

# The Effects of Spread Spectrum Techniques in Mitigating Conducted EMI to LED Luminance

Mohammad Yanuar Hariyawan<sup>\*,\*\*</sup>, Risanuri Hidayat<sup>\*</sup>, and Eka Firmansyah<sup>\*</sup>

<sup>\*</sup>Department of Electrical Engineering and Information Technology, Universitas Gadjah Mada

<sup>\*\*</sup>Department of Electrical Engineering, Politeknik Caltex Riau

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## ABSTRACT

Rapid voltage and current changes in recently ubiquitous LED driver have a potency to interfere other devices. Some solutions with special converter design, component design, EMI filter, and spread-spectrum techniques have been proposed. Due to cost-size-weight constraints, the spread-spectrum technique seems to be a potential candidate in alleviating EMI problem in LED application. In this paper, the effectiveness of conducted EMI suppression performance of the spread-spectrum technique is evaluated. Spread spectrum techniques applied by giving disturbance to the LED driver system with three profile signals, filtered square, triangular, and sine disturbance signal to the switching pattern of a buck LED driver topology. From the experiment results, 472.5 kHz triangular and 525 kHz sine signal can reduce EMI by 42 dB while the filtered square signal can reduce EMI 40.70 dB compared to fundamental constant-frequency reference 669 kHz. The filtered square signal can reduce the average power level better than other signal disturbance of 5.852618 dB $\mu$ V. LED luminance decreases when the spread-spectrum technique is applied to the system.

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## Corresponding Author:

Mohammad Yanuar Hariyawan

Department of Electrical Engineering and Information Technology, Universitas Gadjah Mada

Jalan Grafika No. 2, Yogyakarta, 55281 Indonesia

+62 811760655

yanuar@pcr.ac.id

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## 1. INTRODUCTION

Nowadays, light emitting diodes (LEDs) are becoming increasingly popular use in various applications, such as indoor and outdoor lighting, street lighting, decorations, and vehicle applications. The main purpose of LED lights is energy saving due to the use of low power, high efficiency and low maintenance [1]-[4]. In addition, it is durable, environmentally friendly, and no toxic substances composition compared to other lighting types [5]-[10]. To achieve high efficiency in energy transfer, switched-mode power supply (SMPS) topology is applied, such as buck, boost, flyback, cuk dan buck-boost [11]-[22]. In addition, the SMPS is widely applied due to the benefits offered in terms of size, weight, cost and performance. SMPS is usually implemented using pulse width modulation (PWM). PWM operates at a constant frequency. The weakness of this system is the fundamental and harmonic frequencies emitted through conducted and radiated mechanism. This emission is called electromagnetic interference (EMI). As a result, the potential converter does not meet the standards of electromagnetic compatibility (EMC) [11],[14][23],[24].

SMPS has a periodic switching pattern, i.e. EMI spectrum which consists of the fundamental and harmonic frequencies with significant amplitudes up to the 20th harmonic [25]. This condition could probably pass the limit set by the conducted EMI CISPR 22 Class B standards. Some solutions are used to reduce EMI issues in LED drivers, including the converter designs [12],[19],[18],[22],[26]-[32], components design [17],[33]-[35], EMI filter [30],[36] and spread-spectrum techniques [6], [11], [14], [23], [37]-[39]. Of all these solutions, the spread-spectrum technique is a solution that is inexpensive and efficient in mitigating EMI.

In this paper, conducted EMI mitigation is done by applying a spread-spectrum techniques in buck topology LED driver and observing its effect on the LED luminance. Spread spectrum techniques implemented by giving disturbance to the system with 3 profile of waveform signals, filtered square, triangle and sinusoidal waveform signals.

Effectiveness in mitigating the effects of the conducted EMI and LED luminance will be studied. This will ensure electromagnetic compatibility (EMC) of the system.

## 2. CONDUCTED EMI MITIGATION IN LED DRIVER

All the LED driver have to comply with radiation emission, IEC/EN 61000-6-3 standards, which limits in the 150 kHz to 30 MHz frequency range. This Standard uses the limits specified by CISPR 22 in the USA and the European Norm EN55022. Limits given in CISPR 22 and EN55022 standard are intended for devices related to computers and communications, but this has been adopted as a common limit for all electronic products, including the lighting. CISPR 22 standard for conducted emissions shown in Figure 1.

