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Performance Evaluation of the Newly Developed Impedance Analyzer by Measuring and Comparing the Electrical Parameters of various Composite Materials

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Abstract - This paper describes a newly developed portable impedance instrument based on auto balancing bridge method, capable of making impedance measurements at multiple frequencies. An analog function generator was made by IC max038 stimulates the measurement circuit composed by the reference impedance and the unknown impedance. The frequency across the impedances and the electrical parameters such as Ls, Cp and Rs along with the sub-parameters were digitized and displayed. Then the performance was evaluated by comparing the results obtained by the designed instrument with the results of a commercial impedance analyzer for various composite materials such as ferro-magnetic, ferro-electric and multi-ferrite materials. For each case, the percentage of error is less than 3 to 5 were observed.

Keywords: Function generator, Impedance measurement, Auto balancing bridge, Composite materials, Performance evaluation.

I. INTRODUCTION

Impedance analyzer is an electronic testing instrument used to measure the electrical parameters such as 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 [1]. 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 [2, 7].

II. METHODOLOGY

Auto-Balancing Bridge method:

To perform precise impedance measurements, the voltage applied to the Device Under Test (DUT) and the current flows through the DUT need to be measured. The voltage applied to the DUT is detected as "V1" at the High-Potential (Hp) terminal of the instrument. The terminal is isolated from the High-Current (Hc) terminal, which is the output terminal [4]. This isolation enables accurate detection of the voltage applied to the DUT. The current, flows through the DUT goes to the Low-Current (Lc) terminal. If there exists a certain potential at the Lc terminal, stray capacitance between the terminal and ground is generated and current may flow to ground [11]. 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 "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 [5]. With this configuration, a wide range of impedance can be measured from low-Z to high-Z. Below figure-1 shows the basic diagram of Auto-Balancing-Bridge technique with the Four-Terminal-Pair configuration

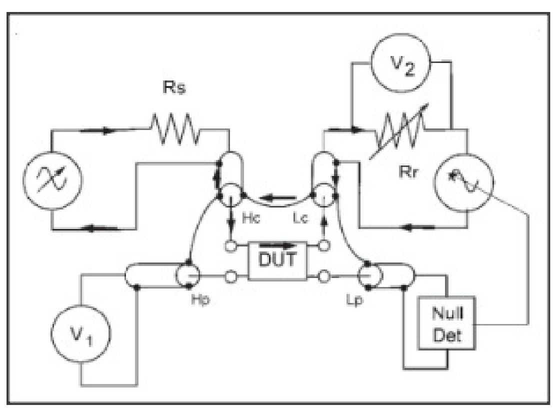

Figure-1 Basic diagram of Auto-Balancing-Bridge technique with the Four-Terminal-Pair configuration

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III. DESIGNED IMPEDANCE ANALYZER

The Impedance analyzer is constructed on a single printed circuit board with minimum components like: STC12C5A60S2- eight-bit Microcontroller [10], TL08XX-Operational amplifier, CD405X-CMOS single 8-channel analog Multiplexer/Demultiplexer, OP07-ultra-low offset voltage operational amplifier and is sufficiently compact as shown in figure-2. 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 [1]. The custom built impedance analyzer having the following specifications: basic accuracy - 3 to 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).

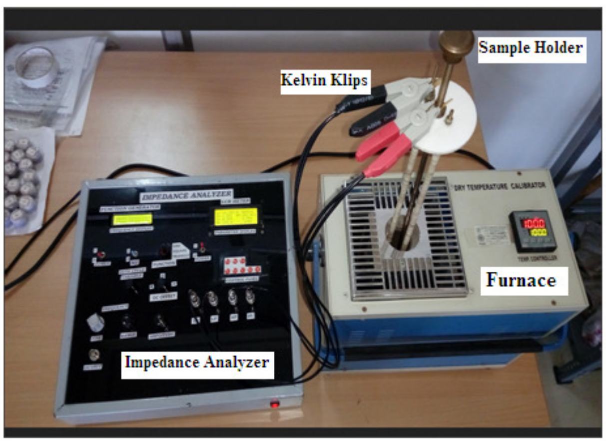

Figure-2 Snap shot of the complete setup of the Designed Impedance Analyzer

IV. PERFORMANCE EVALUATION

This research article mainly deals with the performance evaluation of the designed impedance analyzer by comparing the obtained results with the results of a commercial impedance analyzer – Newton 4th ltd, NumetriQ, Model: PSM 1735, for various composite materials such as ferro-magnetic and ferro-electric materials.

