3 Lead Electrocardiogram(ECG)

Table 1 (Room 104)
Course: Electronic Workshop-2

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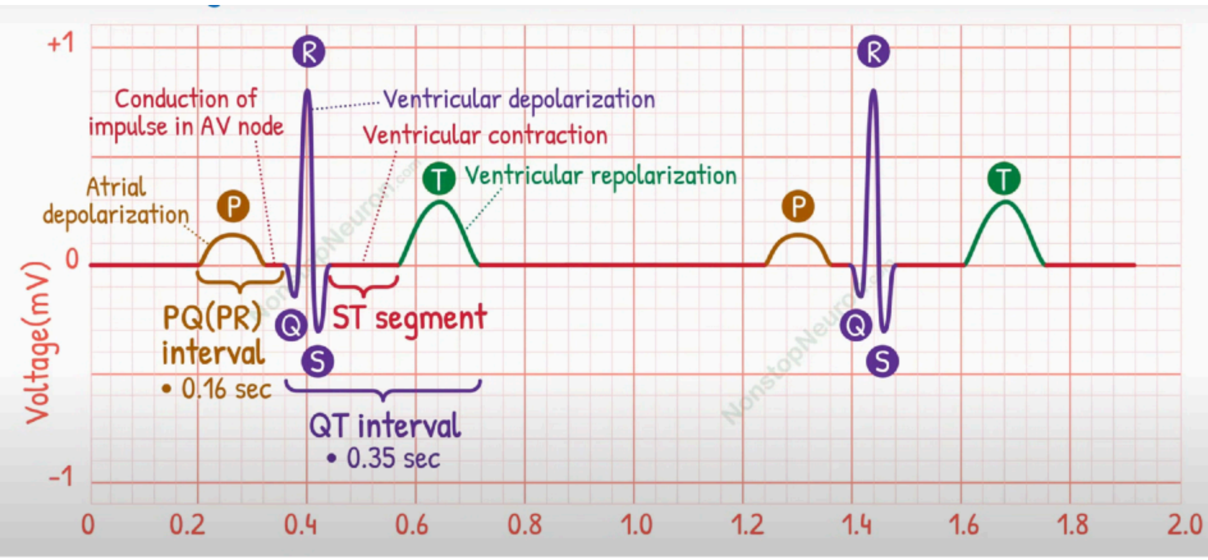
***Abstract*—This electronic document is a report based on a 3-Lead Electrocardiogram (ECG) designed using basic analog components. This report explains the entire procedure of designing a simple ECG circuit. The heartbeat of the person is also calculated using the ECG and displayed on OLED using Arduino.**

I. INTRODUCTION

Electrocardiography is the process of producing an electrocardiogram (ECG or EKG), a recording of the heart's electrical activity through repeated cardiac cycles. Electrocardiography is performed by placing electrodes on the skin. These electrodes measure the change in electrical activity of the heart, which is a result of muscle polarisation followed by depolarisation.

In a resting heart cell, the inside of the cell is negatively charged compared to the outside due to an unequal distribution of ions. The heart is said to be polarized in the above state. The ions include potassium ions and sodium ions. An 'electrical jolt', received by the heart flips the situation, causing the inside of the cell to be more positively charged **as compared** to the outside. The cell is now more permeable to the positively charged sodium ions. The cell is now said to be 'depolarised'.

During a process called repolarisation, as the name suggests, the cell goes back to its initial state. Our objective is to design a circuit that measures the electrical activity of the heart as accurately as possible with the components available in the lab. Another objective of the experiment is to calculate the heartbeat of the person.

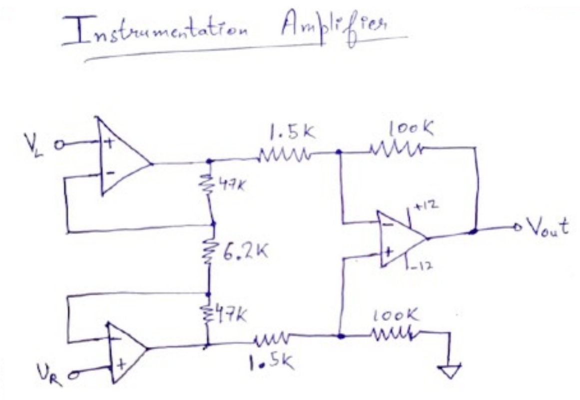


II. DESIGN APPROACH

The electrical activity of the heart is not very high. For instance, the resting membrane potential of cardiac cells is around -90 to -80 millivolts (mV) relative to the extracellular fluid during polarisation. The values during depolarisation are also of the order of millivolts. To observe and measure the output, the ECG needs to be amplified, and the noise component needs to be minimised. We must only allow specific frequency values to be displayed and reject the others

