Department of Electronic and Telecommunication Engineering

University of Moratuwa

EN2090 – Laboratory Practice - II

Report for the Mid-Review

Electronic Stethoscope

Group Number: 28

Name	Index Number
Bandara P.M.N.S.	180066F
Chandanayake S.M.	180085L
Hettiarachchi S.S.	180237G
Wasala W.M.H.M.	180675V

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Department of Electronic and Telecommunication Engineering,
University of Moratuwa
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Abstract

Medical diagnosis is generally considered as a multifaceted factual approach (to solve a disease matrix) in which several observational and analytical aspects play virtually and interactively in order to obtain the required sense of curing the patient. Further, it is obvious to state that auscultation, which could be simply identified as listening to the sounds produced by the (human) body, plays a major role in the above process further; it is known that the Stethoscope is the key element to achieve the preferable outcome of this auscultation.

Stethoscopes are optimally utilized for the purposes of medical requirements especially in detecting normal and/or abnormal respiratory, cardiac, arterial, fetal, venous, intestinal and uterine sounds of humans as well as of animals. In addition, they are also used for achieving various intentions in mechanics and exterminators. In this project, we propose to build an electronic stethoscope which could optimally replace the general functions of a traditional stethoscope that basically consists of a rubber tube and a disk-shaped diaphragm.

Contents

Introduction

In general, it is highly accepted that the auscultation through traditional stethoscopes profoundly requires substantial clinical experiences and better listening skills. In relation, they are fundamentally aimed for medical utilization in diagnosis. Even though this requirement is essential, external noises inside hospitals may lead to produce weak sound signals through stethoscopes and thus the sounds are considerably inaudible. Thus, this may lead to missing any important diagnosis by the listener.

In addition, sometimes, the body itself produces much weaker sound signals in diseases such as in early stages of cardiac dysfunction in which traditional stethoscopes could less be helpful in the diagnosis process. Therefore, it is required to approach these particular problems with a different perspective; which we propose as “electronic stethoscope”. Electronic stethoscopes could overcome the low sound signals by electronically amplifying the body signals after converting acoustic signals into electrical signals. Further, low pass filtering in electronic stethoscopes is intended to reduce the background noises if any occurred.

Project Requirements

We proposed to design an electronic stethoscope which could be utilized as an optimal alternative for a traditional stethoscope as it amplifies the acoustic signals to a considerable gain level; hence nearly no sound is missed. Therefore, this device could be even used by less experienced practitioners in the medical field.

- The entire design is intended to be in analog domain
- The device is intended to operate up to 20Hz in low frequency
- The (low pass) filtering of the device is intended to have at least 1.5kHz cut-off frequency
- The power requirement of the device is intended to have 7.4V DC
- The device is intended to use a stethoscope head and an electric mic (ECM) for sensor purposes
- Volume control is intended to be applied
- Safety precautions for hearing are intended to implement as necessary and suitable
- The output of the device shall be obtained in acoustically
- Further improvements such as visualizing output signals on (android) screen is intended to be included as time availability

Design Innovation

As per the above requirements, we have concluded that the device will fundamentally in need of a Sensor stage, a Pre-amplifier, a Low pass filter (butter-worth), a Power Amplifier, a Voltage Reference circuit and an output stage to have the basic intended functionality. So the basic Stages that the device will go through would be:

