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Electronic Stethoscope

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1 Introduction

Auscultation, the practice of listening to sounds from the heart, lungs, and other organs has been a fundamental diagnostic technique for over two centuries. Traditional acoustic stethoscopes, while simple and reliable, rely entirely on the clinician's auditory perception, which limits their effectiveness in noisy clinical environments. External noise and the natural attenuation of higher-frequency components can obscure subtle but clinically important sounds such as mild heart murmurs.

Electronic stethoscopes overcome these limitations by converting acoustic signals into electrical signals that can be amplified, filtered, and digitally processed. This enables improved signal clarity, active noise suppression, and real-time visualization, while also supporting telemedicine through wireless transmission. This project presents the design and validation of a portable electronic stethoscope integrating a custom acoustic chestpiece, a high-gain analog signal conditioning stage, and a wireless digital processing unit based on the ESP32 microcontroller. The system is optimized to capture heart sounds within the clinically relevant frequency range of 20–200 Hz in a cost-effective and portable form.

2 System Overview

The system consists of four distinct subsystems: acoustic sensing, analog signal conditioning, digital processing, and power management. Figure 1 illustrates the architecture.

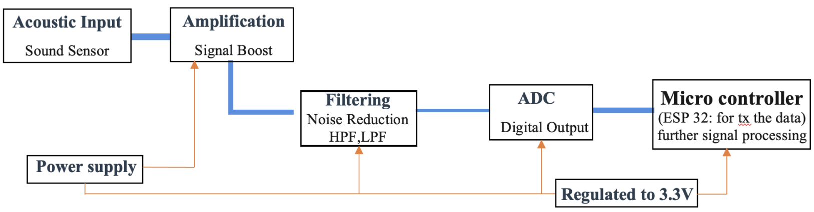


Figure 1: System Architecture Diagram

2.1 Acoustic Sensing

The first stage captures physical vibrations of the body wall caused by heart valves. A mechanical chestpiece couples these vibrations to an air cavity, which drives a high-sensitivity electret microphone.

2.2 Analog Signal Conditioning

The raw signal from the microphone is in the range of millivolts. The analog front-end amplifies this weak signal to a level suitable for the microcontroller's ADC (0–3.3V) and filters out frequencies outside the range of interest.

2.3 Digital Processing & Visualization

The conditioned analog signal is digitized by an ESP32 microcontroller. The ESP32 drives a local OLED display and transmits raw data packets over Wi-Fi using UDP. A custom MATLAB application acts as the receiver, performing digital filtering and rendering the waveform.

2.4 Power Management

The unit is powered by a single 3.7 V Li-Ion cell. An AMS1117 LDO ensures a stable 3.3 V rail, minimizing power supply noise critical for high-gain audio applications.

3 Design Choices and Justification

3.1 Acoustic Sensor Selection

We selected a high-sensitivity Electret Condenser Microphone (ECM) due to its flat frequency response, low cost, and ease of interfacing compared to piezoelectric sensors, which often have high impedance and fragility.

3.2 Amplifier Design Strategy

Heart sounds are low-frequency events, but the microphone signal is extremely weak (μV range). A multi-stage topology was adopted using the LM358 dual operational amplifier to achieve a total gain of 60–80 dB. The LM358 operates on a single 3.3V supply with rail-to-rail output swing.

3.3 Filtering Strategy

The clinical bandwidth for heart sounds is 20 Hz to 200 Hz. An active bandpass filter was implemented to provide a sharp roll-off without signal attenuation.

- **Lower Cutoff (20 Hz):** To reject DC drift and breathing movements.
- **Upper Cutoff (200 Hz):** To eliminate high-frequency hiss.

3.4 Digital Processing Unit

The ESP32 was selected for its dual-core architecture; one core handles ADC sampling while the other manages the Wi-Fi stack. UDP was chosen over TCP for lower latency, essential for real-time visualization.

3.5 Mechanical Chestpiece Design

The stethoscope chestpiece is modeled as a Helmholtz resonator, where the enclosed air volume acts as a compliant spring and the air in the port behaves as an oscillating mass. The resonance frequency is given by

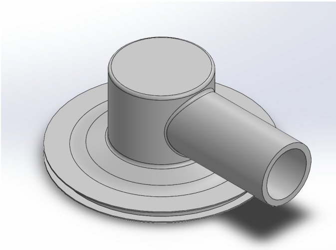
$$f = \frac{c}{2\pi}\sqrt{\frac{A}{VL_{\text{eff}}}} \tag{1}$$

where c is the speed of sound in air, A is the port cross-sectional area, V is the cavity volume, and L_{eff} is the effective neck length including end correction.

