Brain Signal Operated
Technologies
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November 21, 2006

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: *ENSC 440 Design Specification for Brain Signal Controlled Devices*

Dear Dr. Rawicz:

The attached document, *Design Specification for Brain Signal Controlled Devices*, lists the design specifications for our proposed brain signal controlled devices. We are in the process of designing a computer game playable using brain wave signals.

This document describes the design and testing that Brain Signal Controlled Devices will fulfill. We have detailed the hardware, software, and overall system designs necessary to complete the project. We have also proposed a testing plan to validate our devices.

Brain Signal Operated Technologies is currently comprised of three enthusiastic engineering science students: Heng Wei Lan, Aron McKinnon, and Victor Yu. If you have any questions or concerns about our design specification, please contact us at ensc440-bso@sfu.ca.

Sincerely,

Victor Yu

Victor Yu
Chief Financial Officer
BSO Technologies

Enclosure: *Design Specification for Brain Signal Controlled Devices*

Design Specification for

Brain Signal Controlled Devices

BRAIN SIGNAL OPERATED TECHNOLOGIES

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Submitted to: Dr. Andrew Rawicz – ENSC 440
Steve Whitmore – ENSC 305
School of Engineering Science
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Issued Date: November 21, 2006

Executive Summary

Many brain controlled products in the market are not very user-friendly. Consumers often have to spend a vast amount of time and effort before becoming familiar and comfortable using the devices. To solve this problem, Brain Signal Operated Technologies (BSO Technologies) will develop a training system that will make learning to use a Brain Computer Interface (BCI) easy and entertaining.

Our training system will allow users to use their biofeedback indicators in their brains to play the PONG game. The game not only encourages interactions between the two players (trainees), but also provides researchers with the progress of the training subjects. Our training device will be easy to set-up, requiring just the placement of an electrode cap on the trainee's head.

The remainder of this document details the design of the PONG Training System. We plan to complete our prototyping of the game by the end of 2006. Other additional features will be implemented in future developments. If time permits, we will start the production of a brain signal controllable toy.

Table of Contents

List of Figures

Glossary

A/D	Analog to Digital
BCI	Brain Computer Interface
BSO	Brain Signal Operated
DAQ	Data Acquisition
EEG	Electroencephalography
FFT	Fast Fourier Transform
IC	Integrated Circuit
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
PCB	Printed Circuit Board
PCI	Peripheral Component Interconnect

1. Introduction

The PONG Training System is specifically designed to be used on subjects with limited or no previous experience with BCIs. The system uses custom built electrodes to effectively pick up weak electrical signals from a scalp surface. The training system then transmits an amplified, filtered, and analyzed version of these signals onto a computer and presents the brain signals in the form of a video game.

The product will be developed in a series of stages, which begins with a proof of concept device deliverable by the end of 2006. We will implement the complete set of functionality in later stages.

1.1 Scope

This document establishes the design specifications of our PONG Training System. The document explains how the system will be designed to meet all the functional requirements as described in our Functional Specification. Block diagrams, schematics, test plans, and other design details necessary to build the system are all included in Design Specification.

1.2 Intended Audience

The design engineers of BSO Technologies will use this document as a guideline in building the PONG Training System. The project manager will use the document to ensure that the system possesses the proposed functionalities.

2. System Overview

Figure 2-1 shows the overview of our PONG Training System.

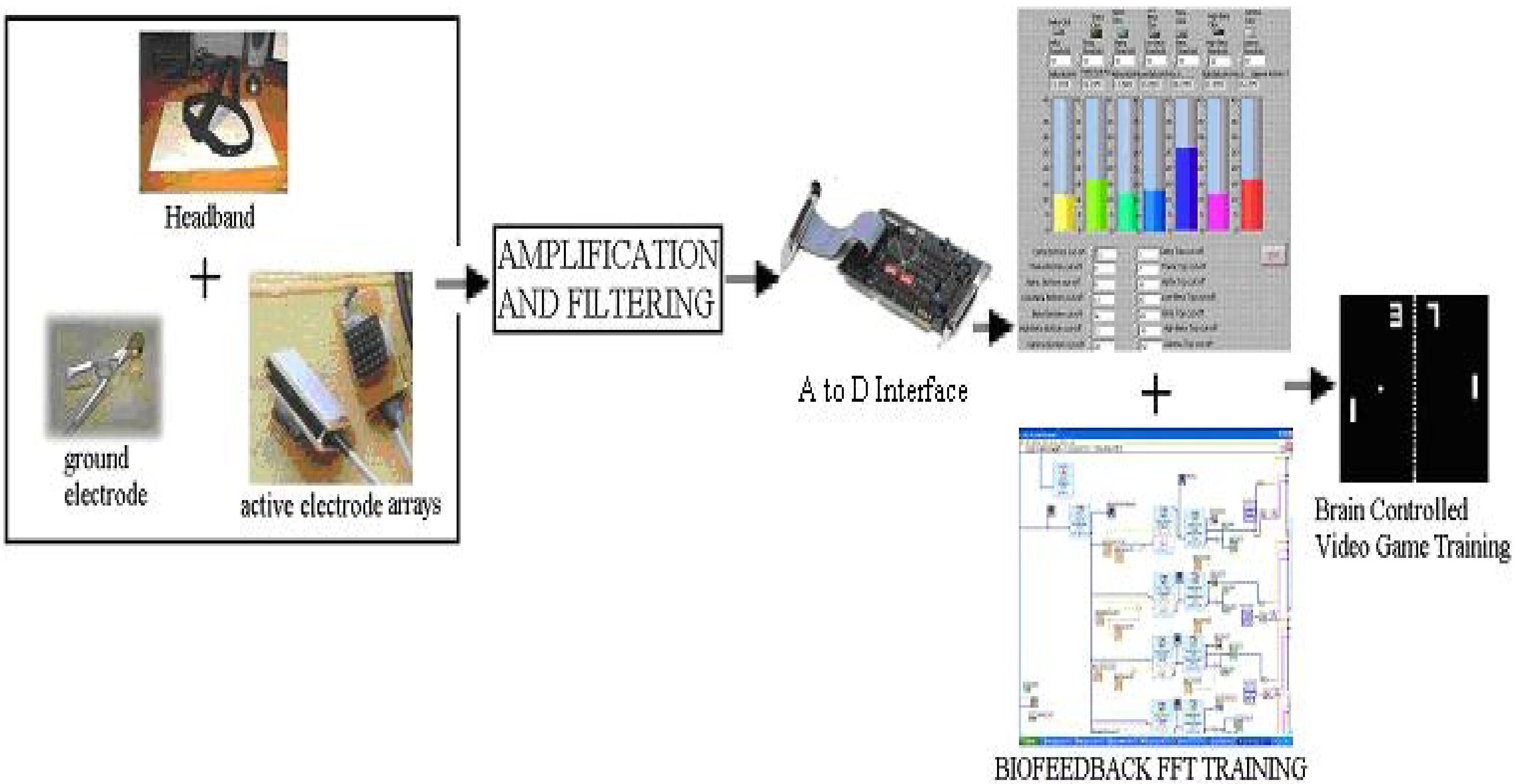


Figure 2-1: PONG Training System Overview

To record the brain wave signals, two active electrodes will be placed on the surface of the subject's scalp. The electrodes will collect the electrical signal polarization in the motor cortex section of the brain. The active electrodes will be held in place with a custom headband and grounded to the subject's ear using a ground electrode. The retrieved signals will undergo pre-amplification and noise reduction before being further amplified and filtered.

