIII. Appendix B: Power Supply/ Amplifier/Filer Simulations

Power Supply:

In order to properly test our power supply prior to building, we used software called Cadence that helped us simulate the isolated parts of our power supply. The testing was done in two states:

Unbiased Reverse Polarity Protection module

Biased Reverse Polarity Protection module

By testing these two areas, we can effectively test the two modules of our Power Supply system, namely our linear dropout voltage regulator and our reverse polarity protection circuit. In testing our reverse polarity protection circuit, we used the circuit in figure 16 to demonstrate that circuit indeed blocks against negative voltage.

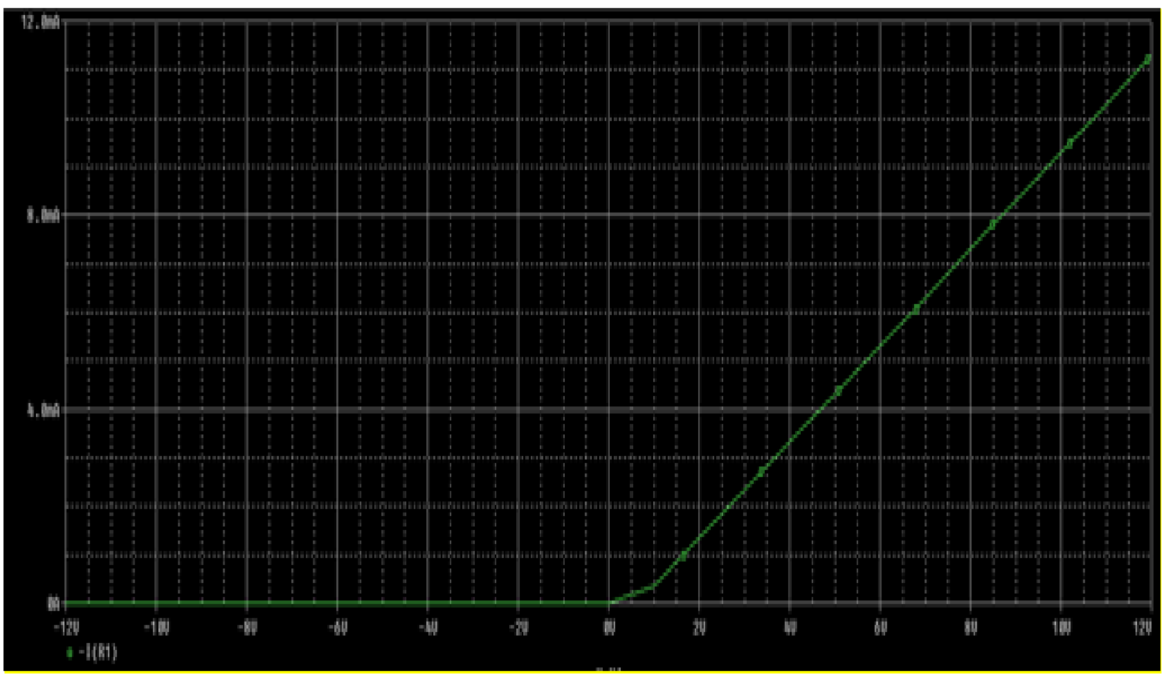

Figure B-1: Unbiased reverse polarity protection current.

Upon closer examination of the graph, we can see that there is no current before 0V, thus confirming our hypothesis that our reverse polarity circuit works. In order to verify its efficiency, we bias our In order to properly test this circuit, we generated an IV graph that measured the steady rectified state:

Figure B-2: Biased reverse polarity protection current.

As one can see, the slope is zero, so a constant current is being emitted across a variety of voltages confirming a steady rectified state.
MOSFET circuit with 30 mA.

Amplifier:

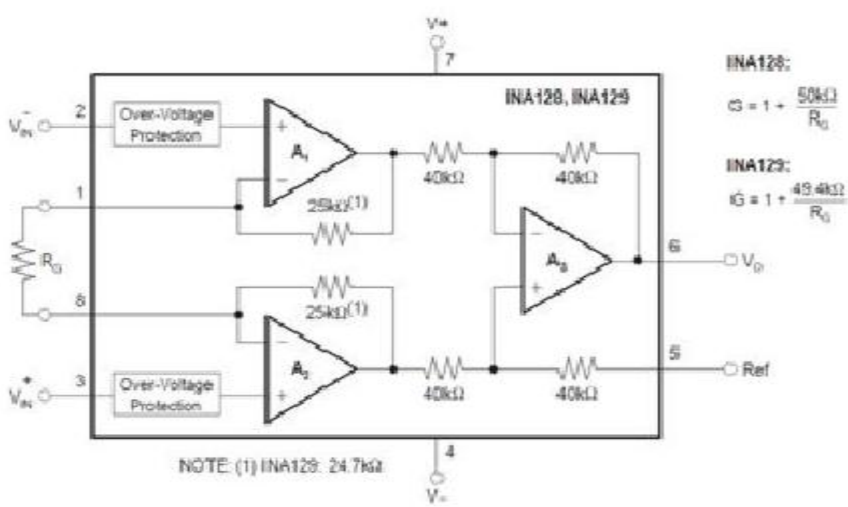

Figure B-3: INA128 amplifier.

