IJARCCE
ISSN (Online) 2278-1021
ISSN (Print) 2319 5940
*International Journal of Advanced Research in Computer and Communication Engineering*
*Vol. 5, Issue 6, June 2016*

# EEG Signal Acquisition for Sleep Analysis

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**Abstract:** This paper describes the design of a portable, low cost EEG (Electroencephalogram) signal acquisition device which also further divides the EEG signals into its frequency components for sleep study .The primary focus of the paper is on signal acquisition and frequency division of the EEG waves into five major components. The uniqueness also lies in the minimal usage of electrodes namely 10 at the most important scalp locations. The input from the electrodes is then subjected to various amplification, filtering, noise removal techniques in both analog and digital domain, however the use of analog filtering is kept to a minimal as we try to exploit the advantages of digitization which include increased accuracy, minimal usage of hardware, and operability at lower frequencies .Further processing of the signals is done using a DSP enabled processor, allowing for digital implementation of filters.

**Keywords:** analog, EEG signals, DSP, amplification

## I. INTRODUCTION

EEG (Electroencephalogram) is a non-invasive simple method used to quantize or measure the electrical activity in the brain which is a result of the voltage fluctuations resulting from the neurons of the brain. The signals are extensively used for detecting epilepsy, sleep disorders, coma brain death etc. In this paper we focus on the division of the signals for sleep analysis and disorders. The brain is actively working at all times even while we are asleep and the brain activity during different stages of the sleep can be realized by the presence of some characteristic brain waves. They are majorly classified into five frequency bands namely the alpha, theta, beta, gamma and delta. The waves lie in the frequencies ranging from 0 to 35Hz approximately and the signals are of the order of micro volts .All other signals which include EMG, EOG, ECG waves or disturbances caused due to blinking, body movement etc. have to be treated as noise or artifacts as they are popularly known and have to be filtered appropriately both in the digital and analog domain. The presence of the signals in lower frequencies makes filtering a very tedious and difficult task. Early amplification also results in the loss of the real signals to noise and other artifacts which are of the order of milli volts as opposed to EEG signals which are of the order of u V (typically less than 100uV).

## II. TYPES OF WAVES

The EEG signal obtained can be filtered out into five waves of different frequency ranges. These waves help doctors to identify brain disorders such as epilepsy and sleep apnea as well as behavioral pattern and emotional states. The five waves are as follows:

- Delta waves: They are of the range 0.5-3 Hz and have the highest amplitude among all the EEG waves. They arise from either the thalamus or cortex of the brain. They are responsible for releasing many hormones such as GHRH and PRL and hence are found to be more
- predominant in women. They are also associated with stage 3 and stage 4 of the sleep cycle.
- Theta waves: They are also known as cortical theta rhythms and have frequency oscillations of 4-8Hz. They are concentrated on the C3 and C4 region of the brain where the hippocampus which is center of emotion, memory and the autonomic nervous system. It is observed quite clearly in small children. In others, it is usually prominent during meditative, drowsy or sleeping states.
- Alpha waves: They range from 8-15Hz due to the coherent and synchronous electrical activity of the thalamic pacemaker cells. They are found during closed eyes, REM sleep and wakeful relaxation at the occipital lobe. They are used in bio feedback training to deal with phobias and calm down hyper active children with stuttering problems
- Beta waves: They are found in the 12.5-30 Hz region. They are further divided into 3 bands- Lo beta(12.5-15 Hz), Beta(15-22 Hz) and Hi Beta(22-30 Hz). They are noticeable during the waking up stage and focuses on cognitive thoughts. It is present when we are figuring out, decision making, excitement and problem solving.
- Gamma waves: It ranges from 25-40 Hz. It is associated with the unity of conscious perception and suggestive thinking. It is the least dominant of all the waves.

## III. METHOD FOR EEG WAVE EXTRACTION

The placement of high quality electrodes is very crucial and important for signal extraction. There are two major types of electrodes available namely disposable and reusable types which obviously vary majorly in their functionality .The electrode disk can be made of gold, silver, Ag-AgCl etc. It can be used with the help of bands or electrode caps which makes placement easier. The International of Societies for Electroencephalography and

IJARCCE
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Clinical Neurophysiology has recommended the 10-20 system (21 electrodes) for analysis. Following the convention the electrodes have to be placed be placed adjacent to each other either at 10% or 20% of the total front-back or right-left distance of the skull.

