A STUDY ON IMPLANTABLE CARDIAC PACEMAKER EMI FROM CELLULAR RADIOS IN SEMI-ECHOIC ENVIRONMENTS

– FDTD Analysis and Experiments in Actual Train Carriage –

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Abstract: Theoretical and experimental studies are conducted on the electromagnetic field (EMF) distributions excited inside train carriages and the implantable cardiac pacemaker EMC issue in the same environment. Both precise computer simulations and experiments using 800 MHz and 2 GHz transmitters in an actual train carriage confirm that excessively high EMF, high enough to affect pacemaker normal functions, does not occur inside the carriage provided the safe distance of 22 cm set for pacemaker users is kept. Methodologies are described first. Typical results of FDTD analysis and actual measurement data are then shown. Finally, considerations and conclusions are made.

Key words: EMC, EMI, Implantable cardiac pace maker, Cellular radio, FDTD, Train carriage

1. Introduction

With regard to the 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. The Bioelectromagnetics effects and RF interference on the implantable medical devices are 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. There is a concern that the simultaneous use of several cellular phones in a train carriage might cause unexpectedly high exposure levels due to the reflection and accumulation of RF waves inside of the carriage [1,2]. Here, we refer to this kind of environment as a semi-echoic environment (SEE).

Now we classify the concern pertaining to the SEE of a train carriage into three hypotheses.

The first hypothesis is the accumulation of electromagnetic fields. Under this hypothesis, the RF field intensity does not attenuate even if the device of interest (DOI) is away from the source, i.e., the cellular radio antenna, since the reflections are confined and so have relatively small transmission and reflection losses. Hence, the internal field strength may increase in proportion to the number of cellular radios. Is this true in an actual train carriage as suggested by the effect seen in cavity resonators, shielded rooms, or reverberation chambers that do not contain loss material?

The second hypothesis is that the safety guideline of 22 cm developed for implantable cardiac pacemaker users [3] may not be applicable in SEE. This suggests that there is a possibility that cardiac pacemaker will malfunction due to RF radio interference in an SEE even if the source is more than 22 cm from the DOI.

The third one is that the EMF level in the SEE could easily exceed the guidelines developed by ICNIRP.

Here we carry out both precise numerical simulations and experiments to examine the first and second hypotheses in an actual environment. For this purpose, we used a typical train carriage now in active service in Japan, and both 800 MHz and 2 GHz bands cellular radio simulators. No prior paper appears to have examined the SEE EMC issue of the interaction between cellular radios and medical devices in an actual environment.

With regard to the third hypothesis, some quantitative discussions suggest that the ICNIRP basic restrictions or even reference levels will not be exceeded in SEEs [4,5]. Accordingly, we do not deal with this subject in this study.

2. Methodology

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 both for the experiments and numerical analyses. Measured results are compared to analytical results to confirm if the computation method described herein can be applied to the realistic and complicated situation wherein humans occupy a train carriage. Then, the computation method is used in order to obtain spatial electric field distributions throughout the inner space of the carriage. Finally, 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. Here, the relative field strength, normalized to a certain reference level, is adopted. The reference level is determined from the experimentally obtained maximum interference distance unique to each cellular system [6].

In order to achieve a precise computation, spatial resolution is set to 1 cm^2.

2-1. Experiments

For this study, we selected a typical train carriage in use in Japan; a commuter train series 1000, Keihin Electric Express Railway Co., Ltd.

Pictures of the actual train carriage used are shown in Figures 1 and 2. The maximum electric field was measured at the interstices of a 3D grid with 1 m pitch. Figures 3 and 4 illustrate schematically the arrangement of transmission antenna and the test system. Fundamental system parameters are summarized in Table 1. Other than this, several test equipment (plural number of actual cellular radios and a spatially high resolution measurement system) are used as well (to be reported in the future).

2-2. Numerical analysis

The numerical analysis was accomplished by applying the finite-difference time-domain (FDTD) technique [7,8]. The FDTD technique is a versatile and efficient tool for the solution of Maxwell's equations in complex structures. 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. Therefore, in the case of analyzing large-scale models such as a carriage, the computational memory size required becomes extremely large.

Fig. 1 Train carriage.
(Keihin Electric Express Railway Co., Ltd.)

Fig. 2 Field measurement.

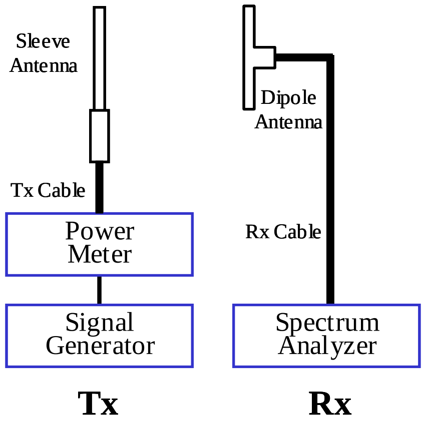

Fig.3 Test system for electric field measurement.

