Realization of Complex Impedance Measurement System Based on the Integrated Circuit AD5933

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Abstract — **This paper describes realization of complex impedance measurement system based on integrated circuit AD5933. AD5933 is controlled by ATmega128 which performs all calculations and creates report for off-line analysis on PC. Created report of measured values of impedance magnitude and phase angle is stored on micro SD card in format which is compatible with MS Excel. Realized device is equipped with self-calibration system which ensures high accuracy in wide impedance range. Device also has alphanumeric LCD for displaying results. Realized system can be used for sensor or complex impedance measurements, structural health monitoring, noninvasive blood impedance measurements, electro-impedance spectroscopy, etc.**

Keywords — **AD5933, complex impedance, microcontrollers, sensors.**

I. INTRODUCTION

FROM biological cell analysis to fuel cell tests, from coatings to cement paste quality control, complex impedance measurement has become a powerful tool in the vast environment of those applications. The basic principle of complex impedance measurement is modeling the unit under test in a combination of electrical components, applying small amplitude of AC voltage or current to the ends of unit under test, over the frequency band of interest. For each frequency in the range, the measured impedance is a complex ratio between the input and output signal [1].

Various design and application of systems for complex impedance measurements can be found in literature. In the following text, some characteristic applications are shown. For example, in [2], [3] authors described design and development of system for structural health monitoring based on complex impedance measurement. Realized system can provide great benefits to many industries such as large cost savings in maintenance of complex structures, e.g. aircraft and civil infrastructure.

Blood coagulation is a complex, dynamic physiological process by which clots are formed to end bleeding at an injured site. In [4] authors presented how impedance measurement can monitor blood coagulation. They used the integrated circuit AD5933 [5]-[8] which offered flexibility, power, and size advantages to the end user over the existing commercially available solutions. More details about various biomedical applications can be found in [9]-[17].

In [18], the seat occupancy detection by measuring the impedance value is presented. The same IC (AD5933) is used to convert the impedance value of the person or object to a digital value. Then the state of occupancy of the seat is determined according to the measured impedance.

Impedance spectroscopy is a method widely used for testing of biological and physicochemical objects. Many times tests are performed on objects located directly in the field. An example of such use of impedance spectroscopy is the testing of the performance of anticorrosion coatings on objects directly in the field e.g. on bridges, pipelines and other steel structures. One realization of the portable analyzer for impedance spectroscopy [19] is also based on the AD5933.

Apple vitality was detected using impedance measurement in [20]. Realized system provides a nondestructive measurement technique which can measure wide range of impedance.

Due to these facts, it is obvious that realization of simple and accurate system for complex impedance measurements is very important as the basic part of more complex devices with usage in various industrial and biomedical applications. In following chapters hardware and software structure of prototype is presented with discussion of obtained experimental results and possible further improvements regarding the accuracy and dimension.

II. DEVICE STRUCTURE

The complex impedance meter presented in this paper is a high precision, low power consumption impedance measurement system which provides programmable frequency sweep and tuning capability for impedance measurement from 1 kΩ to 5 MΩ with system accuracy better than 0.5 % for resistive and 3.5 % for reactive impedances.

Proposed structure of device for complex impedance measurement is presented in Fig. 1. The system is built with an AVR microcontroller ATmega128 [21], Analog Devices network analyzer AD5933, two analog multiplexers 74HTC4051 [22], micro SD card and LCD.

The Atmel AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. The resulting architecture is more code efficient

This work was financially supported by European Commission in the framework of the FP7 project SENSEIVER, grant number 289481.

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while achieving throughputs up to ten times faster than conventional CISC microcontrollers [21].

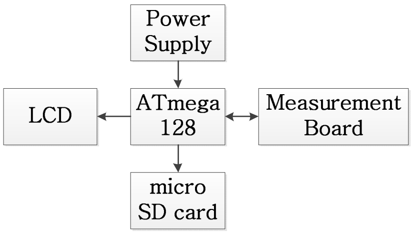


Fig. 1. Block scheme of device for complex impedance measurement

Measurement board is based on the AD5933. The AD5933 fully integrated single-chip impedance analyzer (Fig. 2) is a high-precision impedance-converter system that combines an on-board frequency generator with a 12-bit, 1 MSPS, analog-to-digital converter (ADC). The frequency generator provides an excitation voltage to external complex impedance at a known frequency. The response signal (current) is sampled by the on-board ADC, and a discrete Fourier transform (DFT) is processed by an on-board DSP engine. The DFT algorithm returns real (R) and imaginary (I) data-words at each output frequency. Using these components, the magnitude and relative phase of the impedance at each frequency point along the sweep can be easily calculated [5].

