

CHARACTERISATION AND SEPARATION OF BRAINWAVE SIGNALS

K. SURESH MANIC^{1,*}, AMINATH SAADHA¹, K. PIRAPAHARAN²,
ARAVIND C.V¹

¹School of Engineering, Taylor's University, Taylor's Lakeside Campus,
No. 1 Jalan Taylor's, 47500, Subang Jaya, Selangor DE, Malaysia

²Department of Electrical and Communications Engineering,
Papua New Guinea University of Technology, Lae, Morobe, Papua New Guinea

*Corresponding Author: SureshManic.Kesavan@taylors.edu.my

Abstract

Neurons in the brain communicate through electrical impulses that give rise to both electrical and magnetic fields which are categorized into five different band limits. These waves can be measured outside the skull through an Electro Encephalo Gram (EEG). The utilisation of brainwave detection in other areas such as biomedical engineering and gaming industry is yet to be explored. Categorisation of different rhythms of brainwaves and brainwave pattern analysis make it easier to identify the mental status of a person. This research aims to develop a hardware and software that is tested using function generators to simulate the EEG signal from the brain. It is observed that the initial results based on the above that the device performs as expected and hence can be used as brain wave signal measuring device

Keywords: Characterisation, Brainwave recognition, Brain signal separation.

1. Introduction

Human brain is the largest and most complex organ in the human body. It is responsible for numerous tasks and functions the brain along with the spinal chord and associated peripheral nerves make up the central nervous system. The human brain control all aspects of life such as interpreting senses, initiating body movement, controlling behavior, logical thought and memory. It has fascinated countless scientists leading to the formation of a branch of medicine, neuroscience. The central nervous system control every part of a person's daily life from blinking, breathing and walking.

Abbreviations

BCI	Brain Computer Interface
DAQ	Data Acquisition
EEG	Electro Encephalo Gram
GUI	Graphical User Interface
LARS	Least Angle Regression
LOO	Leave One Out
PCB	Printed Circuit Board
VEP	Visually Evoked Potential

The human brain communicates with specialized nerve cells known as neurons by transmitting electrochemical signals generated by neurotransmitters. These transmissions create voltage changes that give rise to both electrical and magnetic fields that can be measured outside the skull through an Electro Encephalo Gram (EEG). The first interpretation of neurons as electrical conductors was made by Benjamin Franklin in 1751. And in later 1810 the Scottish physician Charles Bell and French physiologist Francoise Magendie discovered that the neurons were bidirectional [1].

The brain can be subdivided into four structures each with a different set of functions. These four structures are the cerebral cortex, cerebellum, brain stem, hypothalamus and thalamus. Moreover since each section of the brain is responsible for its own set of functions, different areas of the brain become more active than others depending on the person's state of mind or physical activities. Through this the EEG potentials for the location of this area of the brain will be higher and the observed frequency will be different based on the type of brain wave that is most prominent. There are five different band limits for the brain wave, namely delta, theta, alpha, beta and gamma. These identifiers are characterized based on the frequency range which is normally from 1 to 80 Hz, with amplitudes of 10 to 100 microvolts [2, 3].

Through analysis of these brainwaves obtained from EEG, gives important insight to the diagnosis of a number conditions that affect the brain such as Alzheimer's, Parkinson disease, epilepsy, dementia and the presence of tumours. The EEG measurements for different parts of the brain can result in identifying and determining the type of activity being carried out by an individual. This is because the cortex can be divided into four different lobes with a specific set of functions [4].

In a study conducted by Freschi [5] a mixed integer linear programming formulation for the problem of brain source localization was tested. A contradictory study by Munck [6] investigates whether it is adequate to model the localization of brain activity as a single mathematical dipole on the basis of Visually Evoked Potential (VEP's). A review on signal processing techniques for human sleep EEG signals by Motamedi-Fakhr et al. considers the three stages necessary for the analysis of EEG [7]. These stages are the pre-processing, feature extraction and feature classification. Signal processing allows for the extraction of detailed information from acquired brainwaves. In a study conducted by Bang et al. a new method for noise reduction in brainwave detection is proposed [8]. It was found that the EEG readings are contaminated by the user's head movement and in order to minimize this noise a frontal viewing camera is utilized. Losonczy et al. [9] in their study about embedded EEG signal acquisition systems also emphasize the importance of eliminating the 50 Hz power supply noise stating

that biological signal conditioning is a combination of consecutive analogue and digital transformations for efficient signal processing and pattern recognition methods. It is also important to ensure that these conditioning procedures do not have any consequence or should have a controlled consequence on the obtained signal to establish the integrity of the biological signals that are obtained.

