Estimation of the EMF in Actual Train Carriage Using the Parallel FDTD Methods

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1. Introduction

In this paper, we show analytical methods and computer simulation of the electromagnetic field (EMF) distributions in a large-scale geometry like an actual train. With regard to the electromagnetic compatibility (EMC) of the portable radio terminals such as cellular phones and data communication transceivers that transmit RF waves, one of the most important and substantial issues is to prevent the occurrence of unwanted effects on the human health due to the RF exposure from such radio devices [1,2]. The RF interference on the implantable medical devices is the major subjects to be considered. Since the portable radios may be used in various environments, accurate and reliable estimations of EMC in practical environments are required. For example, places surrounded by conductive surfaces, e.g., train carriages or cars, are typical environments requiring assessment [3,4]. However, the measurements in the actual environment need enormous costs and it is also difficult to carry out precisely. Here we carry out the precise numerical simulations to examine the EMF actual environment. We employed the FDTD technique and a supercomputer to estimate the EMF distributions excited inside train carriages. Moreover, large-scale parallel computing based upon several node partitions was used because of its memory and speed capabilities. It gives us good perspective within a reasonable computation time. We used a typical train carriage now in active service in Japan, and both 800 MHz and 2 GHz bands cellular radio simulators.

This paper is divided into three sections after this introduction. Section 2 describes the FDTD analysis to estimate the EMF of large-scale geometry. The realistic and complicated situations wherein humans occupy a train carriage are also examined. Section 3 shows the results of the EMF in the train carriage. The simulation results using 800 MHz and 2 GHz transmitters in the passenger carriage are shown. Finally, a brief summary of this paper is provided in the last section.

2. FDTD analysis using parallel computation

The FDTD technique is a versatile and efficient tool for the solution of Maxwell's equations in complex structures [5,6]. It can also treat problem spaces that contain lossy media such as the human body. In the FDTD analysis, the problem space is quantized by Yee cells (cubical cells). On the outer boundary, the FDTD algorithm employs the absorbing boundary condition to simulate the extension of the field sampling space to infinity by suppressing reflection off the outer boundary. The cell size must be small enough to obtain accurate analytical results. Generally, it is less than 1/10 of the wavelength of the frequency for the

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analysis. Therefore, in the case of analyzing large-scale models such as a train carriage, the computational memory size required becomes extremely large. Then we employed a supercomputer to analyze the EMF in the train carriage [7]. The FDTD analysis is used in order to obtain spatial electric field distributions throughout the inner space of the carriage.

First, 800 MHz and 2 GHz standard dipole antennas are employed as most simple and ideal transmission models to estimate the attenuation (propagation) characteristics in the train. Next, the realistic and complicated situations wherein humans occupy a train carriage are examined.

2-1. Geometry and Modeling of Train carriage

The typical train carriage to be examined in this paper is shown in Fig. 1. The Dimensions of the carriage are length of 17500 mm, width of 2780 mm and height of 2200 mm. The FDTD problem space is divided into some regions to be adopted parallel computation by using a supercomputer. Each node operating individually is able to have its own computational main memory of 6.5 GB and eight processor elements. It could be carried out the analysis of electromagnetic fields of large-scale geometry required enormous memory size by using multiple nodes, provided that the electromagnetic components at the boundary plane shared with neighboring nodes. In this paper, six numbers of computational nodes are used to carry out the FDTD analysis of the train carriage. A parallel algorithm for the FDTD method is realized using the MPI library. The inter-process communications are carried out by the use of derived data types [8]. To simplify the computer program and reduce the main memory consumption, we use the PML absorbing boundary condition that makes it to unnecessary to split the field components artificially [9]. The problem space is shown in Fig. 2 and the details of the FDTD analysis configurations are summarized in Table 1. To achieve a precise computation, spatial resolution is set to 1 cm^3 in this paper. Here we use a half-wavelength dipole antenna as cellular radio.

TBL. 1 Parameters for FDTD analyses.

