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Electromagnetic Compatibility Issues in Wireless Medical Telemetry Systems Used in Japan

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Abstract

Recently, the electromagnetic (EM) disturbance emission from electrical devices has been a concern in clinical settings because it is a potential source of electromagnetic interference (EMI) problems for wireless systems containing medical equipment. Within such a clinical context, in this paper, we specifically discuss the interference between wireless medical telemetry systems (WMTSs) and EM noise emitted from light-emitting diode (LED) lamps (LED noise). This interference scenario essentially entails cumbersome constraints and difficulties. For example, the receiving antennas of a WMTS are often placed at a short distance from LED lamps on the ceiling to cover all the patients carrying a transmitter in a medical ward, which makes the evaluation of interference in the near field a necessity. Furthermore, many LED lamps are often simultaneously used, and not only LED lamp units but also their power feeding cables emit EM noise; therefore, the noise source is spatially distributed in actual situations. In this paper, we first report an experimental investigation of the spatial distribution of EM disturbance around an LED lamp and its power line under a basic configuration. In addition, the statistical characteristics of LED noise are studied using measured data as time series. Finally, we perform a quantitative evaluation of the impact of LED noise on the receiver sensitivity of a WMTS. We conclude that band-limited LED noise can be assumed as Gaussian noise with average power equivalent to that of LED noise in the interference evaluation of the WMTS.

1. Introduction

Wireless medical telemetry systems (WMTSs) use wireless communications to monitor a patient's vital signs such as the heart rate with an electrocardiogram (ECG) and the respiration rate in hospitals, and they allow patients to move around within medical wards without being fixed to the bedside. To promote the safe introduction and operation of WMTSs, it is important to consider the range of access, interference by intermodulation, invading waves from other facilities, and effective channel allocation [1]. Additionally, electromagnetic interference (EMI) has been a serious problem with WMTSs with the increase in the number of energy-conservation devices mounted in a switching power supply module [1, 2]. In particular, LED lamps are rapidly being introduced in hospitals, and it is well known that they cause EMI for some common wireless communication and digital broadcasting systems [3]. Similarly, WMTSs can also affected due to EM noise emitted from LED lamps (LED noise) [4].

Although many cases of interference concerning WMTSs and LED lamps have been reported, a quantitative evaluation is still insufficient. In this paper, we first introduce a current EMI issue in WMTSs, then (i) the frequency spectrum of LED noise, (ii) the spatial distribution of the noise amplitude around LED lamps and their power lines, (iii) the statistical properties of band-limited time series of LED noise, and (iv) the experimental evaluation of the degradation of the receiver sensitivity of a WMTS consistently subjected to interference by LED noise are presented.

2. Specifications of WMTSs Used in Japan and Their Current Issues

The Association of Radio Industries and Businesses (ARIB) of Japan has specified the technical requirements for WMTSs [5]. The frequency range from 420 to 450 MHz is assigned for WMTSs in Japan. Japanese WMTSs are classified by their bandwidth and output power. The type-A operation mode, which is most widely used for vital-sign transmission in Japan, is usually employed in patient monitoring. Japanese type-A WMTSs have a narrowband reception (8.5 kHz) and a low power output (1 mW). For an essential application as the WMTS, a sustained connection is the most important requirement, although a high data transmission rate is not necessary. Therefore, to ensure sufficient communication quality, EM noises radiated from surrounding electric devices and unwanted waves from WMTSs in other facilities must be well managed by some means.

Actually, EMI can easily occur with WMTSs because their frequency band of 400 MHz is shared and used by other wireless communication systems, such as amateur radio and nurse call systems. In addition, EM noise from some electrical devices is a considerable issue. The frequency of these disturbances, such as the switching noise from a power supply, exceeds 400 MHz [6]. In the following section, we discuss the switching noise from the power supply built in LED lamps and its impact on the receiver sensitivity of the WMTS.

3. Measurement of EM Noise Emitted from LED Lamp

3.1 Spatial Distribution of LED Noise in Near Field

LED lamps generally employ a switched-mode power supply. However, high-speed switching operation usually causes wideband EM disturbance [3]. To investigate the effect of LED noise on the WMTS, the spectrum distribution and spatial distribution of LED noise were examined. In consideration of that the LED lamp and receiving antenna of WMTSs are sometimes installed close to each other at the ceiling [2], the spectrum distribution of the LED noise was measured assuming that the receiving antenna of the WMTS is arranged near the LED lamp.

