ECG Signal Simulation Using LTspice

1. Introduction

The human heart functions as a powerful pump that beats in a regular pattern to circulate blood throughout the body. Each heartbeat is triggered by electrical signals generated by the heart itself. These signals can be picked up from the surface of the skin and displayed as an electrocardiogram (ECG) - a graph of the heart's electrical activity over time.

A standard ECG waveform consists of five main parts:

- P wave - related to the contraction of the upper chambers (atria)
- QRS complex - corresponds to the contraction of the lower chambers (ventricles)
- T wave - reflects the recovery phase of the heart after a beat

By observing the shape and timing of these waves, medical professionals can detect abnormalities in heart function and rhythm.

2. Project Objective

The objective of this project is to simulate an ECG signal and process it through an analog signal path using LTspice, a popular circuit simulation tool. The setup includes:

- A PWL (Piecewise Linear) waveform source to replicate the shape of an ECG signal
- An Instrumentation Amplifier to boost the signal strength
- A Notch Filter to remove interference from electrical mains (50 Hz)
- A Band-Pass Filter to keep only the relevant parts of the ECG signal (typically between 0.5 Hz and 100 Hz)

3. Circuit Overview

- PWL ECG Source: A synthetic signal shaped using voltage-time pairs to closely resemble a real ECG waveform

- Instrumentation Amplifier: Amplifies the small input signal while ignoring unwanted common signals, using a three-op-amp configuration

- Notch Filter: Removes the 50 Hz noise caused by surrounding electrical devices and power supply systems

- Band-Pass Filter: Allows frequencies within the ECG range to pass through, while reducing unwanted high-frequency noise and DC drift

4. Simulation Results

After connecting and simulating all components in LTspice:

- The PQRST waveform appears clean and recognizable
- Noise at 50 Hz is successfully removed
- Only the medically useful parts of the signal are retained after filtering

Both AC analysis and transient simulation were used to verify the design and effectiveness of the circuit.

5. Applications

This simulation demonstrates how ECG signals can be processed using analog components. It is useful for:

- Understanding ECG signal behavior
- Developing low-cost biomedical circuits
- Learning practical analog circuit design in the medical domain