ELECTROMAGNETIC COMPATIBILITY FOR STATIC CONVERTERS

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Abstract – This work presents an introduction to Electromagnetic Compatibility – EMC, as well as the characteristics and specifications of available equipment at the Electromagnetic Compatibility Laboratory of the Power Electronics Institute. The results of conducted emissions test realized with an electronic transformer for halogen lamps and power supplies are presented. In order to make these units comply with the regulatory limits, filters where projected and implemented. The results of the tests with and without the insertion of the filter are presented.

1. INTRODUCTION

The Power Electronics is an engineering field which uses electronics to process the energy used in various electrical and electronic equipments. Due to this "action" over the energy that comes from the commercial power system, two elements are of extreme importance: the use of frequencies greater than the usual power frequency (50/60Hz), and the processing of high voltages and currents, usually with non-sinusoidal waveform. These elements generate electrical signals and electromagnetic fields, conducted or radiated, which can affect (in a prejudicial way or not) other electrical equipment in the common environment or in the vicinity. These undesired signals can cause electromagnetic interferences, also known as Radio Frequency Interference – RFI, because many times they occur at higher frequencies and can radiate by space or to be conducted by wire.

Besides emitting Electromagnetic Interference – EMI, the control circuits can also be affected by EMI generated by the power stage, by other circuits at vicinity and even by natural phenomenon. When this happens, the circuit is said to be EMI susceptible. Any system that doesn't emit EMI beyond a certain level and also doesn't suffer interferences caused by its surrounding environment has Electromagnetic Compatibility.

In the analysis of EMI, the elements can be classified according to Fig. 1:

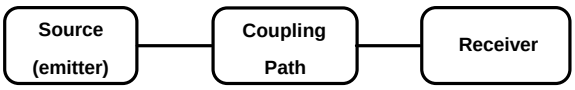

Fig. 1 – Basic elements on Electromagnetic Compatibility.

Static converters can act as sources, paths or receptors of EMI.

Electromagnetic Compatibility areas can be described according to Fig. 2:

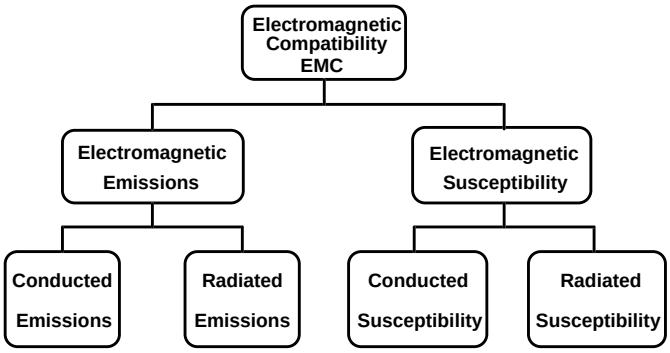

Fig. 2 – Electromagnetic Compatibility areas.

The work, that's being developed at the Electromagnetic Compatibility Laboratory of the Power Electronics Institute emphasizes emissions, specially conducted ones, because the Laboratory has only conditions of doing pre-compliance tests with these emissions. The pre-compliance test is a preparation for the compliance of a product with the regulatory limits.

2. CONDUCTED EMISSIONS

Conducted noise is the biggest problem of EMC in static converters. Basically, every static converter rectifies the main voltage through a diode bridge. This is a source of interference, because the process of rectification generates harmonic components from the current that is injected in the commercial power system. Besides that, every switched mode power supply has a high power oscillator which generates a series of harmonic components, besides the fundamental. Flyback circuits and recovering diodes are also EMI sources. A special problem is the mechanical connection of transistors to heatsinks, which creates a capacitive coupling (parasitic capacitance) to the heatsink with return by the phase or neutral conductor.

