EMC ANALYSIS ON LOW POWER (< 100 W) ELECTRONIC BALLASTS FOR FLUORESCENT LAMPS

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***Abstract* – This paper shows the a partial analysis of the electromagnetic compatibility (EMC) on low power electronic ballasts, observed the international standards of conducted and radiated electromagnetic interference (EMI) and also the current and voltage harmonic distortion. The main purpose is to characterize the sources of production and propagation of electromagnetic noises as well as demonstrate the need of caution on the design of those devices which certifies the accordance to EMC.**

***Keywords* – Electromagnetic Compatibility, Electromagnetic Interference, Electronic Ballasts,**

I. INTRODUCTION

It is already known that switch mode devices produce higher frequency noises than the switching frequency. Besides the frequency operation, there is another problem, the commutation velocity of the electronic switches (dv/dt and di/dt), which contribute to the frequency spectrum diversification and the increasement of the emitted noise. Those disturbances are characterized by distortions on the absorbed current of the power supply network (disturbance voltage) and electromagnetic coupled apparatus through the atmosphere (radiated electromagnetic disturbance). They cause from current distortion on the power supply network and conductors overheat to malfunction, or even damages on appliances operating in the same electromagnetic environment. [1,2,3,4]

Electronic ballasts for illumination consist on electronic converters operating over 20 kHz, therefore they are potentially interfering devices. The electromagnetic interference effects of the illumination equipment are increasing, especially due to the incentive programs to replace electromagnetic ballasts and incandescent light bulbs for fluorescent lamps driven by electronic ballasts.. This provokes the new studies, in course nowadays, to readjust the normalized frequency limits according to the EMC of illumination equipment which use electronic ballasts. [1,5]

The objective of this work is the evaluation of the low power electronic ballasts commercialized in Brazil, as for the conducted and radiated emissions, beyond the harmonic currents, in accordance with the international EMC standards. Measures of the conducted and radiated emissions, measures of the harmonic currents and corrective interventions by applications of filters had been carried through. Causes of these emissions are discussed in searching possible actions and mechanisms to minimizing its effects with minor filters applications.

II. EMC STANDARDIZATION

In Brazil, Sinmetro, the national organization of metrology, standardization and quality, created by a federal law in 1973, is a system formed by either public and private members, working on activities related to metrology, standardization, industrial quality control and conformity certification. Conmetro and its technical committees, Inmetro, ABNT and many other institutions compose the Sinmetro. [6]

However, regarding to electromagnetic compatibility standardization, Brazil is still very outdated. For electronic ballasts, the governmental decree INMETRO/MDIC 188 establishes certification criteria which embraces just general and safety requirements (NBR 14417; 1999) and of performance (NBR 14418; 1999). About electromagnetic compatibility, annex E of NBR 14418; 1999 establishes that the current harmonics in electronic ballasts power supply with potency equals or above 60 W must be according to rule IEC 61.000-3-2, in annex number 2. That is the only EMC qualification demanded to certify electronic reactors in Brazil.

Except for electromedical and telecommunication devices, more severe requirements are not obligatory for the production and marketing of electro/electronic appliances in Brazil, among which are included electronic ballasts for discharge lamps. However, the globalized world market has strongly demanded the qualification of those products, observing the electromagnetic compatibility. Therefore, an evaluation of those EMC criteria for electronic ballasts is necessary, mainly in order to develop the projects in accordance to the international standards and simultaneously allow a compatible price either for internal and exportation market.

For illumination equipment, where electronic ballasts for discharge lamps are included, the frequency range as well as the maximum allowed electromagnetic noise emission (conducted and radiated) and the test procedures are determined by the CISPR 15 and the technical report CISPR 30, according to this standard. Also, the IEC 61.000-3-2 establishes the criteria and limits for the current and voltage harmonics tests. [7,8,9]

Those standards were used in this paper to valuate the EMC problems in low power electronic ballasts available in the brazilian market, including compact lamps.

III. EMC AND THE ELECTRONIC BALLASTS

A large portion of electronic ballasts with power up to 100 W use structure with asymmetric inverter and self oscillating command. This way the switching frequency depends on the charge and the oscillations of the network voltage. This determines that the electromagnetic noise produced spreads through the frequency spectrum, possibly assuming a clearer aspect than the one presented by solid state frequency converters. However, not less important in amount of energy. [10].

