

**EEG Biofeedback System**  
**Final Report**

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## **Abstract**

The physiological effects of meditation have been an active area of research in recent decades and are widely accepted to be highly beneficial for stress reduction and overall well-being. As a result, many physicians have become increasingly intrigued by meditation's clinical potential; developing a device to enhance one's ability to reach a meditative state through biofeedback could prove to be a clinically significant tool. A compact, affordable device was designed and fabricated to acquire clean, human electroencephalogram (EEG) signals and provide auditory feedback upon detection of alpha and theta waves. These rhythms are believed to be strongly linked to the "bliss" state of meditation. Computer simulations have verified the theoretical functionality of the device. Human testing will be conducted to determine its true effectiveness.

## Background

### *Electroencephalography*

The EEG is a particularly powerful clinical tool and has been the gold standard for neurology and psychology research for decades. It is a relatively simple, inexpensive and completely harmless method for analyzing brain

activity. The EEG has inherent

disadvantages when compared to more

invasive or expensive techniques such as decreased spatial and temporal resolution. The EEG

allows for a glance into the global organization of the brain by recording the mass action

potential activity of neurons in the brain and is sufficient for a wide variety of applications.

Typically EEG data is acquired using a high end bioamplifier connected to an array of up to 128 electrodes. The amplifier quality is necessitated by the 10-100 $\mu$ V amplitude of an EEG signal. The

data that is collected is then fed into a digital

computer where it can be analyzed in real time or off-line. Such methodology has led to the

classification of four specific categories of brain activity commonly discussed in EEG literature:

alpha, beta, theta, and delta waves (Fig. 1).

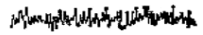

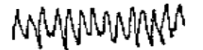

Brain-Wave Frequency	State of Consciousness	Brain Wave Sample
<b>BETA</b> above 13 Hz	Fully-Awake, Alert, Excitement, Tension	
<b>ALPHA</b> 8 to 13 Hz	Deeply-Relaxed, Passive-Awareness, Composed	
<b>THETA</b> 4 to 7 Hz	Drowsiness, Unconscious, Deep-Tranquility. Optimal Meditative State	
<b>DELTA</b> Below 4 Hz	Sleep, Unaware, Deep-Unconsciousness	

Fig. 1 – Overview of specific brainwave types and their associated state of consciousness that are commonly seen in EEG recordings.



Fig. 2 – Commercially available EEG monitor; built-in theta/alpha differentiation display. This unit costs \$1500.

Due to the niche market of EEG, commercially available equipment is all but non-existent. Technology that allows for the detection and delineation of an EEG signal typically costs upward of \$1,500 (fig. 2) [2]. Due to the expertise required for use of such devices and their high price tag, private utilization of such technology is rare.

### ***Meditation***

Meditation has been practiced for thousands of years as a means to reach spiritual enlightenment. The pop culture cliché that is most commonly associated with the end result of meditation is the phenomenon of finding “inner-peace.” It is a belief in many religions that by achieving a pure meditative state (nirvana, enlightenment, ‘inner-peace’, etc.) an individual can attain selflessness and a seemingly complete understanding of the universe [13].

The inherent imagery that is associated with the metaphysical aspects of meditation have resulted in a cross-cultural scientific curiosity with regards to the physical manifestations of meditation; especially intriguing are changes observed in the neural patterns during attainment of such an extraordinary state of mind. Specifically, it has been shown that individuals extensively trained in meditation exhibit alpha wave neural activity while approaching meditation and theta wave activity (4-7 Hz) upon reaching a meditative state [3, 4]. Other signs of meditation include decreased heart rate, oxygen consumption, and metabolism as well as increased skin resistance and peripheral blood flow.

Beyond the physiological characteristics, it is widely accepted that regular practice of meditation can lead to significant health benefits that are directly related to a reduction in stress [4, 8, 9]. In particular, decreased blood pressure, anxiety, and stress hormone levels have been observed. Because of this, more physicians have been advocating the benefits of meditation. If a device that allowed for easier attainment of a meditative state via biofeedback were to be developed, it could have a significant clinical impact. Physiological modalities that could be

directly measured as a strategy for meditation training include muscle activity, skin moisture and brain activity.

### ***Project History***

The EEG Biofeedback project has been open for approximately six years, and considerable progress has been made. The product can be broken into three essential stages: signal acquisition, signal conditioning, and biofeedback. Past groups have tended to focus on a single stage, rather than pursuing all portions concurrently. It was our intention to address all portions of the design in the fall of 2006 in order to create a foundation for developing a functioning prototype by May of 2007. Previous groups' work has been reviewed to accelerate and improve the efficiency of the design process.

The first stage, signal acquisition, requires consideration of electrode type, quantity, and position. All former groups that approached this issue attempted to create their own electrode and final assembly. The first system designed consisted of a dual strap headband with variable electrode positioning. This was accomplished by including small slits in the headband straps for insertion of electrodes, allowing for sufficient electrode position flexibility [10]. Another approach was direct contact of custom-made silver probe electrodes with the scalp as the acquisition device, inserted in an earplug for comfort [6]. To date, no commercial electrodes have been considered by previous groups. Electrode quantity has varied significantly as a direct result of circuit design dictating the number required.

Signal conditioning has been based upon two particular designs. One focused on the amplifier described in "Amplifier Design with a Minimal Number of Parts" [10]. This design is a low-power device that includes a high common mode rejection ratio (CMRR) and a low part count. The second design is a simple instrumentation amplifier [10]. This amplifier allows for a improved gain at the expense of higher power consumption. Filtering has been traditionally

performed using first or second order analog bandpass filters, encompassing the desired alpha (8 – 13 Hz) and theta wave (4 – 7 Hz) regions of the frequency spectrum. First order filtering has proved to lack the necessary roll-off characteristics for the complex task at hand [7]. Most previous teams believed a second-order filter exhibited suitable filter characteristics for alpha and theta wave differentiation. In addition, digital signal processing has been reviewed, but has generally been dismissed due to cost.

