

An Implementation of Analog Portable EEG Signal Extraction System

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Abstract

In this study, it is aimed to perform an analog portable EEG (electroencephalogram) signal extraction system design. A portable biomedical signal recorder is vital to detect symptoms such as encephalitis, epilepsy etc. With coming into our life of EEG signal recording system, the signal acquired from human with help of electrodes has pre-processed for amplification by use of AD620 which is an instrumentation amplifier. Amplified EEG signals have been transmitted into high pass, low pass and notch filters, respectively to eliminate noise which are surrounded from tissues of the body and interference from the nearby electrical sources in the analog circuitry. Then the signals are converted into digital signals by an ADC. Finally, we transmitted EEG signals to computer by using Arduino and a special software application is used to display the output signals on Processing interface program. Two channels EEG recorder system has designed for real-time applications due to controlling and it can be developed to multi-channel systems to obtain reliable results in clinical setting.

Keywords: Analog EEG recorder; amplifier; HPF; LPF; Notch filter

1. Introduction

An electric potential is developed in the neurons. This combined voltage potential from multiple neurons can be measured from different places of the scalp. Electroencephalogram (EEG) measures the electrical activity of the brain by placing EEG probes on the scalp. A German physiologist named Hans Berger recorded the first human EEG in 1924 [1]. Also recording of cerebral activity with few electrodes (less than 16) is widely used in clinical neurology to diagnose seizures. The presence of electrical current in the brain was found by Richard Caton who is an English physician in 1975 [2].

Previously, doctors used patients' facial expressions to diagnose their diseases. These methods are not very inaccurate. Therefore, an objective analysis needs to be performed and it can be by explaining real-time bio-signals electroencephalogram (EEG). In the past, EEG machines were costly and their sizes are very big, and patients had to attend major hospitals in cities for their EEG signals to be measured.

Therefore an effort was made to reduce the size of the EEG machine so that it could be used more than before. Portable EEG machines are currently available in the market; although they solve the issues related to size to some extent, they are still very expensive [3, 4].

Because of all these reasons, we decided to make a portable EEG system with data logger which is simple, cheap, and convenient for patient use. In general, there are four wave groups (alpha, beta, theta, and delta). The EEG rhythm and waveforms are varied by the position of electrode placements on certain parts of the brain (fig.1).

Alpha wave occurs at a frequency between 7,5 and 13Hz. The alpha waves are produced when a person is conscious, relaxed state with eyes closed; the activity is suppressed when the eyes are open. The amplitude of the alpha rhythm intensely occurs in the occipital region and can be ideally recorded at parietal and frontal regions of the scalp.

Beta waves normally occur in the frequency range of 14-30Hz and sometimes even as high as 50Hz for intense activity. Beta waves activities are presented when people are alert or anxious, with their eyes open.

Theta potentials are large amplitude, low frequency between 3.5 and 7.5Hz waves. Theta is abnormal in alert adults but seen during sleep, and small children. Theta waves occur mainly in the parietal and temporal region.

Delta waves have the largest amplitudes and the lowest frequency in less than 3.5Hz. It is normal rhythm for infants less than one year old and in adults in deep sleep. This wave can thus occur solely within the cortex, independent of the activities in lower regions of the brain [5].

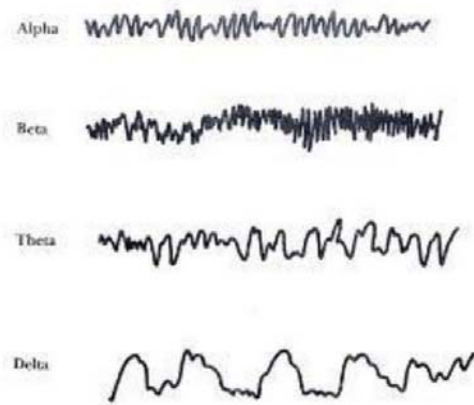


Fig. 1. EEG waveforms

2. Materials and Method

2.1. System Design Concept

In this system, at first we placed electrode in a specific area of the brain. It is seen in figure 2, electrodes are placed the subject's brain as a system. The system which often used to place silver-chloride electrodes for monitoring the clinical EEG is the International Federation 10-20 system as in figure 2. The 10-20 system is not how many electrodes to be put on the scalp but rather a measurement of percentage of 10% or 20% on a certain anatomical landmarks to standardize the placement of electrodes [4]. The positions are defined by certain anatomical reference points as follows: Reference point is left ear. Other electrodes are placed in different position of brain.