Amplification Stage:

To achieve the same, we have implemented an instrumentation amplifier. It aims to amplify low-level signals while rejecting common-mode noise. The gain provided by an instrumentation amplifier is as follows:



$$A_v = \left(1 + \frac{2 \times (47k)}{6.2K}\right) \times \frac{100k}{1.5k}$$

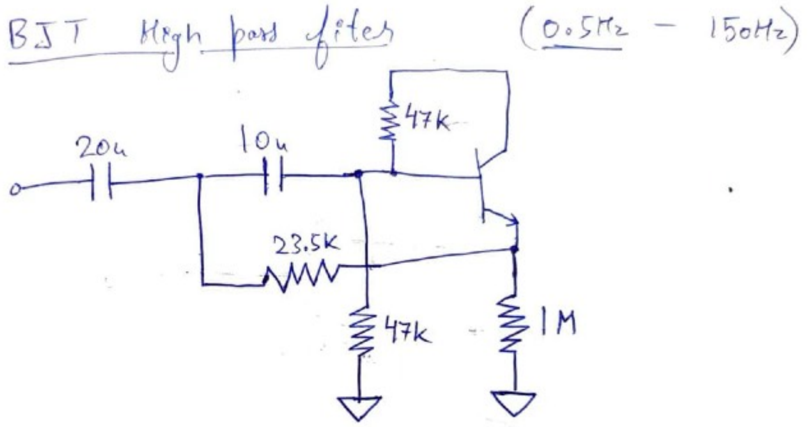
$$= 16.16 \times 66.66$$

$$= 1077.3$$

The advantage of using an instrumentation amplifier is that we can manage the gain of the amplifier using less number of resistors. We require buffer circuits for increasing the impedance of the 2 input voltages, so instead, we also amplify the voltages with an increase in impedance. Then the 3rd opamp is used as a subtractor, which gives the difference of the outputs, and accordingly amplifies based on the values of R2 and R3. Thus, the overall circuit can give us a gain of thousands.

Filter Stage:

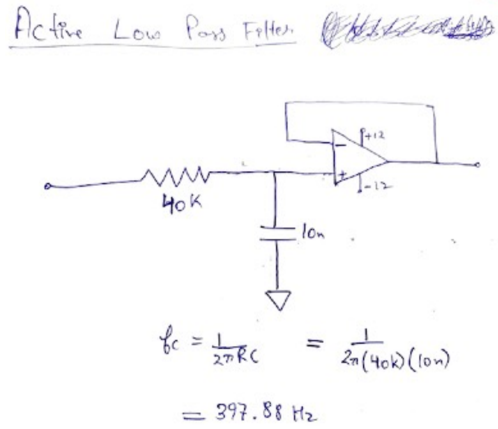
The frequency range for commercial ECG is 0.5 Hz to 150 Hz. So, we were required to make both a low pass and a high pass filter. We decided to implement the high-pass filter using a BJT according to the requirement. The output that we would obtain would be higher based on lower frequencies. Thus, the 2nd-order filter from BJT was decided to be used as a high-pass filter. We have implemented an emitter follower BJT implementation for a high-pass filter.



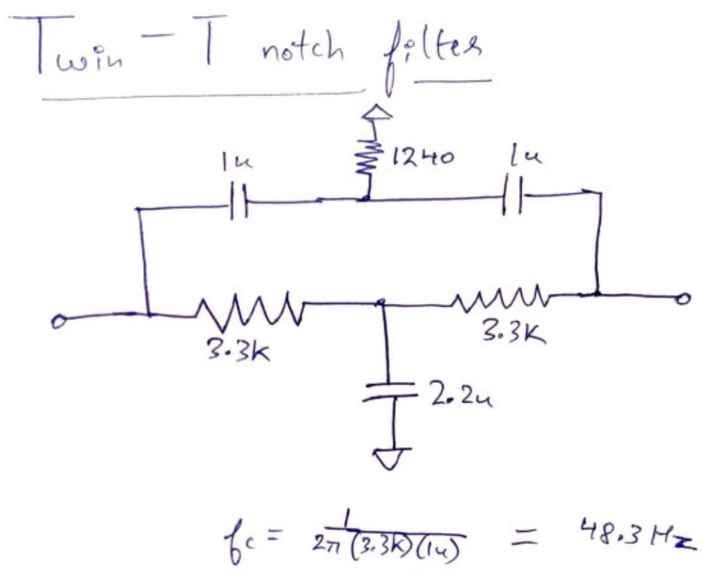
$$f_o = \frac{\sqrt{2}}{4\pi (23.5k)(10u)}$$

