High Frequency Compatible Impedance Analyzer for Ultrasound Transducers Using LabVIEW

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***Abstract*—Impedance analysis is very much useful in finding the characteristics of an electrical system and also helps to find equivalent circuit of different electrical devices including transducers like ultrasound transducers, sensors etc. In this work an impedance analyzer is implemented based on auto balancing bridge for finding the characteristics of ultrasound transducer. The signals for impedance characterization is generated and acquired by using National Instruments function generator NI PXI 5450 and scope NI PXI 5154. LabVIEW software is used for calculation of impedances. Using LabVIEW based Impedance Analyzer we can analyze impedances of a device upto a frequency level of 20MHz**

Keywords-impedance, impedance measurement, ultrasound transducer, phase measurement, ultrasonic transducers

I. INTRODUCTION

The ultrasound transducers are commonly used in noninvasive medical technology for the purposes like arterial distensibility measurements [1]. The electrical impedance characterization is important to select and improve transducers properly for particular application and transducer modeling [2]. Impedance is normally represented in terms of magnitude Z and phase Φ [3]. Also impedance can be represented as $R + j\,\omega X$, where R is the resistance and X is the reactance of a circuit. The magnitude $Z = \sqrt{(R^2 + X^2)}$ and phase is *tan-1(X/R)*. The reactance X depends upon frequency of input signal and its value varies with frequency. So impedance will also vary.

There are different devices present for impedance analysis. But the frequency range of operation is limited. Also configuration, data analysis and storing of data is difficult [5]. So we developed a LabVIEW based impedance analyzer that can operate up to 20 MHz.

There are various methods to find the impedance of a device like bridge method, resonant method, I-V method, RF I-V method, auto balancing bridge method etc. [4]. Auto balancing bridge method is used in this work [5]. Here virtual ground concept is used to find voltage across the DUT (device under test). In this, current flowing through the DUT balances with current flowing through the resistor R. Using the voltage across R, the current flowing through the DUT is found out. In impedance of the DUT is $Z = V/I = (V1/V2)R$. This method allows use of wide frequency range from low frequency to high frequency up to mega hertz range. Automating of impedance analysis for laboratory purpose and other purposes are done using different data acquisition cards and computer [6]. The virtual instrumentation based impedance analyzers simplifies and automates measurement and characterization process [7]. The present virtual impedance analyzers are suitable only for low frequency range calculations [8]. The proposed system will help to measure impedance up to 20MHz frequency ranges with the help of high bandwidth op amp AD8055 and data acquisition cards NI PXIe 5450 and NI PXIe 5154 [9][10].

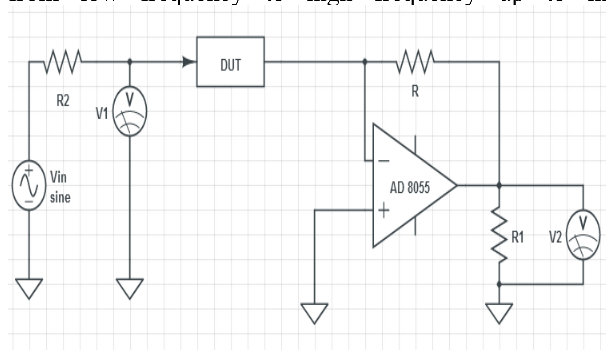

Fig 1 . Auto Balancing Bridge

II. IMPEDANCE ANALISYS

A. Working

The whole impedance analysis is based on auto balancing bridge; national instruments work station and LabVIEW software. As shown in Fig 2 the device under test (DUT) is connected to auto balancing bridge block. Auto balancing bridge balances the current flowing through DUT and resistor R as mentioned above. The voltage *Vin* is generated through NI 5450 card based on user specification at varying frequencies. The signals can be acquired through any NI NI 5154 card. LabVIEW vi finds amplitude and phase of *V1* and *V2* at each frequency. It then finds magnitude of impedance using this formula.