About the commercial impedance analyzer – (Newton 4th ltd, NumetriQ Model: PSM 1735)

An innovative design that incorporates both direct digital synthesis (DDS) [3] and heterodyning techniques, the PSM1735 provides a broad range of measurement functions over a wider frequency range. Typical applications for this product include switched mode power supply, feedback loop analysis; filter test and design, LVDT testing, sweep frequency response analysis of wound components and much more. PSM1735 NumetriQ utilizes the latest DSP and FPGA technology to optimize the use of its analogue hardware providing speed and measurement flexibility without compromise on the performance of each measurement function. The N4L PSM1735 features 0.01dB gain accuracy and 0.02° phase accuracy which is truly market leading performance [9].

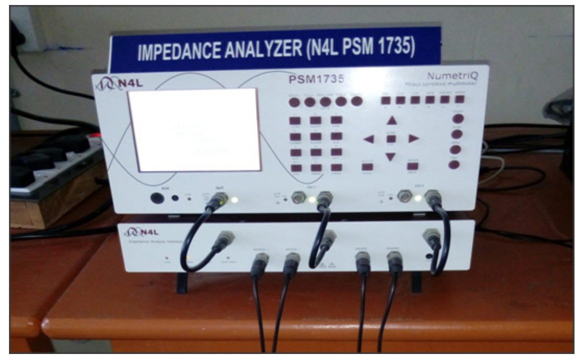

Figure-3 Photo graph of the setup of the commercial impedance analyzer

V. COMPARISON OF THE SPECIFICATIONS BETWEEN COMMERCIAL AND DESIGNED INSTRUMENTS

TABLE-1 SPECIFICATIONS OF COMMERCIAL VERSES DESIGNED IMPEDANCE ANALYZERS

Parameter	Commercial instrument	Designed instrument
Signal source	Direct Digital Synthesis (DDS)	Analog (based on MAX038)
Frequency range	Upto 35 MHz	Upto 15 MHz
Amplitude	10Vpp	4.5Vpp
Frequency and Amplitude control by	DDS (12 bit DAC)	Potentio meter
Accuracy	Frequency: +/- 0.05 % Amplitude: +/- 5 %	Frequency: +/- 0.1 % Amplitude: +/- 2 %
Measurement type	DFT analysis	DFT analysis
Measurements	L, C, R (ac), Q, tanδ, phase, series or parallel circuit	L, C, R, D, Q and ESR series or parallel circuit
Conditions	Auto or Manual	Manual
Display	Numeric values and graph of any measurement	Numeric values
Ranges	100pF to 100uF; 1µH to 100H; 1Ω to 100MΩ;	0.1 pF - 9999µF 0.01µH - 999 H 0.0002 - 19999kΩ

For evaluating the performance of the designed impedance analyzer, I considered the following types of materials

1. $Ni_{0.65}Zn_{0.35}Fe_2O_4$ – Ferrite material [6]
2. $BaTiO_3$ – Ferro electric material

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IJARMATE

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The evaluation was made in two phases.

1. Varying the applied frequency at room temperature (phase-1) [8]

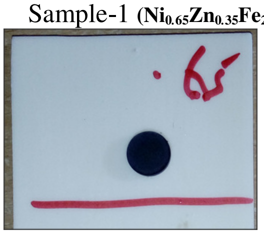
2. Varying the temperature at a fixed frequency (phase-2) [6]

Davuluri Venkatesh et al in May- 2015 published an article entitled "Structural, Magnetic, and Electrical Properties of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ Nanoferrite System" [6], this ferrite was considered as Sample-1 for evaluating the designed impedance analyzer, along with the above said material, I also considered one more materials- $BaTiO_3$ – Ferro electric material as Sample-2.

VI. RESULTS

For the above said material samples, in phase-1 performance evaluation, the studies are as a function of various frequencies, in phase-2 performance evaluation, the studies are as a function of temperature, for both phases, the electrical parameters such as Series Inductance (Is), Parallel Capacitance (Cp) and Series Resistance (Rs) were measured with both the commercial (N4L- PSM1735) impedance analyzer [9] as well as with the designed impedance analyzer.