The final design stage is biofeedback. Auditory and visual feedback methods have been proposed, and the general consensus is that auditory feedback is more practical as meditation often requires eyes being closed. Auditory feedback can be modulated in two specific ways: pitch and volume. It has been found that pitch modulation is a more reliable biofeedback method than volume modulation [10].

### **Client Requirements**

Since this project has been active for several semesters, our client reiterated the goals of the project from a more global perspective. The device would essentially be used for recreational use by people who wish to practice meditation on a regular basis. Therefore, this device would not be used in a clinical setting. Since the recreational use of this product was emphasized, a minimization of cost would consequently be needed, specifically ranging somewhere between \$100 and \$200. Adding to the marketing aspect of the design, the device would need to be rather small and transportable (comparable to the size of an iPod). Finally, and most importantly, the device would need to provide a pleasant form of auditory feedback to help the user recognize the transition into a meditative state without disrupting his or her ability to continue.

## Final Design

The scheme of our final design encompasses three distinct components – the *electrodes*, *bioamplifier*, and *final assembly*.

### **Electrode Design**

One of the primary novelties of

the current design when

compared to previous

proposals is the use of an

active electrode component to

increase signal quality. Noise,

excluding motion and electromyogram artifact, is proportionally reduced as a result of

amplification implemented near the signal source. Commercially available active electrodes were found to be much too expensive for our design, so a custom active electrode design was pursued.

This design consists of a silver, silver-chloride (Ag/AgCl) electrode directly connected to a simple operational amplifier circuit with variable gain. Variable gain is facilitated by the

inclusion of a potentiometer to vary the resistance across one of the components in the device.

This allows for gains ranging from 50 to 2000 based upon the equation  $V_{out} = V_{in}(R_1/R_2)$  which characterizes the amplification circuit illustrated in figure 3. Ultimately, the active component gain value will be finalized for cost, size and performance purposes.

Ag/AgCl electrodes (*Grass-Telefactor, West-Warwick, RI*) were chosen based primarily upon correspondence with a graduate student actively using EEG technology in her research [5] and the superior characteristics of Ag/AgCl compared to other common electrode materials for the acquisition of low level AC potentials [12]. More specifically, Ag/AgCl electrodes are less

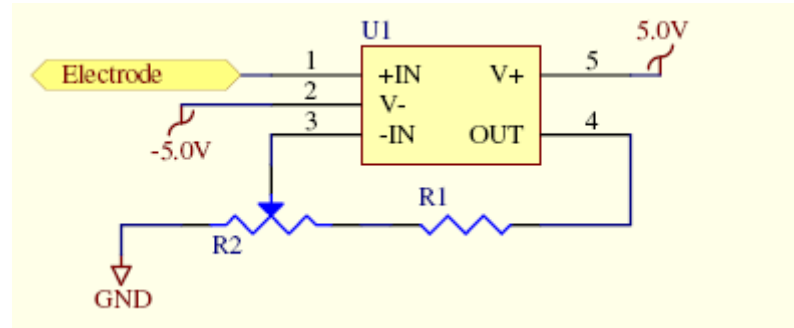


Fig. 3 – Simple operational amplifier used as the active component in the active electrode design.

prone to contamination by low-frequency electromagnetic noise when compared to pure silver or gold electrodes.

Three electrodes are included in the design; two for neural activity recording and one that is clipped onto the user's ear as a reference. Electrolyte gel is applied to the underlying skin to reduce impedance and increase signal clarity. A driven-right leg (DRL) circuit is used to interface the reference electrode with the acquisition electrodes alleviating motion and muscle artifact, which could potentially destroy the desired signal. This reduction is accomplished using common mode rejection to reduce the prevalence of muscle and motion artifact that is common to all three electrodes.

A two electrode scheme is believed to have sufficient resolution to acquire alpha and theta waves from the human cortex, but further testing will be required to verify this forethought. Optimal electrode placement was determined following a literature search, revealing that alpha and theta activity are prominent respectively in the frontal and occipital lobes during meditation [1, 3]. Approximate electrode position is sufficient since EEG characterizes generalized neural activity.

Electrode maintenance and replacement is a simple process as a result of detachable electrodes in the final design. Cleaning can be accomplished by hand washing the electrodes with a light detergent and allowing to air dry. Over time, it is expected that the chloride layer will begin to deteriorate; fortunately, chloride ion redeposition is a straightforward process. It requires a 5% NaCl solution and a three V source. The electrode is connected to the positive terminal of a 1.5 V source and a wire is placed into the solution connected to the -1.5 V source. The electrode is connected to a 100 ohm resistor and placed in the NaCl solution. Chloride deposition is complete when a dark coating is observed on the electrode [12].



### ***Bioamplifier – Preamplifier***

As stated earlier, EEG signals typically have an amplitude in the range of 10-100 $\mu$ V, thereby requiring amplification prior to any signal processing. Small peak to peak amplitude is not the only intricacy to rectify when processing EEG signals. The skin typically provides source impedance on the order of 1-5M $\Omega$ . To acquire the signal effectively, the amplifier must match or have a greater input impedance than the source impedance. Furthermore, the amplifier must reject 60 Hz interference from the signal. Consequently, a relatively high Common Mode Rejection Ratio (CMRR) is desired. As mentioned previously, active electrodes were implemented in this design to aide the preamplification process. Theoretically this addition will not only amplify the signal preceding any filtering stages, but also reduce the prevalence of 60 Hz noise; however, the bioamplifier is still designed with these characteristics in mind.

A high input impedance, high common mode rejection ratio, and moderately high gain instrumentation amplifier is used as the preamplifier component of the bioamplifier [7,10]. The chip used is the INA141 from Texas Instruments [14]. As shown in figure 4, the INA141 is a low power, general purpose instrumentation amplifier that requires low input bias current. It also features a minimum CMRR of 117dB with a variable gain between 10 and 100. R4 and R5 make up 1.5k $\Omega$  across the gain pins, resulting in a gain of 31 for this stage. The use of the INA141 also allows for removal of any potential DC-offset that might be present in the signal. DC-offsets can occur at the maximum of 0.3V. With a gain of 31, the amplifier would bring the DC-offsets to 9.3V, and saturate the amplifier.

