Received noise voltage of wearable transceiver in the presence of fluorescent lamps using high-frequency electronic ballasts

Nozomi Haga[1a]**, Kuniyuki Motojima**[1]**,
Mitsuru Shinagawa**[2]**, and Yuichi Kado**[3]

[1] *Faculty of Science and Technology, Gunma University,*

1–5–1 Tenjin-cho, Kiryu, Gunma 376–8515, Japan

[2] *Faculty of Science and Engineering, Hosei University,*

3–7–2 Kajino-cho, Koganei, Tokyo 184–8584, Japan

[3] *Department of Electronics, Kyoto Institute of Technology,*

Hashikami-cho, Matsugasaki, Sakyo-ku, Kyoto 606–8585, Japan

a) *haga@el.gunma-u.ac.jp*

Abstract: In the development of intrabody communication systems, the most challenging goal is to protect against noise due to other electronic devices. In this regard, it is known that fluorescent lamps using high-frequency electronic ballasts generate significant noise in electromagnetic fields. In this paper, we conduct an experiment of noise voltage received by a wearable transceiver in the presence of fluorescent lamps using high-frequency electronic ballasts, and show that the noise electric fields generated by the lamps result in a significant level of the received noise voltage.
Keywords: intrabody communications, noise, fluorescent lamps
Classification: Microwave and millimeter wave devices, circuits, and systems

References

[1] P. S. Hall and Y. Hao: *Antennas and Propagation for Body-Centric Wireless Communications* (Artech House, Norwood, MA, 2006).
[2] T. G. Zimmerman: IBM Syst. J. **35** (1996) 609. DOI:10.1147/sj.353.0609
[3] K. Fujii, M. Takahashi and K. Ito: IEEE Trans. Antennas Propag. **55** (2007) 2080. DOI:10.1109/TAP.2007.900226
[4] N. Haga, K. Saito, M. Takahashi and K. Ito: IEICE Trans. Commun. **E95-B** (2012) 51. DOI:10.1587/transcom.E95.B.51
[5] A. Sasaki, T. Ishihara, N. Shibata, R. Kawano, H. Morimura and M. Shinagawa: IEEE Trans. Antennas Propag. **61** (2013) 390. DOI:10.1109/TAP.2012.2220110
[6] R. Redl: Proc. IEEE **89** (2001) 926. DOI:10.1109/5.931490
[7] Y. Namba, T. Morita and K. Hirata: Int. Zurich Symp. Electromagn. Compat. (2006) 449. DOI:10.1109/EMCZUR.2006.214968
[8] F. Giezendanner, J. Biela, J. W. Kolar and S. Zudrell-Koch: IEEE Trans. Power Electron. **25** (2010) 2133. DOI:10.1109/TPEL.2010.2046424

[9] I. Wu, H. Ohta, K. Gotoh, S. Ishigami and Y. Matsumoto: IEEE Trans. Electromagn. Compat. **56** (2014) 132. DOI:10.1109/TEMC.2013.2277596

1 Introduction

In recent years, body-centric wireless communications have been studied because they have the potential to improve the quality of health care systems, support systems for specialized occupations, personal entertainment, and so on [1]. They are generally classified into on-, in-, and off-body communications. On-body communications that use frequencies below several tens of megahertz are also known as intrabody communications. The physical channels establishing intrabody communications were first modeled as capacitive circuits [2]. Then, more accurate channel characterization has been made by means of full-wave analysis [3] and improved circuit model based on electrostatic analysis [4].

Although the signal transmission mechanism of intrabody communications has been clarified, the most challenging goal is to protect against noise due to other electronic devices [5]. As we all know, power circuits equipped in electronic devices generate high-frequency noise due to the switching operation of power semiconductors [6]. In particular, the noise whose current path includes parasitic capacitances formed between noise sources and the earth ground, which is known as common-mode noise [6], involves conduction currents into the grounding systems and electromagnetic emissions into the space, and it is potentially transmitted to transceivers.

Fig. 1 shows a circuit model that roughly represents the noise transmission through the grounding system. Here the ground symbol corresponds to the earth ground, and the common node of the inductances corresponds to a distribution board. This circuit model suggests that: the noise voltage source V_0 induces primary current I_1 from C_1 to L_3; then the secondary current I_2 is induced from L_3 to C_2; and it results in received noise voltage across the load impedance R of the transceiver. In other words, the noise source and the transceiver are coupled by the common inductance L_3.
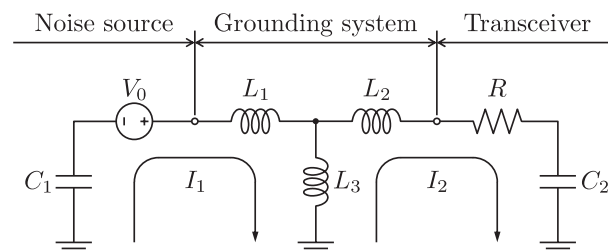

Fig. 1. Circuit model representing noise transmission through the grounding system.

