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Handheld Bioimpedance Spectrometer for the Total Frequency Range of the β-Dispersion

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Abstract

A portable bioimpedance measurement device is useful to provide information non-invasively about patient health in both clinical and home environments. In this work, a handheld bioimpedance spectrometer was developed to realize measurements in the frequency range 5 kHz-1 MHz in order to measure the whole range of the β-dispersion which includes the pathological status. The impedance range was chosen from 10 Ω to 10 kΩ for measurements of even low impedances which are important in special medical applications, such as lung edema.

1. Introduction

There is still a great need for non-invasive monitoring and detection of pathological changes on a regular basis in clinical and home environments to improve the quality of life for patients. Among many non-invasive techniques such as X-ray, ultrasound, magnetic resonance imaging (MRI), bioimpedance spectroscopy is considered as an attractive diagnostic technique for medical applications. It helps to reduce the healthcare cost and provide reliable repeated instantaneous results.

Bioimpedance spectroscopy is based on the injection of a constant current on tissue and the measurement of the resulting voltage at a selected frequency range. The frequency dependence of tissue is known as dispersion. In biological systems, there are three dispersions (alpha, beta, and gamma) from low to high frequencies. The alpha dispersion, from mHz to KHz, relates to the ionic diffusion processes at site of cellular membrane, beta dispersion, from KHz to MHz, is associated with polarization of cellular membranes and gamma dispersion, up to MHz, relates to polarization of water molecules [1]. In this study, we will focus on the beta dispersion since it includes the electrical properties of cells and tissues.

The aim of this work is to have a practical, inexpensive and reliable handheld bioimpedance spectrometer used for a wide range of biomedical applications to control patients in clinical and home environments. For reasons of patient safety [2] a maximal AC-current of 0.5 mA and frequency range between 5 kHz and 1 MHz can be applied. The relevant impedance range of pathological status in different diseases is between 10 Ω and 10 kΩ.

2. State of the Art

Commercial bioimpedance spectrometers are generally designed for specific application such as detection of hypervolemia in peritoneal dialysis [3], lymphedema [4] or detection of lung water [5]. These spectrometers show limitations concerning low impedances and they are expensive.

Tab. 1: Selected examples of requirements for bioimpedance measurements

Devices	Ref.	Current (mA)	Impedance	Frequency	Application	Tools
Commercial bioimpedance spectrometer	[3]	0.2	———	5 KHz -1 MHz	Detection of Hypervolemia in Peritoneal Dialysis Patients	Multi-Frequency Analyzer (BCM: Body Composition Monitor)
	[5]	0.07-0.5	200Ω-800Ω	5 KHz -1 MHz	Detection of lung water	Xitron Hydra 4200
Developed bioimpedance spectrometer	[6]	0.5	Thoracic impedance less than 100 Ω	5 KHz -100 KHz	Early warning of lung edema	AD5933
	[7]	0.14	9Ω-5.7kΩ	20 kHz-1 MHz	Bioimpedance spectroscopy (BIS) measuement	Portable device for BIS
	[8]	0.8	100Ω -1 kΩ	100 kHz-1 MHz	Biological measurments	Cole-Cole Impedance Meter

Several developed bioimpedance spectrometers have limited frequency based on the impedance analyzer AD5933 [6] or make more a focus on higher frequencies [7]. The main disadvantage of the impedance analyzer AD5933 is that it can only limit the voltage and not the current thereby the highest excitation signal is dependent on the value of the impedance. In addition, it is limited to 100 KHz. Some others have limited impedance ranges [8].

3. General Structure of the Handheld Spectrometer

For the impedance measurement of biological systems, there are three basic techniques. The bridge method, the quadrature demodulation method and the magnitude ratio and phase difference detection.

Tab. 2: Selected techniques for bioimpedance measurements

Method	Advantages	Disadvantages
Bridge method [9]	High measurement resolution	Time consuming
Classical analog quadrature demodulation method [10]	———	Large phase error Need for avoiding any mismatch between in-phase (I) and quadrature (Q) references
Digital quadrature demodulation [11]	No need for analog I and Q references	High cost High power consumption
Magnitude ratio and phase difference detection [7]	Cost-effective alternative for real time impedance measurement	———

Tab.2 shows that the bridge method, the classical analog quadrature demodulation method and the digital one are not suitable for the design of handheld bioimpedance spectrometer. This is because of their high cost, high time and power consumption. Thereby, the portable spectrometer in this study is designed on the base of the magnitude ratio and phase difference detection. This method has many advantages comparing to other methods thanks to its rapidity in measurement and simplicity of design. The impedance is calculated from the gain and the phase extracted by comparison of the excitation signal and the response signal (Fig.1).