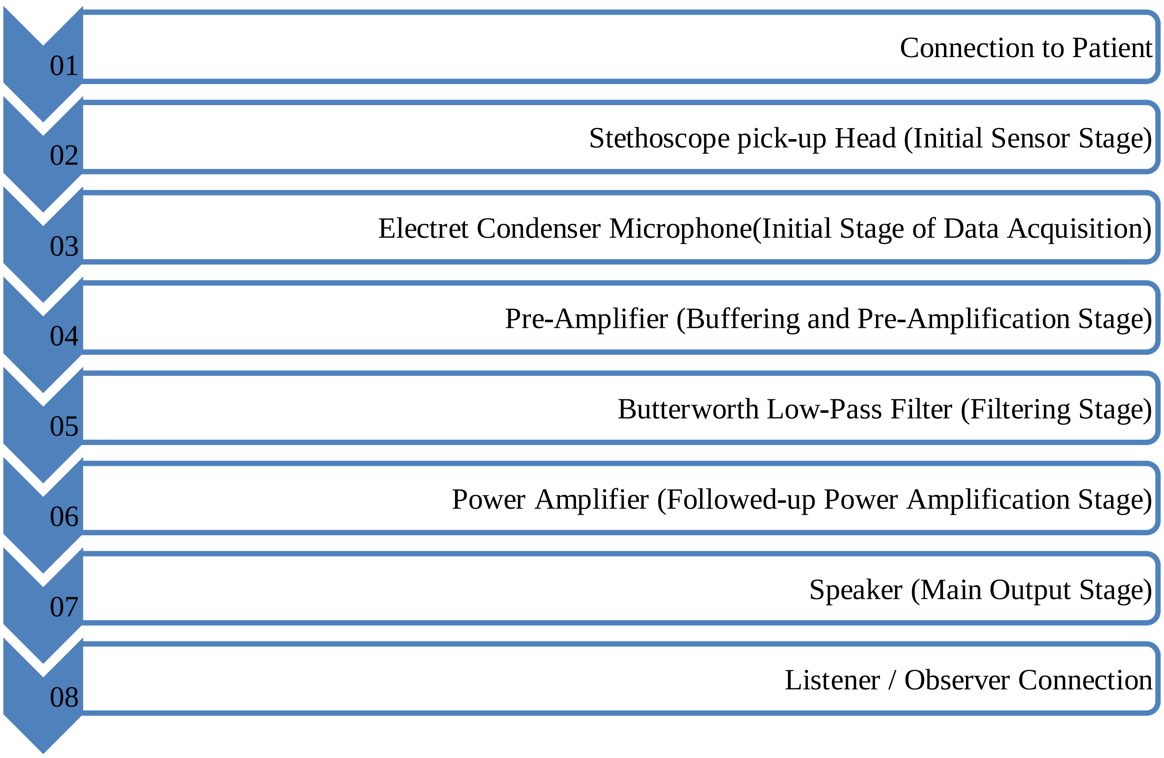
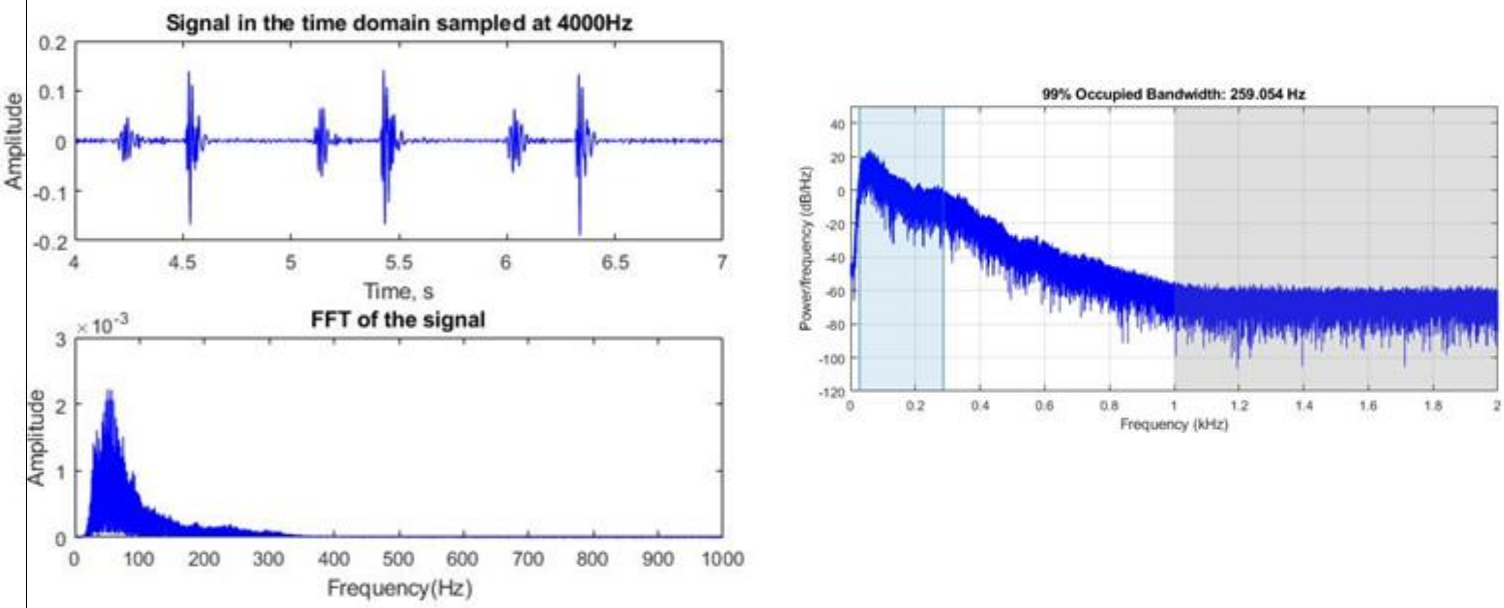


Figure 1: Implemented Functional Flow of the Electronic Stethoscope

Logical Reasoning of Circuit/Component Strategy with relevant calculations

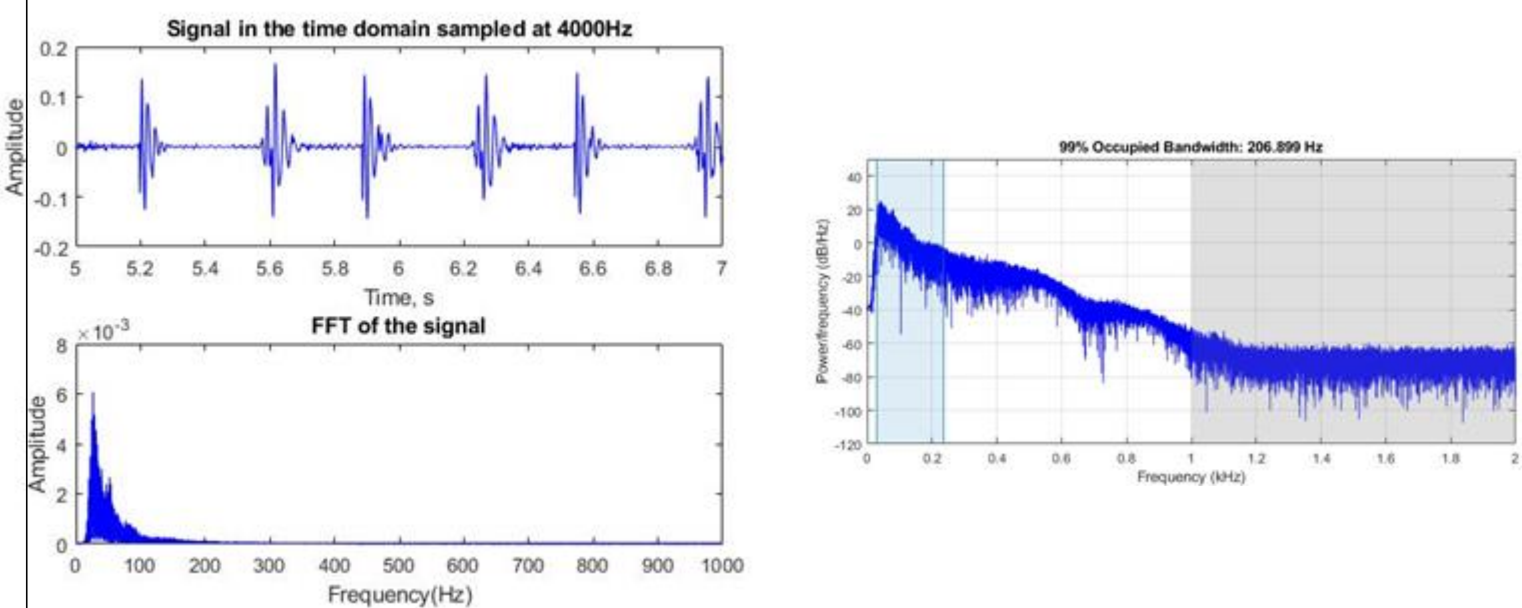
- Heart Sound Analysis

  In order to find the suitable cut-off frequency for the Butterworth low-pass filter, the usable frequency ranges of both normal and abnormal heart sounds must be considered. Therefore, frequency representations of two heart sound signals are analysed in this section. The signals used in this section are recorded from the EKO core stethoscope. The frequency domain representations are extracted using the Fast Fourier Transform and the power spectral density (PSD) is calculated with respect to the mean. Further, 99% power occupied band is highlighted in the periodogram. Similarly, in all the cases we considered, 99% power occupied bandwidth was in the range of 20 - 300 Hz.