Figure 1 shows a basic structure of a self oscillating ballast easily found in the market.

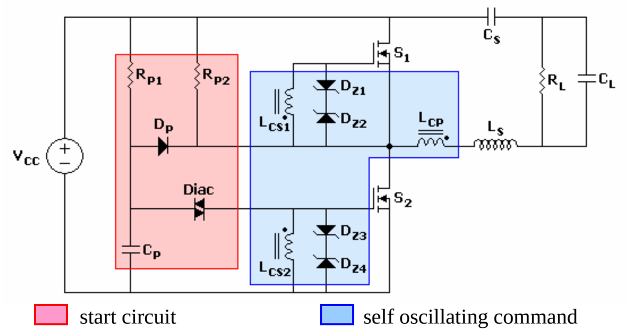

Fig. 1. Self oscillating ballast.

Those converters operate in frequencies that vary from 20 kHz to 50 kHz, producing significant harmonics into the 9 kHz to 30 MHz band. The switching of the transistors in this frequency range demands relatively fast commutation times, with high dv/dt and di/dt levels. This way, those semiconductors change into sources of high-frequency electromagnetic noises, which allied to their inherent features and the other components of the system, diffuse internally and externally of the device. Therefore, the noise is characterized by the voltage harmonics with fundamental frequency identical to the switching frequency (oscillation frequency) which will result in the circulation of current along the circuit.

Those currents will be more intense and will affect the environment of the ballast as small as the impedance of the propagation ways. Those ways include tracks of the printed circuit boards (PCB), component terminals, wires and cables, as well as capacitance and parasitic indutances (coupled systems) that appear due to the non-ideality of the elements of the system.

It is possible to infer, through the test results, that the capacitive coupling between PCB tracks, component terminals and the lamps related to ground reference may reach by tens the pico faradays, consisting on effective means of common mode current propagation (MC). The differential mode propagation (MD) can also be potentialized by the inductive coupling between tracks and component terminals and even between the coupling capacitances between transformer windings or coupled inductors. The oscillation and resonance that occur between capacitances and inductances, especially the parasites, can also contribute for the amplification of the noises.

Every time the multi-frequency low intensity noises circulate through the circuit network, wires, cables and other metal parts, they produce, besides interference itself, electrical losses, which can grow to significant levels, especially if computed in a set of many devices working in the same electromagnetic environment.

Considering the value of 80 dBμV of conducted emission in a single frequency, which is a real value for compact lamps of 20 W (as it is shown in the next item), the power losses in a 5 Ω impedance is -16,99 dB. It means an improper voltage of 10 mV on a 5 Ω impedance causes a power dissipation of 20 μW

$$dB(\mu V) = 90 + 10 \cdot \log_{10} Z + dBm \tag{1}$$

Although this number represents low power loss, considering all the frequencies in the spectrum of the conducted noise, the total of the power by frequency can reach significant levels. Therefore, the electromagnetic noise generated and propagated by illumination devices using electronic ballasts contribute for the reduction of efficiency. In fact, the lower the emission levels improve the power efficiency of the electric system where the device is working. And this is another reason to respect the EMC criteria.

Other EMI related effects are: overheat, transformer saturation, reduction of the effective conductor area to circulate the current. All this contributes to the malfunction of the electric system and to the increase of loss.

IV. EVALUATION ANALYSIS

Two ballasts for two 40 W lamps and which use the power factor correction, identified as ballasts A and B , and a 26 W compact lamp, ballast C were submitted to the EMI tests at MagLab Laboratory of Electromagnetism and Electromagnetic Compatibility of the Electrical Engineering Department of the Federal University of Santa Catarina (EEL/UFSC). The configuration for the conducted and radiated disturbance tests is presented on figures 2 and 3 respectively. They followed the specifications of standards CISPR 16-1, CISPR 16-2 and CISPR 15. The characteristics of the three tested devices are shown in table 1.

