DESIGN OF HARDWARE
FOR
TEMPORAL LOBE EPILEPSY

A thesis submitted in partial fulfilment of requirements for the award of the degree of

B. Tech.

in

Instrumentation and Control Engineering

by

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BONAFIDE CERTIFICATE

This is to certify that the project titled **DESIGN OF HARDWARE FOR TEMPORAL LOBE EPILEPSY** is a bonafide record of the work done by

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ABSTRACT

The aim of this project is to design and develop a hardware system for the detection of temporal lobe epilepsy. Since EEG signals are inherently low-amplitude (in order of microvolts), they require suitable amplification before further processing filtering of the supply line frequency and eliminating noise as much as possible.

The hardware system was verified by connecting the electrode to the T1, T2, T3 and T4 electrodes to check the amplification of the waves and to see if the frequency of the wave obtained was appropriate from the circuit. Additionally, the system aims to achieve minimum loss of information by utilization of an ADC using a 32-bit processor ADuCM362 consisting of 24-bit ADC.

Keywords: EEG; Temporal Lobe Epilepsy; Signal conditioning;

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CHAPTER 1

INTRODUCTION

Electroencephalography (EEG) is of primary interest among various brain monitoring methods used in current BCI research due to its benefits of low cost, convenient operation and non-invasiveness. Researchers are forced to invest effort in developing EEG acquisition systems due to the abundant medical and consumer applications of BCIs and their subsequent reliance on EEG. However, there are multiple challenges in sophistication.

In this paper, we first introduce EEG characteristics and the overall framework of an EEG recording circuit. We then illustrate the details of the circuit piece-wise, laying emphasis on each stage to understand its role. Experimental results obtained in the laboratory using the introduced system are included to support the research and for validation purposes. Finally, the circuit is implemented as the assembled circuit board and is observed to obtain the most accurate pre-processed brain wave with different states of the brain. Lastly, the future scope is discussed.

1.1 INTRODUCTION TO EEG

Electroencephalography (EEG) is a method of electrophysiological monitoring for recording brain electrical activity. Typically it is non-invasive, with the electrodes placed along the scalp, although sometimes invasive electrodes are used as in electrocorticography. EEG measures voltage fluctuations in the brain neurons resulting from ionic current. EEG refers in clinical contexts to recording the spontaneous electrical activity of the brain over a period of time as recorded from multiple electrodes placed on the scalp. Generally, diagnostic applications focus on either event-related potentials or EEG content.

1.2 CHARACTERISTICS OF EEG

EEG signal is usually acquired by means of electrodes on the head surface. It normally ranges from 0.5 μV to 100 μV in amplitude and needs to be amplified several thousand times before it can be captured. It is very faint and easily drowned in artefacts. These varieties of noise jamming of the recorded EEG may be either person-related or technical. Person-related artefacts are unwanted physiological signals that may disturb the EEG; they are majorly EMG, ECG, EOG, minor body movements and sweating. Technical artefacts, such as AC power line noise, can be decreased by decreasing electrode impedance or minimising electrode wire length. The most common of these are 50/60 Hz AC power line fluctuations, impedance fluctuations and cable movements.

1.3 APPLICATIONS

EEG is used to diagnose epilepsy, sleep disorders, depth of anaesthesia, coma, encephalopathy, and brain death. EEG used to be a first-line method of diagnosis for tumours, strokes and other focal brain disorders.

1.3.1 Temporal Lobe Epilepsy

The Temporal lobe epilepsy (TLE) is a chronic disorder of the nervous system characterized by recurrent, unprovoked focal seizures that originate in the temporal lobe of the brain and last about one or two minutes. TLE is the most common form of epilepsy with focal seizures. Focal seizures in the temporal lobe involve small areas of the lobe such as the amygdala and hippocampus

When a seizure begins in the temporal lobe, its effects depend on the precise location of its point of origin, its locus. In 1981, the ILAE recognized three types of seizures occurring in temporal lobe epilepsy. The classification was based on EEG findings which is based on the three key features: where the seizures begin, the level of awareness during a seizure, and other features.

1.4. ELECTRODE PLACEMENT

The *10/20 system* or *International 10/20 system* is a globally recognized method to describe the location of scalp electrodes. The system is based on the relation between an electrode's location and the cerebral cortex's underlying area. To provide adequate coverage of all regions of the brain, the head is divided into proportional distances from prominent skull landmarks (nasion, preauricular points, inion). Label 10-20 identifies proportional percentage distances between the ears and the nose where the electrode points

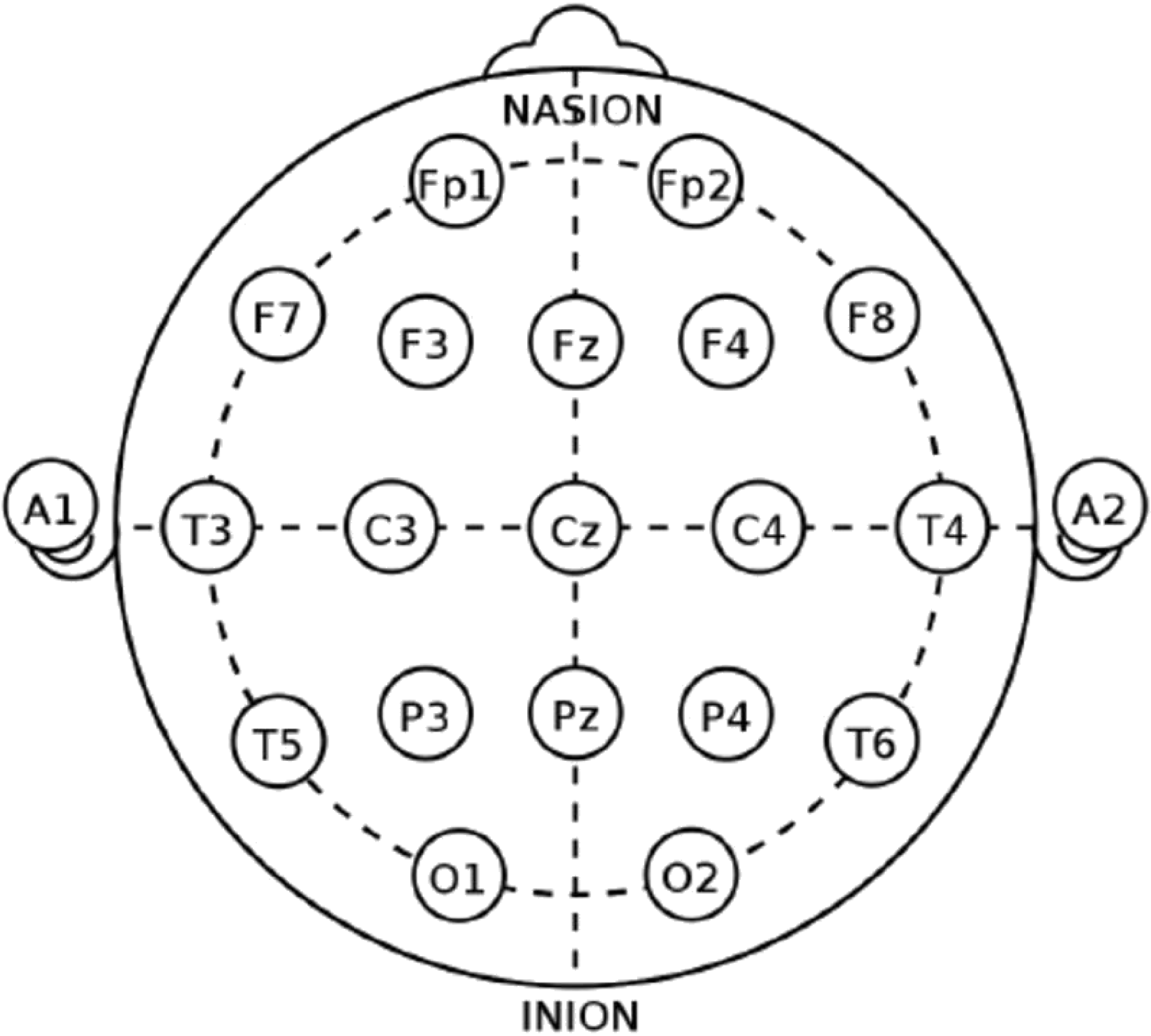


Fig 1.1 - 10/20 system of EEG electrode montages

Table 1.1 : Letter identifiers for electrode montages

Electrode	Lobe
F	Frontal
T	Temporal
C	Central
P	Parietal
O	Occipital

It is prudent to note here that no central lobe exists. The 'C' letter is used for identification purpose only.

The 'Z' (zero) refers to an electrode placed on the mid line. Even numbers (2, 4, 6, 8) refer to electrode positions on the right hemisphere. Odd numbers (1, 3, 5, 7) refer to electrode positions on the left hemisphere.

Four anatomical landmarks are used for the essential positioning of the electrodes: the nasion, which is the point between the forehead and the nose; the inion, which is the lowest point of the skull from the back of the head and is normally indicated by a prominent bump; the pre-auricular points anterior to the ear. Extra positions may be added by utilizing the spaces in between the existing 10/20 system.

1.5. EEG RECORDING

The recording is obtained in conventional EEG scalp by placing electrodes on the scalp with a conductive gel or paste, usually after light abrasion preparation of the scalp area to reduce impedance due to dead skin cells. Typically, many systems use electrodes, each attached to a single wire. Some systems use caps or networks that embed electrodes into; this is especially common when electrode arrays of high density are required.

The international 10–20 system for most clinical and research applications specifies electrode locations and names (except when high-density arrays are used). This system ensures that electrode naming across laboratories is consistent. 19 recording electrodes (plus ground and system reference) are used for most clinical applications. Typically, a smaller number of electrodes are used to record EEG from neonates. Additional electrodes may be added to the standard set-up when a clinical or research application requires increased spatial resolution for a specific brain area.

When recording a more detailed EEG with more electrodes, extra electrodes are added using the 10% division, which fills in intermediate sites halfway between those of the existing 10–20 system. This new electrode-naming system is more complicated giving rise to the Modified Combinatorial Nomenclature (MCN).

This MCN system uses numerals 1, 3, 5, 7 and 9 for the left hemisphere which represent 10%, 20%, 30%, 40% and 50% of the inion-to-nasion distances respectively. The introduction of extra letter codes allows the naming of intermediate electrode sites. Note that these new letter codes do not necessarily refer to an area on the underlying cerebral cortex. The new letter codes for intermediate sites are:

- AF – intermediate between F_p and F,
- FC – between F and C,
- FT – between F and T,
- CP – between C and P,
- TP – between T and P, and
- PO – between P and O.

