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A Cost-Effective Indigenous Wireless Electronic Stethoscope using RF

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Abstract: Stethoscope is one of the important tools for clinical diagnosis such as diagnosis of respiratory and cardiovascular diseases. In this paper we propose the working principle and design of a low cost wireless electronic stethoscope based on Radio Frequency as the wireless medium for transmitting information. To capture the heart sound using the proposed method a condenser microphone is embedded in diaphragm's head suggesting that it converts the acoustic energy into electrical which can also be visualized as varying sinusoids having different time interval. These varying sinusoids representing the heart sound signal is processed through a preamplifier for achieving high gain followed by a filter to remove unwanted variations for desired results, which is transmitted to the receiver by means of a radio frequency module. More than one doctor can do auscultation at a given time by analyzing the heart sounds; hence it has potential to provide a basis for the effective use of Telemedicine in medical diagnosis. This paper has also made the provision of sound data storage available for further analysis simulating the designed prototype with Think Lab.

Keywords: Electronic stethoscope, RF, Heart sound, Telemedicine, Auscultation

1 INTRODUCTION

Auscultation refers to the listening of heart sound in human body and the tool used for such purpose is known as a stethoscope. Cardiac auscultation using stethoscope is considered to be one of the earliest diagnosing procedures for the confirmation of pathologies of heart structure and assessing the current cardiac state. A shoal, bell shaped piece and a stiff diaphragm makes the chest piece of a stethoscope which is connected to the flexible tubes followed with the connection to metal earpieces. Bell and diaphragm are responsible for acquiring lower frequency and higher frequency sounds respectively. Placing the chest piece on skin results in amplified vibrations in the body, these vibrations or acoustic pressure wave travels through the tubes and then transmitting the heart sounds that can be heard from earpieces (Patil, *et al.* 2012). Substantial clinical experience, good listening skills and a fine stethoscope is required for efficient diagnosis of cardiovascular diseases. It is commonly noticed by many cardiologists heart beats are unnatural during physical exercise (Wang, *et al.* 2009) and probably can have a sudden death after returning to the normal heart rate (Wang, *et al.* 2009) heart and blood vessel diseases are also classified as cardiovascular diseases and reported as the most common diseases all over the world (Patil, *et al.* 2012) In this era of growing technological trends and availability of wireless technology at a low cost, with design of such tool for analyzing the heart sounds and diagnosing cardiovascular diseases we can take a leap forward in modernizing our medical facilities and telemedicine systems in Pakistan. This paper proposes the design of low cost affordable wireless stethoscope based on RF technology to process the heart beat signal, which can transmit and stores the signal for further analysis. Previously implemented wireless electronic stethoscopes are based on Zigbee and Bluetooth technology which makes them a better choice for implementation of wireless stethoscope but keeping in mind the cost incurred for developing such systems we have to think for the alternatives to make the system affordable with a trade-off in terms of quality and cost, however zigbee and Bluetooth provides better sound quality but this problem is almost eliminated in RF based wireless stethoscope by using pre-amplifier, filter and power amplifier with variable gains to achieve the noise free results as proposed by zigbee and Bluetooth.

There are two major problems with the conventional stethoscope i.e. Low level sound and short time-period analysis and some limitations are associated with current models of stethoscope available which includes lack of amplification of heart sound, variability of gain, storage of the analog data for further analysis etc. (Wang, *et al.* 2009) The proposed method empowers the user for varying the amplification as per there desired audible needs. Traditional stethoscopes use mechanical means for auscultation resulting in poor sound quality and low accuracy as the signal can get affected by the listening capability of the doctor as well as by the unfavorable environment. This paper provides a review of related work in section II followed by the different types of heart sounds in section III. Section IV explains the design of the proposed system including the circuit

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design with the results provided in Section V and finally the paper is concluded in Section VI.