Figure 1 shows the result of the spectrum distribution of the LED noise for various LED lamps in the case of a distance of 1 cm between the LED lamp and the receiving antenna. Strong radiation was observed in the 400 MHz band for some LED lamps. Generally, the switching frequency of an LED lamp is around 100 kHz, but it seems that the LED noise is generated over the wide frequency range. This noise at high frequencies may be generated by the parasitic capacitance caused by the semiconductor element, PCB, and the installation cable of the LED lamp [3].

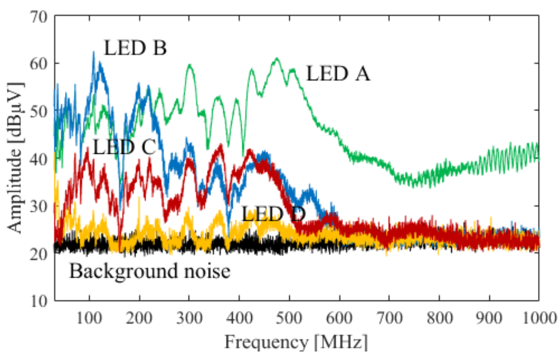

Figure 1. Spectrum distribution of LED noise (resolution bandwidth [RBW]: 100 kHz, peak detector in maximum-hold mode)

Note that LED noise is radiated from not only bulb units but also their power lines [7]. Therefore, to clarify the spatial distribution of the complicated near-field disturbance, we carried out a two-dimensional measurement of the noise amplitude around an LED lamp installed at the center of a duct rail for electrical power feeding. The LED noise peak level was detected at a frequency of 420 MHz at each spatial point around the duct rail. The measurement space (XY plane) was set to 200 cm ×100 cm. The range of X direction was equal to the length of the duct rail and the range of Y direction took more than one wavelength in order to investigate attenuation characteristic of LED noise. The height of the LED was 5 cm above the duct rail. The position of the lamp was (X, Y)=(100 cm, 90 cm).

Figure 2 shows the measured spatial distribution of LED noise using a dipole antenna with a resolution bandwidth (RBW) of 2 MHz. The spatial variation in the X-direction indicates the existence of a standing wave of a disturbance current induced in the duct rail generated by the switching operation in the LED lamp. The peaks and troughs of the noise amplitude along the duct rail appear every half wavelength (420 MHz). Furthermore, focusing on the spatial distribution in the Y direction, we also found that the noise level was simply reduced.

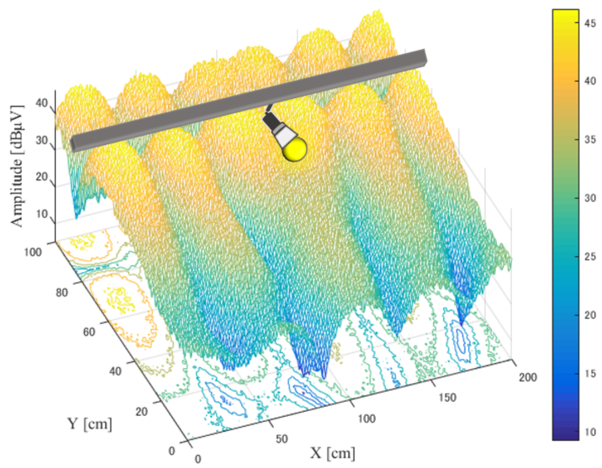

Figure 2. Spatial distribution of LED noise amplitude (dipole antenna, RBW=2 MHz, peak detection)

Figure 3 shows the measurement result obtained with a whip antenna used in a WMTS with an RBW of 10 kHz, which is nearly equal to the bandwidth of the WMTS. This figure can be considered as a case where WMTS actually suffered from LED noise. The spatial distribution shows some ambiguity with a lower amplitude than that of the wideband measurement shown in Figure 2; however, almost the same tendency was obtained.

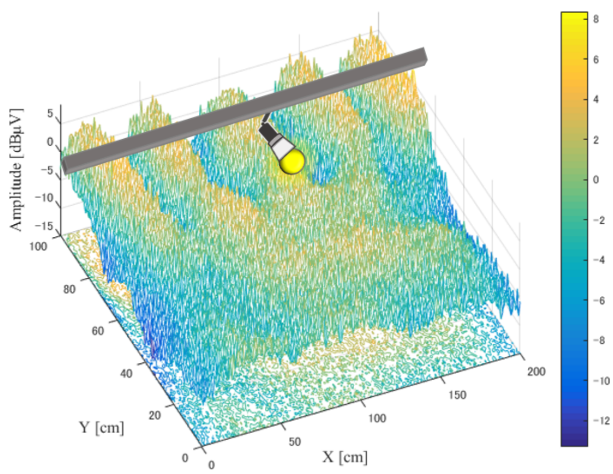

Figure 3. Spatial distribution of LED noise amplitude (whip antenna , RBW= 10 kHz, peak detection)

