# Introduction

Our client this semester is Dr. Daniel Muller from the Institute of Aging in the Mind Body Center. Dr. Muller has been working with meditation and its medicinal uses for over 30 years, and meditation is one of his main fields of study. Meditation is a proven alternative medicine and is effective in combating diseases such as epilepsy, mood disorders, addictions, and it is a stress reducer as well.

Meditation involves one altering their state of mind, so it can be quantized by brain waves. As seen in figure 1, the brain is in one of four states at any given time. When designing our device, we will be primarily concerned only with alpha and theta brain states. Alpha brain waves correspond to the state of mind where one is relaxed but awake. This is the mind state one would be in when they are attempting to meditate, but haven't reached a meditative state yet. Theta waves correspond to the brain state one is in when they have achieved a

Figure 1

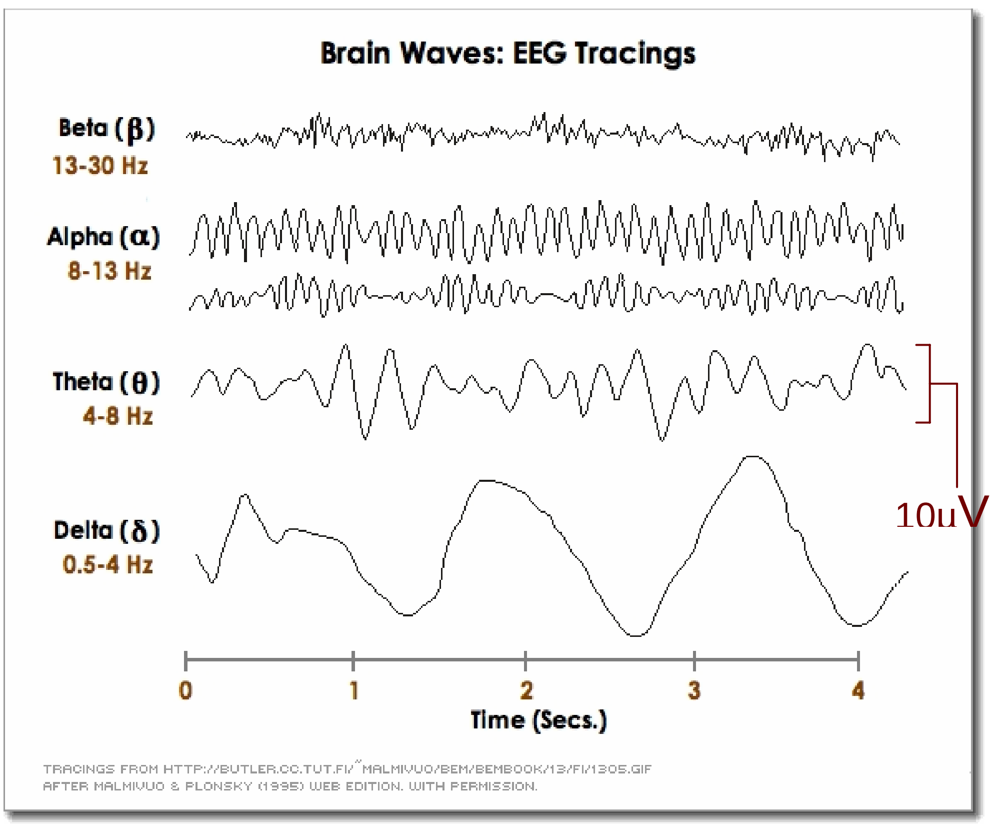


Figure 1: **EEG signals of four different brain states.** Above is an EEG of four different states the brain can be in at any given time. Notice the amplitude of the waves is 10 microvolts.

meditative state. Also, notice the frequencies of the alpha and theta waves; 8 to 13 Hz and 4 to 8 Hz, respectively. These will be important specifications when it comes to building a filter. The amplitude of the waves is on the order of 10 microvolts; another important design specification for amplification.

