CONTINUAL BIOIMPEDANCE MEASUREMENT BY DUAL CHANNEL SYSTEM WITH HIGH DYNAMIC RANGE

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Abstract: Here digital dual channel system for bioimpedance measurement in cardiology is described. The main aim of its application is the frequency analysis of blood flow control. The basic prerequisites of the system discussed are high dynamic range, selectivity, minimal distortion, phase coherency and analysis of complex signal. Hardware design will be one of the main points discussed. The preliminary measurement results confirm that the exact frequency analysis of bioimpedance changes with every heartbeat corresponding to blood flow is possible.

Introduction

The frequency analysis of cardio vascular system control is based on sub-parameters, such as heart rate and blood pressure, which can be measured continually. Until now, the continual measuring of blood flow has been impossible. The Bioimpedance method is able to measure continual blood flow, but standard instruments use the accumulation to eliminate disturbing signal and to achieve better signal to noise ratio. Such an approach is impossible if the frequency analysis should be used. This limitation must be overcome. Some other disadvantage of bioimpedance method in cardiology, i.e. that the changes in impedance are measured, that are only proportionally connected with changes of blood flow, is not so important The relative changes of blood flow are more important than the absolute level of blood flow during the frequency analysis.

The solution of frequency analysis of circulation control must be based upon contribution in two areas:

a) A perfect bioimpedance measuring system, which produces a set of bioimpedance signals for the precise analysis of blood flow.
b) New algorithms for the analysis of measured signals.

This paper is focused on the design of the bioimpedance system.

Materials and Methods

The basic requirements of a perfect bioimpedance system in cardiology are:

a) High dynamic range. The bioimpedance changes corresponding to blood flow are small compared to changes due to respiration, motion and other influences. These changes are as low as 0.001 of basic impedance. For signal-to-noise ratio better then 50 dB, the dynamic range of the system must be better than 110 dB.
b) The evaluation of complex signal. Both signal components (absolute value and phase or real and imaginary part) contain information about blood flow. If only one of these components is used, some information will be lost.
c) Dual channel, orthogonal measurement of bioimpedance signal.
d) Adjustable carrier frequencies in both channels for optimization of measurement conditions, and coherent, highly sensitive receivers.

Bioimpedance system solution. The design is based on Analog Devices circuits. The ADC used is AD6644, and the digital receiver is based on AD6620 – The digital down converter and digital transmitter is based on AD9852 - direct digital synthesis. The control and data transfer is made by the ADSP 2181 digital signal processor. The USB link is used for communication and data transfer to the PC. The basic diagram and measurement connection for one channel system is on Fig.1. The block scheme of the digital part is on Fig. 2.

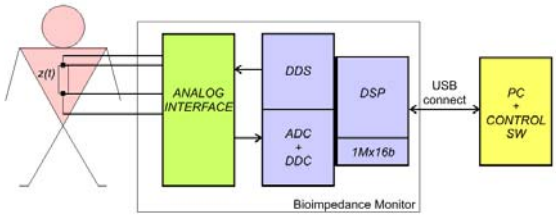

Figure 1: Block diagram of one-channel measuring system

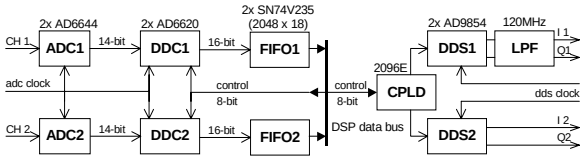

Figure 2: Bioimpedance monitor, digital part

The mechanical design of the digital part is based on four boards: Dual channel receiver; dual channel transmitter; control and communication board and

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coherent clock system. All clock signals must be coherent and phase locked. The resulting digital part of the two channel system is on Fig. 3.

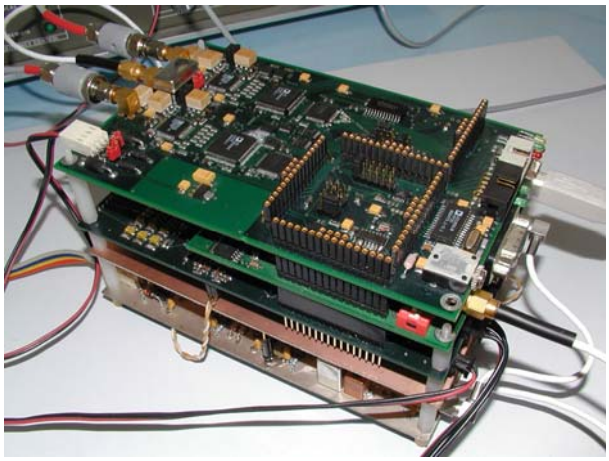

Figure 3: Digital part of two channel system.

Parameters of digital part:
Transmitter: Full-scale output level: 0.35 V p-p into 50 Ω (-5 dBm). Output frequency: from 1 kHz up to 120 MHz (120 MHz low-pass filter). Narrowband SFDR (5 kHz): 86 dB.
Receiver: Full-scale input level:1.2 V p-p into 50 Ω (+5.5 dBm).-3 dB bandwidth: from 10 kHz to 130 MHz (limited by rf transformer). Dynamic range: 148 dBFS/√Hz. Jitter lower than 0.5 ps. Carrier frequency resolution (coherent with transmiter) 0.01 Hz.