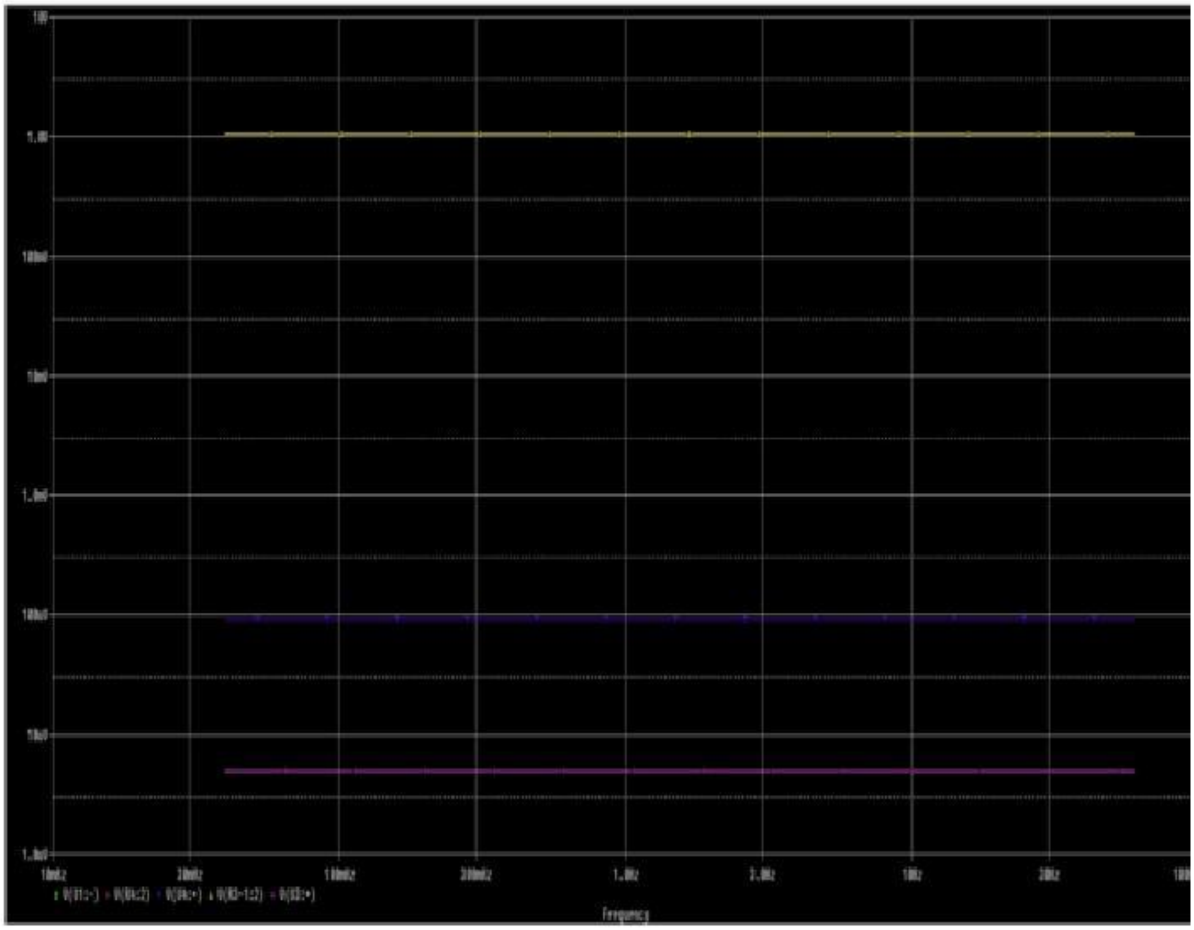

Figure B-4: Simulation of time response of differential instrumentation amplifier.

The simulation shows that dc offset input signal, dc offset being 220 mV from the sensors [4] will have the one sensor with the microvolt signal we want and the other signal will be just the dc offset with some noise. Note: the blue and purple signals are too close to tell apart because of the large dc offset in the simulation, but can easily be differentiated when one looks at the ac time sweep on the next figure. The purple signal is the noise value, the blue signal is the sensor information we want, and the yellow signal shows the output amplified brain wave voltage signal that we want to have with the appropriate 10,000 gain.

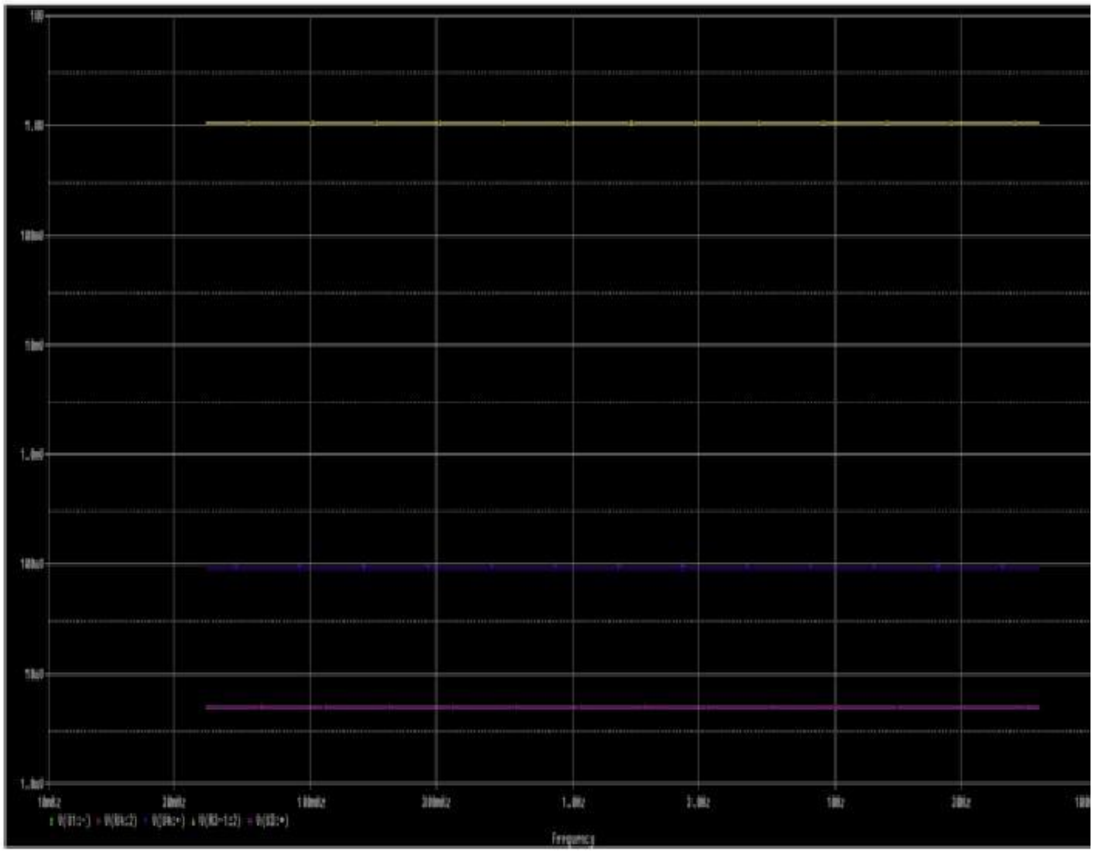

Figure B-5: Simuilation of AC response of differential instrumentation amplifier.

And this simulation being an AC sweep more clearly shows the difference in noise and the signal we want, same color scheme as before with purple as noise, blue as the signal, and yellow as the amplified results. Thus again we see the amplified signal at 10000 gain and that the gain remains the same over the entire frequency band.

Filter:

The idea of these simulations is to show why the filter system needed to be made much more complex with more hardware than what we thought there would be at first in order to get the needed flat band pass response that is needed. The first filter simulation shown below is the frequency response for a simple 2nd order band-pass. This clearly shows a lot of attenuation in the pass-band and very large transition bands.

