International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 48 No. 1 Mar. 2026, pp. 57-63

http://www.ijias.issr-journals.org/

Accuracy determination of Zij and Yij parameters of integrated passive components using WK6500B impedancemeter

***D.A. Oumar*[2-3]*, M.I. Boukhari*[1-2]*, N.I. Mariam*[1]*, S. Capraro*[3]*, and J.J. Rousseau*[3]**

[1]Laboratoire de Recherche en Electronique, Electrotechnique et Energie (LR3E), National Institute of Sciences and Technologies of Abéché, Abéché, Chad

[2]Department of Industrial Engineering and Maintenance, Polytechnical University of Mongo, Mongo, Chad

[3]Univ Lyon, UJM-Saint-Etienne, CNRS, LabHC UMR 5516, F-42023, SAINT-ETIENNE, France

ABSTRACT: The characterization of planar components such as inductors in an important step in better to understand components behavior as a function of frequency. To do this, it is essential to use a dedicated measuring device and an innovative and appropriate characterization method to achieve good accuracy. In this article, we present a new method and techniques for characterizing Zij impedance and Yij admittance parameters of passive components (resistors, capacitors and inductors) using a WK6500B impedancemeter. Obtained results are very encouraging, with good accuracy of less than 1%.

KEYWORDS: Zij and Yij parameters, WK 6500B impedancemeter, integrated passives components.

1 INTRODUCTION

In power electronics, passive components such as inductors or transformers are imperatively essential. Unfortunately, their discrete shape poses problem for their integration. Thus, planarization technology provided solutions to this integration problem [1]. The solution for using these components at high frequencies, requires precise characterization using appropriate devices. For passive components such as inductors, determining the Zij and Yij parameters gives precise information of their behavior as a function of frequency. Our previous works, [2] and [3] has allowed as to develop characterization methods at low and high frequencies. Measurements were made using 4294A impedancemeter which uses current-voltage probes. In addition, LR3E laboratory has recently acquired characterization bench using probes adapted to the characterization of planar passive components. In this work, we present a new characterization method which is bases on our old methods [2] and [3]. The present method is developed using a WK6500B impedancemeter. This is a precis equipment that uses a RF probe. The present paper mainly aims to the development of calibration methods, direct measurement, and four wires using RF probes. For this reason, an admittance and impedance measurement of planar components were realized. The objective is to determine DST electrical model elements. A study for accuracy device by carrying out repeatability and reproducibility measurement were necessary.

For this purpose, it is essential to present firstly the studied planar components as well as its electrical model. In addition, we present the new developed characterization bench, its calibration method and applied uncertainty calculation method. Results and discussions will conclude this paper.

2 DESCRIPTION OF STUDIED PLANAR COMPONENTS

In this section we describe the characterized planar magnetic components. We are dealing quadrupole components. These are planar inductors made on magnetic material as presented in [5]. Following figure 1 present studied components.

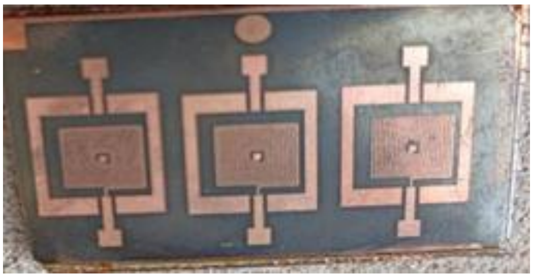

Fig. 1. Studied structure: quadrupole planar inductors

The characterized inductors (Fig.1) are made from a 1mm thick of magnetic material substrate. A copper conductor is used to make spiral shape. Copper thickness is 5µm. the inductor consists of 10 turns with a width of 400µm and separated by 100µm of distance [5].

3 Electrical Model

Furthermore, the studied planar inductor is modeled by the following electrical diagram as shown in fig.2. This model consists of a Ls inductance which accounts the component inductive behavior. The resistances Rs and Rcore represent respectively Joule losses and magnetic losses. Capacitive coupling between turns and ground plane, are represented by capacitors named: Cs, Cm1 and Cm2.

