An Exploration of the OpenEEG Project

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C.H.G.Wright's BioData Systems, Spring 2006

Abstract

The OpenEEG project is an open source attempt to bring electroencephalogram acquisition and processing to the hobbyist and student alike. In this paper I explore the inner workings of everything from the home-cooked hardware to the plethora of free software for EEG analysis. I'll find out just what goes into creating the computer to brain interface. From there, I will experiment with biofeedback and EEG signal processing.

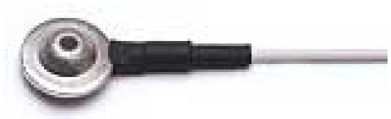
Contents

1 Introduction

The OpenEEG project was formed in 2000 as an open source hardware and software organization aimed at bringing EEG research to students at a low cost. They first designed two PCBs; an analog board that could filter and amplify and a digital board that could sample the signal and pass the data on to a PC. They have since coordinated with Olimex, a parts manufacturer, to have their boards pre-built and ready to order. Along with their low cost hardware, many different software packages have been released. All schematics, source code, and project information is available to the public to download for free.

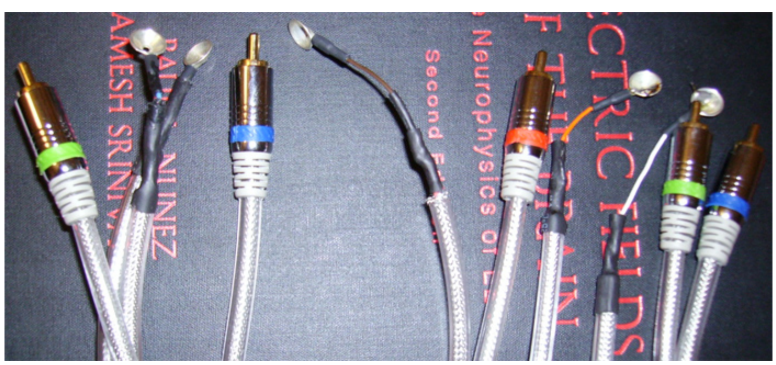
2 Electrodes

2.1 Passive Electrodes



The first step in the gathering of EEG signals is to draw the voltages off of the surface of the scalp. After researching through EEG websites I found that pure Silver or, even better, Silver-Chloride was the best medium to capture the signals from the skin. The electrodes alone do not make very good connections with the skin and a saline gel is needed to help conduct the signals.

The trick to getting a clean signal to the computer is not only the connection to the scalp, but also the shielding around the wire carrying the signal. I decided to go the same route as many other OpenEEGers and use good shielded audio cables. Since I had already ordered some electrodes, I cut the silver part off and attached it to the audio cable. I also wanted to pull signals from anywhere on the head, so I needed pin/needle electrodes. I did the next best thing and soldered a pin tip to another set of silver electrodes. I now had two sets of working, very low resistance, passive electrodes.



2.2 Active Electrodes

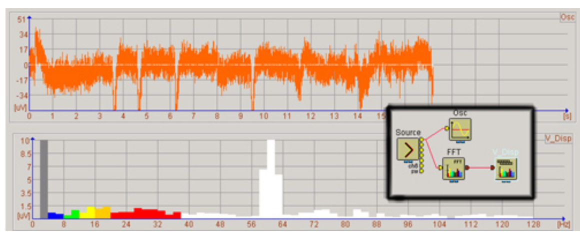
Active electrodes have an amplifier as close to the source of the signal as possible to avoid losing anything in the noise. Another big advantage of having a more amplified signal is not needing slimy

electrode gel. Here is an example of an active electrode made by Jarek Foltynski [3]. I decided against doing all the work to build active electrodes when the passive electrodes worked just fine.

2.3 Driven Right Leg

One of the biggest ways to combat a noisy signal is to hook up a third reference electrode away from the head know as a DRL, which can reduce common-mode signals. It is said to be able to attenuate main hum up to 100 times better than an instrumentation amplifier. [2]

Here we can see a huge spike of noise around 60Hz without the DRL.



After connecting the DRL to the body, the noise is drastically reduced.

Note: You can still pick out the spikes from when I blinked even in the noisy signal.