(a) (b)

Figure 2: A normal heart sound, a - Temporal representation and the frequency spectrum, b - Periodogram



(a) (b)

Figure 3: An abnormal heart sound, a - Temporal representation and the frequency spectrum, b - Periodogram

As highlighted in Figure 2b, 99% power of the normal heart sound appears to be in the range of 40Hz to 221Hz. But in the abnormal case, 99% power occupied bandwidth is reduced compared to the normal case as shown in Figure 3b and the 99% power occupied band is 29 - 235 Hz. Similarly, in

- Electronic Circuit Design
  - Basic Sensor Stage

    We have investigated that, there are several sound capturing sensor elements for basic sensor purposes such as:
    1. Piezoelectric Crystals
    2. Capacitive sensors
    3. Electret Microphone

    Among these options, we analysed that Electret microphones are more feasible for us to implement since they are comparatively cheap and easy to implement on the purpose.

    Further, we intended to use a higher sensitive (high electrical response level at output when an acoustic signal input is given) and high SNR valued Electret microphone device (Preferably Electret Condenser Microphone – ECM) in order for better implementation process. In addition, we expect to use rubber pipe and a funnel for a better closed system.

    Concluded option: CUI Devices CMA-4544PF-W ECM (Gain ~ -44dB)

  - Pre-Amplifier

    This is the immediate following main stage after the basic sensor stage. We have investigated that the Gain which is required and the high pass cut-off frequency are the essential factors while designing the Pre-amplifier for the circuit.
    Hence, we have found about the following options:
    1. TL072 Dual Operational Amplifier
    2. LM358 Operational Amplifier
    3. LMP770X Operational Amplifier

    Previously, among the above options, a selection criteria has been developed based on requirements of gain, cut-off frequency, single-supply inverting, low-noise factor, buffering requirement etc. along with the other components such as resistor values and capacitor values.

    - Assumed Gain: ~18.5dB

$$Gain \sim \frac{Feedback\ Resistor\ Value\ to\ LM358}{Inverting\ Terminal\ Resistor\ Value\ to\ LM358}$$

Feedback Resistor Value ~ 1MOhm, Inverting Terminal Resistor Value ~ 15kOhm)

- Cut-off frequency (high-pass) with respect to microphone: ~10Hz

$$f_c = \frac{1}{2 * pi * RC}$$

Selected Capacitor value: ~1μF, Hence, Resistor Value: ~15kOhm

- Single-Supply Inverted
- Low-noise ECM

Concluded Option: LM358 Op-Amp

- Low-Pass Filter
As we expected to have high ambient noise signal to be added to the acoustic signals, we expected to have low-pass filters in order to get better signal response from the system. As we have analysed, the medical practitioners are only concerned with the acoustic signals from the body below 1.5khz, we expect to have a cut-off frequency of 1.5khz and a cut-off frequency about 300hz for better diagnosis purposes. We have evaluated several below options for us in regard this:
    1. TL072 low-noise, dual operational amplifier
    2. LM358 operational amplifier
    3. OP281GRU operational amplifier
    4. IC741 operational amplifier

Previously, we conducted the relevant simulations with respect to the requirements (gain, cut-off frequency sharpness, roll-off rate) in order to better select the required operational amplifier along with other analog components.

Originally, the reference range of frequency ~ (20 – 1500) Hz

Achievable range of reference ~ (0 – 1500) Hz (As per Physicians) (1st low-pass filter)

Achievable range of reference ~ (0 – 300) Hz (To acquire S1, S2, S3 and S4 of Heart Sound signals) (2nd low-pass filter)

- Low-pass Sallen-key
- Assumed Roll-off rate ~ 12dB/octave

Concluded Option: LM358 Op-Amp

- Power Amplifier
  As we expected to utilize an earphone to get the final stethoscope output, we have to enhance the output power such that it is possible to hear the acoustic signal. Hence, it is needed to use an electronic device which could drive sufficient power with mismatching the input and output impedance levels at this stage with the final output device. Therefore, we have investigated the following options:
  1. LM358 Operational Amplifier
  2. LM386 Operational Amplifier

  We decided the overall suitability of the above components in order for achieving the power contrast and the other necessities.

  In accordance with Maximum Power Transfer theorem,

  LM358 has an impedance mismatch with ECM (in which impedance lies between 300ohm and 500ohm).

  Hence, it is needed to choose an op-amp that could drive the microphone with low voltage.

  Concluded Option: LM386 Op-Amp

- Power supply
  - Single Supply inverted
  - Through a converter (not through a linear regulator – inefficiency) – A trade-off
  - But, Converters cause a voltage notch (low level of noise). We expect to eradicate this noise through filters if possible.

  Concluded Option: 7.4V to 5V Buck Converter DC (LM2596S)

- Voltage Reference
  - The need for a voltage reference circuit for a Single-Supply is considered for better results
  - Is expected to use along with the Buck Converter (which is for Voltage Regulation)
  - The crucial expectation is for the Precision which needs for single-supply

  Concluded Option: LMP7702MA Op-Amp (SOIC Package)

Schematic Design of Circuits

Schematic was designed for the tested circuits. **Altium Designer 17.0** professional software was used to design the schematic. Designed schematic for power circuit, battery level identifier, voltage reference circuit, pre amplifier, filter and power amplifier are displayed below.

