Portable Arduino - Based LCR – Meter

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Abstract – **An Arduino based portable LCR meter is designed, using the impedance converter AD5933 for measuring the reactance. The system combines an on-board frequency generator with a 12-bit, 1 MSPS, analog-to-digital converter (ADC). The built-in frequency generator allows an external complex impedance to be excited with a known frequency. The response signal from the impedance 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 a real (R) and imaginary (I) data-word at each output frequency as the real and imaginary register contents, which can be read from the serial I2C interface. An Arduino controller-board maintains control of the AD5933 via the I2C-compliant serial interface protocol. Measuring of high value capacitances and low-value inductances with impedances in the range 1 Ω - 10 Ω is enabled using additional circuitry with reference resistor added to the unknown reactive component and correction of the real part and the phase of the measured impedance.**

Keywords – **Arduino, LCR-Meter, complex impedance–to digital converter**

I. INTRODUCTION

Traditional LCR meter measures the voltage magnitude, the current magnitude, and the phase angle between the current and voltage. Defining the impedance vector is usually the first step in measuring reactive components like inductivity L or capacitor C. Sophisticated digital LCR meters are not ever available while microcontroller boards are simpler and efficient enough to do the job. Measuring complex impedance is also already quite a simple task with the impedance–to–digital converter of Analog Devices microchip AD5933. The widely used Arduino platform can easily maintain control of the impedance converter AD5933 via the I2C-compliant serial interface protocol. Main contribution here is extending of the measurement range to lower values of the impedance to even 1 Ω -100 Ω. This is accomplished using an additional reference resistor of 100 Ω in series with the unknown impedance and a corrective procedure fulfilled by the Arduino microcontroller afterwards.

A. Impedance vector

Impedance as a vector can be expressed in terms of

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Decart coordinates:
$$Z = R + jX \qquad (1)$$

with real part R and imaginary part X

as well as with polar coordinates:
$$Z = |Z| e^{j\theta} \quad (2)$$

with magnitude $|Z|$ and phase θ.

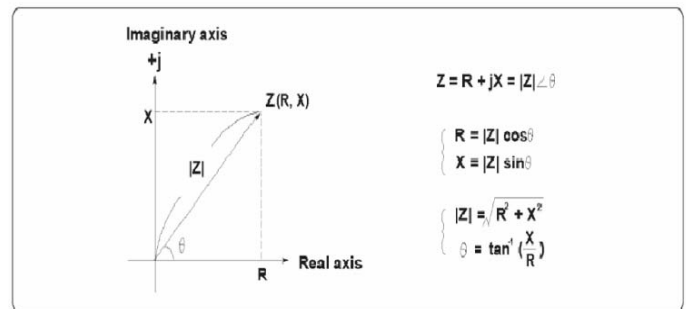Figure 1 shows the relationship between Decart and polar coordinates R, X, $|Z|$ и θ

Fig. 1. Relationship between Decart and polar coordinates R, X, $|Z|$ and θ when describing complex impedance vector Z

B. Measuring impedance using AD5933

There are many measurement methods to choose from when measuring impedance, each of which has advantages and disadvantages. The microchip AD5933 employs the auto balancing bridge method, where the current, flowing through the DUT, also flows through resistor Rr. The potential at the inverting point of the operational amplifier is maintained at zero volts (thus called a "virtual ground").
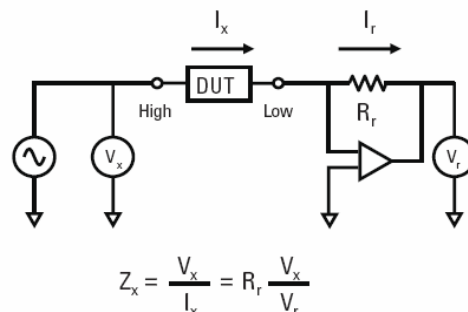

Fig. 2. The auto balancing bridge method for measuring complex impedance [1]

AD5933 is a high precision impedance converter system solution that combines an on-board frequency generator with a 12-bit, 1 MSPS, analog-to-digital converter (ADC). The frequency generator allows an external complex

impedance to be excited with a known frequency. The response signal from the impedance 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 a real (R) and imaginary (I) data-word at each output frequency. A DFT is calculated for each frequency point in the sweep. The result is stored in two 16-bit registers representing the real and the imaginary components R and I of the result. The data is stored in twos complement format. The impedance magnitude and phase are easily calculated using the following equations:

$$Magnitude = \sqrt{R^2 + I^2}$$

$$Phase = \tan^{-1}(I/R) \qquad (3)$$
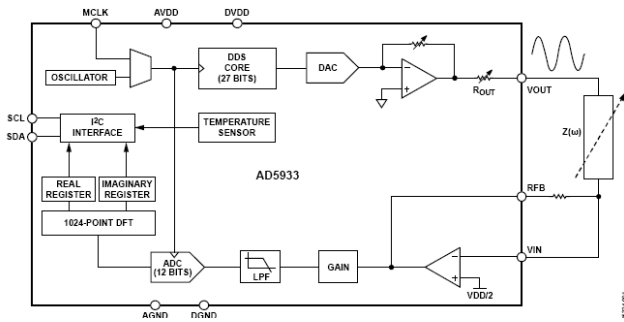

Fig. 3. AD5933 high precision impedance converter system [2]