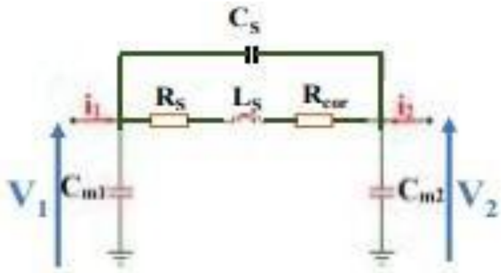

Fig. 2. Electrical model of studied structure

The admittance (Yij) and impedance (Zij) matrix of inductor parameters are characterized by this method using direct measurement. This yields the parameters of the planar device. These parameters are determined by the following relations (1-5):

$$Y_{11}=\left.\frac{I_1}{V_1}\right|_{V_2=0} = \frac{1}{R_S+jL_S\omega} + j(C_{m1}+C_S)\omega \quad (1)$$

$$Y_{12}=\left.\frac{I_1}{V_2}\right|_{V_1=0} = -\frac{1}{R_S+jL_S\omega} + jC_S\omega \quad (2)$$

$$Y_{22}=\left.\frac{I_2}{V_2}\right|_{V_1=0} = \frac{1}{R_S+jL_S\omega} + jC_{m2}\omega \quad (3)$$

$$Z_{11}=\left.\frac{V_1}{I_1}\right|_{I_2=0} = \frac{1}{j(C_{m1}+C_{m2})\omega} \quad (4)$$

$$Z_{22}=\left.\frac{V_2}{I_2}\right|_{I_2=0} = \frac{1}{j(C_{m1}+C_{m2})\omega} \quad (5)$$

4 Characterization Method Using Impedancemeter Wk6500b

In this section, we present firstly developed impedancemeter test bench. Then, we describe, operating principle and calibration (standards and compensations).

4.1 DEVELOPED MEASUREMENT METHOD AND PRINCIPLE

The measurement principle of used impedancemeter utilize 4-points self-balancing bridge method (Fig.3). It consists of measuring injected current into device under test by one pair of cables (Hcur and Lcur) and voltage is measured using the other pair of cables (Hpot and Lpot) [6].

