Neuro-transmitter (EEG) Interface System

Design Review

ECE 445: Senior Design
Group #29

Kevin Armstrong-John Burton-Alex Lostumbo
TA: Ryan May

October 4, 2012

Table of Contents

I. Introduction

1.1 Statement of Purpose

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. Our system will cost under $500, and allow 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. We will rid the necessity to carry a laptop. Along with using a cheaper device design, we will make our device more mobile and more cost-efficient thus creating a very viable product in the EEG market. Our device will 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.

1.2 Objectives

1.2.1 Goals

· Create a fully functional EEG that logs time-stamped data on an SD card
· Keep within a budget of $500
· Meet the ethical and safety requirements and quality of data for research
· SD card should hold at least 2 hours of data logging information

1.2.2 Functions

· 10,000 gain Op-amps to detect and differentiate between voltages produced by brain waves
· Bandpass filtering to remove frequency noise from environment and subconscious controls
· Analog to digital converter that also timestamps and stores the digitized information
· LED display to verify sensors are making the correct contact by measuring their impedances

1.2.3 Benefits

· Making EEG mobile for novel neuroscience research
· Lowering barrier of entry for smaller neuroscience budgets to conduct field research
· Indication in the field of good sensor contact with the research participant's head
· Circuitry involved will be light and packaged for portable usage

1.2.4 Features

· SD card storing at least 2GB of memory equating to at least an hour’s worth of research
· Power supply that lasts at least 5 hours
· We have dual color LEDs that tell us if the sensors are applied properly (impedances are less that 20 kΩ
· All sensors will pass through a common amplification and filtering component, reducing irregularities

II. Design

2.1 Block Diagrams

Overall EEG Functional Block Diagram:

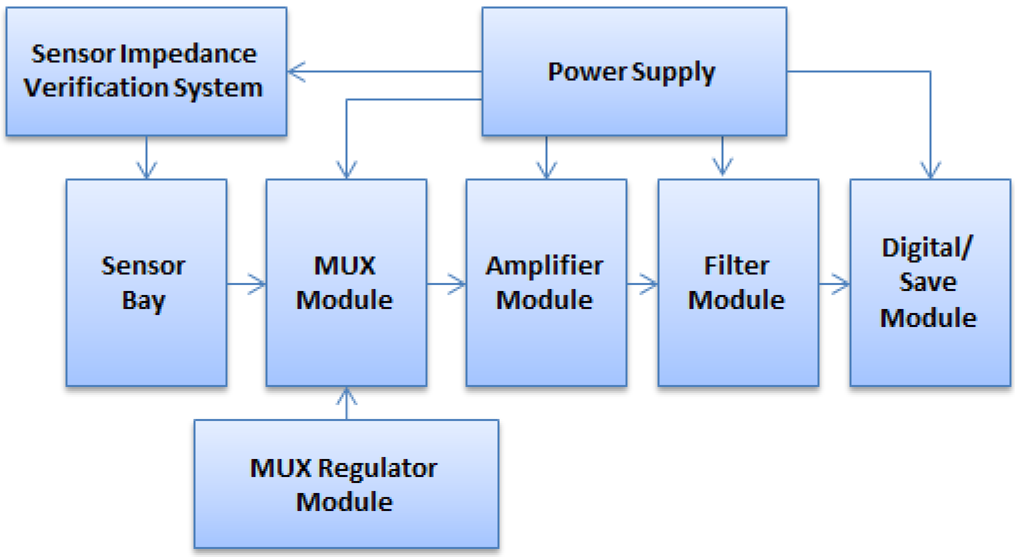


Figure Note: The MUX Regulator Module and Digital/Save module are contained in one Arduino device, but are written in two separate blocks for the reader's clarity

Figure 1a. Overall functional summary layout.

Overall Functional Summary:

The large-scale block diagram describes the connection between the sensors in the EEG cap (listed here as "sensor bay") and our physical device encased in an acrylic box that will be provided by the Electronics shop and be strapped to the back of the EEG cap user. To ensure that the sensors are properly applied to the user, we plan to implement an Impedance Verification System in order to assure both the user and the researcher that the quality of the data being collected is accurate for the experimentation. The amplifier module will take in the signals from the sensors and amplify them in order to bring the voltages into normal detectable levels for the ADC to differentiate between the signals 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. Both the amplifier and filter modules will take place on a PCB board. After filtering out the noise from each sensor, the individual sensor signals will be fed into the Digital/Save Module 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. The SD card and Arduino memory module will organize the signal information by sensor channel.

Overall EEG Physical Block Diagram:

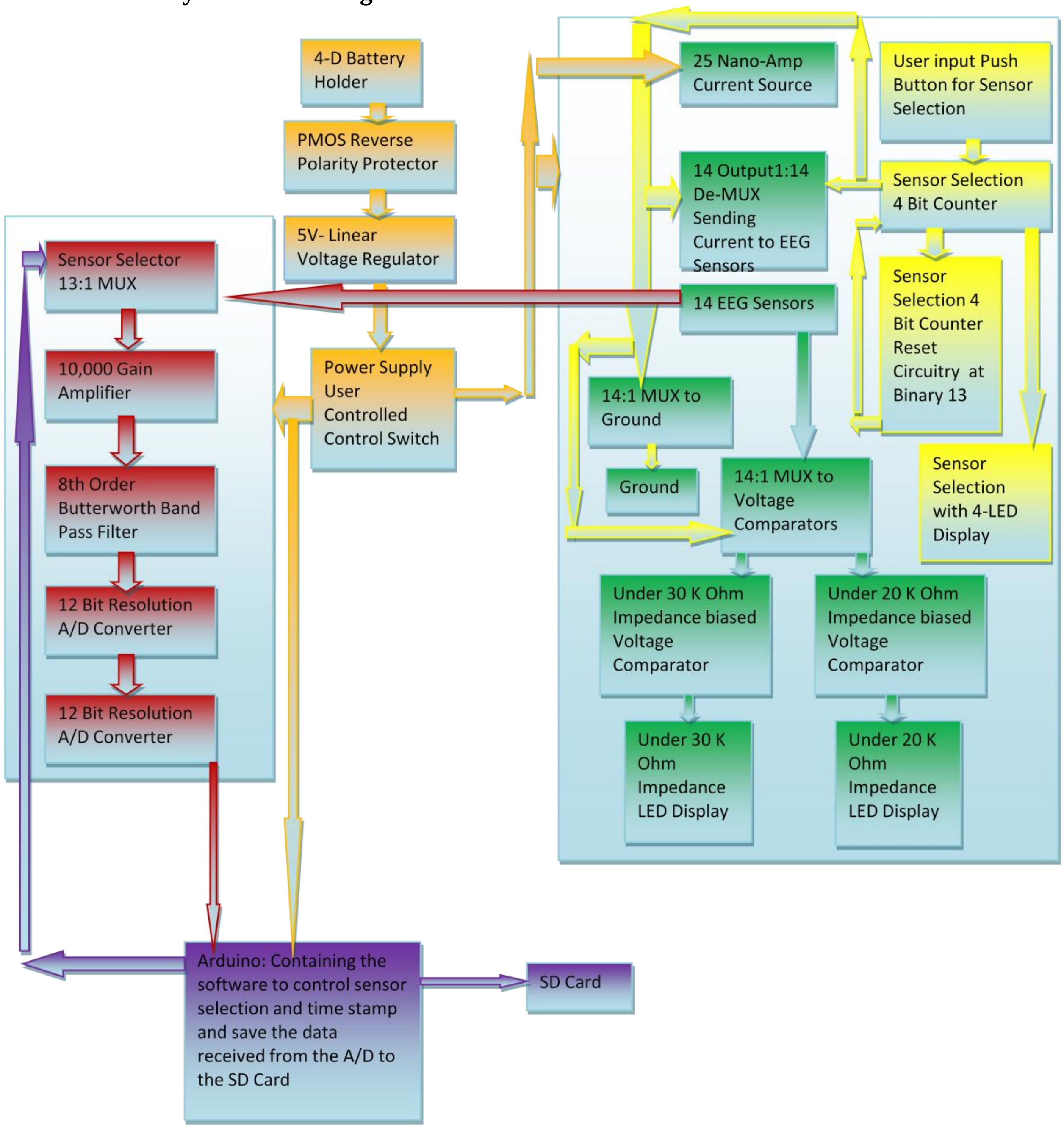


Figure 1b. Overall physical summary layout.

Overall Physical Summary:

Figure 1b. describes the physical blocks that will comprise our project. In red and purple, we have the amplifying and filtering circuitry and microcontroller (Arduino), respectably. In orange is the power supply circuitry. In green and yellow, we have the sensor impedance monitoring circuitry and sensor selection for impedance readings. The blue describes our PCBs: one for the filtering and amplifying and another for the sensor impedance monitoring.

Power Supply:

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 four D batteries that at initial use will have 6 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. 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. 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. 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.

MUX Module:

The MUX module will take input from the sensor bay and one output to the amplification component. For choosing which signal will pass through the MUX, the Arduino will send a signal command in the MUX's SELECT bits. On a macro level, there will be a 16-to-1 MUX provided by analog systems (described in greater detail later in report) that will choose which of the 16 inputs should be outputted to the Arduino. Since we only use thirteen of the sixteen inputs, we will set three of the sixteen to ground, and alternate selection between the signals being sent to the Arduino. The block will go through the sensor inputs one at a time and connect the output to the amplification component. The purpose of this block is to reduce the amount of circuitry involved to amplify and filter all 13 sensor's signals.

Amplifier Module:

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 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 Module:

The filter model will consist of an 8th order Butterworth band pass filter circuit that will remove signals with frequencies above 50 Hz and below 0.16 Hz, while minimizing any reduction in the signal amplitude of those frequencies that are between the two. It will take inputs from the amplifier module and send its outputs to the MUX module. It will primarily be composed of a high pass filter in series with a low pass filter that will be composed of resistors, capacitors, and operational amplifiers. The exact values of the resistors and capacitors will be determined by the Butterworth equation.

Digital/Save Module (Memory module):

The memory module will consist of three devices, an A/D converter, the Arduino board, and a 2GB SD card. It will also consist of a DeMUX that will take its inputs from the output of the A/D converter and send the output to the Arduino board to one of the 13 different output lines that correspond to the 13 sensors used. The DeMUX will be synchronized with the MUX so the sensor currently selected will be passed through amplification, filtering, A/D conversion, and then get put on the specific sensor signal channel on the Arduino to get stored on the SD card. The Arduino attaches a timestamp to each signal and stores the signal in the memory card. This data would be accessible from the memory card by means of a USB cable connection from a computer to the Arduino board.

Sensor Impedance Verification System:

The Sensor Impedance Verification System will monitor the impedance on each of the 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 system will need to be switched on before using and switched off afterwards to not interfere with data collection. The system will have 4 parts: a current source, a selection circuit, a comparator circuit, and the Counter and LED display unit. The current source will supply a small current (in the order of nA) that will be sent to the skin. We will read the voltage over the sensor-skin contact of each sensor (chosen by the selection circuit), and compare those to known voltages that correspond to known impedances (20k and 30k). We will display two LEDs to show the relative impedance. The chosen sensor will also be shown in binary using 4 LEDs. 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 in itself will provide a visual to tell the user if each sensor is correctly applied.

2.1.1 Power Supply

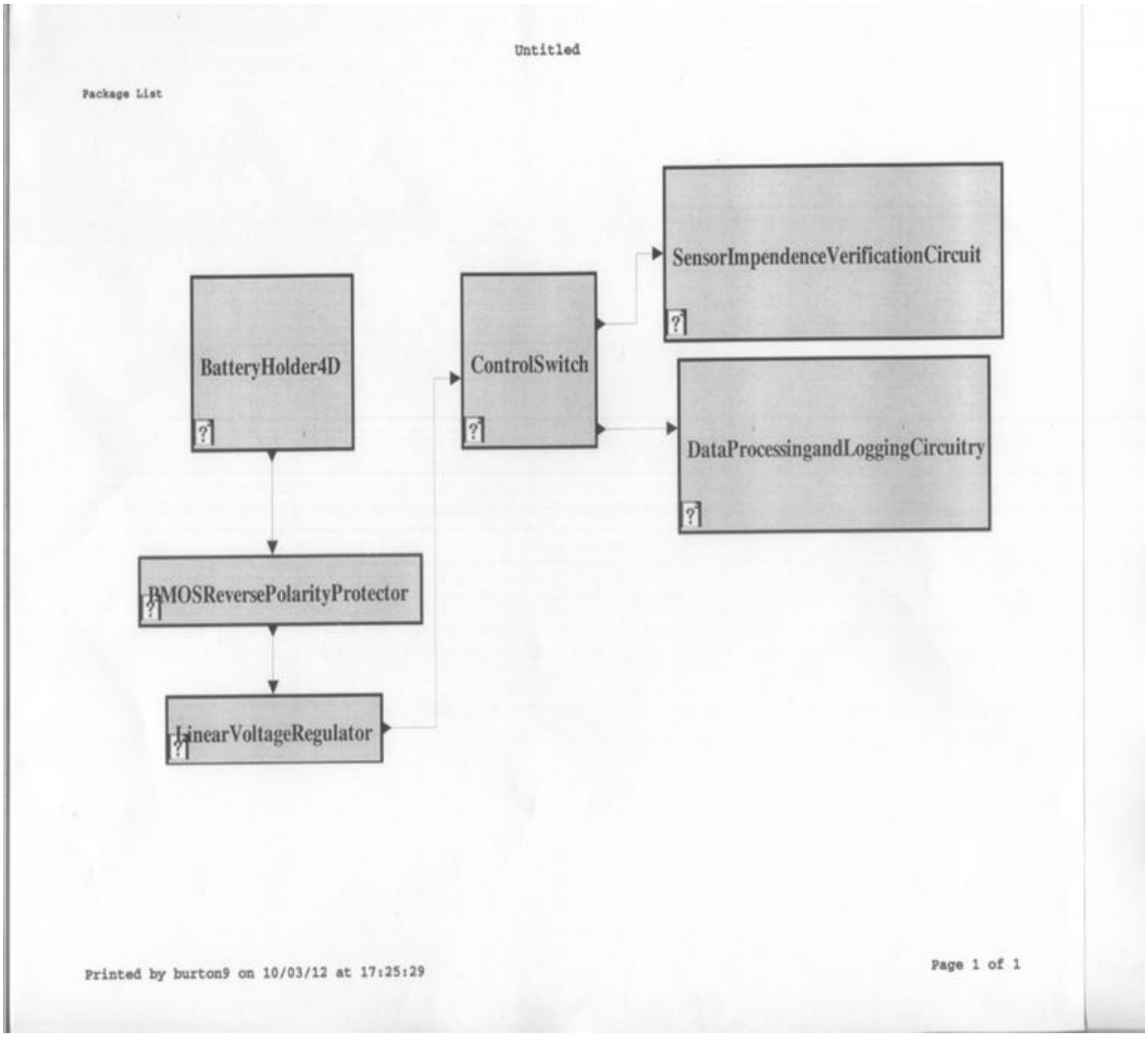


Figure 2. Overall power supply layout.

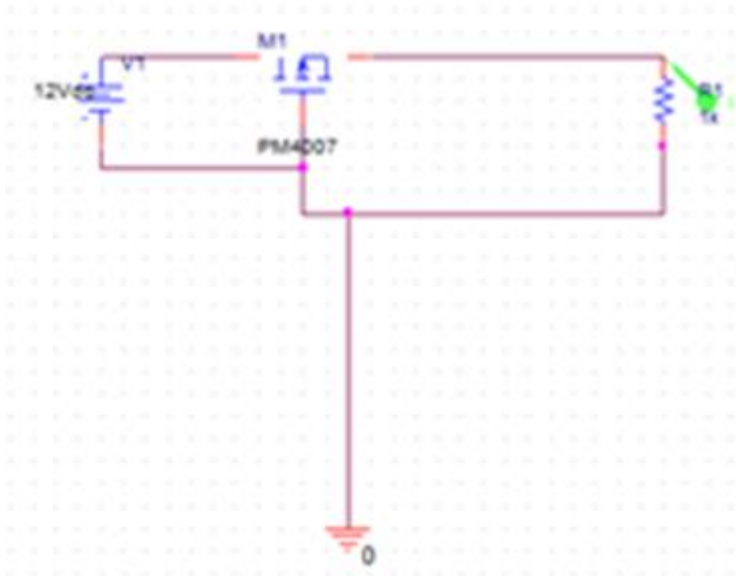


Figure 3. Reverse polarity protection circuit.

Overall Summary:

The power supply for our system takes a voltage input of 5.4 - 6.6 Vdc supplied by 4 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.

Further analysis...