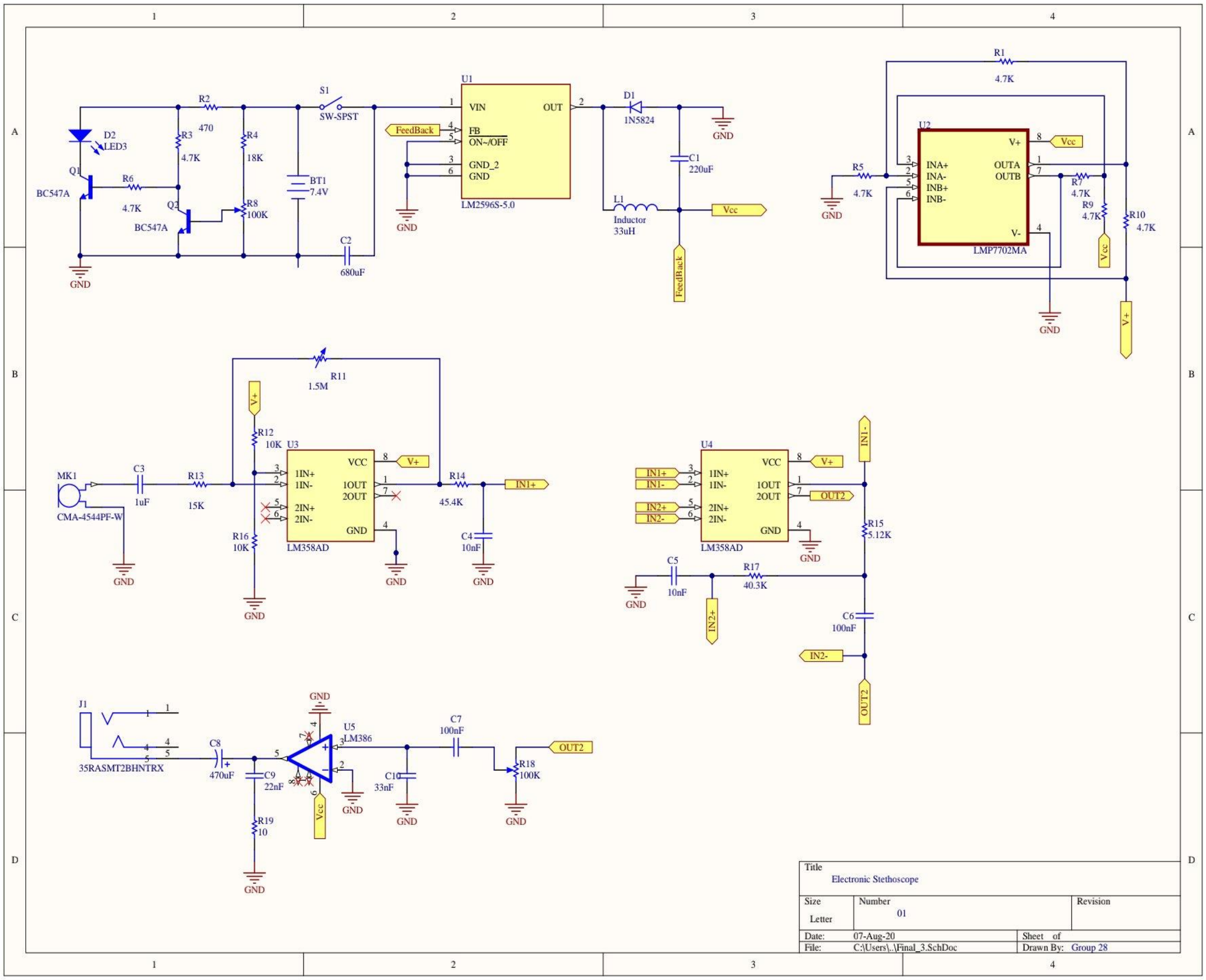


Figure 4: Schematic Diagram using Altium Designer 17.0

Simulation Results

The following simulations were executed using Multisim Education Edition (14.0.1) as separate circuits and afterwards, as a single complete circuit. All the simulated circuits refer to the schematic diagram which is presented above in Figure 4.