Also, the MCN system renames four points of the 10–20 system - T3, T4, T5 and T6 - as T7, T8, P7 and P8 respectively.

High-density arrays (typically via cap or net) can contain up to 256 electrodes more-or-less evenly spaced around the scalp.

Each electrode is connected to one input of a differential amplifier (one amplifier per pair of electrodes); a common system reference electrode is connected to the other input of each differential amplifier. These amplifiers amplify the voltage between the active electrode and the reference (typically 1,000–100,000 times, or 60–100 dB of voltage gain). In analog EEG, the signal is then filtered, and the EEG signal is output as the deflection of pens as paper passes underneath. Most EEG systems these days, however, are digital, and the amplified signal is digitized via an analog-to-digital converter, after being passed through an anti-aliasing filter. Analog-to-digital sampling typically occurs at 256–512 Hz in clinical scalp EEG; sampling rates of up to 20 kHz are used in some research applications.

A series of activation procedures can be used during recording. These procedures may result in normal or abnormal EEG activity that may not be seen otherwise. Hyperventilation, photic stimulation (with strobe light), closure of the eyes, mental activity, deprivation of sleep and sleep include these procedures. Typical seizure medications of a patient may be withdrawn during (inpatient) epilepsy monitoring. The digital EEG signal is stored electronically and can be filtered for display. Typical settings for the high-pass filter and a low-pass filter are 0.5–1 Hz and 35–70 Hz respectively. The high-pass filter filters out slow artifacts such as electrogalvanic signals and artifact of movement, while the low-pass filter filters out high-frequency artifacts such as electromyographic signals. Typically, an additional notch filter is used to remove electrical power lines artifacts.

1.6 ADVANTAGES OF EEG

There are various advantages of using EEG signals, and some of them can be stated as follows:

- Temporal resolution of EEG signal is high.
- EEG measures the electrical activity directly.
- EEG is a non-invasive procedure.
- EEG has ability to analyze brain activity.

The major disadvantage in utilising EEG for diagnosis is that it is difficult to identify the source of electrical activity thus, relate it to a region of the brain.

Useful Applications of EEG

1. Diagnosis of epilepsy and identification of types of seizures is the most common application of EEG. It is the most useful and important test in confirming a diagnosis of epilepsy.
2. Problems with loss of consciousness or dementia may be checked for and verified with medical diagnosis.
3. EEG is the only method to find out if a person in coma is brain-dead.
4. EEG may also be used to watch the brain activity while a person is receiving general anaesthesia during brain surgery.
5. EEG can help confirm if a person has a physical problem (problems in the brain, spinal cord, or nervous system) or a mental health problem.

1.7. EEG FREQUENCY PATTERNS

Different electrical frequencies (Fig 3.3) could be linked to actions and different stages of consciousness. This was done by observing subjects performing different task, like solving mathematical problems, while recording their EEG. Most of EEG waves ranges from 0.5-500 Hz, however following five frequency bands are clinically relevant:

(i) Delta,

(ii) Theta,

(iii) Alpha,

(iv) Beta, and

(v) Gamma.

- **Delta waves**

These waves are the slowest of all and have typical frequencies up to 3 Hz. However, they are the strongest and have highest amplitudes. In infants up to one year of age, they are the dominant rhythm and adults in deep sleep.

- **Theta waves**

Theta waves emerge with eye closure and relaxation with frequencies ranging from 4 Hz to & Hz. These are usually seen in young children or in an exciting state in older children and adults.

- **Alpha waves**

Alpha activity has waves with frequencies ranging from 7.5 Hz to 12.5 Hz. These are seen most frequently in adults. Alpha activity occurs rhythmically on both sides of the head, but on the non-dominant side is often slightly higher in amplitude, especially in right-handed people. With closing eyes (in a relaxing state) they are witnessed and normally disappear with open eyes or under stress.

- **Beta waves**

Beta activity is characterised by quickly moving waves of relatively small amplitude **of less than 30 µ**V. Their typical frequencies range from 14 Hz to 30 Hz.

Beta waves are usually seen in symmetrical distribution on both sides and are most frontally evident. In areas of cortical damage, however, beta waves may be absent or reduced. In patients who are alert or anxious or have their eyes open, it is the dominant rhythm. In general, they are considered normal rhythms and are observed in all age groups.

- **Gamma waves**

Also called fast beta waves, gamma waves are the fastest waves of brain having frequencies between 30 Hz and 45 Hz. They have very low amplitude and present rarely.

Detection of these rhythms plays a major role in the identification of neurological diseases. These waves occur in the center front of the brain, suggesting event-related brain synchronization (ERS).

CHAPTER 2

LITERATURE REVIEW

EEG has become the main focus because of its advantages of low cost, convenient operation and non-invasiveness. Expanding number of research exercises and distinctive studies in BCIs demonstrates potential in this area.

The commercial EEG devices complete most of the EEG signal acquisition equipment for the current BCIs. Recording hardware with a large number of channels is too expensive and it is hard to afford to ordinary users. For these reasons, a lot of research has been spending a lot of energy on reducing the cost of acquiring EEG signals.

Early EEG acquisition systems made use of the 10-20 system of placement of a full set of 21 electrodes, where the "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull. Use of 21 electrodes provided large quantities of indicative data that was required to compensate for potential losses and distortions arising out of the acquisition system.

Furthermore, since the EEG signal represents a voltage difference between two electrodes, one or more electrodes had to be set as a reference so that the output voltage could be measured in relation to that reference point (the most common being the connected ears, which is an average voltage of the electrodes attached to either earlobes or mastoids). However, the use of reference electrodes on the subject itself introduced multiple noise channels and unwanted signals (such as those from muscle movement), which introduced objectionable deviations from the measured signals in reduced channel systems when referenced with the actual signal.

The raw EEG signals obtained from the electrodes have amplitudes of the order of micro volts and contain frequency components of up to 300 Hz. The signal is amplified approximately ten thousand times. Usually, high-pass filters with a cut-off frequency of less than 0.5 Hz are used to remove disturbing components of very low frequency such as breathing components. On the other hand, the use of low-pass filters with a cut-off frequency of approximately 50–100 Hz mitigates high-frequency noise. Notch filters with a 50 Hz null frequency are often needed to ensure the strong 50 Hz power supply is perfectly rejected. By using ADC to store the signal in a computerized system, the signals are converted to digital form.

Mehmet Engin and Tayfun Dalbastı (2006) designed a prototype EEG recording system which consists of an analog and a digital part. Their analog module involves the following units: an input instrumentation amplifier, gain adjustable amplifier, band-pass filter, and a driven-right-leg (DRL) circuit.

Also, Robert Lin and Ren-Guey Lee (2006) have developed a multi-channel wireless EEG acquisition and recording system. The acquisition circuit is composed of pre-amplifiers, filters, and gain amplifiers. Using this system, it is possible to measure and transmit non-successive brain activities such as epilepsy, sleeping disorder and abnormal behaviour over long distances without attenuation.

Giorgos Giannakakis et al, DOI 10.1007/7657_2014_68, Springer Science and Business Media, New York 2014 developed a method for seizure detection and prediction

The above Paper reviews the most widely adopted algorithms for the detection and prediction of epileptic seizures, emphasizing on information theory based and entropy indices. Each method's accuracy has been evaluated through performance measures, assessing the ability of automatic seizure detection/prediction.

Improved Patient-Independent System for Detection of Electrical Onset of Seizures- *Veerasingam Sridevi et al, Journal of Clinical Neurophysiology Volume 00, Number 00, Month 2018*

In this paper, The Support Vector Machine(SVM)was found most suitable for the design of an automated system for clinical study. It was found that the performance of the system mainly depended on three factors: (1) normalization scheme (2) feature extraction, and (3) machine learning algorithm.

The next page is the accumulation of all the literatures related to seizure and circuits developed to detect temporal lobe epilepsy

Authors	Year	Seizure type	Method	Dataset	Best achieved accuracy rate (%)
Yuan et al. [13]	2012	Intractable focal seizures	Linear/nonlinear features, extreme learning machine	21 patients EEG data (81 seizures)	94.9
Zhou et al. [140]	2013	Intractable focal seizures	Lacunarity, Bayesian LDA	21 patients EEG data (81 seizures)	96.67

Authors	Year	Seizure type	Method	Dataset	Best achieved accuracy rate (%)
Liu et al. [10]	1992	Neonatal seizures	Scored autocorrelation Moment	EEG segments (58 with seizures, 59 without seizures)	91.4
Alkan et al. [137]	2005	Absence seizures (petit mal)	MUSIC, autoregressive Spectrum, MPLNN	EEG of 11 subjects (6 normal, 5 epileptic) with 20 absence seizures (petit mal) total	92
Greene et al. [138]	2007	Neonatal seizures	Combination of EEG and ECG features, LD classifier	10 neonates, 633 seizures	86.32
Vukkadala et al. [139]	2009	No specific type	Approximate entropy, Elman neural network	Intracranial EEG of 21 subjects (12 normal, 9 epileptic) containing 30 ictal and 30 non-ictal periods	93.33

Authors	Year	Method	Dataset	Best achieved accuracy rate (%)
Altunay et al. [11]	2010	Linear prediction filter	Bonn EEG database [126]	93.33
Guo et al. [134]	2010	Discrete wavelet transform, line length feature, MLPNN	Bonn EEG database [126]	97.77
Kumar et al. [33]	2010	Entropy measures, Recurrent Elman network (REN)	Bonn EEG database [126]	99.75
Übeyli [122]	2010	Lyapunov exponents, probabilistic neural networks	Bonn EEG database [126]	98.05
Fathima et al. [12]	2011	Discrete wavelet transform	Bonn EEG database [126]	99.5
Guo et al. [135]	2011	Genetic programming features, K-nearest neighbor classifier	Bonn EEG database [126]	99.2
Martis et al. [136]	2012	EMD features	Bonn EEG database [126]	95.33

