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The measurement system for analyzing heart sounds with ECG reference signal

Abstract*. This article present the problem of measurement and analysis heart sounds, and designed the measuring system for recording and analyzing heart sounds and murmurs to isolate specific factors, that allow in future to differentiate specific cases of heart disease. This text presents the issue of listening the heart beat and murmurs in the non-acoustic band in the context of physiological and pathological processes occurring in the human body, and the imperfections of human hearing.*

Streszczenie. *W artykule przedstawiono problematykę pomiarów i analizy dźwięków serca oraz wykonany system pomiarowy służący do rejestracji i analizy tonów i szmerów serca w celu wyodrębnienia cech dystynktywnych pozwalających w dalszej perspektywie na różnicowanie określonych przypadków chorobowych. Przedstawiono problematykę odsłuchu tonów i szmerów serca w zakresie niskich częstotliwości w kontekście procesów fizjologicznych i patologicznych zachodzących w organizmie ludzkim oraz niedoskonałości ludzkiego słuchu. (**System pomiarowy do analizy tonów serca z referencyjnym sygnałem EKG).***

Keywords: phonocardiography, electrocardiography, medical metrology, heart sounds
Słowa kluczowe: fonokardiografia, elektrokardiografia, metrologia medyczna, tony serca

Introduction

According to the statistics of the World Health Organization [1], one of the most common causes of death are diseases of the cardiovascular system, which are also reason of massive disability in population. The presence of these is closely associated with cigarette smoking, unhealthy diet, physical inactivity and psychosocial stress [2]. Therefore, it is very important early detection of heart disease, which may help to reduce the high levels of mortality. An important step in medical research is the examination of cardiac auscultation, on the basis of which can be detected physiological auscultatory phenomena, such as the first and second heart sound and murmurs (accidental and incorrect). Subsequently tests are carried out laboratory blood (including checking cholesterol) and an electrocardiogram (ECG).

Most abnormalities of the heart and the entire cardiovascular system affects its sound, which, with skilful analysis allows you to collect diagnostic information, and consequently to prepare a diagnosis. The basic device used by doctors to listen to the heart sounds and murmurs is a classic (acoustic) or an electronic stethoscope. However, only long-term medical practice and experience will lead to a proper diagnosis.

The doctor who examines a patient, in the group of sounds provided by a stethoscope, seeks to identify abnormal acoustic signals that may indicate a cardiac pathology [3]. The frequency, tone and sound intensity, as well as parameters such as, for example, trend, start and end of cardiac events are essential for the diagnosis of the patient's condition. Normally for the diagnosis of pathologies are heart valves, but does not exclude the possibility of detection also other cardiac pathologies.

Acoustic signals generated by the heart also contain information which man is not being able to analyze through hearing. For designing high-performance audio systems, is assumed that the frequency band for audible range to the human ear oscillate between 16 Hz to 20 kHz. However, in reality, this band is much narrower. Healthy teenager hears sounds between 30 Hz to 18 kHz, but doctors are much older people who have narrower bandwidth between 100 Hz to 8 kHz. It is important to note that presented limits of the frequency ranges are determined by the intensity of the sound much greater than the reference frequency equal to 1 kHz (in the case of the lower limit of audibility 60 dB, which is more than 1000 times). The Heart generate sounds in the frequency range from a single Hertz to about 200-300 Hz [4], where the most of the energy is contained below the threshold of audibility, as illustrated in figure 1.

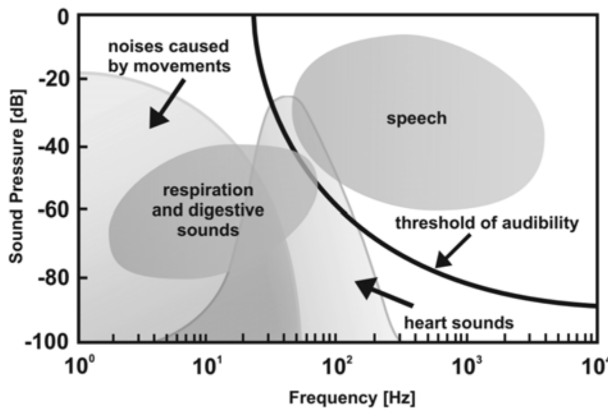

Fig.1. Characteristics of heart sounds against the threshold of audibility and interfering signals (developed on the basis of [5])

Accordingly, the diagnosis even with high-grade stethoscope may not be sufficient to take – even up by an experienced doctor – correct diagnostic decision. On the other hand, achievements of modern electronics and computational techniques, especially in the area of biomedical signal processing give us very large opportunities associated with the faithful registration and comprehensive analysis of the sound. The article presents measurement system to analyze heart sounds based on the listening its sounds independent from the limitation of human hearing.

