Analog Front-End for the Integrated Circuit AD5933 Used in Electrical Bioimpedance Measurements

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Abstract – **In the recent decades the bioimpedance has been used in many areas of medicine. The technological advance of electronics has enabled the increase of bioimpedance applications. Measuring biological tissues is a hard work, which leads to the need of continuous research based on better methods and equipments for diagnosis. Many electronics manufacturers have helped the biomedical area through the development of new electronic components and equipment. The objective of this work is to adapt the impedance meter AD5933 for bioimpedance measurements. It was built two Analog Front-End (AFE) circuits consisted on two different Voltage Controlled Current Source (VCCS), which are a load-in-the-loop and a mirrored modified Howland current sources. Circuits were implemented and both two and four electrode measurements in the frequency range of 5 to 100 kHz were performed. Results showed that both front-end circuits are suitable to be used with the AD5933 at lower frequencies. Also, it might be a low-cost alternative for electrical bioimpedance applications.**

Keywords – **Bioimpedance, Front-End Circuit, Current Source, AD5933.**

I. Introduction

The bioimpedance is defined as the ability that a biological tissue has to oppose the electric current passage [1]. These tissues react to the electrical current passage and can give an important information about the body health state. The bioelectrical impedance analysis (BIA) is widely used in body composition analysis. This technique evaluates the nutritional state of the body and can help in the diagnosis of diseases linked with the body fluids [2]. The BIA has been also benefited other medical areas such as cancer research, organ transplant and healthcare systems [3, 4, 5]. The biological impedance (Z) can be determined by injecting an alternate current (I) into tissue under study and measuring the voltage resultant (V). The result V/I is a complex impedance composed of a resistive part (R) and a capacitive one (Xc). R represents the opposition to the current flowing through the tissue and Xc represents the capacitive effect produced by cell membranes [1].

Although the technique is simple, hardware and software development for biological impedance measuring is a hard work. Many electrical bioimpedance (BIA) applications have been used dedicated circuits as, for example, the AD5933 (from Analog Devices), which is used as an alternative to reduce the complexity and cost of the system [6, 7, 8, 9]. This work develops two analog font-end circuits in order to adapt the impedance meter AD5933 for bioimpedance measurements.

II. Methodology

The main project requirements are the frequency control and the current amplitude to be injected into tissue, which is standardized by the IEC-60601 standard but it depends on the frequency. However, the AD5933 inject a sinusoidal voltage with constant amplitude in a bipolar configuration, which is not a recommended method for BIA human applications. Therefore, it was developed two different circuits in a four-electrode configuration. This approach reduces the influence of the contact impedance of the electrodes and is not load dependent. Both circuits use a VCCS circuit, where the injected current has constant amplitude and it is supposed to be load independent. The first Analog Front-End (AFE-1) circuit uses a Load-in-the-loop VCCS and the second one (AFE-2) uses a mirrored modified Howland VCCS.

A. Impedance Meter AD5933

The AD5933 is a high precision impedance meter consisted of a frequency generator (DDS), digital-to-analog converter (DAC), digital signal processor (DSP), analog-to-digital converter (ADC) and auxiliary circuits. It is can generate a voltage signal with adjustable frequency up to 100 kHz with a resolution of 0.1 Hz. The current flow through the impedance is converted into a voltage and sampled by the ADC. The DSP processes both generated and received signal through an algorithm that performs Discrete Fourier Transform (DFT). The result is the real (R) and imaginary (I) part of the complex signal at each discrete frequency, which it read by the serial I2C interface. Both impedance magnitude and phase are calculated according to the component datasheet [10]. Figure 1 shows the AD5933 functional internal block and external connections, where $Z(\omega)$ is the biological load and RFB is the calibration resistor of 1 kΩ.

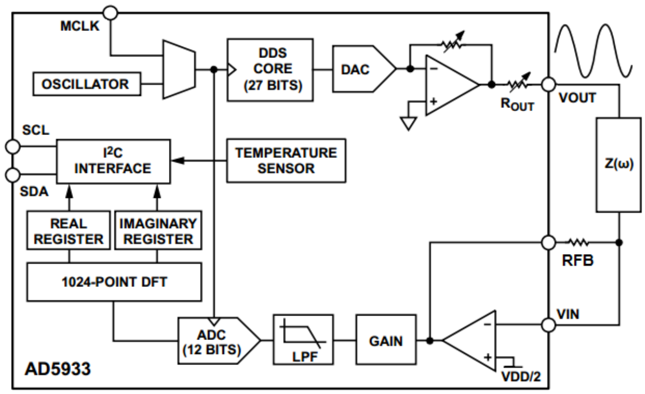

Fig. 1 AD5933 Functional Block Diagram [10]

B. Load-in-the-loop current source – AFE-1

This is a current source where the load (biological tissue) is connected in the negative feedback of the amplifier. A high pass filter (HPF) removes the DC component of the V_{out} signal (=1 Vpp). The current that flows in the load (1mApp) is calculated by the ratio $V_{out}/R1$. The resistor R2 (=1 MΩ) is used to prevent the saturation of the Op-Amp and directly influences the output impedance of the source. An instrumentation amplifier (INA118) measures the voltage drop on the load, which is read by the AD5933. Due to the monopolar AD converter contained inside the AD5933, it is necessary an offset voltage (=Vdd/2) to be summed with the measured voltage.