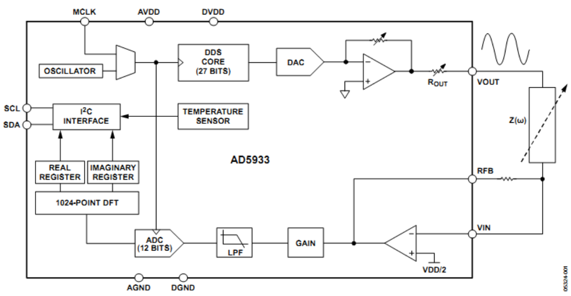


Fig. 2. Functional block diagram of impedance-measurement system

The block diagram of the AD5933 demonstrates the full integration of the impedance measurement system. Local digital processing enables the calculation of the complex impedance of the circuit under test. The system requires initial calibration: a precision resistor is substituted for the impedance to be measured; and a scaling factor is calculated for subsequent measurements.

The AD5933 can measure impedance values between 1 kΩ and 10 MΩ to a system accuracy of 0.5% for excitation frequencies from 1 kHz to 100 kHz.

Single-supply devices, such as the AD5933, often center signal swings around a fixed value of DC bias. This is not an important consideration in most impedance measurements, but DC voltages above a specific threshold cause electrochemical processes to take place in aqueous conducting media in contact with electrodes, altering the sample. To prevent this electrolysis from occurring in measurements with the AD5933 in the current project, the signal conditioning circuit shown in Fig. 3 was used.

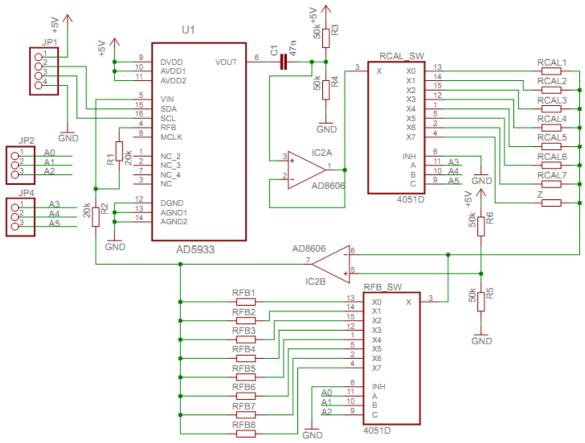
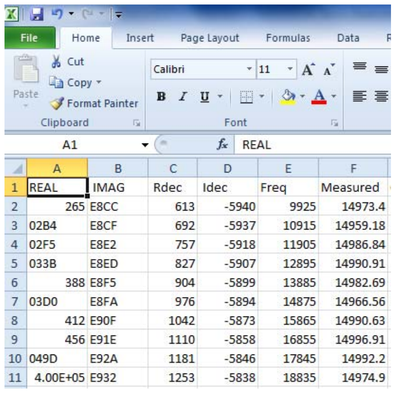


Fig. 3. AD5933 with output signal conditioning, self-calibration system and communication connectors

Created reports with magnitudes and phase angles obtained during frequency sweep are stored on 2 GB micro SD card. FAT16 file system is used to allow manipulation of file with results on PC and off-line processing. The main advantage for using micro SD card as data storage system is the ease of transferring data directly to other electronic devices such as laptops or smart phones which support FAT format as file system.

Example of created report of measured magnitude and phase angle of impedance under test is shown in Fig. 4.



	A	B	C	D	E	F
1	REAL	IMAG	Rdec	Idec	Freq	Measured
2	265	E8CC	613	-5940	9925	14973.4
3	02B4	E8CF	692	-5937	10915	14959.18
4	02F5	E8E2	757	-5918	11905	14986.84
5	033B	E8ED	827	-5907	12895	14990.91
6	388	E8F5	904	-5899	13885	14982.69
7	03D0	E8FA	976	-5894	14875	14966.56
8	412	E90F	1042	-5873	15865	14990.63
9	456	E91E	1110	-5858	16855	14996.91
10	049D	E92A	1181	-5846	17845	14992.2
11	4.00E+05	E932	1253	-5838	18835	14974.9

Fig. 4. Example of created report

Device also has alphanumeric LCD (20x4 characters) for displaying results on the field.

A prototype hardware outcome of device for complex impedance is shown in Fig. 5.

