

RRI-EEG INTERNAL

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EEG Bio-Amplifier

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ABSTRACT :

A low-noise bio-potential amplifier, for use with weak bio-signals such as EEG (electroencephalogram), has been developed, specifically for use in Brain-computer Interface systems. This can be used to remove noise and amplify bio-signals to improve signal quality and provide adequate voltage levels for digitisation and signal processing. Using a series of filters and multi-stage amplification, the bio-amplifier band-passes frequency components in the range 1Hz and 35Hz, and provides a gain in the range 8000 to 1000,000. The gain and offset are adjusted automatically, so as to maintain the output in the 0 - 1V range. This bio-amplifier unit is routinely used in our SSVEP-based BCI system and its performance has been in par with a commercially available system.

INTRODUCTION:

A bio-amplifier that is to be used to measure physiological signals such as EEG have to satisfy specific requirements. The bio-potentials, acquired by means of electrodes placed on the scalp of the subject, are only a of few microvolts in amplitude, and need to be amplified several thousand times before digitisation and storage or processing. In addition, noise and interference signals (eg. 50Hz line pick-up) have to be rejected. Further, the circuit

should ensure that the subject, as well as the bio-amplifier unit is protected from voltage surges, if any. All these requirements call for a careful design. This report describes the bio-amplifier designed in-house. It has been thoroughly tested, and is routinely used in our BCI experiments.

MOTIVATION:

Presently, the existing high-end commercial Brain Computer Interface (BCI) system is a multi-channel generic system consisting of 16 channels each with an automatic gain adjustment. Each channel is provided with a 24-bit Analog to Digital Converter. They are equipped GUIs designed specifically for BCI application like SSVEP / P300/ Motor Imagery/ Speller etc.. Such systems are very expensive. Hence, a low-cost system was devised by us. Our aim in developing an in-house system was to extract and process the signal with minimum amount of time and to perform different actions with a good accuracy and to permit easy customization, with an ultimate aim of providing low cost devices to physically challenged persons.

The in-house system which was developed is a 2-channel system using readily available components. Features like automatic gain and offset control have been incorporated. The digitisation and processing is carried over open source hardware with the firmware programs developed by us. Though the system was aimed to act as a generic system, its robustness and reliability needs to be ensured for different forms of BCI. Presently, the system has been tested and optimised to meet the designed performance, its robustness and reliability assessed and verified across various subjects. Specifically, emphasis was laid on SSVEP (Steady State Visually Evoked Potentials)-based BCI applications as this requires minimal training of the user. It has also been successfully used for motor-imagery based applications.

DESCRIPTION:

Overview of the bio-amplifier:

The bio-amplifier consists of 2 channels with each of them comprising of:

- Power supply circuitry

- Instrumentation amplifier
- Band-pass Filter
- 50 Hz Notch Filter
- Successive gain stages.

Power supply Specifications:

No. of channels	2
Supply current(9V supply)	70mA(2 channels)
Isolation voltage	3000V

EEG amplifier specification:

Gain	15000-1.3x10 ⁶ (variable)
Offset handling capability	>3V
CMRR	>100dB
High pass filter	Fc = 1Hz
Low pass filter	Fc = 35Hz

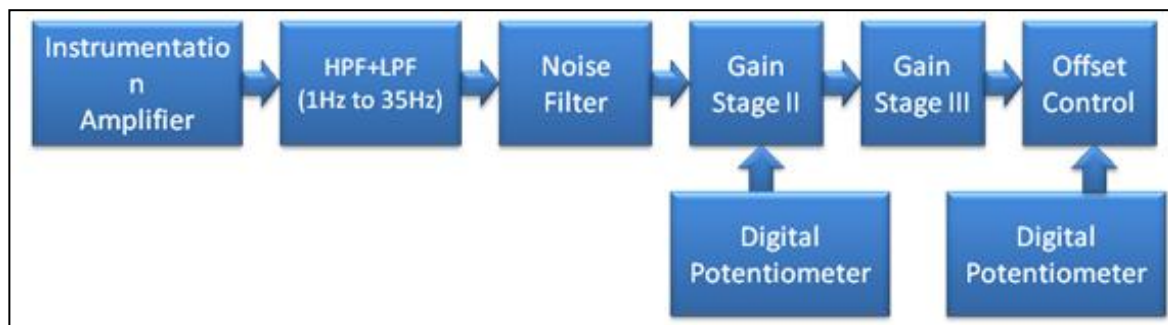


Fig. 3.8: Bio-Amplifier Block Diagram

Power Supply Circuitry:

It consists of a regulated 5 V input from a 9 V battery. The output of the power supply circuit consists of 3 terminals; Vcc, VGND and AGND. AGND is the analog ground which is connected to the negative terminal of the battery while, VGND is the virtual ground which acts as a zero reference line to all the components of the Bio-Amplifier. Since, the Op-Amps require a negative power supply, AGND acts as a negative supply (-Vcc) while, VGND acts

as an actual ground. The output from 7805 regulator powers a DC-DC converter. The DC-DC converter powers rest of the circuitry and also protect the user from possible overvoltages. Following the DC-DC converter are two filters, inductors L2 and L3 and capacitors, these filters are used to reduce the switching noise from DC-DC converter.

