An experimental investigation on typical low frequency amplifiers nonlinear response to microwave/quasi-millimeter wave interference

Hiroki Seo, #Shunichi Futatsumori, Takashi Hikage, Toshio Nojima
Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, Hokkaido, 060-0814 Japan,
futatsumori@emwtinfo.ice.eng.hokudai.ac.jp

1. Introduction

Wireless communication devices such as mobile phones, radio-frequency identification (RFID), electric article surveillance (EAS), and contact less IC cards would be essential components to make up the ubiquitous society. In addition, new wireless devices such as mobile WiMAX and wireless USB have been developed. However, radio waves from these systems have the possibility of affecting other electronics devices and causing unwanted malfunctions in certain circumstances. Accordingly, investigations of electromagnetic interference (EMI) have more importance these days. In particular, EMI effects on medical equipment, including implantable medical devices and other electric instruments used in hospitals, should be precisely investigated because these are used widely in general circumstances. We have been conducting the investigation of the EMI on implantable medical devices [1], [2]. The EMI due to microwave/quasi-millimeter waveband radio waves on low-frequency electronic equipment is mainly caused by nonlinear characteristics of their internal circuits [3]. This is because the envelope of high-frequency signal is detected by the nonlinear response of circuit elements. This nonlinear response is possibly occurred when the frequency of exposure signals is higher than the cut-off frequency of circuit elements.

In this paper, a typical low frequency amplifier nonlinear response to microwave/quasi-millimeter waveband radio waves is presented. To investigate typical characteristics of interference signals generated by the nonlinear response, interference signal levels depending on frequencies and field strengths of exposure signals are experimentally obtained. Firstly, six types of low frequency basic amplifiers consisting of a single transistor or an operational amplifier IC are fabricated. Secondly, to examine the detection level depending on field strength of a 1 GHz exposure signal, the interference signal is measured. The exposure signal is a sine wave with 80 % amplitude modulation at 1 kHz. Then, to obtain the detection level depending on frequency of exposure signal, EMI experiments using a 1 GHz-25 GHz amplitude modulated signal are conducted. Finally, as practical medical equipment operating at low frequency band, measurement of interference signal using the commercially available hearing aids are carried out to obtain the EMI characteristics of actual devices.

2. Low Frequency Amplifiers and Experimental Set-Up

The EMI of medical equipments caused by wireless devices is a substantial problem, because these devices may be exposed to near field, non-uniform and non-plane radio waves. As shown in Fig. 1, although the antenna input powers are small, the field strengths of the near region of transmitting antennas are very high (more than 10 V/m). The horizontal line represents the immunity test specification IEC 61000-4-3, which defines 3 V/m plane wave exposures [4]. To achieve quantitative evaluation of the typical nonlinear response of these devices, six types of low frequency amplifier, which have the approximately 10 dB gain in the frequency range from 100 Hz to 100 kHz, are fabricated. They are comprised of a surface-mount single transistor or an operational amplifier IC. The fabricated amplifiers using the transistor and the operational amplifier

IC are basic common emitter amplifier and non-inverting amplifier, respectively. Figure 2 shows the frequency characteristics of the three amplifiers using the different cut-off frequency transistor.

A schematic diagram of the experimental set-up for examining the detection level is shown in Fig. 3. Assuming the electromagnetic exposure due to actual devices, the distance between the antenna and surface of the plastic box which contains the amplifier substrate, is fixed at 20 mm as shown in Fig. 4. The input port of the amplifiers is connected with a 600 Ω register, which models a high-impedance circuit such as a microphone or a temperature sensor. The output power of the amplifier is connected to the spectrum analyzer through the low-pass filter. This filter removes the exposure signal which would otherwise be fed directly into the spectrum analyzer.

Figure 5 shows a typical measured output spectrum obtained in the experiments. In this case, the exposure signal is a sine wave with 80 % amplitude modulation at 1 kHz. The largest component of the interference signal is observed at 1 kHz which is the lowest order harmonic of the exposure signals' envelope. During the measurements, the polarization of the antenna can be modified in order to obtain maximum interference signal power.

3. Nonlinear Response of Basic Low Frequency Amplifiers

To examine the detection level depending on field strength of a 1 GHz exposure signal, the interference signal are measured. The exposure signal is a sine wave with 80 % amplitude modulation at 1 kHz, the same as the previous section. The electric filed strength of the exposure signal is changed from 5 V/m to 100 V/m, and is measured on the plastic boxes' surface. Figure 6 shows the measured interference signals of the three different low frequency transistor amplifiers. As shown in the figure, the amplitudes of the interference signal generated in the all transistor amplifiers are proportional to the square of the electric field strength of the exposure signal. This is because strong exposure signals become rectified by the amplifier's input stage and then appears as interference signals.