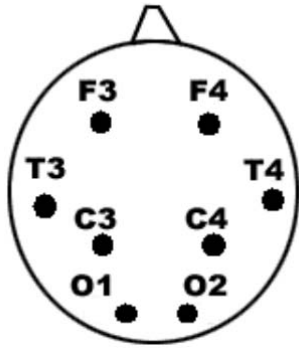


Fig. 2. 10-20 Electrode Placement System. The letter above P = parietal, F = frontal, T= temporal, O = occipital as standardized by the American Electroencephalographic Society. [4]

The Ag-AgCl electrodes are used in the EEG signal acquisition system because of having low impedance, low offset voltage and low noise with high stability. The application gel is needed for preparing the skin before placing electrodes to the skin in order to reduce input impedance and help for efficient transmission of the current through electrode – electrolyte interface [6]. Although an EEG system generally is equipped with more than eight electrodes, we used two electrodes for this system at the beginning.

Figure 3 shows the concept of the system design for prototype EEG signal card system below.

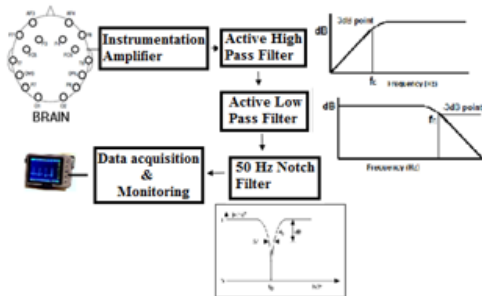


Fig. 3. Structure of the system

The amplitude of the EEG signal is very low (5-500 μV), this makes it difficult to acquire and measure. Hence an amplifier is required to strengthen the signals to a desired or recognizable level. Another problem is the DC offset of the signal which occurs electrode-tissue interface. This DC offset is generally about 20-50 mV and EEG signal is about 500 times less than DC offset. Therefore, instrumentation amplifier has a very low noise, high input impedance and high CMRR (Common Mode Rejection Ratio) is being necessary to amplify EEG signals and reject the DC offset [4, 7].

As in shown in Fig.3, designed system is mainly composed of scalp electrodes, instrumentation amplifier, active high pass filter, active low pass filter and 50 Hz Notch filter and monitor. The overall design was tested in Orcad and was implemented on printed circuit board (PCB). Additionally, PCB circuits were designed with Proteus.

2.2. Signal Amplifier

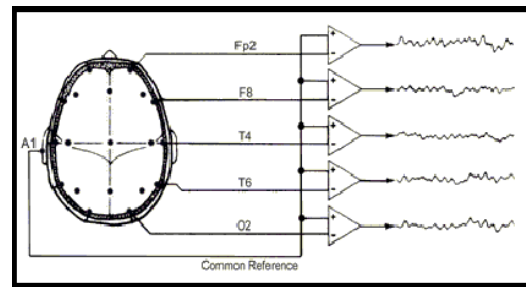


Fig. 4. EEG signals connection with instrumentation amplifier

The magnitude of EEG is about lower than 100 μV , so bio-potential amplifier with high gains and high quality is required.

The instrumentation amplifier amplifies the signal difference and turns down input signals common to both input leads. Occurred noise on both the input leads of the instrumentation amplifier by electrodes and electrode cables which are very close so they influence each other is significant subject, so due to its capability of rejection input signals common to both inputs it can eliminate the noise [3].

Instrumentation amplifier AD620 (Figure 6) was used in this project; it is very suitable for medical instrumentation application and uses low power consumption (1.5mW at 3V), which makes it good for portable design.