The results of the disturbance voltage tests divided in the frequency ranges of 9 kHz to 150 kHz and 150 kHz to 30 MHz, for ballasts A, B and C, are shown on figures 4, 5, 6, 7, 8 and 9. It is possible to realize that the limits are exceeded, showing that neither reactors are according to CISPR 15. For reactors A and B, the figures present a comparison of the disturbance voltage for two different luminary, one of them metallic and grounded directly to the protection terminal of the power supply (reference luminary, according to CISPR 30), while the second luminary has a metal plate, under the 12 mm isolating material plate, and is grounded through the line impedance stabilization network (LISN), by an impedance of 50 Ω / 50 μH. It is evident that the first luminary contributes for the emission increase. For ballast C, the comparison is between a metallic grounded luminary and an isolated one without any kind of ground wire. It is necessary to say that according to the electrical safety rules grounding must be done in all metal case devices.

It is also possible to verify in those figures that the emission peaks happen in multiple frequencies of the ballast output frequencies, or the switching frequency of the inverter stage and there is a difference in that frequency due to the luminary used when testing reactor C.

Fig. 2. Configuration for disturbance voltage tests (MagLab/EEL/UFSC).

Fig. 3. Configuration for radiated disturbance tests (MagLab/EEL/UFSC).

TABELA I
Characteristics of the tested ballasts

Characteristics \ Ballast	A	B	C
Input voltage (V)	127/220	127/220	220
Output power (W)	76	73/71	26
Power factor	0,99	0,97	0,5
Output frequency @ 220 V and 60 Hz (kHz)	23	30	40

About the radiated disturbance tests, figures 10, 11 and 12 show the level of emitted noise by the three ballasts. The limits of CISPR 15 are also exceeded in all three tests, showing one more time that those ballasts are not in accordance with the EMC international standards. By comparing figure 10 with figures 4 and 5, figure 11 with figures 6 and 7 and figure 12 with figures 8 and 9, a huge similarity in the shape of the spectrum of the radiated noise and the conducted noise can be seen, what indicates a connection between the sources of those disturbances. The radiated emissions strongly depends on the currents that characterize the conducted emisions.

Considering that the conducted emissions strongly depend on the capacitive couplings in relation to the grounding plan, being characterized by the common mode currents, mainly for higher frequencies, it becomes evident that the use of metallic and ground wired luminaries allows the conducted emissions, as they increase the number of parasitic capacitances. And also the high frequency currents that characterize the conducted emissions start to circulate through the luminary structure itself, changing them into antennas and radiating most of the power that represents the radiated spectrum.

Ballasts A and B are both covered in metal, grounded directly to the luminary. Thus, another factor contributes to noise emission: the capacitive couplings between tracks and components terminals related to the grounding plan (represented by the luminary). Those couplings can reach tens of picofaradays. For the printed circuit board (PCB) of ballast B (without the components), the capacitance between the +Vcc track and the luminary, measured with the precision impedance analyzer Agilent 4294 A, is 20,5 pF @ 34 kHz (figure 13). There still is the capacitive coupling between the luminary and the lamps, what also happens with the compact lamp.

V. EMI SUPRESSORS APPLICATION

In order to evaluate those couplings, a few interventions in ballast A circuits were made. In first place, the commutation times were increased during the power factor correction stage, which is constituted of a BOOST converter operating in discontinuous conduction mode using a MOSFET as a switch. The BOOST converter operates in the frequency of 47,6 kHz. With a gate resistor (Rg) of the 10 Ω in the original circuit the 40 dB/dec attenuation occur above of 30 MHz. Increasing Rg to 100 Ω, the commutation time (or rise time - tr) proportionally increases and this attenuation occur in 3 MHz, without a significant increase in the commutation losses. Figure 14 contributes for this analysis, were it is possible to observe that the attenuations depend on the conduction time (tc) and the commutation time (tr), where the higher tc and tr are the attenuations will happen in lower frequencies.

During the second intervention, the grounding of the luminary was established by impedance series (140 μH), represented by an inductor that creates a high reactance for higher frequencies. That intervention provided a noise reduction above 2 MHz.

After that, two Y-capacitors (2,2 nF) were added to the circuit, between line and ground and neutral and ground, in the mains input. This way, the common mode current circulation were limited to the ballast internal circuits, as those capacitors create low impedance paths for high frequencies between the mains lines and the ground plan (luminary). Thus, the common mode circulation path is reduced, without reaching the power supply network and decreasing the radiation capacity of the luminary.

