AD5933-based Spectrometer for Electrical Bioimpedance Applications

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Abstract. To build an Electrical Bioimpedance (EBI) spectrometer using the Impedance Measurement System-On-Chip AD5933 together with a 4-Electrode Analog Front End (4E-AFE) has been proven practicable. Such small measurement devices can make possible several new applications of EBI technology, especially when combined with functional textiles, which can enable wearable applications for personal health and home monitoring. After the implementation and functional validation of the 4E-AFE-enabled spectrometer, the next natural step is to validate for which EBI applications the 4E-AFE-enabled system is suitable. To test the applicability of this novel spectrometer on several EBI applications, 2R1C equivalent models have been experimentally obtained and impedance spectroscopy measurements have been performed with the system under study and with the SFB7 EBI spectrometer manufactured by ImpediMed. The 2R1C circuit parameters have been estimated with the BioImp software from the spectra obtained with both EBI spectrometers and the estimated values have been compared with the original values used in each circuit model implementation. The obtained results indicated that the 4E-AFE-enabled system cannot beat the performance of the SFB7 in accuracy but it performs better in preciseness. In any case the overall performance indicates that the 4E-AFE-enabled system can perform spectroscopy measurements in the frequency range from 5 to 100 kHz.

1. Introduction

Over recent years, advances in different technological fields like electronics, physics and materials have made possible to embed complex functional systems into a single integrated circuit producing the System-on-Chip technology. As a result of such technological advances a whole impedance spectrometer is available on a single integrated circuit: the AD5933 [1] from Analog Devices. Such a level of integration together with advances made in textile technology, especially in the development of textile electrodes suitable for applications of Electrical Bioimpedance (EBI) [2], might enable wearable applications for personal health and home monitoring based in EBI measurements.

In this work the performance of a custom-made EBI spectrometer based on the AD5933 in combination with a 4-electrode Analog Front End [3] is evaluated when measuring 3 different

impedance loads modeling three typical EBI applications: Total Body Composition (TBC), Respiration Rate (RR) and Lungs Composition (LC), also known as Pulmonary Edema [4] .

2. Materials and Methods

2.1. Spectrometers and 2R1C models
Two different spectrometers have been used in this work: the ImpediMed SFB7 and a custom-made device based in the AD5933 in combination with an analog front-end to enable 4-electrode impedance measurements [3].
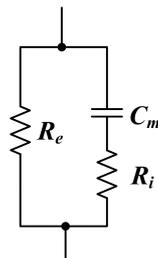

Figure 1. 2R1C parallel bridge model

The measurements have been performed on a 2R1C parallel electrical model representing biological tissue, see Figure 1. The values of the model parameter to build the 2R1C models, R_e, R_i and C_m, were extracted from experimental EBI measurements with the software BioImp [5]. The 2R1C have been build to produce an impedance complex spectrum similar to experimental impedance spectra obtained in the aforementioned applications. The resistors used in the model belong to the E-24 series and a potentiometer was used to trim the values of the circuit parameters, see Table 1, to obtain the intended impedance spectrum.

Table 1. 2R1C Modeling for TBC, RR and LC EBI Applications.

EBI Application	Electrical Equivalent 2R1C Values		
	$R_e\,(\Omega)$	$R_i\,(\Omega)$	C_m (nF)
TBC	917.5	665.4	3.42
RR	58.5	25.58	75.7
LC	81.5	22.15	47.7

2.2. Methods
Using both impedance spectrometers, 100 impedance measurements were performed in the frequency range 5 to 100 kHz on each experimentally-based 2R1C circuit model. For each EBI application the average complex spectrum from the measurements was obtained for each of the impedance spectrometers. A comparison between the resistance and the reactance spectra obtained from each spectrometer has been done.

Using the software BioImp applied on the measured impedance spectra obtained with each of the spectrometers, the value of the 2R1C circuit parameters was estimated and the obtained estimation error was studied to perform a comparison between the SFB7 and the AD5933-based spectrometer.

3. Results

3.1. Spectral Measurements

The reactance and resistance spectra from the impedance measurements for the different EBI applications are plotted in Figure 2. As it is denoted in all the spectral plots, the spectra obtained with both devices are perfectly overlapped for both the resistance and the reactance. Only a small deviation at high frequency can be observed on the reactance of for TBC and RR on Figure 2.b) and 2.d) respectively.
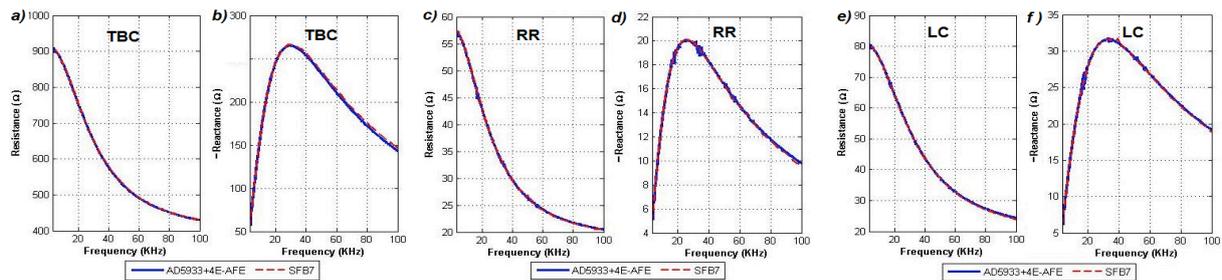

Figure 2. Resistance and reactance spectrum plots from the measurements obtained with the AD5933-based spectrometer in continuous and SFB7 in dashed trace, respectively.

