The Improvement of mHealth Technologies Using AFE-based Integrated Devices

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Abstract —**In this paper we consider the question of the use of analog-front End in the development of mobile devices for the diagnosis of physiological parameters. This approach can be used to create telemedicine systems. An AFE chip is a set of analog, digital, and hybrid circuits that are integrated on a single chip which enables one to create a multi-functional and flexibly configurative device.**

I. Introduction

The modern Health Organization is difficult to imagine without the process of combining the classical methods of research and innovative biotech technologies. The healthcare program of the Russian Federation prioritized the introduction of modern engineering solutions and technologies to overcome the current crisis taking place in the health system.

A promising perspective area to achieve this goal is the development and active application of mobile telemedicine monitoring systems of physiological parameters. They have an important role in the prevention, treatment and rehabilitation of patients with different diseases. Mobile Health (mHealth) includes telemedicine; providing and carrying out diagnostics, therapeutic measures, and control over the patient condition through the use of mobile and wireless devices.

The latest PwC report indicates that telemedicine systems account from the mobile health monitoring of 65% of patients. According to the ITU report in 2015 the number of mobile subscribers exceeded 6 billion people. This explains the popularity of the issue of the organization of the personal involvement of mHealth systems mobile phone[2]. Modern smartphones are equipped with sensors and software that enables the monitoring of various indicators (pedometer, pulse oximeters, consumed and burned calories etc). Today mHealth systems include:

- cardiovascular and respiratory monitoring systems, monitoring system of pressure, glucose, brain activity, sleep phases,
- monitoring systems of integrated indicators
- rapid clinical analysis systems (blood, saliva, urine)
- doctor remote systems
- wearable and implantable sensors of various vital signs
- tracking physical activity (bracelets, smart clothes, glasses)
- monitoring systems of drug use, treatment regimens, educational programs

However, despite the broader perspective of mobile diagnostic systems, there are considerable drawbacks.

Information about the state of human health is strictly confidential. Currently, cloud data storage technology is the most reliable and convenient way to store the received information, but they do not provide an adequate level of data protection. At the moment, there are no documents regulating the process of processing and storage of medical data to the cloud, as well as the organization of certification process applications.

The mHealth low informative value problem to monitor patients' status is also acute. In most In most cases studies conducted, these devices provide a surface screening, not allowing the skilled reveal features of pathology. For example, single-channel ECG used in the tracker bracelet reveals only the basic rhythm disturbances. In the meantime noise detection and monitoring of main hemodynamic parameters require additional diagnostics.

After analyzing the dynamics of mobile health development at the moment, we can conclude that mHealth devices gain prevalence; they are convenient and relatively inexpensive. At the same time, they do not provide full control of the conditions surrounding people suffering from various diseases. Professional medical equipment providing such control is expensive and is not suitable for the ordinary user because of its large weighting parameters, as well as the specificity of the interface configuration and diagnostics.

In order to make mHealth devices more accessible to end users, we could consider implementing an analog input interface, such as Analog Front-End. AFE is a set of analog circuits which utilize operational amplifiers, filters, and sometimes integrated circuits for specific applications, sensors and other electrical circuits and the configurable unit required to interconnect the various sensors to the analog-digital converter and microcontroller.

The main advantages of AFE:

- multifunctionality (ability to replace many types of chips with one device)
- flexibility (the ability to adapt to a variety of user interface requirements, simplify the set-up process)
- minimizing soldering errors
- reducing the size and power consumption

Through such development, we could develop a wearable biomedical information recorder based on the Analog Front-End.

II. Methods

The possibility of increasing the effectiveness of mHealth technologies through the use of AFE interface was confirm by the design of a device for measuring heart rate and respiratory rate, based on the integration of the two-channel ECG and single-channel rheograph. The chip is based on Analog-front End ADS1298 TI. User options of this model allow the synchronous register diverse biological information, such as electrocardiographic and respiration signals. Fig. 1 shows the model of correlation ECG and respiratory signals.