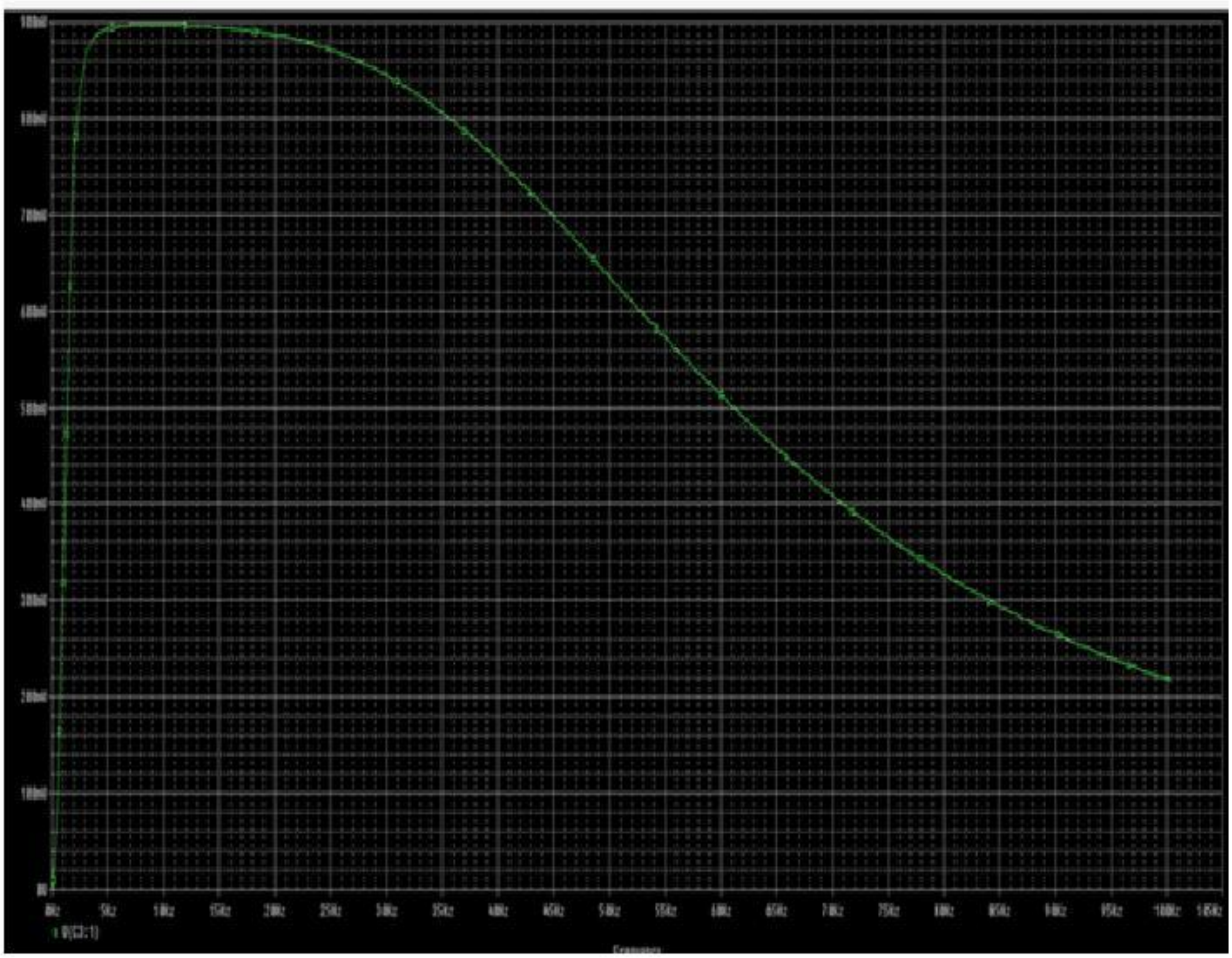

Figure B-6: 2nd order bandpass.

The next step was to take the simple bandpass filter, and take it from a second order system to a fourth order system. The result is shorter transition bands, but also more attenuation over the entirety of the pass band shown in the simulation below.

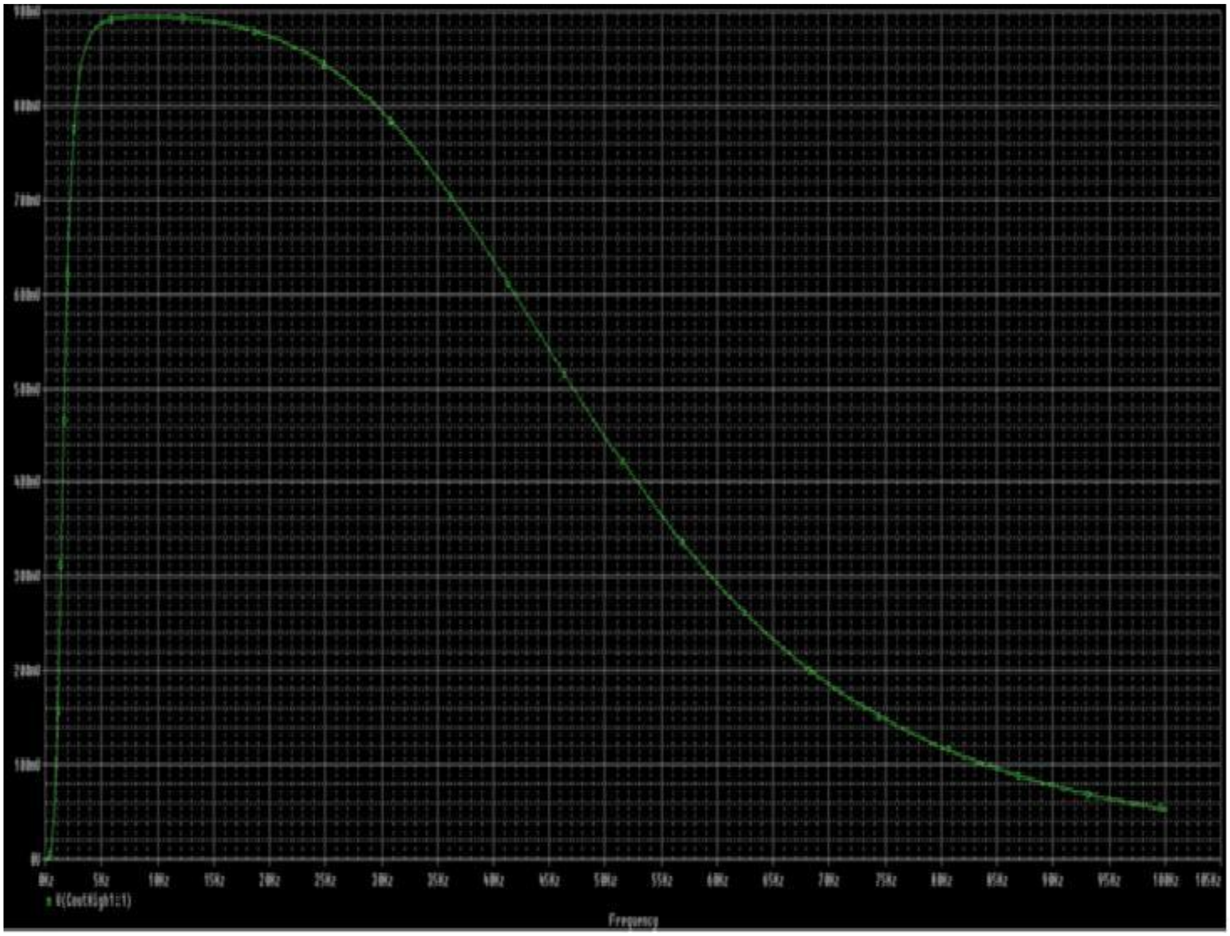

Figure B-7: 4th order bandpass.

Next, we simulated what would happen if we had just the fourth order low-pass in place since filtering out the 0.16 Hz is not the most important feature of the filter since we will use a differential amplifier implementation to remove near dc noise. The 4th order low-pass is shown in red below and clearly shows a shorter transition band at the cost of more attenuation in the pass-band.

