Time and Frequency Domain Evaluation Method of Current Noise on the Power Line connected Multiple LED Bulbs

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Abstract— **The electromagnetic noise generated from the inverter circuit in the LED lighting unit has become a problem influencing to the communication system. The purpose of this research is to examine the evaluation method under the condition of the multiple LED bulbs connected to power line. When the spike-shaped current waveforms generate by switching of inverter, the large amplitude noise at wide frequency band is observed. The current waveform converts to frequency spectrum by short time fast Fourier transform (STFT). Since the spike-shaped waveform diminishes over time, current noise amplitude at time zone during which noise is not generated is very small. The amplitude variation at the peak frequency is small. As the peak frequencies are estimated the power line resonance, current noise generated by spike-shaped noise does not decrease. On the other hand, at the 20 LED bulbs, the current waveform synthesized from each LED bulbs is non-periodic and non-uniform. The variation of amplitude is larger than that of one LED bulb due to distance between LISN to LED bulbs or individual specificity of each LED bulbs. The effective current variating to time is calculated. The maximum histogram at each frequency is coincided with effective current. These methods can be possible to evaluate the noise from the multiple LED bulb.**

Keywords—multiple LED bulbs; current noise; STFT; effective current

I. Introduction

Energy saving LED lighting unit is spreading. However, electromagnetic noise generated from the inverter circuit in the LED lighting unit has become a problem influencing to the communication system [1-2]. Electromagnetic noise regulation generated from LED lighting is specified in CISPR 15 [3]. Generally, a plurality of LED lights unit is used in combination. It is a noise standard for LED lighting alone, and measurement methods and regulation values concerning noise when combining two or more are not defined.

The purpose of this research is to examine the radiation noise from multiple LED bulbs connected to power line. Current and radiation electric field when 20 LED bulbs are connected in cascade are measured so far. The amount of noise also increased as the number of LED bulbs increased. The frequency of the peak spectrum below 200 MHz changed when the number of LED bulbs increases [4]. On the other hand, amplitude and period of the current noise generated from multiple LED bulbs is not constant such as random noise [5]. When current noise is measured using the spectrum analyzer, if the timing of sweeping and the timing of occurrence of noise do not coincide, there is a possibility that noise cannot be measured correctly. For this reason, although measurement was performed with MAX hold, reproducibility cannot be obtained in measurement results. However, the current increment factor with respect to the number of LED bulbs did not become constant.

The purpose of this study is to discuss the evaluation method of current noise generated from multiple LED bulbs. The current waveform is measured by current probe and oscilloscope. Since the waveform converts to frequency spectrum using by a short time fast Fourier transform (STFT), the time variation at each frequency is obtained. The effective current noise from LED bulb is estimated.

II. Mesurement Method of Current Noise

Fig. 1 shows the measurement setup for the current noise flowed on the power line. The 20 LED bulbs of the same manufacturer and identical products were prepared. 20 receptacles are connected using the line which length is 0.15 m. LED bulbs attached in a receptacle one by one.