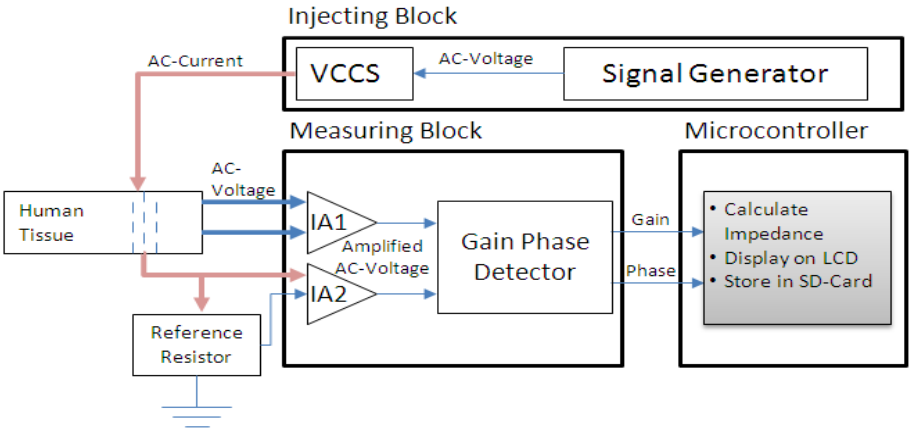


Fig. 1: Block diagram of handheld bioimpedance spectrometer [1]

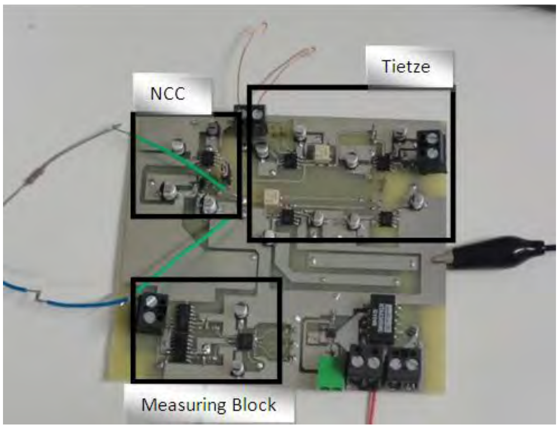
4. System design of portable device

The developed system contains an injecting block, a measuring block, and a digital signal processing unit (Fig.1).

4.1. Injecting block

It consists of a low power signal generator (AD8934) and a voltage controlled current source (VCCS). It is still a challenge to generate an AC-current with constant amplitude from low frequencies up to 1 MHz.

The voltage controlled current source plays an important role to ensure a safe current injected on the human body. A comparative study between several types of Howland circuit and Tietze circuit [1] shows that the amplitude of the current decreases especially in high frequencies due to the presence of stray capacitances. In order to avoid this effect, a negative capacitance circuit was connected to the Tietze circuit (Fig.2 (a)). The resulting voltage controlled current source shows a good performance and accuracy with an error less than 1% along the selected frequency range (Fig.2 (b)).



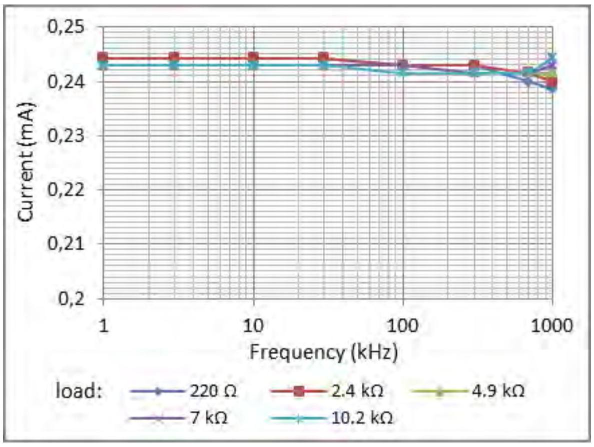


Fig. 2 :

(a) The main board of spectrometer portable *(b) Experimental Result of Tietze with NCC*

4.2. Measuring block

It is realized by means of two instrumentation amplifiers with a high bandwidth and high common mode rejection ratio (CMRR) and a gain phase detector (Fig.2). It is based on the integrated circuit AD8302 [12] for measuring gain and phase difference.