Description of the measurement system – hardware

Featured measuring system consists of three components: a digital stethoscope, recorder of phonocardiograms (PCG) and computer application used to analyze the data.

The first element of the system is a digital stethoscope *Jabes*. Photo showing this stethoscope is in Figure 2. This is an electronic stethoscope powered by two AA batteries, equipped with 3 dedicated filters: *B* (20 – 200) Hz designed for cardiac auscultation, *D* (200 – 500) Hz designed for lung auscultation *W* (20 – 1000) Hz and the widest bandwidth filter containing both of the above. The stethoscope is equipped with an analog output, which is the source for the recorder of phonocardiograms.

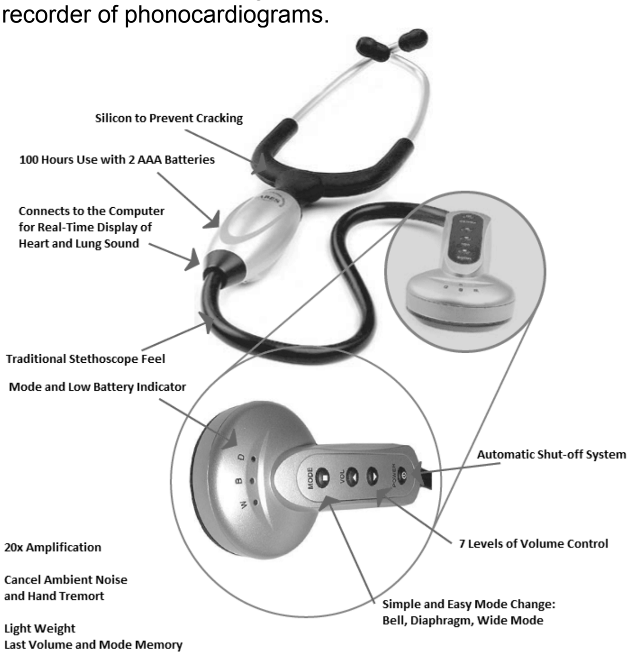

Fig.2. Digital stethoscope Jabes [6]

A stethoscope is the part that is in direct contact with the patient. Its main task is to register the raw signal PCG and transmit it to the recorder. Applied stethoscope is a certified medical device with the necessary analog output allows for recording a signal with independent media. Dedicated B type filter covers the frequency range generated by the heart, making it fully satisfies the requirements of the project.

The second element of the system is recorder of phonocardiograms. The design of this device was the biggest challenge. It must meet, among others, the following requirements:

- acquisition of analog signal PCG and its conversion to digital form,
- simultaneously recording of ECG signal,
- transfer collected data to a computer,
- provide high-quality internal power supply using the USB port as a source,
- providing galvanic isolation power system and measurement circuit.

The analog signal from the stethoscope *Jabes* must be converted into digital form. To accurately reproduce the PCG signal should be used analog-to-digital converter with high-resolution, low-distortion, low differential nonlinearity and low integral nonlinearity. Another important thing is the sampling frequency. According to the Nyquist-Shannon sampling theorem, the sampling frequency should be at least two times higher than the maximum harmonic in sampled signal. According to figure 1, the maximum frequency of the sound generated by the heart, is about 300 Hz. In that case, the sampling frequency should be at least 600 Hz. In order to ensure the possibility of listening in a wider frequency range, the sampling frequency of the system is much higher and it is set to 10 kHz.

ADS8866 is analog-to-digital converter which is used in measurement system, the most important parameters are shown below:

- resolution: 16 bits,
- THD (Total Harmonic Distortion): –108 dB,
- INL and DNL: ±1 LSB,
- sampling frequency: ≤ 100 kHz.