The evaluation of complex signal: The prerequisite is the phase coherence between transmitter and receiver. In the analog system the phase coherency is preserved by mixers. In the digital system the phase coherency depends on clock speed and the control system. Both transmitter and receiver are programmed via one signal processor (DSP) and that is why a time-lag arises from the point of setting up the DDS to the point of setting up the DDC. The problem can be solved by the program with phase differentiation of both chips so that the phase difference between the phase accumulator DDS and DDC is invariable or zero. As the increase of the phase accumulator is dependent on the transmitter frequency, we can optimally suppress this difference by presetting the phase accumulator via offset on the value that will be at time T0p = T0v + ΔTvp (T0p – the point of setting up the receiver, T0v – the point of setting up the transmitter, ΔTvp – time difference between T0p and T0v) equal to the initial value of the receiver phase accumulator in the time of T0p. The time ΔTvp is known and is given by clock frequency DSP (and thus DDC and DDS) and by the number of instructions necessary for setting up the DDC. The number of instructions in this control part must be fixed and set in accordance with clock signals used. The resulting test of phase stability confirms that the phase is absolutely constant – the phase difference between different onsets of measurement is much below the phase corresponding to one clock period.

The time behaviour of complex bioimpedance is on Figure 4. The absolute value of bioimpedance (|Z|) is in the upper part and the phase (φ[°]) is in the lower part. At first, the shape of the phase looks similar to the shape of the absolute value multiplied by -1 and only signal to noise ratio will increases when both parts will be analyzed. However, both signals differ in fine details, and this is important for fine blood flow analysis.

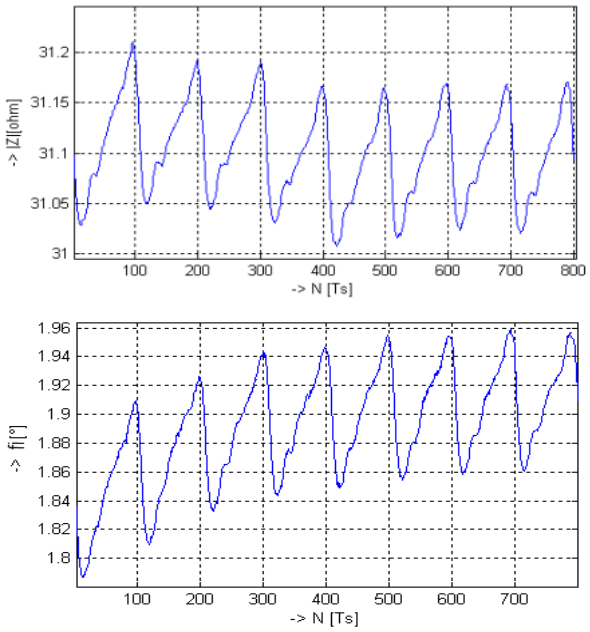

Figure 4: The evaluation time behaviour of absolute impedance value |Z|[Ω] and phase φ[°]

The electrode position and dual channel system issue: Some new bioimpedance measuring systems use separated current circuit with constant current power supply which compares voltage potential to segment impedance. The source current electrodes are placed outside of the reading segment, and reading electrodes are placed at the beginning and end of the sensor segments. This system eliminates impedance effect on the electrode to skin junction.

Typical electrode placement is on Fig.5.

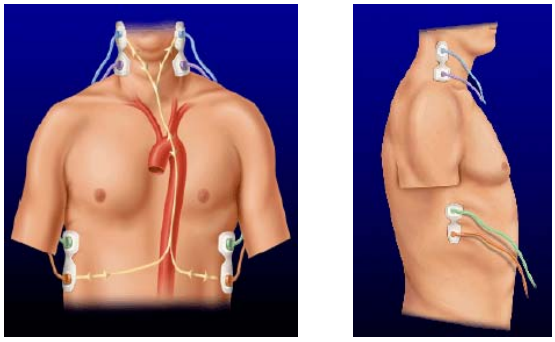

Figure 5: Typical electrode placement on thorax.

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The thorax fluid volume is the most important part of thorax conductance. This high conductance has blood plasma with specific resistance ρ = 65 Ω/cm and specific resistance of whole blood is about ρ = 130 Ω/cm (haematocrit 40%). The specific resistance of fat tissue and lungs is much less, ρ = 300-500 Ω/cm. Because high frequency current conducts better with low specific resistance tissues, the best currents are two large veins which go through the thorax in the same direction as transmitted currents through the cervical vein and aorta pulmonary. Such measurements have the best signal to noise ratio at one channel system.