The amplification stage will strengthen the brain signals to a level suitable for analog to digital (A/D) conversion. The analog signal strengths are adjustable at this stage. This module is also responsible for noise filtering.

The next subsystem will convert the analog signals into digital formats that are interpretable by the computer. The digital analysis will be performed using a commercial software called Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW). This application will analyze the digital signals using a Fast Fourier Transform (FFT).

We will incorporate a frequency bin biofeedback module that allows the subject to calibrate his/her settings and choose appropriate frequency ranges and signal intensities that he or she feels comfortable in using to play the classic PONG game. Finally, the subject will be able to play PONG against another player by controlling the movements of the paddles via brain signals.

3. Active Electrodes

This section outlines the design specifications of active electrodes and their associated circuitry. This subsystem reads the EEG (Electroencephalography) signals from human brains and performs pre-amplification and pre-filtering before sending the brain signals to the amplification stage. All hardware components, which include the two active electrodes and external electronic circuitry, are mounted on a headband.

3.1 Electrodes

The active electrodes will be built by using gold pin array connectors. An example of one is seen in Figure 3-1.

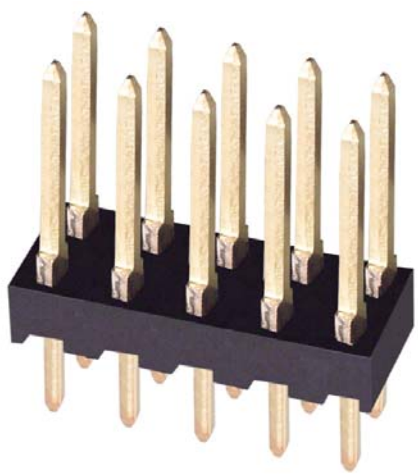


Figure 3-1: Pin Array Electrode

Despite involving a greater amount of efforts when building them, active electrodes provide better results than passive electrodes. Moreover, active electrodes eliminate the needs of skin preparation and conductive gel.

Each player requires two active electrodes detecting two different signals from the brain. These two signals will be used as inputs to the instrumentation amplifier, as discussed in the next section. One additional ground reference electrode will be connected to one of the player's ears.

3.2 Pre-Amplification

For pre-amplification, we have selected the AD625 Integrated Circuit (IC) to help us strengthen the brain signals. AD625 is an instrumentation amplifier that gives us a low input voltage noise (4 nV/√Hz at 1 kHz), a high input impedance (1 GΩ), and a high Common-Mode Rejection Ratio (15 dB at 60 Hz) [1]. Such properties would fulfill Requirements 26, 27, and 28 stated in our Functional Specification.

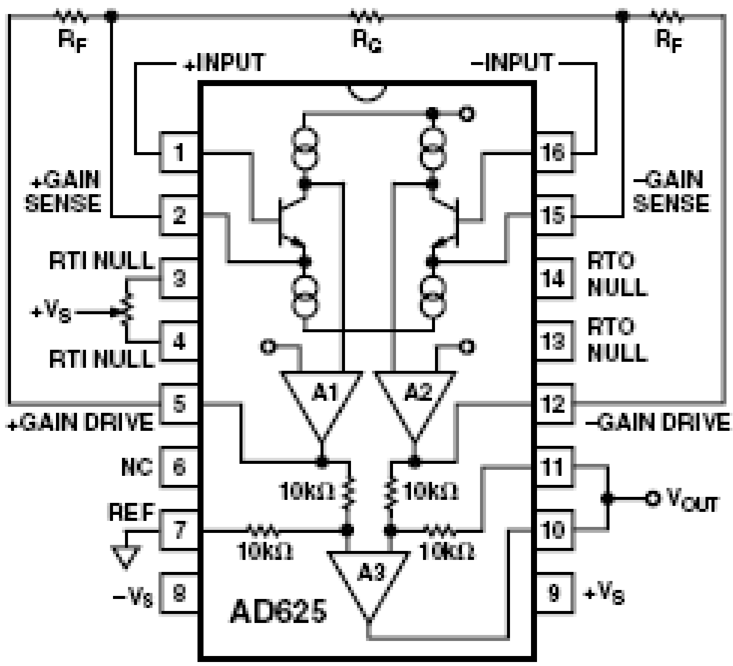


Figure 3-2: AD625 in Fixed Gain Configuration

Figure 3-2 suggests a possible approach to set-up the instrumentation amplifier. The power of the chip will be supplied from the amplifier stage. The gain of the amplifier is defined by the equation

$$G = \frac{2R_F}{R_G} + 1.$$

Hence, to achieve a gain, G, of 100, we select R_F to be 20 kΩ and R_G to be approximately 404 Ω.

The resulting schematic combining the electrodes and the pre-amplification is shown in Figure 3-3.

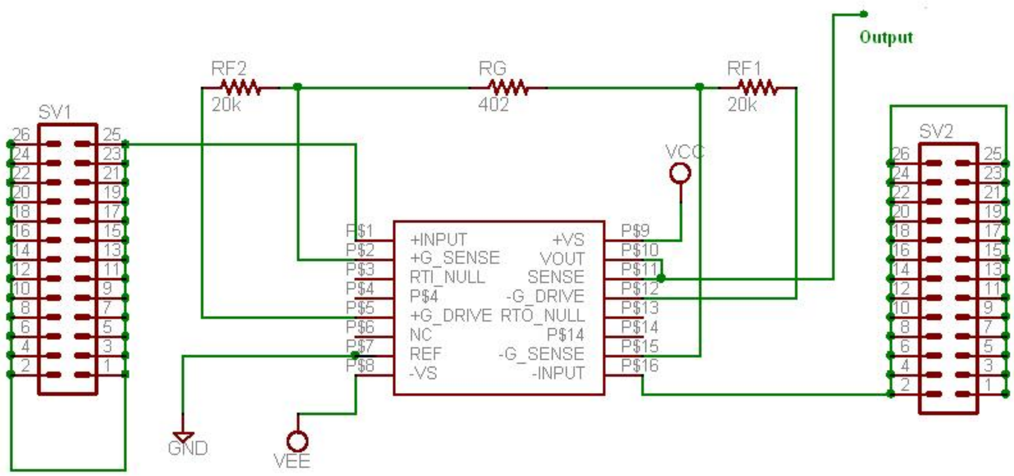


Figure 3-3: Electrode Stage Schematic

The Printed Circuit Board (PCB) design of this stage is included in the appendix for convenience.

3.3 Pre-Filtering

The EEG activity that we are mostly concerned with is the beta waves, which are brain signals associated with thinking and concentrating. Beta waves have a frequency range from 12 to 38 Hz [2]. The primary interference we may encounter is the 60 Hz hum caused by power lines. As a result, we will need a notch filter with a center frequency at 60 Hz.

