Analog Front-End Design and Construction for ECG Monitoring System

Rabiya Begum Mohd Saleem, Ramesh R. Manza, Anubha Jain, and Yusuf Hanif Shaikh

Abstract Cardiac health monitoring has become very important due to the increasing risk of heart diseases. According to W.H.O (World Health Organization), heart disease is the highest killer in the world. ECG is the important investigation test widely used to find any abnormality in the heart's condition. Analog front-end is the important component of an ECG monitoring system. This paper aims to present the proposed Analog Front-End (AFE) Circuit design to be used in an ECG monitoring system. Instrumentation amplifier INA128 is used for amplification of signals acquired through electrodes followed by high-pass and low-pass filters designed for the removal of artifacts from the signals. The AFE is tested on DSO (digital storage oscilloscope) and confirms the standard ECG trace. The quality of the amplified signal is effectively improved by the high-pass and low-pass filters as it can be seen from the trace with no baseline defect and very few high-frequency noises are present at the result. The constructed AFE circuit will be used in an ECG monitoring system for the digital processing of ECG signals for monitoring and diagnosis.

Keywords ECG · Analog Front-end (AFE) · Instrumentation amplifier · Analog filters · Operational amplifiers DSO (digital storage oscilloscope)

R. B. M. Saleem (✉) · R. R. Manza
Department of Computer Science and Information Technology, Dr.Babasaheb Ambedkar, Marathwada University, Aurangabad, Maharashtra, India
e-mail: rabiya.altaf@gmail.com

R. R. Manza
e-mail: manzaramesh@gmail.com

A. Jain
IIS(Deemed to Be University), Jaipur, India
e-mail: anubha.jain@iisuniv.ac.in

Y. H. Shaikh
Shivaji Arts, Commerce and Science College, Kannad, India
e-mail: shaikhyh@gmail.com

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1 Introduction

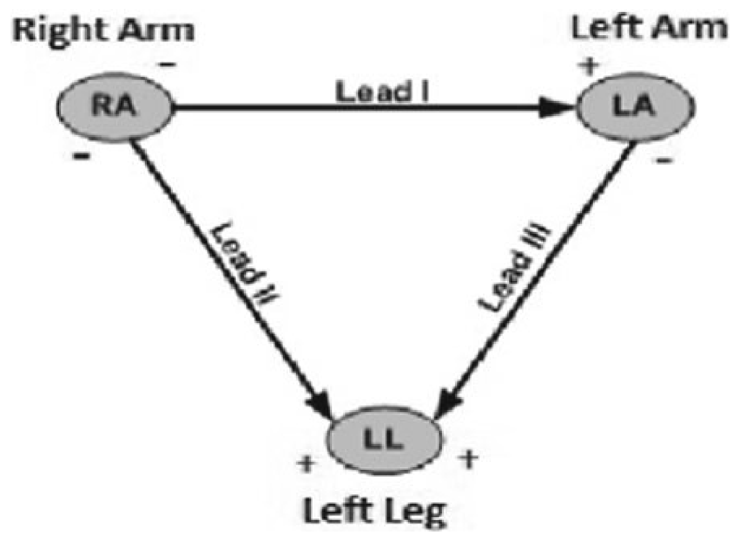
Electrocardiograph abbreviated as ECG is the method of recording the electrical activity of the heart by attaching electrodes to the body surface. This is the initial and important medical test done by Cardiologists to find the abnormality in the person's heart condition and working [1]. The ECG machine is invented by William Einthoven in 1903. He used a series of string galvanometers for his work the machine he invented was having weight of 270 kilograms and required five people to operate it. Later on, technology advances result in better, more portable, and easy to use devices. But the working principle and the terminology used in these devices remain the same as given by William Einthoven. The term Einthoven's triangle is named for him. It refers to the imaginary inverted equilateral triangle centered on the chest and the points being the standard leads on the arms and leg [2] (Fig. 1).

ECG monitoring system includes three basic units. The first unit is an analog front-end unit, second is the Interfacing or microcontroller unit, and the third is the Displaying or Analysis unit. Each unit consists of different components in it and performs the required task.

