Numerical Estimation of EMI Impact on Implantable Cardiac Pacemakers in Elevator Using EMF Distributions Inside Human Body

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Introduction

In recent years, mobile phone usage has extended to a wide range of environment such as places surrounded by conductive surfaces, e.g., train carriages, elevators, and airplanes. There have been concerns that cellular radio can interfere with different types of devices and increased usage in multi-reflection environments has led to concern about the possible effect of electromagnetic interference (EMI) on implantable medical devices (IMDs). Many experimental studies have been carried out in order to assess the EMI generated by cellular radio in free-space and experienced by IMDs including implantable cardiac pacemakers and implantable cardioverter defibrillators (ICDs) [1]-[3]. However, few studies have addressed the effect of EMI on IMDs in elevators. Precise and efficient methods of measuring the electric field (E-field) strength in different regions of multi-reflection environments have not been advanced due to the disturbed fields caused by the presence of measurement equipment and/or human bodies. Therefore, this is achieved by carrying out precise numerical simulations using the Finite-Difference-Time-Domain method [4]. We have already carried out numerical simulations on homogeneous human phantom models and some elevator models to investigate the EMI impact to implantable cardiac pacemakers in elevators; we examined the E-field distribution on the horizontal plane inside elevator[5], outside of human body.

In this paper, we introduce our method for estimating pacemaker EMI using EMF distributions inside the region of the human body into which pacemakers are implanted. The calculated E-field strength is normalized to a certain reference level determined from the experimentally obtained maximum interference distance [6] of implantable cardiac pacemakers. This enables us to carry out quantitative evaluations of the EMI impact to pacemakers by cellular radio transmission. In order to examine the complex situations where human is present in elevators, our analysis considered a realistically-shaped and anatomically-correct human phantom model. A half-wavelength dipole antenna is used to represent a cellular radio operating in the 900 MHz, 1500 MHz, and 2100 MHz frequency bands. All calculations were run on a supercomputer.

FDTD Analysis for Pacemaker EMI Estimation in Elevator

The numerical simulations were carried out by applying the finite-difference time-domain (FDTD) method. In order to estimate the pacemaker EMI, the EMF

values are plotted using histograms and compared a certain reference values determined from the experimentally obtained maximum interference distance of implantable cardiac pacemakers. If there is any region of the histogram that exceeds this reference value, the implication is that there is some possibility of the EMI negatively impacting the pacemaker.

The details of the FDTD analysis configurations are summarized in Table 1. We used a half-wavelength dipole antenna to represent a cellular radio operating in 900 MHz, 1500 MHz and 2100 MHz bands. The time step was set to fill the Courant condition. The time steps used in the simulations were 8.96 psec, 8.77 psec, and 8.50 psec for 900, 1500, 2100 MHz, respectively. Berenger's perfect matched layer [7] having 16 layers and M = 3 were placed at all boundaries of the FDTD problem space to absorb the radiated outgoing waves. The number of iterations has also been confirmed to be sufficient for the frequencies being simulated. The time duration of each simulation was approximately 20 hours. A 3-D representation of the numerical model of the elevator is shown in Figure 1. This is the case in which only one passenger is present in the elevator. The elevator model assumes that the physical properties of the elevator's body mirrors those of perfect electric conductor (PEC). In all models, the elevator door is closed. Figure 2 shows front and side-views of the human phantom model that was placed in the elevator. The phantom model has realistic shapes and is composed of 77 different tissues [8]. The electric properties of the tissues were derived from [9].

Table 1: Computation parameters

Cell size (cubic)	d = 5 mm
Total problem space	324 x 440 x 432 (cells)
Absorbing B. C.	PML (16 layers)
Frequency	900MHz, 1500MHz, 2100MHz
Elevator model	Body: Perfect Electric Conductor Openings: - Rectangular: 300 x 600 mm - Circular; 300 mm diameter
Human phantom model	Inhomogeneous Realistic shape
Required memory	32 GB
Cellular radio	Dipole antenna

Table 2: Maximum Interference Distance for Frequencies used

Frequency	Maximum Interference Distance
900 MHz	16 cm
1500 MHz	6 cm
2100 MHz	2 cm

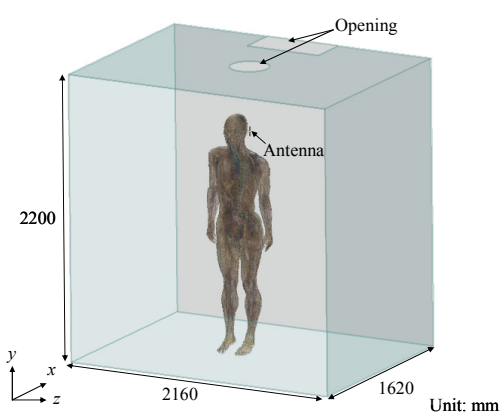


Fig. 1 Representation of the elevator model.

