Large Dynamic Range Amplifier Plus ADC

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Abstract

Nerve and muscle signal sampling proves difficult because of the large difference in magnitudes. Muscle signals loom a hundred or even a thousand times bigger and can hide the nerve signals. The Large Dynamic Range Amplifier plus Analog to Digital Converter (ADC) allows one device to retrieve both muscle and nerve signal information. The device has two parts: the ability to take high-resolution data from tenths of microvolts to several millivolts and filter out environmental noise, such as 60 Hz of electrical power lines or electro galvanic signals. This gives the ability to read muscle and nerve signals using one amplifier or device.

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Chapter I: Introduction:

Neurological disorders such as multiple sclerosis, strokes, traumatic brain injury, and neurodegeneration cause tremors. Tremors defined as unintentional rhythmic muscle movement of one or more parts of the body [1]. More than 2.3 million people in the world suffer from multiple sclerosis and over six million suffer from Parkinson's disease [2]- [3]. These tremor-causing diseases cause significant life changing situations with no real cure or treatment.

A Transcutaneous Electrical Nerve Stimulation (TENS) device analyzes muscle signals. This device designed by CAL Poly students discerns if a tremor occurs based on the muscle signal and sends a signal to control the arm reducing the effect of the tremor. The action potential begins in the brain where it travels through the neurons to the spinal column where it synapses with an interneuron. This interneuron synapses with a motor neuron, which relays the signal from the spinal cord interneuron to the muscle. When a tremor occurs the interneuron becomes under or over stimulated. When the action potential within the motor neuron reaches the synaptic terminal of the neuron, the voltage potential causes the release of acetylcholine across the synapse between the nerve cell and the muscle. The human body uses Acetylcholine, a neurotransmitter, for many applications.. In this case, acetylcholine attaches to receptors on the muscle cell, which causes sodium channels of the muscle to open, creating a local change in membrane voltage potential [4]. Looking at the nerve signals amplitude and frequency as well as the muscle signals determines if the muscle controls voluntarily or involuntarily [5].

Examining the nerve signals flow in your body determines voluntary and involuntary actions. Knowing when an action acts involuntary allows treatment of these actions. Determining existing tremors only viewing muscle signals proves inaccurate. With the addition of nerve signals, one can increase accuracy of tremor detection [6].

The Large Dynamic Range Amplifier Plus ADC (LDRAA) allows the acquisition of both nerve and muscle signals for analysis. A Large dynamic range proves necessary to obtain the small nanovolt nerve signal and the larger millivolt muscle signal. After obtaining both signals, they must run through an ADC to digitize the data for TENS device.

Chapter II: Customer Needs, Requirements, and Specifications

Customer Needs Assessment

After talking with the project proposer, Tina Smilkstein, I have determined the main customer for the Large Dynamic Range Amplifier Plus ADC: Tina Smilkstein and a current ongoing Tremor Project. This device samples both muscle and nerve signals simultaneously, which has a use for the Tremor Project's design [4]. The Tremor Project uses nerve signal information to control a device that assists people who have tremors and help them with controlling these tremors. This amplifier allows for other companies that currently have EMG or EEG devices that want to obtain both signals. The final product customers, the patients, have tremors from diseases such as multiple sclerosis. These customers want a reliable and safe product to suppress tremors.

Requirements and Specifications

The specifications depend upon the requirements. In order for a product to sell in the market, it must have requirements. Requirements constrain the design of the specifications. The first specification accounts for the possible voltage ranges of nerve and muscle signals. This voltage range meets muscle and nerve compatibility of physical signal strengths. The second specification filters the unwanted signals and reduces noise. The third specification, fundamental to the project in that the dynamic range allows sampling both muscle and nerve signals separately. However, because we sample them simultaneously, we need to separate them. The fourth specification resulted due to the large dynamic range input. In order to get the high-resolution data, at least 14 bits required for an ADC. Muscle electrodes can use higher impedance electrodes than nerve ones because of the difference in signal amplitude. To sample both types of signals, electrode impedance limiting

required. Many samples tools require a clock. The large dynamic range amplifier utilizes the microcontroller on the tremor project and uses a clock of 16MHz [7]. The amplifier designed on a printed circuit board to not take up excessive amounts of space, because it needs to interface to the Tremor Project. The Tremor Project helps people that may get tremors. These unpredictable behaviors make the device requirement to run 24 hrs a day.

Table I: Large Dynamic Range Amplifier Plus ADC Requirements and Specifications.

Marketing Requirements	Engineering Specifications	Justification
4, 2	Input range of 10nV to 10mV [8].	Nerve signals differ from tens of nanovolts and muscle signals can go up to 10 millivolts. The amplifier must sample this voltage range.
1, 5	Filter non muscle/nerve signal frequencies (ie: 60Hz from power lines, other cell potentials, noise, actual frequency range TBD with research)	Other signals in the body (such as other cell potentials) and machines attached to the body need filtering to reduce noise, such as 60Hz from power lines.
1, 4	Separate muscle and nerve signals to analyze each signal separately.	The signals lie on top of each other and needs separation for individual analysis
3, 4	Have 14-bit resolution ADC minimum with a sample rate of 1500 Samples/s. [9]	Nerve signals exist in the nanovolts region and because the input has such a large range, it requires adequately analyzing the entire range. Thus a high resolution ADC proves necessary. Nerve signal impulses exist up to approximately 500 Hz, and so a sample rate of 1500 Samples/s should suffice.
2	Electrodes have a maximum impedance of 5kOhms and minimum of 100 Ω	Low impedance electrodes allow sampling the input signals. Too high of a signal blocks signal for amplification and sampling.
6, 7	Dimensions within 100x80 mm PCB	The amplifier designed on a printed circuit board to not take up excessive amounts of space, because it needs to interface to the Tremor Project. No hard requirement for height.
6	Operate for a full day on a full charged battery.	The Tremor Project helps people that may get tremors. These unpredictable behaviors make the device requirement to run 24 hrs a day.
5	Signal to Noise Ratio greater than 100	The small amplitude of the nerve signals requires the system to possess an extremely small noise floor (in the picovolts).

Marketing Requirements

1. Muscle and nerve signal devices compatibility.
2. Amplify input signal
3. High Resolution
4. Large Dynamic Range Input
5. Low Noise

6. Interface to current Tremor Project 7. Low Cost

The requirements and specifications table format derives from [10], Chapter 3.

Table II: Large Dynamic Range Amplifier Plus ADC Deliverables

Delivery Date	Deliverable Description
1/31	Design Review
3/2	7RF Tapeout Date
3/13	EE 461 demo
3/16	EE 461 report
5/18	EE 462 demo
5/18	ABET Sr. Project Analysis
5/26	Sr. Project Expo Poster
6/13	EE 462 Report

Chapter III: Functional Decomposition

Level Zero Block Diagram

The most basic level, the large dynamic range amplifier plus ADC filters, amplifies, and then converts an analog signal to a digital signal. Figure 1 shows the LDRAA generating digital data to the microcontroller. The digital signal derives from electrodes attached to the human body. The LDRAA requires power in the form of a battery and a CLK to properly convert and send data to the microcontroller.

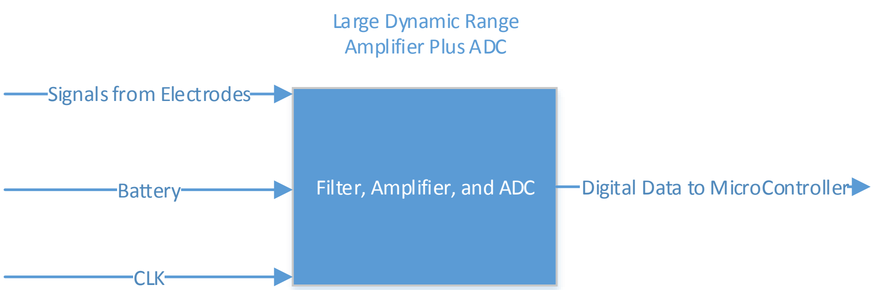


Figure 1: Level Zero Block Diagram

Table III: Large Dynamic Range Amplifier Plus ADC Level Zero Functionality Table

Signal/Function	Description
Module	Filter, Amplifier, and ADC
Inputs	Input signals from electrodes on person's arm or leg. DC Power from a Battery CLK from microcontroller
Output	Digital Data to Microcontroller
Functionality	Takes input signals from electrodes, filters out noise and muscle nerve signals. Amplifies the signals and then puts them through an ADC. [3]

Level One Block Diagram

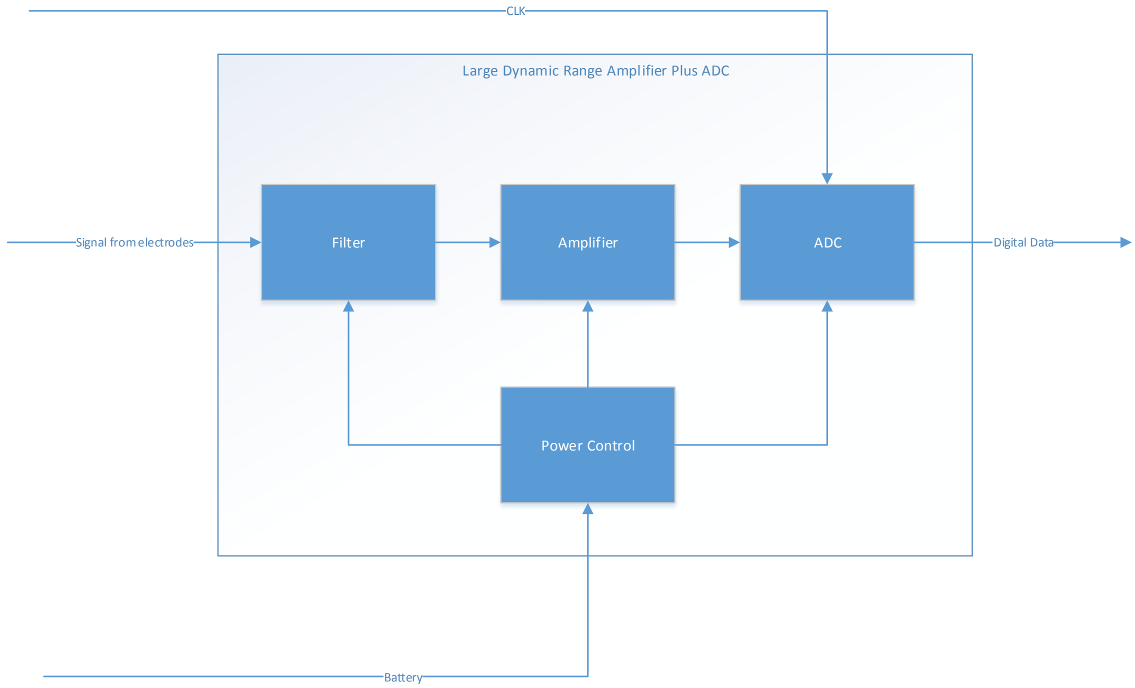


Figure 2: Level One Block Diagram

Table IV: Large Dynamic Range Amplifier Plus ADC Level One Functionality Table

Module	Input	Output	Description
Filter	• Signal from electrodes • Stable reference voltage from power control	• Filtered signal from electrodes	• Filter used to remove high bandwidth noise and heartbeat frequency.
Amplifier	• Filtered signal from electrodes • Stable reference voltage from power control	• Amplified signal	• Amplifies nerve and muscle signals to be large enough for analog to digital conversion.
ADC	• Amplified signal • CLK from microcontroller • Stable reference voltage from power control	• Digital data to microcontroller	• Converts the signals to digital values for the TENS device to analyze. • Possible configuration of SAR or Pipeline topology.
Power Control	• Battery DC Voltage	• Stable reference voltage	• Creates stable voltage reference for each module from the battery.

Level Two Block Diagram

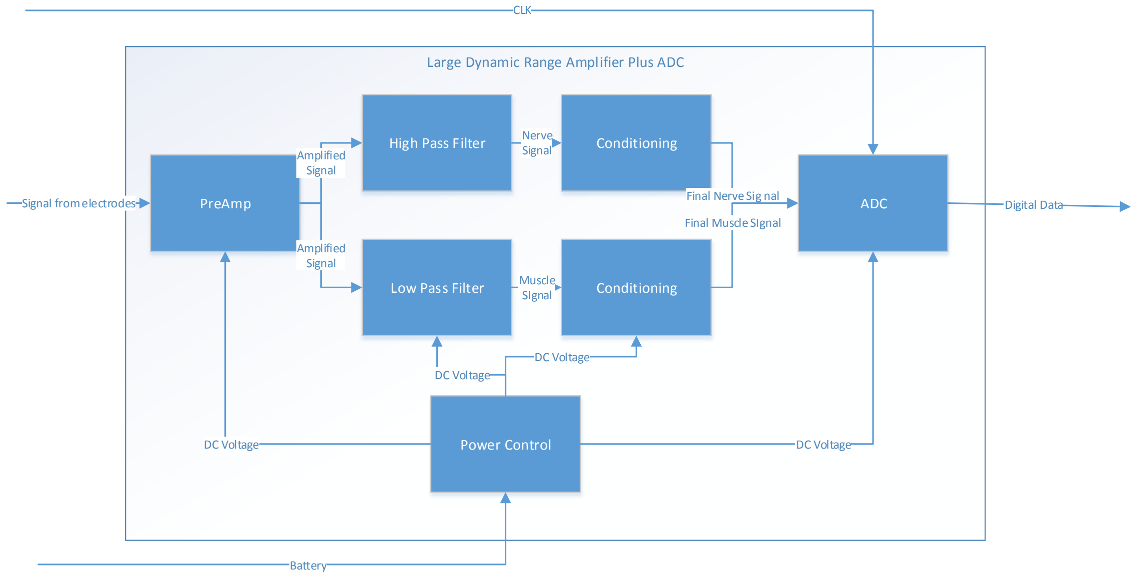


Figure 3: Level Two Block Diagram

Table V: Large Dynamic Range Amplifier Plus ADC Level Two Functionality Table

Module	Input	Output	Description
Pre-Amp	• Signal from electrodes	• Amplified Signal	• Low noise pre amplification before filtering • Large Gain of 2000+
LPF	• Signal from pre-amp	• Filtered muscle signal	• Filter used to remove high frequency nerve signals
HPF	• Signal from pre-amp	• Filtered nerve signal	• Filter to remove low frequency large amplitude muscle signals
Conditioning	• Filtered nerve signal	• Cleaner conditioned nerve signal	• Applies more filtering and buffering to the nerve signal
Power Control	• Four 9 Volt batteries. • Two in series to produce $\pm 18V$ and $\pm 9V$	• Stable reference voltage of $\pm 15V$ and $\pm 9V$	• Creates stable voltage reference for each module from the battery.