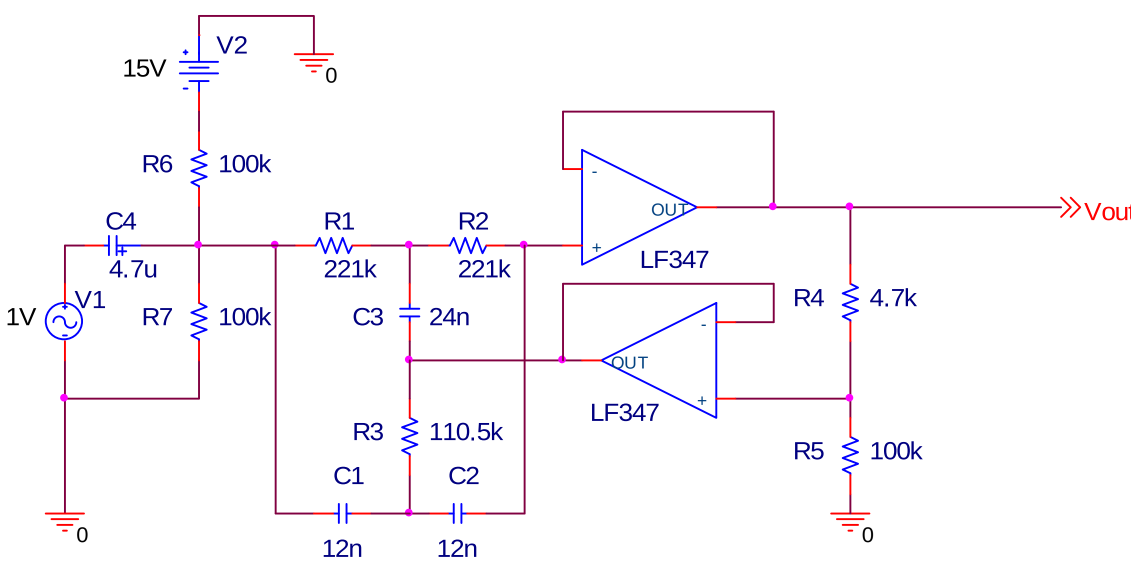


Figure 3-4: Notch Filter

A notch filter adapted from Texas Instruments is illustrated in Figure 3-4 [3]. The circuit is based on the Twin T notch filter configuration, which has the following properties:

- $f_o = \dfrac{1}{2\pi R_1 C_1}$
- $R_1 = R_2 = 2R_3$
- $C_1 = C_2 = \dfrac{C_3}{2}$

We want our center frequency, f_o, to be at 60 Hz. Following that, we can easily choose our R and C values. The frequency response has been plotted in Figure 3-5. Since this is a second-order filter, the notch may be a little bigger than what we had wished. Nevertheless, the magnitude response starts to roll off after 50 Hz, which is outside the expected frequency range of beta waves.

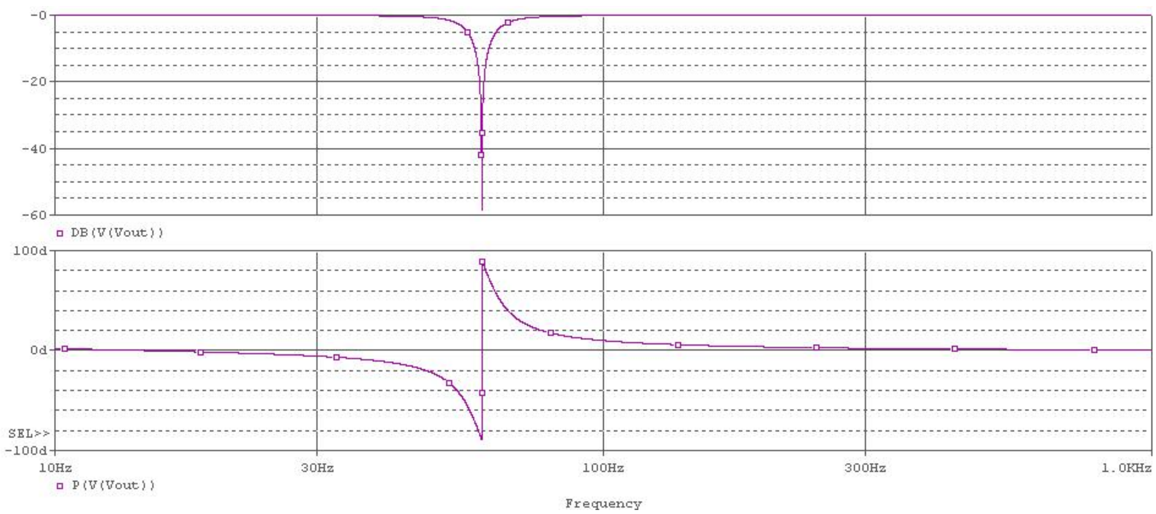


Figure 3-5: Frequency Response of Notch Filter

3.4 Headband

We will supply an electrode cap for each player to place on the head. The purpose of the cap is for electrode attachment and placement. Ideally, the cap should be easily adjustable and of light weight to avoid causing any discomfort on the person who wears it. A straight forward design is to use athletic headbands, which are cheap and easy to acquire.

The most widely used standard for electrode placement is the 10-20 system [4]. Our active electrodes will be attached on the headbands in a way that they land on standard locations for EEG readings when placed on the person's head. Figure 3-6 displays possible electrode placements using the 10-20 System.

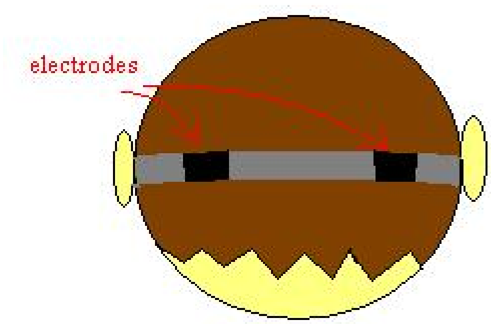


Figure 3-6: 10-20 System for Electrode Placement

Shielded cable will be provided to encapsulate the output wires from this stage before connecting them to the next stage.

4. Amplification and Filtering

This section outlines the design specifications of the amplification and filtering stage. The input of this stage comes from active electrodes via shielded cables. The output of this stage sends the amplified signal to a Data Acquisition card.

This stage contains a 1 kHz low-pass filter, a fixed inverting gain amplifier with a gain of 100, and a variable inverting gain amplifier with a gain of 10-100. Since the two gain circuits are inverting, the amplified signal stays non-inverting. All units of the amplification stage stay inside a metal box to reject outside noise.

4.1 Signal Filtering

To pass low frequency signals from brain activities and attenuate high frequency noises, we attach a simple low-pass RC filter before the amplification. As stated in Function Specification, we want to remove all noise above 1 kHz. Therefore, we can use it as our desired filter cut-off frequency, given by

$$f_C = \frac{1}{2\pi RC}.$$

Thus, we choose R and C to be 1.6 kΩ and 100 nF, respectively. The RC filter is constructed as seen in Figure 4-1.