2 RELATED WORK

Rene Laennec, a French physician invented the first ever stethoscope in 1816. First of their kinds were comprised of wooden tubes having trumpet-like ends, since then this particular tool saw many improvements in itself such as binaural constructions, flexible tubes and interactive designs but the basic functionality and use of mechanical means for listening the heart sound remained unchanged for almost one and a half century. Chien *et al.* in 2004 proposed an idea for wirelessly transmitting the heart sounds by using Bluetooth as a transmitting medium at both ends to display and store in a PDA as a phonocardiograph data. Jatupaiboon *et al.* in 2010 proposed a prototype for storing the heart beat sound filtering it by means of low pass filters, the purpose of this paper was focused on reducing the noise from the said data (Tang *et al.* in 2010), proposed a wireless electronic stethoscope by using Bluetooth in integration with embedded processors for displaying the data on LCD and storing the data for computer-aided diagnosis. (Harsola *et al.* 2011) proposed a design of Peripheral Interface Controller based electronic stethoscope for visualizing and storing of sound data suggesting that the stethoscope should be physically connected and data will be sent through Lab View. (Gururajan *et al.* 2011) conducted a study based on different designs of wireless electronic stethoscopes and their feasibility based on user's perspective to identify issues when using these stethoscopes in telemedicine and e-health platforms. (Patil, *et al.* 2012)proposed the design of contact vibration sensor to minimize the ambient noise in acquiring the heart sound signal, for wireless transmission the authors used Bluetooth for e-healthcare implementation. (Im, *et al.* 2012) suggested the use of Zigbee in wireless electronic stethoscope as a wireless medium for transmitting the sound data with the integration of an embedded processor (Patil, *et al.* 2012)The alarming problem regarding all the previous work is the cost of a particular wireless electronic stethoscope using Zigbee or Bluetooth. Design methodology proposed in this paper consists of front end pickup circuitry followed by the low-pass filter and the design of pre-amplifier and amplifier for delivering an comparatively better audible sound compared to the existing methods. The proposed method due to the use of radio frequency module will also have considerable low cost then the existing proposed methods.

3 BODY SOUND

Heart sounds are referred to as acoustic waves generated by the resultant flow of blood and heartbeat. These vibrations are generated by opening and closing of systole/diastole valves. Referring to **(Fig.1)** we can classify heart sound in two types of waves i.e. S1 wave (Systole) and S2 wave (Diastole).

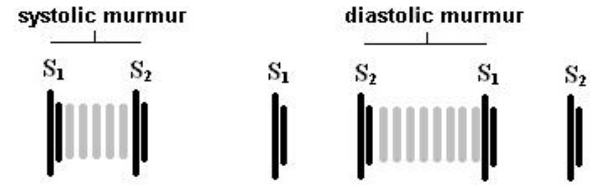


Fig. 1. Normal Heart Sound

Sometimes the valve doesn't work normally, either the valve doesn't opens properly which causes less blood flow or the valve doesn't close tightly causing blood leak backwards, these abnormalities are referred to as murmurs. Murmurs can be systolic or diastolic as shown in **(Fig. 2)**. Murmurs and heartbeats have band limit frequencies between 100-1000 Hz and have a relative low intensity that makes the human hearing perceptible to heart sound signal, therefore the auscultation using acoustic stethoscopes seems to be a bit difficult.

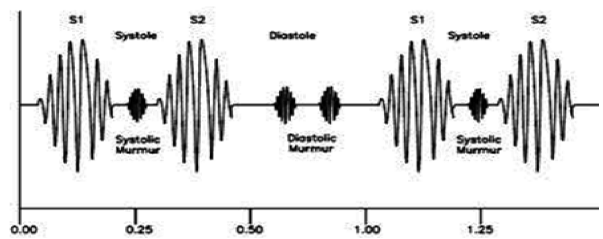


Fig. 2. Murmurs sound

Keeping in view that the traditional stethoscopes have two sides for observing internal sounds, the bell and the diaphragm, different frequencies are used for diagnosis. One uses 20 – 500 Hz range for hearing heart sound and pumping of blood vessels and other uses 200–1000 Hz frequency range to listening respiratory signals 1 and 5. Considering the system architecture of traditional method a low pass filter is designed to eliminate the frequencies above 1000 Hz for reducing the noise, hence picking up sounds having low frequencies.