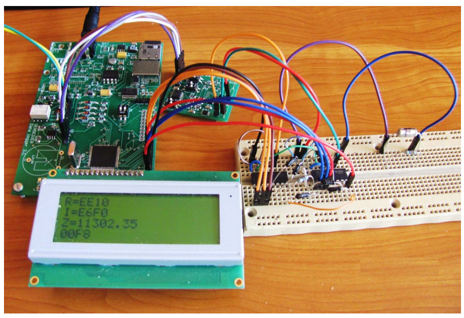


Fig. 5. Hardware outcome of device for complex impedance measuring

III. EXPERIMENTAL RESULTS

For testing purposes the impedance and the phase of resistors and capacitors of known value were measured. Several tests were performed with resistors of different values for calibration and testing but, due to limited space, in this paper will be presented only results for single resistor/capacitor and series/parallel RC network.

Frequency sweep for frequency band from 10 to 19 kHz was performed and in the following text obtained results are presented.

A. Resistor 15 kΩ (1 % tolerance)

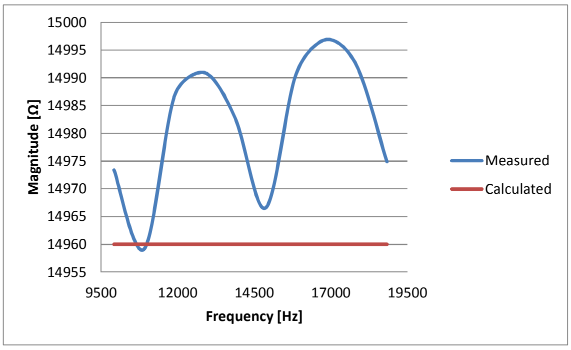


Fig. 6. Comparison between measured and calculated magnitude values for single resistor

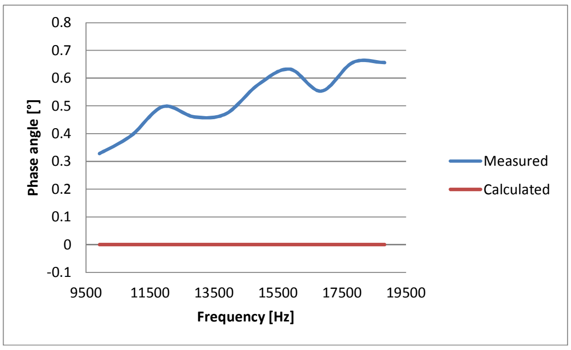


Fig. 7. Comparison between measured and calculated phase angle values for single resistor

From results shown in Fig. 6 and Fig. 7 it can be realized that values measured with developed system are very close values measured with commercial multimeter [23]. Maximum error for magnitude and phase measurements was less than 0.3 % and 0.7 degrees, respectively.

B. Capacitor 1 nF (1% tolerance)

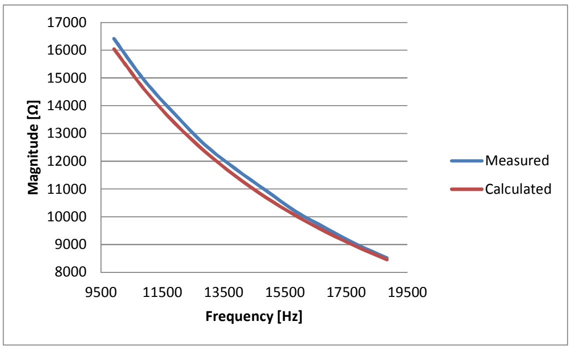


Fig. 8. Comparison between measured and calculated magnitude values for single capacitor

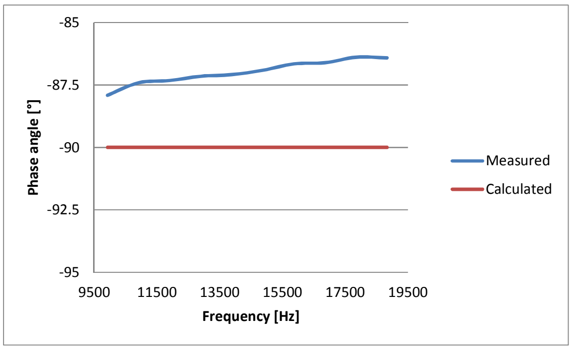


Fig. 9. Comparison between measured and calculated phase angle values for single capacitor

As can be seen from Fig. 8 and Fig. 9, maximum error for magnitude and phase measurements was less than 2 % and 3.5 %, respectively. This higher error than single resistor measurement can be consequence of parasitic capacitances influences as it was expected due the wiring and it is obvious that the future work has to implement prototype on a PCB board to achieve less parasitic parameters and low noise.

