Electronic Stethoscope

Mini Project

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ABSTRACT

Stethoscope is one of the most significant diagnostic tools in a doctor's repertoire. They are used to listen to acoustic signals from the internal organs of the human body. The basic principle behind the working of a stethoscope is reflection of sound. Reflection of sound causes reverberation which leads to an increase in the amplitude of sound. The classical acoustic stethoscopes have some flaws and electronic stethoscopes are a great alternative to them. This work reports on the simulation of an electronic stethoscope done using simulink. Heart sound input data is taken by the microphone sensor. The chest piece comprises the microphone pre amplifier circuit. The amplified data is passed through to the head piece which consists of the ADC unit. The signal thus received is passed through to the speakers. Results obtained are consistent with the expected behaviour of an electronic stethoscope.

INTRODUCTION

The stethoscope is one of the most significant diagnostic instruments in medicine. It is an acoustic medical device for listening to internal sounds in the human body. Heart sound auscultation is one of the most basic ways to assess the state of the cardiac function[1]. The stethoscope was invented in France in 1816 by René Laennec at the Necker-Enfants Malades Hospital in Paris[2]. The original stethoscope was only a wooden tube but this form has evolved through a series of significant changes, such as the addition of earpieces and the development of the combined bell and diaphragm chest piece[3]. Stethoscopes are now also referred to as "Littmann Stethoscopes" after Dr. David Littmann in 1961 developed a new, lighter type of stethoscope with a single binaural tube that vastly improved acoustic technology.

A stethoscope consists of a flexible tube connecting the metal earpieces to the chest piece. The chest piece is made up of a shallow bell-shaped portion and a clear, firm diaphragm. Lower frequency sounds are picked up by the bell, whereas higher frequency sounds are picked up by the diaphragm. Vibrations within the body are increased by the bell or diaphragm when the chest piece is put on the skin. These acoustic pressure waves then flow up the tube, resonating in the earpieces and into the ears of the listener[4].

The classical acoustic model however has some flaws. One problem with acoustic stethoscopes is that the sound level is extremely low and there are some shortcomings in the heart sound analysis[5]. The listener cannot amplify the sounds using a normal acoustic stethoscope. This can be a concern if the only sounds he or she hears through the stethoscope are very quiet. Stethoscope earpieces can also be rather painful. Despite the fact that these are minor issues, modern technology has introduced alternatives to the acoustic stethoscope in the form of electronic stethoscopes.

There are several commercially available electronic stethoscopes in the market. One of them is the Littmann Electronic Stethoscope Model 3000 manufactured by 3M[6]. Amplification is up to 18 times greater than the best non-electronic stethoscopes.
In this report, we provide the details of simulation of an electronic stethoscope done using Simulink.

DESIGN CONSIDERATIONS

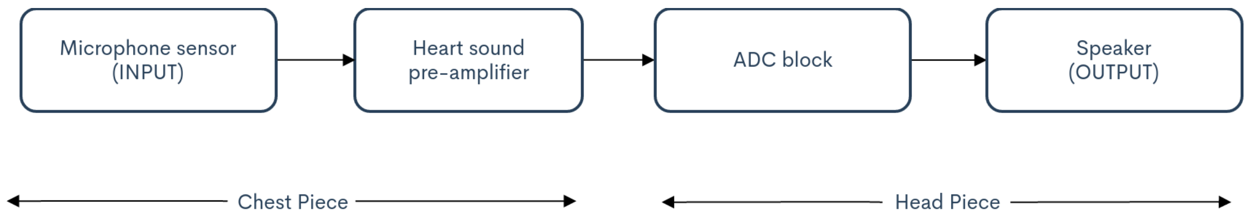
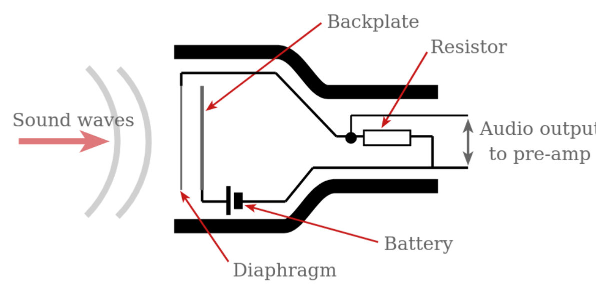


