

# A Wireless Electronic Esophageal Stethoscope for Continuous Monitoring of Cardiovascular and Respiratory Systems during Anaesthesia

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## ABSTRACT

**Background:** The basic requirements for monitoring anesthetized patients during surgery are assessing cardiac and respiratory function. Esophageal stethoscopes have been developed for this purpose, but these devices may not provide clear heart and lung sound due to existence of various noises in operating rooms. In addition, the stethoscope is not applicable for continuous monitoring, and it is unsuitable for observing inaccessible patients in some conditions such as during CT scan.

**Objective:** A wireless electronic esophageal stethoscope is designed for continuous auscultation of heart and lung sounds in anesthetized patients. The system consists of a transmitter and a receiver. The former acquires, amplifies and transmits the acquired sound signals to the latter via a frequency modulation transmitter. The receiver demodulates, amplifies, and delivers the received signal to a headphone to be heard by anesthesiologist.

**Results:** The usability and effectiveness of the designed system was qualitatively evaluated by 5 anesthesiologists in Namazi Hospital and Shahid Chamran Hospital, Shiraz, Iran on 30 patients in several operating rooms in different conditions; e.g., when electro surgery instruments are working. Fortunately, the experts on average ranked good quality for the heard heart and lung sounds and very good on the user friendly being of the instrument.

**Conclusion:** Evaluation results demonstrate that the developed system is capable of capturing and transmitting heart and lung sounds successfully. Therefore, it can be used to continuously monitor anesthetized patients' cardiac and respiratory function. Since via the instrument wireless auscultation is possible, it could be suitable for observing inaccessible patients in several conditions such as during CT scan.

## Keywords

Anesthetic Monitoring, Anesthetic Monitoring Equipment, Bio instrument, esophageal stethoscope, Electronic stethoscope, Heart Sound, Lung Sound

## Introduction

Monitoring the patient's condition during surgery under a general anesthesia is crucial. An anesthesiologist continuously obtains information from the anaesthetized subject. Cardiac and respiratory function is one of this information [1–5]. In general, such information is obtained by measuring and listening to the respiratory and heart sounds.

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Heart sounds reflect the blood turbulence created when the heart valves are closed [6]. In healthy adults, there are two major heart sounds often— the first heart sounds ( $S_1$ ) and second heart sound ( $S_2$ ). The  $S_1$  occurs at the onset of ventricular contraction, or systole. Specifically, the  $S_1$  sound is caused by: a) the rapid block of reverse blood flow due to closure of atrio-ventricular valves (the tricuspid valve and mitral valve); b) oscillation of blood between the root of the aorta and the ventricular walls; and c) vibrations caused by turbulence in the ejected blood flowing rapidly through the ascending aorta and the pulmonary artery. The  $S_2$  sound is occurred at the end of ventricular systole and the beginning of ventricular diastole. This sound is caused by closure of the semilunar valves (the aortic valve and pulmonary valve). The snap shut of these valves causes sudden block of reversing flow blood and ultimately cause vibrations in the arteries and ventricles. In addition to  $S_1$  and  $S_2$ , in some cases a third heart sound ( $S_3$ ) and the fourth heart sound ( $S_4$ ) may be heard. The former is caused by oscillation of blood between the walls of the ventricles in the ventricular rapid-filling phase. Finally, the  $S_4$  sound is caused by atrial contraction displacing blood into the ventricles.

The heart sounds provide important information on myocardial contractility, hemodynamic status, vascular resistance, and pulmonary artery [6]. In anesthesia, heart sounds can be used as indicators of cardiovascular status and anesthetic depth [1–4, 6–10]. With cardiovascular depression from deep anesthesia, the sounds become muffled.

In addition to heart sounds, auscultation of lung sounds enables the anesthesiologist to immediately detect minor disturbances that could ultimately cause patient harm such as airway obstruction and disconnection [1, 3, 4, 11–14]. Difficult or labored breathing may in-

dicate the presence of an airway obstruction. Harsh noises, whistles or squeaks may indicate narrow or obstructed airways or the presence of fluid in the airways. Therefore, heart and lung sounds provide valuable information to the anesthesia provider, and these two parameters should be continuously monitored.