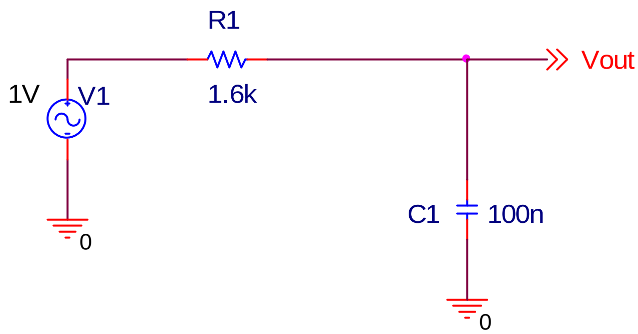


Figure 4-1: Low-Pass RC Filter

The frequency response of this circuit is plotted in Figure 4-2. The top plot shows the magnitude decaying at a rate of 20 dB/decade starting at the cut-off frequency of 1 kHz. The bottom plots shows the -90° phase shift due to the first-order filter.

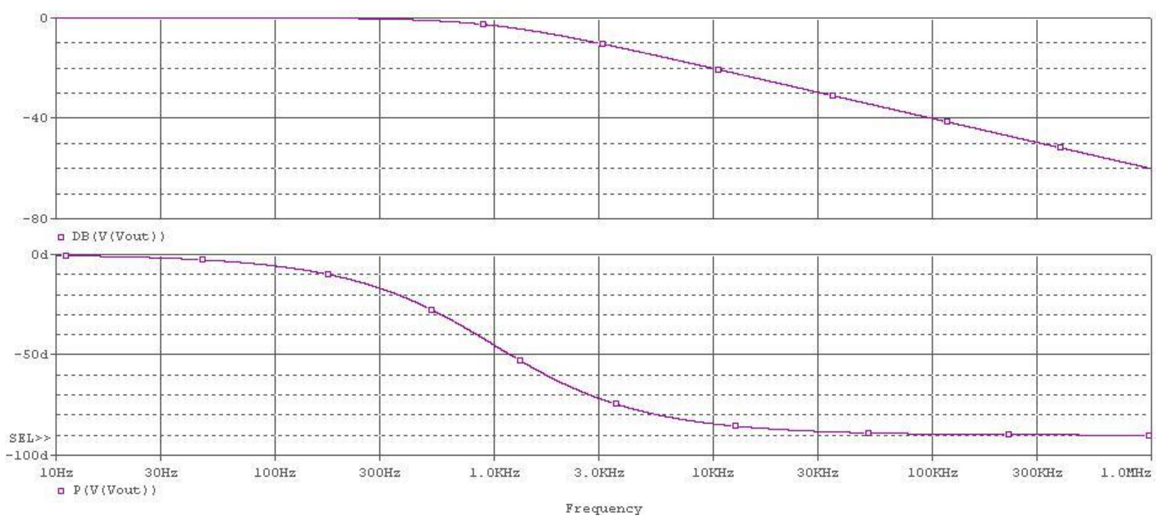


Figure 4-2: Frequency Response of Low-Pass Filter

4.2 Signal Amplification

The amplification stage will contain a fixed gain circuit followed by a variable gain circuit. We will build our amplifiers by connecting operation amplifiers (LF347) in the inverting configuration, as shown in Figure 4-3.

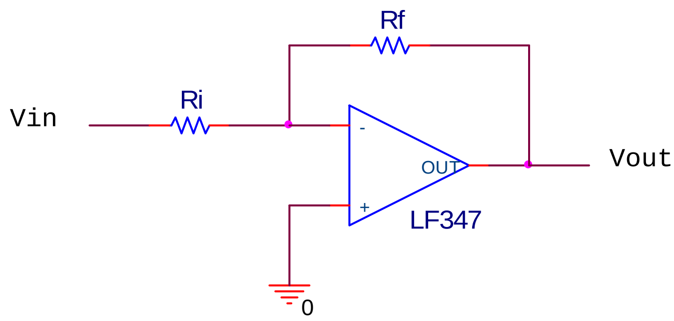


Figure 4-3: Inverting Amplifier

The gain of this amplifier is given by

$$\frac{Vout}{Vin} = -\frac{Rf}{Ri}.$$

The fixed gain circuit will receive signals from the RC filter. To achieve a fixed gain of 100, we can choose *Rf* to be 10 kΩ and *Ri* to be 100 Ω. The strengthened signal will then enter the variable gain circuit. To achieve a variable gain from 10 to 100, we can choose *Rf* to vary from 1 kΩ to 10 kΩ and *Ri* to be 100 Ω. The amplified signal will be sent to the next stage, which is analog to digital conversion.

Figure 4-4 shows the schematic of this stage.

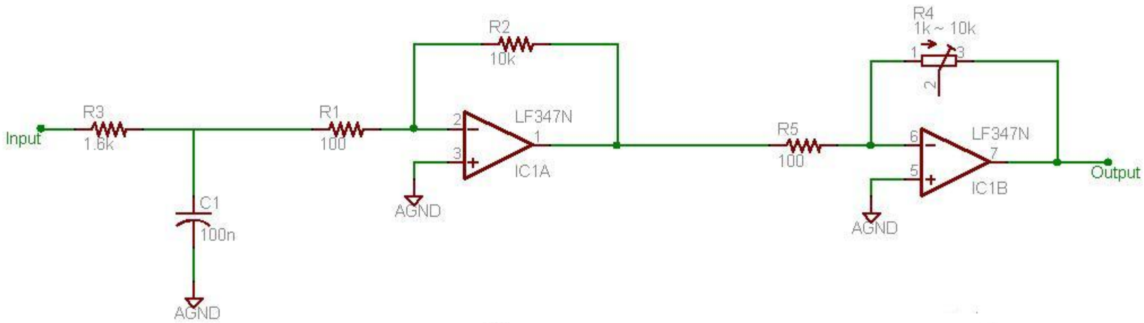


Figure 4-4: Amplification and Filter Stage

The PCB layout is attached in the appendix for reference.

4.3 Power

We will use 12V batteries as our power supply. The batteries will connect to the power pins of the LF347 chip.

5. Analog to Digital Conversion

This section outlines the design specifications of the analog to digital converting module. This phase provides communications between external hardware and the computer software. Like the previous stage, the components of this stage will stay inside a metal box.

5.1 Data Acquisition Card

The amplification and filtering stage will send the brain signals to a Data Acquisition (DAQ) card. We will be using the 6024E DAQ card provided by National Instruments [5]. Figure 5-1 shows the 68 pin assignments of our DAQ card.

