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# Integrated impedance scanner in selected biomeasurement applications – control circuit

**Keywords:** bioelectrical impedance, impedance spectroscopy, tissue, analysis of body composition, BIA - Bioelectrical Impedance Analysis, impedance scanner, microprocessor system, SoC, simulation.

## 1. Introduction

Due to its biological structure and electrical properties, living tissue can be characterized by the Bioelectrical Impedance (BI). Bioimpedance measurements are used in medicine for diagnostic purposes, including the so-called Bioelectrical Impedance Analysis (BIA), which is a noninvasive method of body composition analysis [1-3]. This method is increasingly popular also in sports medicine, aesthetics medicine and dietetics. Several manufacturers offer specialized electronic equipment for professional body composition measurements based on bioimpedance analysis [3]. However, the use of such popular, cheap systems is rather restricted to the dedicated area, and – as a result – in more universal studies one has to adapt the equipment to the particular purpose, which could be difficult, or to purchase much more sophisticated system at much higher price.

The aim of the presented study is to determine and discuss the capabilities of AD5933 integrated circuit (Analog Devices), a System-on-a-Chip (SoC) impedance scanner, in selected Bioelectrical Impedance measurement tasks concerning the above mentioned fields, with a perspective of building a cheap and universal BIA system. The design of an electronic circuit based on ARM microprocessor for control of AD5933 operation is also presented in the paper.

## 2. Material and methods

In the study, a simplified model of the human body was used [4], namely a two-terminal RC circuit (Figure 1). In the impedance measurements, range of frequency from 10 kHz to 90 kHz was applied. However, as results from the literature, in body composition analysis (BIA), the optimal frequency is equal to 50 kHz [2,3,5].

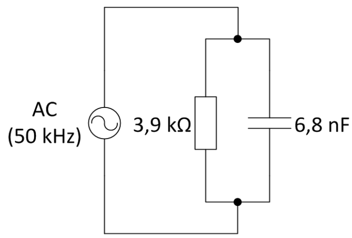


**Fig. 1.** Electrical model of the human body

Comparative measurements of impedance for the electrical model of tissue were performed with the use of integrated circuit AD5933, placed on the evaluation board EVAL-AD5933EBZ (Analog Devices), and Bodycomp-MF, MF-type (MultiFrequency: 5, 50 and 100 kHz) instrument manufactured by the AKERN company, Italy [2,5]. The device is dedicated to bioimpedance measurements of the body, and equipped with the BodyGram software for processing of the results, mainly calculations of body composition.

Similar comparative measurements were carried out for standard samples - physiological solutions (saline solutions with molar concentrations equal to 0,002 M and 0,01 M) in the laboratories of the Department of Medical Physics and Biophysics of the Pomeranian Medical University in Szczecin. In this study, additionally the Quantum II from JBL company (USA) was used. This is the SF-type BIA instrument (SingleFrequency: 50 kHz) [5]. For comparison, only 50 kHz was used.

## 3. Results

The results of impedance measurements for electrical model of the tissue (Figure 1), performed with the use of integrated circuit AD5933, were compared with the results of simulation carried out in the PSpice program for this model. Results of this comparison are shown on Figure 2 and Figure [5]. Both impedance frequency characteristics showed satisfactory similarity.

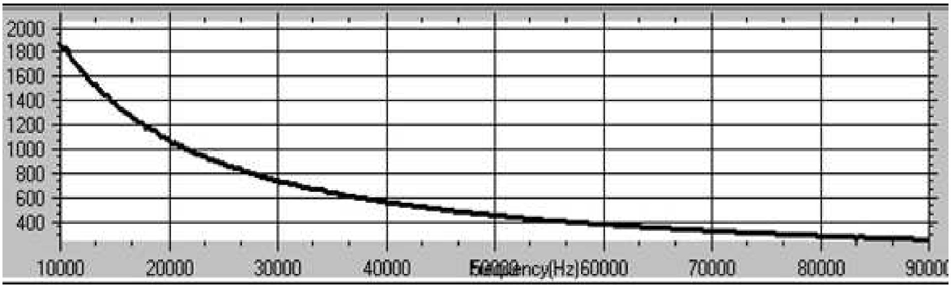


**Fig. 2.** Measurements performed with the AD5933 integrated circuit

Similar compatibility of the results was obtained in comparative measurements with the use of AD5933, Bodycomp-MF and Quantum II for physiological solutions (only single frequency: 50 kHz). Maximum differences of the values of impedance did not exceed a few percent [5].

