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Analog Heart Rate Monitor

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Contents

Abstract

Our project is an ECG waveform output and display heart monitor.The difficult task is to make the small range of the ECG voltage signal: 0.1 mV to 10mV, which is significantly impacted by noise.This is accomplished by a leg drive circuit, an a high pass filter, an instrumentation amplifier,both a notch filter and a low pass filter were utilized. 160 Hz was the bandwidth that was taken into consideration. Attaining this requires only analog electronic parts were employed. electronic digital elements were exclusively utilized in the digital circuit, breadboard, and simulation testing testing was carried out, along with PCB testing. the circuit's functionality. An 3D enclosure was created and constructed to meet the requirements.

1 Introduction

An electrocardiogram (ECG) is a quick test that uses skin-attached sensors to measure electrical signals the heart produces with each beat in order to assess the heart's rhythm and electrical activity. There is an increase in voltage between the right and left arms, with the right leg acting as a feedback mechanism. The ECG leads are used to obtain the voltages of the right arm, left arm, and right leg . The voltage signal's frequency ranges from 0.01 Hz to 250 Hz, while its amplitude spans 0.1 mV to 10 mV.The small amplitude of the ECG raw signals and their susceptibility to noise and disturbances like electrostatic potentials, power line interference, RFI, electrode contact noise, stray capacitance, and bio signal artifacts introduced into an ECG by subject movement, respiration, and muscle tension make it difficult to amplify this signal. The ECG waves may occasionally be overpowered by noise, rendering the amplified signal meaningless.

We used only analog components when designing the ECG monitor, with the exception of the display unit, which amplifies and shows the voltage waveform mentioned above. We have described how we accomplished this in this report. The circuits listed below were used to generate the ECG waveform and provide the desired result.

1. Right Leg Drive Cicruit
2. Instrumentation Amplifier
3. 1st order active Butterworth high pass filter
4. 5th order active Bessel Thompson low pass filter
5. The Notch Filter

Moreover, the power supply and display screen were each connected to a different circuit, each with its own PCB. Variable resistors have been used in each filter circuit to modify the gains, reduce noise and disturbances based on the location, and compensate for unstable power supplies.

2 Functionality and Parameters

2.1 Right Leg Drive

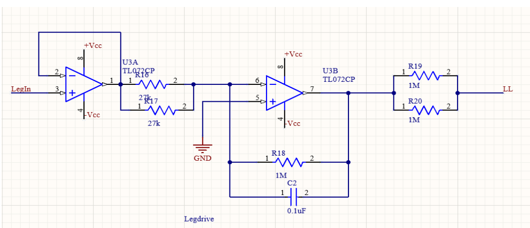


Figure 1: Right Leg Drive Circuit

By inverting, amplifying, and then feeding the signal back to the body through the right leg electrode, a right leg drive circuit is used to cancel the common-mode signal between the left and right arm electrodes.Additionally, the high value resistors in this circuit make sure that the patient is not exposed to a higher current.

2.2 Instrumentation Amplifier

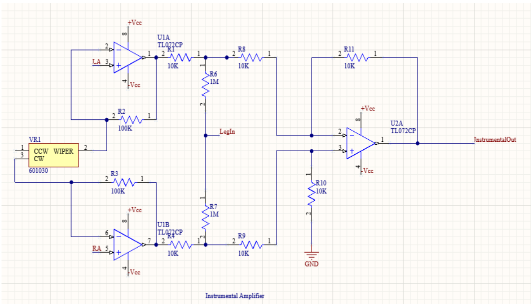


Figure 2:Instrumentation Amplifier

The signal is amplified using this circuit, which also eliminates common noise from the voltages coming from the ECG leads. This circuit converts the three inputs into a single output. Our circuit's gain in the instrumentation amplifier is maintained between 20 and 50. We have adjusted the gain as needed by using a variable resistor.