Fig 1 : Block diagram of proposed model

Microphone selection

Three different types of microphones were researched and compared in order to find the best microphone to employ in our final design. A condenser microphone, a fibre optic microphone, and a MicroElectrical-Mechanical System (MEMS) microphone were the three types of microphones examined for usage.

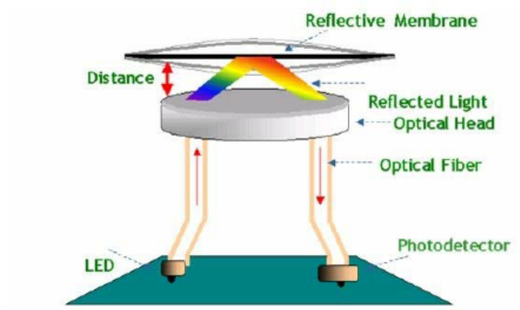
Fig 2 : Condenser microphone[10]



A condenser microphone, for example, functions by converting acoustic energy into electrical energy via a capacitor (Figure 2). The diaphragm, or front plate, is a lightweight material that vibrates when sound waves strike it. The distance between the diaphragm and the rear plate changes as a result, resulting in a change in capacitance as calculated by the formula $C = \frac{\varepsilon A}{d}$. A voltage must be applied across the two capacitor plates in order for the capacitance to vary. This voltage is provided by an external power source, most commonly a tiny battery housed within the microphone. When compared to self-powered microphones like the dynamic microphone, the condenser microphone has a larger output due to the external power supply. Condenser microphones are used in laboratories and sound recording studios because of their sensitivity to sound and outstanding frequency response[7].

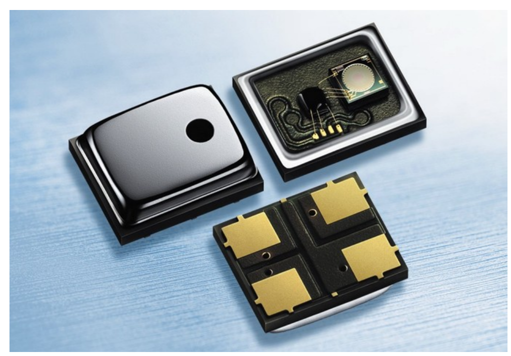
A fibre optic microphone was the second microphone choice (Figure 3). Unlike typical microphones, fibre optic microphones detect changes in light intensity rather than capacitance or magnetic fields. Light from a laser source flows through an optical fibre to the tip of the microphone, where it lights the surface of a reflecting diaphragm. The light intensity reflected off the diaphragm changes when the diaphragm vibrates owing to sound waves. A photo detector detects the change in light intensity transmitted by a second optical cable. For transmission, the photo detector converts the light intensity into an analogue or digital audio signal. Fiber optic microphones are perfect for usage inside industrial turbines or in MRI suites, where typical microphones are ineffectual, because they do not react to electrical or magnetic fields (EMI/RFI immunity) and have a wide frequency response range[8].

Fig 3 : Fibre optic microphone[11]



A MEMS microphone was the final microphone considered (Figure 4). MEMS stands for MicroElectrical-Mechanical System, and it refers to extremely small mechanical devices that are powered by electricity. The mechanics of the microphone are similar to that of a condenser microphone, with the exception that the MEMS microphone is installed on a circuit board of around $15mm^2$ in size. An impedance converter and an output amplifier make up the microphone element, which transmits a digital audio output signal captured from the microphone head[9].

Fig 4 : MEMS microphone[12]



Amplifiers

During our research on various pre-amplifiers available for microphone input, we found two suitable amplifiers that gave us desired output to some extent. One, however, had some noisy superimposed signal and so we selected the other one, providing us a decent amplification with a certain offset voltage.

