Design of High Performance and Low Cost Line Impedance Stabilization Network for University Power Electronics and EMC Laboratories

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Design of High Performance and Low Cost Line Impedance Stabilization Network for University Power Electronics and EMC Laboratories

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***Abstract*--** **This paper proposes how to analyze and design the Line Impedance Stabilization Network (LISN). The details are described component characteristics and how to design air coil inductors in single and multi layers based on a high self resonant frequency response concept. According to the CISPR 16-1 standard, the stabilized impedance 50 Ω of LISN at frequency range 150 kHz to 30 MHz is proved by simulation and experimental results. The proposed LISN is successful design the low cost by compare with commercial LISN. Finally, the performance of the proposed LISN is achieved comparing to CISPR standard and also with commercial LISN.**

***Index Terms*--LISN, AMN, EMI, EMC**

I. INTRODUCTION

Line Impedance Stabilization Network: LISN or Artificial Mains Network: AMN is an important equipment for measuring the conducted Electromagnetic Interference (EMI) emissions following CISPR 16-1 standard. There are three main functions of LISN or AMN. Firstly to prevent incoming Radio Frequency (RF) disturbance from the mains supply. Secondly, to maintain the specified impedance at the equipment under test (EUT) terminal over the working frequency range and finally to couple RF voltage signal from the EUT to the measuring receiver.

There are two basic types of LISN, the v-network and the delta-network. The LISN v-network can be coupled the unsymmetric voltages: the amplitude of the vector voltage V_a or V_b where V_a is the vector voltage between one of the main terminals and earth and V_b is vector voltage between the other main terminals and earth. The LISN delta-network can be coupled the symmetric (Differential Mode: DM) and asymmetric (Common Mode: CM) voltages separately [1].

This paper proposes designing of the artificial mains 50 Ω /50 μH + 5 Ω V-network by improved self resonant frequency (SRF) of inductors as in [2] using air gap winding technique. To improve the previous researched work [2], the line/neutral selector switch as shown in Fig. 1 is removed because of two reasons: firstly, two output ports can provide voltage signal from line to ground and neutral to ground simultaneously as shown in equations (1-2), and lastly, this proposed LISN is designed to apply with other conducted EMI emissions investigated devices such as DM/CM rejection network [3] or Paul-Hardin noise separation network [4] for more advanced research opportunities.

$$V_{Line-Ground} = 50 \cdot (I_{CM} + I_{DM}) \tag{1}$$

$$V_{Neutral-Ground} = 50 \cdot (I_{CM} - I_{DM}) \tag{2}$$

where I_{CM} is a common mode current
I_{DM} is a differential mode current

Fig. 1 shows a suitable circuit with the component values according to CISPR 16-1. These are the recommendable schematic and component values. It may be constructed for use with the current up to 100 A. Moreover, the recommended case dimension following the CISPR is 360x300x180 mm. [1]

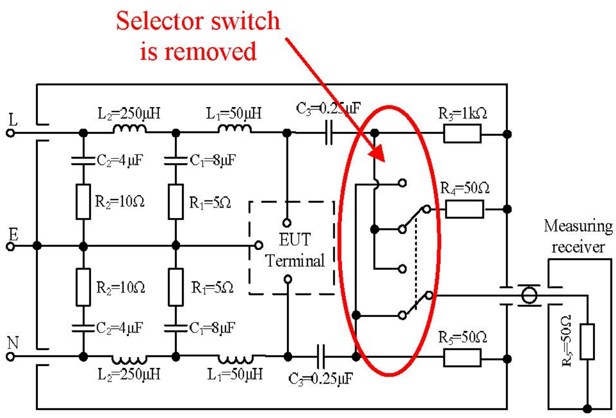

Fig. 1 Artificial mains 50 Ω / 50 μH + 5 Ω V-network.

II. THE PROPOSED SCHEMATIC AND COMPONENT VALUES

Fig. 2 shows proposed schematic of LISN by cut the selector switch off and adding some components such as R_7-R_{10}, C_7-C_8 and two BNC type N terminals (female). Table I shows the proposed LISN component values.

