Pedro Bertemes-Filho, Emiliano Amarante Veiga / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 3, Issue 4, Jul-Aug 2013, pp.2399-2403

The Santa Catarina Mark 1 Bioimpedance System: Preliminary Results

Pedro Bertemes-Filho*, Emiliano Amarante Veiga*
*Department of Electrical Engineering, State University of Santa Catarina, Joinville, Brazil

ABSTRACT

The electrical bioimpedance spectroscopy is used as powerful technique for characterizing biological materials and detecting tissue anomalies. Commercial impedance analyzers can make impedance measurements of biological materials in a wide frequency range. However, they are expensive and have not been manufactured for measuring in vivo biological materials due to safety concerns. This work presents the performance of first bioimpedance system of the State University of Santa Catarina (BIATRON I). It is based on a FPGA which generates the signals and processes the data to be visualized in the computer via an USB interface. It contains an isolated front-end measuring system, guard electrodes for compensating cable capacitances and an impedance probe which can be fully sterilized in autoclaves. Measurements were taken from five saline solutions in order to perform the system frequency response. Data were converted into impedance by using a novel PSO algorithm. Results have shown that the developed system is reliable for measuring impedance spectra of saline solutions. Future measurements from biological tissues are going to be done for a fully characterization.

Keywords **–** Electrical Bioimpedance, FPGA, Guard Electrodes, PSO Algorithm, Tissue Impedance

I. INTRODUCTION

Over a decade the electrical bioimpedance is being investigated as a potential technique for detecting cancerous tissues [1,2,3,4], tumors [5], meningitis [6] and brain cellular oedema [7], for analyzing body composition [8] and bovine milk quality [9,10,11,12]. The EIS is considered a fast, inexpensive, practical and efficient technique [13], which also can be found available for emerging wearable applications [14] and for on-chip systems such as the AD5933 [15]. Commercial impedance analyzers from Agilent Technologies [16], Solartron Analytical [17] or Zurich Instruments [18] can make impedance measurements of biological materials in a wide frequency range. However, they are expensive and have not been manufactured for measuring in vivo biological materials due to safety concerns but they intend to be used as a benchtop instrument. Furthermore, they need extra fixtures for measuring organic samples and also either a lock-in amplifier or front-end system.

This technology is relatively simple, quick and noninvasive way for obtaining the impedance spectrum of the material under study. The impedance is then related to an equivalent electrical model of the material in order to fit to the measured data [19]. The first impedance fitting process was done by Cole [20], so called Cole-Cole function. Artificial Neural Networks [9] and Particle Swam Optimization [21] and other techniques [22] have been used for extracting the electrical properties from the measured impedance spectra.

As multi-frequency excitation signal is required, multiple Direct Digital Synthesizer (DDS) can be used to produce discrete frequencies in the time domain, and then sine waves are obtained by filtering the high-frequency harmonics [23]. Digital Signal Processing (DSP) integrated circuits (IC) are also widely used for this purpose, but they suffer from speed, power consumption and limiting number of storage points [24]. Multi-frequency systems use multiple Digital Direct Synthetizer (DDS) but the synchronization is also difficult [24]. Field-Programmable Gate Array (FPGA) has been proposed as a hardware technology for DSP systems in order to generate multi-frequency sine waves at high speed and accuracy.

The main objective of this work is to present the development and the performance of the first Bioimpedance system of the State University of Santa Catarina for the analysis of biological materials, such as bovine milk. It also presents the fitting processing for converting the measurements either into conductivity or impedance spectra.

II. METHODOLOGY

The prototype of the electrical bioimpedance system is shown in Fig. 1. This is the mark 1 in the State of Santa Catarina (Brazil), which is called BIATRON 1.0. It consists of a signal generator, an injecting current circuit, a measuring system and a PC graphical interface.

