Analysis of the Antenna in Proximity of Human Body Base on the Dual-Grid FDTD Method

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***Abstract*- Dual-grid finite-difference time-domain(DG-FDTD) method is suitable for electromagnetic simulation of multi-scale problems, this paper validate the accuracy of DG-FDTD through a simple simulation. An accurate human model was built based on Zubal human digital phantom, which was used to analyze the electrical performance of the antenna on human body. Simulation results show that human body had a significant influence on the antenna due to the high relative permittivity of the body, the closer from human body, the greater impact on antenna. Because of the shielding of the human body, the antenna radiation power on the backside of human body is 5dB smaller than which in front of human body.**

I. INTRODUCTION

With the development of body-centric wireless communications, more and more communications systems contain antennas in proximity human body, such as mobile phone, Google Glasses and wearable antennas. Body-centric wireless communications will become one of the main ways of communication for end-user in the future [1-3]. It has abundant applications in smart home, personal healthcare, space exploration and military. In these communication systems, wearable antenna's performance will play a key role, but since the antenna is located on the body surface or inside the body, it will be affected by human body inevitably. From the electromagnetic point of view, the human body can be consider as a highly inhomogeneous, and lossy dielectric object, so the effect of human body must be taken into account in antenna design [4].

There are several difficulties in the co-simulation of body with antenna. The first is to establish an accurate model of the human body. up to now, there are several human digital models can be used for electromagnetic simulation[5,6], but some of them are integrated in electromagnetic software, and some of them are not free to get. This paper adopts Zubal Phantom data to establish the human model [7]. The second is to select the appropriate simulation method. Finite-difference time-domain (FDTD) method is a direct time-domain method to solve Maxwell's Equations[8,9], it is suitable to deal with the complex and highly inhomogeneous human body. However, a high spatial resolution is often required for the description of antenna's small geometrical features. Therefore, considering the size of human body and a uniform meshing for the whole FDTD domain, the human body will be a large oversampling area, and the computation time and memory requirements will increase greatly.

For such a multi-scale problems, there are some solutions based on FDTD. Such as sub-gridding FDTD scheme and FDTD combined with other numerical techniques. Sub-gridding FDTD consists of using different resolutions for the description of different areas, finer mesh for antenna area and sparser mesh for body area. Although these method reduces the computation time and memory requirements, they have some drawbacks such as late time instability and reflection from interface between the grids [10].

To overcome these disadvantages, the Dual-grid finite-difference time-domain (DG-FDTD) method is proposed by Raphael Gillard, which has been successfully used to analyze transmission channel between on-body devices [11-13]. This technique divides the original problem into two sub problems each characterized by a different mesh. Then the equivalent principle is used on the surface of two sub problems to reduce the reflection from interface. Hence , for the first, this paper adopts DG-FDTD method to analyze the wearable antenna with accurate human digital model.

II. SIMULATION METHOD

Consider the problem presented in Fig. 1. As it is shown in this figure, the antenna is located in proximity of a dielectric block which represents its environment. Given the proximity of the environment, we must simulate the overall problem to take into account the coupling effects that may generate disturbances in the radiation patterns and input impedance. The simulation is divided into two FDTD simulations steps.

First step of the DG-FDTD. The first step's aims are characterizing the antenna accurately and recording its primary radiation by the use of an excitation recording surface placed around it. Thus the antenna is described using a fine mesh to describe its geometrical features. Absorbing boundary condition is adopted to simulate the infinite open space. The field components on the excitation recording surface are

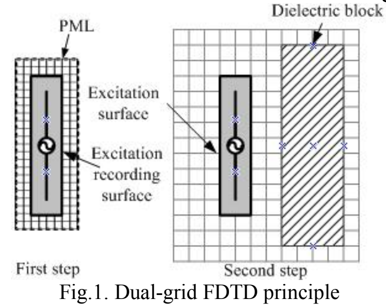


Fig.1. Dual-grid FDTD principle

recorded in a data file for every time step. These records will be used as the excitation of the next step of DG-FDTD. This step starts at t_0 and ends at t_1 when all the electromagnetic energy radiates outside the excitation recording surface.