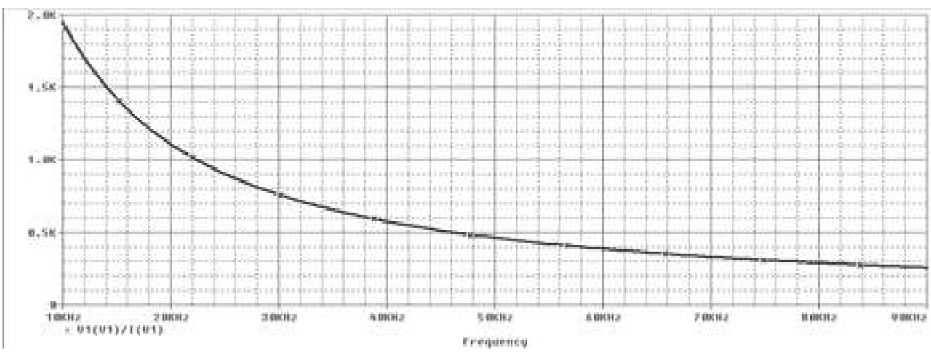

**Fig. 3.** Results of simulation in the PSpice program

## 4. Control circuit

The design of an electronic circuit based on the ARM microprocessor for control of the AD5933 operation was another goal of this research work. First, some important assumptions regarding the project of control circuit had to be made.

The main requirement met by the microcontroller for this project, is to have the hardware implemented I2C bus, or any other compliant bus. This lets us write the software faster, as we don't have to bother with software implementation of I2C. It is needed to communicate with AD5933 module, to take measurements.

Number of pins belonging to the MCU has to be at least sufficient - that is, they have to cover LCD graphical display communication and couple I/O's for tact switch keyboard to control the device.

Hardware implemented SPI bus frees from writing a software version of it. This bus is necessary to write and read measurements data from SD card for later use at a PC.

From two to three timers are needed to properly assign numerous tasks for the MCU. Pulse width modulation (PWM) is needed to control the LCD graphical display backlit brightness, and one of the timers can be used in PWM mode.

Assuming the user would need to upgrade his devices software, sending it to the manufacturer would leave user without the equipment for a longer period of time. That's why it is important to have the ability to update devices software without contribution of the manufacturer. That can be achieved, by having device USB module on board. MCU can be connected to the PC via USB and with bootloader on the microcontroller side, and dedicated application on the PC side, software update can be done.