Sample-1 ($Ni_{0.65}Zn_{0.35}Fe_2O_4$)



Ferro-magnetic material

Sample-2($BaTiO_3$)

Ferro-electric material

TABLE-2 COMMERCIAL VERSES DESIGNED AT ROOM TEMPERATURE

$Ni_{0.65}Zn_{0.35}Fe_2O_4$ (At Room Temperature ≈ 35°C)						
Frequency (Hz)	Commercial Instrument Readings			Designed Instrument Readings		
	Ls (H)	Cp (F)	Rs (Ohm)	Ls (H)	Cp (F)	Rs (Ohm)
1.00E+02	-7.57E+03	4.3823E-10	5.80E+05	-7.07E+03	3.53E-10	5.73E+05
5.00E+02	-2.41E+02	3.7276E-10	2.70E+05	-3.11E+02	3.23E-10	8.86E+04
1.00E+03	-6.76E+01	3.5473E-10	1.00E+05	-8.07E+01	3.12E-10	4.19E+04
1.00E+04	-8.13E-01	3.0799E-10	5.36E+03	-8.99E-01	2.80E-10	4.01E+03
1.00E+05	-9.26E-03	2.7191E-10	4.67E+02	-9.92E-03	2.54E-10	3.92E+02
1.00E+06	-1.03E-04	2.4419E-10	4.14E+01	-1.08E-04	2.33E-10	3.83E+01
1.00E+07	-1.68E-06	1.5014E-10	5.08E+00	-1.72E-06	1.46E-10	8.79E+00
1.50E+07	-1.52E-06	6.5153E-11	-5.32E+01	-2.42E-06	3.15E-11	-1.57E+02

TABLE-3 COMMERCIAL VERSES DESIGNED AT ROOM TEMPERATURE

$BaTiO_3$ (At Room Temperature ≈ 35°C)						
Frequency (Hz)	Commercial Instrument Readings			Designed Instrument Readings		
	Ls (H)	Cp (F)	Rs (Ohm)	Ls (H)	Cp (F)	Rs (Ohm)
1.00E+00	-3.26E+07	5.55E-10	1.29E+08	-4.44E+07	5.44E-10	6.19E+07
1.00E+01	-5.80E+05	4.24E-10	6.48sE+06	-5.84E+05	4.28E-10	4.28E+06
1.00E+02	-6.76E+03	3.72E-10	4.02E+05	-6.75E+03	3.72E-10	3.56E+05
5.00E+02	-2.94E+02	3.42E-10	7.66E+04	-2.93E+02	3.44E-10	7.26E+04
1.00E+03	-7.59E+01	3.32E-10	3.87E+04	-7.59E+01	3.32E-10	3.77E+04
1.00E+04	-8.54E-01	2.95E-10	4.10E+03	-8.50E-01	2.96E-10	4.07E+03
1.00E+05	-9.50E-03	2.66E-10	3.91E+02	-9.46E-03	2.67E-10	3.92E+02
1.00E+06	-1.04E-04	2.43E-10	3.49E+01	-1.04E-04	2.44E-10	3.50E+01
1.00E+07	-1.72E-06	1.47E-10	4.14E+00	-1.72E-06	1.47E-10	4.04E+00