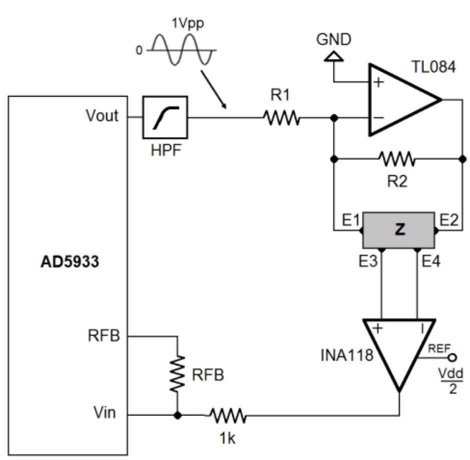

Fig. 2 Schematic of the Load-in-the-Loop Current Source

C. Mirrored Modified Howland Current Source – AFE-2

It consists of a VCCS composed by two symmetrical Howland-modified current sources connected to the load, as shown in Figure 3. The VCCS provides a constant output current (=1 mApp) that is given by the ratio between Vout (=1 Vpp) and the resistor *r* (=1 kΩ). All resistors have a low precision tolerance in order to obtain a good current source performance [13]. It was used resistors with ±1% of tolerance. In order to reduce power consumption, the resistor r of the Howland circuit (see Figure 3) should be much smaller than the value of R (=47 kΩ). The capacitor C (=0.1 µF) prevents DC offset voltages of the amplifier returning and then avoiding saturation. The circuit for measuring the voltage across the load is the same for both AFE-2 and AFE-1.

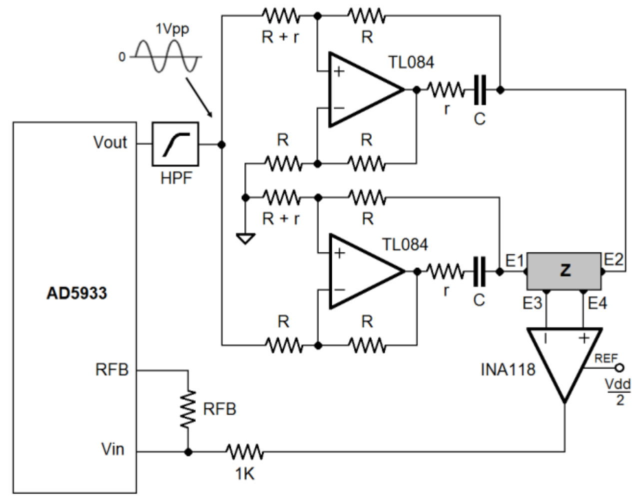

Fig. 3 Schematic of the Mirrored Howland-Modified Current Source

D. Microcontrolled System

A microcontroller (Atmega328 from Atmel) accesses the impedance data under test by means of the I2C interface from AD5933. The software in the microcontroller receives commands from the computer by its the serial interface, which allows the total control of the AD5933. The software permits the user to perform a frequency sweep with a user-defined start frequency, frequency resolution, and number of points in the sweep. In addition, the device allows the user to set both Vout and RFB values. The microcontroller sends the impedance data (both real and imaginary part) by its serial interface at each analyzed frequency. Data are sent in a text format.

III. Results

The system was tested by using two typical biological impedance models. The calibration procedures were based on the AD5933 datasheet, accordingly [10]. In order to cover a wide range of calibration resistance values, the impedance were chosen accordingly. Resistors and capacitors have a tolerance of ±1% and ±10%, respectively. Figures 4 and 5 show the magnitude and phase of the impedances A and B, as well as their respective theoretical values in the frequency range of 5 to 100 kHz.

