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Realization of Digital LCR Meter

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Abstract — **In this paper realization of digital LCR meter is presented. Realized system is based on integrated circuit AD5933 which is controlled by microcontroller ATmega128. Device can calculate resistance, capacitance and inductance of the device under test as well as Dissipation and Quality factors. Operating frequency range is from 5 to 100 kHz with frequency sweep function in maximum 511 steps. Device has full standalone capabilities with LCD for displaying of results and keyboard for configuration. Created report of measured and calculated values is stored on micro SD card in format which is compatible with MS Excel which ensures easy off-line analysis on PC. Accuracy of developed system is tested and verified through comparison with commercial LCR meter.**

Keywords — **AD5933, complex impedance measurement, frequency sweep, LCR meters, microcontrollers**

I. INTRODUCTION

LCR meters are largely used in industries for the measurement of impedances in many different fields: characterization of passive electronic components, characterization of the losses of transformers or coaxial cables and measurement of the antenna inductance of a RFID module [1].

Main requirements for LCR meters are: wide frequency range with programmable frequencies, capability for measuring of primary and secondary parameters, and sweep function [2]. All these requirements are described in the following text.

Electrical components need to be tested at the frequency for which the final product/application will be utilized. So an instrument must provide a wide frequency range with multiple programmable frequencies.

Secondary parameters such as D and Q are useful as measures of the "purity" of a component, that is, how close it is to being ideal or containing only resistance or reactance.

D or tanδ, the dissipation factor, is the ratio of the real part of impedance (resistance) to the imaginary part (reactance). D is commonly used when describing capacitors of all types. A low D indicates an early pure capacitor.

Q, the quality factor, is the reciprocal of D value. For inductors, a high Q indicates a more reactively pure component. The importance of D or Q is the fact that they represent the ratio of resistance to reactance or vice versa.

Primary parameters L, C and R are not the only electrical criteria in characterizing a passive component and there is more information in the secondary parameters than simply D and Q. Measurements of conductance, susceptance, phase angle and ESR can more fully define an electrical component or material.

Another excellent device characterization tool of LCR meters is the parameter sweep function. A sweep is a user-defined number of measurements for a particular test.

A lot of commercial LCR devices is available on the market. For example, LCR Meter MS5308 from Mastech, E4980A/AL Precision LCR Meter from Agilent, 879B from BK Precision, IET Labs 7600 Series, SR715 and SR720 LCR Meters, etc. These instruments display a table or plot of measured results versus a test variable such as frequency, voltage or current. The user defines the lower boundary of the sweep in Hz, Volts or Amps; the upper boundary in Hz, Volts or Amps; the step or number of increments in the sweep.

Design of own LCR meter is challenge for engineers and electronic hobbyists for many years. Some approaches are presented in [3]-[8]. Benefits of developing own system is making custom options related to user specific requirements, easy expansion of system, cheap maintenance, etc. In some cases realization of this approach can be more expensive than commercial available devices, so all requirements must be considered before making of decision. Final solution shall be compromise between price and specific requirements.

In this paper, developed system is controlled by a high-speed microcontroller with embedded logic that controls the display and keypad, as well as setting measurement conditions and performing calculations. Programmable frequency sweep in range from 5 to 100 kHz for impedance range from 1 kΩ to 5 MΩ can be performed. Measurements obtained with developed device are verified with commercial LCR meter.

II. IMPEDANCE MEASUREMENT CONSIDERATIONS

A. Resistance Measurement Considerations

When measuring resistance in a system, it is important to consider the effects of cable resistance. It is also important to notice that interactions between scanning multiple resistances and system cabling can present time-dependent problems [9].

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Resistors are usually measured at DC or low frequency AC where Ohm's Law gives the true value under the assumption that loss factors are accounted for. However, when resistors are used in high frequency circuits they will have both real and reactive components. This can be modeled with a series inductance (L_S) and parallel capacitance (C_P).

B. Capacitance Measurement Considerations

A capacitor is an electronic component that is capable of storing energy as charge. A capacitor, as a practical device, exhibits not only capacitance but also resistance and inductance. A simplified schematic for the equivalent circuit consists of capacitance, inductance, series resistance and parallel resistance [10].

The term ESR or Equivalent Series Resistance combines all losses both series and parallel in a capacitor at a given frequency so that the equivalent circuit is reduced to a simple R-C series connection.

ESR is a dynamic quantity of a capacitor. ESR does not exist as a static quantity therefore it cannot be measured by a conventional DC ohm meter. ESR exists only when alternating current is applied to a capacitor. This symbolic resistor does not really exist as a physical entity so direct measurements across the ESR resistor are not possible.