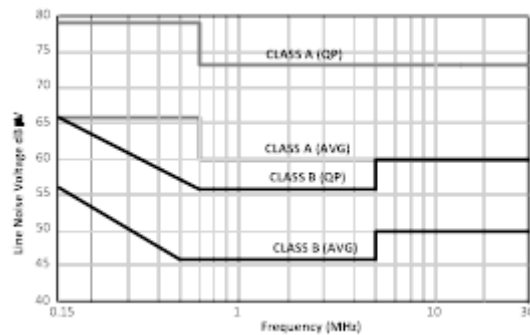


Figure 1. Conducted Emission CISPR 22 Standard

One method to reduce the amplitude of the EMI is to use a variable switching frequency, which is known as spread-spectrum techniques [40]. In this case, the switching converter is not working at a fixed frequency. Frequency will vary within a small range, up and down of the value of the base, it will provide a wider spectrum with a lower amplitude. It is intended to spread a centralized energy into the frequency band, as shown in Figure 2.

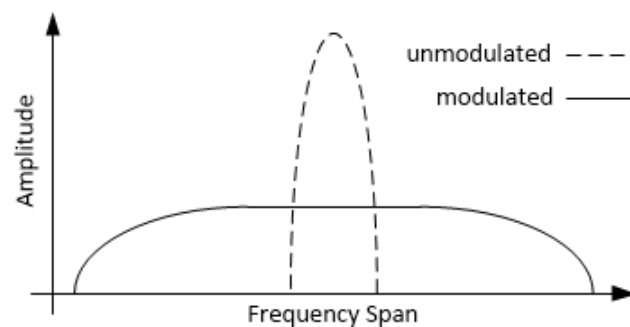


Figure 2. Representation of Signal Clock Frequency with and without Spread-Spectrum Modulation

Spread spectrum technique is used in many applications, class D amplifier [5], [6], the microprocessor clock generator [7]-[9], electronic ballasts [10] and on the LCD display panel [11]. Spread spectrum technique is also adopted in communication protocols such as serial ATA [12]. In the dc/dc switching converter, this technique has been widely studied since 1994 [13] emissions in the common mode and differential mode, both of which can be reduced with frequency modulation.

The research that addresses EMI mitigation techniques in LED driver using spread-spectrum method was first proposed in 2008 [37]. In this study, Gated PWM (GPWM) proposed, distributed switching pulses resulting in lower EMI than the linear PWM. GPWM take advantage of the binary PWM (BPWM): data flow control and the required low amount of buffer memory in processing and storage. LED dimming technique, GPWM recommended for LED video display where it takes a high-level grayscale. This technique offers improved gray level compared with PWM and BPWM.

Frequency jitter technique, proposed to solve EMI problems in PWM dimming LED driver module [6]. PWM dimming circuit consists of a selector and comparator. To spread the switching frequency in a specific band, blocks of frequency jittering are used. Reference voltage in large numbers is needed to obtain different frequencies from which each frequency will represent specific value. Simple resistance divider is used to obtain different reference

voltages. A technique known as spread-spectrum frequency modulation (SSFM) is proposed to mitigate EMI [11]. In this technique, the switching frequency will swing in a narrow range, up and down of the fundamental frequency. This technique produces a wider spectrum with a lower amplitude. Operating frequency will be stretched up to  $\pm 2\sim 4\%$  up and down of the fundamental frequency. Frequency can not be varied too much, because it will affect the average current through the LED.

Active EMI mitigation scheme using pseudorandom frequency modulation is proposed to minimize EMI [14]. It is different from most of the techniques that use DSP or MCU, the proposed mitigation technique uses  $10^{th}$  order linear feedback shift register (LFSR) to generate pseudo-random vectors that are used to control the PWM, which four out of ten bits of LFSR is used to control the PWM. In-depth analysis has been carried out and showed promising results.  $0.35\mu\text{m}$  system is designed in TSMC CMOS process and meet EMI standards for LED driver without sacrificing stability and efficiency. The measurement results show that the proposed timing can reduce EMI by 14 dB while maintaining a constant current of 120 mA.

Probabilistic PWM (PPWM) pulse generation using modified linear feedback shift register (LFSR) is proposed to address EMI [38]. The emergence frequency, peak value, and variety of incoming currents can be reduced by PPWM control, which is stochastic choose PWM pulse timing and control LEDs connected serially, can effectively eliminate the problem of temperature and EMI. The test results showed that PPWM dimming can reduce the average value of the peak inflows of up to 2-5% and a variation of up to 35 %, with the cost of the hardware that is affordable.

Chaos-based pulse width modulation (CPWM) is used to suppress harmonics in the half-bridge resonant (HBR) LED drivers [23]. CPWM proposed to suppress EMI in high-power LED driver. CPWM circuit is used to generate chaos analog circuits by adopting Chua oscillator. By using an external chaotic signal to the PWM control circuit in the power supply half-bridge resonant (HBR) can effectively suppress EMI. The most substantial reduction of EMI by 24 dB, is obtained when using a switching frequency of 565.56 kHz at  $R_{14} = 100\text{k}\Omega$ .