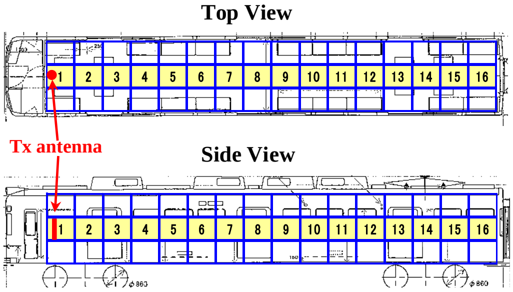

Fig.4 Measurement area in the train carriage.

We employed a supercomputer to analyze the EMF in the train carriage because of its memory and speed capabilities. Moreover, parallel computing based upon several node partitions was used [9].

Figure 5 shows the relation between the problem spaces and computer nodes. The boundary EMFs are shared by neighboring nodes. Details of the FDTD analysis configurations are given in Table 2.

3. Results

Some examples of the numerical and experimental results are shown in the figures 6～9. Figures 6 and 7 confirm that the actual EMF distribution measured along the carriage coincide well with the computer simulation results for both 800 MHz and 2 GHz sources. The peak envelope curbs of the measured EMF distributions exhibit attenuation characteristics although the attenuation factor is small.

The FDTD computer simulation results for the cases of one and five 2-GHz sources (corresponding to the same number users existed) are transmitting coherent RF waves continuously are shown in Figures 8 and 9 as typical examples. As the reference value, we have chosen the EMF strength at the maximum interference distance observed. We can identify whether or not a pacemaker malfunction will occur by identifying those areas where EMF exceeds the reference value. In Figures 8 and 9, none of the spots inside the carriage exceed 0 dB, and this suggests that the EMF strength inside the train carriage does not exceed the safety levels on pacemaker interference at any point.

Table 1 Fundamental system parameters.

TX system					
SG	**Frequency**	**810.075**	**MHz**	**2135.2**	**MHz**
	Power	30	dBm	34	dBm
PM	Foward P	30.2	dBm	34.2	dBm
	Reflected P	10.6	dBm	9.96	dBm
	VSWR	1.2		1.13	
Cable	length	3	m	3	m
	Loss	1.09	dB	1.81	dB
Antenna	Input	29.11	dBm	32.39	dBm
	gain	2.15	dBi	2	dBi

RX system					
Antenna	AF	27.4	dB 1/m	34.9	dB 1/m
Cable	length	7	m	7	m
	Loss	1.48	dB	2.13	dB
SA	Center Freq.	810.075	MHz	2140	MHz
	Span Freq.	100	kHz	20	MHz
	RBW	3	kHz	300	kHz

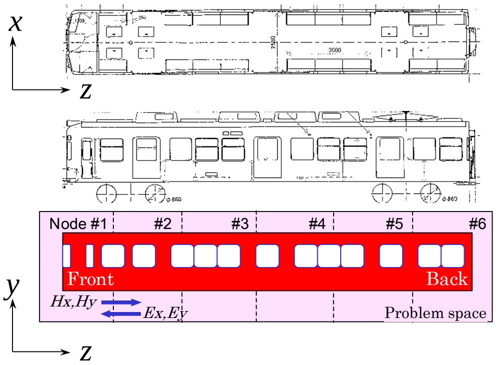

Fig.5 FDTD problem space.

Table 2 Computation parameters.

Cell size (cubic)	*d*=10 mm
Total problem Space	338×330×1824 (cells)
Number of guard cells	30 (in every directions)
Absorbing B. C.	PML (8 layers, M=3)
Time step	*dt* =(1/ (Max2 x Freq)) Freq=800 MHz, Max2=76 Freq=2 GHz, Max2=32
Iteration	450 (800 MHz) 1000(2 GHz)
Required Memory	30.18 GB (5.03 GB×6-node)
Train model	Body: PEC Window glass: ε_r=5.0 σ =10^{-7} Seat: ε_r=1.0 σ =10^{-7}
Exposure phantom model	Homogeneous, ($\varepsilon_r = 50$, $\tan\delta = 1$) Realistic shape (170 cm tall)
Cellular radio	Dipole antenna, 2 cm apart from the phantom head

4. Conclusions

Obtained results imply that the FDTD computer simulation can be used for estimating this type of complicated EMF excitation problems in SEE exactly and precisely. It should not be ignored that the human bodies existing inside the train as passengers or cellular radio users would attenuate EMF energy. Thus, it is improbable that EMF energy is accumulated in carriages, unlike the case of a cavity resonator that has high Q performance.