The simple and low-cost instrument to monitor heart and lung sound is a stethoscope [3, 12, 13, 15–17], but there are several issues with using this device during operation. It may not provide clear heart and lung sound due to existence of various noises in operating rooms. The stethoscope is not applicable for continues monitoring. Finally, it is impossible for the anesthesiologist to be completely observant at all times. Several devices have been developed to resolve these issues. One of these devices is an esophageal stethoscope.

Esophageal stethoscope is an instrument for measuring and monitoring heart sound or respiratory sound during operation. This device consists of a thin, flexible, blind-ended tube attached to a regular stethoscope usually by a small plastic adaptor. There is a thin plastic membrane over the perforated area to prevent fluid entering the lumen of the tube. The advantages of the esophageal stethoscope are that it is less invasive and easy to handling. However, it may not provide clear sounds, specifically in noisy environment. Moreover, the anesthesiologist has to sit down beside the patient all throughout the operation that may not be practical.

Recently, several electronic esophageal stethoscopes have been developed for auscultation of the heart and lung sound during anesthesia [15, 18–22]. Experimental results of qualitative evaluation of these devices revealed that these instruments resolved low signal to noise ratio of the acquired signals. Therefore, these electronic esophageal stethoscopes extend the anaesthesiologist's range

and increase their accuracy. However, in using these instruments still the anesthesiologist has to sit down beside the patient all throughout the operation that may not be practical and may affect the performance of the anesthesiologist. Moreover, monitoring of the heart and lung sounds during anesthesia using these developed stethoscopes is difficult when x-ray examinations (e.g., CT scanning) of the patient is required.

In this paper, we proposed a wireless electronic esophageal stethoscope for continuous auscultation of the heart and lung sounds in anesthetized patients. The remainder of this paper includes a description of the instrument developed for this purpose followed by experimental Evaluation, Discussion and Conclu-

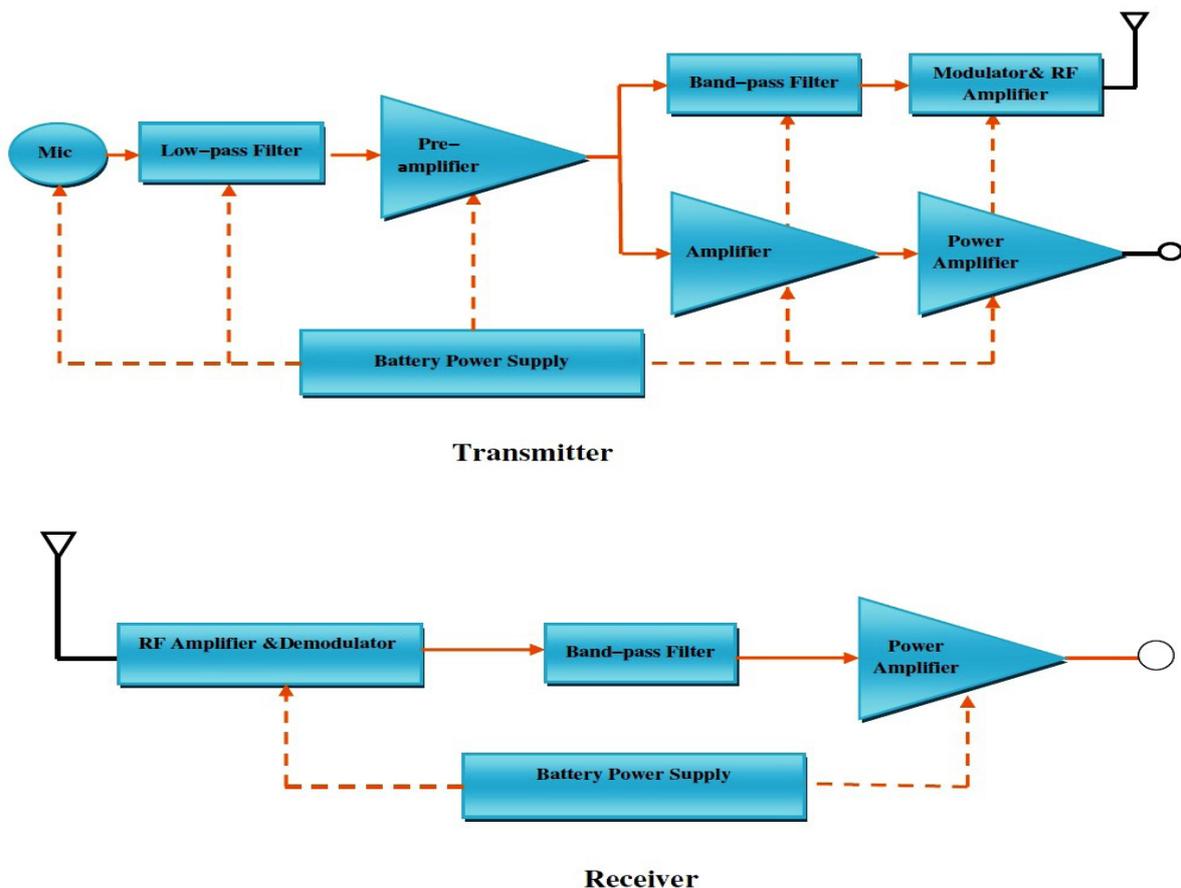
sions sections.