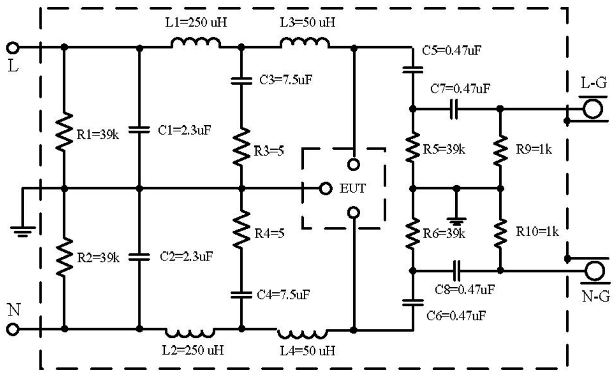

Fig. 2. The proposed schematic of LISN.

TABLE I

PROPOSED LISN COMPONENT VALUES

Component	Value
R_1, R_2	39 kΩ (1 W)
R_3, R_4	5 Ω (5 W)
R_5, R_6	39 kΩ (1 W)
R_7, R_8	1,000 Ω (1/2 W)
C_1, C_2	2.3 μF
C_3, C_4	7.5 μF
C_5, C_6, C_7, C_8	0.47 μF
L_1, L_2	250 μH
L_3, L_4	50 μH

L_3-L_4, C_3-C_4, R_3 and R_5-R_8 define the impedance; L_1-L_2, C_1-C_2 and R_1-R_2 provide the isolation to spurious mains signals and mains impedance variations, and C_6-C_6 decouples the measuring receiver from mains voltage.

III. The Component Details

A. Resisters

All resistors are the carbon type and the tolerance should as small as possible. In fact, the resistor, which made from carbon has small response with high frequency.

B. Capacitors

The capacitors, C_1-C_4, have high capacitance. They should have high rated voltage for the safety reason. Capacitors C_1-C_4 are the metallized polypropylene. Capacitors C_5-C_8 are metallized polyester. The SRF of capacitors are provided from manufacturer. The measured self resonant frequency (SRF) response, using impedance analyzer of C_1-C_2 are about 268 kHz, C_3-C_4 are about 169 kHz and C_5-C_8 are about 1 MHz, respectively.

C. Case of network

The case of network is mounted on a metal frame, which is then closed by metal lids. The bottom and side lids are perforated in order to improve the heat dissipation. The dimension of the case is about 300x280x170 mm. This case is smaller than the example case recommended by CISPR 16-1.

D. Inductor core and dimension

This is the key point to keep the proposed LISN to cheapest cost. Normally, the solenoidal winding of the inductor is wound on a coil former of an insulating material. Because of the product cost and temperature operation, in this paper, the unplasticized polyvinyl chloride (PVC) pipe is chosen to be as a coil former as shown in Fig. 3 [5].

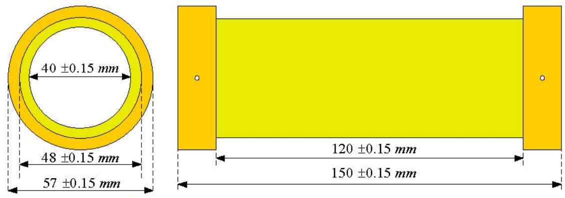

Fig. 3. The coil former of inductors.

IV. Air Core Inductor Design

A. Calculations

The inductors, used in proposed LISN, are an air core with solenoidal winding. The unplasticized polyvinyl chloride (PVC) pipe is chosen to be a coil former. The length, diameter and thickness are 120 mm, 48 ± 0.15 mm, and 1.5 ± 0.15 mm, respectively. The maximum operating temperature of PVC pipe is 60 °C [5]. The number of turn and wire size can evaluate by the equations as shown below [2]:

$$a_{wire} = \frac{I}{J} \tag{3}$$

where a_{wire} is a wire area (mm^2)
I is a rated current (A)
J is a current density (A/mm^2)

The wire size can be evaluated following equation (3). The rated current and current density are defined to be equal to 10 A and 3 A/mm^2, respectively. The wire diameter is 3.333 mm^2 and AWG 14 is chosen.

$$N = \sqrt{\frac{L l_m}{A_c \mu_0}} \tag{4}$$

where N is a total numbers of turn (turns)
L is an inductance (H)
l_m is a mean magnetic length (m)
A_C is a cross section of the core (m^2)
μ_0 is a permeability of air (H/m)

Equation (4) is used specially for calculating the number of turn of L_3 and L_4. The calculated result is about 52 turns by define l_m equal to 120 mm.