A Chinese medical university conducted a study to explore the relationship between EEG recordings and the early prediction of epilepsy prediction [10]. 98 epileptic patients were followed up clinically for at least 13 years and classified into two types of epilepsy, including generalized epilepsy and focal epilepsy. The study revealed that the initial EEG and the following repeat EEGs were useful information that could reflect the long term prognosis of epileptic patients. The correlation analysis also indicated that there were significant correlation between the initial EEG and the clinical outcomes.

Custo et al. [11] proposed to estimate the EEG sources for identifying electrophysiological states are studied. These states represent the spontaneous activity that are evoked by a stimulus or is caused by disease or disorder. The research studies the effects of determining the electrophysiological states based on topography and are tested using established methods. It can be seen that the topographic differences in spontaneous band-limit frequency can be directly related to local variations in attention or to mental diseases or pathologies. Spontaneous activity is also used to describe a limited number of distinct potential maps that are repeated over time. This method is robust against most common artifacts and sets the states driving the method from the obtained EEG data itself.

Rodriguez-Bermúdez et al. [12] exhibited that signals from brain activities can be used as control commands with the help computer to control devices. Four feature extraction methods are used to obtain the features by combining the most useful features for classification with less computational requirements. The classifier that is utilized requires periodic fast adjustment for subsets in the changes of EEG signals. A wrapper methodology based on Least Angle Regression (LARS) and Leave One Out (LOO) [13] is used to build a linear classifier Brain Computer Interface (BCI). It is meant as a fast and accurate linear discriminant integrated with embedded feature for the classification and combines power spectral density analysis and Hjorth parameters. In the studies conducted it is found that from the four bands in an EEG signal, the alpha and beta band is the most concentrated in energy.

There has been little research made into the recognition of brain wave patterns and the separation of brainwaves into different categories. Furthermore the apparatus for measuring the waves tend to be bulky. The presented work aims to contribute to the design of a portable device, capable of acquiring brainwaves, analysing then and displaying the different bandwidths that the wave comprises of in real time. This device is aimed to making the process of obtaining, analysing and evaluating the brainwaves faster and easier so that it may ultimately provide a better understanding of the patient and provide better patient care.

2. Research Methodology

The design stage of the research is based on the realization of the brain wave through the usage of function generators and the classification of it based on

electronic filters. Five function generators are used to produce five different waveforms each representing a bandwidth of the brainwave. The combination of a low pass and high pass filter is used to create a band pass filter that can filter out the unnecessary frequencies and conditions the signal. Signal input is given through the analogue signal generators which are then input into the data acquisition device DAQ mx 6009. The signal is then goes to the LABVIEW software where all the frequencies are then added up to create a mixed signal and this signal then passed through band pass filters which filter out each of the frequencies that are analogous to each band of the brain wave. Signals that are sampled from the Data Acquisition (DAQ) are sent to a signal processing software, LABVIEW [13]. Within this platform the signals are then added up which represents the actual EEG signal from the brain. Band pass filters are then implemented through the software to analyze the signal and separate it into the components frequencies. These signals are then filtered into the different component bands of the brainwave and used analysed through Fast Fourier transform and power spectrum analysis Tests are conducted to evaluate the software and assess whether the five different filters in the setup perform correctly.

The block diagram in Fig. 1 indicates the different stages of obtaining the signal and analyzing it to component categories based on its characteristics.

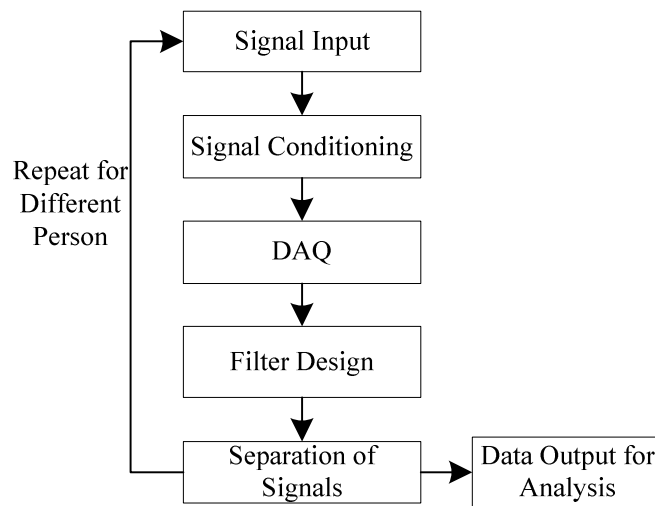


Fig. 1. Flowchart indicating methodology of research development.