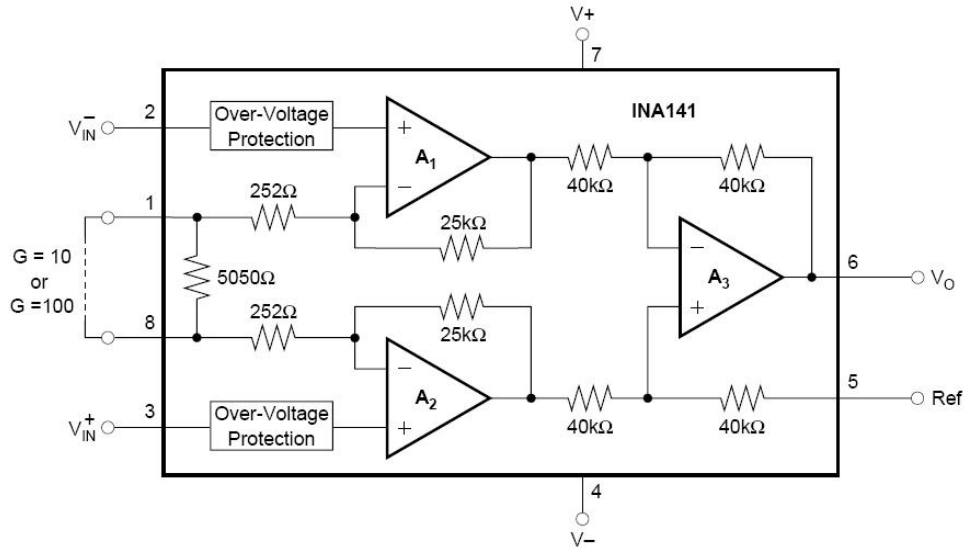


Fig. 4 – The INA141, which served as the instrumentation amplifier for the bioamplifier. [14]

### ***Bioamplifier – Filter, Rectifier, Averager, and Variable Frequency/Amplitude Circuits***

Many new features were integrated into the concepts of previous teams' designs. Preliminary

research revealed that the presence of noise would be the most prominent and daunting task

when designing an EEG. Fortunately, this project does not require the reproduction of actual

brainwaves, but rather a response to the presence of alpha or theta waves. To attain this response,

the EEG must first attenuate all signals outside of the 4-7 Hz (theta) and 8-13 Hz (alpha) ranges.

From the instrumentation amplifier, a 4.7 uF capacitor attenuates frequencies below 3 Hz,

effectively removing any DC presence, before the signal reaches the filters. The signal is then

split into the two parallel alpha and theta filters. Fifth order filters were used to attain sharper roll

off and increase attenuation of frequencies outside of the desired ranges. This is an improvement

in filter clarity over previous filtering efforts, however it adds to the cost and power drain of the

design from an additional operational amplifier for each channel. Previous semesters utilized

bandpass filters at single frequencies for their alpha and theta filters; this method is inadequate

since actual alpha and frequencies vary among individuals within the wave's frequency range.

Two slightly offset bandpass filters form the alpha filter. This approach was used instead of a

cascaded lowpass and highpass filter design because the benefits of its sharper roll off characteristics heavily outweighed the small dip created at approximately 11 Hz. This filter has a range from 8.6 Hz to 14.6 Hz and a gain of about 10. The theta filter consists of a 7.0 Hz cutoff frequency, a lowpass filter with a gain of 10. Each filter is composed of two cascaded 2<sup>nd</sup> order, multiple-feedback, chebyshev filters and a low pass passive filter. All filters were simulated with the Pspice model displayed in figure 8, appendix A. The frequency responses can be seen in Figure 9, appendix A.

After filtering, each signal goes to an opamp for buffered adjustable gain. A 1.0M $\Omega$  resistor is used for the feedback resistor while a 50k $\Omega$  potentiometer is split between the feedback and gain resistors, giving rise to a gain equation of  $G = \frac{1000000 + x}{50000 - x}$ , where x is determined by the potentiometer. This yields a gain ranging from 20 to 1000, and allows for fine tuning of optimal gain levels and viability determination for the active electrodes. If the active electrodes are ineffective, they will be replaced by passive electrodes and the adjustable gain will be compensated here.

Once the AC signal has been properly filtered and amplified, it will be rectified and averaged to produce a DC voltage that changes proportionally to the AC signal. For rectification, four schottky diodes are used to create a full-wave bridge rectifier with a low forward voltage of about 0.3V per diode. In order to have a ground signal throughout the whole circuit and still have the bridge rectifier work properly, the signal cannot enter the rectifier directly. A one-to-one isolation transformer is used for inductive coupling. An inductance of 4.7mH is used because a larger inductance yields lower impedance in low frequencies.

Following rectification, a charging capacitor is utilized to average the signal. Because the DC voltage must change in proportion to the AC signal, the capacitor must also be allowed to

discharge. The resistance to ground from the capacitor is a sum of the resistors R23, R27, and R28 for the theta signal and R2, R33, and R34 for the alpha signal which is about 700kΩ (see figure 10). Multiplied by the 10uF capacitor gives a time constant of about 7.0s which will remove much of the ripple that may exist yet provide a fast enough response for the user to interpret.

Two possible feedback designs were implemented into the circuit - both were included for in-use testing. Only one type may be used at any given time, which can be determined by the placement or removal of certain resistors. The two feedback designs used are a variable frequency feedback design and a variable amplitude feedback design.

The variable frequency design is implemented by populating R27, R33, and R46 and removing R25, R30, and R47. This design utilizes a voltage to frequency converter, part number AD654, which converts the DC voltage to an AC signal in the audible range. The  $V_{in}$  of the V/F converter must be a voltage ranging between 0 and  $V_s-4V$ . Resistors R27 and R28, with R33 and R34 serve as a voltage divider for the input. The current input into  $R_t$  should as close to one mA

as possible but no more than two mA by the relationship  $I = \frac{V_{in}}{(R_A + R_B)}$ . The output frequency of

the AD654 is determined by the equation  $F = \frac{V_{in}}{(10)(R_A + R_B)C_T}$ . The values of R29, R35, R43,

R44, C22, and C29 are based upon the characteristics described in table 1 of appendix B.