Conduction is the mechanism by which emissions are generated and are conducted out of the product along the product's AC power cord. Regulatory agencies impose limits on these conducted emissions for the reason that they are placed on the commercial power system net of the installation. The commercial power distribution system in an installation is a large array of wires connecting the various power outlets from which other electronic systems in the installation receive their AC power. It therefore represents a large "antenna" system from which these conducted emissions can radiate quite efficiently, causing interference in the other electronic systems of the installation. Thus the conducted emissions may cause

radiated emissions, which then may cause interference. Ordinarily, the reduction of these conducted emissions is somewhat simpler than the reduction of radiated emissions, since there's only one path for these emissions that needs to be controlled: the unit's power cord. However, it's important to realize that if a product fails to comply with the limits on conducted emissions, compliance with the limits on radiated emissions it's hard to get. So, the priority is to control conducted emissions.

Manufacturers of electronic products realize that simply complying with the regulatory limits on conducted and radiated emissions does not represent a complete design from the standpoint of EMC. A product must be reasonably insensitive to disturbances that are present on the power system net in order to insure reliable operation of the product. For example, lightning strokes may strike the power transmission lines that feed power to the installation. This may cause disturbances that range from a complete loss of commercial power (which no product is expected to withstand) to momentary power loss due to power system circuit breakers attempting to re-close (which a product is expected to withstand without loss of data or function). The regulatory limits on conducted emissions are intended to control the interference potential of the radiated emissions due to the noise currents that are placed on the commercial power wiring by their being conducted out of the product along its AC power cord. Normally these noise currents are too small to cause direct interference by their conduction into a product along its AC power cord. However, disturbances such as those induced by lightning are of sufficient magnitude to cause interference by their direct conduction into a product via its AC power cord. This type of interference represents a conducted susceptibility problem, and is one that manufacturers realize and try to design a product to withstand. Solutions to the problem of conducted interference include: insertion of a line filter for reducing differential and common mode currents at the input; reducing the capacitive coupling of transistors to heatsinks and a properly designed layout of the printed circuit boards.

3. MEASUREMENT OF CONDUCTED EMISSIONS

It's important to understand the measurement procedure that is used to verify compliance to the conducted emission regulatory limits. The FCC limits on conducted emissions extend from 450kHz to 30MHz, whereas the CISPR 22 conducted emissions limits extend from 150kHz to 30MHz. Emissions measured for verification of compliance with the regulatory limits are to be measured with a Line Impedance Stabilization Network – LISN, inserted between the commercial power outlet and product's AC power cord. The topologies or structures of these LISNs for FCC and CISPR 22 tests are quite similar; the component values are different. A typical test configuration is shown in Fig. 3:

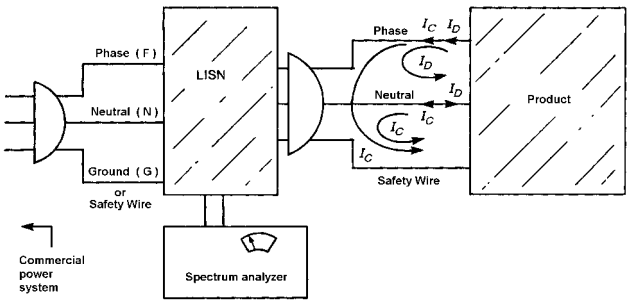

Fig. 3 – Use of a line impedance stabilization network (LISN) in the measurement of conducted emissions.

The purpose of the conducted emissions test is to measure the noise currents that exit the product's AC power cord conductors. At first glance it may appear that these emissions could be simply measured with a current probe. In fact, the military specifies in the standard MIL-STD-461 that conducted emissions must be measured with a current probe. However, the requirement that the measured data be correlatable between measurement sites may render this simple test unrealistic. The impedance seen looking into the AC power system wall outlets varies considerably over the measurement frequency range and from outlet to outlet and building to building. This variability in the loading presented to the product affects the amount of noise that is conducted out the power cord. In order to make this consistent between test sites, the impedance seen by the product looking out the product's AC power cord must be stabilized from measurement site to measurement site. This is the first objective of the LISN – to present constant impedance to the product's power cord outlet over the frequency range of the conducted emission test. Also, the amount of noise that is present on the power system net varies from site to site. This "external" noise enters the product's AC power cord, and, unless it is somehow excluded, will add to the measured conducted emissions. It is desired to measure only those conducted emissions that are due to the product, and this gives the second objective of the LISN – to block conducted emissions that are not due to the product being tested so that only the conducted emissions of the product are measured. Therefore, the two objectives of the LISN are:

(1) To present a constant impedance (50Ω) between the phase conductor and the safety wire and between the neutral conductor and the safety wire.

(2) To prevent external conducted noise on the power system net from contaminating the measurement.

These two objectives are to be satisfied only over the frequency range of the conducted emission test.

4. COMMON AND DIFFERENTIAL MODE CURRENTS

Representing the LISN as 50Ω resistors between phase and safety wire (ground connector) and between neutral and safety wire, as in Fig. 4, simplifies the analysis of conducted emissions. The voltages that are to be measured for verification of compliance to the regulatory limit are the voltages across these 50Ω resistors, and are denoted as $\hat{V}_P$ and $\hat{V}_N$. These voltages are related to the emissions

$$\hat{V}_P = 50 \cdot \hat{I}_P \quad \text{and} \quad \hat{V}_N = 50 \cdot \hat{I}_N$$

One can decompose these currents into a differential mode component that flows out through the phase conductor and returns on the neutral conductor, and a common mode component that flows out through the phase and neutral conductors and returns on the safety wire, as shown on Fig. 4:

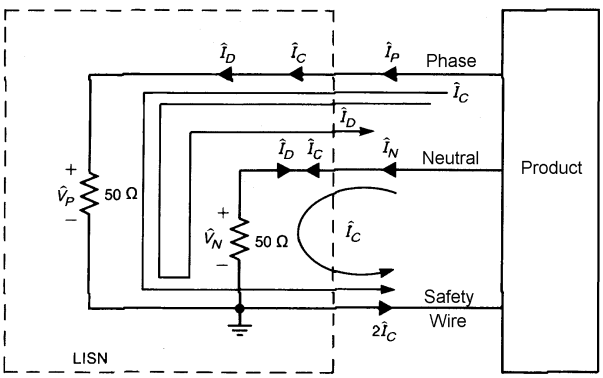

Fig. 4 – Contributions of differential mode and common mode current components on the measured conducted emissions.

The currents on the phase and neutral conductors are:

$$\hat{I}_P = \hat{I}_C + \hat{I}_D \quad \text{and} \quad \hat{I}_N = \hat{I}_C - \hat{I}_D$$

Then $\hat{I}_D = \frac{1}{2} \cdot (\hat{I}_P - \hat{I}_N)$ and $\hat{I}_C = \frac{1}{2} \cdot (\hat{I}_P + \hat{I}_N)$

The measured voltages are:

$$\hat{V}_P = 50 \cdot (\hat{I}_C + \hat{I}_D) \quad \text{and} \quad \hat{V}_N = 50 \cdot (\hat{I}_C - \hat{I}_D)$$

It is important to remember those differential mode currents for conducted emission regulatory compliance is not the functional 60Hz power line currents.

Observe that the differential mode current flows down through one 50Ω and up the other, whereas the common mode currents flow down through both 50Ω resistors. Therefore the contributions due to each current add in $\hat{V}_P$ and subtract in $\hat{V}_N$. Therefore if the common and differential mode currents are of the same magnitude, the phase and neutral voltages will not be the same. Generally, one component dominates the other so that the magnitudes of the phase and neutral voltages are the same:

$$\hat{V}_P = 50 \cdot \hat{I}_C, \quad \hat{I}_C >> \hat{I}_D$$
$$\hat{V}_N = 50 \cdot \hat{I}_C, \quad \hat{I}_C >> \hat{I}_D \text{ or}$$
$$\hat{V}_P = 50 \cdot \hat{I}_D, \quad \hat{I}_D >> \hat{I}_C$$
$$\hat{V}_N = -50 \cdot \hat{I}_D, \hat{I}_D >> \hat{I}_C$$