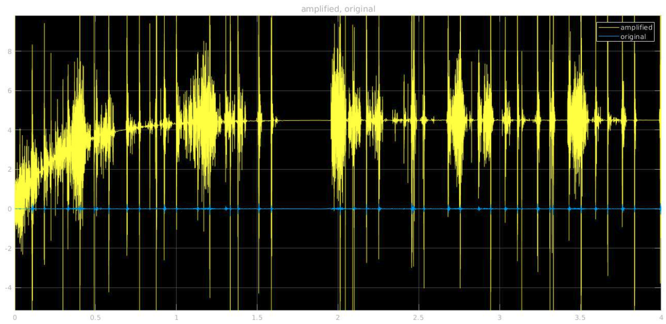


Fig 5 : Rejected pre-amplifier due to unwanted and noisy superimposed signal

The gain of our chosen pre-amplifier circuit is designed to be **22.** It is simply the ratio of the resistances and the increase.

This pre-amplifier circuit also has the added benefit of reducing any DC components and offsets that may emerge, as DC offsets in the noise cancelling signal may cause issues that will compound as the signals pass through the circuit, resulting in a malfunctioning system.

DESIGN EVALUATION

Microphone

To choose the best microphone , we evaluated condenser, fiber optic, and MEMS microphones on a weighted scale which ranges from zero to ten over a variety of design criteria (Table 1).The most important design criteria, such as size and sensitivity/frequency response, were given the most weight.These two features were chosen to be the most essential design features since they are necessary for the microphones to fit on the back of a stethoscope head and provide high-quality sound to the user.

Table 1 : The design matrix for the three microphone options

Weight	Design Aspects	MEMS	Fiber Optics	Condenser
0.3	Size	**10**	9	7
0.3	Sensitivity/Frequency Response	**9**	10	10
0.15	Cost	**8**	3	7
0.1	Power	**9**	7	6
0.1	Feasibility	**8**	5	7

0.05	Interference from Medical Devices	**7**	10	7
	Total	**8.95**	7.85	7.8

Since our priority was to use a microphone which should be small and easy to carry, so, the size of the microphone was very important and therefore given a weight of 0.3. The microphone should be small enough to clip onto the back of an existing stethoscope without being too bulky or uncomfortable for the patient.The microphone's sensitivity and frequency response were equally important, also receiving a weight of 0.3.The microphone's frequency response must allow the user to hear as much as possible of the heart and lung sounds; the microphone must be able to detect noises as low as 100 Hz.With the exception of condenser microphone size, all three microphone options performed well in these two categories.While condenser microphones might fit on the back of a stethoscope head, they were not as compact as MEMS microphones. The fibre optic and condenser microphones could detect sounds as low as 20 Hz, while the condenser and fibre optic microphones could detect noises as low as 100 Hz.

The next important aspect was cost in which MEMS and condenser microphones are both reasonably priced, however fibre optic microphones can cost upwards of $400.00, giving in a poor cost score.
The next two factors, power and design feasibility, each received a 0.1 weighting.The microphones must be able to be driven by a minimal power source, such as a lithium coin battery, and the microphone circuitry must be simple enough for us to develop a prototype. MEMS received a high ranking in this category since it uses the least amount of power of the three, 1.5 Volts. Many companies offer MEMS microphones on prebuilt "evaluation boards," ready to be inserted straight into a prototype, and MEMS also obtained the highest grade in feasibility.