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$$|Z| = (V1/V2)R \quad (1)$$

And phase using

$$\Phi = \Phi(V1) - \Phi(V2) \quad (2)$$

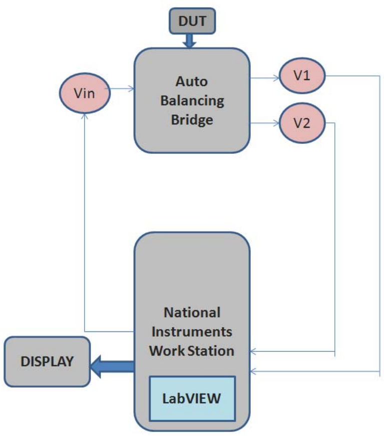

Fig. 2. Block Diagram

B. Implementation

1) *Circuit*: The circuit is based on auto balancing circuit. The schematic of the circuit is shown in Fig.3. The OP AMP used here is AD8055. It is a wide bandwidth (300MHz) op amp with high slew rate up to 1400V/µS. The resistor *R2* is used to avoid high current when DUT is short circuited and the grounded load R1 is used to get better output as *V2*.

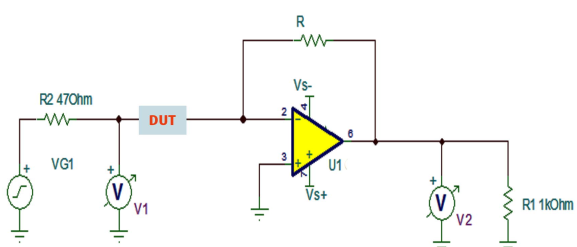

Fig. 3. Circuit Diagram

The feedback resistor plays an important role in impedance measurement. The voltage V2 depends upon value of *R*. It should be adjustable resistor. The value of resistance *R* should select properly to get proper output waveform.L7905 and L7805 are used for creating regulated supply.

C. Components

1) *OP Amp and Resistors*: The op amp here used here is AD8055. The main advantage of this IC is high bandwidth, high slew rate and low offset voltage. The performance of op amp depends mainly on bandwidth. The resistor *R1* is used as a grounded load for better output in *V2* and the resistor *R2* is used for avoid high current if DUT is short circuited

D. National Instruments Workstation

NI function generator card PXI 5450 and Scope card PXI 5154 are configured in this station as shown in figure [9] [10]. NI PXI 5450 is 400MS/s signal generator used for generating input sine wave signals of maximum 1 volt peak to peak amplitude at different frequencies for impedance characterization. NI PXI 5154 is 2GS/s 1GHz digitizer or scope. The maximum input voltage should be 5 volt peak to peak.

E. LabVIEW

LabVIEW is powerful virtual instrumentation software from National Instruments for data acquisition and manipulation [11]. Here LabVIEW is used for the calculation of magnitude and phase of the impedance, save readings into file, plot magnitude and phase versus frequency and generate input sine wave signals with different frequency based on frequency minimum, frequency maximum and step size specified by user through LabVIEW interface. LabVIEW have two panels one is front panel and the other is block diagram. In the front panel we configure user interface and indicators. Block diagram consists of various blocks for the implementation of impedance calculation algorithm

1) *Front Panel:*

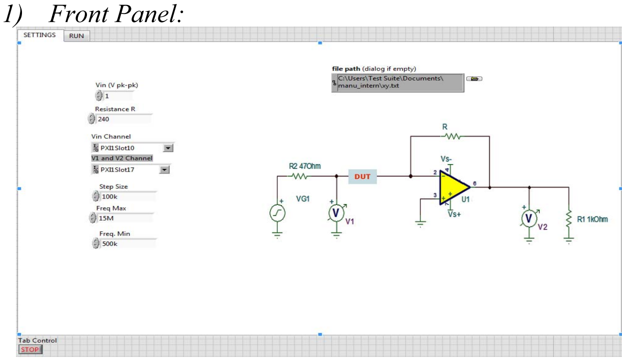

Fig. 4. Settings Tab

The front panel of LabVIEW virtual instrument of impedance analyser is consists of two tabs shown in Fig 4 and 5. Tab 1 is SETTINGS and tab 2 is RUN. In SETTINGS tab user should specify some details and connect DUT based on the schematic shown. In the *Vin* field user should specify amplitude of input sine wave voltage peak to peak. The *Freq. Max* field is to specify maximum frequency and *Freq. Min* is the minimum frequency that you want to apply. Step Size field is to specify the increment of input voltage from frequency minimum to maximum. The *RUN* tab contains four graphs and two buttons. Press *OK* button to initiate impedance analysis. The graphs are magnitude of the impedance versus frequency, phase of the impedance versus frequency, V1 and V2.