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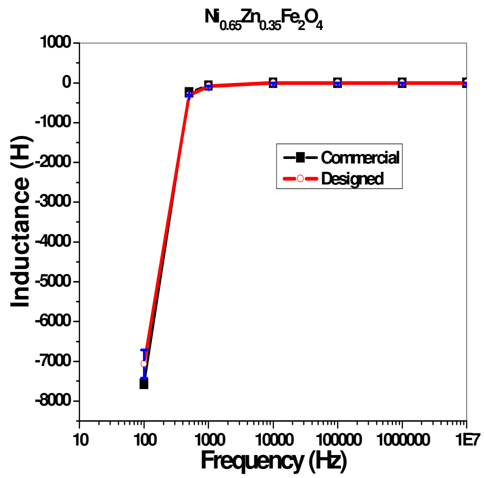
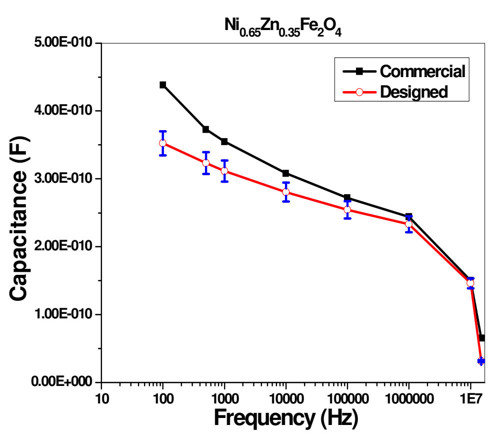
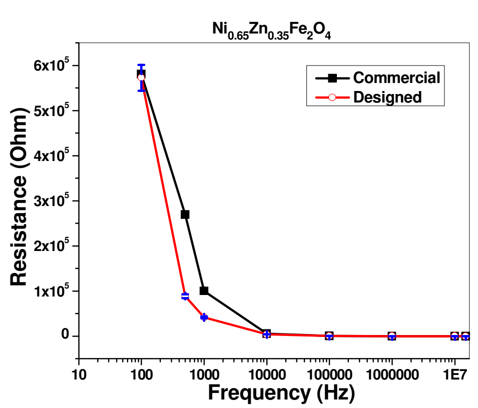


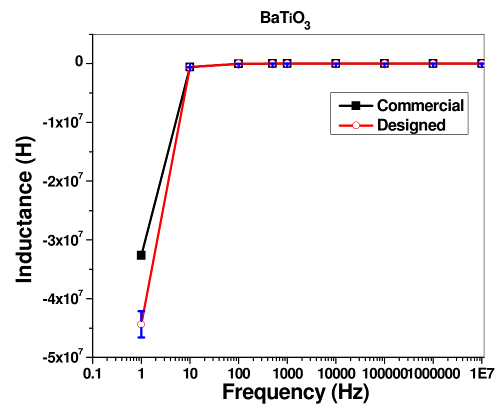
Inductance verses Frequency plot of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at room temperature



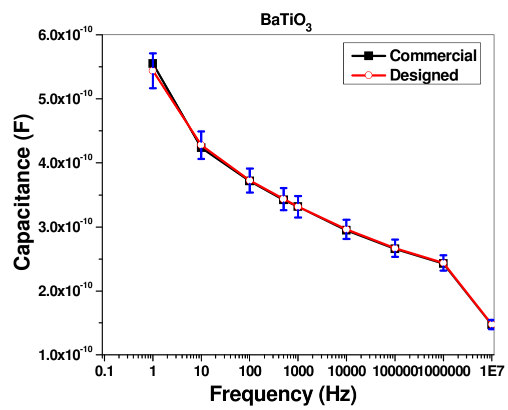
Capacitance verses Frequency plot of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at room temperature



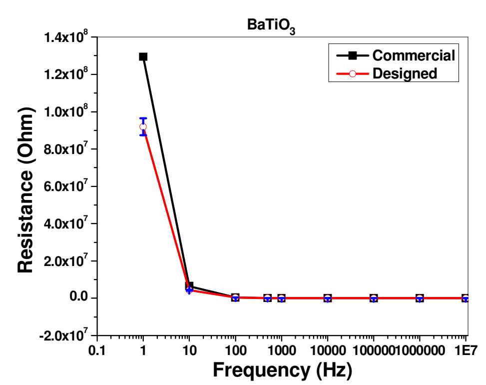
Resistance verses Frequency plot of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at room temperature



