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ECG Acquisition System

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***Abstract*-- Biosignals are recorded as potentials, voltages, and electrical field strengths generated by nerves and muscles. The measurements involve voltages at very low levels, typically ranging between 1µV and 100mV , with high source impedances. Bio signals need to be amplified to make them compatible with devices such as displays, recorders, or A/D converters for computerized equipment. Amplifiers adequate to measure these signals have to satisfy very specific requirements. They have to provide amplification selective to the physiological signal, reject noise and interference signals. This paper, deals with some of the prominent aspects involved in the design of Electrocardiogram (ECG) acquisition system has been discussed with furthermore design and implementation of instrumentation amplifier with appropriate filtering circuits are discussed. The design circuit is tested in real time and results obtained from the test and analysis of result are presented.**

Keywords*: *3-Lead Electrodes; ECG; instrumentation amplifiers; filters; sallen key topology; differential amplifiers.

I. INTRODUCTION

The ECG means Electro = electrical, Cardio = heart and Gram = recording. Typical lead III ECG with its P, QRS, T and U segments is illustrated in fig.1. Three electrodes, two of them are picking up the biological signal and the third providing the reference potential. The input signal to the amplifier consists of five components:

1. The desired biopotential.
2. Undesired biopotentials.
3. A power line interference signal of 50 Hz and its harmonics.
4. Interference signals generated by the tissue/electrode interface.
5. Noise.

The main challenge in ECG acquisition system is to detect the desired potential and attenuation of the amidst undesired biopotentials, noise and 50Hz electrical interference [2].

The ECG acquisition system consisting of instrumentation amplifier amplifies the potentials and which is used to reject the common mode signals collected from electrodes with the gain of 364. This is followed by a Low pass filter (LPF), High pass filter (HPF) with the cut-off frequency of 220Hz and 0.16Hz respectively to attenuate the noise amidst from electrodes. Followed by the notch filter is used for attenuation of 50Hz line interference.

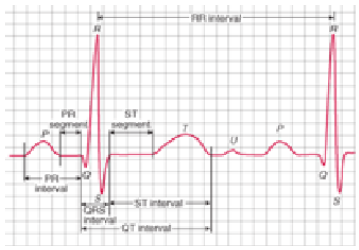

Fig. 1. Normal rhythm of ECG.

II. DESIGN AND IMPLIMENTATION

A. Instrumentation amplifier (IA) and right leg driver (RLD).

Proper design of the amplifier provides rejection of large portion of the signal interferences. Main task of IA is to reject the line frequency interference that is electrostatically or magnetically coupled into the body. The desired biopotential appears as a voltage between the two inputs terminals of IA. Rejection of common mode signals is one of the most important characteristics of the IA [1].

AD620 is a low cost, and high accuracy IA having low noise, practically infinite input impedance used in ECG acquisition system that requires only one external resistor to set gain of 1 to 10,000[4].

The common mode voltage on body is sensed and fed back to right leg. The right leg driver circuit as shown in figure2 drives very small amount of current to right leg to equal the displacement current flowing in the body. This circuit also helps to patient's safety.

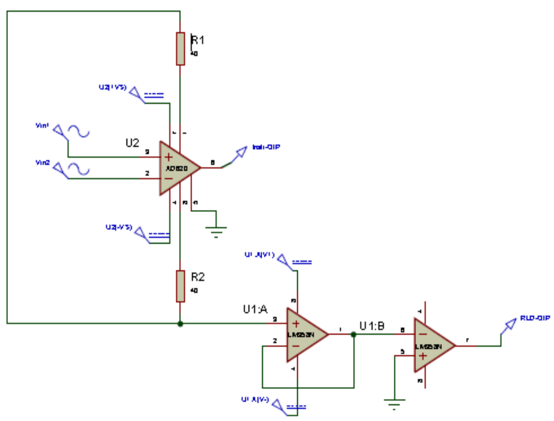

Fig. 2. IA and RLD circuit.