With a forward biased voltage source:

$$Vgs = (Vg-Vs) = 0 - 6 = -6V$$

-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.)

$$Vgs = (Vg-Vs) = 0 - (-12) = +12V$$

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 6 V. 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.

2.1.2 Sensor Impedance Verification System

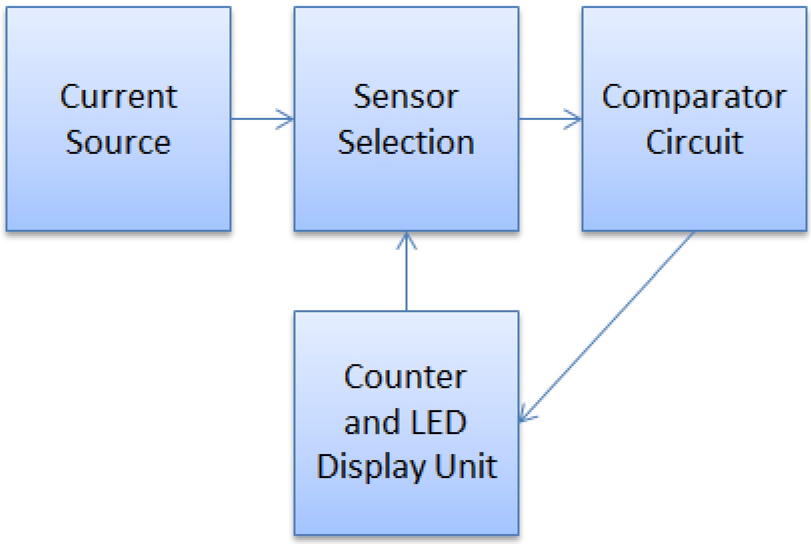


Figure 4. Overall sensor impedance verification layout.

Overall Summary:

The Sensor Impedance Verification System is a necessary component to the project in that it reads the impedances of each of the sensors used in the system. It is important that the sensors are properly applied (an acceptable impedance is less than 30k ohm) 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. One would need to temporarily stop data collection to read impedances on the sensors. Our design has four parts: a current source, a sensor selection, a comparator circuit, and a counter and LED display unit.

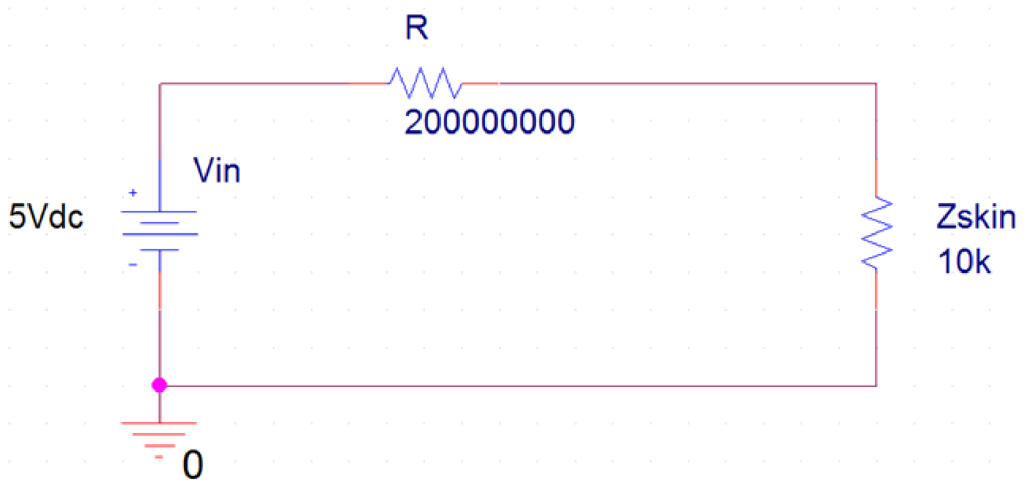


Figure 5. Overall current source layout.

Current Source:

The first block within the sensor impedance verification system is the current source. The safety of our users and the security of the sensors are the two most important design criteria for this block. We must ensure that we do not send too much current through the sensors (the Grass Electrode Sensors can only tolerate less than 1 microamp of current). Current through the skin is also a concern in that too large of a current can severely harm a person. Greater than 1 mA can lead to severe burns, paralysis, or even death. Because we know that the impedance of the skin is somewhere between 5k ohms and 50k ohms, we put a much larger impedance in series with the impedance of the skin to make sure that the current would be constant and small coming off the battery and that there was no way the skin and sensors would be subjected to a large voltage drop.

Note: The current sensor is selected in the Sensor Selection block

Vin / (R+Zskin) = i
5V / (200M ohm + 5k ohm) = i = 2.499E-8 A---->max current expected
5V / (200M ohm + 50k ohm) = i = 2.499E-8 A ---->min current expected
*Note: the current is constant.

The current source must be constant because in the comparator circuit, we compare the voltage over the skin-sensor contact to voltages calculated that assume a constant current of 25 nA. We are comparing the voltages, not direct impedances. To do this we must have a known current and using ohms law we can determine which voltages would correspond to which impedances.

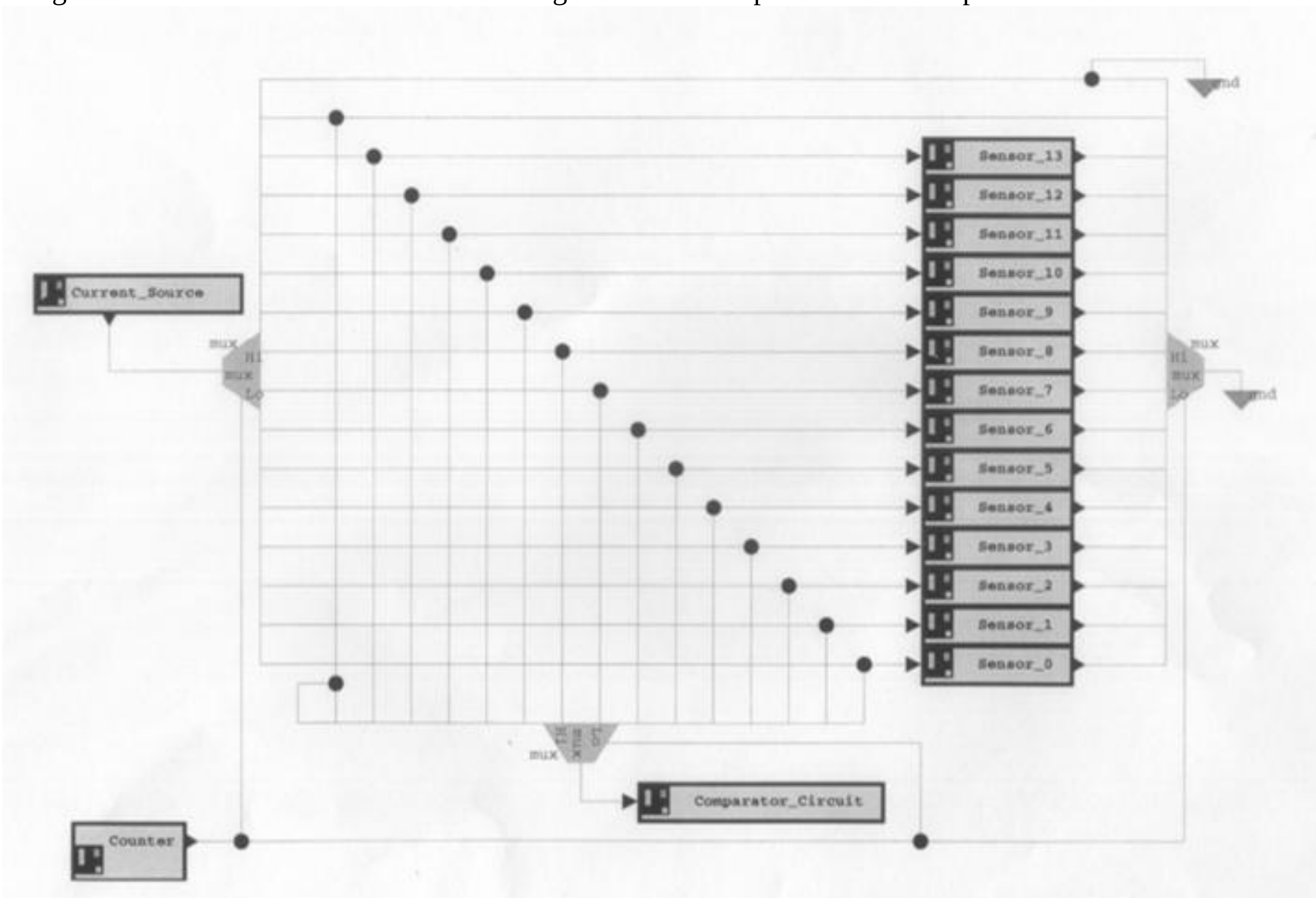


Figure 6. Overall sensor selection layout.

Sensor Selection:

The sensor selection circuit lets the user control which sensor the sensor impedance verification system is reading. The block consists of a push button to control a clock of a counter that up counts current sensor on the push. The counter will count from 0 up to 13 and reset to 0. The circuit will then display which sensor is current by lighting up LEDs that display a number in binary. We would like to read the voltages off of the current sensor and in order to do that we need a circuit that requires two MUXs and a DeMUX. The switches on each of the MUXs and the DeMUX will be controlled by the counter. The first MUX takes in the current driven by the 5Vdc battery and the 200M ohm resistor. The current is then driven to the current sensor chosen by the counter. The sensor must then go to ground. Our sensors only need to be grounded when checking impedance. In fact we do not want our sensors to be grounded during data collection. In order to accomplish this, the other node of each of the sensors then goes into the inputs of a MUX. The current sensor is chosen by the counter and the output of that MUX goes to ground. Because we want to read the voltages across each of the sensors, another MUX reads the voltages of the sensors. The MUX chooses the current sensor and its voltage is sent to the comparator circuit.

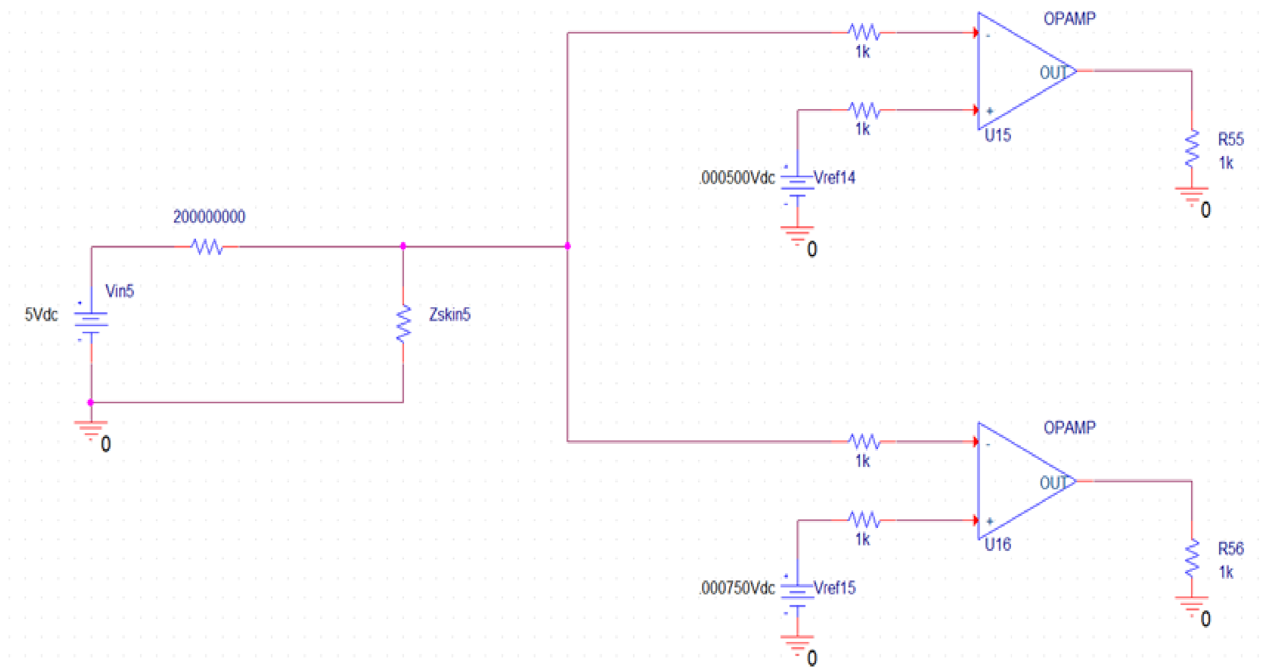


Figure 7. Overall comparator circuit layout.

Comparator Circuit:

The comparator circuit is comprised of two Op-amps that will function as analog comparators. The negative terminals of each of the op-amps are connected to the voltages read from the current sensor. The voltage corresponds to the impedance because the input current is constant. From this we can compare the voltages to known voltages that correspond to known impedances. We are interested in if the impedance of the sensor to skin contact is less than 30k ohms and if it is less than 20k ohms. Less than 30k ohms is a good contact and less than 20k ohms is an excellent contact. We use purchased 2.5 V Vref chips for the positive terminals. The Vrefs are then voltage divided with resistors to produce .50mV and .75 mV to correspond to 20k and 30k ohm impedances shown below:

Zskin,expected * iknown = Vneeded
20k ohm * 2.499E-8 A = .50mV
30k ohm * 2.499E-8 A = .75mV

If the voltage read off the current sensor is less than the corresponding V on the positive terminals, the op-amp will conduct its positive source (5V), thus turning on an LED. If it is greater, the LED remains off. If not, the op-amp conducts the negative input voltage (0V). These voltages will drive the LEDs in the Counter and LED display unit.

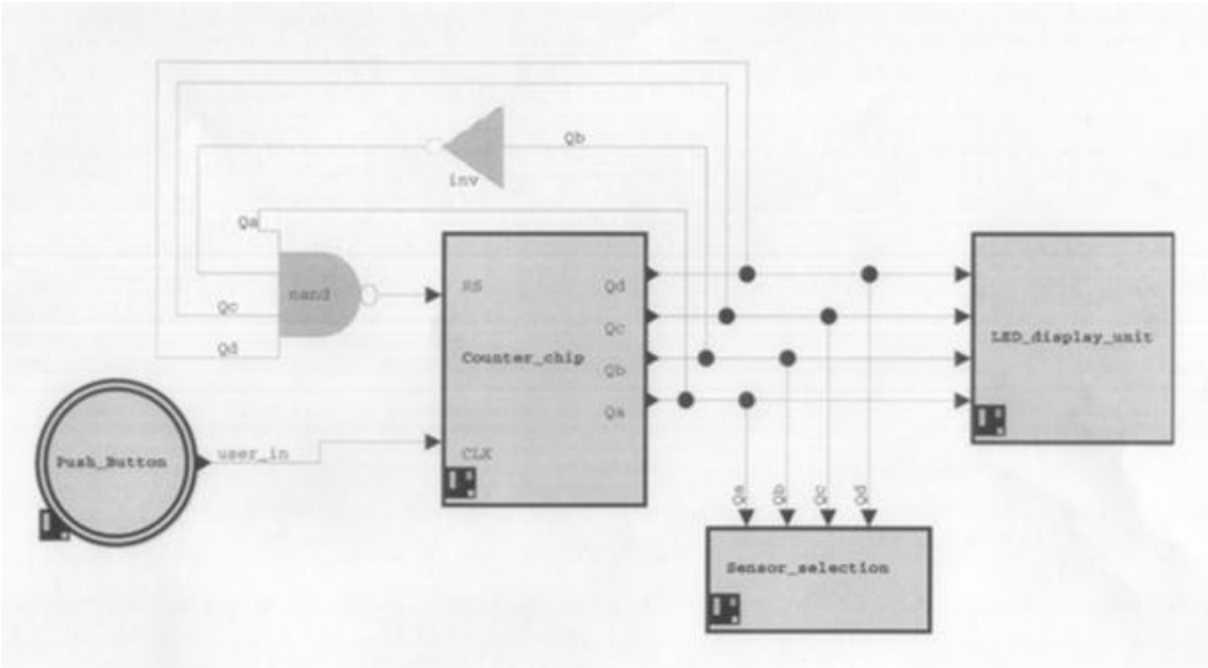


Figure 8. Overall Counter and LED display unit layout.

Counter and LED Display Unit:

The Counter and LED display unit will contain six LEDs. Two green LEDs will correspond to <20k ohms and <30k ohms. If two green LEDs appear, you have excellent contact. If only one appears, you have sufficient contact. If neither LED appears, the impedance is above the accepted value, 30k ohms. The remaining 4 LEDs will display the current sensor number in binary (0-13). The display will show the current sensor number given by the outputs of the counter. The counter is also grouped within this block. The counter contains the number of the current sensor being monitored and is controlled by the user via a push button. This allows the user to scroll through the sensors at the user's own pace in order to check each sensor's contact impedance. The counter will count from 0 up to 13 and then reset back to 0. The counter's outputs will be sent to the LEDs for binary display as well as to the Sensor Selection circuit.