2.2.1 Gain of the Instrumentation Amplifier

$$\text{Gain} = \frac{R_{10}}{R_9}\left(\frac{R_2 + R_3 + VR_1}{VR_1}\right)$$

$$\text{Minimum Gain} = \frac{10\text{k}\Omega}{10\text{k}\Omega}\left(\frac{2 \times 100\text{k}\Omega + 10\text{k}\Omega}{10\text{k}\Omega}\right)$$

$$\text{Minimum Gain} = 21$$

2.3 High Pass Filter

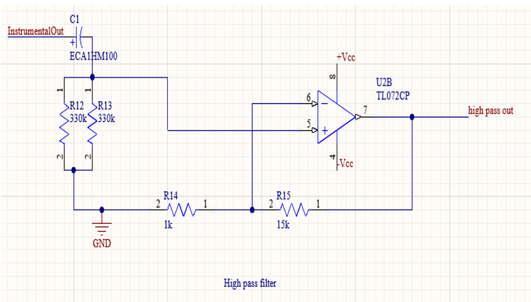


Figure 3:High Pass Filter

A first-order active inverting Butterworth filter has been used. In addition to amplifying the signal even more, this circuit removes the DC offset that developed between the electrodes. The gain of the filter is 16.

2.3.1 Gain and Cutoff Frequency of High Pass Filter

$$\text{Cutoff Frequency}(\text{F}_c) = \frac{1}{2\pi(R_{12}//R_{13})C_1}$$

$$\text{Cutoff Frequency} = \frac{1}{2\pi \times 165\text{k}\Omega \times 10\mu\text{F}}$$

$$\text{F}_c = 0.0965Hz$$

$$\text{Gain} = 1 + \frac{R_{15}}{R_{14}}$$

$$\text{Gain} = 1 + \frac{15\text{k}\Omega}{1\text{k}\Omega} = 16$$

2.4 Low Pass Filter

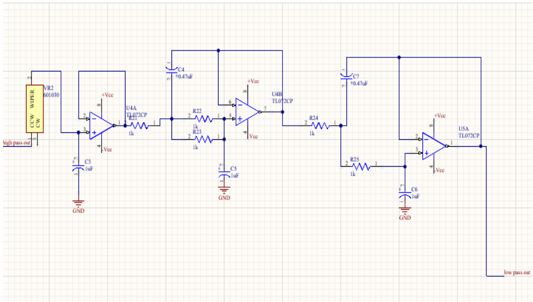


Figure 4:Low Pass Filter

Here, we employed a non-inverting Bessel Thompson filter of the fifth order. Two second order active filters and a series cascaded first order active filter make up this setup. Since each of their gains is a unity, the low pass filter's total gain is also a unity. To change the cutoff frequency, we have employed a variable resistor.

2.4.1 Cutoff Frequency of Low Pass Filter

$$\text{Cutoff Frequency} = \frac{1}{2\pi VR_2C_3}$$

$$\text{Minimum Cutoff Frequency} = \frac{1}{2\pi \times 10\text{k}\Omega \times 1\mu\text{F}}$$

$$\text{Minimum Cutoff Frequency} = 15.91\text{Hz}$$

2.5 Notch Filter

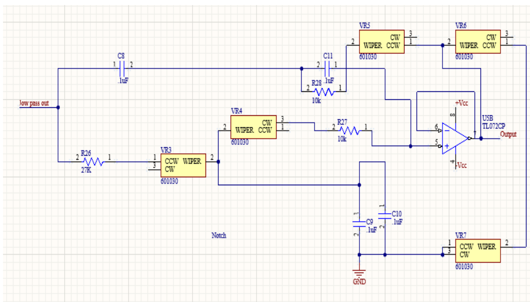


Figure 5:Notch Filter

In this case, a Twin-T style notch filter was utilized. This is how power line interference is removed. 50 Hz is the frequency of the notch filter as a result. To get the steeper roll-off, this calls for a high Q factor or a small transition bandwidth. One of the few RC networks that can provide an infinite deep notch at a specific frequency is the Twin-T notch filter. We have used a unity gain notch filter. Consequently, we applied this specific filter. The filter's quality is determined by the Q factor, also referred to as the quality factor. This is adjusted as needed using a variable resistor. Three resistor values determine the notch frequency. Five tuners are used to adjust that as needed.

