DGTD Method for SAR Evaluation in a Human Head Model Exposed to a Wideband Antenna

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***Abstract*—An accurate and fast algorithm is proposed to evaluate the specific absorption rate (SAR) in an anatomically realistic human head model exposed to a wideband antenna. The algorithm is based on the discontinuous Galerkin time domain (DGTD) method using hybrid meshes. Hexahedral and tetrahedral meshes are used, respectively, to model the human head with a voxel data format and the wideband antenna with curved and thin structures. The hexahedral and tetrahedral meshes are connected with pyramidal meshes. The Debye model is used to model the dispersive property of the human head tissues. The efficiency of the proposed algorithm is demonstrated by numerical results for SAR in CMODEL exposed to an ultra-wideband antenna.**

I. Introduction

In the past few decades, many studies have been performed on the evaluation of electromagnetic energy absorption in the human body exposed to a handset antenna [1], [2]. The head model is a major factor for the uncertainty of the specific absorption rate (SAR) calculation. To accurately evaluate the SAR in the human head, a number of anatomically realistic human models have been created [3], [4]. The finite difference time domain (FDTD) method and finite integration technique (FIT), which can be directly applied to voxel-based models, are the main methods for simulating the human head exposed to microwaves. However, both methods suffer from serious accuracy degradation when used to model antennas that involve curved and complex geometries.

In this paper, the discontinuous Galerkin time domain (DGTD) method applicable to hybrid meshes is proposed to model the electromagnetic problem of a voxel-based human head model exposed to an ultra-wideband (UWB) antenna. The wideband antenna with complex structures is modeled with tetrahedral elements, and the surrounding free space and voxel-based head model are modeled with hexahedral meshes. The hexahedral and tetrahedral meshes are connected with pyramidal elements in the transition region. To describe the dispersive property of the human tissues over a wide frequency band, the Debye model is employed, where the auxiliary differential equation (ADE) method is used to implement the relationship between the electric polarization $\mathbf{P}$ and the electric field $\mathbf{E}$.

II. Theory and Method

In a bio-electromagnetic modeling that requires the simulation of electromagnetic fields in biological tissues over a wide frequency band, it is important to handle the dispersive property of the biological tissues. The dispersive characteristic can be taken into account via the ADE, which relates the electric polarization to the electric field. The source-free Maxwell's equations for dispersive Debye media can be written as

$$\mu\frac{\partial \mathbf{H}}{\partial t} = -\nabla\times\mathbf{E} \tag{1}$$

$$\varepsilon_\infty\frac{\partial \mathbf{E}}{\partial t} = \nabla\times\mathbf{H} - \frac{(\varepsilon_s-\varepsilon_\infty)}{\tau}\mathbf{E} + \frac{1}{\tau}\mathbf{P} \tag{2}$$

$$\frac{\partial \mathbf{P}}{\partial t} = \frac{(\varepsilon_s-\varepsilon_\infty)}{\tau}\mathbf{E} - \frac{1}{\tau}\mathbf{P} \tag{3}$$

where ε_∞ is the optical relative permittivity, ε_s is the static relative permittivity, and τ is the Debye relaxation time constant. With the DGTD scheme, we can obtain the corresponding semi-discrete system for each element as

$$\mu M\frac{\partial H}{\partial t} = -SE + \sum_{i=1}^{n} F_i(E-E^*) \tag{4}$$

$$\begin{aligned}\varepsilon_\infty M\frac{\partial E}{\partial t} &= SH - \sum_{i=1}^{n} F_i(H-H^*) \\ &\quad -\frac{(\varepsilon_s-\varepsilon_\infty)}{\tau}ME + \frac{1}{\tau}MP\end{aligned} \tag{5}$$

$$M\frac{\partial P}{\partial t} = \frac{(\varepsilon_s-\varepsilon_\infty)}{\tau}ME - \frac{1}{\tau}MP \tag{6}$$

where M is the mass matrix, S is the stiff matrix, and F_i is the mass matrix on face i. For the SAR calculation in the anatomically realistic human head model exposed to an UWB antenna, a hybrid mesh approach is adopted as described in Fig. 1. The sub-region containing the wideband antenna is discretized with a tetrahedral mesh and the sub-region with the voxel-based CMODEL is discretized with a structured hexahedral mesh. The two meshes are connected with pyramidal elements in the transition region [5].