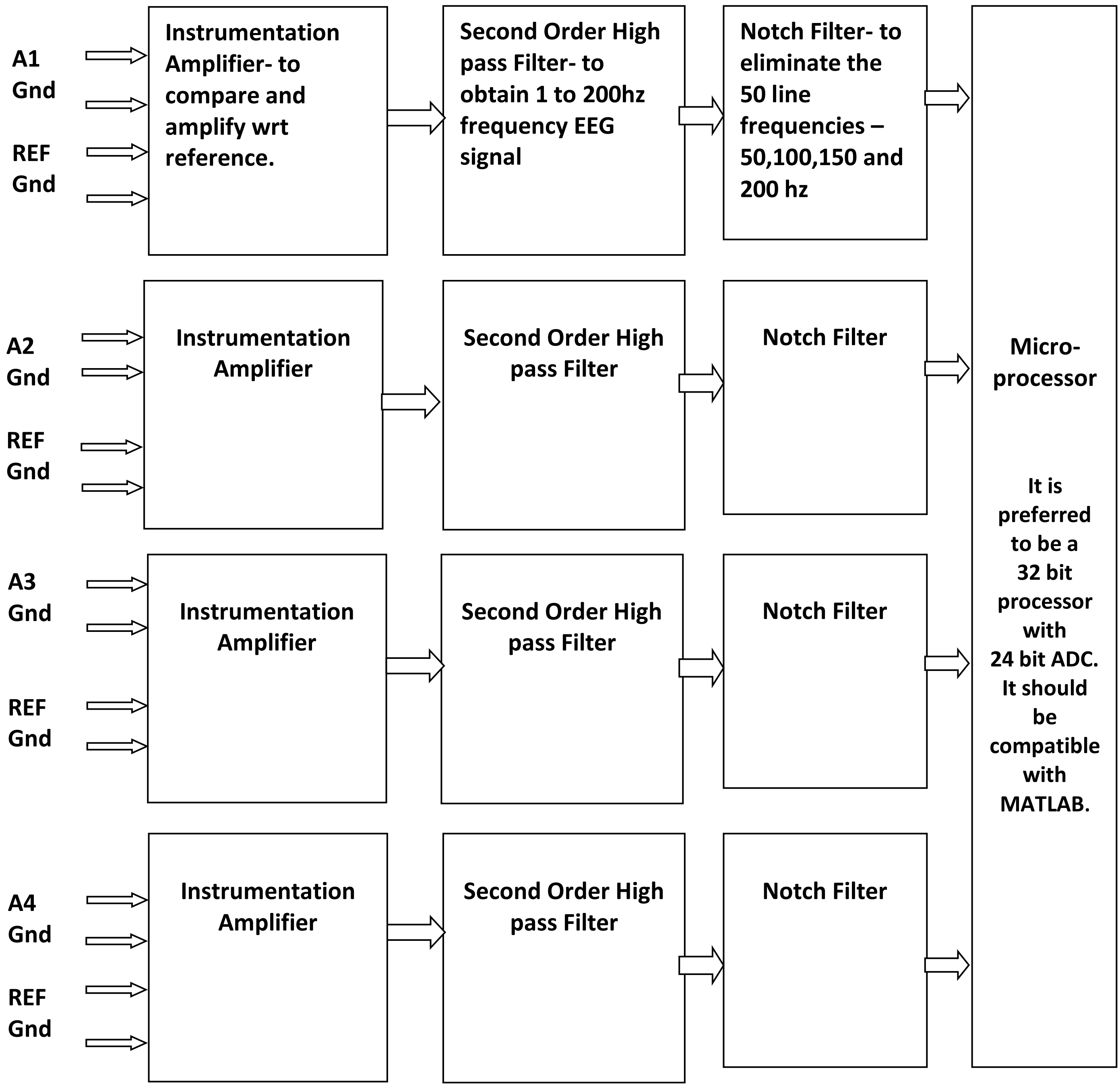
Table 2.1- Summary of all the related literatures, the methods adopted and the accuracy achieved.

CHAPTER 3

HARDWARE DESIGN FOR TEMPORAL LOBE EPILEPSY

3.1. Block Diagram of the system

It is a 4 Probe EEG system to detect Temporal Lobe Epilepsy**.** The A1, A2, A3, A4 are EEG signals obtained from temporal lobe region, two from right side and two from left side respectively for epilepsy patient with the reference taken from the normal patient .



3.2.Overview of the Components

3.2.1 Instrumentation amplifier

EEG signal is very weak, often buried in strong noise interference. The preamplifier must have high input impedance, high common mode rejection ratio, low noise, nonlinearity, strong anti-interference ability and proper frequency and dynamic range amplifier performance. So, the preamplifier plays the most important role of the whole circuit design. It not only extracts the useful EEG signal, but also reduces the interference signals to the lowest level. An instrumentation amplifier has been selescted to achieve this function. The instrumentation amplifier is a type of differential amplifier hat has been outfitted with input buffer amplifiers which eliminate the need for input impedance matching and thus make the amplifier particularly suitable for use in measurement and test equipment. Additional characteristics include very low DC offset, low drift, low noise, very high open-loop gain, very high common-mode rejection ratio, and very high input impedances.

The chip INA114 is used as it is suitable for this application. The chip has very low offset voltage of 50 **µ**V and rejects common signal with 115 dB. The structure of INA114 is composed of 3 operational amplifiers as shown in Figure 4.3. These are arranged so that there is one operational amplifier to buffer each **input (+, −), and one** to produce the desired output with adequate impedance matching for the function.

In this circuit, common mode signals will be passed through the input buffers at unity gain, but differential voltages will be significantly amplified. The gain of the circuit cannot be set to amplify beyond a limit because of the DC component in the output.

$$G = \frac{V_{out}}{\Delta Vin} = 1+\frac{50k\Omega}{Rg} = 1+ \frac{50k\Omega}{2.2k\Omega} = 22.7$$

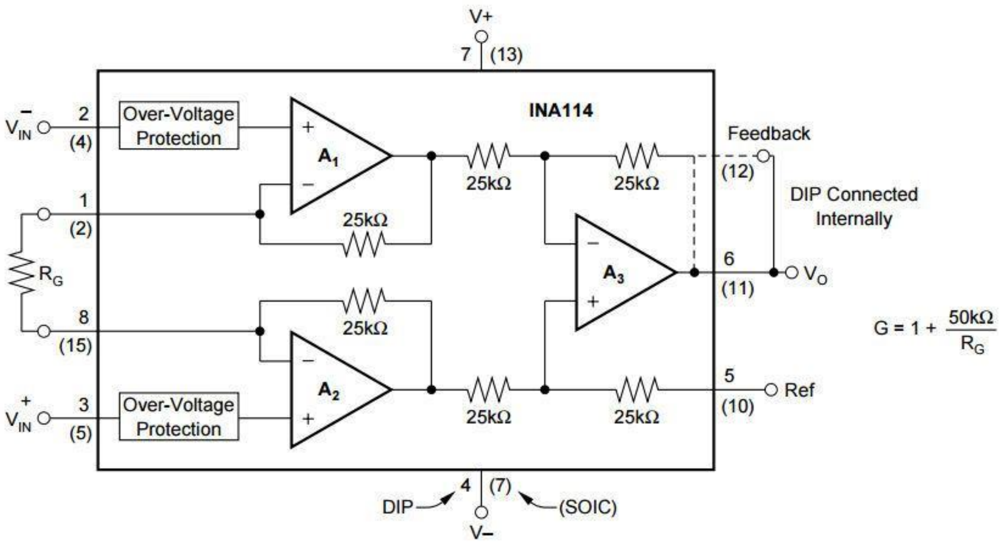


Fig 3.1 - Circuit diagram of instrumentation amplifier

3.2.2.Band-pass filter

The next component of the circuit is a band-pass filter, which contains a low-pass filter and a high-pass filter. What emerges from the series combination of these two filter circuits is a circuit that will only allow passage of those frequencies that are neither too high nor too low. The low-pass filter is an active two order Butterworth filter with Sallen-key topology composed of the resistors and capacitors R_9, R_{13}, C_6, C_7, and an operational amplifier. Equation below describes the transfer function of this filter.

$$H(s) = \frac{1/R_9 R_{13} C_6 C_7}{S^2 + (\frac{1}{R_9 C_6} + \frac{1}{R_{13} C_6})S + \frac{1}{R_9 R_{13} C_6 C_7}}$$

In this circuit, R_9 is equal to R_{13} and C_6 is equal to C_7. The damping coefficient is equal to 2, and the -3 dB frequency as illustrated by equation below is 201.06 Hz.

$$fc = \omega_c / 2\pi = \frac{\sqrt{\sqrt{2}-1}}{2\pi} \frac{1}{R_9 C_6} \approx 201.06 Hz$$

The filter is appropriate to prevent all aliasing artefacts in the analog-to-digital converter (ADC). However, because EEG the signal we are trying to measure is naturally filtered, it is quite possible that a lower sample rate, for example 256 Hz or 512 Hz is sufficient for most purposes.

After the low-pass filter, the capacitors C_8 and C_9 and the resistors R_{10} and R_{11} provide second-order Butterworth high-pass filter with Sallen-key topology. The high-pass transfer function of this circuit is described by equation below. The high corner frequency as circuit is given by equation below.

$$H(s) = \frac{S^2}{S^2 + \left(\frac{1}{R_{10}C_8} + \frac{1}{R_{11}C_9}\right)S + \frac{1}{R_{10}R_{11}C_8C_9}}$$

$$f_c = \frac{\omega_c}{2\pi} = 0.63Hz$$

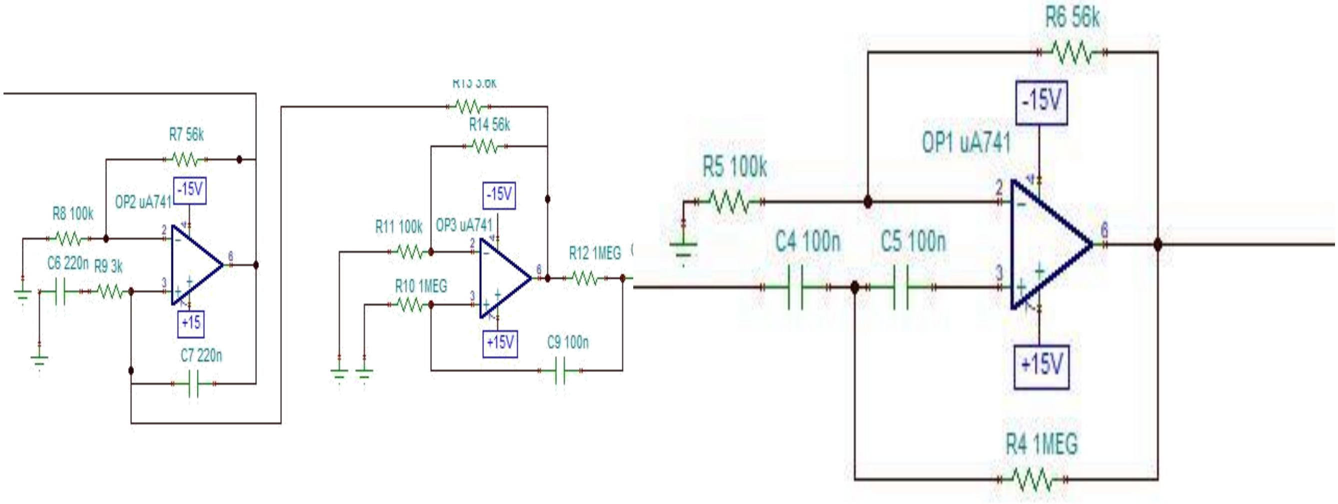


Fig 3.2 – Band pass Filter Circuit

3.2.3. Notch filter

Till this stage, this circuit has good common mode rejection capability and it can get good EEG signal acquisition effect even without the notch filter. However, in a noisier environment, 50 Hz interference that arises from the standard AC electrical line current still exists. It also can originate from the computer and ADC card. The 50 Hz interference sometimes strings into the circuit. It can be eliminated by a notch filter designed to selectively remove 50 Hz activity from the signal. Especially since the EEG is very weak, the interference can pose a serious threat to signal integrity. In addition, if this EEG amplifier circuit with a 50 Hz rejection filter is used to greatly reduce the interference, the latter software processing stage will be made simpler. In this project, a twin-T network notch filter is used. It is depicted in Figure below.