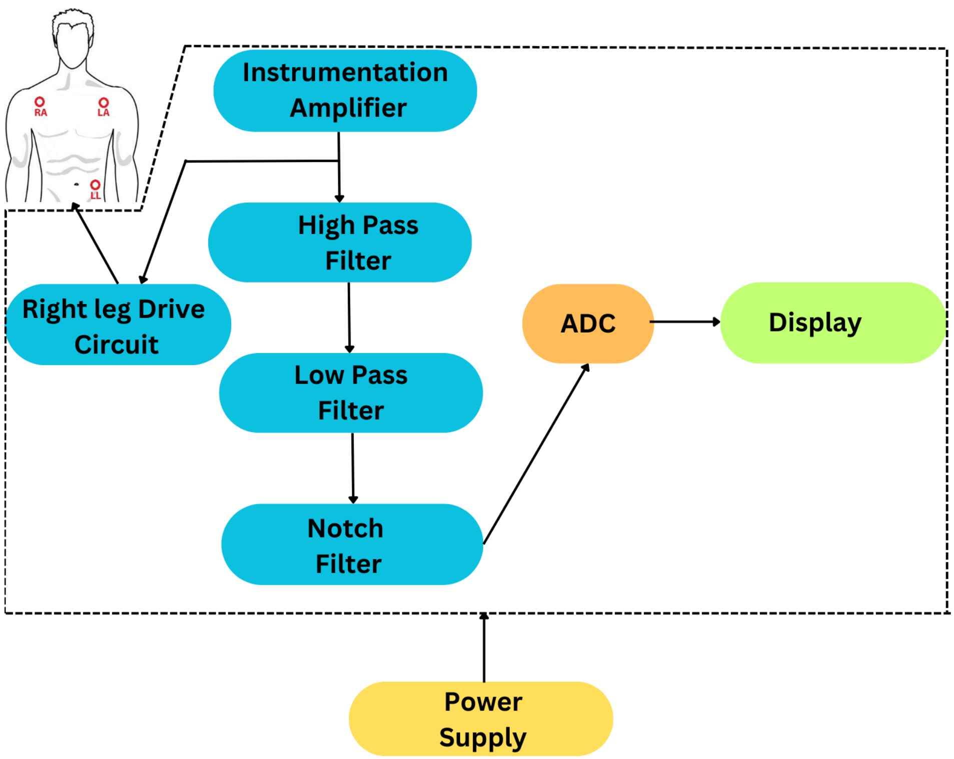
2.5.1 Cutoff Frequency of Notch Filter

$$\text{Cutoff Frequency} = \frac{1}{2\pi(R_{26} + VR_3)C_8}$$

$$\text{Minimum Cutoff Frequency} = \frac{1}{2\pi \times 37\text{k}\Omega \times 0.1\mu\text{F}}$$

$$\text{Minimum Cutoff Frequency} = 43.015 \text{ Hz}$$

3 System Architecture



4 Component Selection

The selected operational amplifier for our analog ECG monitor is the TL072CP, chosen for its specific characteristics that align with the requirements of our design:

1.High Slew Rate (20 V/s typical): This feature enables quick responsiveness to rapid changes in input signals, making the TL072CP ideal for applications like ECG monitoring where signal fidelity is crucial.

2.Low Offset Voltage (1 mV typical): The TL072CP minimizes voltage differences between its input terminals when no signal is applied, ensuring accurate signal amplification.

3.Low Offset Voltage Drift (2 V/°C): With minimal drift over a wide temperature range, the amplifier's performance remains stable.

4.Low Power Consumption (940 A/ch typical): The TL072CP is energy-efficient, drawing a modest current.

5.Wide Common-Mode and Differential Voltage Ranges:Common-mode input voltage range includes VCC+, allowing flexibility in signal levels. The differential voltage range accommodates various input signals. Low Input Bias and Offset Currents: These characteristics minimize the impact of input currents on the circuit.

6.Low Noise (18 nV/Hz typical at 1 kHz): Crucial for sensitive applications like ECG monitoring, the TL072CP maintains low noise levels.

7.Output Short-Circuit Protection: The amplifier is designed to withstand short-circuits at its output.

8.Low Total Harmonic Distortion (0.003% typical): Maintaining signal integrity, the TL072CP exhibits low distortion levels.