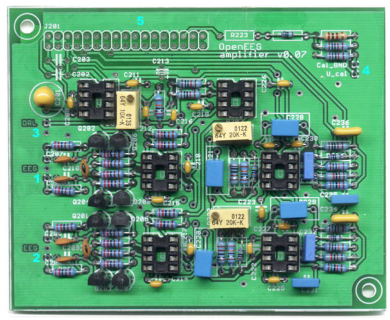
3 Hardware

As with many projects in the open source community, there are no standards and therefore, many different devices do primarily the same thing. In fact, there are numerous different hardware design schematics floating around the internet that can be used with the same software packages for EEG signal acquisition. In the OpenEEG community, there are only two devices that are highlighted; the ModularEEG and the scEEG.

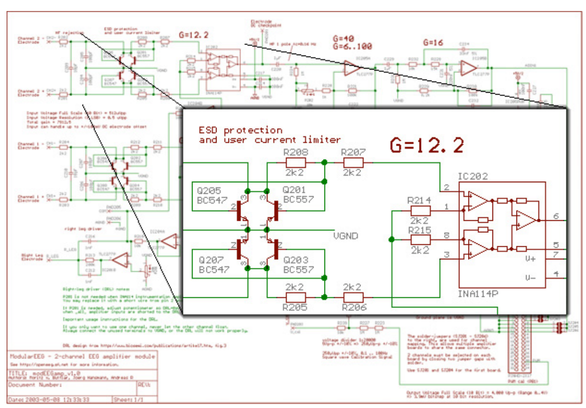
3.1 ModularEEG

The ModularEEG device is made up of an analog board for filtering and a digital board for signal processing. Multiple 2 channel analog boards can be connected to a single digital board to form up to 6 channels of EEG capturing. A ModularEEG system can be built within the range of $200 to $400 dollars, which makes it perfect for students that wish to explore EEG signals without spending thousands of dollars for a high-end system. The boards can be purchased bare and then assembled by the customer or pre-assembled directly from Olimex [1].

3.1.1 ModularEEG Analog Board



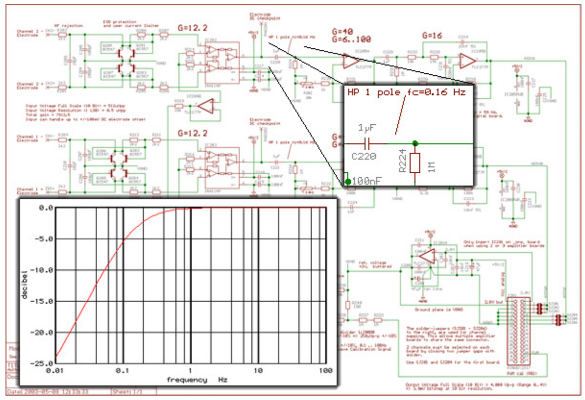
The signal entering the analog board from the probe is a very weak signal, around 10 uV, and is also full of noise, primarily 60Hz main hum. This signal is going to need to be filtered and amplified enough that the digital board can process it. The first stop on the tour of the analog board is the protection circuit. The protection circuit helps to limit the current hence protecting the circuit components from static and also the person hooked up to it, via electrodes, from getting shocked.

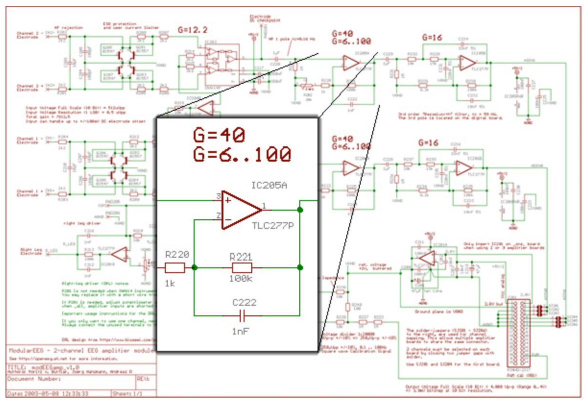


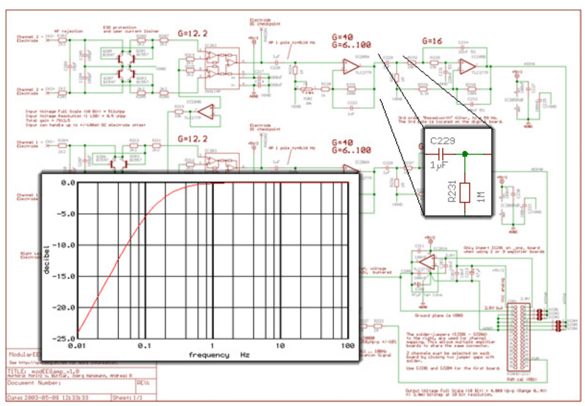
Next, the signal travels through an instrumentation amplifier that provides a gain of 12. After the first stage of amplification, the filtering process begins with a high pass filter to get rid of any DC components.