1.1 Literature Review

Many researchers contributed to designing of ECG machines that are based on ASIC, FPGA, and microcontrollers. Some are based on computers, and others are portable having an LCD display or an oscilloscope. Till date, there is a scope to overcome certain limitations and improvements. Designing an ECG machine starts with an analog front-end (AFE) which can be designed using amplifiers and filters. Some of the reviews are included here to understand the design of AFE.

Fig. 1. Einthoven's triangle



Yin Fen Low et al. proposed an ECG system designed with AFE Analog Front-End circuit consisting of amplifier, bandpass filter, and a notch filter [3]. Dipali Bansal et al. developed an AFE circuit using a series of amplifier followed by an active bandpass filter and the driven right leg circuit. They had used operational amplifier IC 7401 for each circuit [4]. Mohd. Aftab Usmani et al. proposed an AFE with instrumentation amplifier, a high-pass filter, and a low-pass filter [5]. Naazneen M. G. et al. worked on designing AFE using instrumentation amplifier having a gain of 1000. The output of the amplification stage is then given to the low-pass filter designed with 150-Hz frequency [6]. B. N. Patel and D. N. Shah proposed an ECG system to be used with PC or laptop using a sound card. They designed the Analog front-end circuit with AD620 instrumentation amplifier with high-pass, low-pass, bandpass, and notch filters for removal of noise [7]. Movva Pavani and K.Kishore Kumar presented the design of low-cost, compact, and wireless 12 lead ECG system, The AFE system is designed using ADS 1198 which is multichannel, a low-power device having ADC's and ADCs along with the programmable gain amplifiers [8]. Shivani Maski, Prof. S.S.Mungona proposed a low-cost ECG monitoring system using smart devices like phones or laptops. They have used ECG module AD8232 for signal Acquisition [9]. Sannidhan M. S. et al. proposed the digital ECG Data Acquisition System that uses Analog Front-end chip from TI (ADS129x), specially designed to obtain biomedical samples up to 8 electrodes to obtain the raw ECG data with 24-bit analog to digital converters with variable gain amplifier and an on-board oscillator [10]. This proposed work aims to make the system accurate, easy to use, portable, low cost, and reliable.

1.2 Design Challenges

The challenges in designing an analog front-end include

1. The selection of amplifier as ECG signals are the weak signals having a very low amplitude that demands a suitable amplifier with low-power, adjustable gain, and high common-mode rejection ratio with excellent accuracy.
2. Designing suitable filters that can effectively filter the ECG signal without any loss of valuable information from the signals as ECG signals are mainly affected by artifacts.

2 Materials and Methodology

AFE circuit consists of Electrodes, Instrumentation amplifier, High-pass filter, low-pass filter. The In-Amp takes input from the electrodes and outputs the amplified signal to a high-pass filter, the output of high-pass filter is given to low-pass filter and the final filtered output is taken from low-pass filter and displayed on DSO. The circuit is supplied voltage through 9-V batteries (Fig. 2).

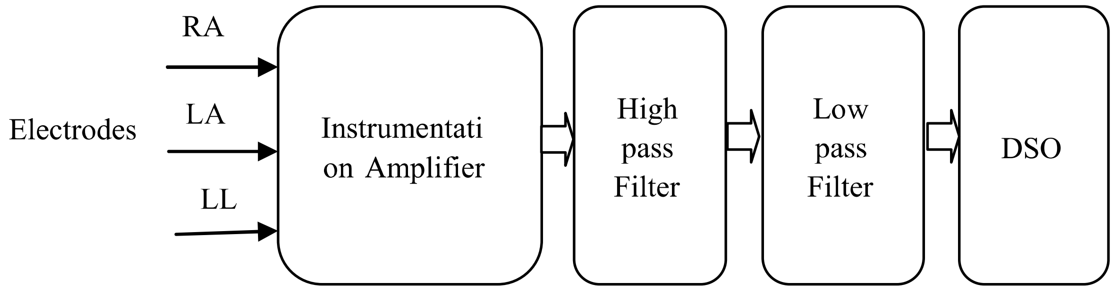


Fig. 2. Block diagram of analog front end

2.1 Electrodes/Sensor

The standard Ag–Ag–Cl electrodes are the most widely used for all applications of biological electrode systems. In this work, we are using Ag–Ag–Cl electrodes. The Ag–Ag–Cl electrodes are made up of silver and are coated with chloride ions. These electrodes work as a transducer which senses the biopotential from the human body and converts it into a signal. These sensors are able to sense very low-amplitude signals having voltage 0.05–10 mV [4].