### 3. RESEARCH METHOD

The core of the experimental setup is the LM3409 LED driver demonstration board buck topology. The evaluation board provides interference to the switching system. The evaluation board is designed to drive 4 LEDs ( $V_O = 15\text{V}$ ) at average maximum current LED ( $I_{LED}=1\text{A}$ ) of the DC input voltage ( $V_{IN}=24\text{V}$ ). Switching frequency ( $FSW=525\text{ kHz}$ ) is the frequency to be achieved for the nominal point of operation, though FSW varies throughout the operating range. LM3409 demonstration board schematic converter shown in Figure 3, can accept input voltages with range 6V to 42V. If the input voltage drop below the LED string voltage, converter drop out and ideally  $V_O = V_{IN}$ .

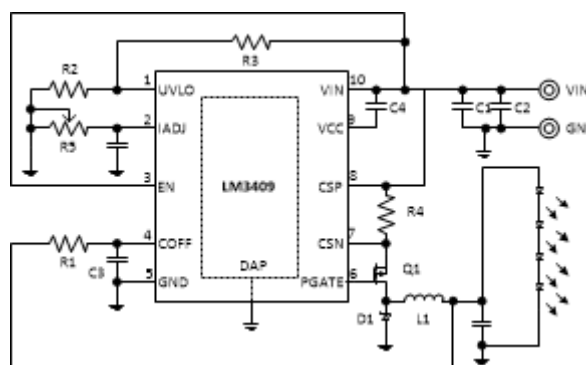


Figure 3. Schematic LM3409 LED Driver Buck Converter Evaluation Board

Two variations on the LED driver system testing was conducted to observe effectiveness of the system in reducing EMI, the LED driver in normal operation and LED driver with three wave forms as signal disturbance as shown in Figure 4. Converter set up testing is done using standard CISPR 22. Measurements were performed in 125 kHz - 925 kHz frequency range. The purpose of this arrangement is to create a test environment that is uniform to clarify the effect of the method chosen. By using the method and arrangement, it is expected the difference between a constant switching frequency and spreading switching frequency can be distinguished easily.

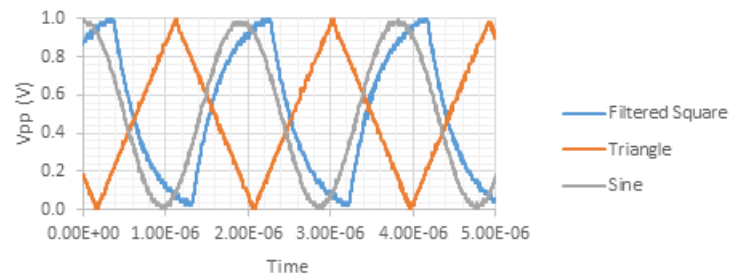


Figure 4. Three Profiles Signal Interference

### 3.1. Constant-Frequency Reference Converter

The experimental setup is carried out under normal conditions without any disturbance on IADJ pin with an input voltage of 24 volts. In the IC LM3409, there is IADJ pin connected to R5 potentiometer (250 K $\Omega$ ) (Figure 3). IADJ pin has function to adjust the brightness of LED lights by providing output voltage and current variations. Block diagram of the test can be seen in Figure 5. The parameters measured in this test is a spectrum EMI and LED luminance changes, when IADJ change from 0.01 V to 1.2 V.

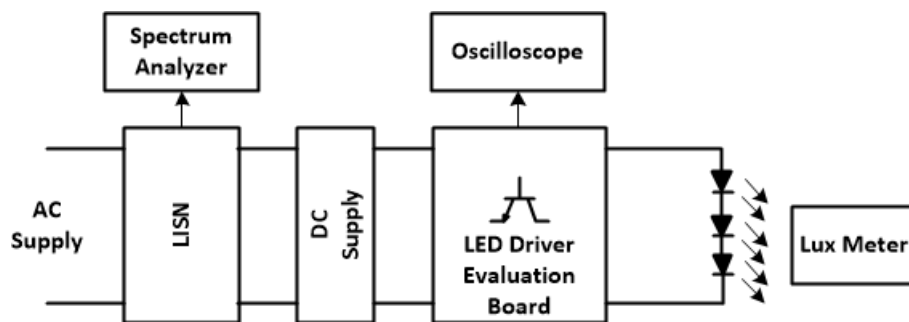


Figure 5. Block Diagram of Performance Testing Constant-Frequency Reference LED Driver

### 3.2. LED Driver Performance Test by Feeding Disturbance to IADC Test Point

This experiment step is done with the conditions providing disturbances in IADJ pin when R5 potentiometer set in minimum conditions value. These disturbance signals comes in three types of waveform, sine, filtered square, and the triangle that generates by function generator. Disturbance waveform signal has a voltage of 0-1 Vpp with the frequency of  $\pm 10\%$  of the working frequency of 525 kHz LED driver. The signal frequency will be set in 472.5 kHz, 498.75 kHz, 525 kHz, 551.25 kHz and 577.5 kHz. Block diagram of the current testing system is given in the form of three waveform disturbance signals can be seen in Figure 6.