Rheography - a method of research of general and regional circulation, is based on the graphic recording of changes in the electrical resistance of tissue arising from the passage of the pulse wave (16-300 kHz). The act of breathing affects the resistance value of tissues and organs mainly by changes in blood filling veins. During inhalation, the blood flow in the chest cavity, the heart and venous blood at the periphery become smaller and the resistance of tissues and organs increases. In exhalation venous blood accumulates in peripheral veins and, respectively, peripheral resistance decreases. Graphical registration of pulse and respiratory resistance of the body vibrations is the basis for the physical method of rheography [5].

A more complete understanding of the pulse oscillation of electrical resistance is obtained with allowance (ratio) of the base resistance of the test portion. Full impedance (resistance) is composed of two values, permanent base impedance, due to the general hyperemia of tissues and their resistance, and variable or pulse impedance caused by variations in blood supply during the cardiac cycle. The magnitude of the pulse impedance is 0.5-1% of the total impedance. However, the pulse impedance is the object of rheography research[4].

Another application of time-domain measurement is full impedance of pneumography respiratory period One can speak about the possibility of unambiguous determination circuit resistance, whereas in a homogeneous biological conductor it is not. We can not simulate the thorax as a chain of elements connected in parallel, consisting of lung, heart, bone, etc. Instead, the current distribution forms the entire volume of the conductor, creating a leading or vector field.

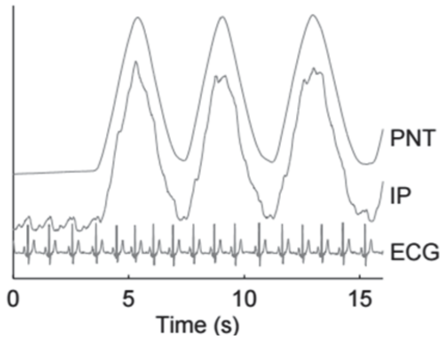

Fig.1 The model of correlation ECG and respiratory signals

The measured impedance volume conductor V is calculated by integrating the product of the reciprocal of conductivity □, and sensitivity across the field area S [1]

$$Z = \int_V \frac{1}{\sigma} S = \int_V \frac{1}{\sigma} J_{LE} \times J_{LI} \quad (1)$$

where J_{le} - field current conductor, J_{II}-voltage conductor field

Changes in lung electrical resistance are the result of the following two effects:

1) During inhalation, the chest gas volume increases in with respect to the fluid volume. This leads to a decrease in conductivity.
2) During inhalation, the conduction path length increases due to the expansion.

Recorded together, these two effects cause the appearance of electrical impedance. There is a correlation between the change in impedance and volume of inhaled air. This relationship is close to linear. The impedance component generates varying voltage component ΔV when the current is injected. This changing voltage component is a parameter that represents the greatest interest, as this component can be used to determine the frequency of human breathing. Typically, impedance Z in the range of 0,1 Ω to 1 ohm. Voltage ΔV, in turn, depends on the magnitude of the supplied current. [8].

III. Modulation

Investigation of the respiratory flow rate based on the principle of impedance pneumography. For this, an AC high frequency signal (100mkA,10 kHz) is applied to the object. The amplitude modulated signal is generated as a result of respiratory movements. The resulting modulated signal should be demodulated to extract the low-frequency breathing signal. After demodulation this signal is supplied for noise removing to low-pass filter with frequency 2-4 Hz bandwidth[3]. Fig. 2 shows the analog part of the developed system.[6]

To synchronize the signals are generated and detected using the principle of pulse width modulation. (Fig. 3). The device uses 32 kHz modulation frequency.

