High-Frequency Compensation of LCR Meter For Impedance Standards

Preeti Dagar[1], **Gurmeet Singh**[2]
[1]Dept of Electronics and Communication
[2]HOD, Dept of Electronics and Communication
[1,2]PDM University, Haryana, India

Abstract- *One of the major challenges in power electronic applications is the presence of parasitic elements at the contact between DUT and the measuring instruments. Thus, it affects the impedance measurement of the components at high-frequencies. In many applications' impedance analyzers can be used to characterize resistors, capacitors, inductors and transformers, but they have their limitations which can be problematic for power components. Still they are most convenient to characterize a component; also, high accuracy can be achieved more often. As we know that the electrical impedance is a complex (magnitude and phase) spectra of impedance and frequency. Thus, even a small change in magnitude, a small variation in the degree of the phase or even a small change of frequency can affect the experimental measurement. Thus, we have tried to design a new test fixture for compensating these parasitic components at high-frequency and to measure impedance as accurately as possible.*

Keywords- High-frequency, impedance, test fixture, parasitic components, compensating.

I. INTRODUCTION

Several challenges are present in characterizing the passive components in any power electronic applications. In many applications' impedance analyzers can be used to characterize resistors, capacitors, inductors and transformers, but they have their limitations which can be problematic for power components. Still they are most convenient to characterize a component; also high accuracy can be achieved more often.

Impedance analyzers using four-terminal (4T) or four-terminal-pair (4TP) connections for connecting device under test (DUT) can accurately measure much lower impedances. However, the parasitic components present in the test fixture can becomes a severe problem for present and future microprocessor power delivery circuits as the impedances required is very low.

1.1 Parasitic components

Generally, the values of L, C and R components are represented by the nominal values of capacitance, inductance or resistance at specific or standard conditions. But all the components in a circuit are neither purely resistive nor purely reactive. Parasitic components are always present in all real-world devices like unwanted inductance in resistors, unwanted resistance in capacitors, unwanted capacitance in inductors, etc.

Parasitic are also present due to different types of materials used in manufacturing and due to different manufacturing technologies. These parasitic reside in components, thus affecting the components usefulness and accuracy. These parasitic components combined with primary elements, makes a component looks like a complex circuit as.

1.2 Compensation

Compensation reduces the effects of the error sources exist between the DUT and the instrument's calibration plane. It is done by measuring the test fixture residuals. Compensation and calibration are not the same thing and it cannot replace calibration. The compensated data accuracy depends on the calibration accuracy of the instrument; thus, we have to perform compensation after calibration is completed. Three commonly used compensation techniques are:

1. Offset compensation,
2. Open/short compensation and
3. Open/short/ load compensation.

1.3 Calibration:

Most of the RF vector measurement instruments, such as network analyzers, need to be calibrated each time a measurement is initiated or a frequency setting is changed. The RF I-V measurement instrument requires calibration as well. At higher frequencies, a change in the instrument's operating conditions, such as environmental temperature, humidity, frequency setting, etc., have a greater effect on measurement accuracy. This nature of RF vector measurement makes it difficult to sufficiently maintain the calibrated measurement performance over a long period of time. Thus, users have to periodically perform requisite calibration. Note: Calibration is necessary each time a measurement setup is changed. Calibration is executed in reference to three standard terminations: open, short, and load. All three must be performed. To improve the accuracy of low dissipation factor measurements (high Q factor), calibration with a low-loss capacitor can be performed.

1.4 Test fixture:

To connect the device under test (DUT) to an impedance analyzer a test fixture is needed. A test fixture uses the four-terminal-pair (4TP) configuration with the auto-balancing bridge as shown in figure 4. Unfortunately, commercially available test fixtures are not adequate for measuring very low impedances at frequencies extending into the MHz range, as is becoming critical for developing high-performance high-current power systems for microprocessor power delivery [8].

The 4TP configuration is useful for preventing stray impedances of the cables, such as series inductance and resistance and shunt capacitance from appearing in the measurement [17], but the stray impedances near DUT remain like resistance of the ground path adjacent to the DUT.

The quality of the fixture is important to determine the limit of the total measurement accuracy. In this report we discuss on how to choose or how to fabricate a test fixture for auto-balancing bridge instruments.

Figure 1.1: Aluminum fabricated test fixture

Designing of fixtures depends upon many factors, which are analyzed to get design inputs for fixtures. The list of factors is as follow:

1) Study of work-piece and finished component size and geometry.
2) Type and capacity of the machine on which fixture is to be used.
3) Location on the machine on which fixture is to be connected.
4) Available devices and their accuracy.
5) Rigidity of the machine tool in consideration.
6) Study of ejecting devices, safety devices etc.
7) Required level of the accuracy in the work.