Then, a second stage of amplification boosts the signal by a gain of 40. It is important to note how the amplification is done in steps and certain bands of frequencies are eliminated.

A second high pass filter is then implemented. The purpose of this filter, as documented on the ModularEEG design website [2], is to filter out any DC charge that has accumulated on the probes.

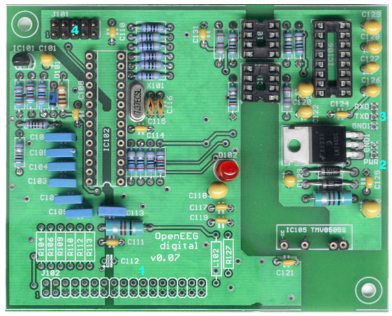




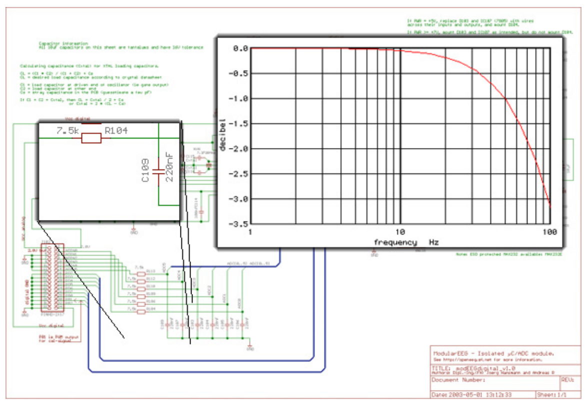


Finally, the signal passes through the last stage of amplification and is ready to be passed on to the digital board.

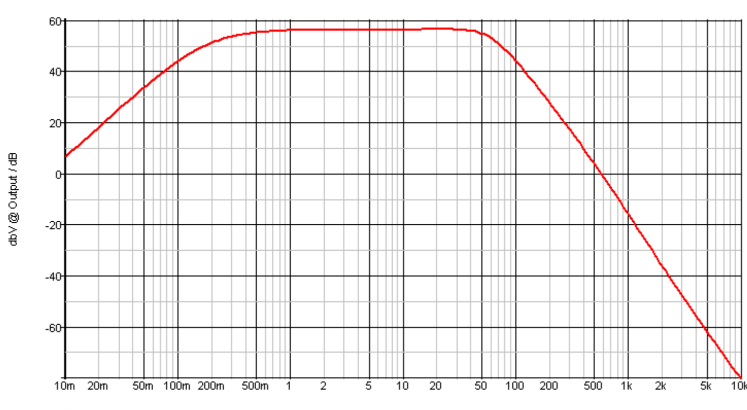
3.1.2 ModularEEG Digital Board



Confusingly enough, the final piece of the analog signal's path is a low pass filter located on the digital board.



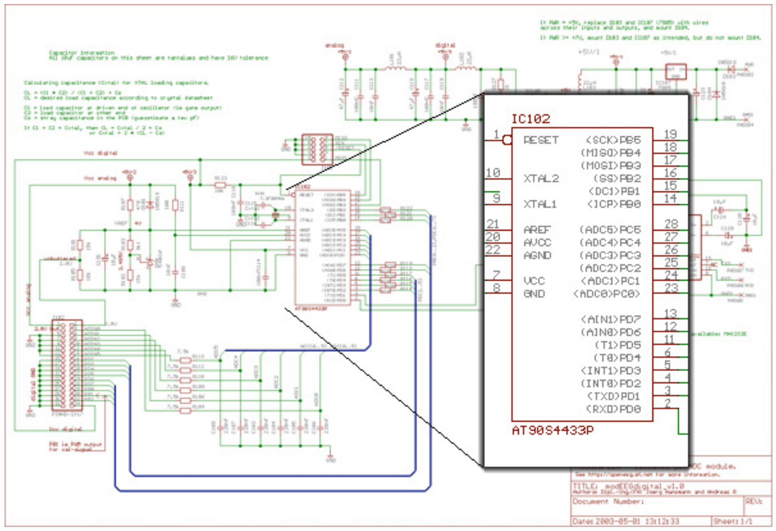
Here is the final gain of the entire filter from the ModularEEG boards straight from the OpenEEG website:



The final design is deemed a "besselworth", they explain it best as:

> ...it is modeled to be a blend of a Butterworth and a Bessel filter; The group delay is flatter than that of a Butterworth filter, but not absolutely flat as that of a Bessel filter.

The "knee" on the boundary between the pass and transition bands is more rounded than that of a Buttherworth filter, yet sharper than that of a Bessel filter. [2]



The main component of the digital board is its micro-controller, the ATmega8. The chip can do 10-bit analog to digital conversion on 6 different channels. When the signal leaves the micro-controller, it passes through an opto-coupler to provide circuit isolation. It is then passed on via RS-232 serial communication to the PC. Due to the nature of an open source project, the firmware for the ATmega8 is available for download straight from the main OpenEEG website. [2] I went for a quick dip into the firmware code and discovered it was pretty easy stuff. A timer clocked at 256Hz overflows and calls the analog to digital conversion on each channel. The information is then packaged into a packet and sent out to the RS-232 communication. I also purchased the small programming cable that allows the user to update the firmware of the chip.

3.2 Alternative Hardware: scEEG

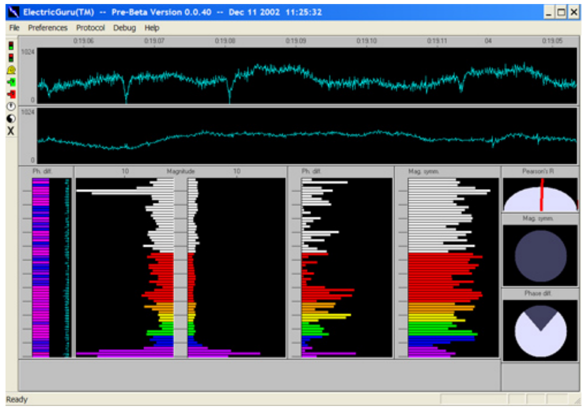
An alternate method is also mentioned called the SoundcardEEG. Even though most sound cards filter the frequencies lower than 20hz because of human hearing abilities, a method of frequency modulation can be implemented in hardware to pass EEG signals through to a computer that can use software to first demodulate and then analyze the EEG signals. This is a cheap method that requires little extra hardware, but they don't have any working modules released to the public so I decided to go with the ModularEEG boards.

4 Software

Now that the EEG signal is filtered, amplified, sampled, and passed on to the PC, it's time for a software package to work with the data. There are many different applications that are all available for download from the OpenEEG website. [2] Some are basic and limited to simple oscilloscope and FFT display, while others boast realtime complex EEG analysis. I picked out a few dissimilar applications to study in depth.

4.1 Electric Guru

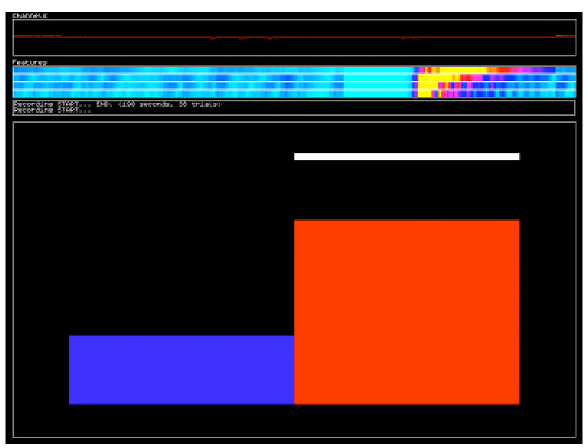
Electric Guru was the first open source EEG application I downloaded. It is a very simple but powerful application that is good for troubleshooting and checking that your electrodes are reading valid signals.