ACH8	34	68	ACH0
ACH1	33	67	AIGND
AIGND	32	66	ACH9
ACH10	31	65	ACH2
ACH3	30	64	AIGND
AIGND	29	63	ACH11
ACH4	28	62	AISENSE
AIGND	27	61	ACH12
ACH13	26	60	ACH5
ACH6	25	59	AIGND
AIGND	24	58	ACH14
ACH15	23	57	ACH7
DAC0OUT[1]	22	56	AIGND
DAC1OUT[1]	21	55	AOGND
RESERVED	20	54	AOGND
DIO4	19	53	DGND
DGND	18	52	DIO0
DIO1	17	51	DIO5
DIO6	16	50	DGND
DGND	15	49	DIO2
+5 V	14	48	DIO7
DGND	13	47	DIO3
DGND	12	46	SCANCLK
PFI0/TRIG1	11	45	EXTSTROBE*
PFI1/TRIG2	10	44	DGND
DGND	9	43	PFI2/CONVERT*
+5 V	8	42	PFI3/GPCTR1_SOURCE
DGND	7	41	PFI4/GPCTR1_GATE
PFI5/UPDATE*	6	40	GPCTR1_OUT
PFI6/WFTRIG	5	39	DGND
DGND	4	38	PFI7/STARTSCAN
PFI9/GPCTR0_GATE	3	37	PFI8/GPCTR0_SOURCE
GPCTR0_OUT	2	36	DGND
FREQ_OUT	1	35	DGND

Figure 5-1: Pin Assignments for 6024E

The DAQ card is PCI (Peripheral Component Interconnect) bus compatible. Hence, we can use it to send our signals from the amplification stage to a computer for further processing. DAQ will undergo appropriate conversions to transform our signals into a form that the computer can understand.

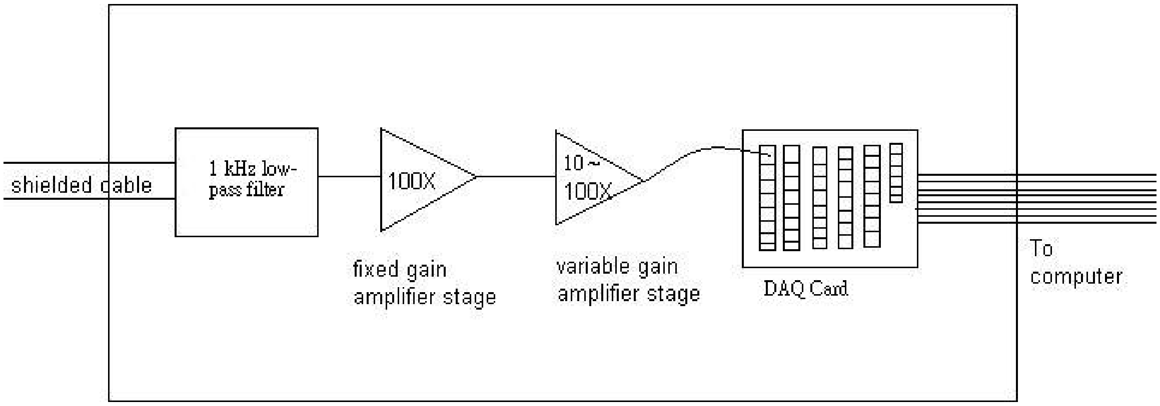


Figure 5-2: Metal Box Design

Figure 5-2 shows the components inside the metal box, which includes the amplification and filtering stage and the A/D conversion stage.

6. Graphical Biofeedback Display

This section outlines the design specifications of the graphical biofeedback display. In this phase, we will interpret the signals received from the A/D conversion stage using LabVIEW. Here, users will be trained to "talk" to the computer by thinking.

6.1 Power Spectrum Analysis

Figure 6-1 shows a screen shot of the user biofeedback display in LabVIEW.

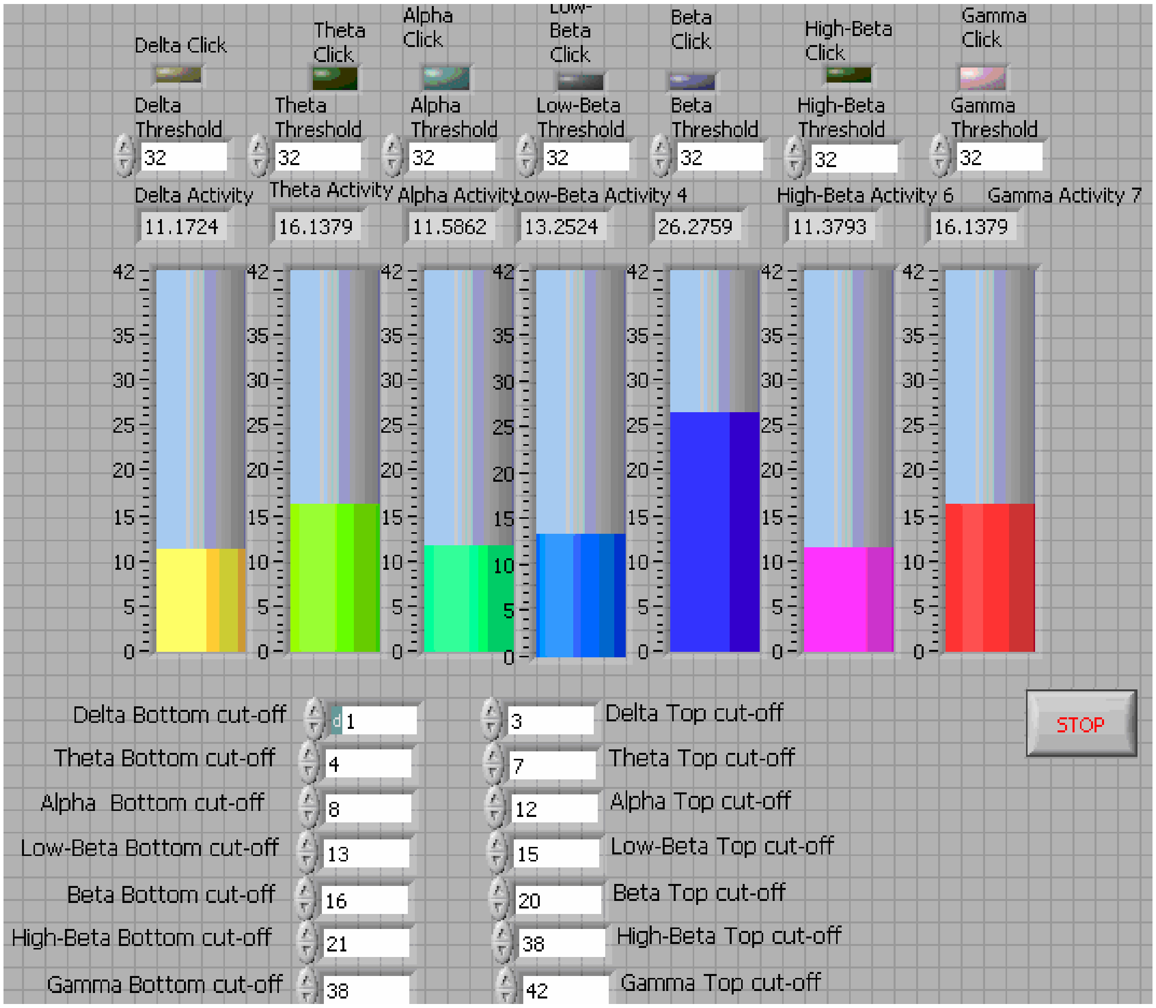


Figure 6-1: Biofeedback Display

The biofeedback module allows users to see the characteristics of their brain waves. This interface displays the power spectrum amplitudes of the brain signal's frequency bandwidths in real time. Users can see the effects their thoughts have on the power bars. More importantly, subjects can learn to tune their thought power spectrum to different ranges. Once users have become better at controlling the amplitudes of the spectrum, they can use their preferred settings to play the PONG game.