- Gain design:

$$G = 1 + \left(\frac{49.4k\Omega}{R_G}\right) = 1 + \left(\frac{49.4k\Omega}{136\Omega}\right) = 364dB.$$

- Analog analysis:

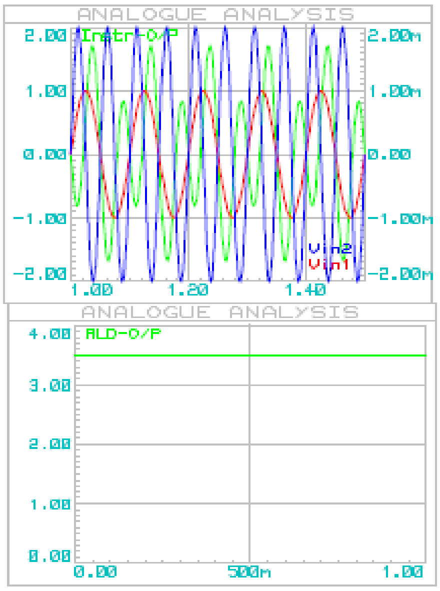

Fig. 3. Analog analysis of IA and RLD.

B. Filters

Sallen key topology is used for design of filters in ECG acquisition system and has been designed and tested. Filters uses a unity gain voltage amplifier with practically infinite input impedance and zero output impedance to design low pass, high pass and notch filter.

a. Low pass filter

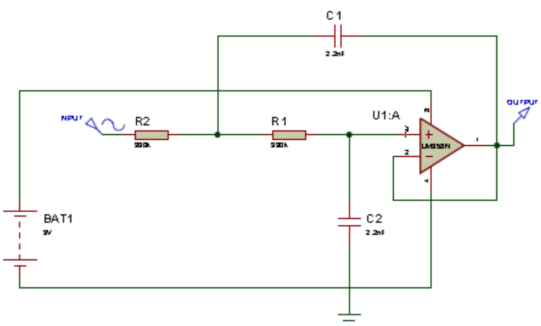

Fig. 4. LPF circuit.

- Cut-off frequency design:

$$F_C = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \frac{1}{2\pi \times 330k \times 2.2n} = 219 \text{ Hz}$$

Where $R_1 = R_2 = 330k$ and $C_1 = C_2 = 2.2n$.

- Frequency response:

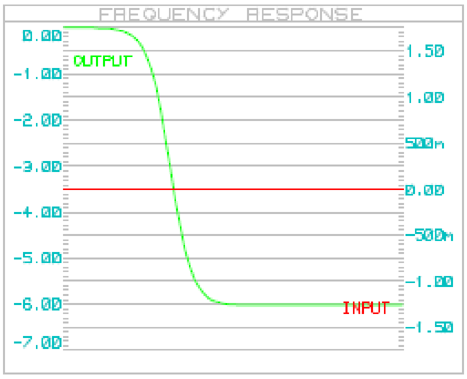

Fig. 5. Frequency response of LPF.

b. High pass filter

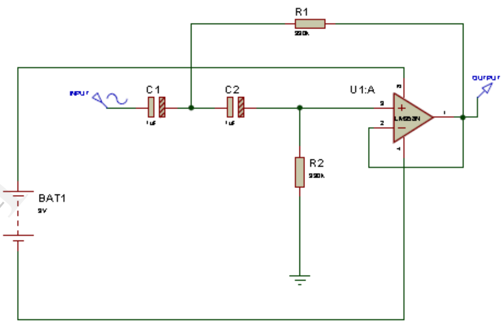

Fig. 6. HPF circuit.

- Cut-off frequency design:

$$F_C = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \frac{1}{2\pi \times 990k \times 1\mu} = 0.16 \text{ Hz}$$

Where $R_1 = R_2 = 990k$ and $C_1 = C_2 = 1\mu$.

- Frequency response:

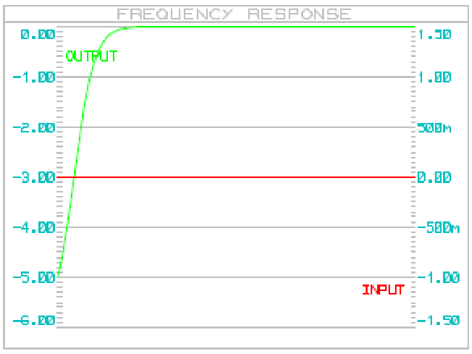

Fig. 7. Frequency response of HPF.

c. Notch filter

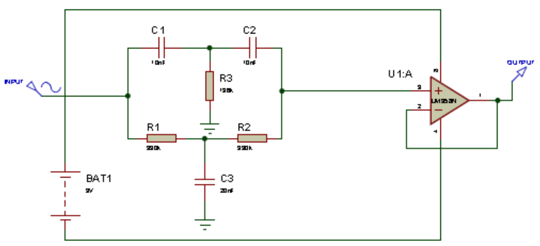

Fig. 8. Notch filter circuit.