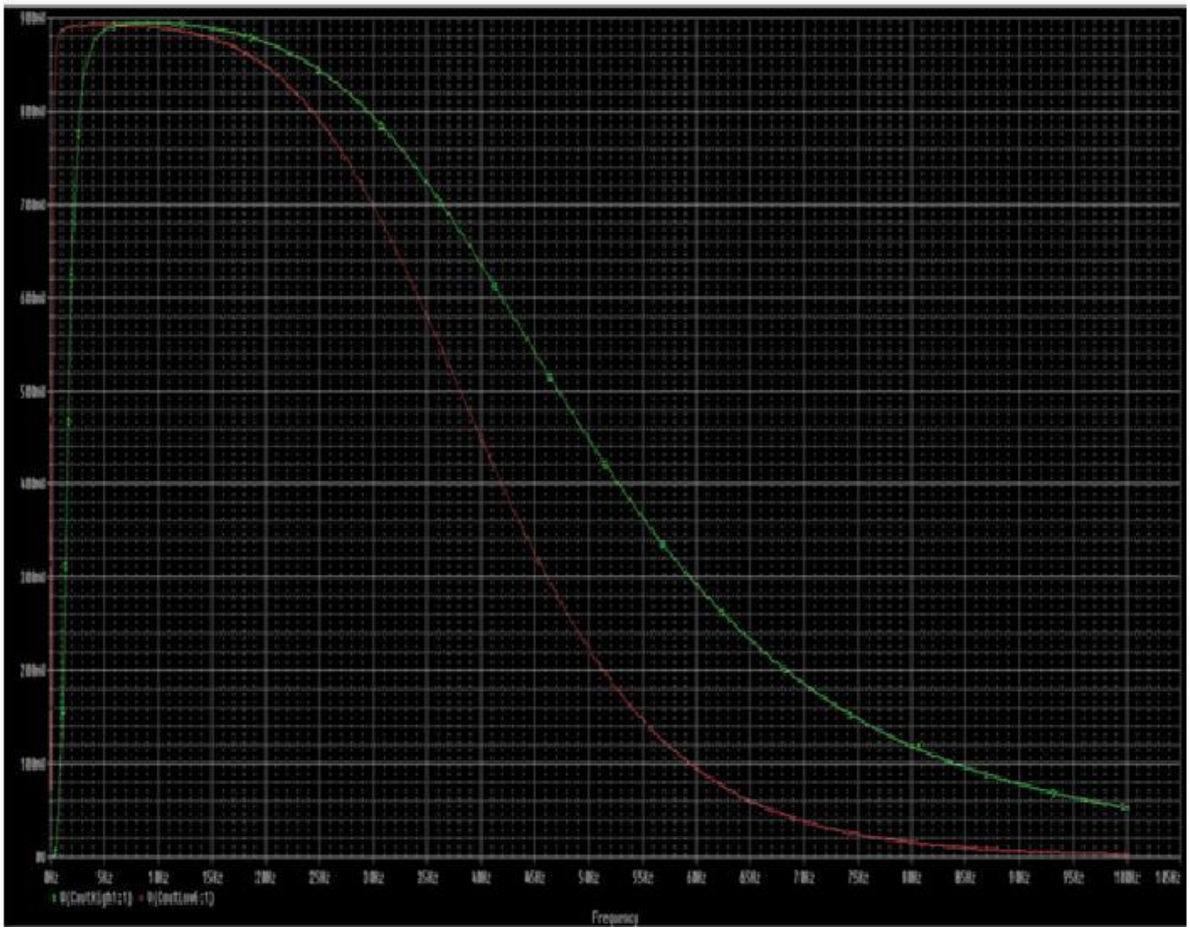

Figure B-8: 4th order bandpass in green and a 4th order low-pass.

Thus it became clear that simply increasing the order would not give the desired result of a very flat pass band. Only a filter with weighted poles designed to give a flat pass-band would work and that is the very definition of the Butterworth filter. The Butterworth filter response is shown below in yellow. Also a bode plot is included. From both it is clear to see, the 8th order band pass Butterworth gives a very flat pass band and very sharp transitions. It is far superior to the previous methods used with its very flat pass-band and very sharp transition bands.

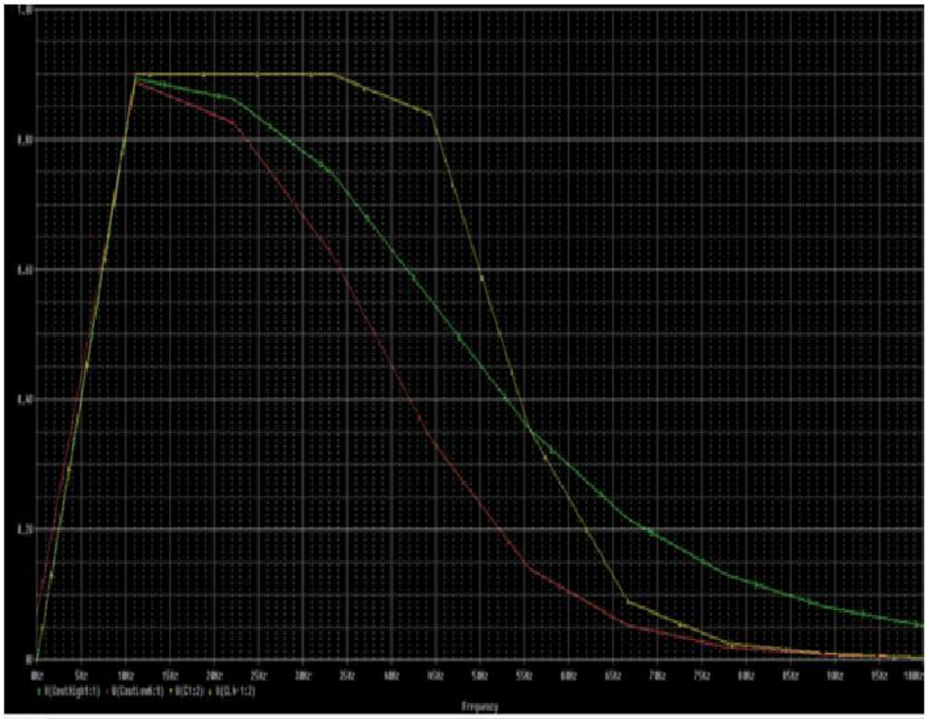

Figure B-9: In yellow, an 8th order bandpass Butterworth.

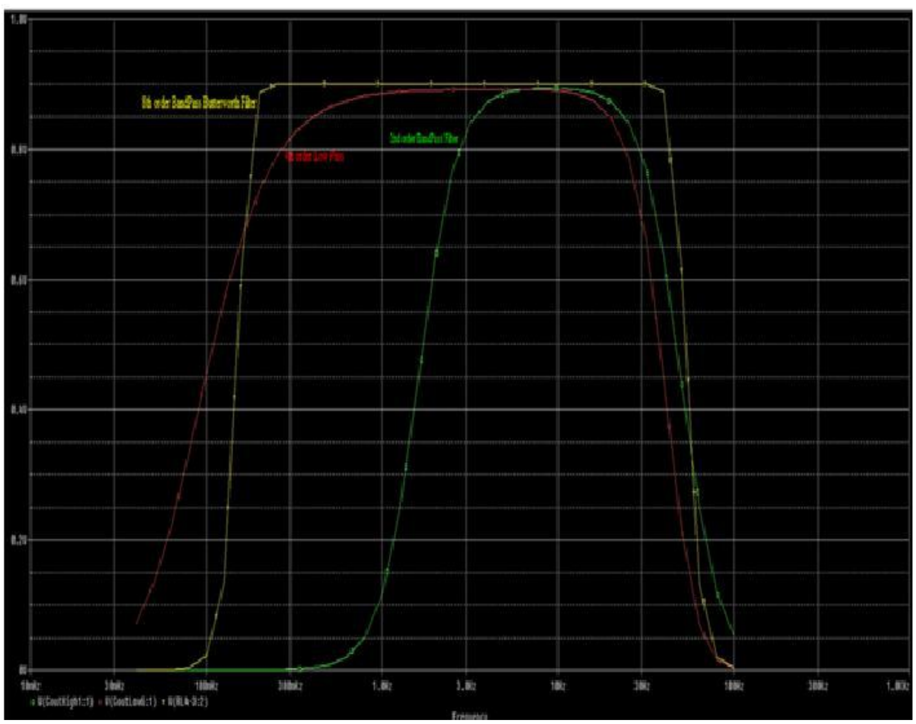

Figure B-10: Figure 9 in log scale.