7. PONG Game

This section outlines the design specifications of the PONG game. In this stage, we will implement the PONG game in the LabVIEW environment.

7.1 Game Implementation

A sample block diagram of the designed PONG game can be seen in Figure 7-1.

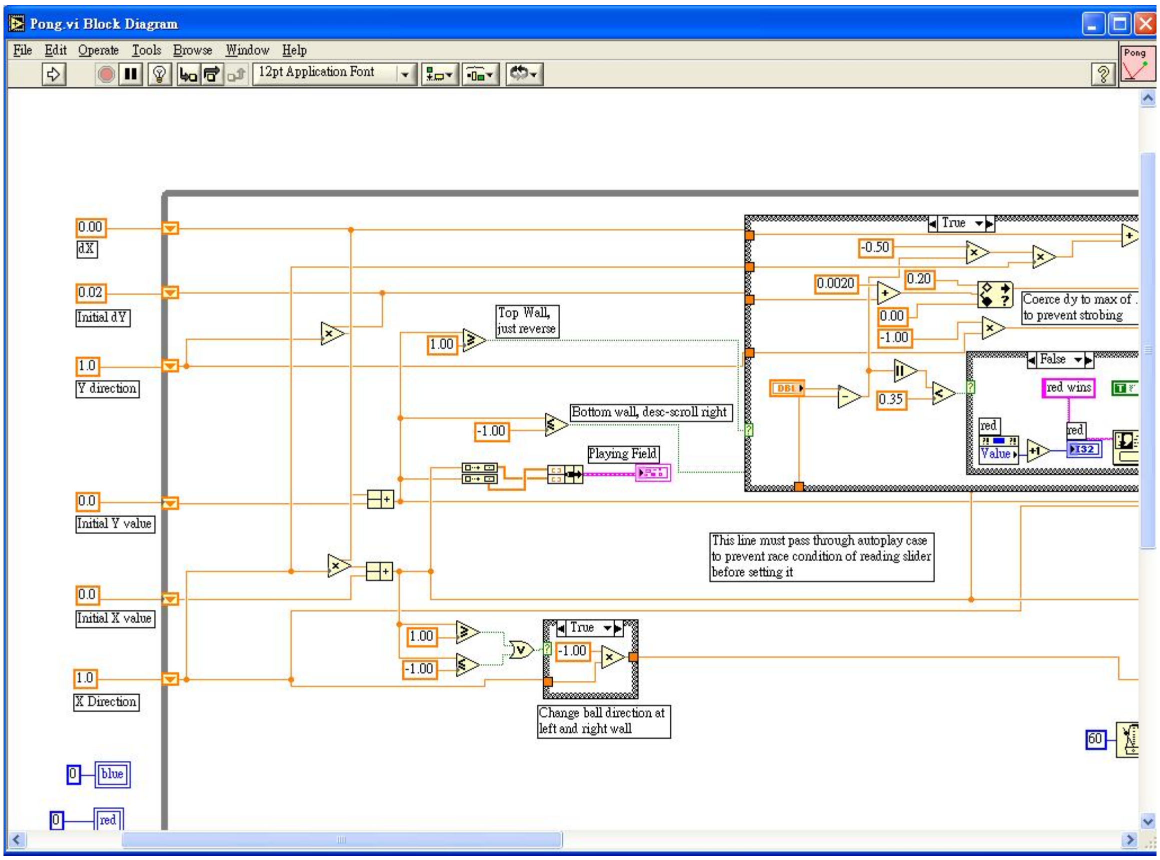


Figure 7-1: PONG Game Block Diagram

The game consists of a playing field for the ball to move around and two paddles to re-direct the movements of the ball. The x and y coordinates of the playing field have a range from -1.5 to +1.5. Initially, the ball starts at the middle of the field, i.e. coordinate (0, 0), and moves towards one of the paddles. Whenever the ball contacts a paddle or a horizontal wall, we compute the new movement of the ball by multiplying -1 in the x or the y direction. Whenever the ball contacts the vertical wall, the point ends. The winning player will have his/her point total incremented. Players can quit the game by pressing the "STOP" button using the mouse.

A sample screen shot of the game is captured in Figure 7-2. This is what end users will see.

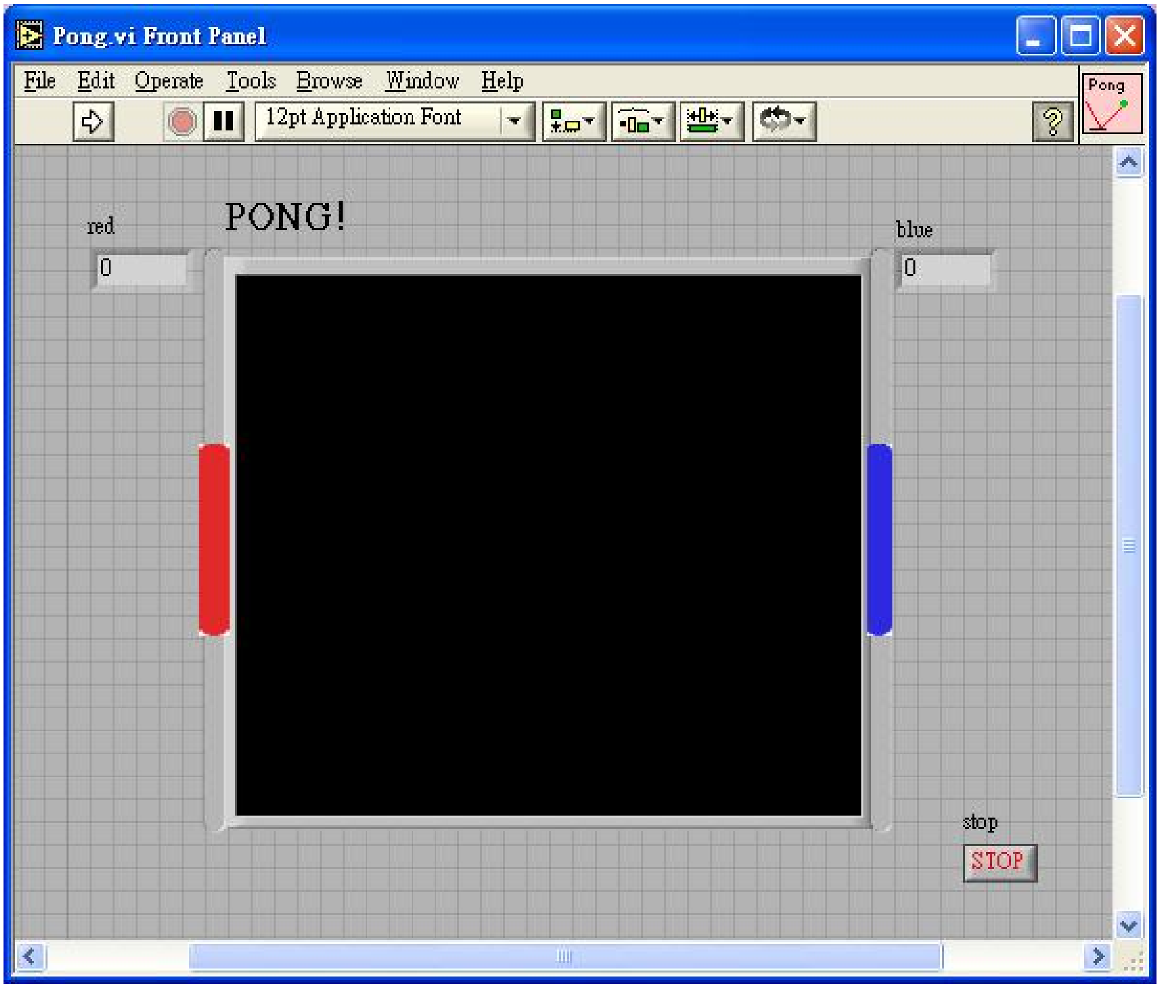


Figure 7-2: PONG Game User Interface

Additional game controls and features may be added according to customer requests.