Cell size (cubic)	Δ=10 mm
Total problem Space	338×330×1810 cells
Number of guard cells	22 (in every directions)
Absorbing B. C.	PML (8 layer, M=3)
Time step	Δt = (1/(Max2 x Freq.)) Max2=76 for 800 MHz Max2=32 for 2 GHz
Iteration	450 (800 MHz) 1000 (2 GHz)
Required Memory	30.18 GB (5.03 GB x 6-node)
Train model	Body: PEC Window glass: ε_r=5.0 and σ=10^{-7} Seat: ε_r =1.0 and σ=10^{-7}

2-2. Realistic and complicated situations including Humans

In the actual train, the effect of the loss by the passenger body cannot be disregarded. Then, to examine the realistic and complicated situations wherein humans occupy a train carriage,

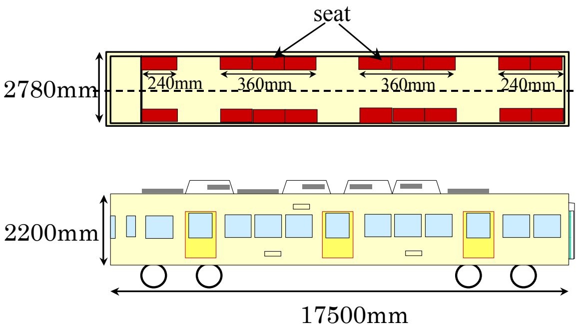

Fig. 1 Typical train carriage.

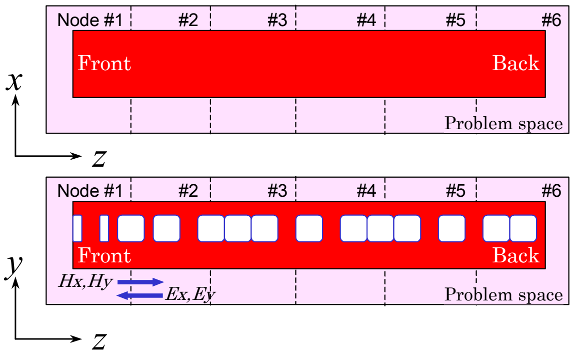

Fig. 2 FDTD problem space divided into six computer nodes.

we apply the homogeneous human phantom model in the FDTD analysis. Fig. 3 shows the detailed standing human phantom model. The height of the phantom is 1700 mm and it has realistic shape and homogeneous electric parameters of $\varepsilon_r = 50$ and $\tan\delta = 1$. Also we use a half-wavelength dipole antenna as cellular radio that is 10 cm apart from the phantom head.

3. Results

Some numerical examples are shown in the Fig. 4 to 7. Figs. 4 and 5 show the EMF distribution along the length direction of the train carriage simulation results for both 800 MHz and 2 GHz sources. We confirm that these simulation results for both 800 MHz and 2 GHz sources coincide well with the Experimental results measured along the actual carriage [10]. The peak envelope curbs of the measured EMF distributions exhibit attenuation characteristics although the attenuation factor is small.

Figs. 6 and 7 show the simulation results for the cases of 2-GHz source and passenger exist in the train carriage. In the Fig. 6, a passenger standing in the center of carriage with one transmitter set up at height of 1580 mm from the floor. Here, we adopt a field histogram to estimate the percentage of the same strength area. The relative field strength, normalized to a certain reference level determined from the experimentally obtained maximum interference distance, is used [4]. Fig. 7 shows the result for the case of 20 passengers in the carriage and half of the passengers use the cellular. These figures suggest that the EMF strength inside the train carriage does not exceed the reference value.

4. Summaries and Conclusions

The purpose of this paper is to estimate the EMF in the large-scale geometries like a train carriage. Obtained results imply that the parallel FDTD computer simulation can be considered to be effective for estimating this type of complicated EMF excitation problems precisely. It should not be ignored that the human bodies existing inside the train as passengers or cellular radio users would attenuate EMF energy.

The field histograms are derived from the spatial distributions to estimate the percentage of the same strength area. The histogram is useful to carry out a complete estimation in the whole area.

Finally, we conclude that the study method developed here can be applied easily to other similar EMC problems.