2.2 Instrumentation Amplifier

An instrumentation amplifier is a differential amplifier designed using operational amplifiers with high-input impedance and high common-mode rejection ratio. An Instrumentation Amplifier is used for low-frequency signals $\ll$1 MHz to provide a large amount of gain. It amplifies the input signal rejecting Common-Mode Noise that is present in the input signal [11]. For this work, we are using Texas instruments IC INA128 which is low-power general-purpose instrumentation amplifier offering excellent accuracy. It is having a variable gain up to 10000 and common-mode rejection up to 120db [12]. The gain is taken as 1000 by keeping R_G value 50 K (Fig. 3).

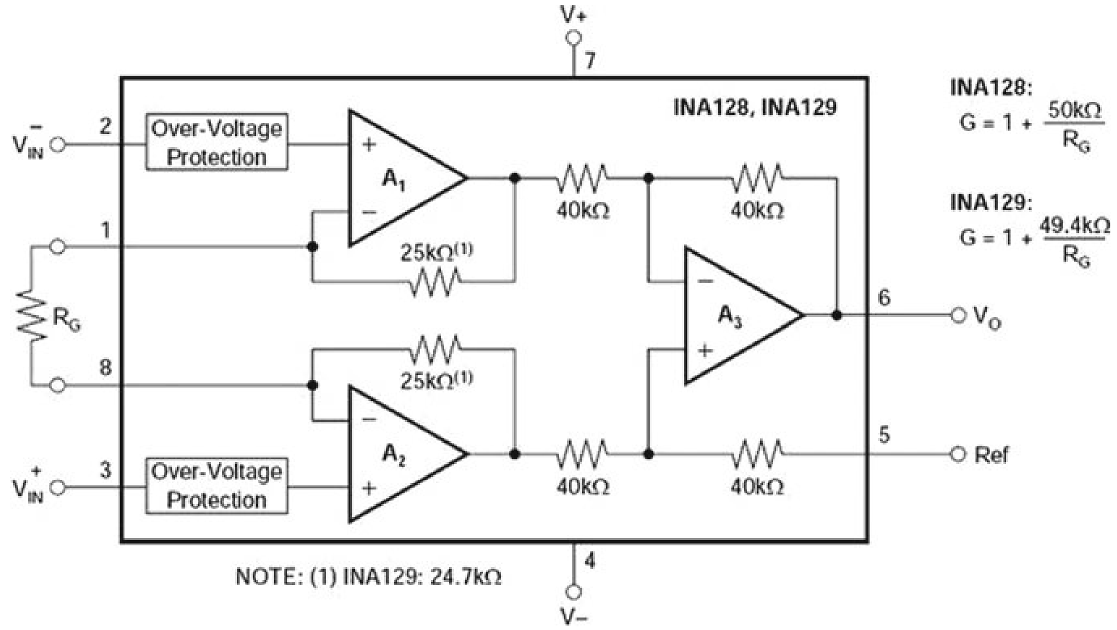
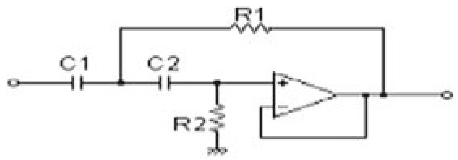


Fig. 3. Circuit diagram and gain equation of INA128

Fig. 4. Circuit diagram of High-pass filter



→Vout(s)