8. Test Plan

This section outlines the test plan of our PONG Training System. Each subsystem will be tested individually before being integrated with other subsystems. Then, a combination of subsystems will be tested together before the entire system test is conducted.

8.1 Testing Active Electrodes

Each active electrode will be tested on its own before a pair is being tested together.

8.1.1 Signal Reception Verification

Using a function generator to generate a small sine wave, such as 0.5 V, at around 30 Hz, we can pass it through a voltage divider, as demonstrated in Figure 8-1.

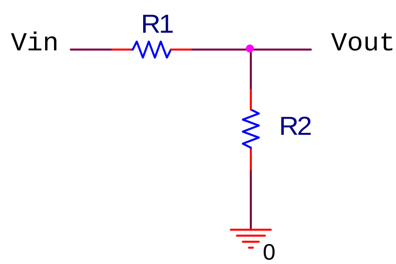


Figure 8-1: Voltage Divider

By choosing appropriate values for the resistors, such as 10 MΩ for *R1* and 100 Ω for *R2*, we can get a very small voltage signal at around 5 μV, mimicking that of beta waves from brains. The signal can be fed to one side of the gold pin array electrode, and we can measure the response on the other side.

8.1.2 Pre-Amplification Verification

We can use the same 5 μV generated above to verify the functionality of the pre-amplification component. Instead of passing the signal through the pin electrode, we can feed it to the differential inputs of the instrumentation amplifier. Then, we measure the output of the amplifier and make sure it is 100 times as strong as the differential inputs.

Alternately, we can generate a stronger signal using the function generator to ease up the verification process because signals in the micro range are hard to observe and unstable.

8.1.3 Notch Filter Verification

An arbitrary signal or the output from the previous component will be used as the input to the notch filter. The output of the filter will be observed and the frequency response will be plotted. We will compare the experimental plot with the theoretical plot in Figure 3-5.

8.1.4 Cable Transmission Verification

Similarly, an arbitrary signal or the output from the previous component will be used as the input to the shielded cable. The output signal will be compared to the input signal.

8.1.5 Headband Flexibility Verification

The headband will be worn by randomly selected people to make sure it fits on heads of all sizes.

8.2 Testing Amplification and Filtering

This stage will first be tested using externally generated inputs. After those tests pass, the input will come from the output of the electrode stage.

8.2.1 Low-Pass Filter Verification

The function generator will create a sine wave of 0.5 V at 30 Hz. The voltage divider in Figure 8-1 can help us reduce the signal to 0.5 mV by choosing100 kΩ for *R1* and 100 Ω for *R2*. This signal will be passed to the low-pass filter, whose frequency response will be plotted. The experimental results will be compared to the theoretical results in Figure 4-2.

8.2.2 Fixed Gain Verification

The voltage divided signal (0.5 mV at 30 Hz) from above can be sent to the fixed gain amplifier. The amplifier, with a gain of 100, should have an output of 0.05 V at 30 Hz.

8.2.3 Adjustable Gain Verification

The output of the fixed gain stage can be fed to the input of the adjustable gain amplifier. The output of the amplifier is expected to be adjustable from 0.5 V to 5 V at 30 Hz.

8.3 Testing Analog to Digital Conversion

We use the function generator to create a sine wave with 5 V amplitude at 30 Hz. The signal will be connected to each analog input channel of the DAQ card. Then, we hook up the card to a computer and create a testing file in LabVIEW to verify that it can receive information from each analog input.

8.4 Testing Graphical Biofeedback Display

Trainees will be asked to adjust different power spectrum bars in LabVIEW to verify that each bar is working properly.

8.5 Testing PONG Game

After generating a 5 V sine wave operating at 30 Hz, we pass it through a voltage divider similar to Figure 8-1. However, this time *R2* will be a variable resistor. The output of the voltage divider will be connected to an analog input channel in the DAQ card. We then reference that input channel to one of the paddles in PONG. Next, we run the game and adjust the variable resistor to change the amplitude of the analog input signal. The paddle should move according to the changes of the input. We repeat the same thing for the other paddle. Finally we test both paddles simultaneously.

8.6 Testing Overall System

After each subsystem can function on its own, we can perform the overall system test. Two players will be hooked up to the system by wearing electrode caps. Player one will be asked to control the movements of his/her paddle in PONG using his/her brain. If successful, player two will be asked to do the same thing. At last, the two players can enjoy the brain wave game by playing against each other!

9. Conclusion

The document describes the design specifications of our brain signal controlled devices. We plan to finish the prototype of the PONG Training System by the end of 2006 and work on the Remote Control Car after that. We believe that by December 31, 2006, our PONG Training System will provide research subjects with a fun and competitive gaming experience.

10. References

[1] Analog Devices, “AD625 Programmable Gain Instrumentation Amplifier,” 2006. [Online]. Available: http://www.analog.com/UploadedFiles/Data_Sheets/AD625.pdfl [Accessed Oct. 28, 2006].