Adjusting the potentiometers R43 and R44 results in a wide range of frequencies and does not violate the current rule. This circuit requires R44 be set to 900Ω for the alpha channel which gives a frequency of 359 Hz and a current of 0.79 mA. R43 is set to 1010Ω for the theta channel, giving a frequency of 158 Hz and a current of 0.74 mA.

The other mode of feedback, the variable amplitude design, can be implemented by the population of R25, R30, and R47 and the removal of R27, R33, and R46. This results in a new time constant of approximately 10 seconds. This design employs a 555 timer to generate a specific frequency while the DC signal determines the amplitude. An opamp sums the two DC signals from without causing interference. The 555 timer is configured in adjustable operation, which runs as a multivibrator, generating a specific frequency based on the equation

$$F = \frac{1.44}{(R_A + 2R_B)C} \text{ and a duty cycle of } D = \frac{R_B}{R_A + 2R_B}. \text{ It is recommended that } R_A \text{ remain above}$$

1.0 kΩ. R26, R31, R32, R45, C21, and C24 were determined based on the characteristics described in table 2 of appendix B. The output of the 555 timer is trailed by a voltage follower, designed to prevent the output from the two channels interfering with each other.

The resistance of headphones is typically 32 Ω and requires about 12 mW of power [14]. If the signal output reaches a maximum of 5.0V, then R36, R37, R39, and R40 must be chosen so an appropriate power is delivered to the headphones. The total resistance needed between the

$$\text{output and ground is determined with the equation } R_{total} = \sqrt{\frac{V_{out}^2}{P_{headphone}} R_{headphone}} = \sqrt{\frac{5^2}{.012}} 32 = 258\Omega.$$

This means an additional 226 Ω is required at each channel to provide the headphones.

Component R38 is replaced by a 0.47 uF capacitor to serve as a lowpass filter and give the output a more sinusoidal waveform, generating a more pleasing sound than a square wave.

Each feedback design has its advantages and disadvantages. In the variable frequency design, the frequency is determined by the equation  $F = \frac{V_{in}}{(10)(R_A + R_B)C_T}$  which means as the

user leaves the alpha or theta ranges  $V_{in}$  will decrease, causing the frequency to increase away from its set value. This will not only be distracting to someone who hasn't yet achieved

meditation, but the theta channel voltage could reach a value that causes a frequency of 359 Hz, an unacceptable alpha state false alarm. The variable amplitude design utilizes cheaper 555 timers and has a set frequency, eliminating potential for false positives. Also, if the user is not displaying any alpha or theta waves, then there will be no output. This provides a clear indication of progress when sound initiates; however it may also influence users to suspect broken hardware if no progress is made.

Once this circuit design was finalized, a PCB was designed and made by Advanced Circuits. Noise being the main issue in the design of this circuit, having a PCB made was a crucial step in the development of this project. Integrated circuit chips are used wherever possible to reduce the noise resulting from component tolerances and the antennae effect of larger components. Another potential source of noise lies in the circuit itself. As current travels through the copper traces and components, a small voltage will develop in the internal resistance of the traces and parts. To minimize this, a wide trace width and large vias were used in the board layout. Additionally, components are placed close to their adjacent parts to minimize the distance traveled by the signals.

### ***Final Assembly***

The final goal of this project is to develop a highly marketable product. Our client desires a product that will appeal to the trendsetting youth. A system composed of head-straps, electrodes, ear clips, and some method of gel application is inherently obtrusive and intimidating. With this in mind, the first priority of the overall assembly was to keep the system as small, simple, and comfortable as possible.

To obtain an adequate signal, electrode disks must remain in constant contact with the users scalp. Typically electrode pads are held to the skin or hair with a light strength adhesive. Before using the EEG, the user must first apply a small amount of electrode gel, lowering skin-

electrode impedance. The sticky faced electrode pad is then fixated to the desired location. This process is lengthy and potentially aggravating; a commercial system requires a much better method of electrode and gel application.

The final design uses a headband for both electrode adherence and gel delivery. The inelastic, yet smooth-textured headband tightens on user with Velcro. The material was chosen due for ease of component mounting while maintaining comfort and a variable circumference. In future work, other headbands and tightening modes will be considered. Also, a directional indicator to aid the user in correctly aligning the headband and positioning the electrodes must be added in future generations.

The electrodes are securely affixed to the inner surface of the headband to maintain continuous skin contact at the desired location. The attachment system must be reliable, without compromising comfort. Additionally, the electrodes will require frequent cleaning and chloride ion redeposition without harming any active components of the electrode; the final design must not allow the electrode attachment or active component integrity disrupt the electrode maintenance. Consequently, a detachable electrode design is implemented. The active components,

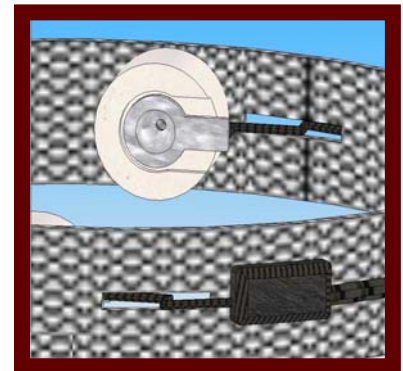


Figure 5 – Electrode Placement

assembled on a PCB, are statically fixed to the outer headband surface. A small wire traverses from the PCB through the headband to a female connector on the inner headband surface. The electrode disk attaches to the female connector to complete the circuit. A plastic plate on the back of the electrode holds a button snap, which fastens the electrode to the headband, preventing the electrode from sliding or rotating from its desired location and orientation. The electrode, now attached to both the active chip and headband, rests in the center of a small

cylindrical foam pad. The hollow-centered, carved pad conforms to the shape of the electrode. A small hole in the headband lies directly behind the electrode. Holes in the electrode, foam pad and headband align, creating a small corridor from outside the headband to the user's skin. The corridor exists for electrode gel delivery after the headband is secured to the user. The gel is delivered from a flat tipped syringe; however, later generations will use a less threatening mode of delivery. This design affords extremely simple electrode maintenance, without posing any threat to the headband or active components. It allows for quick, easy gel application, thus reducing preparation time. Finally, it looks and feels comfortable while keeping the electrodes completely stationary.