2.3 High-Pass Filter

The purpose of high-pass filter is to remove low-frequency components such as motion artifact, respiratory variation, and baseline wander. Second-order Sallen–Key high-pass filter is designed for 0.2-Hz cutoff frequency using an operational amplifier IC LF353 [5]. Figure 4 shows the circuit diagram and Fig. 5 is the bode diagram showing frequency plot [13]. The transfer function equation for the filter is

$$G(s) = s^2 + 243902.43902439s + 14872099940.512 \tag{1}$$

2.4 Low-Pass Filter

Low-pass filter is used to remove high-frequency muscle artifact and external interference. Second-order Sallen–Key low-pass filter is designed with a cutoff frequency of 1000 Hz using an operational amplifier IC OPA277 [5]. Figure 6 shows the circuit diagram and Fig. 7 is the bode diagram showing frequency plot [14]. The transfer

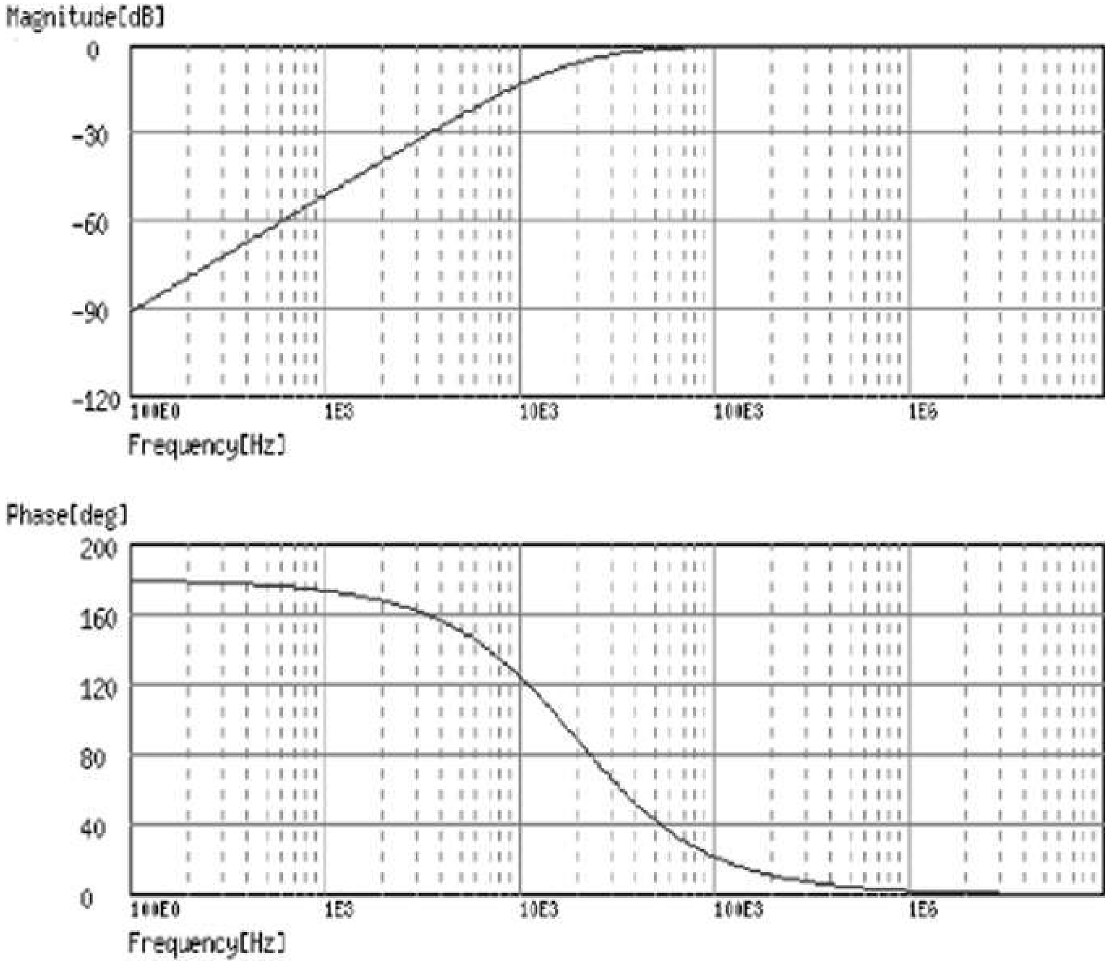
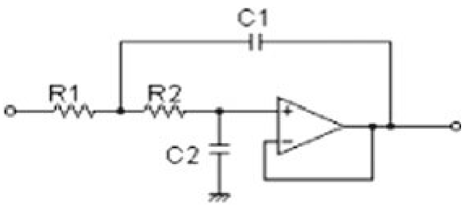


