IOP Conf. Series: Materials Science and Engineering **732** (2020) 012099 doi:10.1088/1757-899X/732/1/012099

Conducted emission mitigation in LED driver by chaotic modulation

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Abstract. Light-emitting diode (LED) lamps are becoming popular in a wide range of applications, due to low power, high efficiency, and low maintenance. To achieve high efficiency in energy, transfer in the LED driver, a switched-mode power supply (SMPS) topology is applied. SMPS operates at a constant frequency; it generates significant emission in some of the frequencies through conducted and radiated mechanisms. Several solutions are proposed to mitigate the EMI (electromagnetic interference), such as converter design, component selection, EMI filtering, and spread spectrum techniques. Spread-spectrum is a cheap and efficient solution in the conducted emission mitigation. This research performs conducted emission mitigation by modifying the switching on the LED driver using chaotic signals. The Lorenz equation was selected to produce chaotic signals. The effect of EMI caused by the chaotic signal has been analyzed toward the performance of the system, compared with performance when periodic signals modulated it. Lorenz's injection signals have reduced distribution over broader bandwidth compared to other injection signals. The average EMI reduction produced by Lorenz signal was the highest compared with other modulated signals of 10.63 dB.

1. Introduction

Electromagnetic interference (EMI) causes significant problems in electronic circuits, especially in high-frequency applications. Electrical devices produce electromagnetic pulses that makeup EMI. It can affect other electronics device performance. A switched-mode power supply (SMPS) topology [1-8] is applied in the LED driver to achieve high efficiency in energy transfer. Since it has advantages regarding size, weight, cost, performance, and less contain toxic compositions compared with another lamp [9-12].

SMPS is implemented using pulse width modulation (PWM), which operates at a constant frequency; it generates significant emission in some of the frequencies through conducted and radiated mechanisms. This emission is called electromagnetic interference (EMI). As a result, converters have a potency that might not meet the electromagnetic compatibility (EMC) standard [13]. Several solutions are proposed to mitigate the EMI, such as converter design, component selection, EMI filtering, and spread spectrum techniques [13-21].

The development of LED driver currently leads to a power supply with a digital controller requiring a microcontroller [22-25]. Thus, the application of the spread-spectrum technique is very suitable for the condition. Although it should be understood, to function effectively, this solution needs to be combined with other methods. Other solutions may be will sacrifice the advantages of switching converters regarding size, weight, cost, and performance due to the addition of components.

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This research performs the EMI mitigation of the LED driver using the spread spectrum method by generating a chaotic signal that was injected into the LED driver. The effect of EMI caused by spread-spectrum technique is analyzed toward the performance of the system and compared with periodic signals and also compared with other methods in previous studies.

2. LED driver EMI mitigation technique

Since 2008, LED driver design used various EMI mitigation techniques. The study discusses the EMI mitigation techniques on the LED driver using the spread spectrum method as it was first proposed in 2008 [26,27]. In this study, gated PWM (GPWM) is proposed, switching pulses are distributed, resulting in lower EMI compared to linear PWM.

The jittering frequency technique is proposed to solve EMI problems in the PWM LED driver dimming module through simulations [28]. A technique known as spread spectrum frequency modulation (SSFM) is proposed to mitigate EMI [20], switching frequency swings in a narrow band, up and down from fundamental frequency. This technique produces a broader spectrum with a lower amplitude. The operating frequency is stretched up to ± 2 ~ 4% up and down from its fundamental frequency. Figure 2 shows the LED driver controller IC system used in the study.

The proposed EMI mitigation scheme uses pseudorandom frequency modulation; the switching frequency clock spectrum is spread over a specific frequency range to minimize EMI [21]. The proposed EMI mitigation technique uses linear feedback shift registers (LFSR) 10th order, as shown in Figure 3, to generate the pseudorandom vector used to control PWM. The measurement results show that the proposed timings can reduce EMI by 14 dB while maintaining a constant current of 120 mA.

