Characterization and Correction of Calibration Jigs for LISN Impedance Measurements

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***Abstract*—The papers deals with the influence of the calibration jig to the impedance measurement result. The goal is to characterize two different designs of calibration jigs and to correct the LISN impedance accordingly. Without proper correction there is a large difference of the phase angle. It is found that the correction works properly. However the results are not without ambiguity, due to the lack of the definition of a measurand. Assumptions regarding a suitable calibration plane must be made for proper phase angle measurements.**

***Keywords*—calibration; equivalent circuit; impedance measurement; parasitic capacitance; phase measurement**

I. Introduction

The measurement of common mode conducted emissions from equipment under test (EUT) requires the use of a Line Impedance Stabilization Network (LISN). Such measurements are required by several standard [1,2,3].

A LISN shall fulfill several tasks:

- To supply the EUT with proper, DC or AC, power
- To suppress the RF voltage of the mains: Isolate the EUT from mains
- To terminate the power cord of the EUT with a defined impedance
- To conduct the RF voltage to the EMI Receiver

Several authors [4,5] found problems with the measurement accuracy if these characteristics of the LISN are not defined well. Others [6,7] tried to calculate the measurement uncertainty.

The standardization committees considered different properties as important, but all specified the absolute values of the input impedance. CISPR [1] standardized the phase angle too. Tomasin [5] calculated the error of voltage measurement for different phase angles.

Typically a limit is given with the nominal value, in case of Ref. [1] ± 20% for the absolute value and ± 11.54° for the phase angle of the input impedance. This requirement has to be fulfilled in the frequency range from 100 kHz to 108 MHz.

To check the compliance of a LISN to this limit the impedance shall be measured with an uncertainty smaller than this tolerance. So far very few papers about measurement accuracy of LISN impedance measurement exist [8,9].

II. Measurement Procedure

The most common way to measure impedance is to use a vector network analyzer (VNA). After a one port calibration with open, short and load standards the VNA is connected to the LISN via a calibration jig. The measured $\underline{S11}$ is calculated to impedance with

$$\underline{Z}=50\,\frac{1+\underline{S}_{11}}{1-\underline{S}_{11}} \tag{1}$$

The result is the impedance at the calibration plane which means the combination of the impedance of the LISN and parasitic impedances of the calibration jig. Practitioners who follow the standard [3] will accept the data given by the VNA as impedance from the LISN. This approach will work fine as long everybody will use the same calibration jig especially the jig from the manufacturer. So some manufacturers sell their jigs or publish the design in the manual of the LISN. Problems will occur if a third party test house will do a measurement with their own jig design. This will lead to different results or even a non-compliant result.

Reference [9] gives guidance to minimize the parasitic inductance of the calibration jig by keeping wires as short as possible. Reference [8] gives advice to the design of the jig. However parasitic impedance cannot be avoided nor neglected in the frequency range above 1 MHz. The technical correct way is to estimate the parameters of the calibration jig and to correct for them. Before it is possible to characterize a calibration jig it is required to draw a line between LISN and jig. This is done by the measurand.

III. Definition of Measurand

Before one can start a measurement or even an uncertainty calculation it shall be defined what to measure: the measurand. In case of impedance it is required to define a voltage and a current. The definition of the voltage and current is quite simply in the LF world. In the RF world it is much more complicated.

a) b)

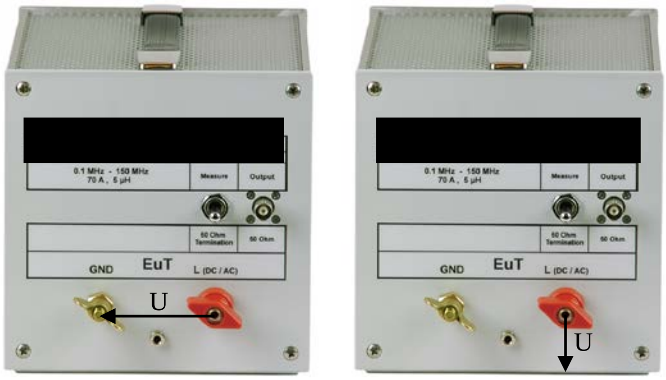


Fig. 1. *Definition of voltage a) to another pin b) to the reference ground plane*