The problem that our client presents to us is this; meditation is a learned practice so it is inherently difficult to master without some sort of feedback. Feedback would tell the person trying to meditate what state of mind they are in, and how close to a meditative state they are. Our client would like us to design and construct a device that would detect a person's brain state by measuring brain waves with electrodes. Then, the brain waves would be selectively filtered and amplified eliminating any noise. Lastly, the brain wave would be turned into some sort of biofeedback signal, such as a light or a sound to notify the user what brain state they are in, alpha or theta, and how close to meditation they are. Below is a simple schematic of how the device would work.

Figure 2

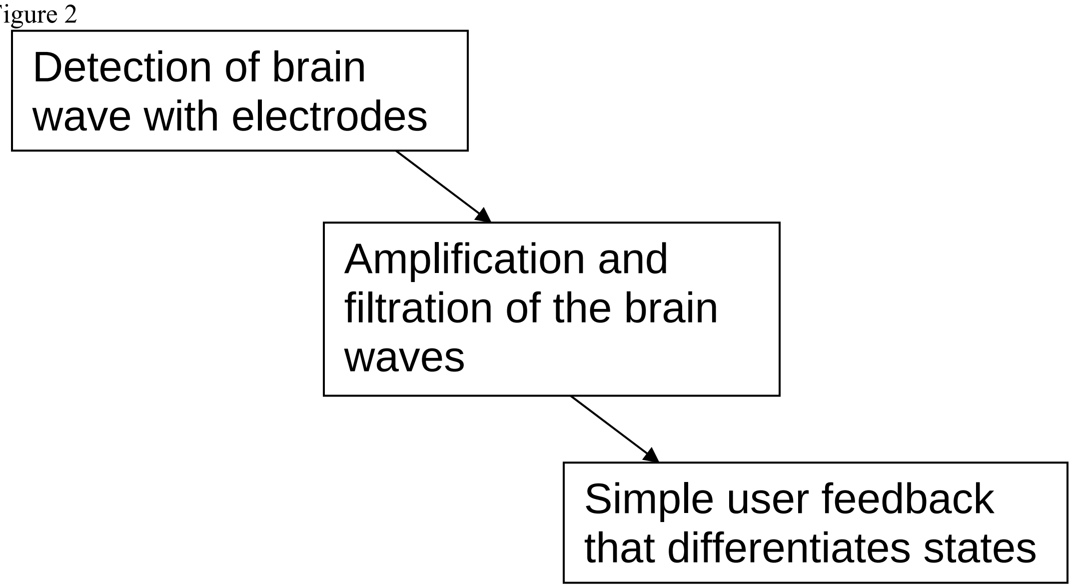


*Figure 2*: **Schematic diagram of design operation.** The ideal design would detect, amplify/filter, and translate brain waves into a biofeedback signal that would notify a person trying to meditate what state of mind they are in; either alpha or theta.

This is not a new project, however, as it has been worked on for the past nine semesters and all of the stages described in the diagram above have been worked on, and a lot of progress has been made. However, a lot more needs to be done before a final prototype can be presented to our client. The problem that has given past groups the most difficulty has been the amplification and filtration of the detected signals. Therefore, this semester we will attempt to construct a successful filtering and amplification circuit to incorporate into the prototype that was constructed and modified by the Fall 2005 group.

## History

The biofeedback and stress management project has been active for the last five years.  Overall, there have been three main goals, namely, signal acquisition, amplification/filtering, and feedback.  Previous work has primarily involved similar design components including: electrodes, amplifiers, filters, rectifiers, averagers, and voltage controlled oscillators.