1.5 Four-Terminal-Pair Configuration

In this paper we are using four-terminal-pair (4TP) auto-balancing bridge system [11], as shown in figure 1.2. This system minimizes the effect of stray impedance in the interconnections. Voltage across the DUT is measured at the high-potential (H_p) terminal pair with respect to a virtual ground maintained by the low-potential (L_p) terminal pair by feedback control of a second source at the low-current terminal pair. Signal is applied at the high-current terminal pair. The analyzer can compute complex impedance from the magnitude and phase of the measure voltage and current.

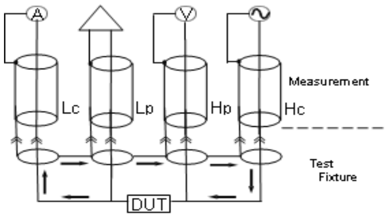

Figure 1.2: Schematic of the Auto Balancing Bridge Measurement [11]

II. IMPEDANCE METROLOGY

One of the important parameters used to characterize the electronic components, circuits and devices is impedance. Impedance (Z) is defined as the total opposition a device or circuit offers to the flow of an AC at a given frequency. It is a complex quantity and thus shown in a vector plane. Impedance vector consists of resistance(R) as its real part which is constant regardless of frequency and reactance (X) as its imaginary part which with frequency due to capacitance and inductance

The measurement of result of electrical impedance is a complex (magnitude and phase) spectra of impedance and frequency. The spectra typically have smooth and small features; mostly a small percent variation in magnitude, less than a degree variation in phase angle or a small change in frequency, represents all the experimental information available. Therefore, high measurement accuracy and strict control on the employed instrument become necessary to achieve meaningful measurements. If the calibration is performed Today, commercial instruments having frequency bandwidths extended from a few Hz to tens of MHz are available, which are easy to operate and have a fast response.

In top-class instruments resolutions of six or seven digits and high measurement repeatability are commonly found, which gives the operator a false feeling of a very high accuracy of measurement. But in reality, relative accuracy specifications can be in range of audio frequencies, but can be degrading to a few percent after 100 kHz. Further accuracy degradation can occur because of the connections to be measured, especially when impedances in the higher or lower ranges are involved. Measurement accuracy can be improved by the compensation of parasitic impedances given by connections and fixtures and by a periodic instrument calibration in a short period (hours) with proper impedance standard sets, the accuracy can be improved greatly. The calibration of impedance standards in the high frequency range is a challenge for metrology laboratories. Primary impedance standards and coaxial transformer bridges, allows the realization of SI impedance units (ohms, henry and farad) with accuracy, but it has limitation on frequency range of about 1 kHz. The same instruments can be used to generate high accuracy impedance scales in the audio frequency range (20 Hz-20 kHz), but at higher frequencies a new measurement method have to be considered.

III. RESULT AND DISCUSSION

Table 3.1: Un-compensated and compensated value of impedance for 0.1-ohm resistor

Nominal value	Meas. Freq.(in kHz)	Un-compensated value of Z(in Ω)	Compensated value of Z(in Ω)
0.1Ω	1	0.1367	0.1372
	10	0.1369	0.1373
	100	0.1374	0.1378
	1000	0.1441	0.1451
	10000	0.4085	0.4135
	20000	0.7829	0.7773
	30000		0.9172
	31000		1.1825
	32000		1.2193
	33000		1.2561
	34000		1.2869
	35000		1.3297
	36000		1.3665