The voltage can be either defined to another pin or to the reference ground plane, see Fig. 1. Although different terms are used CISPR 16-1-2 “reference earth” and CISPR 16-2-1 [10] “reference ground plane” it is meant the same. Depending on the measurement setup the LISN is placed directly on the reference ground plane or above on a non-conducting table. However a low inductive connection is required. In this case the impedance $\underline{Z}_{GND}$ between the pin and the reference ground plane the effect can be neglected. Fig. 2 shows a simple model which can be expressed by

$$U_{LISN} \approx U_{MEAS} \quad \text{if} \quad \underline{Z}_{GND} \ll \underline{Z}_{LISN} \tag{2}$$

The RF current flowing through a pin needs a definition of the phase plane. While this is done for all RF connectors, see Fig. 3, definitions are required for non RF connectors. LISN use a large variety of power plugs. The LISN the author uses, see Fig. 1, has a combined 4 mm plug with screw for a cable shoe. The definition of the phase plane is not clear in this case, possibilities given in Fig. 4, are at the location where the cable shoe is screwed or at the front of the plug.

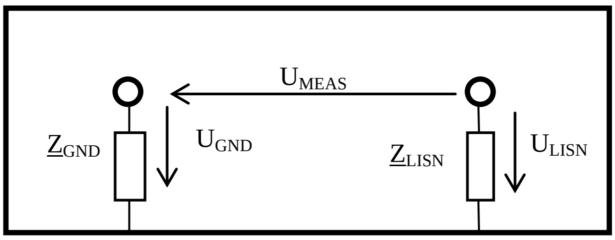


Fig. 2. *Definition of voltage a) to another pin b) to the reference ground plane*

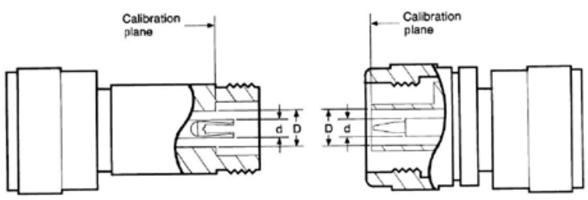


Fig. 3. *Definition of calibration plane for a Type N Connector [11]*

a) b)

Fig. 4. *Definition of calibration planes at a) cable shoe b) front*

IV. Characterization

The parasitic impedances of the calibration jig are modelled as shunt capacitance and series inductance, see Fig. 5. This model with concentrated elements is valid since the jig is much smaller than the wavelength of 3 m at 100 MHz.

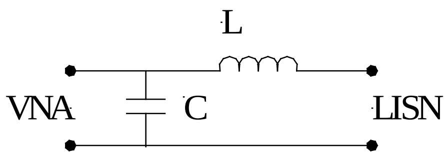


Fig. 5. *Model of calibration jig with concentrated elements*

In a two-step process both values are measured. The first step is to measure the impedance of the jig while the LISN side is left open. For the second step an identical second jig is required. Both jigs are connected back to back while the second jig is short circuited. Fig. 6 shows the back to back configuration where the capacitor of the second jig is short circuited.

