Portable Electroencephalogram Biofeedback Device

Mid-Semester Report

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§1. Abstract

Biofeedback is a therapy currently being researched to treat many psychological and physiological disorders. It is not known how attempting to control autonomic functions of the brain helps, however results overwhelmingly point towards biofeedback's legitimacy. EEG biofeedback, monitoring and altering of brain activity, has been shown to effectively treat such problems as epilepsy, mood disorders, addictions, and attention-deficit/hyperactivity disorder. Current EEG biofeedback devices are made for clinical, not personal use. An inexpensive device is required to process brain signals and provide logical indications of brain activity is required. Several electrode types and feedback mechanisms as well as a design for high-gain amplifiers have been researched and analyzed. Current designs and anticipated future work are also discussed.

§2. Problem Statement

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 the presence of EEG alpha and theta waves.

§3. Introduction

Pharmacological therapies have been the standard way of treating most types of disorders and syndromes. However a new branch of medicine is currently becoming more developed. Alternative therapies are currently being prescribed by physicians include such treatments as acupuncture, chiropractics, and biofeedback. These treatments' mechanisms are not very well understood, however their results show progress in patient rehabilitation.

One of the most promising, biofeedback allows the user to view their own autonomic physiological changes. Physiological variation like pulse, blood pressure, respiratory rate, and brain activity can be monitored and eventually can lead to proficiency in controlling these automatic changes.

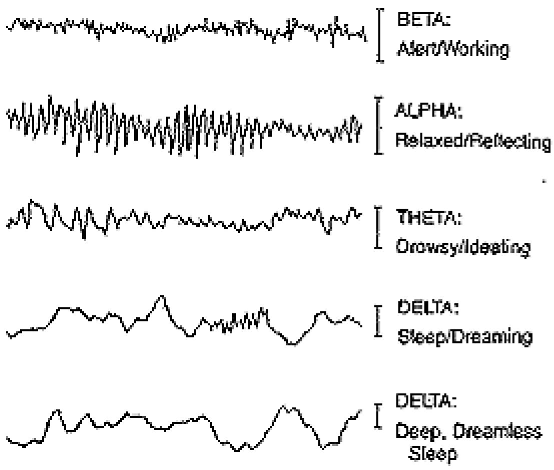

Figure 1. Raw EEG Data

Our client, Dan Muller, M.D., Ph. D., prescribes meditation as a means of mental health management. In order for inexperienced patients to learn how to meditate, a device is needed to tell the user exactly what type of activity their brain is currently undergoing.

When meditation occurs, a specific frequency of waves is observed in the brain. Typical active brain waves are called beta waves and vary from 15-40Hz. Relaxation and drowsiness can be seen as alpha waves in the 8-15Hz range. Meditation occurs in the theta waveform at 4-7Hz.

In order to monitor neuro-biofeedback, electroencephalographs (EEGs) are used to measure surface voltages on the scalp caused by neuron action potentials in the brain. These action potentials in the cells directly relate to how much brain activity is present, thus quantitatively representing brain activity.

When the user can quantitatively observe the state that their brain is in, they can begin to coach themselves into lower frequencies of brain activity than without the aid of a biofeedback device. This allows the user to achieve a theta waveform/meditation much faster and with greater ease in the future. With frequent use, EEG biofeedback has shown to improve a variety of ailments such as addictions, mood disorders, epilepsy, and attention-deficit/hyperactive disorder (Raymond, 2005).

§4. Literature Search

A patent search revealed several methods (6,855,112; 5,450,855; 5,280,793) for regulating neural responses via monitoring them on a display for the purposes of biofeedback.

Commercially available products are very expensive and are not typically EEG specific. For instance, the Stens NeXus-10 serves as an electroencephalogram (EEG), electrocardiogram (ECG), electromyogram (EMG), and slow cortical potentials (SCP). This device, while providing professional grade quality, will also run the buyer $4395. C2 and ProComp also manufacture high quality EEG biofeedback devices starting at about $2000.

§5. Design Constraints

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.

The device should also be small and portable, have the ability to be used daily, relatively simple, and comfortable as it will be used while meditating. In order to conserve costs, internal and external parts need as simple and minimal as allowed.

All aspects of the device need to be in compliance with AAMI and FDA standards and regulations for related devices.

§6. Proposed Designs

The EEG biofeedback device is actually an accumulation of three different areas of designs; electrodes for signal acquisition, an amplifier to create signal amplification and processing, and a biofeedback method for signal feedback. Described here are the individual designs for each.