To the input of the converter connected is an anti-aliasing filter with an upper cut-off frequency of about 4.2 kHz. Figure 3 shows a fragment of the schematic with the A/D converter ADS8866. Before the filter is also a signal setting system from the stethoscope, which is designed to adjust the amplitude of the signal processing to the range of the ADC.

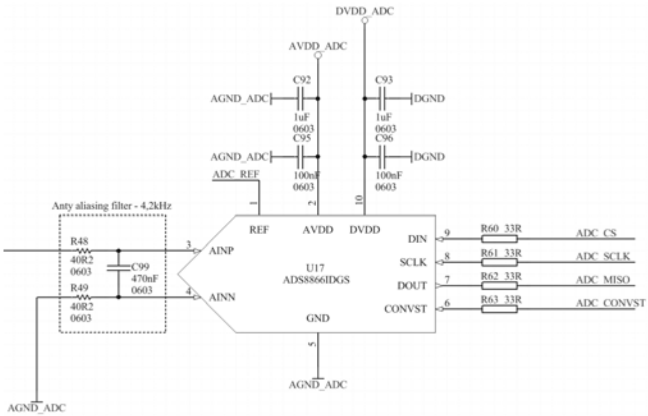

Fig.3. ADS8866 - connection diagram

PCG signal is - in relation to the ECG signal - signal with a high frequency and high amplitude. For the measurement of ECG we used analog-to-digital converter ADS1296, this is 6-channel, 24-bit delta-sigma converter. It is powered by a symmetrical supply and is dedicated to working with signals ECG, EEG and EMG. ADS1296 has in its structure 6 channels, each of which is equipped with a separate EMI filter and amplifier circuit. ADC inputs are connected with protective diodes to the DB9 connector, where doctor can connects ECG electrodes. Both of these converters supervise the 32-bit microcontroller with RISC architecture and with type of core: ARM Cortex M4 - STM32F437. The main task of the control unit is to exchange configuration information with an application installed on a PC, for example: set gain of the ECG signal, set time of recording and data transmission.

Described recorder is additionally equipped with a *micro-SD* card slot, so you can save the data on the memory card, and wireless transmission systems: Bluetooth 2.0 and Wi-Fi. In the future these will be used to transmit a signal PCG to the applications installed on your mobile phone.

The last element of the recorder is shown in Figure 4. This is the power supply system. The task of designing this system was very difficult, due to the requirements as to the quality and diversity of the necessary voltages. The power source is computer's USB port and more specifically power converter located in the USB driver. Unfortunately voltage from the USB port is very low quality. First, the supply voltage via capacitors goes to the DC / DC converter, which provides galvanic isolation of voltage. The next element is EMI filter, the resonance frequency is about 100 MHz. Next the voltage is connected to a group of capacitors and coils, and it is divided into individual segments of the device. The LDO output regulator (MIC5219) provides the voltage of 3.3 V, and is the source of powering the digital segment. Analog section needs a symmetrical power. LDO Regulator TPS73201 provides a positive voltage of 2.5 V for analog section. TPS60403 is an inverter which feeds the LDO regulator TPS72301, which provides a negative voltage of -2.5 V also for analog section. Thanks to the separation of power supply and the ground on the part of the digital and analog, allowed to obtain satisfactory power quality.

