Problems using LISN in EMI characterization of power electronic converters

Jean Christophe CREBIER, James ROUDET, Jean Luc SCHANEN
Laboratoire d'Electrotechnique de Grenoble (LEG)
INPG/UJF-CNRS UMR 5529
ENSIEG, BP 46, 38402 St Martin d'Hères cedex,
GRENOBLE, FRANCE
Phone 33/(0)4.76.82.62.99 Fax 33/(0)4.76.82.63.00
E-mail: crebier@leg.ensieg.inpg.fr

Abstract - LISN are used in conducted disturbance measurements for reproducibility and standard experiments. However, depending on topology choice and electrical environment, the behavior of this device might generate errors. LISN tasks are recalled with respect to corresponding standards. Theoretical studies of single and double cell LISN are made (with respect to input and output variable impedance). It is shown that single cell devices might be quite susceptible with respect to line impedance. Converter input impedance effect is underlined. Besides, depending on LISN characteristics, the addition of passive components between the measurement device and the converter induces behavior changes. This might even disturb converter behavior itself. Finally, practical measurement condition effects are discussed.

I. Introduction

Conducted disturbances are currents fed to the power lines through line cables or/and green wire (ground). These currents might propagate trough the interconnected power supply cords which are large antennas. As a result, electromagnetic compatibility standards FCC and CISPR [1-2] specify disturbance limits with respect to the frequency range and the device class. In order to be commercialized, any power device must comply with standard limits measured under specific conditions. Disturbances have to be characterized and measured correctly. As far as conducted emissions are concerned, a LISN (Line Impedance Stabilization Network) is required. It permits specific measurement conditions.

Often, people working on measurements are experiment specialists in EMC area and do not know always the device(s) under investigation. The problem pointed out here and presented to the community in this paper, is that it might have interactions between the tested equipment and the measurement setup and most especially the LISN. It is especially the case for power electronic converters. Indeed, for some specific applications, the LISN seems to generate experimentation errors. Besides, the possible topologies do not always allow efficient measurements.

The aim of this paper is to present and to discuss several problems that we should keep in mind whenever measurements with LISN are performed. First LISN tasks are recalled. Several possible topologies are presented (with respect to standard specifications). Then, LSIN measurement environment is considered and discussed. Specific application problems with power electronic converters are then underlined. Finally, practical problems are presented and measurement validity is discussed depending on test conditions.

II LISN presentation

A. LISN definition and tasks.

For standard measurements, the LISN is inserted between the power supply and the converter under investigation [3]. FCC and CISPR conducted emission limits are defined for measurements between phases/neutral and ground. Each LISN can be represented by a quadripole as it is shown figure 1. It realizes four important tasks.

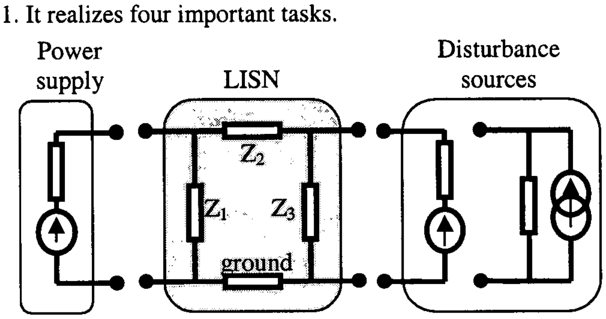


Figure 1: General topology of LISN measurement setup.

- First it allows to supply the equipment (low frequency behavior figure 2). This means that AC power can flow trough it.

- It feeds and concentrates disturbances trough the measurement points (figure 3).
- Then, it is designed to prevent external noise to modify measurements (leading to wrong values) as shown in the figure 3.
- Finally it presents constant impedance Z_3 with respect to the frequency which allows measurement reproducibility from site to site.

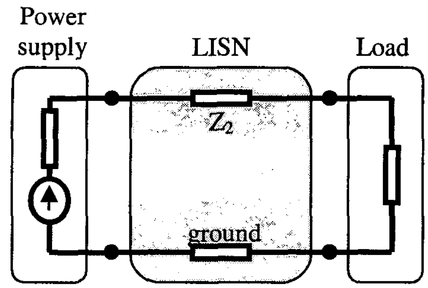


Figure 2: Simplified schematic in the low frequency range.

