Evaluation of Electromagnetic Compatibility of Compact Fluorescent Lamp (CFL)

Amevi Acakpovi
Department of Electrical/Electronic Engineering
Accra Technical University
Accra, Ghana
Email: acakpovia@gmail.com

Ade Ogunsola
Rail Systems and Technical Fellow
Parsons Corporation
United Kingdom
Email:ade.ogunsola@saudiparsons.com

Sohair Fakhry
EMC Laboratory Division
Polytechnique Metrology Center
Cairo, Egypt
Email: drsohairfakhry@gmail.com

Nana Yaw Asabere
Department of Computer Sciences
Accra Technical University
Accra, Ghana
Email: yawasabere2011@gmail.com

Haruna Mohammed
Department of Graduate Studies
Open University Malaysia
Accra, Ghana
Email: rasoolmohammed2003@yahoo.com

Kweku Arthur
Department of Telecommunications Engineering
Ghana Technology University College
Accra, Ghana
Email: jarthur@gtuc.edu.gh

***Abstract* – This paper presents an experimental evaluation of electromagnetic emission of CFLs. The importance of this study derives from the fact that CFLs have been globally adopted and used as an effort towards energy efficiency. The ubiquitous presence of CFLs in every home, calls for the investigation of their integrity with regard to EMC. The approach adopted in this paper was purely experimental. Tests were conducted in the Polytechnic Metrology Center (PMC) of Egypt, an internationally renowned laboratory for conducting EMC test. The tests were done in accordance with the specifications of relevant IEC and CISPR standards. Findings revealed that the tested CFLs passed most of the test including harmonic current emission, radiated electromagnetic disturbances, radiated emission electric field, voltage changes, fluctuation and flicker, voltage dips and short interruption, immunity to electromagnetic RF field 80 MHz-1 GHz and surge immunity. However, the conducted emission test within the range of 9 KHz – 30 MHz failed according to the CISPR 15 standard. This paper suggested the design of special EMI filters to mitigate the conducted emission problem.**

Index Terms* - *EMC, emission, electromagnetic disturbances, voltage fluctuation, flicker, CFL, immunity.

I. Introduction

Electromagnetic Compatibility (EMC) is the ability of an equipment or system to function satisfactorily without introducing intolerable electromagnetic disturbances to any other device or living being in the close environment [1].

Subsequently, EMC standards help to establish whether an electronic product is likely to affect or be affected by the operation of other electromagnetic devices operating in the same environment. It is important to note that electromagnetism effects are difficult to eliminate completely but can be considerably reduced with improved system design. It is therefore imperative to control the electromagnetic pollution caused by electronic devices to ensure safety of apparatus and reduce health risks. With EMC standards, it may be possible for different electronic devices to function reliably in the same environment. There are enormous sources of electromagnetic emissions that may be encountered in power supplies, electronic devices, lighting and their accessories, motor, arc welding devices to mention few. Also, a number of potential electromagnetic emission receptors including the same electronic circuits and devices, radio receivers, human body and many more.

The Increasing usage of electrical and electronic devices in our everyday activities has contributed significantly to the increase in the emission of Electromagnetic Interference (EMI). Electromagnetic interference is unwanted electromagnetic energy polluting the environment. The electromagnetic environment forms integral part of the world in which we live. As explained in the previous paragraph, EMI is present almost everywhere and may be caused by natural sources or derived from man-made activities. Lightning, Sun Radiation, Atomic particles, Astronomical effects constitute natural sources of EMI while Radio, TV, Telephone Transmissions, X-Ray can be classified as man-made. Moreover, the existence of conditions such as non-linear load, unintentional load switching, arcing, power distribution, vehicle ignition and Switch-Mode Power Supplies significantly contribute to the generation of EMI.

The necessity of considering EMC for home appliances is therefore important and inevitable. Microwave, CFL, remote control with laser light or infrared and many other appliances create a weighting electromagnetic field in which we navigate to do perform our activities. Particularly, CFLs have become so popular in Ghana especially after being promoted by the government of Ghana in 2007 as reliable energy saving lamps.