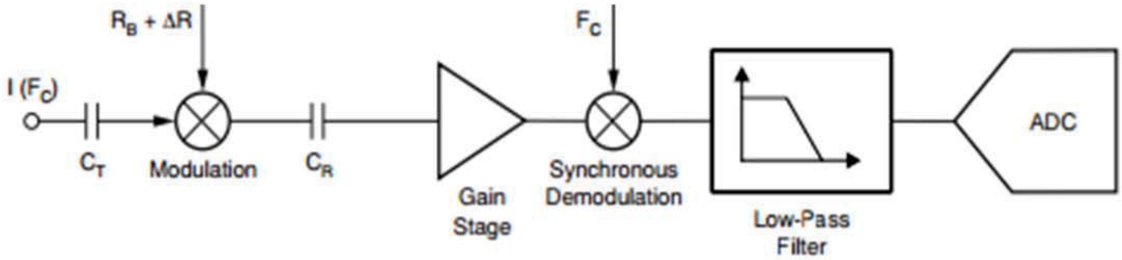

Fig.2. Conceptual block diagram of modulation chain

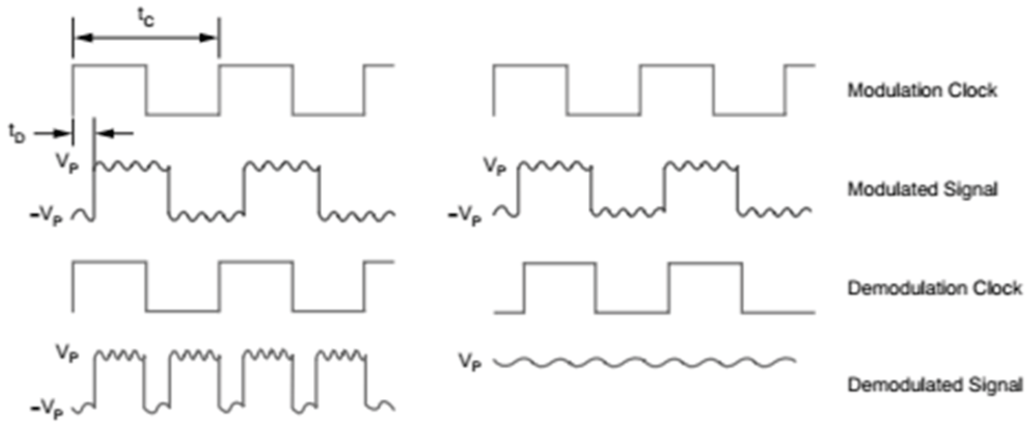

Fig.3. Signal demodulation clock with same phase as modulation clock and phase adjusted for delay in signal path [6]

The amplification demodulator with a time delay calculated in the fall to 0, under the condition that a demodulation phase offset can return back to the demodulator value 1. The carrier signal is subjected to low-frequency noise because of cable capacitance and noise arising from the finite interface amplifiers bandwidth. This filtering results in slower rise and fall times on the modulated signal, which then have to be demodulated. In this case, we can talk about the phase shift of the demodulator counter to account for the delay, but the final rise / fall can continue to cause an increase in the fall in the value of the demodulator. Fig. 3 shows the effect of the end of temporary transition to the demodulated output.[6]

IV. Data acquisition system

The structure of the ADS1298 chip functional circuitry includes:

- RC filter;
- comparator;
- input multiplexers;
- amplifiers with programmable gain;
- clock, providing a small size and low power consumption; circuit electrode "right foot" for filtering the in-phase component;
- 24-bit sigma-delta ADC;
- internal reference voltage;

The device can reduce power consumption by more than 94% compared with discrete implementations, while required board space reducing reaches 86%. 4 uVpp input noise is optimal indicator for the values provided by CE / IEC 60601 requirements for the most accurate measurements of high-performance portable equipment.[6] AFE simplifies the design of the system at the expense of accommodating up to 50 components on a single chip. Block diagram of the system shown in Fig. 4.

As previously indicated, pneumo reoghraphy requires supplying current to the body. ANSI / AAMI ES1-1993 standard allows the implementation of up to 100 mA of current at 10 kHz. At lower frequencies, the current which is applied to the tissue surface can be reduced. The modulating signal at a frequency FC can be represented as a rectangular function or a sine wave. Demodulation is performed on the same frequency. Capacitor CT blocks DC components in the transmitter signal, while the capacitor CR is used for the same purpose at the receiver side. In an ideal situation, it is necessary to minimize the amount of electrical capacity, so that the network frequency (50 Hz to 60 Hz), any resistance present in the body, was high. However, in practice, the nominal values of capacitors are chosen largely to prevent signal attenuation.