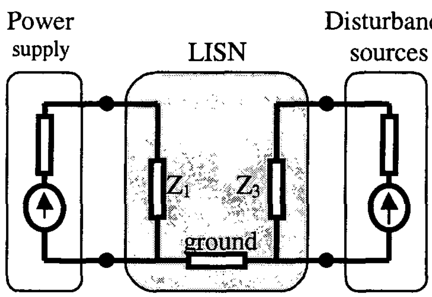


Figure 3: Simplified schematic inn the high frequency range.

B. LISN Structures.

There are several LISN topologies. The idea is to design a simple structure, which can perform as well as it is possible the above requested tasks. The simplest topology is the single cell structure plotted figure 4 (in fat). It can be excited by power supply voltage source(s) and common mode V_{pg} and differential mode V_{pp} disturbance sources.

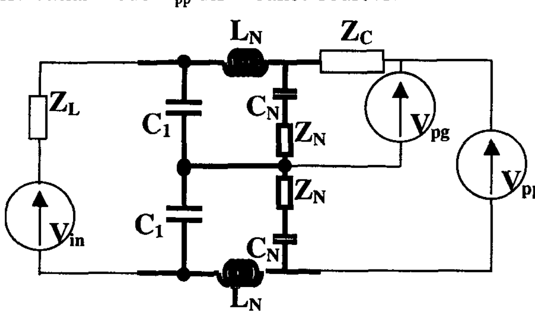


Figure 4: Single cell LISN topology.

In the low frequency range, inductors L_N must provide a low impedance path for the AC power whereas capacitors C_N and C_1 must provide a high impedance path (in order to reduce leakage currents and not overload measurement resistors). In the high frequency range, capacitor C_1 and inductors L_N act as a filter and divert external noise. Capacitor C_N and Z_N resistor provide a specific path for measured disturbances with a constant impedance with respect to frequency. This characteristic impedance is defined by standards. It can be described by a 50Ω resistor being in parallel with a 50μH inductor in series with a 5Ω resistor. The corresponding characteristic is given below (figure 5) and standards specify that the LISN characteristic impedance must remain inside 20% margin above and below the theoretical characteristic.

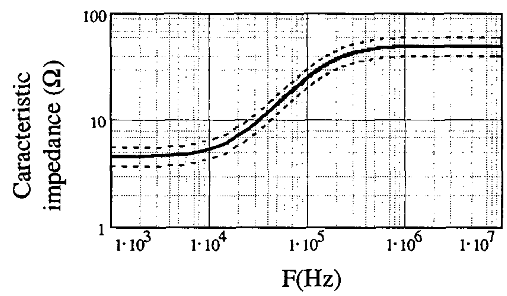


Figure 5: Specified LISN input impedance characteristic and its margins.

Depending on standard frequency range band A and band B, correct behavior is achieved using different component values. For FCC, band B frequency range starts from 450kHz up to 30MHz whereas for the CISPR, it starts from 150kHz. Considering band A, LISN can't be used always and a current probe might be preferred. In order to perform efficient external noise filtering, the CISPR LISN requires greater input inductors due to lower frequency range. This ends up to slightly more complex topologies. Classical single cell can be used with more specific Z_N impedance or a two cell topology can be considered. This topology is given below figure 6

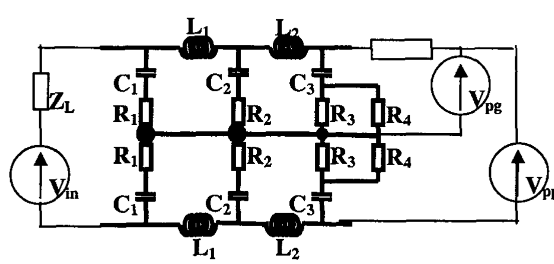


Figure 6: Double cell LISN topology.

Component values are recalled in the following tables I and II for both topologies.

Table I:
Single cell LISN component values.

	CRPAUL [4]	NAVE [3]	SCHWAB
C_1	1μF	1μF - 10μF	1μF
L_N	50μH	50μH	250μH
C_N	0.1μF	0.1μF - 1μF	0.1μF
Z_N	50Ω	50Ω	50Ω// (50Ω+50μH)

Table II:
Double cell LISN component values.

	L_1	C_1	R_1	L_2	C_2
CISPR16	250μH	4μF	10Ω	50μH	8μF
[SWB]	250μH	1μF	10Ω	50μH	8μH
	R_2	C_3	R_3	R_4	
CISPR16	5Ω	250nF	50Ω	1kΩ	
[SWB]	5Ω	220nF	50Ω	1kΩ	

III Power supply impedance effect

The idea is to verify what is the LISN susceptibility with respect to power supply impedance. Looking at the LISN characteristic impedance from the converter side, three cases are treated. First, power supply is short-circuited (Z_L=0). Then it is replaced by an inductor (which is a realistic equivalent circuit in the high frequency range). Finally high impedance case is considered (Z_L=∞). Single and double cell topologies are studied.