The government of Ghana launched a campaign in August 2007 to distribute energy-saving Compact Fluorescent Light (CFLs) bulbs. This was a power usage efficiency policy intervention measure employed to lower electricity demand, scale up peak electricity savings and other benefits such as carbon dioxide

(CO_2) savings and investment delay in electricity generation expansion (Energy commission of Ghana report).

It is well established that the higher usage of CFLs for residential and industrial lighting offer a significant increase in energy efficiency compared with conventional incandescent lamps. By controlling the lighting in such a way that the energy consumption due to lighting is minimized [2]. The usage of CFL has been recognized as the fastest way to reduce electricity demand, reduce coal or fossil fuel use for thermal electric power generation, and reduce the environmental impact of global warming [3]. Globally, the use of inefficient incandescent light bulbs is gradually phasing out in an effort to reduce greenhouse emissions [4]–[7].

Despite these numerous gains of CFLs lamps as mentioned above, the major issues with regards to the environment were mercury emissions, disposal of CFLs and radiation of electromagnetic waves. These waves can cause interference in various electronic devices. The common mode current which is principally responsible for interference emission generates conducted radiations transmitted in the mains power supply as specified in the [8], [9]. The incandescent lamps radiate mostly infrared radiation at any temperature that they can withstand [10]. The CFL lamps should be designed such that its electromagnetic wave interference is minimized. An electronic device such as the CFL lamp is said to be electromagnetically compatible with its environment if it is able to function compatibly with other electronic systems and not produce or be susceptible to interference. The CFL bulbs generates EM wave in a form of a radio wave frequencies. Significant portion of these frequencies may radiate directly from the bulbs and its electronic ballast and be conducted into the electrical wiring in the homes and offices causing poor power quality. The intensity of the radiation decreases naturally with distance.

This paper investigates the electromagnetic compatibility of CFLs tested experimentally in the Polytechnique Metrology Center (EMC) of Cairo in Egypt. The assessment considered all the necessary EMC test and requirements described in available IEC, EN and CIPR international standards.

The rest of the paper is organised as follow: section two presents the background and key terms used in EMC, section three present a brief perspective on the various test conducted with their requirements. This section is followed by the presentation of result and analysis in section four. Finally, section five presents the discussion and section six, the conclusion

II. BACKGROUND ON EMC AND KEY TERMS

This section covers specific terms and provide description of concepts that are applicable to electromagnetic theory and its practical use in electronics.

- Emission: is the emanation of electromagnetic energy from a given source [11]
- Electromagnetic Disturbance (EMD): is any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter. An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself [12].
- [12] divides existing equipment into two groups: Group 1 and Group 2. Furthermore, each group is subdivided into two classes: Class A and Class B.
- Group 1: this group deal with devices that work with conductively coupled radio frequency energy for their internal operation. It also covers all equipment for which there is intentional generation of electromagnetic waves [12].
- Group 2: covers any industrial, scientific and medical (ISM) equipment in which radio-frequency energy is intentionally generated and/or used in the form of electromagnetic radiation for the treatment of material, and EDM and arc welding equipment. Excluded from the testing requirements and limits of [12] are components and subassemblies not intended to perform any stand-alone ISM function.
- Class A: is equipment suitable for use in all establishments other than domestic and those directly connected to a low voltage power supply network which supplies buildings used for domestic purposes.
- Class B: is equipment suitable for use in domestic establishments and in establishments directly connected to a low voltage power supply network which supplies buildings used for domestic purposes.
- Electromagnetic Waves: Movement and acceleration of an electron in atom caused by electric field creates electromagnetic radiation. Electromagnetic wave contains of an electric field (V/m) and a magnetic field (A/m) which are placed in two different directions with 90-degree angle beside each other.
- Electromagnetic Interference (EMI): is the degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance (EMD) [11].
- EMI Sink: can be defined as those devices characterised by negligible emission levels and whose operation may be affected by external electromagnetic disturbance. Consequently, EMC issues of such devices consist mainly of their immunity and susceptibility because conducted and radiated emissions can be safely ignored.
- Electromagnetic Compatibility (EMC): The ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbance to anything in that environment. Electromagnetic compatibility ensures equipment, device or more generally any electrical or electronic system functions satisfactorily in the presence of electromagnetic waves induced or generated by similar devices or natural causes in its

vicinity. EMC also requires the device to properly work without introducing or generating unacceptable electromagnetic disturbance to other equipment in the environment.

