Design and Development of Portable Digital LCR Meter by Auto Balancing Bridge Method

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Abstract-This paper describes the development and evaluation of a custom-built LCR meter, which uses a multiplexed bridge circuit to characterize the properties of electronic components. The LCR meter is constructed on a single printed circuit board with minimum components like: 8-bitMicrocontroller, TL08XX-Operational amplifier [1], CD405x-CMOS single 8-channel analog Multiplexer/Demultiplexer [2], OP07-ultra-low offset voltage operational amplifier [3] and is sufficiently compact for integration into a handheld format. The instrument is designed to measure the inductance (L), capacitance (C), and resistance (R) of a component along with sub parameters- D, Q, θ, Effective Series Resistance at different frequencies. The custom built LCR meter having the following specifications: basic accuracy- 0.3%-0.5%, auto range mode, auto calibration, test range – R (0.0002 Ω — 9.999 MΩ), L (0.01 µH — 1000 H) and C (0.1 pF — 10000uF). The designed instrument performance is compared with a standard a LCR meter, the percentage of error between them is less than 1.

Key words: Auto balancing bridge, Microcontroller, 8-channel analog Multiplexer/Demultiplexer, Operational amplifier and PCB with minimum components

I. INTRODUCTION

LCR meter is an electronic testing instrument used to measure the inductance (L), capacitance (C) and resistance (R) of a component. Inductance is the property of an electrical circuit causing voltage to be generated proportional to the rate of change of current in a circuit. Capacitance is the ability of a body to hold an electrical charge, it is a measure of the amount of electrical energy stored for a given electric potential. The electrical Resistance is a measure of its opposition to the passage of an electric current. In general, these quantities are not measured directly, but determined from a measurement of impedance. Impedance is a parameter used to evaluate the characteristics of electronic components. Impedance (Z) is defined as the total opposition a component offers to the flow of an alternating current at a given frequency.

II. IMPEDANCE PARAMETERS

Impedance is represented as a complex, vector quantity. A polar coordinate system is used to map the vector as shown in figure 1, where quadrants one and two correspond to passive inductance and passive capacitance respectively, quadrants three and four correspond to negative resistance. The impedance vector consists of a real part, resistance (R), and an imaginary part, reactance (X). Capacitance (C) and inductance (L) are derived from resistance (R) and reactance (X). The two forms of reactance are inductive (XL) and capacitive (XC). The Quality Factor (Q) and the Dissipation Factor (D) are also derived from resistance and reactance. These parameters serve as measures of reactance purity. When Q is larger or D is smaller, the quality is better. Q is defined as the ratio of the energy stored in a component to the energy dissipated by the component. D is the inverse of Q. D is also equal to "tan δ", where δ is the dielectric loss angle (δ is the complementary angle to θ - the phase angle). Both D and Q are dimensionless quantities. Figure 2 describes the relationship between impedance and the derived parameters.

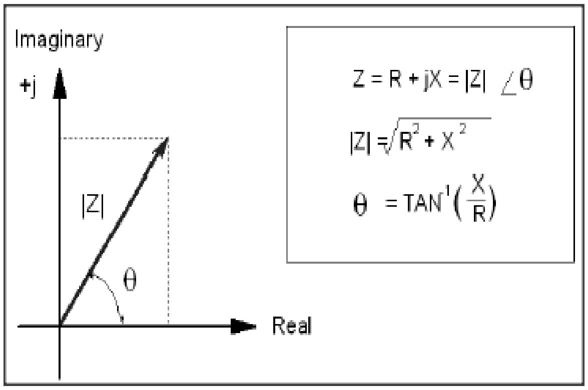

Figure 1. Impedance Vector

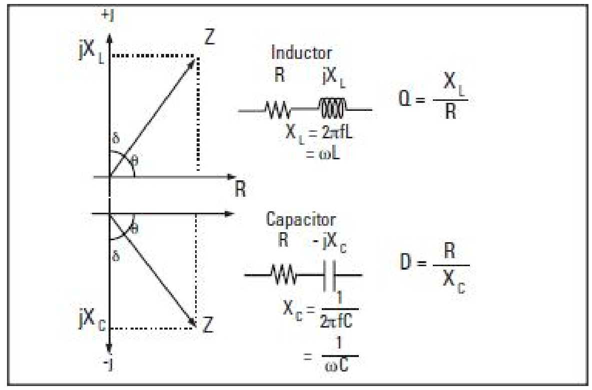

Figure 2. Capacitor and Inductor Parameters

Impedance is measured using a variety of methods; Table 1 shows the comparison between major impedance measurement methods as well as the frequency ranges covered.