3.2. 2R1C Circuit Parameters Estimation

The average values estimated for the 2R1C parameters from the impedance measurements obtained with both spectrometers are indicated in Table 2. For each of the applications, the relative differences respect the real values of the circuit components, as indicated in Table 1, are indicated by the relative error. The Standard Deviation obtained with both spectrometers for the estimation of each of the parameters is also indicated. For all the applications and all the parameters with the exception of the estimation of C_m for TBC, the SFB7 exhibit a smaller error than the AD5933-based spectrometer. Regarding to the Standard Deviation, it is the AD5933-based spectrometer the one that presents lower values for each of the parameters and all three applications.

Table 2. Error and Accuracy on 2R1C Parameters Estimation, SFB7 vs. AD5933+4E-AFE

EBI Application		TBC		RR		LC	
Parameter		SFB7	AD+AFE	SFB7	AD+AFE	SFB7	AD+AFE
	Average Value (Ω)	917,88	914,15	58,33	57,89	81,37	81,07
R_e	Standard Deviation	0,1594	0,0423	0,0177	0,0077	0,0193	0,0131
	Relative Error	0,04%	0,36%	0,29%	1,03%	0,16%	0,53%
	Average Value (Ω)	664,49	676,3	25,60	26,00	22,25	22,95
R_i	Standard Deviation	0,5540	0,1280	0,0493	0,0238	0,0498	0,0193
	Relative Error	0,14%	1,64%	0,08%	1,63%	0,44%	3,63%
	Average Value (nF)	3,34	3,37	74,56	74,08	46,67	46,28
C_m	Standard Deviation	0,0009	0,0003	0,0444	0,0181	0,0149	0,0117
	Relative Error	2,22%	1,47%	1,50%	2,14%	2,16%	2,97%

4. Discussion

The spectral plots obtained with both spectrometers show that the AD5933-based spectrometer with the 4-electrode enabling front-end produced complex impedance spectra that are almost exact to the spectra obtained with the SFB7.
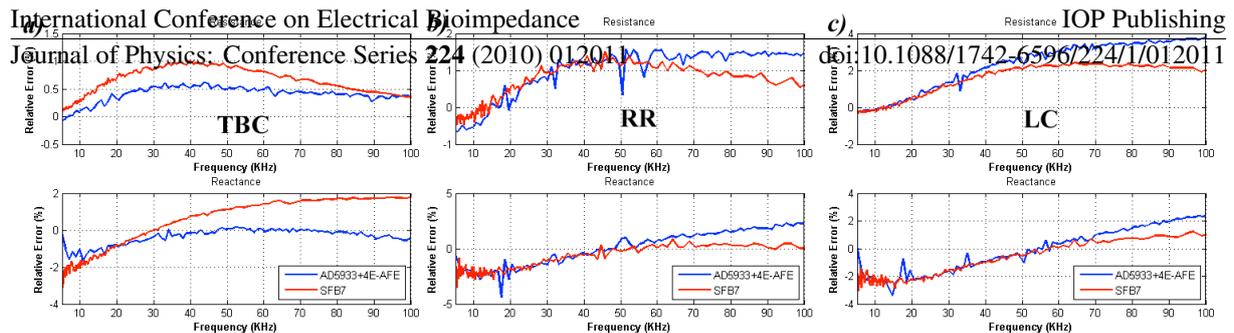
Figure 3. Relative measurement error in the resistance and the reactance obtained for the measurements with both EBI spectrometers for the three applications under study: TBC, RR and LC in a),b) and c) respectively

The analysis of the error data provided by Table 2 and Figure 3, suggest that the SFB7 presents a better accuracy than the AD5933-based spectrometer. In any case the estimation errors produced with both devices are generally low.

In the other hand according to Table 2, the preciseness shown by the custom-made impedance spectrometer based on the AD5933 is higher than the preciseness obtained with the SFB7. Both dispersions and errors obtained with both equipments are small compared with the high variability of the clinical measurements. E.g. in the measuring of Lungs Circulate Air Volume [5] the error measured with a neumotacometer and with Electrical Impedance Tomography (EIT) is around 20%, compared with the worst case studied in this work for RR the error drops below 4%.

5. Conclusion

The good complex spectroscopy performance exhibited by the AD5933-based spectrometer as well as the high accuracy and precision exhibited for the 2R1C model parameter estimation, which is critical in applications of total body composition assessment [6], strongly supports that EBI spectrometers based in SOC solutions like the AD5933 can be use in typical EBI applications like body composition analysis, respiration rate and pulmonary edema.

The reduced size of the AD5933, its small power consumption [7] together with the availability of off-the-shelf Bluetooth solutions indicate that the implementation of portable applications of EBI is close, even wearable if combined with textile garments [8] and electrodes [2].

6. References

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