Wideband Bio-impedance Spectroscopy using Voltage Source and Tetra-polar Electrode Configuration

Pil Joong Yoo, Dae Hyun Lee, Tong In Oh and Eung Je Woo

Department of Biomedical Engineering, Kyung Hee University, Korea

E-mail: ejwoo@khu.ac.kr

Abstract. Most bio-impedance spectroscopy (BIS) systems inject sinusoidal current with a variable frequency into a sample with a known geometry through a pair of electrodes. Adopting the so-called tetra-polar configuration, it measures induced voltage data on a separate pair of electrodes. Impedance spectra are plotted in a certain range of frequency. We found that its accuracy decreases at high frequencies primarily due to the deteriorated performance of the constant current source at high frequencies. Using a previous BIS system we developed, we found that the overall performance can be kept high up to several hundred kHz. In this study, we propose a design of a wideband BIS system using a constant voltage source. It is based on the simple voltage division between an internal resistor and an external sample or load. We switch the value of the internal resistor (R_s) so that the source voltage is divided more or less equally. Two pairs of electrodes are attached to the sample. Two independent voltmeters are used to separately measure two voltages across the chosen internal resistor and the sample. The voltage measurement across the sample is done between the second electrode pair only. This enables us to adopt the tetra-polar configuration to avoid the problem related with contact impedances. We describe the design, construction and performance of the new BIS system with 468 Hz to 2.2 MHz bandwidth. We will compare the results with those using the impedance analyzer.

Keyword: bio-impedance spectroscopy, voltage source

1. Introduction

A bio-impedance spectroscopy (BIS) system measures admittivity spectra of biological tissues. Using an RC circuit model, we obtain conductivity and permittivity of the sample. Repeating the measurement at multiple frequencies, we may produce admittivity spectra of the sample. Since 1960s, numerous studies have shown that there exist large variations in admittivity spectra of different biological tissues [1-3]. Results of BIS studies have significantly contributed to our understandings of electromagnetic phenomena inside the human body.

These may be classified into two types according to the source. In the first type, active current source injects current into a tissue sample with a known geometry and measure induced voltage to find its admittance or impedance [4,5]. The second type uses voltage source instead of using current source. Some calibration methods are applied to the result for minimizing the impact of stray capacitance, drift and/or non-ideality [6]. In order to improve the measurement accuracy, the amount of injecting current is measured with sense resistor at the output stage and then, admittance is calibrated with this value.

We have developed a BIS system using a balanced current source and a voltmeter in the frequency range of 10 Hz to 500 kHz [7]. One pair of electrodes was used to inject current to a sample and the other pair measured induced voltage to remove the contact impedance terms in the

measurement. For frequencies above 5 kHz, we adopted multiple generalized impedance converter (GIC) circuits to minimize the output capacitance of the current source. Although we calibrated the balanced current source for its maximal output impedance, its performance was degraded at frequencies above 500 kHz primarily due to effects of stray capacitances. In this study, we suggest improving the performance at high frequencies using a method based on a voltage source and two voltmeters. We adjusted the sense resistor at the output stage to get better accuracy.

2. Method

2.1 KHU Mark2 BIS system design

We may consider our previous BIS system comprising a balanced constant current source and a voltmeter as a one-channel multi-frequency EIT system [7]. Because it is based on the current source, the highest operating frequency was limited by 500 kHz. In designing a new BIS system, we adopted a voltage source and tried to minimize the size so that it is portable.

Figure 1 shows the structure of the new BIS system including a voltage source and two voltmeters. We apply a sinusoidal voltage with a variable frequency to the series connection of the internal current-sensing resistor R_s and the sample. Measuring the voltage across R_s by using one voltmeter, we know how much current is being injected. We use the second voltmeter to measure the induced voltage across the sample. Using two separate pairs of electrodes attached on the sample, we can adopt the tetra-polar electrode configuration to reject effects of unknown contact impedances. We expect that the constant voltage source is advantageous at frequencies above 500 kHz.

The FPGA (Cyclon III EP3C10F256C8N, Altera, USA) controls two ADCs (AD9235BRUZ-65, Analog Devices, USA) and one DAC (AD9783, Analog Devices, USA) for digital phase-sensitive demodulations and voltage waveform generation. The DSP (TMS320F2812, Texas Instruments, USA) exchanges commands and data with each modules implemented within the FPGA through 2 SCI ways to control all functions of the impedance measurement. A PC with BIS software is connected to the BIS system through an isolated USB port for graphical user interface and output display.