Finally, an X-capacitor (220 nF) was added between line and neutral in the mains input. The differential mode currents have now low impedance and circulate limited to the ballast internal circuits.

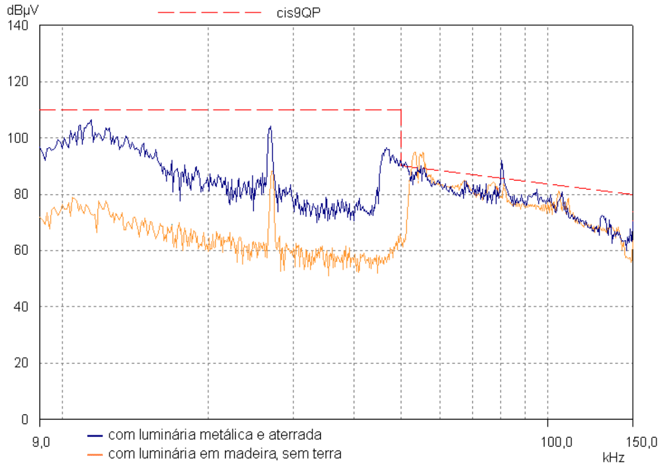

Fig. 4. Disturbance voltage (9 kHz to 150 kHz) – Ballast A.

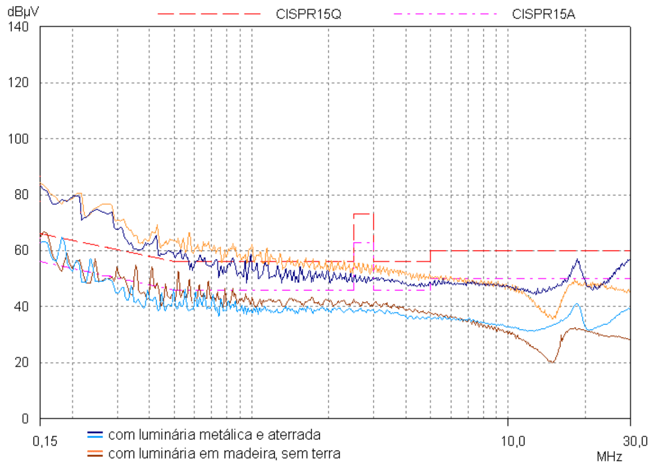

Fig. 5. Disturbance voltage (150 kHz to 30 MHz) – Ballast A.

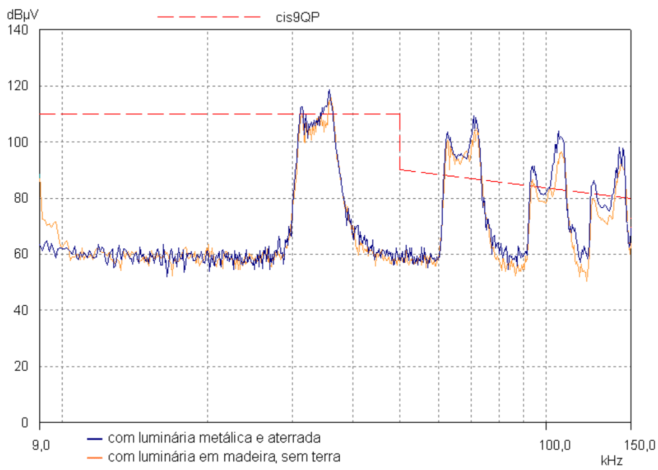

Fig. 6. Disturbance voltage (9 kHz to 150 kHz) – Ballast B.

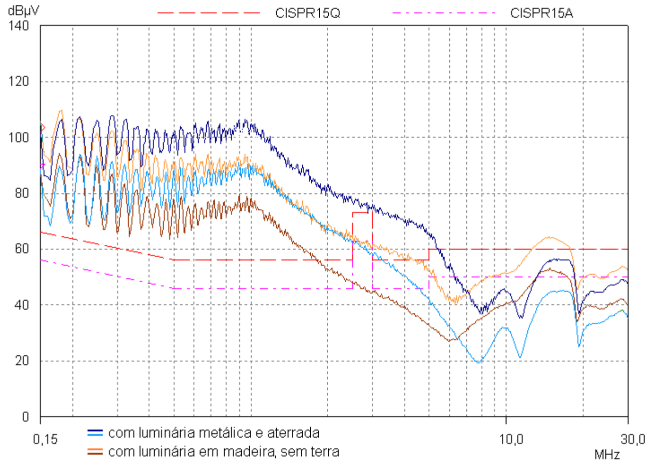

Fig. 7. Disturbance voltage (150 kHz to 30 MHz) – Ballast B.