The circuitry of this stage of the Bio-Amplifier is as shown below:

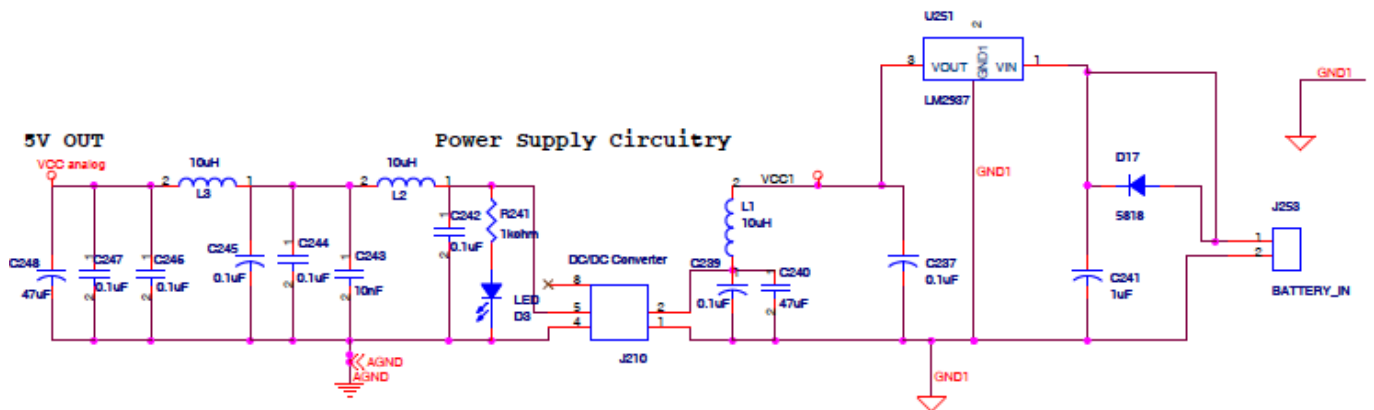


Fig. 3.9: Power supply circuitry of Bio-Amplifier

Instrumentation Amplifier Stage:

In order to reduce the impact of noisy environment, a differential amplifier which has high common mode rejection ratio and a high input impedance is used. The instrumentation amplifier INA 114 IC provides these characteristics. The specifications of this amplifier are as follows:

- Operating Voltage range: ± 2.25 V to ± 18 V.
- Input over-voltage protection: ± 40 V.
- Input Impedance: $\sim 10^{10}$ Ω .
- CMRR: 115 dB

This, component, available as an 8-pin dip plastic package, is used in the bio-amplifier to measure the voltage difference between two locations on the scalp (signal and reference). This stage also includes a protection circuitry comprising of Electro-Static Discharge (ESD) Diodes in order to protect the Instrumentation Amplifier and user as well.

This stage of the Bio-Amplifier is as shown below :