4.3. Digital signal processing unit

A Digital Signal Processor (DSP) is a specialized microprocessor with an architecture optimized for the fast operational needs of digital signal processing. The main functions of DSP are measuring, filtering or converting analog signals to digital form and treating them. The DSP is integrated in a control block (Fig.3), which includes an LCD-Display, keyboard and SD-card. It allows the user to select the necessary frequency range, tunes the sine waves generated by the frequency generator, calculates the impedance from the signals of the gain phase detector, displays the results and stores them on SD-card.

Fig. 3: Block diagram of the control block

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4.3.1. Interfacing the DSP to the sine wave generator AD9834

The AD9834 can operate at clock rates up to 40 MHz and is compatible with DSP and microcontroller standards. Connection with external device is ensured using an internal serial interface block which has 3 pins:

- SDATA Serial data input: The 16-bit serial data-word is applied to this pin.
- SCLK Serial Clock Input: Data is shifted into the AD9834 on each falling SCLK edge.
- FSYNC Active Low Control Input: When FSYNC is taken low, the internal logic is informed that a new word is being loaded into the device.

These pins are connected to any SPI module includes in the DSP such as SDATA connected to SPISIMO Slave In, Master Out, SCLK connected to SPICLK: Clock and FSYNC connected to SPISTE\: Transmissions enable.

The octal buffer 74HCT244 is a digital buffer assures the interface between DSP and AD9834. In fact Serial Data applied, clock and the transmission enable signals should be buffered before being applied to the serial interface. This Interface between TMS320F2808 and AD9834 is shown in Fig.4.

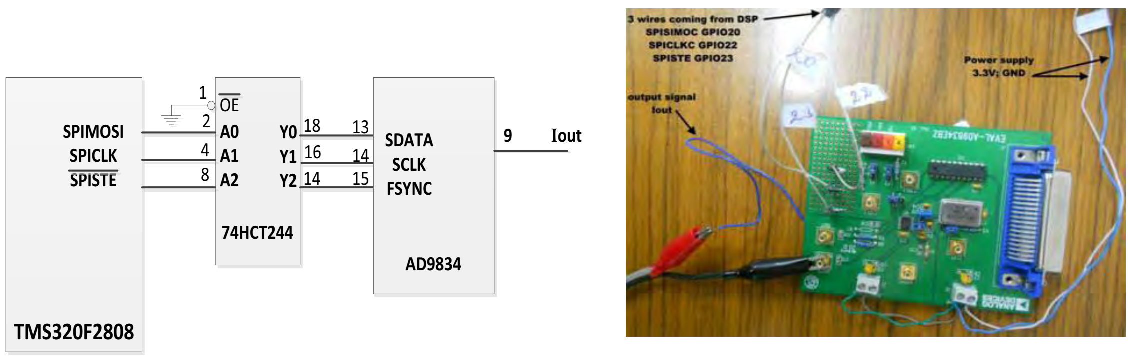

Fig. 4: *Interface between TMS320F2808 and AD9834*

4.3.2. Interfacing the DSP to the gain phase detector AD8302

AD8302 provides the gain and the phase to the ADC block which converts them from analog to digital form then calculates the impedance value. Pins 13 and 9 of AD8302 output simultaneously the gain and the phase; these two pins are connected to two inputs pins of the ADC block: ADCINA0 and ADCINB0 as mentioned in Fig.5.

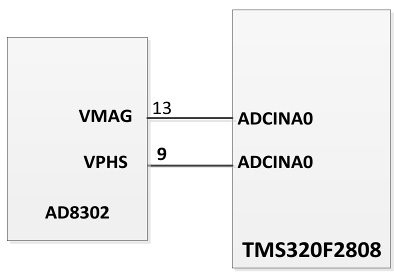

Fig. 5: *Interface between TMS320F2808 and AD9302*

4.3.3. Interfacing the DSP to Keypad, LCD and SD Card

The keypad can be interfaced easily to our DSP TMS320F2808 as it doesn't need any particular protocol. Its pins are connected to general purpose GPIO pins. For LCD and SD card, they can use serial peripheral interface (SPI) or parallel (SD) interface to connect to the host. SPI mode is simpler than SD mode which is usually used for high capacity cards, for our application we use SPI mode (Fig.6).

