Numerical Estimation Methodology for RFID/Active Implantable Medical Device-EMI based upon FDTD Analysis

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Abstract

A numerical estimation methodology for RFID /Active Implantable Medical Device (AIMD) EMI based upon FDTD analysis is presented. This methodology can be applied to low-band RFID. In this paper, an example for RFID interrogator in the frequency band of 13.56 MHz (ISO/IEC 18000-3 MODE 1) is shown. It assumes that RFID interrogators operating in the low or HF frequency bands might cause EMI on the AIMDs through the interference voltage induced by the magnetic flux excited by the RFID interrogator. Calculated interference voltage was compared with the EMI characteristics obtained by in-vitro EMI experiments to validate the analysis result. The estimated EMI characteristics obtained by the experiments and the FDTD analysis agreed well.

1. Introduction

Radio-frequency identification (RFID) technology supports non-contact automatic recognition along with fast data reading, multi-target recognition and invisible recognition [1]. As a key enabler of supply chain management and near field communication, RFID systems improve operation efficiency when they are employed for logistics, manufacturing, and public utilities. However, they are wireless devices and so emit electromagnetic fields (EMF) that could potentially cause electro-magnetic interference (EMI) for other electronic devices. The EMI faced by active implantable medical devices (AIMDs) due to wireless communication devices has become a very controversial issue in recent years. This is because the number of AIMD users is increasing every year due to technological advances in AIMDs and the aging of the population. Regarding the EMI experienced by AIMDs, including pacemakers and ICDs, both in vitro and in vivo research have been conducted. In particular, the interference caused by mobile phone systems is being investigated on a massive scale [2-6]. Concerning the EMI due to RFID, the Ministry of Internal Affairs and Communications of Japan reported research results to determine the guidelines to prevent the EMI [7]. On the other hand, we have carried out in vitro EMI experiments to investigate the EMI occurrence conditions [8-10]. Other research concerning the EMI on AIMDs due to RFID readerwriters is carried out [11].

This paper describes a novel numerical RFID/AIMD-EMI estimation methodology based upon FDTD analysis. This methodology can be applied to ISO/IEC 18000-2 Type A and -3 MODE 1 RFID interrogator. An example for ISO/IEC 18000-3 MODE 1 interrogator in the frequency band of 13.56 MHz is shown. Firstly, AIMD EMI due to low-band RFID interrogator and in-vitro EMI measurement system are outlined. Secondly, a numerical HF RFID interrogator antenna model and a human torso phantom model are constructed. Then, the measured and calculated magnetic field distributions generated around an antenna are compared to confirm the validity of the numerical antenna model. Next, interference voltage induced at the connector of the pacemaker is calculated based upon the FDTD method. Finally, to validate the analysis result, the calculated interference voltage is compared with the EMI characteristics obtained by in-vitro EMI experiments.

2. AIMD EMI Due to Low-Band RFID Interrogators and In-vitro measurement system

For low-band RFID interrogators using 125 kHz and HF (13.56 MHz), inductive coupling is used to allow communication between RFID interrogator antenna and tags. The induced voltage is rectified to DC voltage and activates the tag’s function. Accordingly, the magnetic field from the RFID interrogator antenna might impose significant EMI on the AIMDs. With regard to this supposition, experimental studies were conducted and it was confirmed that EMI occurrence depends on the total magnetic flux that is interlinked with the one turn coil formed with the AIMD, the lead-wire and the direct body current path in the human torso [9,10]. The induced voltage generated in the terminal of AIMDs is defined as “interference voltage”. If the interference voltage exceeds the AIMD’s sensing threshold level, it cannot recognize correct electrocardiogram (ECG) signals and may cause malfunctions.
To obtain EMI characteristics of actual AIMDs due to RFID interrogator, in-vitro EMI experimental investigations have been carried out [8-11]. Figure 1 shows the measurement system used for the experiments [8-10]. This system is based on the one previously proposed for the estimation of EMI due to mobile phones described in [12]. The test system consists of a flat human torso phantom, an ECG signal generator, a chart recorder, an oscilloscope, a measurement platform and RFID interrogator antenna. The human torso phantom shown in Fig. 2 is a modification of Irnich’s model. The torso phantom is positioned parallel to the antenna. In the test, distance between antennas and the torso phantom is varied in order to determine the maximum interference distance (distance where EMI disappears). The maximum interference distance (MID) at the different antenna input powers are measured in centimeters.