A PWM pulse generation probabilistically using a modified LFSR proposed for mitigating EMI [14]. The appearance of a frequency, peak value, and inrush currents can be reduced by probabilistic control of PWM (PPWM). It stochastically selects the timing of the PWM pulse. The test results show that the average peak inrush current can be reduced to 5 % (-6 dB) and variations up to 35% (-9.1 dB).

Chaos-based PWM (CPWM) proposed to suppress harmonics in half-bridge resonant (HBR) LEDs driver [22]. It adopted a Chua Oscillator to generate chaos signal and analog circuits that. Using external chaotic signals in the PWM control circuit in a half-bridge resonant (HBR) power supply can effectively suppress EMI. The most significant EMI reduction of 24 dB is obtained when using 565.56 kHz switching frequency at R14 = 100kΩ.

Previous studies applying spread spectrum techniques to mitigate EMI are still based on computer and hardware simulation approach. It underlies the research on the development of CE mitigation techniques on the LED driver using spread spectrum techniques and its effects which can later be developed through software.

3. Research method

The research methodology stage of the EMI mitigation techniques on the LED driver evaluation board buck topology with spread spectrum technique is shown in Figure 1. The purpose of CE test is to measure noise current coming out of the product. The set-up of the LED driver measurement is done using the CISPR 22 standard. The equipment and materials employed in this CE testing are LED LM3409 buck topology evaluation board (Figure 2), LED lamp, Spectrum Analyzer (SA), arbitrary function generator (AFG)-AFG 2225, line impedance stabilization network (LISN) -LIS20 Amitec and flux meter.

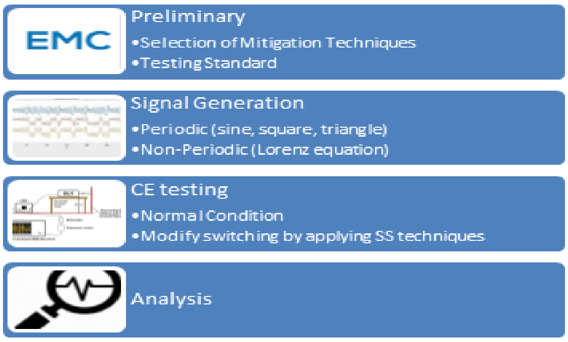


Figure 1. Research stages.

When performing CE testing, a LISN is placed between the equipment under test (EUT) and the power source [29]. The CE test is performed on two conditions; (1) when the LED driver operates under normal conditions and (2) when the LED driver is operated by applying the spread spectrum method. The dc/dc converter in the switch-mode converter is based on the pulse width modulation (PWM) technique. When the converter is working under normal conditions, a constant switching frequency is generated. While a periodic and chaotic injection signal is given, the switching frequency is no longer constant. In this research, chaotic pulses will be produced by the Lorenz equation:

$$\frac{dx}{dy} = \sigma(y - x) \tag{1}$$

$$\frac{dy}{dt} = \rho x - y - xz \tag{2}$$

$$\frac{dz}{dt} = xy - \beta z \tag{3}$$

by setting the value $\sigma = 10$, $\rho = 28$, and $\beta = 8/3$, the system produces chaotic oscillations [30].

When the LED driver is operating in normal conditions, it is used as a reference. It compared when the spread spectrum method is applied so that EMI mitigation performance is known. The CE test results in the CE spectrum and the LED luminance changes of the two conditions. The core of this CE test is the LM3409 LED driver evaluation board with a load of 4 LEDs connected series, as shown in Figure 2. There is no modification to the circuit, when periodic and non-periodic signals are injected.