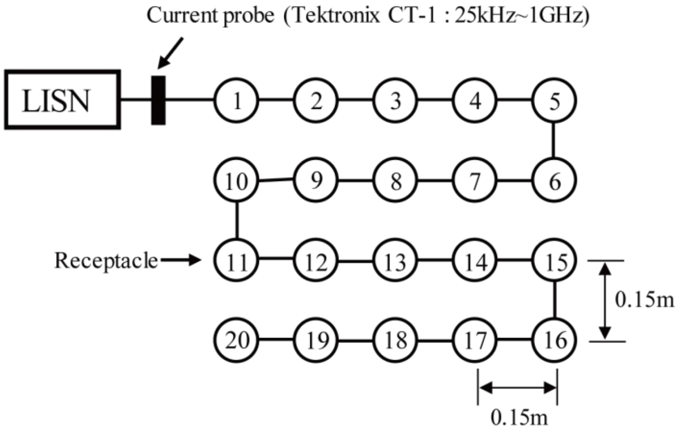
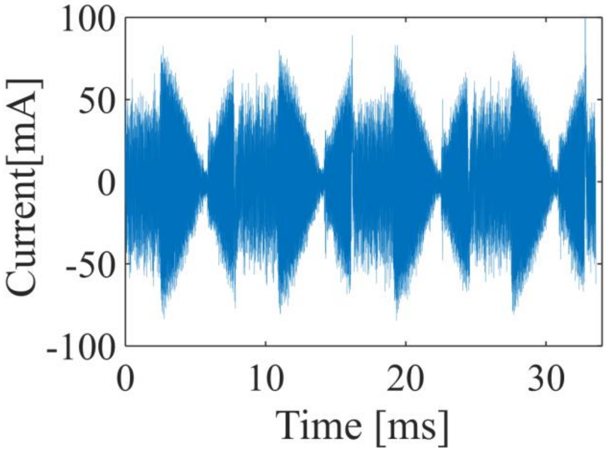
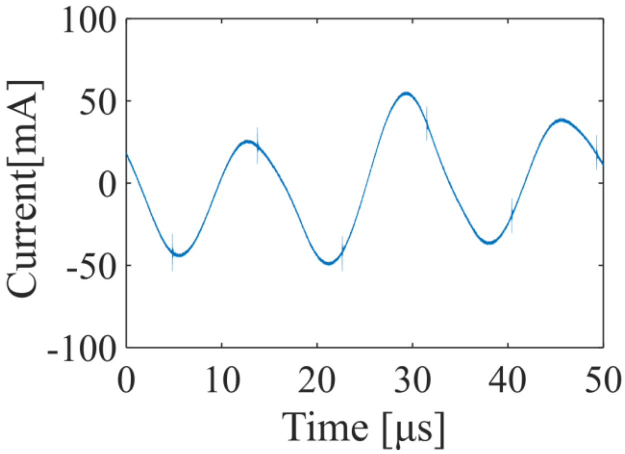


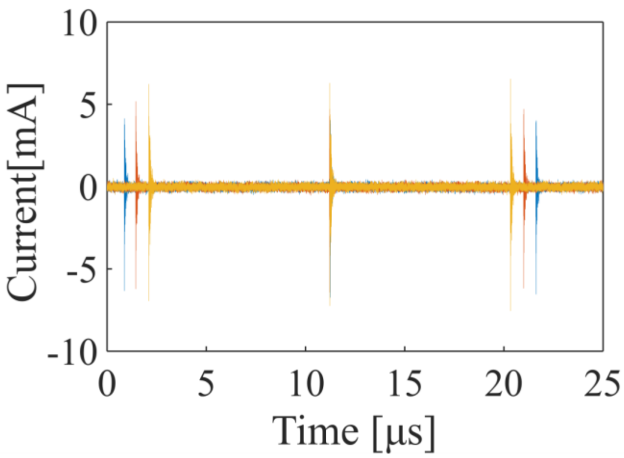
Fig. 1 LED lighting unit



(a)

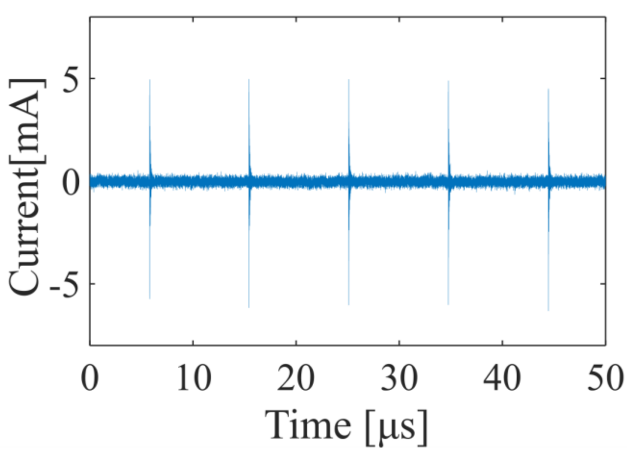


(b)

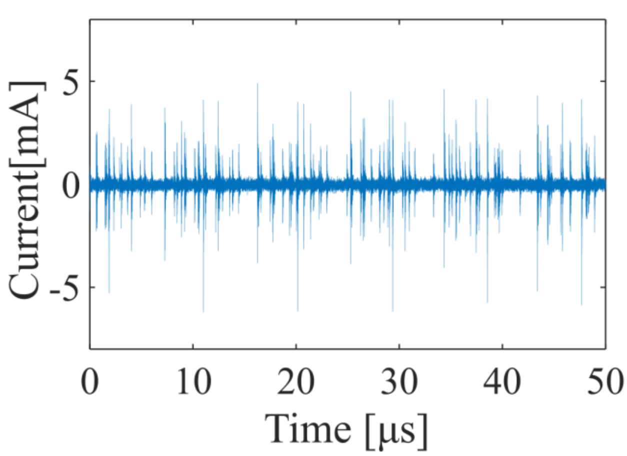


(c)

Fig. 2 Current waveform of one LED, (a) Whole waveform, (b) Expanded waveform and (c) Waveform after passing through the filter.