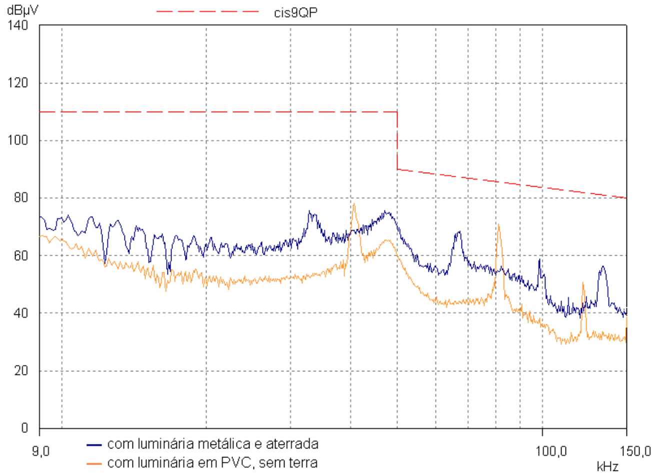

Fig. 8. Disturbance voltage (9 kHz to 150 kHz) – Ballast C.

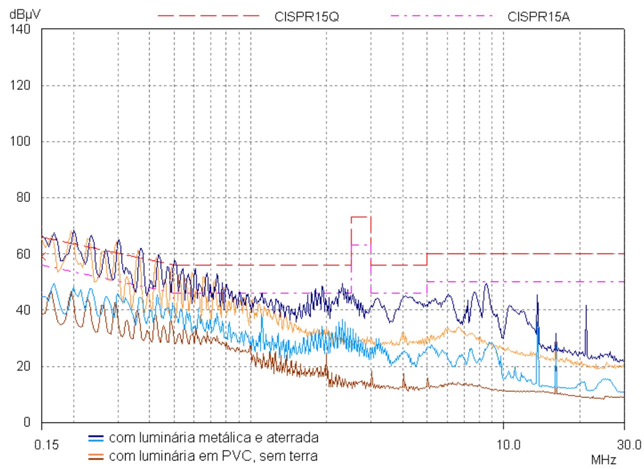

Fig. 9. Disturbance voltage (150 kHz to 30 MHz) – Ballast C.

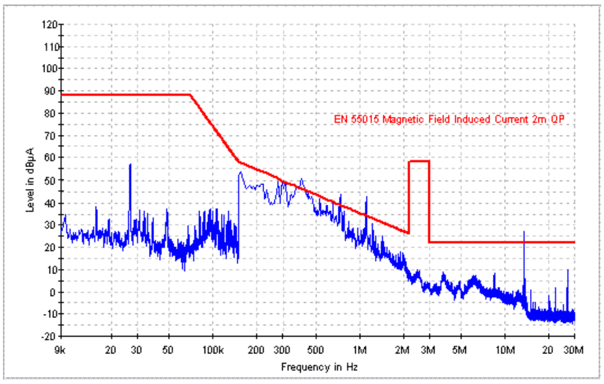

Fig. 10. Radiated disturbance (9 kHz to 30 MHz) – Ballast A.

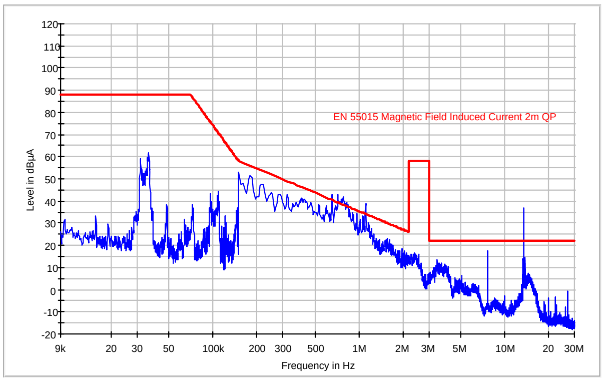

Fig. 11. Radiated disturbance (9 kHz to 30 MHz) – Ballast B.