Fig. 5. Frequency analysis of High-pass filter

Fig. 6. Circuit diagram of Low-pass filter



Vin(s)→ →Vout(s)

function equation for the filter is

$$G(s) = s^2 + 12500s + 39.0625 \tag{2}$$

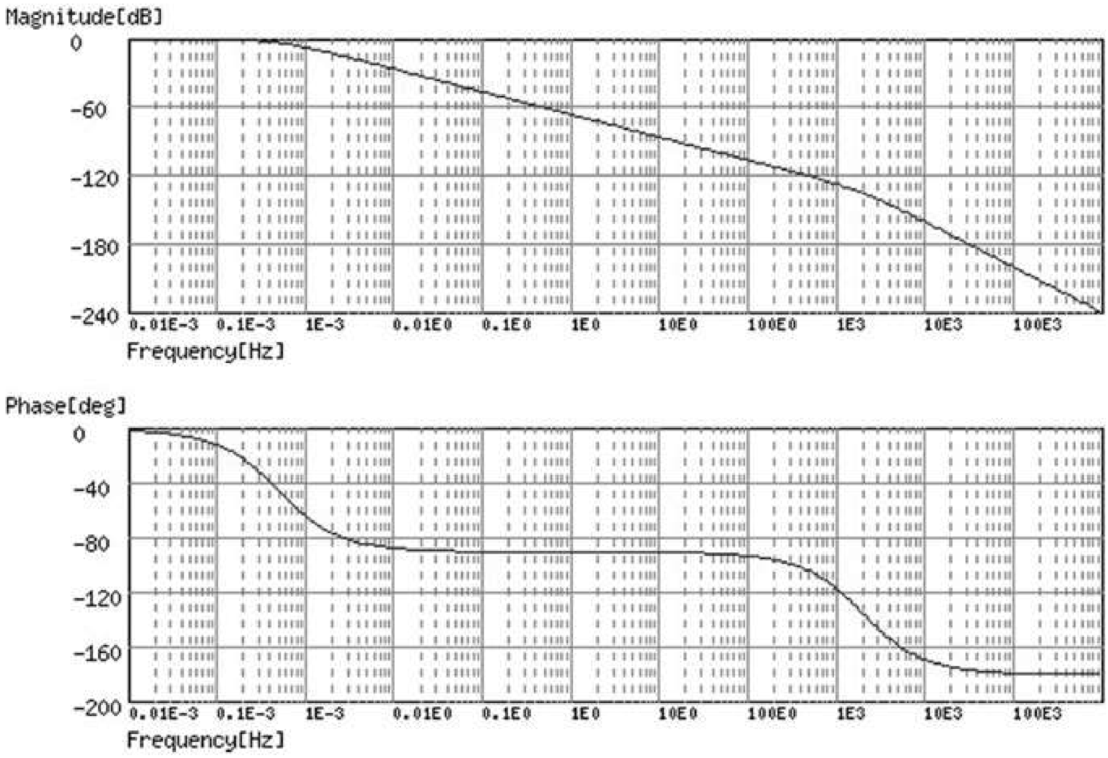


Fig. 7. Frequency analysis of Low-pass filter

3 Results

The proposed AFE circuit gives satisfactory results as the major challenge in designing the AFE was to obtain the noise-free signal which has been achieved successfully. When the raw signal is acquired from the electrodes, it needs amplification, with amplification the signal also catches the unwanted environmental disturbances that are effectively removed by the analog filters designed with a suitable frequency of ECG signal. According to the literature survey, in recent years the researchers are using the advanced and available AFE modules which are very compact in size but are costly. The proposed AFE circuit design is as good as these ready modules and gives accurate results as same as them with very low cost and very simple to use. The constructed AFE is tested on DSO; Fig. 8 shows the ECG trace on DSO and Fig. 9 shows the constructed AFE kit.