4 PROPOSED SYSTEM METHODOLOGY

System design of the proposed method is divided into two main components i.e. Transmitter and Receiver. **(Fig. 3)** depicts the architectural diagram of transmitter. Sub-components of the transmitter are explained individually in this section.

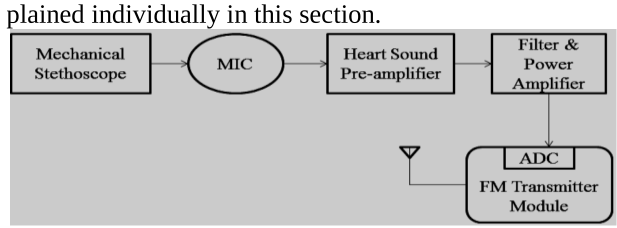


Fig. 3. Transmitter

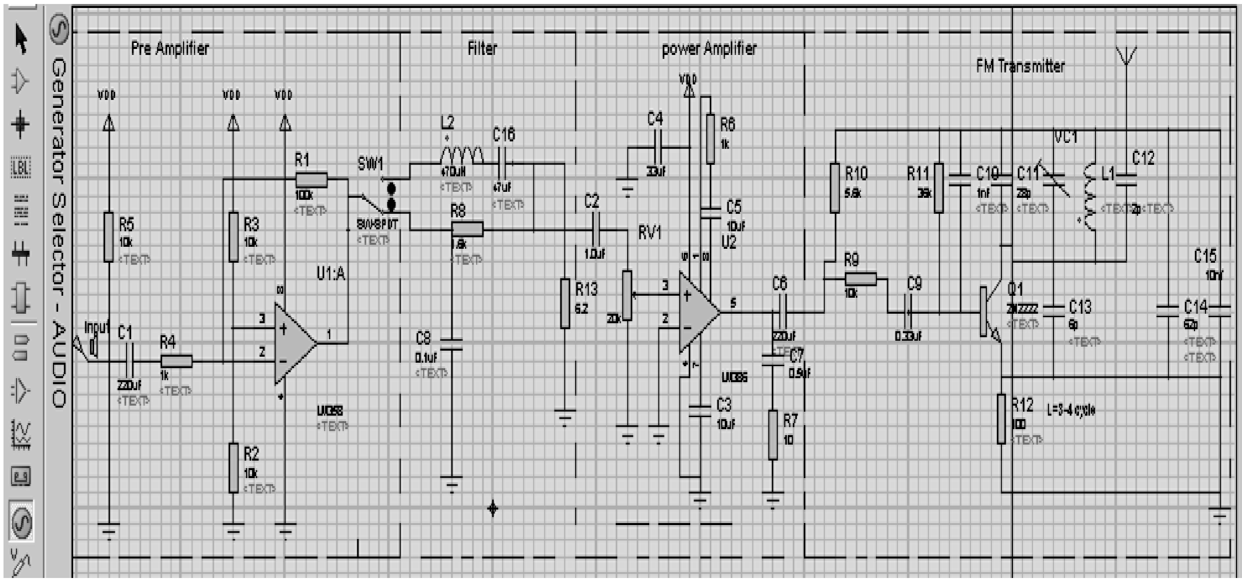


Fig. 4. Transmitter

4.1 FRONT END CIRCUITRY

Proteus version 7.6 software is used for designing the circuit shown in figure 4, objectives of the circuit design is to achieve the amplification of signal from condenser microphone with reduced noise for maintaining a good signal strength while maintaining low power consumption and most important of all, designing a low cost circuit. Other parameters considered for design of analog circuit includes gain, frequency response, harmonic distortion and noise.

4.1.1 Preamplifier

Each of the sub section is marked in **(Fig. 4)** for better understanding; pre-amplifier section in figure 4 is responsible for increasing the low-signal acquired from the microphone to threshold-level, hence making the signal compatible for further amplification. In order to accomplish this task a voltage gain was provided to the circuit from microphone, an OP-AMP (Operational Amplifier) is used in pre-amplifier section for achieving a voltage gain of 3, for this circuit LM358 OP-AMP was chosen due to its low power consumption which draws a small amount of current and can be powered by a 3-volt DC supply, another reason for choosing LM358 OP-AMP is its low cost which helps us achieve two of three proposed objectives. The variability in gain can be achieved either by varying the resistance between pin 1 and 2 or varying the resistance between microphone and pin 2.