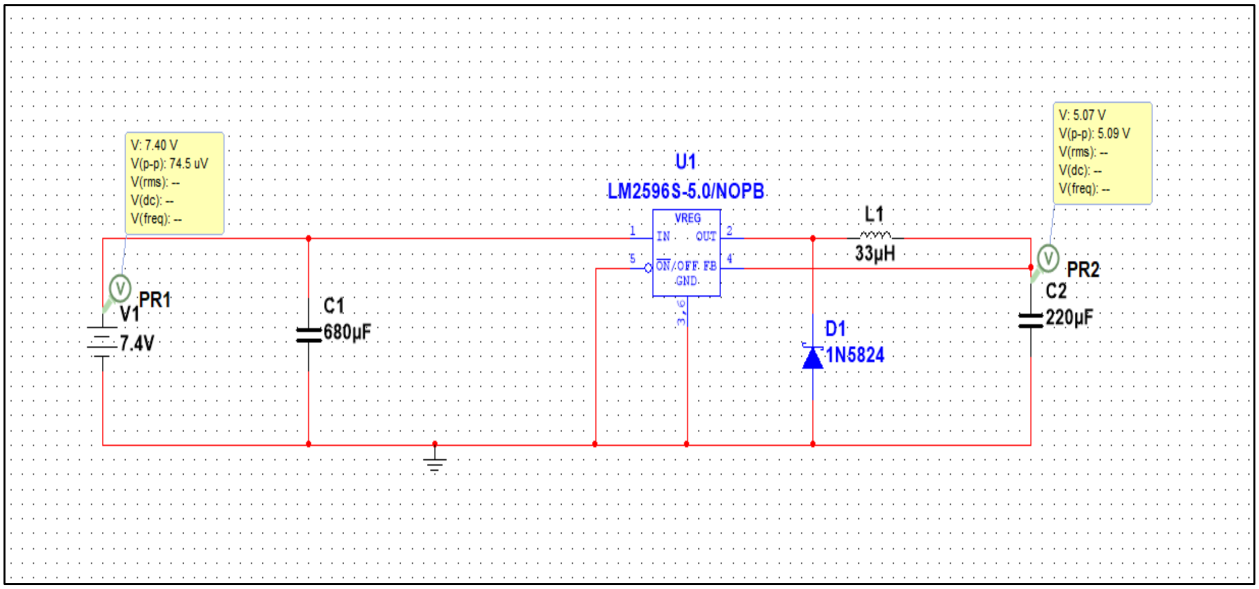


Figure 5: Power Circuit Simulation

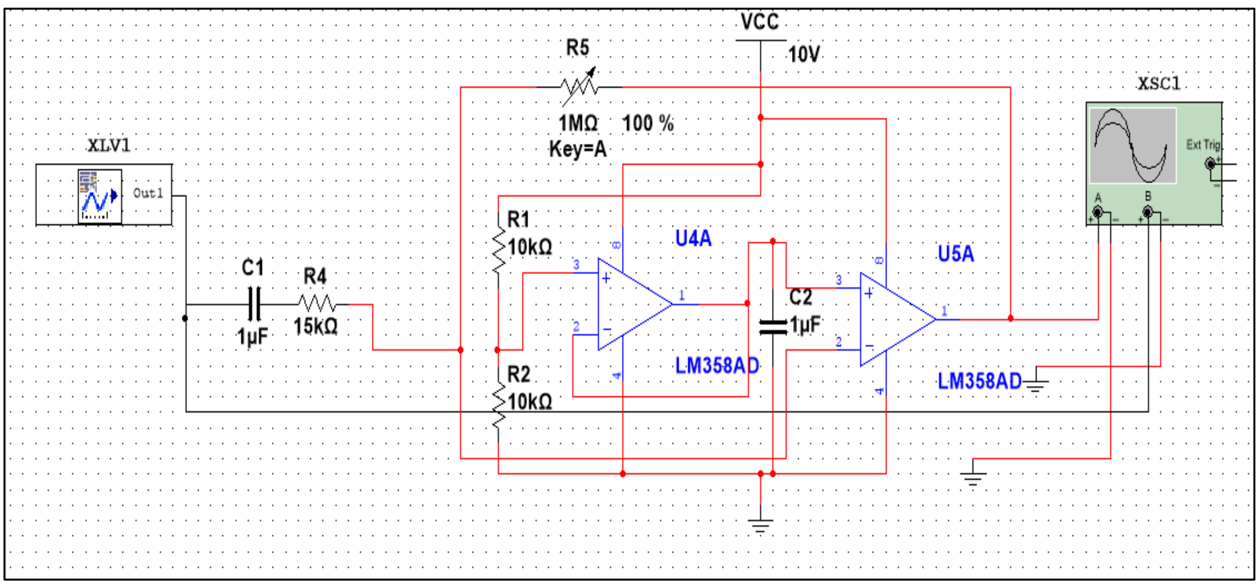


Figure 6: Pre-Amplifier Circuit

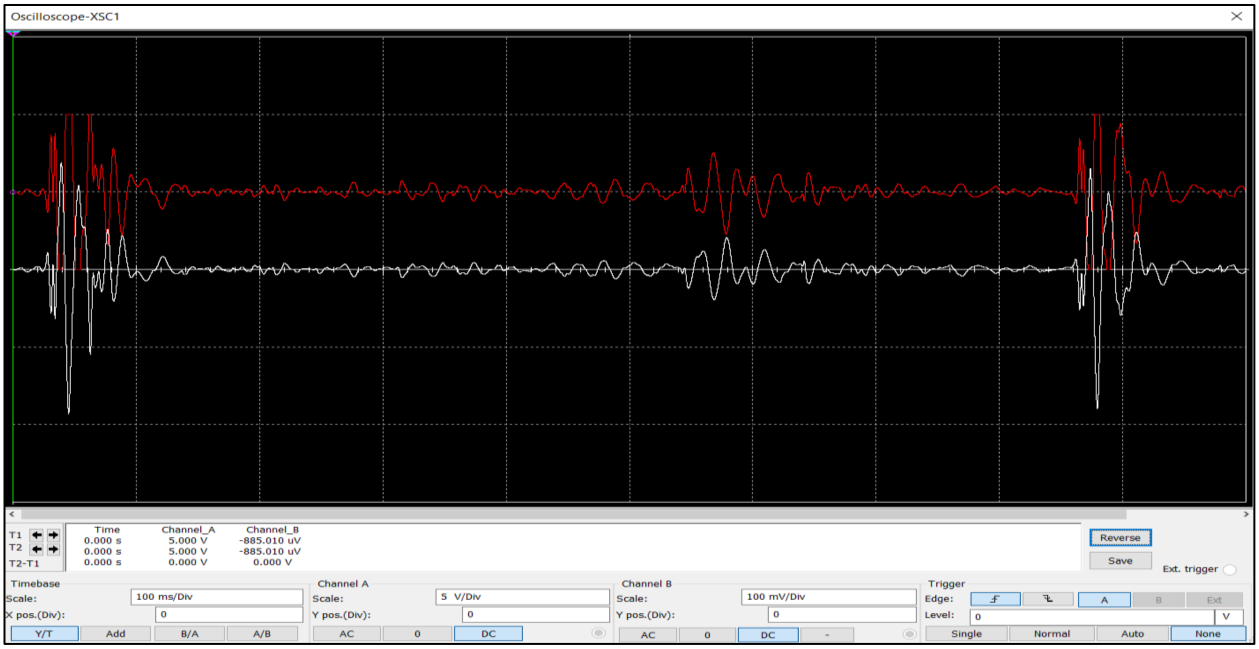


Figure 7: Output from the Pre-Amplifier (of a real heart sound signal)