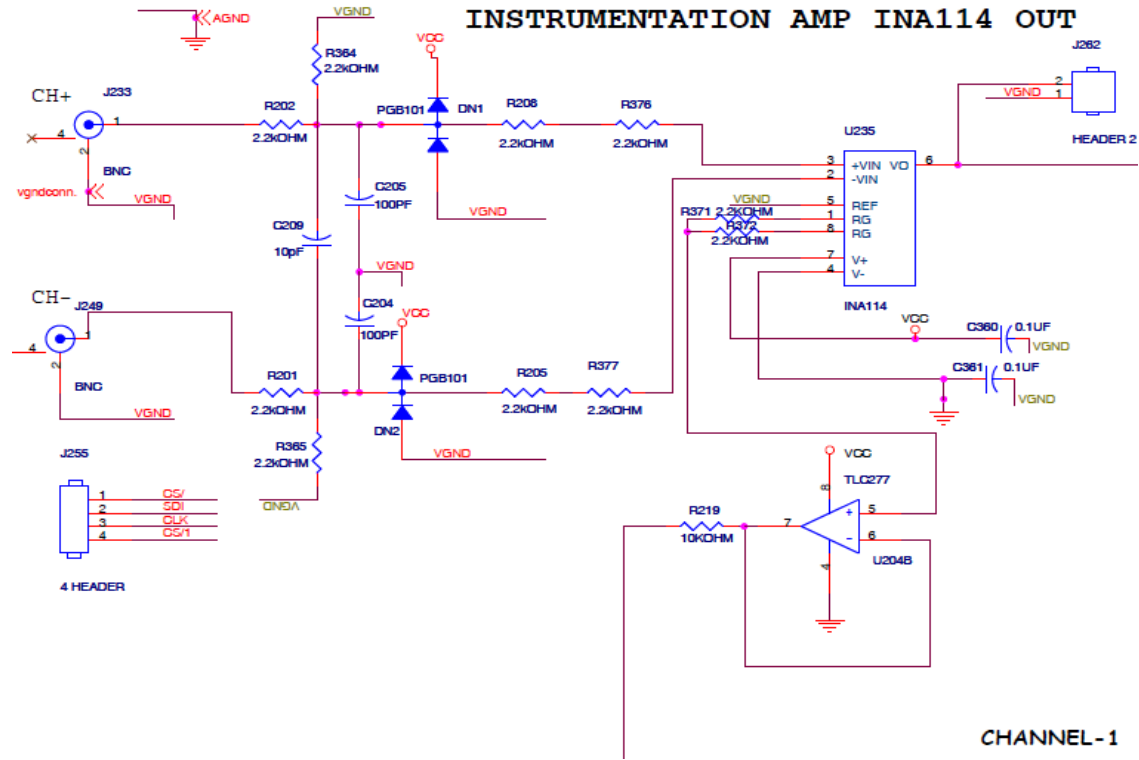


Fig. 3.10: Instrumentation Amplifier Circuitry of Bio-Amplifier

Band-Pass Filter:

It is a combination of a High-pass Filter and a Low-Pass Filter. The High-Pass Filter is of single stage with a cut-off frequency of 1 Hz while, the Low-Pass Filter comprises of 3 stages with a cut-off of 35 Hz. It is used to minimize the distortion and restricting the frequency band to the range of 1-35 Hz which is also the frequency range of interest for generating SSVEP signals. The High-Pass Filter is used to remove the DC offset.

The schematic diagram of the Band-Pass Filter is as shown below:

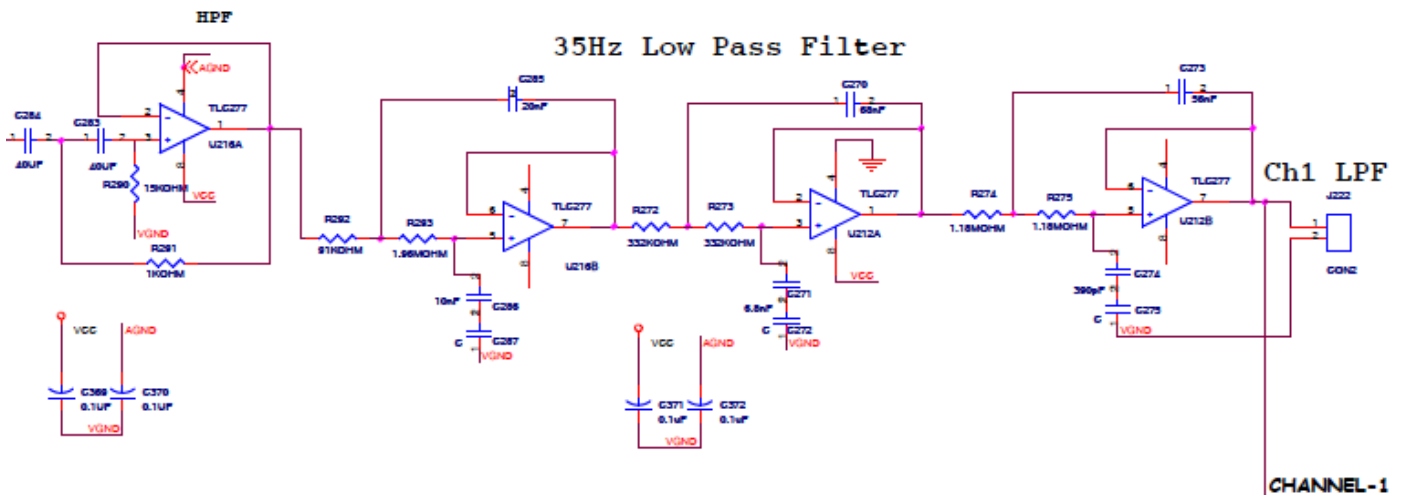


Fig. 3.11: Band-pass Filter Circuitry of Bio-Amplifier

The Band-Pass Filter comprises of Op-Amps, Resistors and Capacitors with specifications as shown in the above schematic.

The High-Pass Filter is a single stage Filter with a Gain of 1. The design of this filter with the above circuit is as tabulated below:

R1	R2	C1	C2	Op-Amp
15k	1k	40uF	40uF	TLC277

The Low-Pass Filter which has been designed is of topology Chebyshev (Sallen Key) of order 6 and stages 3. It has a Gain of 1 and allowable pass-band ripple of 0.5 dB. It has been assembled and tested for its performance stage-wise.