The dissipation factor (DF), tan δ, is a quantity of material properties, which is essentially dependent of polarization behavior respectively polarization losses as well as conductivity properties.

The classic base circuit for the determination of the capacity and the dissipation factor is the C-tanδ measuring bridge of Schering [11].

C. Inductance Measurement Considerations

An inductor is an electronic component that is capable of storing energy as current. A representation of real-world inductors includes series resistance (resistive losses in the conductor), R_S, the parallel capacitance (equivalent capacitive effect between the turns of the coil), C_P, and the parallel resistance (sum of all losses attributable to the core material), R_P. These parasitic elements impact the inductor impedance at different test frequencies [10].

Quality factor (Q) is the ratio of reactance to resistance and therefore is unit less. It is the measure of how "pure" or "real" an inductor is (that is, how much the inductor contains only reactance). The higher the Q of an inductor, the fewer losses the inductor contains [2].

III. Device structure

The complex impedance meter presented in this paper is a high precision, low power consumption system which provides programmable frequency sweep for impedance measurement in range from 1 kΩ to 5 MΩ. Frequency sweep can be performed in range from 5 to 100 kHz with maximum 511 steps.

Proposed structure of device for complex impedance measurement reported earlier in [12], [13] is used in realization of LCR meter presented in this paper. A hardware outcome of LCR device is shown in Fig. 1.

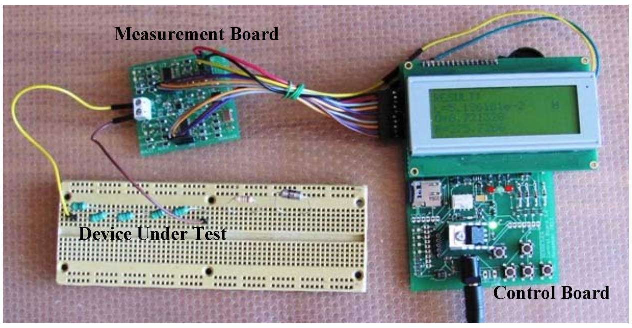


Figure 1. Hardware outcome of digital LCR meter

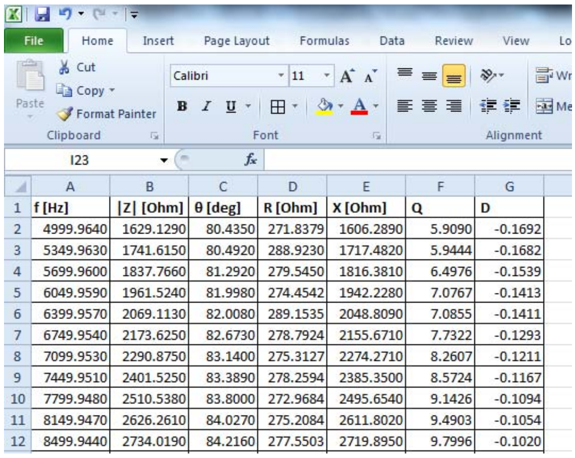
Created report with magnitudes and phase angles obtained during frequency sweep are stored on micro SD card. Example of created report with measured and calculated values for real and imaginary part of impedance, Q and D is shown in Fig. 2. If magnitude (|Z|) and phase angle (θ) of device under test are known these values can be easily calculated as follows:

$$R = |Z|\ cos\vartheta \quad (1)$$

$$X = |Z|\ sin\vartheta \quad (2)$$

$$D = R / X \quad (3)$$

$$Q = 1 / D = X / R \quad (4)$$



	A	B	C	D	E	F	G
1	f [Hz]	|Z| [Ohm]	θ [deg]	R [Ohm]	X [Ohm]	Q	D
2	4999.9640	1629.1290	80.4350	271.8379	1606.2890	5.9090	-0.1692
3	5349.9630	1741.6150	80.4920	288.9230	1717.4820	5.9444	-0.1682
4	5699.9600	1837.7660	81.2920	279.5450	1816.3810	6.4976	-0.1539
5	6049.9590	1961.5240	81.9980	274.4542	1942.2280	7.0767	-0.1413
6	6399.9570	2069.1130	82.0080	289.1535	2048.8090	7.0855	-0.1411
7	6749.9540	2173.6250	82.6730	278.7924	2155.6710	7.7322	-0.1293
8	7099.9530	2290.8750	83.1400	275.3127	2274.2710	8.2607	-0.1211
9	7449.9510	2401.5250	83.3890	278.2594	2385.3500	8.5724	-0.1167
10	7799.9480	2510.5380	83.8000	272.9684	2495.6540	9.1426	-0.1094
11	8149.9470	2626.2610	84.0270	275.2084	2611.8020	9.4903	-0.1054
12	8499.9440	2734.0190	84.2160	277.5503	2719.8950	9.7996	-0.1020

Figure 2. Example of created report

IV. Experimental results and discussion

For obtaining reference results for devices under test, HP 4194A impedance analyzer (Fig. 3) was used. HP 4194A is capable to perform measurements for impedances between 0.1 mΩ to 1.6 MΩ in frequency range from 100 Hz to 40 MHz with 0.17 % accuracy [14].