A. Short-circuited line impedance.

As far as LISN characteristic impedance is concerned (looking at de phase to ground impedance), we can say that it is quite susceptible in case of short circuited line impedance. This is illustrated in the following plot figure 7.

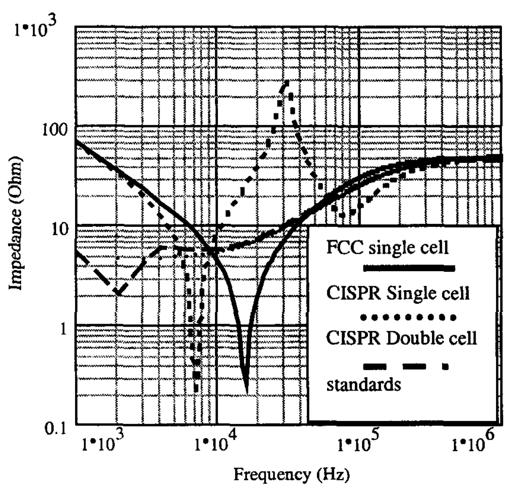


Figure 7: LISN characteristic impedance with a line side short circuit.

If standard measurements are required, correction factor must be considered. For the above case, LISN correction factors are plotted below figure 8.

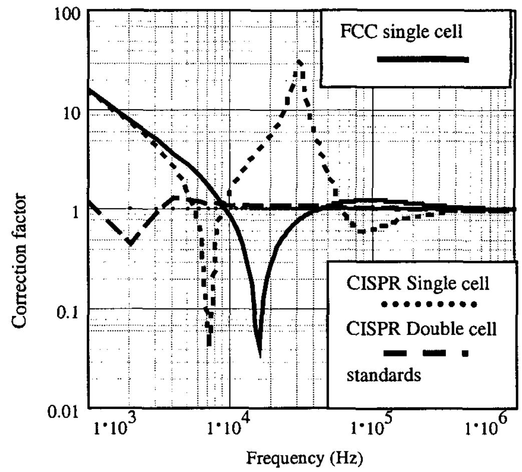


Figure 8: Measurement correction factors with a line side short circuit.

As far as LISN phase to phase impedance is concerned (looking from the converter side), the line side short-circuit has almost no effect on FCC single cell LISN characteristic.

However, in case of CISPR LISN, line side short circuit is not negligible in the low frequency range. Indeed, L_N, C_N and Z_N correspond to a band reject impedance. On the single cell topology, it is quite visible figure 9 whereas it is almost not visible on the two-cell topology. This LISN behavior might generate converter dysfunction.

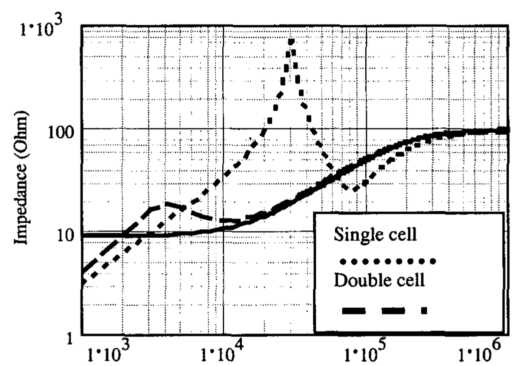


Figure 9: CISPR LISN phase to phase impedance with a line side short circuit.

One way to reduce the impact of this resonance on the single cell topology is to use greater C_N capacitor.

B. Inductive line impedance.

If the line impedance is taken into account, there is another specific behavior. In first approximation, let's consider a line side inductor of 0.1mH. In this case all LISN topologies are really susceptible. This is illustrated figure 10 for phase to phase impedance case and figure 11 for phase to ground impedance of the LISN.

These quite large resonances might really affect converter behavior. Indeed, switching frequencies are in resonance's frequency ranges. Once more the two-cell device provide better characteristics.