Inductance verses Frequency plot of $BaTiO_3$at room temperature



Capacitance verses Frequency plot of $BaTiO_3$at room temperature



Resistance verses Frequency plot of $BaTiO_3$at room temperature

TABLE-4 COMMERCIAL VERSES DESIGNED AT FIXED FREQUENCY

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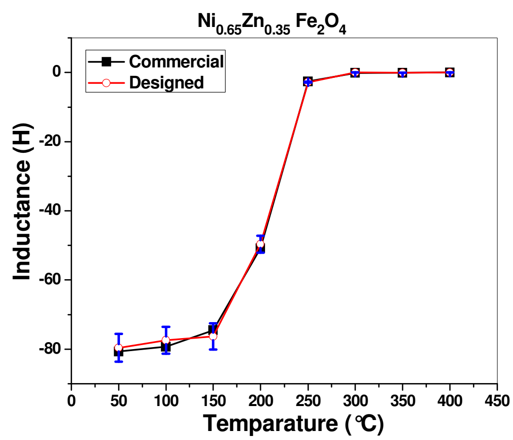
IJARMATE
International Journal of Advanced Research in Management, Architecture, Technology and Engineering
(IJARMATE) Vol. 3, Issue 3, March 2017

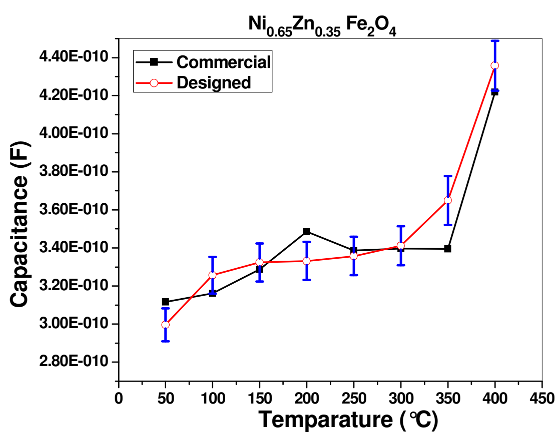
$Ni_{0.65}Zn_{0.35}Fe_2O_4$ at 1KHz Frequency						
Temperature (°C)	Commercial Instrument Readings			Designed Instrument Readings		
	Ls (H)	Cp (F)	Rs (Ohm)	Ls (H)	Cp (F)	Rs (Ohm)
50	-8.07E+01	3.12E-10	4.19E+04	-7.96E+01	3.00E-10	3.87E+04
100	-7.93E+01	3.16E-10	5.06E+04	-7.75E+01	3.26E-10	6.04E+04
150	-7.46E+01	3.29E-10	8.56E+04	-7.63E+01	3.32E-10	8.17E+04
200	-5.08E+01	3.49E-10	2.09E+05	-4.96E+01	3.33E-10	2.46E+05
250	-2.55E+00	3.39E-10	8.53E+04	-2.76E+00	3.36E-10	7.92E+04
300	-1.17E-01	3.40E-10	1.86E+04	-1.78E-02	3.41E-10	2.14E+04
350	-2.46E-02	3.40E-10	8.52E+03	-3.43E-02	3.65E-10	6.92E+03
400	-8.01E-04	4.22E-10	1.38E+03	-1.60E-03	4.36E-10	1.02E+04

TABLE-5 COMMERCIAL VERSES DESIGNED AT FIXED FREQUENCY

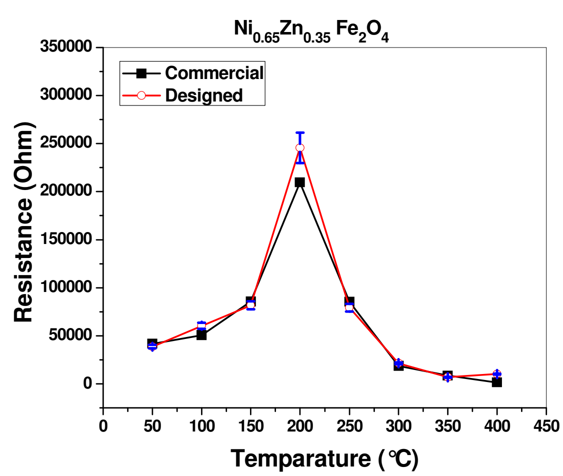
$BaTiO_3$ at 1KHz Frequency						
Temperature (°C)	Commercial Instrument Readings			Designed Instrument Readings		
	Ls (H)	Cp (F)	Rs (Ohm)	Ls (H)	Cp (F)	Rs (Ohm)
40	-7.59E+01	3.32E-10	3.87E+04	-7.77E+01	3.25E-10	3.98E+04
80	-7.58E+01	3.32E-10	3.66E+04	-7.67E+01	3.28E-10	3.84E+04
120	-7.55E+01	3.34E-10	3.49E+04	-7.50E+01	3.28E-10	3.65E+04
160	-7.37E+01	3.42E-10	3.34E+04	-7.26E+01	3.32E-10	3.48E+04
200	-7.27E+01	3.47E-10	3.12E+04	-7.17E+01	3.40E-10	2.97E+04
240	-7.31E+01	3.45E-10	2.82E+04	-7.11E+01	3.41E-10	2.68E+04
280	-7.27E+01	3.47E-10	3.39E+04	-7.16E+01	3.50E-10	3.52E+04
300	-7.24E+01	3.48E-10	3.51E+04	-7.09E+01	3.50E-10	3.65E+04