Method	Advantage	Disadvantage	Frequency range	Application
Auto-Balancing-Bridge	Most accurate, Wide impedance measurement range Wide frequency coverage	Limited frequency coverage	5 Hz – 40 MHz	All impedance measurement applications in low frequency
I-V	Grounded device measurement Probing measurement	Limited frequency and impedance measurement range	10 kHz–100 MHz	In-circuit impedance measurement
RF I-V	Accurate impedance measurement through the GHz range Grounded device measurement	Limited frequency coverage	1 MHz – 1.8 GHz	Components and materials measurement in RF
Network analysis	Very broad frequency coverage (LF through microwave)	Impedance measurement range is limited to values close to the characteristic impedance of the analyzer	≥ 10 kHz	Components and materials measurement

Table 1. Comparison of impedance measurement methods

III. DESCRIPTION OF THE AUTO-BALANCING-BRIDGE LCR METER

Figure 3 shows the circuit diagram of the Auto-Balancing-Bridge method [6]. To perform precise impedance measurements, the voltage applied to the device under test (DUT) and the current which flows through the DUT need to be accurately measured. The voltage applied to the DUT is detected as V_1 at the High-Potential (Hp) terminal of the instrument. The terminal is isolated from the High-Current (Hc) terminal which is a signal output terminal. This isolation enables accurate detection of the voltage applied to the DUT. The current which flows through the DUT, goes to the Low-Current (Lc) terminal. If there exist a certain potential at the Lc terminal, stray capacitance between the terminal and ground is generated and current may flow to ground. To avoid this, the LOW terminal is kept near the voltage level of ground. This is called a Virtual Ground and it is functionally dependent on a feedback loop. The feedback loop is called a null-loop. The null amplifier consists of an input amplifier, a narrowband high-gain amplifier and an output amplifier. This circuit maintains the virtual ground at the Lp terminal, and pulls the current to a range resistor. By detecting the voltage of the range resistors, the current which flows through the DUT is measured. Impedance analyzers usually have several range resistors in order to achieve high-resolution for various current measurements. With the technology of this feedback loop, the cabling method called a Four-Terminal-Pair (4TP) [5] configuration is used. This configuration minimizes error factors that exist in the measurement path as shown in Figure 4. The measurement path refers to the path from the voltage/current measuring circuit in the instrument to the DUT connection. The 4TP configuration removes influences such as the series residual impedance of a cable, stray capacitance between cables and mutual inductance of cables. With this configuration, a wide range of impedance can be measured from low- Z to high- Z. Figure 5 shows the circuit diagram of the latest Auto-Balancing-Bridge technology. The signal generated by a signal source will flow in the circuit. This methodology can provide the most accurate measurements through the use of the Auto-Balancing-Bridge method with the Four-Terminal-Pair configuration [8].