The signal acquisition phase involves electrode type, quantity, and placement. Electrode types include disposable, reusable (non-disposable), and active/dry electrodes. Disposable electrodes are usually sold in bulk, have self-contained electrolyte gel or require gel application, and are for one-time use.  Reusable electrodes are usually sold in smaller quantities, designed to be more resilient, can be used multiple times, and require the application of an electrolyte gel or solution.  Active/dry electrodes do not require electrolyte gels or solutions for conductivity, because they have specialized electrical components positioned very close to the skin and consequently are the most expensive of the electrode types (1).  The electrolyte gel provides more conductivity, but also results in necessary clean up after use.  More recent teams have turned to the use of electrolyte solutions absorbed into the electrodes rather than gels or pastes. Use of electrolyte solutions seems to have provided easier clean up than the more viscous gels and pastes (3). Most groups have found self-made reusable electrode systems to be most affordable and versatile in terms of electrode position and user cranium size. The first electrode system in Fall 1999 involved dual (horizontal-vertical) head-straps and multiple slits for variable electrode positions (2). Subsequent groups have developed similar systems and additionally have proposed multiple electrode probes (3, 6). Most recently, in the Fall 2005, the electrode system involved earplugs (soaked with 2% NaCl solution) fitted over the end of silver wire (3). There were three electrodes with positions at $C_3$, $C_4$, $C_Z$, which were based on the 10-20 international system for electrode placement (3). Previous teams have utilized quantities ranging from 3 to 5 electrodes with one being a ground electrode (1, 2, 3, 6). Decisions of electrode quantity and placement have been made by the evaluation of desired circuit simplicity and the target signal frequencies.

The second phase of the project is amplification and filtering. Most of the previous teams have cited two amplifier designs that were incorporated into their circuits. The first amplifier design was from "Amplifier Design with a Minimal Number of Parts" by A. C. MettingVanRijn, et al (4). This design proposed an amplifier with high Common Mode Rejection Ratio (CMRR), minimal part count, and reduced power consumption. This amplifier design was ideal for most groups that desired battery operation and portability. The second amplifier design was a basic instrumentation amplifier (4). This instrumentation amplifier had the advantage of having greater gain (signal amplitude), but at the expense of increased power consumption, which could have cause issues with battery utilization. Proposed amplifier gains in previous years have ranged from 15,000 to 100,000 (1, 2). For filtering, most of the earlier groups used 1st or 2nd order band-pass filters and later groups pursued digital signal processing to isolate the frequencies of interest. As the filtering effectiveness increased (i.e., from 1st to 2nd order filters and from analog to digital processing), the circuit complexity and cost also increased. Citations were made to a band-pass filter design and digital signal processing techniques from “A Spectrum Analyzer for EEG Signals” by V. K. Jain and A. Agarwal (5).

The final phase of the project is feedback. Previous groups have sought two types of feedback, namely, auditory and visual. Some groups used one or both, giving the user an option with the reasoning being that some may find one type of feedback more distracting than the other. Some designs have even provided feedback to outside observers, who may be monitoring the meditator. Most feedback processes in the past have been real-time or continuous meaning that the user always had some indication of their status. Auditory feedback has been achieved though the change in pitch (frequency) or volume. It was deemed much easier for the human ear to discern changes in pitch rather than volume of sound (2). Visual feedback has been attained through the use of light emitting diodes (LEDs), where light intensity or color would be indicative of meditation status (6). Pre-selection of a desired brain state has been used by a majority of the previous groups for circuit simplicity. This pre-selection would involve rotating a dial or altering a switch to the brain state one was training for (i.e., alpha or theta).

Some common challenges faced by the previous teams include weak signals due either to electrode selection and/or to poor contact with the scalp through hair, difficulties with auditory feedback in that the sound response was sometimes distracting to the person meditating, low and high frequency interference, and signal baseline drift. The main challenge has been signal interference resulting in complications during testing.

## Client Specifications

Our client, Dr. Muller, has proposed the following desired device characteristics. The device is to be intended for recreational (non-clinical) use to aid those learning how to meditate. The device should therefore provide some sort of feedback to the user to indicate the progress of the meditation. The device should not be overly expensive and should be easily transportable (i.e., lightweight and small overall size). The ultimate goal of the device would be to help the learning meditator to the point where the biofeedback would be unnecessary for the user to meditate effectively (i.e., after training with the device, the user would know how they should feel in the meditative state, where theta brain waves are predominant).

## Device Parameters

Desired amplification parameters include high gain, high CMMR, and minimal number of parts. Amplification of the brain signals requires high gain, because normal brain signals range from 10 – 100 μV in amplitude. Amplification of these signals by 100,000 (the highest amplification proposed by previous groups) would result in an output voltage between 1 – 10 V. Minimal number of parts ties into device portability, specifically in size and weight. A heavy and bulky device would not at all be easily portable by the user and might even distract the user during device operation.

