Department of Electronic and Telecommunication Engineering

University of Moratuwa

AnalogHeart ECG Monitor

Team Meditrones

EN2091 - Laboratory Practice and Projects

Aazir.M.M.M - 220005R
Boralugoda.M.S - 220074B
Liyanage.D.L.B.B - 220362G
Madusanka.S.P.S - 220374U

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Abstract

Our project was to create a circuitry that is capable of apprehending the ECG waveform and displaying it.This was achieved only using analog electronic components and they were used for several stages such as amplification, filtering and sampling purposes. Circuit is mainly made of instrumentation Amplifier , High Pass Filter,Low Pass Filter and a Notch Filter. This report also includes the PCB designs, simulations and the 3D Enclosure design made to meet the project requirements.

1. Introduction

An electrocardiogram (ECG) is a straightforward diagnostic method used to evaluate the electrical activity of the heart by identifying electrical impulses produced by electrodes affixed to the skin during each heartbeat. By using a feedback mechanism through the right leg, the voltage differential between the left and right arms is amplified. These voltages from the right arm, left arm, and right leg are measured via ECG leads. The voltage signal has a frequency between 0.01 Hz and 180 Hz and an amplitude between 0.001 mV and 100 mV (usually 1 mV).

The limited amplitude of the raw ECG signals and their vulnerability to distortion from a variety of causes, including noise, power line interference, radiofrequency interference, noise from electrode contact, stray capacitance and other biological factors makes it difficult to amplify and filter the ECG signal. Our circuit is composed of analog components like resistors, capacitors and OpAmps that is capable of amplifying and filtering out the ECG signal. Our circuit comprises of the following sections;

- Instrumentation Amplifier
- First Order Active High Pass Filter
- Fifth Order Active Low Pass Filter
- Notch Filter
- Right Leg Drive

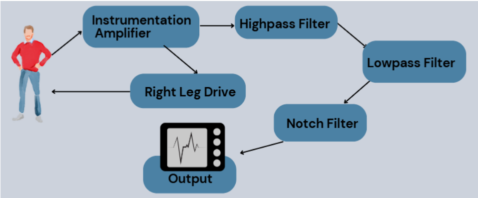


Figure 1: Functional block diagram

After simulating the circuit using LT-Spice we successfully implemented the prototype circuit and designed a PCB using Altium as well as an enclosure to meet the user demands using Solidworks.

2. Functionality

2.1. Instrumentation Amplifier

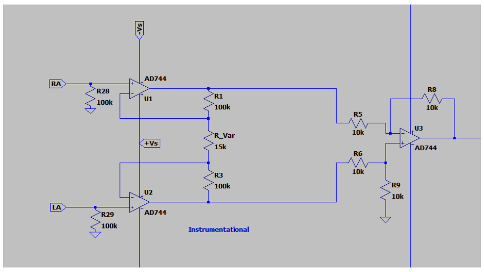


Figure 2: Instrumentation Amplifier

The main purpose of the instrumentation amplifier is to amplify the small electrical signals produced by the heart, which are typically in the millivolt range. It achieves this by amplifying the differential voltage between two electrodes while suppressing common-mode signals, such as interference from nearby power lines or artifacts from other biosignals.

In our instrumentation amplifier circuit design, it utilizes two TL072CP operational amplifiers. This IC was chosen for its moderate Common Mode Rejection Ratio (CMRR), with a value of 80 dB, making it sufficient for the amplification process. The circuit receives input through two ECG leads placed near Right and Left collarbones, and the gain can be adjusted using a variable resistor located centrally.