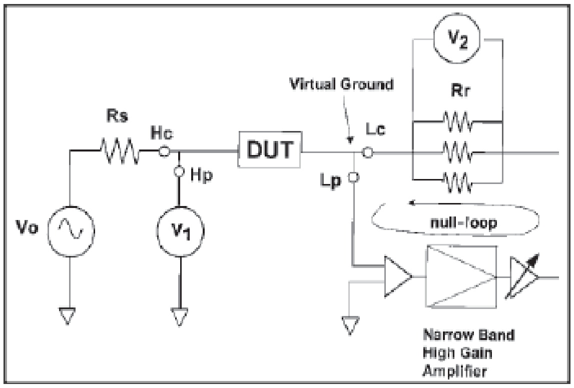

Figure 3. Circuit diagram of the Auto-Balancing -Bridge method

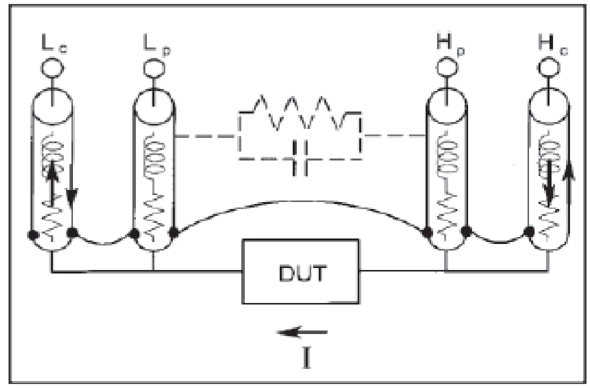

Figure 4. Four-Terminal-Pair configuration

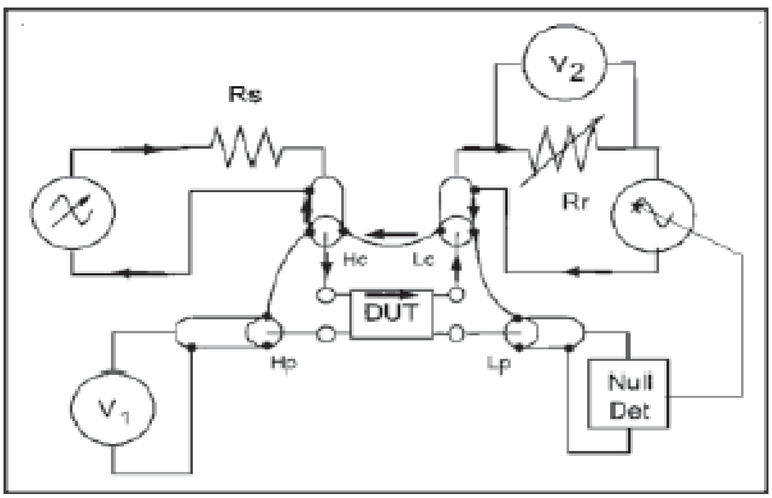

Figure 5. Combination of the Auto-Balancing-Bridge with the Four-Terminal-Pair configuration

IV. DESIGN AND FABRICATION

The LCR meter is constructed on a single printed circuit board with minimum components like: STC12C5A60S2- eight-bit Microcontroller [4], TL08XX-Operational amplifier, CD405x-CMOS single 8-channel analog Multiplexer/Demultiplexer, OP07-ultra-low offset voltage operational amplifier and is sufficiently compact for integration into a handheld format as shown in figures 7a, 7b, 7c, and 7d. The instrument is designed to measure the inductance (L), capacitance (C), and resistance (R) of a component along with sub parameters- D, Q, θ, ESR at different frequencies. The custom built LCR meter having the following specifications: basic accuracy- 0.3%-0.5%, auto range mode, auto calibration, test range – R (0.0002 Ω — 9.999 MΩ), L (0.01 μH — 1000 H) and C (0.1 pF — 10000uF).