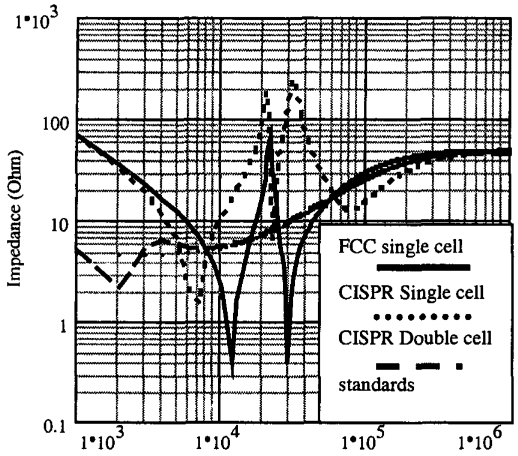


Figure 10: Characteristic impedance of LISN for a 0.1mH line side inductor.

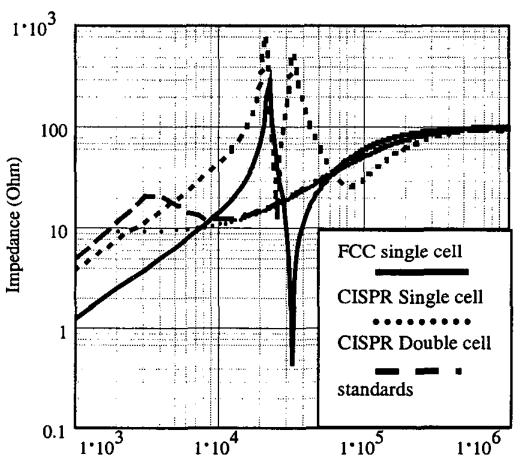


Figure 11: Phase to phase impedance of LISN for line side inductor of 0.1mH.

C. High impedance case.

Considering line side open circuit, the LISN characteristic impedance changes for all topologies as it is shown below figure 13. The problem remains the same for the single cell LISN. For the other device, the problem does not appear in the study range. This is illustrated figure 12.

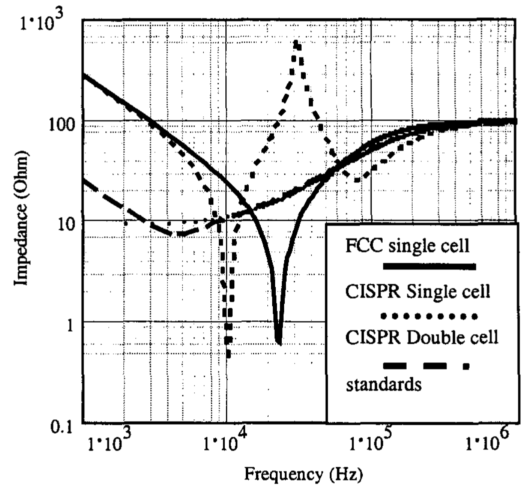


Figure 12: characteristic impedance of LISN for line side open circuit.

D. Comments.

From this study, it clearly appears that single cell LISN characteristic impedance might be quite susceptible to line impedance. The more complex two-cell topology gives better results. However this kind of devices requires very good and close to ideal components. The two-cell furthermore components increase cost and quality requirements.

Single cell LISN topologies are more simple and understandable. They can be used with correction factors taking care that LISN does not affect converter behavior. In order to calculate these correction factors, line impedance must be studied. Several papers present how to do this [5]. From this study it appears that measurement device behavior is not always perfect and that it must be considered

IV Converter input impedance effect

The converter side impedance Z_C can affect measurements but also converter behavior. This mainly depends on type of impedance and therefore which kind of converter is investigated.

There are mainly two kinds of power electronic converters. These are on one hand voltage input converter such as buck derived converters (with an input capacitor) and on the other hand current input converters such as the boost rectifiers (with an input inductor). Both of them can interact with LISN components.

Voltage input converters have large input capacitors might resonate with LISN inductors. Besides, in case of current input converters, there is an inductor on the converter side. LISN presence can affect converter behavior as it is going to be underlined. LISN additional inductors might also change greatly operation point leading to disturbed behavior or wrong measurements.

A. Capacitor input impedance analysis.

Designer should always keep in mind that converter with large input capacitor won't be able to take advantage of line impedance. In the low frequency range, LISN sensor branches will act as a current divider and not as an inductive impedance. This might maximize disturbances. Besides, LISN inductors can resonate with input filter capacitor of the converter as it is shown in the spectral representation below (figure 13). In order to cancel these problems, filter design [6] should always consider LISN.