The carrier signal generates in the voltage register, and converts into a current signal in passing through the receiver. The configuration shown in Fig. 5 generates only a pseudo-constant current because it varies depending on the change in resistance RBeff and resistance ΔR. As already mentioned, the base impedance (RBeff) consists of cable resistance and the resistance of the electrode and the fixed impedance is the resistance of the chest cavity.

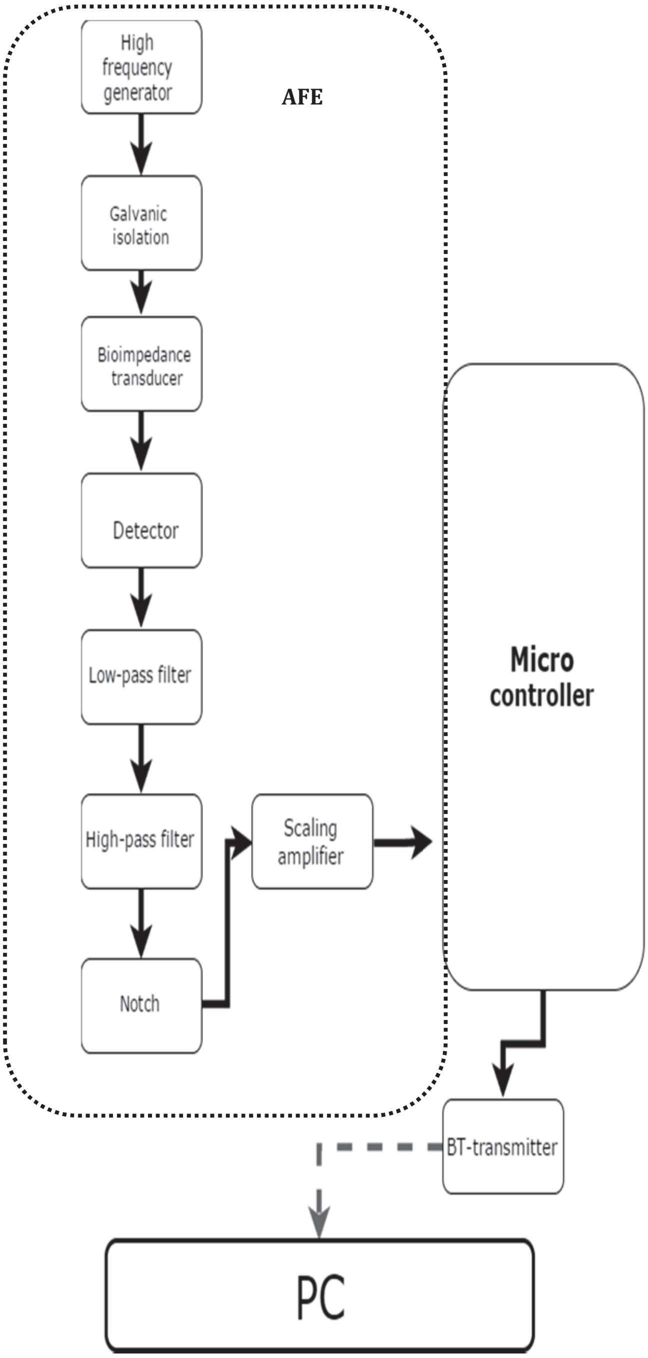

Fig.4 Block diagram of the monitoring system

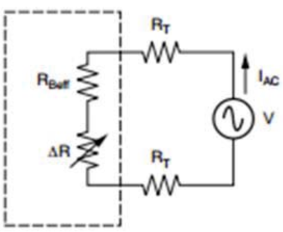

Fig.5. Carrier signal. General concept [6]

Fig. 6 shows a circuit generating of a square wave modulating signal. In the first half cycle, node X is connected to Y and VA at node VB (solid line). In the second half of the cycle, the compound is recovered from the node X is connected to the node Y and VB to VA (dashed line). This configuration creates a square wave signal at the node X and Y. Both signals VA and VB should have a low noise level. [7]