Our method of measurement is the referential montage where each channel represents the difference between a certain electrode and a reference electrode. The most preferred positions for the reference include the midline area and the mastoids.

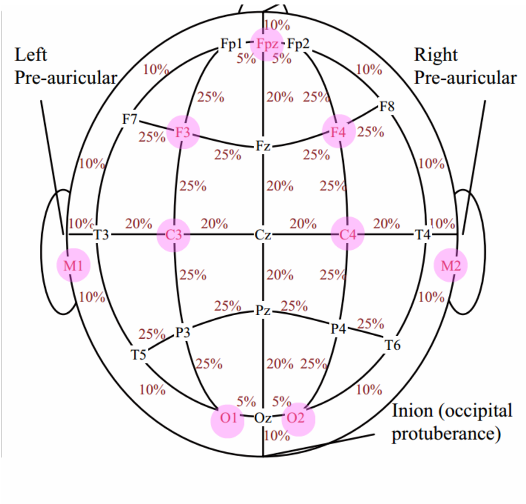


Fig1.Electrode placements

In our aim to reduce complexity and still maintain efficiency we have identified ten major positions for signal acquisition.
Central leads (Cz, C3,C4) most of the sleep activity is detectable with these leads. Frontal leads( F3,F4),Occipital leads(Oz,O3,O4) and mastoid leads(M1,M2) for reference.

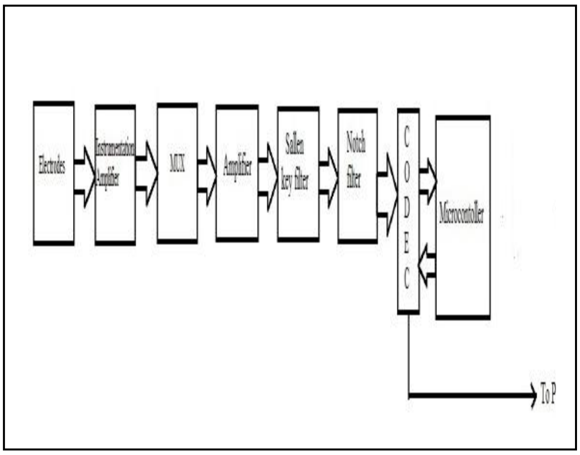


Fig2. Block diagram

## IV. BLOCK DAIGRAM

### A. INSTRUMENTATION AMPLIFIER

At the first stage the signal from the electrodes is fed into the Instrumentation amplifier where one of the inputs is from the mastoids and the other from the respective electrodes. With the use of an IA we amplify the signal from µ V to orders of mV by setting appropriate resistor values. The characteristic features should include low input bias current and voltages, high CMRR values as noise reduction forms an integral part at the first stage. A two stage amplifier forms a good choice because if the gain is set too high in the first stage itself it might cause distortions in the output for fast changing inputs.

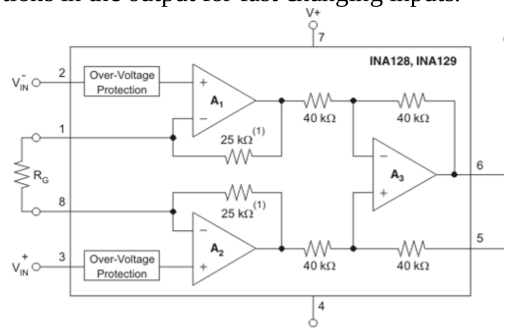


Fig3. INA126 Instrumentation amplifier

With reference to the above circuit the gain values can be set by appropriately choosing the value of R. The amplifier gain can be varied from 1 to 10000 with the input bias currents as low as 5nA.

### B. MULTIPLEXER DESIGN

The outputs of the instrumentation amplifiers are then time multiplexed for signal processing. The selection lines are given as clock signals for continuous switching between the inputs.