### Materials and Methods

Figure 1 shows a block diagram of the designed system. As shown, the instrument consists of two parts, a transmitter and a receiver. Following is a description of each part.

#### Transmitter

The transmitter acquires, filters, amplifies and wirelessly sends the heart sound and lung sound data to the receiver. The schematic circuit of the transmitter is shown in Figure 2. The sound is captured by a microphone connected to an esophageal catheter. A microphone with a 20 Hz to 20 KHz frequency range was selected to capture all the frequency characteris-



**Figure 1:** Block diagram of the designed wireless electronic esophageal stethoscope

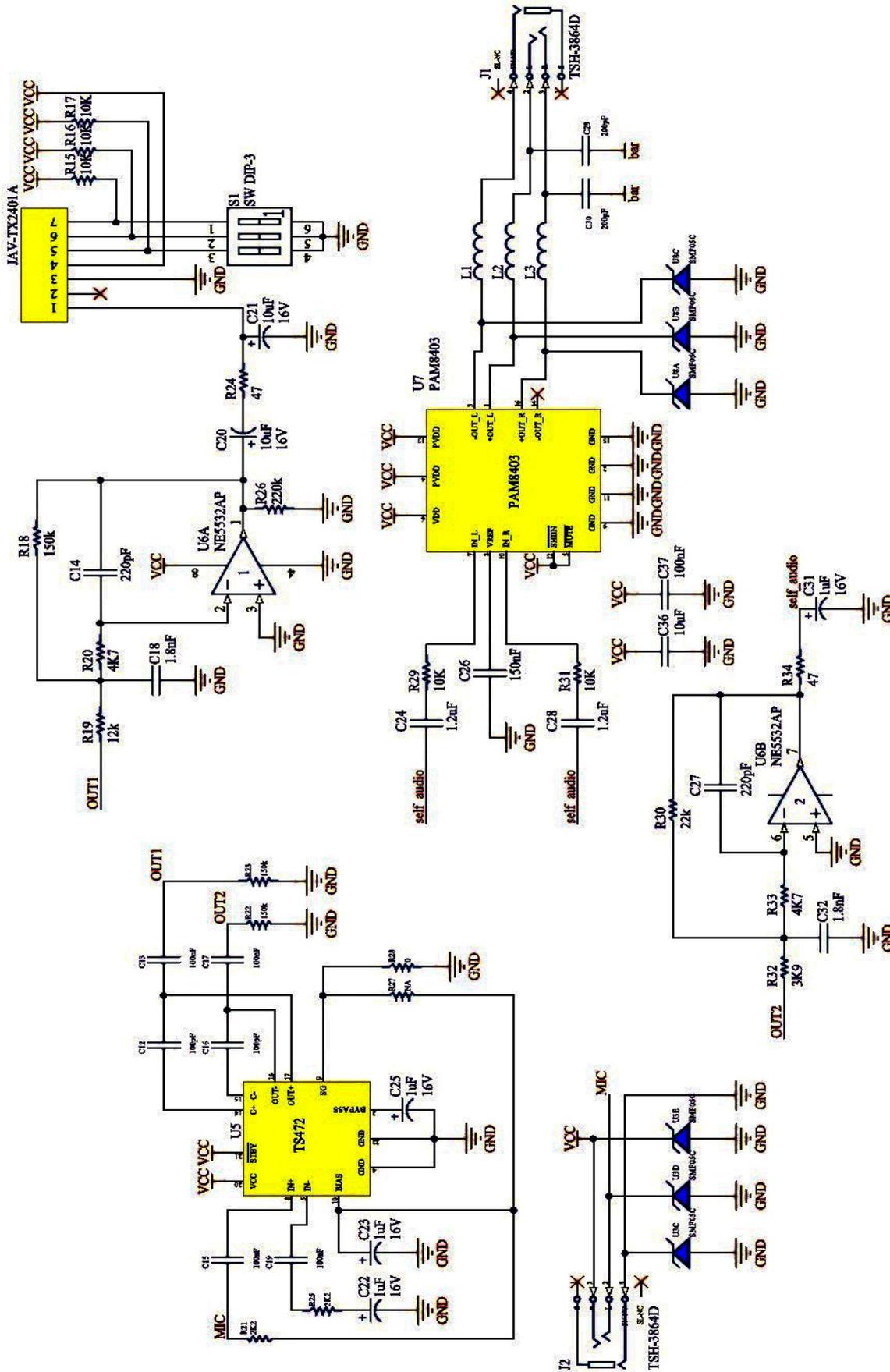


Figure 2: Transmitter circuit diagram of the designed wireless electronic esophageal stethoscope

tics of the heart and lung sound.

The signal from the microphone is contaminated by noise and is very feeble too. Sources of noise are background noise and power line noise. Interference and low amplitude of the acquired signal may cause difficult for the anesthesiologist to differentiate every sound. Therefore, low pass filter with cut off frequency of around 27 KHz is used to reduce the effect of noise and a pre-amplifier is employed to increase the input signal amplitude by a gain factor of 50. The pre-amplifiers provide initial amplification and better noise rejection. The designed pre-amplifier is also an active low-pass filter that boosts signals and enhances the signal-to-noise ratio of the captured signal simultaneously.

The output signal from the pre-amplifier is amplified by an amplifier and a power amplifier to supply the necessary power to drive the headphones and for further processing. This amplifier has a variable gain that helps adjusting the amplitude of the signal for the correct analysis.