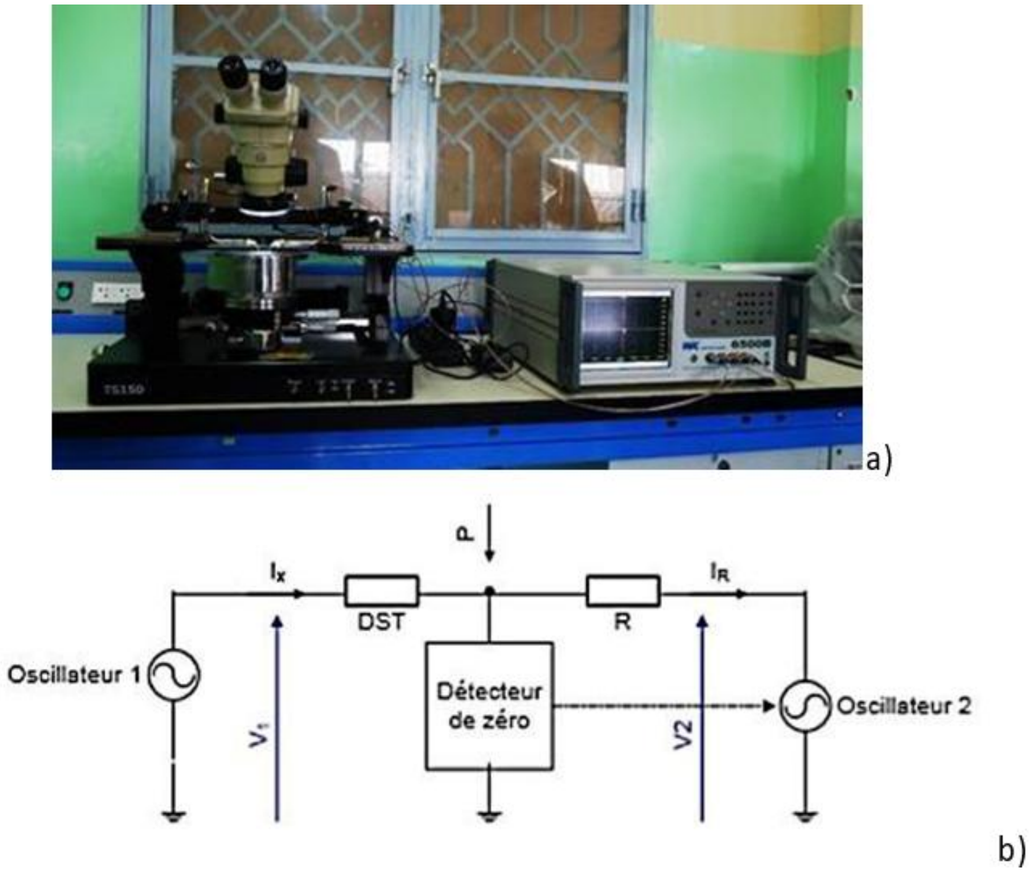

Fig. 3. Measurement principle: self-balancing bridge for impedance analyzers [7], [8]

4.2 CALIBRATION METHOD AND COMPENSATION

As any measurement instrument, impedancemeter must also be calibrated before any measurement are taken. Calibration eliminates systematic and random errors. The ideal calibrations dedicated to this studied device are: Open, Short and Load. In our case, the calibration steps performed are similar to those of authors in [9]. They are divided into two stages. First, we perform the open-short and load calibration with connector 1J1011, as shown in Fig.4.a [10]. The second stage of calibration takes place. After connecting GSC probe tips [11] to the terminals of the

42941A probe, we perform an Open/Short/Load compensation to eliminate errors in the measurement system using a calibration standard. This was done by maintaining the calibration settings at following values:

- Source (level) = 500mV;
- Open: conductance G= 0pS and capacitance C= 0fF;
- Short: R= 0Ω and L= 0pH;
- Load: R= 100Ω and L= 0H;
- Valid range: 40 Hz – 120 MHz

Fig.4.a

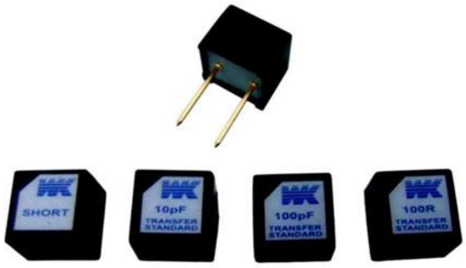

Fig.4.b

Fig. 4. J1011 Connector and B) Calibration Standard

4.3 MEASUREMENT METHOD

We use measurement techniques and configurations according to component parameters to be measured. In particular impedance or impedance, according to the following configurations [12].

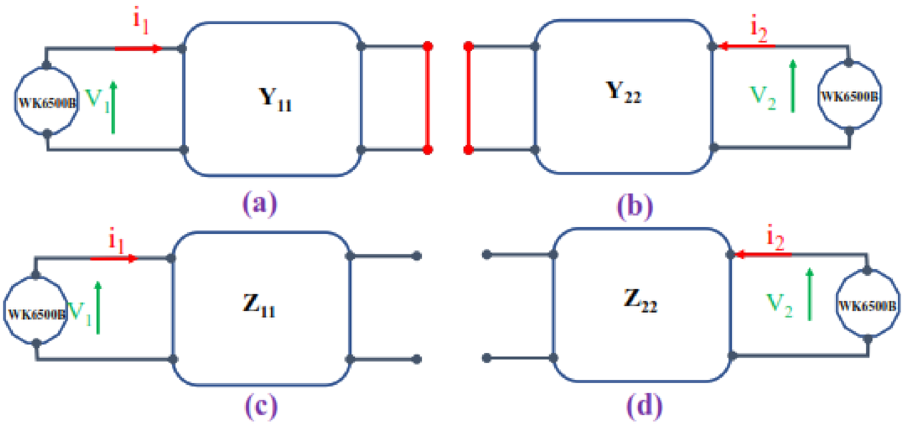

Fig. 5. Configuration's measurements

The two-ports characterization is suitable for the quadrupole component case of a planar inductor. This measurement requires two RF-GSG probes or one RF-GSG probe with four Kelvin probes (Fig.6). Depending to the configuration, the admittance parameters Y11 and Y22 or the impedance parameters Z11 and Z22 of the component can be measured. Therefore, we have developed a measurement methodology for each parameter in order to measure the Zij and Yij parameters. Namely, one method for impedance parameters and another for admittance parameters. Firstly, for admittance parameters, as in the case of impedance parameter measurements, admittance parameters measurement, requires an appropriate technique. The Y11 and Y22 parameters are measured by short-circuiting port (2). In the case of Y11 and Port (1) in the case of Y22, respectively. Fig.6 illustrates this direct measurement technique. The short-circuit is created using an RF measurement probe connected to a short standard on one of the two ends of the component.