Electric Guru includes the signal plotted in the time domain along with frequency response and phase differences.

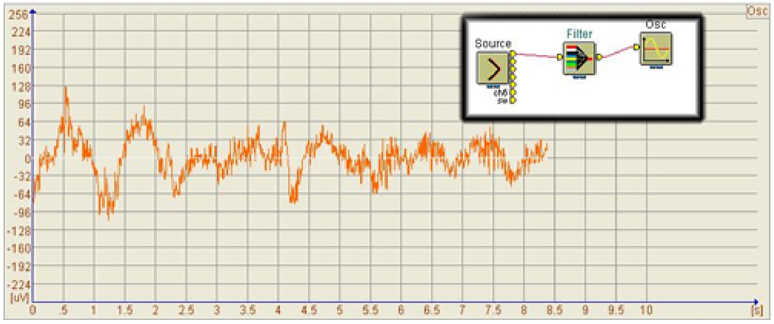
4.2 ABI BCI

ABI Brain Computer Interface is a small windows application that implements a neural network for Biofeedback training. It works by taking a raw EEG signal and filtering it down to frequencies that you specify. It then sends those specific, filtered signals into a two layer feed-forward neural network that learns how to differentiate between two or more different types of signals. For instance, there is a left white box and a right white box on the screen, and the user is supposed to do one mental task when the left box is displayed and a separate mental task with the right box comes up. The neural net then attempts to start predicting what mental task you are performing.



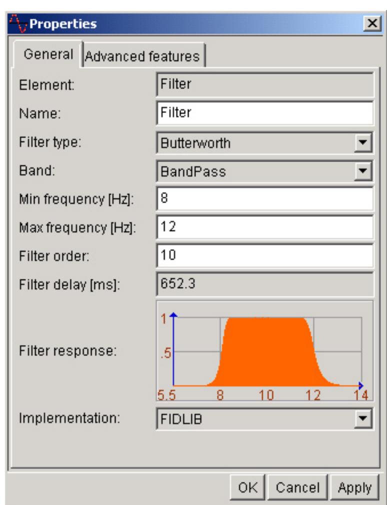
4.3 BioEra

BioEra is by far the best program I could find to interact with my OpenEEG module. It allows the user to build designs out of a large list of components. For example, I could drop in a filter, connect it to my incoming signal, configure it, and then connect it to an oscilloscope object.

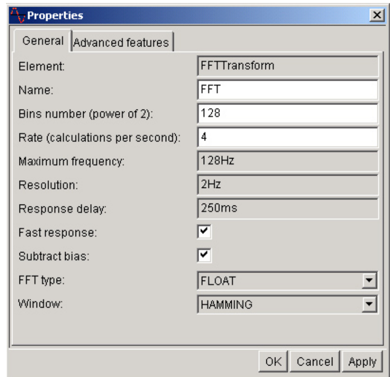


If you wanted to see an FFT, you just drop it in and connect it to a display.

BioEra also provides the user with enormous control of each component. Here is an example of how to configure a filter:



As you make changes to how the filter works, its frequency response is automatically updated.



You can also customize how the FFT will work.

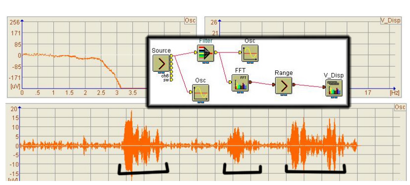
4.3.1 Eye Movement

The first thing I tested in BioEra was a simple threshold module to decide which way I was looking.

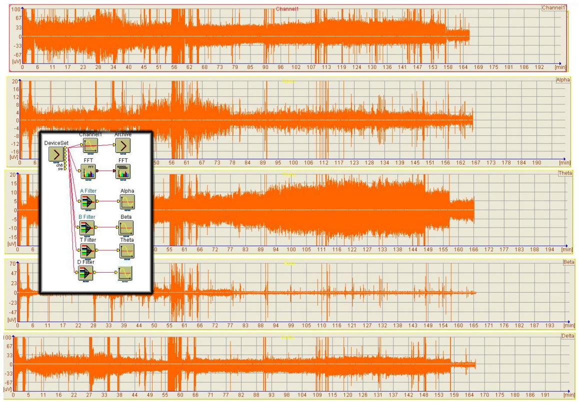
I set it up so which ever circle you looked at would turn green. It worked really well, but it was just facial muscle signals not actual EEG signals.