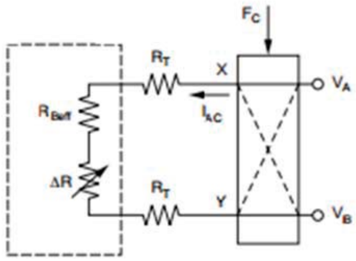

Fig.6. Square Wave Carrier Implementation [6]

The patient may be connected between the electrodes A and B, to provide a base impedance (RB) and a variable component (ΔR). Resistors RT limit the nominal value of the AC, which is applied to an object. Capacitors A block any direct current produced in the body. Capacitors B are used as a secondary means to prevent any errors (e.g. short circuit on the generator) from excessively high values of constant currents generated in the patient. [8]

Using of bipolar impedance measurement providing excitation and measuring of voltage from one electrode gives less noise immunity to compare with tetrapolar connection, where the signal generator and the recorder are separated into two different electrodes.

Besides this, it was found empirically that the signal strength depends on the electrode size. It is also necessary to note that the respiration signal amplitude increases, and the artifact is reducing with increase of excitation frequency. Given this fact it is possible to use a scheme of adaptive filtering, where the resistance is registered simultaneously at two frequencies (57 kHz and 185 kHz).

During our work it was designed PCB based on the specificity of AFE. PCB analog circuit was shared so that the impact of introduced it to minimize the impact on the operation of the circuit. At the same time the characteristics of analog circuit devices were the same as the model characteristics. The noise and disturbance signals are the main problems that limit the qualitative characteristics of the circuits. Noise may be emitted by a source, and by the other scheme elements. Analog circuit often located on the circuit board with high-speed digital components including digital signal processors (DSP). High-frequency logic signals generate significant radio frequency interference (RFI).

In this system we applied the separation of ground to the analog and digital part - one of the simple and effective methods of noise elimination. One or more layers of a multilayer printed circuit board is usually given to the given for ground polygons layer.

All connections were made to the analog ground plane components of the analog circuit (formed analog ground) and to the digital ground plane components of the digital circuit (formed by digital ground). Only after that digital and analog ground were united at the source.

Separation does not mean the electrical insulation of analog and digital ground parts. They have to be connected together in one low-impedance node. All signal currents and power currents in this circuit must be returned to the earth in a single point, which will serve as the system ground. In the AFE the elements are located on the one integrated scheme that reduces the soldering error and the influence of noise.