Second step of the DG-FDTD. The second step's calculation region contains the whole problem in which both the antenna and the dielectric block locate. It aims at calculating the antenna radiation while taking into account the coupling effect between the antenna and the dielectric block. The whole region is described using a coarse mesh to reduce memory requirement. Absorbing boundary condition located outside the whole region is adopted to calculate the antenna radiation. The field components recorded in first step are used as excitation source in this step, which is realized by using the total-field/scattered-field boundary condition on the excitation surface to ensure that only scattered-field exist inside the excitation surface. This step starts at t_0 and ends at t_2 generally longer than t_1 to allow the electromagnetic energy radiates outside the whole region. The Mesh density of the second step is chosen in order to correctly represent the dielectric block, but it only provides a coarse description of the antennas. More specifically, it is not fine enough to simulate the antenna radiation in first step, but it is just enough to simulate the reflected signal received by the antenna in second step.

Since grid density and time step are inconsistent in the two steps, an interpolation process of the field component recorded in first step is need before it is used as excitation source in second step. It is a fine-to-coarse interpolation process, the spatial interpolation can be realized by weighted averaging the electromagnetic fields of neighboring grid, and the temporal interpolation can be realized by weighted averaging the electromagnetic fields of adjacent time.

Post processing. After the above two steps, we can calculate the reflection coefficient S_{11} and the antenna radiation pattern. S11 is calculated as follows:

$$S_{11} = \frac{V_{tot}(f) - Z_0 I_{tot}(f)}{V_{tot}(f) + Z_0 I_{tot}(f)} \tag{1}$$

$$V_{tot}(t) = V_{step1}(t) + V_{step2}(t) \tag{2}$$

$$I_{tot}(t) = I_{step1}(t) + I_{step2}(t) \tag{3}$$

Where $V_{tot}(f)$ and $I_{tot}(f)$ are the Fourier transform of the corresponding voltage $V_{tot}(t)$ and current $I_{tot}(t)$ of the feeding point. The $V_{tot}(t)$ and $I_{tot}(t)$ are the sum of the simulation results of the two steps. Radiation pattern calculation is completed in the second step, which is the same as the conventional FDTD method.

Before adopting the DG-FDTD principle to analyze the antenna in proximity of human body, we validate its accuracy through a simple problem. As it is shown in Fig. 1, a dipole antenna is located in proximity of a dielectric block, the size of the dielectric block is 160mm×24mm×200mm, and the relative permittivity is 50. The length of dipole antenna is 136mm. The distance between antenna and dielectric block is 24mm.

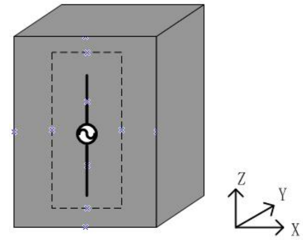


Fig.2. Model for validating the DG-FDTD principle

This problem is simulated using two different FDTD principles. In DG-FDTD principle, the first step's volume size is 32×32×168, spatial step is dx=dy=dz=1mm, time step is dt=1.7ps, iterations is 10000. The second step's volume size is 50×22×60, spatial step is dx=dy=dz=4mm, time step is dt=6.8ps, iterations is 10000. A fine meshing FDTD simulation is used as the reference, it's fine spatial step is dx=dy=dz=1mm for the whole calculate domain, time step is dt=1.7ps, iterations is 30000.

Fig. 3 shows the reflection coefficients of the antenna in free space and place near the dielectric block two different FDTD principles. It is seen from Fig. 3 that, the resonant frequency of the dipole antenna is at 1.04GHz. Since the presence of the dielectric block, the resonant frequency

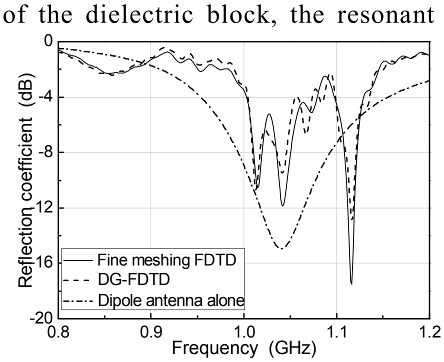
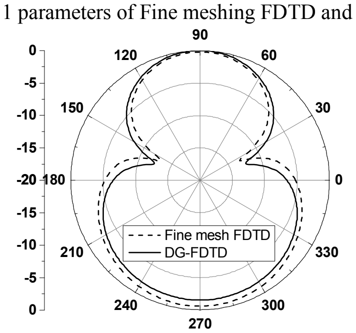
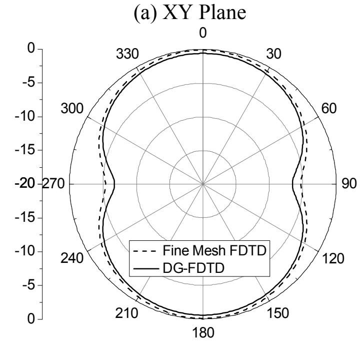