Acknowledgements

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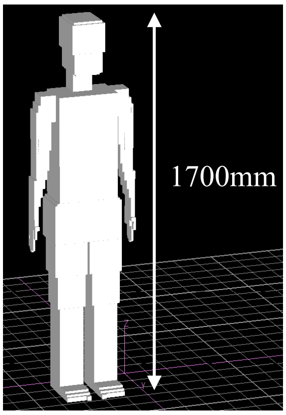

Fig. 3 detailed human phantom model.

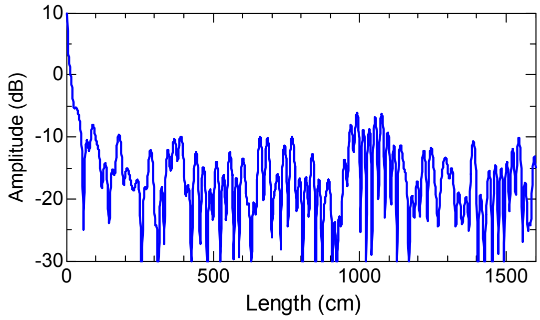

Fig. 4 EMF distribution: 800 MHz source.

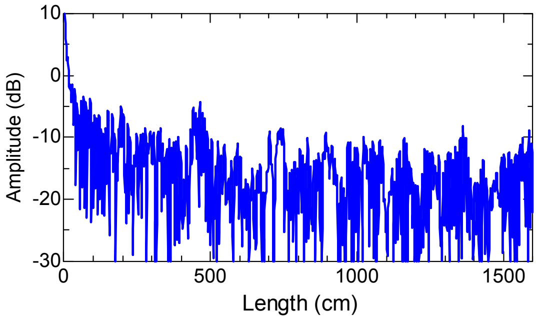

Fig. 5 EMF distribution: 2 GHz source.

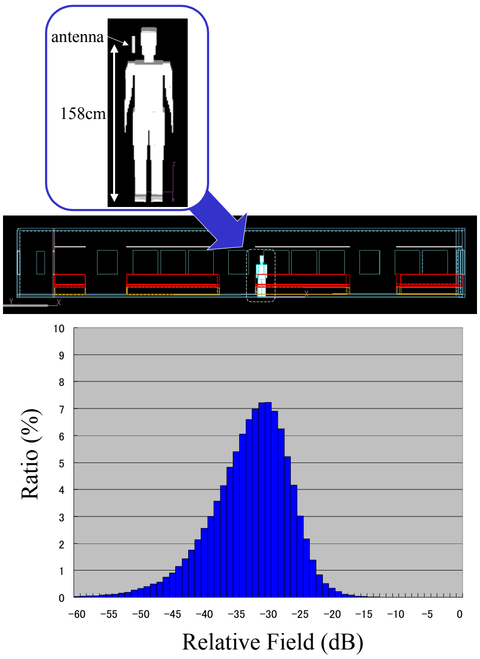

Fig. 6 EMF histogram.
(one cellular user)

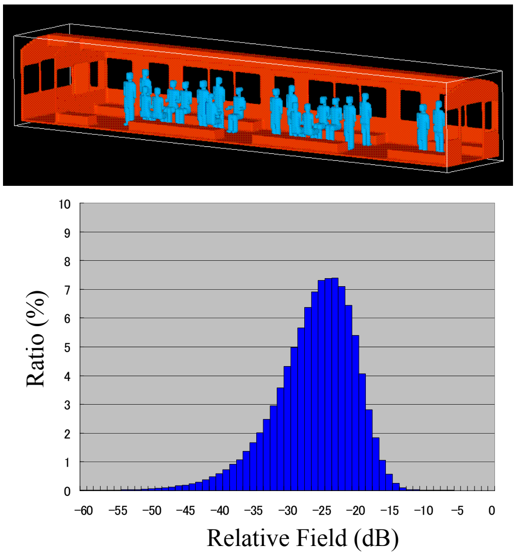

Fig. 7 EMF histogram.
(20 passengers :10 cellular users)