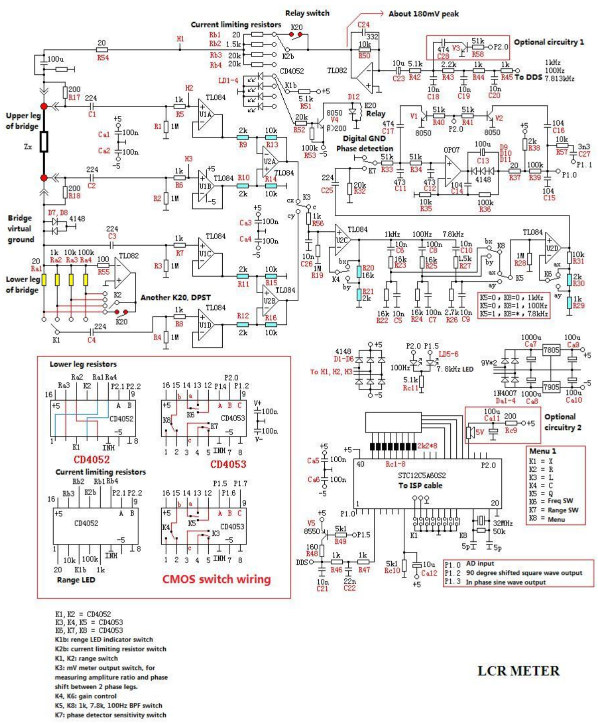

Figure 7a. Circuit diagram of the LCR meter

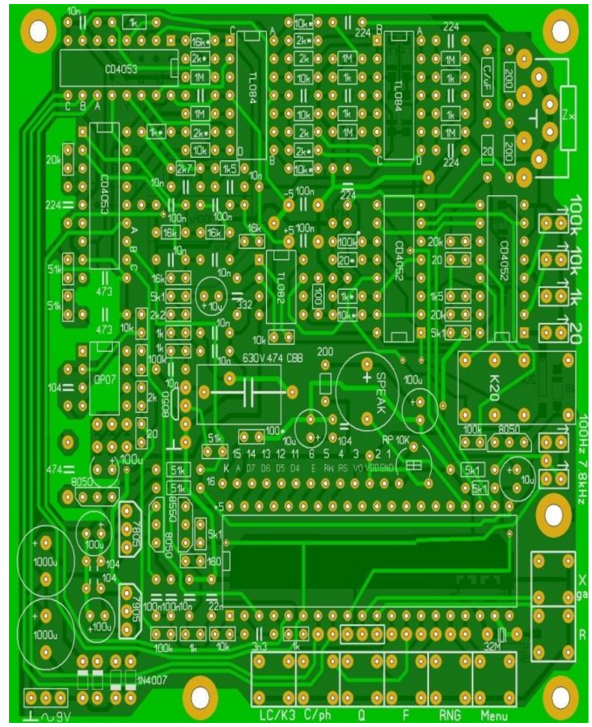

Figure 7b. Printer Circuit Board of LCR meter

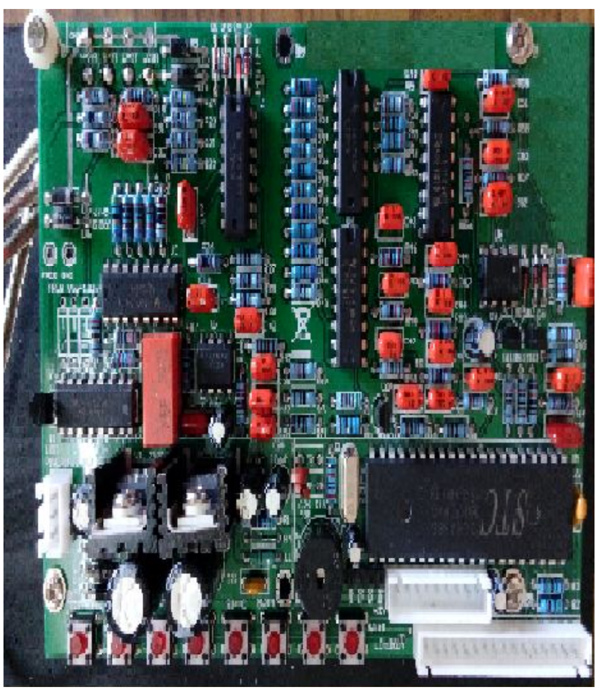

Figure 7c. Fabricated LCR meter

Figure 7d. Front panel of fabricated LCR meter

V. OPERATION

The device under test (DUT) is subjected to an AC voltage source [6]. The meter measures the voltage across and the current through the DUT. From the ratio of these the meter can determine the magnitude of the impedance. The phase angle between the voltage and current is also measured. In combination with the impedance, the equivalent capacitance or inductance, and resistance, of the DUT can be calculated and displayed. The meter assumes either a parallel or a series model for the elements. LR measurements have the elements in series and that CR measurements have the elements in parallel. This handheld LCR meters typically have selectable test frequencies of 100 Hz, 1 KHz