For testing purposes the magnitude and phase angle of resistors, capacitors and inductors of known values were measured. The same components were used for tests with developed LCR meter. In both cases, frequency sweep for frequency band from 5 to 100 kHz was performed and in the following text comparison of obtained results is presented.

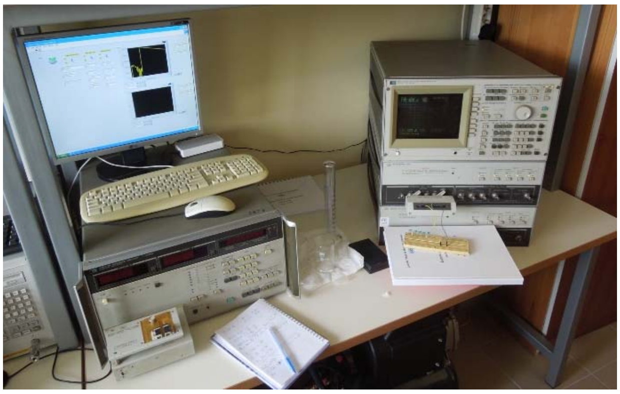


Figure 3. HP 4194A impedance analyzer

A. *Resistor 17.8 kΩ (1 % tolerance)*

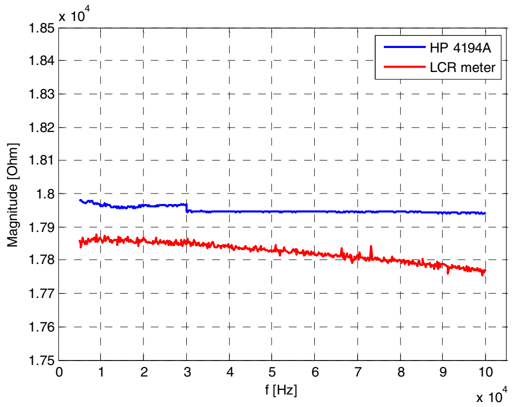


Figure 4. Comparison of magnitude values

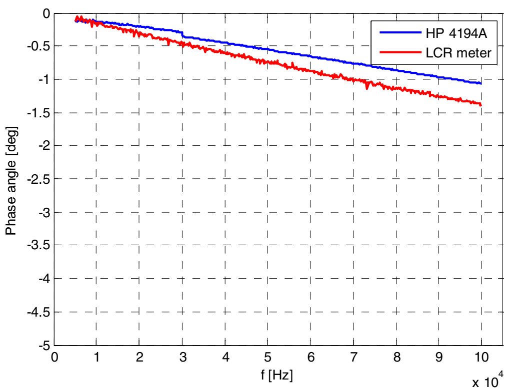


Figure 5. Comparison of phase angle values

Measurement of resistance produces very good results in comparison with results obtained with commercial LCR meter. Error in phase angle measurement had linear increasing on higher frequencies, as it was expected. Measurement of impedance magnitude had very small error, less than 0.2 %.