## 4. RESULT AND ANALYSIS

### 4.1. LED Driver Performance Test in Constant-Frequency Reference

The EMI generated on every change in the value of IADJ can be seen in Figure 7, it can be seen that when R5 value change, IADJ voltage and working frequency also changes. When compared with the CISPR 22 Class B, the level of power generated at each operating frequency exceeding the limit set by CISPR 22 Class B. The average power levels generated for all amplitude value is about 39.834 dB $\mu$ V. In the 563 kHz-683 KHz frequency range, generated power levels above the maximum value set by CISPR. The highest power level exceeds the standard, occurs when the test point IADJ given voltage 0.2Vpp at a frequency of 627 KHz. When compared to standard CISPR having a difference of 15.9 dB $\mu$ V.

When IADJ pin given different input voltages, LED luminance will change, can be seen in Figure 8. The LED luminance will increase when IADJ changed from 0.023 mV to 849 mV, after which the 849 mV to 1200 mV decreased LED luminance .

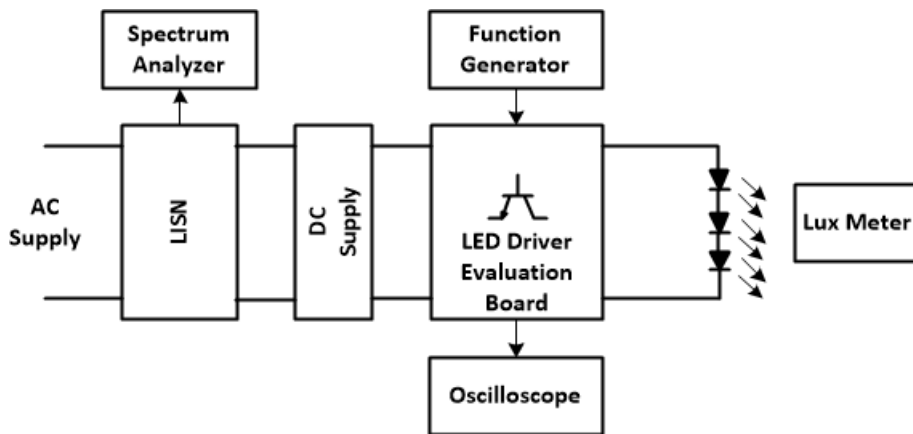


Figure 6. Block Diagram of Performance Testing LED Driver by Giving Disturbance to IADJ