Then, to obtain the detection level depending on the frequency of exposure signal, the interference signals are measured using a 1 GHz-25 GHz amplitude modulated exposure signal. The electric field strength on the surface of plastic box is fixed at 80 V/m. Figure 7 shows the measured interference signals of the three different low frequency transistor amplifiers as a function of exposure signal frequency. The interference signals are rapidly decreased when the frequency of exposure signal is increased. In addition, the amplitudes are below the noise floor (approximately -90 dBm) for more than a 20 GHz exposure signal. The interference signal powers are decreased by between 16.0 dB/oct and 18.2 dB/oct (16.7 dB/oct on average). The cut-off frequencies of the transistors are 100 MHz (Transistor No. 1), 6 GHz (Transistor No. 2) and 9 GHz (Transistor No. 3). It is confirmed that the interference signal is generated by the exposure signal, which is higher frequency than the cut-off frequency of transistors.

4. Nonlinear Response of Hearing Aids

As practical medical equipment operating at low frequency band, measurements using the commercially available hearing aids are carried out. The devices used for the measurements are 3 types of body worn hearing aids from different manufactures. The test procedures are the same as the measurements of the basic low frequency amplifiers. Figure 8 shows the measured interference signal amplitude generated by a 1 GHz exposure signal. The saturation of the output level in the hearing aid Type B is caused by the output level limiting circuit. In, addition, Fig. 9 shows the measured interference signal amplitudes as a function of exposure signal frequency. As the same as the basic low frequency amplifiers, the interference signals are proportional to the square of the electric field strength.

5. Conclusions

The nonlinear response of the basic low frequency amplifiers and the hearing aids due to microwave/quasi-millimeter wave were experimentally investigated. The basic low frequency amplifiers are typical circuits employed in the medical equipments such as implantable medical devices. We confirmed the 1 kHz interference signal levels were proportional to the square of exposed electric field strength. In addition, it was confirmed that interference signal levels were rapidly decreased when the frequency of exposure signal was increased. An important finding was that the interference signal generated in either the amplifiers or the hearing aids were below the noise floor, when the frequency of exposure signal was above 20 GHz. As a future works, interference signals generated in actual implantable medical devices will be carried out.

Acknowledgments

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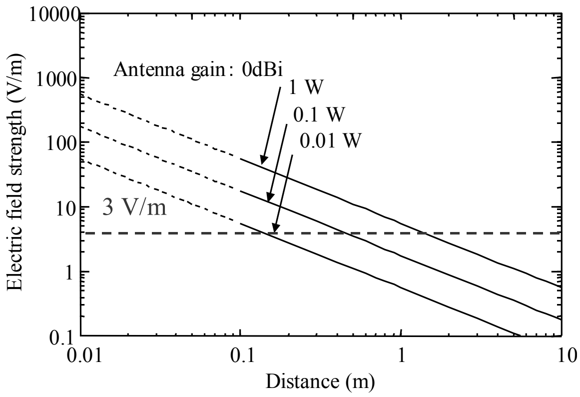

Figure 1: The calculated electric field strength generated by a point wave source

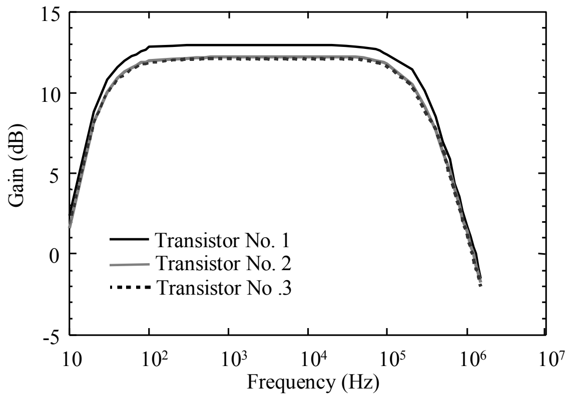

Figure 2: The measured frequency characteristics of the low frequency transistor amplifiers

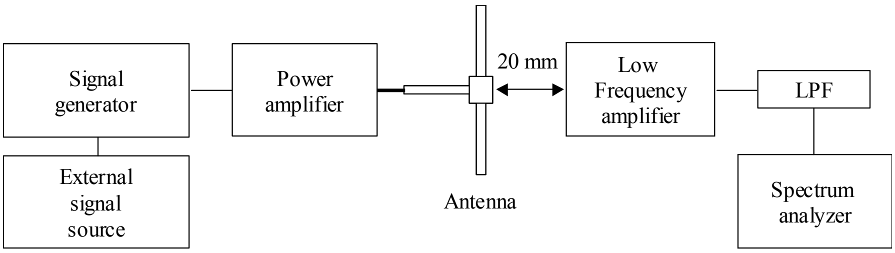

Figure 3: A schematic diagram of the experimental set-up for examining the detection level