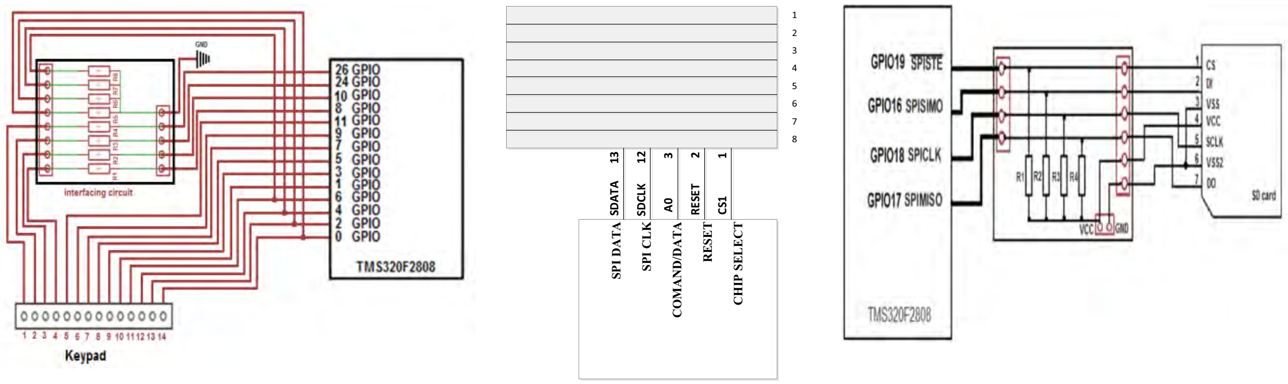

Fig. 6: *Interface between TMS320F2808 and Keypad, LCD and SD Card*

5. Conclusion

In our analysis, we have designed a handheld bioimpedance spectrometer based on magnitude ratio and phase difference detection method. Regarding the first aspect, it is processed within a safe injected current lower than 0.5 mA. Having a constant current injected through a frequency range up to 1 MHz is considered as a challenge. To cope with that, we use the Tietze circuit connected to Negative Capacitance Circuit (NCC) with a deviation less than 1%. Secondly, it works within the total frequency range of beta dispersion, from 5 KHz to 1 MHz, with impedance varying from 10 Ω to 10 kΩ. The chosen frequency and impedance range include the pathological status in different medical applications.

6. References

[1] H.P. Schwan, J.H.Lawrence, C.A.Tobias "Electrical properties of tissue and cell suspensions. In: Advances in Biological and Medical physics", Eds. Vol V, 147-209, Acad.Press,1957.

[2] D. Bouchaala, X. Chen, Q. Shi, O. Kanoun and N. Derbel, « Comparative study of voltage controlled current source for bioimpedance measurement », 9th International Multi-Conference on Systems, Signals & Devices, March 2012.

[3] H. Ender *et al*. Bioimpedance Spectroscopy for the Detection of Hypervolemia in Peritoneal Dialysis Patients. *Advances in Peritoneal Dialysis*, Vol. 27, 2011

[4] http://www.impedimed.com/products/

[5] L. Beckmann *et al*. Monitoring of body fluid in patients with chronic heart failure using Bioimpedance Spectroscopy. O. Dössel and W.C. Schlegel(Eds.): WC 2009,IFMBE Proceedings 25/VII, pp. 532–535, 2009.

[6] T.Schlebusch *et al*. On the road to a textile integrated bioimpedance early warning system for lung edema. International Conference on Body Sensor Networks, 2010.

[7] Y. Yang, J. Wang, G. N. Yu et al.: "Design and preliminary evaluation of a portable device for the measurement of bioimpedance spectroscopy". Physiol. Meas., Vol. 27, pp. 1293 – 1310, 2006

[8] H. Solmaz, Y. Ulgen, and M. Tumer Design of a microcontroller based Cole-Cole impedance meter for testing biological tissues. IFMBE Proceeding, vol. 25, pp.488-491, 2009

[9] P.Steendijk, G.Mur *et al.* The four-electrode resistivity technique in anisotropic media: theoretical analysis and application on myocardial tissue in vivo *IEEE Trans. Biomed. Eng.* **40** 1138–48, 1993.

[10] R. Pallas-Areny and J.G.Webster, Bioelectric impedance measurements using synchronous sampling *IEEE Trans.Biomed. Eng.* **40** 824–9, 1993.

[11] R. Casanella, O.Casas and R. Pall`as-Areny, Differential synchronous emodulator for modulating sensors and impedance measurements *Meas. Sci. Technol.* **16** 1637–43, 2005.

[12] AD8302 Data Sheet 2002 Analog Devices, (available in PDF format from http://www.analog.com/UploadedFiles/Data Sheets/97075782AD8302 a.pdf)