9.Wide Supply Voltage Range:Operates from ±2.25 V to ±20 V or 4.5 V to 40 V, providing flexibility in power supply options.

5 PCB Design

Altium Designer was used to design and print three printed circuit boards (PCBs): a power circuit, a heart monitor circuit, and a display circuit which are shown in figures 7,8 and 9. Three layers make up the ECG PCB. The ground pour and +15V top layer are poured into the bottom layer. For routing, both the top and bottom layers are utilized. To prevent capacitance from building up, the power supply PCB was printed in two layers, with the remaining layer being grounded, but routed in a single layer. Pours of ground are made into both lower layers. To facilitate easy replacement, all of the integrated circuits are coupled with IC bases. Pin headers and jumpers have been used to connect the ICs to external accessories.

6 Enclosure Design

The enclosure for our device was created using Solidworks, as shown in Figure 10. It's designed for user convenience, featuring a removable top cover and detachable front, making it easy to fix or replace components. The front section has a power-on switch and a knob for tuning the instrumental amplifier, providing better operational control. For easy connectivity, the enclosure has strategically placed holes with adapters for the power cable and 3.5mm jack. This design focuses on user-friendly features. Additionally, a separate enclosure was designed specifically for the power supply circuit.

7 Software Simulation and Hardware Testing

Using LTSpice, we first simulated our complete circuit.After that, it's put into practice on a breadboard with some modifications to get the least amount of noise in the signal. We can see the overall testing improvement from the oscilloscope display changes.

8 Conclusion & Future Works

Our future work involves integrating a display for immediate visual feedback on the ECG waveform, enhancing user understanding and experience. Real-time data plotting via serial communication has been implemented successfully, thanks to the easy integration of an ESP32 into our device. Even though the results of our early efforts were encouraging, we are dedicated to improving and streamlining the procedure to guarantee even higher graph plotting accuracy. Our goal is to remove any delays that may have occurred in the early phases, going above and beyond to provide a remarkable and accurate graphical depiction of the data.

9 Contribution of Group Members

Index Number	Contribution
1.210321X	Enclosure designing Circuit designing
2.210504L	Circuit designing Simulation
3.210687X	Circuit designing Enclosure designing
4.210732H	Pcb designing Simulation

10 Bill of Materials

	Component	Quantity	Unit Cost	Cost
1	TL072 Operation Amplifier	5	Rs.50	Rs.250
2	1/4w Resistors	30	Rs.3	Rs.90
3	Capacitors - Polarized and non polarized	15	Rs.3	Rs.45
4	Variable Resistors	7	Rs.15	Rs.105
5	PCB			Rs.1500
6	Enclosure printing			Rs.4500
7	Other components			Rs.1000
Total				**Rs.7490**

11 References

1. Du WY, Jose W. Design of an ECG sensor circuitry for cardiovascular disease diagnosis https://medcraveonline.com/I of-an-ecg-sensor-circuitry-for-cardiovascular-disease-diagnosis.html 2.Article -https://electronics.stackexchange.com/qu the-right-op-amp-for-ecg-application