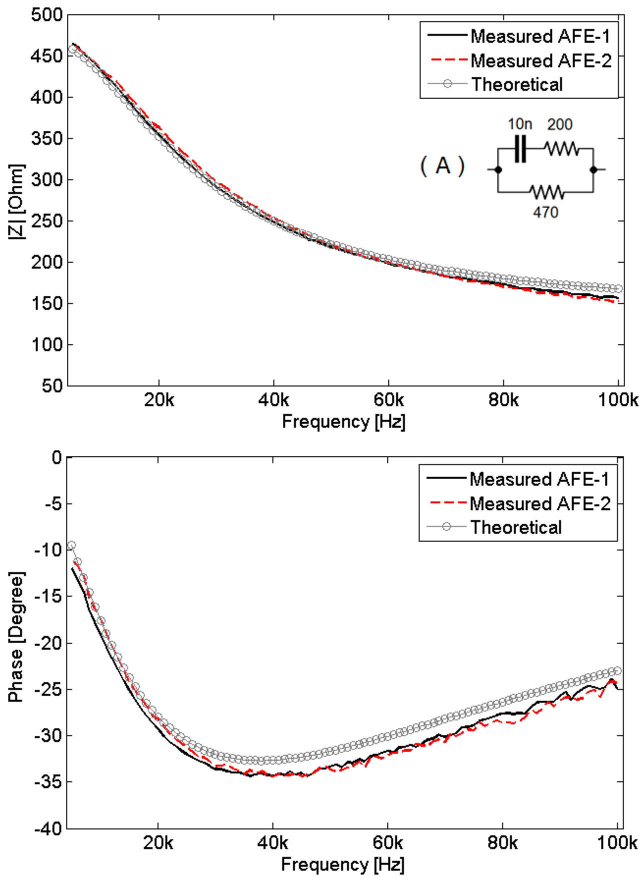

Fig. 4 Frequency response of both module and phase load impedance A.

Both theoretical impedance module and phase (load A) range from 50 to 85% below the RFB value (=1 kΩ). On the other hand, it varies 20% above and 50% below the RFB. The AFE-2 presented a better performance than the AFE-1, especially for frequencies higher than 50 kHz. As expected, the errors increase with increasing frequency, but they were higher for the load B. Figure 6 shows the relative errors for both module and phase load impedance B. It was only analized at 5, 50 and 100 kHz, according to the literature of BIA systems.

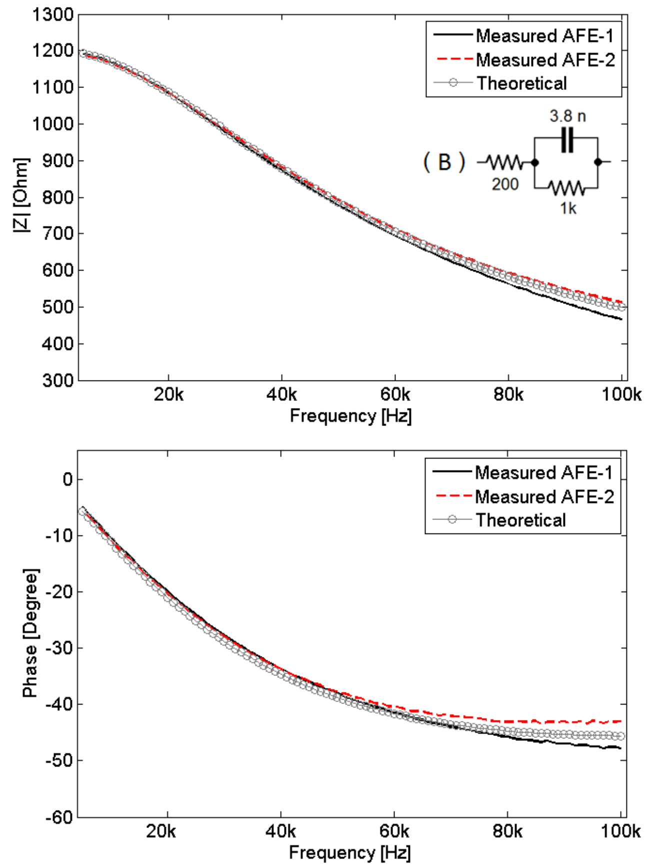

Fig. 5 Frequency response of both module and phase load impedance B.

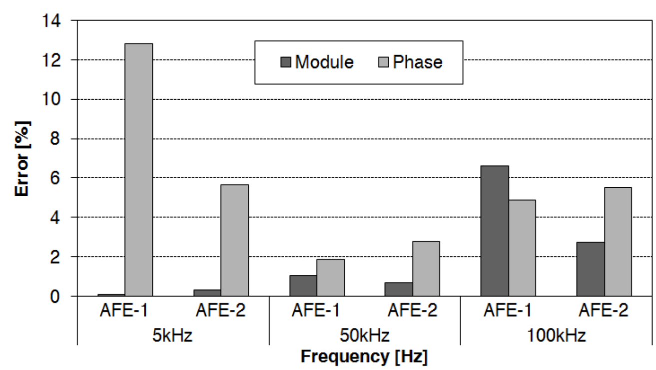

Fig. 6 Error analysis at 3 discrete frequencies for both module and phase load impedance B.