The signal exits the active component and travels along the headband's outer surface. All wires are twisted and shielded to help attenuate EMF interference. An active electrode is placed at both the front center and back center of the user's scalp, which are ideal locations for detecting alpha and theta waves. In addition to the two active electrodes, a driven right leg reference electrode hangs from the left center of the headband. The three dimensional design of the entire assembly can be seen in figure 6, notice the placement of the reference

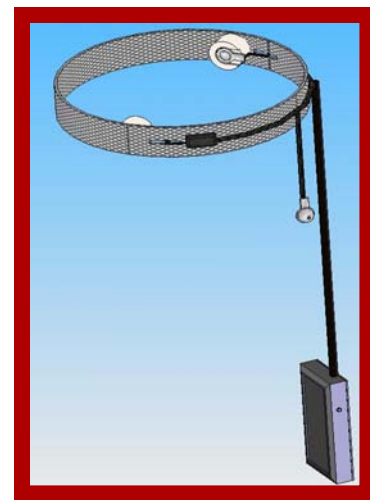


Figure 6 - 3D drawing of final design

electrode and the main cable. The electrode is embedded within a small plastic clip, with a foam pad on the adjacent edge. The clip is firmly latches onto the user's left earlobe without causing significant irritation.

The wires of the three electrodes meet in the midpoint of the back left quadrant of the headband. All wires accrue into one large shielded cable. The cable hangs from the headband,



running to the bioamplifier box, which can clip onto the user's belt or pant waistline. The entire assembly in use can be seen in figure 7. The single large cable carries all signals from electrodes as well all power sources and grounds to the active components. The bioamplifier is powered by two 9 volt batteries, which accounts for the large majority of the product's weight and size. A large, on/off button located on the side of the bioamplifier accounts for the entirety of the intuitive user controls. The final output from the small box is the headphone jack.

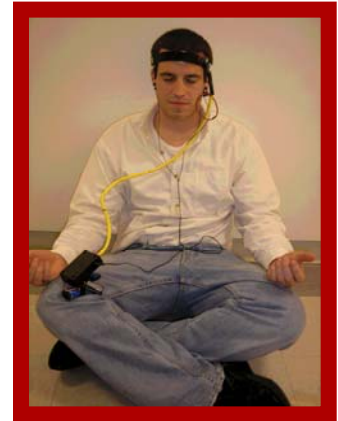


Figure 7 - Prototype in use

Headphones with their own volume control are recommended since no volume control has been built into the bioamplifier. Later generations will be designed to include this feature.

### **Cost Analysis**

A cost analysis was performed for different production quantities, ranging from 1 to 10,000 units. The high flexibility of the design contributed largely to cost estimates. Potentiometers, frequently placed in the design, allow for easy gain adjustment in the bioamplifier and active electrodes. Both voltage to frequency converters and 555 timers were included as two potential methods of biofeedback. Also, the driven right leg circuit is designed so it can be turned on or off in the bioamplifier. All of these features allow post production assessment of design capability. The cost analysis includes the price of all of these components. A finalized design, after testing, would eliminate the superfluous parts and, in turn, reduce cost. When finalized, the board will likely be smaller. Potentially, more boards, if reduced in size, could fit onto the same sized PCB, which again would reduce production cost. For all of these reasons, the analysis presented is meant as a conservative cost projection.

The prototype costs approximately \$74.00 per unit. This high cost is generally due to the high price of purchasing electrical components in small quantities. A PCB costs \$48.00 to print a

single unit; however due to PCB design, each print contains four bioamplifier boards, reducing the PCB cost to \$12 per prototype. Along with the PCB, the electrodes, headband and voltage to frequency converter attribute for nearly half of the entire production cost. In fact, the voltage to frequency converter costs over \$17.00, over 20% of the entire cost. This is substantial considering the voltage to frequency converter may ultimately be removed from the final design.

Prices are reduced dramatically in mass production to just under \$43.00 per unit at 10,000 units produced. The PCB, which cost \$48.00 per four bioamplifier print, is quoted at approximately \$5.00 per board in mass production. Even at large quantities, the voltage to frequency converter costs over \$10.50 per unit; if eliminated from the final design, the components could be acquired for approximately \$32.00 per unit. The complete cost spreadsheet for both the prototype and 10,000 units can be seen in tables 3 and 4 respectively in appendix B.

### **Future Work**

Since a sense of flexibility has been implemented throughout the components of the design, it will be very simple to make the appropriate modifications to the prototype while the electronics undergo debugging next semester. However, extensive simulations and testing with the circuit board and active electrodes will have to be done to verify the correct behavior of the electronics. Once it is established that everything beyond the isolation stage of our bioamplifier is per our initial requirements (rectifier/averager, variable frequency circuit, variable amplitude circuit, and feedback through the headphones), the potentiometers used in the active electrodes will be removed and replaced with fixed resistances. These potentiometers were initially used in the prototype in order to allow for variable gain throughout the amplifier. Once optimal gain values are determined at each stage of the circuit from the debugging phase of the project, we can increase, decrease, or remove the gain at the active electrode level accordingly. In addition to finalizing all resistor values, the debugging phase of the project will also encompass an

evaluation of the performance of the driven right leg reference electrode and the active electrode designs. Since signal is acquired at this stage, it is imperative to the rest of the prototype that the functionality of this stage coexists with the other components of the prototype. An assessment of the current draw and the average battery life will also be made, since our client has reiterated that the product would be ideally mass produced for the general public. That being said, a reasonable current draw/battery life should be implemented. After establishing the correct behavior of the electronics and the associated components, a validation of the design will be performed via human subject testing.

