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Design and Implementation of a Variable Gain Amplifier for Biomedical Signal Acquisition

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***Abstract*—In India and in other developing countries many poor people dies due to non-availability of proper health monitoring and health caring systems in hospitals. This is because of the high cost of available health monitoring and caring systems which cannot be afforded by small hospitals or organizations which provide free treatment for the poor people. The basic element in the health monitoring system is amplifier which amplify the biomedical signal to the appropriate level so that it can be detected faithfully by the further signal processing and display system. The aim of this paper is to design and implement a variable gain amplifier for biomedical signal. Variable gain provide the facility to increase or decrease the gain depending upon the acquiring signal and same amplifier hardware can be used for acquiring various biomedical signals. The circuit was simulated on Multisim and the prototype version was built on general PCB.**

Keywords-Multisim; Biomedical Signals; Gain; Filters; TinaTI;

I. INTRODUCTION

Around the globe, especially in India and in other developing countries, there are a large number of poor people who died every year due to poor health monitoring facilities in the hospitals. This amount is very high in the hospitals which are located in the villages where people are very poor and hospitals don't have enough fund to procure the costly machines which are used only for health monitoring. In urban areas too there are big hospitals which have all type of facilities but the cost of treatment there is a big issue for a poor person. Many poor people spend their whole life saving money just on treatment in the hospitals. The situation is worse for the new born babies. Every year countless new born babies die due to non-availability of basic infrastructure to hold the babies. So, if we can decrease the cost of the equipments being used by the hospitals then they will have enough funds to provide the infrastructure for poor patients.

Being an engineer our work is to lower down the cost by implementing some innovating idea in the present available solutions. This thing inspired us to develop a low cost monitoring system and the same monitoring system can be used to acquire and display various biomedical signals like ECG, EMG etc, just by varying the gain of the amplifier used to amplify the signal. Amplifier acts as the heart of the monitoring system, as it amplifies the biomedical signals which have very low voltage level. Amplifier amplifies the signal upto that level where it can be faithfully detected by the further processing system to process and display.

In this paper we have designed and implemented an amplifier for biomedical application having adjustable gain. The gain is tunable manually according to the application. We have used AD620 IC for designing instrumentation amplifier, TL084 for implementing high pass and low pass filters on the hardware and IC UAF42 for implementing Notch filter. The filter and amplifier is also simulated on the Multisim 2008 and TinaTI software. The hardware of the amplifier is tested on labview using the National Instruments data acquisition card NI ELVIS.

II. NATURE OF BIOMEDICAL SIGNAL

Living organisms are made up of many component systems – the human body includes the nervous system, the cardiovascular system, and the musculoskeletal system, among others. Each system is made up of several subsystems that carry on many physiological processes. Physiological processes are complex phenomena, including nervous or hormonal stimulation and control; inputs and outputs that could be in the form of physical material, neurotransmitters, or information; and action that could be mechanical, electrical or biochemical. Most physiological processes are accompanied by or manifest themselves as signals that reflect their nature and activities. Such signals could be of many types, including biochemical in the form of hormones and neurotransmitters, electrical in the form of potential or current, and physical in the form of pressure of temperature.

Diseases or defects in a biological system cause alterations in its normal physiological processes, leading to pathological processes that affect the performance, health, and general well-being of the system. A pathological process is typically associated with signals that are different in some respects from the corresponding normal signals that are different in some

respects from the corresponding signals. If we possess a good understanding of a system of interest, it becomes possible to observe the corresponding signals and assess the state of the system, i.e. by observing the signal related to different physiological process we can find out whether there is a problem in the system or not.

The origins of these biomedical signals related to the physiological process are from action potentials. The action potential (AP) [1-4] is the electrical signal that accompanies the mechanical contraction of a single cell when stimulated by an electrical current. It is caused by the flow of sodium, potassium, chloride and other ions across the cell membrane. The action potential is the basic component of all bioelectrical signals. It provides information on the nature of physiological activity at the single-cell level.

A cell in its resting state is said to be polarized. Most cells maintain a resting potential of the order of -60 to -100 mV until some disturbance or stimulus upsets the equilibrium. When a cell is excited by ionic currents or an external stimulus, the membrane changes its characteristics and begins to allow the flow of sodium and potassium ions through it. A new state of equilibrium is reached after the rush ions stops. This change represents the beginning of the action potential, with a peak value of about +20mV for most cells. An excited cell displaying an action potential is said to be depolarized; the process is called depolarization.

