Impact of LED lamp noise on receiver sensitivity of wireless medical telemetry system

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Abstract: To evaluate the electromagnetic interference (EMI) in a wireless medical telemetry system (WMTS) caused by LED lamp emission, the statistical characteristics of noise and its impact on the receiver sensitivity of the WMTS were investigated. Noise from LED lamp is generally wide-band owing to high-speed switching, but the WMTS employs narrow-band reception of 8.5 kHz. The amplitude probability distribution of band-limited noise from LED lamp agrees well with that of Gaussian noise with average power equal to that of band-limited LED noise. The increase in the required signal power of the WMTS for critical reception, caused by LED noise, was almost the same as that in the case of purely Gaussian noise with equal power. The above results indicate that LED noise interfering with a WMTS channel can be well modeled by Gaussian noise, and that the interference effect can be simply represented by the reduction in the receiving carrier-to-noise ratio (CNR), enabling easier evaluation of the impact of interference in the WMTS by using the CNR.

Keywords: LED lamp wireless medical telemetry system, receiver sensitivity, amplitude probability distribution, switching noise

Classification: Electromagnetic Compatibility (EMC)

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1 Introduction

Wireless medical telemetry systems (WMTSs), now widely used in hospitals, require radio-frequency (RF) communication to send patient vital signs [e.g., electrocardiogram (ECG), respiration rate, blood pressure, and arterial oxygen saturation] to enable remote monitoring from a central staff station without restricting the movement of patients. Each patient has a small transmitter connected to an electrode on their body. Receiving antennas are installed in several locations in the hospital. In Japan, the 400 MHz frequency band has been allocated to WMTSs used as the specified low-power radio stations by the Japanese Radio Law.

In recent years, WMTSs have encountered a fatal electromagnetic interference problem caused by electromagnetic noise emitted from LED lamps [1] since the receiving antennas of WMTSs are, in many cases, installed in the ceiling of patient rooms or the corridors of wards at short distances from LED lamps owing to space or structural limitations [2]. Since this interference phenomenon is a life-threatening problem in some cases, it is strongly desired to formulate guidelines on the use of WMTSs and LED lamps in hospitals. In this study, the statistical characteristics of noise emitted from LED lamps and its impact on the receiver sensitivity of WMTS were investigated.

2 Statistical characteristics of noise emitted from LED lamps

Generally, LED lamps employ a switched-mode power supply to control the power supply to obtain suitable light intensity with energy-saving performance. This steep voltage variation induces broadband pulsed noise emission. The upper bound frequency of the noise spectrum can exceed 500 MHz in some instances [3]. This characteristic strongly depends on the transition times of the upstroke and downstroke of the power voltage induced by the switching operation [4]. Fig. 1 shows examples of frequency spectra of the noise from LED lamps measured in an anechoic chamber using a near-field probe and a spectrum analyzer [resolution bandwidth (RBW) of 0.1 MHz, peak detector in maximum-hold mode] with a preamplifier at a measurement distance of 0.01 m. Commercially available LED lamps that generate relatively strong noise emission, LED-A, -B, -C, and -D, are
used for the measurement. A strong noise component in the frequency band of 400 MHz is observed for LED-A and -B.

![Fig. 1. Frequency spectra (LED-A, -B, -C, and -D).](image)

Also, CISPR 15 is an international standard that regulates the limits of radiation noise in the range from 30 to 1000 MHz from LED lamps. However, the measurement method described in the standard is not suitable for the evaluation of the impact of the WMTS. The distance between the receiving antenna and the wave source is set to 3 m, but the distance between the receiving antenna of the WMTS and LED lamps in real situations is much shorter. Our measurement is carried out with the distance between the antenna and LED lamp fixed at 0.05 m, assuming a practical layout of the worst case in which the distance between the WMTS receiving antenna and LED lamp is very small. Moreover, the measurement bandwidth of 100 kHz and the quasi-peak (QP) detection are specified in the standard, but the bandwidth of the WMTS is much narrower and QP detection correlates with the quality of analog communication. However, the WMTS employs digital strategies such as frequency shift keying (FSK).

On the other hand, the amplitude probability distribution (APD) is promising statistical information for such interference evaluation and is directly correlated with the performance of digital communication systems subjected to interference [5]. The APD is the complementary cumulative distribution of the envelope amplitude $r$ of noise and is given as

$$APD(x) = 1 - \int_{-\infty}^{x} p(r) \, dr = \int_{x}^{\infty} p(r) \, dr,$$

where $p(r)$ is the probability density function of $r$. The APD can also be explained as the exceedance probability that an envelope $r$ and amplitude $x$.

In order to obtain the APD of LED noise, the time variation in the envelope amplitude of LED noise at the frequency of one of the WMTS channels (444.7625 MHz) was measured using a spectrum analyzer in the zero-span mode. A whip antenna used in an actual WMTS was employed as a sensor in the measurement to investigate the impact of disturbance on the WMTS.

Fig. 2(a) depicts the time series data of the noise envelope from LED-A at an RBW of 1 MHz. A sequential impulse waveform with a repetition rate of 100 kHz was observed. Fig. 2(b) depicts the empirical APDs of noise from LED-A, -B, -C, and -D with this wide RBW (1 MHz), obtained by data processing through a
histogram of the time series data shown in Fig. 1. The APD measured with an RBW of 1 MHz shows a horizontal plateau on the curve, which means that the time variation in the amplitude has a pulse component, and the corresponding probability of reaching a plateau indicates the average duty cycle of the pulses.