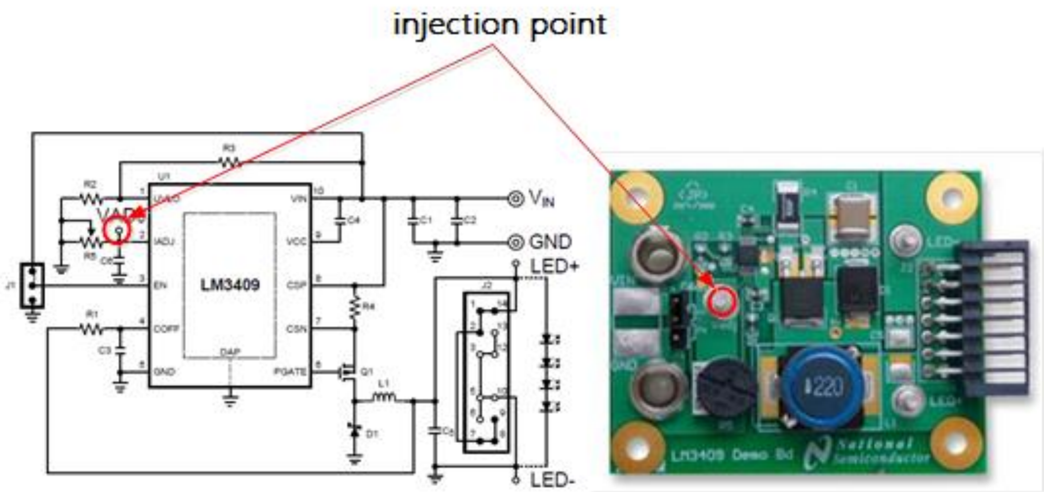


Figure 2. LM 3409 evaluation board.

3.1. Operation of the LED driver under normal condition
Measurement test set up of the LED driver under normal conditions, shown in Figure 3 (thin line). A front end is used as a dc voltage source of the LED driver during the test. The EMI current spectrum is measured by using SA. In this measurement, it is observed CE spectrum and LED luminance changes as VADJ voltage changes.

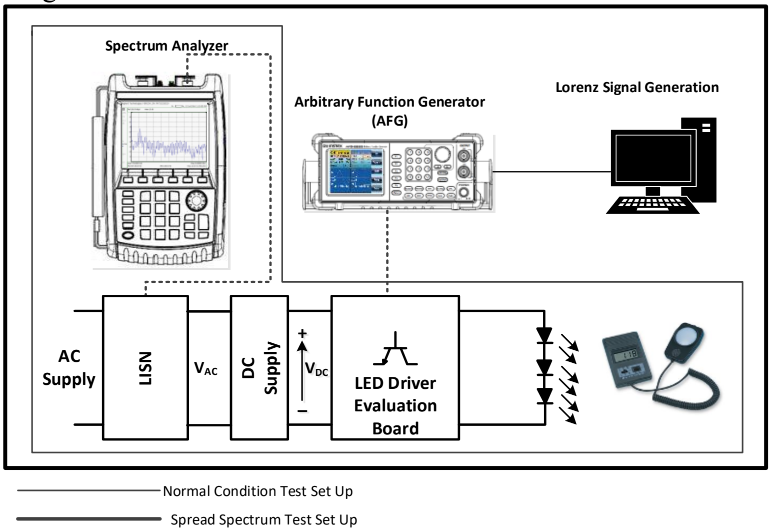
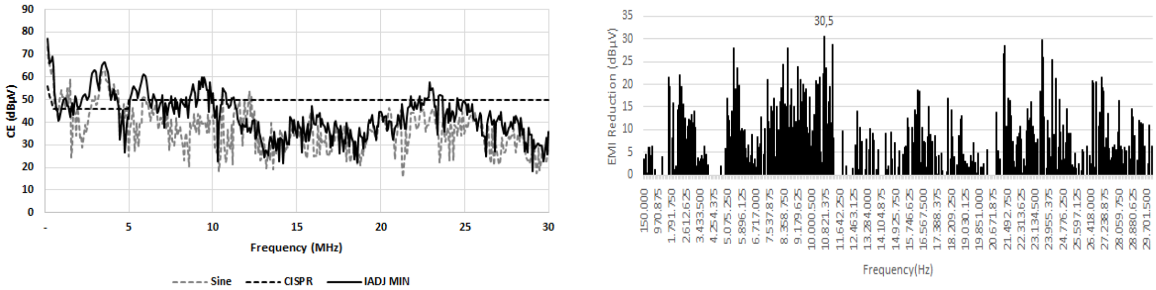


Figure 3. Measurement test set-up (thin line) under normal condition and when spread spectrum is applied (bold line).