The general purpose of instrumentation amplifier offering excellent accuracy that eliminates common signal with 115dB (CMRR = 90 dB minimum). It has very low offset voltage of about 100 μV and very low drift voltage of 1 $\mu\text{V}/^\circ\text{C}$. The instrumentation amplifier is adjusted about 100 times to amplify; it cannot be adjusted to more than that value owing to DC component (power supply is +/- 5V) and amplified DC component is always lower than dc voltage level provided by the power supply because it can be useful for signal as it will be affected by noise [7, 9].

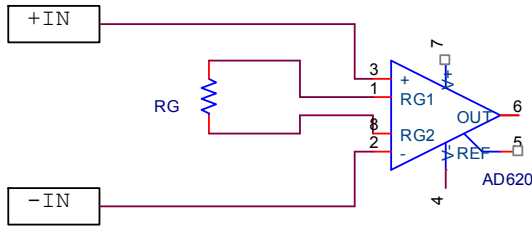


Fig. 5. Circuit diagram of instrumentation amplifier

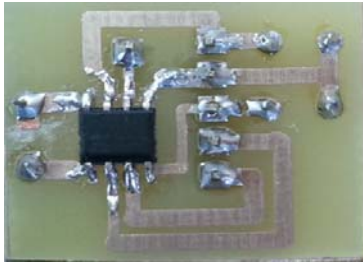


Fig. 6. PCB circuit of instrumentation amplifier

Figure 5 shows circuit of instrumentation amplifiers, this amplifier amplifies the signals about 100 times. The gain equation of the amplifier is given below,

$$RG = 100 \text{ k}\Omega / (G - 1) \quad (1)$$

The Rg resistor was set 1 kΩ therefore using the gain formula (1) for AD623, the gain will be 100.

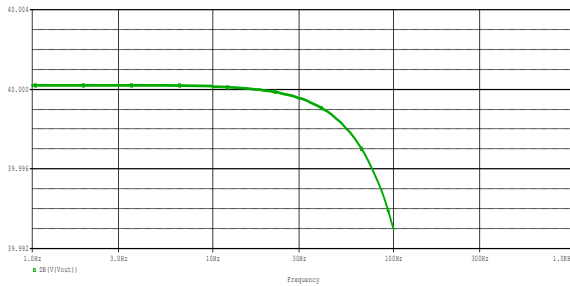


Fig. 7. Frequency response of the EEG amplifier

Figure 7 illustrates frequency response of the EEG amplifier and the gain is 40 dB. Using gain formula (2) in dB, we can get 100 for V2/V1.

$$\text{dB} = 20 \log_{10} (V2/V1) \quad (2)$$

2.3. Active Filter Design

The frequency range of the EEG signals for the normal human adult subject will be of 1 Hz to 40 Hz and it can extend up to 100 Hz based on the unnatural functionality of the brain. In the acquisition of the EEG signals there will be interference from sources of different things which can be from surroundings or within the body. The noise from the internal tissues is contributed by the potentials developed across them interfering with recordings at the surface. These signals will largely be of frequency more than 100Hz. Also the DC offsets

from electrical instruments will be observed in the low frequency range with the mean frequency of 0.5 Hz. The interference due to the AC electrical lines is at 50Hz which is also a source of noise [9, 10].

The system is necessary to preprocess the signal using a filter which is capable of eliminating interference signals. Thus we designed three filters which are active high pass filter, active low pass filter and 50 Hz Notch filter.

2.3.1. Design of Low Pass Butterworth Filter

In the first stage, we used active low pass filter in our design. As shown in figure 6, the 6th order low pass Butterworth filter is designed by cascading the three 2nd order filters with known filter coefficients and standard capacitor values by calculating the resistor values. We used AD8572 opamp for this design. It has low offset voltage, high gain and very low input bias current (10 pA). Cut-off frequency of the filter is 100 Hz at the gain of -3dB. Circuit of the filter is given fig. 8 and pcb circuit is fig. 9.