12 Appendix

Appendix 01- PCBs and Enclosure Design

PCB design using Altium Designer

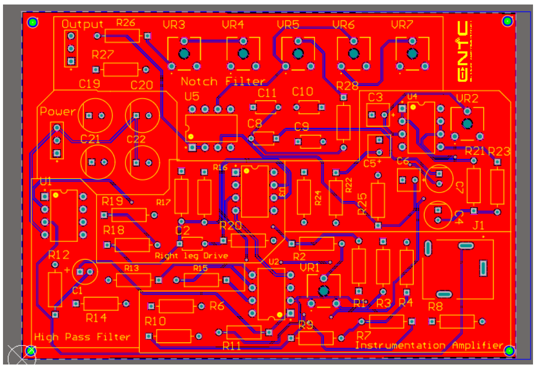


Figure 7:Top Layer

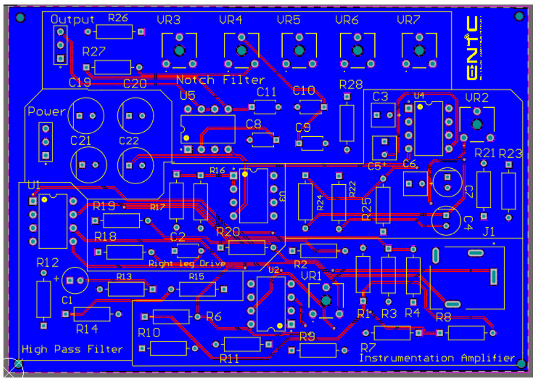


Figure 8:Bottom Layer

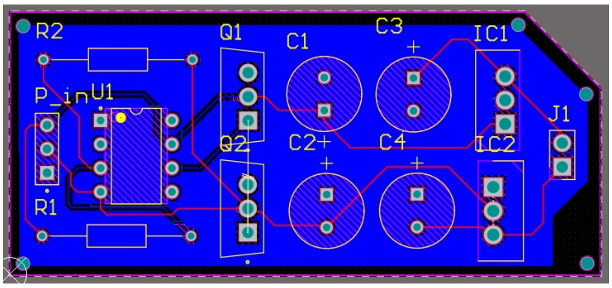