The design of each of the 3 stages with the above circuit is as tabulated below:

STAGE	R1	R2	C1	C2	Op-Amp
1	91k	1.96M	20nF	10nF	TLC277
2	332k	332k	68nF	6.8nF	TLC277
3	1.18M	1.18M	56nF	390pF	TLC277

50 Hz Notch Filter:

It is of Twin-T configuration and it is used to reject the 50 Hz noise from the acquired signal in order to improve the quality of the signal. The filter also provides gain Of 3.5.

The schematic diagram of this stage of the Bio-Amplifier is as shown below:

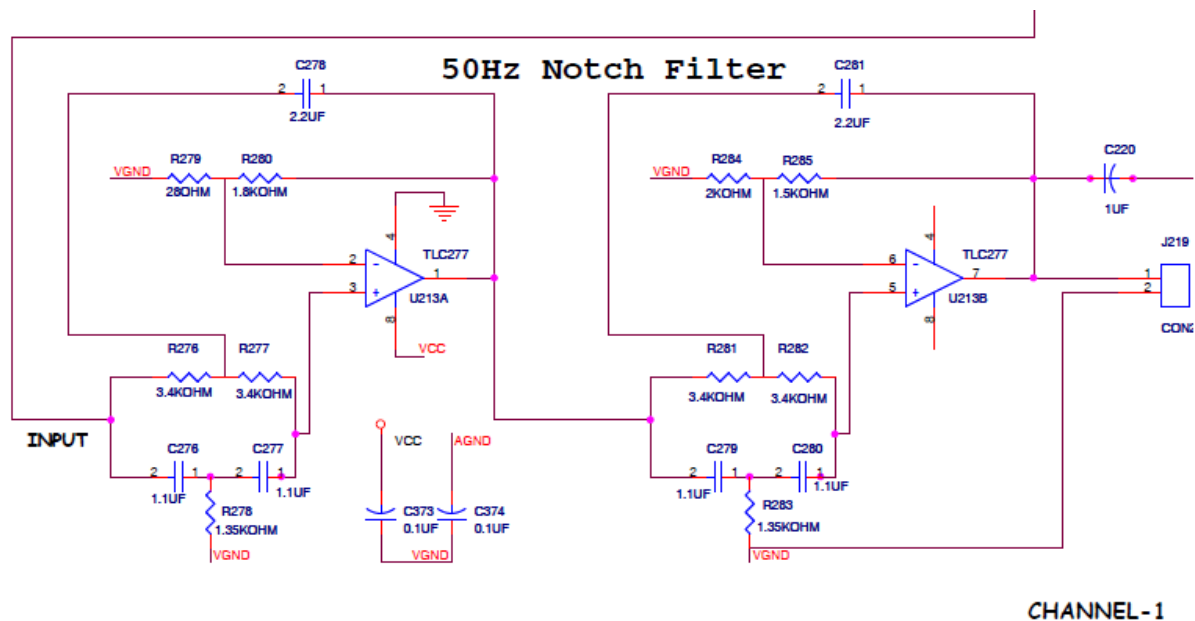


Fig. 3.12: 50 Hz Notch Filter Circuitry of Bio-Amplifier

Successive Gain Stages:

The signal strength is further improved by cascaded amplifiers. The amplified signal is finally passed to an Arduino UNO Board for digitisation and processing. A low pass filter is used in the final stage of the bio-amplifier to prevent aliasing effect when the signals are digitized.

The cascaded amplifiers consist of three stages as shown in the below schematic:

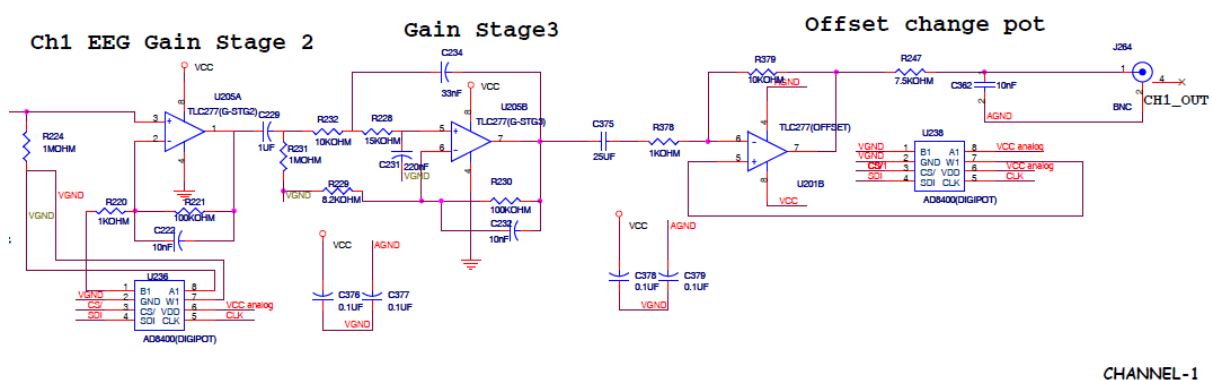


Fig. 3.13: Additional Gain Stages Circuitry of Bio-Amplifier

After the first gain stage (instrumentation amplifier), the second gain stage in the Bio-amplifier has a variable gain. The gain is varied automatically, to ensure that the final amplified signal has a peak-to-peak amplitude suited for the digitisation board. The gain is varied using a Digital Potentiometer (AD8400). The circuit configuration is that of a Non-Inverting amplifier using TLC277 Op-Amp and is as shown in the circuit of “Ch1 EEG Gain Stage 2” in the above schematic. This circuit offers 256 different gains controlled through an SPI compatible serial digital interface by loading the D value into the digital potentiometer, which would vary the resistance value of the digital potentiometer from 50 Ω to 10 k Ω using the following expression:

$$G = \frac{1 + \left(\frac{256 - D}{256}\right) * R_{AB}}{R_2}$$

where,

D - Code loaded in the digital potentiometer whose value ranges from 0-255.

After the second gain stage (gain using Digi-pot), the third gain stage in the Bio-amplifier, is a gain stage fixed with a value of 12. The circuit configuration is that of a Non-Inverting amplifier using TLC277 Op-Amp and is as shown in the circuit of 'Gain Stage 3' in the above schematic.

The circuit of “DC offset change pot” provides a Gain of 10 and gives the user the flexibility to vary the DC offset of the acquired and processed signal with respect to AGND. The DC offset is then varied using another Digital potentiometer by loading a suitable D value through SPI compatible serial digital interface. Thus, the resistance of the digital potentiometer is varied from 50 Ω to 10 k Ω depending on the D value loaded using the expression:

$$R_{WB} = \left(\frac{D}{256}\right) * R_{AB} + R_W$$

where,

D - Code loaded in the digital potentiometer whose value ranges from 0-255.

R_{AB} - nominal end-to-end resistance.

R_W - wiper resistance which has a fixed value of 50 Ω .

R_{WB} - Resistance across wiper and B terminal.

FABRICATION DETAILS:

The whole circuitry of the Bio-amplifier is enclosed within a metal box of dimensions, 22 x 15 x 4 cm. The top plate of the box is mounted with two Arduino Uno Boards; one for controlling the digital potentiometers and the other for acquiring and processing the EEG signals. These two Arduino boards have been enclosed within another metal enclosure of dimensions, 17 x 9 x 4 cm.

The front and back panels have provisions for the output channel connections (like, output 1, output 2 and Drive Right Leg (DRL)) and the input channel connections (like, CH1+, CH1-, CH2+ and CH2-) respectively.

The module that has been designed and fabricated along with the above mentioned dimensions is as shown below:

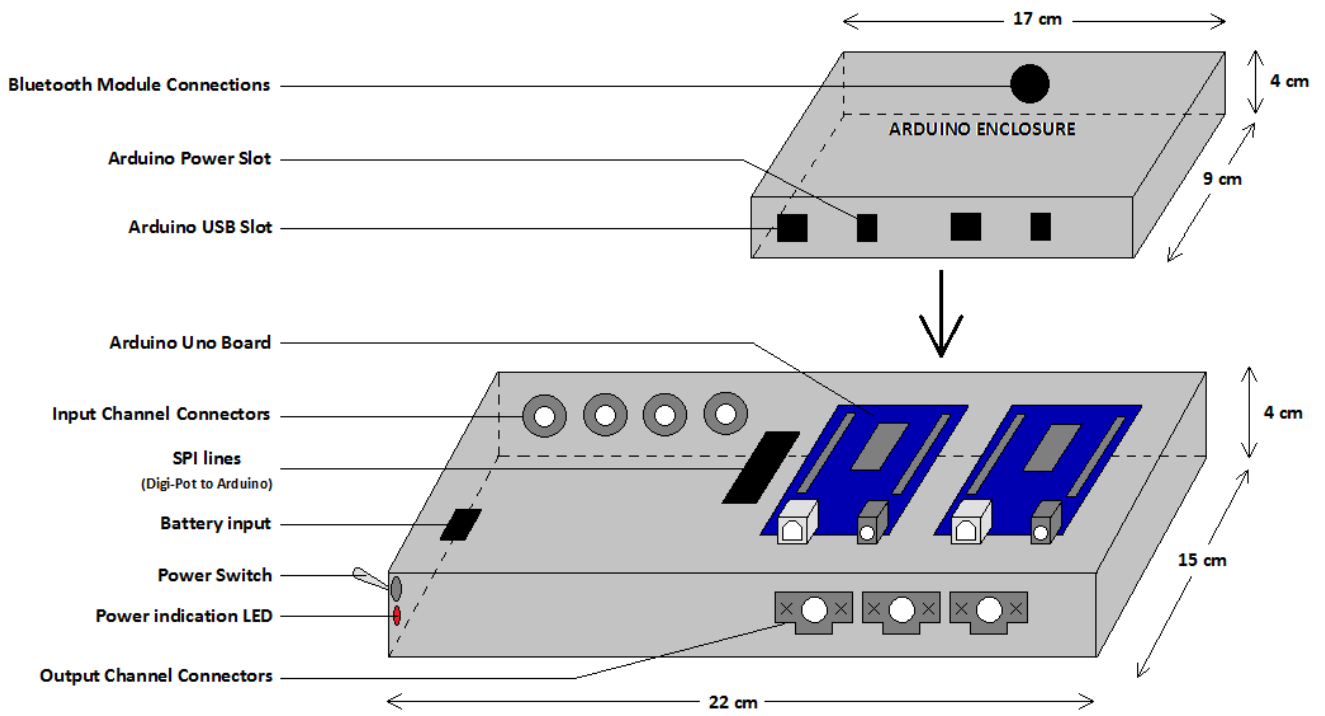


Fig. 4.1: Construction and Fabrication of Bio-Amplifier Module

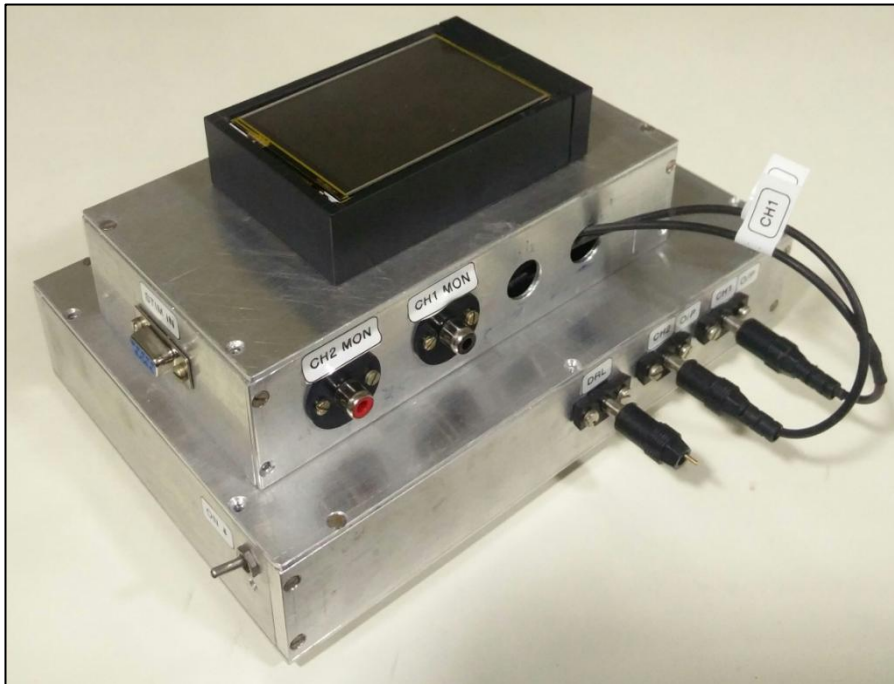


Fig. 4.1: Picture of Bio-Amplifier

The PCB that has been enclosed with the above metal box is a 2-layered card assembled with the various discrete components that make up the Bio-amplifier circuitry.

MEASUREMENT DETAILS:

Bio-Amplifier Output Characteristics:

To measure the output characteristics of the Low-Pass Filter in the Bio-Amplifier, a Laboratory setup had been made where in, the signal generator was used as the signal source. During the setup the signal generator was set to provide a 2 mV sinusoidal signal. The frequency was then swept in the range of 5 - 60 Hz and the instrumentation gain (1st stage gain) was set to be a factor of 200. The voltage output was measured to obtain the following plot:

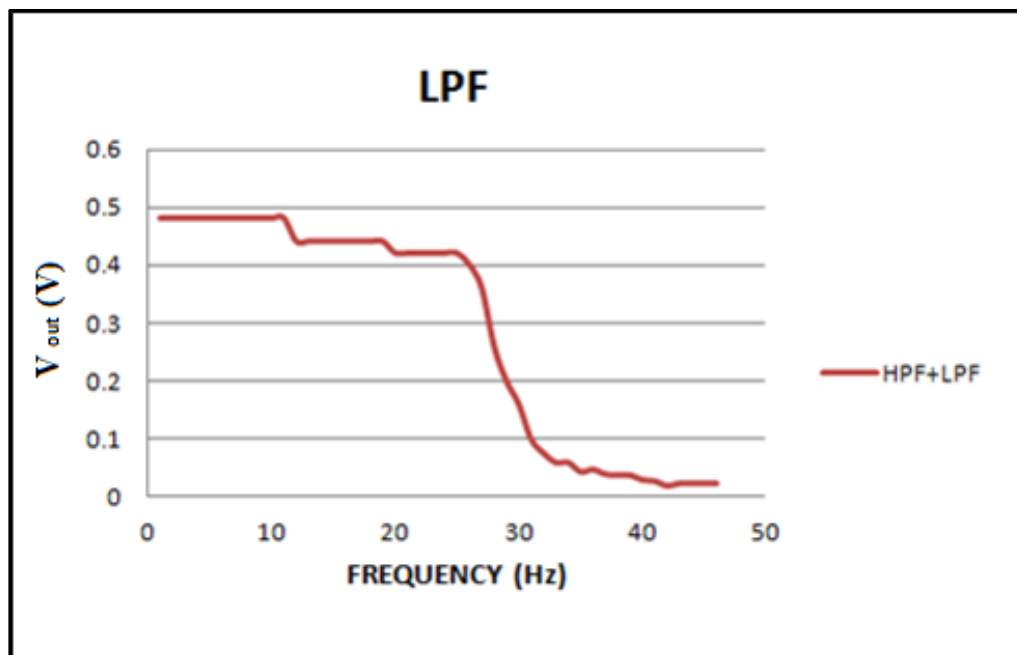


Fig. 5.5: Output characteristics of Low-Pass Filter in Bio-Amplifier

As it can be seen in the above plot, the Low-Pass Filter which has been designed and tested, has the cut-off frequency of 32 Hz.

To measure the output characteristics of the Notch Filter in the Bio-Amplifier, the same setup as described above was made and the Gain was set to be a factor of 3.5. The bandpass filter and notch filter was cascaded and the output voltage was then measured and plotted against frequency to obtain the below plot:

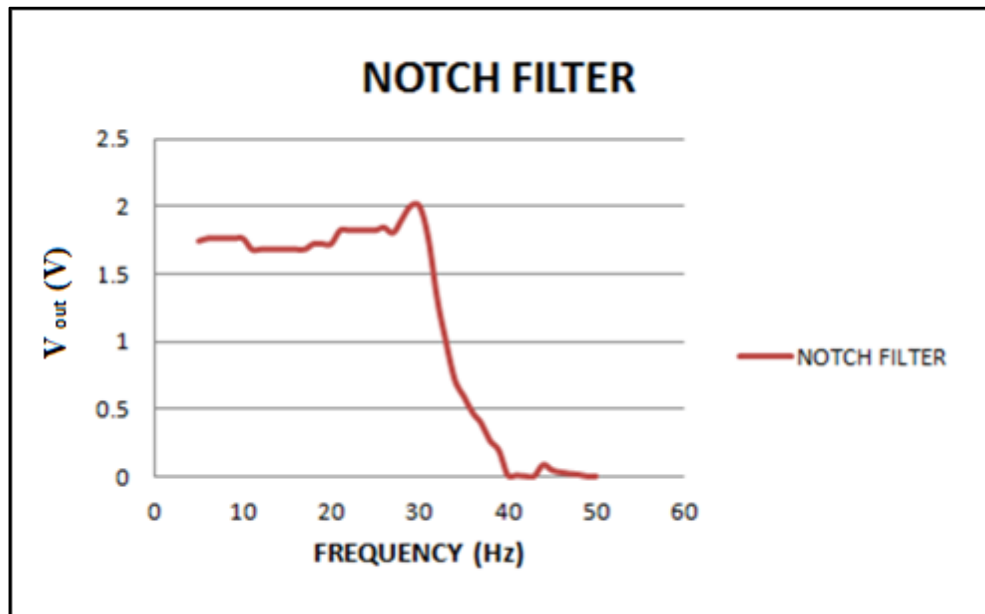


Fig. 5.6: Output characteristics of Notch Filter in Bio-Amplifier

Initially the Low-Pass Filter was designed to have a cut-off at 100 Hz in order to observe the frequencies of the SSVEP elicited across various subjects. In order to reject the power-line noise at 50 Hz, a Notch filter with the above characteristics was designed. Through trial and error method, it has been observed that the subjects more or less respond in the frequency range, 10 - 30 Hz. Therefore the cut-off frequency of the low-pass filter was reduced to 35 Hz and the Notch filter remained in the circuit for a better attenuation of 50 Hz power line interference.

After the Notch Filter stage, the signal is passed through a Cascaded Gain stages for further amplification. The gain and offset value is fixed using digipot, the output voltage is noted in the frequency range 1Hz to 60Hz. The characteristics of the output voltage for gain setting value of 45,000 are as shown below:

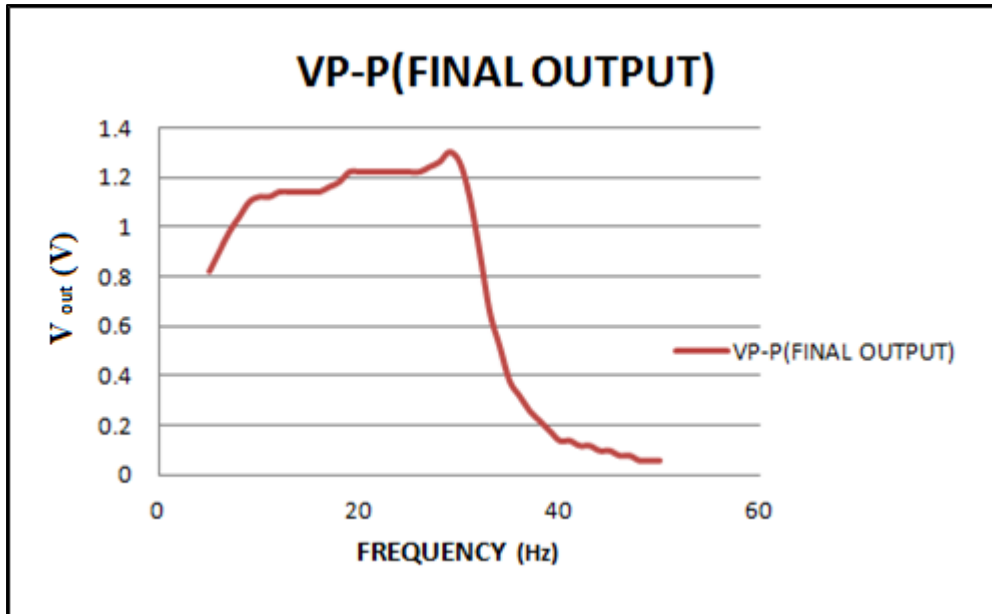


Fig. 5.7: voltage output characteristics of Bio-Amplifier

The gain is adjusted such that the minimum output is of the order volt for further processing.

Raw EEG Plot:

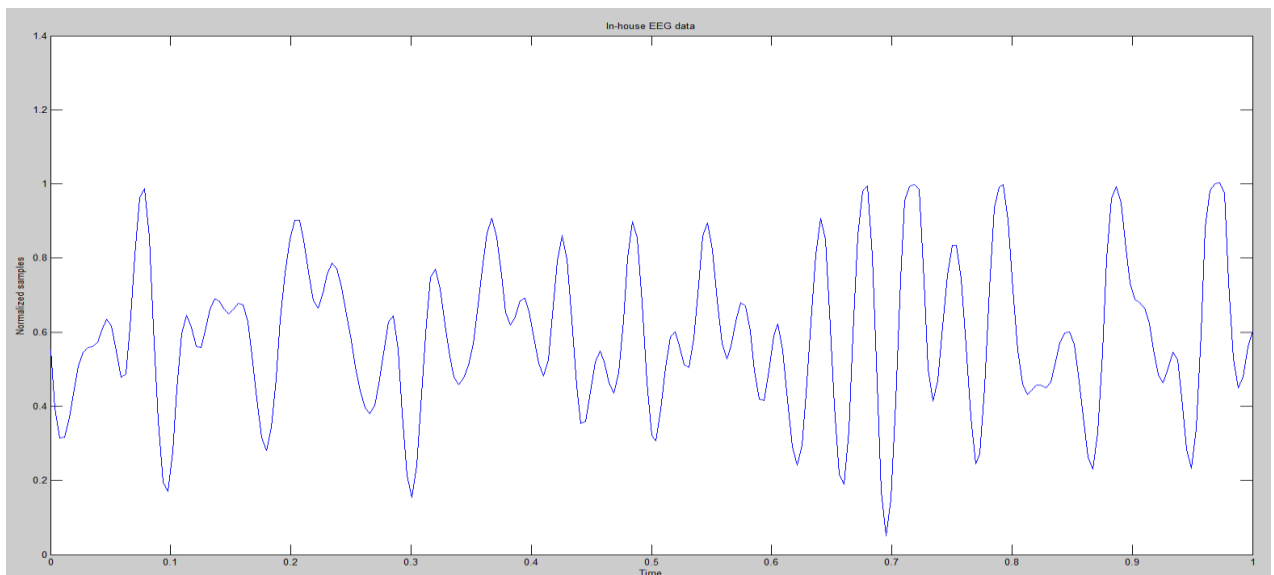


Fig. 5.1: Raw EEG Plot

CONCLUSION:

As can be seen from the above description about the system which has been presently been designed and developed, can be used to acquire, process and recognize SSVEP signals of different frequencies ranging from 10-30 Hz. It can be further integrated with action devices for BCI applications. At present, this system has been integrated with action devices such as, Robo-car and Robotic arm, and it has been tested and verified for its performance across different subjects.

For the future applications, this system can have multiple channels and error free processing algorithm in order to improve the SSVEP recognition and also, it can be miniaturized for improving its portability.

Acknowledgements :

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References:

1. *An Exploration of the OpenEEG Project* by Austin Griffith, Spring 2006.
2. *A Brain-Computer Interface Based on Steady State Visual Evoked Potentials for Controlling a Robot* by Robert Prueck, Christoph Guger.

Appendix:

1. Schematic of Bio-Amplifier
2. Bill of Materials.