Nerve and muscle cells repolarize rapidly, with and action potential duration of about 1 ms. Heart muscle cells repolarize slowly, with an action potential duration of 150-300 ms. The action potential is always the same for a given cell, regardless of the method of excitation or the intensity of the stimulus beyond a threshold. After an action potential, there is a period during which a cell cannot respond to any new stimulus, known as the absolute refractory period (about 1 ms in nerve cells). Figure 1 shows action potentials recorded from cells. An action potential propagates along a muscle fiber or an unmyelinated nerve fiber.

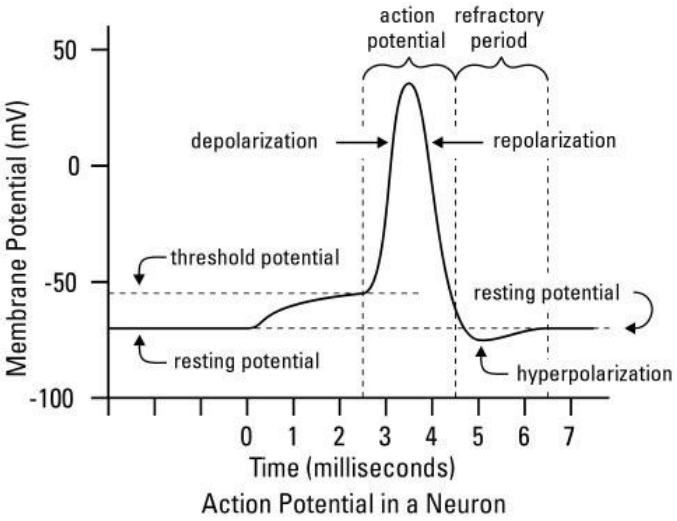


Fig. 1: Diagram for action potential

There are various types of biomedical signals related to different processes. Some are given as: ENG: The electroneurogram is an electrical signal observed as a stimulus and the associated nerve action potential propagate over the length of a nerve. It may be used to measure the velocity of propagation of a stimulus or action potential in a nerve[ ]. EMG: the electromyogram signal is from the motor neuron of the central nervous spinal cord. ECG: the electrocardiogram is the electrical manifestation of the contractile activity of the heart, and can be recorded fairly easily with surface electrodes on the limbs or chest. The ECG is perhaps the most commonly known, recognized and used biomedical signal. The rhythm of the heart in terms of beats per minute may be easily estimated by counting the readily identifiable waves. EEG: the electroencephalogram represents the electrical activity of the brain. This signal is used to diagnose the various problems related to the brain injury. EGG: the electrical activity of the stomach consists of rhythmic waves of depolarization and repolarization of its constituent smooth muscle cells. The activity originates in the mid-corpus of the stomach, with intervals of about 20s in humans. Frequency and voltage ranges of these signals are shown in table 1.

Table 1: Frequency and voltage ranges of various Biomedical signals

S.No.	Name of the Signals	Frequency	voltage
1.	EMG	10-350 Hz	< 50µV
2.	ECG	.05-100 Hz	1-10mV
3.	EEG	.5-30Hz	< 1mV
4.	EGG	.2-10MHz	-80- -30 mV

III. EXTRACTION OF THE BIO SIGNAL

There are different methods and locations according to the signal which is to be taken. e.g. If we want to extract ECG signal there are three different type of configuration of the leads. This signal can be taken from chest, or right arm, left arm and right or left leg. There are 3 lead system and 12 lead system too for acquiring the signal.

Other example is if we want to take EEG signal it will be taken from the scalp. It has 24 lead system or 32 or 128 lead system. These leads can be attached to the surface of the scalp or there are needle electrodes which can penetrate in upper layer of the scalp.

A. Electrodes for signal extraction

Electrodes [5-7] are the transducers which converts the ionic current in the body to the electronic current. The Biosignals can be measured by applying conductive elements or electrodes to the skin surface, or invasively within the muscle. Surface extraction of the signal is the more common method of measurement, since it is non-invasive and can be conducted by personnel other than medical doctors, with minimal risk to the subject [8].