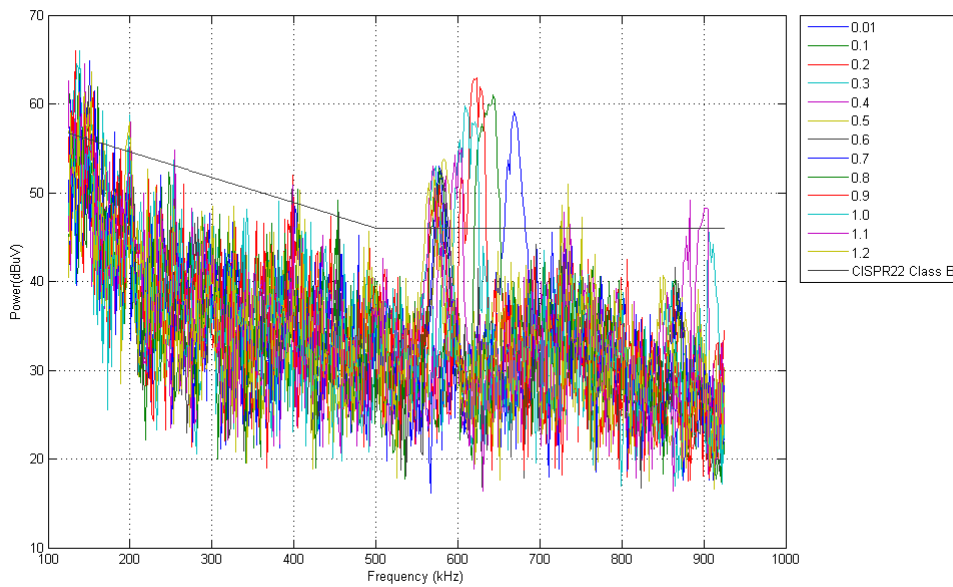


Figure 7. LED Luminance Vs IADJ

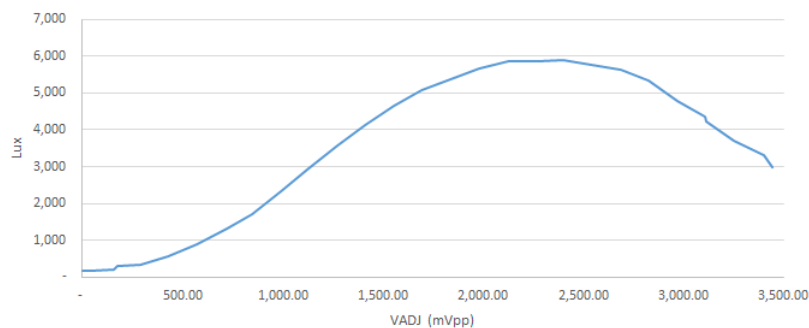


Figure 8. LED Luminance Vs IADJ

## 4.2. LED Driver Performance by Feeding Disturbance on IADJ

### 4.2.1. Filtered Square Profile Signal Disturbance

When given filtered square profile signal disturbance on the IADJ pin, the signal level is obtained as shown in Figure 9. In the frequency range from 563 kHz-683 kHz, there is a decrease in power level when given filtered IJECE Vol. 6, No. 3, June 2016: 1332 – 1343

square signal disturbance on IADJ pin. The average power level generated by the five frequency is about  $28.6 \text{ dB}\mu\text{V}$ . When compared with the power level of the reference signal power level there is a reduction about  $5.8 \text{ dB}\mu\text{V}$ . The most significant reduction of power level occurs at  $525 \text{ kHz}$ , its about  $41.90 \text{ dB}$ , this value is quite significant if compared with previous research [14],[23]. The overall level of power generated by the filtered square signal below the established standards CISPR 22 Class B. Meanwhile the luminance produced by the LED when given the disruption of filtered square waveform is about  $146 \text{ lux}$ . The switching frequency varies between  $292\text{-}675 \text{ kHz}$  as shown in Figure 10.

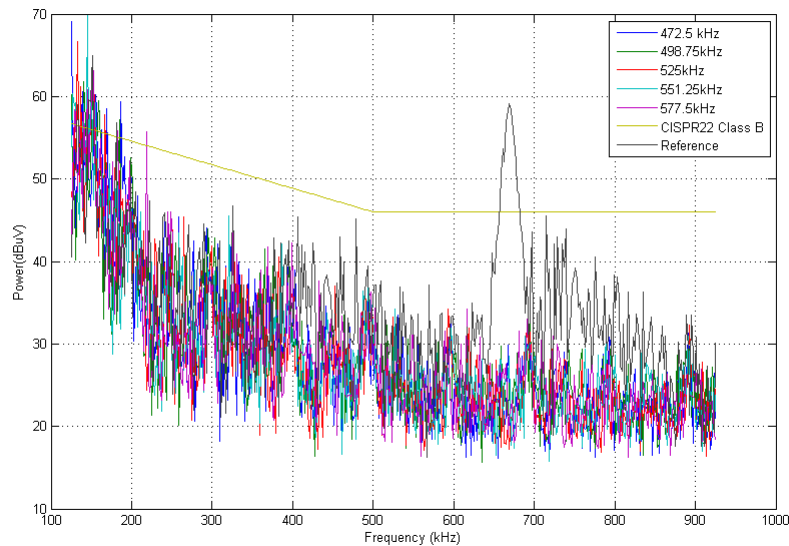


Figure 9. Power Levels Distribution when Given Filtered Square Signal Disturbance

