Design and Simulation of a Complete ECG Analog Front-End with Wilson Central Terminal and Multi-Stage Filtering for Reliable Cardiac Monitoring

ROOBAK S

Dept of Electronics and Communication Engineering

Sri Eshwar College of Engineering, Coimbatore

Abstract

This paper presents the design and simulation of a complete analog front-end system for Electrocardiogram (ECG) signal acquisition using the open-source eSim 2.3 platform. ECG signals are inherently weak and highly susceptible to interference such as power-line noise and baseline drift. The proposed design integrates a precision instrumentation amplifier, a twin-T notch filter, and band-limiting filters to ensure effective amplification and filtering of ECG signals. Simulation results validate the system's capability to remove noise and interference while preserving the essential cardiac signal features. This work highlights the potential of open-source design tools in biomedical electronics. The approach enhances signal clarity, ensuring accurate detection of cardiac events such as arrhythmias. It also demonstrates how analog signal processing principles can be effectively applied to biomedical applications. Furthermore, the project contributes to advancing healthcare-focused circuit design through reliable simulation and validation.

Keywords: ECG, Instrumentation Amplifier, Notch Filter, Low Pass Filter, High Pass Filter, Signal Conditioning, Biomedical Electronics

I. INTRODUCTION

Electrocardiogram (ECG) is one of the most important biomedical signals used for cardiac monitoring and diagnosis, but its very low amplitude makes it highly vulnerable to interference. Accurate acquisition requires circuits with high amplification and excellent noise rejection to preserve the integrity of the signal. Common sources of distortion include 50/60 Hz power-line interference and baseline drift caused by respiration or body movement, which can obscure clinically significant details. To address these issues, a carefully designed analog front-end is essential for enhancing signal clarity. This work focuses on the design and simulation of a modular ECG front-end in eSim 2.3, built with discrete components and op-amp subcircuits. The multi-stage design emphasizes amplification, notch filtering, and baseline correction to ensure reliable conditioning. A well-structured front-end improves signal quality while retaining key features such as the P-wave, QRS complex, and T-wave. Overall, the design effectively bridges theoretical principles with practical biomedical applications.

II. PURPOSE OF CIRCUIT

The primary purpose of the ECG analog front-end is to acquire weak cardiac signals and condition them for reliable analysis. Since ECG signals are of very low amplitude, the circuit must provide high input impedance and excellent common-mode noise rejection, which is achieved through an instrumentation amplifier stage. Power-line interference, typically at 50/60 Hz, is a major source of distortion and is suppressed using an active twin-T notch filter. To further refine the signal, a low-pass filter is employed to attenuate high-frequency noise, such as muscle artifacts, while a high-pass filter removes baseline drift and unwanted DC offsets. By combining these stages, the system ensures that the essential features of the ECG waveform, including the P-wave, QRS complex, and T-wave, are preserved accurately. This makes the design highly suitable for both clinical diagnosis and research-oriented ECG acquisition, providing a reliable and stable signal conditioning framework..

III. WORKING PRINCIPLE

- Stage 1: Instrumentation Amplifier – A three-op-amp configuration using avsd_opamp blocks in eSim provides differential amplification with adjustable gain via resistors and potentiometers.
- Stage 2: Notch Filter – A twin-T active notch filter suppresses 50/60 Hz power-line interference while minimizing distortion of the ECG spectrum
- Stage 3: Low-Pass Filter – Implemented as a second-order Sallen-Key topology with ~150 Hz cutoff, this stage reduces muscle artifacts and high-frequency noise.
- Stage 4: High-Pass Filter – An active first-order filter with ~0.5 Hz cutoff eliminates baseline wander and DC components.