ADC	• Amplified signal • CLK from microcontroller • Stable reference voltage from power control	• Digital data to microcontroller	• 8 channel Delta Sigma ADC

Chapter IV: Design

The LDRAA needs to essentially filter out the large low frequency muscle signals. The frequencies of muscle and nerve signals are within a decade apart. The amplitude difference is as much as 120dB. This means that you would need at least a 6th order filter just to make the muscle signal the same magnitude as the nerve signal. To completely filter out the muscle signal would require at least a 10th order filter or higher. The circuitry and stability of such a strong filter is impractical.

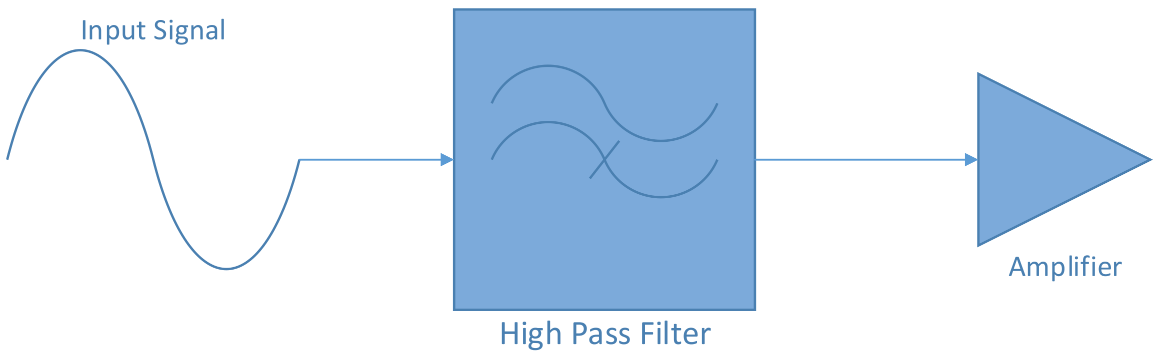


Figure 4: Basic Design Requirement

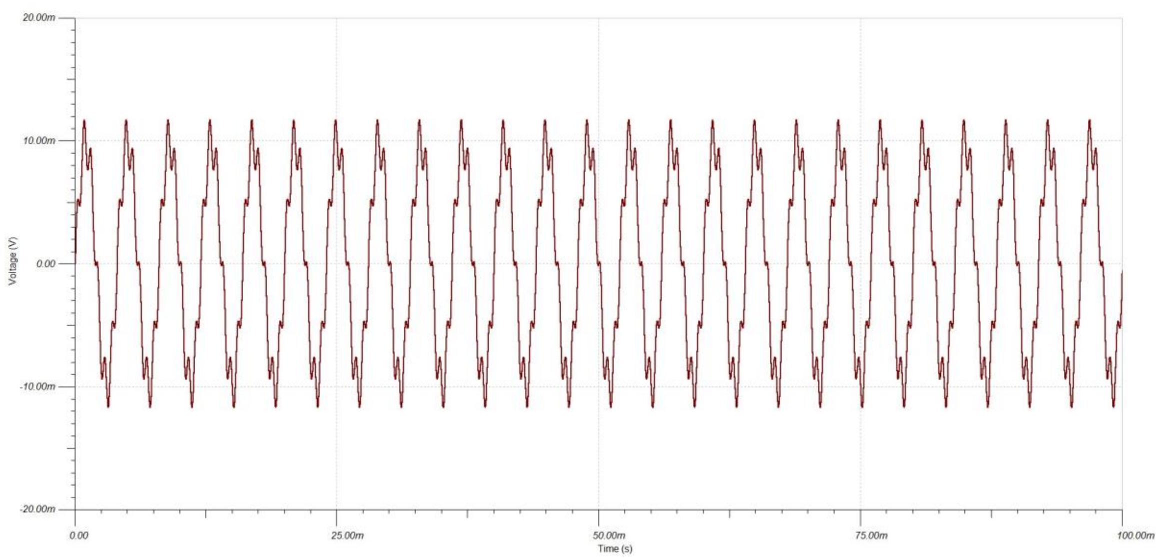


Figure 5: Example Input Signal

Essentially, a high pass filter needs to be created. A proposed idea is to use the original signal and filter out the high frequency nerve signal. If you then subtract these signals, then the result must be the high frequency nerve signals.

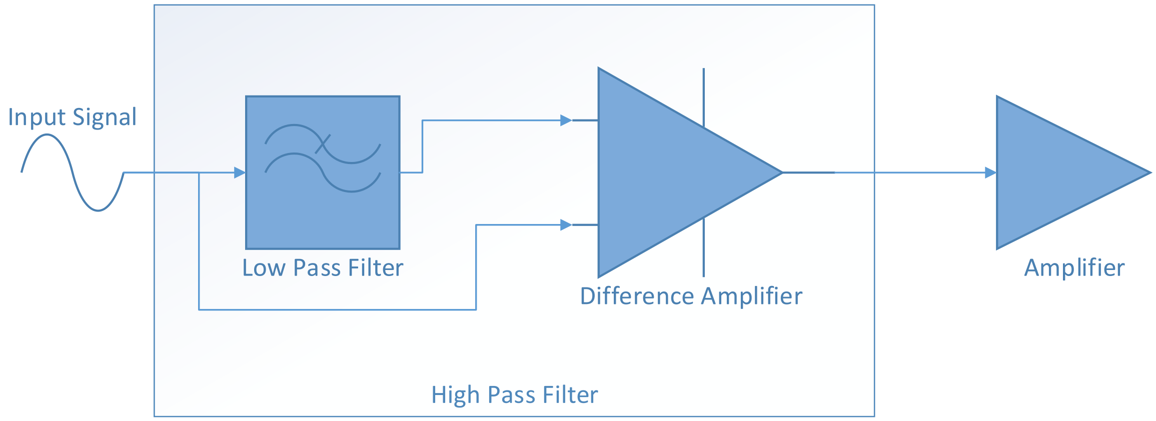


Figure 6: Basic Operation of Separating Large Amplitude Different Signals

Design Input Stage

Knowing the signals are small, the first stage comprises of a pre-amplification (pre-amp) circuit. The largest consideration for the pre-amp is low noise, high gain, and large input impedance. The beginning stage of a circuit introduces the most noise, and so a low noise instrumentation amplifier was chosen. The body also produces a static 60Hz wave. By using an instrumentation amplifier, you can subtract the common signal between two nodes and therefore eliminate the 60Hz wave.

The skin can be seen with a large amount of resistance if not prepared correctly. The dead skin, oil and other materials on the skin shows the skin with mega ohms worth of impedance. Therefore skin preparation and an input stage with a large amount of input impedance is needed. The INA166 is an instrumentation operation amplifier that has extremely low noise, very high gain, and 60 mega ohms of input impedance.

Design Nerve Separation

1. Low Pass and Subtraction

Straight forward implementation of the concept in Figure 6, I should be able to take a signal, put it through a low-pass filter, and then just subtract the signals from each other.

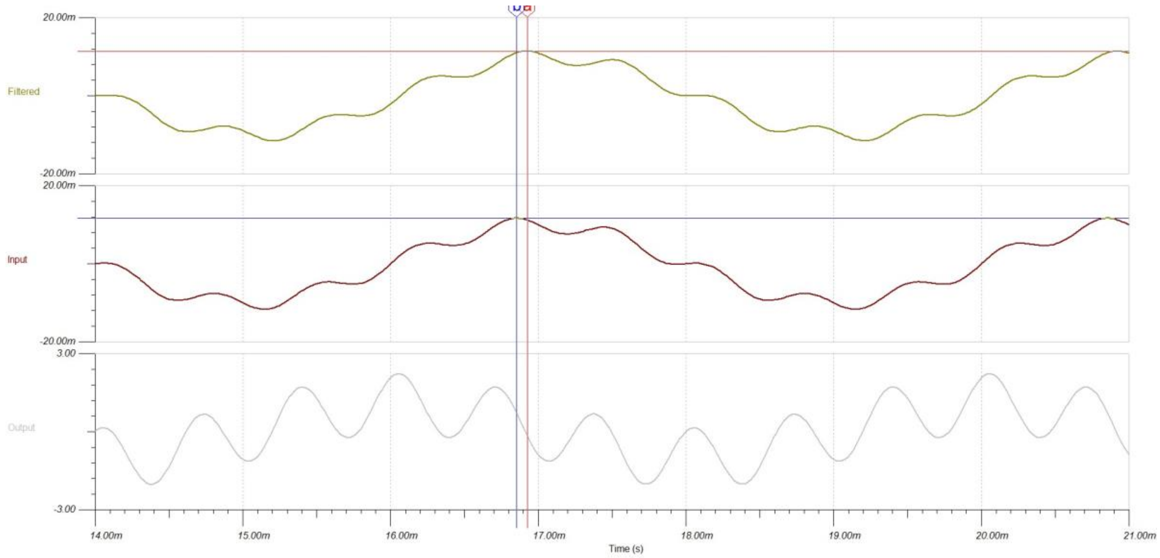


Figure 7: Example of Phase Delay when implementing design I

As you can see from the simulations, there is a small delay through the low-pass filter, which cause the signals to not align in the time domain for the difference amplifier. The circuit used to test this design was a simple active RC filter and an instrumentation amplifier.

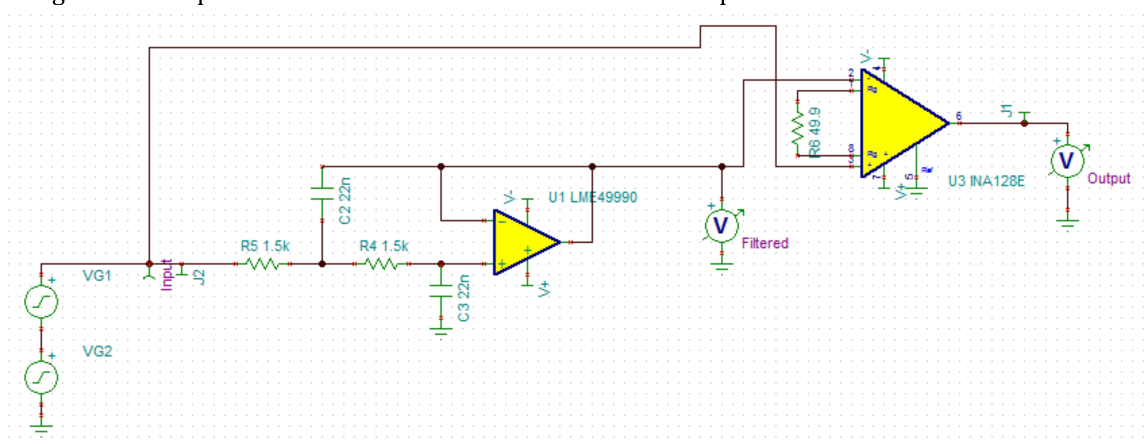


Figure 8: Design I Test Circuit

For a general simulation, the signals tested used an input signal of 2mVpp and 10mVpp at 1.5 kHz and 250 Hz respectively. The LME49990 was chosen as a very low noise operational amplifier.

2. Low-Pass, All Pass, and Subtraction

The problem with the first design was that the signals could not be aligned in the time domain due to the delay of the low-pass filter. The next thought then was if there was a way to remove the delay of the low-pass filter, which couldn't be done because of the phase response of a low-pass filter. So an

all-pass filter was thought to be able to potentially introduce the required delay.