To represent the effects of the common-mode noise conducted through grounding systems, one of the authors has proposed an extended circuit model in which the effects of the common-mode noise are represented by a simple voltage source,

and has shown that the signal-to-noise ratio (SNR) can be improved by implementing a common-mode choke (CMC) coil to the Rx electrodes [5]. At the same time, however, it was reported that there is another noise component that cannot be represented by the model in [5], and it was left for further studies.

In this regard, one of the possible reasons is that the noise transmitted through the space, that is, the so-called radiated noise, is not taken into account in the previous model. As mentioned before, the current path of the common-mode noise often includes the parasitic capacitances formed between noise sources and the earth ground, which is represented by C_1 in Fig. 1. This means that when the common-mode current flows in the grounding system, electric fields should be generated somewhere. In fact, it is known that fluorescent lamps using high-frequency electronic ballasts generate significant noise electromagnetic fields [7, 8]. Most recently, the noise generated by the power circuits of light-emitting diode (LED) lamps has been actively discussed [9]. If the transceiver is in the vicinity of such noise sources and is immersed in the noise electric fields, the noise should directly be transmitted to the transceiver even if the transceiver is not connected to the grounding system.

However, the significance of these noise electric fields on intrabody communication channels has not been clarified. In this paper, we made an experiment of noise voltage received by a wearable transceiver in the presence of fluorescent lamps using high-frequency electronic ballasts, and show that the noise electric fields generated by the lamps result in a significant level of the received noise voltage.

2 Battery-powered receiver used for measurement

As mentioned before, the noise can be transmitted to the Rx through both the grounding systems and space. To remove the contribution of the former, a battery-powered Rx was used in the measurement.

Fig. 2 shows the battery-powered Rx, which consists of a glass epoxy universal circuit board of $72\,mm \times 95\,mm \times 1.2\,mm$ and two copper electrodes of $72\,mm \times 95\,mm \times 0.5\,mm$. The electrode that faces the human body is called the "bottom" electrode, and that which faces space is called the "top" electrode. They are separated by a gap of 5 mm. The circuit board is stacked on the top electrode, and the gap between them is 5 mm. The ground and the signal terminals of the circuit are connected to the top and the bottom electrodes, respectively.

The receiving circuit is optimized for 10 MHz, which is a typical frequency for intrabody communications [3]. To explain the frequency dependence of the receiving sensitivity, Fig. 3 shows the equivalent circuit of the input stage of the Rx. Here the ground symbol corresponds to the circuit ground of the Rx. The Rx electrodes are represented by Thévenin's equivalent voltage source V_0 in series with the capacitance of 16.9 pF, where V_0 is the received open voltage between the electrodes, and 16.9 pF is the input capacitance of the electrodes. The value of the capacitance (16.9 pF) was estimated by means of electrostatic analysis based on the method of moments, and it may slightly vary depending on the environment surrounding the electrodes. The Rx electrodes drive the buffer amplifier of which
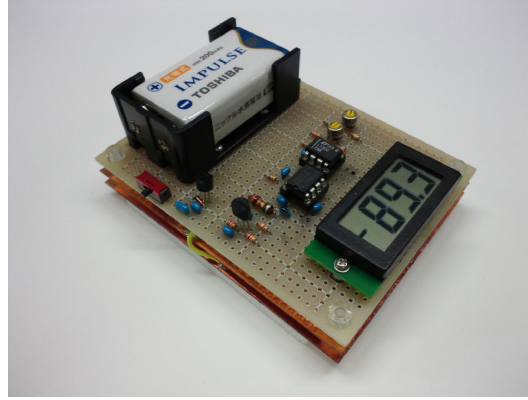
Fig. 2. Battery-powered receiver.

input and output impedances are $10\,\text{k}\Omega$ and $30\,\Omega$, respectively. For the impedance matching between the output impedance of the buffer amplifier ($30\,\Omega$) and the input impedance of the detector ($1.1\,\text{k}\Omega$), a low-pass type *LC* matching circuit is inserted between them.
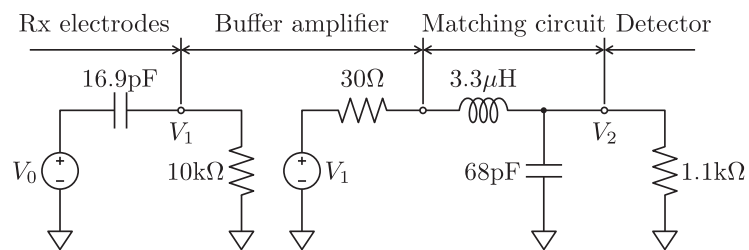

Fig. 3. Equivalent circuit of the input stage of the Rx.

Fig. 4 plots the voltage transfer function, which is defined as the ratio of the voltage across the detector V_2 to the received open voltage V_0, that is, V_2/V_0. The high-pass characteristic below 1 MHz is due to the *RC* circuit consisting of $16.9\,\text{pF}$ and $10\,\text{k}\Omega$. On the other hand, the low-pass characteristic above 10 MHz is due to the *LC* matching circuit, and it has a role to reject high-frequency interfering waves such as the frequency modulation (FM) broadcast band, which is 76 to 90 MHz in Japan. The detected voltage V_2 is displayed on a digital panel meter in decibel scale.