In dual channel measurement, the second channel is placed orthogonal to the first channel. The second channel is carrying additional information about blood volume change in heart and lungs. This gives us a better evaluation of blood flow. The signal to noise ratio in this second channel is about 10 dB worse than in the first, but again, the fine changes of shape are important. The optimal placement of second channel electrodes is in the horizontal heart line. The carrier frequency of both channels has to be coherent, and with frequencies different by at least by 200 Hz.

Adjustable carrier frequency and coherent, high sensitive receivers: The digital design preserves these parameters without problems. The used carrier frequency is usually in the area of 20 kHz to 100 kHz. Frequencies lower then 20 kHz should theoretically make interference with bioelectrical activity of tissue (for example ECG 0.05 - 100Hz). On frequencies up to 100 kHz specific resistance of blood constant depends only on percent value of haematocrit in tissues. For frequencies higher then 100 kHz, high-frequency currents conduct through blood corpuscles and specific resistance falls with increasing current frequency.

The optimal carrier frequency may be determined according to measured signal to noise ratio, or according to the shape of signals. Moreover, the optimization may be done at an absolute level of impedance or at phase. According to our measurement, the optimal carrier frequency differs according to the tested parameter, and a mean level of 50 kHz is currently being used.

Results and discussion

The present results are limited by two factors:

i) The measurement system used had only one analog interface. The second interface, which preserves the needed safety in accordance with the rules, is currently being finished. This is why the results are not presented from dual channel orthogonal measurement. The shapes of the new signals in the second channel are quiet different, but the signal to noise ratio in the second channel is about 10 dB lower. The findings will be more meaningful only if both channels are measured at the same time.

ii) Algorithms for analysis blood flow from multiparameter bioimpedacnce signal are currently being developed and we expect greater findings in this area.

Comparison of high dynamic range and selectivity findings to standard commercial equipment BOMED. The designed system is on Fig. 6. BOMED - commercial equipment, BDR - designed system, Zx - time evolution of bioimpedance magnitude; -dZ/dt - bioimpedance derivation. All measurement conditions – i.e. current, electrode position, carrier frequency, were the same on both instruments.

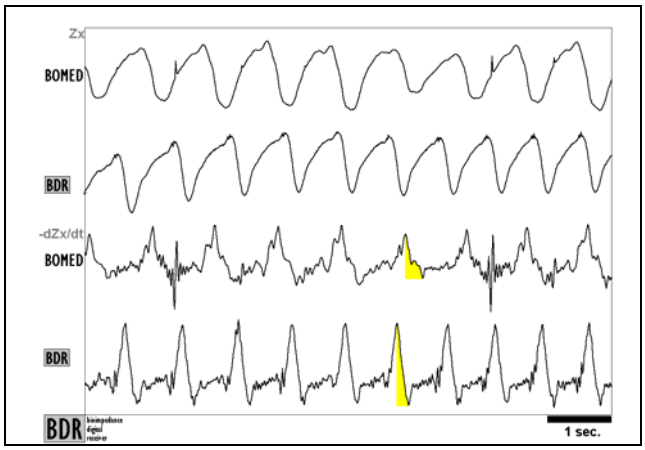

Figure 6: The measured bioimpedance signals (Zx) and their derivative (dZx/dt) at commercial system BOMED and designed system. Measurement parameters were the same in both cases.

The basic test of blood flow analysis beat to beat is on Fig. 7. The measurement in rest, with deep, controlled breathing 0.1 Hz was used. The direct breathing influence on bioimpadance was eliminated by an ideal (made by FFT) high pass filter with a cut-off frequency 0.25 Hz.

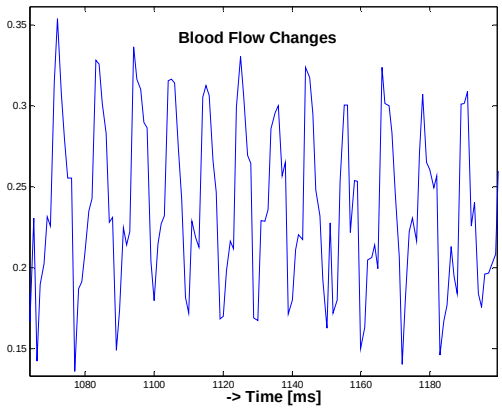

Figure 7: The time evolution of blood flow.

The designed system is the first step for the frequency analysis of blood flow control. The achieved results confirm the possibility of continuous blood flow measurement, however, the results will strongly depend on algorithms for blood flow analysis and their

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contribution. In the presented system, signal to noise ratio and distortion are not the main problems. Most difficulty will occur in validating the results. The analysis of multiparameter bioimpedance signals may give different results in accordance to weight assigned to different parameters. The proper algorithms must be tested in agreement with such commonly used signals as ECG and blood pressure.

Conclusions

The presented dual channel system is able to measure high dynamic range (148 dBFS/Hz), and complex bioimpedance signals. It has a very high signal to noise and distortion ratio. The accumulation is not needed, and the system is able to measure blood flow beat to beat. The way to frequency analysis of blood flow control is open. The problem of frequency analysis of blood flow control remains. The algorithms for the continuous blood flow computing from measured signals are under development.

Acknowledgement

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