§6.1 Plate Electrodes

The plate electrode is the commonly used electrode for the EEG devices. As the name suggests, the electrode is made of flat disc plate generally around 6-10mm in diameter and made of either gold or silver as they act as good conducting material. Electrode with silver and silver chloride coating on it is considered superior to

Figure 2. Plate Electrodes (http://www.electrodestore.com)

the only gold and silver electrodes as they provide low signal quality. The electrode has a hole at the top for electrolyte injection. The electrolyte acts as a conductor and provides better signal quality. The plate is attached to the shielded lead wires with ranges from 48" – 80". The shielding of wires is necessary for better signal quality. The electrode is placed on the scalp with the help of electrolytic gel containing adhesive properties. The advantage of such electrode is that it is passive in nature; hence do not require any kind of complex circuitry within the electrodes. Such electrodes generally have a life span of 1-2 years. Practically, it is difficult to attach the electrodes to the scalp and get good conductivity. In addition to this, the gel leaves the hair oily and sticky and is also a challenge to clean the electrode after every usage. The cost of the plate electrodes ranges from $70-90 depending upon the size of the disc, kind of plating, and the length of the cable attached to the plate.

§6.2 Pin Electrodes

This electrode design consists of a basic array of metal conducting pins fixed to a square electrode base board. These conducting pins, also known as header strips, are made of thin gold or silver metal and are between .5" and 1" in length. One hole is drilled in the electrode base board, a square piece of circuit board, for each of the 16 to 32 pins in the electrode. Each pin is then placed in a hole and soldered into position on the back of the electrode base board. Two of these electrodes are to be mounted on a headband and held firmly against the scalp.

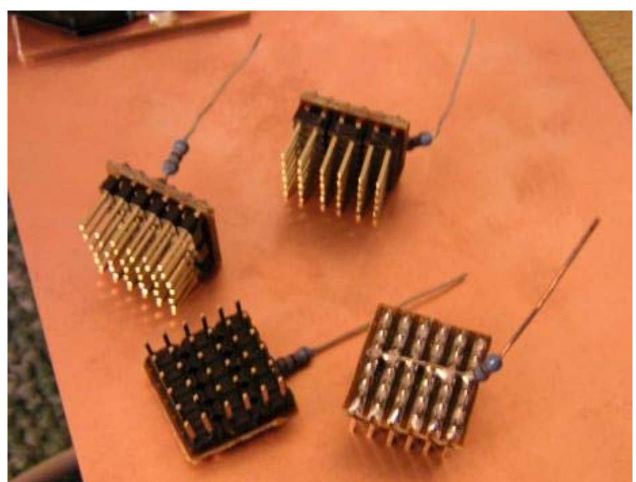

Figure 3. Pin Electrodes (http://openeeg.sourceforge.net)

The electrical signal from the brain is then measured by the electrode and transmitted to the amplifier.

One of several advantages of this electrode design is that it does not require preparation prior to use. The electrode does not require abrasive skin cleansing or the use of messy conductive gels. The long pins are easily able to burrow between hair and make direct contact with the scalp. The electrodes will also be reusable, which will cut down on the long-term costs associated with disposable, non-reusable electrodes.

There are also a few potential disadvantages linked with this electrode design. The complete lack of a conducting gel may result in poor signal quality. Also, because the electrodes are not connected to the scalp with an adhesive they are prone to slide along the scalp, which would cause destructive interference in the signal. One potential solution to this problem would be further tightening the electrodes to the scalp, although this could compromise the comfort level of the patient.

§6.3 Sponge Electrodes

Figure 4. Coaxial Headband (http://openeeg.sourceforge.net)

The coaxial cable design consists of a series of four to six homemade passive electrodes contained by a plastic headband worn in the typical fashion. Coaxial cable is stripped down to leave a stem of wire exposed, which is covered by foam rubber ear plugs (or other suitable porous and soft material) to ensure comfort and improved contact. Either individual and disposable plugs, or the entire apparatus, are soaked in an electrolyte solution – for simplicity's sake, currently salt water – to aid in making good contact with the scalp surface. To sufficiently measure small voltage differences in pertinent areas of the brain, the array of electrode "plugs" are arranged in an arch over the upper frontal portion of the head, representing part of the typical layout of electrodes used in clinical applications. The signal will be carried directly through copper wire to the device housing the amplifier, therefore reducing disturbances or noise a built-in amplifier or other source of interference would create.

§6.4 Amplifier

Due to the minute scale of the potentials on the scalp, the electrode signal must be amplified before it can be analyzed or processed. The instrumentation amplifier is designed to enhance the signal provided by the electrodes through a voltage increase, making the output much more practical for analysis. A differential amplifier will analyze the potential difference between the inputs for each channel, with all electrodes referenced to a common ground. Amplifier properties most important to instrumentation include common mode rejection ratio (CMRR), gain, noise, and frequency bandwidth (Rémond, 1976).