As discussed, the main objective of this work was to design a system that can be used for observing inaccessible patients during CT scan. For this purpose, the system wirelessly sends the acquired signals (heart and breath sounds) to a receiver if needed. The output of the pre-amplifier is band-pass filtered and then is delivered to the frequency modulation (FM) unit and radio frequency (RF) amplifier. The output of the RF amplifier is then sent to the receiver via an antenna. The transmission frequency range of the transmitter is 2400 to 2483 MHz. If the receiver is not receiving signal correctly, the transmission frequency can be adjusted using three DIP switches to get a desirable signal.

## Receiver

The receiver processes and delivers the heart

sound data to a head phone. Figure 3 shows the schematic circuit of the receiver system. As shown the hardware design of the receiver consists of an RF amplifier, a demodulator, a low-pass filter and an audio amplifier. The received signal may be feeble, contaminated by the background noise. Therefore, the signal is amplified using a RF amplifier and then is filtered using a simple RC low filter ( $R_5$  and  $C_1$  in Figure 3). The filtered output signal is boosted by a digitally controlled programmable gain power amplifier to pick up this signal and helps drive the sound for a head phone. On Figure 3 this power amplifier consists of  $U_1$ ,  $U_2$  and  $U_3$ .

## Results and Discussion

The designed transmitter and receiver circuit was first evaluated using a computer simulation via PsPice software and then fabricated and tested in real world. The parts were delicately transferred to a designed printed circuit board (PCB) shown in Figure 4. The overall mounted system is shown in Figure 5.

The usability and effectiveness of the designed system was qualitatively evaluated by five anesthesiologists in Namazi Hospital and Shahid Chamran Hospital, Shiraz, Iran on 30 patients. Five well-experienced anesthesiologists have been asked to qualitatively provide feedback on the user friendly being of the instruments and on the quality of the heart sound heard from a headphone connected to the output of transmitter/receiver. The system was tested in different conditions in an operating room; e.g., when electro surgery instruments were working. The experts, fortunately, on average they ranked good quality for the heart sound and very good on the user friendly.