- Electromagnetic disturbance is an ambiguous term but typically any degradation on the normal performance of a system that is resulted from electromagnetic waves is recognized as electromagnetic disturbance. Obviously, it will be nearly impossible to shield a device from any undesirable electromagnetic field. Therefore, any device should be tolerant to a level of disturbance. In other words, electronic devices are expected to demonstrate "immunity" and correctly operate even when some level of disturbance exists. Specific details on the level of tolerance and compatibility have attracted much attention and numerous protocols and standards have been defined to regulate such details about EMC.

III. EMC TESTS: EXPERIMENTAL APPROACH

The test listed in table 1 below were conducted to establish the EMC of the CFLS in line with the relevant standards

TABLE I. VARIOUS TEST CONDUCTED WITH RELEVANT STANDARDS

No.	Test Name	Standard Used
1	Harmonic current emission	IEC 61000-3-2, [13]
2	Radiated Electromagnetic Disturbances (Frequency Range 9 KHz to 30 MHz)	CISPR 15, [14]
3	Conducted emission 9 KHz – 30 MHz (Voltage disturbances)	CISPR 15, [14]
4	Radiated emission electric field, 30 MHz – 300 MHz	CISPR 15, [14]
5	Voltage changes , fluctuation and flicker	IEC 61000-3-3, [15]
6	Voltage dips and short interruption	EN 61000-4-11 IEC 61547, [16], [17]
7	Immunity to electromagnetic RF fields 80 MHz – 1 GHz	IEC 61547 IEC 61000-4-20, [17], [18]
8	Fast Transient Burst Test	IEC 61000-4-4 IEC 61547, [17], [19]
9	Immunity to Electrostatic Discharges	IEC 61000-4-2, IEC 61547,[17], [20]
10	Surge Immunity Test	IEC 61000-4-5, IEC 61547 [17], [21]

In addition, the specifications of the lamp used are listed in Table 2 as follow. Figure 1 illustrates the lamp used for the test.

TABLE II. TESTED LAMP SPECIFICATIONS

Power	20 (W)
Reference Voltage	220 (W)
Rated Frequency	50 (Hz)

Figure 1. Tested Lamp

The following sections provide a brief description of experimental method used for each test conducted

i.Harmonic current emission (IEC 61000-3-2)

This test was conducted according to IEC 61000-3-2. The measurement of the harmonic current is done according to Figure 2, where a spectrum analyser is used.

Figure 2. Harmonic current analysis

ii. Radiated Electromagnetic Disturbances, Frequency Range 9 KHz to 30 MHz (CISPR 15)

The test has been carried out according to CISPR 15. The quasi-peak limits of the magnetic components of radiated disturbance field strength in the frequency range of 9 KHz to 30 MHz measured as a current in loop antenna. The lighting equipment has been placed in the centre of the antenna as shown in Figure 3.

Figure 3. Lamp under test

A current probe (1 V/A) is used to measure the current induced in the loop antenna in accordance with CISPR15. The same method was applied by means of a coaxial switch to measure the current in the three field directions:

iii. Conducted emission 9 KHz – 30 MHz, Voltage disturbances (CISPR 15)

iv. Radiated emission electric field, 30 MHz – 300 MHz This test is carried out based on the specifics of CISPR 15. The experimental setup is presented in Figure 4 below

Figure 4. Conducted emission test

v. Radiated emission electric field, 30 MHz – 300 MHz (IEC 61000-3-3)

The test has been done based on CISPR15. The expanded uncertainty factor was set to K =2 which is equivalent to 4.43 dB. Measurement were taken in x, y and z directions as recommended by the standard. The setup for measurement in each of the positions is illustrated as follow in Figure 5,6 and 7.