Finally, interference from medical devices was ranked as the sixth most important design feature. It was the least important of the six, with a weight of 0.05. Due to its EMI/RFI immunity, the fibre optic microphone received the highest score in this category, whereas the other two types received lower scores due to their components being susceptible to magnetic interference.
As seen in **Table 1**, MEMS microphones obtained the highest overall score of 8.95, followed by fibre optic microphones at 7.85 and condenser microphones at 7.8. As a result, the MEMS microphone was chosen as the final design's microphone. A small condenser microphone will be used instead if the MEMS microphone proves unsatisfactory .[13]

Speaker

The choice of a speaker for the final design was critical, because even if the rest of the design worked flawlessly, there would be no working product if the speaker lacked the required frequency range. For the final design, the team chose the Pyle Home PCB4BK 4- Inch 200-Watt Mini Cube Bookshelf Speaker. The frequency response curve of this speaker was 20 Hz to 18 kHz, which covered the frequency range required by the design. The speaker itself had an eight ohm impedance, and the box was quite modest, measuring 4.8 inches in height, 4.8 inches in width, and 5.2 inches in depth. This speaker was attached to the circuit at the output and reproduced the circuit's heart and lung noises.[13]

RESULTS

A circuit of signal acquisition and conditioning for the electronic stethoscope is designed. With the help of Simulink this circuit has been simulated. Audio file is given as input to the circuit and ideally to be checked for output with the help of an oscilloscope. Complete circuit is simulated for heart sound.

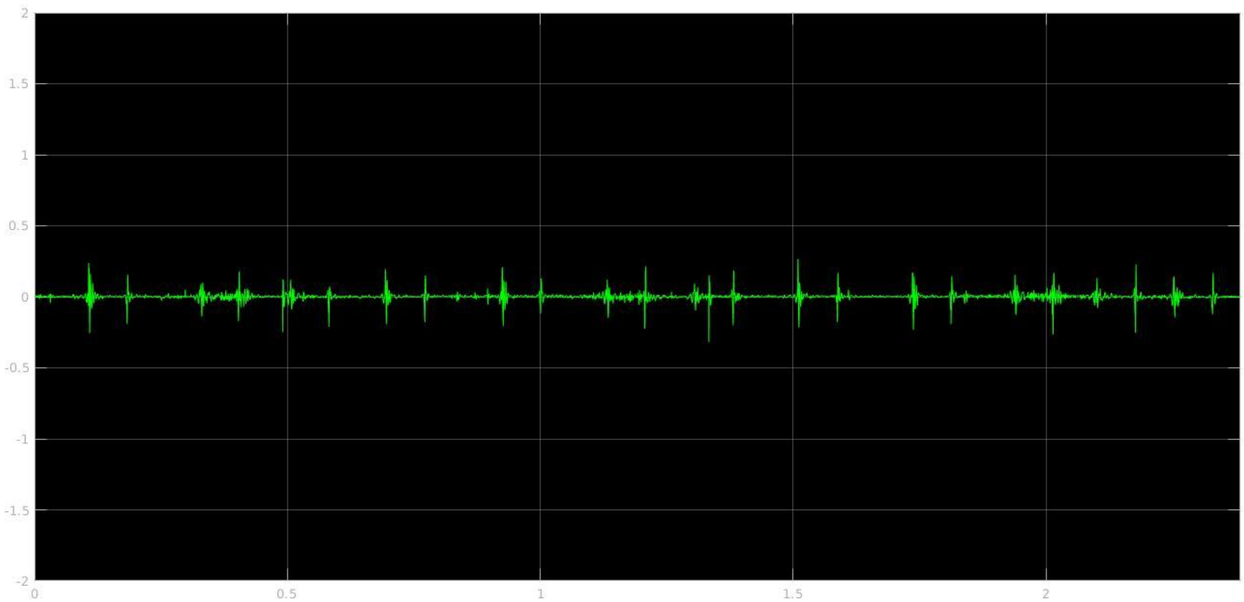


Fig 6 : Heart sound as input

Heart sound with frequency of **55.9 Hz** and amplitude of $2.396 * 10^{-2} V$ is given as input. The audio file is an excerpt from the Kaggle heartbeat dataset, which was recorded by ECG.