3 Measurement setup

Fig. 5 shows the measurement setup in our laboratory. The Rx was mounted on the right side of the body (height: 1.71 m, weight: 54 kg) so that the long side of the electrodes was along the height of the body. The bottom electrode and the body are separated by an expanded polystyrene board with a thickness of 5 mm. Its central position d from the soles, which is shown in Fig. 5, was varied in the range of $100\,\text{mm} \leq d \leq 1600\,\text{mm}$. Two parallel fluorescent tubes with a length of 1200 mm were approximately 870 mm above the head, and the distance between the tubes was 60 mm. The switching frequency of the ballasts is approximately 50 kHz.

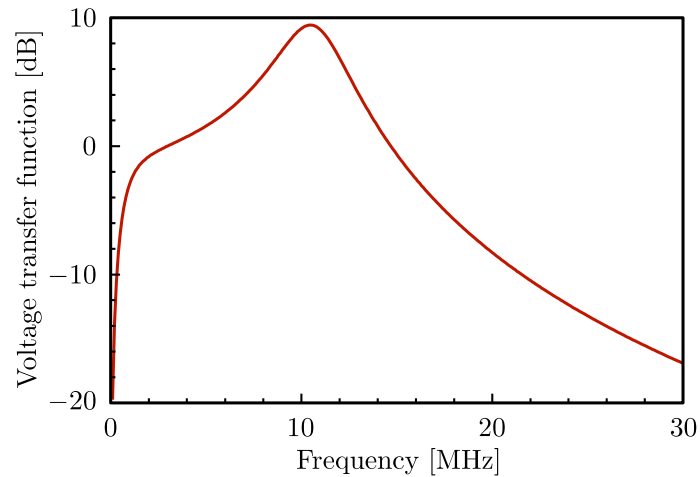**Fig. 4.** Voltage transfer function V_2/V_0 of the input stage of the Rx.

Fig. 5. Measurement setup in the laboratory.

The received noise level was measured in four conditions:

1. The Rx was ungrounded and the lamps were unlighted.
2. The Rx was ungrounded and the lamps were lighted.
3. The Rx was grounded and the lamps were unlighted.
4. The Rx was grounded and the lamps were lighted.

When the Rx was grounded, the top electrode was connected to the earth terminal of the electrical outlet through a grounding wire made of a 1.8-meter-long rubber-covered cable and an electrical clip.

4 Measured received voltage

Fig. 6 plots the measured noise levels. Here 0 dB corresponds to the level when 10-MHz sinusoidal voltage of 1 V is directly input to the buffer amplifier of the Rx. When the fluorescent lamps were unlighted, the received level in the grounded

condition is approximately 30 to 40 dB greater than that in the ungrounded condition. This may be explained by the previous model in [5]. When the fluorescent lamps were lighted, the received level considerably increases even if the Rx is ungrounded. This cannot be explained only by the previous model, in which the noise transmitted through the grounding system is assumed. It should be noted that the received level in the ungrounded condition strongly depends on the Rx position d, that is, it is strong when $d \leq 400$ mm and $d \geq 1300$ mm, and its profile has a dip in the range of 900 mm $\leq d \leq 1100$ mm.
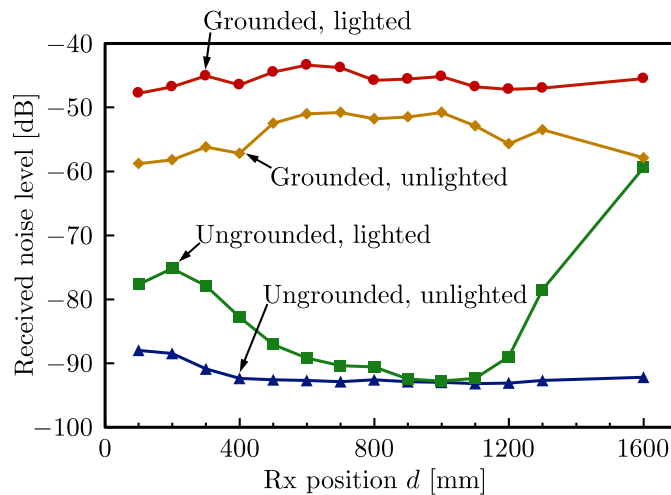

Fig. 6. Measured noise levels in the laboratory.

5 Conclusion

In the present paper, we conduct an experiment of noise voltage received by a wearable transceiver in the presence of fluorescent lamps using high-frequency electronic ballasts. The results show that the received noise level considerably increases when the lamps are lighted, even if the Rx is not grounded. In addition, the received noise level when the Rx was ungrounded and the lamps were lighted strongly depends on the Rx position d.

Acknowledgments