Figure 5. Measurement in X position

Figure 6. Measurement in Y position

Figure 7. Measurement in Z position

vi. Voltage changes, fluctuation and flicker was carried out according to EN 61000-3-3

vii. Voltage dips and short interruption was also carried out according to EN 61000-4-11, IEC 61547.

viii. Immunity to electromagnetic RF fields 80 MHz – 1 GHz was carried in accordance with EN 61000-4-20, IEC 61547

ix. Fast Transient Burst Test was carried in accordance with EN 61000-4-4, IEC 61547)

x. Immunity to Electrostatic Discharges was carried according to EN 61000-4-2, IEC 61547

xi. Surge Immunity Test was also carried according to EN 61000-4-5, IEC 61547.

IV. RESULTS

This section presents the results obtained per each test in Table 3 followed by specific graph for various tests.

TABLE III. RESULT OBTAINED FOR EACH TEST

No.	Test Name	Standard Used	Result
1	Harmonic current emission	IEC 61000 – 3 – 2	Pass
2	Radiated Electromagnetic Disturbances (Frequency Range 9 KHz to 30 MHz)	CISPR 15	Pass
3	Conducted emission 9 KHz – 30 MHz (Voltage disturbances)	CISPR 15	**Fail**
4	Radiated emission electric field, 30 MHz – 300 MHz	CISPR 15	Pass
5	Voltage changes , fluctuation and flicker	IEC 61000 – 3 – 3	Pass
6	Voltage dips and short interruption	EN 61000 – 4 – 11 IEC 61547	Pass
7	Immunity to electromagnetic RF fields 80 MHz – 1 GHz	IEC 61547 IEC 61000 – 4 – 20	Pass
8	Fast Transient Burst Test	IEC 61000 – 4 – 4 IEC 61547	Pass
9	Immunity to Electrostatic Discharges	IEC 61000 – 4 – 2 IEC 61547	Pass
10	Surge Immunity Test	IEC 61000 – 4 – 5 IEC 61547	Pass

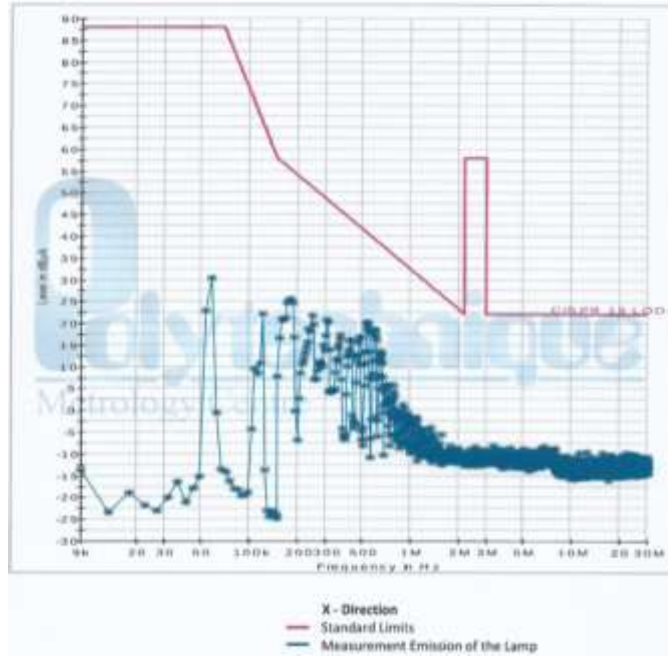

Figure 8. Radiated Electromagnetic Disturbances (frequency Range 9 KHz – 30 MHz) – X direction