2.2. Right Leg Drive

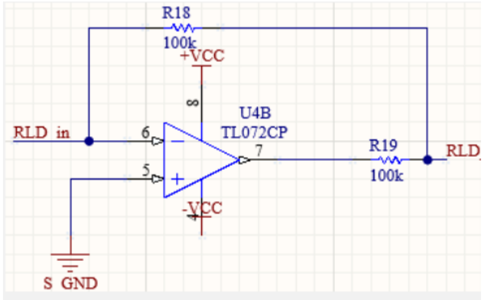


Figure 3: Right Leg Drive

The Right Leg Drive (RLD) circuit is used to reduce the common-mode noise between the two input electrodes. This is achieved by getting the original signal, inverting and amplifying it, then sending it back to the body through an electrode placed below the ribs. Here we use a single TL072CP IC and it acts as an inverting unity gain buffer.

2.3. Filter Designing

Selection of the proper cut off frequencies and the orders of the filters were few key things we had to consider when designing the circuit, by the literature review we did we came to a conclusion that the bandwidth of 160 Hz would be ideal and achievable from the available resources.The filter circuit consists of 1st Order High Pass Filter, 5th Low Pass Bessel Filter and a Twin-T Notch Filter.We decided to use TL072CP OpAmps for our filter circuits due to its better performance under noise.

2.4. High Pass Filter

Used to remove low-frequency noise and the DC offset from the ECG signal, such as baseline wander caused by patient movement or breathing. We decided to use a first order High Pass Filter because its performance met our expectations and we didn't want to make the circuit bulky and costly by increasing order of the filter, the cut off frequency of the filter was 0.15 Hz.

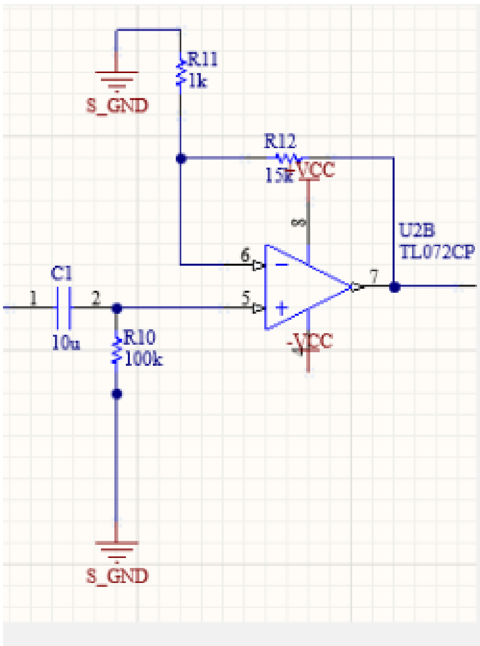


Figure 4: High Pass Filter

2.5. Low Pass Filter

Used to eliminate high-frequency noise from the ECG signal, such as muscle artifacts or electromagnetic interference. In our design we used a fifth order bessel filter by casacading two 2nd order sallen-key filters with a first order active filter.We chose the cut-off frequency to be 164 Hz. We were able to acheieve the expected output from the filter in this configuration.

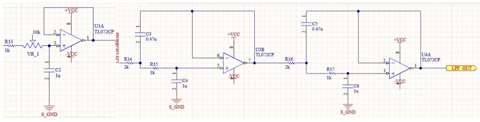


Figure 5: Low Pass Filter

2.6. Notch Filter

A Notch Filter was used mainly to overcome the power-line and other external interferences, this also improves the SNR of the ECG signal which preserves the P,Q,R,S,T complexes of the signal. Furthermore it is important to eliminate the power interference noise before feeding to the ADC as because it will sample the power noise as well which could complicate the signal processing. We used a Twin-T Notch Filter configuration and used external potentiometers to manually adjust the precise cut-off frequency and the steepness of the response.

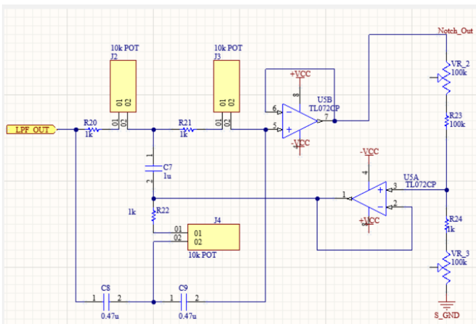


Figure 6: Twin-T Notch Filter

2.7. Power Circuit

The OpAmps TL072CP we are using need a dual supply as we decided to use a boost converter TPS61040 to produce +12V and -12V to power up the Opamps.Also we have used a DC-DC booster to power up the ESP-32 module after regulating through AMS117-3.3 regulator.
Furthermore we have proposed to use to a Lipo Battery to make the device portable and a charging module to make it user friendly for the user to recharge.