5. ELECTROMAGNETIC COMPATIBILITY STANDARDS

The great part of developed nations has regulatory agencies that created specific EMC standards. As examples, one can mention the BSI (*British Standards Institute*) in the UK, the FCC (*Federal Communications Commission*) in the United States, the VDE (*Verband Deutscher Elektrotechniker*) in Germany, the VCCI (*Voluntary Control Council for Interference by Information Technology Equipment*) in Japan, as well as the military standards usually referred as MIL-STD.

The standards divide the frequency spectrum in a range where the conduction of emission currents is usual (150 kHz to 30 MHz) and another range where radiated emissions are preponderant (30 MHz to 1 GHz). The IEC (*International Electrotechnical Commission*) created a subcommittee in 1934 called CISPR (*International Special Committee on Radio Interference*) to prepare general standards of EMC to avoid that each country creates its own standard. These CISPR standards were followed and used by many years.

In 1986 the European Community defined a new standard, the EN55022, based on the CISPR 22 published in 1985. The equivalent Brazilian standard is the NBR12304 – "Limits and methods of measuring radio-interference in information technology equipment (ITE)", published in April of 1992, is also based on CISPR 22. This standard, over various denominations, includes information technology equipment, such as: data reception equipment as keyboards and data entry lines, data processing and storing equipment. This standard applies to conducted and radiated emissions, and subdivides the equipments in two classes. Class A has minor restrictions and serves to industrial and commercial equipment. It uses 30m as distance of measuring radiated emissions and can be less restrictive for household appliances. Class B is for household purposes and the measuring distance is 10m.

The limits for conducted emissions in CISPR 22 are shown in tables 1 and 2. The values are presented using Quasi-Peak (QP) and Average (AV) detectors.

TABLE 1: Conducted Emissions in CISPR 22 – Class A

Frequency (MHz)	μV QP (AV)	dBμV QP (AV)
0,15 – 0,5	8912,5 (1995)	79 (66)
0,5 - 30	4467 (1000)	73 (60)

TABLE 2:Conducted Emissions inCISPR 22 – Class B

Frequency (MHz)	µV QP (AV)	dBµV QP (AV)
0,15	1995 (631)	66 (56)
0,5	631 (199,5)	56 (46)
0,5 – 5	631 (199,5)	56 (46)
5 – 30	1000 (316)	60 (50)

There are three categories of EMC standards:

⇒ Generic Standards: These are general standards and are applied in the absence of specific standards.

⇒ Basic Standards: They Apply to all products and describe measuring procedures.

⇒ Product Standards: They are specific to a product or family of products.

Generic Standards

EN 50081-1 - Generic Emissions
Part 1 – Household, Commercial.

EN 50081-2 - Generic Emissions
Part 2 - Industrial

EN 50082-1 - Generic Susceptibility
Part 1 - Household, Commercial.

EN 50082-2 - Generic Susceptibility
Part 2 – Industrial

TABLE 3: Basic Standards – Describe physical phenomenon and measurement techniques.

		Europe	International
Definitions, basic principles		EN 61000	IEC 1000-1-1
Measuring equipment		-	CISPR 16.1
Measuring methods	Emission	-	CISPR 16.2
	Susceptibilit	EN61000-4-1	IEC 1000-4-1
Harmonics		EN60555	IEC555
Interference Sources	ESD	EN 61000-4-2	IEC 1000-4-2
	EM Fields	EN 61000-4-3	IEC 1000-4-3
	BURST	EN 61000-4-4	IEC 1000-4-4
	SURGE	EN 61000-4-5	IEC 1000-4-5