The signal is obtained from five different signal generators each of which represent a band of the brainwave signal. It then passes through the the signal conditioning and acquisition is carried out through hardware. The addition of signal to create a mixed signal that represent the EEG and the filtration into the different bands are carried out through the software. A Graphical User Interface (GUI) is then developed through LABVIEW in order to make it easier for users to visualize the data. This interface shows the activity of the signal generator, the signal that is obtained and the filtered out signals and is displayed in Fig. 2.

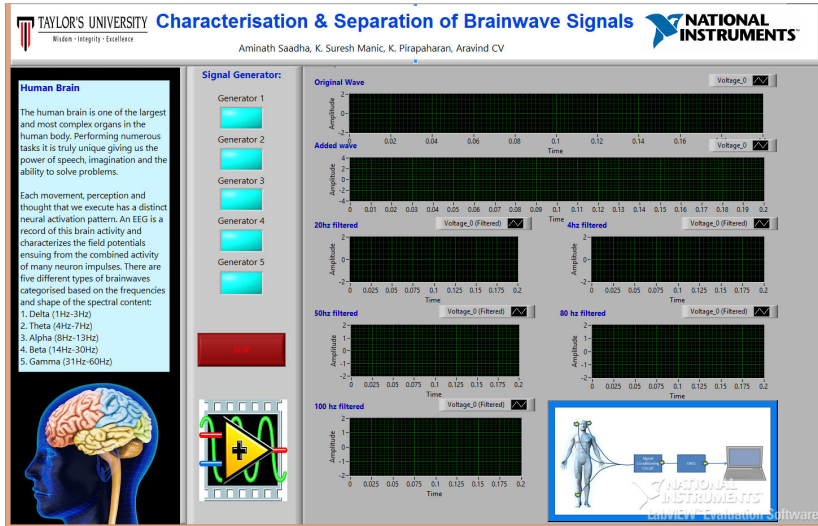


Fig. 2. Graphical user interface developed for analysis.

2.1. Signal acquisition

This is the selection of electrodes for sensing the brainwave from the skin. Conventional wet electrodes require extensive skin preparation and application of electrolytic gel for high quality low amplitude recording, which is the type of waveform that will be generated from the brain.

The gel is used to obtain a dielectric semi-permeable barrier between the electrode and the epidermis, therefore enhancing electrical conductivity through the outermost layer of the skin. Usage of such wet electrodes are time consuming and will make the device less portable therefore the electrodes used in this study is to be fabricated under the method indicated by Matteucci, where dry spiked electrodes are utilized for measurement of EEG [14]. These electrodes are suitable for long term usage and overcome the impedance problem of the skin. The electrodes that are to be used in this research are the passive electrodes available from AD Instruments. The Passive Electrode captures the signal without a built in amplifier. Therefore a principal aim when using this electrode is to reduce all possible skin resistances as much as possible. With these electrodes signal to noise ratio decreases and many movement artifacts are amplified along with the signal.

2.2. Hardware implementation

This is the design and fabrication of the hardware units for the EEG recording. It will mainly focus on the analogue section of the project. Brain waves are analogue signals and the waves captured by the electrodes will be amplified. Some problems that are to be faced in this section include noise levels. The brainwaves detected by the EEG will have very small amplitude that will have to be amplified using an amplifier circuit [15]. However the raw waveform will have

noise interference included in it and the noise signals will be amplified along with the original brainwave signal. In order to reduce the noise interference and provide high amplifying factor, an instrumentation amplifier (AD 620) is used. Since brainwaves are between the frequencies of 3 Hz-60 Hz, it is important to use a low-pass and high-pass filters to avoid unwanted noise. Hence pair of Butterworth filters constructed using LM741 amplifiers which are used for a smoother response and unity gain in order to eliminate any noise amplification. Finally a 50 Hz notch filter is designed using LM741 for eliminating the noise accumulation from the 60 Hz power supply. Figures 3(a) and (b) show the laboratory setup for characterization of brain wave and hardware setup for filter design. All the circuits are designed through MULTISM transferred to ULTBORD to create the Printed Circuit Board (PCB). The footprints for the components are selected beforehand and are then arranged on the board layout. Adjustments are made to ensure the smallest working design for the PCB design. Finally the PCB's made for the signal acquisition and conditioning.

