A Study on Required Distance between a Scattering Body and Absorbing Boundaries for Large-Scale FDTD Calculations

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1. Introduction

As informatization grows rapidly in recent years, we have been using wireless communication in various fields, which is essential to our social and business activity, e.g., broadcast and mobile communications operated from Medium Frequency to Ultra High Frequency (UHF) bands. On the other hand, there is a possibility that human beings may be scared with harmful effects of electromagnetic wave. For avoiding potential harms of electromagnetic wave, we need further studies on health effects of electromagnetic field (EMF).

In the case of the far-field exposure in Very High Frequency (VHF) band, it is reported that the whole-body resonance could occur [1,2]. At the whole-body resonance, the whole-body SAR could be maximum value. The RF safety guidelines [3-5] therefore recommend the most strict exposure limits in VHF band.

Recently, some countries including Japan have started the terrestrial digital TV broadcast services. This may cause public concerns about whole-body exposure to VHF and UHF wave from TV broadcast towers. In most previous studies, however, low-resolution voxel models have been used in numerical calculation in VHF band because of the limitation of the computation resources [1,2].

In this paper, the preliminary study for the calculation using the high-resolution voxel models of average Japanese adult male and female are described. The Finite-difference Time-domain (FDTD) calculation using millimeter-resolution whole-body human voxel models requires huge computer resources. This frequently makes detailed investigation with changing various parameters to be difficult. We have therefore investigated the appropriate distance between the human body and the absorbing boundaries.

2. Method and Models

2. 1. FDTD Method

FDTD method with scattering-field formulations was used in this paper. The 2nd approximation of Liao's absorbing boundary and PML bounardy conditions were employed as absorbing boundary condition (ABC) in order to simulate radiation into free space [6,7]. The calculation code runs on the vector super computer (NEC SX-6).

2. 2. Human Models

We are going to use high-resolution models in numerical calculation. These models have been

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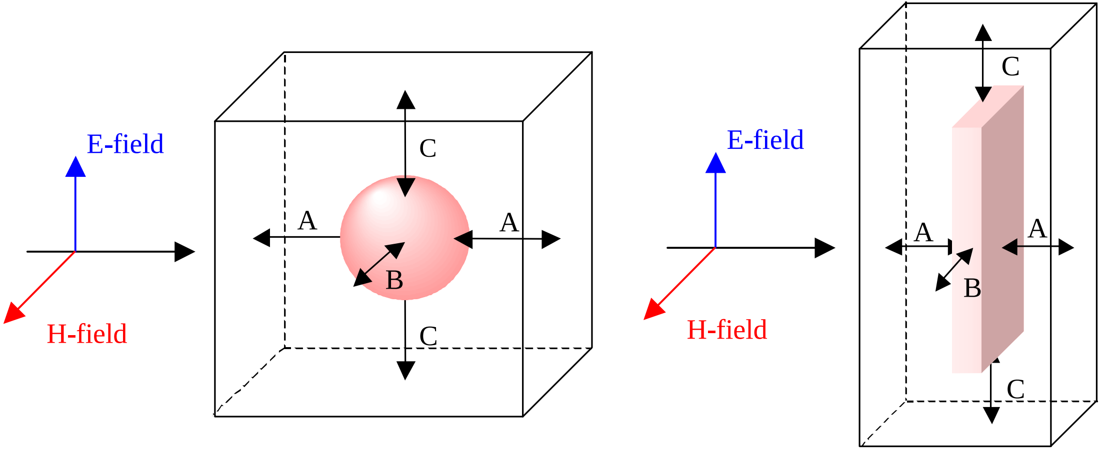
developed from MR images of Japanese adult male and female volunteers. Each model consists of cubical voxels with a side of 2 mm and is segmented into 51 tissues and organs. These tissues and organs have similar weight of those of the average Japanese adult male and female. The details of these models are described in [8].

In this paper, we use more simple human models. One is a sphere model of which diameter is 1.7 m. Another is a rectangular model with the dimension of 13 x 29 x 173 [cm]. The calculation of the sphere model is compared with Mie theory [9]. Because the rectangular model has similar weight and height with the realistic human models, it has a similar Q-factor of the whole-body resonance with that of the realistic human models. These simple models have a homogeneous tissue of 2/3-muscle. The electrical properties are derived from [10].

The coordinate system and the geometrical relationship between the human models and the EMF are shown in Fig. 1.



(a) Sphere model (b) Rectangular model

Figure 1: Simple human body models.

3. Results and Discussion

3. 1. Sphere Model

Figure 2 shows frequency characteristics of whole averaged SAR when cell-size is 1 cm and 5 mm. It is shown that the FDTD calculations are in good agreement with Mie theory in frequencies lower than 100 MHz, while there are relatively large errors in higher frequencies. On the other hand, the FDTD calculation with 5-mm cells agrees well with Mie theory in the higher frequency region, which means that the errors of the FDTD calculation with 1-cm cells in the higher frequency region is due to the relatively coarse cell size compared with the wavelength in the tissue.

The FDTD calculation with 5-mm cells however demonstrates larger error in the lower frequency region than that with 1-cm cells, especially at the whole-body resonant frequency. There are 80 cells from the sphere to the Liao's ABC in the FDTD calculation with 5-mm cells in order to retain the same distance of the FDTD calculation with 1-cm cells. This result suggests that the accuracy of the SAR calculation depends on the frequency characteristics of the Liao's ABC. In order to investigate this hypothesis, we doubled the width of calculation region along each direction of orthogonal coordinates. Tested calculation conditions are listed in Table.1.