3.2. Operation of LED driver when applied spread spectrum method
Measurement test set up an operation of the LED driver when it applied spread-spectrum, shown in Figure 3 (thick line). The implementation of the spread spectrum method is done by giving a signal injection with a particular characteristic. At this stage, before the LED driver is injected Lorenz signal, previously given an injection periodic signal (sine, square, and triangle). At this stage of testing, the spectrum of CE and LED luminance known whether there is an energy spread when compared to the reference (LED driver while operating under normal conditions). To implement Lorenz signal that has chaotic characteristics, first simulated in PC and then deployed in AFG.

4. Result and analysis
While the driver LED switching system is modulated using periodic and non-periodic signals, the CE and luminance values also change. Under normal conditions, the LED has 301 lux lighting. When a sine signal injects to the IADJ pin, Figure 4 (a) shows CE spectrum produced by the system and a luminance of 304 lux. In the 5 MHz to 30 MHz frequency range, EMI levels were generated below the EMI level towards normal conditions and CISPR 22 class B standard, as shown in Figure 4 (b). The most significant EMI reduction occurs at a frequency of 10.746 MHz of 30.5 dBμV. In the 5 MHz-8.1 MHz frequency range, there is a significant reduction of the EMI compared with other frequency ranges. The performance of the EMI mitigation is better if there is a reduction in all frequency ranges. There are some points that there is no reduction, at which point the EMI result is higher than the EMI when the system is operating under normal conditions.

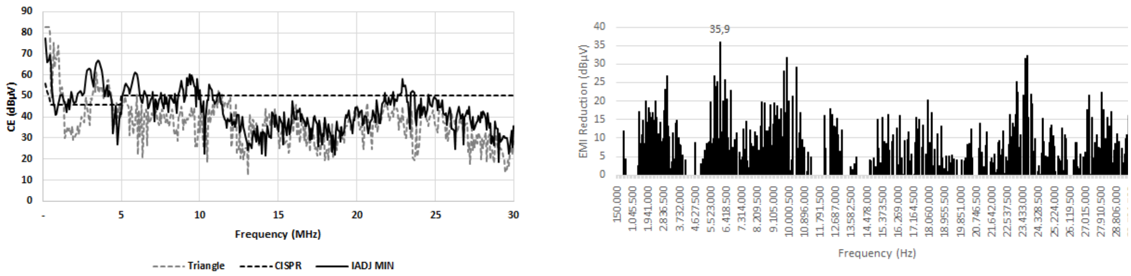


(a) (b)

Figure 4. (a) CE power level and (b) EMI reduction when LED driver injected by sine signal.

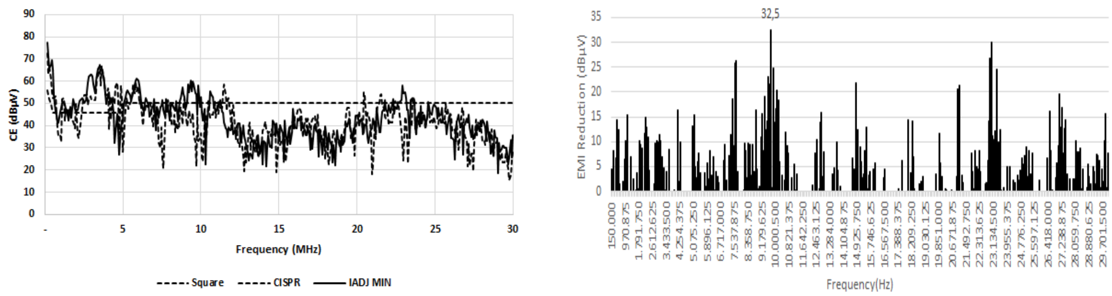
When the LED driver injected by a triangle modulating signal, Figure 5 (a) shows CE spectrum generated by the system and luminance of 306 lux. In the frequency range of 1.493 MHz up to 30 MHz, EMI levels are generated below the EMI level, as shown in Figure 5. The most significant EMI reduction occurs at a frequency of 6.045 MHz 35.9 dBµV. From Figure 5 (b) in the 5.224 MHz-9.5 MHz frequency range, there is a significant reduction of the EMI compared with other frequency ranges. In other frequency ranges where no reduction occurs, EMI is higher than when the system is in normal condition.