3.2 Statistical Characteristics of Time Series of Band-limited LED noise

Generally, LED lamps radiate a sequence of impulse waves for each operation of switched-mode supply [3]. Figure 4 shows an example of the time domain envelope(-detected) waveform of the radiation noise from LED lamp-A observed with a spectrum analyzer tuned at 444.7625 MHz with an RBW of 1 MHz. On the other hand, WMTSs have narrow band reception of 8.5 kHz, which is narrower than the pulse repetition frequency of the LED noise. Figure 5 shows the time domain envelope waveform of the radiation noise from LED lamp-A with an RBW of 10 kHz. The identification of sequential and impulsive waves is difficult.

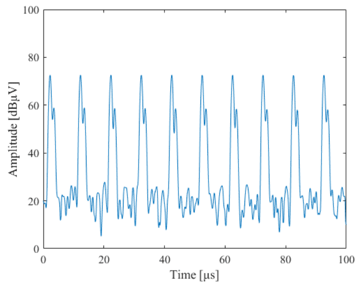

Figure 4. Time domain waveform of radiation noise from LED lamp-A (RBW: 1 MHz, sweep time: 100 μs)

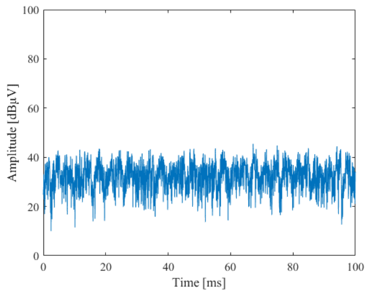

Figure 5. Time domain waveform of radiation noise from LED lamp-A (RBW: 10 kHz, sweep time: 100 ms)

It has been reported that the statistical characteristics of EM noise are similar to those of Gaussian noise when the RBW becomes narrow [3]. In this section, we investigated the relationship between the statistical characteristics of band-limited LED noise and Gaussian noise. The amplitude probability distribution (APD) is commonly regarded as promising statistical information for such EMI evaluation and is directly correlated with the performance of digital communication systems subjected to EMI [8]. The APD is defined as

$$APD(x) = \sum_{i=1}^{n(x)} W_i(x)/T_0, \tag{1}$$

where W_i indicates the duration in which the noise envelope $x(t)$ exceeds a certain level x, the variable i (ranging from 1 to n) is the number of times that $x(t)$ exceeds x, and T_0 is the total measurement time. We used time series data of band-limited noise from four LED lamps to obtain the APDs. Additionally, we calculated the APD of a band-limited Gaussian noise, APD_r, which has average power equal to that of the measured LED noise. $APD_r(r)$ is given by the following Rayleigh distribution.

$$APD_r(r) = \exp\left(-\frac{r^2}{2\sigma^2}\right) \tag{2}$$

Here, r is the instantaneous envelope voltage and σ^2 is the average power of the LED noise. Figure 6 shows the measured and calculated APDs of noise with a narrow band (10 kHz). Each APD of the measured LED noise is in good agreement with the calculated APD of Gaussian noise. This agreement suggests that the impact of EMI on WMTSs can be easily evaluated by approximating the LED noise radiation with Gaussian noise.

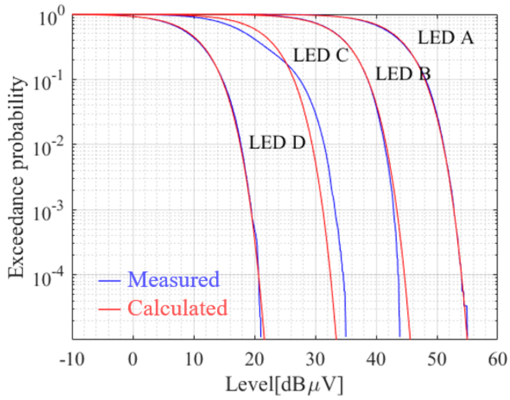

Figure 6. Comparison between measured and calculated APDs

4. Receiver Sensitivity of Affected WMTS

As described earlier, most of the technical requirements for WMTSs are specified in the ARIB standard [5]. However, the minimum reception sensitivity of the receiver is under the sole discretion of the manufacturer. We investigated the critical reception of WMTSs subjected to EMI by LED noise. Figure 7 shows a schematic diagram of the measurement setup.