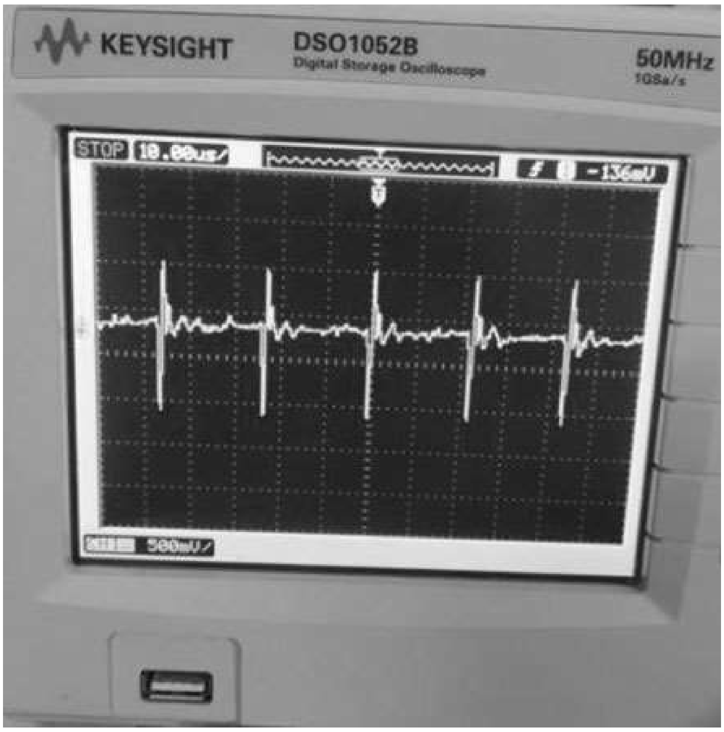


Fig. 8. ECG trace on DSO

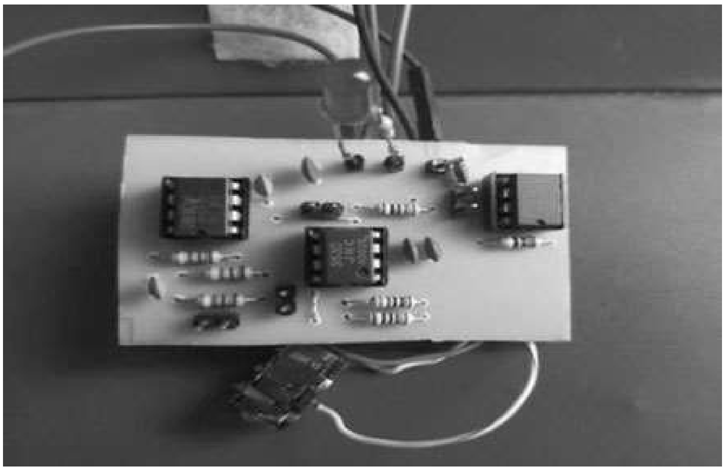


Fig. 9. Constructed AFE kit

4 Conclusion

The AFE circuit is designed and constructed using instrumentation amplifiers and operational amplifiers. The signals are acquired using Ag–Ag–Cl electrodes and amplified, with amplification the signal also picks some high- and low-frequency noises which are tried to be eliminated using high-pass and low-pass filters. The resultant signal is then plotted on DSO1052B 50 MHz. The plotted signal satisfies the standard ECG trace. The constructed AFE circuit is very compact as we have used the TI IC INA 128 which is an instrumentation amplifier a single chip in place of using 3–4 operational amplifiers, and hence, it also reduces the complexity of circuit. The prices of all the components used are very less as compared to the available AFE in the market so it also tries to make the kit less cost-effective. We faced many difficulties while implementing as ECG signals are very uncertain in nature and are of very low impedance they are mainly affected by noises by the patient's respiration itself, the circuit is powered in DC voltage there is no chance of any voltage or current shocks.

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Limitations and Future Work The designed analog filter removes the noises up to certain limits, hence there is a need for digital filters that can be implemented in software for this AFE. The second limitation of this device is that, if we want to work with AC power, then it needs isolation between the patient and the device for safety purposes.

The future work will be interfacing this AFE to a laptop for digitization and analysis of the obtained signals for diagnosis as well as for monitoring and making the system wireless using Bluetooth.

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