(a)



(b)

Fig. 3 Current waveform flowing on power line, (a) One LED bulb and (b) 20 LED bulbs.

In order to make always constant of the impedance on the power supply side, Line Impedance Stabilization Network (LISN) is used, and AC 100V power is applied to LED bulbs through LISN. A current probe (Tektronix CT - 1) detected current waveform flowing through the power line. Current probe is inserted near LISN, and detected voltage is measured with an oscilloscope (Keysight DSOS 804 A, 10 bit 20GSa/s).

III. Current Noise flowing on the Power Line

Fig. 2 shows the current waveform that flows when one LED bulb is connected to the power line. Fig. 2 (a) shows the long span waveform. It can be seen that the amplitude of the current noise generated from the LED bulb changes greatly with time. Fig. 2 (b) shows a waveform obtained by enlarging the current waveform of Fig. 2 (a). A sinusoidal period of about 67 kHz was observed. This is considered to be a waveform by switching of the inverter circuit. Spike-shaped noise is observed near the maximum or minimum value of

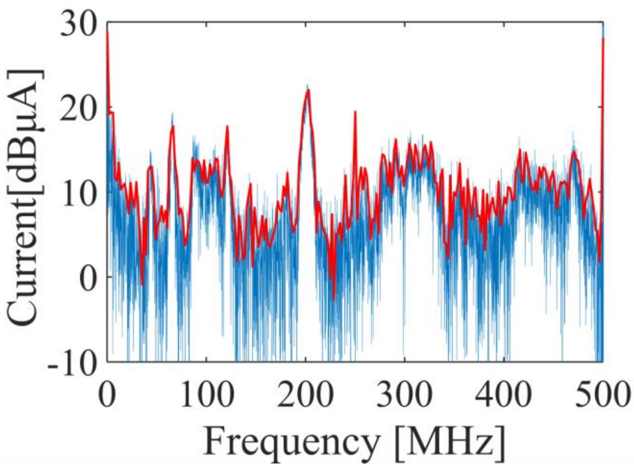
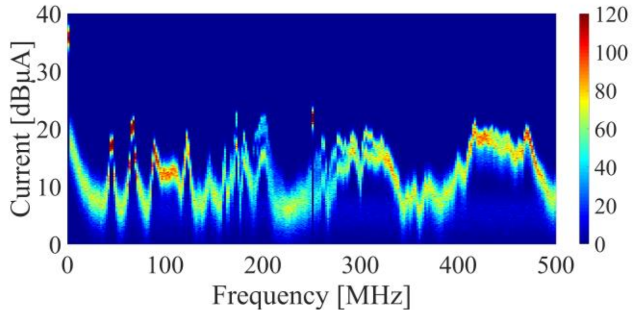
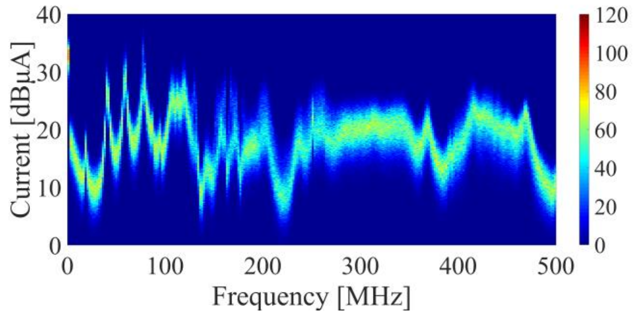


Fig.4 Current spectrum of one time of STFT for one LED



(a)



(b)

Fig. 5 Histogram of current spectrum, (a) one LED and (b) 20 LED bulbs.

sinusoidal wave. The spike-shaped noise rising or falling in fast time has wideband harmonics from kHz to GHz band. That spike-shaped noise is a main cause of the radiation noise at wideband. In this study, EMI problem caused by spike-shaped noise is discussed.