4.3.2 Alpha Waves

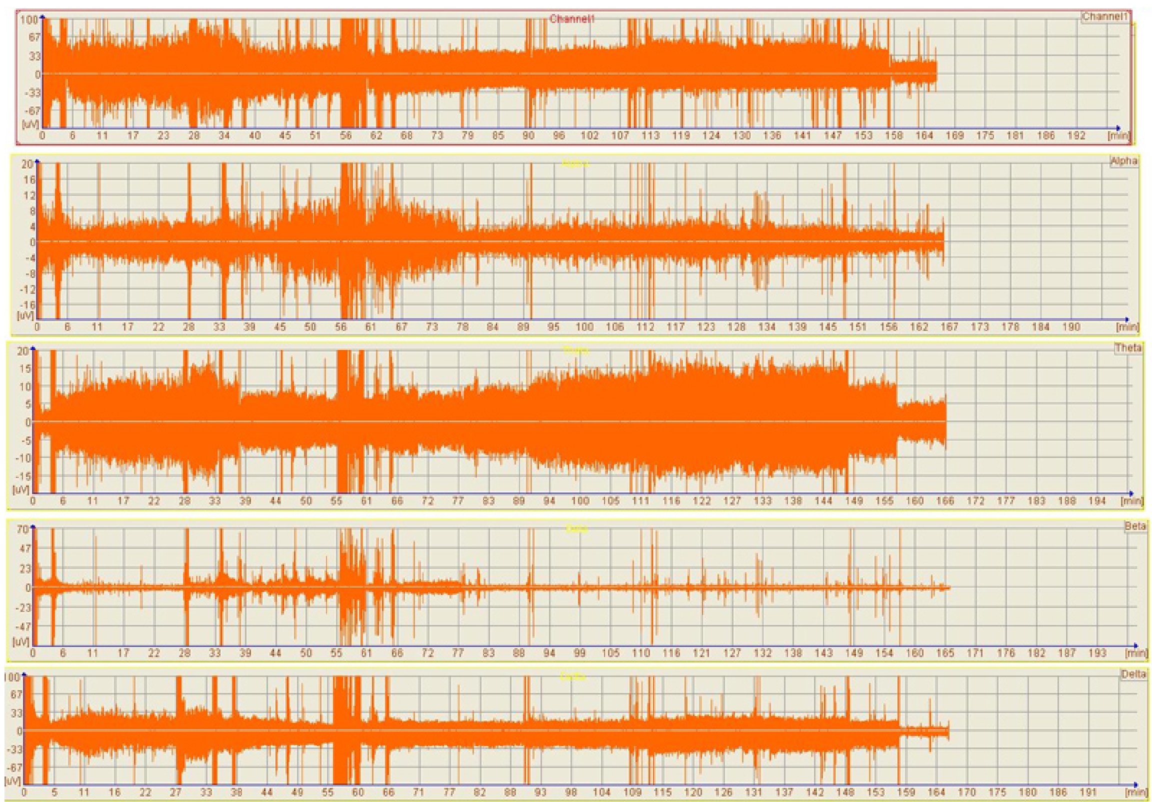
I knew that alpha waves would probably be the easiest EEG signal to capture. After building a BioEra setup that would filter out everything but the alpha band, I hooked the electrodes up the same way I had them to capture my eye movement. I couldn't see any distinct changes between having my eyes open or closed. After some reading, I found that the human alpha rhythm is quite interesting. The most important thing I discovered was that the best place to pull alpha waves is near the back of the head in the occipital cortex. [5] After this discovery, I took the needle electrodes I had built and hooked them up to the back of my head. After the signal settled down, I watched it for a while and then closed my eyes. When I opened my eyes I was amazed to see that the alpha wave had greatly increased while my eyes were closed.