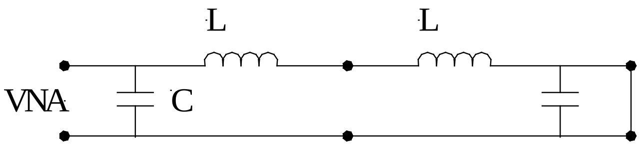


Fig. 6. *Back to back configuration with second jig*

This is done for two different calibration jigs, the jig delivered by the manufacturer called Jig A and a self-build jig called Jig B, see Fig. 7. Jig A is intended to measure the impedance between live and the ground connector and is screwed like a cable shoe. Jig B connects the 4 mm plug with the reference ground plane.

a) b)

Fig. 7. *LISN with mounted calibration jig a) Jig A b) Jig B*

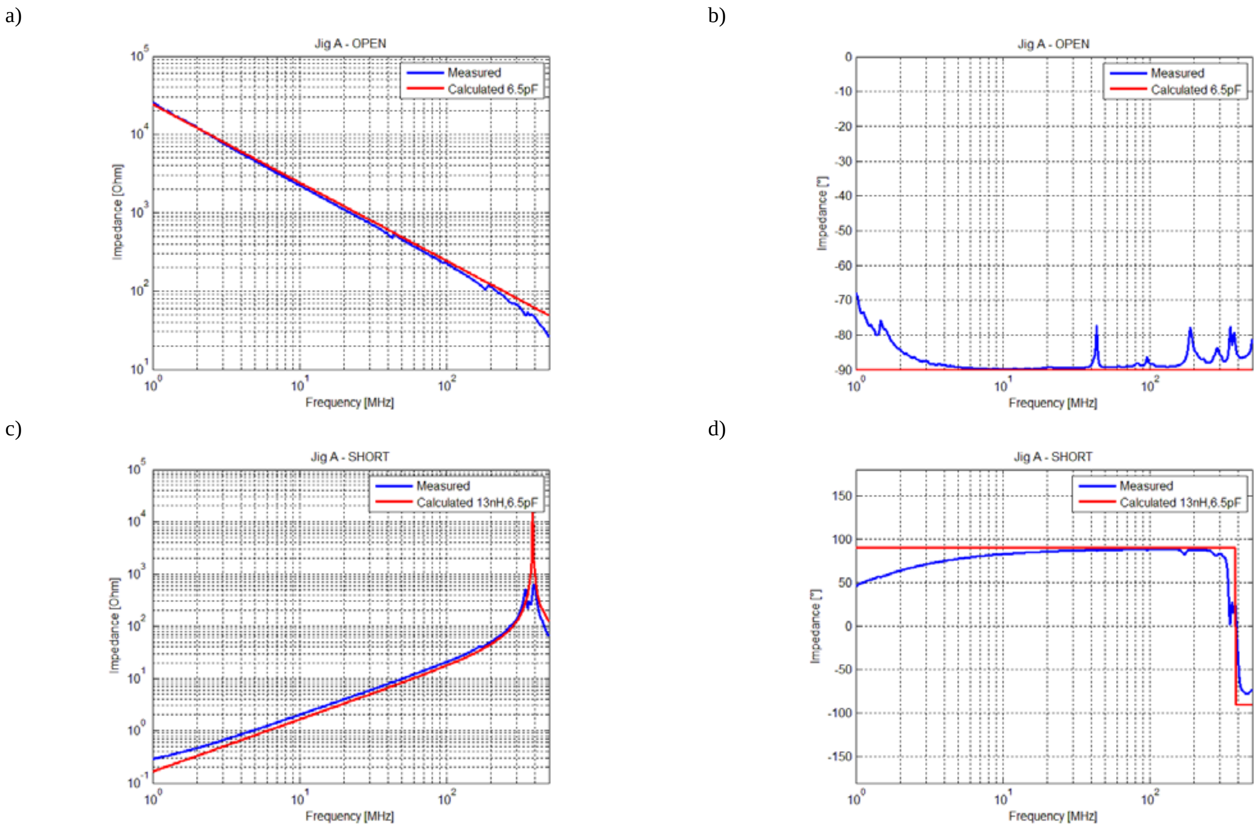


Fig. 8. Impedance of calibration Jig A a) absolute value open b) phase open c) absolute value short d) phase short