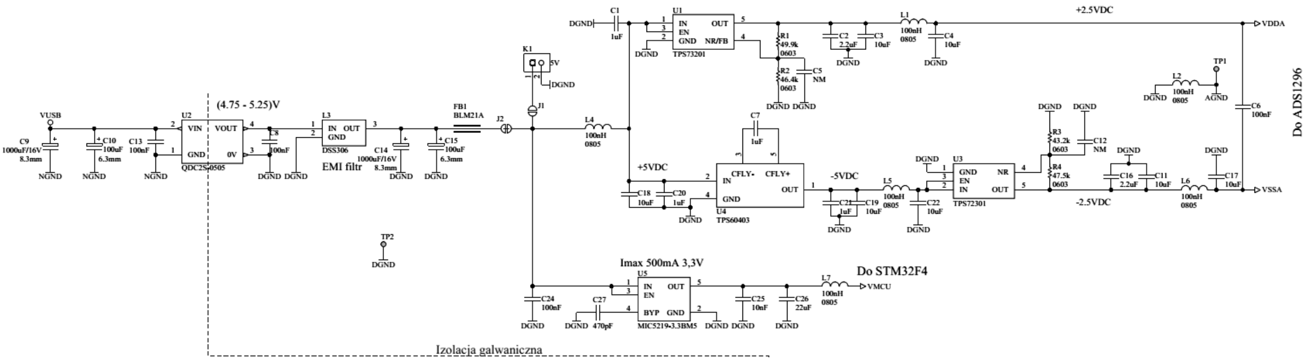

Fig.4. The power supply system for recorder of phonocardiograms

The following are waveforms showing how the quality improves of power supply in the subsequent stages of the system power supply.

Measurements were made by oscilloscope LeCroy-9361. Figure 5 shows the voltage (only AC coupling) on the output USB port. The measurement was performed with an input sensitivity 20 mV/div. We can observe high noise spikes in a signal which amplitude exceeds 60 mV. The next waveform shown in Figure 6, shows the voltage (only AC coupling) at the output of the regulator MIC5219 which supplies the digital part of the device. The measurement was performed with an input sensitivity 5 mV/div.

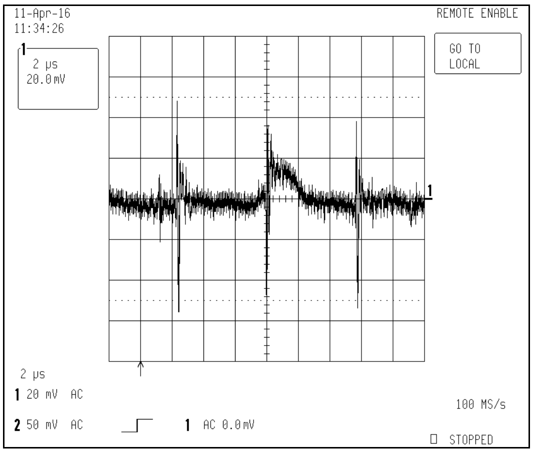

Fig.5. Voltage at the output on the USB port (AC coupling)

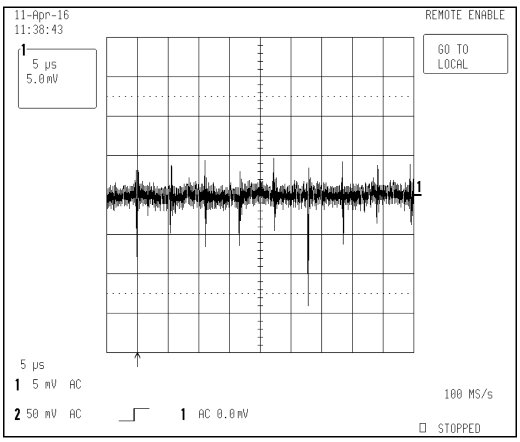

Fig.6. Voltage at the output on the regulator MIC5219 (AC coupling)

The last waveform shown in Figure 7 shows the voltage (only AC coupling) at the analog section: +2.5 V. The measurement was performed with an input sensitivity 5 mV/div.

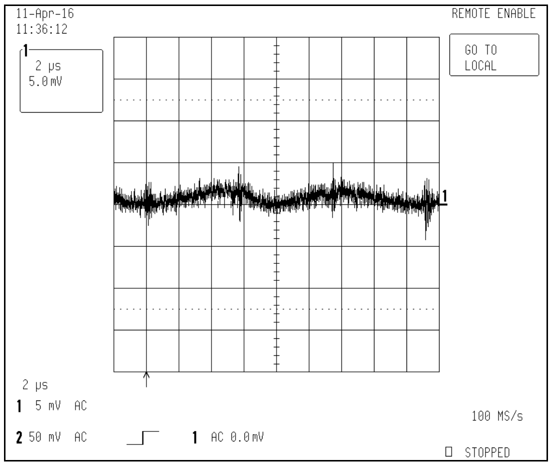

Fig.7. Voltage supply of analogue part (AC coupling)

We can observe a significant improvement, reducing and smoothing the ripple voltage. Without a doubt, this has a huge impact on the quality of the system operation. Figure 8 shows photographs of the constructed recorder of phonocardiograms.