Now this design is good, but with the instrumentation amplifier in use we will no longer need to worry about filtering out the dc component which then means we can just use the low pass part of the filter. The final filter design in use currently is an 8th order low-pass Butterworth filter designed to attenuate signals above 50 Hz . This give the following bode plot.

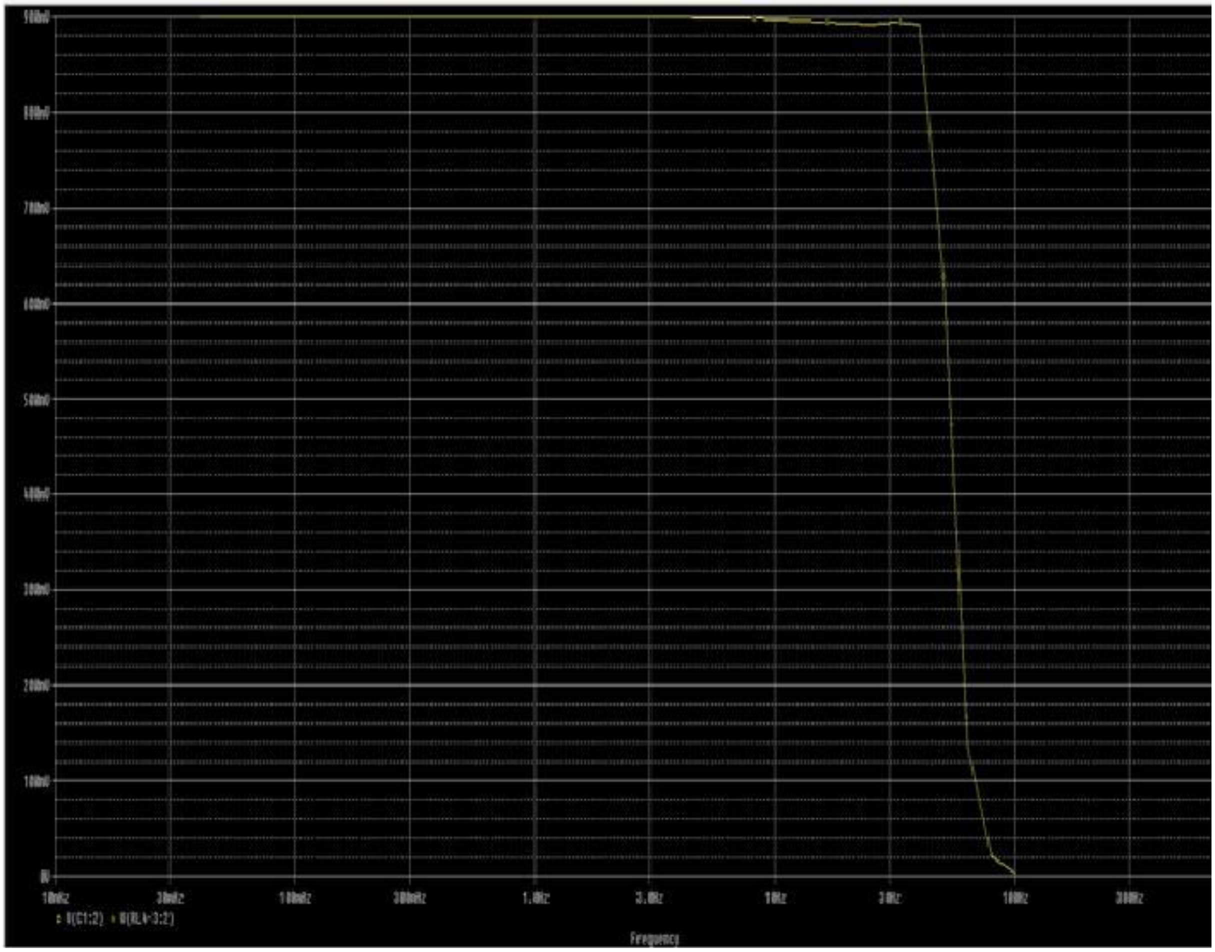

Figure B-11: 8th order Butterworth lowpass in log scale.

Design Schematic:

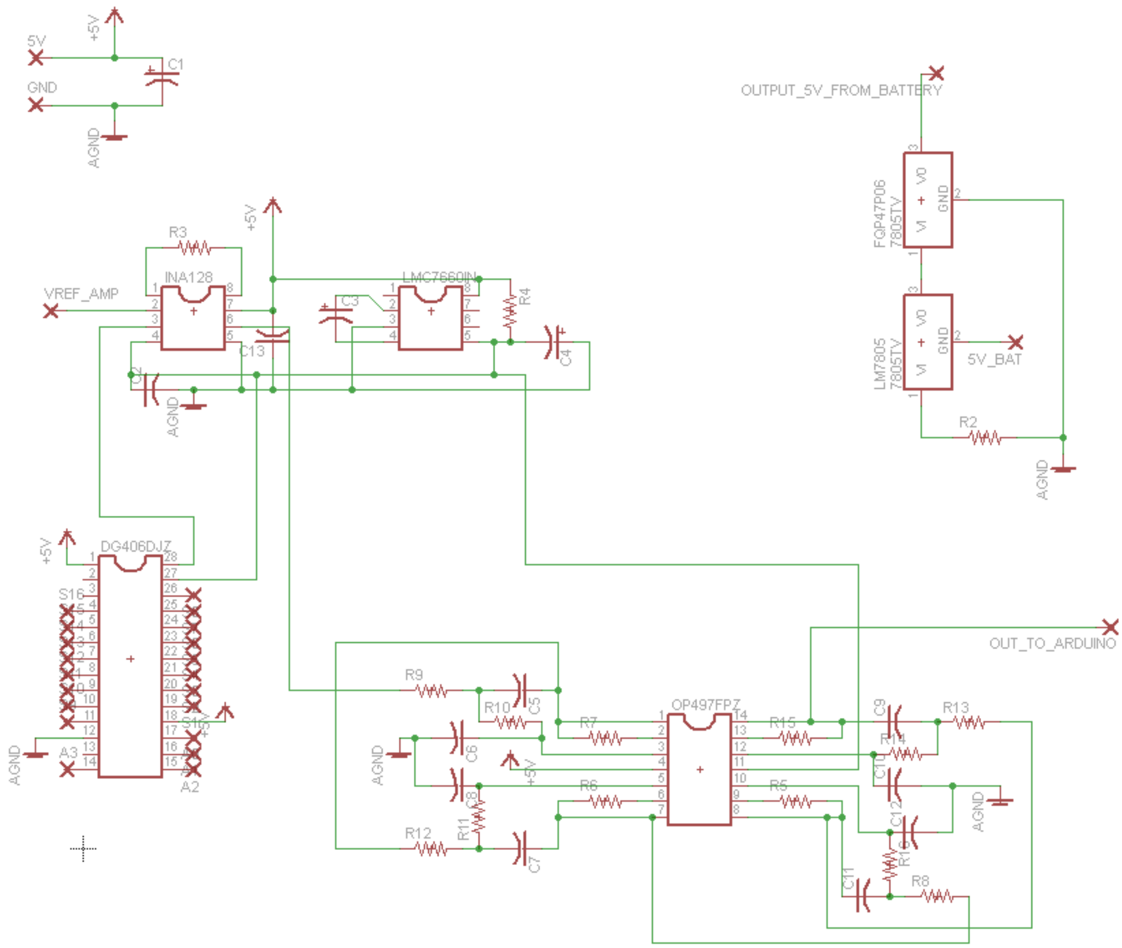

Figure B-12: Amplifier, filter, power supply schematic.