Two types of surface electrodes are commonly in use. The first one is dry electrodes in direct contact with the skin and the

second one is jelled electrodes using an electrolytic jell as a chemical interface between the metallic parts of the electrode [8].

Jelled electrodes uses an electrolytic jell as a chemical interface between the skin and the metallic part of the electrode. Oxidative or reductive chemical reaction take place in the contact region of the metal surface and the jell. Silver-silver-chloride (Ag-AgCl) is the most common composite for the metallic part of gelled electrodes. The AgCl layer allows current from the muscle to pass more freely across the junction between the electrolyte and the electrode. This introduces less electrical noise into the measurement, as compared with equivalent metallic electrodes (e.g. Ag). Due to this fact, Ag-AgCl electrodes are used in over 80% of surface application [9].

Jelled electrodes can either be disposable or reusable. Disposable electrodes are the most common since they are very light. Disposable electrodes come in a wide assortment of shapes and sizes, and the materials comprising the patch and the form of the conductive jell varies between manufacturers. With proper application, disposable electrodes minimize the risk of electrode displacement even during rapid movements.

In our experiment for the acquisition purpose of the EMG signal we have used disposal jelled electrodes. Figure 2 shows the picture of the electrodes used in our experiment.

Fig.2: Disposal Jelled Electrodes

IV. AMPLIFIER DESIGN

Surface amplifier picks up and detects the desired biosignals with the use of electrodes, and adds another electrode between the two electrodes in order to reduce the noise and improve the common-mode rejection ratio. Reduce the impact of EMG "common mode" component through the two pickup electrodes, and achieve the amplification of EMG acquisition through the amplification "differential Mode" section.

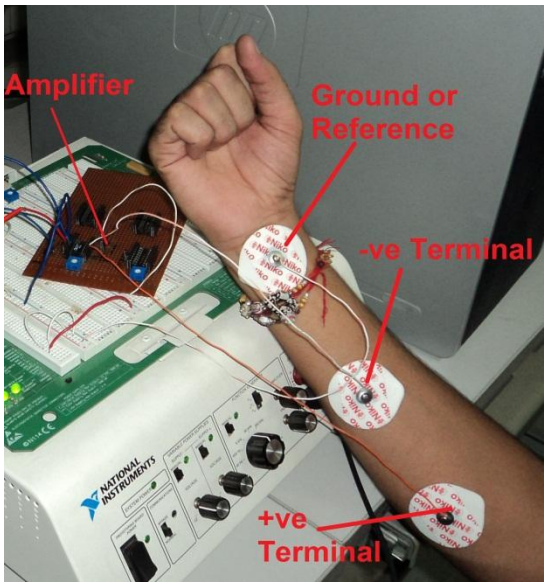


Fig.3: Differential mode Electrode Arrangement

The electrode placement on the body is in itself requiring a good knowledge of the origination of various signals. E.g. for ECG recording we have to place the electrode at different section of the body [12]. The Fig.3 shows the electrode arrangement for the EMG signal measurement.

Now, First of all, pick up the desired signal power with two electrodes and pre-zoom the bio signal by use of low-noise differential pre-amplification of Instrumentation Amplifier AD620, and put the reference level signal into AD620. While put the signal which preamp from AD620 into the high-pass filter circuit to weed out low-frequency noise and DC component. Second, weed out the impact of 50Hz frequency noise in the system by use of the 50Hz frequency notch filter. Now put the bio signal into the low-pass filter circuit to remove the high-frequency noise. The last, put the transformation of the bio signal into the follow-up of the A/D conversion unit circuit in order to further processing the signal. The following block diagram shows the all steps involved into amplifier design.

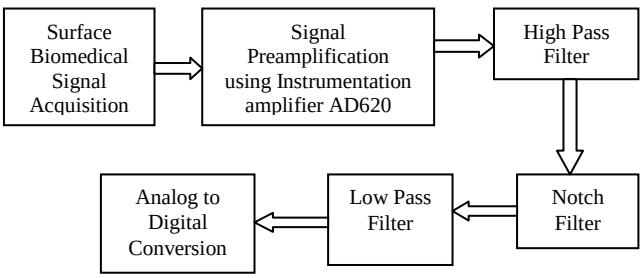


Fig.4: Conditioning circuit for the Amplifier

A. PreAmplifier

The preamplifier makes use of the Instrumentation amplifier AD620 [10]. This chip has a lot of benefits such as low cost, high accuracy and requires only one external resistor to set gains of 1 to 10,000. Absolute value trimming allows the

user to program gain accurately (to 0.15% at G=100) with only one resistor. It has 100 dB min common-mode rejection ratio, Low noise and excellent ac specifications over 120 kHz bandwidth. It can effectively reduce the electrode contact with the skin produces noise.