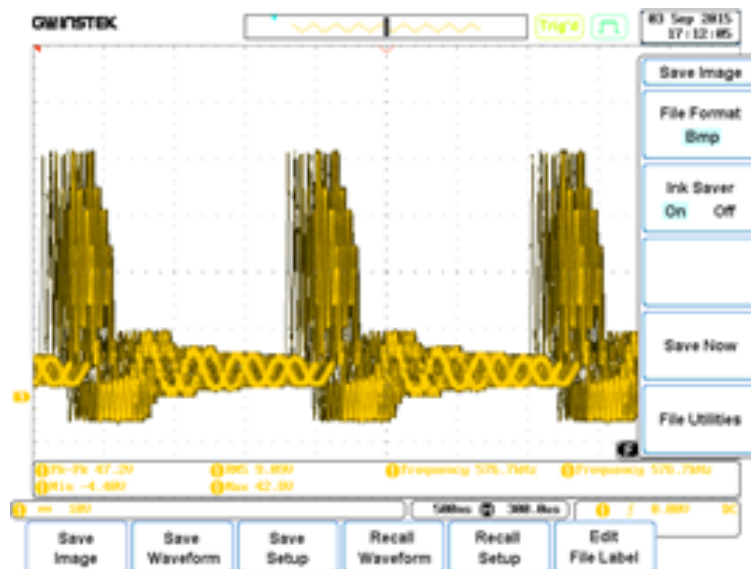


Figure 10. Switching Frequency when Given Filtered Square Signal Disturbance

#### 4.2.2. Triangle Wave Signal Disturbance

When given triangular waveform with frequency range of  $563 \text{ kHz}\text{-}683 \text{ kHz}$  at IADJ point there is power level reduction as shown in Figure 11. The average power level generated by the five frequency is about  $29.6 \text{ dB}\mu\text{V}$ .

When compared with the power level of the reference power level signal there is a decrease of 4.8 dB $\mu$ V. The most significant reduction of power level occurs when system is given 498.75 kHz triangle signal, its about 40.60 dB this value is also quite significant if compared with previous research [14],[23]. As is the case when the system is given a filtered square waveform, the overall level of power generated by triangular waveform resulting disturbance levels below established standards CISPR 22 Class B. Whereas the luminance produced by the LED current when given triangular waveform is about 146 lux. The switching frequency varies between 281-683 kHz as shown in Figure 12.

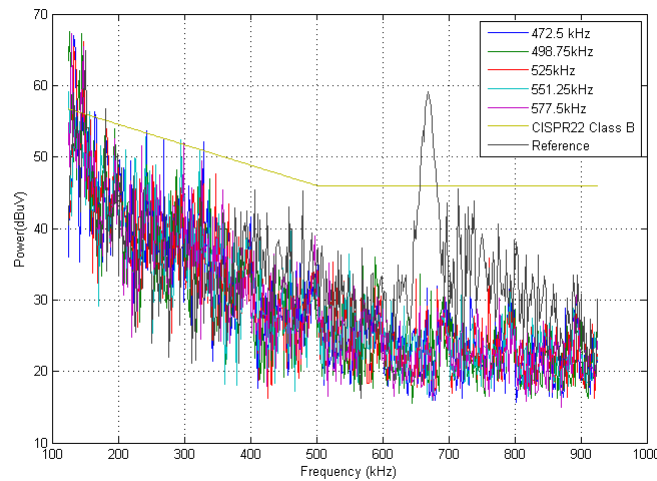


Figure 11. Power Levels Distribution when Given Triangle Signal Disturbance

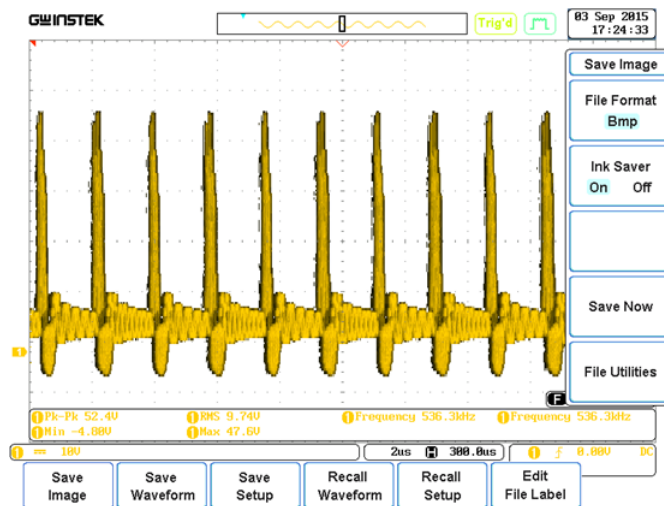


Figure 12. Switching Frequency when Given Triangle Signal Disturbance

### 4.2.3. Sine Wave Signal Disturbance

When given sine waveform disturbances on IADJ point as shown in Figure 14, in the 563 kHz-683 kHz frequency range, there is a decrease in power level. The average power level generated by the five frequency is about 29.5 dB $\mu$ V. When compared with the power level reference signal there is a decrease in the power level about 4.9 dB $\mu$ V. The most significant reduction of power level occurs when the frequency of 525 kHz, is about 42 dB, this value is also quite significant if compared with previous research [14],[23]. As is the case when the system is given a signal disturbance filtered square and triangles waveform, the overall level of power generated by the sine waveform, the resulting disturbance levels below established standards CISPR 22 Class B. Whereas the luminance produced by the

LED current is given filtered square waveform is about 139 lux. The switching frequency varies between 290-657kHz as shown in Figure 13.