B. *Capacitor 1 nF (1% tolerance)*

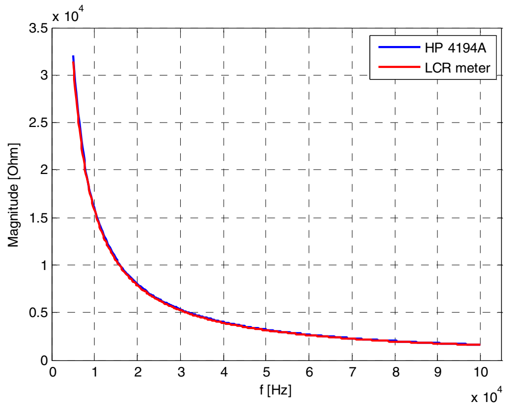


Figure 6. Comparison of magnitude values

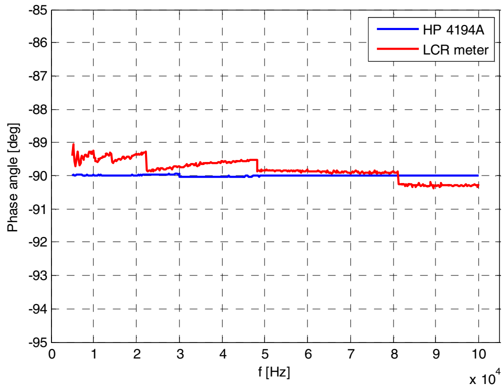


Figure 7. Comparison of phase angle values

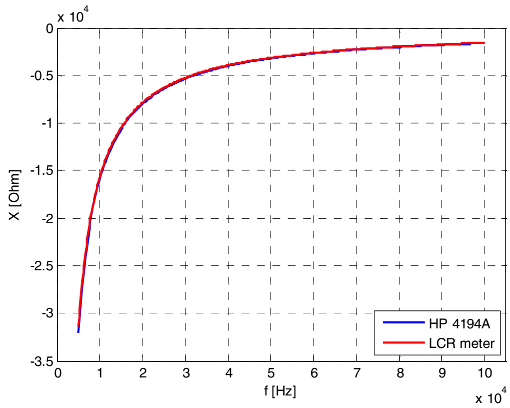


Figure 8. Comparison of impedance imaginary part values

During capacitance measurement, as may be seen in presented results, error in phase angle measurement is the lowest in frequency range from 50 to 80 kHz. Obtained uncertainty in lower frequency range can produce significant error in calculations by mathematical operations of multiplication and division. Because of that, frequency range for calculations was narrowed to 50-80 kHz.