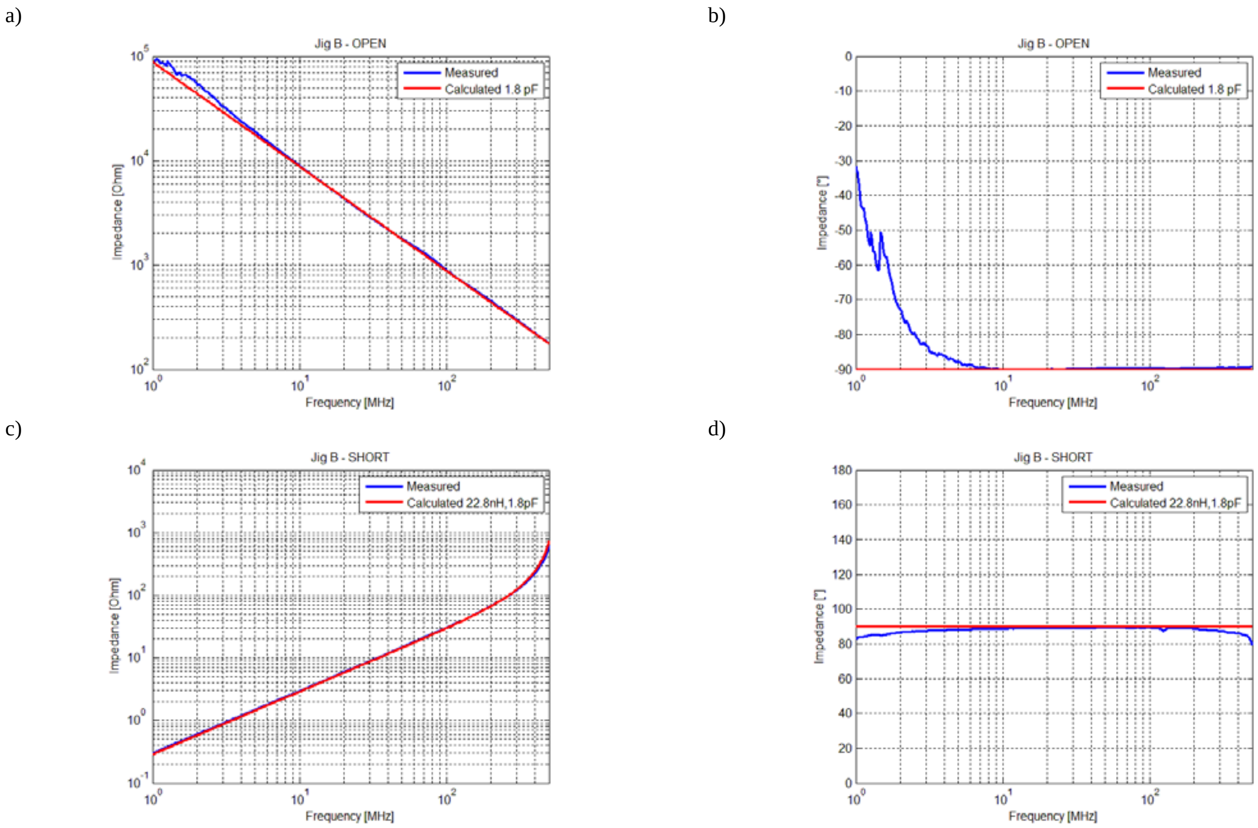


Fig. 9. Impedance of calibration Jig B a) absolute value open b) phase open c) absolute value short d) phase short

Fig. 8 and 9 show the measured impedance in the frequency range from 1 MHz to 500 MHz. The values of the lumped elements of the equivalent circuits are chosen to fit the measured impedance. There is a good agreement of both impedance traces especially in the required frequency range up to 108 MHz. Some of the plots show measurement errors of the measured impedance. If the impedance becomes much higher or lower than 50 Ω the reflection coefficient becomes small. The reflected wave gets very small so the accuracy of the VNA is reduced.

Table 1 shows the measured parameters of the calibration jigs. It can be seen, that one jig is more capacitive and less inductive than the other one.