2.8. Analog to Digital Conversion circuit

The signal is taken into the ESP32 Micro-controller through one of the chip's inbuilt Analog to Digital conversion pins.
The constraint for ADC conversion is to provide signals only between 0-3.3V to the input pin.Since the notch filter output clearly exceeds this range we implemented a level shifting circuit to shift and scale down the output signal to the 0-3.3V range.

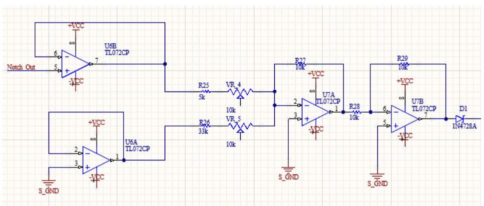


Figure 7: Scaling and Shifting Circuit

3. Design Parameters

3.1. Instrumentation Amplifier

We have used an external potentiometer to vary the gain of the Instrumentaional Amplifier.

$$\text{Gain} - \quad 1 + \frac{2R_1}{R_{\text{var}}} = 1 + \frac{2 \times 100}{R_{\text{var}}}$$

Furthermore we have used TL072CP OpAmps for this and used 0805 package SMD resistors to make the circuitry compact.

3.2. High Pass Filter

Included another gain from the active filter and the gain is around 17.25 where as the cut-off frequency is about 0.15Hz.

$$G = 1 + \frac{R_{13}}{R_{12}} \qquad f_c = \frac{1}{2\pi RC}$$

3.3. Low Pass Filter

We have used a fifth order Bessel filter with a cutoff frequency of 164.15Hz.

$$f_c = \frac{1}{2\pi\sqrt{R_{21}R_{24}C_6C_7}}$$

$$= \frac{1}{2\pi\sqrt{2 \times 1 \times 0.47 \times 1}}$$

3.4. Notch Filter

The Notch filter has the Twin-T configuration and we have used external potentiometers to manually set the cutoff frequency and the steepness of the frequency response.

$$f_n = \frac{1}{2\pi RC} = \frac{10^3}{2\pi \times 6.8 \times 0.47}$$

4. PCB Design

PCB design was made using Altium software which is a professional tool for building PCBs and used two layers to meet the quality standards. Power traces were routed using a trace width of 25mils to make sure the PCB is safe during power transmission and the signal traces were 15mils which is sufficient to keep the signal integrity.
The signal processing circuit was isolated from the power circuit and the ADC circuit to make sure there is minimum interference to the ECG signal from other components.SMD components were soldered by hand and placed IC bases for convenient replacement of OpAmps when required. All the layers and schematics are shown in the Appendix.

5. Enclosure Design

The enclosure is designed using Solidworks CAD software and this has several key components. It has a removable lid, a battery holder to place the batteries and remove them as required, it has a charging port to charge the batteries.Further it has a mount to place the display on the top lid and made required cuts for the ventilation inside the device. The 3D drawings are shown in the Appendix below.

6. Simulations and test Results

First we made the circuit in LTspice and confirmed the filers are working as expected and later we gave an ecg wave with noise and we were able to observe the filtered and amplified ECG from our simulated circuit.
Later we developed the Prototype circuit and we were able to achieve the expected outcomes from the circuit we build. All the results are shown below in the Appendix.

7. Final Prototype

Shown below is the final product with the PCB mounted and components assembled inside the enclosure with the three electrodes.