IV. Discussions

Topologies used in both current sources are simple and easy to be buitl. The topology shown in AFE-1 was widely used in the 60s, but it was replaced by other circuits due to its high frequency limitation required in many BIA applications. Recently, a research has been showed that the evolution of the electronic components enables the use of a simple VCCS topology (AFE-1) for BIA applications [11]. Acceptable results by Macias *et al* [12] were found in the AFE-1 topology when assessing the circuit performance up to 1MHz. The AFE-2 topology has a good stability for the frequency range used in this work, but depends strongly on the symmetry between the current sources [13].

A critical limitation is the system calibration, where a resistive load has to be equal to the calibration resistor (RFB) when calculating the gain of the system [10]. Impedance values higher than 30% of RFB saturate the ADC input and compromises the system accuracy. Additionally, impedance values lower than RFB generates low voltages in the ADC input which is easily affect by noise interference. Thus, the correct choice of RFB is essential to determine the correct impedance load. However, in EBI applications the dynamic range is small and is possible to have a good precision for a proper calibration. The calibration problem is noted in the impedance A, where the values significantly lower than RFB (50 to 85%). In this case, the measured voltage is very low and can to explain the phase response slightly noisy. For the impedance B, the values range is relatively close to RFB and can be noted a similar value to the theoretical model. The obtained results were satisfactory at 50 kHz, which enable the AFE-1 and AFE-2 circuits to be used in a single frequency BIA analysis (SF-BIA).

V. CONCLUSION

The main requirements in this work were the low-cost and portability. Two different VCCS topologies were developed to adapt the AD5933 impedance analyzer for EBI using. It can be concluded that both proposed Front-End circuits are suitable for BIA applications in the frequency range of 5 to 100 kHz.

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REFERENCES

1. Martinsen ΦG and Grimnes S. (2008) Bioimpedance and Bioelectricity Basics. Academic Press, 2 Edition
2. Mialich MS, Faccioli JM Sicchieri et al. (2014) Analysis of Body Composition: A Critical Review of the Use of Bioelectrical Impedance Analysis. International Journal of Clinical Nutrition, Vol. 2, No.1, 1-10
3. Kamat DK, Chavan AP and Patil PM. (2014) Bio-Impedance Measurement System for Analysis of Skin Diseases. International Journal of Application or Innovation in Engineering & Management (IJAIEM), Volume 3, Issue 2, February 2014.
4. Fleury A, Sugar M and Chau T. (2015) E-textiles in Clinical Rehabilitation: A Scoping Review. Electronics 2015, 4, 173-203
5. Ferreira J, Seoane F, and Lindecrantz K. (2011) AD5933-Based Electrical Bioimpedance Spectrometer. Towards Textile-Enabled Applications. 33rd Annual International Conference of the IEEE EMBS, Boston, Massachusetts USA, August 30 - September 3, 2011
6. Pliquett U and Barthel A. (2012) Interfacing the AD5933 for bioimpedance measurements with front ends providing galvanostatic or potentiostatic excitation. First Latin-American Conference on Bioimpedance (CLABIO 2012), Journal of Physics: Conference Series 407
7. Martínez-Teruel J, García-Sánchez T, Fontova A et al. (2013) Electrical Impedance Spectroscopy cell monitoring in a miniaturized bioreactor. 119th IMEKO TC 4 Symposium and 17th IWADC Workshop Advances in Instrumentation and Sensors Interoperability, July 18-19, 2013, Barcelona, Spain
8. Margo C, Katrib J, Nadi M et al. (2013) A four-electrode low frequency impedance spectroscopy measurement system using the AD5933 measurement chip. Physiol. Meas. 34, 391–405
9. Seoane F, Ferreira J and Sanchéz JJ. (2008) An analog front-end enables electrical impedance spectroscopy system on-chip for biomedical applications. Physiol. Meas. 29, S267–S278
10. AD5933 Application notes at http://www.analog.com
11. Seoane F, Macías M, Bragós R et al. (2011) Simple voltage-controlled current source for wideband electrical bioimpedance spectroscopy: circuit dependences and limitations. Meas. Sci. Technol. 22, 11pp
12. Macías R, Seoane F and Bragós R. (2010) Performance of the Load-in-the-Loop Single Op-Amp Voltage Controlled Current Source from the Op-Amp Parameters. International Conference on Electrical Bioimpedance IOP Publishing Journal of Physics: Conference Series 224
13. Bertemes-Filho P, Felipe A and Vincence VC. (2013) High Accurate Howland Current Source: Output Constraints Analysis. Circuits and Systems, 4, 451-458

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