$$\text{Cut-off frequency (LPF)} = 1 / 2\pi RC = 100\text{Hz};$$

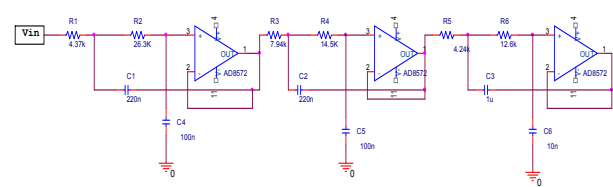


Fig. 8. Circuit diagram of Butterworth low pass filter



Fig. 9. Pcb design of Butterworth low pass filter

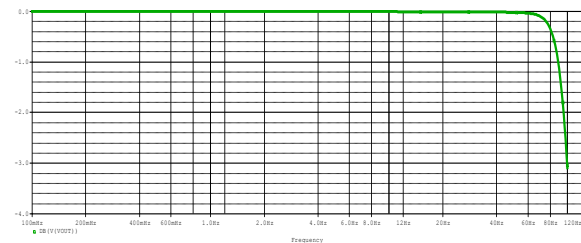


Fig. 10. Frequency response of 6th order low pass Butterworth filter

2.3.2. Design of High Pass Butterworth Filter

The high pass filters are applied to system after the Instrumentation Amplifier removes DC offsets. Its cutoff frequency is 0.5Hz (figure 9). There is a second high pass filter stage, filter is applied after the first operational amplifier

because amplification brings some new DC component to signal cause of amplifier offset and drift [11].

In this stage, we used 2nd order Butterworth filter. To obtain a filter with a flat frequency response and sharp transition region at 1 Hz cut-off frequency and the gain -3 dB, a 2nd order filter is sufficient for the desired performance with known filter coefficients and standard capacitor values by calculating the resistor values. We used AD8572 opamp for this filter. Figure 11 shows the circuit of active high filter and its pcb circuit is given in figure 12.

Cut-off frequency (HPF)= $1 / 2\pi RC = 0.5 \text{ Hz}$;

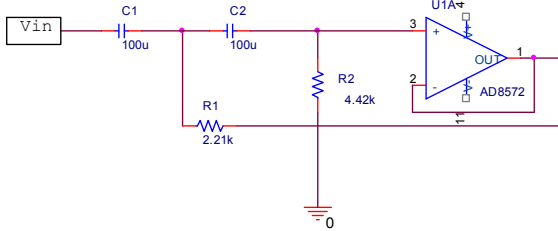


Fig. 11. Circuit diagram of Butterworth high pass filter

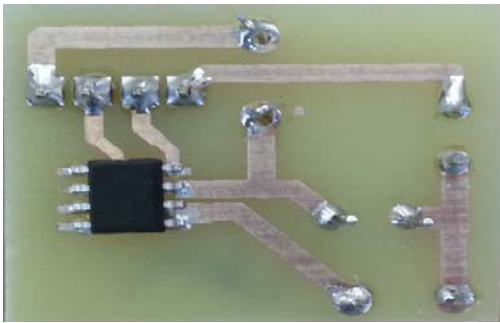


Fig.12. Pcb design of Butterworth high pass filter

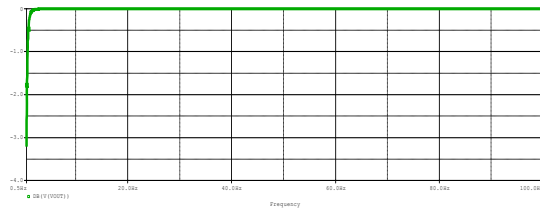


Fig. 13. Frequency response of 2nd order high pass Butterworth filter

2.3.3. Notch Filter Design

Active 50Hz Notch filter which is a type of band-stop filter that reduces a narrow range of frequencies is designed to filter the noise caused by the interference from the surrounding electrical lines. Hence, the Notch filter is designed at last. We designed notch filter using a twin-T topology. To implement this notch filter, AD8572 operational amplifier is selected again. Figure 14 shows circuit diagram of notch filter. The frequency response of the designed notch

filter is given in figure 16 which shows large attenuation at 50 Hz. The gain of the designed notch filter is 1.98 dB.