Once the magnitude of the impedance (|Z|) and the impedance phase angle (ZØ, in radians) are correctly calculated, it is possible to determine the magnitude of the real (resistive) and imaginary (reactive) component of the impedance ($Z_{UNKNOWN}$) by the vector projection of the impedance magnitude onto the real and imaginary impedance axis using the following formulas:

The real component is given by

$$|Z_{REAL}| = |Z| \times \cos (ZØ) \qquad (4)$$

The imaginary component is given by

$$|Z_{IMAG}| = |Z| \times \sin (ZØ) \qquad (5)$$

The system should be calibrated before measuring the unknown impedance applying known reference resistor at the input of the trans-impedance converter. Once calibrated, the magnitude of the impedance and relative phase of the impedance at each frequency point along the sweep is easily calculated. This is done off chip using the real and imaginary register contents, which can be read from the serial I2C interface.

The AD5933 permits the user to perform a frequency sweep with a user-defined start frequency, frequency resolution, and number of points in the sweep. In addition, the device allows the user to program the peak-to-peak value of the output sinusoidal signal as an excitation to the external unknown impedance connected between the VOUT and VIN pins.

Control of the AD5933 is carried out via the I2C-compliant serial interface protocol. The AD5933 is connected to this bus as a slave device under the control of a master device – the Arduino microcontroller board in this case. Arduino is connected via USB to a Personal Computer using open source coding for control and calculating the results [3].

Fig. 4. Arduino microcontroller board [3]

II. MAKING RELIABLY ACCURATE LCR MEASUREMENTS

A. Model considerations

In real-world applications, loads are neither purely reactive nor purely resistive. However, they can be easily modeled either as a series or parallel combination of a resistive and a reactive load. It is not uncommon for LCR meter measurements to be off by more than 20% due to the specific test parameters and characteristics of the component being tested. The vector nature of impedance and behavior of series-parallel circuits are keys to making reliably accurate LCR measurements.
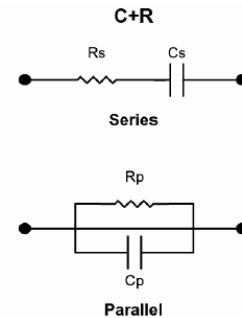

Fig. 5. Equivalent series and parallel models of capacitors C

The relationships between real and imaginary part of the impedance and the model components are given by:

$$Zs = Rs - j/\omega Cs = Rs(1-j/D) \qquad (6)$$

$$Zp = Rp/(1+ j\omega CpRp) \qquad (7)$$

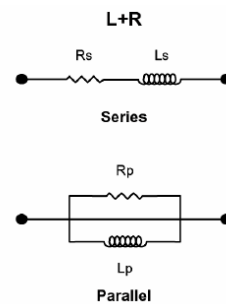$$D = \omega CsRs = 1/\omega CpRp \qquad (8)$$

Fig. 6. Equivalent series and parallel models of inductors L

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The relationships between real and imaginary part of the impedance and the model components are given by:

$$Zs = Rs + j\omega Ls = Rs(1+jQ) \qquad (10)$$

$$Zp = j\omega LpRp/(Rp + j\omega Lp) \qquad (11)$$

$$Q = 1/D = \omega Ls/Rs = Rp/\omega Lp \qquad (12)$$

For high D - Dissipation (low Q - Quality) devices, either the series or parallel model is a better approximation of the real impedance equivalent circuit than the other one. Low D (high Q) devices do not yield a significant difference in measured C or L values due to the measurement circuit mode. Since the relationships between the series and parallel mode measurement values are a function of D^2, when D is below 0.03, the difference between Cs and Cp values (also between Ls and Lp values) is less than 0.1%. D and Q values do not depend on the measurement circuit modes.

B. Range considerations

AD5933 has an impedance measurement range from 1 kΩ to 10 MΩ and is capable of measuring in the range of 100 Ω to 1 kΩ with additional circuitry [2]. Having in mind that high-value capacitance measurement is categorized in the low impedance measurement typically in the range of x Ω, here an additional circuit is used to extend the measurement range from 1 Ω to 100 Ω, thus allowing high-value capacitance measurement. The same range can be used also for low-value inductance measurement with excitation frequency at the high end of the AD5933 ranging to a maximum frequency of 100 kHz.

The AD5933 is capable of measuring impedance values up to 10 MΩ if the system gain settings are chosen correctly for the impedance subrange of interest [2].