- Cut-off frequency design:

$$F_C = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = \frac{1}{2\pi \times 330k \times 10n} = 48.2\text{Hz}$$

Where $R_1 = R_2 = 330k$ and $C_1 = C_2 = 10n$.

- Frequency response:

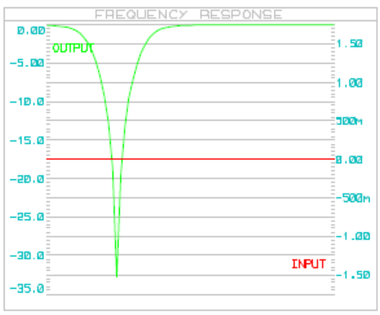

Fig. 9. Frequency response of notch filter.

III. CIRCUIT OUTLINE

The fig.10 shows entire circuit diagram of the ECG acquisition system. It consists of IA, active HPF, LPF and notch filter. Right arm (RA) and left arm (LA) electrodes have to be connecting J1 connector which is input to the IA. Here we need perfect linearity regardless of signal amplitude and instant output response regardless of the speed of the signal. Due to these two requirements we have used the AD620 (U1) as IA. And it is type of differential amplifier and that is connected with input buffer amplifiers. The differential amplifier amplifies difference between two potentials from electrodes but does not amplify the particular voltage. It has some important characteristics that are its very low DC offset, low drift, low noise, very high Common mode rejection ratio (CMRR) and input impedance and low output impedance. Gain of the IA can be adjusted by external resistances R1 and R2.

We need flat start and stop band frequency response in filter design to remove undesired potential and noise. Due to this reason we have used Butterworth filter which will uses sallen key topology for its design. The HPF, LPF and notch filters are designed with cut-off frequency of 0.16, 220 and 50Hz respectively. Amplification of the output signal is done by changing the value of resistances R11 and R10. LM358 (U2 AND U4) is used in design of filters.

Unfortunately the human body can acts as an antenna which picks up electromagnetic interference especially 50Hz noise from electric power lines. To avoid this reason we need a Right leg driver circuit (LM358-U3) which will reduces common mode interferences. Right leg connected to output of an U3:A. Due to this interface displacement current flow through output resistance instead of body and patient is ungrounded when high voltage appears between patient and ground. J2 and J3 are power supply and output connectors respectively.

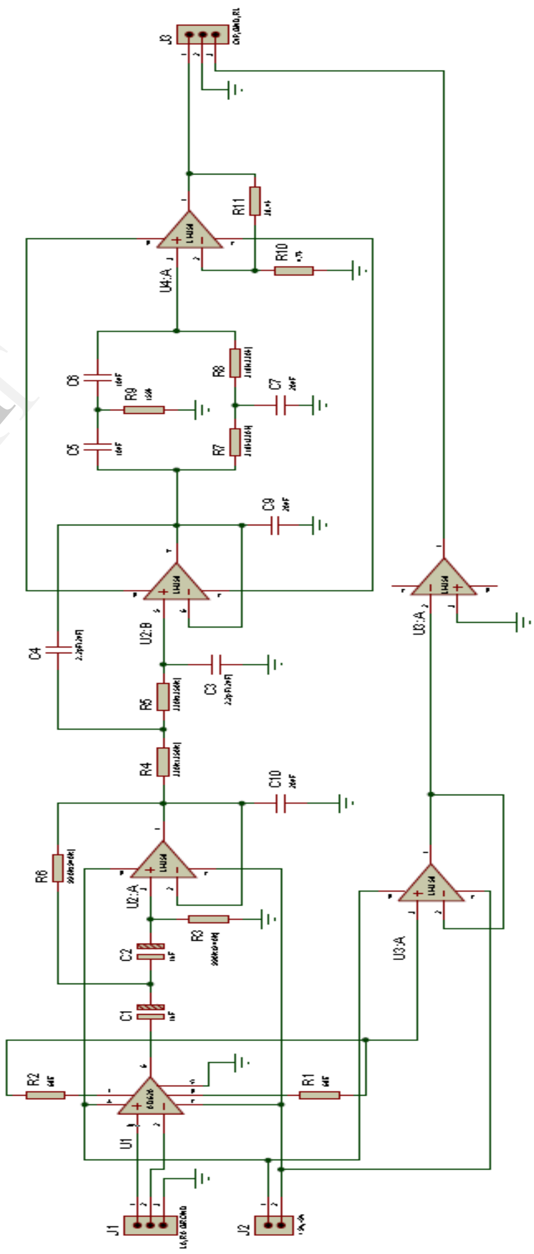

Fig. 10. Circuit diagram of Electrocardiogram acquisition system

IV. EXPERIMENTAL RESULTS

Following figures shows the real time results which are tested in Lab. All the filters are used in system are active analog filters. These filters are designed properly to get noise free output as much as possible. Now days, existing systems are designed with digital filters to reduce the noise and which will increases cost. According to that results are shown below. Fig.11 shows experimental setup of ECG acquisition system