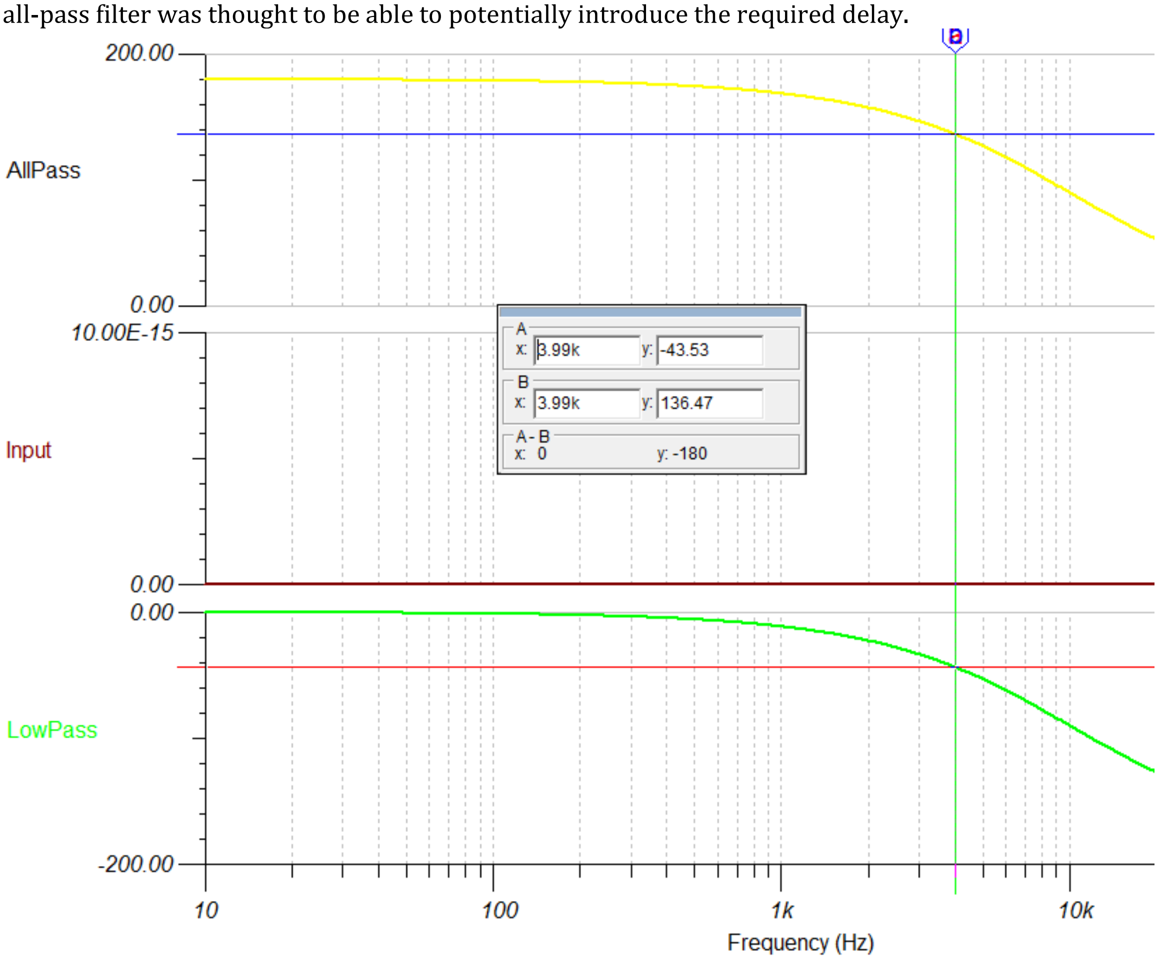


Figure 9: All-pass Design I Phase

From Figure 9, the response of the all-pass filter design introduces a phase delay, but opposite that of the low-pass filter. In order to align the phases, a thought of inverting the low-pass filter could introduce the 180-degree phase shift required to line them up. This would work if the signals were periodic and constant, but because body signals amplitudes are not consistent, the phase signals are not the same at 540 degrees as 180 degrees.

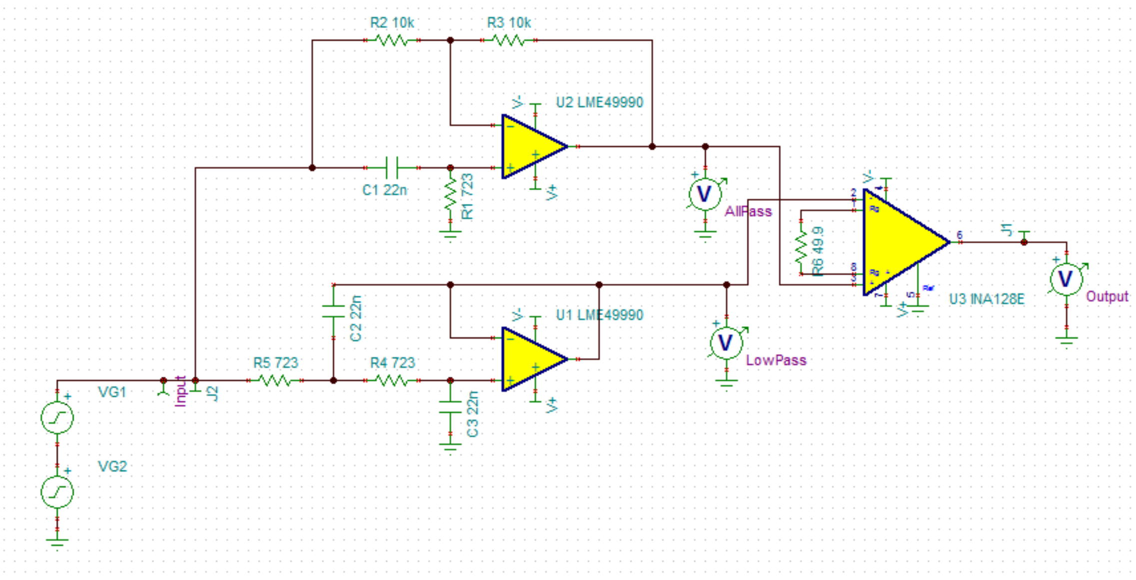


Figure 10: All-pass Design I Circuit

I have learned of All-pass filters from courses, but never implemented them before. The topology used in Figure 10 with R1, R2, R3, C1, and U2 [11] is an all-pass filter using a high-pass base configuration. How it works is that as the input into C1 increases in frequency, the positive terminal of U2 sees the full signal. And then the amplifier acts as a unity gain amplifier. When the signal is low frequency, the terminal looks grounded, and therefore the amplifier acts as an inverting amplifier with a gain of one. However, the phase is initially inverted at low frequencies, and decreases at higher frequencies. From the phase, it can be seen that this topology also will not work, so another all-pass configuration was discovered and implemented.

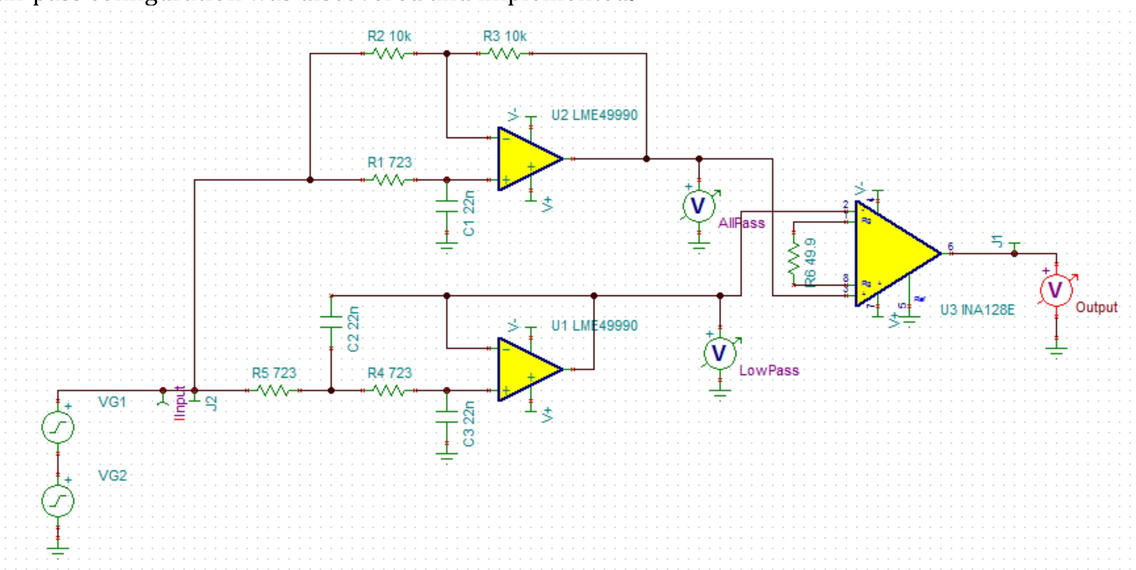
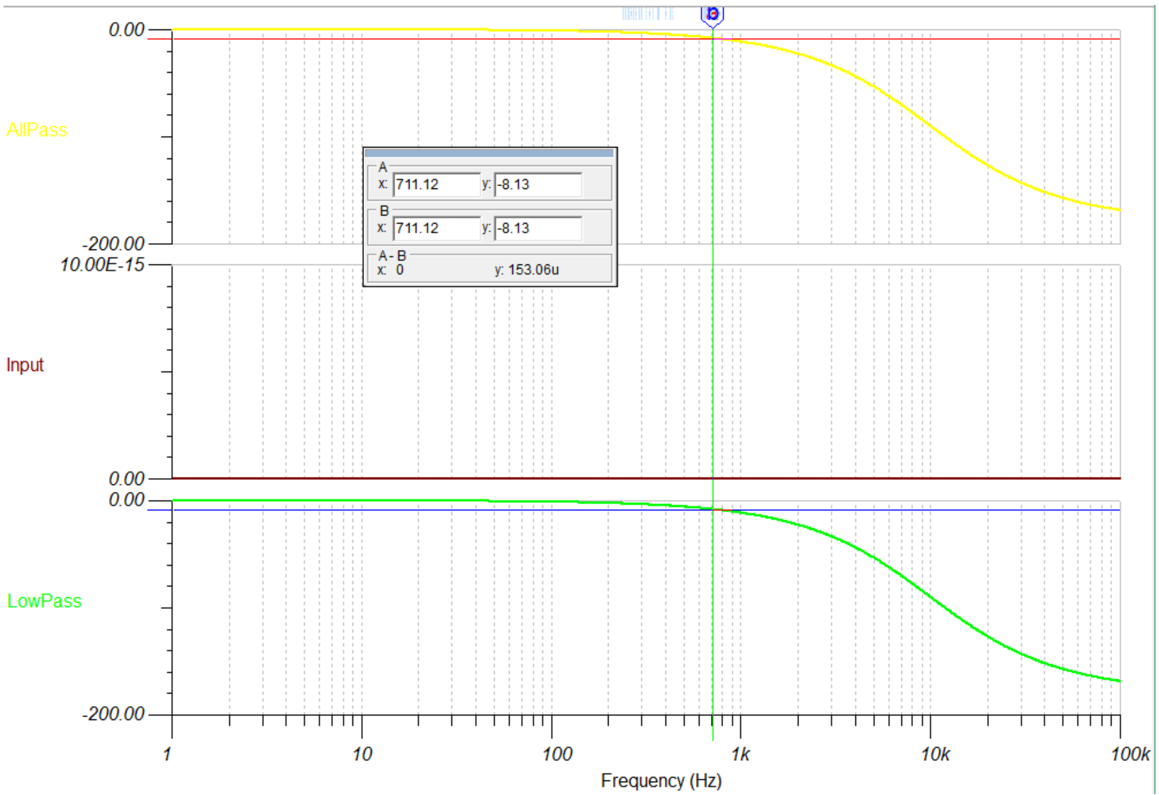


Figure 11: All-pass Design II Circuit

Just from observation, the difference between Design I and II is the RC configuration in the all-pass circuit. This gives you the phase starting at 0 and decreasing. So, rather than the inverted 180-degree phase, the all-pass introduces the 90-degree phase shift following the low-pass filter. Not only does the phase at cutoff need to be the same, but the actual phase at all frequencies need to be the same. Therefore, the low-pass filter topology and all-pass filter topology are required to be the same.



Muscle signals are most prominent around 250Hz, but can go up to 500Hz. Nerve signals are typically 1kHz or greater. In order to get no attenuation during the passband, a cutoff frequency of 10kHz was chosen for the low-pass filter.

$$f_c = \frac{1}{2\pi\sqrt{R_3R_4C_1C_2}} = \frac{1}{2\pi\sqrt{(723)^2(22x10^{-9})}} \approx 10kHz$$

$$A_v = 1$$

Lastly, after the signals are separated, we are left with just the high frequency nerve signals. A little bit of condition is applied to get the signal to full-scale for the ADC and smooth the signal a bit. The structure is a high pass filter and a non-inverting amplifier as seen in Figure 12.

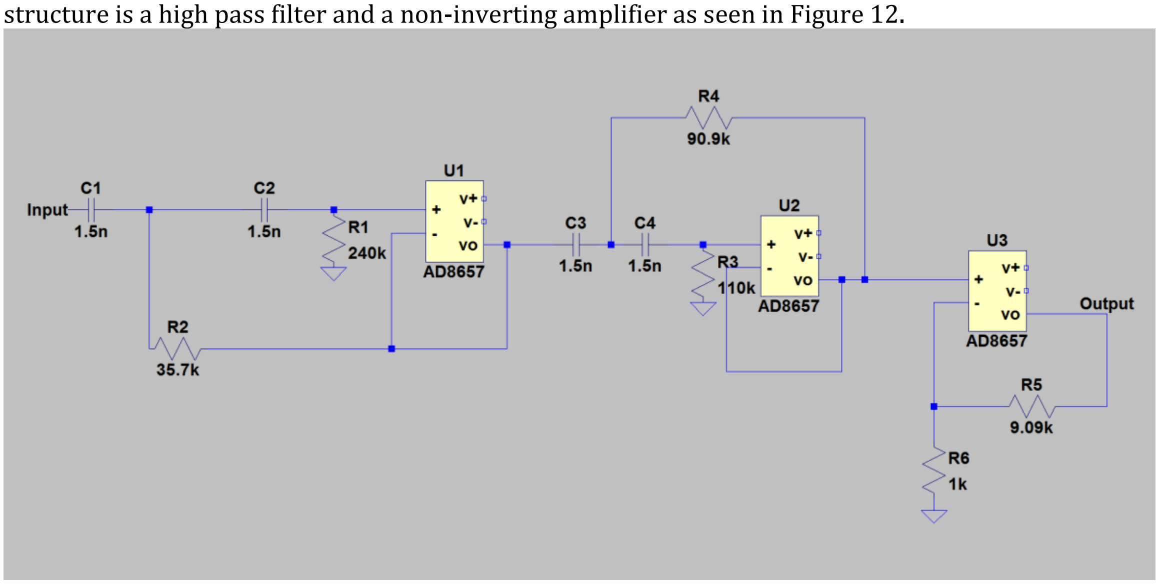


Figure 12: Nerve Signal Conditioning Circuit

Design Muscle Separation

The muscle signal is only the large amplitude signal at a low frequency. A low-pass filter is capable of obtaining the muscle signal. A fourth order Butterworth active low-pass was chosen with a cutoff of 500 Hz. The reason is because the Butterworth has a very flat passband with a medium strength cutoff. The filter topology and component values were determined using the Analog Filter Wizard [12].