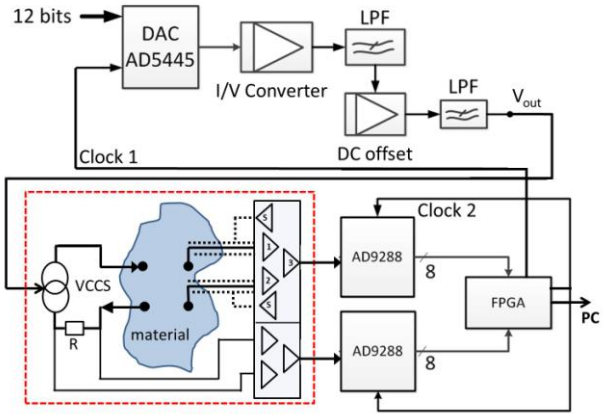

Figure1. Schematic diagram of the bioimpedance system, where VCCS is a voltage controlled current source and R is a shunt resistor.

2.1 HARDWARE DESCRIPTION

The sine wave generator is based on FPGA Spartan 3 from Xilinx (model XC3S200), which contains a DDS module with a phase generator and a sine/cosine lookup table [25]. The frequency is controlled by software using phase increments. The data was converted to digital by a DAC (Digital to Analog Converter) of 8 bits at a sampling rate of 667 kHz. 25 discrete frequencies were generated over a frequency range from 0.1 to 500 kHz. More details about the generating process can be seen in Veiga *et al* [26].

The voltage signal is converted into a current by a modified Howland bipolar current source [27], which converts an input voltage of 1 Vpp (peak-to-peak) to an output current of 1mApp over the frequency range. Both load voltage an injecting current are simultaneously measured. The system uses double shield coaxial cables for better performance at higher frequencies. The outers shield of the measuring cables are buffered by each respective input voltage.

The current is injected by two electrodes of the probe, which was designed for this study and it is shown in Fig. 2. It can be seen that it contains a tip with 4 gold electrodes equally separated by 2.4 mm and the electrode diameters are 1.5 mm. The developed impedance probe can be sterilized in autoclaves.

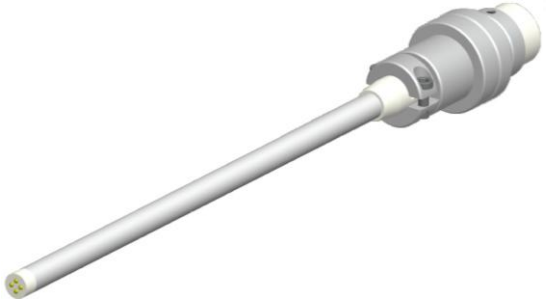

Figure 2. Developed impedance probe for the BIATRON 1.0 system.

The final prototype version 1.0 for the bioimpedance system is shown in Fig. 3.

Figure 3. Inside view of the BIATRON 1.0 system.

Both impedance modulus and phase are processed and sent to a computer via an USB connection. Also, the hardware is controlled by the user by using a graphical interface which was developed in C++. The screen of the graphical interface is shown in figure 4. This shows a measurement cross a resistive load of 100 Ω at 100 Hz. It can be seen that either single or sweep frequency can be selected. Also, both graphics and all data points can be saved for post-processing.

Figure 4. Screen shot showing the graphical interface of the BIATRON 1.0 system.

2.2 PROBE CALIBRATION

In order to calibrate de impedance probe, five different saline solutions were measured by using the prototype BIATRON 1.0 over the frequency range from 0.1 to 500 kHz. The dc conductivity of each saline solution was measured by a conductivity meter (model CD4303) from Digital Instruments. Table 1 shows the conductivity meter readings at dc frequency. The equivalent measured impedance of the solutions can be calculated in (1) [28], where ρ is inversely proportional to the conductivity σ and δ is the probe factor. By assuming point electrodes, the probe factor can be calculated in (2), where A and B are the injecting electrodes, C and D are the measuring electrodes, R_{AC}, R_{AD}, R_{BD} and R_{BC} are the distance between electrodes centers.

Table 1. Conductivity meter results of 5 saline solutions.