When the LED driver modulated by square modulating signal, the CE spectrum generated by the system is shown in Figure 6 (a) with a luminance of 306 lux. In the 12 MHz to 21 MHz frequency range, EMI levels are generated below the EMI level, although not as significant as the reduction compared to triangle and sinus signals, as shown in Figure 6 (b). The most significant EMI reduction occurs at a frequency of 9.702 MHz of 32.5 dBµV.



(a) (b)

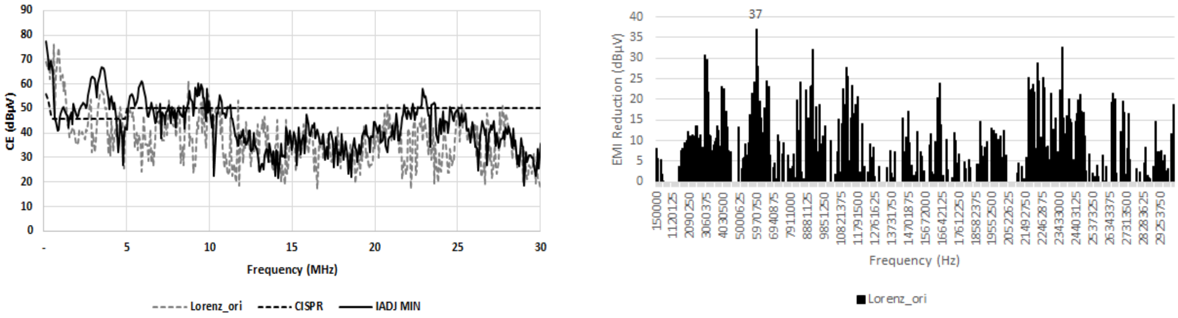
Figure 5. (a) CE power level and (b) EMI reduction when LED driver injected by triangle signal.



(a) (b)

Figure 6. (a) CE power level and (b) EMI reduction when LED driver injected by square signal.

When the LED driver was injected by Lorenz modulating signal, it produced CE as shown in Figure 7 (a) and luminance of 456 lux. It was the highest luminance value when compared to periodic modulating signals. In the frequency range of 4.627 MHz up to 30 MHz, EMI levels are generated below the EMI level when the LED driver is working under normal conditions and the CISPR 22 Class B standard. Figure 7 (b) shows the highest EMI reduction intensity, almost in all frequency range, there was EMI reduction. The most significant EMI reduction occurs at a frequency of 5.896 MHz of 37 dBµV; this value is the most significant reduction value compared with periodic modulating signals.



(a) (b)

Figure 7. (a) CE power level and (b) EMI reduction when LED driver injected by Lorenz signal.