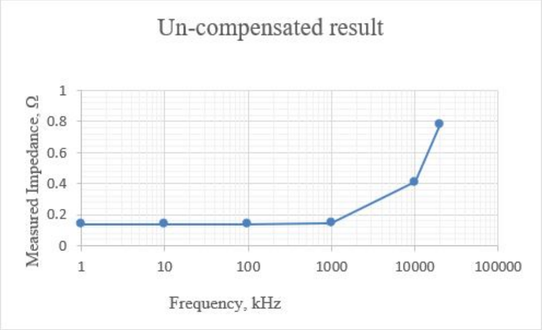

Figure 3.1: Grape for un-compensated value of impedance for 0.1-ohm resistor

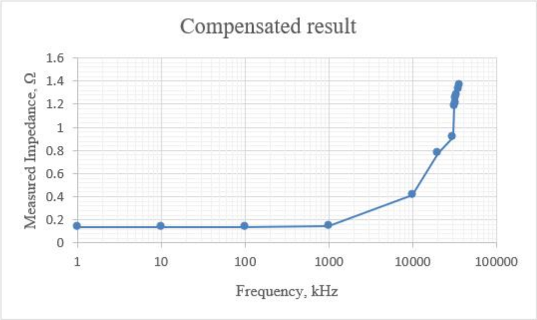

Figure 3.2: Grape for compensated value of impedance for 0.1 ohm's resistor

Table 3.2: Un-compensated and compensated value of impedance for 1-ohm resistor

Nominal value	Meas. Freq.(in kHz)	Un-compensated value of Z(in Ω)	Compensated value of Z(in Ω)
1Ω	1	1.0112	1.0113
	10	1.0112	1.0113
	100	1.0115	1.0115
	1000	1.0278	1.0135
	10000	1.2130	1.0867
	20000	1.2798	1.2680
	30000		1.5186
	40000		1.8096
	50000		2.1231
	60000		2.4494
	70000		2.7844
	80000		3.1268
	90000		3.2732
	91000		3.5073
	92000		3.5422
	93000		3.5761

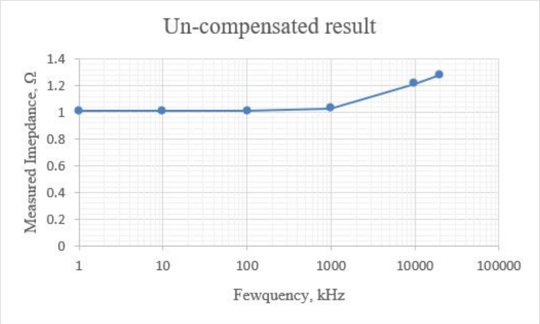

Figure 3.3: Grape for un-compensated value of impedance for 1-ohm resistor

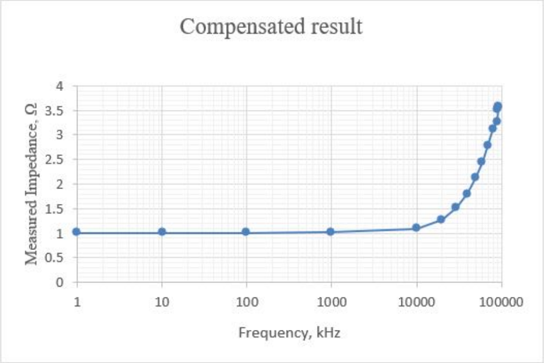

Figure 3.4: Grape for compensated value of impedance for 1-ohm resistor

Table 3.3: Un-compensated and compensated value of impedance for 10-ohm resistor

Nominal value	**Meas. Freq.(in kHz)**	**Un-compensated value of Z(in Ω)**	**Compensated value of Z(in Ω)**
10Ω	1	9.6084	9.6083
	10	9.6085	9.6084
	100	9.6083	9.6083
	1000	9.5737	9.6084
	10000	9.5215	9.6148
	20000	9.7210	9.6287
	30000		9.6525
	40000		9.6876
	50000		9.7341
	60000		9.8087
	70000		9.8664
	80000		9.9420
	90000		10.0660
	100000		10.1587
	110000		10.2428
	120000		10.2440

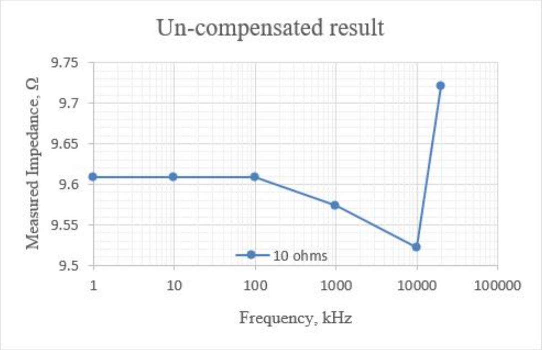

Figure3.5: Grape for un-compensated value of impedance for 10-ohm resistor

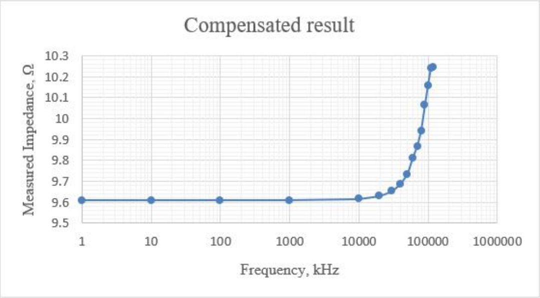

Figure 3.6: Grape for compensated value of impedance for 10-ohm resistor

Table 3.4: Un-compensated and compensated value of impedance for 1 ohm's resistor

