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Spectral Analysis of Conducted Emission Characteristics of LED Lightings with Dimmable Driver for Passenger Train

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Dimmable driver system of LED train lightings can provide a higher level of comfortable to the passengers because the level of illumination can be adjusted. However, dimmable LED driver can generate high conducted emission (CE) noise through mains terminal that can interrupt the performance of electronic devices connected to the same mains network. This paper investigates frequency spectral properties of conducted emission of LED train lightings with dimmable driver. Correlations between level of illumination, power consumption, and conducted emission spectrum are analyzed and presented.

Keywords: c*onducted emission, illumination, LED, spectrum, dimmer*

1. Introduction

Nowadays, LED (Light Emitting Diode) lightings are widely used in the various sectors. LED lightings have many advantages, such as more homogeneous in radiance spread, clearer in illumination and more efficient. LED lightings have approximately 50% energy saving because no filament used and only few electrics power converted to heat energy[1]. LED lightings also have longer lifetime compared to fluorescent lamps with filament. In recent years, LED lightings utilization is increasing significantly in the transportation sectors especially on passenger trains. Despite of having many advantages, LED lightings also generate unwanted electromagnetic noise. Electromagnetic noise is originated from the high frequency switching of LED driver systems. Therefore, Electromagnetic Compatibility (EMC) test become important for the reliability of LED improvement[2].

The function of dimming system is to adjust light intensity and to reduce energy consumed by LED lightings[3]. Electromagnetic emission on LED lightings propagate through mains network, so this noise will disturb other nearby electronic equipments. Most of LED lightings have to comply with standard regulation such as in FCC CFR 47 section 15 and CISPR 15 standard[4]. One of EMC requirements is CE test.

There are several researches were carried out related to conducted emission of electromagnetic waves on LED lightings. The conducted measurement refers to CISPR 15 standard[5,6,7]. The measurement result is compared with the standard and is found that exceedingly high level of CE noise is caused by high frequency switching of LED driver.

The simplest method to drive LEDs is by connecting them in series with a current limiting resistor. This passive method requires the lowest cost and is free from harmonic distortion and electromagnetic interference. While it is widely used in very low power applications, it is deemed unattractive in higher power applications because a lot of energy is wasted in the resistor. Another passive current limiting method that is more efficient and also EMI-free can be achieved by using inductors[8]. However it has a drawback that the inductor is bulky since it is operating in low frequency (50/60 Hz).

Modern LED drivers nowadays employ high frequency (50 kHz – 1 MHz)[9] switching method, which offers high efficiency, smaller size, and dimming feature. There have been proposed numerous switched-mode LED driver topologies, such as buck-boost, SEPIC, fly-back, and many other variations and combinations of them. They can be classified into three categories, i.e. one stage, two stage, and three stage converters. One stage converters provide the main function of output current regulation, while the two stage converters add power factor correction (PFC) features. Three stage converters, which are based on the two stage converters, further add even current sharing and dimming features in multi LED strings applications. Each design has its own advantages and disadvantages in terms of cost, size, lifetime, safety, energy efficiency, power handling, output stability, total harmonic distortion, as well as electromagnetic interference (EMI).

On LED lightings with dimming system, the rate of power consumption will be different depending on light intensity emitted by the LED lamp. In this case, the amount of electromagnetic noise generated is also likely to be different. Based on description above, it is necessary to conduct research about the characteristic of electromagnetic noise from conducted emission on LED lightings with dimming system. This paper aims to present a conducted emission spectrum characteristic of LED lightings with various dimming configurations. In this study, measurement of CE were conducted and presented in the frequency range from 9 kHz up to 30 MHz referring to CISPR 15:2013 standard.

2. Experimental Details

In this paper, the LED lamp sample is a passenger train LED lighting that use 36W constant current type driver. The measured variables are illumination level (lux), power consumption (watt) and conducted emission spectrum. The light intensities were measured at 160 cm from the surface of lamp perpendicular to the position of LED lamp. Conducted emission measurement was performed with illumination level variations of 268 lux, 303 lux, and 334 lux. Illumination levels from LED were measured by RS 180-7133 light meter. Power (watt) data that were displayed on GW Instek APS 1120a regulated power supplies also were recorded at the beginning of each CE test. Based on CISPR 15:2013 LED lightings for the interior lighting of ships and passenger rail vehicles are considered as indoor lighting equipment and the relevant clause 5.2 is applied. Spectrum of CE signal was measured at the mains terminals of the LED lamp. Based on CISPR 15:2013, the LISN (Line Impedance Stabilization Network) and the LED lamp were positioned 0.8 m ± 20% apart and were connected by the bundled two-wire power cables of 0.8 m long.