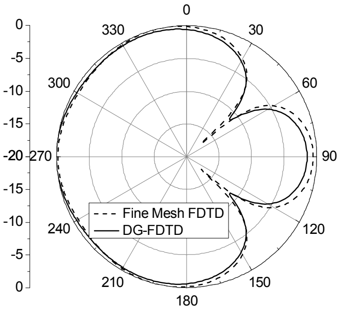
Fig.3. S11 parameters of Fine meshing FDTD and DG-FDTD



(a) XY Plane



(b) XZ Plane



(c) YZ Plane

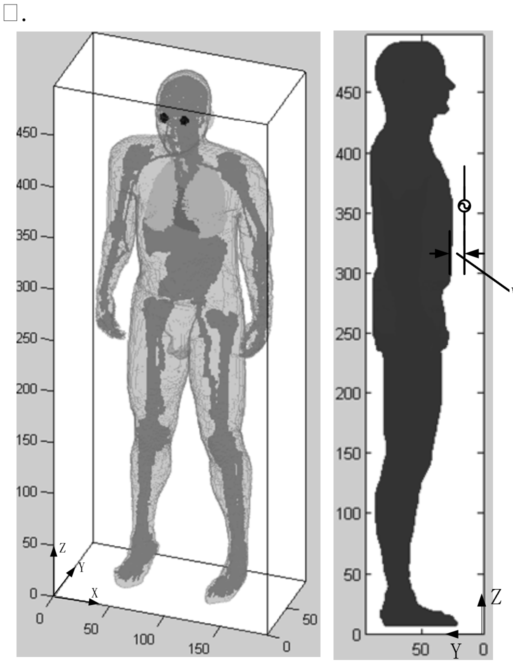
Fig.4. Normalized radiation patterns of FDTD and DG-FDTD at 1.1GHz

increases to 1.12GHz and the operation band becomes narrow. The reflection coefficients calculated by DG-FDTD shows excellent agreement with the reflection coefficients calculated by fine meshing FDTD principle. Fig. 4 shows the radiation patterns of the antenna calculated by the two FDTD principles agree with each other very well.

By the comparison of reflection coefficient and radiation patterns of two different FDTD principles, we can conclude that the DG-FDTD algorithm is accurate enough to analyze the antenna in proximity of human body.

III. Analysis Of The Antenna Nearby Human Body

In order to accurately predict the effect of the human body on antenna, the human model should be as accurate as possible. This paper adopts Zubal Phantom data [7], which is established base on computer tomography(CT) and magnetic resonance imaging (MRI) data of two living human males. It is segmented into 88 different organ types, the resolution of Zubal Phantom data is 3.6×3.6×3.6mm. Three-dimensional human model is shown in Fig.5. In order to show clearly, it draws only brain, eyes, bones, and stomach. The permittivity and conductivity [14] for the 31 tissues at 1GHz are shown in Table□.



(a) (b)

Figure. 5. (a)Zubal human digital phantom (b) Position of the antenna

TABLE□

Permittivity and Conductivity Of Human Tissues at 1GHz

Tissue	ε_r	σ [S/m]
Skin Dry	40.936	0.89977
Brain White Matter	38.577	0.6219
spinal cord	32.252	0.59997
Bone Cancellous	20.584	0.36395
Muscle	54.811	0.97819
Lung Inflated	21.825	0.47406
Heart	59.29	1.2836
Liver	46.401	0.89708
Gall Bladder	58.997	1.2883
Kidney	57.939	1.4495
Cartilage	42.317	0.82886
Oesophagus	64.797	1.2316
Stomach	64.797	1.2316
Small Intestine	58.872	2.2179
Colon	57.482	1.1274
Pancreas	59.47	1.0788
Fat	5.447	0.053502
Blood	61.065	1.5829
Bone Marrow	5.4854	0.042803
Lymph	59.47	1.0788
Thyroid	59.47	1.0788
Trachea	41.779	0.80232
Spleen	56.611	1.3227
Testis	60.259	1.2527
Prostate	60.259	1.2527
Duodenum	64.797	1.2316
Mucous Membrane	45.711	0.88181
Cerebellum	48.858	1.308
Tongue	55.017	0.97508
Lens	46.399	0.82431
Tooth	12.363	0.15566