1) *Block Diagram:*

The block diagram consists of various blocks are known as vi (virtual instruments) is shown in Fig.6. There are some blocks for initialization and generation of signals through NI PXIe 5450 at various frequencies and other blocks for calculation, storing and displaying magnitude and phase of impedances. The frequency is updated by adding frequency minimum with product of step size and one incremented count of while loop iteration in LabVIEW vi.

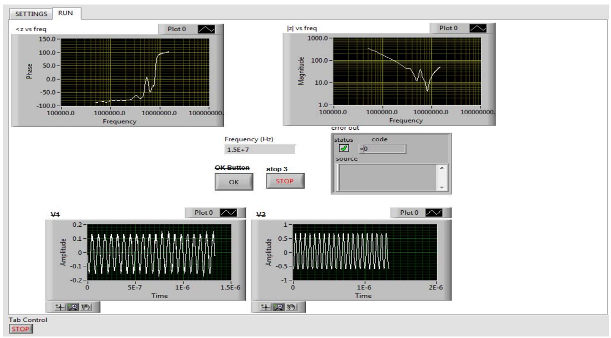

Fig. 5. Run Tab

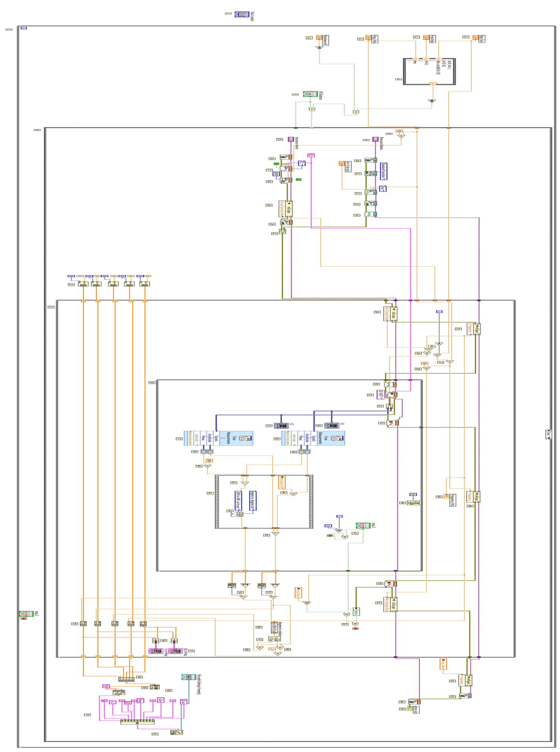

Fig 6. Block Diagram

III. RESULTS

The Impedance analyzer is tested with RC series, RC parallel and Ultrasound transducer. The results are given below.

A. *RC Series Circuit*

The impedance value measured at different frequencies ranging from 0.5 MHz to 15 MHz of a RC series circuit made up of 1 K resistor and 22 pF capacitor is given below as table. The magnitude and phase plot is shown in Fig.7 and 8 respectively.

Frequency(Hz)	Magnitude(Ω)	Phase(Degree)
500000	14646.65	-79.25
2100000	3388.62	-74.07
4000000	1909.09	-61.05
6200000	1384.22	-48.01
8000000	1204.51	-40.21
15000000	852.68	-16.55

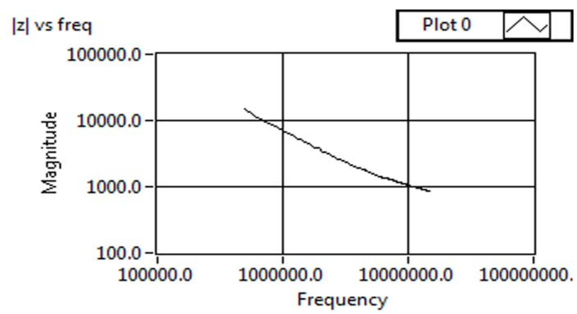

Fig. 7. Magnitude Plot

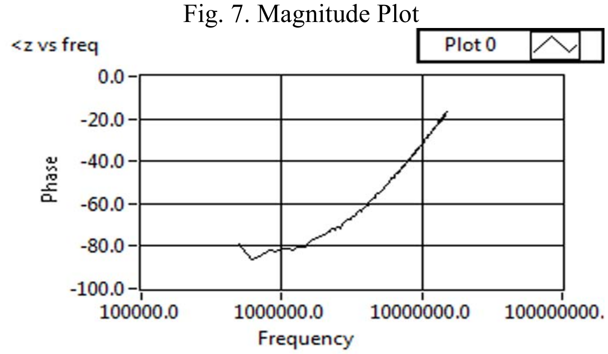

Fig. 8. Phase Plot

B. *Ultrasound Transducer*

The impedance value measured at different frequencies ranging from 0.5 MHz to 15 MHz of an ultrasound transducer is given below as table. The magnitude and phase plot is shown in Fig.9 and 10 respectively.