Nominal value	**Meas. Freq.(in kHz)**	**Un-compensated value of Z(in Ω)**	**Compensated value of Z(in Ω)**
100 Ω	1	100.0224	100.0156
	10	100.0142	100.0138
	100	100.0132	100.0138
	1000	99.6517	100.0134
	10000	99.0483	100.0057
	20000	99.9758	99.9885
	30000		99.9760
	40000		99.9789
	50000		99.9991
	60000		100.0425
	70000		100.1195
	80000		100.2113
	90000		100.3129
	100000		100.4603
	110000		100.5736
	120000		100.7078

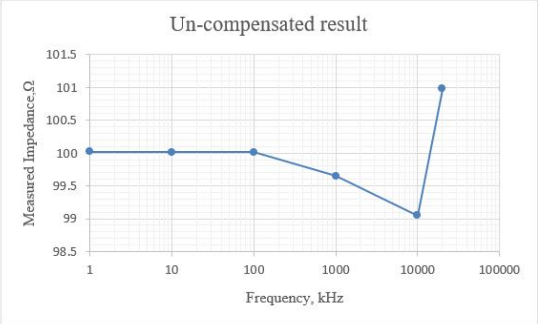

Figure 3.7: Grape for un-compensated value of impedance for 100-ohm resistor

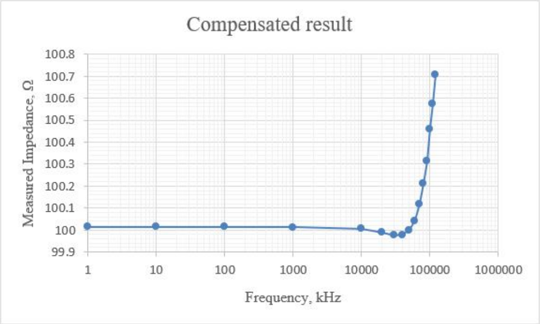

Figure 3.8: Grape for compensated value of impedance for 10-ohm resistor

Table 3.5: Un-compensated and compensated value of impedance for 1 kilo-ohm resistor

Nominal value	**Meas. Freq.(in kHz)**	**Un-compensated value of Z(in KΩ)**	**Compensated value of Z(in KΩ)**
1 KΩ	1	1.0006	1.0006
	10	1.0006	1.0006
	100	1.0004	1.0007
	1000	9.9674	1.0006
	10000	9.8860	0.9985
	20000	1.0038	0.9943
	30000		0.9884
	40000		0.9807
	50000		0.9710
	60000		0.9594
	70000		0.9465
	80000		0.9320
	90000		0.9164
	100000		0.8996
	110000		0.8810
	120000		0.8651

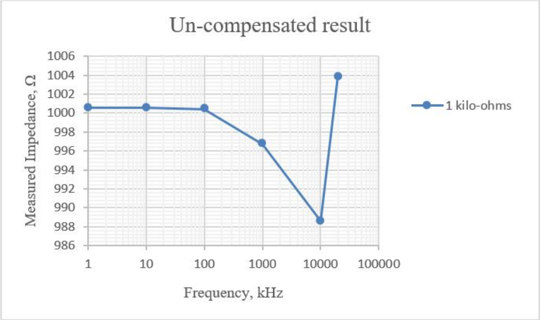

Figure 3.9: Grape for un-compensated value of impedance for 1 kilo-ohm resistor

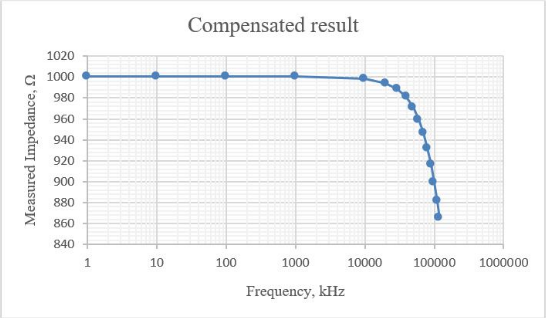

Figure 3.10: Grape for compensated value of impedance for 1 kilo-ohm resistor

Table 3.6: Un-compensated and compensated value of impedance for 10 kilo-ohm resistor