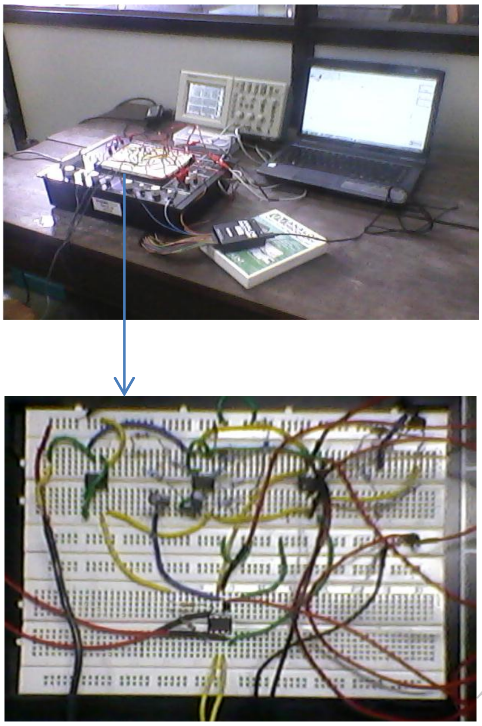

Fig. 11. Experimental setup of ECG acquisition system

The output of IA is amidst with undesired potential and line interference. This is removed by proper design of filters as shown by amplified signal in fig.12 and fig. 13.

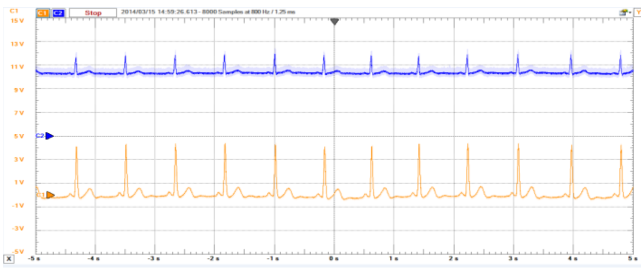

Fig. 12. Output of IA and Notch filter.

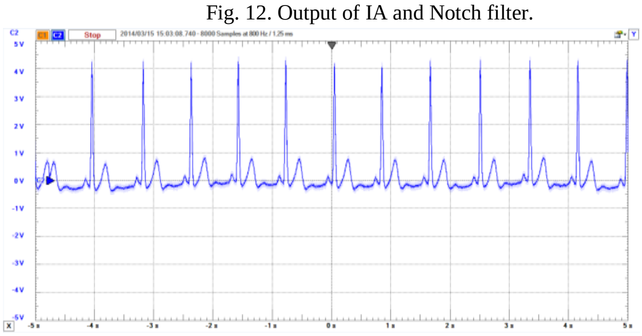

Fig. 13. Output of Notch filter.

V. ANALYSIS

Following table shows the analysis of ECG acquisition system. Actual output values are taken from real time results, these values are compared with standard values and comparison is satisfied.

- Heart beat calculation:

R-R interval as per the experimental result is 800ms.

$$\frac{1}{800\times10^{-3}}\times60 = 75\text{bpm}$$

TABLEI. Result Analysis

PQRST WAVE	NORMAL	ACTUAL OUTPUT
P_{WAVE}	0.12 to 1.20sec	0.11sec
QRS_{WAVE}	<=0.12sec	0.10sec
T_{WAVE}	Not usually measured	0.218sec

VI. CONCLUSION

The electrocardiogram is a very important clinical diagnostic tool. To measure the potential difference on the body's surface successfully amidst the common-mode voltage and noise requires very subtle design. By using RLD circuit, a high-pass filter, low-pass filters, notch filter and an instrumentation amplifier, the signal can be detected amidst the noise. Finally, the acquisition of ECG signal is amplified to make them compatible with devices such as displays, recorders, or A/D converters for computerized equipment. Amplifiers adequate to measure this signal may satisfy to specific requirements.

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