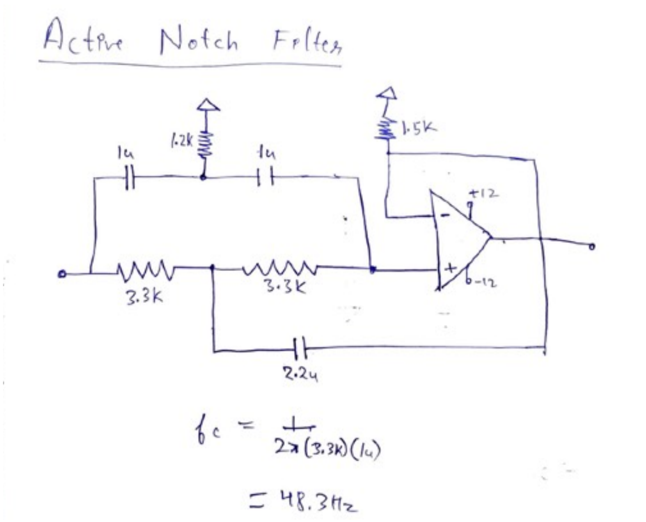
$$= 0.48 \text{ Hz}$$

The low-pass filter, to cover more range, and as per mentor suggestion, we kept the cutoff to 400Hz, rather than 150Hz. It was the 1st order active low-pass filter.



But the important part of filtering is filtering out the 50Hz supply noise coming from the device itself. To tackle that frequency, we have also incorporated two notch filters. A notch filter significantly attenuates specific frequency signals but passes all other frequency components with negligible attenuation. Two notch filters have been used to minimize the 50Hz noise component as much as possible. Here is the circuit diagram of the same. Below is the circuit diagram of a passive notch filter:



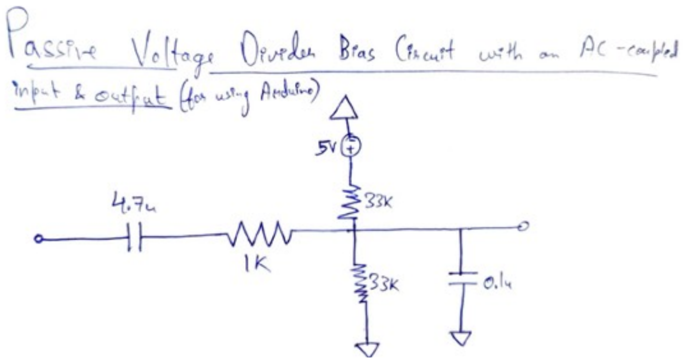


Why Two Notch?

Filter Type	Role
Active Notch	Deep, precise rejection using op-amp gain control
Passive Notch	Extra attenuation, wide rejection, backup filtering
Together	High rejection, sharp and clean notch, robust performance

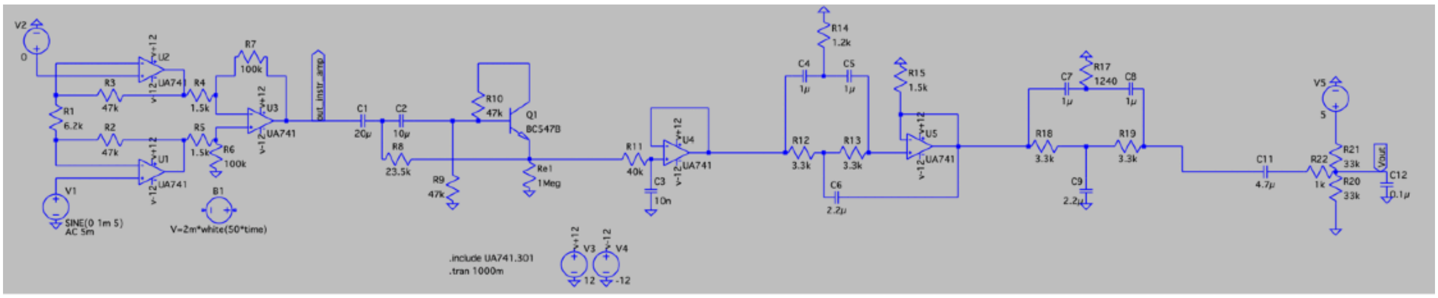
Arduino Input Biasing & AC Coupling Stage

This is a **passive voltage divider bias circuit with an AC-coupled input and output**, often used in **analog audio or signal conditioning systems** as a **DC biasing stage** for an amplifier or other active device input. Here, it is used to feed an analog ECG signal to Arduino.