Figure 9:Power supply circuit

Enclosure design using Solidworks

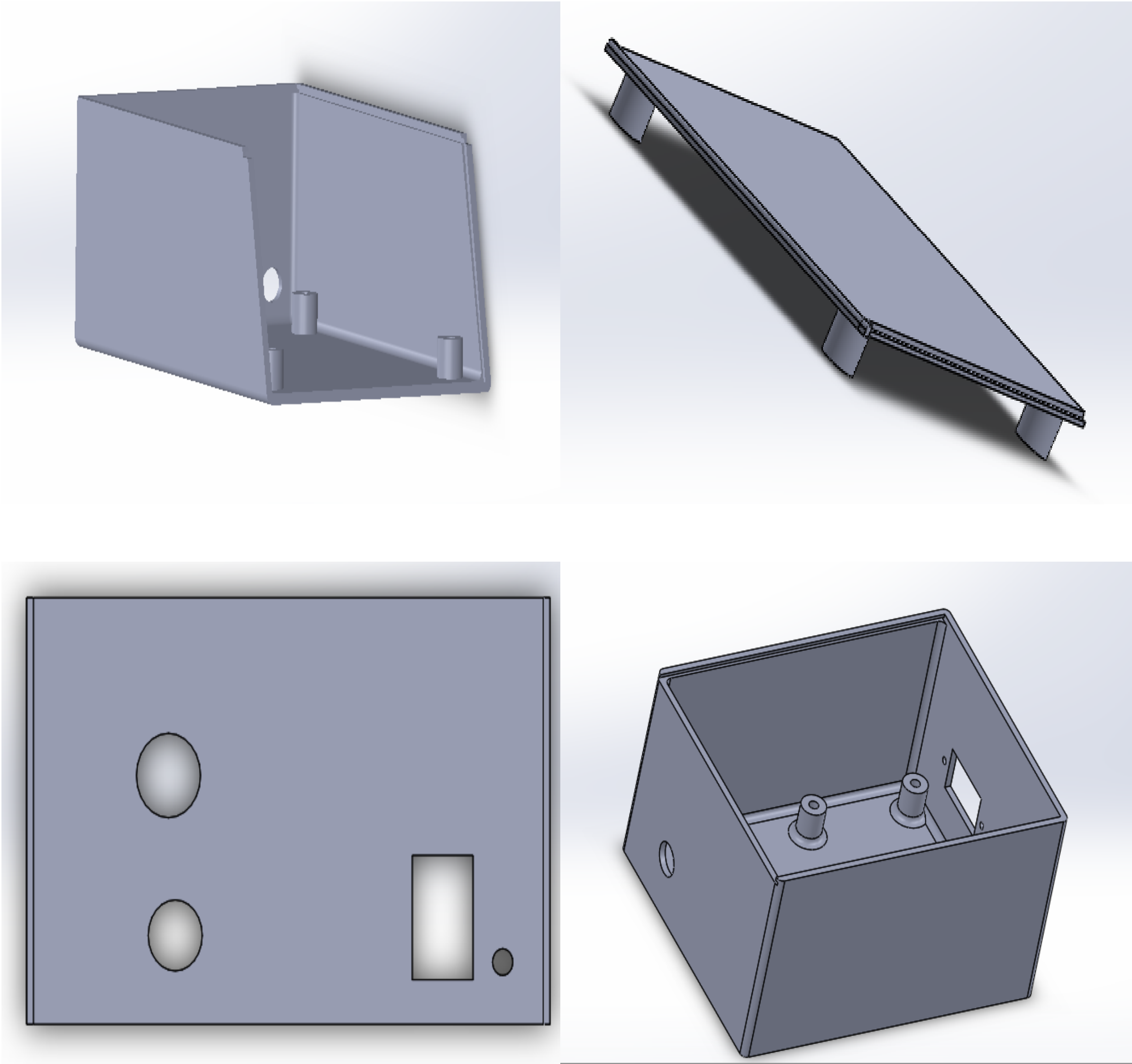


Figure 10 : Enclosure design of the ECG monitor and Power supply unit

Appendix 02- Simulation and Testing LT Spice Simulation and Results