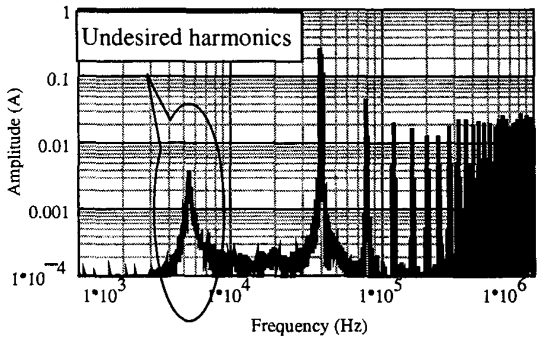


Figure 13: 5kHz resonance due to interaction between LISN and input filter capacitor.

This means that either the input capacitor or the LISN inductors must be chosen carefully.

B. Inductive input impedance analysis;

The idea is to show that input current converters might be affected by LISN use. For example, let's consider a boost rectifier operating in continuous (figure 14) current mode.

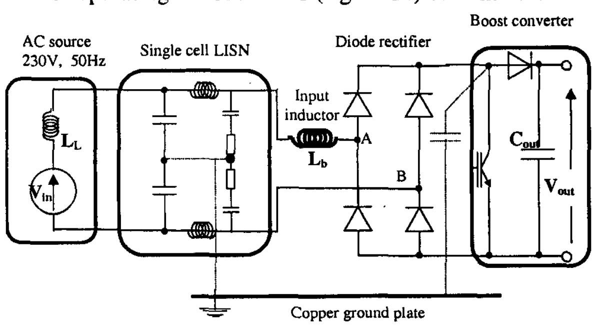


Figure 14: Studied topology with a boost rectifier.

The plot below (figure 15) shows what will be the impedance seen by the converter. We can clearly see that CISPR single cell LISN components resonate in classical switching frequency range. It is due to C_N capacitors in series with the converter inductor L_b that create a series resonant circuit. If converter switching frequency is close to the resonance frequency, then the converter might be greatly disturbed.

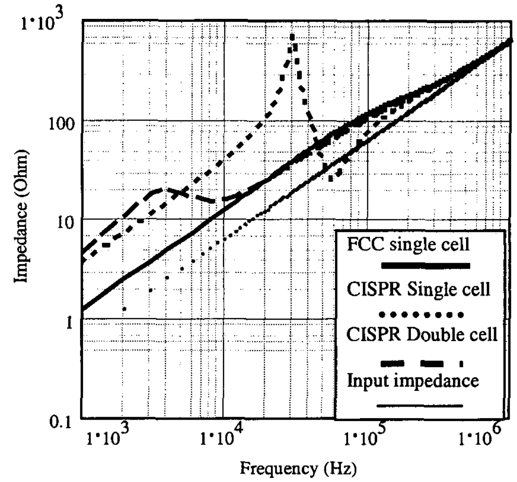


Figure 15: Differential impedance of LISN for line side open circuit.

This problem might appears on the other LISN depending on the converter side impedance value. As a result, when ever LISN are used for standard measurements on current input converters, we should keep in mind this problem and set C_N capacitors correctly in order to lower resonance frequency and to avoid this problem.

C. Modified operation point.

Due to additional line impedance (quite large in case of CISPR single cell LISN), input current converter operation point might be changed. This can be illustrated on a vector based representation where additional input inductors would lead to different operation points.

This problem can really affect discontinuous current mode operation rectifiers because large additional inductor will modify power flow level for a same duty cycle. This might even lead to continuous current mode operation involving converter dysfunction.

C. Measurements errors.

Due to additional inductor the current ripple through the inductor will change depending on the ratio between the boost inductor and the LISN inductor. This can easily be shown considering the equation (1) of the inductor ripple current (neglecting the input filter capacitor C_{in}).

$$\Delta I_L = \frac{V_{in} - V_{out}}{L_{total}} .\alpha T \qquad (1)$$

The greater will be the inductor, the smaller will be the current ripple inducing harmonic reduction and wrong measurements of high frequency harmonic levels. Below (figure 16) is shown the inductor spectrum frequency around the converter switching frequency of the two possible setups with and without LISN. It clearly demonstrates the impact of the measurement device on the validity of experiments.

Operation point changes might also modify input current spectral representation as it has been demonstrated in [7].

Besides, converter operating in hysteric mode such as full bridge rectifiers or limit continuous/discontinuous current mode rectifier might provide wrong measurements. Indeed additional impedance of CISPR single cell device would lead to lower switching frequencies for example.