IX. Appendix C: Arduino Appendix

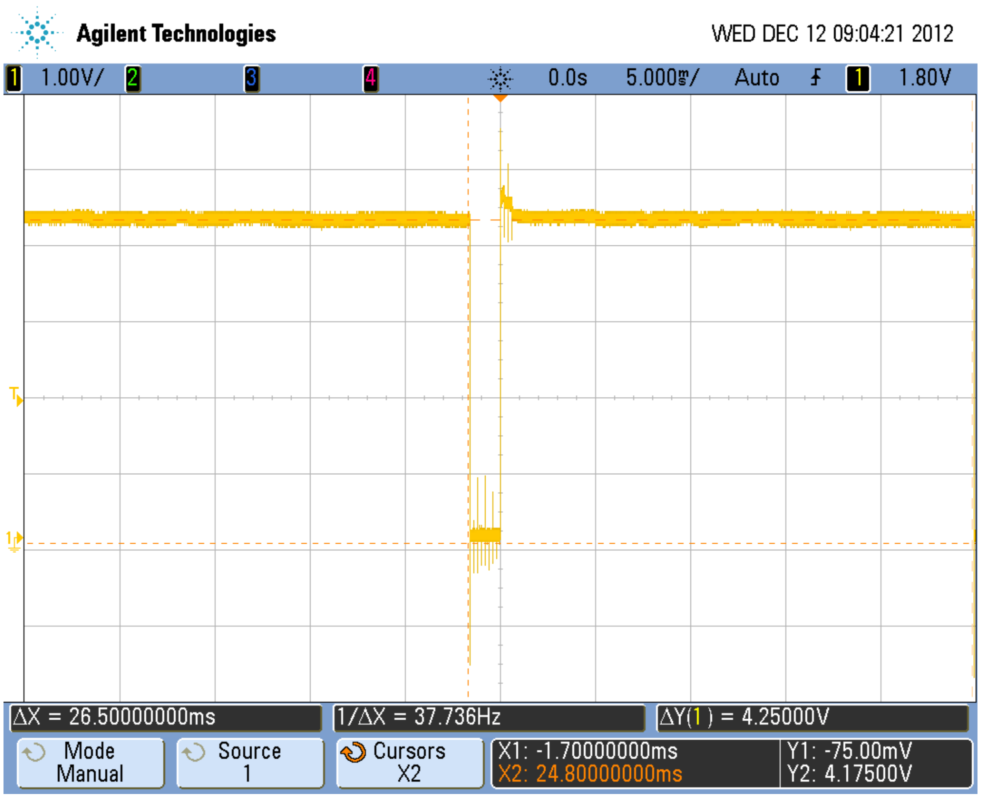

Figure C-1: MUX counter least significant bit.

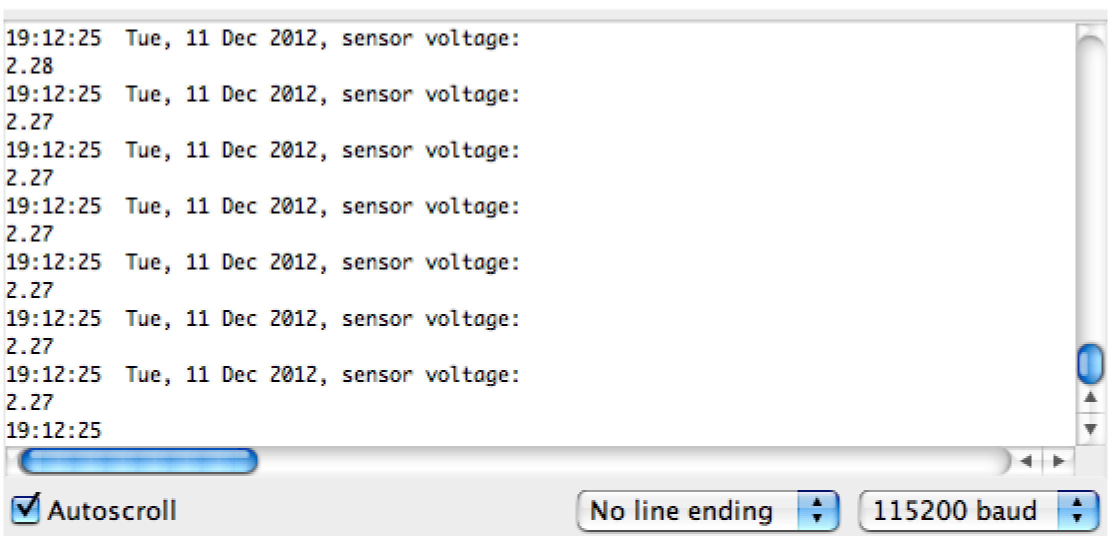

Figure C-2: The A/D conversion with an input of 2V power supply.