An example signals recorded using the designed instrument is shown in Figure 6. As show, both heart and lung sounds were captured and amplified with clear audibility such

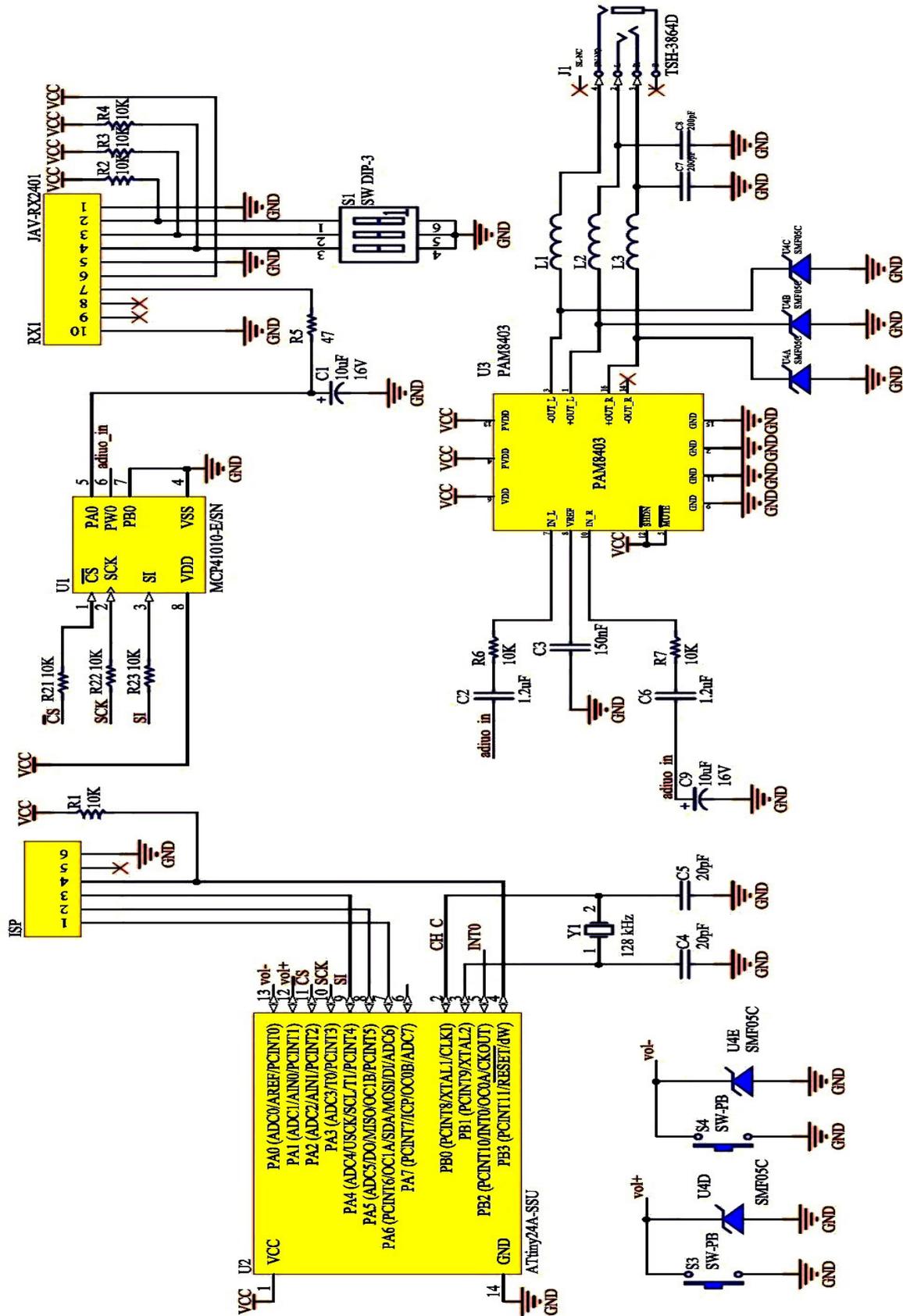