The frequency of switching should be appropriate to avoid aliasing of the signals. A small amount of error is introduced in the output due to delay and slight overlap which can be overlooked as it does not make a huge difference in accuracy.

| SELECTION INPUT | ELECTRODE POSITIONS |
|---|---|
| 000 | Cz |
| 001 | C3 |
| 010 | C4 |
| 011 | F3 |
| 100 | F4 |
| 101 | Oz |
| 110 | O3 |
| 111 | O4 |

Table1.Electrode Placement

### C. ANALOG FILTERING

Rejection of the dc offset is necessary before amplification to produce the required dynamic range. A very simple approach to doing the same is to use a capacitor which can block dc content and allow all frequencies ranging till 35-70Hz.A series of analog filters (high pass and low pass) can also be used to limit the frequencies between the ranges of 1Hz to 35-70Hz.The high pas filter typically filters out slow artifacts such as electro galvanic signals and movements. A notch filter is used to limit the artifacts caused due to electrical power lines, it is typically of the

IJARCCE

ISSN (Online) 2278-1021
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frequency 60Hz in the US and 50Hz in many other countries.

D. DIGITISATION

The EEG waves can be processed either in analog or digital domains. Processing in the digital domain has several advantages. A simple code can be written to perform the signal processing operations in contrast to the large amounts of circuitry required if the same were to be done in the analog domain. This reduces the cost as well as complexity and size. Digital filters can have a higher order and precision. Using a DSP for this purpose also has the additional advantage of memory and faster computation.

The data can be stored. The need to tune analog components during their production and their maintenance is eliminated. Our design uses digital implementation of filters on ARM Cortex-M4 and extensively uses its DSP capabilities. For the digital filtering process STM32F407VG is used which has arm cortex m4 as its core. It is a high performance processor with efficient control and signal processing capabilities.

STM32F407VG is capable of implementing full DSP instructions that are available on Kiel platform. The signals obtained from the electrode and the analog circuit cannot be processed by the microcontroller. The signals need to be converted to digital signals before they are fed to the microcontroller. This is accomplished using either an ADC or a codec.

In our design we make use of a codec, Wolfsonn pi Audio card. It extends and enhances the board with audio features beyond its native HDMI output with onboard HD Audio, at 24-bit, 192KHz. It offers a high speed codec which has a 3.5 mm jack Stereo Line .It has various medical applications and can be used with ease.

The line-in jack of the codec accepts analog signals as input. It performs sampling, quantization and encoding to convert the analog signals to digital signals. After being processed by the microcontroller, the line-out jack receives the signals, which it converts back into analog signals by the method of reconstruction. The codec is also capable of compressing the data it receives to increase speed.

Filters of different cut-off frequencies are implemented digitally on the ARM Cortex-M4 platform. The filters are low pass. Hamming window filters are used, with an order of 80 for sharper cut-offs and better accuracy. The delay induced due to the higher order is acceptable. Most of the required signals have frequencies below 35Hz. According to the Nyquist sampling theorem for lowpass signals, the sampling frequency should be greater than or equal to twice the highest frequency. Thus a sampling frequency of 500Hz, which is used in our design, is sufficient.

As mentioned above, we have implemented digital filters in code on ARM Cortex-M4. We have used built in functions to perform the filtering action. The built-in function requires the filter coefficients for a given order, cut-off frequencies and window type. This can be generated using the fir1 function on MATLAB. This function requires normalized frequencies to be entered.

The normalized lower cut-off frequency will be 2*(lower cut-off frequency)/(sampling frequency) and the normalized upper cut-off frequency will be 2*(upper cut-off frequency)/(sampling frequency). The results obtained are displayed below. Each wave is plotted separately.