4.1.2 Filter

Second sub section as per **(Fig. 4)** is the filtering section suggesting that a low-pass RC filter can be used for limiting the audible frequencies. The cut-off frequency for this particular filter is set to be 500 Hz,which means that the frequencies below this cut-off frequencies will be passed and frequencies above the cut-off frequency will be left out, however to achieve this characteristic of the suggested filter a 3.2 kΩ resistor along with a 0.1 μF capacitor is used. To simulate the working of diaphragm and bell two filters are implemented, both bell and diaphragm have the detection range of 20 – 500 Hz and 200 – 1000 Hz respectively. Bell can be simulated by simulating a low-pass filter and diaphragm can be simulated by simulating a band-pass filter allowing the frequency with in the respective range. These filters could be used in switching mode implying that the low-pass filter mode is used for listening sounds of heart and blood vessels and the band-pass filter mode is used for listening respiratory sounds. This feature provides flexibility for physicians to switch between two modes to deal with respiratory and heart problem separately.

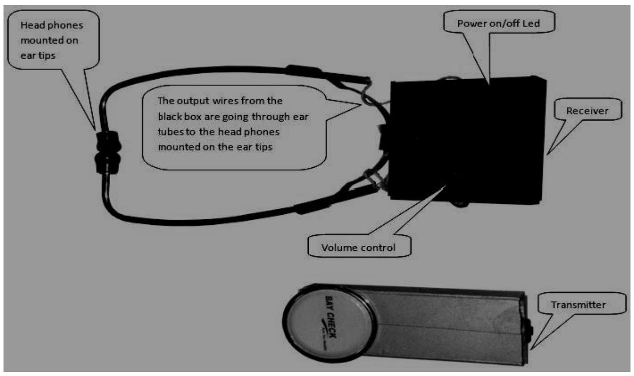
4.1.3 Amplifier

Third sub section refers to the amplification process which supplies the imperative power to drive the headphones. Amplification is achieved by using LM386 which is a power amplifier and can achieve the gain up to 40, however the value of gain can be varied by varying the capacitance and resistance between pins 1 & 8. The gain was limited to 40 as the increase in gain will increase the probability of occurrence of noise and distortion. Additionally a volume control is also implemented to provide the physician an element of usability. The volume is controlled by implementing a 20 kΩ variable resistor.

4.1.4 *RF Transmitter Module*

Finally the processed signal is passed to the RF transmitter module for transmitting the sound data, the transmission is achieved by using 2n222 transistor which uses FM modulation techniques. Preference to 2n222 transistor is given due to its low cost, low voltage requirements and non-usage of external component except the antenna. Additionally a variable capacitor of 22 pF is used that can be used to adjust the resonant frequency of the tank circuit.

Fig. 6. Prototype Model



4.2 RECEIVER

The architectural diagram of the receiver is shown in **(Fig. 5)** The proposed receiver is comprised of FM receiver module followed by the power amplifier and finally the physician listen the heart sound using a headphone. The transmitted signal is received at the receiver module and passed to power amplifier which amplifies the signal using gain control with same mechanism as used at transmitter side.

The amplified signal is then passed to the headphones however this method also employs the storage facility on PC for further analysis, using this feature will take a leap forward in medical facilities provided in Pakistan as it will allow the physicians to send the data over internet for further consultation with experts in this field to ensure the authenticity of diagnosis.

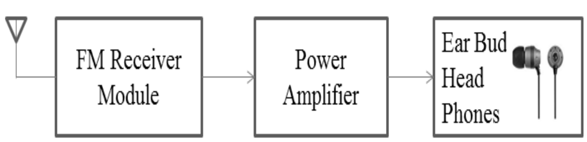


Fig. 5. Receiver

5 RESULTS AND SIMULATION OF SIGNAL SYSTEMS

To characterize the performance of the system a prototype wireless electronic stethoscope was developed and analysis on recorded heart sound has been performed on Think Lab Software, prototype model is shown in **(Fig. 6)**. The black box in figure 6 is the receiver in which the power amplifier and FM receiver module has been embedded. The amplification provided by all three filters was approximately measured to be 40dB and dynamic range of the prototype is approximately 75dB. The amplification provided by the filters gives significant flexibility to the physicians and provides a reason of preference of proposed stethoscope over non-electronic stethoscopes.