Solution	Conductivity [mS/cm]
A	5.88
B	4.08
C	2.20
D	1.46
E	0.84

$$Z_{calc} = \frac{\rho}{2\pi} \cdot \delta \quad (1)$$

$$\delta = \frac{1}{R_{AC}} - \frac{1}{R_{AD}} + \frac{1}{R_{BD}} - \frac{1}{R_{BC}} \quad (2)$$

By the fact that the bioimpedance system imposes a phase shift error when measuring the equivalent impedance of the saline solutions, an impedance model was used in order to fit the measured data into the modeled one. Figure 5 shows the impedance model used in this work, where Cs and Rs represent the series impedance of the bioimpedance system and Rc represents the equivalent resistance of the saline solution under study.

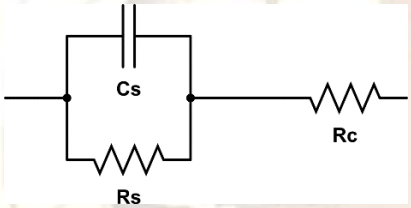

Figure 5. Fitting impedance model used in the calibration process.

The expected impedance from model showed in Fig. 4 can be calculated in (3). The fitting process was performed by using the Particle Swarm Optimization (PSO) algorithm, which is be fully in [21].

$$Z_{total} = Rc + \frac{Rs}{1+(\omega \cdot Rs \cdot Cs)} - j\frac{\omega \cdot Cs \cdot (Rs)^2}{1+(\omega \cdot Rs \cdot Cs)^2} \quad (3)$$

III. RESULTS

Figure 6 shows the spectra of the conductivity measured by the BIATRON 1.0 developed system and taking into account the equation 1. It can be seen in Figure XX that the conductivity increases as increasing frequency, which might be caused by strays capacitance from the electronic system. The maximum mean error for all solutions was found to be approximately 20.3% at higher frequencies.

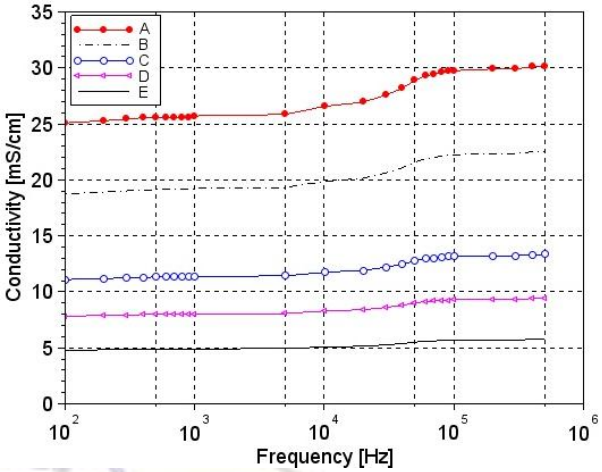

Figure 6. Conductivity frequency response of the saline solution measured by the BIATRON 1.0 system.

Figure 7 shows the measured and fitted impedance modulus of the saline solution *A* (see table 1) measured by the BIARON 1.0 system. The measured data was then calculated according to (1) and the fitted data as obtained by the PSO algorithm. It can be seen that the data can be fitted by the algorithm with a maximum error of 0.08 Ω at low frequency.

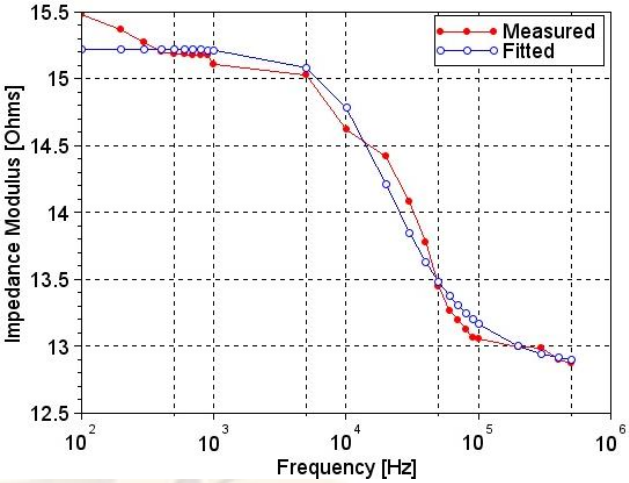

Figure 7. Impedance spectra of the saline solution *A*.