Desired filter parameters include the incorporation of band-pass filters and separation of the brain state frequencies. A band pass filter (combination of low-pass and high-pass filters) may be used to isolate the various brain wave types from each other and to reduce interferences. For this project, the bandwidths of interest include alpha (relaxed) ranging from 8 – 15 Hz and theta (meditation) ranging from 4 – 7 Hz. In order to achieve the design specifications, our circuit will be composed of three sections: preliminary amplification, filtration, main amplification.

## Preliminary amplification

The purpose of this section is to amplify the voltages measured by the electrodes, so we can manipulate the voltage without distorting/eliminating the signals. We will use differential amplifiers with a gain of 25. The limit for preliminary amplification is set at the gain of 25 to avoid saturation of the operational amplifiers (typically 12V) because of the possible DC-offsets. The DC-offsets can occur at the maximum of 0.3V; with gain of 25, the amplification would bring the artifact to 7.5V— a value close to saturation of the operational amplifier. One important principle in the implementation of differential amplifiers is the Common-Mode-Rejection ratio (CMMR). The CMMR quantify the performance of a differential amplifier. Two configurations of differential amplifier, both having high CMRR, are sketched on the next page (figure 3 and figure 4).

The main difference between the two circuit layouts reside in the placement of the resistors. The differential amplifier depicted by figure 3 has resistors between the electrodes and the first operational amplifiers. This placement of resistors would cause attenuation of the measure voltages prior to amplification. Attenuation is the effect the resistors would have on the signal, both noise and the desired signal, which would result in the loss of both signal and noise. The loss of any signal is an undesired effect.

The circuit layout depicted by figure 4 will better suit our design specifications. There is no resistor before the first operational amplifiers; therefore there would be no attenuation of signals. The circuit layout in figure 4 is also commonly used in the amplification of electrocardiogram (ECG), which measures the biological stimulation of the heart by action potentials. The ECG has many similar properties as EEG, and we believe figure 4 circuit would work well for us after modification.

Figures 3 and 4

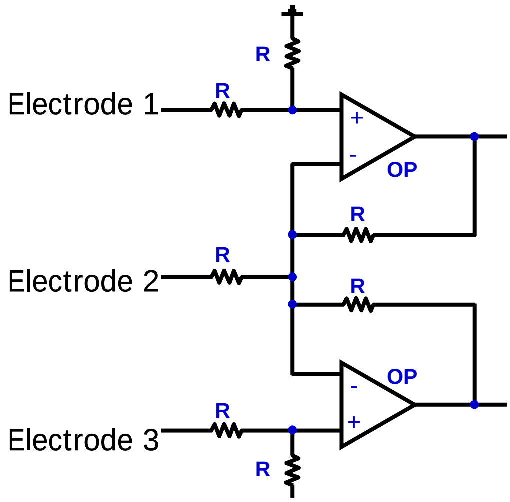


Figure 3: text book example of a differential amplifier. Differences in voltages between electrodes (reference with electrode 2) are amplified. Attenuation would occur due to resistors placement.

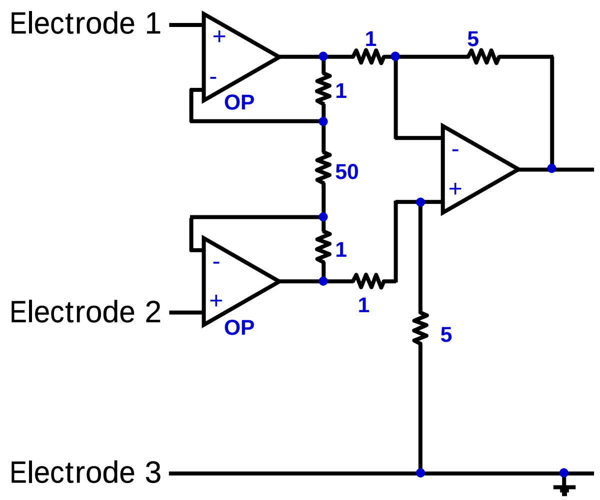


Figure 4: instrumentation differential amplifiers commonly found in the electrocardiogram. No resistor between electrodes and first operational amplifier, therefore no