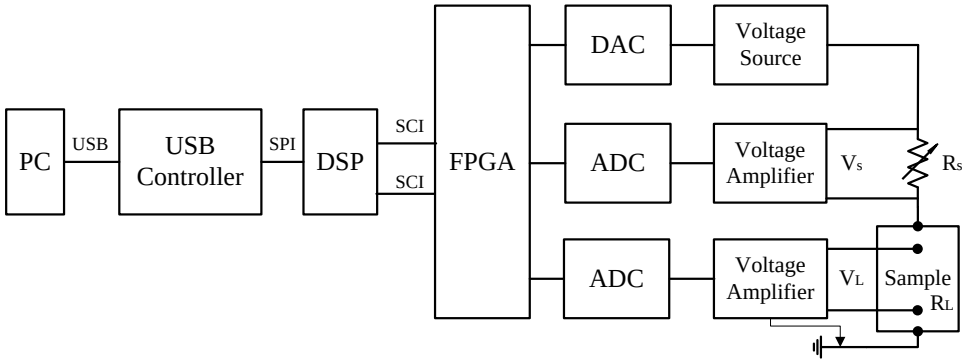


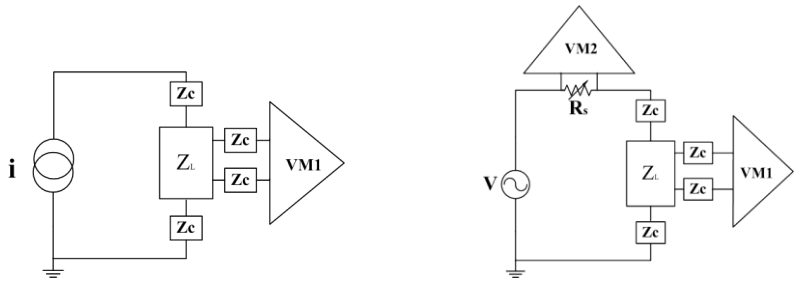
Figure 1. Structure of the new KHU Mark2 BIS system.

2.2 Bio-impedance measurement

The voltage from the constant voltage source is divided by the internal current-sensing resistor R_s and the sample. We measure induced voltages across R_s and the sample simultaneously. Since we adjust the value of R_s so that magnitudes of two voltages are comparable, every impedance measurement includes two measurements. We used a digital potentiometer (DS1267, Dallas semiconductor, USA) to control the value of R_s. If internal current-sensing resistor (R_s) is too smaller than that of sample (R_L), V_s has worse SNR. It can also have bad effects to the result when we calibrate it using V_s. On the contrary to this, total resistance may be too large because internal current sensing resistance is bigger than sample. Output characteristic of voltage source will be worse. So that, we have to adjust R_s until it will have similar value as the sample resistance. In the new design, we needed to increase the

bandwidth of voltage amplifiers for impedance measurements at frequencies beyond 500 kHz. We also increased the sampling frequency of the ADC.

We use two independent voltmeters to separately measure two voltages across R_s and the sample. Figure 2 shows two tetra-polar electrode configurations. Since there is no contact impedance across the internal current-sensing resistor, we directly measure voltage across it. For the voltage measurement across the sample, we always use a separate pair of electrodes where no probing current flows. This enables us to adopt the tetra-polar configuration to avoid the problem related with contact impedances.



(a) (b)

Figure 2. Tetra-polar electrode configuration for (a) current source and (b) voltage source. VM is a voltmeter and Z_C is a contact impedance.

2.3 Digital control and communication

The DSP operates at 150 MHz clock speed to increase the overall speed of the system. We adopted USB technology for communicating with PC. The USB port is electrically isolated from the BIS system. The single FPGA performed multiple functions including data communication, demodulations, waveform generation and control.

3. Result

Figure 3 shows voltage spectra of a parallel RC components of 100 Ω and 10, 100, 2000 nF. We measured load resistance for comparing results in BIS system and impedance analyzer (SI1260, Solartron). We can see that measured data using the voltage source closely follows the numerical simulation results and measurement data using the impedance analyzer.

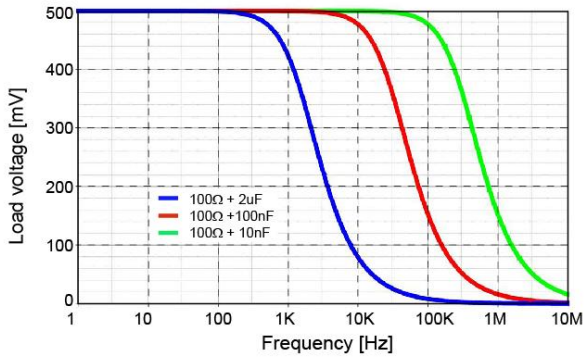


Figure 3. PSPICE simulation of load voltage across a parallel RC circuit (blue line: 100Ω+2uF, red line: 100Ω+100nF, green line: 100Ω+10nF).