The filter frequency parameter is 50 Hz to match with AC line noise. The electrical components share the following relationship.

$$R_{16} = R_{18} = 2R_{17} = 1.5\ \mathrm{M}\Omega$$

$$C_{10} = C_{11} = C_{12} = C_{13} = 1\ \mathrm{nF} \qquad)$$

The twin-T notch filter requires high accuracy resistors and capacitors owing to the extreme values used. Care must be taken to ensure minimal tolerance in these components, since errors in the components’ values will push/pull the rejection frequency away from the center frequency of 50 Hz.

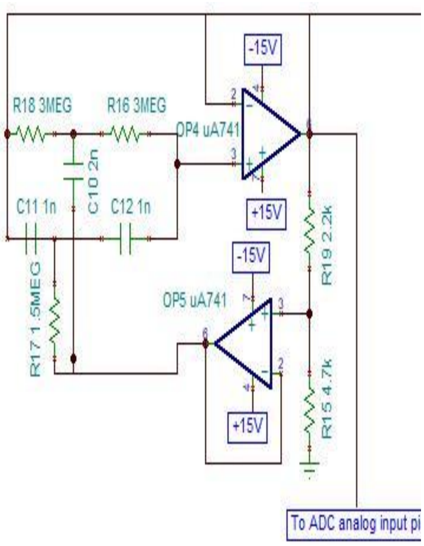


Fig 3.3 - Circuit diagram for notch filter

3.2.4. Analog to digital conversion

In order to reduce power utilisation and complexity of the EEG acquisition system, ADuCM362, a 32-bit processor with a single 24-bit inbuilt ADC is used as the core processor. The sampling rate of the ADC is 400 samples per second for the highest resolution in the system. The minimum reference voltage is 1 V. After digitized in the processor, the EEG signals can be viewed and logged on a computer by a wired serial through the Keil u vision which would be done and is tabulated in the future works.
The SPI protocol is adopted in accordance the data transmission speed.

CHAPTER 4

EXPERIMENTATION

This chapter will present all the experimentation and will explain on how it was carried out . The initial experimental setup with the electrode placement and the condition of the person tested is explained and the methodology followed for carrying out the experimentation is explained in detail.

4.1. EXPERIMENTAL SETUP

In the experimental Setup, the breadboard circuit implementation is demonstrated followed by the assembled Circuit board being able to capture the brain waves after amplification and filtering in a DSO is being obtained. The breadboard circuit was tested after the Matlab filter responses were obtained and the gain was finalised and the Proteus simulations were checked for the right passive components.

Fig 4.1 –Hardware Design Check implemented using Breadboard

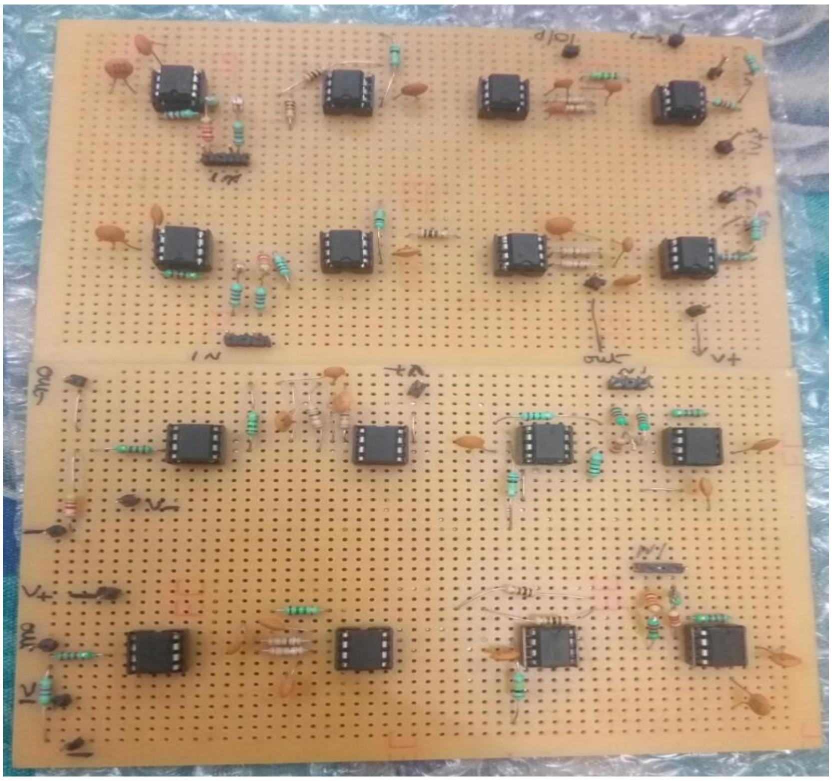


Fig 4.2.- Assembled Circuit Board after the breadboard circuit check

The experiment carried out with the assembled Circuit Board and the electrodes to capture the brain waves is placed as follows with the below conditions

- The reference was taken as common and was taken from Fpz in the middle line sagittal plane.
- Fpz-5 cm from the Nasion (0.1*50(full length from nasion to inion)
- T1,T3 was taken from the left hemisphere.
- T3- 6cm from dip of the left ear(0.1*60(full length from ear to ear))
- T4- 6cm from dip of the right ear(0.1*60(full length from ear to ear))
- T1 was taken at the mid between Fpz and T3 and placed a little lower by the arc interference from the centre of the skull
- T2 was taken at the mid between Fpz and T4 and placed a little lower by the arc interference from the centre of the skull
- CONDITION OF BRAIN – Sitting Relaxed

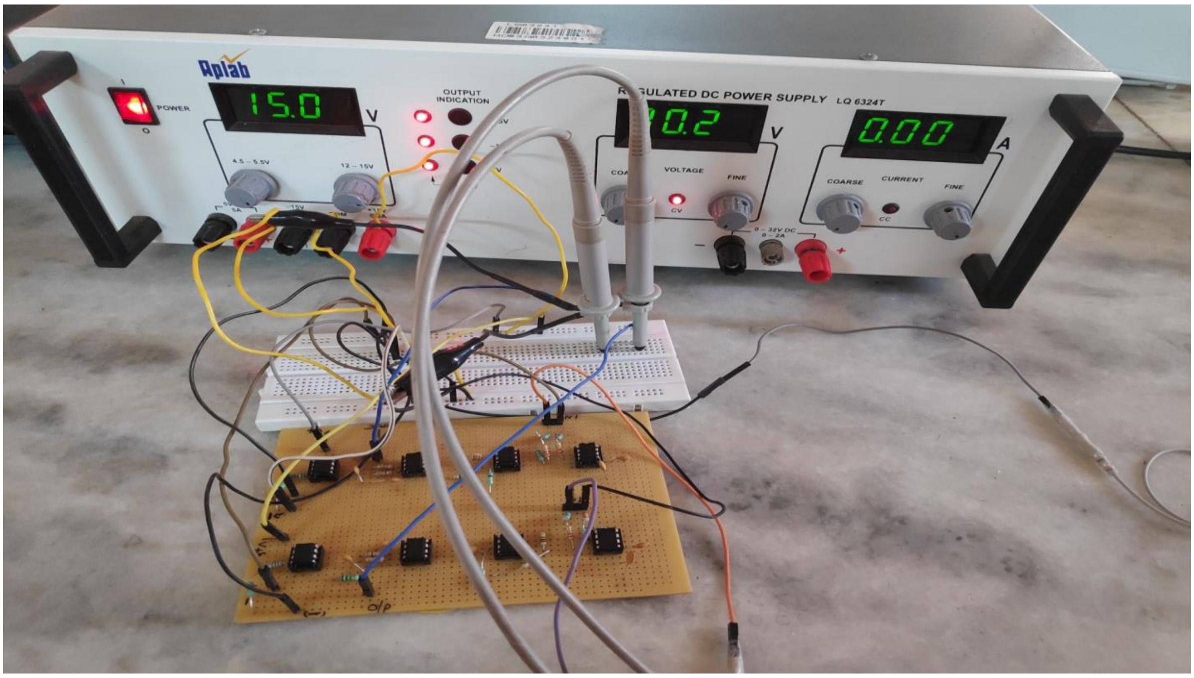


Fig 4.3 – Connection with the power supply and the DSO for the assembled Circuit board

The Setup was calibrated using the sine wave being given as the input from the function generator and the results of the calibrated setup is discussed in the Table 4.1 below.

Input Signal Amplitude(mV)	**Input Signal Frequency (Hz)**	**Output Signal Amplitude(V)**	**Output Signal Frequency (Hz)**
1	50	0.013	12.5
5	50	0.98	32
10	50	0.208	48.1
25	50	0.55	32.5
50	50	1.14	45
100	50	1.96	47.5
250	50	2.97	42
500	50	5.16	31.7

750	50	7.87	44
1000	50	9.89	40
10	75	0.228	69.6
50	30	1.14	32.5

The above calibrated table shows how the setup is serving the purpose of amplification and filtering of the 50Hz supply line calibrated to the setup's highest effectiveness.

Fig 4.4 is a sample result for 1mV, 50 Hz input Sine wave with ground as reference for the calibration , probe check and the gain check of the setup

Fig 4.5 - 50 Hz, 80mV sinusoidal wave as measuring electrode input to 50 Hz, 50mV sinusoidal wave as reference electrode input with Instrumentation amplifier gain as 22.7 as per design.