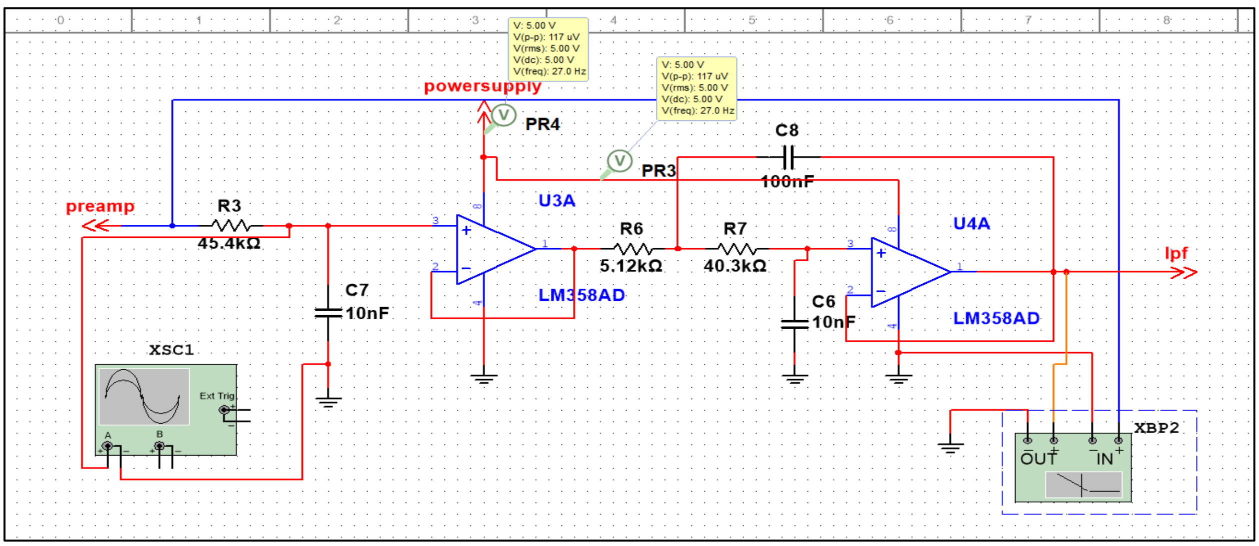


Figure 8: Low Pass Filter Circuit for 300Hz

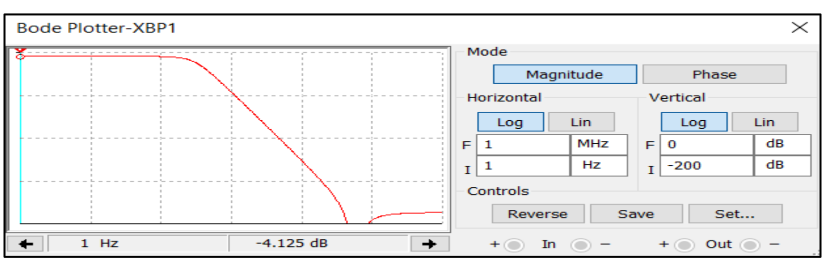


Figure 9: Low Pass Output (300Hz) in frequency domain

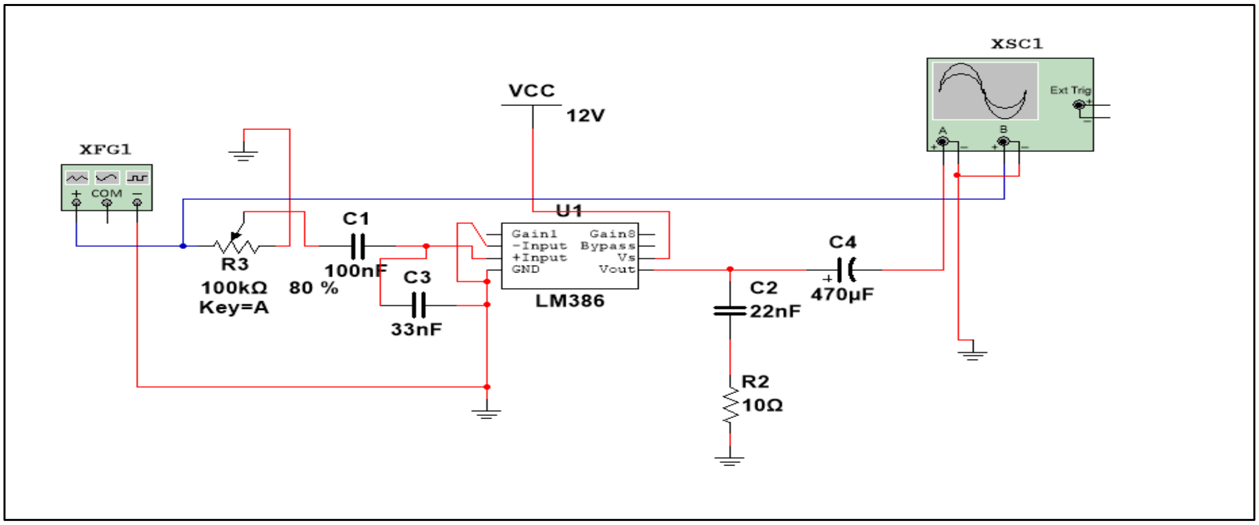


Figure 10: Power Amplifier Circuit

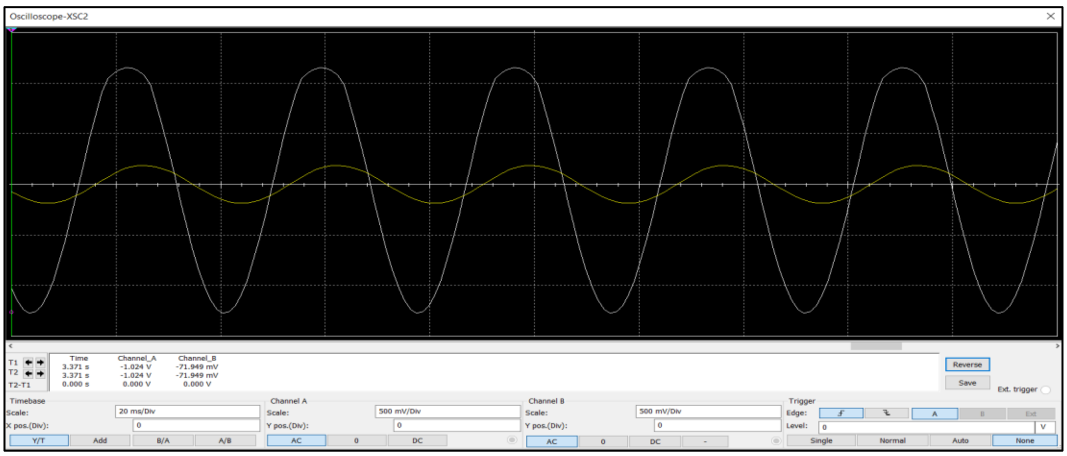


Figure 11: Power Amplifier Output for a sample sinusoidal signal

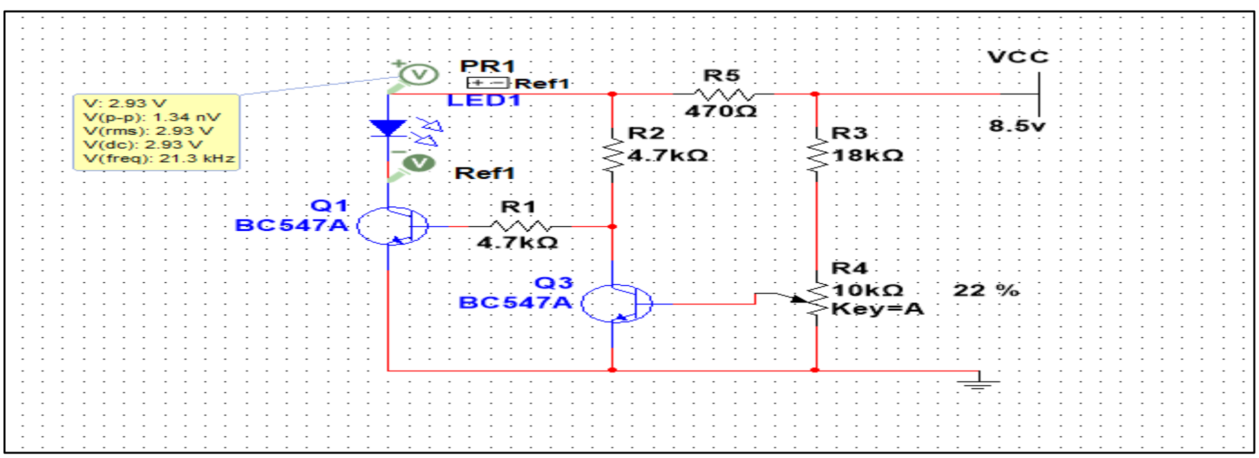


Figure 12: Battery Level Identifier Circuit