TABLE I. MEASURED PARAMETERS OF THE CALIBRATION JIGS

Jig	**C [pF]**	**L [nH]**
A	6.5	13
B	1.8	22.8

V. CORRECTION

With the known lumped elements it is possible to calculate the impedance of the LISN if the calibration plane is defined.

A. *Calibration plane at the location of the cable shoe*

The length of the 4 mm rod of calibration Jig B is chosen that it ends at the calibration plane cable shoe, see Fig. 10. In this case no further corrections except for L and C are required.

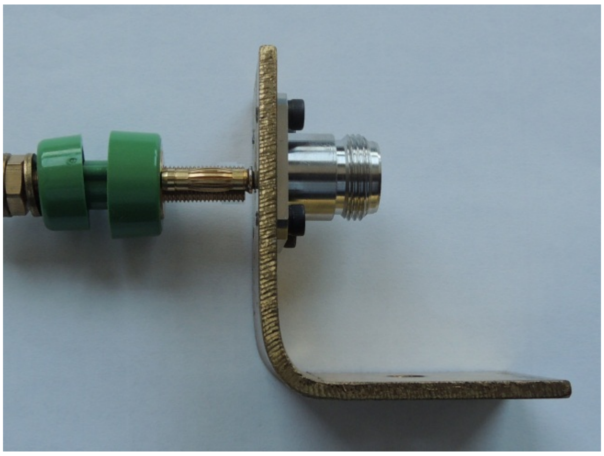


Fig. 10. *Length selection of plug and jig B*

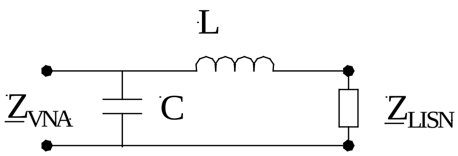


Fig. 11. *Equivalent circuit of LISN and calibration jig*

Also for calibration Jig B no additional correction is required since it is directly screwed at the place for the cable shoe. From the equivalent circuit shown in Fig. 11 the impedance measured with the VNA is

$$\underline{Z_{VNA}} = \frac{1}{j\omega C + \frac{1}{j\omega L + \underline{Z_{LISN}}}} \tag{3}$$

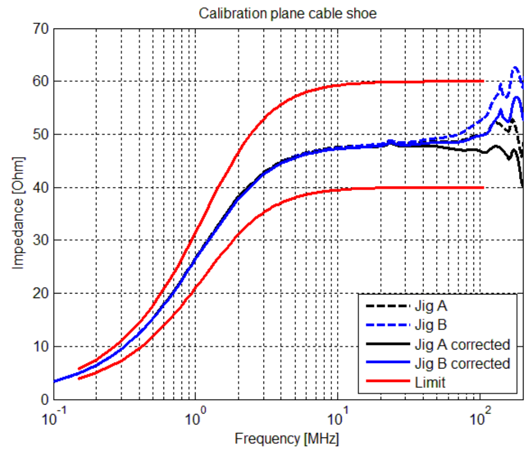
This is converted to

$$\underline{Z_{LISN}} = \frac{1}{\frac{1}{\underline{Z_{VNA}}} - j\omega C} - j\omega L \tag{4}$$

This correction is applied to the measured impedance with the VNA, see Fig. 12.

It shows that the correction has only a small influence on the absolute value but a large influence on the phase. Before correction the difference is around 10° at 100 MHz, approximately the same value as the tolerance. After correction both phase traces are much closer and fulfill the requirement of CISPR 16-1-2.

a)



b)

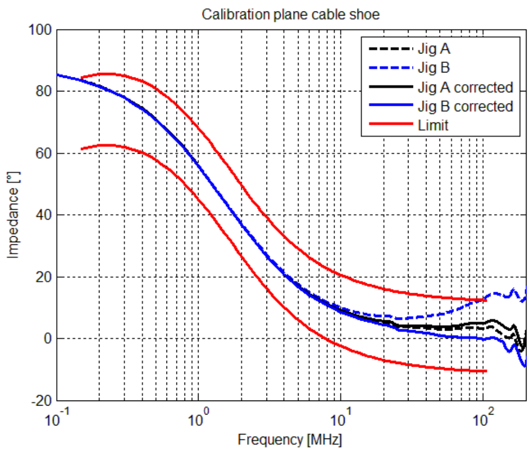


Fig. 12. *: LISN Impedance at calibration plane cable shoe a) absolute value b) phase*

B. *Calibration plane at the front of the plug*

If the correction is applied to another calibration plane a modification of correction scheme is necessary.