When enlarging and measuring the spike-shaped noise with an oscilloscope, the waveform overflows from the measurement range due to the sinusoidal component seen at Fig. 2 (b). For this reason, it is not possible to obtain the frequency characteristic of the spike-shaped noise. The sinusoidal signal of 67 kHz was removed using a high-pass filter whose low cutoff frequency f_L=3 MHz and only spike-shaped noise was obtained.

Fig. 2 (c) shows the waveform of one LED bulb after passing through the high pass filter. Three locations waveform with different times are shown. The period and the amplitude of the spike-shaped noise are different. For this reason, it is considered that the timing of switching varies even with one LED bulb.

Fig. 3 (a) shows a current waveform of one LED bulb and (b) shows the current waveform when 20 LED bulbs are connected. In the case of one LED bulb, the spike-shaped noise seems to be periodic. When 20 LED bulbs are used, the spike-shaped noise generated from each LED bulb is added. Amplitude and period are different, and non-uniform and non-periodic noise can be observed in a short time.

IV. Analysis of Current Noise

For the non-periodic and non-uniform noise, degree of change in the amplitude value for the frequency domain is evaluated. FFT is used as a method of converting the time waveform to the frequency domain. By analyzing measured whole waveform shown in Fig. 2 (a), FFT can extract characteristics of each frequency. However, noise floor increases when the whole waveform is converted by FFT, the specific characteristics cannot be observed. In addition, in order to evaluate the timing of switching and the variation of non-uniform and non-periodic noise, it is possible to obtain the time variation of the spectrum by converting the waveform to the frequency domain by STFT. The length of the current waveform obtained by one measurement is 33.5 ms (20 GSa/s, 400 Mpoint). STFT repeats at 8.19 μs (2^{14} points) intervals. Depending on the timing of switching, the amplitude of the result of the STFT varies.

Fig. 4 shows the current spectrum of one time of STFT for one LED bulb. At frequencies below 200 MHz, multiple peak frequencies appear. The peak frequencies below 100 MHz are observed at 44.6, 65.8 and 87.5 MHz. This is considered to be a noise component due to power line resonance [4]. Since the amplitude fluctuation is large at frequencies with small noise components, envelope processing was performed (red line).

STFT results are executed every 8.19 μs, and the amplitude is plotted by histogram as shown in Fig. 5. The amplitude of results of the STFT is counted every 1 dB resolution. For example, when the amplitude of one STFT result at 100 MHz is 15.5 dBμA, one count in the range from 15 to 16 dB is added. The red portion indicates that the amplitude value in that range is large. In other words, the fluctuation with time is small and the noise is constantly emitted stably. Blue is a region where the number is small.

Fig. 5 (a) is the histogram of the one LED bulb. Since the red part at peak frequencies below 100 MHz can be observed, the time variation of the amplitude at peak frequency is very small. On the other hand, at the peak frequency above the 150 MHz, it can be seen that there is a large variation of the amplitude at the peak frequency. There are two reasons for this. For first reason, it is conceivable that the harmonic component due to switching has large amplitude variation with time.

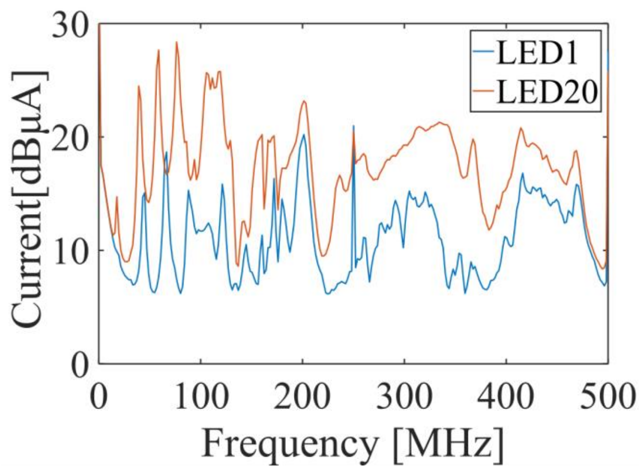


Fig. 6 Effective current at one LED and 20 LED

Second reason, resonance sharpness Q of power line is not high above 150 MHz [4]. Because power line is connected lamp receptacle by screw, the power line does not have a uniform transmission line structure.