## V. RESULTS

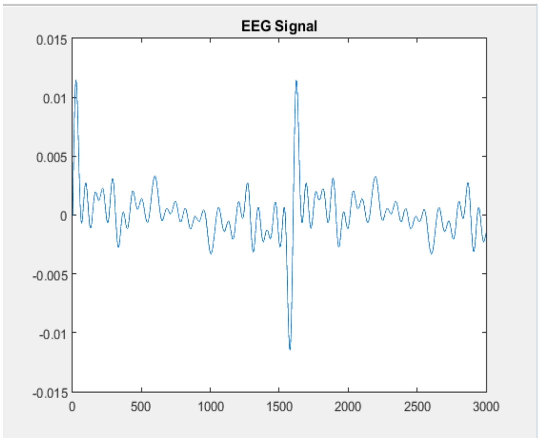


Fig4. Filtered and amplified EEG signal Waveform

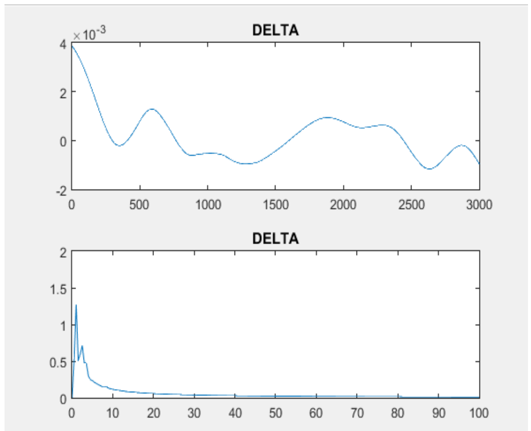


Fig5. Delta waves in Time and Frequency domain

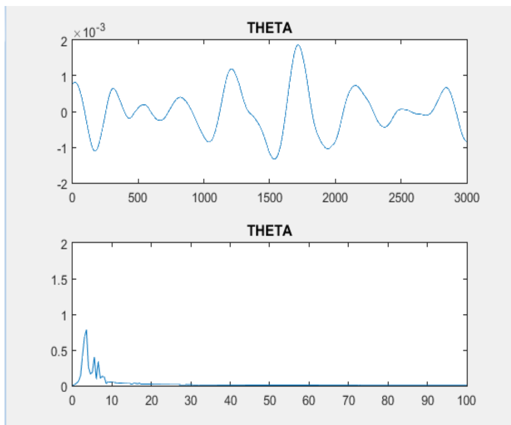


Fig6. Theta waves in Time and Frequency domain


DOI 10.17148/IJARCCE.2016.5648

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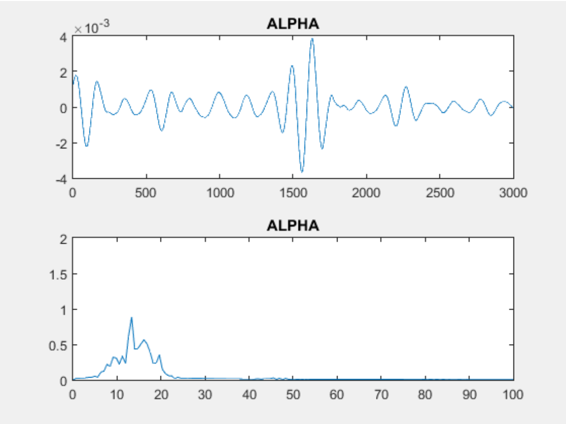


Fig7. Alpha waves in Time and Frequency domain

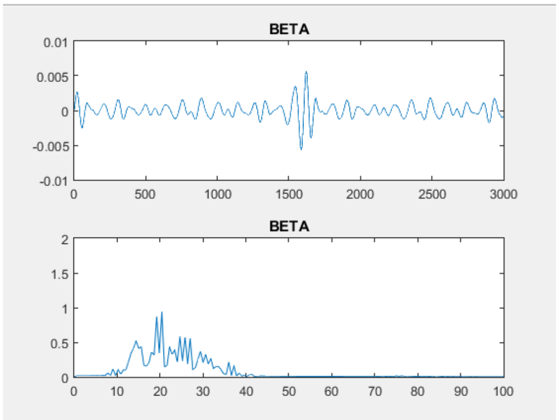


Fig8. Beta waves in Time and Frequency domain

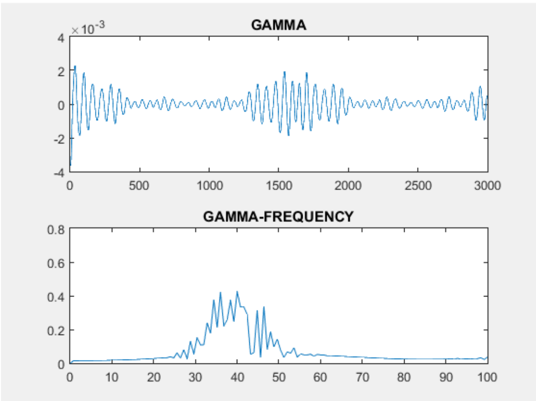


Fig9. Gamma waves in Time and Frequency domain

## VI. CONCLUSION

The device has a wide scope for various applications as it has a simple design that has the capacity to evolve into application specific devices. The board used can also store data of previous readings for further diagnosis. Other medical parameters such as ECG, EMG, EOG and so on can be interfaced along with this to make a complete system. The device can be developed such that it is able to analyze the waves and predict any brain disorders to help the doctors. The design is low cost and can be made portable which is useful in hospitals, homes and primary healthcare centers.

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DOI 10.17148/IJARCCE.2016.5648