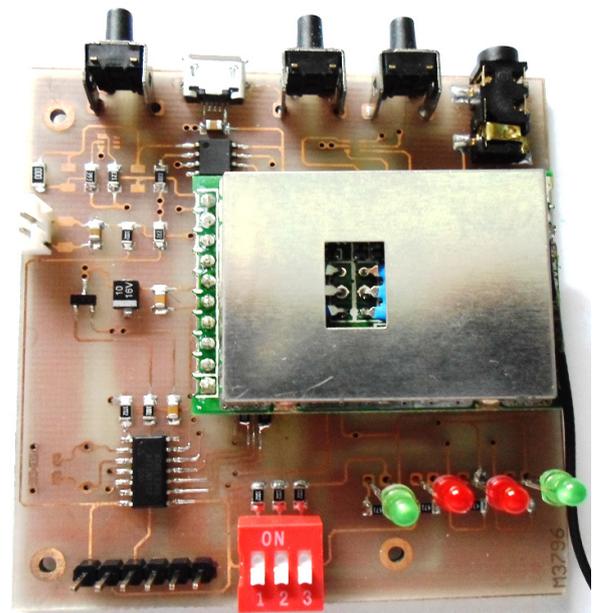
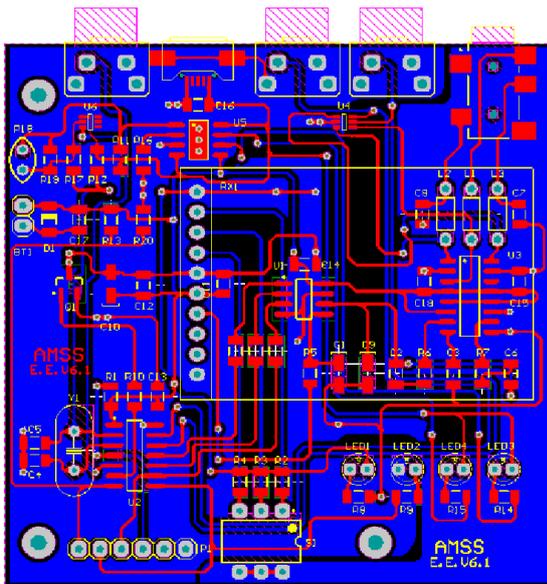
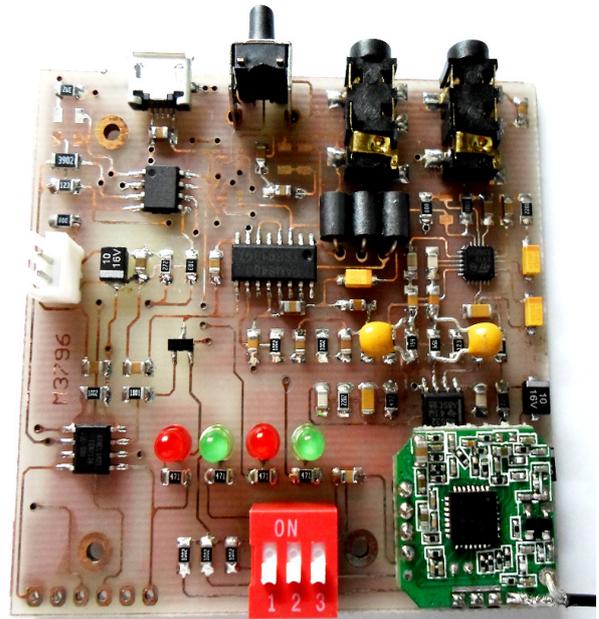
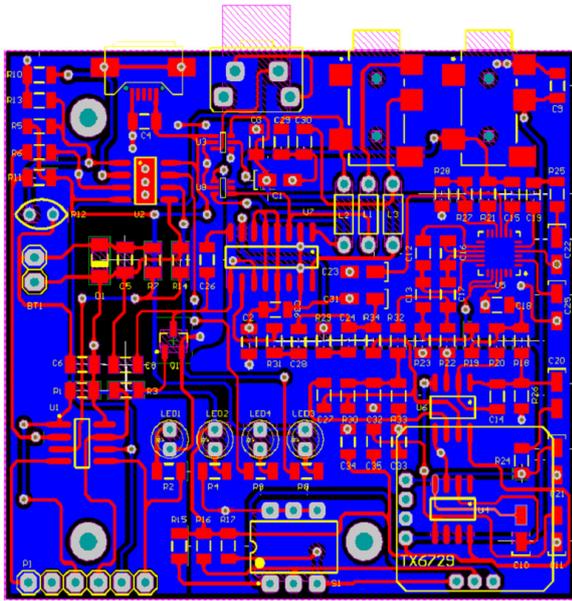
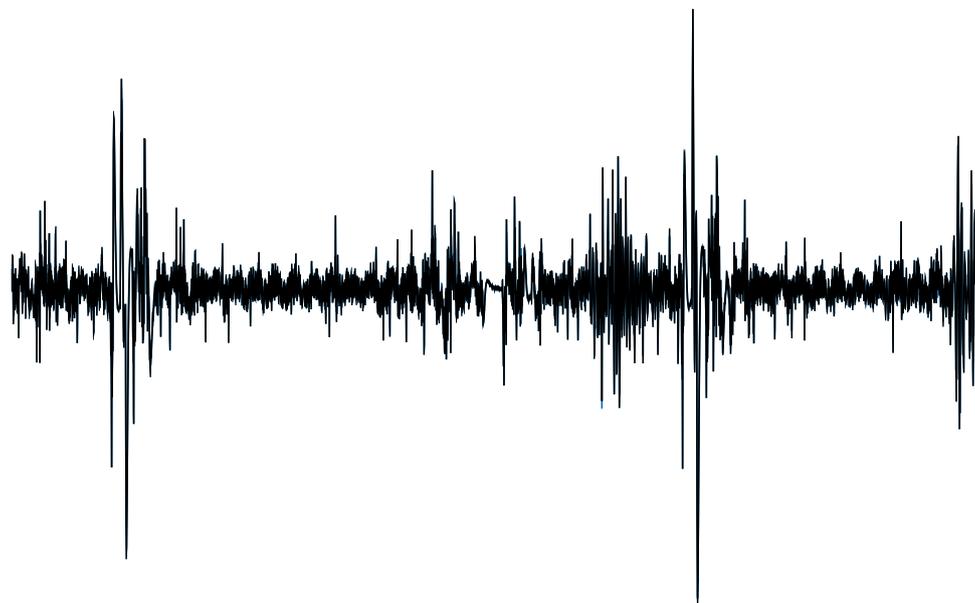