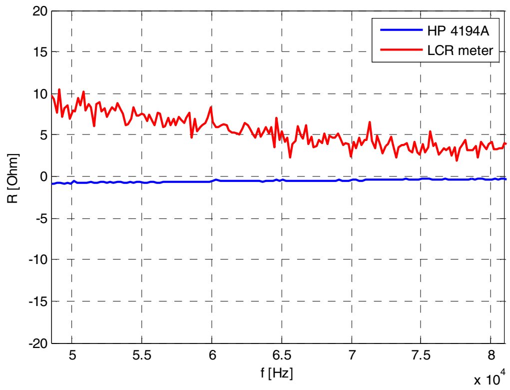


Figure 9. Comparison of impedance real part values

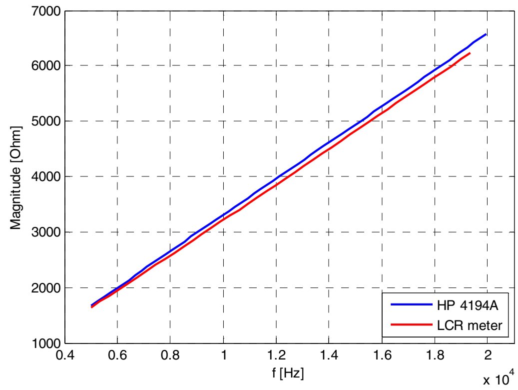


Figure 12. Comparison of magnitude values

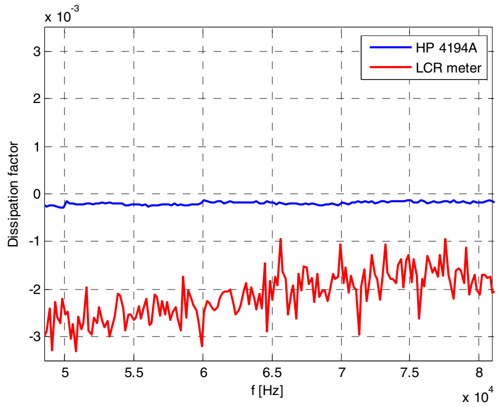


Figure 10. Comparison of Dissipation factor

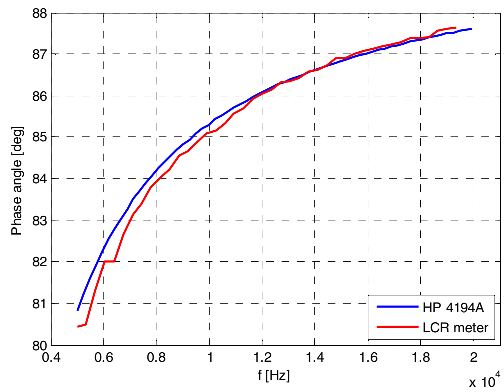


Figure 13. Comparison of phase angle values

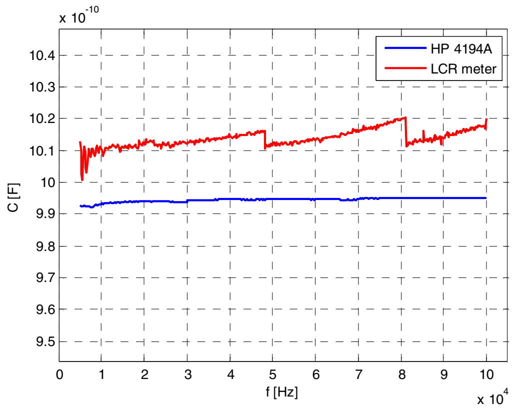


Figure 11. Comparison of calculated values for capacitance

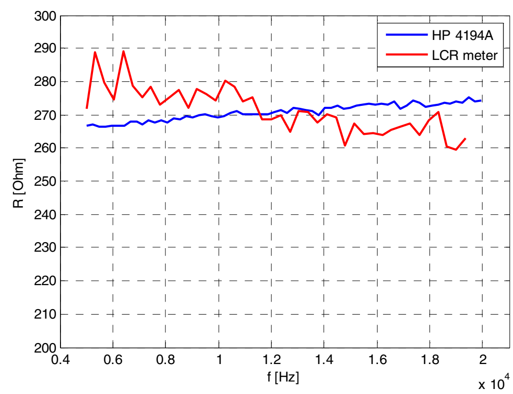


Figure 14. Comparison of impedance real part values

C. Five inductors of L=10 mH connected in series

Similar behavior was noted in inductance measurement, too. On higher frequencies non-linearity was significant so it was decided to limit maximum frequency on 20 kHz.

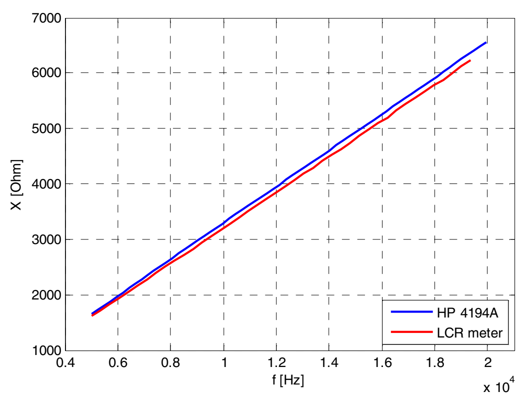


Figure 15. Comparison of impedance imaginary part values

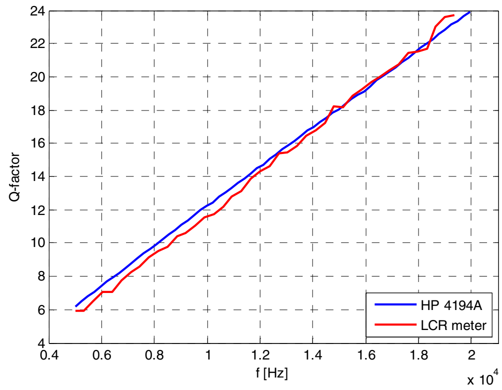


Figure 16. Comparison of Quality factor

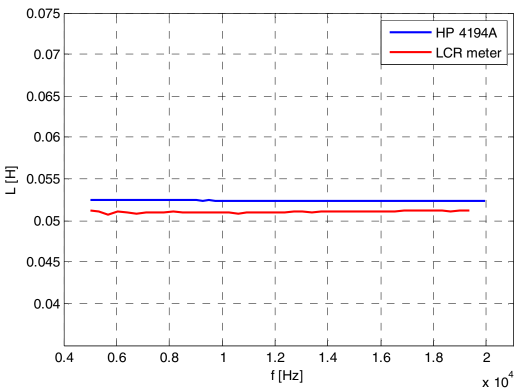


Figure 17. Comparison of calculated values for inductance

As can be seen from Fig. 4 to Fig. 17, obtained results are very close to theoretical results.

Maximum error for magnitude and phase angle measurements was less than 2 % and 1.4 degrees in whole range of frequency, respectively.

V. CONCLUSION

Previously developed system for complex impedance measurements is improved in several aspects. New system is more reliable and stable, has higher accuracy and smaller dimensions. New software features are calculation of capacitance and Dissipation factor for capacitors as well as inductance and Quality factor for inductors. Device is designed in aim to perform operations as low-cost LCR meter with accuracy close to commercial devices.

This non-linearity issue is marked as very important task in future work. More detailed investigation and estimation of possible solution are necessary to ensure more accurate operation in complete frequency range.

Realized system can be used in a wide variety of hobbyist and commercial applications, including complex impedance measurement, impedance spectrometry, biomedical and automotive sensors, proximity sensors, FFT processing, structural health monitoring, etc.

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