III. Numerical Results

In this SAR simulation, the CMODEL [4] human head model is exposed to an UWB antenna [6] operating from 3.5 to 8.5 GHz, as shown in Fig. 2, where the head is meshed

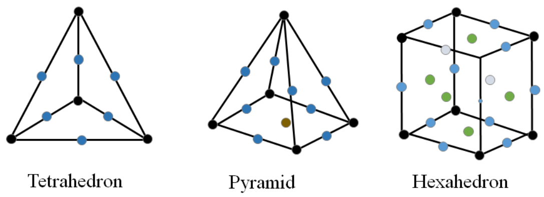


Fig. 1: Hybrid elements.

with hexahedral elements, and the antenna is discretized with tetrahedral elements.

The whole numerical system contains 549,682 hexahedra, 13,980 tetrahedra, and 372 pyramids. The fields are expanded with second-order basis functions. The distance between the head model and the antenna is 5 mm. The UWB antenna is printed on a 0.76-mm-thick arlon dielectric substrate ($\varepsilon_r = 3.8$) and is fed with a 50-Ω lumped port. The spline contour of the radiating part is specified by control points $P_i = (x_i, y_i)$, and the ground plane is modeled with a spline curve with control points $Q_j = (x_j, y_j)$. All the dimensions and control points are shown in Fig. 3. The simulation is performed on a laptop equipped with a Core i7 4900HQ CPU and 24Gb memory. The computation is parallelized with message passing interface (MPI) using four processors. The total number of time-steps is 7700, and the total computing time is 4 hrs and 27 mins. The S-parameter of the antenna is shown in Fig. 4, where it can be seen that the operating band is from 3.8 to 8.5 GHz. The SAR at 5 and 8 GHz are calculated and are shown in Fig. 5.

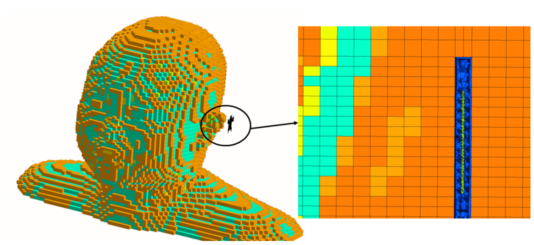
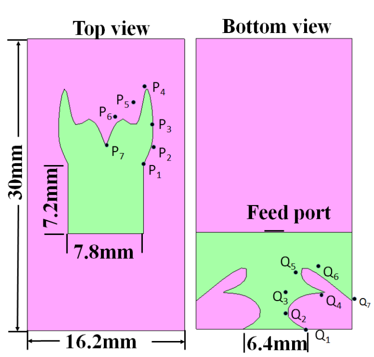


Fig. 2: CMODEL exposed to an UWB antenna modeled with hybrid meshes.



P_1	3.9	17.2
P_2	4.5	18.5
P_3	4.8	19.6
P_4	4.1	24.8
P_5	2.7	21.2
P_6	2.1	21.7
P_7	0	19
Q_1	3.2	0
Q_2	1.4	1.5
Q_3	3.2	3.5
Q_4	5.3	3.8
Q_5	3.1	5
Q_6	2.8	5.8
Q_7	8.1	2.9

Fig. 3: Configuration and parameters of the UWB antenna.

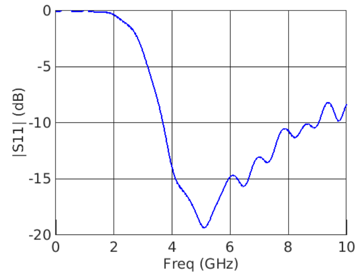


Fig. 4: $|S_{11}|$ of the UWB antenna.

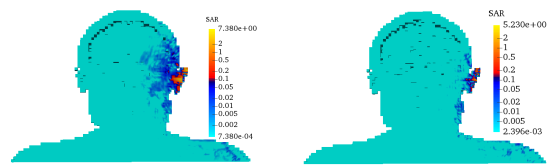


Fig. 5: SAR distribution in CMODEL. Left: 5 GHz. Right: 8 GHz.

IV. Conclusion

A DGTD method applicable to hybrid meshes is developed to evaluate the SAR distribution in a voxel-based head model exposed to an UWB antenna. The dispersive characteristic of the human tissues is considered using the Debye model. Numerical results are presented to demonstrate the efficiency of the evaluation and to show the SAR distributions in the CMODEL head model.

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