Nominal value	**Meas. Freq.(in kHz)**	**Un-compensated value of Z(in KΩ)**	**Compensated value of Z(in KΩ)**
10 KΩ	1	10.0079	10.0079
	10	10.0080	10.0080
	100	10.0068	10.0075
	1000	9.9527	9.9914
	10000	9.2182	9.1643
	20000	7.7273	7.6495
	30000		6.2568
	40000		5.1797
	50000		4.3601
	60000		3.7455
	70000		3.2675
	80000		2.8872
	90000		2.5813
	100000		2.3262
	110000		2.1213
	120000		1.9422

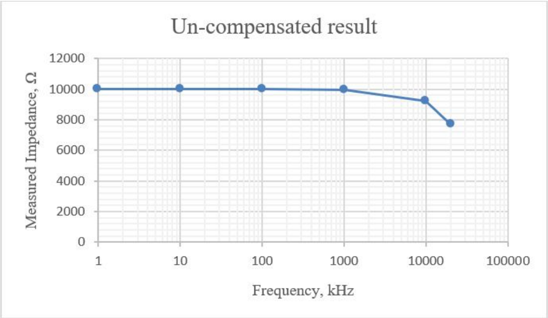

Figure 3.11: Grape for compensated value of impedance for 10 kilo-ohm resistor

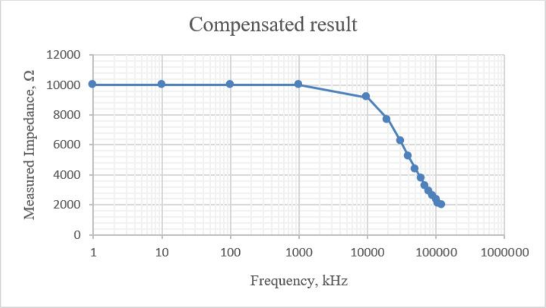

Figure 3.12: Grape for compensated value of impedance for 10 kilo-ohm resistor

Table 3.7: Un-compensated and compensated value of impedance for 100 kilo-ohm resistor

Nominal value	Meas. Freq.(in kHz)	Un-compensated value of Z(in KΩ)	Compensated value of Z(in KΩ)
100 KΩ	1	100.0935	100.0936
	10	100.0953	100.0959
	100	99.9461	99.9457
	1000	91.5732	91.9535
	10000	24.1155	24.2933
	20000	12.8117	12.6427
	30000		8.5533
	40000		6.4662
	50000		5.1956
	60000		4.3403
	70000		3.7211
	80000		3.2582
	90000		2.8956
	100000		2.5960
	110000		2.3632
	120000		2.1674

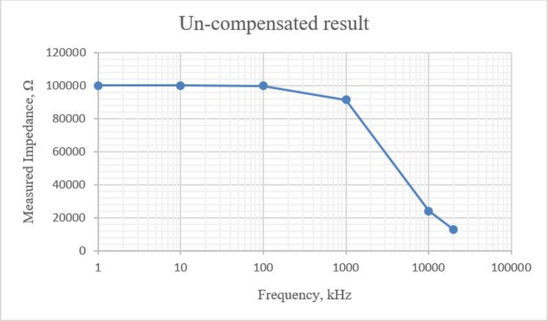

Figure 3.13: Grape for compensated value of impedance for 100-kilo-ohm resistor

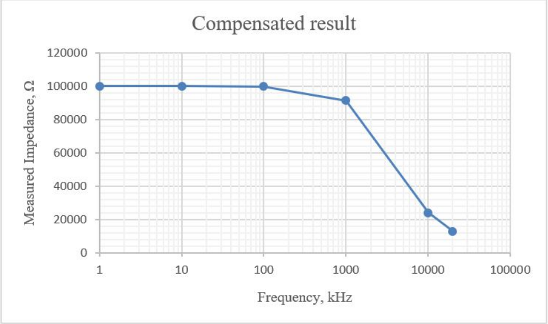

Figure 3.14: Grape for compensated value of impedance for 100-kilo-ohm resistor

IV. CONCLUSION AND FUTURE WORK

In this report we have tried to compensate the LCR meter and to measure impedance at higher frequencies (up to 120 MHz). From the measured values given in the tables in the measurement and result section it can be understand that impedance of an resistance can be easily measured up to 20 MHz frequency i.e. in audio-frequency range. But as we continue to measure impedance in higher range errors occurs due to parasitic components present in the passive components. As we start measuring impedance at higher frequency the impedance due to parasitic components present in the element gets added. We use a test fixture to perform compensation for higher frequencies (above 20MHz, up to 120 MHz). From the tables and graphs in the measurement and result section it can be observed that after compensation the value of impedance is easily measured for frequencies up to 120 MHz.