and 7.8 kHz. The display resolution and measurement range capability will change with test frequency. The custom built LCR meter having the following specifications: basic accuracy- 0.5%-1%, auto range mode, auto calibration, test range – R (0.0002 Ω — 9.999 MΩ), L (0.01 µH — 1000 H) and C (0.1 pF — 10000uF).
The measuring error in impedance measurement is a complex function of the measurand so that reference impedance valued in the whole measuring range is needed for the calibration. Thus self calibration system was developed in this design. The measuring errors are compensated by the signal processing using the self-calibration measuring data. The measuring accuracy of the resulted measuring system depends only on the tolerance of the reference elements.

Features of designed LCR meter:

- **Display:** LCD display shows measured values, entered parameters, instrument status, and user messages.
- **Making Measurements:** Measurements are performed at test frequencies of 100 Hz, 1 kHz, and 7.8 kHz, built-in drive voltage can be set to preset the voltage level. Measurements are taken at rates of 2, 10 or 20 samples per second. Both series and parallel equivalent circuit models of a component are supported.
- **Auto measurement:** AUTO measurement mode automates the selection of setup parameters and quickly determines the appropriate device model for whatever component is being measured.
- **Calibration:** Automatically corrects both open and short circuit parameters at all frequencies and all ranges.
- **Test Fixtures:** This LCR meters have a Kelvin fixture which uses two wires to carry the test current and two independent wires to sense the voltage across the device under test. This prevents the voltage drop in the current carrying wires from affecting the voltage measurement. Radial components are simply inserted into the test fixture, one lead in each side. Axial devices require the use of the axial fixture adapters which will also be provided

VI. RESULTS AND DISCUSSION

After the completion of the design and fabrication of the LCR meter, its performance was tested by making various measurements on a group of components like resistors, inductors and capacitors. The measurands are with **+/-** 10% tolerance. The values of the components shown by the LCR meter are compared with the printed values on the components and tabulated in table 2a, 2b, and 2c. Figures 8a, 8b, 8c, 8d, 8e and 8f are some of the evidences for the estimation of the designed LCR meter's performance. The graphs 1, 2, and 3 shows that the measured values of the components are track the marked values on the components.

S.N0	**Resistor - R in ohms** Marked value with +/- 10 % tolerance	**LCR Meter Display** in ohms	**Q**	**D**	**Theta**	**Measured Frequency**
1	10	10.54	0.083	9.999	4.758	1KHz
2	50	50.34	0.018	9.999	1.007	1KHz
3	100	98.47	0.009	9.999	0.495	1KHz
4	110	110.49	0.009	9.999	0.494	1KHz
5	1010	1017.3	0.012	9.999	0.02	1KHz
6	10K	9.836K	0.001	9.999	0.035	1KHz
7	50K	50.34K	0	9.999	0.005	1KHz
8	100K	99.63K	0.003	9.999	0.143	1KHz
9	500K	499.8K	0.001	9.999	0.005	1KHz
10	1000K	926K	0.006	9.999	-0.338	1KHz

Table 2a. Comparison of marked and measured values of Resistance with sub-parameters

S.N0	**Inductor - L in Henry** Marked value with +/- 10 % tolerance	**LCR Meter Display** in Henrys	**Q**	**D**	**Theta**	**ESR**	**Measured Frequency**
1	10 micro H	10.1	0.645	1.551	32.84	1.445	1KHz
2	50 micro H	52.08	0.712	1.404	35.46	1.661	1KHz