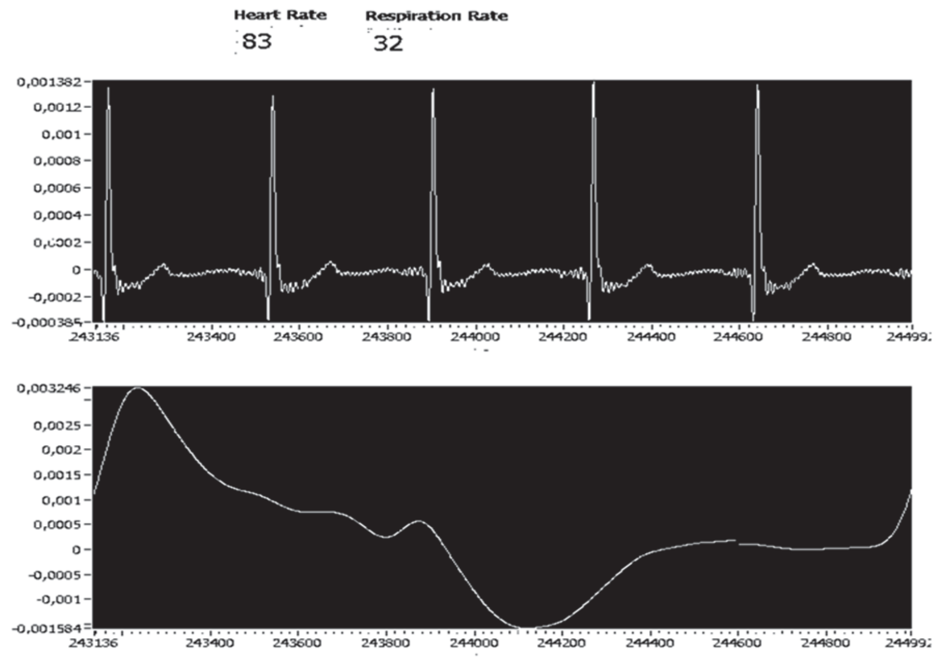

Fig.7 Graphic interpretation of the recorded signal

For recording, processing and transmission of results to a personal computer (PC) one must use the microcontroller (ATMEGA328). In the process of signal processing involving various components of the microcontroller – ADC, input-output ports, registers, ALU, interface port to PC etc. Scaling the amplifier needs to agree with the signal amplitude range of the ADC of the microcontroller.

Portability of device is provided by wireless transmission system with low power Bluetooth data interface. Digitized signal is transmitted to the PC with Bluetooth-module HC-05. In the radio frequency spectrum, Bluetooth wireless technology is allocated in 79 radio channels in the range 2,4465-2,4835 GHz (about 1 MHz each). The 2.4 GHz band refers to the unlicensed industrial, scientific, and medical band ISM (Industrial, Scientific, Medical), which allows free use of Bluetooth devices. Bluetooth modules are capable of transmitting data at speeds up to 720 kbit / s over a distance of 10 to 100 meters. FHSS technology uses frequency hopping principles. According to a pseudorandom algorithm the transmitter proceeds from one operating frequency to another. Full duplex with transmitting channels is used for communication and receiving data (Time DivisionDuplex-TDD). At each time, thetransmitter uses only one channel. Frequency tuning takes place simultaneously in the transmitter and the receiver according to the law previously fixed pseudo-random sequence. There can be up to 1600 frequency changes per one second. This method provides confidentiality and immunity programs. Each device has a unique 48-bit network address format compatible with the standard IEEE 802 local area networks.

V. Results

Graphical representation of the received signal shows in Fig 7. Signal Processing occurs by LabView program with further data analysis and finding correlation component.

Several persons in different situations (stress and rest) participated in experiment. Fig. 8 shows the resulting histogram. During our testing we obtained high-quality signal resistant to noise. The stress-test was carried out with the high physical activity that let us consider this system of high noise immunity and proves advantages of using the AFE. Our results demonstrate that using of AFE is possible not only for static diagnostic systems but also for daily monitoring systems used to be full of noise signals (eg, fitness trackers).

The static series of heart rate (RH) and respiration rate (RR) ratio and density function of these values shown in the Fig.9. This diagram proves the normal accuracy of received signals.

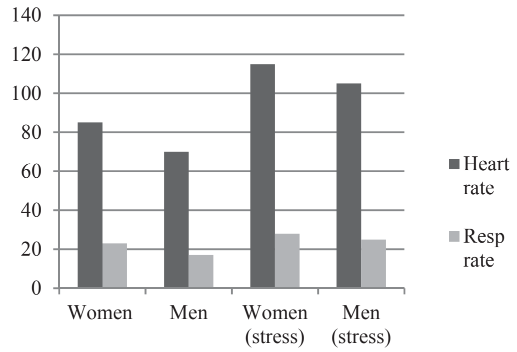

Fig.8 The histogram of ECG and respiratory signal average value

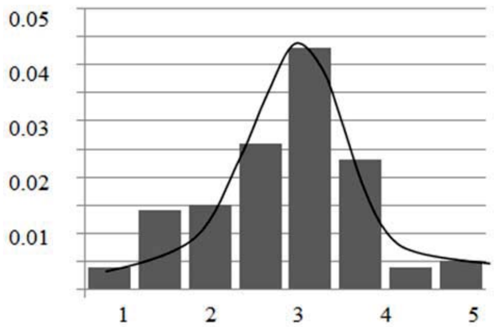

Fig.9 Static series and the density function of RH and RR ratio

VI. Conclusion

Drawing from this study, we have shown the possibility for further development of more informative mHealth equipment to levels comparable with equally informative professional equipment, all the while maintaining low cost and small size. A further challenge to mHealth technologies is the standardization of reports and data to ensure compatibility with modern telemedicine systems in meeting information protection requirements.

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