L_1 and L_2 design in multi layer coil using the Wheeler's formula in equations (5-6) [6].

$$L(\mu H) = \frac{0.0315 \cdot N^2 \cdot \left(\frac{r_1 + r_2}{2}\right)^2}{6 \cdot \left(\frac{r_1 + r_2}{2}\right) + 9 l_m + 10(r_2 - r_1)} \tag{5}$$

where r_1 is a core inner radius (mm)
r_2 is an outer radius include the width of wire (mm)

$$N = (N_1 \cdot N_2) - (N_2 / 2) \tag{6}$$

where N_1 is the number of turns per layer (turns)
N_2 is the number of layers (layers)

Equation (5) is used for designing the number of turn for L_1 and L_2, The three layers were chosen. The result from equations (5-6) can be found that the number of turns per layer of L_1 and L_2 is about 39 turns per layer.

B. Winding Techniques

L_1 and L_2 are designed in multilayer. To limit inter-winding capacitance effect, air gap is added for reducing the turn-to-core and stray capacitance. The turn-to-core capacitance (C_{tc}) is equal to two times of total capacitance ($2C_{tt}$). The stray capacitance (C_s) is equal to $C_{tt}/n-1$ [7]. Figs. 4-5 show winding technique applied for L_1 and L_2. The SRF measurement result is about 960 kHz as shown in Fig. 6.

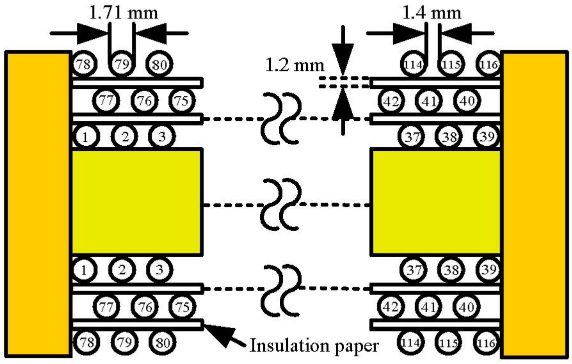

Fig. 4. Model multilayer winding technique of L_1 and L_2.

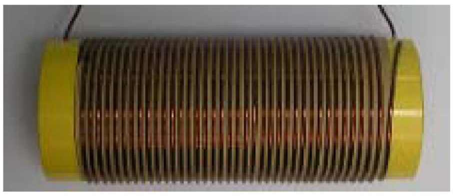

Fig. 5. Multilayer winding with air gap of L_1 and L_2.

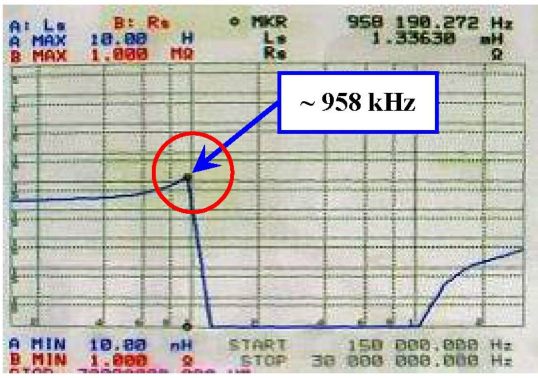

Fig. 6. Measured impedance characteristics of L_1 and L_2.

L_3 and L_4 are single layer with 0.61 mm gap as shown in Fig. 7-8 and the SRF measurement result is about 23 MHz as shown in Fig. 9.

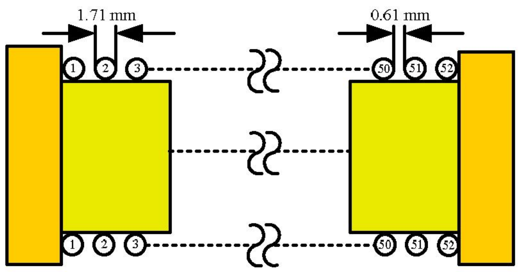

Fig. 7. Model winding technique of L_3 and L_4.

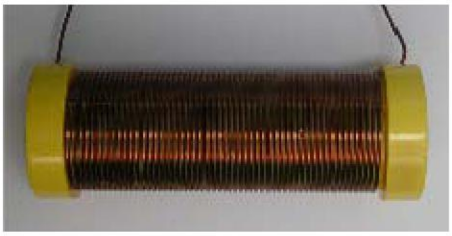

Fig. 8. Single layer winding with air gap of L_3 and L_4.

