A high accuracy Bioimpedance Measurement System
System design and first measurements

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Abstract—Bioimpedance measurements are an important tool in biomedical engineering and life sciences. Bioimpedance describes the response of living tissue to an applied electrical current and allows therefore conclusions about the condition and composition of the investigated tissue.

This work describes the design and development of a high accuracy Bioimpedance Measurement System (BMS), which is able to measure amplitude and phase of a complex bioimpedance under test. The developed system is based on a System on Chip (SoC) Field Programmable Gate Array (FPGA), is in compliance with the IEC60601-1 and works in a frequency range of 10 kHz to 250 kHz.

Keywords- System on Chip (SoC), Field Programmable Gate Array (FPGA)

I. INTRODUCTION

Bioimpedance measurements are a well known technique in biomedical engineering and life science for the investigation of tissue condition and composition. Furthermore it can be used as functional method e.g. for pulse or breath detection or for the estimation of cardiac output [1, 2, 3].

This paper describes design and development of a high accuracy Bioimpedance Measurement System (BMS), which drives a well-known current trough a human body and measures the resulting voltage to calculate impedance magnitude and phase via the four electrode measurement method. The developed BMS is based on a System on Chip (SoC) Field Programmable Gate Array (FPGA) and is in compliance with the IEC60601-1. It works in a frequency range of 10 kHz to 250 kHz with a current range from 500 µA to 5 mA, while maintaining an excellent SNR and SFDR.

II. SYSTEM DESIGN

The principle block diagram of the BMS design is shown in figure 1. The BMS consists of an embedded system and a host PC. The embedded system is in charge for current excitation, data acquisition, filtering, and data transmission to the host PC. On the PC, the received measurement data will be further conditioned and analyzed.

The embedded system is governed by a FPGA SoC. The excitation waveform is generated inside the FPGA (LFXP2-8E from Lattice Semiconductor) via Direct Digital Synthesis (DDS). The DDS is highly flexible and allows arbitrary excitation waveforms. The digital signal is afterwards converted into a current with a 16 bit Digital to Analog Converter (DAC, LTC1668 from Linear Technology) in combination with an AD8130 (Analog Devices) based Voltage Controlled Current Source (VCCS) [4]. The current is adjustable in a range of 500 µA to 5 mA within a frequency range from 10 kHz to 250 kHz. To increase the current accuracy, the injected current is measured over a shunt resistor on the low side of the impedance under test (see figure 1).

The data acquisition is realized using a dual Analog to Digital Converter (ADC, LTC2296 from Linear Technology) in combination with two Programmable Gain Amplifiers (PGA, AD8250 from Analog Devices) for maintaining an optimal SNR at different loads. After the data is acquired and filtered inside the FPGA it is transmitted via a high speed USB 2.0 link to the host PC.

Figure 1. Principle block diagram of the developed Bioimpedance Measurement System.

Figure 2. Manufactured BMS PCB - main components are FPGA (A), DAC (B), VCCS (C), ADC (D), USB interface (E), current out and current in connectors (F), differential voltage connectors (G), PGAs and band pass filters (H), power supply (I).
III. FIRST RESULTS

For first system verification different resistors have been used as impedances under test. The achieved Signal to Noise Ratio (SNR) is about 80 dB, with a Spurious Free Dynamic Range (SFDR) of about 60 dB. The preliminary measured system transfer function seems to be highly linear in the focused frequency bandwidth. The absolute accuracy is about 1% to 10% depending on the load, and the variance over time is smaller than 0.25 % both without any calibration. Employing a calibration function the absolute accuracy could be increased to less than 1%.

The result of the measurement of a simple electrode-skin-interface phantom is shown in figure 3, 4 and 5. The excitation current was sinusoidal with amplitude of 5 mA; the measured frequency range was 12 kHz to 244 kHz. The used phantom consists of parallel a $R_i || C_1$ element in series to a resistance $R_2$ ($R_1 = 82 \, \text{k}\Omega$, $C_1 = 47 \, \text{nF}$, $R_2 = 200 \, \Omega$).

![Figure 3](image-url)  
Figure 3. Frequency spectrum of the measured voltage across the electrode-skin-interface phantom. One hundred periods are measured at $f_{\text{sample}} = 6.25 \, \text{MHz}$, with 5 mA current excitation at a frequency of 48.828 kHz.

![Figure 4](image-url)  
Figure 4. Frequency spectrum of the measured current through the shunt resistor. One hundred periods are measured at $f_{\text{sample}} = 6.25 \, \text{MHz}$, with 5 mA current excitation at a frequency of 48.828 kHz.

![Figure 5](image-url)  
Figure 5. Measured impedance (filled squares) in comparison to the theoretical impedance (blank squares), split in magnitude $|Z|$ and phase of the electrode-skin-interface phantom.

IV. SUMMARY AND OUTLOOK

We successfully designed, developed, manufactured and tested a high accuracy bioimpedance measurement system, which measures amplitude and phase. First measurements with the developed system showing promising results with an absolute accuracy of about 2% in a frequency range of 10 kHz to 250 kHz.

In future a full calibration over different loads and frequencies has to be done to further increase the measurement accuracy.

ACKNOWLEDGMENT

This work is financed by the program for the Future-Economy out of the European Regional Development Fund (ERDF).

REFERENCES