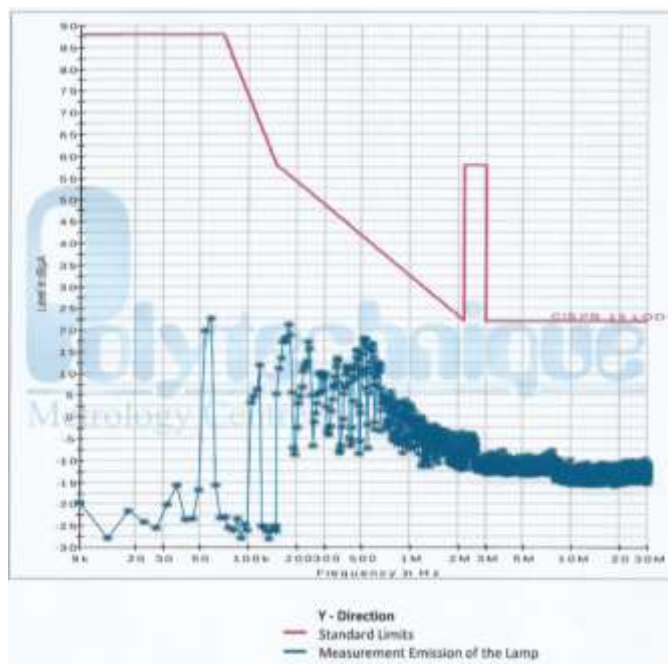

Figure 9. Radiated Electromagnetic Disturbances (frequency Range 9 KHz – 30 MHz) – Y direction

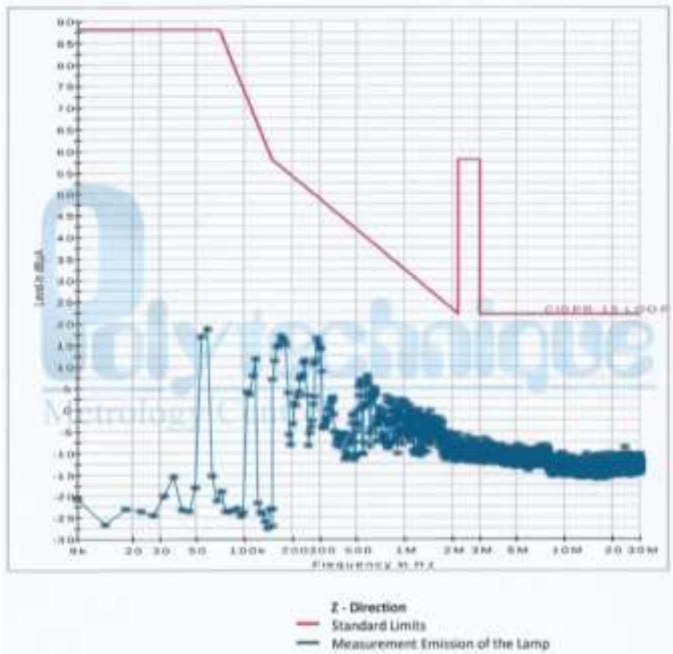

Figure 10. Radiated Electromagnetic Disturbances (frequency Range 9 KHz – 30 MHz) – Z direction