TABLE 4: Product Standards – Define limits to a determined sort of products

		Europe	International
ISM Industrial, Scientific and Medical Equipment	Emission	EN 55011	CISPR 11
Household Appliances	Emission	EN 55014-1	CISPR 14-1
	Susceptibility	EN 55014-2	CISPR 14-2
Lightning	Emission	EN 55015-1	CISPR 15
	Susceptibility	EN 55015-2	IEC 3439
ITE Information Technology Equipment	Emission	EN 55022	CISPR 22
	Susceptibility	EN 55022	CISPR 22

⇒ Some standards present practically the same contents under diverse denominations, but sometimes they have little variations. The standard IEC1000-3, was denominated as EN61000-3 by the European community and since 1997 also renumbered do IEC 61000-3

6. THE POWER ELECTRONICS INSTITUTE'S ELECTROMAGNETIC COMPATIBILITY LABORATORY

The Electromagnetic Compatibility Laboratory of the Power Electronics Institute has been operational, since early 1998. The aim is to develop researches and to render services for the community in the area of electromagnetic compatibility. The laboratory is able to realize tests of pre-compliance on conducted interferences following a set of standards, or define specific limits. The most used standards are:

⇒ EN55011 Class A and B

⇒ EN55022 Class A and B

⇒ FCC 15 Class A and B

The laboratory has the following equipment:

⇒ Spectrum Analyzer HP8591EM, 9 kHz-1,8 GHz

⇒ Amplifier HP8447F, 9 kHz-1,3 GHz

⇒ LISN EMCO 3810, 9 kHz-30 MHz

⇒ Transient Limiter HP 11947A

⇒ Close-Field Probe HP de 9kHz a 30 MHz (*Sniffer*)

⇒ Close-Field Probe HP de 30 MHz a 1 GHz (*Sniffer)*

⇒ ESD Simulator NSG 435, Schaffner

⇒ Microcomputer and printer for emitting reports.

There are available too two antennas for doing radiated emissions measurement, though there is not an adequate site for doing radiated measurements yet. The antennas are a biconical for a frequency range of 30MHz to 1GHz and a log periodic for a frequency range of 200MHz to 1GHz.

The close field probes are intended to make the local detection (at PCB level) of the critical elements in electromagnetic emissions.

As a study case, the results from a test realized with an electronic transformer for halogen lamps, with and without the metallic cover, are presented. It was measured the ambient noise, the noise without the metallic cover and the noise with the metallic cover. The results of the tests are presented in figures 5, 6 and 7. Comparing figures 6 and 7, it can be seen the shielding effect of the cover for the radiated emissions.

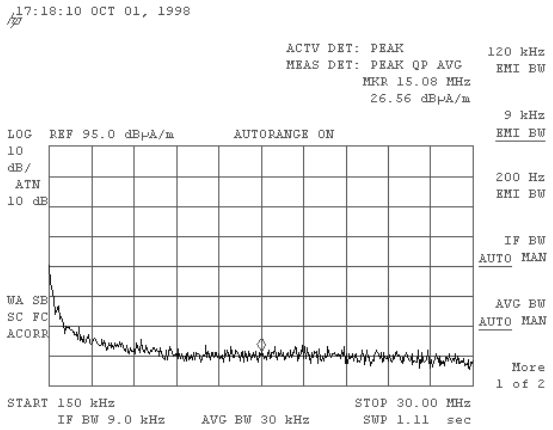

Fig. 5 – Ambient noise.

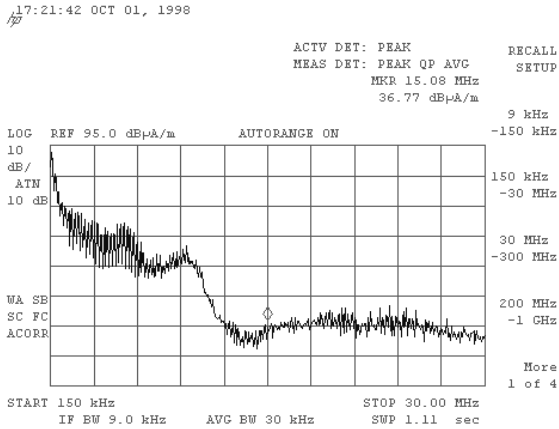

Fig. 6 – Noise over the transformer (without cover).