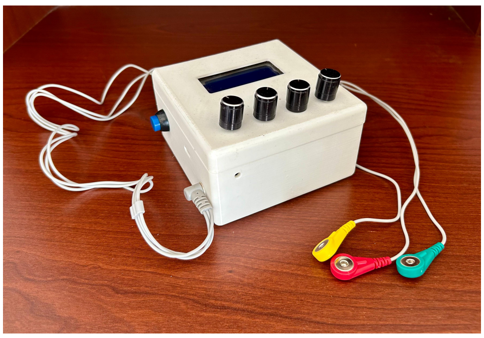


Figure 8: Final Product

8. Task Allocation

Aazir.M.M.M- Circuit design, enclosure design, and circuit optimization.

Boralugoda.M.S- PCB design, documentation, and circuit testing.

Liyanage.D.L.B.B- Circuit design, PCB design, and soldering.

Madusanka.S.P.S- Enclosure design and circuit testing.

9. Resources

GitHub repository including all the schematic files, PCB and enclosure design files and code can be found here:
`https://github.com/Banu-Liyanage/AnalogHeart-by-Meditrones`

10. References

Refer to the Texas Instruments guide on op-amp design [1]. For ECG sensor circuit designs, see the MedCrave article [2]. Detailed specifications for the TL072 op-amp are available in the datasheet [3].

Bibliography

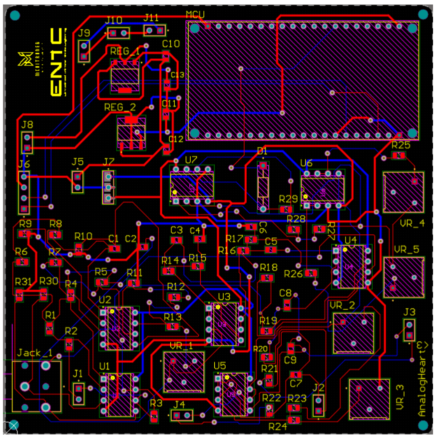
[1] T. Instruments, *Op amps for everyone design guide*, Accessed: 20-Dec-2024, 2002. [Online]. Available: `https://www.ti.com/lit/an/sloa049d/sloa049d.pdf`.

[2] A. Idris, "Design of an ecg sensor circuitry for cardiovascular disease diagnosis," *International Journal of Bioengineering and Biomedical Science*, 2018, Accessed: 20-Dec-2024. [Online]. Available: `https://medcraveonline.com/IJBSBE/design-of-an-ecg-sensor-circuitry-for-cardiovascular-disease-diagnosis.html`.

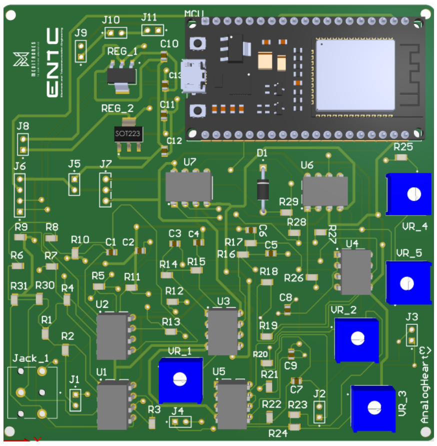
[3] T. Instruments, *Tl072 low-noise jfet-input operational amplifier datasheet*, Accessed: 20-Dec-2024, 2021. [Online]. Available: `https://www.ti.com/lit/ds/symlink/tl072.pdf`.