The internal gain resistors of AD620 are trimmed to an absolute value of 24.7kΩ, allowing the gain to be programmed accurately with a single external resistor. Then, The gain equation is given by

$$G = \frac{49.4k\Omega}{R_g} + 1$$

So, we can vary the gain by varying the resistor $\mathbf{R_g}$. We have put the variable resistor instead of constant value in order to make it more versatile for different signal acquisition. Hence by use of same amplifier we can acquire any biomedical signal just by adjusting its gain for the particular Biomedical signal.

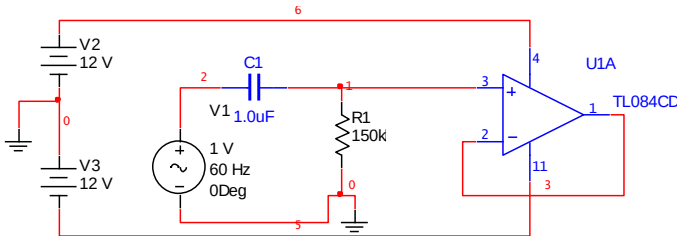
B. High Pass Filter

High pass filter is used to remove the motion artifacts and D.C. component in the signal. Keeping in mind the frequency range of measuring biomedical signals we have provided the variable resistance in order to change the cutoff frequency of the high pass filter. We have implemented the 1st order active filter, in unity gain mode, using the IC TL84 [10]. This IC has four operational amplifiers. We have used only one OP-AMP to implement the filter [11].

The cut-off frequency of the high pass filter is given by the following relation:

$$f = \frac{1}{2\pi RC} Hz$$

We can vary the value of resistance R to vary the cutoff frequency of the filter. The following figure (Fig.5) shows the simulation results of the high pass filter. Here the cut off frequency or -3dB frequency is 0.78 Hz.



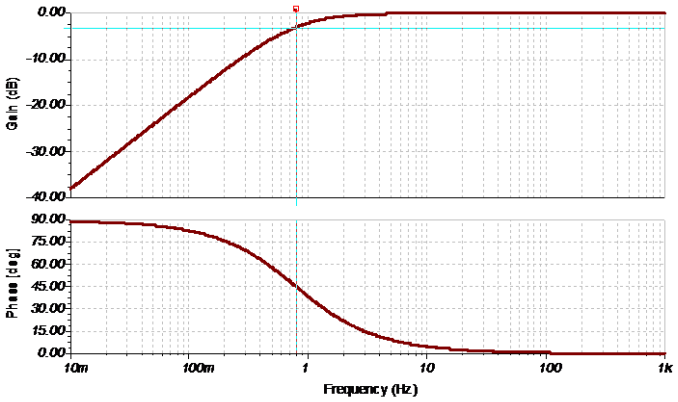


Fig.5: Simulation of High pass filter

C. Nothch Filter

After preamplifier, we must use the 50Hz notch filter to cut off 50Hz noise. It is usually to use a low-pass filter and a high-pass filter. The notch frequency is given by:

$$f = \frac{1}{2\pi RC} Hz$$

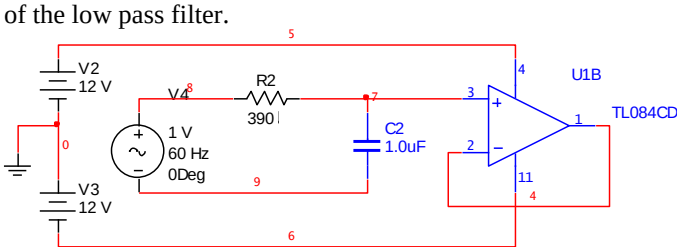
$$Q = \frac{1}{2(2 - A_{up})};\ A_{up} = 1 + \frac{R_f}{R_1}$$

However, when the accuracy of this notch is bad, the notch will affect the notch frequency and quality factor. So, use the burr-brown UAF42 chip to compose the T notch. Set parameters and make the Notch center frequency to be 49.8Hz and 50.2Hz by use of software CAD-FILTER42 from burr-brown.