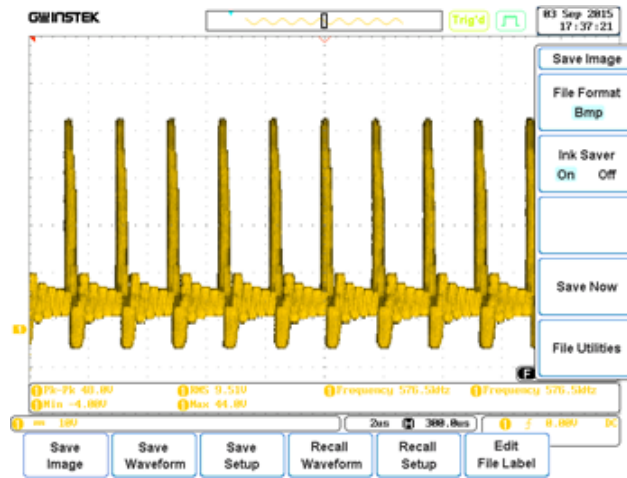


Figure 13. Switching Frequency when Given Sine Signal Disturbance

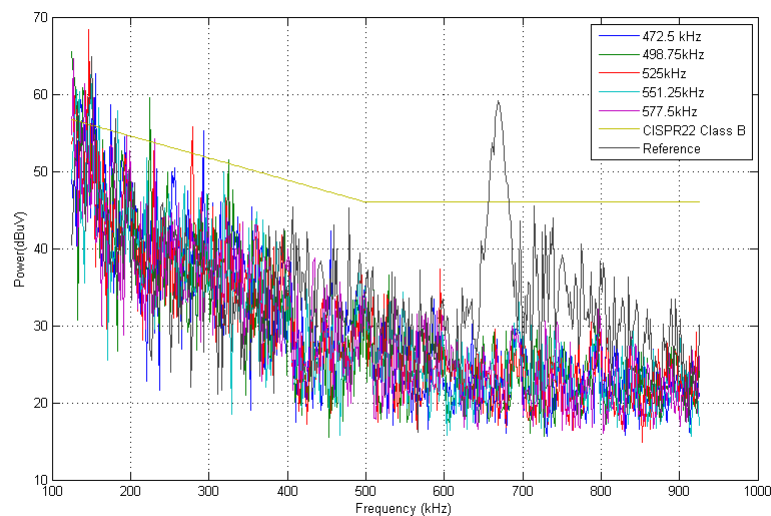


Figure 14. Power Levels when Given Sine Signal Disturbance

When the system is given three periodic waveforms at the point IADJ with a frequency of 525 kHz and compared with a reference signal when the minimum dimming, filtered square has a better performance when compared with other waveform to suppress EMI, as shown in Figure 15. The average level of the power generated by the third signal is equal to 29.26143 dB $\mu$  V. The average power level of squared filtered waveform has the smallest value when compared with others waveform is about 28.56309 dB $\mu$  V. The average reduction power level of the third signal at 5.154281 dB $\mu$  V, and filtered square waveform have better power level reduction is about 5.852618 dB $\mu$  V. The average power level reduction of the third signal at 5.154281 dB $\mu$  V, and filtered square waveform have better power level reduction is about 5.852618 dB $\mu$  V. The most significant reduction of power level occurs when system given 525 kHz triangle disturbance, is about 42 dB reduction, this value is quite significant if compared with previous research [14],[23] which use non-periodic signal to mitigate EMI. Measurement results showed that the proposed mitigation scheme using 10<sup>th</sup> order LFSR to generate pseudo-random vectors can reduce EMI only 14 dB [14]. CPWM which adopt Chua oscillator to generate chaotic signal can reduce EMI only 24 dB [23].

When the pin VDJ given disturbance, LED luminance decreases compared with LED driver works in constant-frequency reference. When the system works on a constant-frequency reference with a voltage of 0.07 to 1,129 mVpp,



lux varies between 178-2,960 lux, as in Figure 8. LED luminance decrease significantly, less than about 2814 lux. As filtered square and triangle disturbance signal given at LED driver, luminance LED system is about 146 lux. whereas sinusoidal signals produce luminance 139 lux, as shown in Figure 16.