# Filtration

This section of the design circuit will allow us to pick out frequencies of input signals that are of importance to meditation; we will use band-pass filters built from combination of high-pass and low-pass filters. Two circuit layouts were considered for the design: first-order filter (figure 5) and second-order filter (figure 6). Beside difference in complexity, the two filters also differ in their fall-off values. Fall-off values are measures of the rate of voltage decrease outside the band of allowed frequencies (figure 5 and figure 6); the higher the fall-off value, the more ideal the circuit filters. Although second-order filter has higher fall-off value, we believe first-order filter will work well for our purpose in designing a circuit to be used in non-clinical environments.

Figure 5 and 6

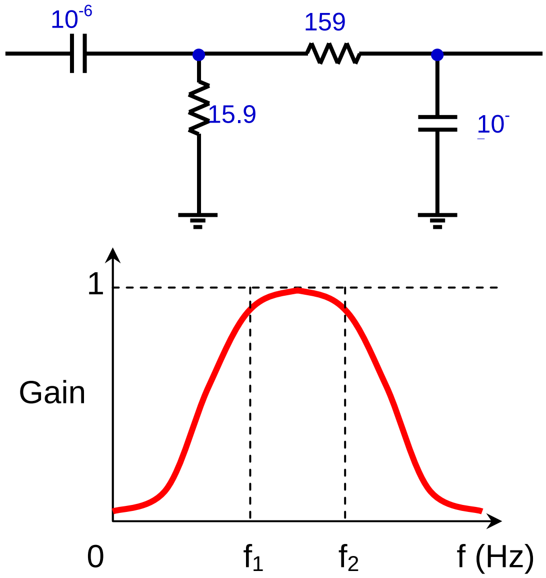


Figure 5: first-order filter circuit layout. The bottom diagram depicts the rate of voltage decrease outside the band of allowed frequencies (fall-off value).

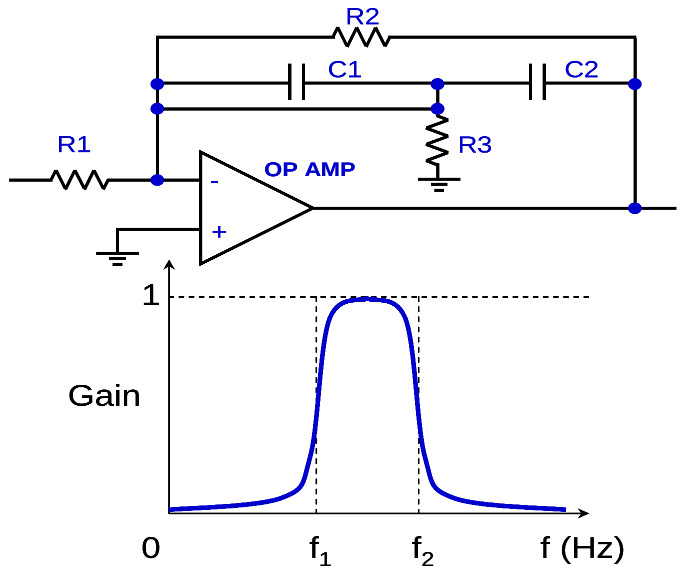


Figure 6: second-order filter circuit layout. The bottom diagram depicts the rate of voltage decrease outside the band of allowed frequencies (fall-off value).

# Main amplification

In order to amplify the voltages measure by the electrodes to an interpretable signal, we need an overall gain of $10^5$. The preliminary stage provides a gain of 25; the main amplification stage will provide the remaining gain of 4000. We plan to achieve the gain of 4000 in our circuit by using a non-inverting amplifier (figure 5). This operation amplifier setup are easy to implement into our circuit, and the gain of the non-inverting amplifier can be easily adjust by the ratio the resistors.