Two main amplifier designs have been previously proposed: a basic instrumentation amplifier, as well as an "amplifier with minimal parts" designed by VanRijn. Both previous circuits had difficulties with receiving a clear and consistent signal, which may be a problem with their amplifier, filter, or electrode design. The basic instrumentation amplifier design they proposed was rejected after a single preliminary test produced no results. Their consensus was that the VanRijn amplifier was the best suited for the device, but results were still unsatisfactory and they predicted additional problems with amplifier saturation due to DC drift.

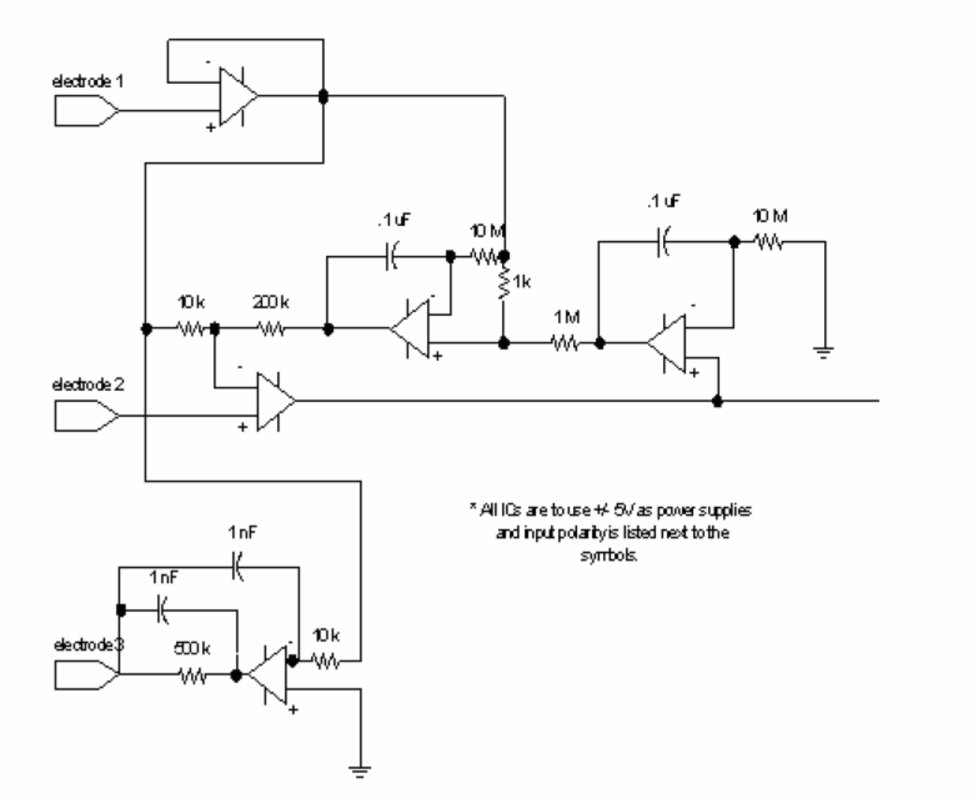

Figure 5. A diagram of the proposed circuit from the EPICS Fall 2002 group, based on the VanRijn amplifier design.

This amplifier is to be used in personal device designed for qualitative analysis. With this in mind, it is in our best interest to keep the design simple, sacrificing accuracy for lower cost. While considering the previous groups' designs, it was decided to move back to the most basic design and proceed from there by modifying the circuit to eliminate signal and saturation problems. Our initial design is a common instrumentation amplifier in two stages. The first stage is a differential amplifier with modest gain, and the second stage is a simple non-inverting amplifier that will produce the remaining gain required. The frequency bandwidth is shaped by first a high-pass filter followed by a low-pass filter integrated with the design. This type of amplifier is commonly referred to as a band-pass amplifier because only certain frequencies are amplified, while the rest are attenuated.