On the other hand, the WMTS employs a narrow-band reception of 8.5 kHz. Additionally, the measurement bandwidth should be approximately the same as the bandwidth of the communication signal in the evaluation of the WMTS using the APD [5]. Fig. 2(c) depicts the time series data of band-limited noise from LED-A at an RBW of 10 kHz, which was also equivalent to that of the WMTS. The identification of the impulsive characteristics of this noise is difficult. Fig. 2(d) depicts the empirical APDs of noise with this narrow RBW (10 kHz), as obtained using the data in Fig. 2(c). The APD curve of Gaussian noise that has power equal to that of each measured noise with a 10 kHz bandwidth is calculated using Eq. (2), i.e., the theoretical APD of the Rayleigh-distributed envelope amplitude.

\[
APD(x) = \exp\left(-\frac{x^2}{2\sigma^2}\right)
\]  

For the APDs for the RBW of 10 kHz, there is no plateau and the curve smoothly decreases. In fact, each APD of the measured noise is in good agreement with the theoretical APD of Gaussian noise. Therefore, we are able to approximate LED noise by Gaussian noise in a statistical sense, and this will enable easier analysis of the impact of interference in the WMTS.

Fig. 2. Characteristics of noise emitted from LED lamp.
3 Critical reception of WMTS subjected to interference by LED emission

The technical requirements for WMTSs are specified in the ARIB standard [6], and the operation mode called “type-A”, which is the most popular vital-sign transmission method in Japan, is usually employed. Hence, the consideration in this study is focused on the type-A system. Although parameters such as the frequency channel allocation (420 to 450 MHz with 12.5 kHz channel bandwidth), modulation scheme (FSK), and antenna power (1 mW) are specified in [6], the minimum reception sensitivity of the receiver is the sole discretion of the manufacturer, and the other added value of their products is dependent on their technical achievement. In this section, the receiver sensitivity of the WMTS in the presence of LED lamp emission is experimentally determined.

Fig. 3(a) shows a schematic diagram of the whole experimental system. The transmitter of the WMTS, of which the carrier frequency is 429.25 MHz, is connected to a vital-sign simulator and sends normal ECG signals at a rate of 80 waves per minute in a transverse electromagnetic (TEM) cell to extract the WMTS signal. This signal is recorded by an RF-capturing apparatus and reproduced by the RF player to maintain a constant transmitting power and avoid unwanted electromagnetic coupling of the telemetry signal from the transmitter to the receiver. On the other hand, we used two types of noise source and switched them in this experiment. Noise emitted from the LED lamp bulb mounted in an anechoic chamber is acquired via the whip antenna 0.05 m from the bulb. Additionally, the noise generator generates purely Gaussian noise in the 400 MHz band, whose power within the WMTS bandwidth (8.5 kHz) is adjusted to be the same as the average noise power from each LED lamp bulb. Acquired noise is coupled to the WMTS signal, and eventually, the interfered signal is led to the WMTS receiver. The degradation of wireless reception owing to the noise is evaluated by visual examination of the ECG waveforms on the receiver display. The critical WMTS signal level for normal reception is found by decreasing the signal level using an attenuator (ATT) using decision criteria of normal reception defined such that no abnormality on ECG waves is observed during one hundred wave periods. The WMTS signal power $C$ and noise power $I$ or Gaussian noise power $N$ are each measured at the input port of the receiver in a bandwidth of 8.5 kHz using the spectrum analyzer. When the average power of $I$ is close to the noise floor of the spectrum analyzer, the actual $I$ is calculated by

$$I \text{ [dBm/8.5 kHz]} = (I_{\text{LED}} \cdot A_c + (1 - A_c) \cdot kT_0 B), \quad (3)$$

where $I_{\text{LED}}$ is the average power of noise (which should be much higher than the noise floor of the spectrum analyzer) measured with no attenuation, $A_c$ is the attenuation (less than or equal to unity), $kT_0$ is the thermal noise of $-174 \text{ dBm/Hz}$, and $B$ is the bandwidth of the WMTS (8.5 kHz).

Fig. 3(b) shows the required signal power for critical reception in the WMTS, corresponding to noise power for LED-A, LED-B, amplified LED-B, and Gaussian approximated noise. The noise power was adjusted for weak to strong emission using the AMP and ATT. The average power of noise from LED-B is much lower. However, the WMTS usually includes some AMPs to receive weak signals under
any circumstances at hospital wards. This means that the weak signals of both the WMTS and the LED noise are amplified. Therefore, interference with the actual WMTS may occur as a result of amplified LED noise in clinical settings.

LED noise and Gaussian noise produce similar degradation in the WMTS, confirming that the Gaussian approximation is promising for the evaluation of interference in the WMTS caused by LED lamps. The required CNR is provided as approximately 15 ± 2 dB, as shown by the difference between the required signal power (vertical axis) and the noise power (horizontal axis) in Fig. 3(b).

4 Conclusion

We evaluated the electromagnetic interference in a WMTS caused by LED lamp emission. Considering that the WMTS employs a narrow reception bandwidth of 8.5 kHz, the disturbance from LED lamp was assumed to be approximated by Gaussian noise because the LED noise was limited to the bandwidth of the WMTS signal. It was demonstrated that the empirical APD of band-limited noise from each LED lamp agreed well with the APD of Gaussian noise with power equal to that of the measured noise. Moreover, the required signal power of the WMTS for critical reception under interference due to LED noise was almost the same as that under interference due to Gaussian noise. Therefore, it is possible to evaluate real clinical settings containing LED devices by approximating LED noise by Gaussian noise of equal power, which enables easier evaluation of the impact of interference on WMTSs.