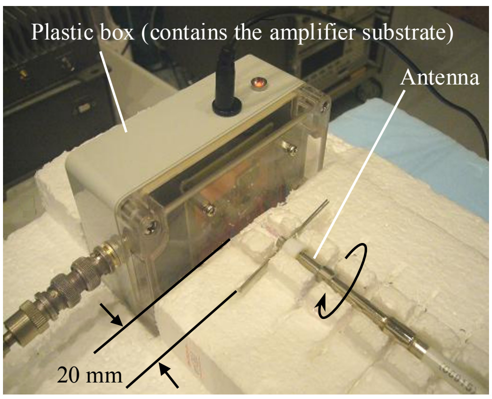

Figure 4: The overview of the amplifier and the exposure antenna

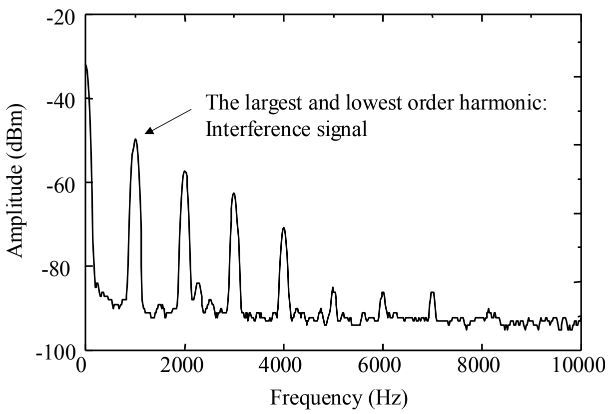

Figure 5: Typical output spectrum obtained at the measurements

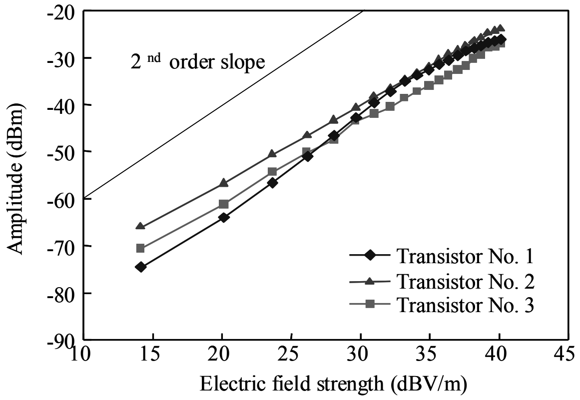

Figure 6: The measured interference signals of the low frequency transistor amplifiers

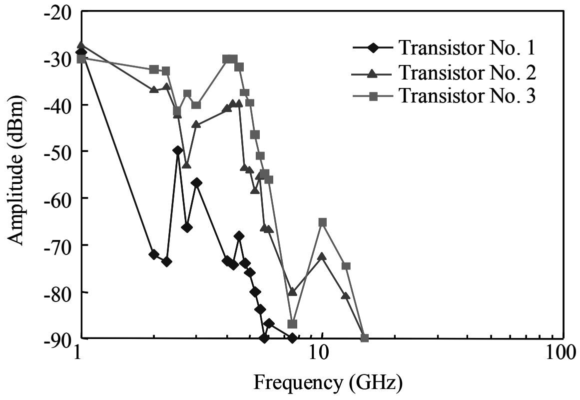

Figure 7: The measured frequency characteristics the low frequency transistor amplifiers as a function of exposure signal frequency

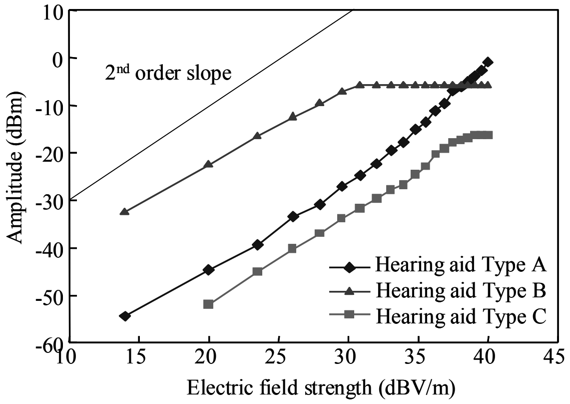

Figure 8: The measured interference signals of the hearing aids

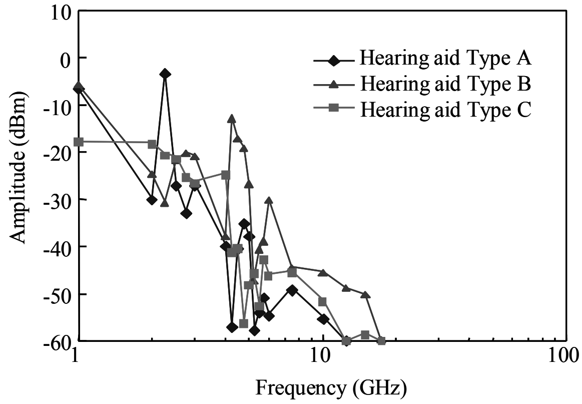

Figure 9: The measured frequency characteristics the hearing aids as a function of exposure signal frequency

References

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