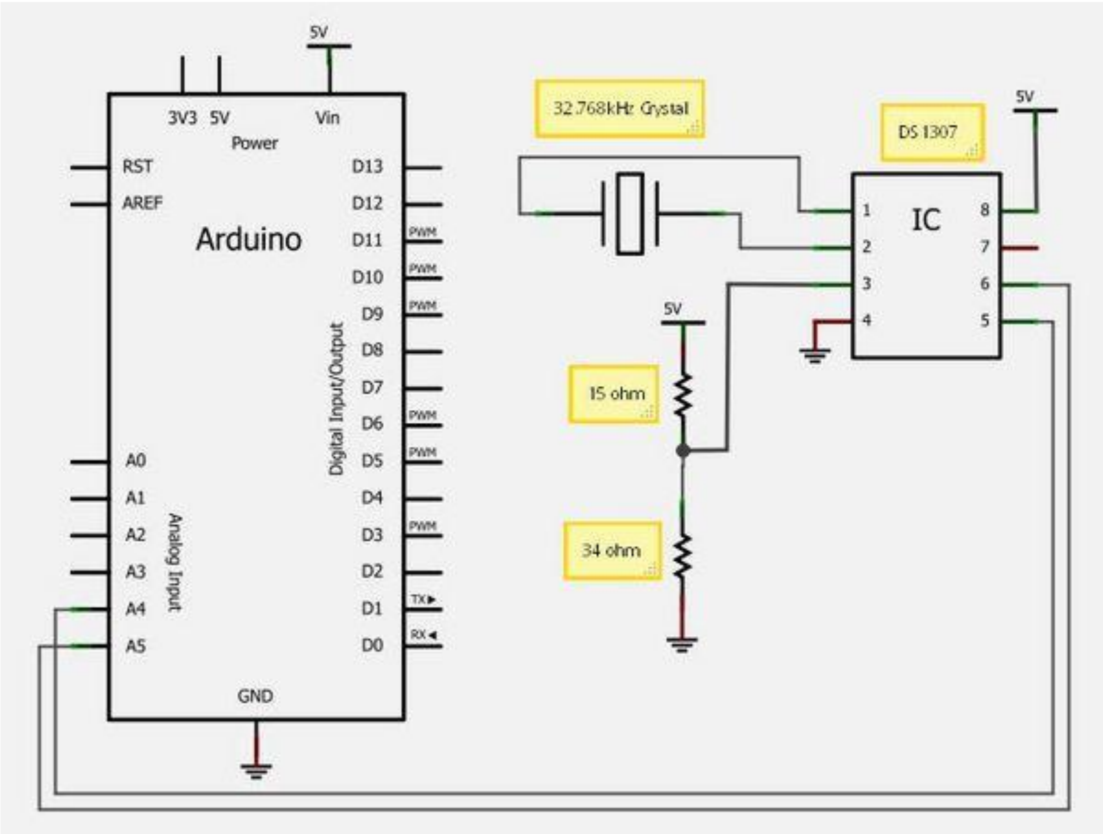

Figure C-3: An alternative design with IC chip schematic.

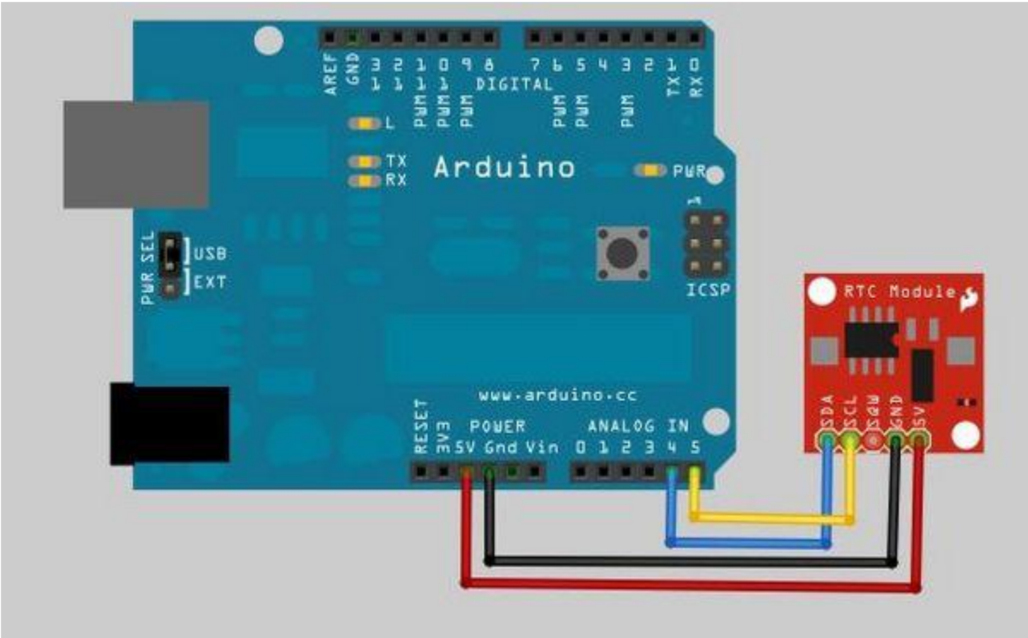

Figure C-4: Our final Arduino schematic design.

X. Appendix D: Verification Tables

Impedance Verification System

Performance Requirement	**Verification Procedure**
1. Manual input switch should change the selected sensor.	1. Press tactile push button and verify visualized sensor on binary LEDs. **Result:** This verification passed. This verifies that our systems clock can be controlled by the user.
2. Counts properly. Starts at 0 and resets at 13.	2. Flip switch through sensor numbers. It should reset after 13. **Result:** This verification passed. The system can count through the sensors (0-13) and reset properly.
3. Comparators show correct outputs for these 5 inputs: a) 16 kohms b) 24 kohms c) 27 kohms d) 36 kohms e) open circuit (>Mohms)	3. Outputs are displayed on LEDs that correspond to less than 20 kohms and less than 30 kohms. LEDs light up if condition isn't met. < 20 kohms < 30 kohms a) No LED a) No LED b) LED b) No LED c) LED c) No LED d) LED d) LED e) LED e) LED **Result:** This verification passed. The system as a whole can handle varying impedances and accurately depict where they lie. Warning lights (LEDs) appear when the conditions aren't met.
4. Current through the 200 Mohm resistor should be: a) 22-27 nA b) regardless of sensor impedance	4. If system works as a whole, these are verified. a) Current will be measured with an ammeter across the 200 Mohm resistor. b) Current will be measured with an ammeter across the 200 Mohm resistor when impedance changes. **Result:** This verification passed. Because the system worked as a whole, we can assume the current does what we expected.
5. MUXes and DeMUXes are wired correctly.	5. If system works as a whole, this is verified. LEDs will be placed on each input resistance line. Changing the selected input sensor will light up the corresponding LED. **Result:** This verification passed. Because the system worked as a whole, we can assume the MUXes and DeMUXes are properly wired.

6. Negative power supply provides -4.5 - 5 Vdc.	6. If system works as a whole, this is verified. A voltmeter will be used to read the output of the negative power supply. **Result:** This verification passed. Because the system worked as a whole, we can assume the voltage outputted is what we expect it to be.
7. Amplifier multiplies by 4500-5000 V/V.	7. If system works as a whole, this is verified. A voltmeter will be used to read the input and the output of the amplifier with sensor 0 selected. **Result:** This verification passed. Because the system worked as a whole, we can assume the amplification is what we expect it to be.
8. Seven Segment Display correctly displays the selected sensor number in decimal.	8. If system works as a whole, this is verified. User will switch through the 14 sensors and read off the 7 Segment Displays. **Result:** This verification passed. Because the system worked as a whole, we can assume the voltages across the impedances were amplified correctly as they needed to be compared to hardcoded values.

Amplifier

Performance Requirement	**Verification Procedure**
1. Total Amplification Gain 10000 +/-30% total Gain	1. Total Amplification Gain We will test this performance requirement by sending an input voltage from the function generator of 0.0001 volts peak to peak and measure the output voltage with the oscilloscope. Specifically the input Vpp and output Vpp will be displayed on the oscilloscope and compared. A resulting voltage of 1 volt +/- 30% will show the correct amount of gain, 10000, while any other value will indicate a flawed amplification stage. **Result:** Verification passed. With 0.0001 volts peak to peak in, 1.25 volts peak to peak was the output which is within the tolerances.
2. Frequency Response of Amplifier Circuit The gain of the circuit must stay constant from the range of 0 to 50 Hz the frequencies that we will be analyzing.	2. Frequency Response of Circuit We will test this performance requirement by sending an input voltage from the function generator of 0.0001 volts peak to peak and measure the output voltage with the oscilloscope. Specifically the input Vpp and output Vpp will be displayed on the oscilloscope and compared. We will then vary the frequency of the voltage wave

	from zero to 60 Hz. We will check that the output voltage stays around 1 volt +/- 30%, especially from the 0 to 50 Hz range. As long as the voltage does not go above or below 30% over those frequencies from 1 volt, then the test will pass. **Result:** The verification passed. The output voltage peak to peak stayed within the 30% tolerance of 1Vpp for the entire 0-60 Hz range