The above complete circuit has been simulated for different types of lung sound, heart sound and murmur sound by giving an audio file as input to the circuit and analyzing the output on oscilloscope with the cut-off frequency between 100 and 1000 Hz. As the prototype provides the functionality for listening both sounds i.e. heart and lungs therefore figure 7 shows the input provided to the software for heart sound and **(Fig. 8,9)** show the results after passing the input sound from pre-amplifier and power amplifier stage

Similarly **(Fig. 10)** shows the input provided to the software for lung sound and **(Fig. 11-12)** show the results of sound passing after pre-amplifier and power amplifier stage.

Fig. 7. Heart sound as input

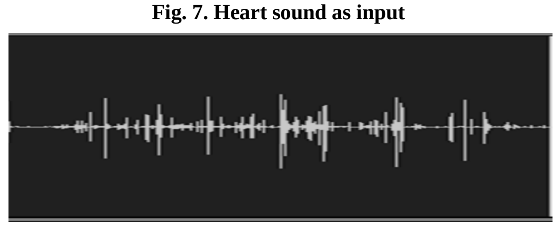


Fig. 8. Output at preamplifier stage

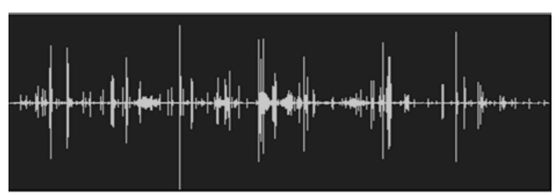


Fig. 9. Output after power amp and at filter stage

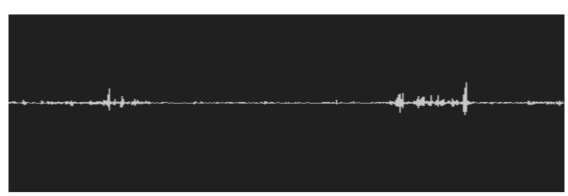


Fig. 10. Normal lung sound at input stage

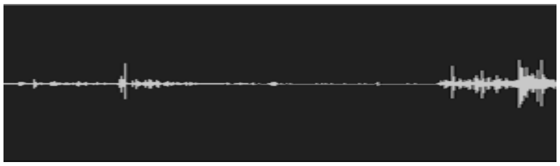


Fig. 11. Preamplifier stage

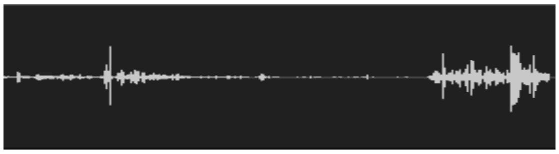


Fig. 12. At power amp and filter stage

A brief comparison has also been carried out and the proposed prototype model results have been compared with the results simulated using 3M Littman stethoscope. **(Fig. 13 and 14)** shows the acquisition of heart and lung sounds using 3M Littman stethoscope and the proposed prototype.

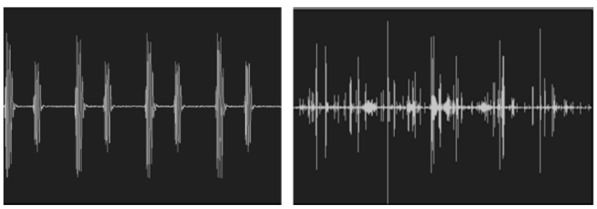


Fig. 13. From left (a) Heart sound recorded using 3M Littman Stethoscope (b) Heart Sound recorded using Proposed Prototype