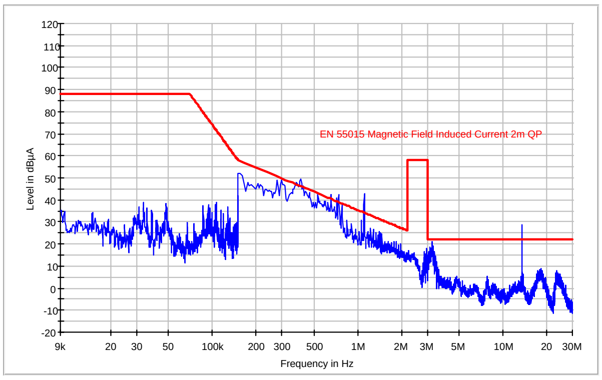

Fig. 12. Radiated disturbance (9 kHz to 30 MHz) – Ballast C.

The result of the intervention can be verified in figure 15, where the disturbance voltage between 150 kHz and 30 MHz for both original and modified circuits is presented.

Figure 16 shows the filters added to the circuit. The components are been selected to produce low or high reactances in specific frequencies.

VI. HARMONIC CURRENTS

The low frequency harmonics examination, between 120 Hz and 3 kHz was done in accordance to the criteria of rule IEC 61.000-3-2. Ballasts A and B showed active correction of the power factor, so they respected the regulations, being then the results omitted. However, the compact lamp (ballast C) presented high harmonics level, as it is possible to see in figure 17, causing a low power factor. This figure also presents the main voltage and the current demanded by the ballast. Those measurements were done with the help of a DPA 500 harmonics analyzer, an ACS 500 power supply and a ISMDPA control software, all produced by EM Test.

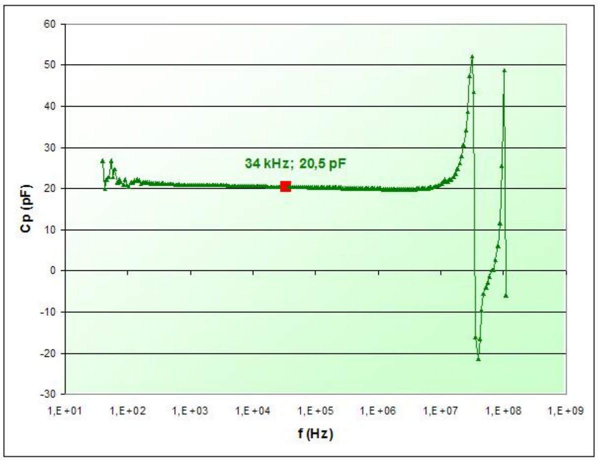

Fig. 13. Capacitance between -Vcc track and the luminary – Reactor B.

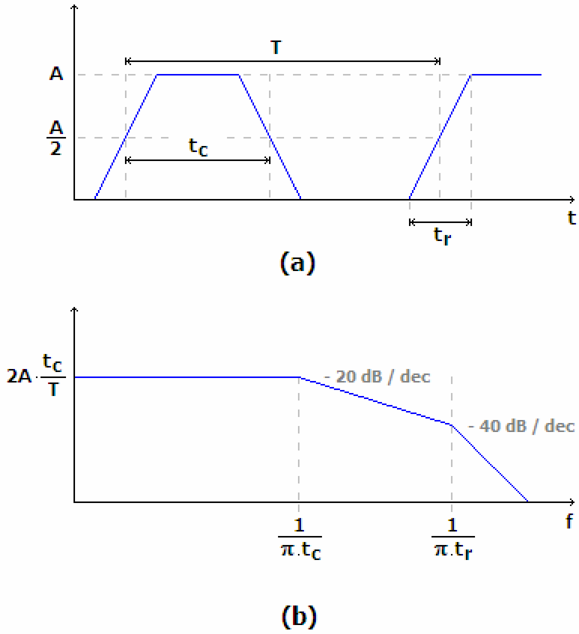

Fig. 14. Typical trigger command signal and its harmonic spectrum.