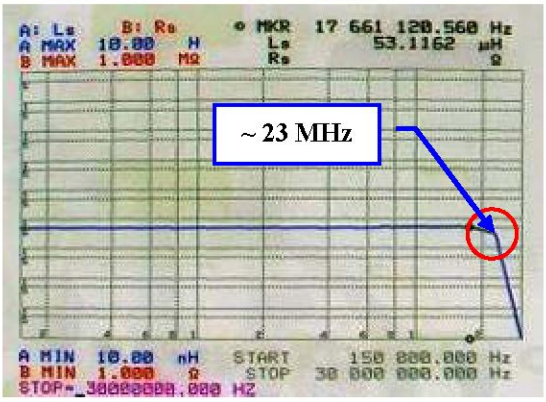

Fig. 9. Measured impedance characteristics of L_3 and L_4.

Actually, the SRF of L_3 and L_4 are good performance about 17 MHz even though they are not added the air gap. Then the improvement of the SRF also keep the size of core, the small air gap about 0.6 mm is added. But the air gap of L_1 and L_2, bigger than L_3 and L_4 is chosen to upgrade SRF from about 570 kHz to 960 kHz. Because of the previous research [2], it has some output impedance testing problems at high frequency which could not comply with the CISPR 16-1 requirement.

V. Impedance Simulation of Proposed LISN

The simulated circuit of proposed LISN, neglected the effect of parasitic elements, is shown in Fig. 10. The AC sweep function of PSpice program is used to simulate the impedance at EUT port.

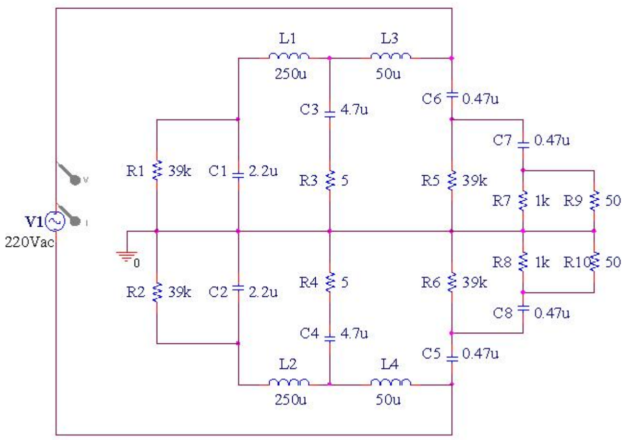

Fig. 10. Simulated circuit by PSpice program.

The simulated result is shown in Fig. 11. The curve increases rapidly in frequency range 30 kHz to 300 kHz and after that the curve provides the stabilized impedance about 47 Ω until 30 MHz. The simulated result of proposed LISN shows stabilized impedance following standard in frequency range of 150 kHz to 30 MHz.

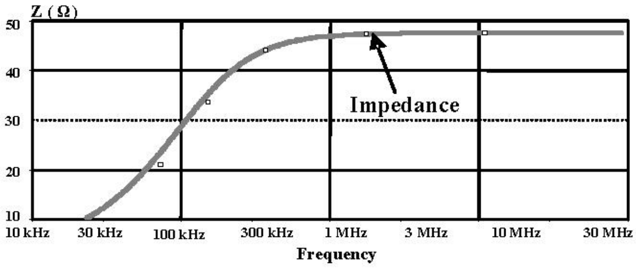

Fig. 11. The impedance at EUT connector.

VI. Experimental Results

According to CISPR 16-1, the requirements for LISN or AMN testing are the output impedance and the insertion loss. But, due to limitation of equipment in laboratory, the insertion loss can not test. With these reasons, the experiment has divided to three subtopics. The first experiment is to confirm the CISPR 16-1 requirement by measured impedance at EUT terminals of proposed LISN. The second is measured the conducted EMI by using the proposed LISN comparing with commercial LISN. Finally, the temperature of air gap inductor is verified.

A. Impedance testing method

The impedance measurement, based on CISPR 16-1 methodology, is tested as shown in Fig. 12 [1]. Broadband load 50 Ω has to connect to BNC RF connector, normally connected to EMI receiver of proposed LISN. The impedance of proposed LISN is measured at EUT terminals between line to ground and neutral to ground respectively.