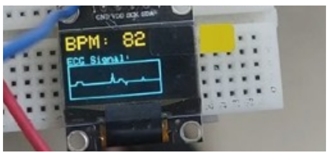


$$V_{\text{bias}} = \frac{R20}{R20 + R21} \cdot 5V = \frac{33k}{33k + 33k} \cdot 5V = 2.5V$$

Here is the final circuit diagram for the same:



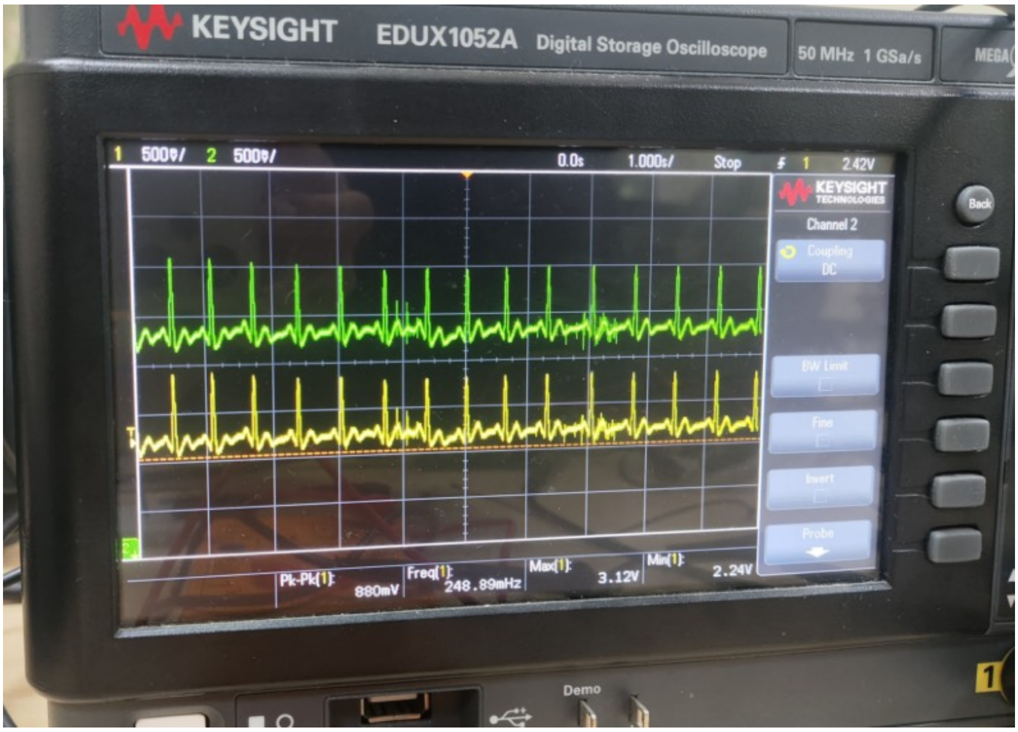
There are a total of three electrodes needed to capture the electrical activity of the heart. The first electrode is placed under the right clavicle near the right shoulder within the rib cage frame, and the second electrode is placed under the left clavicle near the left shoulder within the rib cage. The third electrode acts as a reference electrode and is placed on the left side below the pectoral muscles lower edge of left rib cage. Apart from displaying the electrocardiogram, the heartbeat (measured in beats/min) has also been calculated by taking the ECG as input to the Arduino and the BPM calculated by signal conditioning is displayed on an OLED.



III. Results

The output waveform from the circuit is:

The frequency response analysis on the oscilloscope showcased the functioning of the low-pass filter of 400 Hz and the notch filter of 50 Hz.