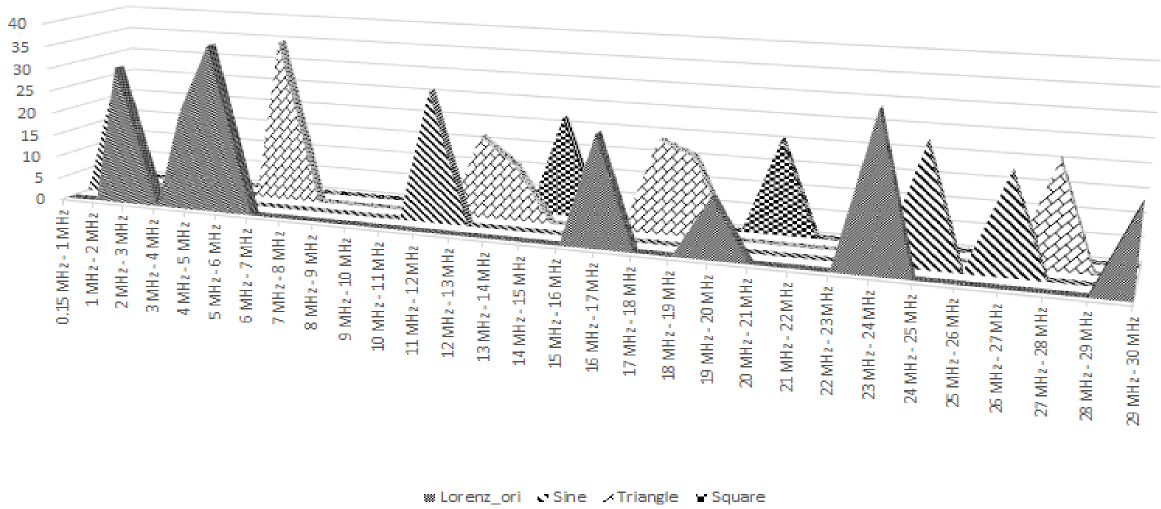
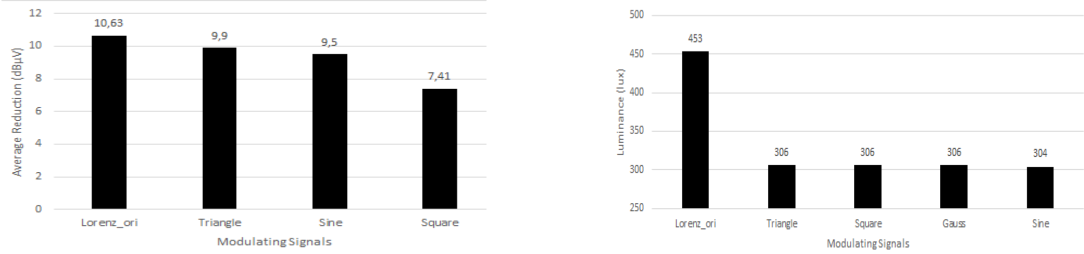


Figure 8. EMI reduction 1 MHz when spread spectrum implemented in LED driver.

Non-periodic injection signals show better performance than the periodic modulating signals. Either EMI mitigation performance or the performance of LED converters regarding luminance generated by LEDs when injected non-periodic signals. Lorenz's injection signal has a reduction distribution over a broader frequency range compared with other injection signals, as shown in Figure 8. The average EMI reduction produced by Lorenz injection signal is the highest compared with other injection signals of 10.63 dB, as shown in Figure 9 (a). Lorenz signals provide better luminance than periodic modulating signals. When the LED driver was modulated by Lorenz signal, a luminance of 456 lux was generated or an increase of 51.5% compared with the luminance of the LED converter under normal conditions, as shown in Figure 9 (b).



(a) (b)

Figure 9. (a) EMI average reduction and (b) Luminance change when spread spectrum implemented in LED driver.

5. Conclusion

The modulating signals with non-periodic characteristics indicate better performance than periodic signals, either EMI mitigation performance or luminance produced by the LED driver. Lorenz's modulating signals have reduced distribution over a more extensive frequency range compared to other modulating signals. The average EMI reduction produced by Lorenz modulating signal is the highest compared with other modulating signals of 10.63 dB. System performance, when implemented spread spectrum method, can be seen in LED luminance, which tends to produce constant value when given periodic modulating signals. When the LED driver was given a Lorenz modulating signal, resulting luminance of 453 lux, or an increase of 51.5% compared with the luminance of the LED converter under normal conditions.

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