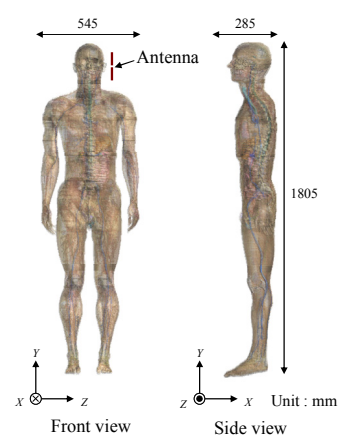


Fig. 2 Numerical phantom model.

The mobile phone is modeled as a half wavelength dipole antenna. The antenna is located 20 mm from the human phantom's head and is 1700 mm above the floor. In order to achieve our stated goal of determining whether the field strengths are within the safe limits for pacemaker operation, it is necessary to normalize the values against a reference level that represents the threshold values for each frequency. The maximum interference distances at which dipole antennas should be placed from cardiac pacemakers have been determined experimentally for each frequency. These distances are shown in Table 2.

We propose a method that estimates EMI impact inside the phantom model. Cardiac pacemaker is set at a location just below the collar-bone. Therefore, the area near the collar-bone, where most pacemakers are implanted, is examined. The electric field values in this region are compared against a reference level that might cause pacemaker malfunction. Figure 3 shows an example of the region considered. The region within the maximum interference distance from feeding point, which is explained in more detail below, is not examined. The volumes of the regions examined were approximately 320 cm^3, 310 cm^3, 310 cm^3 for the frequencies of 900 MHz, 1500 MHz, and 2100 MHz, respectively. The user position was changed from the center of the elevator to a corner of the elevator and the effect of this change was determined. Figure 4 shows different position of the phantom in the elevator.

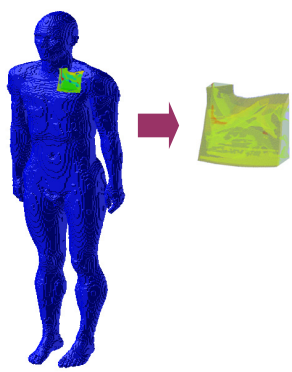
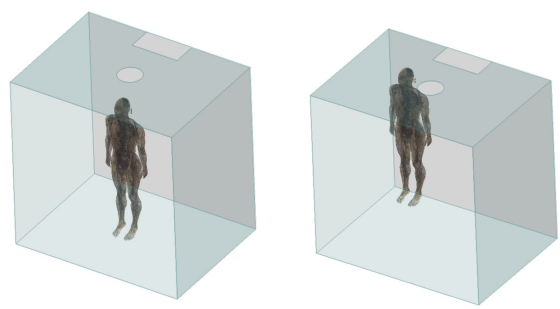


Fig. 3 Representation of the extracted regions.



(a) center (b) corner

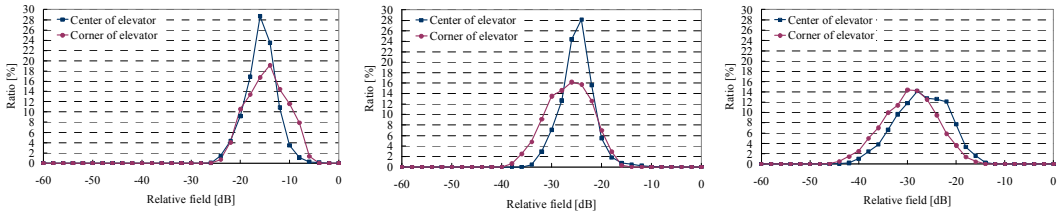
Fig. 4 Position of the phantom inside the elevator

Results and Conclusions

In order to investigate whether or not there are certain positions in the elevator where implantable cardiac pacemakers are more susceptible to EMI, human phantom model is placed in center or corner of the elevator as a user.

Figure 5 shows the E-field histograms for the 3 frequencies examined. The histograms were derived from electric field strength values in the region of interest as shown in Figure 3. The E-field values were normalized to the reference value obtained using dipole antenna and pacemaker model inside torso model.

It is observed that the differences in maximum E-field strength with this change in position are about 2dB, 6dB, and 2dB for the frequencies 900 MHz, 1500 MHz, 2100 MHz, respectively.



(a) 900 MHz (b) 1500 MHz (c) 2100 MHz

Fig. 5 E-field histograms of the region of interest
(Variation in E-field as the position of the human models changes for frequencies)

These results indicate that, for all frequencies carried out, none of the E-field strengths were sufficient to trigger pacemaker malfunction.

This paper presented a detailed investigation of pacemaker EMI in the elevator. EMI impact in the elevators was estimated using precise numerical analyses and an anatomically-correct human phantom model at the three mobile phone frequency bands. We proposed a method for EMI impact estimation. The E-field strengths in the region of pacemaker implant were examined by comparing E-field strengths with reference values obtained by using the maximum interference distance of implantable cardiac pacemakers. It is therefore shown that EMI impact on implantable cardiac pacemakers can be precisely assessed using inhomogeneous human phantom model based on proposed method.

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