A small impedance value (≤500 Ω) placed between the V_{OUT} and V_{IN} pins results in an increase in signal current flowing through the impedance for a fixed excitation voltage in accordance with Ohm's law. The output stage of the amplifier available at the V_{OUT} pin may not be able to provide the required increase in current through the impedance. The voltage presented at the V_{IN} pin is hard biased at $V_{DD}/2$ due to the virtual earth on the receive side I-V amplifier. The increased current sink/source requirement placed on the output of the receive side I-V amplifier may also cause the amplifier to operate outside of the linear region. This causes significant errors in subsequent impedance measurements. A circuit that helps to minimize these effects is shown in Figure 7 [2]. The aim of this circuit is to place the AD5933 system gain within its linear range when measuring small impedances by using an additional external amplifier circuit along the signal path. The external amplifier AD8531 attenuates the peak-to-peak excitation voltage at V_{OUT} by a resistor divider R1 and R2, thereby reducing the signal current flowing through the impedance and minimizing the effect of the output series resistance in the impedance calculations. Here a resistor ratio of R2/R1 = 10 is used reducing thus the excitation voltage maximal 200mV pek-to-peak. $Z_{UNKNOWN}$ recognizes the output series resistance of the external amplifier which is typically much less than 100 Ω. The AD8531 is a rail-to-rail input/output single-supply amplifier featuring 250 mA output drive current. This high

output current allows for driving either resistive or capacitive loads. AC performance is very good with 3 MHz bandwidth, 5 V/µs slew rate, and low distortion [4].
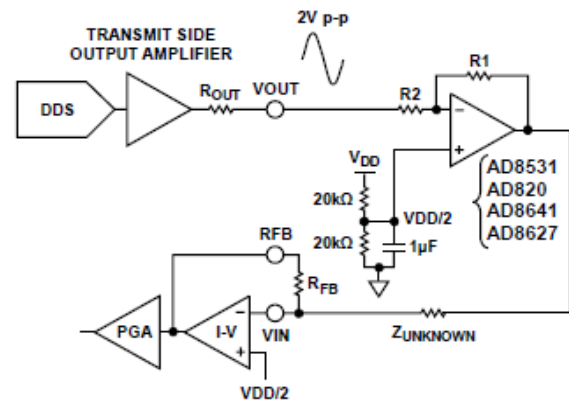

Fig. 7. Additional circuit extends the measurement range to lower than 100Ω [4]

The external amplifier buffers the unknown impedance from the effects of R_{OUT} and introduces smaller output impedance in series with $Z_{UNKNOWN}$. The key point is that one can add one reference resistor – here with a value of 100 Ω in series with the unknown small impedance thus enabling its measurement. After completing calculation of real and imaginary part this reference resistive part is subtracted from the real part of the impedance. The corrected value of the real part is then used to find the actual phase angle of the measured unknown impedance. This correction procedure is part of the Arduino–program that enables extending the measurement range of impedances to as low as 1 Ω. This way the external additional circuit together with the correction procedure in the Arduino-microcontroller allows the system to be used for measuring high-value capacitors as well as low-value inductivities in a reasonably defined frequency range.

This additional circuit enables successful measuring in three ranges defined as:
1. Range for impedances between 1 kΩ to 10 MΩ
2. Range for impedances between 100 Ω to 1 kΩ
3. Range for impedances between 1 Ω to 100 Ω

III. EXPERIMENTAL RESULTS

The system was tested for measuring high-value capacitors and low-value inductivities in the lowest impedance range. 1mF tantalum capacitors as maximal value was measured successfully with excitation frequencies from 10Hz to 100Hz. Estimation of the Equivalent Series Resistance is possible within 10%, and measurement of capacitance within 10% of the values, obtained from comparative measurement with Agilent LCR meter. Measurement of low-value inductivities is limited basically by the maximal frequency of 100kHz that the AD5933 can maintain at his excitation output. Thus a low - limit value of 10µH for measured inductivities is set with a corresponding theoretical impedance of 6.28 Ω at 100kHz. A calibrated inductor with very high quality factor Q=100 was used to test the Arduino-based LCR meter. The results for inductance and quality factor were within less than 5% from the calibrated values over the frequency range from 90kHz to 100kHz.

IV. CONCLUSION

Arduino-based LCR–meter is described, capable of measuring large capacitor as well as small inductance values. The system is build around the AD5933 microchip connected to Arduino via I2C interface. A small additional reference resistor of 100 Ω enables measurement of small impedances using correcting procedure algorithm.

REFERENCES

[1]http://www.tnlc.ncsu.edu/files/testing/manuals/ImpedanceMea surementHandbookRev3.pdf
[2]http://www.analog.com/static/importedfiles/data_sheets/AD59 33.pdf
[3] Petar Georgiev Doychev FNo 5729 on "Arduino microcontroller system. Applications, guidelines and instructions. Sample implementations. "Master degree Thesis, Sofia University, Faculty of Physics, 2013
[4] http://www.analog.com
[5] C. P. Providakis, E. V. Liarakos, and E. Kampianakis, Nondestructive Wireless Monitoring of Early-Age Concrete Strength Gain Using an Innovative Electromechanical Impedance Sensing System; Hindawi Publishing Corporation, Smart Materials Research, Volume 2013, Article ID 932568, 10 pages http://dx.doi.org/10.1155/2013/932568