Output Obtained: Elimination of 50Hz input wave and the Vp-p=800mV(approximately near 30mv*22.7= 681mV for the design theoretical)

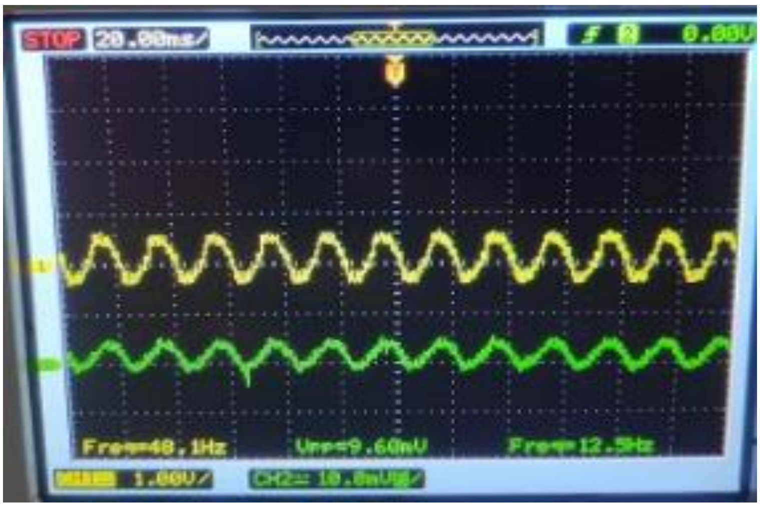


Fig 4.4 Sample Result of Sine wave Calibration Check

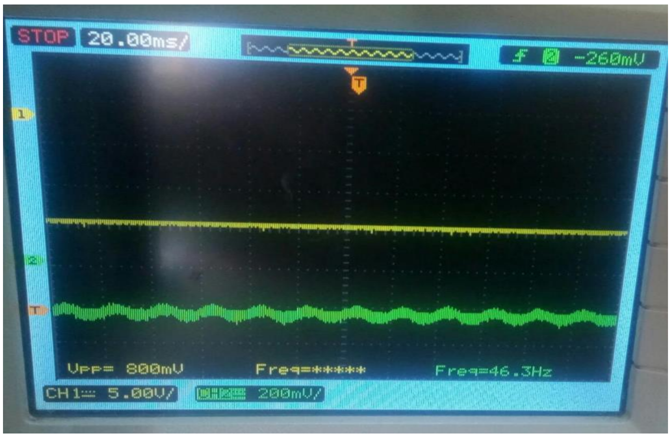


Fig 4.5 Check of Elimination of Supply line and gain amplification

The figure below shows the placement of the electrodes at the Fpz, T1, T3 and the setup for the accurate amplified and filtered brain wave to be obtained in DSO for which the conditions are discussed in the above page.

Fig 4.6:- Connection of Electrodes for pre-processed brain wave detection

4.2. METHODOLOGY OF RESEARCH

The individual stages of the system were set up and tested in the simulations initially. On obtaining acceptable functioning values, the stages were interconnected to construct the acquisition system as a whole. After verification of the simulation results, it was implemented on the breadboard for verification, then proceeded to the final assembled circuit board where it was calibrated to obtain the most accurate pre-processed brain wave signals. The system was tested using sinusoidal test signals of varying frequencies and amplitudes within reasonable limits to mimic actual EEG signals in the breadboard setup and to calibrate the assembled circuit board. The processed output signals were viewed on a digital storage oscilloscope (DSO. Finally, EEG electrode was placed at montage T3 of the international 10/20 system of electrode placement and the obtained signal was validated.

4.3. PROCESSOR AND IT'S FEATURES

The processor chosen is ADuCM362 from Analog Devices. The reason for choosing the above processor are:-

- Low power, Precision Analog Microprocessor
- ARM Cortex-M3 32-bit processor
- Single 24-bit ADC
- Programmable ADC output rate (3.5 Hz to 3.906 kHz)
- Up to 256 kB Flash/EE memory, 24 kB SRAM
- Power supply range: 1.8 V to 3.6 V (maximum)
- Specified for −40°C to +125°C operation

The below figure shows the pin diagram of the ADuCM362 which is compatible with Keil u Vision which is used for feature extraction and detection of temporal lobe epilepsy.

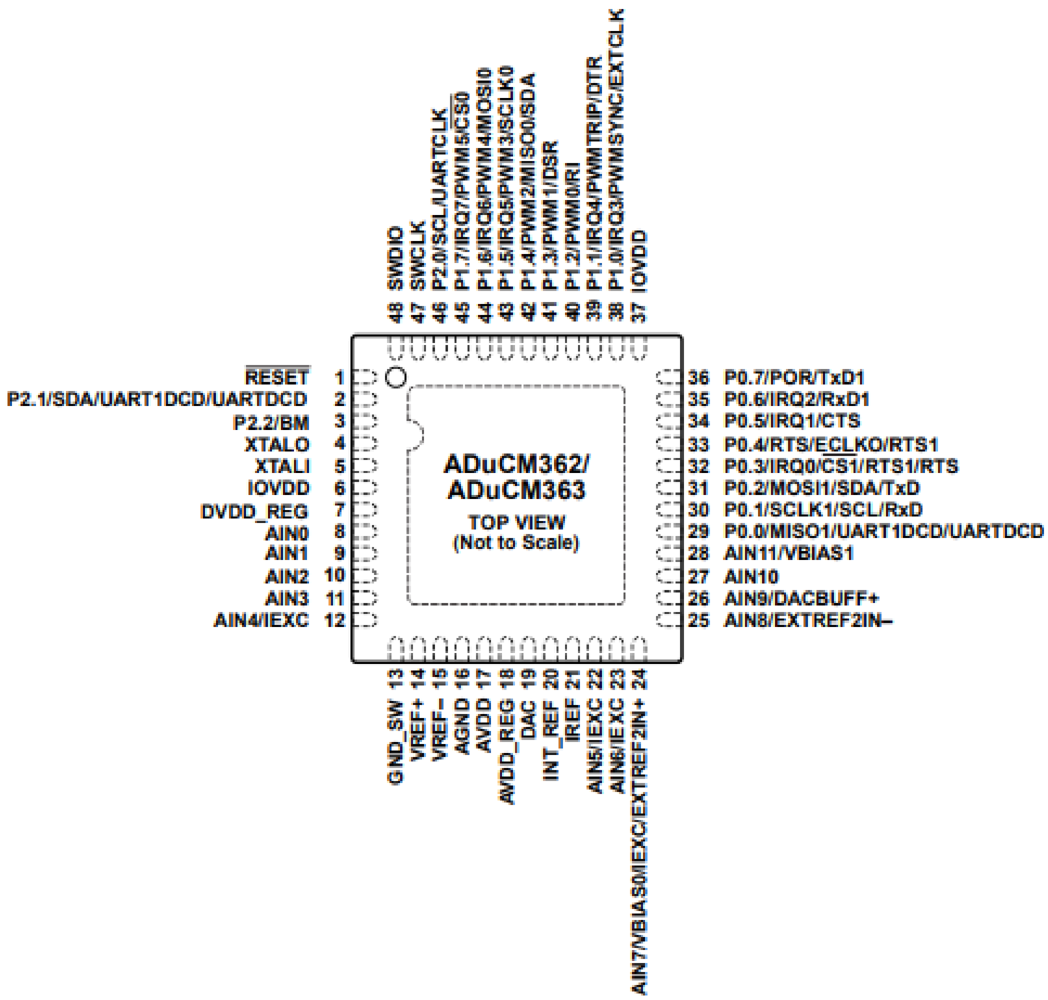


Fig 4.7 – Pin Diagram of ADuCM362 processor

EVAL- ADuCM362/363

The Evaluation Board made up of the AduCM362/363 is used as the microcontroller to interface the real-time EEG signal obtained with the software obtained and for the detection of the Temporal Lobe Epilepsy. The features of the EVAL-ADuCM362 are as follows:-

- 2 power supply options: 5 V from a USB port connected to the Segger J-Link OB emulator or 1.8 V to 3.6 V from an external power supply
- On-board resistance temperature detector (RTD) for temperature measurements
- Access to all analog and digital pins
- Power and general-purpose LEDs
- Reset and download push-buttons
- 8-pin connector to the Segger J-Link OB emulator
- 32.768 kHz external crystal

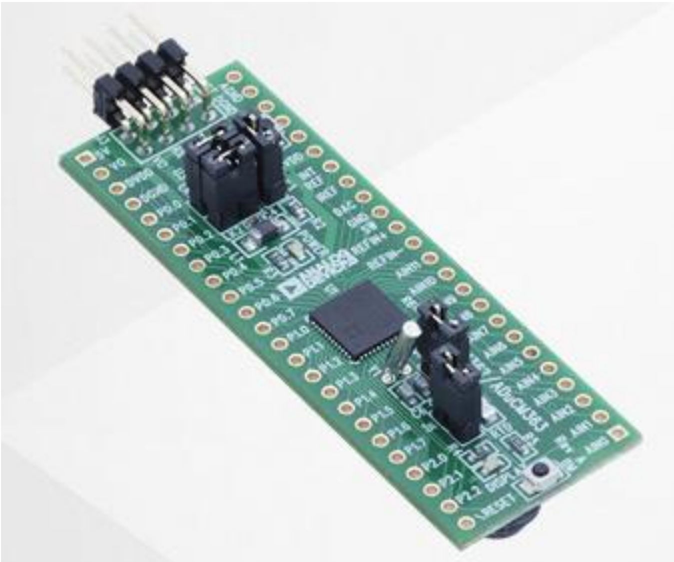


Fig 4.8 – EVAL-ADuCM362

COMPATIBILITY WITH SOFTWARE : EVAL-ADuCM362 is checked for it's compatibility with Keil u vision as it is a Cortex M-3 Processor and Cortex-M3 processor-based devices have been tested with µvision simulator. This is capable of incorporating he code using the CMSIS-DSP tool box and ARM-MATHLib for code transfer from Matlab.

CHAPTER 5

RESULTS AND DISCUSSIONS

In this chapter, we discuss the results obtained through simulations of MATLAB, Proteus and the results through the breadboard circuit implementation and assembled circuit board for the most accurate form of pre-processed brain waves and the future scope of the work is discussed.