2.1.3 The Arduino System

2.1.3.1 SD Card Memory Feedback Diagram:

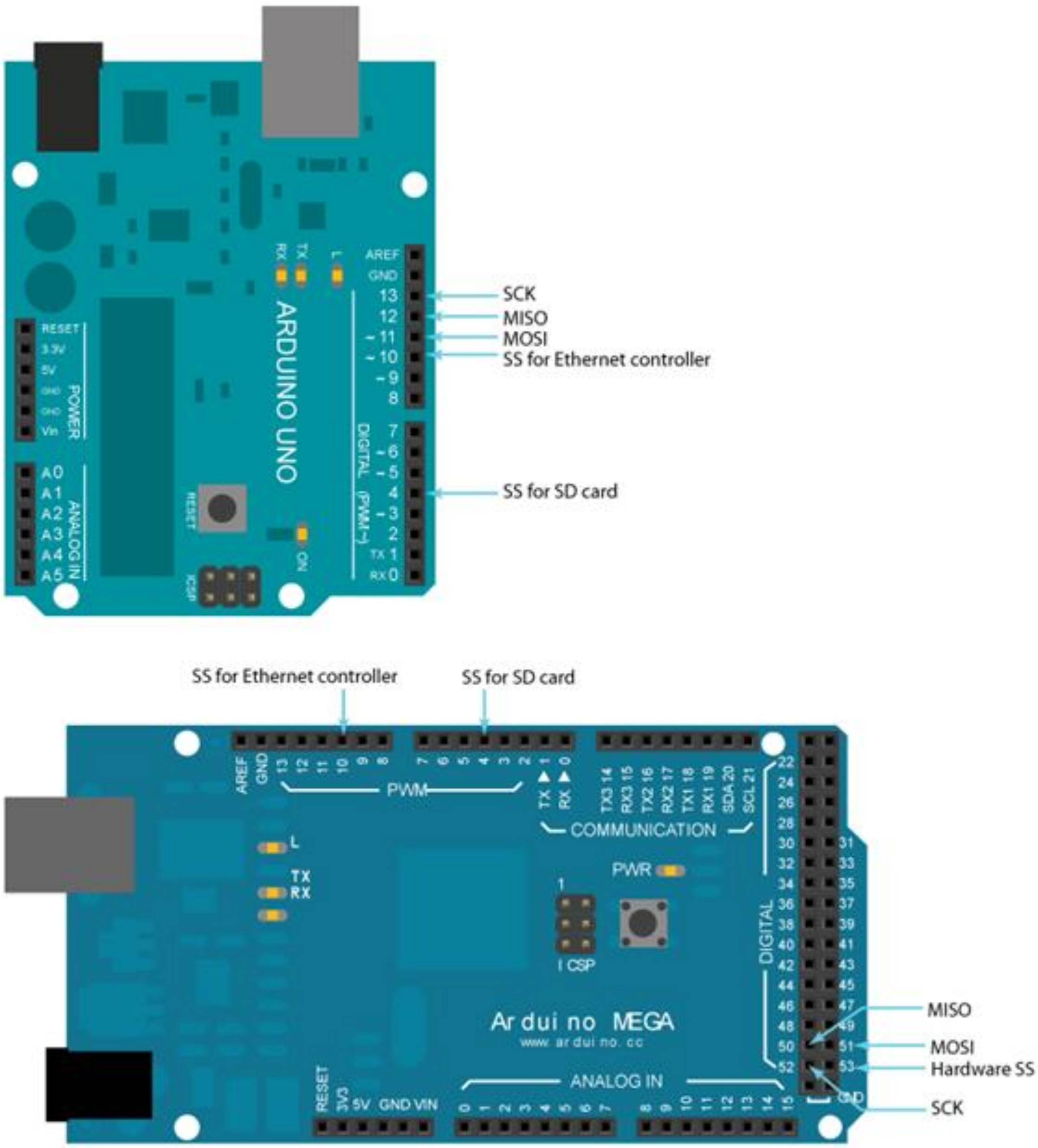


Figure 9. The Arduino microcontroller.

SD Library

The SD library allows for reading from and writing to SD cards, e.g. on the Arduino Ethernet Shield. It is built on sdfatlib by William Greiman. The library supports FAT16 and FAT32 file systems on standard SD cards and SDHC cards. It uses short 8.3 names for files. The file names passed to the SD library functions can include paths separated by forward-slashes, /, e.g. "directory/filename.txt". Because the working directory is always the root of the SD card, a name refers to the same file whether or not it includes a leading slash (e.g. "/file.txt" is equivalent to "file.txt"). As of version 1.0, the library supports opening multiple files.

The communication between the microcontroller and the SD card uses SPI, which takes place on digital pins 11, 12, and 13 (on most Arduino boards) or 50, 51, and 52 (Arduino Mega). Additionally, another pin must be used to select the SD card. This can be the hardware SS pin - pin 10 (on most Arduino boards) or pin 53 (on the Mega) - or another pin specified in the call to SD.begin(). **Note that even if you don't use the hardware SS pin, it must be left as an output or the SD library won't work.**

Notes on using the Library and various shields

SD class

The SD class provides functions for accessing the SD card and manipulating its files and directories.

- begin()
- exists()
- mkdir()
- open()
- remove()
- rmdir()

File class

The File class allows for reading from and writing to individual files on the SD card.

- available()
- close()
- flush()
- peek()
- position()
- print()
- println()
- seek()
- size()
- read()
- write()
- isDirectory()
- openNextFile()
- rewindDirectory()

**Reproduced from the Arduino Ethernet Shield page*

Figure 10. The SD library included with the Arduino.

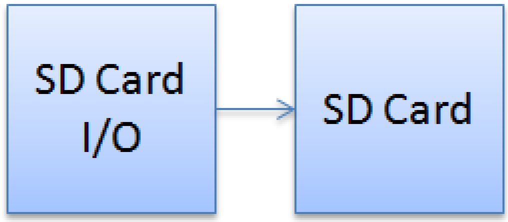


Figure 11. Overall SD Memory Feedback layout.

Overall Summary:
In the 6”x6”x6” enclosure provided by the Electronics Shop, there will be an opening for the user to insert and remove the 2GB SD card. Within the enclosure, there is a separate compartment slot for the SD card reader, allowing the users access to insert and remove the SD card. The single signal output from the MUX will be fed into the Arduino board(represented here as SD Card I/O Module) that will timestamp each signal as it is selected one-by-one and store the signals onto a 2GB SD card. The specifics regarding MUX signal selection will be explained in greater detail later in this report.

SD Card I/O:
Our I/O device for the sensor signals will be amplified and filtered, and then each of the signals will go into the Arduino board, where each signal is time stamped and stored on to the 2GB SD card.

SD Card:
This is a standard 2GB SD card that will hold at least 1.5 hours’ worth of sensor data. The user would be able to unlock this data by means of the Arduino SDLibrary (described above), and a USB-to-Ethernet adapter connection that links the Arduino board to the computer.

2.1.3.2 Clock Management and Selection System:

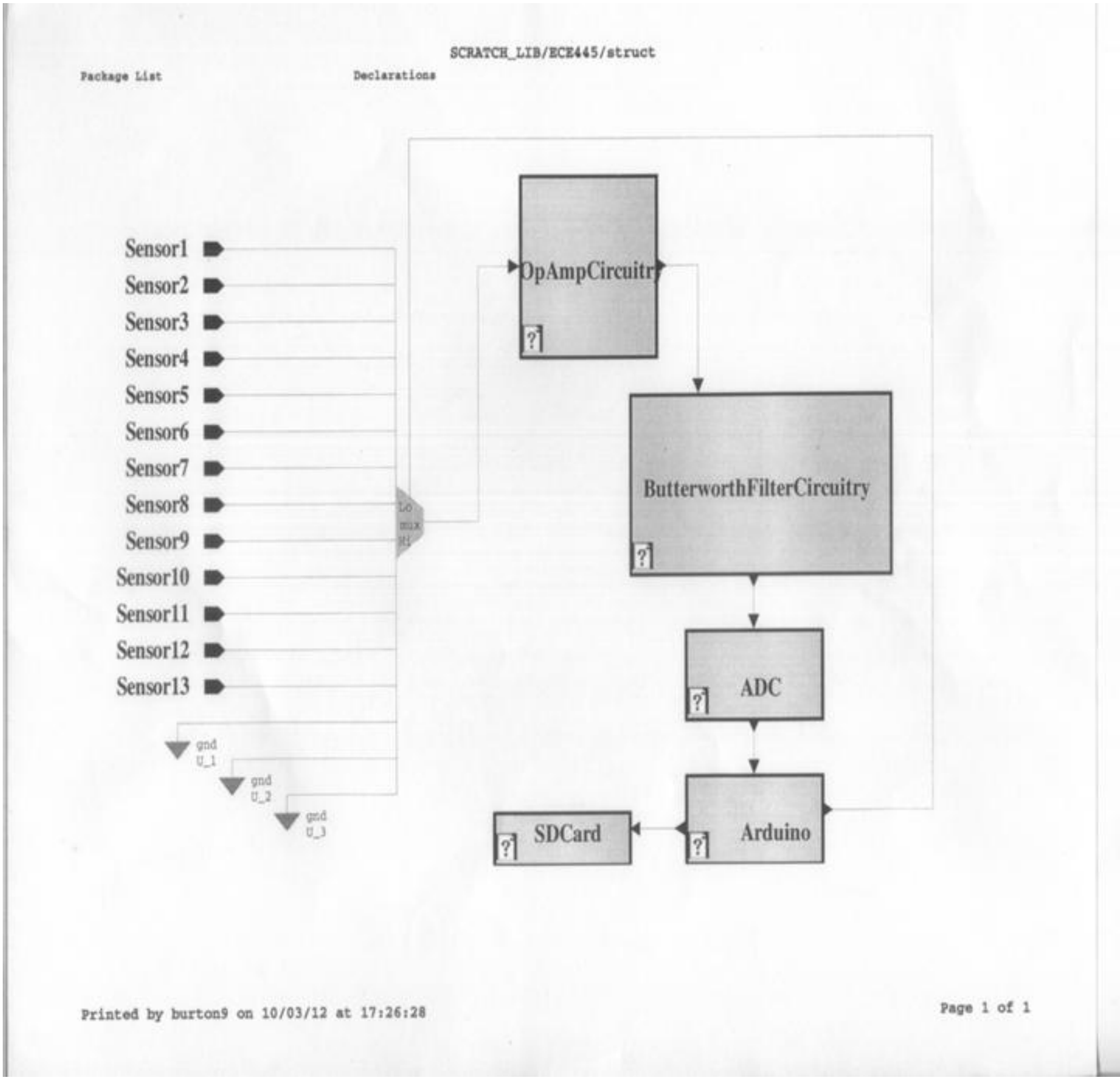


Figure 12. Overview of data analyzing and logging circuit.

Overall Clock Management and Selection Summary:

Essentially, the Arduino will regulate the selection of each of the thirteen signals (there are a total of fourteen signals, where two signals come from the same reference ground and twelve data signals to be processed). As described earlier, the twelve signals used for processing will enter the 16x1 MUX and the SCK on the Arduino will send a signal pulse that will select the signals incrementally from one to twelve. This frequency rate will be executed at the Nyquist rate of the largest frequency received. This is to allow for parallel signal processing in a serial manner without aliasing. In our case, we have the largest signal being 50 Hz. Therefore the sampling frequency emitted as a SELECT pulse from the Arduino's SCK wil be 2*50 Hz=100 Hz sampling rate. The signal data will be processed from a for loop structure as described in pseudo code below:

```
/*
 SD card datalogger
*/

#include
// For the SD Shield Plus
const int chipSelect = 10;

// This is to talk to the real time clock
#include "Wire.h"
#define DS1307_I2C_ADDRESS 0x68  // This is the I2C address

// Global Variables
int i;
byte second, minute, hour, dayOfWeek, dayOfMonth, month, year;

void setup()
{
 Wire.begin();
 Serial.begin(9600);
 Serial.print("Initializing SD card...\n");
 // make sure that the default chip select pin is set to
 // output, even if you don't use it:
 pinMode(chipSelect, OUTPUT);
 Serial.print("chipSelect set to output\n");

 // see if the card is present and can be initialized:
 if (!SD.begin(chipSelect))
 {
	Serial.println("Card failed, or not present\n");
	// don't do anything more:
	return;
 }
 Serial.println("card initialized.\n");
}

void loop()
{
```

```
// make a string for assembling the data to log:
String dataString = getDateDs1307();
dataString += String(",");

// read three sensors and append to the string:
for (int analogPin = 0; analogPin < 3; analogPin++)
{
        int sensor = analogRead(analogPin);
        dataString += String(sensor);
        if (analogPin < 2)
        {
        dataString += ",";
        }
}

// open the file. note that only one file can be open at a time,
// so you have to close this one before opening another.
File dataFile = SD.open("datalog.csv", FILE_WRITE);

// if the file is available, write to it:
if (dataFile)
{
        dataFile.println(dataString);
        dataFile.close();
        // print to the serial port too:
        Serial.println(dataString);

}
// if the file isn't open, pop up an error:
else
{
        Serial.println("error opening datalog.csv");
}
delay(100);

SCK=100;
```

Flowchart:

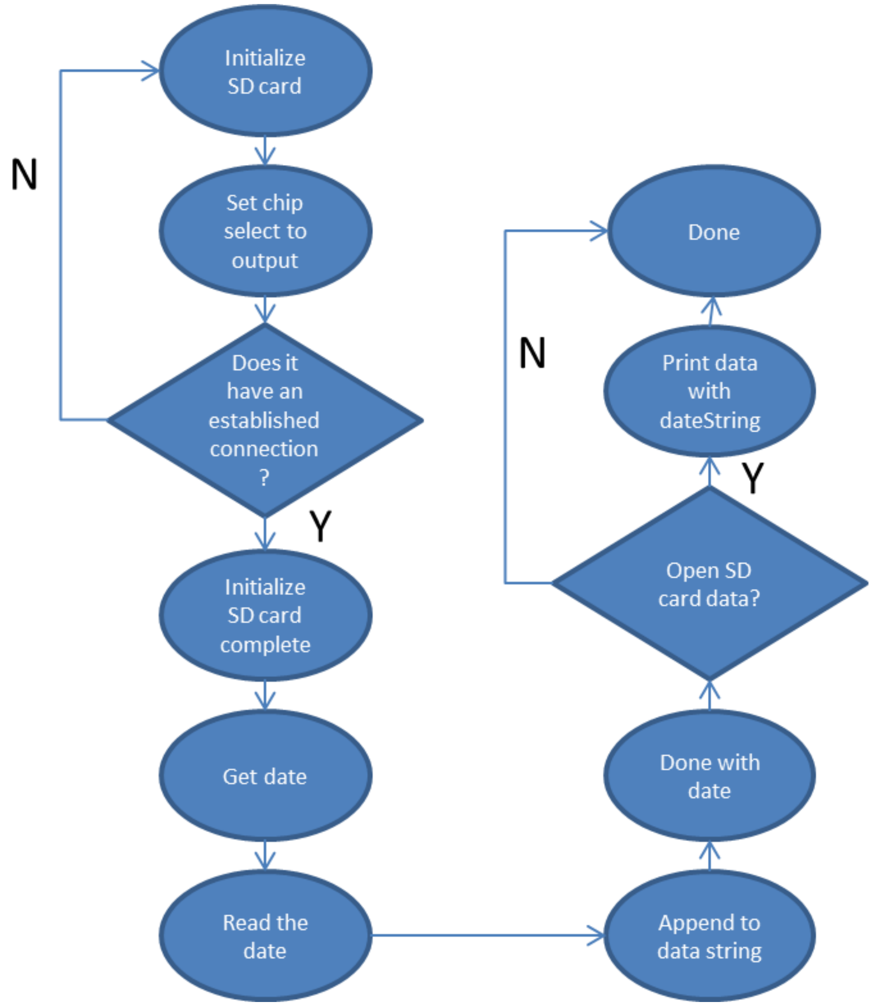


Figure 13. Programming flowchart.