11. Appendix

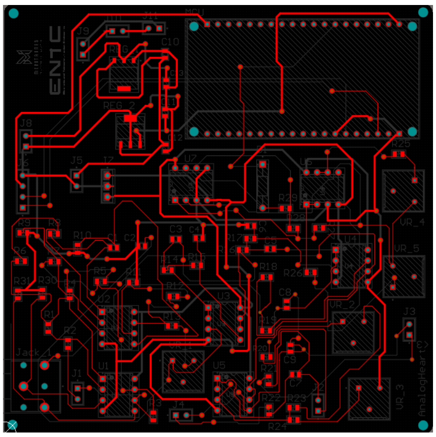
11.1. PCB Layout from Altium Designer



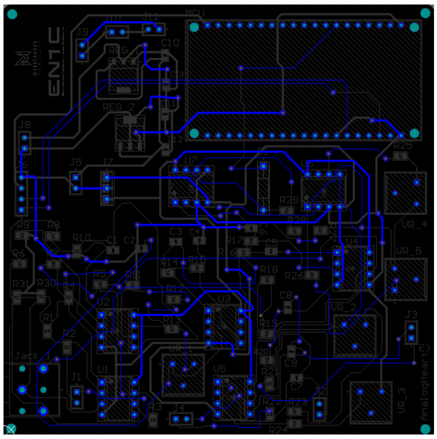
(a) All Layers of the PCB



(b) 3D View of the PCB



(c) Top Layer



(d) Bottom Layer

11.2. Enclsoure Design using Solidworks

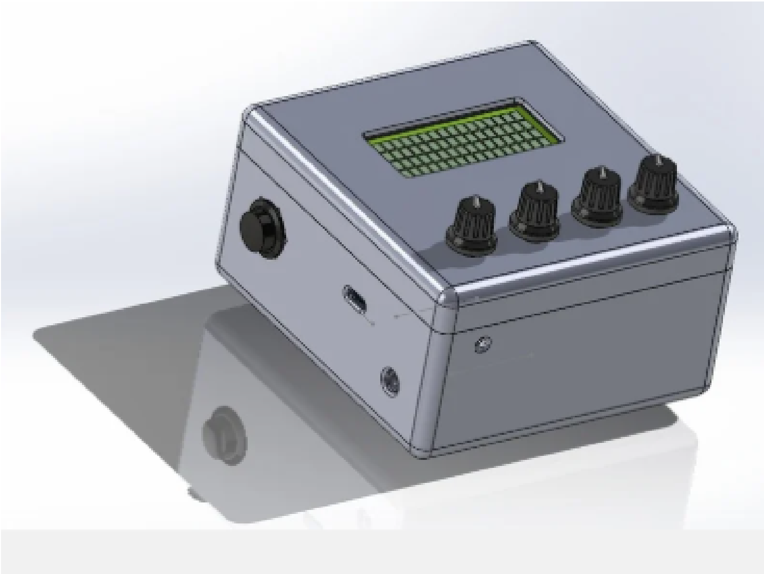