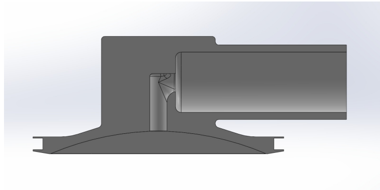
Using $c = 343$ m/s, a circular port of diameter 2.5 mm ($A = 4.91 \times 10^{-6}$ m^2), an effective neck length of $L_{\text{eff}} = 14.1$ mm, and a cavity volume of $V = 1.13 \times 10^{-5}$ m^3, the resulting Helmholtz resonance frequency is approximately

$$f \approx 215 \text{ Hz}. \tag{2}$$

Primary heart sounds (S1 and S2) mainly lie in the 20–150 Hz range, while practical stethoscope designs provide improved audibility within approximately 100–300 Hz. Accordingly, the chestpiece geometry was selected to enhance low-frequency heart sounds, with tuning biased toward the S1 component (50–60 Hz).



(a) External View



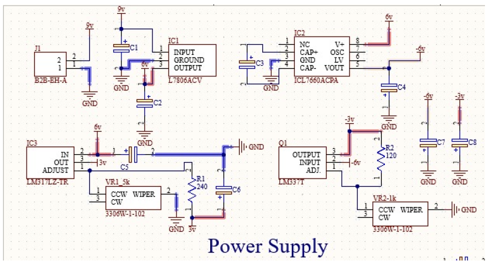
(b) Internal Cavity

Figure 2: Mechanical Design Renderings

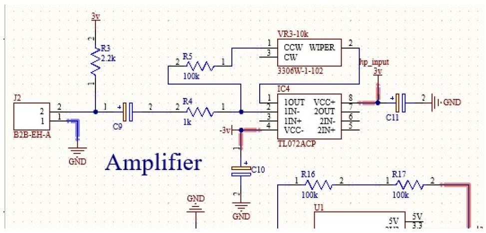
4 Hardware Implementation

The circuit consists of three main blocks:

1. **Pre-Amplifier:** Non-inverting stage, gain ≈ 100 V/V.
2. **Active Filters:** High-Pass and Low-Pass filters.
3. **Virtual Ground:** A 1.65V reference for single-supply AC swing.

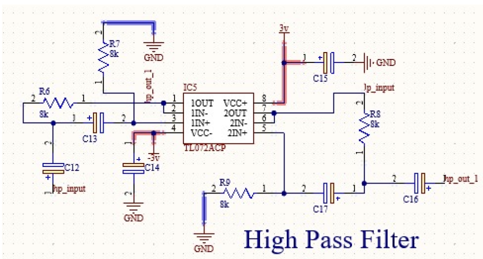


(a) Power supply image

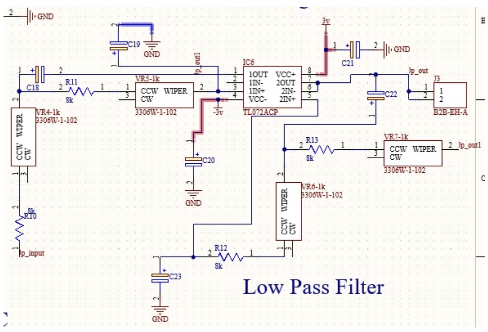


(b) Pre-Amplifier Stage Circuit

Figure 3: Active Filtering Stages



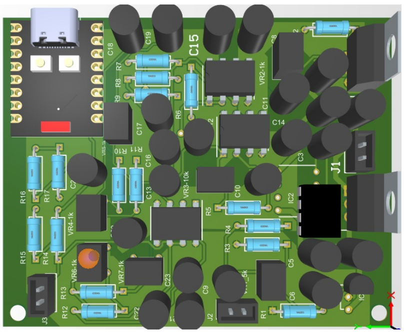
(a) High Pass Filter



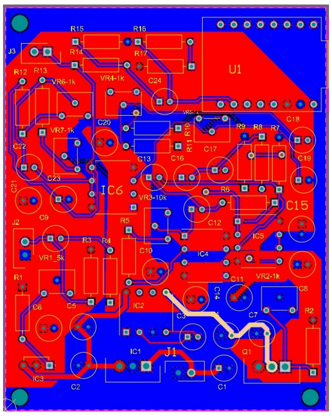
(b) Low Pass Filter

Figure 4: Active Filtering Stages

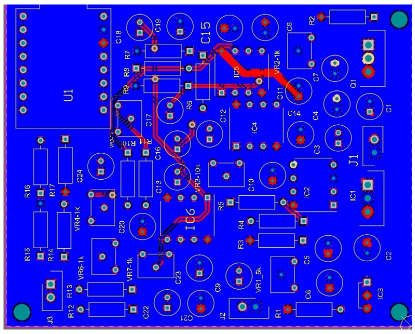
A TP4056 module manages the Li-ion battery. Decoupling capacitors (100nF, 10μF) filter power supply noise.