2.1.4 Amplifier

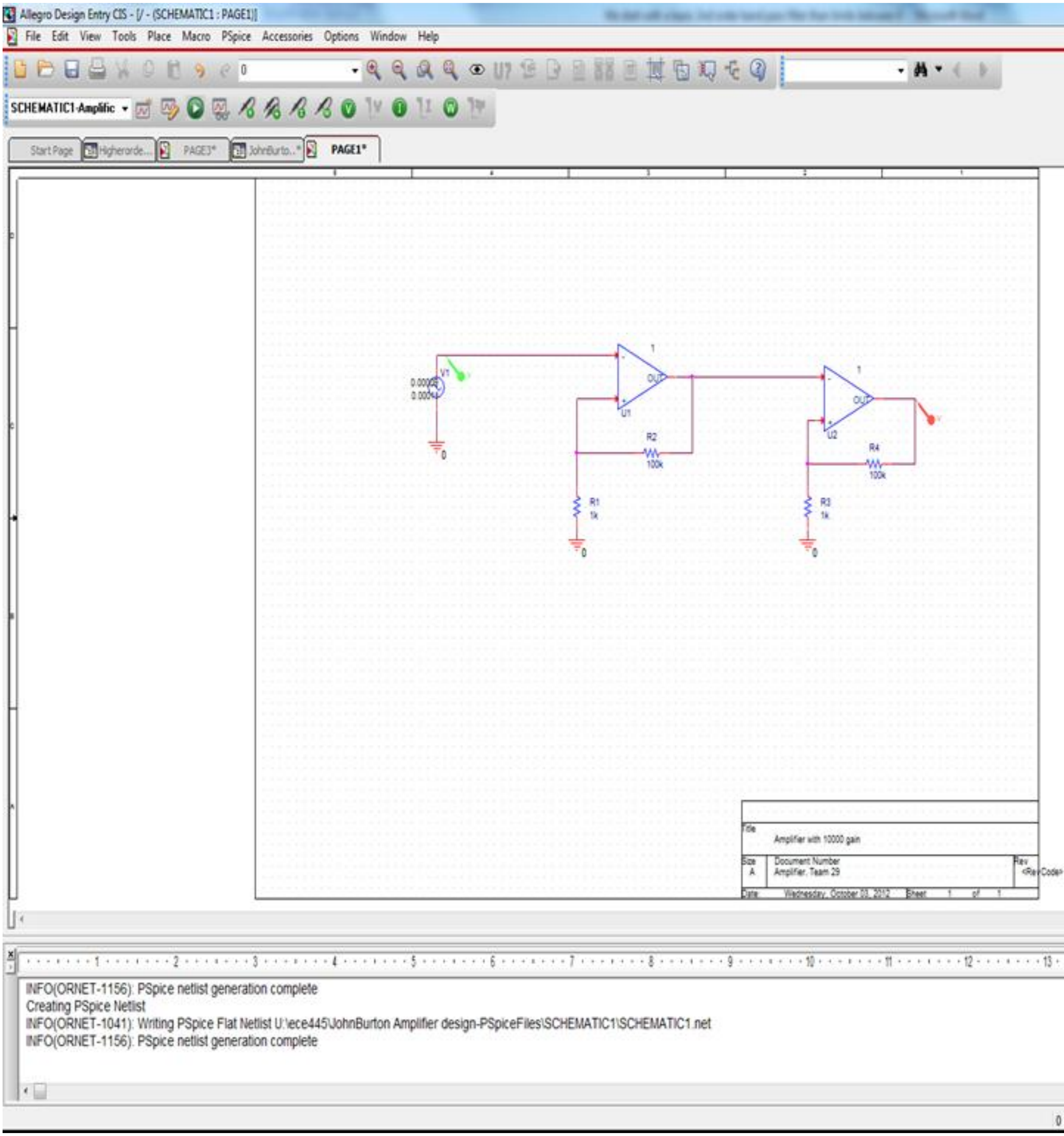


Figure 14. Overall amplifier circuitry layout.

Overall Amplifier Summary:

The amplifier takes in voltage signals of about 20 to 200 microvolts and output voltages with between 0.2to 2 volts. This is done so that the A/D can easily differentiate between the different voltage levels with a certain amount of resolution. In order to make this happen, there needs to be a 10,000 gain from the input voltage to the output voltage. Theoretically this could have been done in one stage, however most amplifiers operate with gains around 100 and as such it makes more sense to cascade the two stages. To calculate the gain we do the following:

The calculation centers on the fact that the voltage at both the positive and negative inputs is the same. This arises from the fact that the gain of the amplifier is exceedingly high. If the output of the circuit remains within rails of the supply voltage of the amplifier, then the output voltage divided by the gain means that there is virtually no difference between the two inputs.

As the input to the op-amp draws virtually no current, the current flowing in the resistors R1 and R2 is the same. The voltage at the inverting input is formed from a potential divider consisting of R1 and R2, and as the voltage at both inputs is the same, the voltage at the inverting input must be the same as that at the noninverting input. This means that Vin = Vout x R1 / (R1 + R2). Hence the voltage gain of the circuit A can be taken as:

A = Vout/Vin = (R1+R2)/R1= (R1)/(R1) + (R2)/(R1) = 1 + R2 / R1

And if R2/R1 is much greater than 1 then A approximatly equals R2/R1.
Now we can see how cascading works. This Vout will become the Vin2 for the next stage of the circuit. Thus:

Vin2 = Vout2 x R3/(R3+R4)
A2 = Vout2/Vin2 = 1 + R4/R3

But we want Vout2/Vin to get Atotal. Thus:
Vin2 = Vout = Vout2 x R3/(R3+R4) = Vin x (1+ R2/R1)

Thus:
Vout2/Vin = (1 +R2/R1) x (1+R4/R3)

And if R2/R1 and R4/R3 are much greater than 1 then this would be approximately:

Vout2/Vin = (R2/R1) x (R4/R3)

And if R4= R2, and R3=R1, then Vout2/Vin = (R2/R1) ^2
Thus a total gain of 10,000, would only need a gain of 100 at each stage. As such R2 needs to be 100 times R1. This will be verified in the simulations section.

2.1.5 Filter

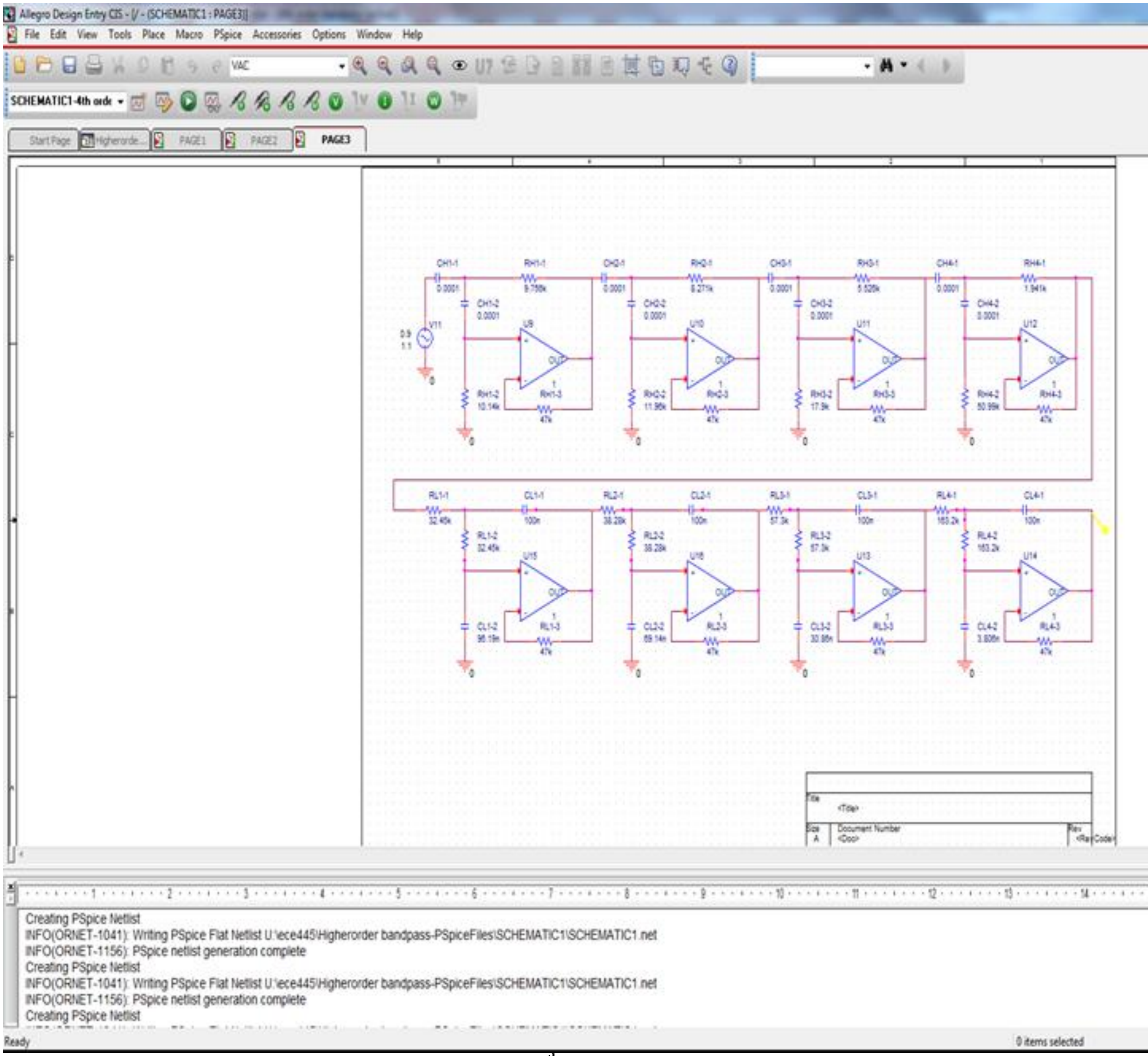


Figure 15. Overall filter circuitry layout (8th order Butterworth bandpass).

Overall Filter Summary:

The design of the filter needs to be such that it can remove frequencies above 50 Hz, and also remove frequencies below 0.16 Hz. The reason for this is that below 0.16 Hz there are brain functions like sweeting being continuously done that are not part of the data we are looking at and would provide a large amount of noise into our signal. Also, over time as the person wearing this device moves around more and more, actions like sweeting would greatly increase causing a huge fluctuation in voltages that would interfere with the data we are collecting. The reason to remove signals about 50 Hz, is because the power that runs through the walls and in our environment is at 60 Hz and we do not want that data interfering with our results. We put the limit at 50 rather than 60Hz, to increase the distance from the transition region to insure noise attenuation as well as the fact that European power systems operate at 50Hz and we want our device designed to be valid in Europe as well. In order to have this, we started with a simple low pass filter in series with a high pass filter. This gave a simple 2nd order bandpass filter, but the transition bands were quite large and there was a lot of ripple in the passband. So we then doubled the previous circuitry to get a simple fourth order band-pass filter. This gave better results, as shown in the simulations, but not enough to be useful. The transition bands were still two large and there was too much attenuation in the passband. We realized that we could possibly not worry about filtering out the 0.16 Hz and just use a fourth order low pass to get a passband with less attenuation. This improved the passband attenuation but was still not enough to be what we wanted. It was decided what we needed was a filter mathematically designed so that its poles would produce as flat of a pass band as possible. This leads to the Butterworth filter design. Butterworth filters use a weighting of polynomials to have poles at different frequencies that when taken together for the group yield the frequency at which the filter should operate. Thus the individual stages will combine to form an extremely flat band pass, but will come at the expense of a larger transition band. Thus to get a more exact transition band it is necessary to have higher orders of the Butterworth. Thus this lead to the fourth order Butterworth band pass given above. The bode plot can be found in the simulation section.

2.2 Performance Requirements

Sensor Impedance Verification System

Performance Requirement	Verification Procedure
Current Source The current source needs to produce a constant current of around 22.5-27.5nA while connected in series to a sensor-skin connection. The current source needs to provide this current regardless of the impedance of the skin-sensor contact as the impedance will change depending on each person and the quality of the application of the sensor.	Current Source The Zskin will be replaced with different known impedances of values within that we should expect to read from the skin to sensor contact. The first test will be to replace Zskin with a 10k ohm resistor. The circuit should be able to provide current within the 22.5-27.5nA range as read by an ammeter. The second test will be to replace Zskin with a 25k ohm impedance. The circuit should be able to provide a current within the 22.5-27.5 nA range as read by an ammeter. The third test will be to replace Zskin with a 40k ohm impedance. The circuit should also be able to provide a current within the 22.5-27.5nA range as read by an ammeter. The current generated when connected to any impedance should be similar, within a +-10% difference. Each current read with the different impedances replacing Zskin should be within the 22.5-27.5nA range as read by an ammeter.
Sensor Selection The sensor selection circuitry needs to be able to connect the current source in series to the current Zskin through the DeMUX as selected by the counter, and then connected to ground through a MUX, also selected by the counter, to complete the circuit. The current Vzskin must be connected in parallel to the comparator circuit through a second MUX, with switches selected by the counter.	Sensor Selection The sensor selection will be verified by first reading the input voltage of the DeMUX and comparing it to the currently selected output line using a voltmeter. The voltage on the negative terminal of the currently selected Zskin will also need to be measured with a voltmeter to make sure it is connected to ground to complete the circuit. The currently selected input line of the second MUX will its voltage to be measured and compared to the output using a voltmeter to verify the voltage across Zskin is properly being passed through the second MUX in the circuit.
Comparator Circuit The comparator circuit uses two voltage dividers to change a Vref=2.4-2.6V into 450-550uV and 675-825uV that are connected to the positive terminals and need to be verified because they are our direct comparisons to the our relative resistances we would like to	Comparator Circuit Using a voltmeter, we will measure the voltage across the positive terminal of the first comparator to verify the voltage after the voltage divider is approximately 450-550uV. Then we will use a voltmeter to measure the voltage across the positive terminal of the second comparator to

compare Vzskin against. The first comparator (<20kohms) needs to be able to output high when the input is less than 20k ohms (which results in a voltage less than 450-550uV). Otherwise it must output low. The second comparator (<30kohms) needs to be able to output high when the input is less than 30k ohms (which results in a voltage less than 675-825uV). Otherwise it must output low.	verify the voltage after the voltage divider is approximately 675-825uV. We will create a voltage of 350-425uV, which corresponds to less than 20k ohms, using a wave function generator and input it into our circuit (as the input that would normally come from the sensor selection). The outputs on the first comparator (<20k ohms) should be high. The output of the second comparator should also be high. We will create a voltage of 575-650uV, which corresponds to less than 30k ohms and greater than 20k ohms, using a wave function generator and input it into our circuit (as the input that would normally come from the sensor selection). The outputs on the first comparator (<20k ohms) should be low. The output of the second comparator (<30k ohms) should be high. We will create a voltage of 850-925uV, which corresponds to greater than 30k ohms, using a wave function generator and input it into our circuit (as the input that would normally come from the sensor selection). The outputs on the first comparator (<20k ohms) should be low. The output of the second comparator (<30k ohms) should also be low.
Counter and LED Display Unit The 2 LEDs that display the relative impedances (<20k and <30k ohms) must light depending on the impedance across the sensors. The four LEDs need to display the current sensor number as given by the counter in binary. The counter must count from 0 to 13 and must reset when it reaches 13 and continue back to 0 in binary.	Counter and LED Display Unit We will put the Current source in series with a resistor and attach it directly to the LED Display Unit . The first resistor will be approximately 10k ohms. Both LEDs should light. The second resistor will be approximately 25k ohms. The first LED should be dark, while the second LED should appear bright. The third resistor will be approximately 40k ohms. Neither LED should light up. We will attach the outputs of the counter to the LEDs and begin counting by pressing the push button and see if the LEDs correctly display the output in binary. The counter must reset at 13 because we only have 14 inputs to look at. We will begin counting and pay close attention to the LEDs attached. Once the LEDs reach 13, the next current value must be 0. Effectively we will know it works if it never reaches 14 or 15.

	After reset, the counter should continue to up count as usual and must reset each time it reaches 13.

Power Supply System

Performance Requirement	Verification Procedure
Dramatic Voltage Response We need the power supply to compensate for voltage fluctuations. In order to properly maintain a steady voltage between 4.2-4.8V, we must have a solid rectifier circuit.	Dramatic Voltage Response To test this feature, we will take a set of voltages at a variety of different points 0.1V, 2V, 5V, 10V, and 15V to test voltage fluctuations that may be triggered if the amplifier and/or filter circuits jump in power demand, forcing our power source in extenuating circumstances.
Reverse Polarity Protection The sensor selection circuitry needs to be able to connect the current source in series to the current Zskin through the DeMUX as selected by the counter, and then connected to ground through a MUX, also selected by the counter, to complete the circuit. The current Vzskin must be connected in parallel to the comparator circuit through a second MUX, with switches selected by the counter.	Reverse Polarity Protection We will test this performance requirement by sending a current in the opposite direction of the voltage source. If a negative voltage is read, then our reverse polarity protection circuit is not working. Else if the voltage remains at zero under bias current flowing against the voltage source, our reverse polarity protection circuit works well.