5.1. FINDINGS

5.1.1. MATLAB

The simulation circuit implemented in Simulink are depicted in the Figure below

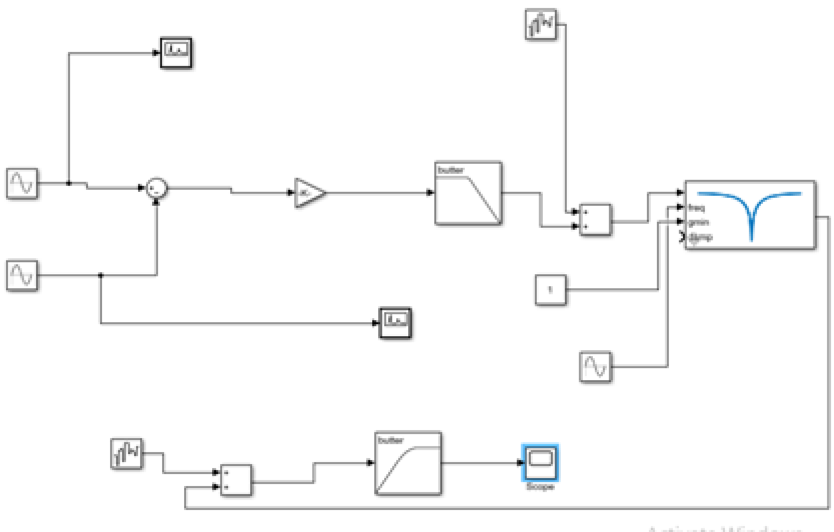


Fig 5.1 – Simulink Circuit

Band-pass filter

The band-pass filter was successfully implemented with the following specifications:

Lower -3 dB frequency: 0.56 Hz

Upper -3 dB frequency: 180 Hz

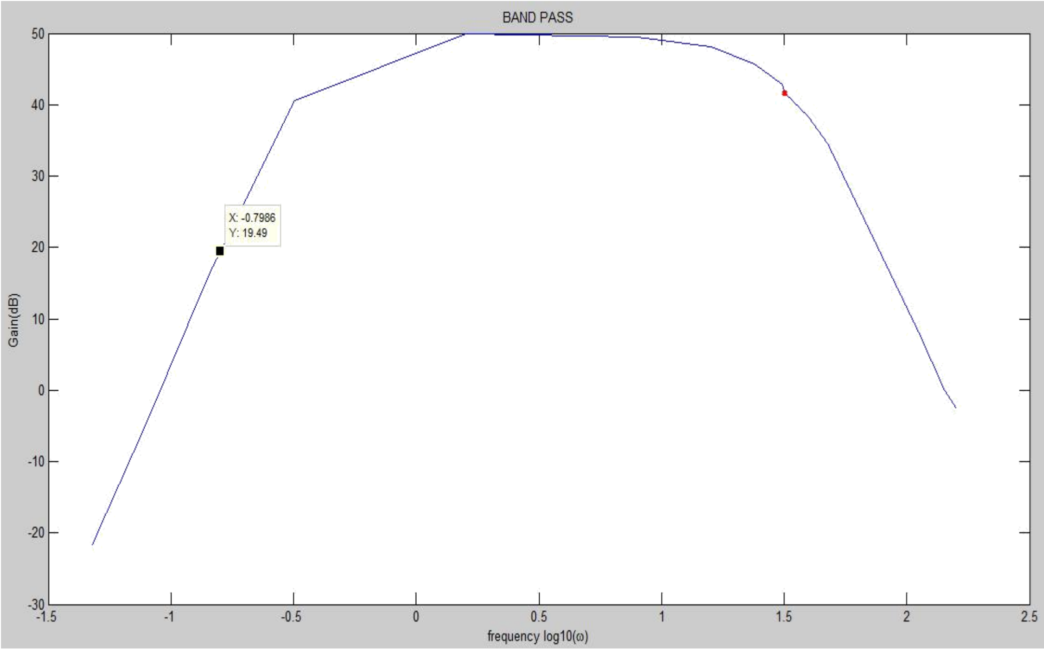


Fig 5.2 - Frequency response of band-pass filter

5.2.2 Notch filter

The notch filter was successfully implemented with the following specifications:

Reject frequency: 51 Hz

A table of practical input-output values obtained using the notch filter can be found in Table . The frequency response of the notch filter as obtained in MATLAB can be found in Figure .

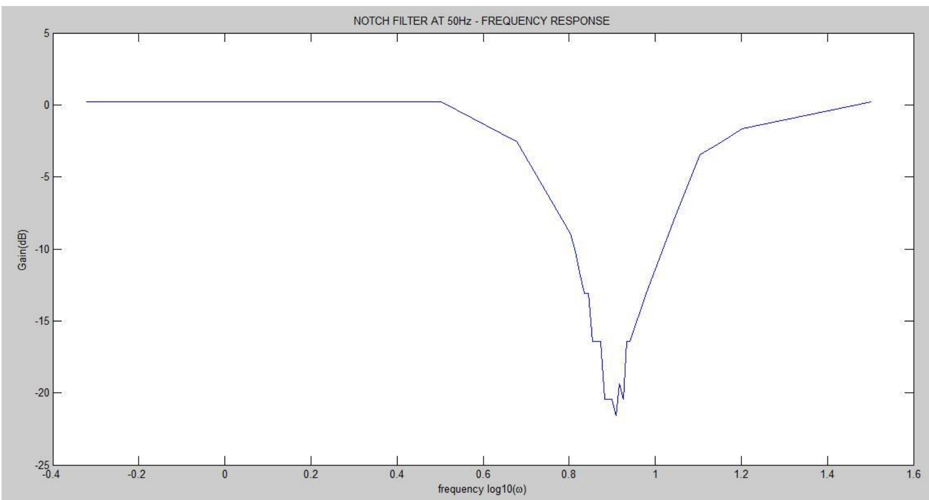


Fig 5.3 -Frequency response of notch filter

Frequency of sinusoidal signal (Hz)	Amplitude of output signal (V)
3	1.01
10	1.01
20	1.01
30	0.88
40	0.64
41	0.60
42	0.56
43	0.52
44	0.52
45	0.44
46	0.44
47	0.44
48	0.36
49	0.36
50	0.36
51	0.34
52	0.36
53	0.38
54	0.44
55	0.44
60	0.52
70	0.68
80	0.84
90	0.88
100	0.92
200	1.01

Table 5.1: Input and Output values obtained from Notch filter

After interconnecting all the signal processing stages, the following results are obtained. Processed output signals were logged to a computer system using MATLAB software.

Time response of a processed EEG signal in one channel as obtained in MATLAB in real-time is depicted in Figure 5.5. The following was observed about the EEG signal strength:

Amplitude of EEG signal before processing: 200 µV

Amplitude of EEG signal post processing: 4 V

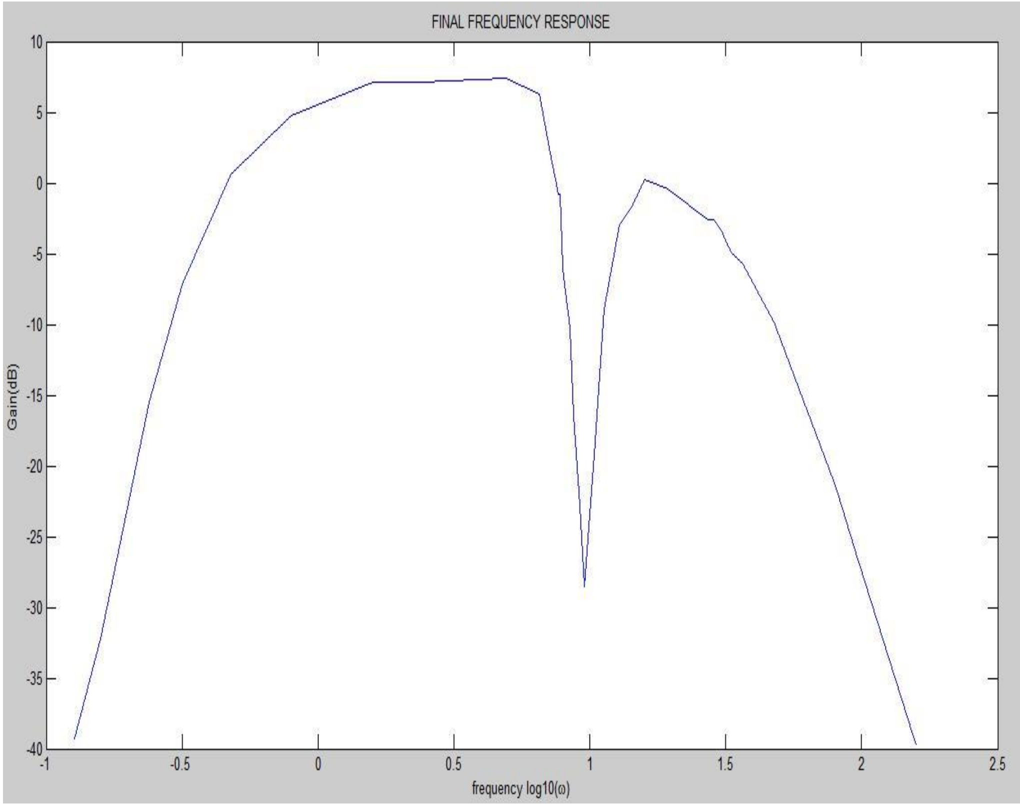


Fig 5.4 -Frequency response of Output obtained after preprocessing

5.1.2. PROTEUS

The Circuit with the corresponding gain value was designed using the Instrumentation amplifier with the right chosen variable gain resistor value of 2.2k for 22.7 amplification gain value, Band pass filter designed to pass 1-200 Hz and the reject frequency of 51 Hz was suitably implemented using the Notch filter circuit.

The below figure shows the implementation of the full circuit which is to be implemented in the assembled Circuit Board for obtaining the most accurate pre-processed brain waves.

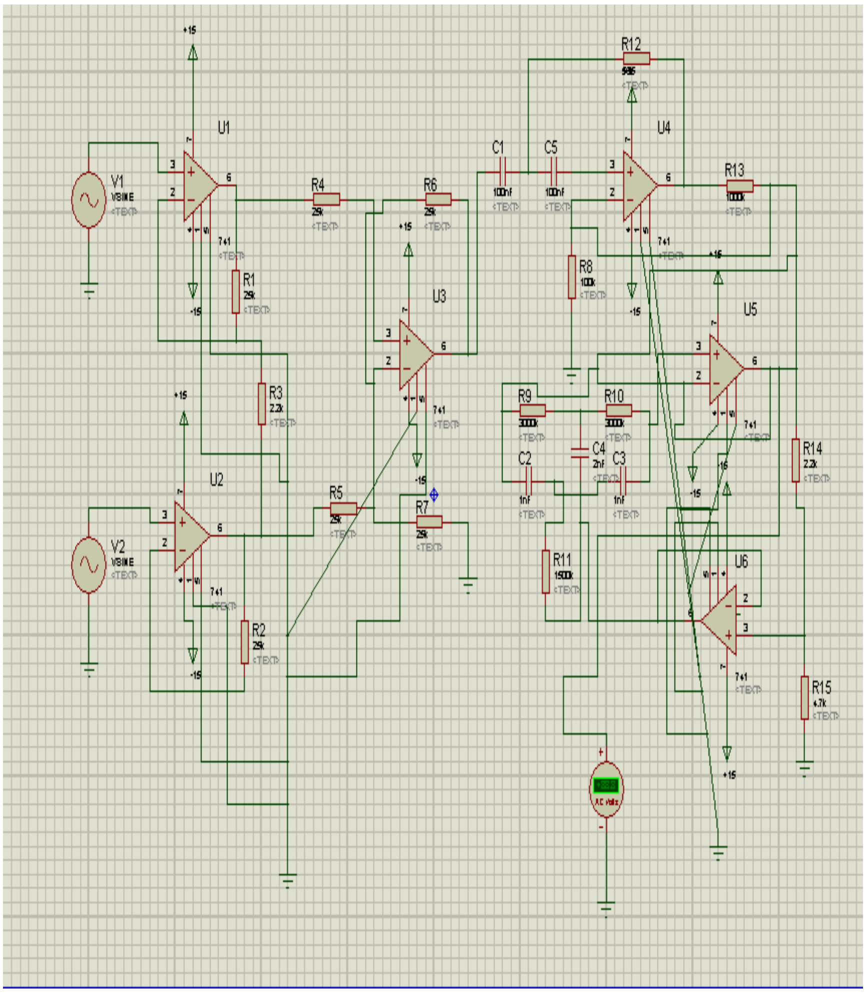


Fig 5.5 – Proteus Circuit Simulation Full pre-processed hardware circuit

Fig 5.6 - When 0.005V, 50hz measuring sinusoidal signal is given with 0.004V,50hz reference signal to above Simulation Circuit , there is the elimination of the 50hz frequency signal entirely in the notch filter output.