Frequency(Hz)	Magnitude(Ω)	Phase(Degree)
900000	198.69	-85.88
2600000	55.64	-77.01
6800000	13.2	-36.29
8800000	8.99	83.97
11900000	31.86	98.62
14600000	50.83	105.88

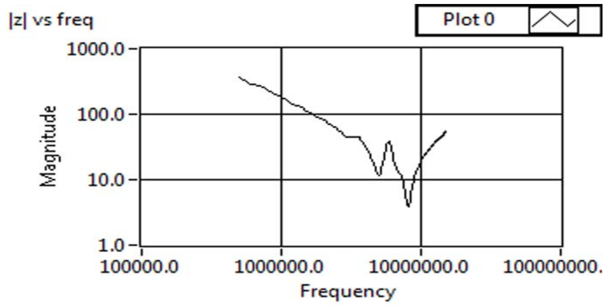

Fig. 9. Magnitude Plot

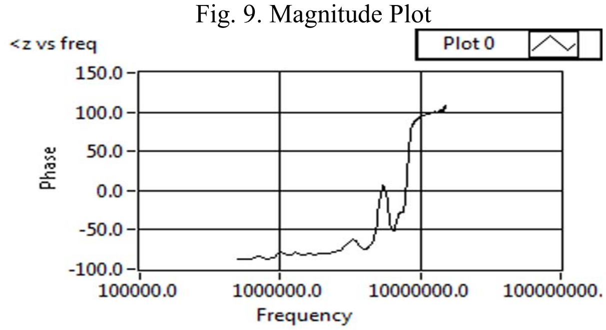

Fig. 10. Phase Plot

IV. Calibration

The RC series and parallel circuit with their actual and calculated values given as table below.

A. *RC Series Circuit*

In this section theoretical and measured values of magnitude and phase of RC series circuit made up of 1K and 22pF capacitor is described as table.

Freq(Hz)	Maq(T)(Ω)	Mag(M)(Ω)	P(T)	P(M)
2000000	3752	3604.81	-74.55	-74.58
3200000	2472	2360.17	-66.14	-65.86
6500000	1496.2	1344.72	-48.06	-45.69
8700000	1300.55	1146.88	-39.74	-36.73
10200000	122.98	1035.03	-35.35	-30.98

”T” stands for theoretical, ”M” stands for measured, ”Freq” stands for frequency, ”Mag” stands for magnitude and ”P” stands for phase.

We can calibrate the system by comparing theoretical and measured values of RC circuit given as table above.

V. Repeatability

The magnitude and phase of one ultrasound transducer in two trials are given below as table to show the repeatability. We can see that the device shows good repeatability.

Freq(Hz)	Mag(1)(Ω)	Mag(2)(Ω)	P(1)	P(2)
500000	371.17	368.54	-87.2	-87.79
2100000	76.94	77.16	-79.76	-80.48
5400000	20.81	20.83	6.1	4.81
7800000	5.65	5.58	-14.54	-15.54

”1” stands for 1st trial and ”2” stands for 2nd trial, ”Freq” stands for frequency, ”Mag” stands for magnitude and ”P” stands for phase.

VI. Advantages

The LabVIEW based impedance analyzer helps for easy analysis of signals for finding magnitude and phase of impedance of DUT and also it gives a good and easy user interface. The auto balancing bridge used in this device gives high accuracy in measurement of voltage signals for input signal varies from few hertz to megahertz up to 20MHz.

VII. Future Works

Trying to replace AD8055 with another op amp with better features related to bandwidth, slew rate and offset error that will improve the operating range of Impedance Analyzer.

VIII. Conclusion

LabVIEW based Impedance Analyzer helps for automated characterization of any electrical device. This device provides impedance analysis of a device from Hz to MHz range with good accuracy and repeatability. This is a simple device based on simple technology and easy to implement and also easy to use.

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