  Through the stages the ECG signal is amplified, cleaned, and prepared for further digital processing or display

IV.CIRCUIT DIAGRAM

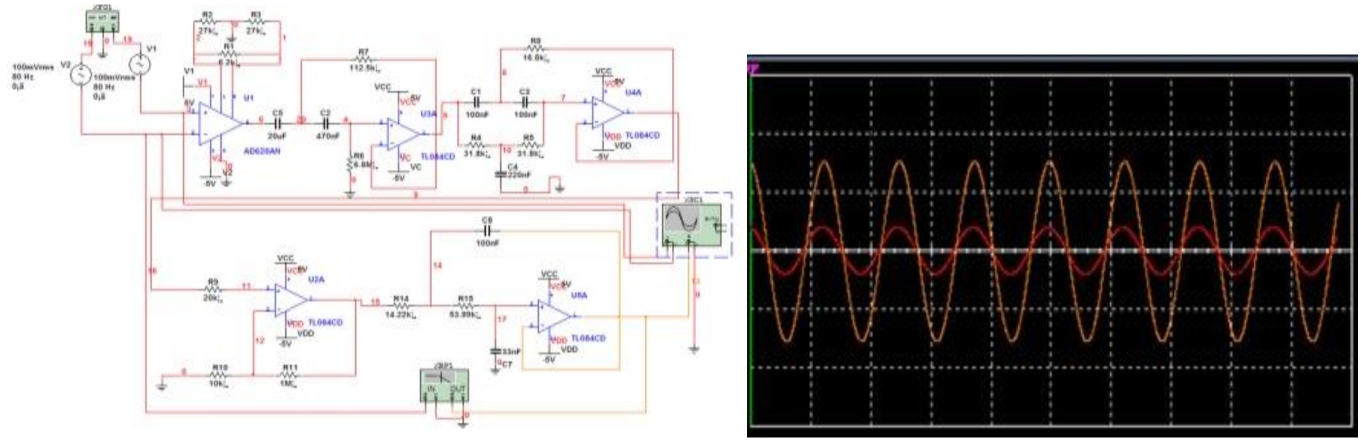

Fig. 1: ECG Analog Front-End with sample output waveform

V. Proposed System

The proposed system introduces a multi-stage ECG analog front-end circuit implemented using eSim software, aiming to demonstrate the acquisition and conditioning of weak cardiac signals while suppressing noise and interference. The system, based on an instrumentation amplifier, twin-T notch filter, and active band-pass filters, amplifies the ECG signal and removes power-line interference, baseline drift, and high-frequency noise. It effectively processes the signal stage by stage, ensuring a clean and clinically relevant ECG waveform suitable for further analysis or display.