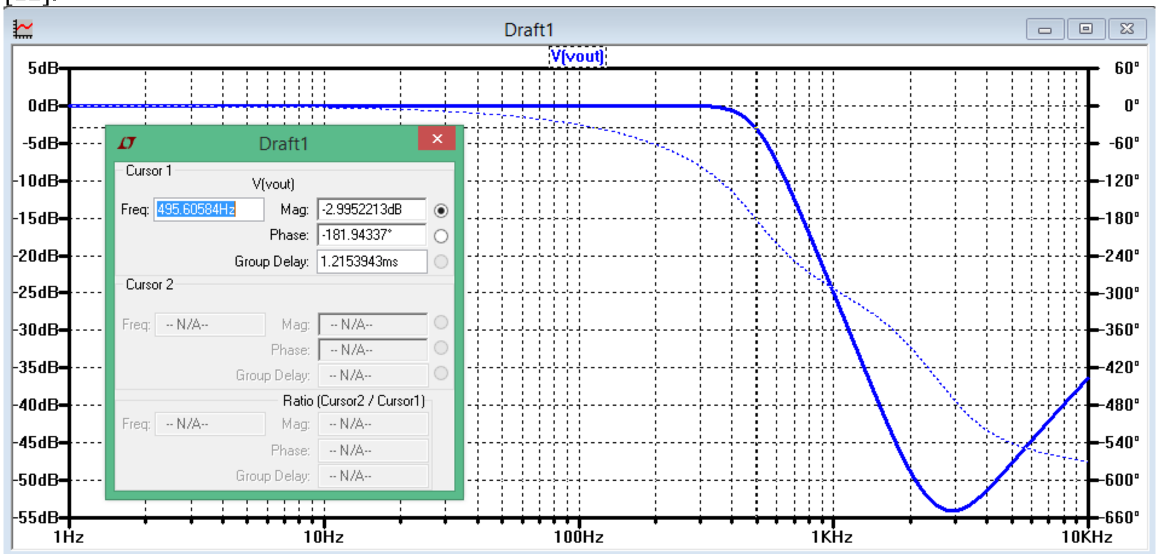


Figure 13: Frequency Response of Low Pass Filter, 500Hz cutoff

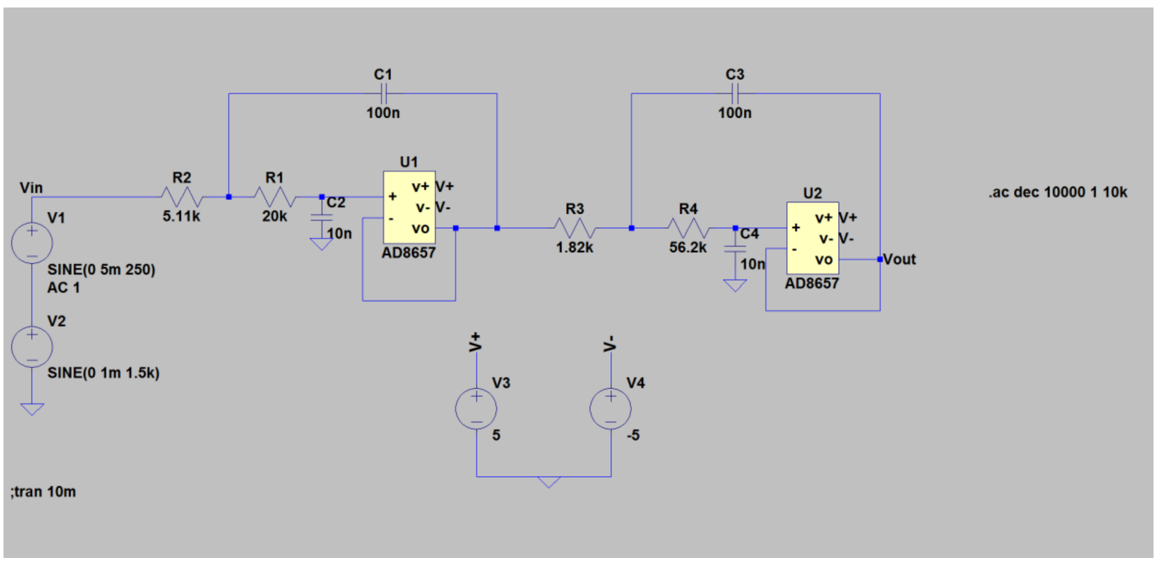


Figure 14: Low Pass Filter Circuit Diagram

Board Design and Schematic

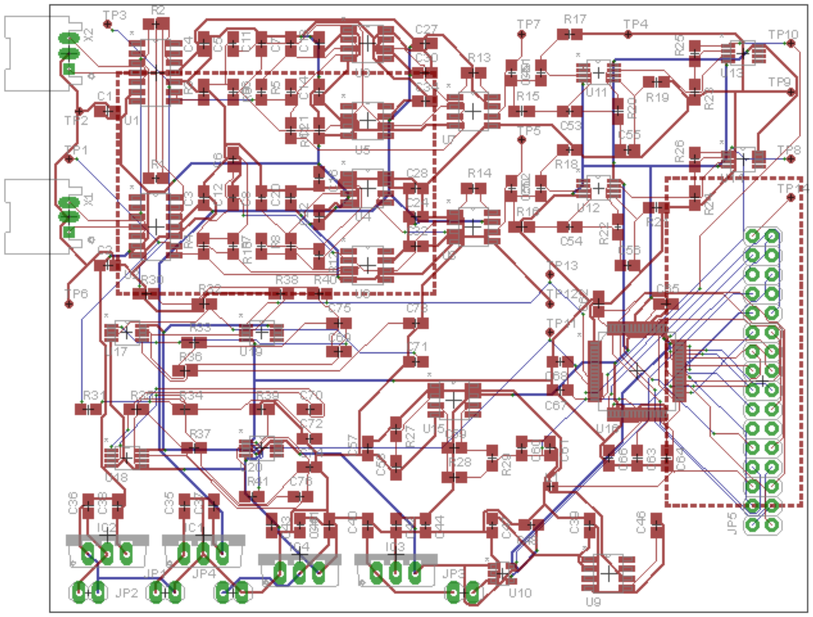


Figure 15: Board Layout

The INA166 is the input stage to the entire board. The signal then goes through the LME49990 ultra low noise amplifiers (all-pass and low-pass filters) and get subtracted using the INA128 instrumentation amplifier. The remaining signal is the high frequency signal. This then gets routed to the nerve signal conditioning circuit as seen in Figure 18.

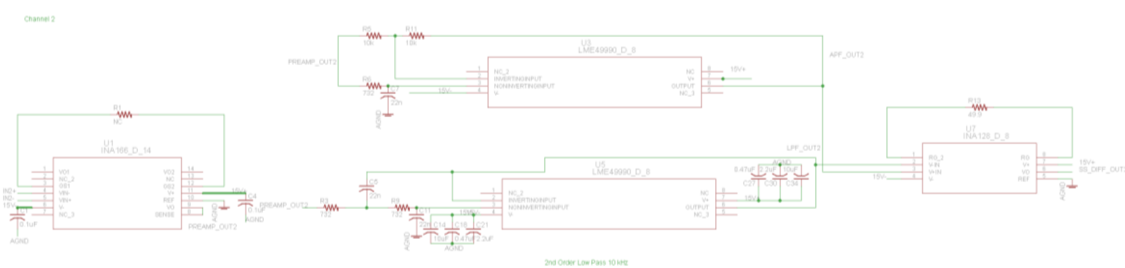


Figure 16: Channel Two of the Input Stage and Nerve Signal Separation (Actual)

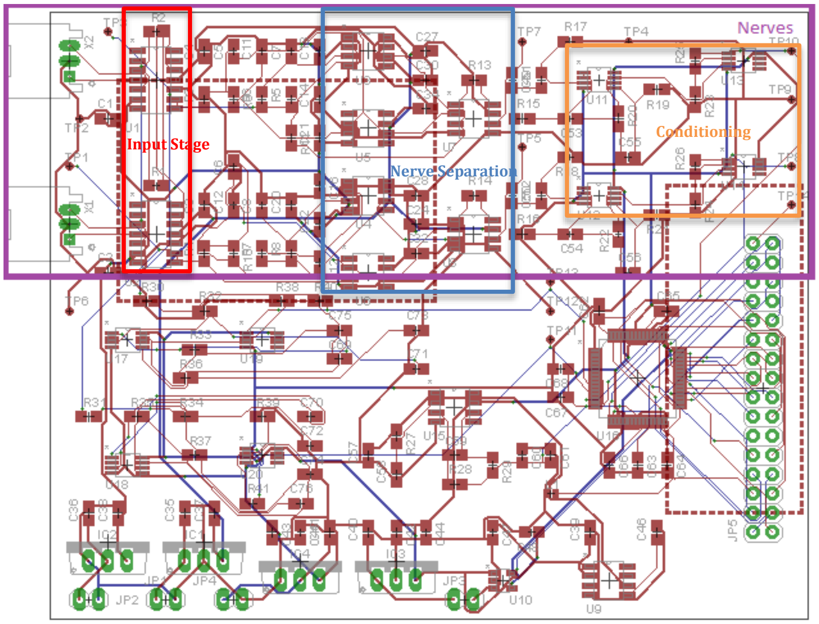


Figure 17: Nerve Separation on the board layout. Two channels

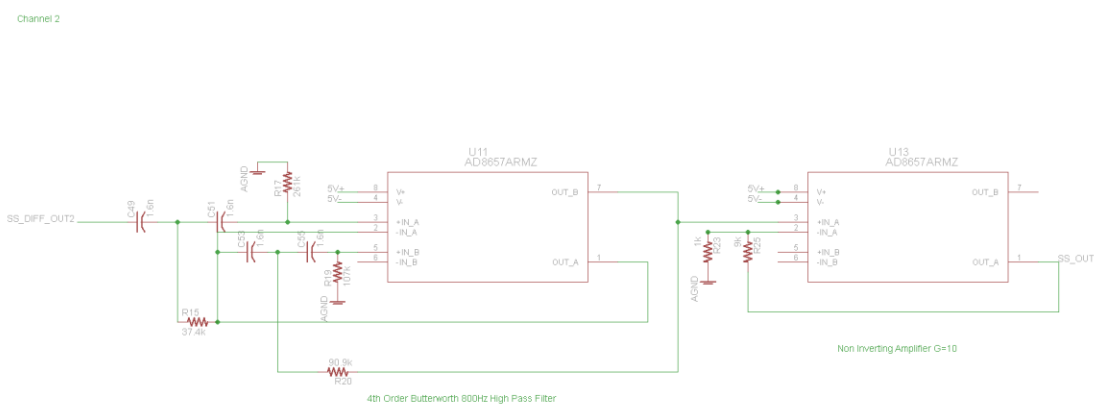


Figure 18: Nerve Signal Conditioning Circuit (Actual)

The nerve signal conditioning circuit provides another high pass filter and little amplification in order to smooth out the signal more.

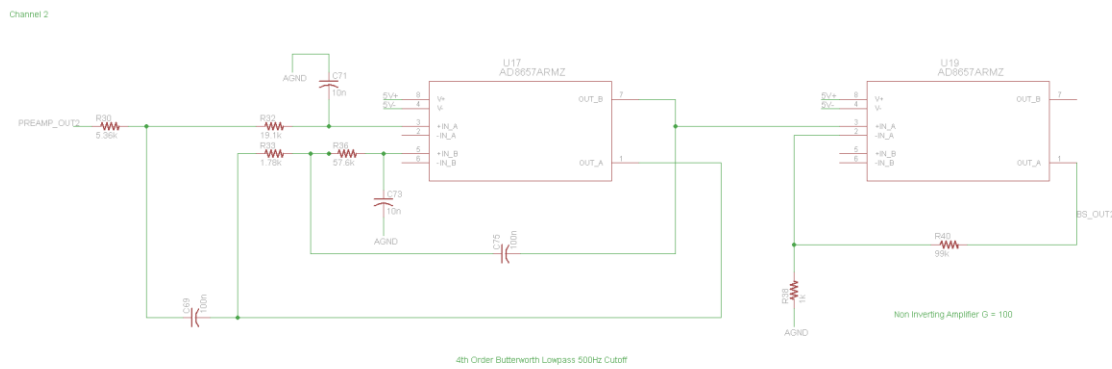


Figure 19: Muscle Filtering and Conditioning Circuit (Actual)

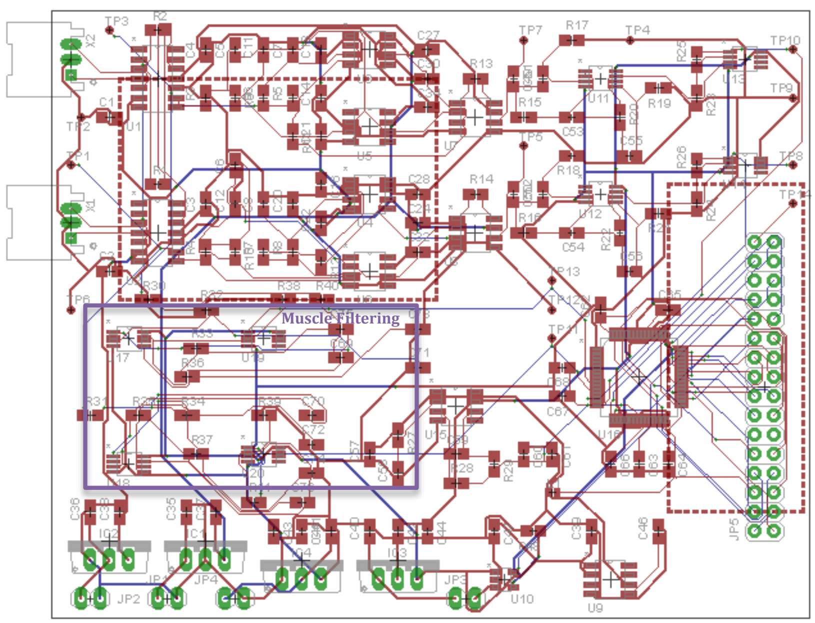


Figure 20: Muscle Filtering and Conditioning Board Layout

The signal is taken from the INA166 and then put through a low pass filter with a non-inverting amplifier. Both muscle filtering channels run parallel to each other just as the nerve separation circuit runs parallel to each other.