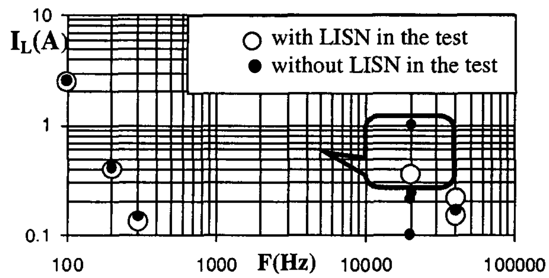


Figure 16: First current harmonics with 1.2mH boost inductor.

All these examples present effects of LISN on operation point and measurements of power electronic converters. As a result, the power electronic designer should always keep in mind that LISN has to be inserted for standard measurements.

V. Other problems.

First of all, it has to be underlined that LISN sensor branches (50Ω resistors) should be able to handle power losses. Indeed, it can be shown that converters can comply with parts of standards while low frequency disturbances generate consequent losses. It seems important to use at least 1W resistor for quite disturbing measurements.

A second problem due to standards requirements is that LISN must be used with copper ground plane. This means that common mode propagation paths are going to be greater (see figure 17). This might disturb converter operation because consequent common mode current could flow trough ground plate. This might also lead to worst case common mode current measurements.

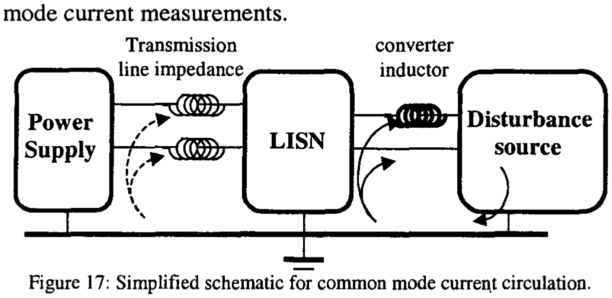
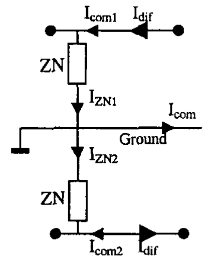


Figure 17: Simplified schematic for common mode current circulation.

Finally measurement interpretation can be difficult when LISN is used for filter design as it is proposed in [6]. Indeed, due to non ideal components and non symmetrical propagation paths, common and differential mode disturbances can't really be separated (see figure 18).



$$I_{R1} = I_{dif}+I_{com1}$$
$$I_{R2} = I_{dif}-I_{com2}$$
$$I_{com} = I_{R1}-I_{R2} = I_{com2}+ I_{com1}$$
$$I_{dif} = (I_{R1}+I_{R2})/2$$

Figure 18: Common and differential mode measured current.

Generally, it is still possible to get common mode current but it is not possible to get differential mode current. It is still possible to consider quasi-common and quasi-differential mode currents as proposed in [8]. But in specific cases, differential and common mode disturbances being comparable in amplitude make difficult the identification. This problem increases difficulties in converter filter design.

Conclusion:

LISN study has shown that depending on topology choice, it is difficult to comply with standard specifications. Several aspects concerning the behavior of the single cell LISN have underlined that it is susceptible to line side impedance. This can be cancel using correction factors. On the other hand the double cell LISN present interesting characteristics. On practical point of view, the LISN can generate measurement errors depending on the type of converter under investigation. To conclude, we highly recommend to take into account effects of converter and line impedance for measurement interpretation. Besides special care in LISN component choice could avoid interaction with the converter (resonance).

References:

[1] FCC, "FCC methods of measurement of radio noise emissions from computing devices", FCC/OST MP-4 (July 1987).

[2] CISPR 16, "CISPR specification for radio interference measuring apparatus and measurement methods" second edition, 1987.

[3] M. Nave, "Line Impedance Stabilization Networks: theory and use" RFI/EMI Corner, 1985, pp54-56.

[4] C.R. Paul, "introduction to electromagnetic compatibility", Wiley & sons, 1992.

[5] P.J. Kawasniok, M.D. Bui, A.J. Kozlowski, S.S. Stuchly, "Technique for measurement of power line impedance in frequency range from 500kHz to 500MHz", IEEE trans. on EMC vol 35 n°1 Feb. 1993.

[6] M. Nave, "EMC in filter design" Van Nostrand Reinhold, New York, 1991.

[7] M. Nave, "The effects of duty cycle on switch mode power supplies common mode: Theory and experiment", IEEE Int. Symp. on EMC'89, Washington, pp223-226.

[8] M. Nave, "A novel differential mode rejection network for conducted emission diagnostics", IEEE Int. Symp. on EMC'89, Washington, pp223-226.