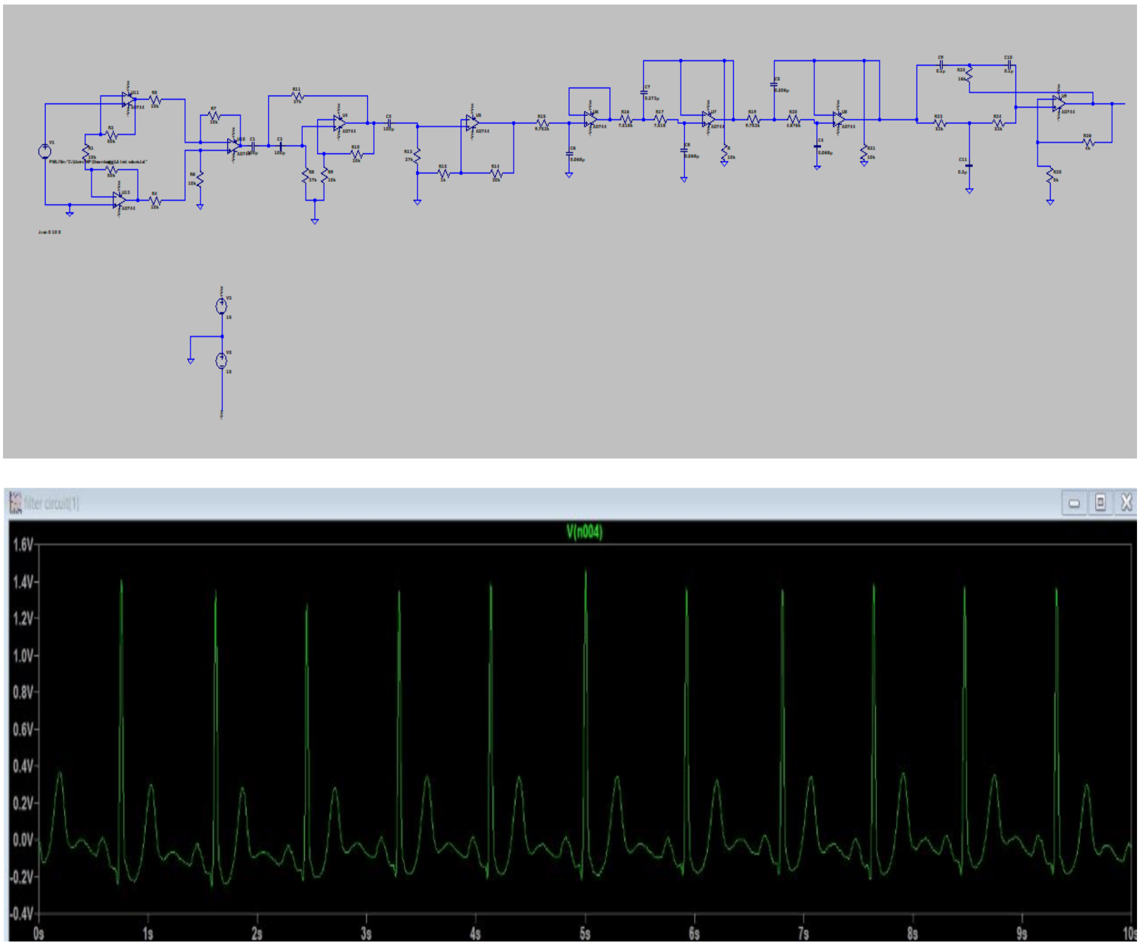


Figure 11 : LT spice simulation and resultant waveform

Bread Board Implementation and Results

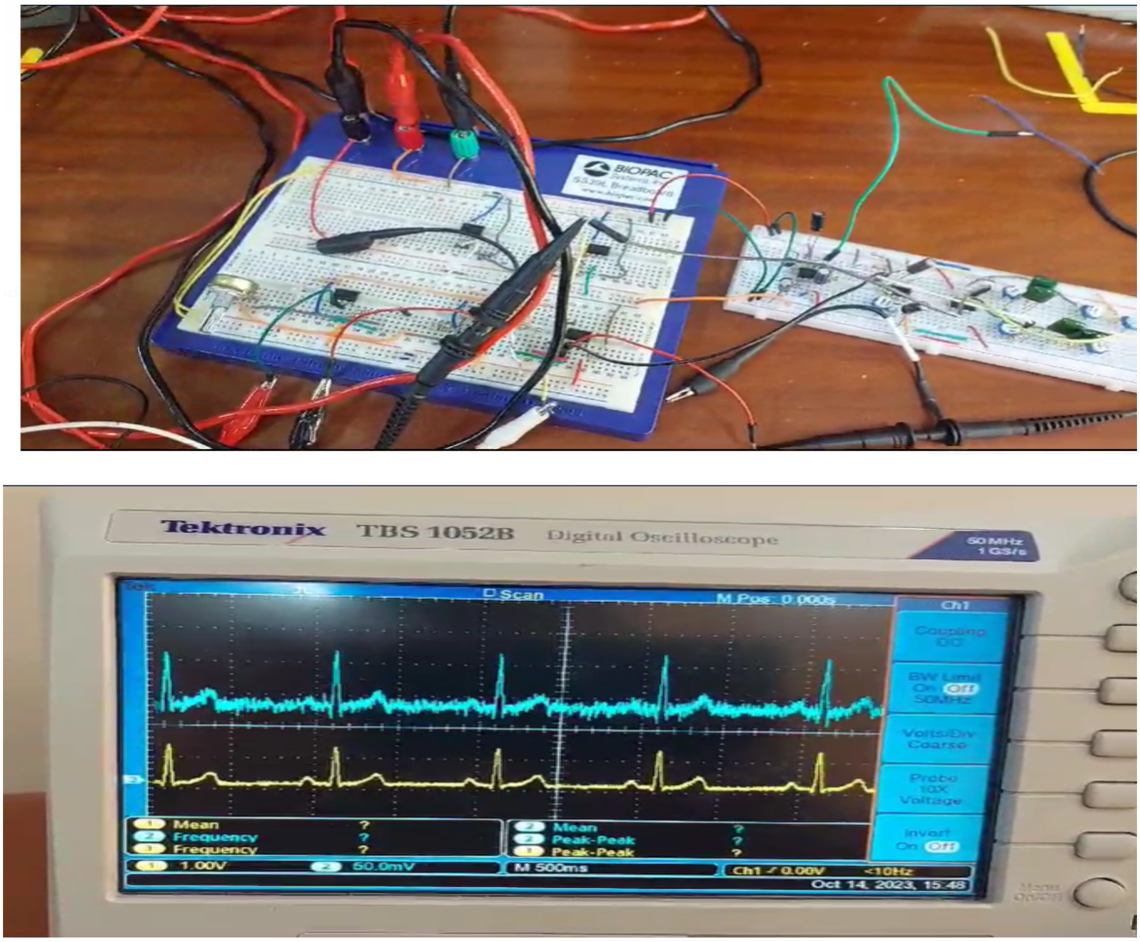


Figure 12 : Breadboard implementation and Oscilloscope waveform

Final Results