Table 1. CE Limits at Mains Terminals

Frequency Range	**Limits dB (μV)**[a]	
	Quasi-peak	**Average**
9 kHz to 50 kHz	110	-
50 kHz to 150 kHz	90 to 80[b]	-
150 kHz to 0.5 MHz	66 to 56[b]	56 to 46[b]
0.5 MHz to 5.0 MHz	56	46
5 MHz to 30 MHz	60	50

a. At the transition frequency, the lower limit applies.
b. The limit decreases linearly with the algorithm of frequency in the ranges 50 kHz to 150 kHz and 150 kHz to 0.5 MHz.
c. For electrodeless lamp and luminaries, the limit in the frequency range of 2.51 MHz to 3.0 MHz is 73 dB(μV) quasi-peak and 63 dB(μV) average.

The CE spectrum was measured by Advantest U3741 spectrum analyzer. Then the quasi-peak data were measured using Teseq SCR 3501 EMI receiver. Measurement arrangement layout is described in Figure 1. This measurement result is then compared against the standard limit. The limit of the mains terminal disturbance voltage or CE for frequency range 9 kHz to 30 MHz are given in Table 1.

3. Result and Discussion

Frequency spectral resulted from CE test are shown in Figure 2. The red line in the Figure 2 and 3 is the limit of Quasi Peak level and the pink line in the Figure 2 is the limit of average level. Conducted emission spectrum at frequencies 9 kHz up to 30 MHz shows that there is no signal which has CE disturbance level above the standard limit and it means this tested LED lamp complied with CE clause of EMC standard. At the frequencies from 150 kHz up to 1 MHz, it is shown a figure of switching effect caused by the LED driver. Figure 3 and Table 2 describe the phenomena specifically at frequencies from 0.0664 MHz up to 0.0953 MHz.

By comparing the signal with different illumination level at Figure 3 and Table 2, we find at frequency 0.0664 MHz the level of CE disturbance voltage rises up from 39.9 dB(μV) up to 46.8 dB(μV) as effects of increasing in illumination level from 268 lux up to 334 lux. From the spectrums we can also find by increasing the illumination level from 268 lux up to 334 lux caused one of the peak frequencies shifted from 0.0953 MHz to 0.0833 MHz and their quasi-peak level of CE disturbance voltage also increase from 54.8 dB(μV) up to 57.8 dB(μV).

Table 2. Power consumption, frequency and disturbance voltage level of the LED lamp with dimmable driver, measured at line-to-ground coupling

Illumination level lux	Power Watt	Frequency MHz	Level QP dB (μV)	Level Peak dB (μV)
1st peak (at frequency 0.0664 MHz)				
268	22	0.0664	39.9	50.4
303	25	0.0664	42.9	56.6
334	29	0.0664	46.8	58.5
2nd peak (shifted frequency)				
268	22	0.0953	54.8	63.2
303	25	0.0851	55.4	65.1
334	29	0.0833	57.9	69.4

Increasing level of CE caused by rising of illumination level can be explained by the fact that CE disturbance level is proportional to power consumption. The LED power consumption measured at the mains input as shown in Table 2 was indirect indication of DC current consumption at the LED chips. Since the driver used in this sample LED lamp is constant current driver type, the level of DC current changes along with the set point adjusted by dimming control. The DC current was proportional to the switching current in the driver. Higher switching current caused higher common mode noise source that coupled to the ground system, and it was shown as CE spectrum. In terms of switching frequency, switched-mode drivers can be categorized in two major classes, i.e. fixed frequency and variable frequency[10]. In the fixed frequency method, output current regulation is done by varying the duty cycle, which is the switching ON state duration in each cycle. On the other hand, the variable frequency method regulates the output current by keeping the ON state duration constant but changing the repetition rate, and thus varying the switching frequency. In this measurement, frequency shift occurrence is possibly caused by the variation of the switching frequency of the LED driver.

4. Conclusion

Due to the nature of high frequency switching, switched-mode drivers inherently generate electromagnetic emissions that need to be paid attention of in the design phase so that they can comply with the relevant EMC standards. The LED lamp with dimmable system driver provides different CE spectrum profile when illumination levels increase/decrease. Increasing illumination level will increase the CE disturbance voltage at one or more frequency.