C. Series RC network (R=15 kΩ, C=1nF)

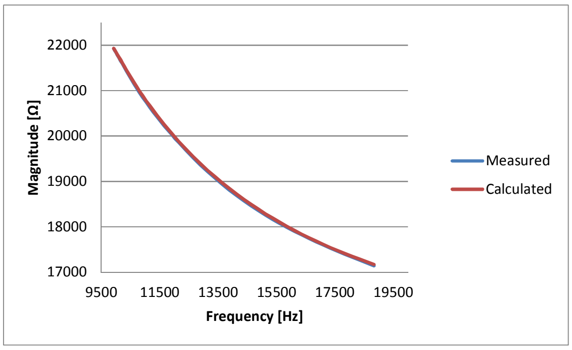


Fig. 10. Comparison between measured and calculated magnitude values for series RC network

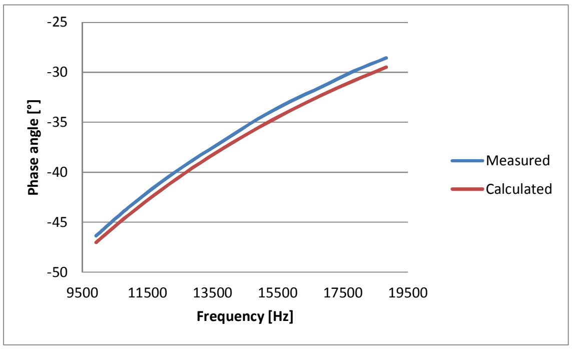


Fig. 11. Comparison between measured and calculated phase angle values for series RC network

As can be seen from Fig. 10 and Fig. 11, maximum error for magnitude and phase measurements was 0.3 % and 5.5 %, respectively.

D. Parallel RC network (R=15 kΩ, C=1nF)

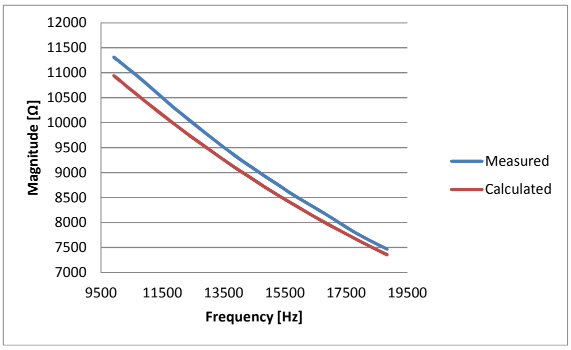


Fig. 12. Comparison between measured and calculated magnitude values for parallel RC network

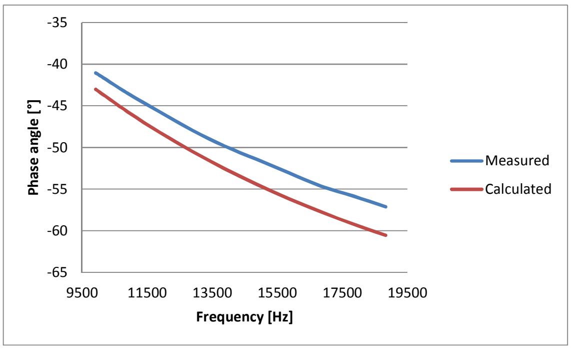


Fig. 13. Comparison between measured and calculated phase angle values for parallel RC network

As can be seen from Fig. 12 and Fig. 13, maximum error for magnitude and phase measurements was 3 % and 5.5 %, respectively.

IV. CONCLUSION

The AD5933 single-chip impedance analyzer has been successfully applied to the measurement of complex impedance. Due to the simple structure, it can be made as a portable impedance measurement device, which is used in a lot of scientific and industrial fields such as electrochemical analysis, bioelectrical impedance analysis and material property analysis. Achieved accuracy is good enough for most of possible applications.

Developed system for complex impedance measurement offers flexibility, power, and size advantages to the end user over the solutions presented in literature. Micro SD card and battery supply ensure full hand-held capabilities in possible portable applications.

Due to the limitation of the precision resistors used in calibration of the system, the accuracy is only proved in relatively low frequency. For the next step, frequency independent high precision resistors can be adopted and the system needs recalibrated for the best results. The second thing for the future work is the prototype can be further implemented on a PCB board to achieve less parasitic parameters and low noise. Also usage of analog switch with low on-resistance can improve accuracy for impedances below 1 kΩ. All this together with using of high precision external oscillator for AD5933 may further increase the accuracy of the measurements.

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