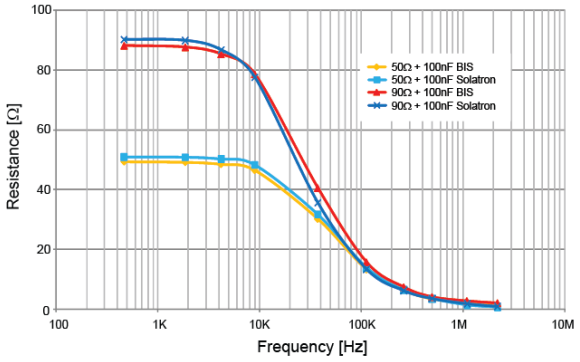


Figure 4. Comparison of the resistance in BIS system and impedance analyzer.

Figure 5 shows the developed new BIS system implemented in a single PCB. We tried to measure

the resistivity of carrot with BIS and impedance analyzer as shown in figure 6. Both results have similar trend of spectra.

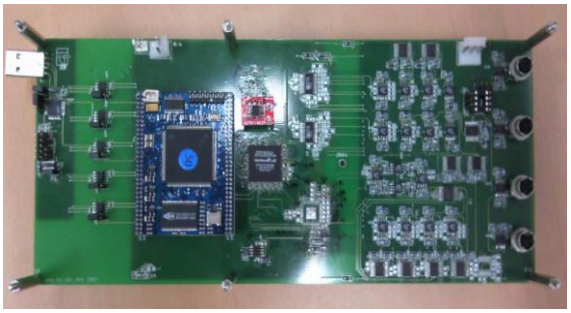


Figure 5. BIS Mark2 system.

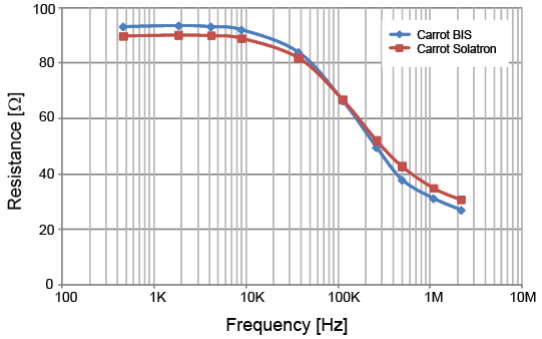


Figure 6. Comparison of the resistance of carrot in BIS system and impedance analyzer.

4. Conclusion and discussion

We developed a wideband BIS system using a voltage source and two voltmeters. We used voltage measurements across an internal current-sensing resistor to calibrate the impedance of the sample. Simultaneously measuring two voltages from the internal resistor and the sample, we adjusted the resistance value of the internal resistor for better measurement accuracy. The tetra-polar electrode configuration was still possible using the voltage source. We need to look at the performance of the developed BIS system by comparison with BIS system which uses current source. Since we have minimized the size of the system, we plan to construct a portable BIS system for application in electrical bio-impedance studies.

Acknowledgement

This work was supported by the SRC/ERC program (R11-2002-103) of MOST/NRF

Reference

[1] Geddes, Baker Geddes L A and Baker L E 1967 The specific resistance of biological material: a compendium of data for the biomedical engineer and physiologist *Med. Biol. Eng.* **5** 271–293

[2] Gabriel S, Lau R W and Gabriel C 1996 The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz *Phys. Med. Biol.* **41** 2251–2269

[3] Grimnes S and Martinsen O G 2000 Bioimpedance and Bioelectricity Basics *London, UK: Academic*

[4] Hong H, Rahal M, Demosthenous A and Bayford R H, Comparison of a new integrated current source with the modified Howland circuit for EIT applications, *Physiol. Meas*. **30**, 999-1007.

[5] Hartov A, Mazzarese R A, Reiss F R, Kerner T E, Osterman K S, Williams D B and Paulsen K D 2000 A multichannel continuously selectable multifrequency electrical impedance spectroscopy measurement system *IEEE Trans Biomed Eng.* **47**, 49-58.

[6] Saulnier G J, Ross A S and Liu N 2006 A high-precision voltage source for EIT, *Physiol. Meas*. **27**, S221-S236.

[7] T. I. Oh, H. Koo, K. H. Lee, S. M. Kim, J. Lee, S. W. Kim, J. K. Seo and E. J. Woo 2008 Validation of a multi-frequency electrical impedance tomography (mfEIT) system KHU Mark1: impedance spectroscopy and time-difference imaging *Physiol. Meas*. **29**, 295-307.