eSIM CIRCUIT

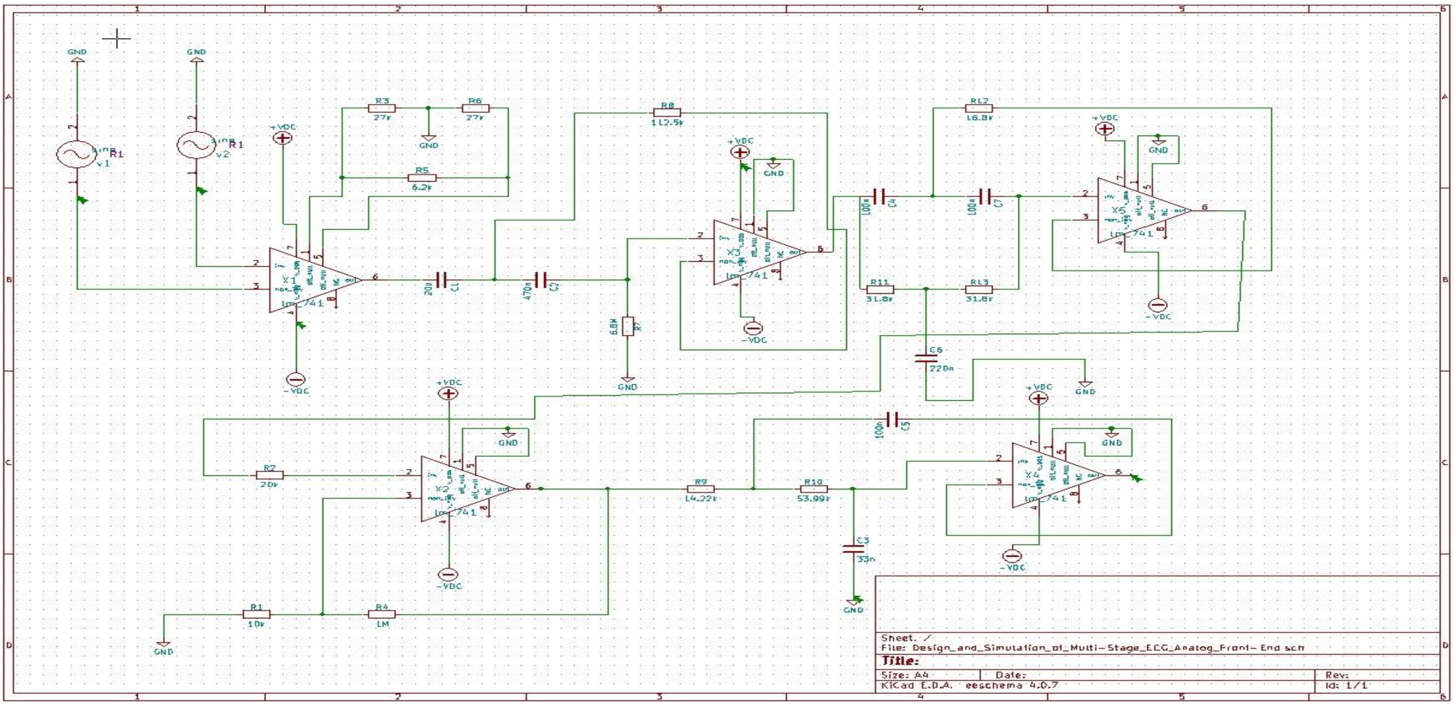

Fig. 2: ECG Analog Front-End Circuit in eSim

The circuit consists of an instrumentation amplifier followed by twin-T notch and band-pass filter stages. Each stage amplifies, filters, and shapes the ECG signal while suppressing noise and interference. Intermediate nodes show progressive signal conditioning and baseline correction. At the output, the processed signal provides a clean and clinically relevant ECG waveform suitable for display or further analysis.