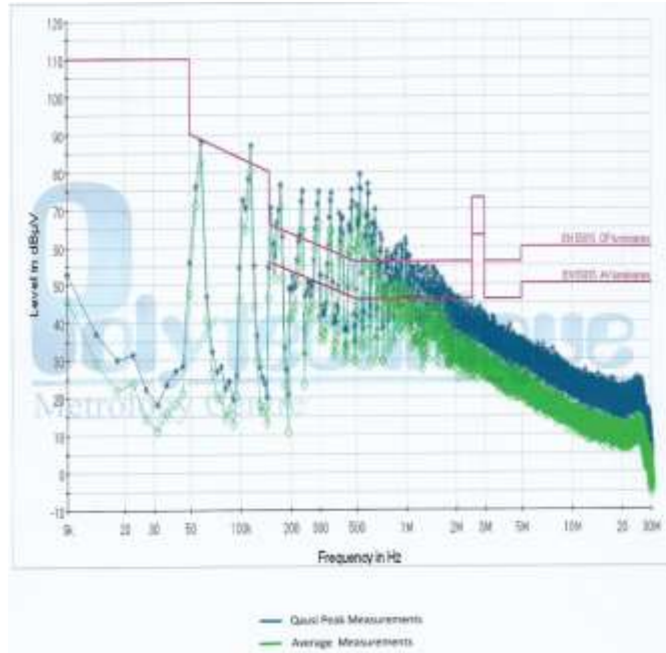

Figure 11. Conducted Emission AC Power Line N

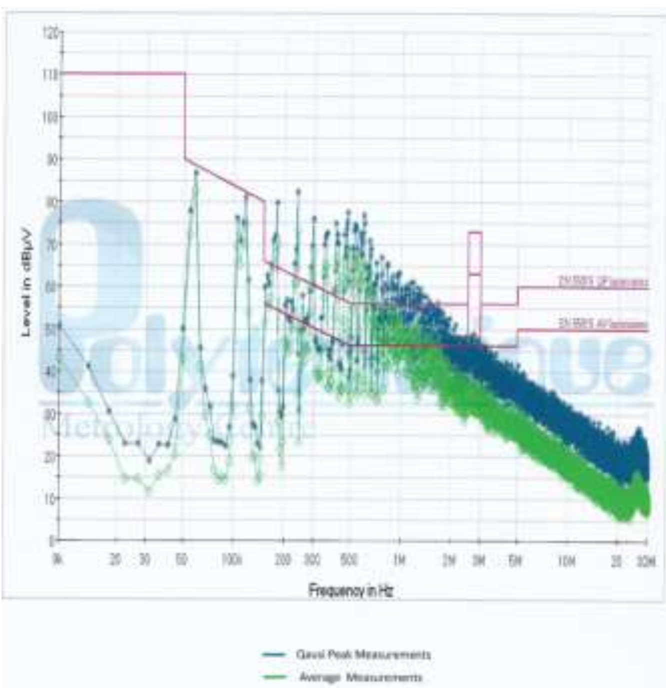

Figure 12. Conducted Emission AC Power Line L1

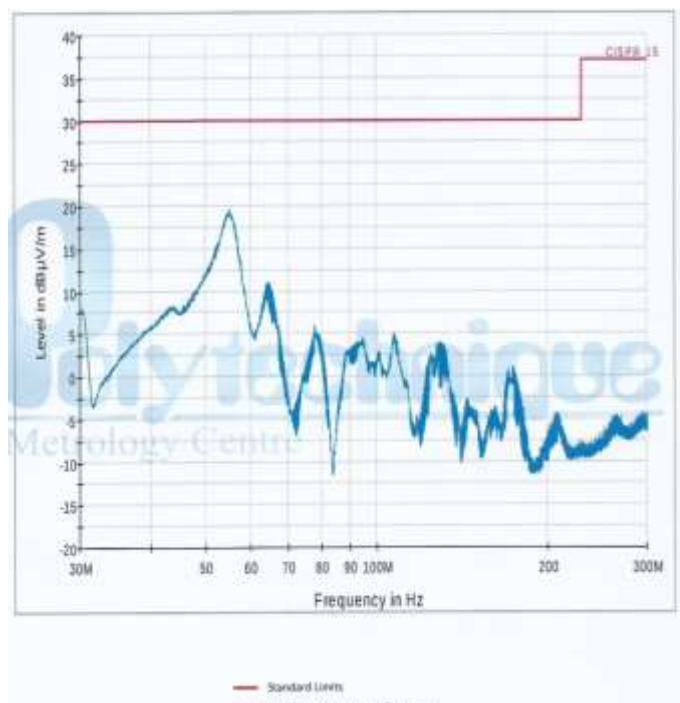

Figure 13. Radiated emission electric field 30 MHz – 300 MHz

V. Discussion

From the experiment, it was clearly demonstrated that the CFL bulbs passed almost all the CISRP and IEC standards except CISRP 15 for Conducted emission 9 KHz – 30 MHz. Figure 9, 10 show the experimental graphical results of the conducted emission within the 9 KHz – 30 MHz frequency band that failed the test. The CFL lamp basically composes of the ballast, the lamp, the electrodes wire and the power supply terminals. These components generate electromagnetic wave in different ways that can be a source of EMI in its operating environment to other devices. The electronic ballasts operate at a frequency range of 20–60 KHz [22]. The power cables that connects the ballast to the mains power supply can conduct current from these frequencies into the mains power network. In reference to the Standard CISRP 15 F/399/CDV, the common mode current generates conducted radiations which are principally responsible for the disturbance emission transmitted in the mains power supply network [23].