PCB Layout

Designed PCB is L letter shaped and it consists of three layers. Considering user comfortability, PCB board has been designed as small as possible. ECM, headphone jack and ON/OFF switch have been placed in suitable places. Altium Designer 17.0 software was used to design PCB layout.

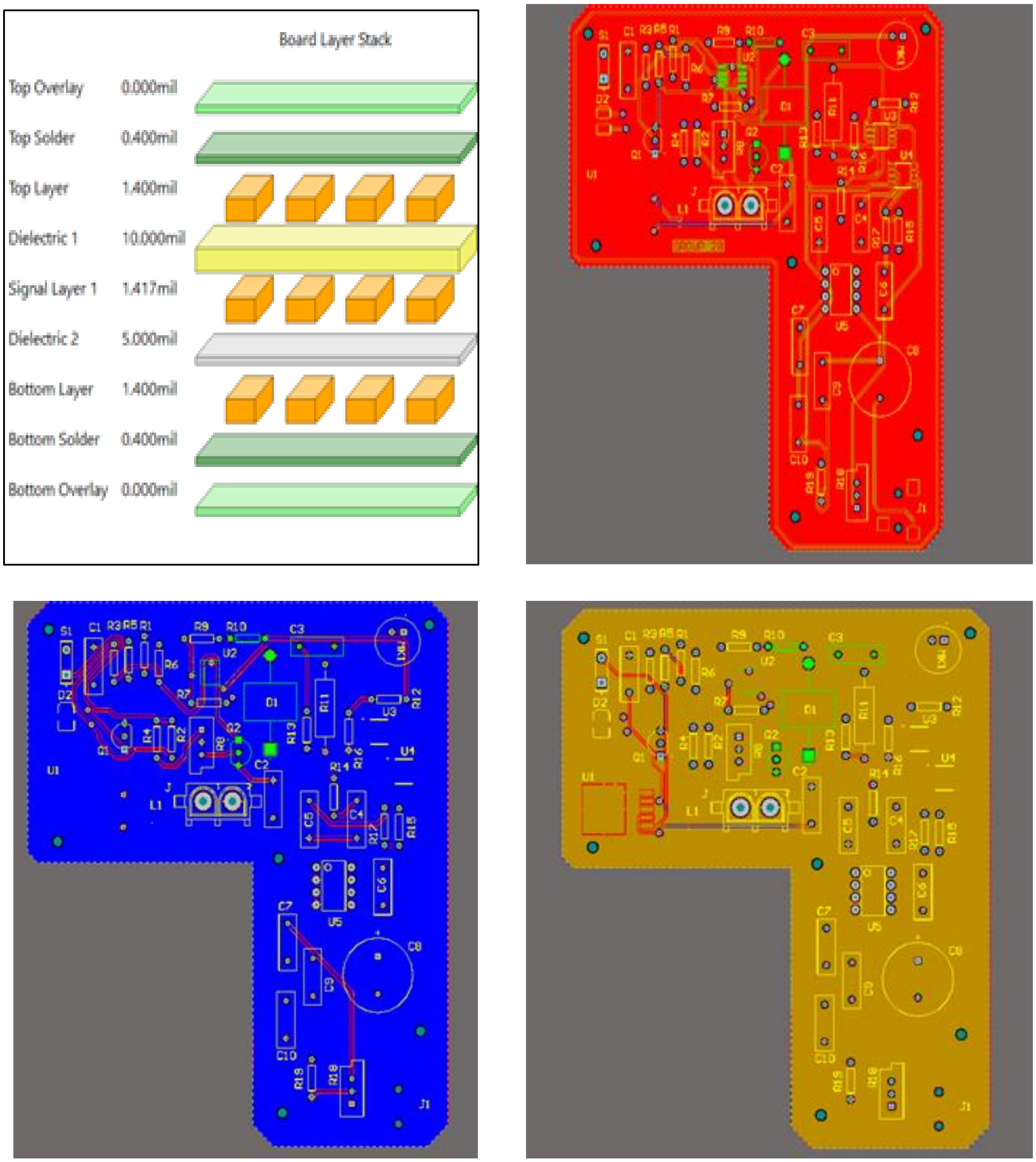


Figure 13: Layer Details (Left-Upper), Top Layer (Right-Upper), Bottom Layer (Left-Lower) and Signal Layer (Right-Lower)