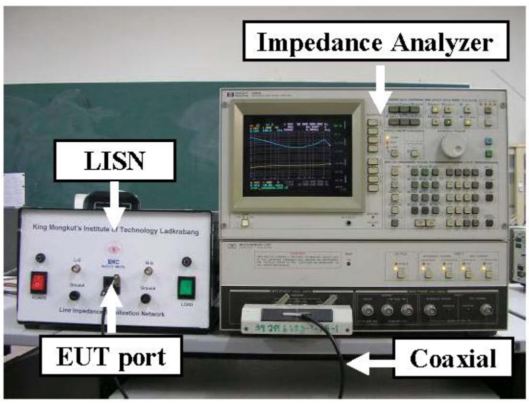

Fig. 12. Impedance testing setup.

The measured impedance from impedance/gain-phase analyzer, as shown in Figs. 13-14, guarantees that the proposed LISN can be provided the impedance about 50 Ω within ±20 % tolerance at frequency range 150 kHz–30 MHz for both line to ground and neutral to ground.

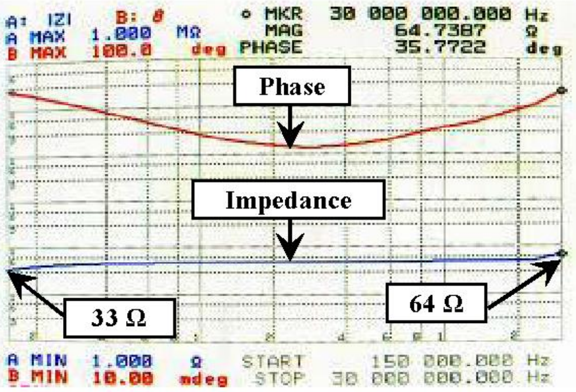

Fig. 13. The measured impedance of proposed LISN at EUT port Line to Ground side.

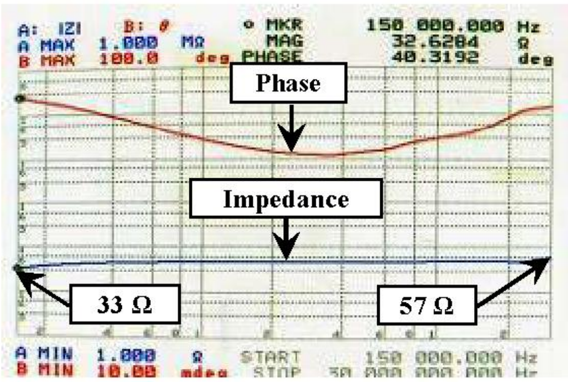

Fig. 14. The measured impedance of proposed LISN at EUT port Neutral to Ground side.

B. Conducted EMI testing method

In fact, LISN is a device used to transfer energy to load and to detect the conducted EMI to EMI receiver. From these reasons, the proposed LISN has to measure conducted EMI by comparing between the proposed LISN and the commercial LISN. The conditions are the frequency range 150 kHz–30 MHz following CISPR 22 standard and switching power supply is used as an EUT. Figs. 15-16 show line to ground and neutral to ground noise floor when measured before connecting the EUT. The conducted EMI measured by proposed LISN (blue line) is nearly close to commercial LISN (red line) as shown in Figs. 15-18.

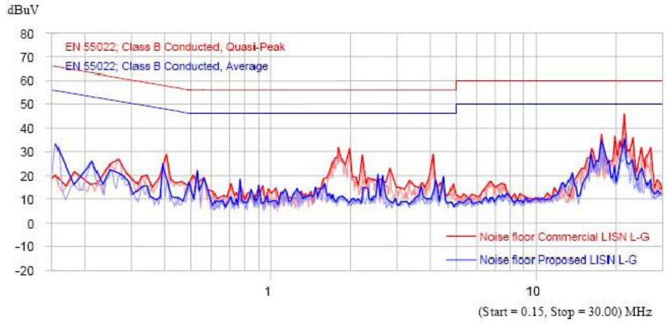

Fig. 15. The measured Line to Ground noise floor.

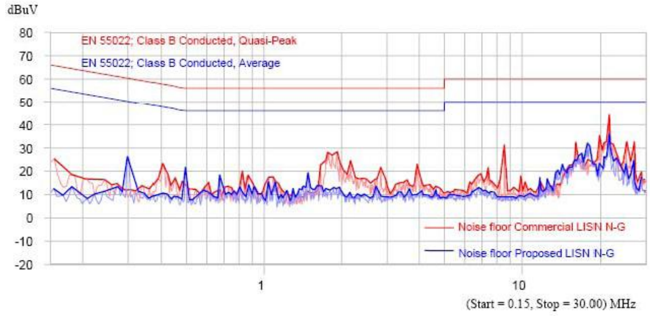

Fig. 16. The measured Neutral to Ground noise floor.