It is shown that expanding calculation region along with E-field direction makes the FDTD calculation to be closer to the Mie theory. However, it is difficult to determine whether the required distance evaluated in this section is adequate for the FDTD calculation using the realistic human models or not because the resonant peak of the sphere model is significantly moderate compared with that of the human body [1,2]. In the next section, therefore, we have investigated on the adequate distance using the rectangular model that has a similar resonant characteristic with that of the human model.

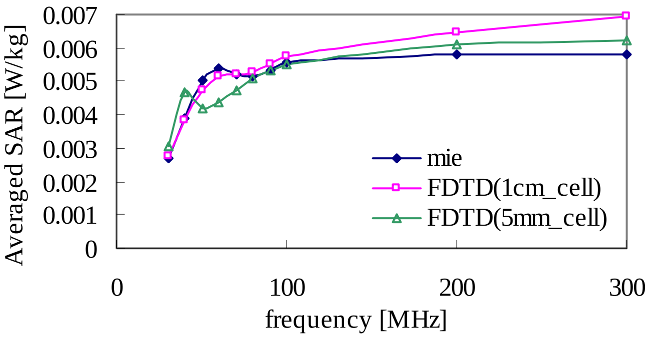


Figure 2: Frequency characteristics of averaged SAR of the homogeneous sphere exposed to plane wave (power density: 1mW/cm^2).

Table 1: The conditions of the calculation region. “a”, “b” and “c” mean distance between sphere and ABC along each direction of orthogonal coordinates (See Fig. 1).

Distance between sphere and ABC [cell]	Averaged SAR [W/kg]	Error from theory [%]
Mie theory	0.005032	-
a, b, c=80	0.0041967	16.6
a=330, b=80, c=80	0.0046309	7.97
a=80, b=330, c=80	0.004183	16.9
a=80, b=80, c=330	0.0041939	16.7

3. 2. Rectangular Model

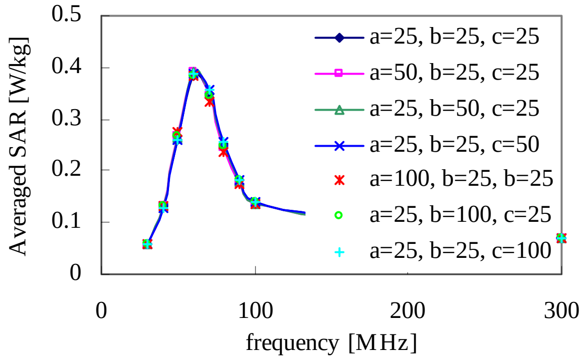


Figure 3: frequency characteristics of the whole-body averaged SAR of the rectangular model were calculated using FDTD with Liao’s ABC expanding calculation domain along each direction of orthogonal coordinates

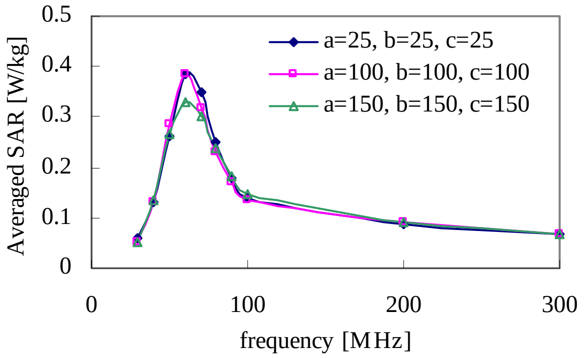


Figure 4: Frequency characteristics of the whole-body averaged SAR of the rectangular model calculated using FDTD with Liao’s ABC.

Calculated frequency characteristics of the whole-body averaged SAR of the rectangular model using FDTD with Liao’s ABC are shown in Fig. 3. The calculation region is expanded along each direction of orthogonal coordinates. It is shown that there are little differences among all the cases.

Then we have expanded the calculation region along all direction (Fig. 4). Unlike to Fig. 3, the SAR around the resonant peak changes as expanding the calculation region.

Figure 5 shows the whole-body averaged SAR as function of the distance between the rectangular model and the Liao's ABC as well as the PML ABC. The characteristics on the distance are different from those at each other frequencies. Comparing to the Liao's ABC, it is shown that PML ABC provides more stable characteristics.

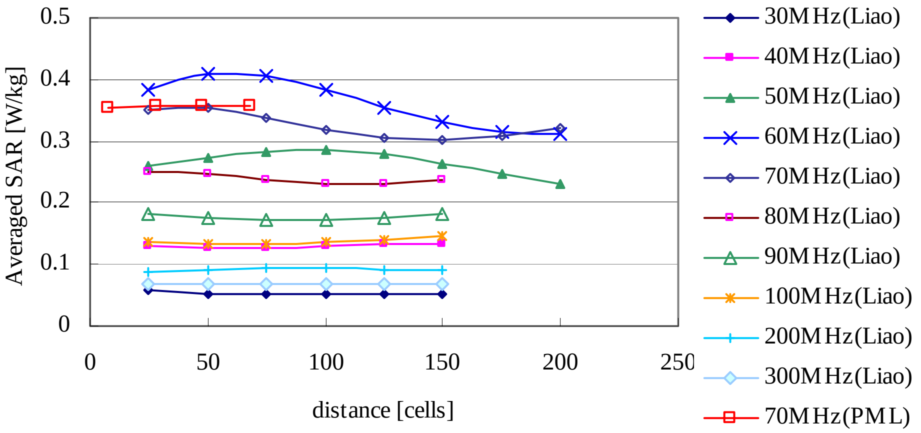


Figure 5: Distance characteristics of the whole-body averaged SAR of the rectangular model between the block and ABC

4. Conclusion

We have investigated on the required distance between the human models and the ABC. Preliminary results suggest that the required distance depends on the shape of the scattering body, frequency, and type of the ABC.

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