Figure 7

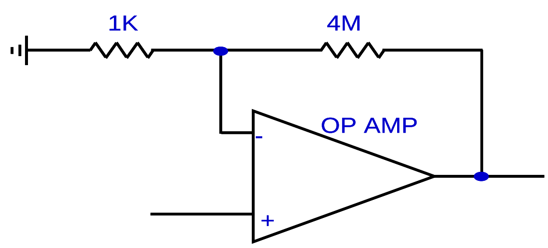


Figure 7: non-inverting amplifier. The gain of the circuit can be adjust by the ratio of the resistors. Currently, the gain of the operation amplifier is $4*106\Omega / 10^3\ \Omega = 4000$.

# Proposed Design

Figure 8

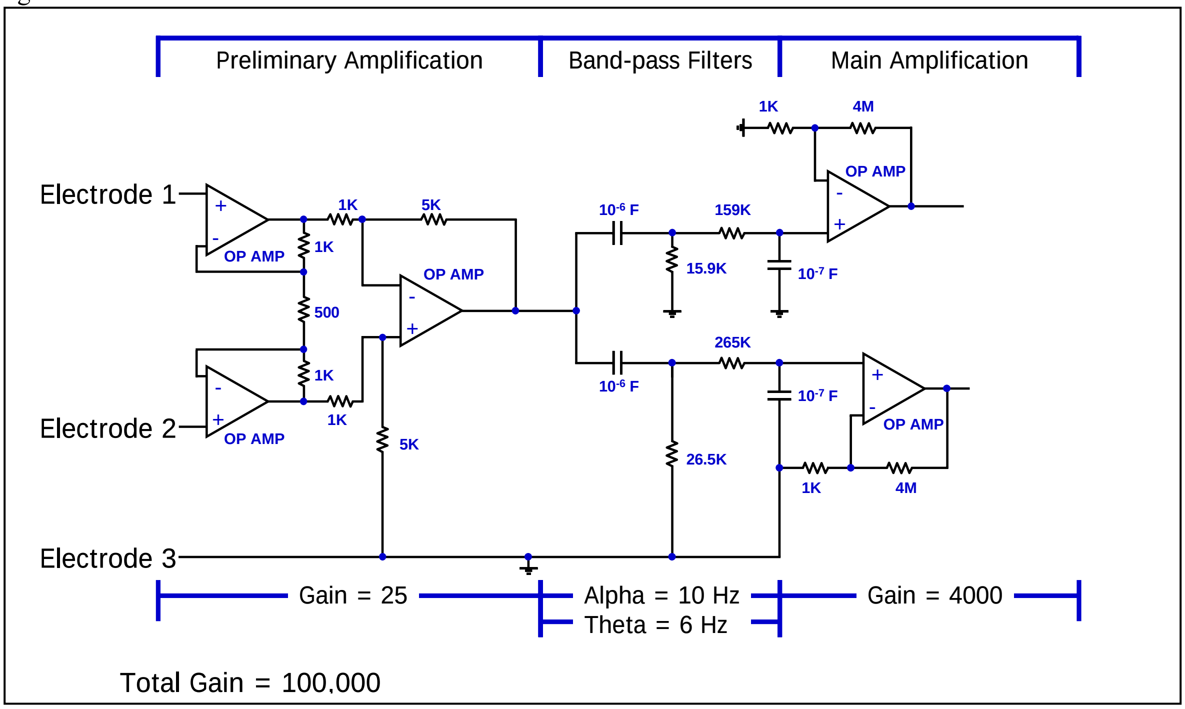


Figure 8 is a representation of the circuit that the team plans to build for testing. It has three components: primary amplification, filtration, and main amplification. The total gain of this amplifier will be about 100,000, which will convert the biological 10-100 microvolt signals into more usable voltages.

Figure 8 shows the schematics of the proposed design. The proposed design incorporates all of the three components mentioned earlier. The three electrodes from the device are first passed through the primary amplification device where the signal is amplified 25 times. From there, the signal is split into two separate signals before it is passed through the filtration devices. One signal will be passed through a filter that selectively filters alpha brain waves, centered at 10 Hz. The other filter will selectively filter theta brain waves, which are centered at 6 Hz. Each filtered signal will then be passed through the main amplification devices which will cause a gain of 4000. With gains of 100,000, the 10-100 microvolt signals will be amplified sufficiently to appear at the output as 1-10 V.