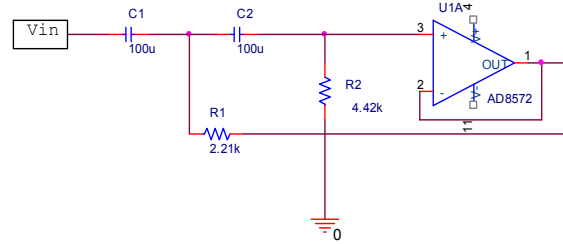


Fig. 14. Circuit diagram of Notch filter

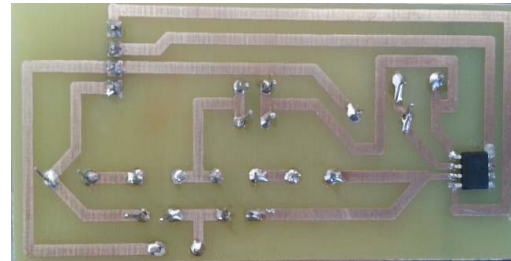


Fig. 15. Pcb design of Notch filter

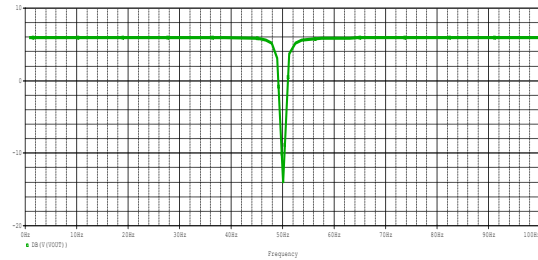


Fig. 16. Frequency response of Notch filter

2.4. Digital Conversion and Data Transfer Design

From the analog circuit which includes design of the amplifier and an active filter (series of sub-filters in cascade structure), an analog signal with gain of 5000V/V which is free from known noise frequencies is obtained [6]. This signal has to be digitized in order to transfer into the analysis platform which is Arduino micro controller. The Atmega32 microcontroller has an ADC with 8 multiplexed channels, each of them with a resolution of 10 bits. The working frequency of Atmega32 which is 16 MHz was programmed in the system. Its ADC clock works with 125 KHz. Furthermore, it is possible to select the ADC pre-scaler with the value of 8 in order to obtain a 10 bits resolution which is necessary fix the ADC clock with a frequency between 50 and 200 KHz. This information above is indicated in the datasheet of the microcontroller. The transform result is illustrated in two 8 bit registers [12].

The serial communication speed of Processing interface programme is set to just 9600 bits per second to monitor EEG data which are transmitted to interface programme. Otherwise microprocessor and Processing programme are not compatible each other.

The Atmega32 microcontroller includes a registry unit where the data to be transmitted by the serial port is stored, the values of micro controller output voltage and computer input voltage are adapted using the max 232 integrated circuit.

```

eminarard $
#define DIGITAL_IN D7

void setup() {
  Serial.begin(9600);
}

void loop()
{
  int val = DigitalRead(DIGITAL_IN);
  Serial.write( 0xff);
  Serial.write( (val >> 8) & 0xff);
  Serial.write( val & 0xff);
}

```

Fig. 17. Arduino code of the system

After this stage, we use Processing program which is designed with java for Arduino. We transmitted digital signals to computer in order to convert by means of ADC. Then EEG signals were monitored in processing program.

2.5. Power Management

This section describes the power supply design for amplifier integrated chips. As this project is designed and aimed to develop a portable instrumentation, the power supply range for operational amplifiers is selected to be at low voltage range which can be supplied by small batteries.

This project is designed to work on the voltage range of above 3 volts. Also there is a need to supply constant power source to the operational amplifiers since the battery voltage is degraded with continuous usage [12]. Hence a constant $\pm 5V$ power is supplied from a 9V battery using a voltage regulator. The voltage regulator circuit with the coupling capacitors is shown in figure 18.

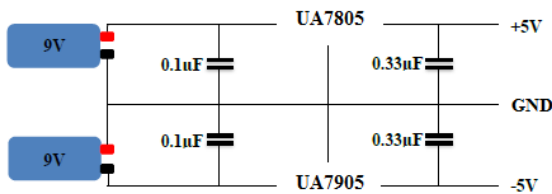


Fig. 18. Power Management of the system

3. Results



Fig. 19. Designed all of the system on the breadboard

We designed this system on the breadboard and connected all of the connections which relevant to the EEG signal system. Then, a man who were placed the electrodes his brain and the signals were monitored with computer. Fig.19 shows the designed all of the system on the breadboard.