In addition to making the appropriate adjustments to the electronics, there will be modifications to the other aspects of the prototype as well. The circuit will need to be modified so that it will function with a single 9V battery; this movement will allow for a reduction in the size and weight of the amplifier. Obviously, before moving to the commercialization phase of the project, we need to enhance the aesthetics and ergonomics of the prototype. Specifically, the focus will be on the headband and the attachment of the electrodes. This includes, but not limited to: adjustable electrode location, headband fastening mechanism, and headband material. There are also preliminary plans to introduce a new method for inserting the electrode gel solution. As established earlier, syringes are currently used to inject the gel solution into the electrode aperture. A possible alternative would be to pour the solution into a small chamber that is attached to the headband, and squeeze the solution into the aperture.

There are other improvements to the design that could be taken into consideration in the future. Once it is verified that the design of the electronics can output an auditory feedback, the frequency outputs will later be adjusted to acquire a frequency near 350 Hz for a theta response, which clinical research asserts is the most pleasant sounding frequency to the human ear. The

alpha feedback will be set at a 10% difference from the 350 Hz, which ensures the ability for users to differentiate the tones while remaining in a pleasant sounding pitch range.

Finally, it has been suggested to take some of the analog aspects of the design and make them digital. While the feasibility and cost of this option is questionable, in theory, it might allow for a more versatile and robust design.

# Appendix A

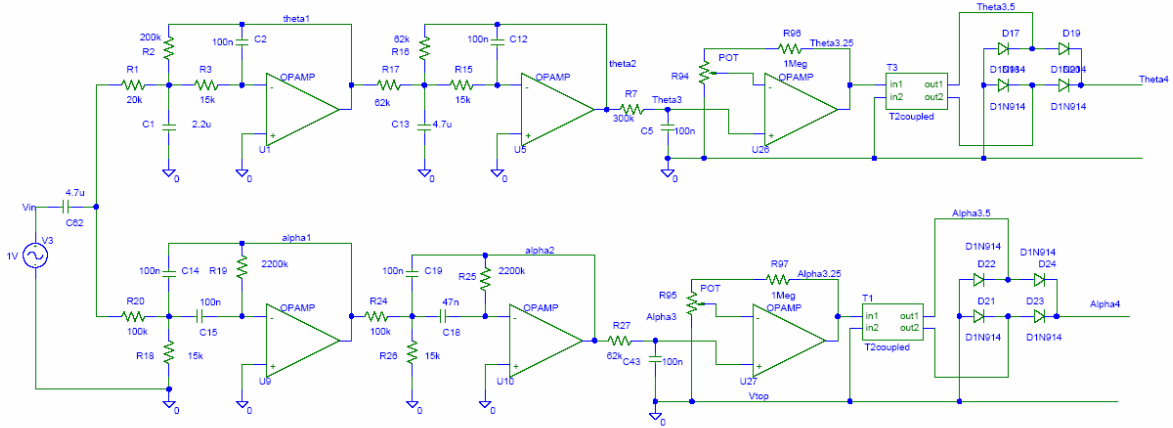


Figure 8 - Circuit diagram from Pspice simulations.

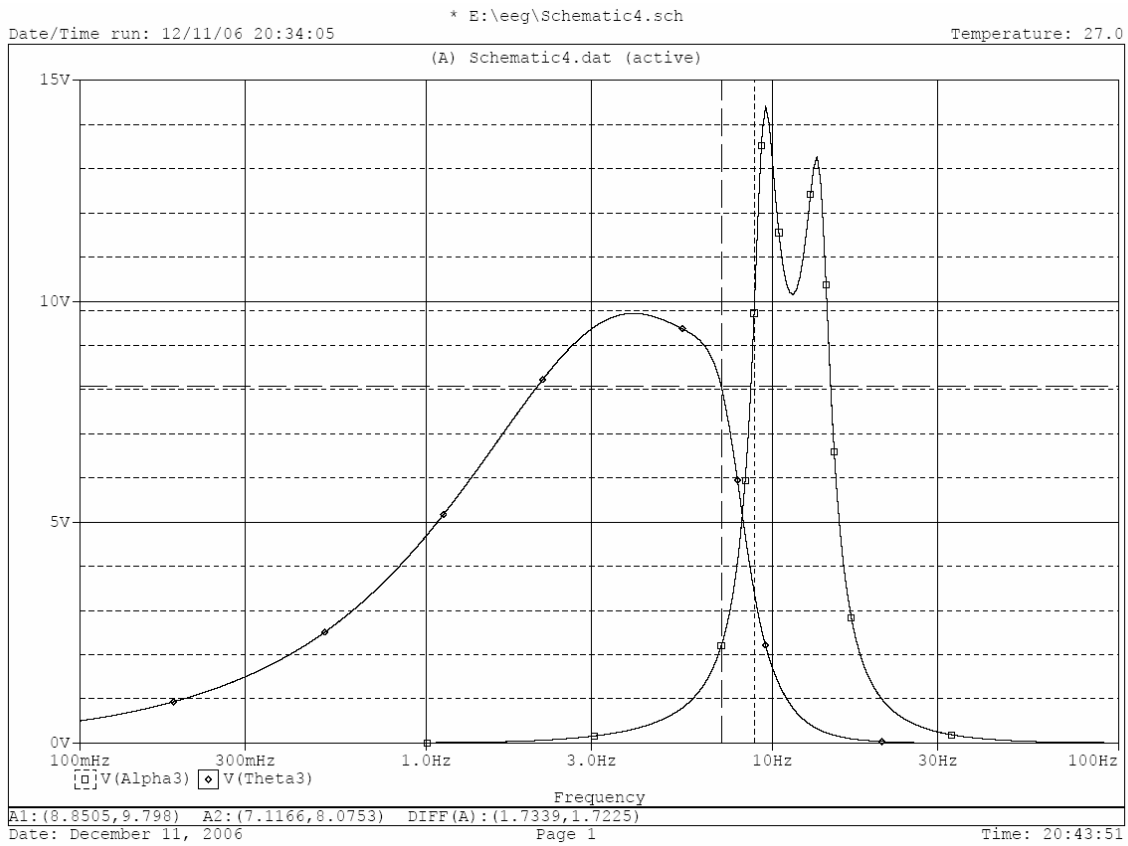


Figure 9 - Frequency response of alpha and theta filters in pspice simulation.