Acknowledgments

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Figure captions

Figure 1. Schematic arrangement of Conducted Emission test
Figure 2. Conducted emission frequency spectrum 0.009 MHz up to 30 MHz
Figure 3. Comparison conducted emission spectrum at when LED set to 268 lux, 303 lux and 334 lux

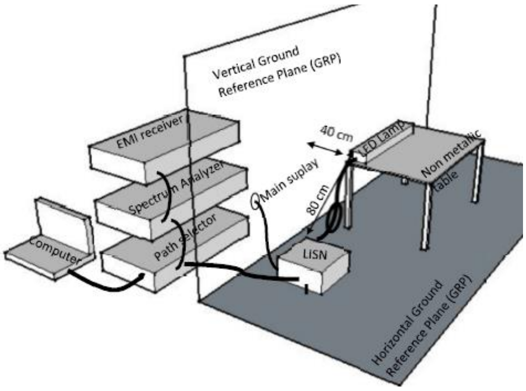

Figure 1. Sudrajat et al.

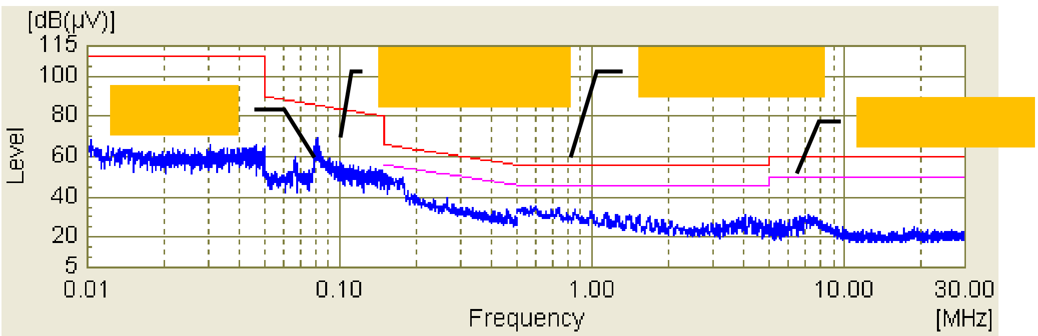

Figure 2. Sudrajat et al.

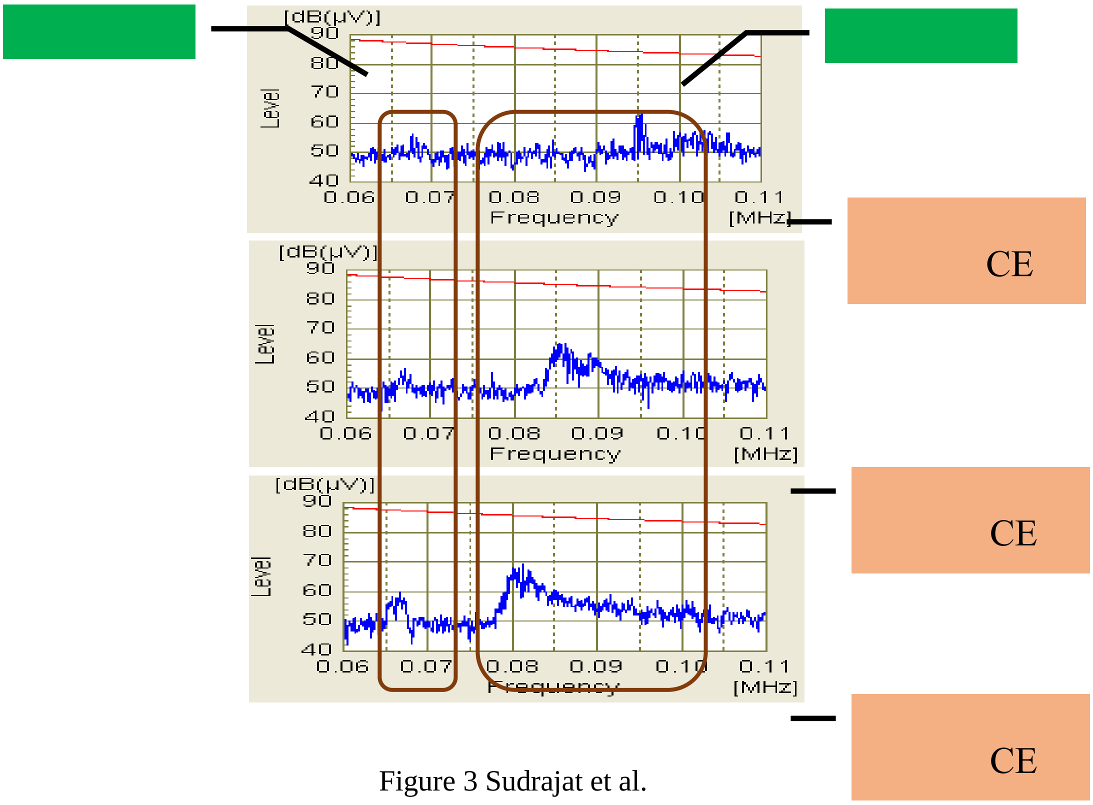

Figure 3 Sudrajat et al.