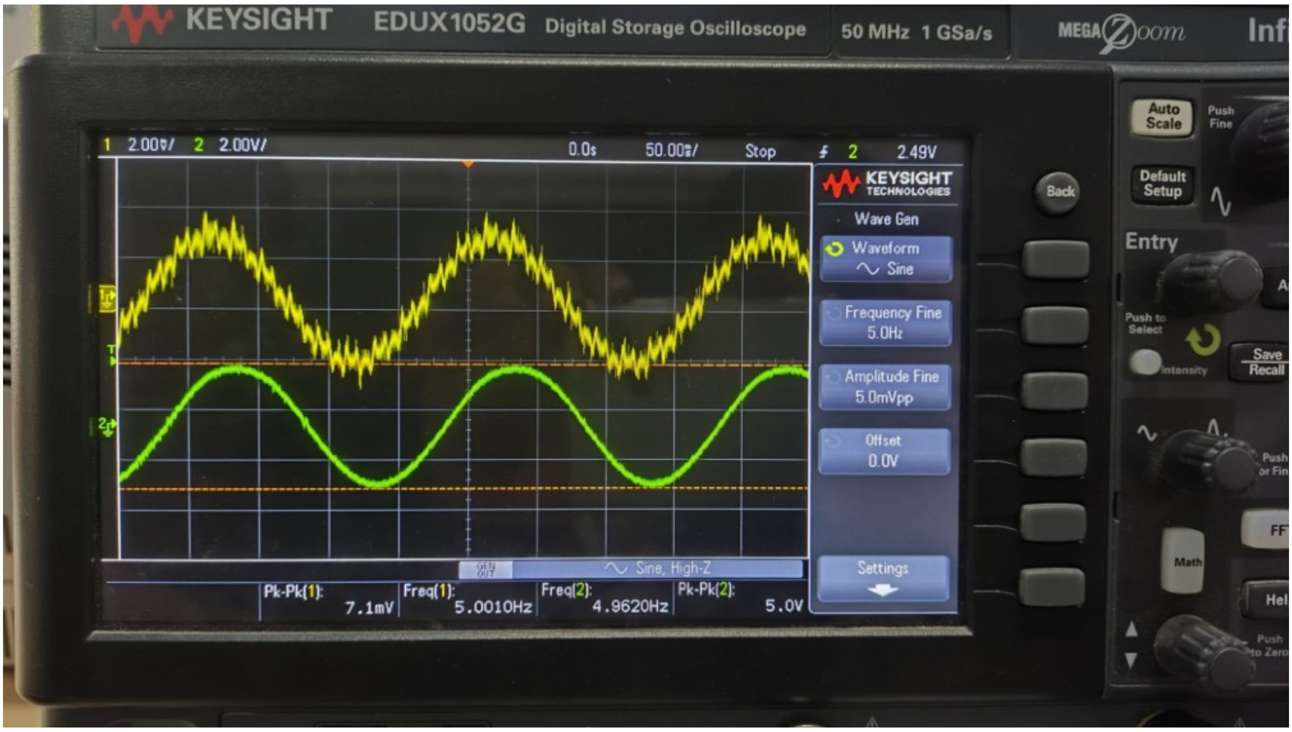
The output range is from 2.14V to 3.12V, centred at 2.5V (as required for Arduino analog input)

The observed gain is less than the desired (theoretical) gain because the notch filter, apart from attenuating the 50Hz, also attenuates slightly the other immediate frequencies.

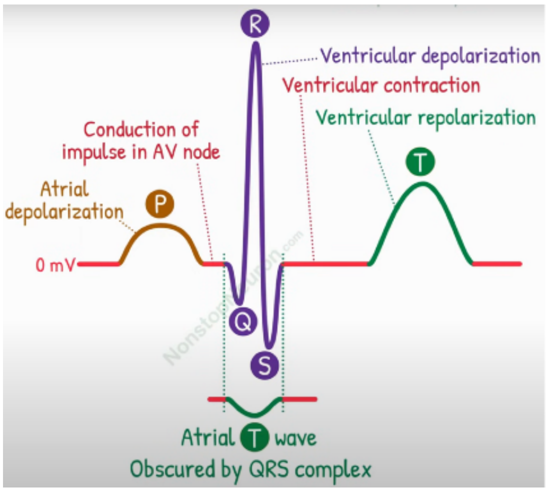
A Major Tradeoff:

1. Attenuation of 50Hz noise for overall gain.
   To remove the 50Hz noise more efficiently, we implemented 2 notch filters in our circuit. Due to this, the side lobes also got widened due to attenuation, decreasing the frequency components of the output. Thus, to counter this attenuation, we had a gain of almost 1100 to get output in the desired voltage range.
   The heartbeat was calculated every 10 seconds using Arduino UNO The DAC in Arduino, with a corresponding threshold, gives us the binary data regarding the analog output, which was then used to calculate the heartbeat.