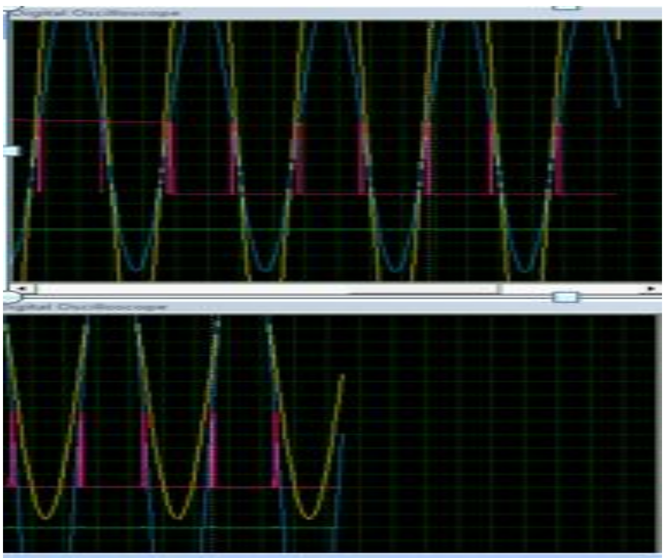


Fig 5.6 Case 1- Proteus Result

Fig 5.7 -When 0.005V, 80hz was given in the Measuring signal and 0.004 V, 50hz in the reference signal, it gets amplified 22.7(Instrumentation amplifier gain) and the output is 180mv from the notch filter.

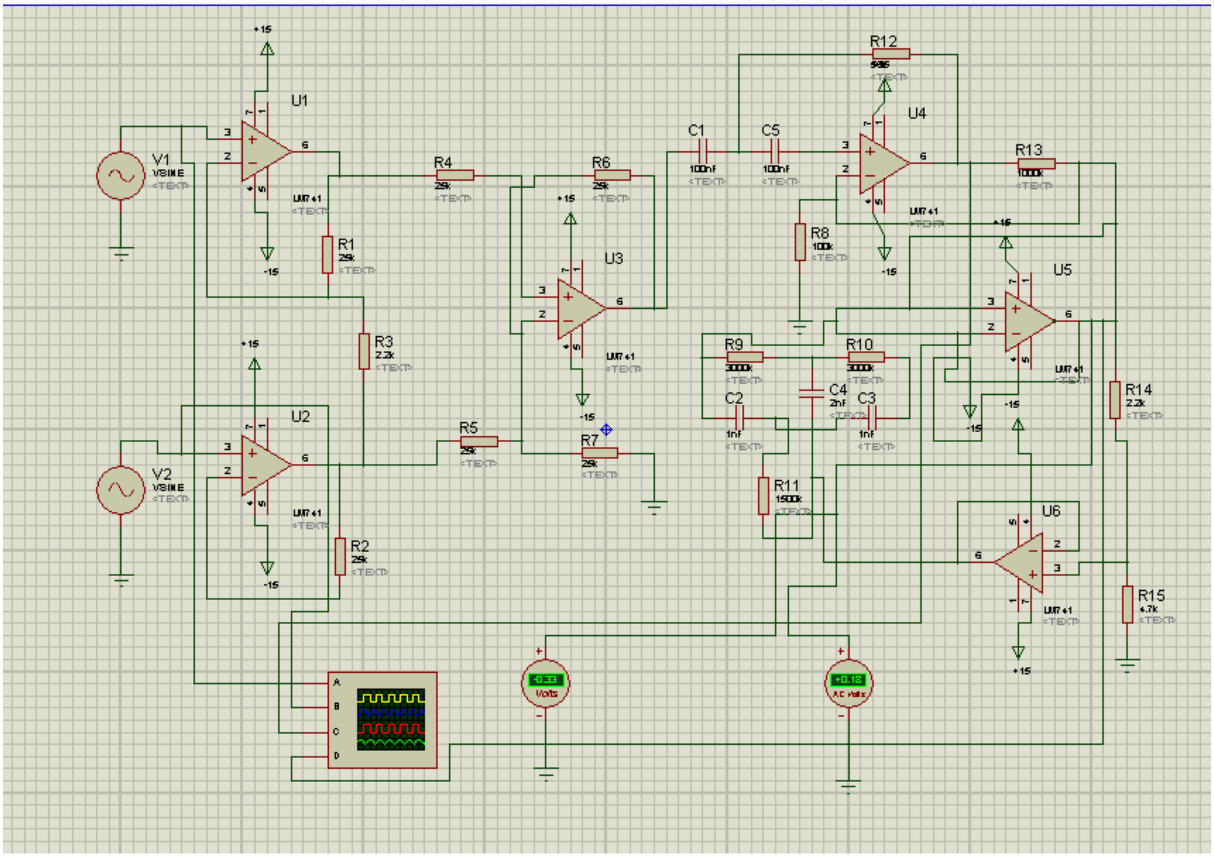


Fig 5.7 Case 2- Proteus Result

5.1.3. Breadboard Circuit Implementation

The Circuit verified by Proteus was tested using breadboard. The Setup and Connections was discussed in Fig 4.1 in the Experimentation chapter. The results obtained at different situations are as follows:-

Fig 5.8- 50 Hz, 80mV sinusoidal wave as measuring electrode input to 50 Hz, 50mV sinusoidal wave as reference electrode input with Instrumentation amplifier gain as 22.7 as per design.

Output Obtained : Elimination of 50Hz input wave and the Vp-p=800mV(approximately near 30mv*22.7= 681mV)

Fig 5.9 - 250 Hz, 100mV sinusoidal wave as measuring electrode input to 50 Hz, 30mV sinusoidal wave as reference electrode input with Instrumentation amplifier gain as 22.7 as per design.

Output Obtained : Elimination of 50Hz input wave and the Vp-p=1.56V(approximately near 70mv*22.7= 1.589V)

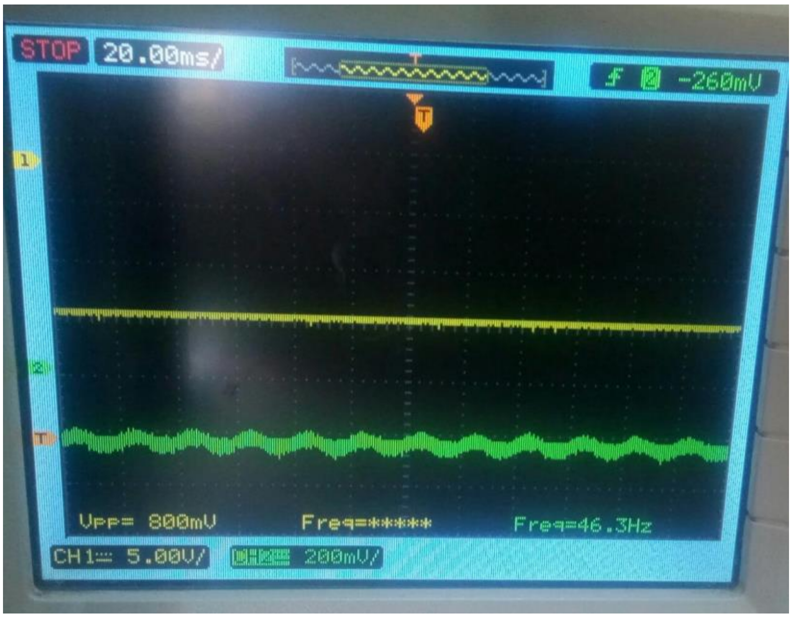


Fig 5.8 Case 1- Breadboard Result

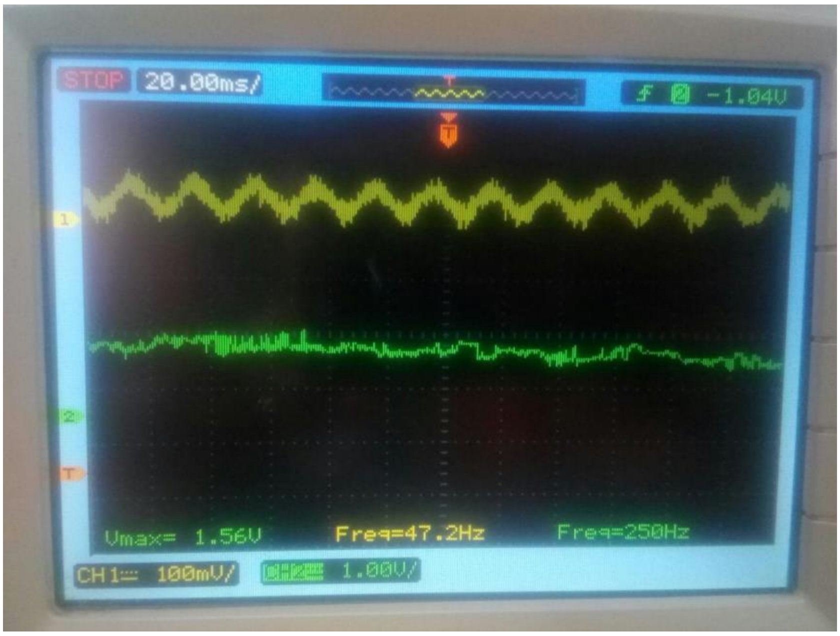


Fig 5.9 Case 2- Breadboard Result

5.2. Assembled Circuit Board Results

The Assembled Circuit Board was shown in Figure in Chapter 4- Experimentation. The further evaluation of it by the right electrode placement and electrical circuit connection for the assembled circuit board was shown in figure in Chapter -4.