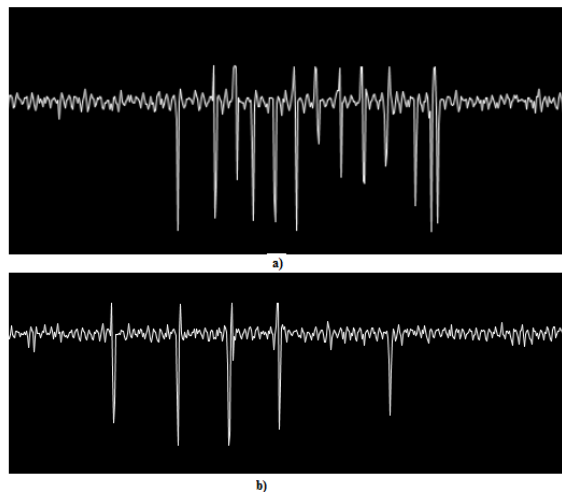


Fig. 20. Frequency response of Notch filter

A low noise EEG biopotential two channels amplifier is designed and investigated. In this system, we present the design and implementation of prototype hardware for acquiring the Electroencephalographic signals from the human subject and display them on monitor. In the experiment, although an EEG system generally is equipped with more than eight electrodes, we used two electrodes for this system at the beginning, one of which is a reference electrode connected to the earlobe. The other one is placed at the region of brain for EEG waves. The EEG signals acquired from the subject who is a 30 years-old man was pre-conditioned to be amplified with a 36.3dB gain which is ideally designed for 40dB gain. Then the signal passed the Butterworth high pass filter which has $f_{cut-off}$ frequency. The filter attenuates the frequencies less than 1Hz. Later the signal passes into the low pass a notch filter, respectively. Shortly the filters ideally designed these

frequencies between 1Hz to 100Hz rejecting 50Hz. The gain of the pass band frequencies is between 0dB and -3dB which is designed for 0dB gain.

Figure 21 shows the plot of Matlab analysis of signal. We transmitted the EEG signals which were acquired from the designed EEG card system to Matlab. But we connected the system to electrical line which is frequency of 50 Hz. As it is seen in frequency analysis, the system peaked at 50Hz without Notch Filter. Also figure 21 indicates the changes of frequency range of EEG signals between 0 and 50 Hz.

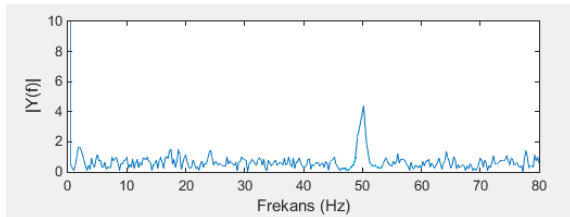


Fig. 21. Plot of Matlab frequency analysis of EEG signal

4. Conclusion

Finally, the system was designed and tested successfully. In future works, the system which can be used in different control experiment will be tested and compared with the present hierarchical approach and the application will be used by a number of volunteers and it presents usefulness for doctors due to determining the patient's problems in the health sector. The EEG signals are also used for biomedical control systems. These signals are used with BCI (Brain Computer Interface) a wheelchair, robotic arm and spelling which are controlled through this method.

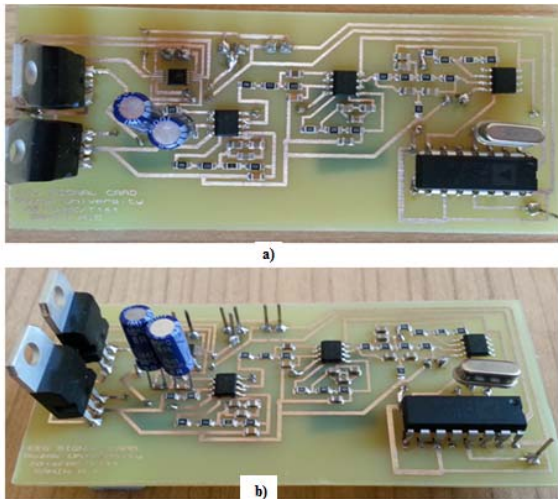


Fig. 22. Pcb card design all of the system

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