3	1mH	1137 micro H	2.445	0.409	67.75	2.853	1KHz
4	4 milli H	4.109 milli H	5.337	0.187	79.39	4.8	1KHz
5	10 milli H	10.010 milli H	10.46	0.096	84.54	5.88	1KHz
6	100 milli H	103.55milli H	27.29	0.037	87.9	23	1KHz
7	500 milli H	502.0 milli H	57.91	0.017	89.01	56	1KHz
8	1 H	983.0 milli H	65.81	0.015	89.13	0.092	1KHz
9	5 H	4.954 H	58.02	0.014	89.06	1.98 Mohms	1KHz
10	10 H	9.972 H	60.87	0.016	89.21	3.6 M ohms	1KHz

Table 2b. Comparison of marked and measured values of Inductance with sub-parameters

S.N0	**Capacitor- C in Farads** Marked value with +/- 10 % tolerance	**LCR Meter Display** in Farads	**Q**	**D**	**Theta**	**ESR**	**Measured Frequency**
1	22 pico F	19.9 pico F	16.23	0.049	-93.19	> 20 M ohms	1KHz
2	10 nano F	10.826 nano F	330.2	0.003	-89.83	5.01 M ohms	1KHz
3	100 nano F	99.85 nano F	321.5	0.003	-89.82	7 ohms	1KHz
4	0.22 micro F	209.7 nano F	57.12	0.018	-89.94	13.6	1KHz
5	0.47 micro F	444.0 nano F	52.97	0.019	-88.92	6.9 ohms	1KHz
6	1 micro F	937.3 nano F	21.98	0.045	-87.4	7.9 ohms	1KHz
7	4.7 micro F	4.345 micro F	9.29	0.108	-83.85	4.04 ohms	1KHz
8	10 micro F	9.838 micro F	5.778	0.173	-80.18	2.87 ohms	1KHz
9	22 micro F	20.26 micro F	6.338	0.158	-80.97	1.276 ohms	1KHz

Table 2c. Comparison of marked and measured values of Capacitance with sub-parameters

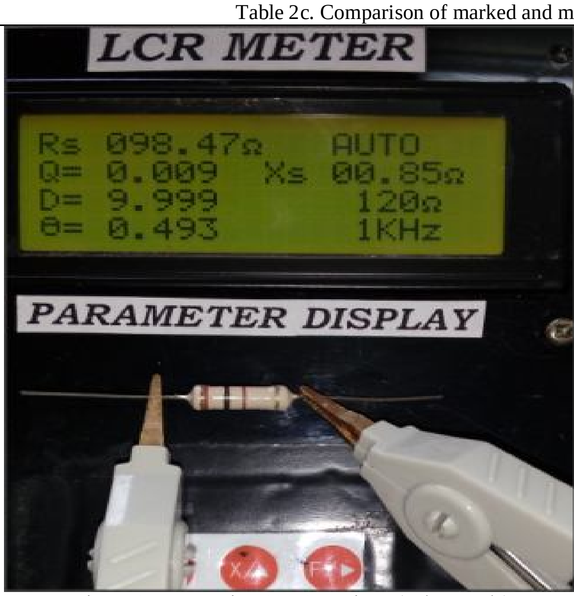

Figure 8a. Measuring 100 Ω Resistor (colour code)

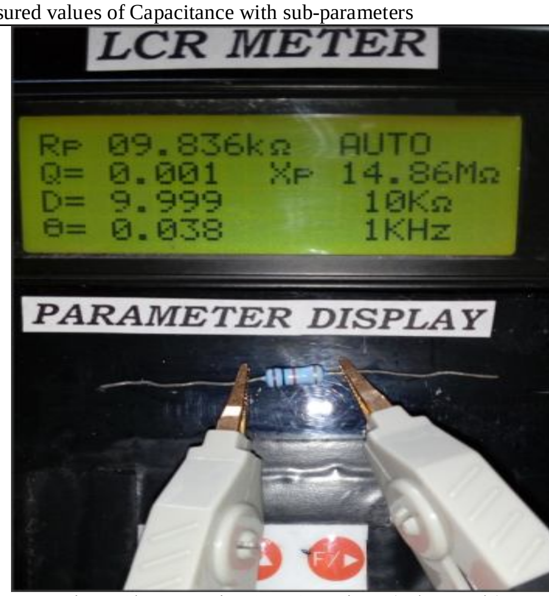

Figure 8b. Measuring 10 KΩ Resistor (colour code)