The fitting mean errors for all the solution is show in table 2. It can be seen that the mean error increases as increasing the resistivity of the solution. This might be explained by the fitting process error at low frequency as the error is at its maximum.

Table 2. Mean errors of the measured equivalent impedance of the solutions.

Solution	Error [mΩ]
A	80
B	100
C	180
D	260
E	420

It is shown in table 3 the comparison between the measured and calculated data according to (1). It can be seen that the highest error occurred for the lowest resistive solution, which might be explained by the fact that the equation 1 does not take into account the finite size of the electrodes and then the probe factor might be different.

Table 3. Comparison between measured and calculated impedance at 1 kHz.

Solution	$Z_{measured}$ [Ω]	$Z_{calculated}$ [Ω]	Error [%]
A	10.5	11.3	7.4
B	15.6	16.3	4.3
C	29.5	30.1	1.9
D	43.8	45.3	3.4
E	74.5	78.3	4.7

IV. CONCLUSION

The preliminary results from the first Bioimpedance system of the State University of Santa Catarina (BIATRON I) showed that the device is reliable for measuring saline solution impedance over the frequency range 0.1 to 500 kHz. Further measurements from biological tissues are going to be taken and a complete characterization be performed.

V. ACKNOWLEDGEMENTS

We thank the State University of Santa Catarina (UDESC) and the Foundation for Research Support of Santa Catarina (FAPESC) for the financial support under grant TO 2454/2011-6.

REFERENCES

[1] S. Abdul, B.H. Brown, P. Milnes, and J. Tidy, The use of Electrical Impedance Spectroscopy in the detection of Cervical Intraepithelial Neoplasia, *Int J. Gynecological Cancer, 16*, 2006, 1823-1832.

[2] A. Keshtkar, Z. Satlehnia, and B. Shokouhi, Cancer Detection Using Electrical Impedance Technique (Tabriz Mark 1), *Pathology Research International*, 2012, 1-5.

[3] P. Aberg, I. Nicander, and S. Ollmar, Minimally invasive electrical impedance spectroscopy of skin exemplified by skin cancer assessments, *Proc. of the EMBS Annual Int. Conf.*, Cancun, Mexico, 2003, 3211-3214.

[4] P. Aberg, I. Nicander, J. Hansson, P. Geladi, U. Holmgren, and S. Ollmar, Skin Cancer Identification Using Multifrequency Electrical Impedance—A Potential Screening Tool, *IEEE Transactions on Biomedical Engineering 51(12)*, 204, 2097-2102

[5] C. Skourou, A. Rohr, P.J. Hoopes, and K.D. Paulsen, In vivo EIS characterization of tumor tissue properties is dominated by excess extracellular fluid, *Phys. Med. Biol. 52(2)*, 2007, 347–363.

[6] B.K. Van Kreel, Multi-frequency bioimpedance measurements of children in intensive care, *Med. Biol. Eng. Comput, 39(5)*, 2001, 551–557.

[7] B.E. Lingwood, K.R. Dunster, P.B. Colditz, and L.C. Ward, Noninvasive measurement of cerebral bioimpedance for detection of cerebral edema in the neonatal piglet, *Brain Res. 945(1)*, 2002, 97–105.

[8] U.M. Moissl, P. Wabel, P.W. Chamney, I. Bosaeus, N.W. Levin, A. Bosy-Westphal, O. Korth, M.J. Müller, L. Ellegård, V. Malmros, C. Kaitwatcharachai, M.K. Kuhlmann, F. Zhu, and N.J. Fuller, Body fluid volume determination via body composition spectroscopy in health and disease, *Physiological Measurement, 27(9)*, 2006, 921-933.

[9] P. Bertemes-Filho, L.H. Negri, and A.S. Paterno, Detection of Bovine Milk Adulterants Using Bioimpedance Measurements and Artificial Neural Network, *Proc. 5th European Conference of the International Federation for Medical and Biological Engineering*, Budapest, Hungary, 2011, 1275-1278.

[10] C. Piton, A. Dasen, and I. Bardoux, Assessment of the impedance measure for a rapid evaluation of the bacteriological quality of raw milk, *Lait, (68)*, 1988, 467-484.