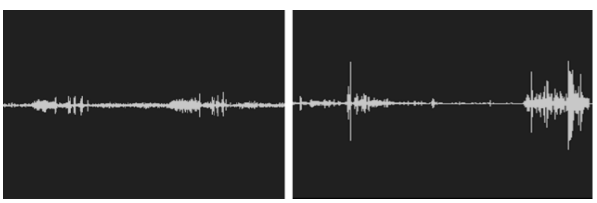


Fig. 14. From Left (a) Lung sound recorded using 3M Littman Stethoscope (b) Lung sound recorded using Proposed Prototype

(Fig. 13) depicts the comparison between the recordings of heart sounds using 3M Littman Stethoscope and recordings of hear sounds from our proposed prototype, though the result from the prototype model is not as good as 3M Littman Stethoscope but the sound is still audible and clear which refers to the "noise filtered sound" thus the results for the heart and lung sounds after amplification gives acceptable sound even in noisy environments. Use of sophisticated filters can minimize the effect of noise due to which efficient auscultation can be performed hence increasing the accuracy of diagnosis. Provision of volume control has also been added along with the feature of PC storage, indeed by using the proposed prototype patient auscultation can be monitored by multiple physicians at the same time but the main motive of this design is to give a low cost product that could increase the availability of such tools for efficient diagnosis in medical field, in this regard table 1 provides a brief comparison of technique proposed with the features and cost incurred for development of said prototype.

5.1 *TRANSMISSION CHARACTERISTICS* CONSTRAINTS:

The transmission of heart and lungs sound are affected by number of constraints but can be classified in two categories, either the constraints are related to patients such as thickness of chest wall, breast size, emphysema and obesity or the constraints may relate to the environment/external sources including air traffic, construction work, voices near the auscultation room and hearing loss from doctor. To overcome these constraints the following set of features are included in the prototype.

- Low frequency transmissions of sounds are passed through filters for improving transmission characteristic.
- Provision of mode selection between bell and diaphragm.
- Provision of Volume control.
- Comfortable ergonomic design.
- Mounting of Headphones that can fit suitably to the ears.

(Table 1) also highlights the features included in existing wireless electronic stethoscopes as well as in the proposed prototype.

Table. 1. Comparison of proposed prototype with available wireless electronic stethoscopes in market.

Technique	Features	Cost
3M Littman 3200 Electronic Stethoscope with Bluetooth	Patient can listen to their own sound, noise reduction techniques employed, visualization of patient's heart sound as a phonocardiogram, easy to operate, transmission of sound with optimal quality	Around $349.95
Wireless Electronic Stethoscope based on Zigbee	Low level heart and lung sounds are amplified with clear audibility in noisy environments, Proper auscultation through gain control facility along with power amplifier and frequency selection,	Around $50
Wireless Electronic Stethoscope based on RF	Heart and lung sounds are amplified for clear audible sounds even in noisy environments, Volume control facility, Wireless auscultation, Auscultation by multiple physicians at the same time.	Around $11

6 CONCLUSION

A design of low cost wireless electronic stethoscope has been proposed and analysis based on simulations has been carried out in this paper. The proposed system have the functionality to store the data for further analysis and effective diagnosis hence improving the accuracy in diagnosis of cardio vascular diseases. The analysis of signaling system is done by using Think lab software and the design/simulation is done by using Proteus 7.6 software. Comparison has also been made between the wireless electronic stethoscope design by 3M Littman and the proposed prototype in terms of features, sound recording for heart and lungs and the cost of production. However there is a difference between the results of 3M Littman stethoscope and the proposed prototype but when compared to the cost incurred this trade-off can be much beneficial for the physician's community in country like Pakistan where they have to think twice for purchasing such a high cost wireless stethoscope. Furthermore the proposed prototype can make a leap forward in implementing the e-health and telemedicine systems in Pakistan especially in monsoon season when the country is heavily affected by the floods and people in rural and affected areas could not get proper medical attention.

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FTP site for pricing of Littman wireless stethoscopes based on Zigbee" http://www.medicalsupplydepot.com/Holiday-Gifts-for-the-Medical-Student/Littmann-3200-Bluetooth-Electronic-Stethoscope.html" 12/10/2014.