Filter

Performance Requirement	**Verification Procedure**
1. Frequencies above 50 Hz attenuated.	1. Frequencies above 50 Hz attenuated. This will be tested by sending a 1 volt waveform from the function generator at a frequency from 60 Hz +/-2 Hz to the input of the filter. An oscilloscope will measure the output voltage and the verification will pass if the output voltage peak to peak is 0.5 volts or less. **Result:** This verification passed. At 60 Hz the output signal is attenuated to 400 mV or 0.4 volts peak to peak which is the correct functionality desired.
2. Frequencies from 0 to 50 Hz passed with equivalent gain. Frequencies above 0 Hz and below 50Hz need to be passed with almost uniform gain.	2. Frequencies from 0 to 50 Hz passed with equivalent gain. This will be tested by sending a 1 volt waveform from the function generator at frequencies sweeping from 0Hz to 50Hz +/-0.2 Hz to the input of the filter. An oscilloscope will measure the output voltage and the verification will pass if the output voltage peak to peak is 1 volt +/- 30% through 80% of all the frequencies. **Result:** The verification passed. From zero to 40 Hz the output voltage is 1 volt peak to peak. From 40 Hz to 50 Hz the signal drops to 0.8 volts peak to peak especially the closer to 50 Hz that one gets. This is still within the tolerances acceptable and thus the verification passes.

Power Supply

Performance Requirement	**Verification Procedure**
1. 5 volt LDO power regulation We need the power supply to compensate for voltage fluctuations. In order to properly maintain a steady voltage between 4.7-5.3V, we must have a consistent circuit.	1. To test this feature, we will input a set of voltages at a variety of different voltages from 6-12 volts to the LDO and measure the output voltage on the oscilloscope. Correct functionality will show these voltages regulated down to 5 volts +/- 30% **Result:** The verification passed. The input voltages varied from 6-12 volts will give output voltages of 4.8 volts which is within the prescribed tolerances.

2. Reverse Polarity Protection The circuitry of the entire power supply needs to be protected from incorrectly put batteries.	2. Reverse Polarity Protection This will be verified by putting reverse voltage to a p-mosfet protection circuitry and measure the output in an oscilloscope with a voltage value close to zero volts. Close being +/- 0.3 volts from zero. **Result:** The verification passed. Reverse voltage leads to -0.088 volts output of the protection system which is within the tolerances.
3. Negative power supply of -4 to -5 volts This is needed to operate the amplifier and the op amp used in the filter	3. To test this feature, 5 volts will be put into the switched capacitor inverter and the output will be measure on an oscilloscope with correct functionality to be -5 volts +/- 30%. **Result:** This verification passed. Input of 5 volt led to -4.7 volts output. Thus this is within the tolerance and the verification is met.

Arduino

Performance Requirement	Verification Procedure
UTC to RTC time We need to convert from the standard Universal Time Counter to Real Time Counter in order to have a time that saves the data in a format that we understand.	UTC to RTC time We will input a constant signal at 30mA into the Arduino to see if the signal is being properly time stamped on to the SD card. We will verify if this is correct by plugging in the SD card on to one of our laptops and examining the information.
MUX Binary Counting In order to have the MUX count in appropriate manner, we need to make sure that the four signals sent from the Arduino ports A2-A5 are properly counting from 1 to 12 in binary	MUX Binary Counting To test this we must set up four LEDs to verify that the Arduino is indeed sending the correct four signal sequence for each count to the MUX. To verify, we will do the following: 1) Arrange four LEDs vertically aligned with one end connected to ground and the other connected to a horizontal row that has a wire connected to one of the ports A2-A5. 2) Down press the red LED button on the Arduino and watch the LEDs increment in a four bit binary count from 1 to 12

MUX Counter Rate

In order to properly increment the MUX SELECT bits, we must confirm that the rate at which the MUX is counting is one binary number every 600 milliseconds.

MUX Counter Rate

This rate (1 binary count/600 milliseconds) is very difficult to verify with a pair of eyes and a stopwatch, so the verification procedure implemented would be the following:

1) Take a wire where one end connects to an oscilloscope and the other is a banana wire split
2) Plug the black wire into the Arduino board ground while placing the red wire into the lowest binary bit port (A2).
3) This lowest port represents the binary 2^0. Out of the decimal to binary count 1 through 12, this port is set to HIGH once every two numbers that are counted. If we are incrementing the binary rate, this should have a frequency of HIGH every second.
4) Now to check the second port (A3). This is 2^2 and will be set to HIGH six out of the twelve number count or 1 set every 0.1 seconds (same as port A2 tested in step 3). We test this port since it is individually set. ‘
5) Moving to A4, the second most significant bit, this is set five times every twelve number count. This frequency should be set at 1/0.12 seconds or set HIGH at a frequency of 8.33 times/second.
6) The most significant bit A5 is set to HIGH five times every 12 count. This is the same frequency as A4, 8.33 times set to HIGH/second.

MUX Voltage Requirement

In order for the SELECT bits to be read, the input signal into the SELECT port must be between 0V-3.5V.

MUX Voltage Requirement

Set the counter to ON by down-pressing the red reset button on the Arduino board. Take a voltmeter and parallel connect it to the first port (A2), checking to see if the voltage reading does not exceed 3.3-3.5V. Repeat this with each port A2-A5.

SD Card Clock Rate

SD Card Clock Rate

The clock rate for the Atmega328, the processor that the Arduino board is built on, must have a set CPU (Central Processing Unit) frequency of 2.0 MHz.

To verify the CPU clock rate, we need to first understand how the Atmega328 works with the Arduino. The Atmega328 has a port called SPI (Serial Peripheral Interface). We set the SPI Control register bits 1 and 0 to HIGH and set the SPI2X to HIGH by setting bit 0 in the SPI Status Register to HIGH in order to get 2*1.0MHz clock rate. We set the port 11 to F_CPU, the frequency of the CPU or as we know it the clock rate for processing the data. We connect a wire with one end to an oscilloscope and the other with banana plugs (black to ground and red to port 11 in the Arduino board). Rate should appear 2.0 MHz, with a 0.02 fluctuation.

SD Card Synchronization

We need to see that the data being written to the SD card makes sense from the input data we are sending with the MUX

SD Card Synchronization

To verify this synchronization, we will do the following:

1) Insert the SD card into the Arduino slot
2) Print one signal every 0.166 ms, therefore allowing each set of signals processed to alternate which of the 12 signals will represent the timestamp for that specific instance. For example, if we run the counter 1 through 12 signals in 1.99 ms, signal 11 will get printed to the SD card since the processing delay is 0.166 ms. During the next 12 count cycle, signal 10 will get printed to the SD card.
3) To verify this data against the voltage signal, we will input a constant 5V from a power supply for all 12 signals and have the Amplifier and Filter circuits connected serially between the 1V power supply and the pin signal input for the Arduino that we want to be printed to the SD Card. The printed voltage should be 2V.
4) To check the SD card, we will plug the SD card into the SD card reader connected to the computer.
5) Open up the text file created by the

Arduino and check the data printed to the SD card.