Figure 3: Schematic diagram of the receiver of the designed wireless electronic esophageal stethoscope



**Figure 4:** The designed printed circuit board (i.e.,PCB) for transmitter (top) and the receiver (bottom) of the developed wireless electronic esophageal stethoscope.

**Figure 5:** The transmitter (top) and receiver (bottom) of developed wireless electronic esophageal stethoscope.



**Figure 6:** An example of a signal acquired using the developed wireless electronic esophageal stethoscope

that proper auscultation is possible that means the instrument be an effective and suitable device for observing inaccessible patients in several conditions such as during CT scan.

## Conclusion

Monitoring cardiac and respiratory function during surgery under a general anesthesia is crucial. Electronic esophageal stethoscopes have been developed for the purpose of real-time monitoring of this information visually, but these devices are unsuitable for observing inaccessible patients during MRI or CT scan. In this work, an embedded wireless digital stethoscope consists of a transmitter and a receiver is designed and fabricated to resolve this issue. In experimental evaluation of real word operating environment, heart and lung sound was successfully recorded, transmitted and delivered to a head phone to be heard and analyzed by the anesthesiologist. The developed instrument provides wireless auscultation,

therefore this instrument could be an effective and suitable device for observing inaccessible patients in several conditions such as during CT scan.

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## Conflict of Interest

None

## References

1. Miller RD. Miller's Anesthesia. 6th ed. Philadelphia: Churchill Livingstone; 2005. p. 1266-1267.
2. Hansen PB, Luisada AA, Miletich DJ, Albrecht RF. Phonocardiography as a monitor of cardiac performance during anesthesia. *Anesth Analg.*