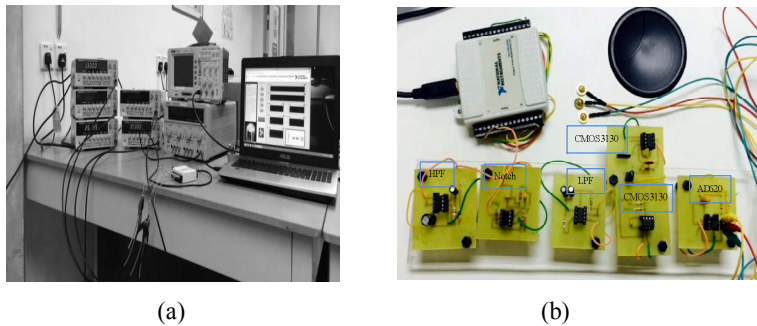


Fig. 3(a) Laboratory setup for characterization of the brainwaves
(b) Hardware electronic filter design.

3. Brainwave Measurements

The implementation stage aims to acquire the brainwaves, separate them into different components and analyse them based on the activity of the subject [16]. Experimental conditions are created which will stimulate the brain to produce a type of brainwave and the results are then obtained. Two studies are to be conducted, under the condition of the subjects (test models) being relaxed with the eye closed and the other when the subject is in deep mental thought. Both these studies are tested for the repeatability and reproducibility of the brainwave that is acquired. The subjects used in the study are of the age range 24-27 with no gender bias, where by two of them are male and the other is female.

Three case studies are conducted to obtain the brain wave and analyse which signal is most prominent while conducting that particular activity. Three components of the brain wave namely alpha beta and gamma are measured. This is to because theta and delta rhythms are mainly found in babies and in very deep sleep modes.

Case 1: Relaxed mode

The subject is given 15 minutes to listen to some relaxing music and sit in a relaxed position in an office ergonomic chair with a good back rest. This gives the

subject enough time to properly relax, calm their thoughts and empty the mind. After the fifteen minutes readings are taken from the subject while sitting down and with eyes closed.

Case 2: Intense mental thinking

The subject is given a mathematical question with fifteen minutes to complete it. Brainwaves are acquired 5 minutes into the exercise while the subject is still answering the problem. The duration for completing the exercise in order to ensure that the subject does not slack off and is really into thinking on solving the problem.

Case 3: Changes in brainwave when going from relaxed to intense mental thinking

In this experimental setup the subject is at first allowed to relax and then after 10 minutes of relaxation a mathematical problem is given to subject to solve. Brainwave readings are taken every five minutes to measure the alpha and beta waves to see the changes in component brainwaves with change in mental activity.

4. Results

The design process involving all the filters is to be analysed for repeatability and reproducibility. There are two main sections for the results discussion. The first is for the results obtained in the design realization section of the methodology. The second section looks into the real time brain wave results that have been obtained in the signal analysis section.

4.1 Brainwave realization

Two tests are conducted to evaluate the detection of frequency of components in signal after filtration and to check whether the intensity of the signal is detected. For test1 two case studies are conducted to since the device is intended to be used for people with different personality, meaning that the brainwaves vary from person to person. In the first case signals are all within the frequency band of the band pass filter. This test assumes that all the frequencies of brain waves are present in this signal and tests the detection of all the frequencies. In Case 2 the signal from a signal generator is changed so that it does not fall in any filter category. This signal assumes that the subject does not produce one frequency of brain wave at that moment and all other frequencies are being detected. Table 1 shows the frequency of signal from each signal generator for the two cases. A second test is designed to check whether the intensity of the brain wave is detected by the software. For this study the amplitude of the 4 Hz signal generator is increased from the input while the amplitude of other frequencies is maintained constant.