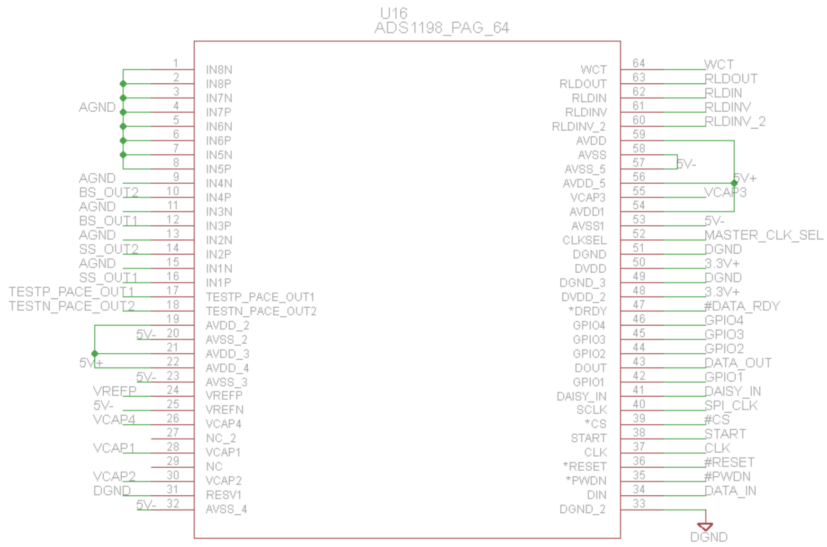


Figure 21: ADS1198 ADC

The ADS 1198 was chosen because it is specified for EMG sensor sampling. It is an eight channel ADC; only four are being used in this board revision.

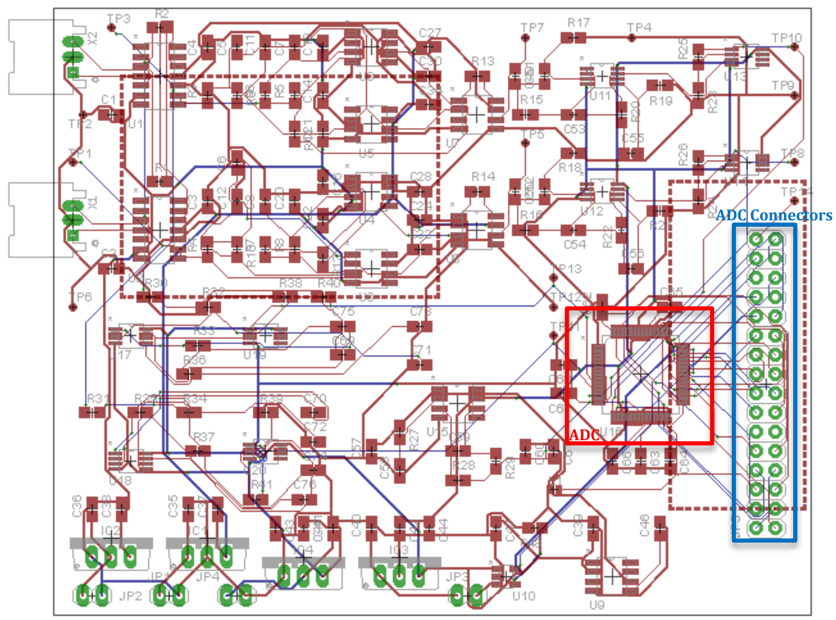


Figure 22: Board layout of ADC and Connectors

The connectors are just through-hole pins that match the size of any generic header. This is used so the microcontroller can easily access the pins of the ADC.

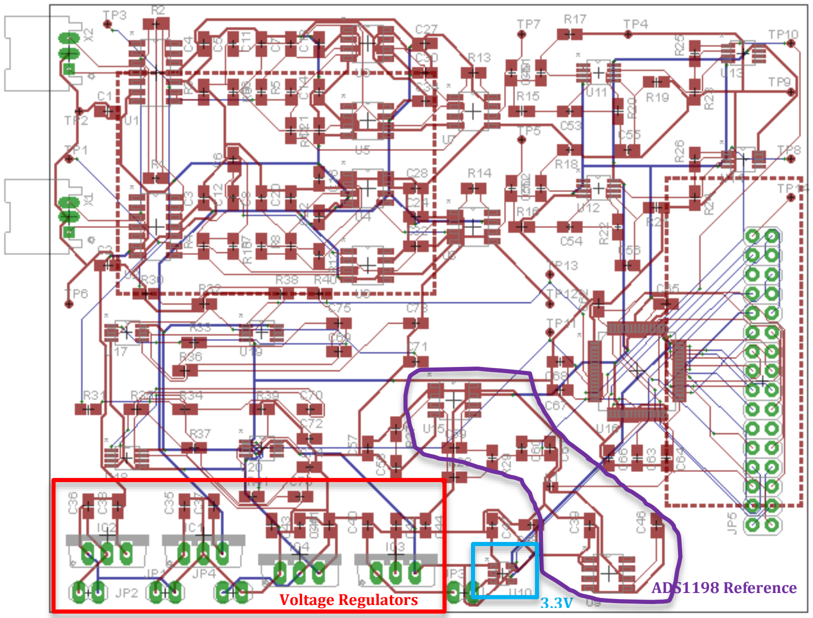


Figure 23: Board Layout for Power

Lastly, power chosen for the board. The parts chosen were the 7805, 7905, 7815, and 7915. These are generic voltage regulators to supply the $\pm 5V$ and $\pm 15V$ power supplies for the devices. The ADC also requires a 2.5V reference and so the REF5025 was used to produce a 2.5V reference. The REF5025 was recommended in the ADS1198 datasheet. Another supply required for the ADS1198 is the 3.3V for all the digital signals. This is provided using the LP3990. All capacitors for bypassing and stability for the regulators and ADC were chosen using the datasheets of the respective devices.

Chapter V: Test Results

There were issues obtaining signals from electrodes. Therefore all results are obtained using a function generator.

Equipment:

Agilent Technologies	MSO-X 2012A Oscilloscope
Rigol	DG1062 Function Generator
Agilent Technologies	E3630A Triple Output Power Supply

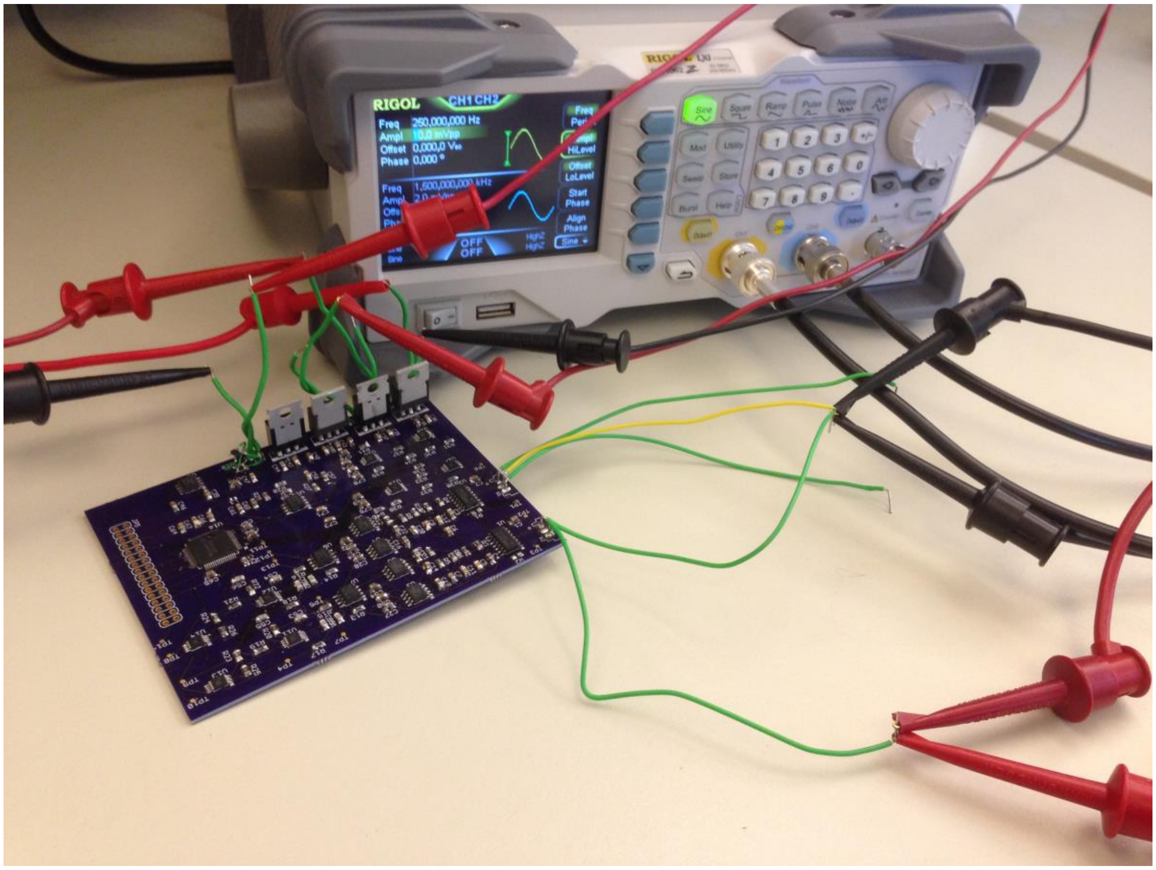


Figure 24: Setup Connections

Test Conditions:
Input 1: 250 Hz 10mVpp sine
Input 2: 1.5kHz 2mVpp sine

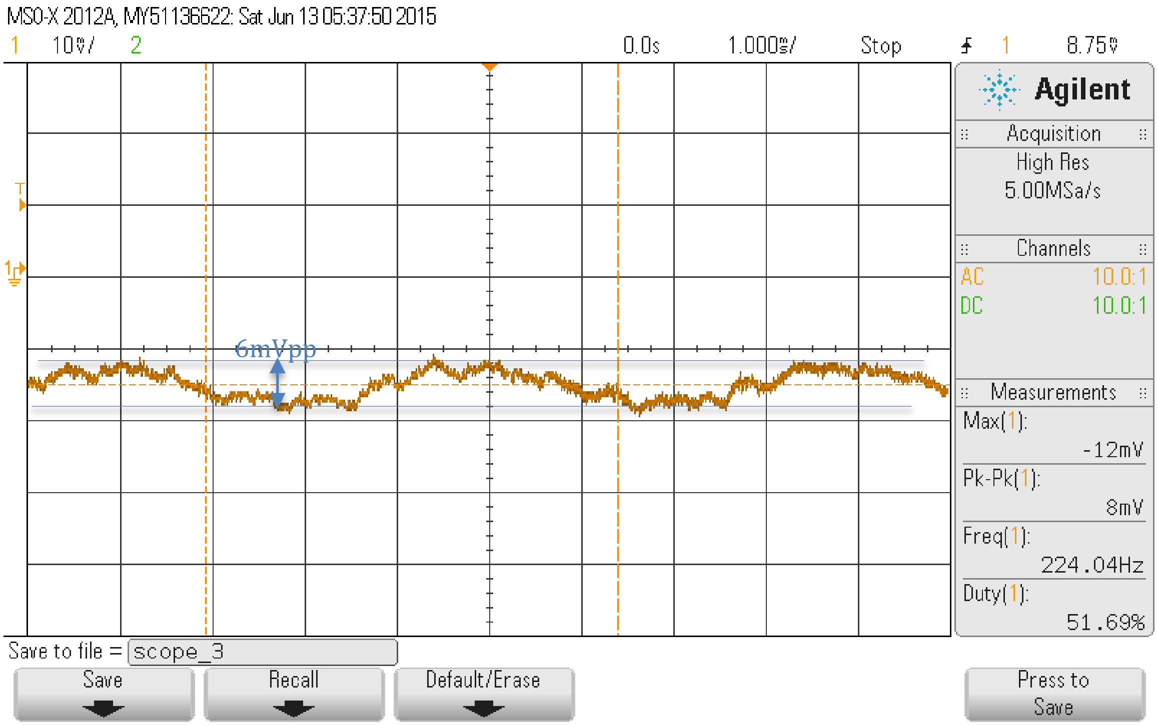


Figure 25: Actual input signal (2mVpp 1.5kHz on top of 10mVpp 250Hz)

Because the oscilloscope can only read down to 10mVpp divisions, a scaled version of the input was recorded to better view what the signal should look like.