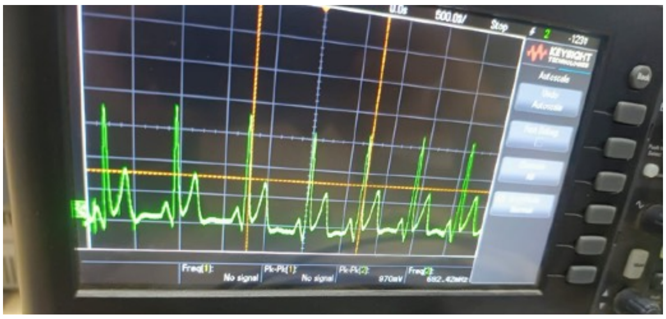
Output for a noisy Sinusoidal input:



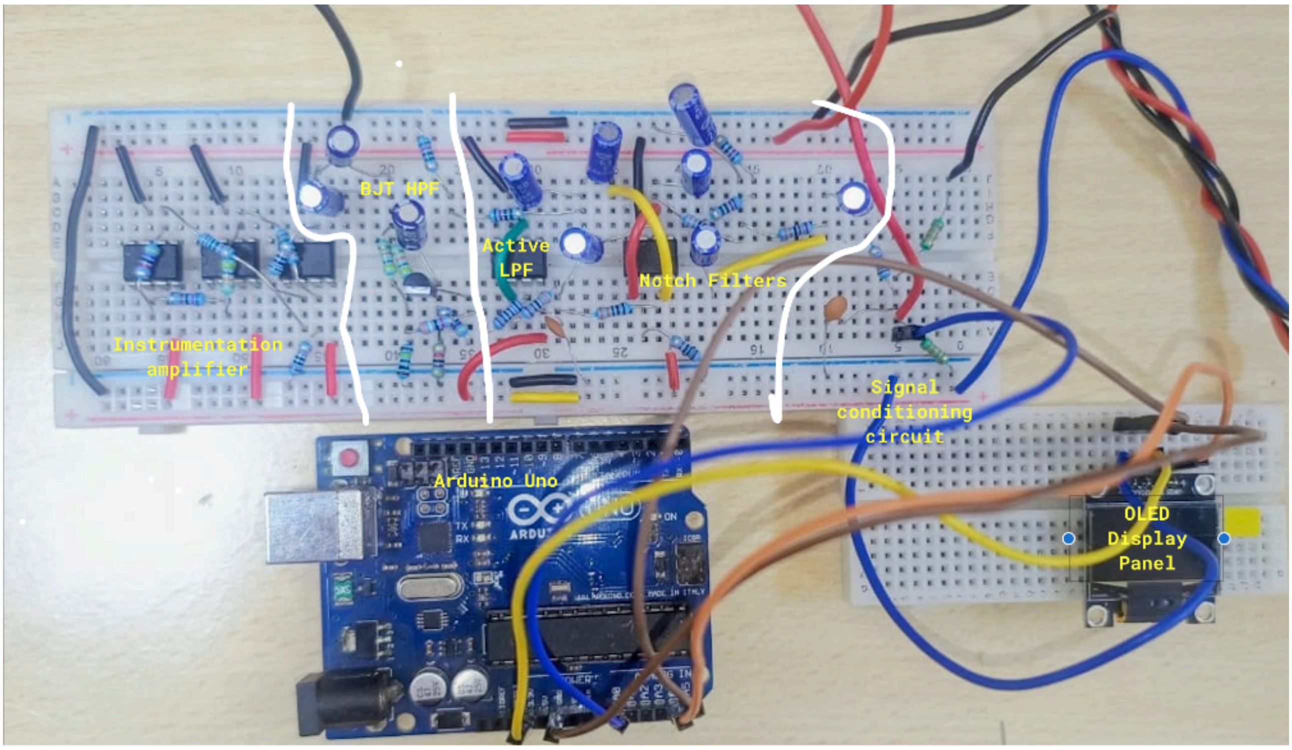
The output nature of an ECG:



Actual Output of the ECG:



Final Overall Circuit:



Demonstration Video:

[Video Link]()