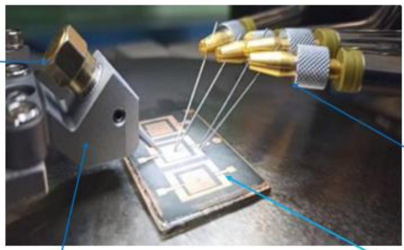

Fig. 6. Measurement configuration of Y11 and Y22 parameters

Secondly, for the impedance parameters, Z11 and Z22, these are obtained when the second port is open circuit. i.e., i2 or i1= 0A, to measure Z11 and Z22 respectively. From the figure 7 above, illustrating the Yij measurement methos, simply lift the tip to which the short standard is connected.

In general, the parameters that can be measured at no load and in short circuit are not all independent [7]. For a passive quadrupole, these parameters are linked by the following relationship:

Z11 * Y11 = Z11 * Y22 [7] (9)

4.4 Measurement Uncertainty With Wk6500b Impedancemeter

Determining the uncertainty measurement of WK6500B impedancemeter is complex. It takes into account all effects, including those of the power source, calibration, measurement frequency band, bandwidth and measured impedance. The following equation can be used to calculate this relative uncertainty (E) [13].

The uncertainty introduced by the device are summarized in the tables below [11]:

- **1m long cables**

Frequency range	Admittance in open circuit Y_0 (S)	Impedance of short circuit Z_S (Ω)	Scalar impedance errors ISZ (%)
> 10kHz à 50kHz	>10n	< 200µ	-
> 50kHz à 1MHz	>40n	< 500µ	0.1
> 1MHz à 15 MHz	> 1µ	< 5 m	1
> 15 MHz à 50 MHz	> 10 µ	< 10 m	1
>50 MHz	> 20 µ	< 20 m	2

- **2m long cables**

Frequency range	Admittance in open circuit Y0 (S)	Impedance f short circuit ZS (Ω)	Scalar impedance errors ISZ (%)
> 10kHz à 50kHz	>30n	< 1m	-
> 50kHz à 1MHz	>120n	< 1.5m	0.3
> 1MHz à 15 MHz	> 4µ	< 5 m	1
> 15 MHz à 50 MHz	> 15 µ	< 10 m	1
> 50 MHz	> 20 µ	< 20 m	2

For additional value of Z, calculated error is follows:

Zerror = $\pm\left[Y0 * Z + \frac{Z_S}{Z}\right] * 100 + ISZ$ [14] (10)

F= 485 kHz, therefore Y0= 120nS, Zs= 1mΩ, error of 0.3% and Zerror = 0.34%

The introduced error trough measurement via a connector is given in the following table: The repeatability performed on the connector has an uncertainty of ΔA= 0.1%.

ΔB = 0.4%

ΔT = √((0.4 * 0.4 + 0.1 * 0.1)) so ΔT = 0.42%

5 Results

In this section, we present measurement results for the characterized planar devices. We present results of two-ports measurements consisting solely of the Zij and Yij parameters of the integrated inductors. The figure 7 below, shows Y11, Y22, Z11 and Z22 parameters curves represent either the admittance or the impedance. The orange curves represent the phase.