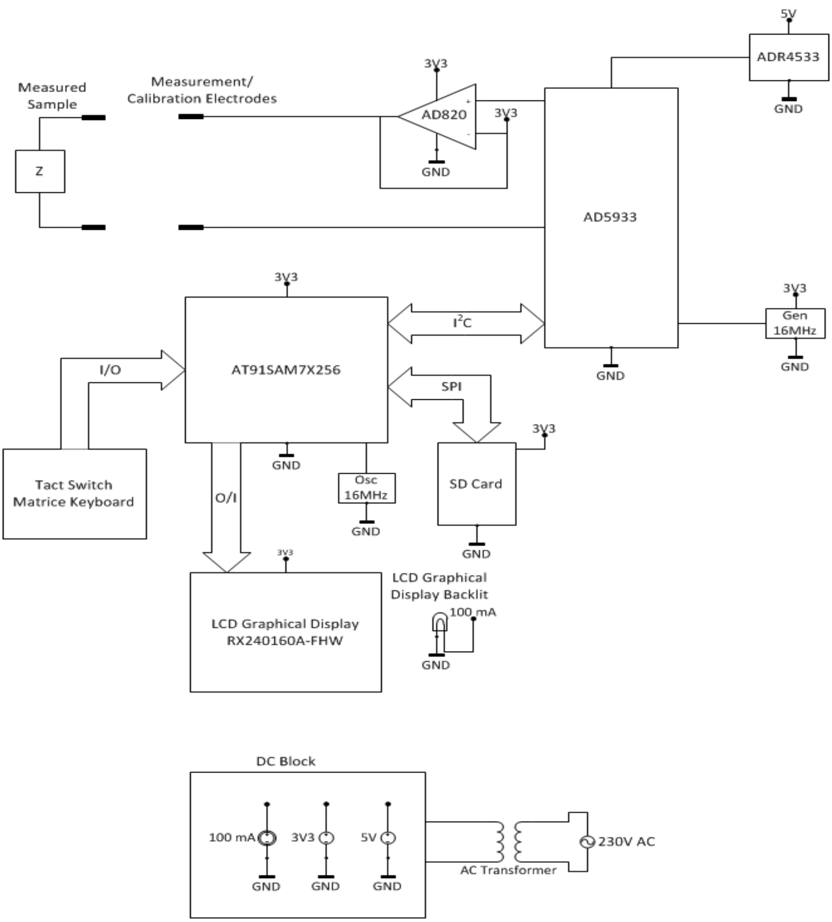


**Fig. 4.** Block diagram of the microprocessor-based BI-measurement system (explanations in the text)

This application at some point can be quite computationally extensive (i.e. drawing plots on the display). Also, it has to do some arithmetic operations. In that case, 32-bit microcontroller is preferable.

At last, MCU's memory has to be big enough to store the compiled program, and be able to execute all assumed tasks within least external components.

Taking under consideration all of the requirements met by this project, we decided to use for our prototype (and preferably for the final stationary version of the instrument) the AT91SAM7256 microcontroller produced by Atmel (ARM architecture). This module covers all needs of the application, leaving some "free space" for hardware and software expansions which are likely to take place when using the device for research purposes. Also its capacities are much better than AVR and PIC microcontrollers for the same price.

On Figure 4 the schematic diagram of the microprocessor BI-measurement system is shown.

For development work on the project, two evaluation boards were used: EVAL-AD5933EBZ (Analog Devices) with the integrated impedance scanner AD5933 and a popular development board with the AT91SAM7256 microcontroller (Atmel). Additional devices and modules shown on Figure 4 are described below.

ADR4533 – reference voltage (3.3 V); proper measurement can be done only if stable (not changing over time) voltage is applied to the analog and digital sections of the system; AD5933 operates with very low current, that is why it can be also supplied with the ADR4533.

Generator 16 MHz – system clock for the AD5933 circuit.

AD820 – used as an amplifier/buffer for the output excitation signals generated by the AD5933 scanner.

## 5. Conclusions

The results of the comparative impedance measurements fully justify the use of AD5933 module in BIA research. System-On-a-Chip (SoC), implemented in the layout, is a full-featured impedance spectroscopy measuring device.

Research tasks for further work, in which it is planned to use the results of current studies, include:

- construction of the BIA device for assessment of body composition; this application is important in the field of medical diagnostics, dietetics as well as aesthetic medicine;
- development of measuring instrument for assessment of fatigue degree after exercise (physical effort); as part of a separate study, using adapted Bodycomp-MF apparatus, we obtained very promising results for measuring with BI

technique the lactate and anaerobic thresholds of blood (LT and AT); results of this research are important mainly in sports medicine;

- development of a system for BI measurement using graphene-based biosensor; the BI-SENSOR project is currently run at the West Pomeranian University of Technology, Szczecin, under the GRAPH-TECH research and development program; such application is extremely important in advanced medical diagnostics.

In all the above specified tasks, two versions of equipment will be designed on the basis of AD5933 scanner: universal systems for stationary laboratory use, and mobile instruments for simple, fast field tests (mainly PoC, i.e. Point-of-Care devices).

Thanks to innovative solutions, it will be possible to achieve commercialization effects for the results of presented research.

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The work was in part supported by the grant “Multifunctional graphene-based biosensor for medical diagnosis (BI-SENSOR)” from the National Centre for Research and Development (NCBiR)

## Abstract

In the paper the results of preliminary experiments concerning bioelectrical impedance measurements using integrated impedance scanner AD5933 (Analog Devices) are described. Results of performed simulations are also presented. Design of a control circuit based on ARM microprocessor is described. Possible applications of the bioelectrical impedance spectroscopy method in measurements of selected characteristics of the human organism are discussed as well as plans for future development of dedicated, specialized equipment.

## Streszczenie

W pracy przedstawiono wyniki wstępnych eksperymentów dotyczących pomiarów impedancji bioelektrycznej przy użyciu zintegrowanego skanera AD5933. Zaprezentowano wyniki przeprowadzonych symulacji oraz konstrukcję układu sterowania w oparciu o mikroprocesor. Omówiono możliwe zastosowania tej metody spektroskopii impedancji bioelektrycznej w pomiarach wybranych cech ludzkiego organizmu, a także możliwości przyszłego rozwoju dedykowanego urządzenia specjalistycznego.


**Słowa kluczowe:** impedancja bioelektryczna, spektroskopia impedancji, tkanki, analiza składu ciała, BIA – analiza impedancji bioelektrycznej, skaner impedancyjny, system mikroprocesorowy, symulacje