Figure 9: 3D view of the enclosure

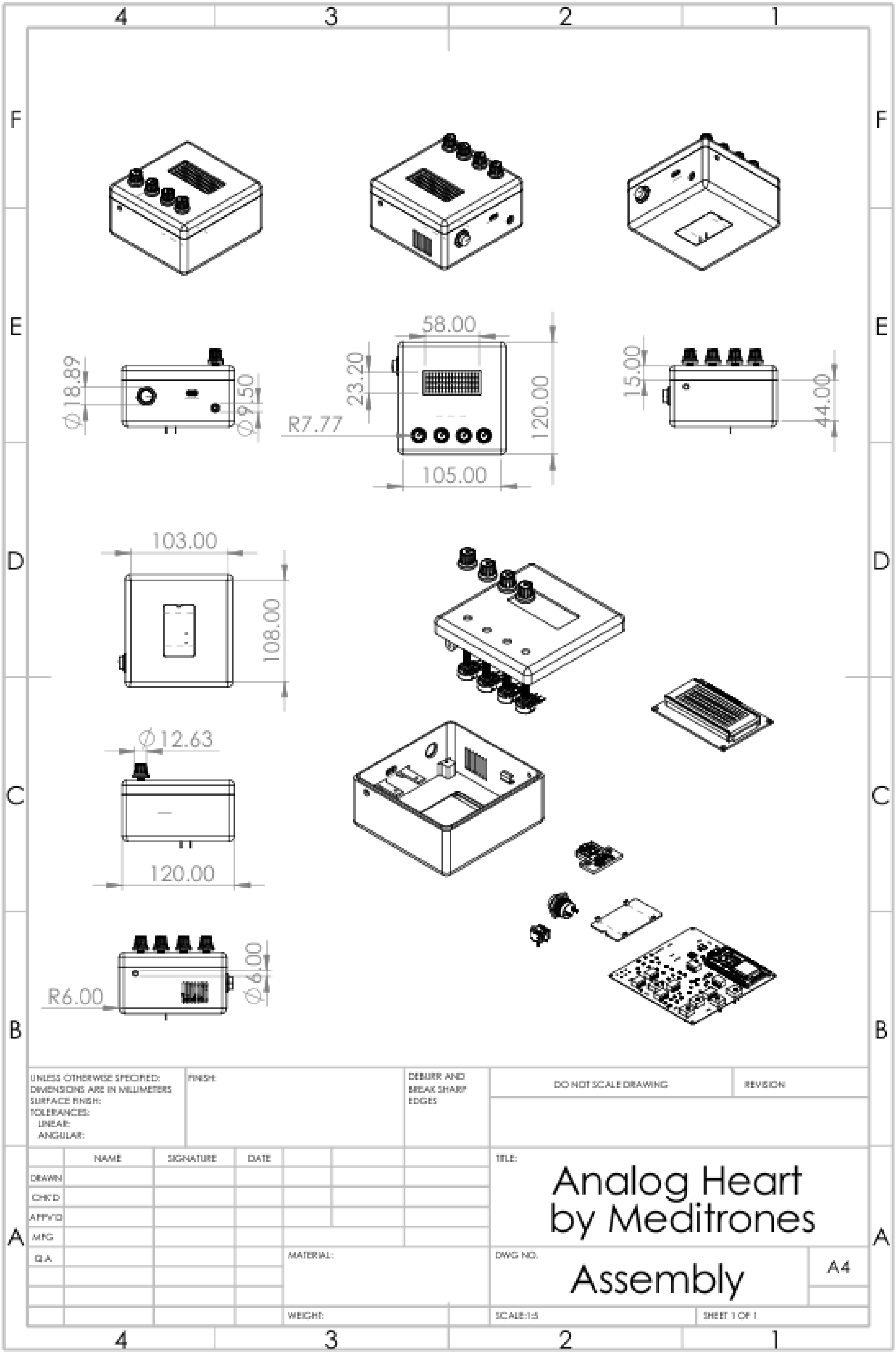


Figure 10: Drawings

11.3. Circuit Simulation and results

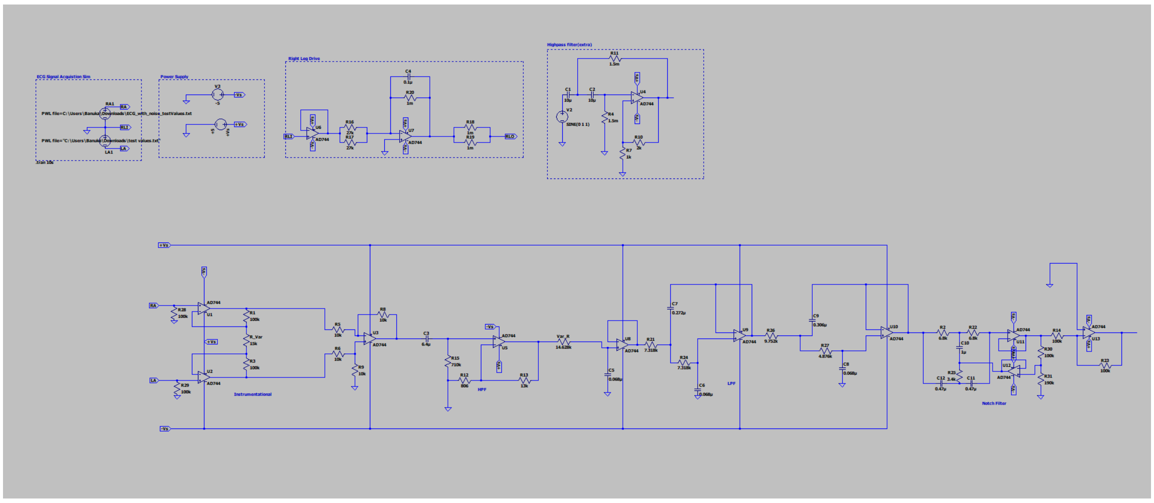


Figure 11: LTspice Schematic

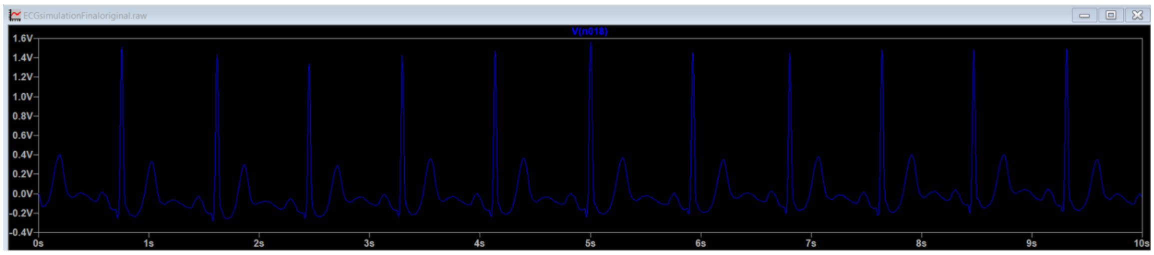


Figure 12: Simulation output from the LTSpice schematic