Amplifier

Performance Requirement	Verification Procedure
1st Stage Gain 100 +/-10% Gain after the first Stage	1st Stage Gain We will test this performance requirement by sending an input voltage from the function generator of 0.0001 volts DC and measure the output voltage after the first stage with a voltmeter. A resulting voltage of 0.01 +/- 10% will show the correct amount of gain, 100, while any other value will indicate a flawed first stage.
Total Amplification Gain 10000 +/-10% total Gain	Total Amplification Gain We will test this performance requirement by sending an input

	voltage from the function generator of 0.0001 volts DC and measure the output voltage after the final stage with a voltmeter. A resulting voltage of 1 volt +/- 10% will show the correct amount of gain, 10000, while any other value will indicate a flawed amplification stage.
Frequency Response of Circuit The gain of the circuit must stay constant from the range of 0.16Hz to 50 Hz the frequencies that we will be analyzing.	Frequency Response of Circuit We will test this performance requirement by sending an input voltage from the function generator of 0.0001 volts DC and measure the output voltage after the final stage with a voltmeter. 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 +/- 10 %, especially from the 0.16 to 50 Hz range. As long as the voltage does not go above or below 10% over those frequencies from 1 volt, then the test will pass.

Filter

Performance Requirement	**Verification Procedure**
Frequencies above 50 Hz attenuated.	Frequencies above 50 Hz attenuated. This will be tested by sending a 1 volt waveform from the function generator at a frequency from 55 Hz +/-2 Hz to the input of the filter. A voltmeter will measure the output voltage and the verification will pass if the output voltage is 0.5 volts or less.
Frequencies from 0.16 to 50 Hz passed with equivalent gain. Frequencies above 0.16 Hz and below 50Hz need to be passed with almost	Frequencies from 0.16 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 0.16 Hz to 50Hz +/-0.2 Hz to the input of the filter. A voltmeter will measure the output voltage and the verification will pass if the output voltage is 1 volt +/- 20% through all of the frequencies.
Frequencies below 0.16 Hz attenuated.	Frequencies below 0.16 Hz attenuated. This will be tested by sending a 1 volt waveform from the function generator at a frequency from 0.16 Hz +/-0.2 Hz to the input of the filter. A voltmeter will measure the output voltage and the verification will pass if the output voltage is 0.5 volts or less.

2.3 Simulations
2.3.1 Power Supply System

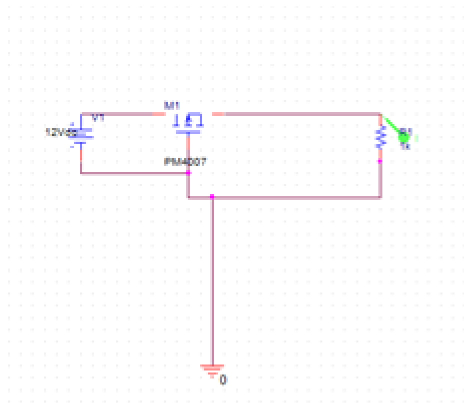


Figure 16. PMOS inverse voltage polarity circuit protection.

Testing:

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:

1. Unbiased Reverse Polarity Protection module
2. 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.

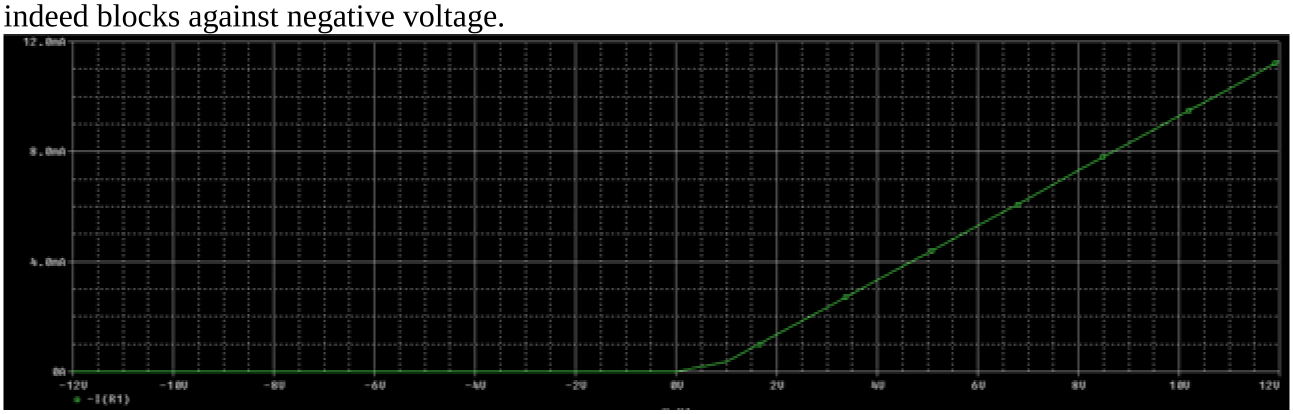
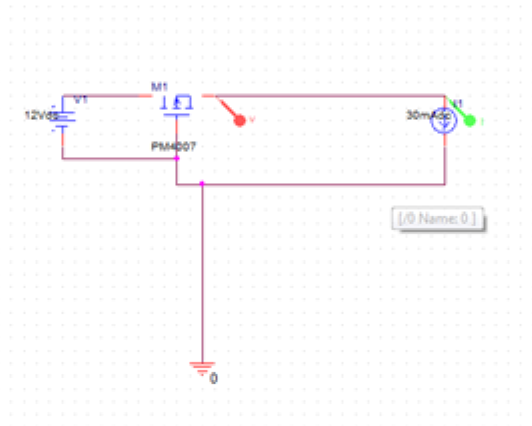


Figure 17. Unbiased reverse polarity protection current.

Upon close 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 MOSFET circuit with 30 mA. Below is the circuit that we used:



In order to properly test this circuit, we generated an IV graph that measured the steady rectified state:

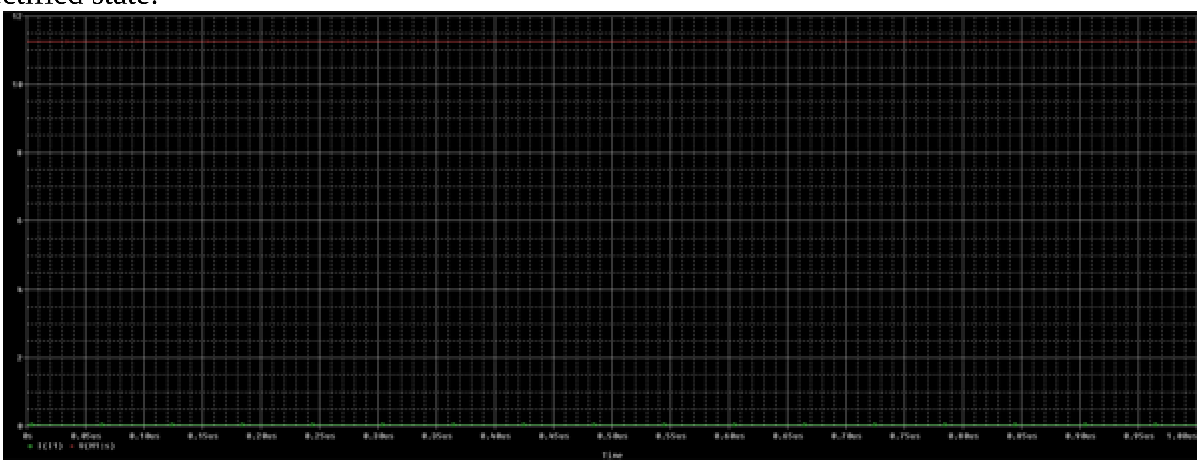


Figure 18. Biased reverse polarity protection current.

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.

2.3.2 Sensor Impedance Verification System

Testing:

In order to properly test our sensor impedance verification prior to building, we used software called Cadence that helped us simulate two important stages of the system:

1. Current Source
2. Comparator Circuit

By testing these two subcomponents of the block, we can show that the current in fact is independent of the load impedance (Zskin) and that the correct LEDs light up based on the load impedance.

The current source was simulated by replacing the skin impedance with known values that correspond to the spectrum of impedances we plan to see.

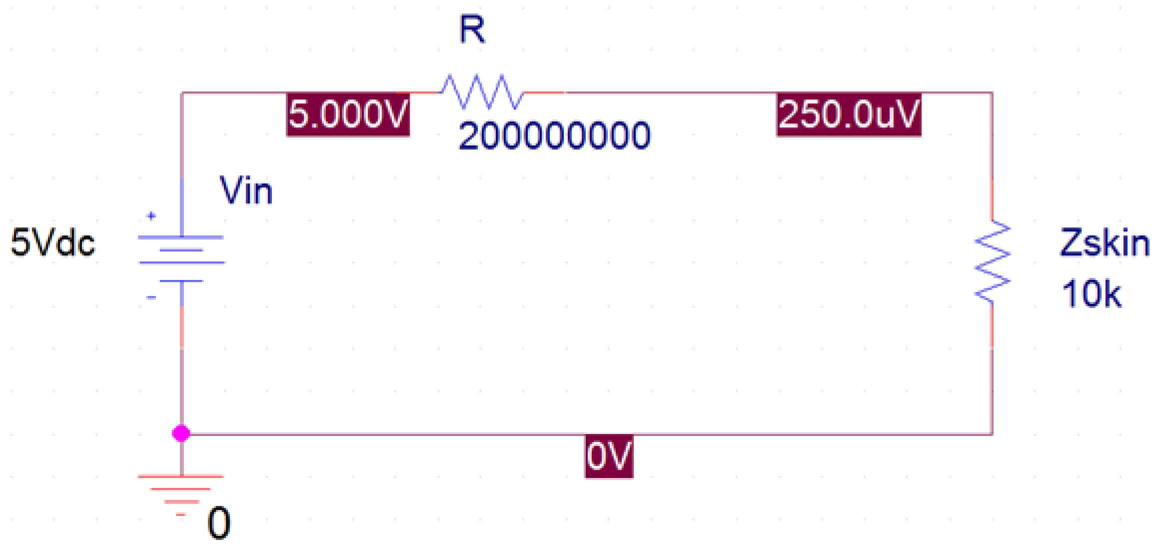


Figure 19. 10k ohm resistance applied.

The figure above shows Zskin substituted by a 10k ohm resistor. 10k ohms is within the spectrum of values of impedance we expect to see. By Ohm's Law: V=IR

$$5V/(200M + 10k) = 25\ nA$$

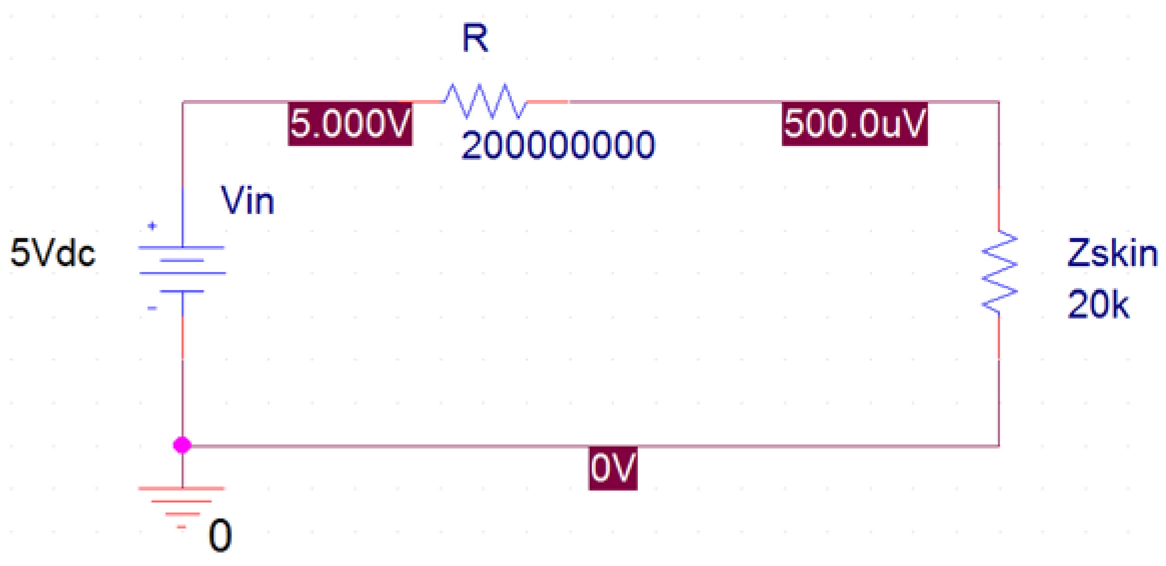


Figure 20. 20k ohm resistance applied.

The figure above shows Zskin substituted by a 20k ohm resistor. 20k ohms is within the spectrum of values of impedance we expect to see. By Ohm's Law: V=IR

5V/(200M + 20k) = 25 nA

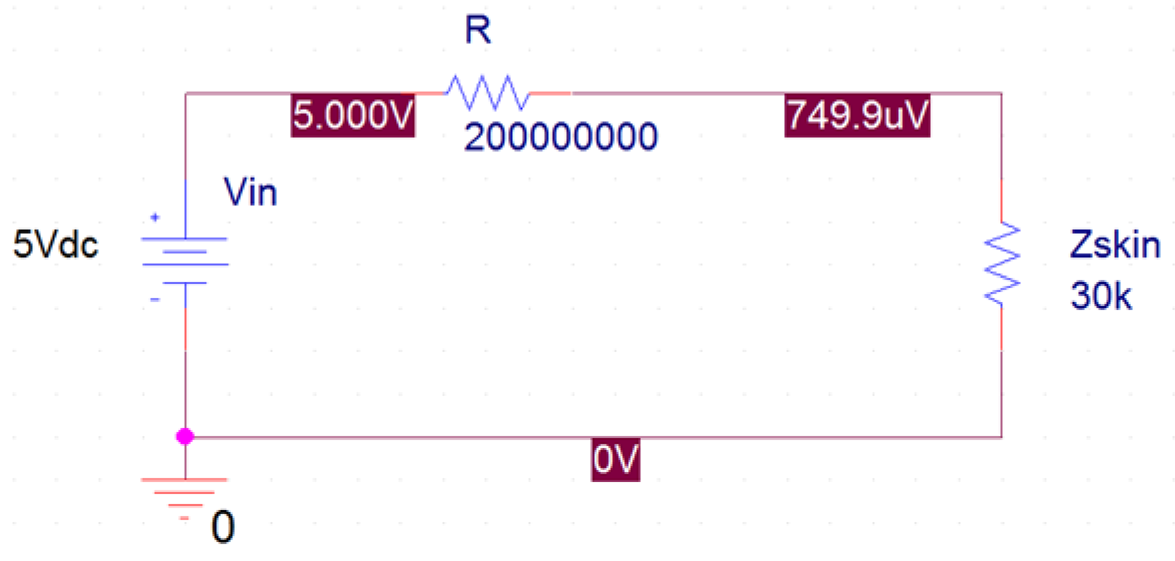


Figure 21. 30k ohm resistance applied.

The figure above shows Zskin substituted by a 30k ohm resistor. 30k ohms is within the spectrum of values of impedance we expect to see. By Ohm's Law: V=IR

5V/(200M + 30k) = 25 nA

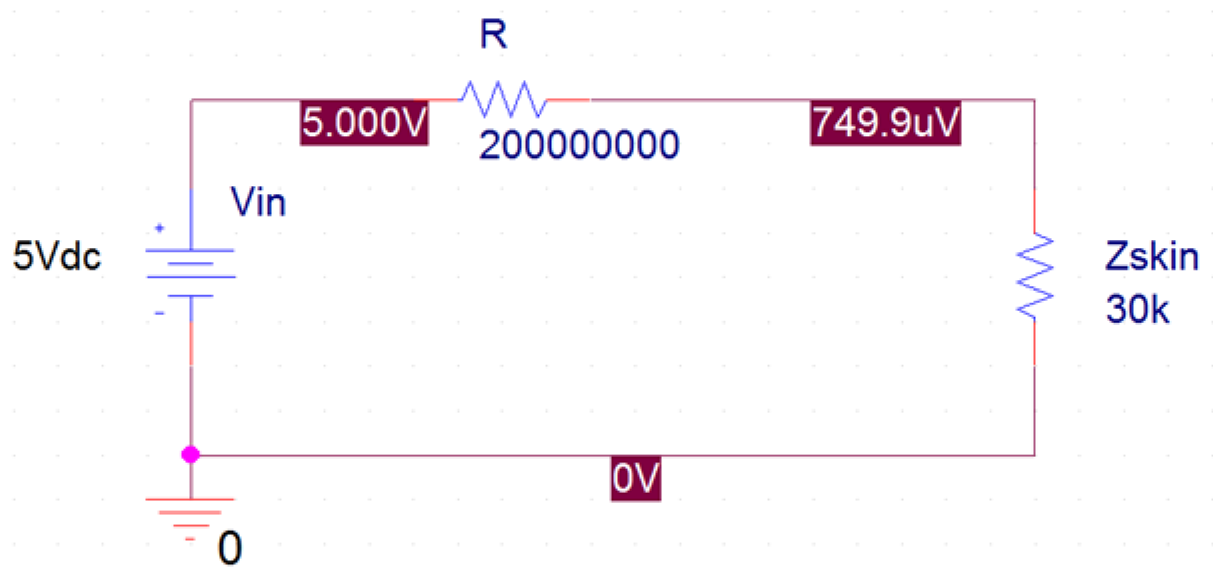


Figure 22. 40k ohm resistance applied.