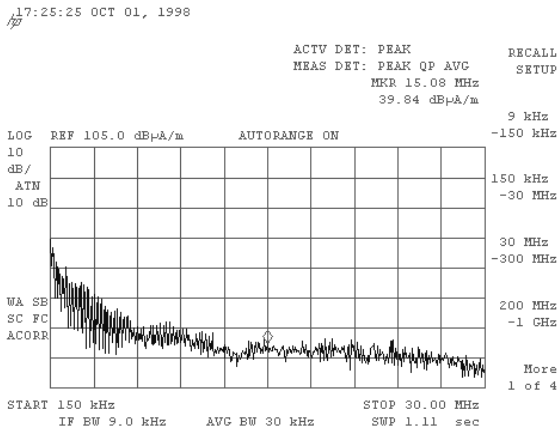

Fig. 7 - Noise over the transformer (with cover).

7. EXPERIMENTAL RESULTS

For this work, it was proposed the project and the implementation of a filter to limit the conducted emissions from an electronic transformer for halogen lamps.

7.1 - Electronic transformer:

Electrical Characteristics:

- ✓ Primary Side: 127V +5% -10% AC 50/60Hz
- ✓ Secondary Side: 12V AC (≅ 45 kHz)
- ✓ Maximum Current: 5 A
- ✓ Power Factor: 0,98
- ✓

For the filter project was used a classical topology, as described in [4] and a software for projects of filter for attenuating EMI, described in [5]. With this software it was possible to verify that the PI topology was enough to limit the conducted emissions [6], putting the transformer into compliance with the standard for lightning equipment. The component values used for the common mode choke and for the capacitors were approximated to the commercial values available at the laboratory. The schematic diagram of the filter is shown in Fig. 8:

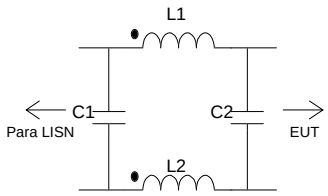

Fig. 8 – Filter schematic diagram.

Where:

$C1 = C2 = 0{,}22\mu F$ Suppression capacitors, X1 type.

$L1 = L2 = 12mH$ Common mode choke

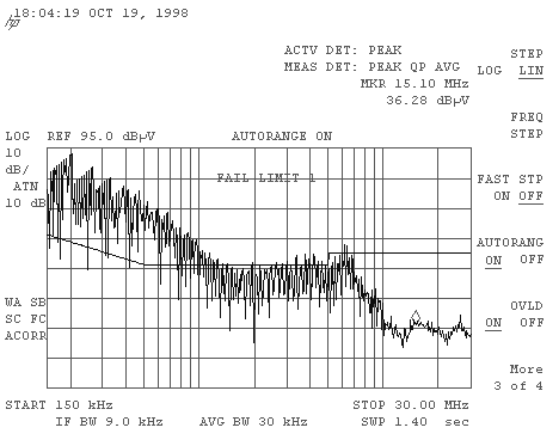

*Fig. 9 – **Conducted Emission test result without the insertion of the filter.***

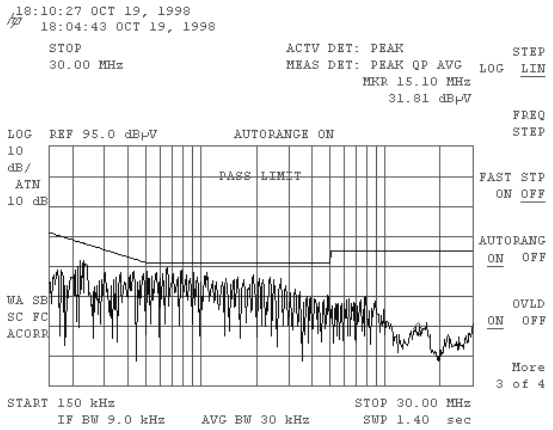

Fig. 10 – ***Conducted Emission test result with the insertion of the filter.***

7.2 - Power Supply

Conducted emission of a switch mode power supplies tested according to EN55022 (Information Technology Equipment), Class B.