The Results obtained through the Circuit are discussed as follows. The figure5.10 shows the T3 Electrode output, figure 5.11 shows the T1 Electrode output, figure5.12 shows the T4 Electrode output and figure 5.13 shows the T2 Electrode output.

Fig 5.10- T3 Electrode output- Vp-p:20mv, frequency:24.7 Hz

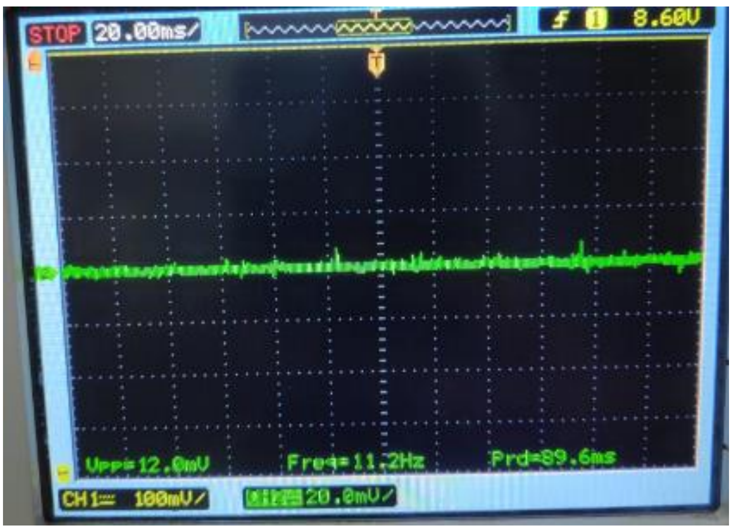


Fig 5.11 - T1 Electrode output- Vp-p:12mv, frequency:11.2 Hz

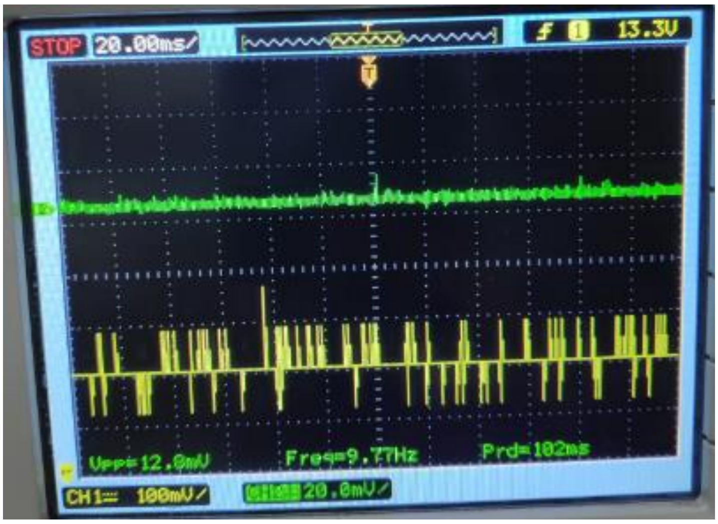


Fig 5.12 - T4 Electrode output- Vp-p:12mv, frequency:9.7 Hz

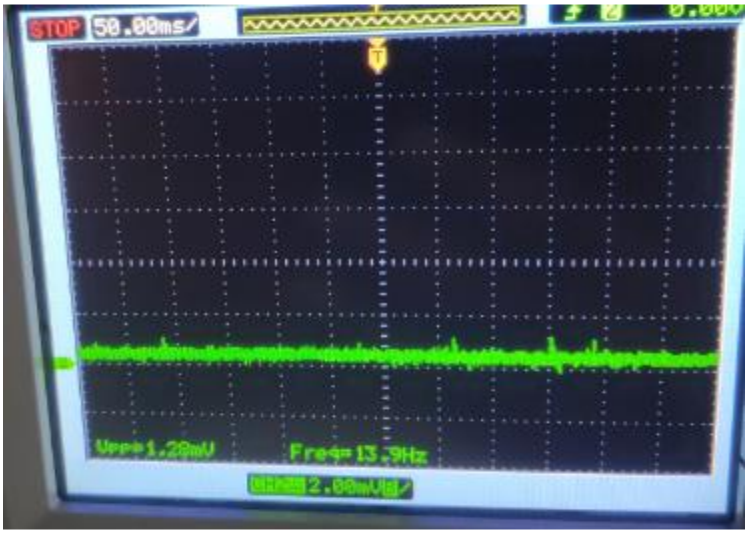
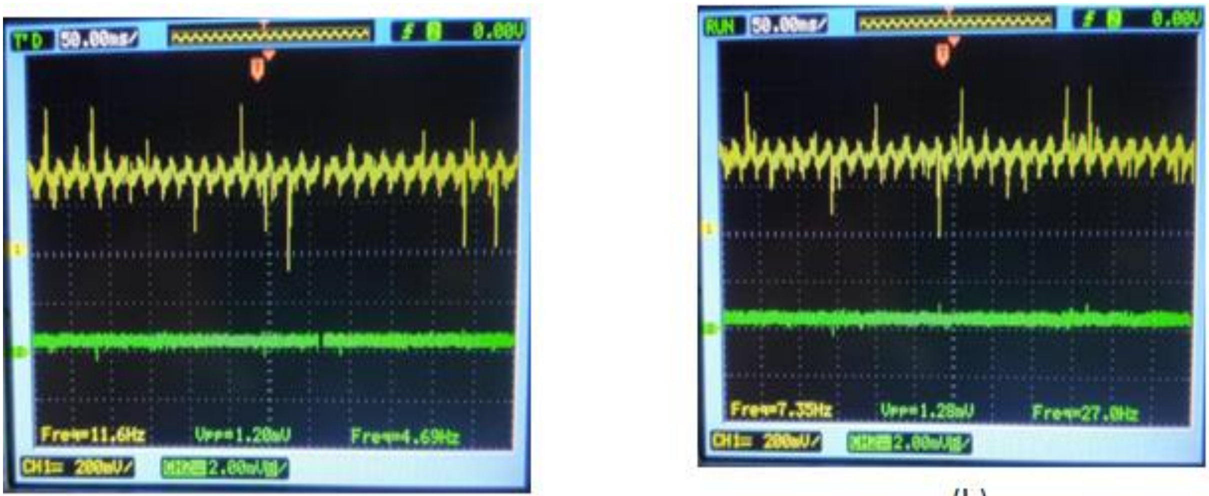


Fig 5.13 - T2 Electrode output- Vp-p:1.20mv, frequency:13.9 Hz

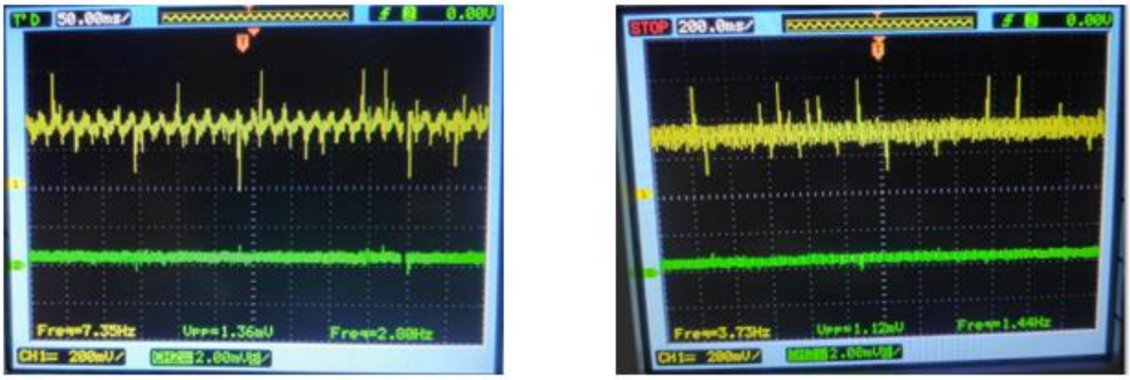
The next set of results are taken when the patient is on active and relaxed state. The figure 5.14 (a) shows T1, T3 electrode result and figure (b) shows T2, T4 electrode result in active state (beta waves). It indicates low amplitude and high state frequency waves in the electrode.



(a) (b)

Fig 5.14(a) shows T1, T3 electrode result and figure (b) shows T2, T4 electrode result (active state)

The figure 5.15 (a) shows T1, T3 electrode result and figure (b) shows T2, T4 electrode result in relaxed state (alpha to thetha waves) .It indicates low-medium amplitude and lower frequency waves in the electrode



(a) (b)

.

Fig 5.15 (a) shows T1, T3 electrode result and figure (b) shows T2, T4 electrode result (relaxed state)

The table below shows the frequency and amplitude obtained by the respective states of the brain. In active state, we get high frequency and low amplitude due to the beta waves and in relaxed state we get low frequency due the change in brain waves from beta to alpha or thetha waves. This is the observed conclusion from the result and fter 15-20 minutes of relaxation with the electrodes connected.

TABLE 5.2 – Pre-processed brain waves obtained from the setup at different states of the brain

State of Brain	Frequency T1,T3(Hz)	Frequency T2, T4 (Hz)	Amplitude (mV)
Active State	11.6,4.69	7.35,27	1.20,1.20
Relaxed State	7.35,2.00	3.73,1.44	1.36,1.12

5.3 CONCLUSION

The performance of the signal acquisition circuitry is close to ideal after calibration and testing. Minor inconsistencies are introduced owing to stray capacitance of lead and connecting wires, tolerances of resistors and capacitors employed, junction resistances arising from breadboard connections and environmental fluctuations in working environment. The pre-processed brain waves obtained are a good depiction of how the around 50uV brain wave signal is amplified to 1 mV by the hardware system and the frequency varies based on the state of the brain and undergoes transition when it changes from active to relaxed state. This needs to be processed in the software for feature extraction and to detect temporal lobe epilepsy.

5.4 FUTURE SCOPE

1.The system needs to be interfaced with the processor and the feature extraction is to be done for the detection of Temporal Lobe Epilepsy in Keil u Vision as the processor providing 24-bit resolution – AduCM362 is compatible to Keil only.

2.The system's capability can be enhanced to form a kit where on the detection of temporal Lobe Epilepsy, immediately an alarm can be interfaced to indicate the onset.

3.The transmission of signals from site of modulation to site of data accumulation could be achieved by wireless means. This would allow for longer transmission ranges without loss or distortion of the signals, and convenience in control of consumer BCI-compatible devices.

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