Inductance verses Temperature plot of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at 1KHz Frequency



Capacitance verses Temperature plot $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at 1KHz Frequency



Resistance verses Temperature plot of $Ni_{0.65}Zn_{0.35}Fe_2O_4$ at 1KHz

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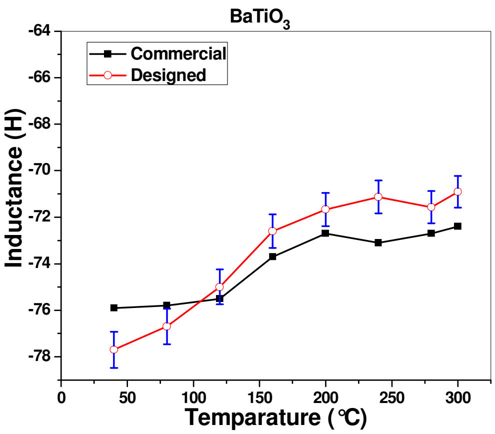
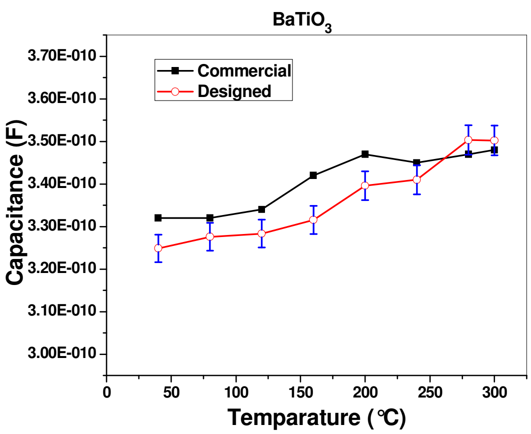
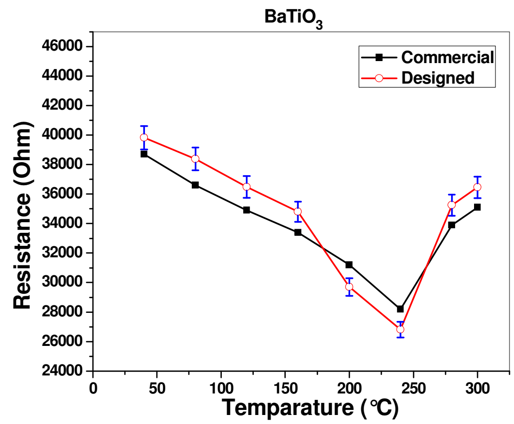


FrequencyInductance verses Temperature plot of $BaTiO_3$ at 1KHz Frequency



Capacitance verses Temperature plot of $BaTiO_3$ at 1KHz Frequency



Resistance verses Temperature plot of $BaTiO_3$ at 1KHz Frequency

By observing the above tables and the corresponding plots, it was conclude that the designed impedance analyzer's results were almost matched with the results obtained by the commercial impedance analyzer and also observed that the percentage of error between the results was less than 3 to 5.

VII. CONCLUSION

After the completion of design and fabrication of the impedance analyzer, its performance was evaluated by making the measurements of various electrical parameters by varing frequency and temperature of various composite materials and also comparing the results produced by the designed instrument with the results obtained by a commercial instrument –N4L NumeriQ, model: PSM 1735. The results of both the instruments are tabulated and plotted for each material, in each case, it is observed that the deviation between the results of these two instruments was less than 5 percent. However, further improvements are needed for the designed instrument in terms of measurement of large valued R, L and C components of some materials and improvement is required for high frequency measurements.

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