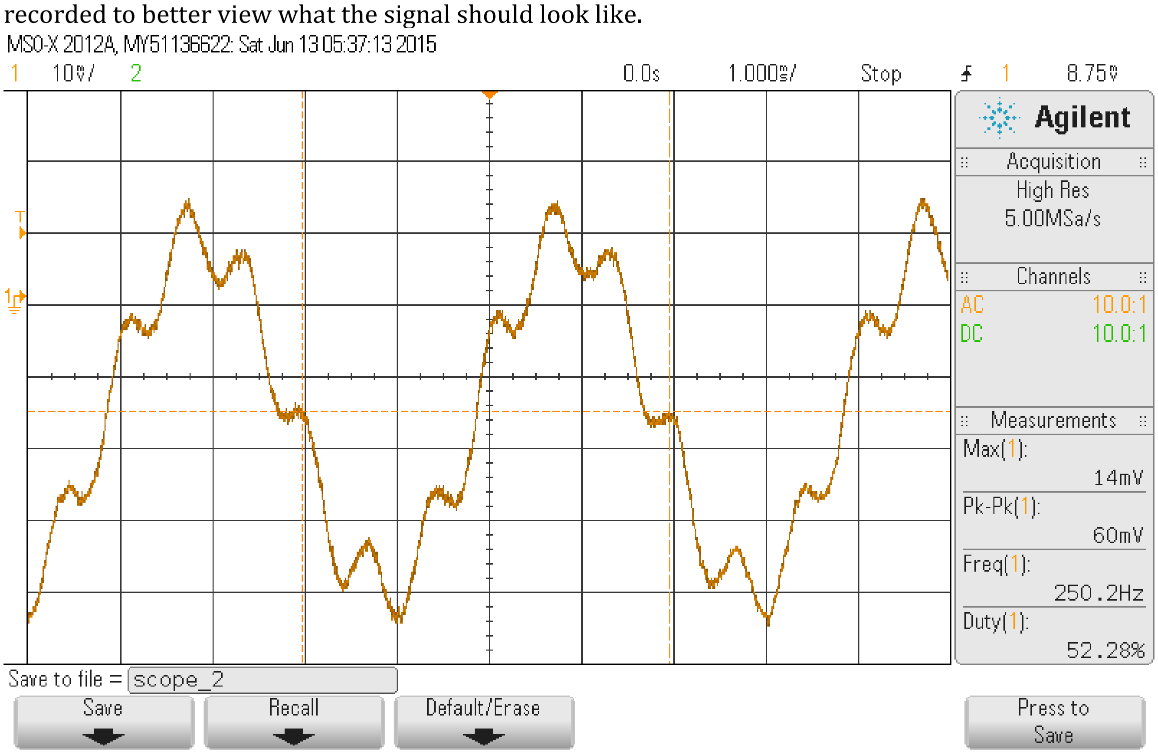


Figure 26: Scaled input signal (20mVpp 1.5kHz on top of 100mVpp 250Hz)

Remember that these signals are from a function generator and not a human body, and therefore the gain settings are not correct and railing may occur.

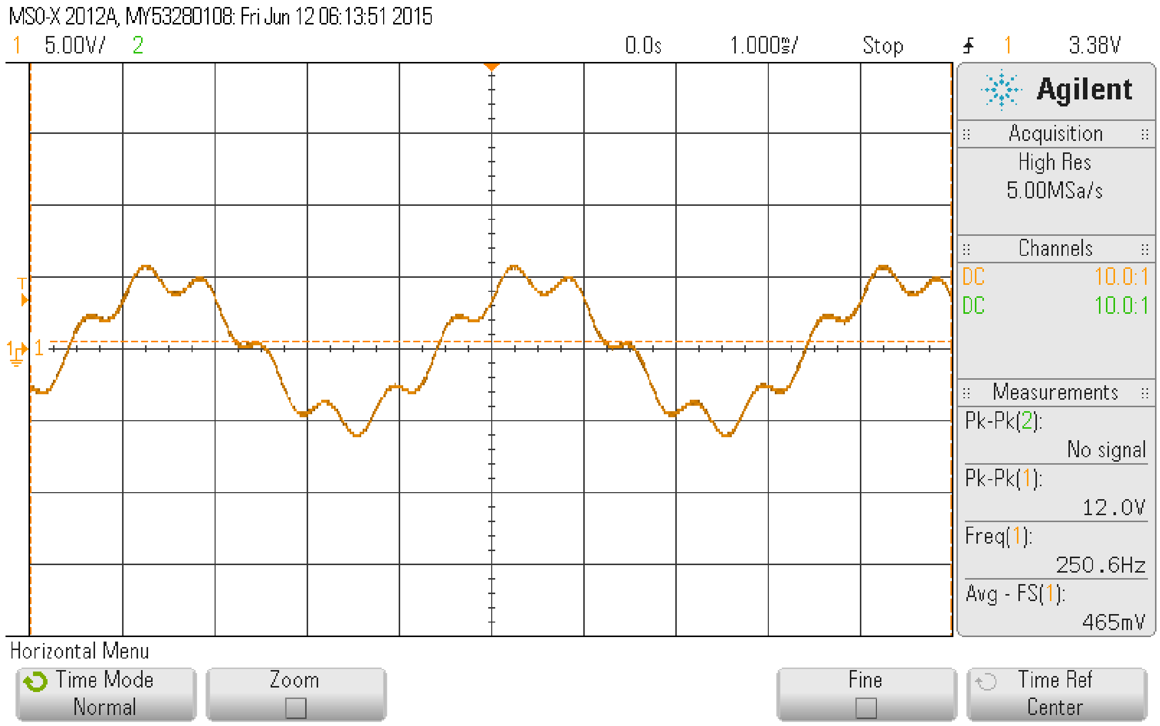


Figure 27: Signal output of preamp

It can be seen that the signal from the pre-amp looks very much like the scaled input in Figure 26. The amplifier is successfully amplifying the signal in Figure 25.

$$A_{expected} = 2000$$

$$A_{actual} = \frac{12}{.006} = 2000$$

So now we have an amplified signal that has both a high frequency and low frequency component.

Figure 28: Signal through the "highpass" filter before any conditioning

As you can see, the 1.5kHz signal is clearly obtained, although railed due to gain settings.

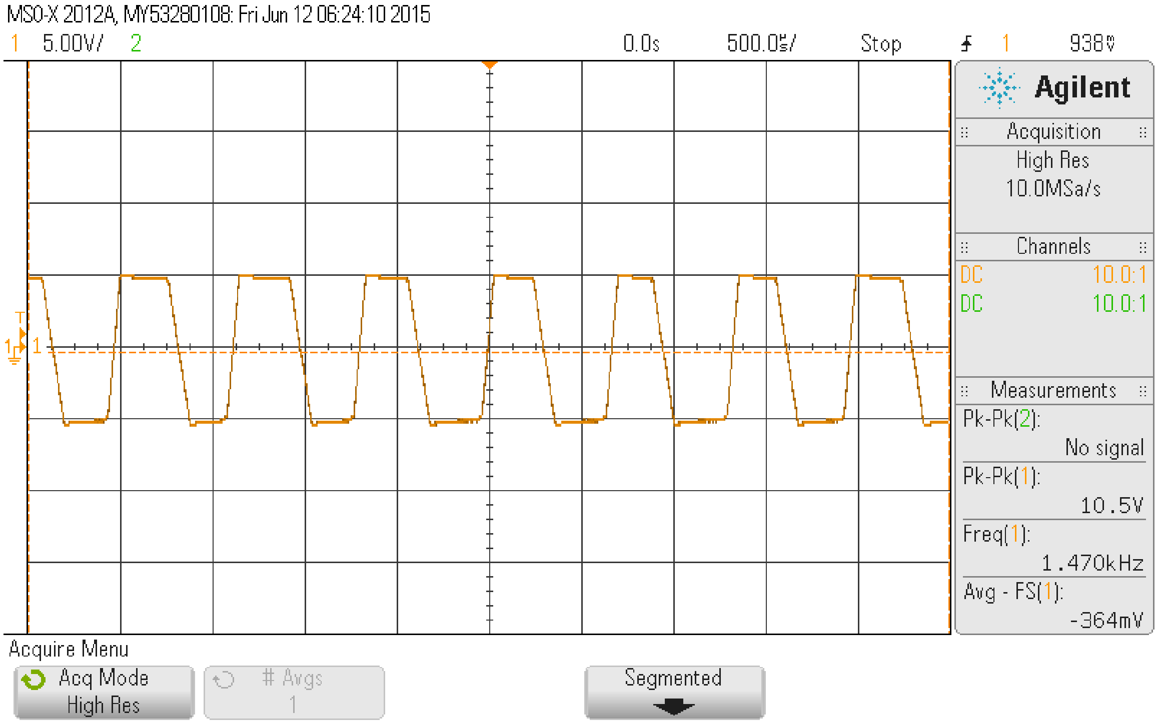


Figure 29: Signal after final conditioning

As you can see, the signal is much cleaner after the final conditioning.

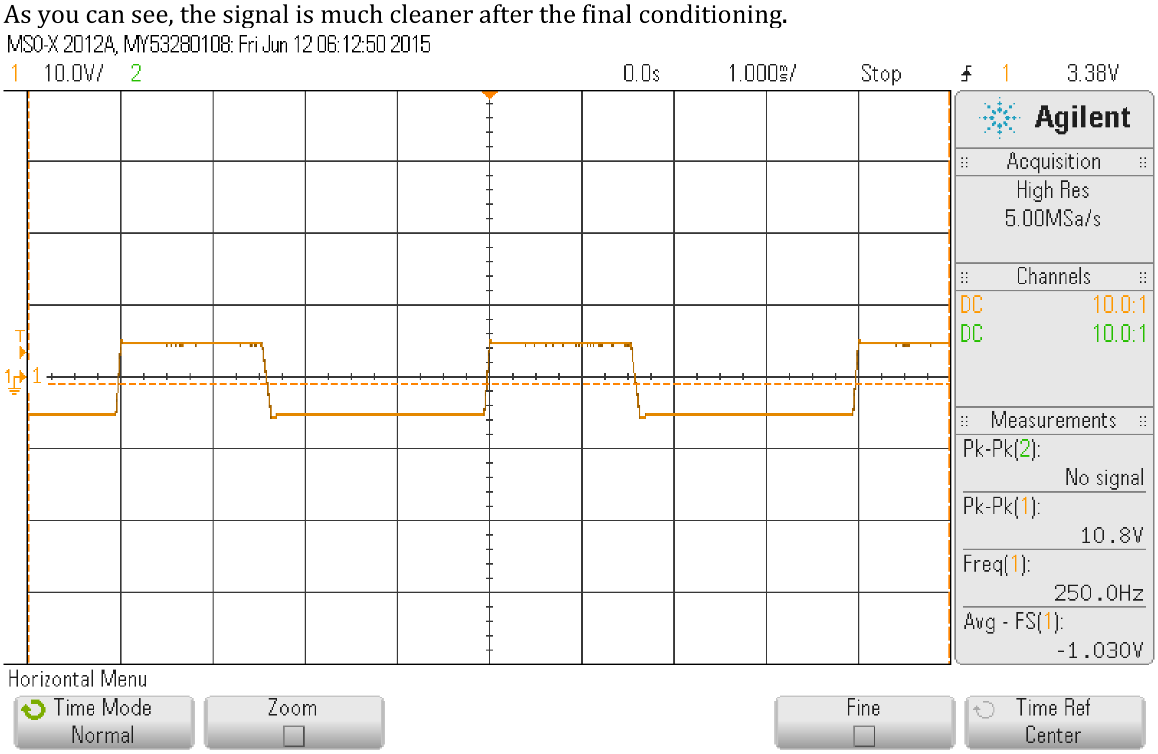


Figure 30: Muscle Signal, Low pass filter

A clean 250Hz wave is obtained through the low pass filter. All signals were successfully separated and obtained.

Chapter VI: Errors and Fixes

1. When looking at component values, please refer to the BoM rather than the values listed on the schematic.
2. The silkscreen on the board has several names overlapping each other making it difficult to determine which part goes where. Refer to the image in the supplemental files folder for the updated silkscreen.

3. The LP3990 (U10) had a mismatch between the schematic pins and the pa

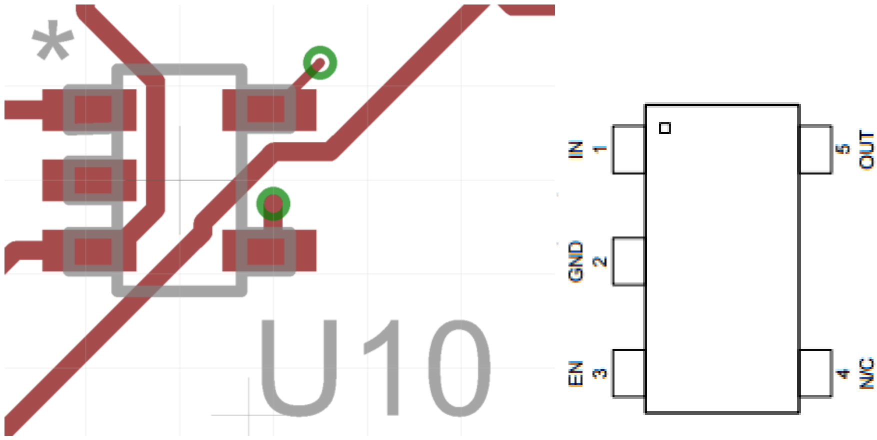


Figure 31: Pin/Schematic Mismatch with LP3990

On the board, it can be seen that Pin 2 is NC. Pin 3 is connected to GND, Pin 4 is OUT, and Pin 5 is EN. The chip was deadbugged and so the pins should be swapped as shown.

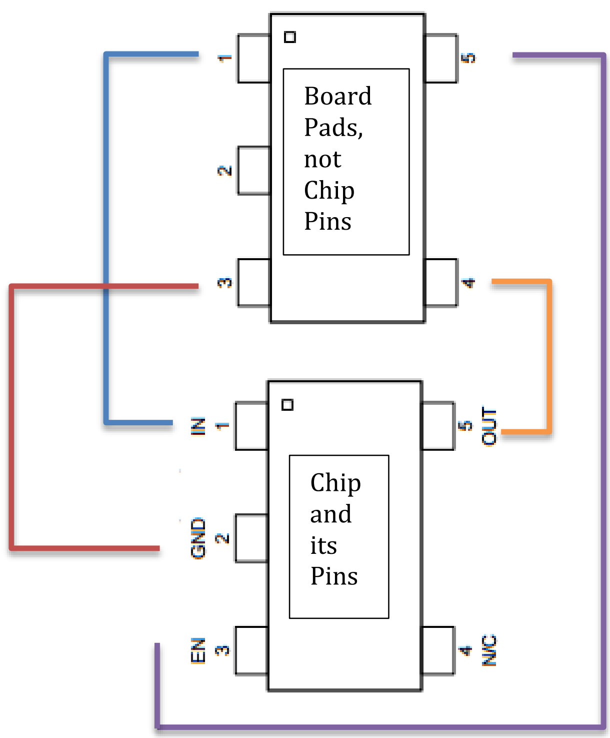


Figure 32: Corrected Pin/Pad placement. Top Picture is the pads. Bottom picture is the actual chip. Have to deadbug the chip so that the correct pins meet the correct pads.