As the histogram of the current from the 20 number of LED bulbs is shown in Fig. 5 (b), the current amplitude becomes larger by about 10 dB than that of one LED bulb shown in Fig. 5 (a). The resonance peaks are appeared at 40.2, 57.7, 76.8 and 93.9 MHz. The number of peaks below 100 MHz is increased compared with that of one LED bulb. Because the capacitor of the power converter circuit into the LED bulb adds power line, it is consider that the resonance condition by *LC* circuit on the power line is changed [4].

In the case of one LED bulb, the variation of the amplitude is small at the resonance frequency. However, the variation was large even at the resonance frequency at 20 LED bulbs. It is consider that there are two reason of this case. For first reason, each LED bulb has a different individual difference in the amplitude value of the noise. Second reason, the distance between each LED bulb and current probe is difference. The traveling wave of current generated from LED bulb is added with reflecting wave, and standing wave is observed on the power line. The shape of the standing wave varies depending on the measurement point on the power line, because the standing wave varies from maximum to minimum at the λ/4 cycle. Even at the resonance frequency, the amplitude value varies depending on the position of LED bulb. When the 20 LED bulbs are connected power line, these phenomena occur at each LED bulbs, and current noise is synthesized by radiated noise from each LED bulbs.

The magnitude of the noise is obtained the effective current at each frequency of (1) for the amplitude that varies with time.

$$I(f) = \sqrt{\frac{1}{T}\int_0^T i(t,f)dt} \qquad (1)$$

Where, T is the time of the measured whole waveform, and the dt is time of one STFT.

The results of one STFT are converted to effective current spectrum by (1). Fig. 6 shows the power spectrum for one and 20 LED bulbs. As the number of LED bulb increases, the current amplitude increases to approximately 10 to 15dB. Since the result of power spectrum line in Fig.6 is coincided with the large number of the histogram point as shown in Fig. 5, it is considered that the effective component giving noise interference can be represented by the effective current spectrum.

V. Conclusion

As a method of evaluating current noise generated from a plurality of LED bulbs connected to the power line, the measured current waveform is converted to the frequency spectrum used by STFT. The spike-shaped current waveform due to switching of inverter circuit is observed. When the spike-shaped current waveforms generate, the large amplitude noise at wide frequency band is observed. The current waveform converts to frequency spectrum by STFT. Since the spike-shaped waveform diminishes over time, current noise amplitude at time zone during which noise is not generated is very small. The amplitude variation at the peak frequency is small. As the peak frequencies are estimated the power line resonance, current noise generated by spike-shaped noise does not decrease. On the other hand, at the 20 LED bulbs, the current waveform synthesized from each LED bulbs is non-periodic and non-uniform. The variation of amplitude is larger than that of one LED due to distance between LISN to LED bulbs or individual specificity of each LED bulbs. The effective current variating to time is calculated. The maximum histogram at each frequency is coincided with effective current. We consider that these methods can be used to evaluate the noise from multiple LED bulbs connected to power line.

In the future, we want to analyze the noise fluctuation caused by switching.

[1] T. Kasuga, T. Ohashi, S. Yamada and H. Inoue, “A study on measurement method of near electric field noise from LED bulbs”, 2012 Proceedings of SICE Annual Conference (SICE) pp. 428 – 432, (2012).

[2] I. Wu, H. Ohta, K. Gotoh, S. Ishigami and Y. Matsumoto, “Characteristics of radiation noise from an LED lamp and its effect on the BER performance of an OFDM system for DTTB”, IEEE Transactions on EMC, vol. 56, pp. 132-142, (2014).

[3] CISPR 15 ed. 8.0, “Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment”, International Special Committee on Radio Interference, May 2013.

[4] Y. Hanaoka, S. Yamada, T. Kasuga and H. Inoue, “Study on current noise and transmission characteristics for electric power line with LED bulbs”, IEICE Tech. report, EMCJ2017-28, (2017).

[5] A. Komori, Y. Hanaoka, T. Kasuga and H. Inoue, “Study on currnet noise gerated from multiple LED bulb”, 2018 IEICE Soicety Conference, B-4-39, (2018).