We have examined the case where only five cellular radio users occupy the carriage. Other FDTD analyses that consider more users will be conducted, and more detailed discussions will be published later. We can conclude that pacemaker malfunction due to cellular radio EMF will not occur at all in a train carriage even if several (up to five) cellular radios are transmitting RF power at the maximum level simultaneously provided the 22 cm safety distance guideline is kept.

As mentioned above, it is improbable that the hypotheses proposed come true in the actual world as far as actual train carriages concerned. The reason for the critical differences between the hypotheses and the real world is the considerable attenuation of EMF provided by the human body. Finally, we hope that this study will contribute to easing anxiety and uneasiness of implantable cardiac pacemaker users on these EMC issues. The study method developed here can be applied to other similar EMC problems in semi-echoic environment, such as elevators and areas covered with metal walls.

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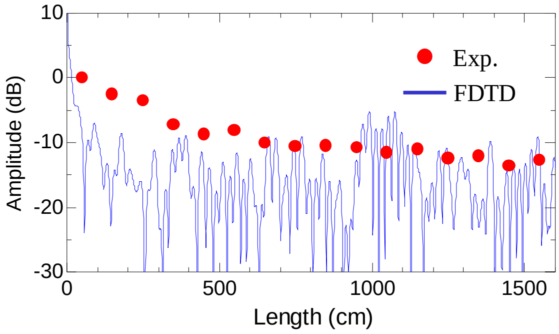

Fig. 6 EMF distribution: 800 MHz source.

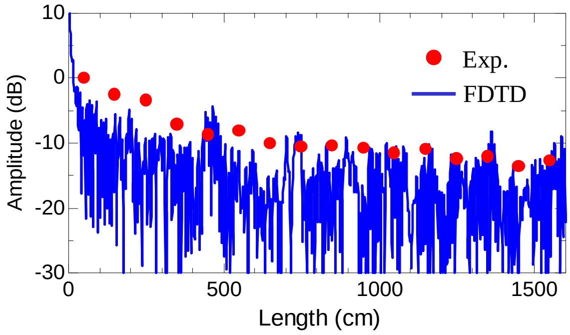

Fig. 7 EMF distribution: 2 GHz source.

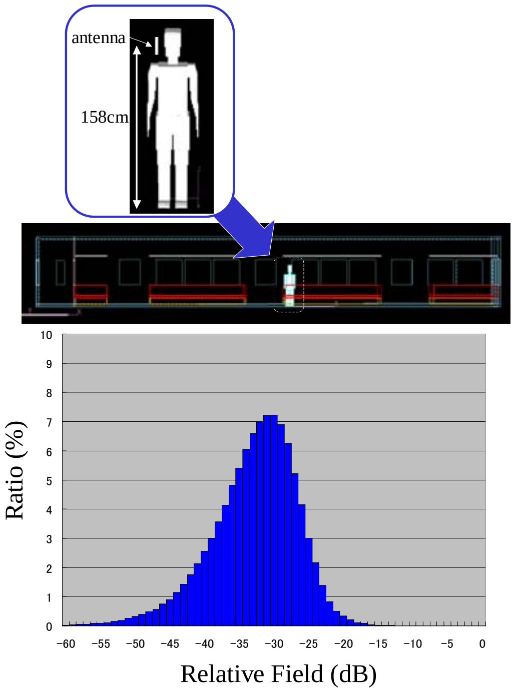

Fig. 8 EMF strength inside the train carriage. (In the horizontal plane at the height of 1.58 m from the train floor for one cellular user)

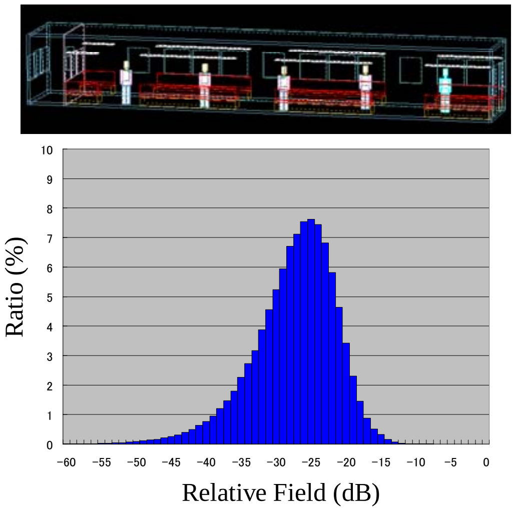

Fig. 9 EMF strength inside the train carriage (In the horizontal plane for 5 cellular users)