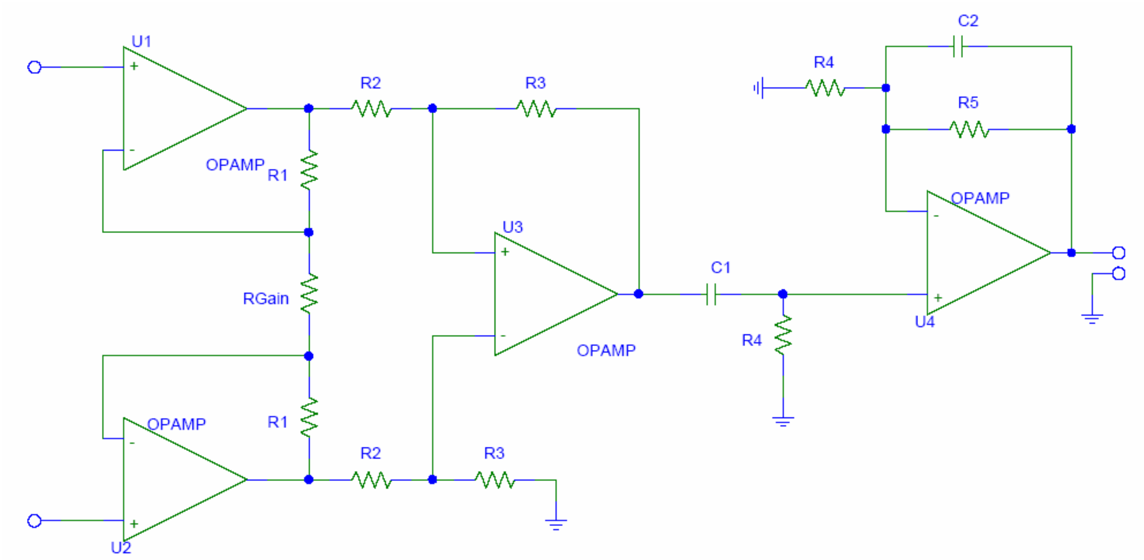

Figure 6. A diagram of our proposed circuit, based off a common instrumentation amplifier.

Basic circuit analysis provides us with several equations for the properties of this amplifier. These equations are good for preliminary calculations; however, a prototype must be built and tested to determine the actual properties of our non-ideal solution.

$$Gain = \left[\left(1 + \frac{2R_1}{R_{Gain}}\right)\frac{R_3}{R_2}\right]\frac{R_5}{R_4} \qquad f_{low} = \frac{1}{R_4 C_1 2\pi} \qquad f_{high} = \frac{1}{R_5 C_2 2\pi}$$

Currently the amplifier is designed to pass only the relevant frequencies, in this case the frequencies of theta (4-7 Hz) and alpha (8-15Hz) waves. These frequencies will be separated in the signal processing stage, which has not yet been developed. Adequate gain will amplify μV signals from the electrodes to 10-100 mV signals for analysis. This puts our gain on the order of 10^4. It may be beneficial to include a potentiometer that will adjust gain within a certain range for best results. The CMRR should be kept as high as possible for more accurate readings. Methods for improving the CMRR include adding a driven right leg (DRL) electrode, component matching, and electrode placement and design [3,4]. Component matching problems can also be addressed by using potentiometers in place of certain resistors, and "tuning" the circuit for best results.

These features have been left out of the initial design to save cost, and will be added as needed to improve performance.

§6.5 Feedback Method

When using the device, the feedback method is going to be the key to success. Without it, the user will not know where they lie on the meditation spectrum. Because of its direct interaction with the user, the mechanism must be easily understood as well as simply represented.

One way that feedback was previously approached by past groups was through the use of LED glasses in which the intensity of the light represented the frequency of the brain waives. We decided to stray from this design for two reasons; it's complexity in design and it required the user to keep their eyes open to accurately tell the intensity at witch the lights were shining.

The proposed design for the biofeedback device is made simpler by using an audio signal. The user does not then have to open their eyes, which provides more relaxed states to be achieved. The audio signals pitch will aid the user in gauging how relaxed they are. As the user becomes more relaxed and their brain waves decrease in frequency, the pitch will become lower and lower. Lower pitches also seem to be more relaxing, which is why the pitch does not increase with relaxation.

This effect is hoped to be achieved with the aid of frequency multipliers to make the relatively slow brain waves (4-15Hz) into audible tones (>~30Hz). The circuitry of the biofeedback method has yet to be further researched as well as the tone quality of the raw EEG data.

§7. Future Work

As seen in the design matrix (Figure 7), the coaxial electrodes look to be the most promising design to pursue at this point. After construction and testing of the electrodes, it can be decided as to the quality of their signal. In the event that a poor signal is produced, another electrode style will have to be developed.

There remain several outstanding elements of the design that need to be tested besides the electrodes. The amplifier without the DRL will be tested for its CMRR and if it is too high for acceptable quality, the DRL circuit will also need to be tested. The integration of the feedback method and the amplifier also need to be further developed, however, we must first get an acceptable signal before attempting to process it.

	Ease of manufacture	Comfort	Preparation simplicity	Cost	Aesthetics	Durability (reusability)	Overall
Coaxial cable headband	**8**	**6**	**8**	**9**	**7**	**8**	**7.6**
Pin electrodes	**2**	**4**	**10**	**4**	**7**	**10**	**6.2**
Plate electrodes	**10**	**4**	**2**	**1**	**3**	**6**	**4.3**

Figure 7. Design Matrix

§8. References

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MettingVanRijn AC, Peper A, Grimbergen CA. 1994. Amplifiers for Bioelectric Events: A Design With a Minimal Number of Parts. *Medical & Biological Engineering & Computing*, 1994, 32:305-310.

§9. Product Design Specifications

Portable Electroencephalogram Biofeedback Device

PRODUCT DESIGN SPECIFICATION

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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.