Enclosure Design

An enclosure was designed to include the printed circuit board and the battery using SOLIDWORKS software. The 3-D model of the enclosure is shown in the figures below.

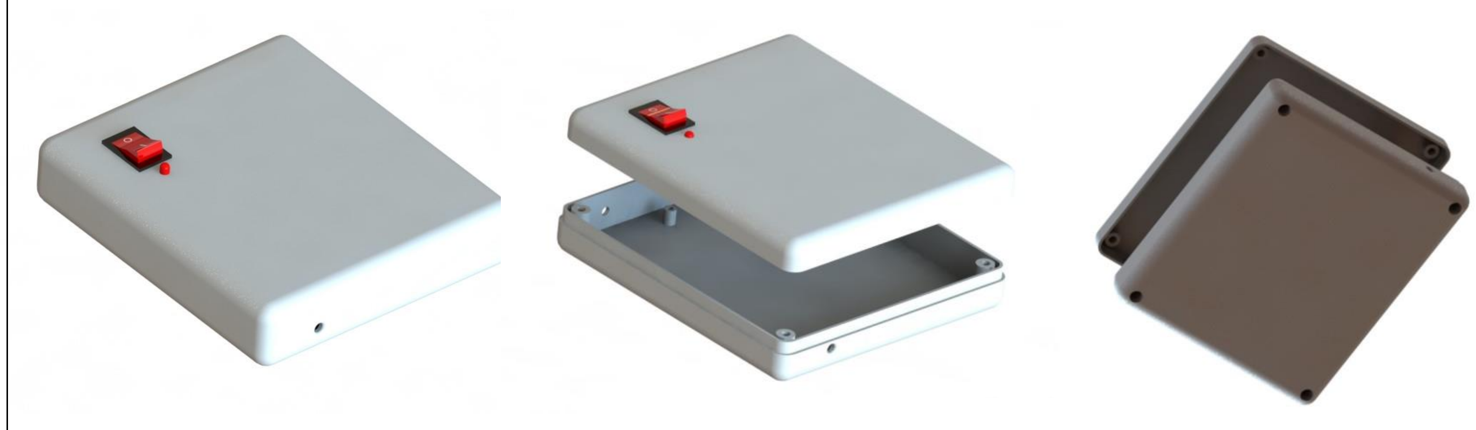


Figure 14: 3D model of the enclosure

Completion Road Map

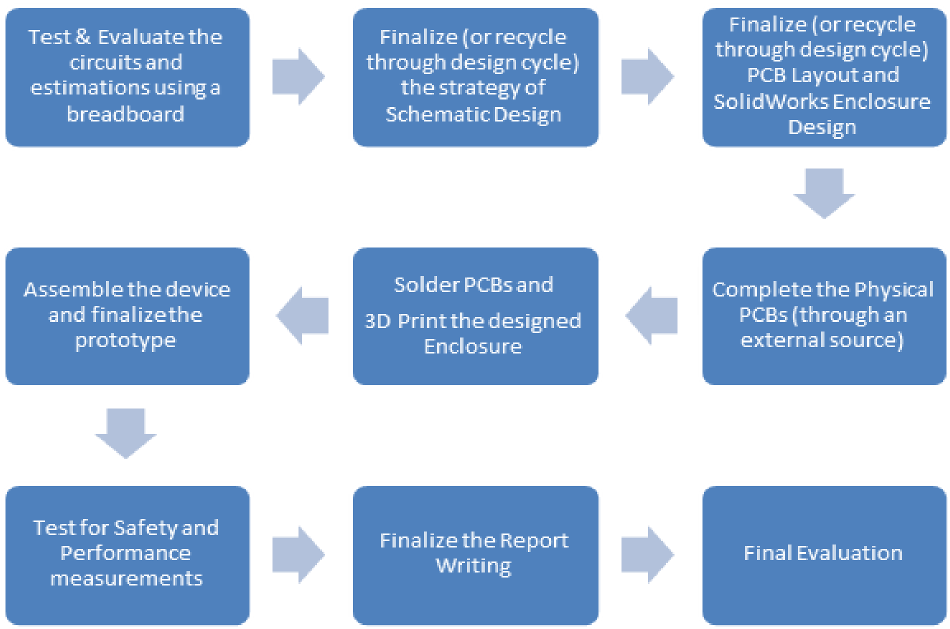


Figure 15: Flow Chart for Expected Completion Road Map

Conclusion

It could be concluded that the need for this kind of device is critical and justified through this project and the project has accomplished the major design milestones which cause to determine the overall success of the project. Further, it has been observed that all the required options for the initial concept of the project are achieved at the design phase with several additional and comparatively advanced (in ergonomics) features.

Further, it has been observed the stage of Breadboard testing will cohesively cause the Engineering design cycle to be stepped again (if necessary) and it is our dedication for getting better results from the best achievable design and/or strategy inside the given scope. Thus, it is vital to state that the Schematic design, PCB Layout and the dimensions of the Enclosure design are yet to be finalized after the Breadboard testing and Evaluation.

Furthermore, we hope to express our sincere gratitude for Ms. Theshani Nuradha, Mr. Kithmin Wickramasinghe, Mr. Hiran and Ms. Malsha Perera for their invaluable and continuous guidance for this project.