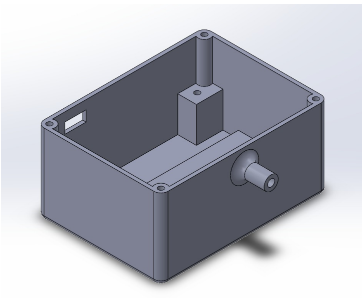
(a) Final PCB layout 3D



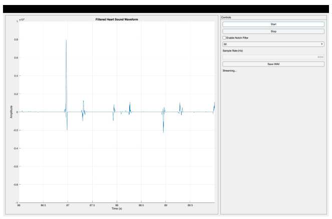
(b) PCB Top Layer



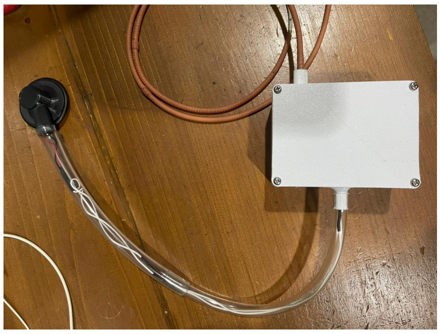
(c) PCB Bottom Layer



(d) Enclosure design



(e) MATLAB GUI



(f) Final product

5 Firmware & Software

5.1 ESP32 Firmware (C++)

The firmware ensures a stable sampling rate of 8000 Hz using precision timing.

```
#define SAMPLE_RATE 8000
#define PACKET_SAMPLES 256
uint16_t samples[PACKET_SAMPLES];
unsigned long microsPerSample = 1000000 / SAMPLE_RATE;

void loop() {
  for (int i=0; i<PACKET_SAMPLES; i++) {
    while (micros() - lastMicros < microsPerSample);
    lastMicros += microsPerSample;
    samples[i] = analogRead(MIC_PIN);
  }
  udp.beginPacket(remoteIP, remotePort);
  udp.write((uint8_t*)samples, sizeof(samples));
  udp.endPacket();
}
```

Listing 1: ESP32 Sampling Logic

5.2 MATLAB GUI

The application implements a digital notch filter centered at 50 Hz. The raw UDP data stream is processed through this filter in real-time before being stored in a circular buffer for smooth visualization. Finally, the signal is dynamically scaled based on the user-defined gain to ensure the waveform remains visible despite amplitude variations.

6 Validation and Measurements

6.1 Frequency Response Gain

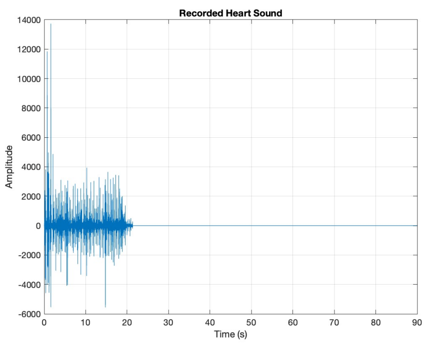
Frequency sweep tests confirmed effective bandwidth of 20 Hz – 200 Hz. The measured system gain was $\approx$ 70 dB. Current consumption was 120 mA, yielding 8 hours battery life.

Table 1: Validation Summary

Parameter	**Measured**	**Target**
Frequency	20 Hz–200 Hz	20 Hz–200 Hz
Sys. Gain	$\sim$70 dB	60–80 dB
Current Draw	120 mA	<150 mA

6.2 Clinical Signal Acquisition

The device successfully captured S1 and S2 heart sounds with distinct separation (Figure **??**). In here that window size is fixed to 90s so that may not be easily visualize the image that saved as png. So that I place the image that capture during the apturing time.



(a) Recorded Heart Sound 1 (S1/S2 peaks)

(b) Recorded Heart Sound 2

Figure 6: Comparison of Recorded Heart Sound Measurements.

7 Conclusion

This project demonstrated a low-cost, portable electronic stethoscope. Experimental validation confirmed reliable operation within the 20–200 Hz bandwidth. The modular design with Wi-Fi connectivity enables real-time visual diagnostics and potential for remote monitoring.