OUTPUT WAVEFORM

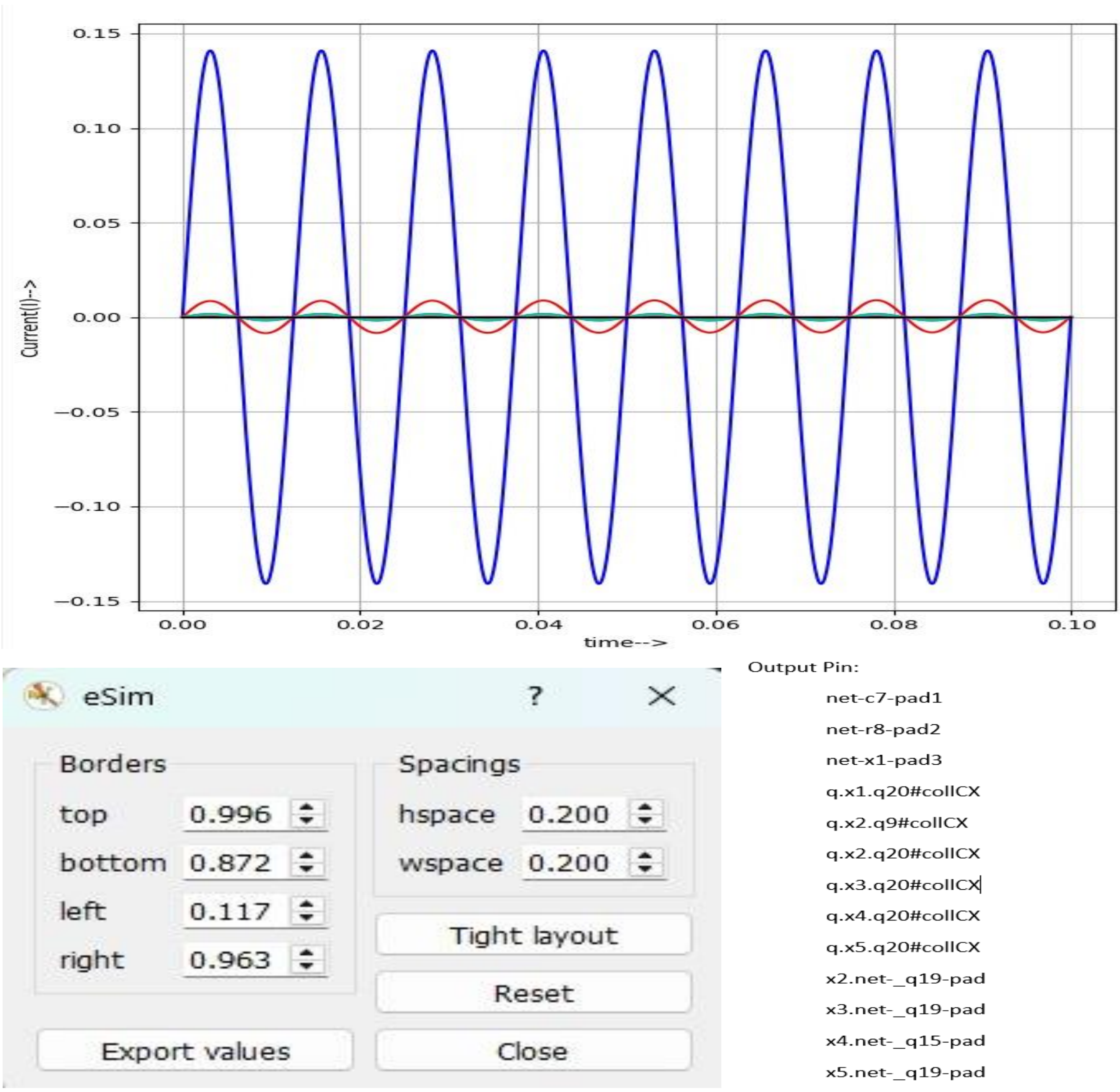

Fig. 3: Output ECG Analog Front-End Circuit in eSim

Fig. 3 The waveform displays the amplified ECG signal after processing through the analog front-end circuit in eSim. The signal's stable oscillations, reduced baseline drift, and attenuated noise/interference demonstrate the effectiveness of the multi-stage filtering and amplification design.

V. CONCLUSION

In this study, we explored the design and simulation of a multi-stage ECG analog front-end circuit using eSim. The circuit architecture, incorporating an instrumentation amplifier, twin-T notch filter, and active band-pass filters, plays a crucial role in biomedical signal acquisition by amplifying weak ECG signals and effectively mitigating noise and interference. This approach provides a reliable method for conditioning the ECG waveform while preserving clinically significant features such as the P-wave, QRS complex, and T-wave. Through simulation in eSim, valuable insights were gained regarding stage-wise signal amplification, filtering, and baseline correction. Overall, eSim proved to be an effective platform for analyzing the circuit's performance under both transient and steady-state conditions.

VI. REFERENCE

1) Z. Chen, Y. Zhu, “Study of oscillation characteristics for quartz crystal oscillators based on equivalent multi-physics model,” Advanced Control for Applications: Engineering and Industrial Systems, 2024.
2) Robaei, M. (2015). "Design and Implementation of an ECG Front-End Circuit." Middle East Technical University Thesis.
3) M. Kumar, “Voltage Mode Notch Filter Using Differential Difference Current Conveyor,” IEEE Conference, 2012.
4) R. Hasnul Azha, S. Ramli, “Design of Analog Front-End Circuit for ECG Signal Acquisition,” Int. Journal of Electronics and Communications, 2016.
5) Sergio Franco, Design with Operational Amplifiers and Analog Integrated Circuits, 4th Edition, McGraw-Hill, 2014.
6) Adel S. Sedra, Kenneth C. Smith, Microelectronic Circuits, 7th Edition, Oxford University Press, 2015.