[11] S. McDougalla, P. Murdough, W. Pankey, C. Delaney, J. Barlow, and D. Scruton, Relationship among somatic cell count, *Small Rumin Res, 40(3)*, 2001, 245-254.

[12] Yang L and Bashir R, Electrical/electrochemical impedance for rapid detection of foodborne pathogenic bacteria, *Biotech Advanced*, 26, 2008, 135-150.

[13] S. Grimnes, and O.G. Martinsen, *Bioimpedance and Bioelectricity Basics* (Norway: Academic Press, 2000).

[14] A. Yúfera, and A. Rueda, Design of A CMOS Closed-Loop System Useful for Bio-Impedance Measurements, *Proc. 16th IEEE International Conference on Electronics, Circuits and Systems*, Tunisia, 2009, 948-951.

[15] J. Ferreira, F. Seoane, A. Ansede, and R. Bragos, AD5933-based spectrometer for electrical bioimpedance applications, *Journal of Physics: Conference Series, 224*, 2012, 1-4.

[16] I. Marinova, and V. Mateev, Determination of Electromagnetic Properties of Human Tissues, *World Academy of Science, Engineering and Technology*, *42*, 2010, 733-737.

[17] R.E. Schmukler, and J.W. Dixon, Microprocessor controlled bioimpedance measurements, *14th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Paris, France, 1992, 2381.

[18] S. Emaminejad, M. Javanmard, R. Dutton, and R. Davis, Microfluidic diagnostic tool for the developing world: contactless impedance flow cytometry, *Lab on a Chip*,*12*, 2012, 4499-4507.

[19] U.G. Kyle, I. Bosaeus, A.D. De Lorenzo, P. Deurenberg, M. Elia, J.M. Gomez, B.L. Heitmann, L.K. Smith, J.C. Melchior, M. Pirlich, H. Scharfetter, A.M.W.J. Schols, and C. Pichardm, Bioelectrical impedance analysis - part I: review of principles and methods, Clinical Nutrition, 23, 2004, 1226-1243.

[20] K.S. Cole, and R.H. Cole, Dispersion and Absorption in Dielectrics - I Alternating Current Characteristics, *J. Chem. Phys., (9)*, 1941, 341–352.

[21] L.H. Negri, P. Bertemes-Filho, and A.S. Paterno, Computational intelligence algorithms for bioimpedance-based classification of biological material, *Proc. 5th European Conference of the International Federation for Medical and Biological Engineering*, Budapest, Hungary, 2012, 1229–1232.

[22] A.S. Paterno, R.A. Stiz, and P. Bertemes-Filho, Frequency-domain reconstruction of signals in electrical bioimpedance spectroscopy, *Medical & Biological Engineering & Computing*, *47(10)*, 2009, 1093-1102.

[23] X. Zhang, H. Wang, S. Chen, and Y. Zhang, FPGA-based Multi-frequency Excitation and Modulation Technology in EIT System, *Proc. 3rd International Conference on Biomedical Engineering and Informatics*, Yantai, China, 2010, 907-911.

[24] R. Woods, J. McAllister, G. Lightbody, and Ying YI, *FPGA-based Implementation of Signal Processing Systems* (Chichester: John Wiley & Sons, 2008).

[25] Xilinx, Spartan-3 FPGA Starter Kit Board User Guide, http://www.xilinx.com/support/documentation/boards_and_kits/ug130.pdf, access: June 2013.

[26] E.A. Veiga, and P. Bertemes-Filho, Bioelectrical impedance analysis of bovine milk fat, *Journal of Physics*: *Conference Series*, 407, 2012, 1-4.

[27] R.A. Stiz, P. Bertemes-Filho, A. Ramos, and V.C. Vincence, Wide Band Howland Bipolar Current Source using AGC Amplifier, *IEEE Latin America Transactions*, *7*, 2009, 514-518.

[28] P. Bertemes-Filho, *Tissue Characterization using an Impedance Spectroscopy Probe*, doctoral diss., The University of Sheffield, Sheffield, UK, 2002.