Table 1. Case studies conducted to test the design.

Case	Signal Generator frequency (Hz)				
	1	2	3	4	5
1	4	20	50	80	100
2	4	20	50	120	100

Figure 4 shows the results from Test 1 - Case 1, where all the signals are detected as shown by their representative amplitudes. However in Fig. 5 which

displays the results for Case 2 the amplitude for the 80 Hz signal is almost null indicating that there is no signal and that the filters function as expected.

Figure 6 displays the results for Test 2 where the detection of intensity of a signal is detected. As expected the amplitude which corresponds to the intensity of the wave is increased which is shown in the greater amplitude of the signal.

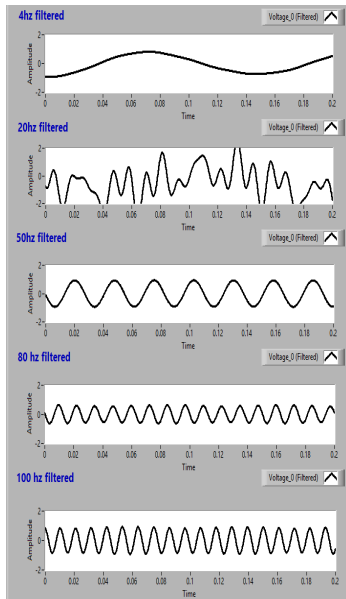


Fig. 4. Results for Test 1 Case 1.

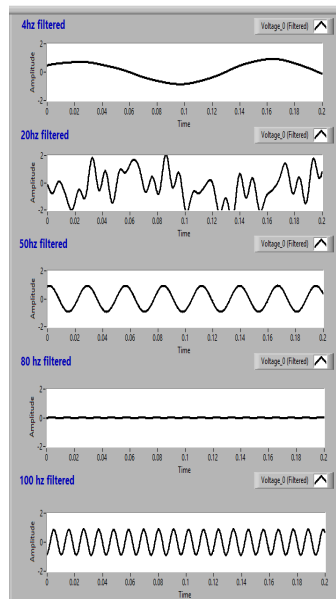


Fig. 5. Results for Test 1 Case 2.

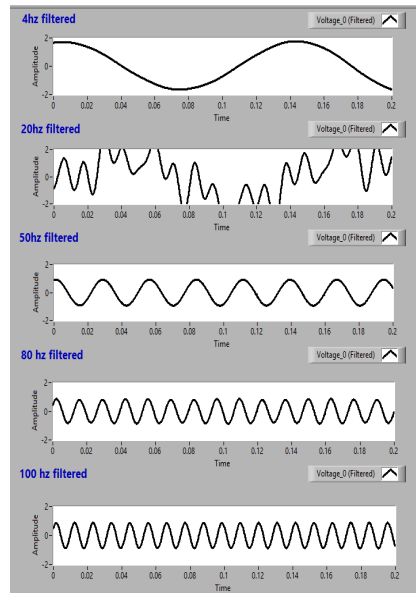


Fig. 6. Results for intensity test.

4.2. Results of real-time brainwave analysis

Three case studies are conducted to obtain the brain wave and analyse which signal is most prominent while conducting that particular activity. Three components of the brain wave namely alpha beta and gamma are measured.

In relaxed mode (Case 1), measurements are taken after the subject is given enough time to properly relax, calm their thoughts and empty the mind. Signals are acquired and analysed for 3 different subjects and the results are tabulated in Table 2.

Table 2 tabulates the results of the ratio of amplitude division in the component frequencies for Case 1. It shows that the alpha wave is predominant during relaxed and eye closed conditions for all three subjects. This wave is emitted in a higher intensity by the subjects during this form of activity.

Also the spectrum of α , β and γ waves for the subject 1 is shown in shown in Fig. 7 for relaxed mode. Figure 7 sows the alpha wave is most predominant with 15mV amplitude corresponding to 70% intensity. The power spectrum analysis also corresponds with this high amplitude and shows a larger peak at the frequency of alpha waves between 8-13 Hz. The beta and gamma waveforms have amplitude of 6 - 6.4 mV.

Table 2. Ratio of amplitude of component bandwidth for Case 1.