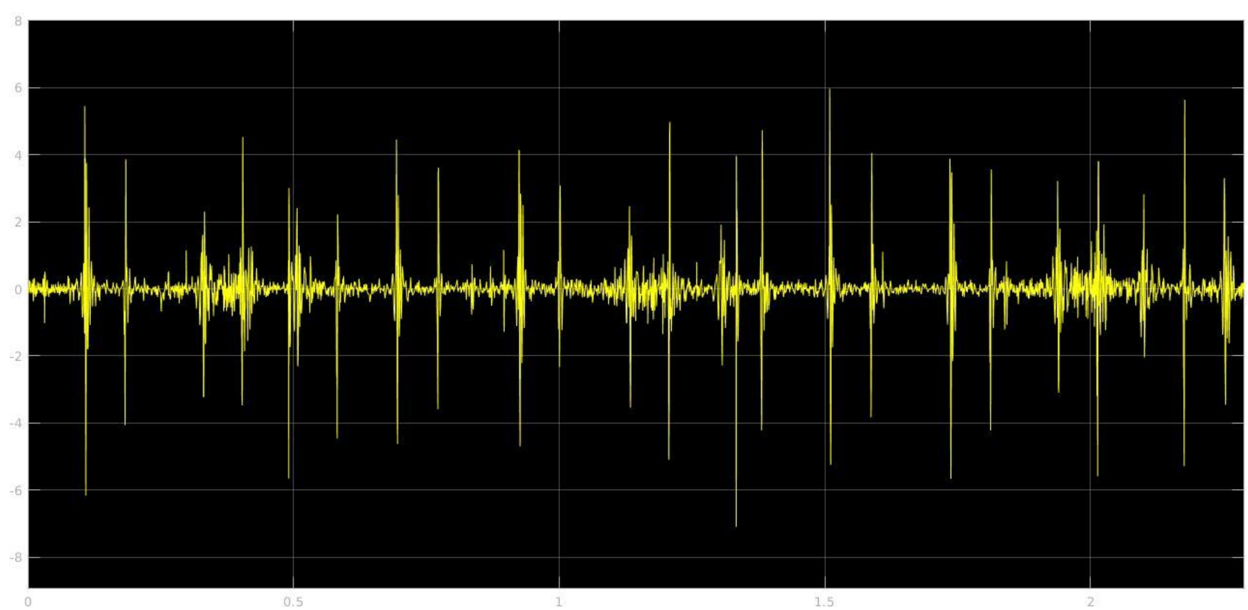


Fig 7 : Output obtained at preamplifier stage

After passing the audio input signal at preamplifier stage , we obtained the amplified audio signal with frequency of **48.673 Hz** and amplified amplitude of $6.784 * 10^{-1}V$ which can be seen in Fig 7.