The figure above shows Zskin substituted by a 40k ohm resistor. 40k ohms is within the spectrum of values of impedance we expect to see. By Ohm's Law: V=IR

$$5V/(200M + 40k) = 25\ nA$$

Because the resistance of the skin to sensor contact is very small relative to the resistor we chose in series, the current stays constant. We chose the current to be small so as to not harm the sensors or the user, but larger than currents we plan on seeing in data collection because we do not want any interference. The figures above demonstrate that we do in fact generate a constant current regardless of attached sensor impedances.

The next component we want to test is the comparator circuit. We attach different loads within the values we plan on seeing and see if the LEDs are turned on or off. The LEDs are shown as resistors connected between the outputs of our op-amp comparators and ground.

There are two values of impedances that we care about, since we are really displaying a relative impedance of the sensors: 20k and 30k ohms. A lit LED attached to the top comparator tells us in the impedance is less than 20k ohms. A lit LED attached to the bottom comparator tells us in the impedance is less than 30k ohms. IF neither light is on, the measured impedance is greater than 30k ohms. 5V drops across the LEDs determine that the LEDs are on and 0V drops let us know the LEDs are off.

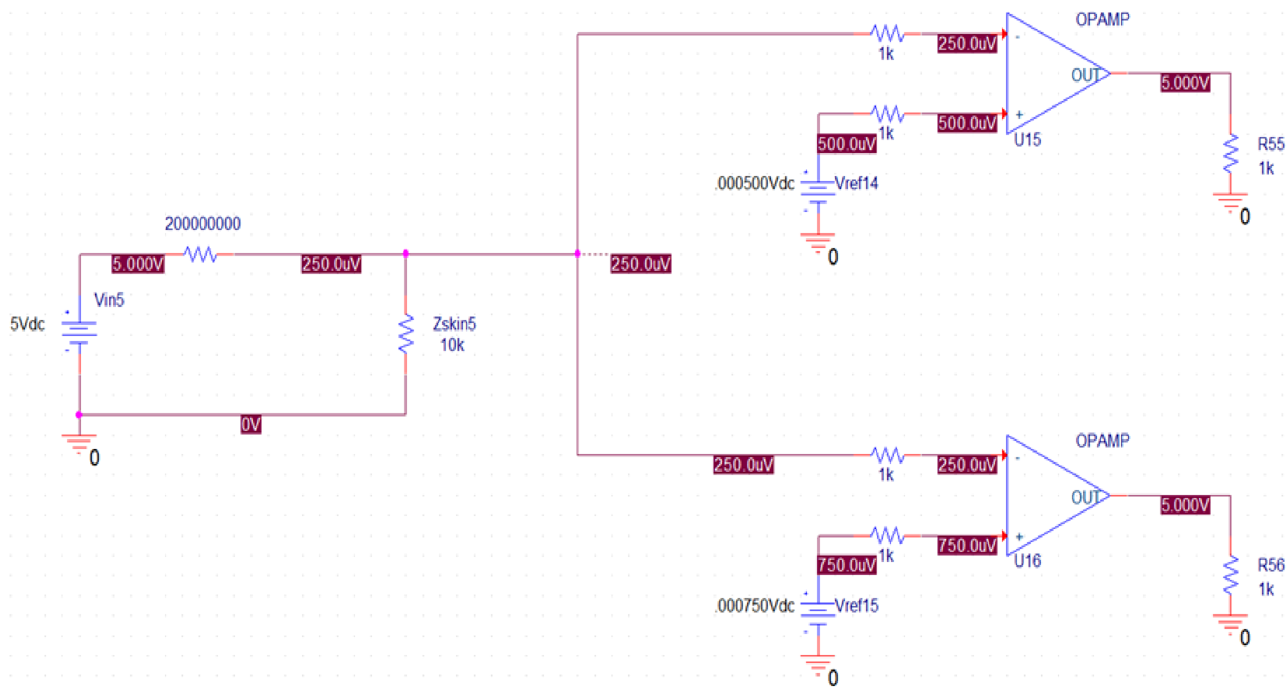


Figure 23. 10k ohm resistance applied.

The figure above shows us our comparator circuit with a 10k ohm load connected. 10k ohms is within the range of impedances we expect to see. The circuit shows us that both LEDs are lit, which corresponds correctly to the impedance being not only less than 30k ohms, but also less than 20k ohms.

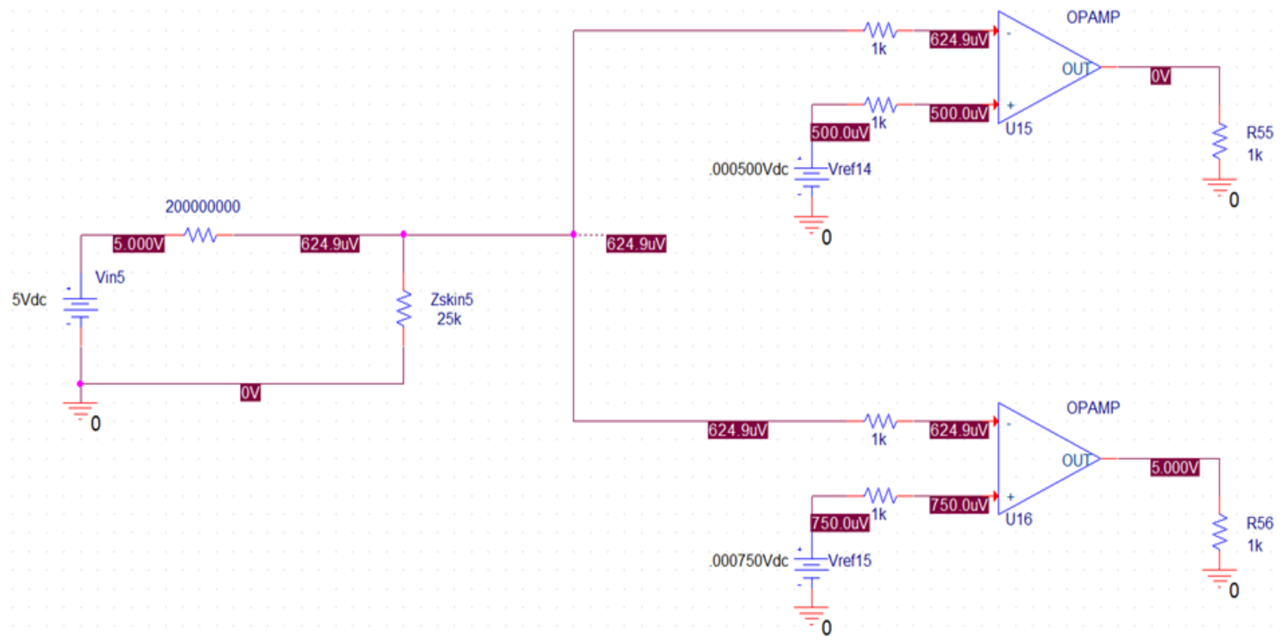


Figure 24. 25k ohm resistance applied.

This time the figure above shows us our comparator circuit with a 25k ohm load connected. 25k ohms is also within the range of impedances we expect to see. The circuit shows us that only one of the LEDs is lit, the bottom one, which corresponds to an impedance less than 30k ohms, which is indeed correct.

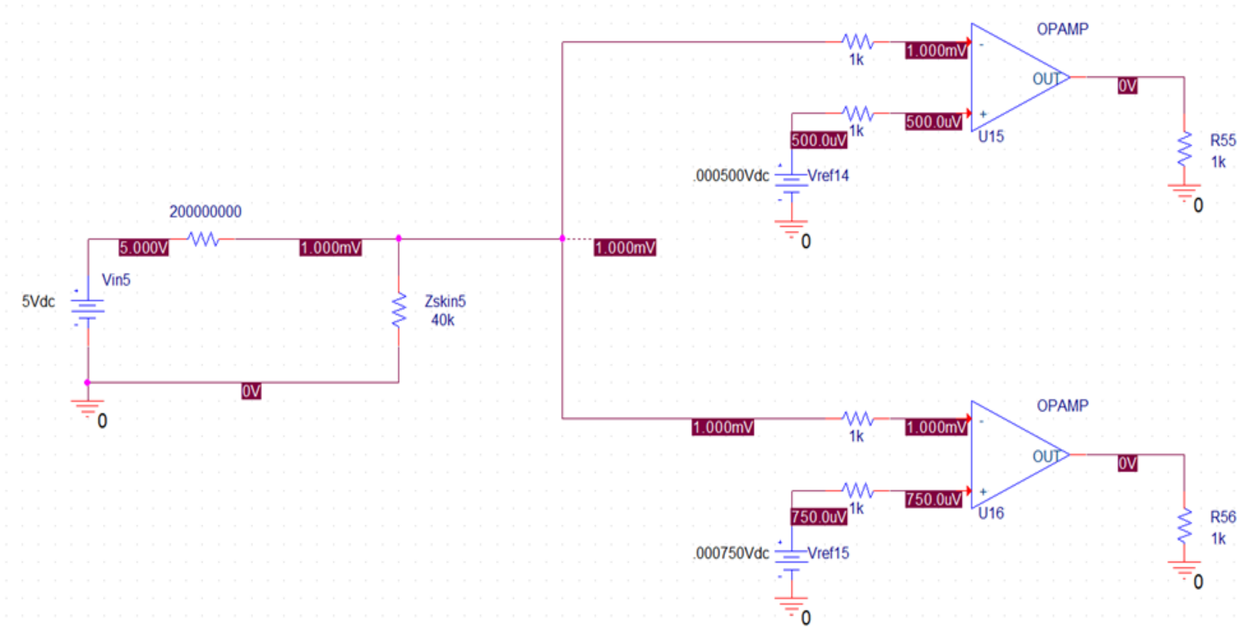


Figure 25. 40k ohm resistance applied.

Our final simulation of the sensor impedance verification system shows us the comparator circuit with an attached skin impedance of 40k ohms. 40k ohms is too large of a impedance to tolerate for our circuit and will skew our data if left untouched. In this case, we want to show the user that the impedance is too large to tolerate. We do this by leaving both LEDs unlit. Our simulation above shows us that yes, we do actually have two LEDs left turned off, corresponding to a skin to sensor contact impedance of 30k ohms or greater.

The overall purpose of simulation of the comparator circuitry before building the design is to check if the logic within the circuit functions as planned. Based on our simulations, we did just that. The current source provides a constant current that is independent of the skin-sensor impedance, which is another term for how well the sensor is applied to the skin. The comparator circuitry accurately determines the relative impedances of the sensors. From this we can believe that this block is functioning as expected and proceed to assembly.

2.3.3 Amplification Simulation

In simulating the most important thing to see is that the first stage is indeed having a 100 gain from the input to the output. This is confirmed in the simulation below.

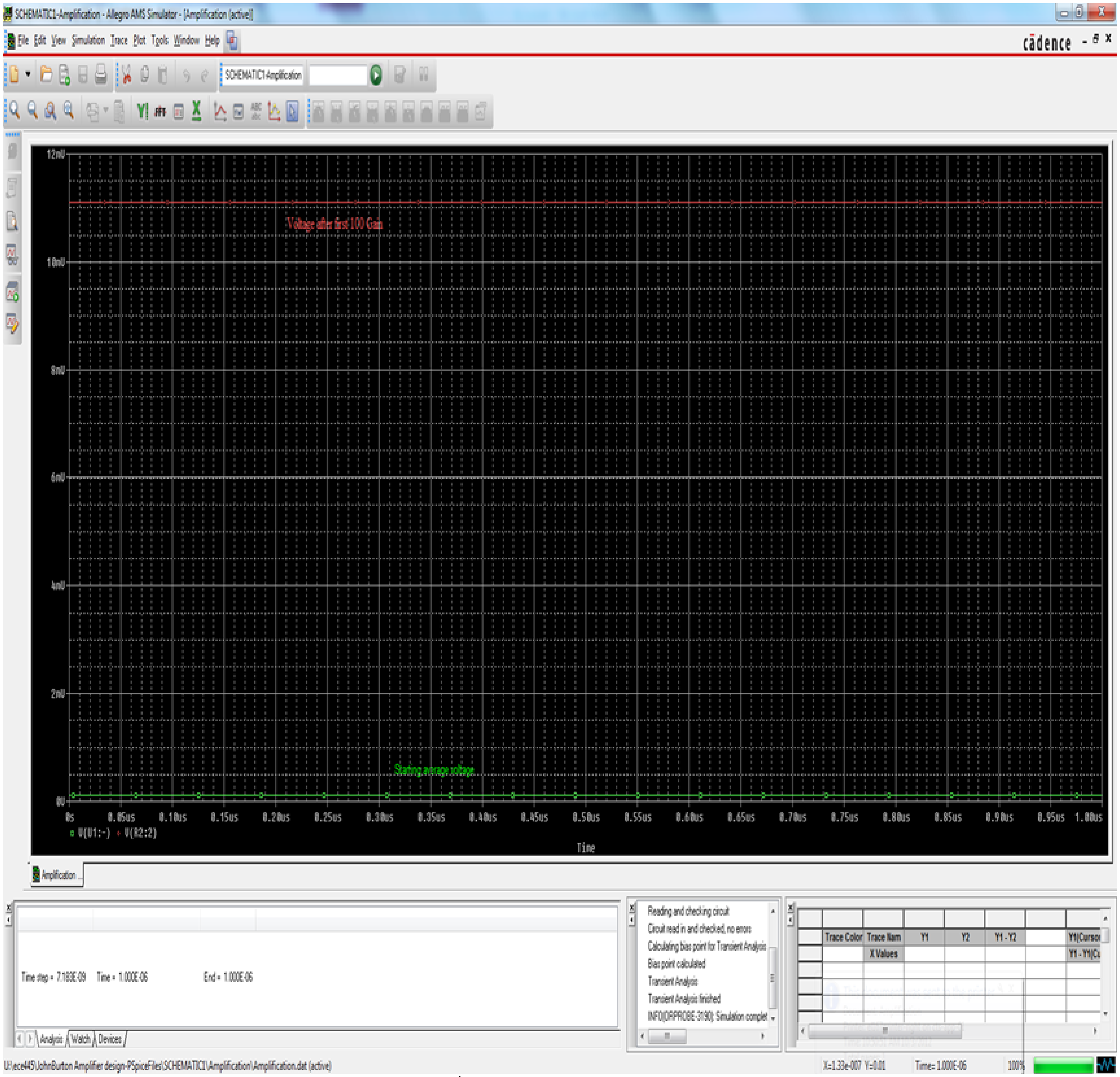


Figure 26. 1st stage amplifier test.

The next most important thing to check is that the total gain from the input to the final output is indeed 10,000 as required. The simulation below confirms that this is indeed the case.