Figure 8c. Measuring 100 mH Inductor (box)

Figure 8d. Measuring 10 mH Inductor (box)

Figure 8e. Measuring 0.22µFarads Capacitor

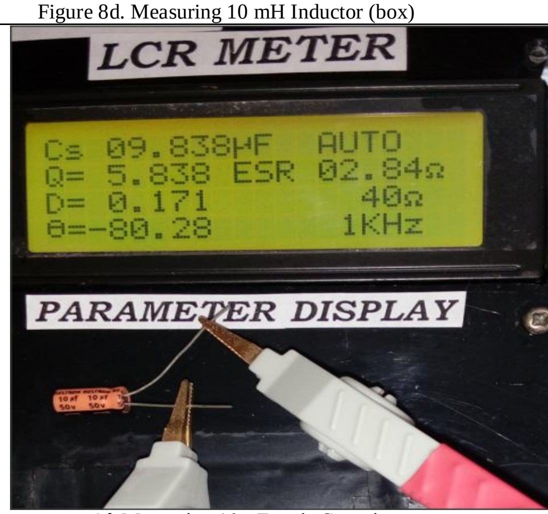

Figure 8f. Measuring 10 µFarads Capacitor

Figure 8. Measurement of Resistors, Inductors and Capacitors by using the designed LCR meter

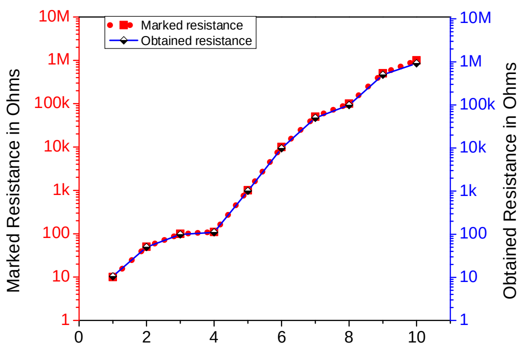

Figure 1. Marked resistance verses obtained resistance

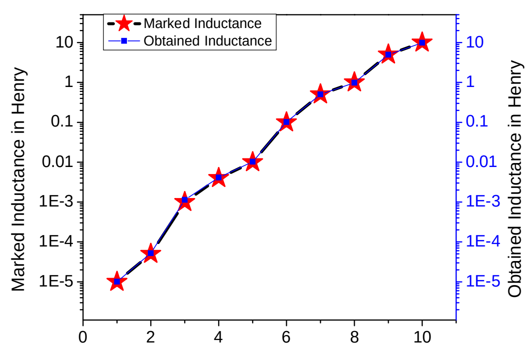

Figure 2. Marked inductance verses obtained inductance

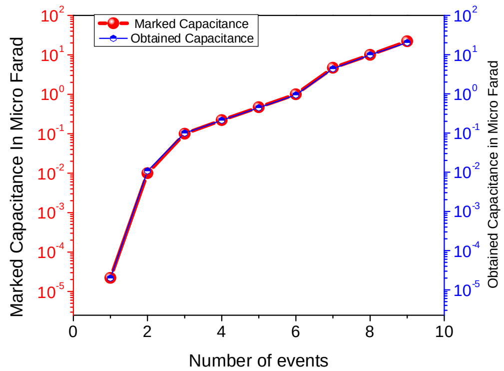

Figure 3. Marked capacitance verses obtained capacitance

VII. CONCLUSION

This paper describes the design and fabrication of low cost LCR meter, useful for research and educational purpose. It is very easy to operate, because automatic ranging system was incorporated and it also automatically selects the type of components we measure. It automatically switches between series and parallel connection of the measured components. The front panel controls are user friendly. Experimental results shows that the designed LCR meter is of high precision, small size, convenient and stable in use. The graphs 1, 2, and 3 shows that the measured values of the components are track the marked values on the components, the error percentage is almost less than 1. However, further improvements are needed for the measurement of large valued R, L and C components and improvement is required for high frequency measurements.

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