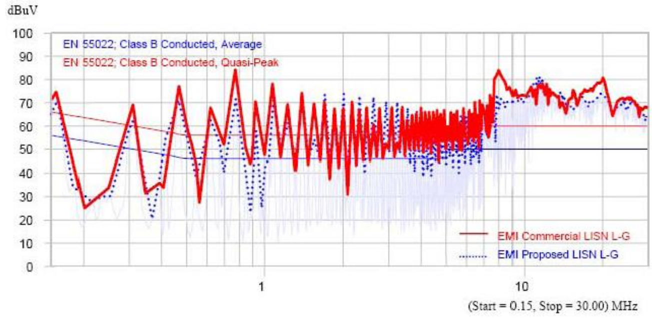

Fig. 17. The measured Line to Ground conducted EMI.

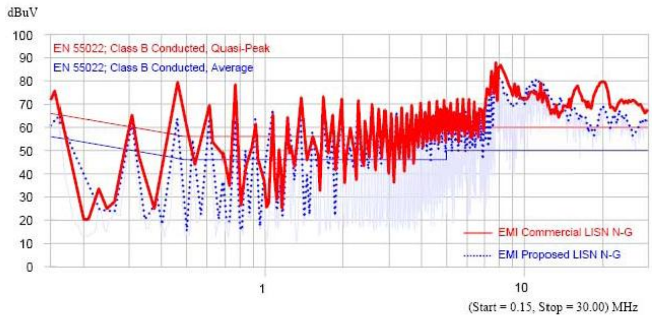

Fig. 18. The measured Neutral to Ground conducted EMI.

C. Operating temperature testing method

The operating temperature is measured at the middle of core winding of proposed LISN by using infrared thermometer. The testing time period is 60 minutes. The testing conditions are measured in every 5 minutes pass and connecting the continuous 8 A load (incandescent lamp) at EUT connector. From the experimental results as shown in Fig. 19, it can be seen that the operating temperature of proposed LISN is about 10 °C less than maximum temperature limit of PVC cores of proposed LISN.

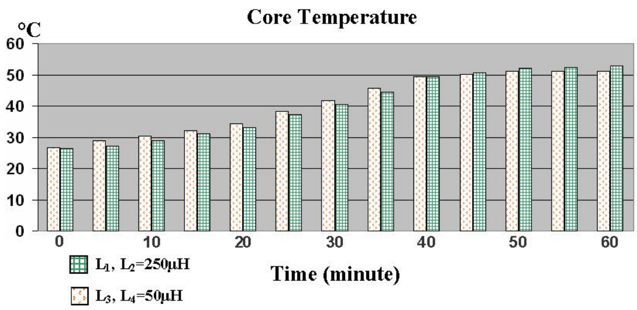

Fig. 19. Temperature measurement

VII. Conclusion

From all of the experimental results, it can be concluded that the proposed LISN can be provided the defined impedance 50 Ω ±20% and RF coupling signal as the functions of commercial LISN with a cheaper cost due to remove the selector switch and change type of inductor core material from bekalite to PVC. The total cost of the proposed LISN is about 100 US dollars. Finally, the proposed LISN has tested with continuous 8 A load at EUT connector for 60 minutes. The measured temperature at all devices is less than the temperature limit of devices.

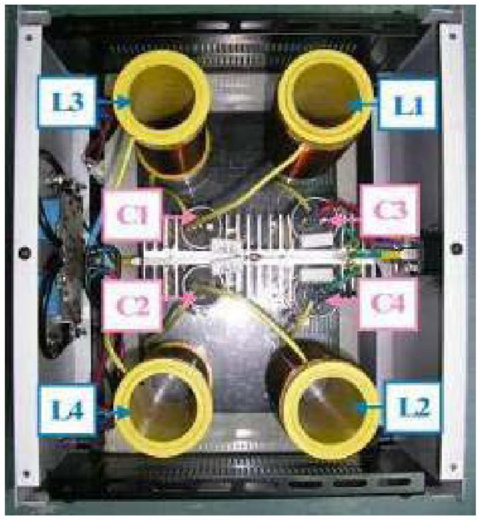

Fig. 20. Top view of the proposed LISN.

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