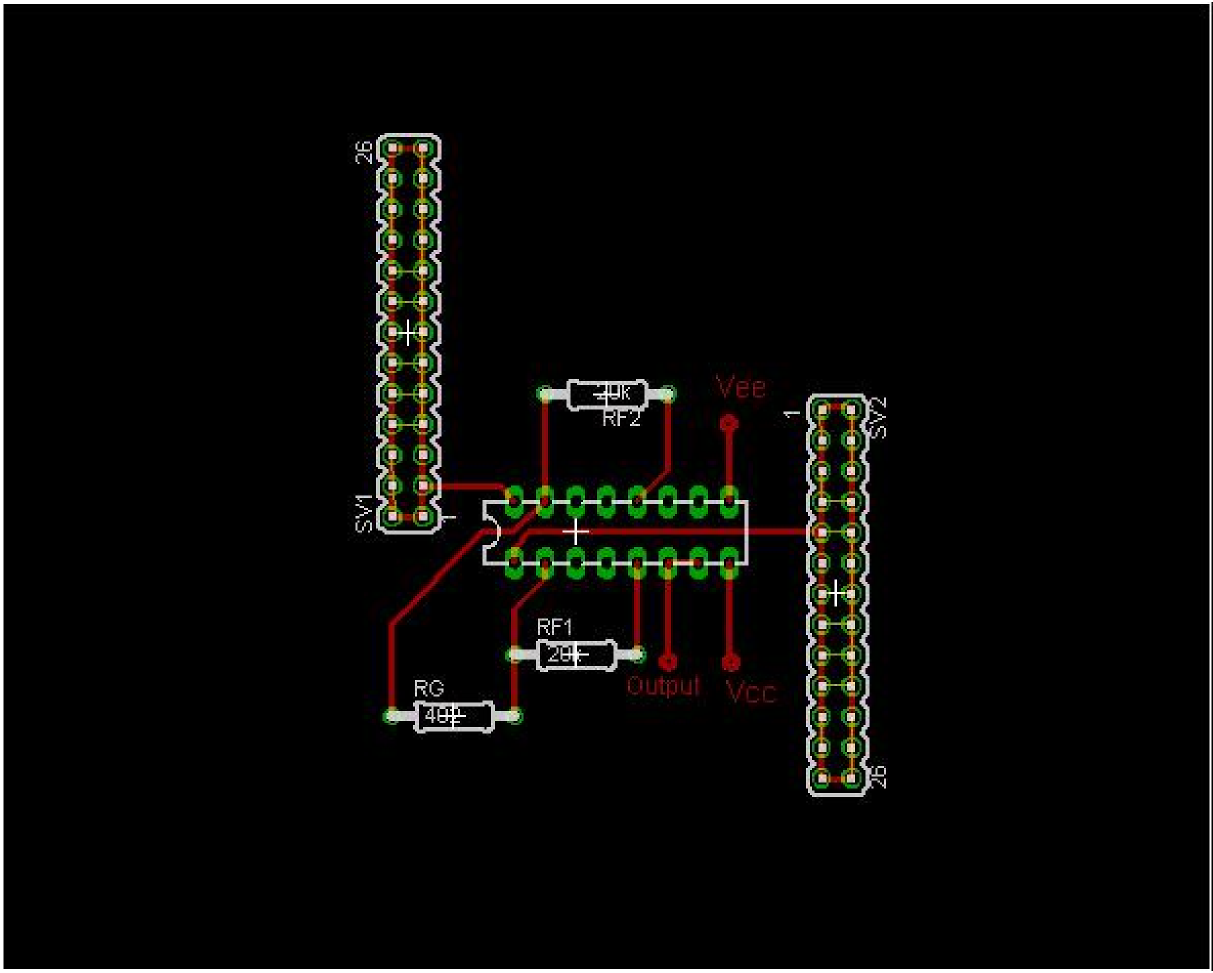
[2] Wikipedia, “Brainwave Synchronization,” Nov. 2006. [Online]. Available: http://en.wikipedia.org/wiki/Brainwave_synchronization [Accessed Oct. 28, 2006].

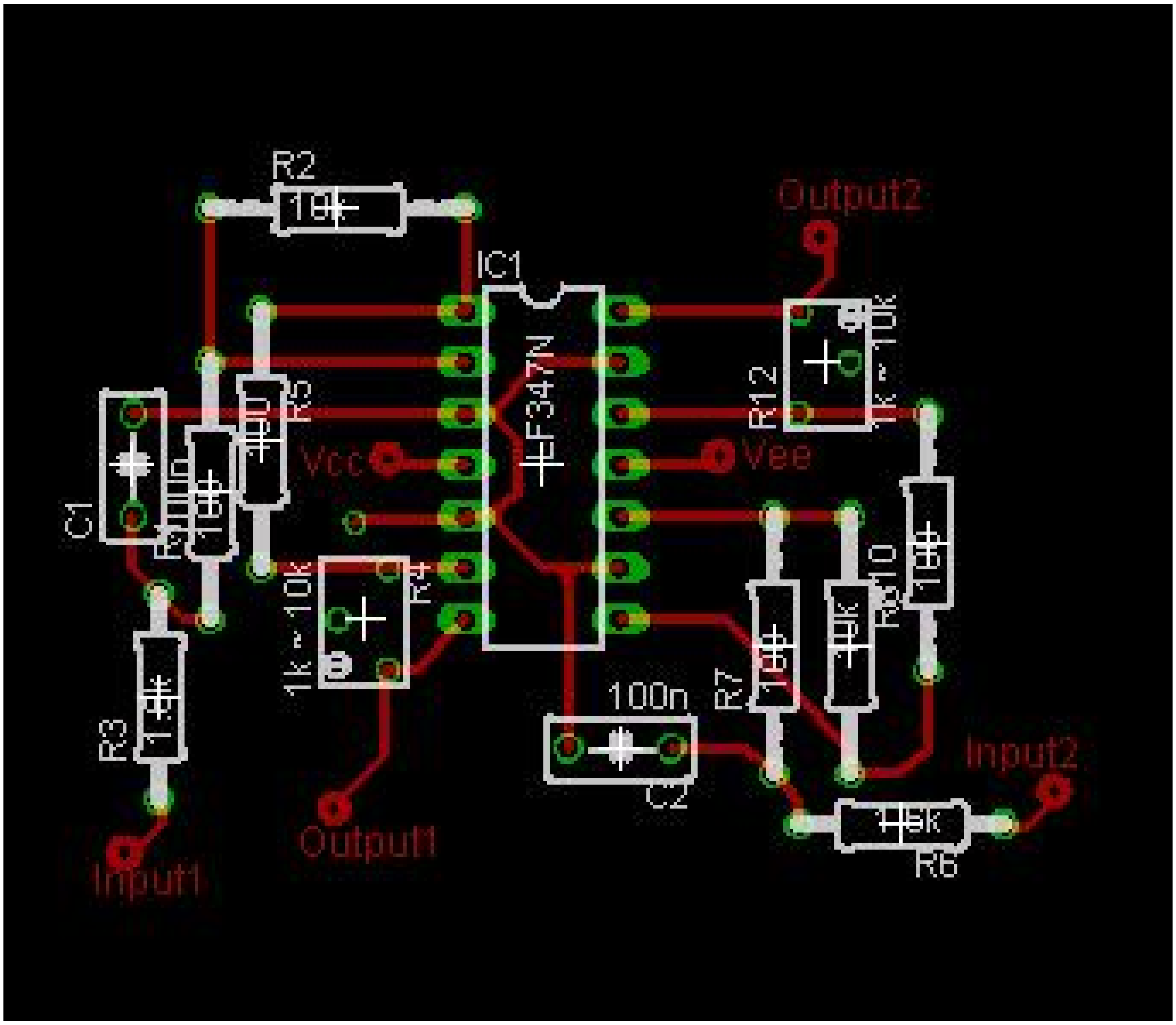
[3] B. Carter, “Audio Application for Op Amps, Part II,” 2006. [Online]. Available: http://www.analogzone.com/avt08062.pdf [Accessed Nov. 22, 2006].

[4] E. Chudler, “The 10-20 System of Electrode Placement,” Nov. 2006. [Online]. Available: http://faculty.washington.edu/chudler/1020.html [Accessed Oct. 28, 2006].

[5] National Instruments, “DAQ 6023E/6024E/6025E User Manual,” 2000. [Online]. Available: http://www.ni.com/pdf/manuals/322072c.pdf [Accessed Nov. 20, 2006].

Appendix A – PCB Designs




R2
IC1
Output2
R12
Vcc
Vee
C1
R5
R4
1k ~ 10k
R3
R7
100n
C2
Input2
R6
Output1
Input1