4. I'm not sure how it happened, but I did not connect certain pins on the nerve conditioning and the muscle circuits.

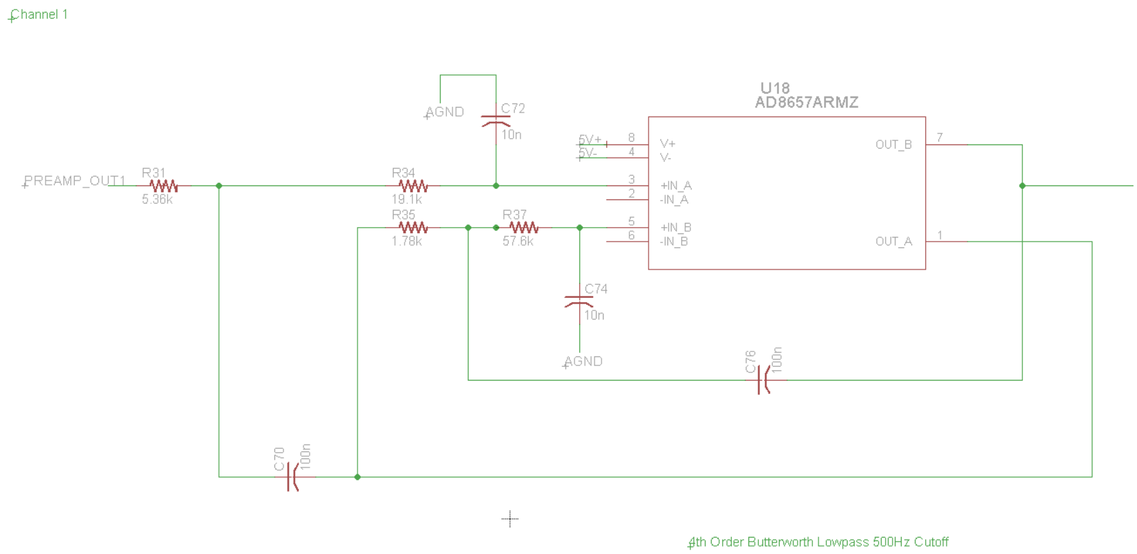


Figure 33: Muscle Conditioning Circuit Error

It can be seen that –IN_A and –IN_B are unconnected. Each of them should be connected to the output of their respective terminals, following the design of Figure 19.

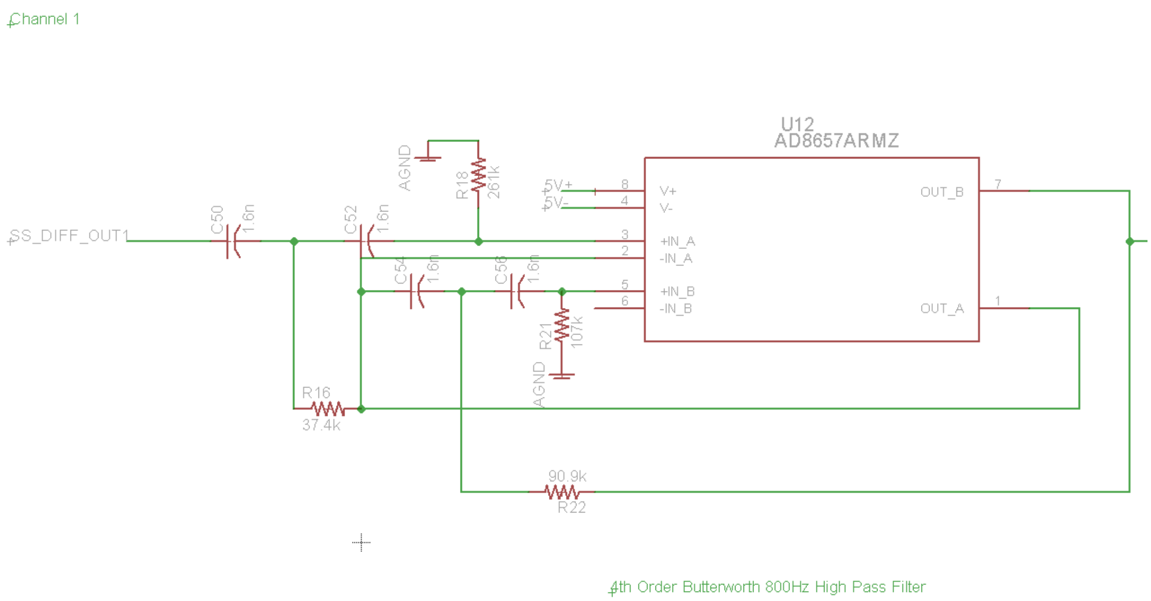


Figure 34: Nerve Conditioning Circuit Error

In the nerve conditioning circuit, the feedback for –IN_B is also not connected. However, it should be connected to the output B as shown in Figure 12.

5. These problems have not been fixed because the Eagle Cad software [13] license has expired.

Appendix A: References

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Appendix B: Board BoM

Part	Value	Device	Package	Description
C1	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C2	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C3	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C4	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C5	22n	C-USC0805	C0805	CAPACITOR, American symbol
C6	22n	C-USC0805	C0805	CAPACITOR, American symbol
C7	22n	C-USC0805	C0805	CAPACITOR, American symbol
C8	22n	C-USC0805	C0805	CAPACITOR, American symbol
C11	22n	C-USC0805	C0805	CAPACITOR, American symbol
C12	22n	C-USC0805	C0805	CAPACITOR, American symbol
C14	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C16	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C18	0.47uF	C-USC0805	C0805	CAPACITOR, American symbol
C20	0.47uF	C-USC0805	C0805	CAPACITOR, American symbol
C21	2.2uF	C-USC0805	C0805	CAPACITOR, American symbol
C22	2.2uF	C-USC0805	C0805	CAPACITOR, American symbol
C24	0.47uF	C-USC0805	C0805	CAPACITOR, American symbol
C27	0.47uF	C-USC0805	C0805	CAPACITOR, American symbol
C28	2.2uF	C-USC0805	C0805	CAPACITOR, American symbol
C30	2.2uF	C-USC0805	C0805	CAPACITOR, American symbol

C32	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C34	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C35	0.33uF	C-USC0805	C0805	CAPACITOR, American symbol
C36	0.33uF	C-USC0805	C0805	CAPACITOR, American symbol
C37	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C38	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C39	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C40	0.33uF	C-USC0805	C0805	CAPACITOR, American symbol
C41	0.33uF	C-USC0805	C0805	CAPACITOR, American symbol
C42	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C43	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C44	1uF	C-USC0805	C0805	CAPACITOR, American symbol
C45	1uF	C-USC0805	C0805	CAPACITOR, American symbol
C46	22uF	C-USC0805	C0805	CAPACITOR, American symbol
C47	1uF	C-USC0805	C0805	CAPACITOR, American symbol
C48	1uF	C-USC0805	C0805	CAPACITOR, American symbol
C49	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C50	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C51	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C52	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C53	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C54	1.5n	C-USC0805	C0805	CAPACITOR, American

				symbol
C55	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C56	1.5n	C-USC0805	C0805	CAPACITOR, American symbol
C57	22uF	C-USC0805	C0805	CAPACITOR, American symbol
C58	100uF	C-USC0805	C0805	CAPACITOR, American symbol
C59	10pF	C-USC0805	C0805	CAPACITOR, American symbol
C60	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C61	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C62	100pF	C-USC0805	C0805	CAPACITOR, American symbol
C63	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C64	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C65	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C66	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C67	0.1uF	C-USC0805	C0805	CAPACITOR, American symbol
C68	10uF	C-USC0805	C0805	CAPACITOR, American symbol
C69	100n	C-USC0805	C0805	CAPACITOR, American symbol
C70	100n	C-USC0805	C0805	CAPACITOR, American symbol
C71	10n	C-USC0805	C0805	CAPACITOR, American symbol
C72	10n	C-USC0805	C0805	CAPACITOR, American symbol
C73	10n	C-USC0805	C0805	CAPACITOR, American symbol
C74	10n	C-USC0805	C0805	CAPACITOR, American symbol
C75	100n	C-USC0805	C0805	CAPACITOR, American symbol

C76	100n	C-USC0805	C0805	CAPACITOR, American symbol
IC1	7815TV	7815TV	TO220V	Positive VOLTAGE REGULATOR
IC2	7915TV	7915V	TO220V	Negative VOLTAGE REGULATOR
IC3	7805TV	7805TV	TO220V	Positive VOLTAGE REGULATOR
IC4	7905TV	7905V	TO220V	Negative VOLTAGE REGULATOR
JP1		PINHD-1X2	1X02	PIN HEADER
JP2		PINHD-1X2	1X02	PIN HEADER
JP3		PINHD-1X2	1X02	PIN HEADER
JP4		PINHD-1X2	1X02	PIN HEADER
JP5		PINHD-2X16	2X16	PIN HEADER
L1	BLM15HB121SN1	BLM15HB121SN1	402	EMIFIL (R) Chip Ferrite Bead for GHz Noise
R1	NC	R-US_R0805	R0805	RESISTOR, American symbol
R2	NC	R-US_R0805	R0805	RESISTOR, American symbol
R3	750	R-US_R0805	R0805	RESISTOR, American symbol
R4	750	R-US_R0805	R0805	RESISTOR, American symbol
R5	10k	R-US_R0805	R0805	RESISTOR, American symbol
R6	750	R-US_R0805	R0805	RESISTOR, American symbol
R7	10k	R-US_R0805	R0805	RESISTOR, American symbol
R8	750	R-US_R0805	R0805	RESISTOR, American symbol
R9	750	R-US_R0805	R0805	RESISTOR, American symbol
R10	750	R-US_R0805	R0805	RESISTOR, American symbol
R11	10k	R-US_R0805	R0805	RESISTOR, American symbol
R12	10k	R-US_R0805	R0805	RESISTOR, American symbol
R13	49.9	R-US_R0805	R0805	RESISTOR, American symbol
R14	49.9	R-US_R0805	R0805	RESISTOR, American symbol
R15	35.7k	R-US_R0805	R0805	RESISTOR, American symbol
R16	35.7k	R-US_R0805	R0805	RESISTOR, American symbol
R17	240k	R-US_R0805	R0805	RESISTOR, American symbol
R18	240k	R-US_R0805	R0805	RESISTOR, American symbol
R19	110k	R-US_R0805	R0805	RESISTOR, American symbol
R20	90.9k	R-US_R0805	R0805	RESISTOR, American symbol
R21	110k	R-US_R0805	R0805	RESISTOR, American symbol
R22	90.9k	R-US_R0805	R0805	RESISTOR, American symbol
R23	1k	R-US_R0805	R0805	RESISTOR, American symbol

R24	1k	R-US_R0805	R0805	RESISTOR, American symbol
R25	9.09k	R-US_R0805	R0805	RESISTOR, American symbol
R26	9.09k	R-US_R0805	R0805	RESISTOR, American symbol
R27	100	R-US_R0805	R0805	RESISTOR, American symbol
R28	100k	R-US_R0805	R0805	RESISTOR, American symbol
R29	100	R-US_R0805	R0805	RESISTOR, American symbol
R30	5.11k	R-US_R0805	R0805	RESISTOR, American symbol
R31	5.11k	R-US_R0805	R0805	RESISTOR, American symbol
R32	20k	R-US_R0805	R0805	RESISTOR, American symbol
R33	1.82k	R-US_R0805	R0805	RESISTOR, American symbol
R34	20k	R-US_R0805	R0805	RESISTOR, American symbol
R35	1.82k	R-US_R0805	R0805	RESISTOR, American symbol
R36	56.2k	R-US_R0805	R0805	RESISTOR, American symbol
R37	56.2k	R-US_R0805	R0805	RESISTOR, American symbol
R38	1k	R-US_R0805	R0805	RESISTOR, American symbol
R39	1k	R-US_R0805	R0805	RESISTOR, American symbol
R40	100k	R-US_R0805	R0805	RESISTOR, American symbol
R41	100k	R-US_R0805	R0805	RESISTOR, American symbol
TP1	TPTP11R	TPTP11R	TP11R	Test pad
TP2	TPTP11R	TPTP11R	TP11R	Test pad
TP3	TPTP11R	TPTP11R	TP11R	Test pad
TP4	TPTP11R	TPTP11R	TP11R	Test pad
TP5	TPTP11R	TPTP11R	TP11R	Test pad
TP6	TPTP11R	TPTP11R	TP11R	Test pad
TP7	TPTP11R	TPTP11R	TP11R	Test pad
TP8	TPTP11R	TPTP11R	TP11R	Test pad
TP9	TPTP11R	TPTP11R	TP11R	Test pad
TP10	TPTP11R	TPTP11R	TP11R	Test pad
TP11	TPTP11R	TPTP11R	TP11R	Test pad
TP12	TPTP11R	TPTP11R	TP11R	Test pad
TP13	TPTP11R	TPTP11R	TP11R	Test pad
TP14	TPTP11R	TPTP11R	TP11R	Test pad
U1	INA166_D_14	INA166_D_14	D14	
U2	INA166_D_14	INA166_D_14	D14	
U3	LME49990_D_8	LME49990_D_8	M08A	
U4	LME49990_D_8	LME49990_D_8	M08A	
U5	LME49990_D_8	LME49990_D_8	M08A	
U6	LME49990_D_8	LME49990_D_8	M08A	
U7	INA128_D_8	INA128_D_8	D8	

U8	INA128_D_8	INA128_D_8	D8	
U9	REF5025_D_8	REF5025_D_8	D8	
U10	LP3990_DBV_5	LP3990_DBV_5	MF05A	
U11	AD8657ARMZ	AD8657ARMZ	RM_8	
U12	AD8657ARMZ	AD8657ARMZ	RM_8	
U13	AD8657ARMZ	AD8657ARMZ	RM_8	
U14	AD8657ARMZ	AD8657ARMZ	RM_8	
U15	OPA211_D_8	OPA211_D_8	D8	
U16	ADS1198_PAG_64	ADS1198_PAG_64	PAG64	
U17	AD8657ARMZ	AD8657ARMZ	RM_8	
U18	AD8657ARMZ	AD8657ARMZ	RM_8	
U19	AD8657ARMZ	AD8657ARMZ	RM_8	
U20	AD8657ARMZ	AD8657ARMZ	RM_8	
X1	SHERLOCK-3PRIGHT-ANGLE	SHERLOCK-3PRIGHT-ANGLE	35363-036*	3-pin Molex SherlockTM connector system
X2	SHERLOCK-3PRIGHT-ANGLE	SHERLOCK-3PRIGHT-ANGLE	35363-036*	3-pin Molex SherlockTM connector system

Appendix C. Senior Project Analysis

Project Title: Large Dynamic Range Amplifier plus ADC
Student's Name: Ted Hsueh Student **Signature:**
Advisor's Name: Tina Smilkstein **Advisor's Initials:** **Date:**

Summary of Functional Requirements

The Large Dynamic Range Amplifier plus ADC (LDRAA) allows for sampling of nerve and muscle signals simultaneously. The device combines with a transcutaneous electrical nerve stimulation (TENS) device. This allows the TENS device to pick up nerve and muscle signals to identify a tremor attack and provide the appropriate response. The LDRAA filters environmental noise, separates the nerve and muscle signals, amplifies them, and then converts them to a digital signal. The TENS device microcontroller controls the LDRAA.