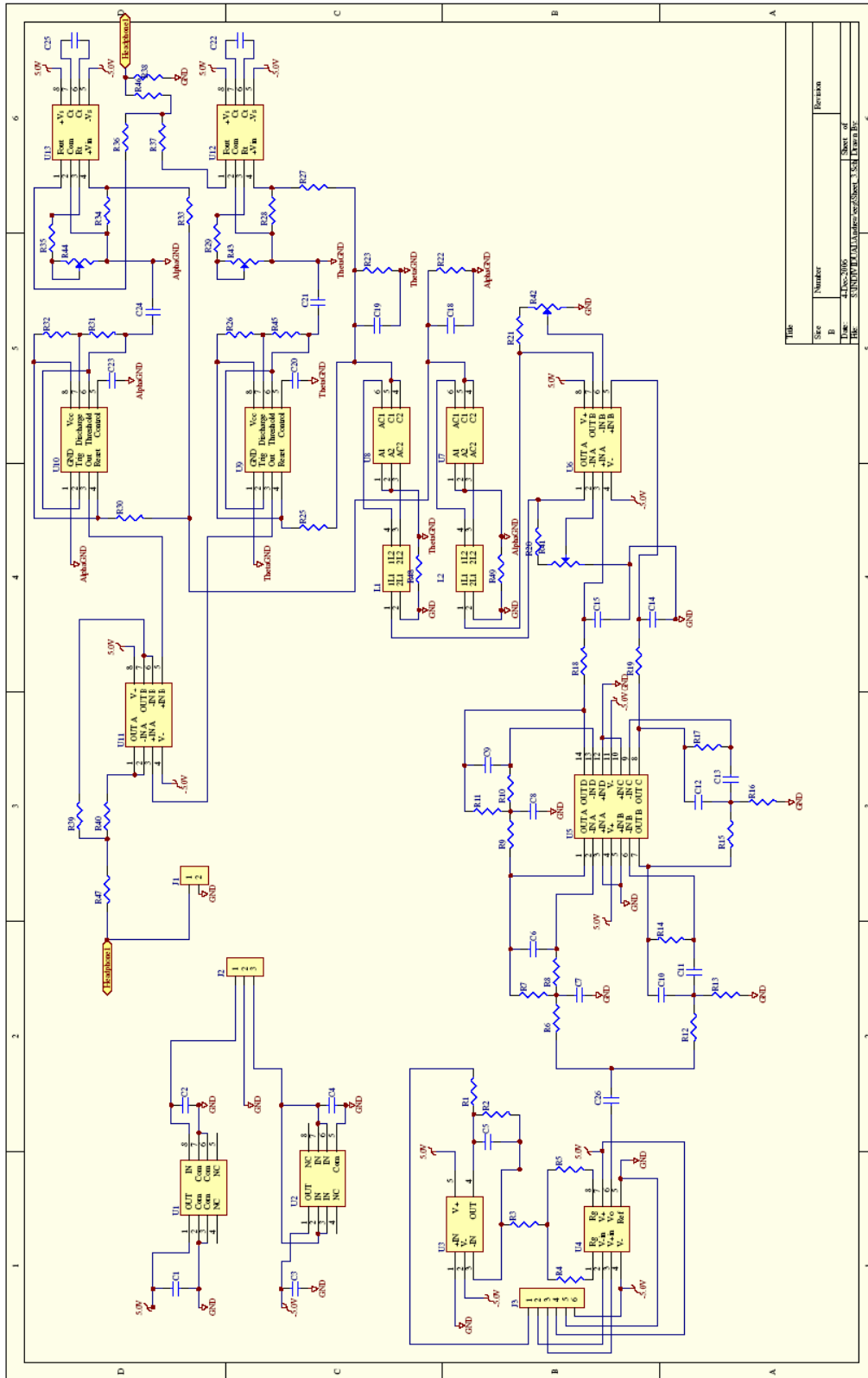


Figure 10 – Overall schematic of bioamplifier

## Appendix B

	$R_A(\Omega)$	$R_B(\Omega)$	$V_{in}(max)$	$C_T(\mu F)$	Frequency(Hz)	I(mA)
Alpha	750 (R35)	0-50k (R44)	1.3V	0.22 (C25)	788-12	1.730-0.026
Theta	750 (R29)	0-50k (R43)	1.3V	0.47 (C22)	369-5	1.730-0.026

Table 1 - Table for frequency variable feedback

	$R_A(\Omega)$	$R_B(\Omega)$	C( $\mu F$ )	Frequency(Hz)	Duty Cycle
Alpha	1.0k (R32)	200k (R31)	0.01 (C24)	359	0.499
Theta	1.0k (R26)	20k (R45)	0.22 (C21)	158	0.488