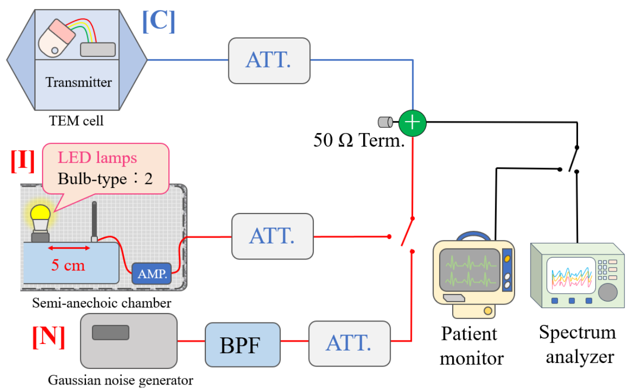

Figure 7. Expetimental setup to examine receiver sensitivity of affected WMTS

The type-A transmitter of the wireless medical telemeter with a carrier frequency of 429.25 MHz was connected to a vital-sign simulator and sent normal ECG signals at a rate of 80 waves per minute. The transmitter and vital-sign simulator were placed in a transverse electromagnetic

(TEM) cell to extract telemetry signals. On the other hand, LED noise was acquired via the whip antenna 5 cm from the LED lamp. In addition, Gaussian noise in the 400 MHz band was generated by the noise generator, whose power within the wireless medical telemetry bandwidth (8.5 kHz) was adjusted to be the same as the average noise power from each LED lamp. Both the telemetry signal and the noise were inputted into the patient monitor through a hybrid coupler. The degradation of wireless reception owing to the noise was evaluated by visual examination of the ECG waveforms on the display of the patient monitor. The critical telemetry signal level for normal reception was found by decreasing the signal level with an attenuator (ATT) using the decision criteria of defined normal reception such that no abnormality in ECG waves is observed during 100 wave periods.

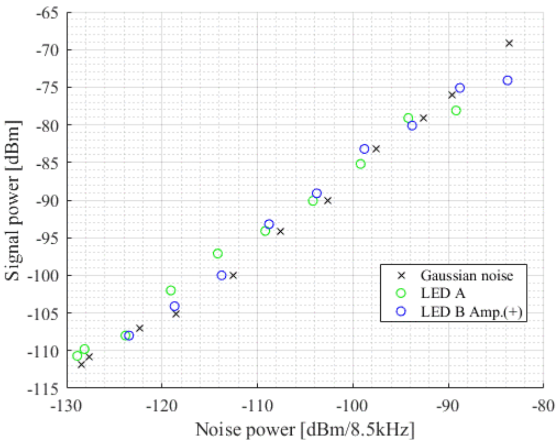

Figure 8. Degradation of communication performance in the WMTS in the presence of LED noise and Gaussian noise

Figure 8 shows the required signal power for critical reception in the WMTS as a function of the noise power for LED noise and Gaussian noise. The LED noise and Gaussian noise produce similar degradation in the WMTS, confirming that the Gaussian approximation is promising for the evaluation of EMI in the WMTS caused by LED lamps. In addition, the required signal level where the receiving antenna was placed near the LED lamp is predictable using the result of the previous electromagnetic noise distribution measurement.

5. Conclusions

We have discussed EMI issues, especially in clinical settings in Japan. In recent years, EMI caused by radiation noise from LED lamps has been a serious problem for WMTSs because of the spatial restriction on the ceiling where the victim antenna and disturbance sources are installed close to each other. We initially showed the two-dimensional spatial distribution of the EM disturbance in the near field of an installed LED lamp by performing both wideband and narrowband measurements. The spatial variation caused by a standing wave of the disturbance current was observed in the parallel direction to the power feeding line, and the noise amplitude decreased away from the duct rail in the perpendicular direction. Next, the statistical characteristics of the time series of the band-limited EM disturbance in the WMTS were analyzed. The APD of the band-limited disturbance was well approximated as Gaussian noise with average power equivalent to that of the EM disturbance when the measurement bandwidth was equal to 8.5 kHz. Finally, we showed the degradation of the receiver sensitivity of the WMTS caused by LED noise, in comparison with the degradation in the presence of Gaussian noise. Good agreement was observed between the LED noise and the Gaussian noise, which implies that a simple Gaussian evaluation is sufficient for EMI analysis for WMTSs.

7. References

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