Subject	α Wave	β Wave	γ Wave
1	0.7	0.2	0.1
2	0.8	0.19	0.2
3	0.5	0.3	0.1

In intense mental thinking mode (case2), subjects are given a mathematical question to solve before taking the readings. Data is taken 5 minutes into the exercise. Table 3 summarizes the results indicating the distribution of power among the bandwidths.

Table 3 tabulates the results of the ratio of amplitude division in the component frequencies for Case 2. It shows that the beta wave is predominant when subjects are under heavy metal duress and performing logical thinking. This wave is emitted in a higher intensity by all the subjects during this form of activity.

Table 3. Ratio of amplitude of component bandwidth for Case 2.

Subject	α Wave	β Wave	γ Wave
1	0.2	0.7	0.1
2	0.17	0.78	0.3
3	0.23	0.67	0.21

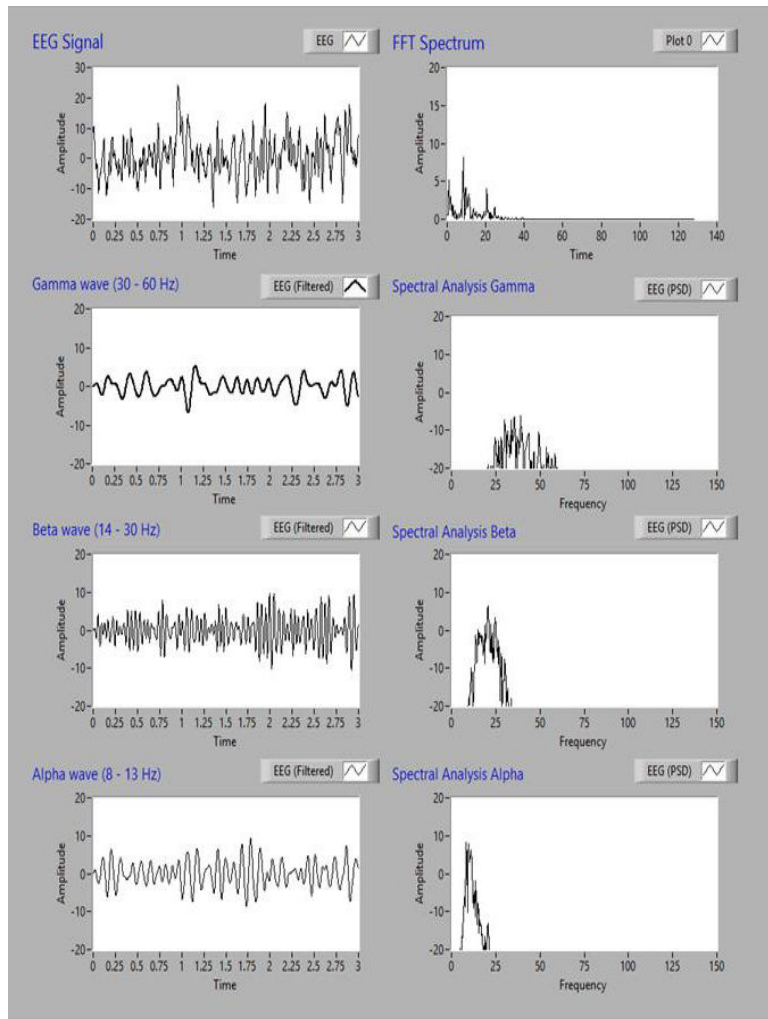


Fig. 7. Time and spectral components of signals for Subject 1 (Relaxed).

The spectrum of α , β and γ waves for the subject 1 is shown in shown in Figure 8 for intense thinking mode. Figure 8 shows that the beta wave is most predominant with 13.4 mV amplitude corresponding to 67% intensity. The power spectrum analysis also corresponds with this high amplitude and shows a larger peak at the frequency of beta waves between 14-30 Hz. The alpha and gamma waveforms have an amplitude of 5.5 - 4 mV, changes when going from relaxed to intense mental thinking mode (Case 3), the subjects are at first allowed to relax and then after 10 minutes of relaxation a mathematical problem is given to every subject to solve. Brainwave readings are taken every five minutes to measure the alpha and beta waves to see the changes in component brainwaves with change in mental activity. Table 4 shows the power spectrum readings for the changes at five minute intervals.