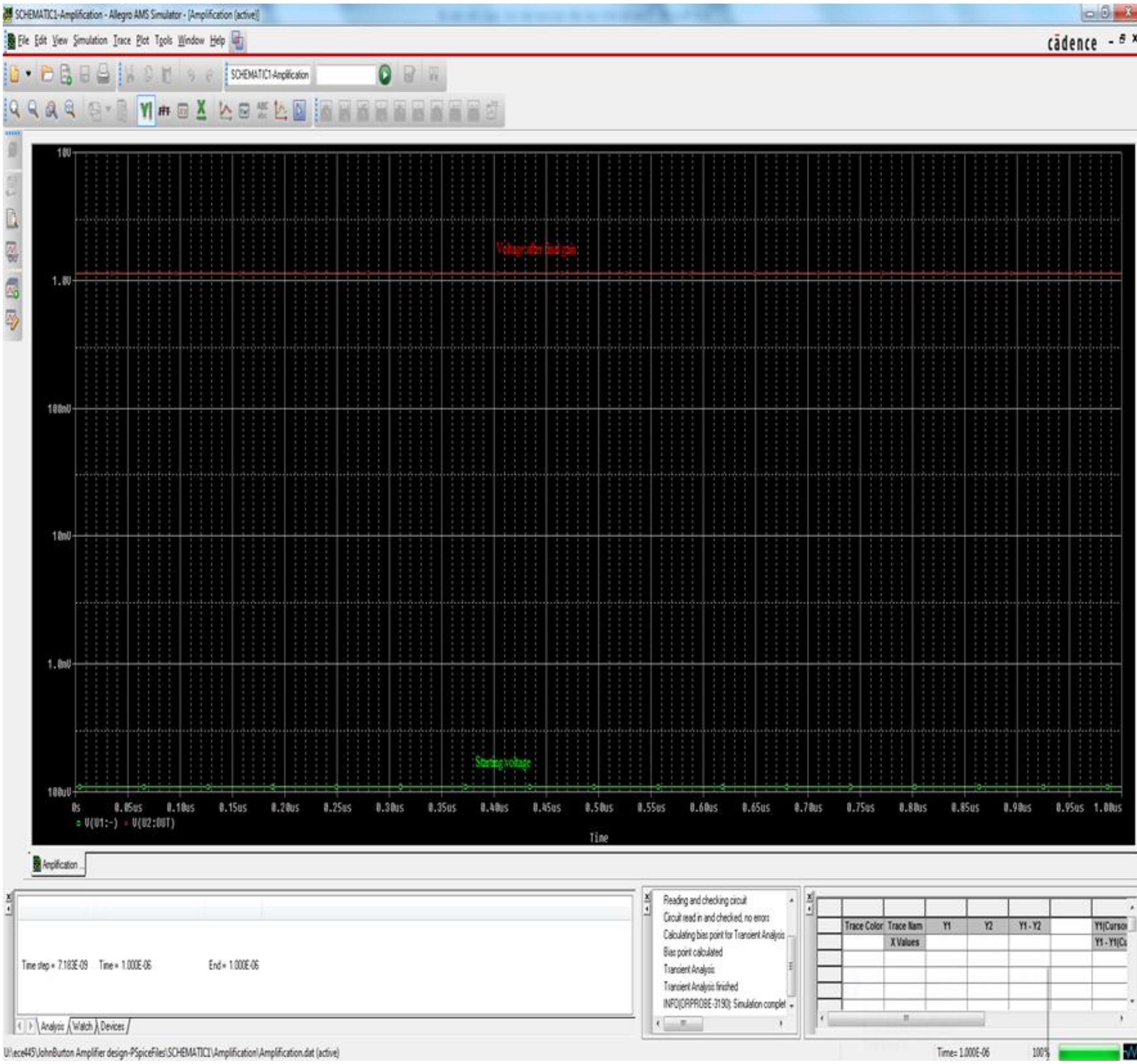


Figure 27. Total amplification gain.

Lastly, we need to see that as the voltage input frequency is changed, that the gain of the circuit does not very. The reason for this is that as frequency gets larger, the max gain of the circuit no longer depends on the resistor setup, but instead must depend on the max gain of the op amp. The figure below confirms that indeed, as frequency is increased the total gain does not change for this circuit for the 0.16-50 Hz that we would be concerned with.

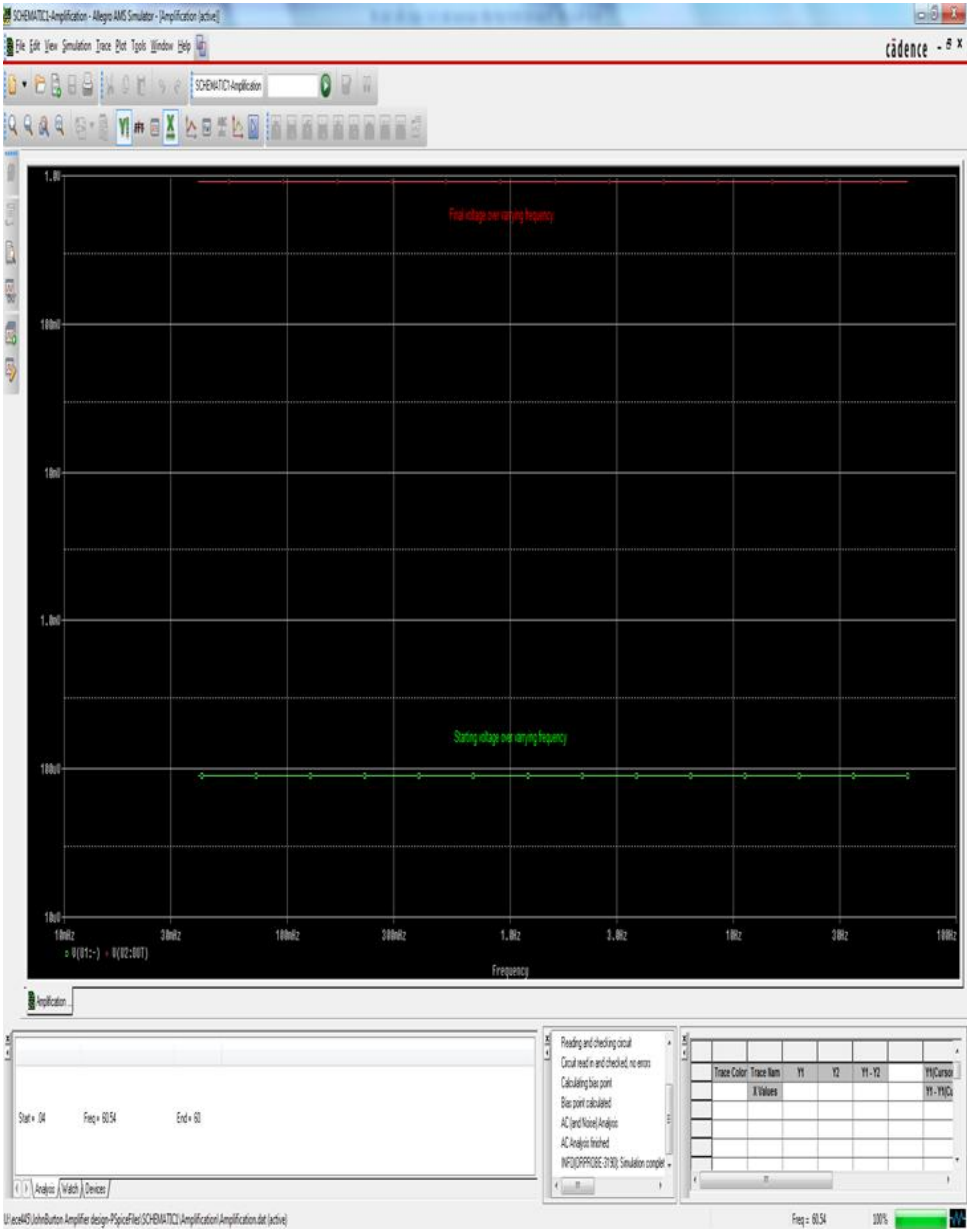


Figure 28. Gain at various frequencies.

2.3.4 Filter Simulation and Bode Plot

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 bandpass. This clearly shows a lot of attenuation in the passband and very large transition bands.

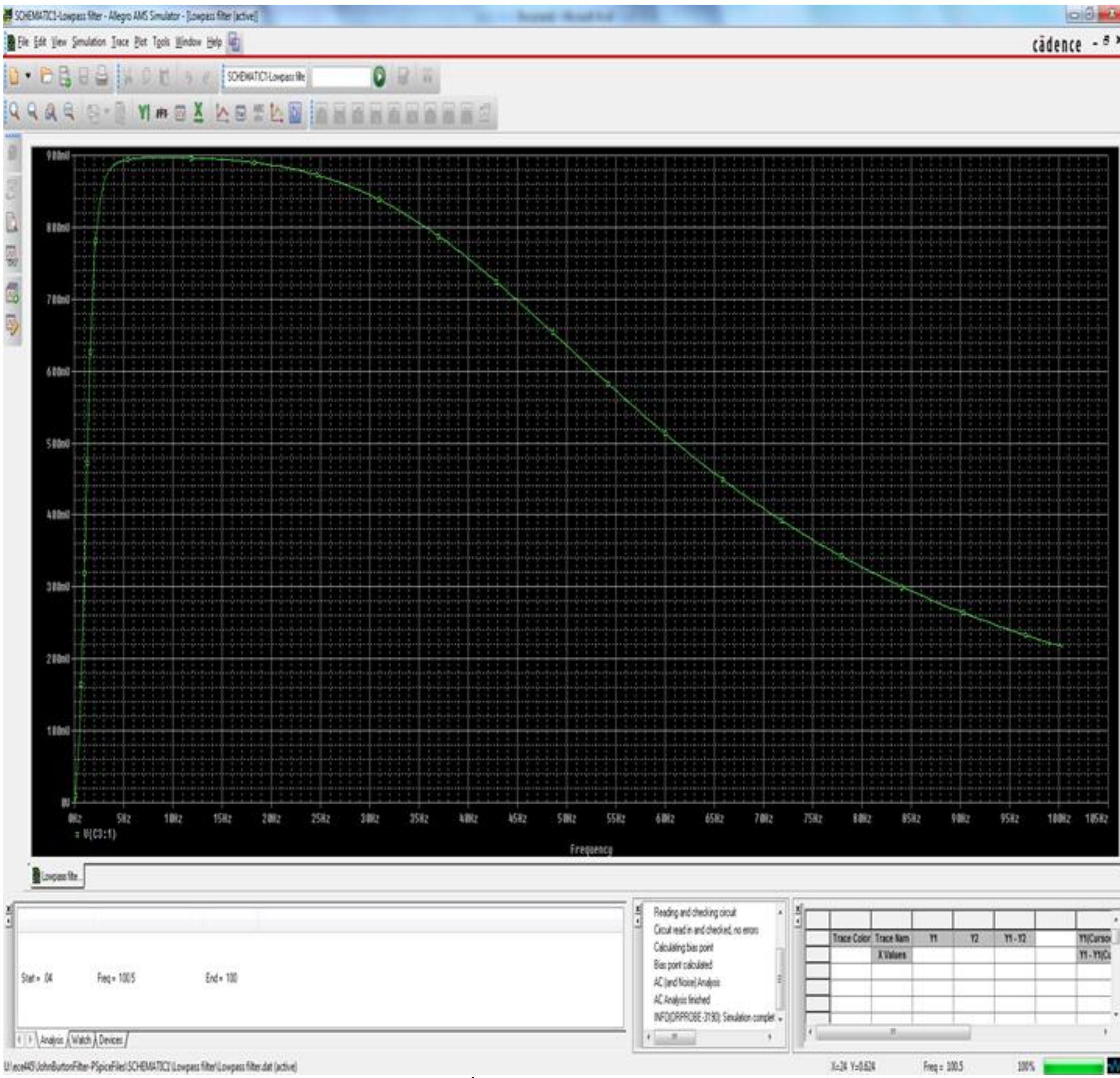


Figure 29. 2nd order bandpass.

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.

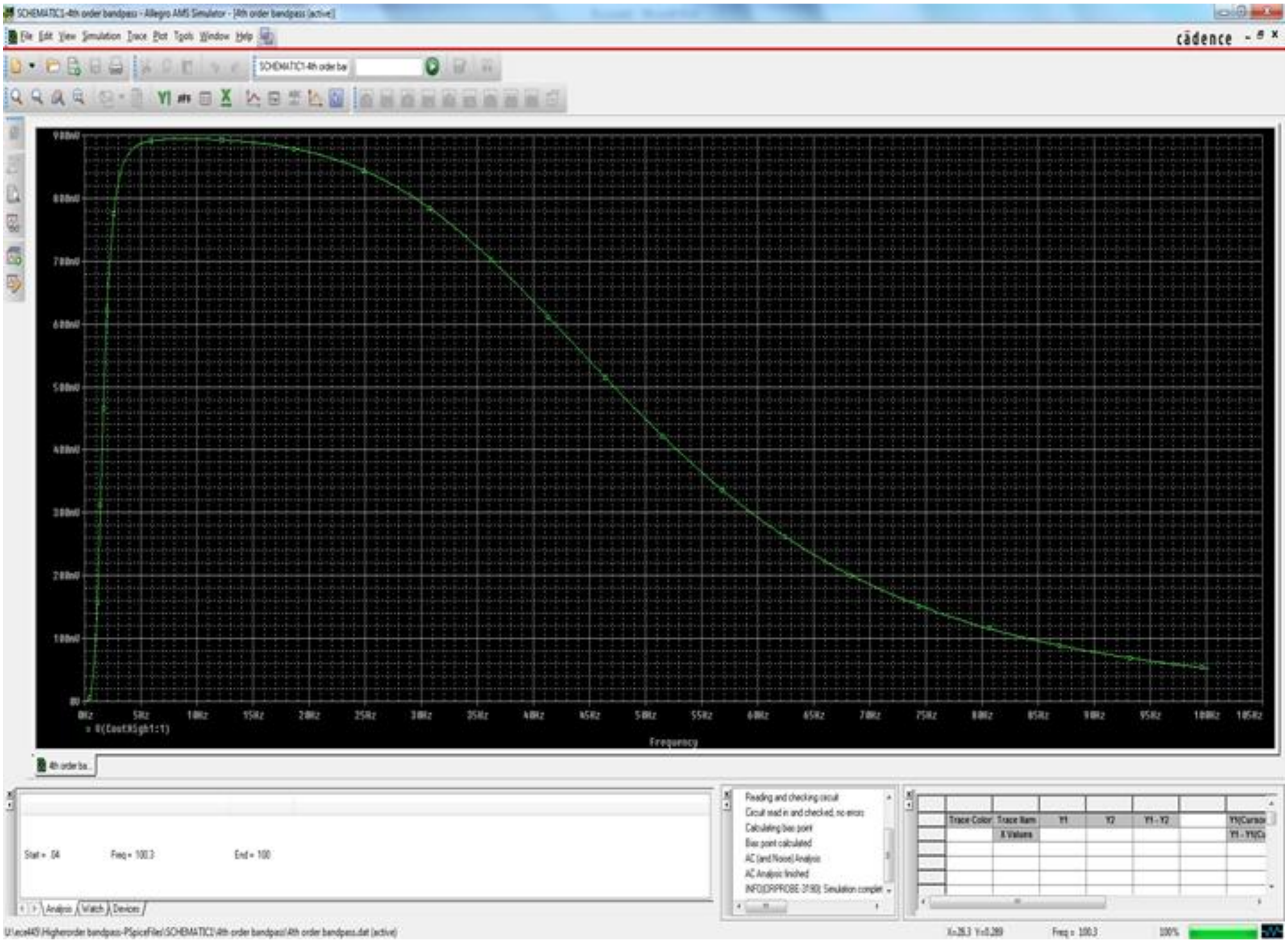


Figure 30. 4th order bandpass.

Next, we simulated what would happen if we had just the fourth order lowpass in place since filtering out the 0.16 Hz is not the most important feature of the filter. The 4th order lowpass is shown in red below and clearly shows a shorter transition band at the cost of more attenuation in the pass band.