## Future Plans

Testing must be done on the circuit in order to see if the designed circuit behaves as expected. Once the circuit is built, the first action the team will do is to pass waves of known frequencies from a waveform generator through the circuit and measuring the output using an oscilloscope. Any components that are not behaving as desired will be modified to get adequate responses from the circuit.

The heart has a very distinct electrical signal, known as the ECG. With an amplitude of 1 millivolt, the heart is the strongest signal that can be detected on the surface of the skin. Using gel electrodes, which are proven to be capable of detecting bodily signals, and modifying circuit values to be incorporable into a device that will detect electrocardiograms and use an oscilloscope to measure the output of the circuit. This will test the circuit on biological signals yet still allow the testers to easily detect the targeted signal. EEG signals can be very difficult to recognize as they are not defined, where ECG signals will give the relatively inexperienced group a chance to recognize biological signals.

The values will again be converted to a range where EEG signals can be measured again. Using gel electrodes again, the group will begin to try and pick up EEG signals using an oscilloscope to measure the outputs. These values will be compared to professionally accepted EEG signals so that the output will be known to be significant. Modifications can be made at this point and will be done to maximize the output of the signal and minimize noise from non-biological sources.

After all testing of the circuit prove to be successful and meaningful data can be discerned from noise, the group will incorporate the circuit design into the Fall 2005 semester's prototype. This group reported that they did pick up meaningful data with the electrodes they used and the assumption we made is that they were successful in identifying the biological waves our group is interested in.

## Future Work

Testing a new circuit design takes patience and resolve. Our group decided that the main goal for this semester was to find a circuit design that will be successful in amplifying and filtering the detected signals, as this portion has given the previous groups many problems. However, there are yet additional portions of this project that must be completed. This may or may not be worked on by our group, it depends on how successful the initial design is and how much time our group has to work on the additional necessities of the project.

From the circuit, the signals must pass through signal processors. The most logical selection would be to use a comparator. Comparators take a raw signal and convert it to a digital signal. A signal that reaches the designed threshold will cause the comparator to saturate, giving the same DC voltage for all points above the threshold. If the designed threshold is not reached, the comparator will not give any output. The comparator would pass the signals into a feedback device that would be activated when the device receives output from the comparator. Aesthetics would need to be considered and all final testing would need to be conducted.

# References


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# Appendix

## Product Design Specifications

**Function:** The portable EEG (brain wave monitor) will take an incoming signal from a series of electrodes, amplify the signal to measurable and interpretable levels, filter out specific frequencies and present the occurrence of those distinctive brain waves in a manner applicable for biofeedback.

**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

**Design Requirements:**

*Physical and Operational Characteristics*

- Performance: Device should be able to be used for a minimum of two hours on a single battery charge, with the possibility of daily use.

- 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.

- 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.
- Size & Weight: Device should be portable and easy to transport.

- Accuracy and Reliability: Device should produce feedback accurate enough for qualitative analysis, not necessarily clinical applications.

- 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.

- Materials: Should incorporate a maximum number of reusable parts.

- Life in Service: Device should last a minimum of 5 years.

*Production Characteristics*

- Quantity: The portable EEG will be relatively mass-produced for consumer delivery.

- Target Product Cost: $100 - 200, compared to commercial versions ranging from $1,000 – 5,000

Other Characteristics

- Standards and Specifications: Meets national standards for electronic devices, as well as FDA requirements (Level 1 or 2?).

- Customer: Device should be conducive to a meditative environment (comfortable, a user-friendly, simple interface)

- Patient-related concerns: Preparation of the electrodes may be extensive, requiring daily cleaning, and eventual replacement.

- Competition: Should be able to produce comparable signal quality and feedback for a lower price, smaller packaging, and no necessary training.

*N.B. A patent search found a similar device using rapid LEDs as the feedback mechanism.*