3. Estimation of EMI Occurrence Based on Numerical Analysis

Numerical models of the HF RFID interrogator single-loop antennas and a human torso phantom were constructed. To obtain the desired resonance frequency and near field characteristic, a parallel capacitance was connected to the antenna coil. FDTD analyses of numerical models were conducted by using EMF simulation software based on the FDTD method [13]. Figure 3 shows an example of calculated example of antenna input impedance. As shown in the figure, the parallel resonance of the antenna was confirmed to occur at 13.56 MHz. In addition, the human torso phantom model, which contains the implantable-cardiac pacemaker model, is shown in Fig. 4. The torso phantom employed for the in-vitro EMI experiments is a modification of Irnich’s model [3]. This human torso phantom is composed of an acrylic tank filled with saline solution (1.8 g/l). The dielectric constant and the electric conductivity of each material at 13.56 MHz were input to the model. The coaxial lead wires, which sense the human heart beat signal and stimulate the cardiac muscle, were connected to the pacemakers’ terminals. The interference voltage was evaluated at these terminals.

In order to estimate the validity of this simulation method, experimental HF RFID interrogator antennas were constructed. These antennas have the same dimensions as the numerical models. Figure 5 is a picture of a fabricated antenna that consists of a single turn copper coil and a matching circuit; the coil’s dimensions were 300 mm × 300 mm (width × height). Their return loss was more than -20 dB at 13.56 MHz. The magnetic field distribution at the surface of the antenna (xy-plane shown in Fig. 6) was measured in detail using a three-dimensional automatic field measurement system. Figure 7 shows the two-dimensional magnetic field strength of the measured and calculated values. These values are normalized against the maximum values. The calculated values agree well with the measured values. Figure 8 shows the normalized induced voltage at the terminal versus distance z from the surface of the RFID interrogator reader/writer antenna model. The input powers of the two antennas were the same. The induced voltages for two different antenna sizes are shown as well. Antenna A has a large coil, 300 mm × 300 mm (width × height). Antenna B has a relatively small coil, 200 mm × 200 mm (width × height). When distance z is 0 cm, the induced voltage of antenna A is more than twice that of antenna B, even though its input power is the same. This is because the difference in magnetic field distribution strongly influences the induced voltage, rather than the maximum magnetic field strength at one point. By using the FDTD method to evaluate the interference voltage, precise and accurate estimation can be achieved.

In order to validate the analysis result, the calculated interference voltage was compared to the EMI characteristics obtained by in-vitro EMI experiments. The in-vitro EMI experiments were conducted using the fabricated antennas described above. In the experiments, pacemaker malfunctions such as omission of pacing pulses or the generation of asynchronous pulses were identified and recorded. The positions of the antenna and the human torso phantom were set to be the same as in the analysis. The MID was measured and recorded.

Figure 9 shows the MIDs versus the antenna input power. The solid and dashed lines show the analyzed results of each antenna based upon the FDTD method. These lines show the shortest distance at which the interference voltage exceeds the specific threshold voltage. The threshold voltage was experimentally obtained using a susceptible pacemaker and estimations were made on this pacemaker. In addition, the closed circles and the closed triangles indicate the MIDs obtained in the experiments. As shown in the figure, the calculated results agree very well with the experimental results.

4. Conclusion

The proposed numerical assessment methodology of RFID/AIMD-EMI was confirmed based on the result of the in-vitro experiments and the numerical analyses. The calculated results of induced voltage based on FDTD analysis agreed well with experimental ones. The good repeatability of the experiments and detailed modeling in the analyses achieve this high accuracy estimation. These results clarify the interference voltages due to the magnetic field generated...
around the low-band RFID interrogator reader/writer antenna and they can be estimated by using precise and detailed analysis.

5. Acknowledgments

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6. References

13. SEMCAD X: Schmid & Partner Engineering AG, Zurich, Switzerland
Figure 3. Input antenna impedance of 13.56 MHz numerical model

Figure 4. Numerical torso phantom with AIMD model

Figure 5. 13.56 MHz antenna model for experimental validation

Figure 6. Spatial arrangement of antenna and torso models

Figure 7. 13.56 MHz magnetic field distribution near antenna

(a) Measured

(b) Calculated

Figure 8. Calculated terminal voltage versus distance between antenna and phantom

Figure 9. Predicted and measured MIDs versus antenna input powers