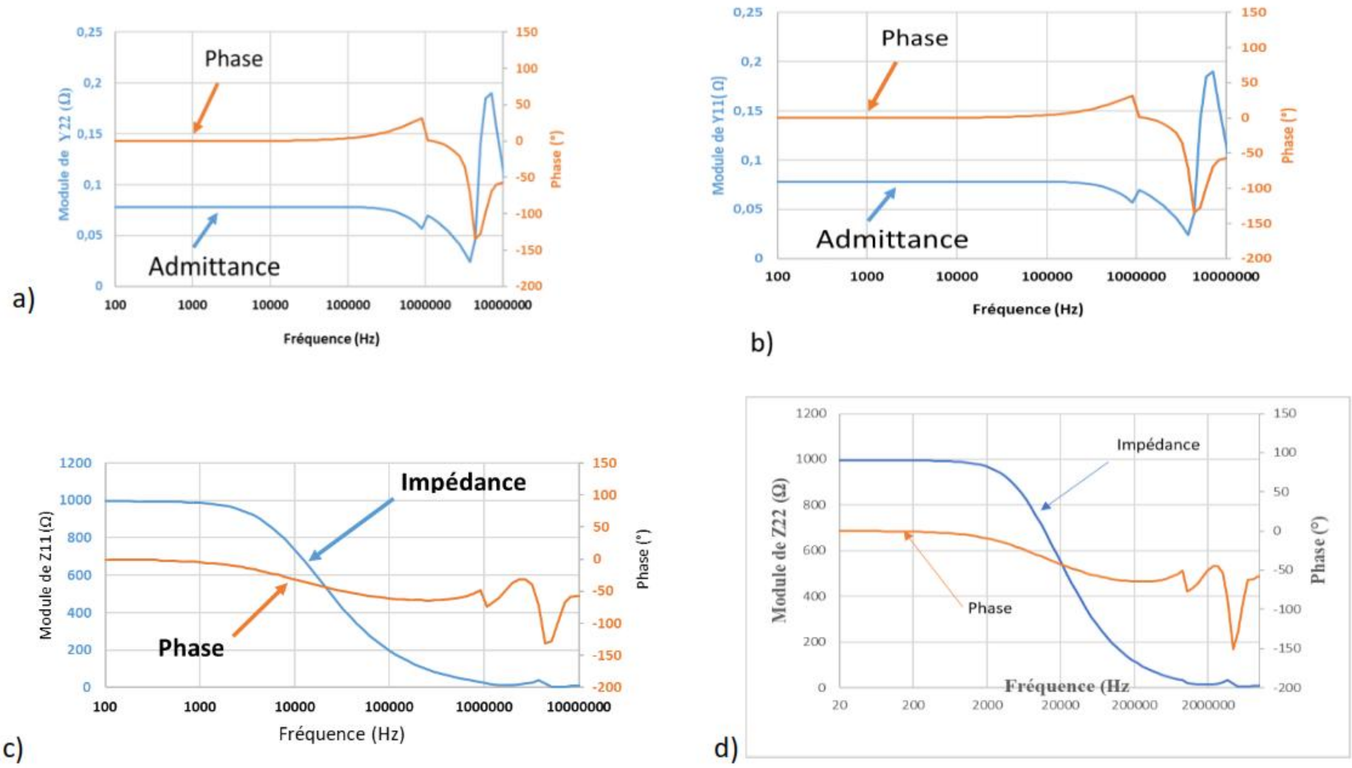

Fig. 7. The admittance parameters Yij and impedance parameters Zij, a) Y 11; b) Y22; c) Z11 and d) Z22

In figure 7, graphs a, b, c and d represent the admittance and impedance parameters Y11, Y22, Z11 and Z22 of the measured planar inductor, respectively.

The shape of the curves as a function of frequency clearly reflects the behavior of the inductor. It can be seen that at very low frequencies, from DC to tens of kilohertz. The component behaves purely resistively. This behavior is reflected on the different curves by a horizontal straight line. At medium frequencies, the device behaves as a pure inductor with a slope of ±20dB per decade according to the impedance Zij or admittance Yij parameters.

Conclusion

The quadrupole measurements were performed using the cable measurement configuration. The accuracy of these measurements is limited at low frequencies due to measurement errors caused by a lack of phase compensation.

6 Extraction Of Components Parameters

Considering the different parameters Ls, Cm1, Cm2 and Cs according to their respective frequency ranges. The different elements are extracted using the indicated method in the below table.