4.3.3 Sleep Cycles



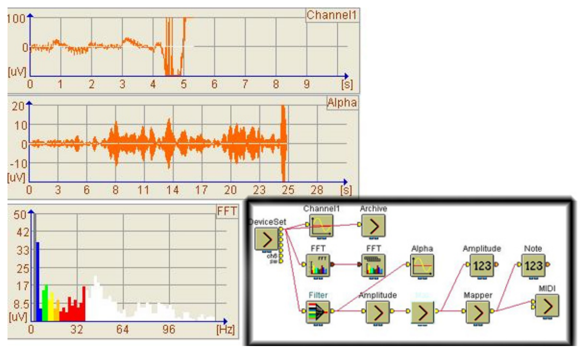
I recorded my sleep for a night and was surprised to see very distinct stages as the night went on.



From these charts, I can see the my alpha fades in and out, but my theta and my delta have very sharp transitions. Also, my beta rhythm was only visible right before and after I fell asleep, but never during deep sleep. Eventually, I would like to use both channels to do these readings. The first channel I will leave on the back of my head to get these nice transitions between stages, but the second channel could be used on my forehead to show eye movement during REM.

5 Neurofeedback

Biofeedback is a method of understanding, through feedback, and ultimately controlling functions of the body that we previously were unaware of. [6] Neurofeedback is a type of biofeedback that deals specifically with brain functions. Neurofeedback can be used to help patients overcome mental disabilities such as ADHD by practicing enhancing or avoiding certain frequency bands that represent underlying neurological processes. In my case, I used neurofeedback to enhance my alpha waves.



Within fifteen minutes of meditation-like relaxation, I was able to generate longer, stronger alpha waves. I did this using an example that came with the BioEra package. It uses your alpha wave to control the pitch of a MIDI output sound. Meaning, when my alpha waves are high, the pitch of the instrument also increases. When I have my eyes open the pitch then decreases to a low hum. By listening carefully and concentrating on what made the pitch higher, I was able to produce longer, higher MIDI outputs. My best explanation of how to get better alpha, and this is going to sound a little strange, is relaxing enough that I feel like I'm sliding down an enclosed water slide. Yeah, that's pretty weird, but for some reason, my alpha went crazy when I tried not to think of anything else but that.

6 Future Work

6.1 The Perfect Alarm

Although the body naturally adjusts its sleep rhythms to a human being's time schedule, I would like to interface the ModularEEG device with an alarm clock that could wake a subject up at precise times within their circadian sleep cycle. I feel that this could maximize a person's rest and help compensate for ever-changing sleep patterns. Along with this, a person could evaluate how they are sleeping by recording sleep stage information and viewing it compared to a base case they recorded.

6.2 Game Control

On the fun side, I would like to use an application called NeuroServer to interface with an online computer game I designed in the fall of 2005 named AIBattle. NeuroServer can pull and filter an EEG signal and then send corresponding TCP/IP data to an internet server. I would like to have a ModularEEG device judging a persons relaxation vs. aggression and use that information to control the game's swarms respectively.

7 Conclusion

I was able to completely build and experiment with the ModularEEG device within a semester's time on a college student's budget. Although my signal processing skills were sub-par, I could still filter and work with multiple frequency bands pulled in realtime from my own brain. This device has not been proven to be completely safe, however, it worked fine for me on 4 different computers in three different locations. Using BioEra, I believe a student with more knowledge could put together some pretty remarkable experiments. Also, I have just skimmed the surface of the neurofeedback and I believe that further investigation could lead to a better understanding of one's neurological processes. With products like the ModularEEG device, students are starting to learn more and more about their own EEG, but I would like to close by saying that many times something like the OpenEEG project can promise too much to the end user and then end up being a disappointment. So please, take this experiment for what it's worth... you can pull alpha waves from your own brain for around 300 bucks and about 25 hours of soldering and fine tuning.

References

[1] OLIMEX Ltd, http://www.olimex.com/, BULGARIA.

[2] The ModularEEG Design, http://openeeg.sourceforge.net/doc/modeeg/modeeg_design.html

[3] Active Electrodes, http://bioera.net/ae/

[4] The ABI software, http://www.dcc.uchile.cl/ peortega/abi/

[5] Paul L. Nunez and Ramesh Srinivasan, Electric Fields of the Brain, 2nd ed. , 2006.

[6] David G. Danskin and Mark A. Crow, Biofeedback An Introduction and Guide, 1st ed. , 1981.

[7] Ramoser and Pfurtscheller Real-Time EEG Analysis with Subject-Specific Spatial Patterns for BCI, December 2000.

[8] Barbara B. Brown Infinite Well-Being, 1985.