In case of Jig A the LISN impedance is measured 15 mm to close to the front plane. To correct for this the impedance of a 15 mm long wire 40 mm above a ground plane is added to the measured impedance.

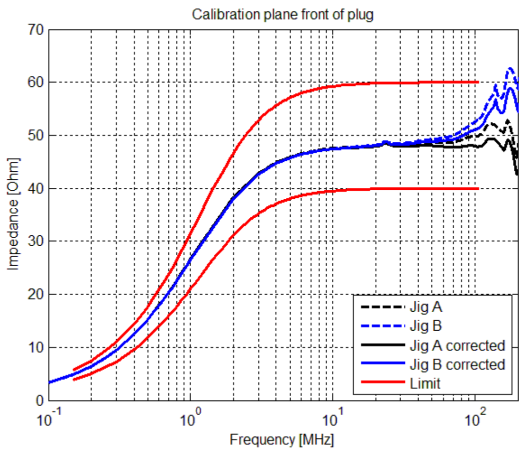
$$\underline{Z_{LISN}} = \frac{1}{\frac{1}{Z_{VNA}} - j\omega C} - j\omega L + j\omega L_A \quad (2)$$

The impedance L_A of this wire [12] is calculated by

$$L_A = \frac{l\mu_0 ln\left(\frac{2s}{D} + \sqrt{\left(\frac{2s}{D}\right)^2 - 1}\right)}{2\pi} = 11\,nH \quad (5)$$

$$l = 15mm, s = 40mm, D = 4mm$$

a)



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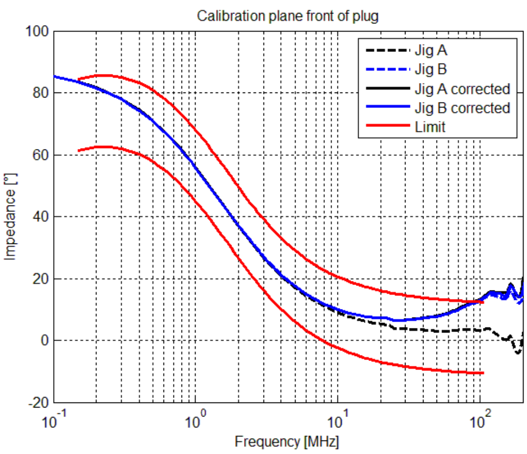

Fig. 13. *: LISN Impedance at calibration plane front of plug a) absolute value b) phase*

In case of Jig B an additional calibration was performed. The 4 mm rod has been dismounted and short circuited with a metallic plate to the ground plane. The new parameters of the calibration jig are 4.5 nH and 1.8 pF.

Figure 12 shows the result of this modified correction. As before the influence to the absolute value is small. Both traces of the corrected phase are nearly identical and do not fulfill the requirement of CISPR 16-1-2.

VI. Conclusion

The paper shows that the construction of the calibration jig has a major influence on the measurement result and the measurement uncertainty. To compensate for the influence a correction of the parasitic capacitance and inductance is required and feasible. This was shown for a particular design of a jig, but the principle is valid for other design also. The parasitic impedances of the jig are determined via measurement. For a correction a clearly defined measurand is required. In the relevant standards the definition of a calibration plane of the LISN is missing. Depending on this definition a LISN can be compliant or non-compliant regarding the impedance requirement. So the standardization committees are asked to improve this.

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