11.4. Circuit Testing

Figure 13: Output from the Prototype circuit

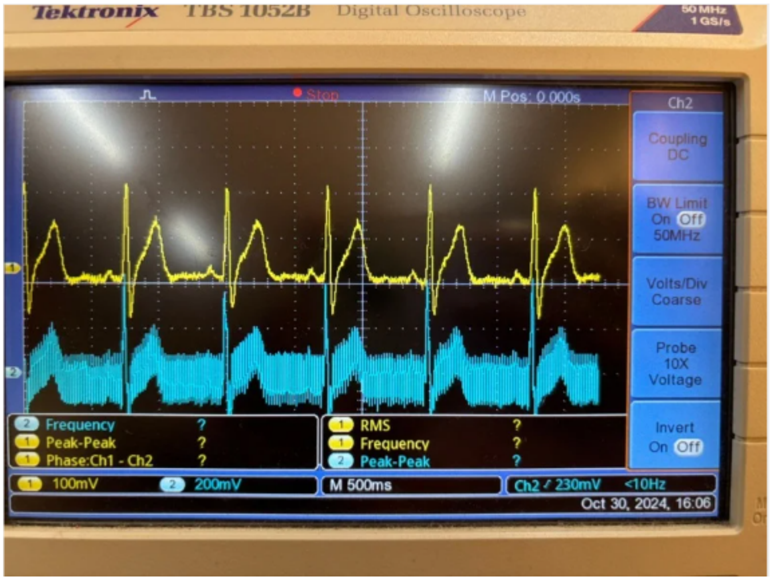


Figure 14: ECG wave from a live subject and the filtered wave, here the blue wave shows the input from the subject with noise and the yellow wave shows the final wave after amplifying and filtering