Nowadays (March 2007), the relative analysis of the effects of the PCB inductive couplings, added to the parasites capacitances related to the luminary and the non-ideality characteristics of the components are in development, where the PEEC (Partial Element Equivalent Circuit) method is used, in addition to the electronic simulation in order to determine the contribution of those EMI effects. The objective is also to develop the improvement of the PCB layout, minimizing the use of filters and allowing low cost EMC projects. The results will be revealed in future papers.

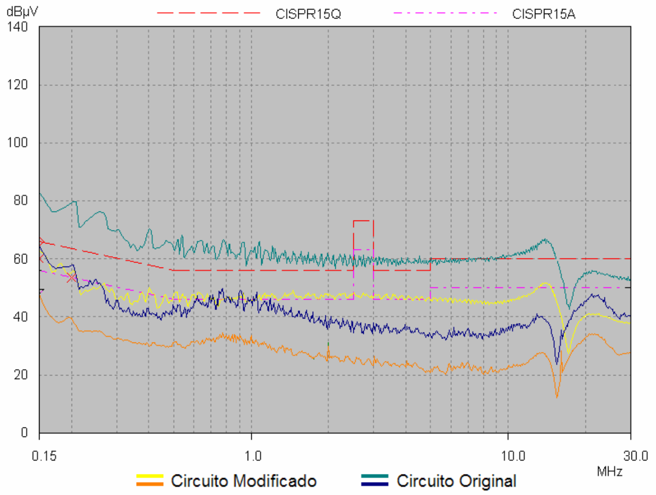

Fig. 15. EMI for original and modified circuits – Ballast A.

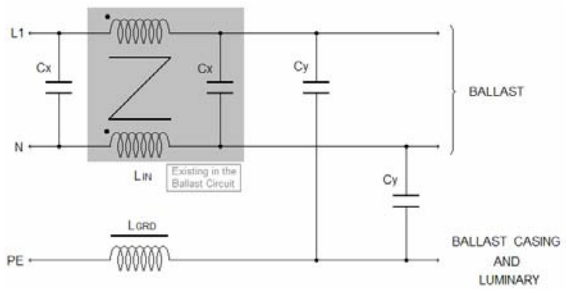

Fig. 16. Voltage and current harmonics – Ballast C.

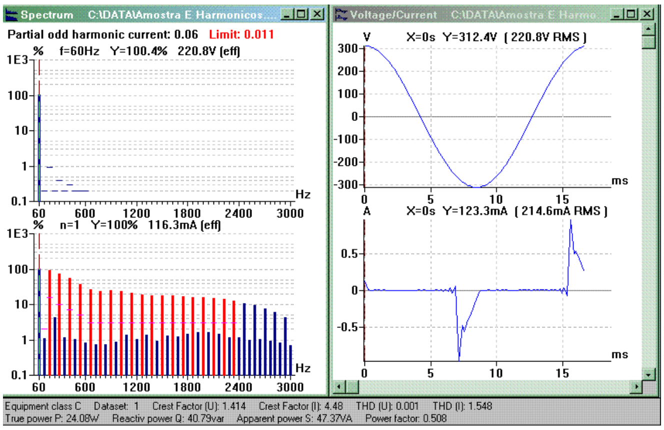

Fig. 17. Voltage and current harmonics – Ballast C.

VII. CONCLUSIONS

The valuation made through the tests and analyses indicates that even under low power conditions, as the compact 26 W lamp, the EMC problems are evident. The existing coupling between the PCB and the luminary and between the luminary and the lamps present serious EMC problems, in addition to the parasite effects of the circuit components and even stronger to its layout. Therefore, the design of devices like low power electronic ballasts those effects must be considered.

A simple adjustment of the transistors commutation time and the use of conventional filters cause improvement in the emitted noise levels. However, the development of a good layout, that besides the segregation of power and command stages, provide smaller capacitive and inductive couplings, allied to the usage of components with better characteristics (less parasite effect) may reduce the production and the propagation of electromagnetic noise, contributing for the reduction of radiated disturbance. Those actions minimize the use of filters and result in equipments in accordance with the regulations with lower cost. And considering a smaller amount of components by eliminating the necessity of filters, the result is lighter and smaller equipment with higher reliability.

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