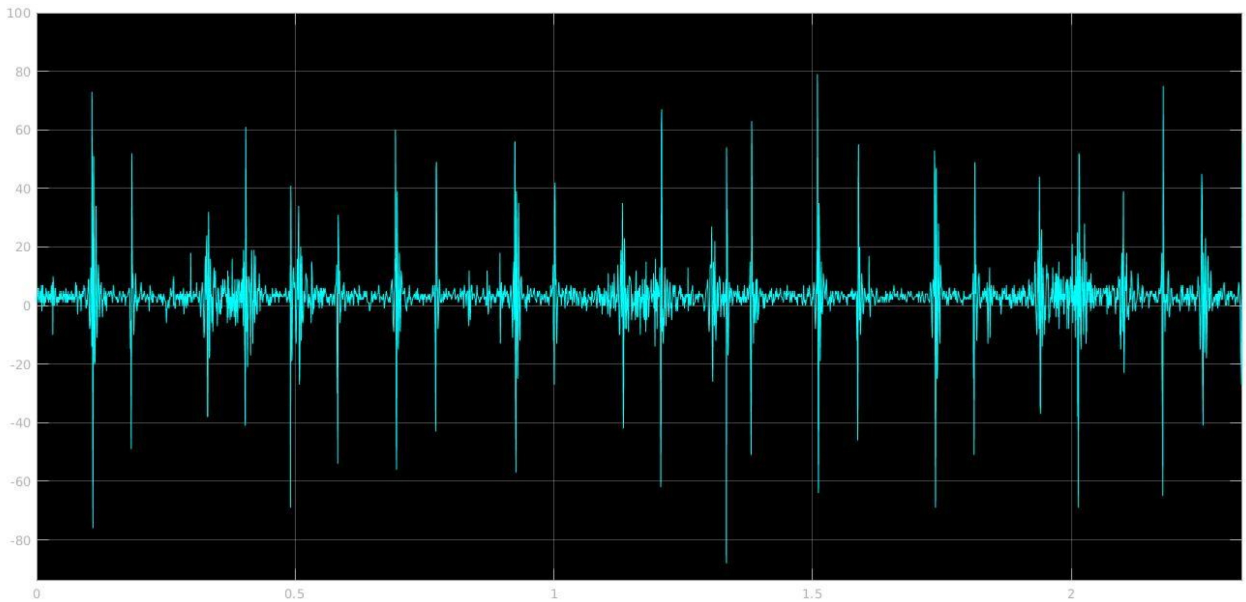


Fig 8 : Output at ADC stage

When the signal obtained at the preamplifier stage is passed through ADC we get the amplified audio signal with frequency of **58.408 Hz** and amplitude of **8.7 V** which is **363 times greater** than the amplitude of the original audio input signal. See below figure for comparison.

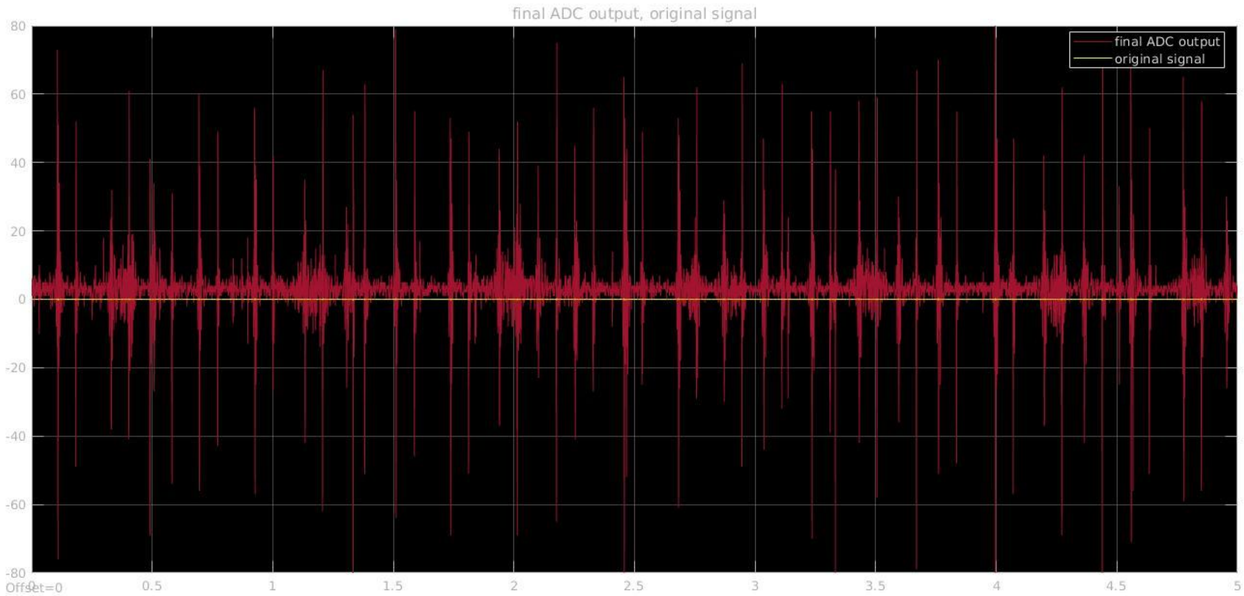


Fig 9 : Comparison between original and final heartbeat signal

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APPENDIX - Complete Circuit Diagram