- 1989;**68**:385-7. doi.org/10.1213/00000539-198903000-00037. PubMed PMID: 2919778.
3. Watt RC, Mylrea KC. Monitoring the anesthetized patient in the operating room. *Med Instrum.* 1983;**17**:383-8. PubMed PMID: 6321921.
  4. Pasch T. Noninvasive monitoring. *Anasth Intensivther Notfallmed.* 1989;**24**:3-10. doi.org/10.1055/s-2007-1001519. PubMed PMID: 2653088.
  5. Pasch T. Goals and methods of patient monitoring. *Therapeutische Umschau. Revue therapeutique.* 1991;**48**:395-9.
  6. Harris A, Sutton G, Towers M. Physiological and clinical aspects of cardiac auscultation. London; 2013.
  7. Rence WG, Cullen SC, Hamilton WK. Observations on the heart sounds during anesthesia with cyclopropane or ether. *Anesthesiology.* 1956;**17**:26-9. doi.org/10.1097/00000542-195601000-00004. PubMed PMID: 13283338.
  8. Manecke GR, Jr., Nemirov MA, Bicker AA, Adsumelli RN, Poppers PJ. The effect of halothane on the amplitude and frequency characteristics of heart sounds in children. *Anesth Analg.* 1999;**88**:263-7. PubMed PMID: 9972738.
  9. Duck Shin Y, Hoon Yim K, Hi Park S, Wook Jeon Y, Ho Bae J, Soo Lee T, et al. The correlation between the first heart sound and cardiac output as measured by using digital esophageal stethoscope under anaesthesia. *Pak J Med Sci.* 2014;**30**:276-81. PubMed PMID: 24772126.
  10. Campbell WW. Evaluation and management of peripheral nerve injury. *Clin Neurophysiol.* 2008;**119**:1951-65. doi.org/10.1016/j.clinph.2008.03.018. PubMed PMID: 18482862.
  11. Sainsbury DA. Monitoring heart and breath sounds by telemetry. *Anaesth Intensive Care.* 1985;**13**:415-6. PubMed PMID: 4073459.
  12. Manecke GR, Jr., Poppers PJ. Esophageal stethoscope placement depth: its effect on heart and lung sound monitoring during general anesthesia. *Anesth Analg.* 1998;**86**:1276-9. PubMed PMID: 9620519.
  13. Suzuki A, Makino H, Sanjo Y, Nakai T, Mochizuki K, Shiraishi Y, et al. A visual stethoscope for pediatric patient. *Paediatr Anaesth.* 2008;**18**:339. doi.org/10.1111/j.1460-9592.2008.02480.x. PubMed PMID: 18315648.
  14. Gnitecki J, Moussavi ZM. Separating heart sounds from lung sounds. Accurate diagnosis of respiratory disease depends on understanding noises. *IEEE Eng Med Biol Mag.* 2007;**26**:20-9. doi.org/10.1109/MEMB.2007.289118. PubMed PMID: 17278769.
  15. Park SH, Shin YD, Bae JH, Kwon EJ, Lee TS, Shin JY, et al. Heart sounds analysis via esophageal stethoscope system in beagles. *J Clin Monit Comput.* 2013;**27**:535-9. doi.org/10.1007/s10877-013-9459-0. PubMed PMID: 23529343.
  16. Shindler DM. Practical cardiac auscultation. *Crit Care Nurs Q.* 2007;**30**:166-80. doi.org/10.1097/01.CNQ.0000264260.20994.36. PubMed PMID: 17356358.
  17. Henneberg S, Hok B, Wiklund L, Sjodin G. Remote auscultatory patient monitoring during magnetic resonance imaging. *J Clin Monit.* 1992;**8**:37-43. doi.org/10.1007/BF01618086. PubMed PMID: 1538251.
  18. Karki S, Kaariainen M, Lekkala J. Measurement of heart sounds with EMFi transducer. *Conf Proc IEEE Eng Med Biol Soc.* 2007;2007:1683-6. doi.org/10.1109/iembs.2007.4352632. PubMed PMID: 18002298.
  19. Mizutani AR, Ozaki G, Benumof JL. A low-cost, high-fidelity FM wireless precordial radiostethoscope for continuous monitoring of heart and breath sounds. *J Clin Monit.* 1990;**6**:61-4. doi.org/10.1007/BF02832184. PubMed PMID: 2295900.
  20. Rao CC, Krishna G. Anaesthetic considerations for magnetic resonance imaging. *Ann Acad Med Singapore.* 1994;**23**:531-5. PubMed PMID: 7979128.
  21. Trieger N, Erlichman M, Barkin M, Goldsmith D, Schiffman L, Levin D, et al. Anesthesia monitoring of the ambulatory patient. *Anesth Prog.* 1976;**23**:79-87. PubMed PMID: 1065235. PubMed PMID: 2515797.
  22. Murphy R. Computerized multichannel lung sound analysis. Development of acoustic instruments for diagnosis and manage-

ment of medical conditions. *IEEE Eng Med Biol Mag.* 2007;**26**:16-9. doi.org/10.1109/

MEMB.2007.289117. PubMed PMID: 17278768.