D. Low Pass Filter

After 50Hz notch filter, it will use low-pass filter to cut off high frequency noise affected. Most of biomedical signal are restricted to the 500Hz frequency range. We have implemented a low pass filter having the cut off frequency or -3dB frequency 400Hz. The cut-off frequency of the low pass filter is given by the same formula as in the case of high pass filter.

The following figure (Fig. 6) shows the simulation results of the low pass filter.



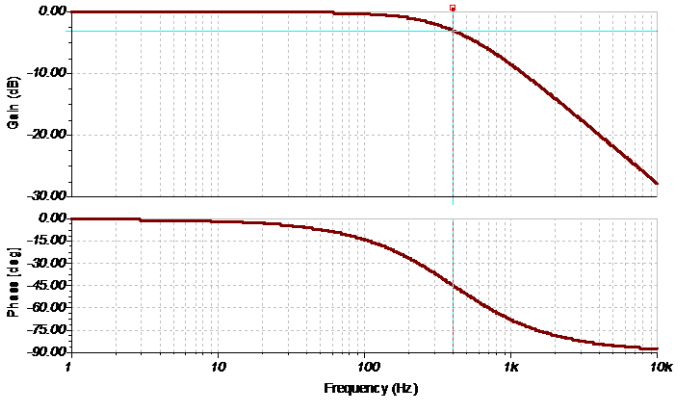


Fig. 6: Simulation of Low pass filter

V. RESULTS

The Analog to digital conversion section is used in order to see the waveforms on computer. In our prototype in place of A/D conversion we have used National Instruments data acquisition device NI ELVIS. Figure 7-9 shows the row waveform of ECG and EMG signals taken from the amplifier.

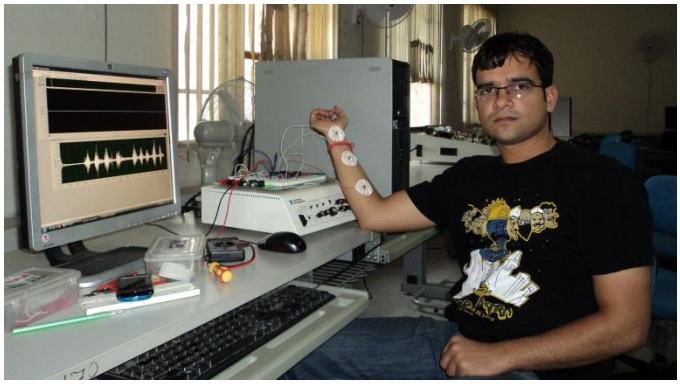


Fig. 7: Setup of the Instruments

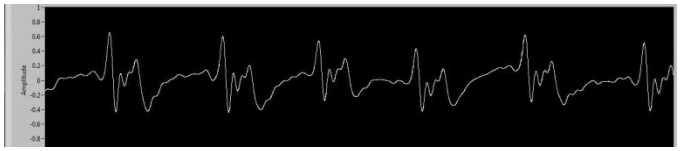


Fig. 8: Row ECG signal on labview

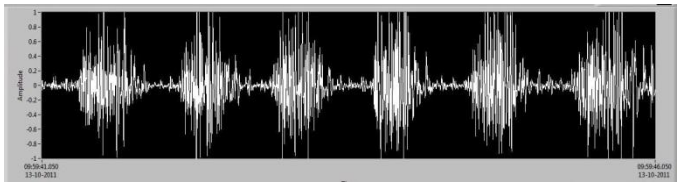


Fig. 9: Row EMG signal

VI. CONCLUSION

Biomedical signals are so weak that they can be easily impacted by the surrounding noise. So, more care is to be taken for electrodes and lead wires, as they take the signal to the amplifier. To design the biomedical signal acquisition device it is not only to amplify the biomedical signal, but more work is accurately extracted the biomedical signal from a strong noise environments. Amplifier must weed out the 50Hz frequency out of the signal and shield the surrounding noise. The further analysis by using digital filters can be done after taken the signal to the computer. But this article is by use of the hardware design and software analysis composing; present the acquisition of biomedical signal interference amplification device which can effectively remove the noise.

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