Impedance metrology is an old but still active field for study, thus there is still a lot to be done in this. In this dissection we tried to study a very small part of the impedance metrology for resistance. But we have a long path to cover. Some of the works that can be done in nearing future on impedance metrology are as follows:

1) High-frequency compensation on LCR meter for capacitance standards
2) High-frequency compensations on LCR meter for inductive standards
3) Defining impedance standard for different passive components
4) Link different definitions for impedance and traceability route to each field
5) Frequency compensation on LCR meter for frequency greater than 120 MHz

REFERENCES

[1] Parvis M.; Vallan A.; CallegaroL.(2003), ”Automatic compensation system for impedance measurement”, *IEEE Transactions on Instrumentation and Measurement*, vol. 52 n. 4, pp. 1239-1242. - ISSN 0018-9456

[2] Kiyoshi Suzuki, Toshiaki Aoki, and Katsumi Yokoi (1993), “A Calibration Method for Four-Terminal-Pair High-Frequency Resistance Standards”, *IEEE Transactions on Instrumentation and Measurement*, Vol 42, No 2

[3] Kavar Nilesh, AmitKumar, Rajendra Patel(2015), “A Review On Two-Stage CMOS Operational Amplifier Using Frequency Compensation Techniques”, *International Journal of Advance Engineering and Research Development (IJAERD)*, Volume 2,Issue 3, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

[4] Hoi Lee, and Philip K. T. Mok(2003), “Active-Feedback Frequency-Compensation Technique for Low-Power Multistage Amplifiers”, *IEEE Journal Of Solid-State Circuits*, Vol. 38, No. 3

[5] Shailesh S.Pachbhai, LaukikP.Raut (2014), “A Review on Design of Fixtures”, *International Journal of Engineering Research and General Science* Volume 2, Issue 2, ISSN 2091-2730.

[6] Nicholas J Contrino(2010), “Design, Fabrication, and Testing of a Fixture for use in the Carburization of Steel”, *Worcester Polytechnic Institute*.

[7] Raghavendra Gupta, Prof. Sunny Jain (2013), “A Review Paper on Frequency Compensation of Transconductance Operational Amplifier (OTA)”, *International Journal of Science and Research* (IJSR) ISSN: 2319-7064.

[8] S. Prabhakaran, C. R. Sullivan (2002), “Impedance-Analyzer Measurement of High-Frequency Power Passives: Techniques for High Power and Low Impedance”, *IEEE Industry Applications Society Annual Meeting*, pp. 1360–1367.

[9] Kent H. Lundberg (2004), “Internal and External Op-Amp Compensation: A Control-Centric Tutorial”, *In American Control Conference*, 2004.

[10] Xiaolong Yue, Fang Zhuo, Hao Yi (2014), “A New Impedance Measurement Method Based on High Frequency Compensation”, *In International Power Electronics Conference*, 2014.

[11] Josep M. Torrents and Ramon Pallàs-Areny (2002), “Compensation of Impedance Meters When Using an External Front-End Amplifier”, *IEEE Transactions on Instrumentation And Measurement*, VOL. 51, NO. 2, APRIL 2002.

[12] Agilent Technologies (1999-2000), “New Technologies for Accurate Impedance Measurement (40 Hz to 110 MHz)”

[13] B. H. Evenblij and J. A. Ferreira (2001), “A physical method to incorporate parasitic elements in a circuit simulator based on the partial inductance concept”, In *32nd Annual Power Electronics Specialists Conference*, 2001.

[14] Charles R. Sullivan, Yuqin Sun, and Alexandra M. Kern (2002), “Improved distributed model for capacitors in high-performance packages”, In *IEEE Industry Applications Conference 37th IAS Annual Meeting*, 2002

[15] Satish Prabhakaran, Daniel E. Kreider, Yu Lin, Charles R. Sullivan, and Christopher G. Levey (2000), “Fabrication of thin-film V-Groove inductors using composite magnetic materials”, In *International Workshop on Integrated Power Packaging*, June 2000.

[16] Keysight Technologies, “Impedance Measurement Handbook, A guide to measurement technology and techniques”, 6th Edition

[17] Luca Callegaro (2008), “The metrology of electrical impedance at high frequency: a review”, *In Measurement Science and Technology*, 2008