Harmonics current such as the third harmonics (3 x 50 Hz or 3 x 60 Hz etc.) are predominantly generated by the common mode current. These results in the generation of interference within the wide range of frequencies (0 to 100 kHz or even 5 MHz). The interferences generated by the low-frequency band are observed in conducted form. The operation of the CFL electronic ballast involve arcing that changes regularly from On to Off. It is worth noting that CFL ballast can operate at high frequencies up to 50 kHz to eliminate flickers. The operation frequencies are far higher than the supply frequency; this sudden change in frequency which is achieved by non-linear devices is an evidence of the generation of EMI [24].

This results in the generation of high electromagnetic emissions. These radiated or conducted high emissions may lead to signal interference and may also be dangerous to human exposure. It is quite possible that the conducted emission (voltage disturbances) was due to small changes in the voltages as a result of flickering effects. The electronic ballast integrated into the bulb's is also designed to control the current running to the lamp. This allows the lamp to receive sufficient voltage to start up, while lowering the voltage to ensure that the lamp does not extremely overheat and burn out. In other words, when the lamp is switched on, the ballast delivers a quick surge of high voltage power to start the arc between the lamp's electrodes. Subsequently, the voltage reduces at a steady rate to keep the lamp glowing. The current flow in the CFL electronic ballast is not a pure sinusoidal wave. Previous studies including [24], [25] dealt with the nonlinear noise sources from electronic circuits.

A perfect EMI reduction of the CFL can be achieved by using different techniques. Commonly used techniques are passive and active filters. Thus, the electromagnetic interference generated by the electronic ballast of the CFL can be drastically decreased by factoring into the design an EMI filter in the main power supplies to the electronic ballast circuit. Flyback Cuk and SEPIC are well suited for allow high-frequency insulation1

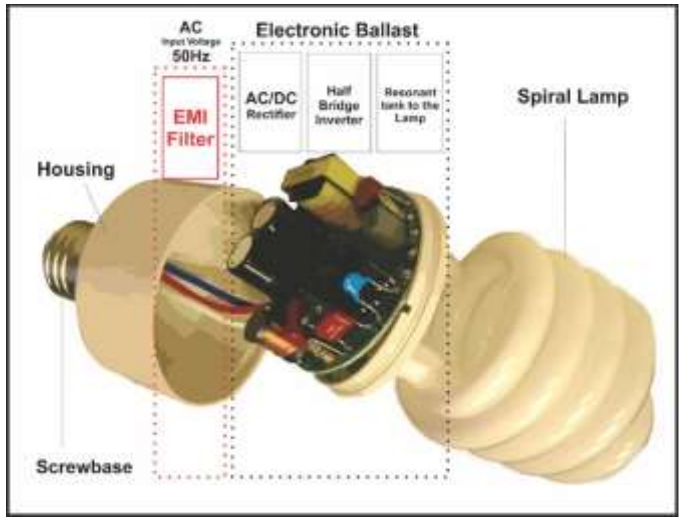

Figure 14. Passive Filter

The main power supply wires within the ballast are configured in a straight mode as indicated in Figure 13. They can be configured in twisted mode to reduce susceptibility to induced currents. Since magnetic field alternates, the induced current reverses direction, resulting in the creation of alternating current. If the wires are configured in a twisted mode, the induced current in the adjacent loops will cancel one another. As the magnetic field alternates, the induced current in each loop reverses direction and cancels each other.

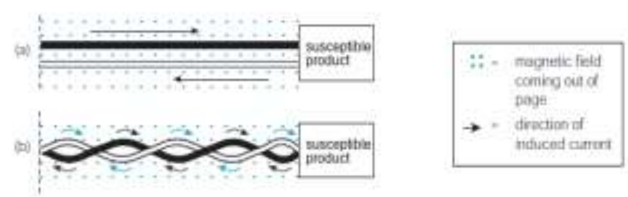

Figure 1. Twisted lines

An isolated transformer can also be applied to help filter the conducted emission. Remember that within the transformer, the law of induction dictates that transformation takes place without any electrical connection between the input and output. The benefit of the isolation transformer is that it filters out electrical spikes on the input, thereby providing better power quality on the output. The reverse of the principle of operation of the isolated transformer is applicable when incorporated into the design of the CFL bulbs to filter the conducted emission generated by the electronic ballast.