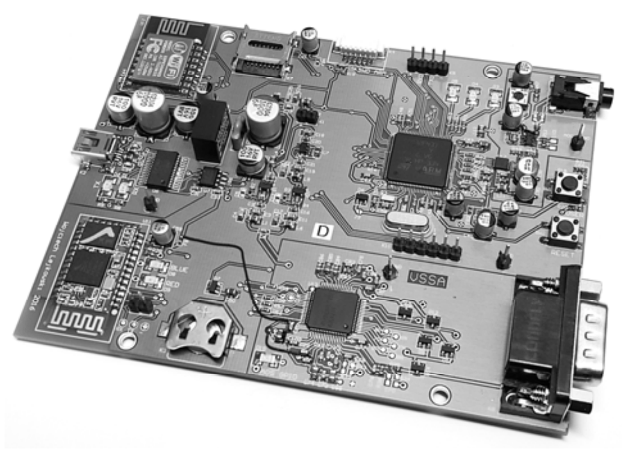

Fig.8. The Photography of the constructed electronic module

Description of the measurement system – software

Presented application is used to collect enough data from healthy and sick patients to later analysis of those data. The data is transmitted to the application and stored on computer. Recorder of phonocardiograms is fully controlled from within the application. The application was written in *Matlab* language. The main application window is shown in Figure 9.

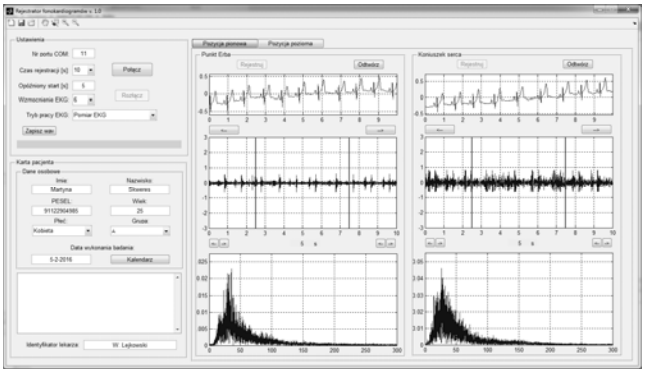

Fig.9. Main application window

Application user can set some settings, for example recording time of signal (from 1 to 30 seconds), gain of the ECG signal and the mode of operation of the analog-to-digital converter. If mode of operation is set to test signal, the input of converter are connected to the internal source of signal, which shape is rectangular. In the main window, it is also a patient card in which the doctor completes data such as name, PESEL number, sex and the group to which assigned the patient:

- A – spontaneous hypertension without comorbidities,
- B – high blood pressure and the left ventricle hypertrophy,
- C – arterial hypertension and left ventricular hypertrophy and heart failure characteristics,
- Z – healthy.

In addition, in the patient card is place for the patient's description. Doctor makes a preliminary analysis of the case and is characterized by disease or states that this is the case properly. This allows each individual registration is described, which provides a basis for further data analysis.

The application has two tabs: vertical and horizontal position (patient is standing or lying), and each tab has two measuring points: Erb's point and the cardiac apex. This means that a doctor should perform a total of four examine. When the patient is standing, first in Erb's point and second in the cardiac apex and a second pair of tests at the same points when the patient is lying.

In the top windows application is displayed ECG signal, while in the middle PCG signal synchronized with the ECG signal. In the window with PCG signal are available red cursors, which can be freely manipulated using the buttons which are below the window. The lower windows shows Fourier Transform which are compute from PCG signals which is between cursors (red vertical lines).

The physician who uses the application has the ability to load a previously collected data from the file, listening to each of the four signals PCG, and record these runs in audio format with the extension .wav.

Summary

In the auscultation of the heart is still much to discover, the problem contains many unknowns, which the explanation can be crucial in the diagnosis of cardiovascular disease. Further cooperation with cardiologists from the Military Institute of Medicine is sure to bring the expected results. The system described in the article is fully completed. In the next stage, the authors plan to establish a representative base PCG and ECG signals recorded in the *Department of Cardiology and Internal Diseases*. Further, among others spectral [7] and wavelet [8] analysis of the data will be conducted for detection of the relevant distinctive features [9]. To achieve this goal we will probably have to split the signal into smaller segments containing characteristics features. [10]

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