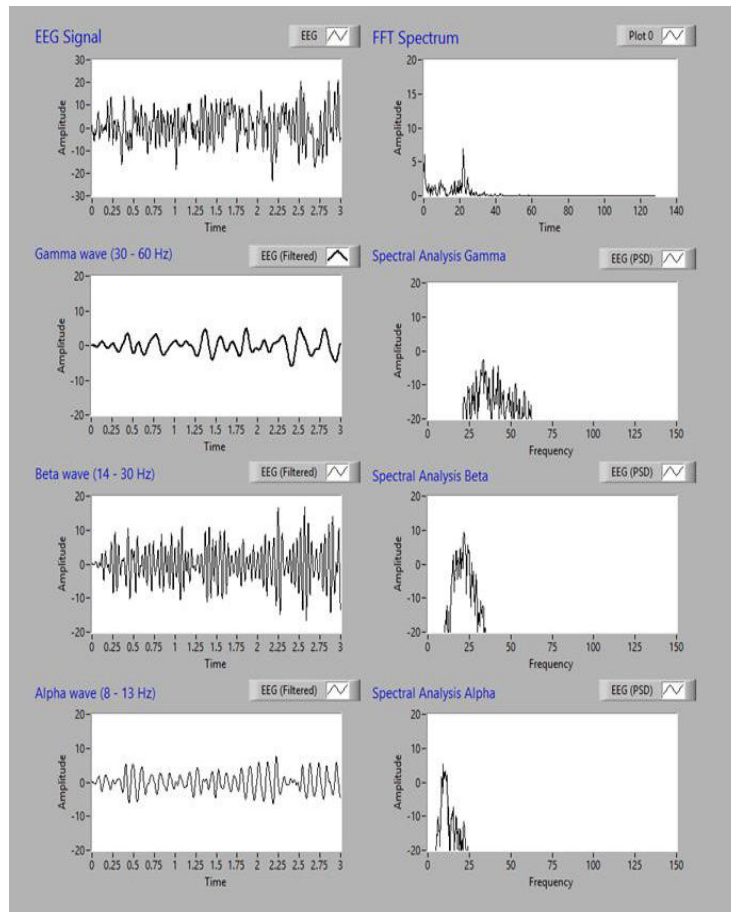


Fig. 8. Time and spectral components of signals for Subject 1 (Thinking).

Table 4 shows the changes in beta value over time as the subject transitions from mental relaxation to intense mental thinking. It can be seen that the alpha waves are dominant, having a higher amplitude during the first 10 minutes while the subject is not thinking with the eye closed. After the ten minutes the beta waves take dominance as indicated in Table 4, showing that these waves are abundant and almost of 70 - 80 % when subject undergoes intense mental thinking while trying to solve the mathematical problem.

Table 4. Power spectrum readings for alpha and beta wave over a period.

	Time							
	5 Minutes		10 Minutes		15 Minutes		20 Minutes	
	α	β	α	β	α	β	α	β
Subject 1	0.60	0.3	0.70	0.43	0.20	0.70	0.18	0.69
Subject 2	0.75	0.25	0.64	0.22	0.17	0.78	0.35	0.75
Subject 3	0.54	0.17	0.67	0.3	0.23	0.67	0.14	0.55

It can be summarised that the alpha waves are emitted more while the subject is relaxed and beta waves are predominant during intense mental activity.

5. Conclusions

This research proposes a system that would allow for real time acquisition of EEG waves. The system is designed by realizing the brainwaves through the usage of different function generators and then the design was verified by applying known frequencies as input. This design was then implemented in real time through the usage of electrodes for obtaining the brainwaves [17]. It was found that the proposed system was with an error of 5.27%. The system was then tested at different conditions to test the conditions of the brain and to see the type of wave that was emitted at different conditions. It was also found that alpha waves were dominant during relaxation almost at 60% and beta waves are of 70% during intense mental thinking.

The current system acquires brainwaves through only one channel. This is from a small area of the brain. Added channels will help in acquiring a more realistic brainwave, over a larger area, therefore giving more accurate results. Further, the sampling rate of the analogue brainwave can be increased in order to have better digitization and reconstruction of the wave.

In order to come to a general conclusion of brainwave characteristics with different mental activities, broad range of data must be obtained for numerous conditions and over a larger population to generate a master data base to demonstrate that the band patterns for the brainwave have direct correlation to mental activities. This enables us for better verification of our findings and the formation of a reliable database.

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