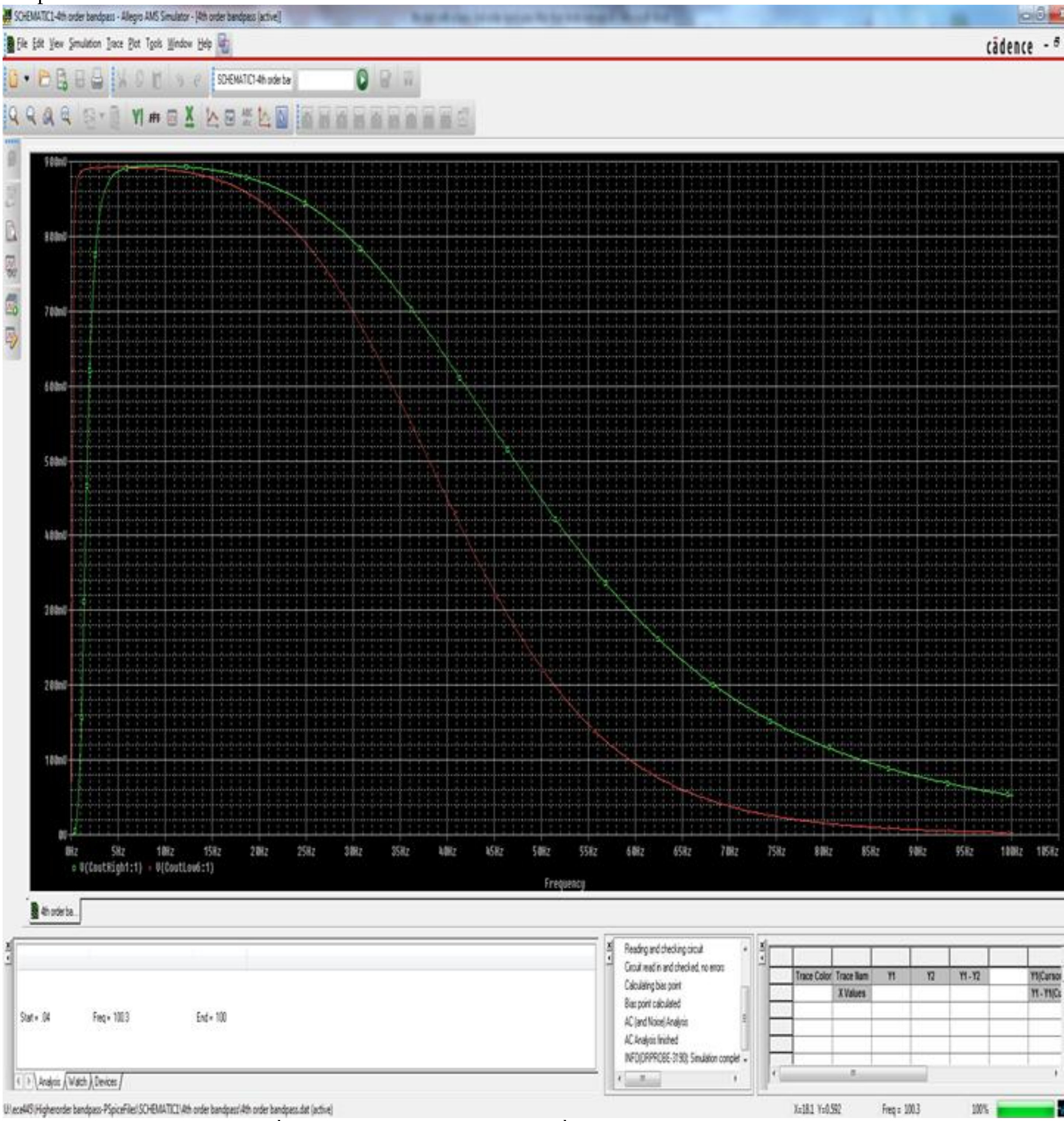


Figure 31. 4th order bandpass in green and a 4th order lowpass in red.

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 passband 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 passband and very sharp transition bands.

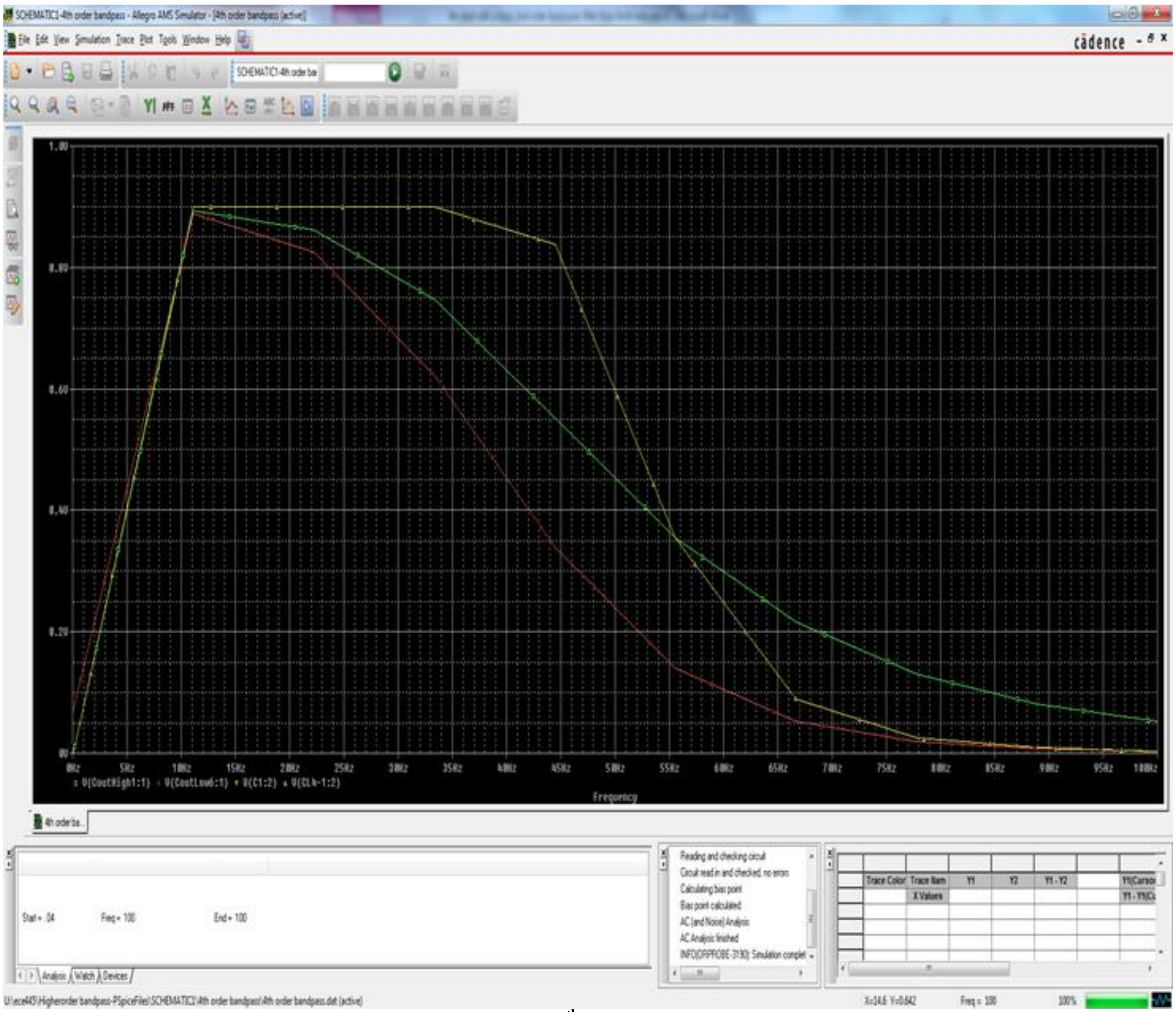


Figure 32. Figure 31 and in yellow, an 8th order bandpass Butterworth.

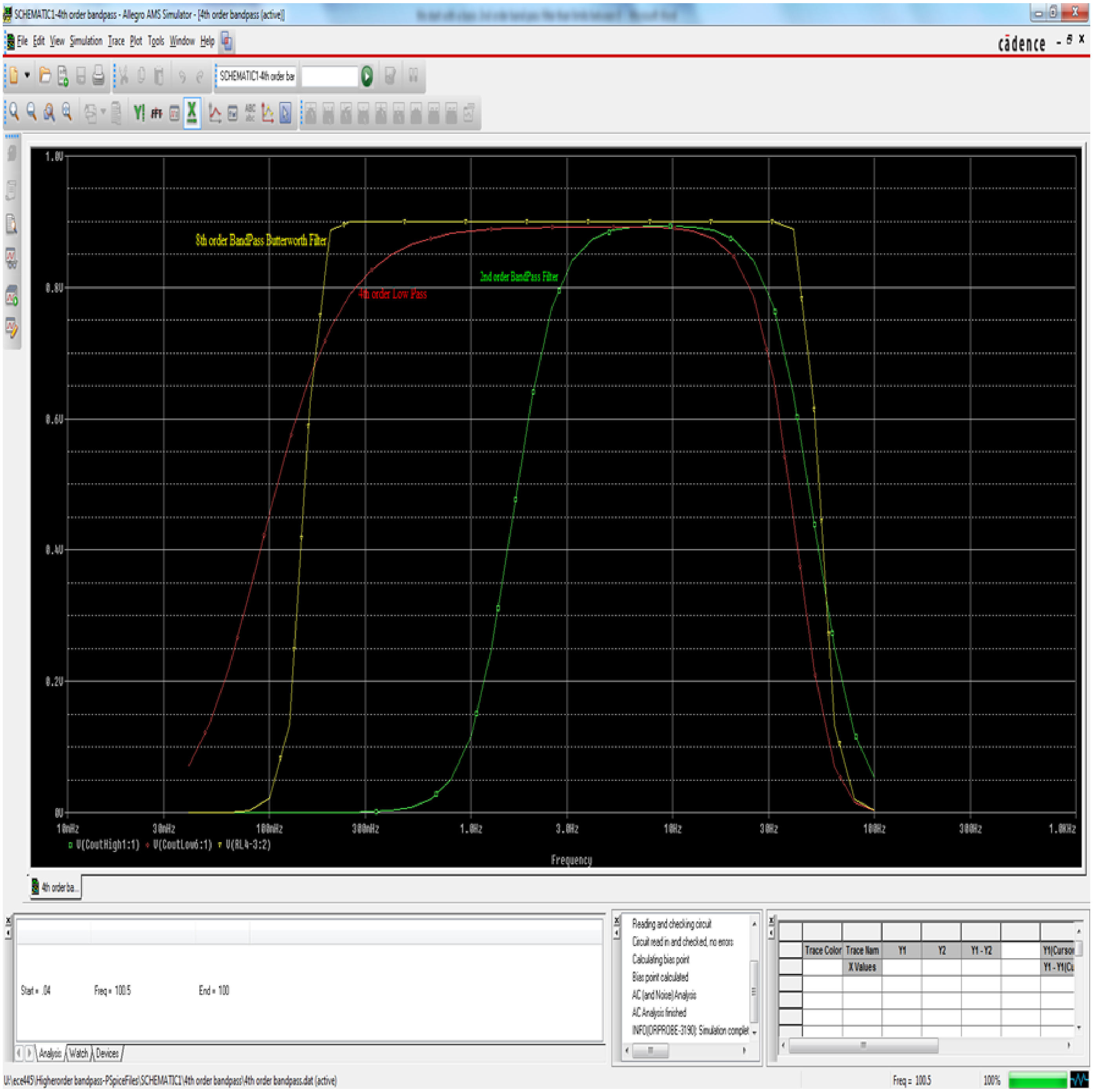


Figure 33. Figure 32 in log scale.

III. Verification

Tolerance Analysis

For our tolerance testing, the signal amplification and filtering modules must achieve a high precision low noise filter so that we do not corrupt our data with noise and commit it to memory. Our tests will be checking for a 10,000 voltage gain, no current saturation, and keeping the bandpass filter transition band and loss in signal amplitude in the pass-band to a minimum to preserve the signal from 0.16Hz to 50Hz. Specifically we will be performing simulations using Simulink to measure gain, and output current and to fine tune the resistor values making up the amplifier component. Also, we will be using Simulink to simulate the specific frequencies that the pass band occurs at for different types of filters (Butterworth, Chebychev, etc.), as-well as showing the sensitivity to attenuation in the pass-band for these filters. Based on power consumption, the cost, and the effectiveness of different filter types, we will decide which the final filter to use for our system. The passband needs to be at the correct frequencies. We will adjust the order of the filtering system based on the need to reduce noise.

IV. COST ANALYSIS

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 Cost

Item	Part Number	Unit Cost	Quantity	Total (USD)
Op Amps .5 slew rate	LM741C	0.27	2	0.54
100k ohm resistors	NTE HWCC410	2.04	2	4.08
5k ohm resistors	CFR/RT13	0.50	1	0.50
1k ohm resistors	RC07GF102JTR	1.19/5	7	2.38
1 ohm resistors	CF-1/4WS	0.50	2	0.50

Op Amps .4 slew rate	ADA 4092	2.50	8	20.00
47k ohm resistor	YJ0-365-08	1.19/5	24	5.95
100uF Capacitor	027-360	1.00	8	8.00
100nF capacitor	AC1444	1.69	8	13.52
150k ohm resistors	271-1109	1.19/5	12	3.57
200M ohm resistor	-	5.50	1	5.50
1:16 DeMUX	HEF4514B	0.93	1	0.93
16:1 MUX	16BTC/883	7.52	2	7.52
Push Button	PB-143	3.95	1	3.95
Counter Chip	74163	2.80	1	2.80
NAND logic gate	74HC21D	0.27	1	0.27
Analog Comparators	LM339	2.29	2	4.58
Vref (2.5 +- .5%)	TI LM4040C25	0.25	2	0.50
ADC Converter	LTC2301HMS#PBF	4.01	1	4.01
Voltage Regulator	LDO-7805	1.00	1	1.00
PMOS	FQP47P06	2.06	1	2.06
4 D battery holder	270-396	2.19	1	2.19
4 Pack of D Batteries	E95BP-4	13.00	4	13.00
Green LEDs	276-022	1.69	10	16.90
1GB SD Card	SanDisk SDSDB-2048	9.99	1	9.99
Arduino Microcontroller	DEV-11229	59.95	1	59.95
Purchased enclosure 24”x24”x1/8”	-	22.33	1	22.33
PCB Board	-	33.00	1	33.00

4.3 Grand Total

Section	Total
Labor	39,375.00
Parts	249.52
Total	39,624.52

4.4 Schedule

Week	Task	Responsibility
9/16	Turn in proposal	John
	Research LED circuit, get Arduino	Kevin
	Research amplifier/filter circuits	Alex
9/23	Pull up datasheet for Amplifier/Filter circuit, PSPICE simulations	John
	Write out code for storing channel data to SD card	Kevin
	Conduct PSPICE simulations	Alex
9/30	Design Review	Alex
	Order parts for power supply, amplifier/filter circuits	John
	Look into PCB board, order LED parts	Kevin
10/7	Construct Arduino test harness	Kevin
	Build power supply	Alex
	Layout PCB board design	John
10/14	Assemble the amplifier and filter circuits	John
	Program channel inputs and test for tolerance in Arduino	Kevin
	Prepare documentation for Mock up demo	Alex
10/21	Prepare for Individual Progress reports; read over journals	Kevin, Alex, John
	Tolerance analysis	Alex

	Begin final paper(overview portion), presentation(Introductory slides)	Kevin
10/28	Verification of specs	John
	Update final paper(Write-up Arduino portion)	Kevin
	Update presentation	Alex
11/4	Mock-up Demo (individual focuses)	Kevin, Alex, John
	Fix remaining issues	John
	Completion of Modules	Alex
	Rehearse the A/D converter, MUX, Arduino logic flow	Kevin
11/11	Check memory data is compatible with software	Kevin
	Edit final paper	John
	Edit presentation	Alex
11/18	Thanksgiving break	Kevin
	Thanksgiving break	Alex
	Thanksgiving break	John
11/25	Finish final draft of paper	Kevin
	Finish final draft of presentation	Alex
	Practice demo	John
12/2	Demo the Arduino writing to the SD card	Kevin
	Demo	John
	Demo	Alex
12/9	Tidy up the overall aesthetics of our presentation	Kevin
	Final Paper	John
	Check In Supplies	Alex

V. ENGINEERING ETHICS

We will ensure that we abide to the following standards from the IEEE Code of Ethics:

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."*

Our group is 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.

Our project contains an 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.

5. *"to improve the understanding of technology; its appropriate application, and potential consequences."*

We are bound by this ethical code to act accordingly in society. We must showcase the power that lies behind advancements in technology, but avoid ambiguity at all costs about the potential consequences of such new inventions. Our project will lay new ground in the field of neurological research, but all of our actions have unanticipated and unforeseeable consequences.

6. *"to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations."*

Although we are not officially certified with a medical or engineering license, we are closely working with those that have earned at least their Bachelor's of Science (Ryan May), while Prof. Andrew Singer and Kyle Matthewson both have achieved a doctoral status in the field of engineering and neuroscience, respectively.

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 we can with our limited budget. Kyle Matthewson, 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.

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.

VI. Resources:

- "Arduino - SD." *Arduino - SD*. Scott Fitzgerald, 11 Nov. 2011. Web. 01 Oct. 2012. <http://arduino.cc/en/Reference/SD>.
- "P-FET Reverse Voltage Polarity Protection Tutorial." *YouTube*. YouTube, 01 Dec. 2011. Web. 01 Oct. 2012. <http://www.youtube.com/watch?v=IrB-FPcv1Dc>.
- "Analog Filter Design Demystified." - *Tutorial*. N.p., n.d. Web. 02 Oct. 2012. <http://www.maximintegrated.com/app-notes/index.mvp/id/1795>.
- "The ModularEEG Design." *The ModularEEG Design*. N.p., n.d. Web. 26 Sept. 2012. <http://openeeg.sourceforge.net/doc/modeeg/modeeg_design.html>.