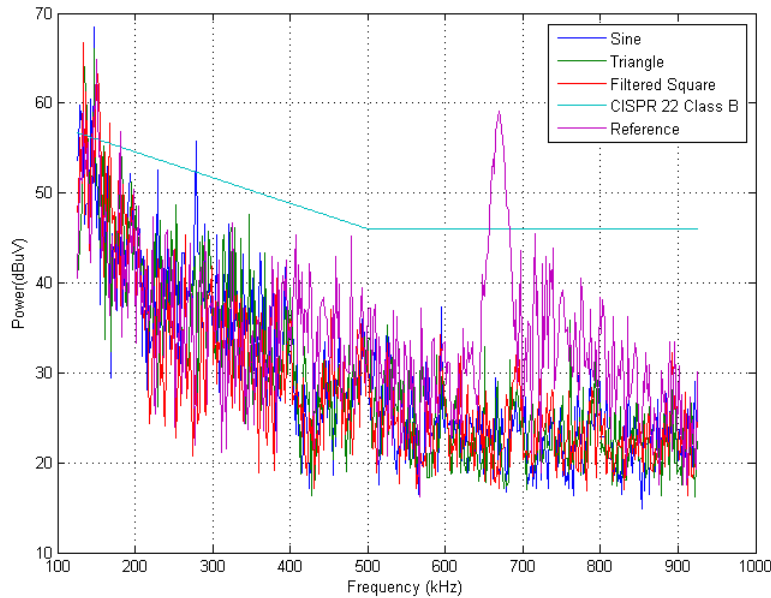


Figure 15. Comparison of Power Level Distribution 3 Different Signals Disturbance at 525 kHz

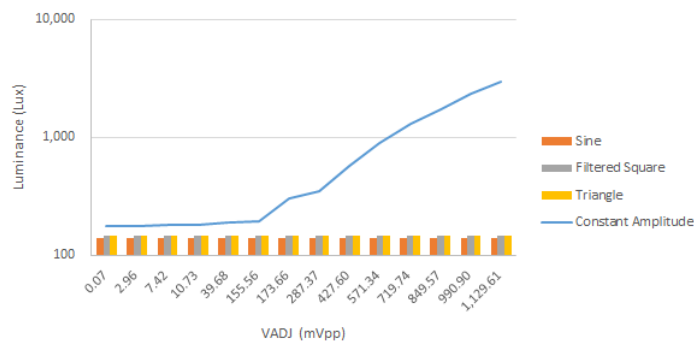


Figure 16. LED Luminance when Given Disturbance

**5. CONCLUSION**

The experiment results confirms that the spread-spectrum technique is effective in mitigating conducted EMI generated by the LED driver but sacrificing LED luminance. The results show that when the system is given filtered square, triangular and sine waveform disturbance signal can mitigate EMI generated by the LED driver. From the test results, 525 kHz sine signal is the most efficient signal disturbance to mitigate EMI by 42 dB then followed by filtered square signal that can mitigate EMI by 41.9 dB. The lowest average power level is achieved by filtered square signal is about 36.447 dB $\mu$ . The filtered square signal most significant can reduce the average power level about 3.27 dB $\mu$ V. By providing three types of signal disturbance on the LED driver system resulting in decreased levels of LED luminance.

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## BIOGRAPHIES OF AUTHORS



**Mohammad Yanuar Hariyawan** is a Lecturer at Electrical Department, Politeknik Caltex Riau, Pekanbaru, Indonesia. Currently, He is a PhD Student at the Department of Electrical Engineering and Information Technology, Gadjah Mada University, Yogyakarta 55281, Indonesia. He received his BsC in Telecommunication Multimedia in 2001 from Sepuluh Nopember Institute of Technology, Indonesia, M.T in 2008 from the Sepuluh Nopember Institute of Technology, Indonesia. His research interest includes Electromagnetic Compatibility, and RF Harvesting.



**Risanuri Hidayat** is a lecturer at the Department of Electrical Engineering and Information Technology, Gadjah Mada University, Yogyakarta 55281, Indonesia. He received his BSc in Electrical Engineering in 1992, M.Sc (Electrical Engineering) in 2002 from the Information and Communication Technology, Agder University College, Norway and PhD in 2009 at Telecommunication Engineering, King Mongkuts Institute of Technology Ladkrabang (KMITL), Bangkok, Thailand. His research interest includes Signal Processing, Digital and Analog Circuit Design, and telecommunication Systems, Data Communication and Networking, Java Programming and its Applications and Speech and Image Recognition.



**Eka Firmansyah** is a lecturer at the Department of Electrical Engineering and Information Technology, Gadjah Mada University, Yogyakarta 55281, Indonesia. He was born in Yogyakarta, Indonesia on March 3rd, 1979. He got his BSc in electrical engineering from UGM, Indonesia in 2001, M.Eng in Power Electronics from NTU, Singapore in 2005, and Ph.D. in Power Electronics from Kyushu University, Japan in 2010. His research interest is in PFC topology and inverter circuit for renewable energy and motor control.