Table 2 - Table for amplitude variable feedback

Part number	Part name	Supplier	# Ordered	Price	Cost/ part	parts/u nit	Cost/ unit
INA121UA pb	8-soic INST AMP	Digi-Key	1	5	5	1	5.00
MC79L05ACDRG4	Voltage regulator	TI	10	free	free	1	0.00
OPA2379AIDG4	Op. Amp.	Digi-Key	1	1.88	1.88	1	1.88
OPA379AIDCKTG4	Op. Amp.	Digi-Key	3	6.39	2.13	3	6.39
OPA4379AIPWRG4	Op. Amp.	Digi-Key	1	3.38	3.38	1	3.38
UA78L05ACDRG4	100 mA Reg	Digi-key	1	0.4	0.4	1	0.40
AD654	V-F converter	Digi-Key	2	17.08	8.54	2	17.08
CSS-73B16	Buzzer magnet	Digi-Key	1	2.28	2.28	1	2.28
3214W-1-503E	Potentiometer	Digi-key	2	6.44	3.22	2	6.44
-	4 board Printed PCB		4	48	12	1	12.00
Wbt-dsc	Ag/AgCl Electrodes	Electrode Store	100	36	2.78	3	8.33
-	Headband	Dad's Knife-shop	1	4.98	4.98	1	4.98
-	9 volt battery	Target	6	3	0.5	2	1.00
278-513	Shielded wire	RadioShack	50 ft.	10	.2/ft	8 ft.	1.60
Hm361-nd	Small plastic box	Digi-Key	1	2.88	2.88	1	2.88
-	Caps and resistors		40	0.2	0.005	40	0.20
<b>Total Cost</b>							<b>73.8</b>

Table 3 - Cost analysis spread sheet to make a single prototype. The analysis does not include costs of labor. In reality many components were acquired as donations/free samples from vendors which dramatically reduced cost.

Part number	Part name	Supplier	# Ordered	Price	Cost/part	parts/unit	Cost/unit
INA121UA pb	8-soic INST AMP	Digi-Key	10000	30500	3.05	1	3.05
MC79L05ACDRG4	Voltage regulator	TI	10000	780	0.078	1	0.08
OPA2379AIDG4	Op. Amp.	Digi-Key	10000	9375	0.9375	1	0.94
OPA379AIDCKTG4	Op. Amp.	Digi-Key	30000	32640	1.088	3	3.26
OPA4379AIPWRG4	Op. Amp.	Digi-Key	10000	18375	1.8375	1	1.84
UA78L05ACDRG4	100 mA Reg	Digi-key	10000	1020	0.102	1	0.10
AD654	V-F converter	Digi-Key	20000	106750	5.3375	2	10.68
CSS-73B16	Buzzer magnet	Digi-Key	10000	10375	1.0375	1	1.04
3214W-1-503E	Potentiometer	Digi-key	10000	11500	1.15	2	2.30
-	4 board Printed PCB		2500	3125	1.25	1	1.25
Wbt-dsc	Ag/AgCl Electrodes	Electrode Store	30000	36.00	2.50	3	7.51
-	Headband	Dad's Knife-shop	1	4.98	4.98	1	4.98
-	9 volt battery	Target	6	3.00	0.5	2	1.00
278-513	Shielded wire	RadioShack	50 ft.	10.00	.2/ft	~8 ft.	1.60
Hm361-nd	Small plastic box	Digi-Key	1	2.88	2.88	1	2.88
-	Caps and resistors		40	0.20	0.005	40	0.20
<b>Total Cost</b>							<b>42.7</b>

Table 4 - The full cost analysis to make 10,000 units of the prototype. Most prices are best on quotes through major vendors like Digi-Key or TI; however some prices were conservative estimates and would likely be less expensive in actuality. A final design could be expected to have lower cost than this projection.



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## **Product Design Specification – EEG Biofeedback System**

**12/13/06**

### **Team Members:**

Andrew Eley  
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Cullen Rotroff

### **Function**

The goal of our project is to design and build an inexpensive, portable electroencephalogram (EEG - brain wave monitor) that teaches meditation practitioners to achieve optimal meditation by indicating the presence of EEG alpha and theta waves. This shall be achieved through a relatively inexpensive, minimally distracting, and potentially portable device intended for commercial use.

### **Client Requirements**

- A device that minimizes complicated user input (simplistic like an iPod)
- Final cost of \$100-200
- A type of biofeedback output that is not distracting to the user during meditation
- Portable
- Aesthetically pleasing
- Pursue patent if possible

### **Design Requirements**

#### **1. Physical and Operational Characteristics**

- a. *Performance requirements:* Device should be able to be used for a minimum of two hours on a single battery charge, with the possibility of daily use.
- b. *Safety:* Device should be free from danger of shock, and be appropriately labeled to warn of this danger as well as damaging interaction with electrical components. Product should meet all underwriter laboratories (UL standards).
- c. *Accuracy and Reliability:* Device should produce feedback accurate enough for qualitative analysis for personal use, not clinical applications.
- d. *Life in Service:* Device should last a minimum of 5 years.
- e. *Shelf Life:* In standard storage conditions, the product should last indefinitely without batteries
- f. *Operating Environment:* Device should be able to be operated by one person, in reasonable indoor/outdoor conditions (not extremes such as in rain/bathtub), and be able to withstand the typical wear associated with accidents and everyday use.
- g. *Ergonomics:* Circuitry should be contained in a light handheld case with an intuitive user interface. The electrodes should be comfortable for extended periods of use no shorter than 45 minutes. They should be easily placed without necessitating scalp discomfort or hair removal.
- h. *Size/Weight:* Device should be portable and easy to transport. The device should weigh no more than 1 pound.

- i. *Materials*: Should incorporate a maximum number of reusable parts. The outer case should be made of plastic.
- j. *Aesthetics, Appearance, and Finish*: Device should be minimally complicated visually, with an interface similar to that of portable music players (such as an iPod). The shape should be rectangular, and colors should be pleasing to the eye without being distracting.

## **2. Production Characteristics**

- a. *Quantity*: The portable EEG will ultimately be mass-produced for consumer delivery; however, the scope of our project requires a single prototype.
- b. *Target Product Cost*: \$100 - 200, compared to commercial versions ranging from \$1,000 – 5,000

## **3. Miscellaneous**

- a. *Standards and Specifications*: Meets national standards for electronic devices, as well as FDA requirements (Level 1 or 2?).
- b. *Customer*: Device should be conducive to a meditative environment (comfortable, a user-friendly, simple interface). The device should be targeted towards a youthful, healthy, mind and body conscious demographic.
- c. *Patient-related concerns*: The electrodes may require basic daily maintenance and preparation.
- d. *Competition*: Should be able to produce comparable signal quality and feedback for a lower price, smaller packaging, and no necessary training.