VI. Conclusion

In summary, this paper dealt with the experimental analysis of the compatibility of CFL. The CFL were tested according to relevant standard with sizeable samples defined in the standard.

It came out that the CFL passed all the test at the exception of the Conducted Emission test within the range of 9 KHz to 15 MHz. The CFL EMI level can be drastically reduced with the integration of special filters in the electronic ballast components. Additionally, reconfiguring the wiring layout in a twisted mode and shielding wires can help minimize the effect of EMI.

References

[1] IEC 61000-2-2 AMD2, *Electromagnetic compatibility (EMC) - Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*. 2018.

[2] L. Martirano, “Lighting systems to save energy in educational classrooms,” in *2011 10th International Conference on Environment and Electrical Engineering*, 2011, pp. 1–5.

[3] D. Rawat and P. Sauni, “Importance and Prospects of Renewable Energy: Emerging Issues in India,” *Int. J. Art Humanit. Sci.*, 2015.

[4] J. Edge and H. Mckeen-edwards, “Light Bulbs and Bright Ideas ?: The Global Diffusion of a Ban on Incandescent Light Bulbs,” in *80th Annual Conference of the Canadian Political Science Association*, 2008.

[5] J. D. Cabrera Santelices, J.-L. Bertholet, and B. M. Lachal, “Evaluation of an energy efficiency program for low-income households,” in *International Energy Policies & Programmes Evaluation Conference*, 2014.

[6] R. F. Karlicek, “Smart Lighting – More Than Illumination,” 2018.

[7] N. A. Itabor, L. E. Damisah, J. O. Olatunji, T. O. Eyakwanor, O. O. Akingba, and R. O. Orerome, “Energy Efficiency in Building : Case of Post Graduate Hostels at the University of Benin, Nigeria,” *Phys. Sci. Res. Int.*, 2015.

[8] R. ISTOK, “Relation Between Disturbance Radiation of CFL and Resonant Frequency of Power Supply Cable,” *Adv. Electr. Comput. Eng.*, 2009.

[9] IEC-CISPR/CIS/D, *Electromagnetic disturbances related to electric/electronic equipment on vehicles and internal combustion engine powered devices*. 2016.

[10] D. L. Klipstein, *The Great Internet Light Bulb Book, Part I*. .

[11] IEC 60050, *International Electrotechnical Vocabulary - Details for IEV number 161-01-08: "(electromagnetic) emission"* 1990.

[12] CISPR 11 AMD2, *Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement*. 2019.

[13] IEC 61000-3-2, *Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)*. 2018.

[14] CISPR 15, *Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment*. 2018.

[15] IEC 61000-3-3 AMD1, *Electromagnetic compatibility (EMC) - Part 3-3: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection*. 2017.

[16] IEC 61000-4-11, *Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests*. 2017.

[17] IEC 61547, *Equipment for general lighting purposes - EMC immunity requirements*. 2009.

[18] IEC 61000-4-20, *Electromagnetic compatibility (EMC) - Part 4-20: Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides*. 2010.

[19] IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*. 2012.

[20] IEC 61000-4-2, *Electromagnetic compatibility (EMC) - Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test*. 2008.

[21] IEC 61000-4-5, *Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test*. 2017.

[22] H. C. Yen, Z. J. Huang, and K. H. Lee, “Fluorescent Lamp Model for High-Frequency Electronic Ballasts,” 2006.

[23] W. Sulisz and M. Paprota, “Modeling of the propagation and evolution of nonlinear waves in a wave train,” *Arch. Mech.*, 2011.

[24] J. Cunill-Sol??, J. J. Mesas, and L. Sainz, “Low-watt compact fluorescent lamps with electronic ballasts,” in *International Conference on Power Engineering, Energy and Electrical Drives*, 2011.

[25] S. K. Das and S. N. Das, “Modeling of Coupled Roll and Yaw Damping of a Floating Body in Waves,” *Math. Probl. Eng.*, 2007.