Primary Constraints

Separation of nerve and muscle signals at potentially the same frequency. Noise floor less than the nerve signal. The nerve signal exists in the 10's of nanovolts and therefore the signal to system noise ratio (SNR) must stay large. An input range of one million units, tens of nanovolts to tens of millivolts required. A battery powers the system and lasts at least a month. 14 bits required for data resolution.

Economics

- **Human Capital**

  This device creates a helpful situation for those suffering from tremors. People suffering from tremors can more easily hold and control cups or utensils. With this device, someone may get a tremor and the LDRAA alerts the TENS device which stimulates the user. The stimulation acts opposite of the tremor to reduce the strength of the tremor.
- **Financial Capital**

  This device process requires necessary monetary funds to pay trained workers to operate machinery to fabricate boards and assemble and install components. Initial cost resides high due to training, mask fabrication, and equipment. The regular production costs remain low. Prototyping and testing the design require research and development funds.
- **Manufactured or Real Capital**

  Production costs lie low because the manufacturing process stands well defined and known. The labor costs minimizes when the fabrication becomes automated. The product requires numerous components including but not limited to ICs, resistors, capacitors, inductors, PCB's, and solder. The components found easily in the market and not custom designed for this product.
- **Natural Capital**

  This product uses the Earth's resources in its components. Earth's metals such as silicon, tin, silver, copper. Also the land the manufacturing building lies on.
- **When and where do costs and benefits accrue throughout the project's lifecycle?**

  The biggest cost lies in the design and initial equipment and training needed for production of the product. Steady low cost of materials, manufacturing and shipping drive the normal production cycle. The benefits accrue on sales of the product and the use of the product in

people’s daily lives. The product use allows people with tremors to manage and recover from incidents, thus productivity increases in everyday economies.

- **What inputs does the experiment require? How much does the project cost? Who pays?**

The device takes signals from two or more electrodes connected to a person’s arm or leg. The device also takes controls and clock from the TENS device. Finally a battery provides power to the device.

The estimated cost of the project:

Table VI: Large Dynamic Range Amplifier Cost Estimate

Material		Total Cost (USD)	Comments
Battery		$17.33	A Battery costs about $2 each. Switch between DC Supplies and batteries, for testing.
Breadboard		$45.00	Three bread boards at around $5.00 each.
Printed Circuit Board		$121.67	Getting a PCB fabricated for my design.
Discrete Passive Components	Resistors	$15.00	Cost includes resistors, capacitors, inductors, wires. Sets generally cost ~$15.00, plus shipping.
	Capacitors	$15.83	
	Wires	$15.00	
Active Components	ADC	$36.67	The ADC and Op Amps range up to $15 each. However, these Op Amps spec high end and most likely overqualified for my project. I expect to find what I need for about half that. The voltage regulators cost closer to $1 each and isolators cost about $4. I likely need more than one of each device; I assume 5 of each type for testing purposes.
	Op Amps	$36.67	
	Voltage Regulators	$6.25	
	Digital Isolators	$22.50	
Labor		$22,720.00	The total time for this project: 284 days. I expect to average around 2 hours a day and I would think my time equates to worth ~$40/hours.
Total		$23,051.92	Summation of all costs

The design and prototype of the project acquires funding by me, the designer. Additional equipment used in development includes oscilloscopes, multimeters, function generators, dc power supplies, and assorted accessories used with the equipment provided by the CAL Poly EE department.

- **How much does the project earn? Who profits?**

The project aimed to make no monetary profit standalone. This means that I do not plan to sell the product on the market, but rather allow the TENS device designers to use the product in their product. The TENS device designers and users profit from this project. The designers gain monetary value from selling the TENS device to customers. The customers gain a device to significantly improve their quality of life.

- **Timing**

Product emerges after the final testing phase completes, expected in spring 2015. The product holds a lifecycle of 10 years, with battery replacement as needed. Figure 35 shows the initial estimated development time of this project.

ID	Task	Start	Finish	Duration
1	Proposal	9/1/2014	9/22/2014	16d
2	Requirements and Specifications	9/24/2014	11/17/2014	39d
3	Research	9/22/2014	1/1/2015	74d
4	Block Diagram	10/8/2014	10/13/2014	4d
5	Gantt Chart	10/22/2014	10/27/2014	4d
6	Cost Estimates	10/22/2014	10/27/2014	4d
7	Project Plan Report	9/22/2014	12/5/2014	55d
8	Design I	12/1/2014	1/7/2015	28d
9	Build I	1/1/2015	1/14/2015	10d
10	Test I	1/7/2015	1/21/2015	11d
11	Design II	1/19/2015	1/30/2015	10d
12	Build II	1/28/2015	2/6/2015	8d
13	Test II	2/5/2015	2/12/2015	6d
14	Interim Report	2/16/2015	3/13/2015	20d
15	Design III	3/9/2015	3/30/2015	16d
16	Build III	3/30/2015	4/7/2015	7d
17	Test III	4/6/2015	4/14/2015	7d
18	Design IV	4/13/2015	4/21/2015	7d
19	Build IV	4/15/2015	5/7/2015	17d
20	Test IV	5/7/2015	5/25/2015	13d
21	Senior Project Report	3/30/2015	6/5/2015	50d

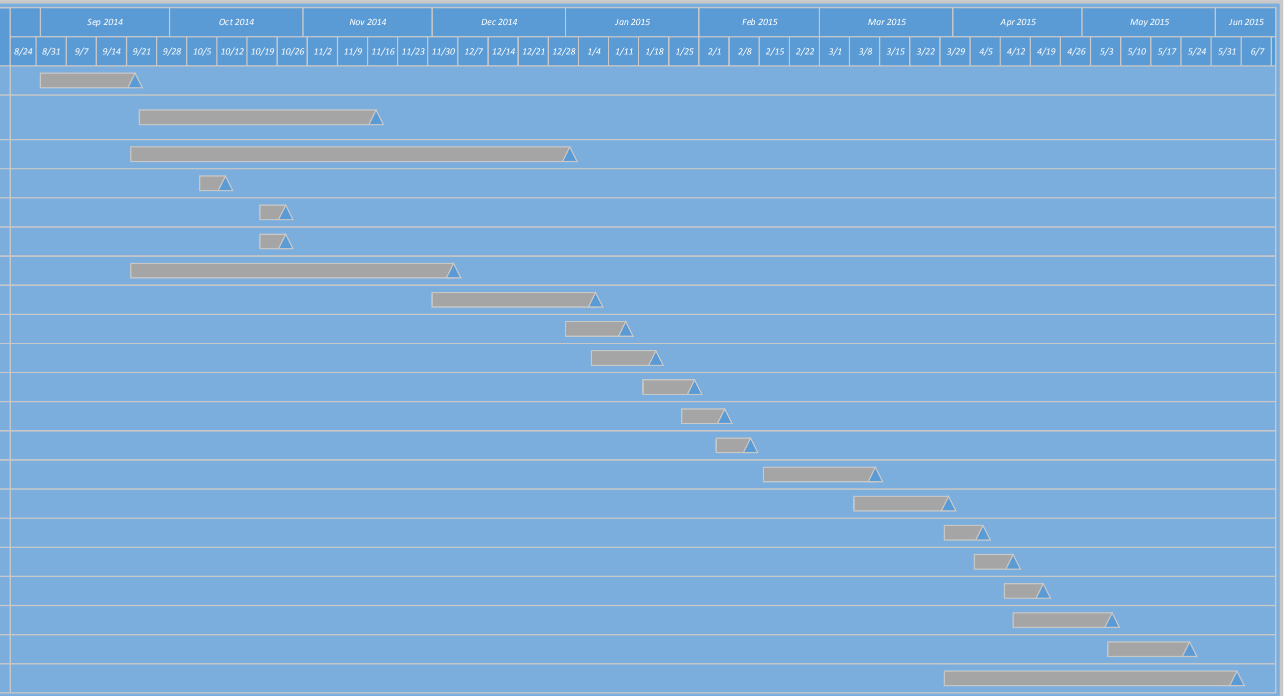

Figure 35: Initial Estimated Development Time.

Manufacturing

If this product becomes manufactured on a commercial basis, one of these should go to every person suffering from tremor causing diseases such as multiple sclerosis within five years. This means getting the product cost low enough for consumers to purchase or making it eligible for insurance programs. MS affects an estimate of 2.3 million people worldwide [16]. Therefore, we hope to sell an average of 460,000 units per year (2.3 million/5yrs). The manufacturing costs for this device estimated from the cost estimates in Table A. The LDRAA aims to cost around $300.00 per board assembled. Manufacturing occurs with the TENS system and LDRAA together, not individually. The TENS system doesn't have a price, but a TENS unit costs upwards of $90.00. A TENS system with tremor reduction functions would cost upwards of $500-$1000. The profit if sold at $1000 sits at approximately $500 a unit. A year's profit would yield $500 x 460,000 = $230,000,000. With a lifetime of 10 years, the system would cost merely $100 a year at highest cost.

Environmental

This project produces negative environmental impacts during its production. Negative impacts include the generation of carbon monoxide, carbon dioxide and other pollutants generated during manufacturing of the product and the product components. Some components drain the earth's natural resources from harvesting materials like copper, aluminum, and tin. Harvesting these materials requires energy to mine and drill that disturb the surrounding ecosystems. Harvesting also produces harmful toxic byproducts. As with all electronic components, disposal negatively affects the dumpsite environment. Components selected comply with RoHS compliance to ensure minimal affects with use and disposal.

Manufacturability

Automated machines manufacture the production level of this device. The drawback of RoHS compliance means lead free solder. This means the potential for not making good connections or burning pads increases. All parts hand soldered for the research and development level of this product. Building becomes less efficient and more open to mistakes.

Sustainability

The LDRAA should operate for ten years. The only intended sustainability issue requires regular battery replacement. Therefore, no further natural resources beyond the battery required for ten years. Unintentional sustainability issues includes a unit attaches to an individual's arm or leg, and therefore may receive physical shocks, possibilities of components becoming loose and need replacement. In the event of this occurring, purchasing the LDRAA individually proves possible and the user can replace the unit themselves. Further improvements to the LDRAA minimize power consumption and decrease the PCB footprint. Reducing power consumption lies in improving on the quiescent power draw of the amplifier. Options of reducing PCB footprint exist, such as increasing layers of the PCB, reducing components, reducing component size, and altering layout.

Ethical

The design follows the golden rule; *treat others as you would like them to treat you*. This product caters to trying to reduce the symptoms and allow users to experience more of the world. If someone could make my life less frustrating and more bearable, it would mean the world. This product tries to give people who suffer from multiple sclerosis control of their body.

This product follows the IEEE Code of Ethics, most specifically 1, 3, 5, and 7. This product aims to improve the safety and welfare of the public. Those with tremors potentially endanger themselves and the people around them. With more control of these tremors, public safety increases. The LDRAA with the TENS system reduce the impact of tremors, not negate them entirely. The LDRAA exists to improve upon the TENS system and allow it to sense and control tremors more effectively. The use of such a medical device must pass regulations of the FDA.

Health and Safety

The TENS system, the possibility of sending an incorrect signal to control the tremor exists. Also manufacturing health and safety concerns exist in production. This includes machinery breaking down and

operating machinery incorrectly. Prototyping health and safety concerns involve hand soldering, most likely with non-RoHS compliant solder. This mean potential burns or inhalation of lead.

Social and Political

This project generates positive public social interest in assisting those with an incurable disease. The success of this project directly affects the TENS system designers and the customers of the TENS system. Without the product, the TENS system efficiency reduction affects the customers with a lesser performing product. Others affected include manufacturers of components and PCB's. Also shipping companies as well as marketing websites or ads used to sell the product. This product benefits the customers with a greater performing TENS system and generates revenue for the TENS system. The stakeholders benefit, but not quantifiably. The customers gain a large amount of happiness reducing their tremors. The TENS system designers receive a large profit. The only concern for the customers resides in whether or not the device lies in insurance programs.

Development

The Monte-Carlo technique determines if a system passes spec at worst conditions. Pipeline ADCs researched as a method of sampling data. Investigating a method of controlling a variable gain amplifier via a DAC took place. This project provided the opportunity to learn about PCB layout and design consideration.