Extracted elements	Parameters and tools used	Numerical values
RS in (Ω)	In low frequency ***Rs = Real*** $(\frac{1}{Y_{11}})$	***12.8Ω***
Inductance LS (µH) from ***Re(Y11)***	$Y_{11} = \frac{Rs}{(Rs.Rs + (Ls.\omega).(Ls.\omega))}$	***3.e-4 H***
$C_S + Cm_1$ (pF)	***At the resonance frequency of Z_{11} or Z_{22}***	-
$Cm_1 + Cm_2$ (pF)	***At the resonance frequency of Y_2***	-
$C_S + Cm_2$ (pF)	***Slope of -20dB/dec of Z_{11}***	-

The measurement range was limited at low frequencies, i.e., below resonance frequence. So, it is impossible to extract capacitances Cm1, Cm2 and Cs values correctly and with sufficient accuracy. Nevertheless, this measurement band allows us to correctly extract resistance value of 12.8Ω and inductance value of 300µH with an accuracy better than 1%.

7 Conclusion

In this article, we have presented developed techniques and methodology for characterizing and extracting planar inductors by measuring the Zij and Yij parameters using WK6500B impedancemeter. In two-ports characterization, several impedance and impedance parameters (Z11, Z22, Y11 and Y22) are measured. At the end of the measurement, we correctly extracted internal resistance values and intrinsic inductance of integrated component (planar inductor with magnetic substrate) with an accuracy of less than 1%.

References

[1] T. B. a. G. R. Hans Meier, «Miniaturization and Advanced Functionalities of SAW Devices, » IEEE, Vols. %1 sur %2. VOL. 49, n° %1 NO. 4, APRIL 2001.

[2] K.-S. L. C.-R. K. K.-M. K. a. J.-W. J. Young Yun, «Basic RF Characteristics of the Microstrip Line Employing Periodically Perforated Ground Metal and Its Application to Highly Miniaturized On-Chip Passive Components on GaAs MMIC, » IEEE, Vols. %1 sur %2VOL. 54, n° %1 NO. 10, OCTOBER 2006.

[3] D. A. o. D. Ali, «Métrologie: Caractérisation des paramètre Zij et Yij des composants planaires magnétiques., » Laboratoire Hubert Curien, Université Jean Monnet de Saint-Etienne, France, 2015.

[4] C. Yang, « F. Liu, T. Ren, L. Liu, H. Feng, A.Z. Wang, H. Long, Fully integrated ferrite based inductors for RF ICs, » Sensors and Actuator, p. pp.365–370., 2006.

[5] M. A. Taha, «Conception, réalisation, modélisation et caractérisation d'un transformateur planaire de commande, » Laboratoire Hubert Curien de Saint Etienne, France, 2017.

[6] Probe, http://www.americanprobe.com/public/PDF/Agilent/Cap_Meas_An_Overview.pdf disponible en ligne, consulté le 17 -11-2016., 2016.

[7] X. M. Jean-Pierre Kedarec, « Identifying the magnetic part of the equivalent circuit of n-winding transformer». IEEE Transactions on Instrumentation and Measurement, Institute of Electrical and Electronics Engineers (IEEE), 56 (1), pp.14, Grenoble, 2007.

[8] Agilent, « Technical document, Agilent Accurate Impedance Measurement with Cascade Microtech Probe System Application Note 1369-3, » 2013.

[9] Agilent, Keysight Technologies Accessories Catalog for Impedance Measurements, Agilent, 2016.

[10] Agilent, « Technical document, Agilent Accurate Impedance Measurement with Cascade Microtech Probe System Application Note 1369-3, » 2015.

[11] A. Probe, « American probe, » 20 Février 2017.
[En ligne]. Available: http://www.americanprobe.com/public/PDF/Agilent/Cap_Meas_An_Overview.pdf

[12] M. I. B. &. S. C. &. D. P. &. J. P. C. &. J. J. R. D. A. Oumar, «Two-port integrated planar devices frequency characterization,» IEEE, Symposium on Design, Test, Integration & Packaging of MEMS and MOEMS, pp. 978-1-7281-8901, 2020.

[13] Agilent, Agilent 4294, A Precision Impedance Analyzer Operation Manual, Seventh Edition, Hyogo-Japan: Agilent Technologie, 2000.

[14] Wayne Kerr, Technical data sheet, precision impedance analyser, 6500B User Manual, Wayne Kerr Electronic, 2008.