⇒ Input Voltage 220 V, 200W

Output Voltage (V)	+5	-5	+12	-12
Current (A)	20	0,5	8,0	0,5

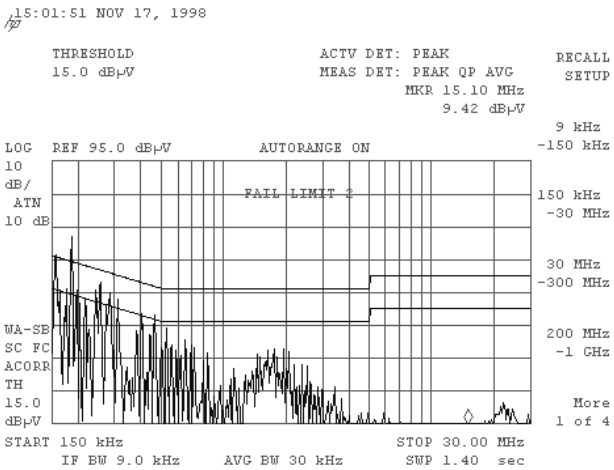

Fig. 11 – Conducted emission on phase conductor.

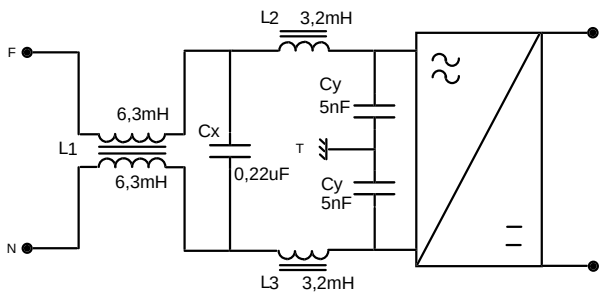

Fig.12 – Filter circuit.

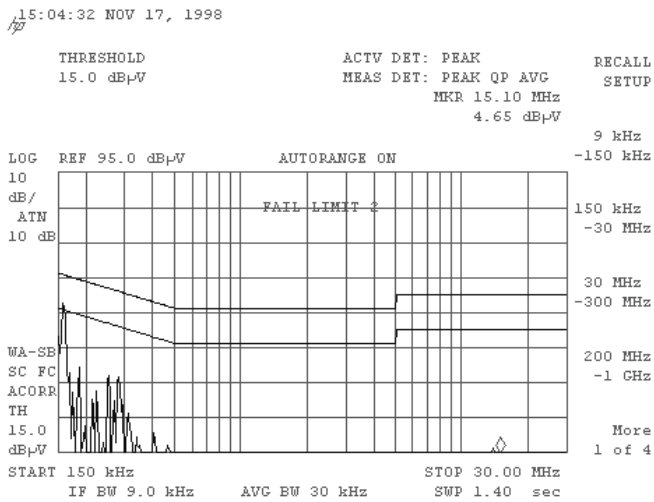

Fig. 13 – Emission with filter

8. CONCLUSIONS

Some basic concepts of Electromagnetic Compatibility were presented, as well as a general sight over the actual standards.

The implemented filter where efficient in attenuating the conducted emissions from the equipment under test. With a simple construction, the filter could reduce the conducted emissions in the frequency range of the conducted measurements. The software used to project the filter [5], helped in choosing the correct topology and the values of the filter components.

The diagnose of close emissions realized on the electronic transformer with the close field probe proved the efficiency of using a metallic cover to attenuate radiated emissions.

9. REFERENCES

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