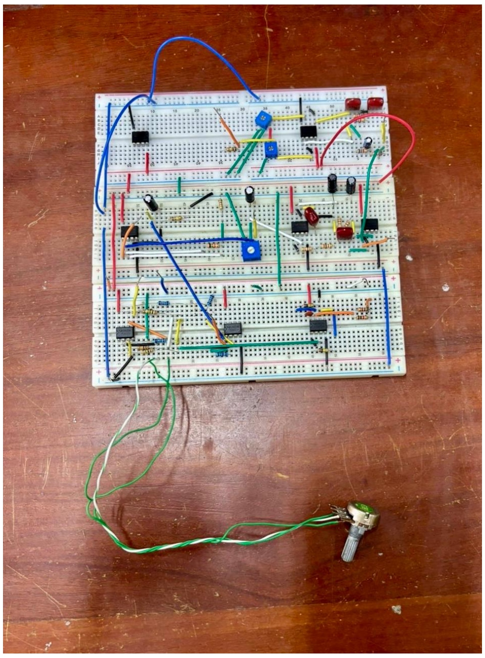


Figure 15: Initial Breadboard Circuit

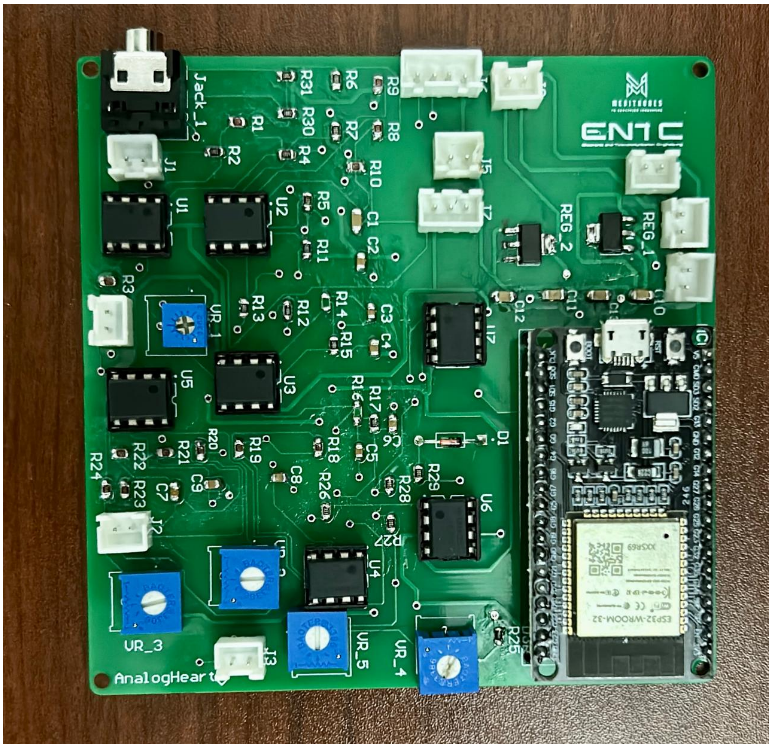


Figure 16: Final Soldered PCB

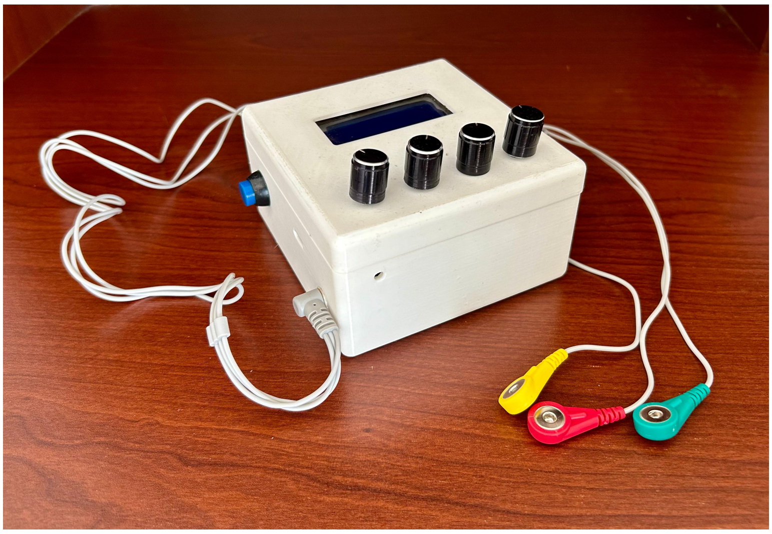


Figure 17: Final Device