The generally forms of wearable antenna are dipole antenna or microstrip patch antenna. In order to compare conveniently, we will use dipole antenna to analyze the effect of human body. As it is shown in Fig. 5(b), the antenna is located at human chest, 25mm or 36mm away from human body. In DG-FDTD algorithm, the first step's volume size is 20×20×96, spatial step is dx=dy=dz=1.8mm, time step is dt=3.1ps, iterations is 10000. The second step's volume size is 96×48×249, spatial step is dx=dy=dz=7.2mm, time step is dt=12.4ps, iterations is 15000.

Fig. 6 shows the reflection coefficients of the antenna. S11_36mm and S11_25mm denote the reflection coefficients

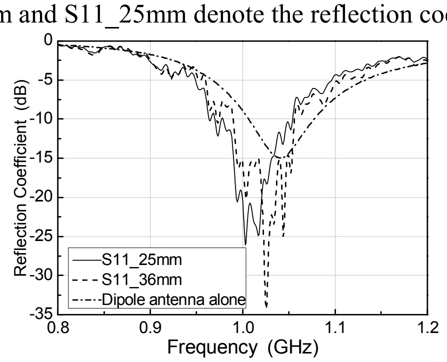
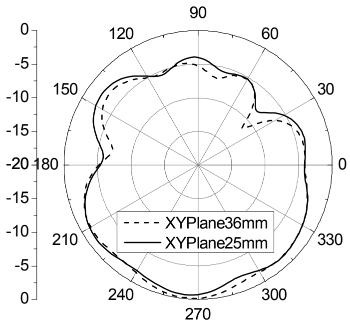
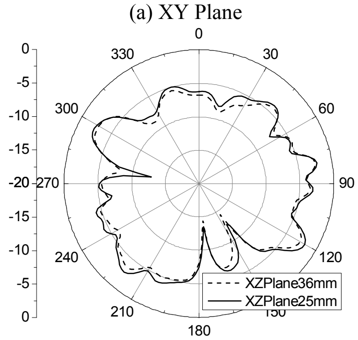


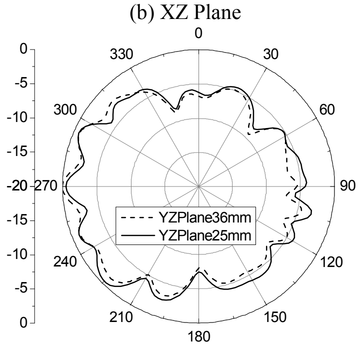
Figure.6. S11 of dipole antenna on human body



(a) XY Plane



(b) XZ Plane



(c) YZ Plane

Fig.7. Normalized radiation patterns of dipole antenna at 1GHz

with distances 36mm and 25mm away from human chest. It is seen from Fig. 6 that, the resonant frequency decreases and the operation band becomes broad. The closer to human body, the more resonance frequency shift. At a distance of 36mm and 25mm from the body, the reflection coefficients are both good. Antenna can radiate effectively.

Fig. 7 shows the radiation patterns of the antenna at 1GHz. It is seen from Fig. 7 that, there is little difference between the radiation patterns with different distances. But they are both impacted by the human body. It is seen from Fig. 7(a) and Fig. 7(c) that, The main direction of the radiation is in front of human chest. The radiated power behind the human body is 5dB smaller than which in front of chest. Omni-directional property is usually required in wearable antenna design, so it is possible to place more antennas on body surface. It is seen from Fig. 7(b) that, the radiation pattern is not symmetric about the YZ plane. This is because the human organs are not symmetric about the YZ plane in Zubal human model. This also means that the human body effects the antenna's radiation greatly. Accurate human model is essential in wearable antenna design.

IV. CONCLUSION

This paper tests the accuracy of the DG-FDTD method, and establishes an accurate human model for FDTD simulation. The simulation results of antenna in proximity of human chest show that, human body has significant effect on the reflection coefficient and radiation pattern of antenna. The conclusions may be useful for wearable antenna design.

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