Exposure Assessment Using the Dual-Grid Finite-Difference Time-Domain Method

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Exposure Assessment Using the Dual-Grid Finite-Difference Time-Domain Method

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***Abstract*—A new way to carry out numerical cellular telephone simulation in the presence of the head is presented. Here, two finite-difference time-domain (FDTD) simulations with different spatial and time resolutions are sequentially combined to perform a dual-grid FDTD (DG-FDTD) simulation. The DG-FDTD approach has the significant advantages to remain stable along the computation and to be easy to implement in a typical FDTD code. When compared with classical FDTD analysis, the DG-FDTD approach exhibits a reduction in computation time and memory requirements by a factor of 2.3 and 3.2, respectively, while providing accurate results both in near-field and far-field radiation.**

***Index Terms*—Cellular telephone, dosimetry, finite-difference time-domain (FDTD) methods.**

I. Introduction

THE recent rapid growth of cellular telephone industry has generated numerous questions concerning possible health hazards due to electromagnetic (EM) field exposure. As a result, guidelines in terms of specific absorption rate (SAR) have been published by the IEEE [1] and the ICNIRP [2] for limiting EM radiation. The SAR (W/kg) gives a measure of the EM energy absorbed by the human tissues. It is given by

$$SAR = \frac{\sigma |E|^2}{2\rho} \tag{1}$$

where E is the electric field distribution (V/m) inside the tissues that are partly characterized by their conductivity σ (Siemens/m) and mass density ρ ($\mathrm{kg/m^3}$). Due to the difficulties in making SAR measurements, numerical simulations are often used.

The finite-difference time-domain (FDTD) method [3] is the favorite technique in numerical dosimetry problems since it easily handles strongly inhomogeneous media [4]. The FDTD method usually involves an uniform grid of cubical cells that are small enough to correctly evaluate the EM field variations. However, both the execution time and the memory requirements of the simulation increase when the cell size decreases. Fortunately, the EM penetration into the human body at high frequencies is mainly superficial. Therefore, only the area exposed to EM radiation must be finely meshed.

Subgridding techniques have already been applied to overcome the oversampling problem [5], [6]. Subgridding FDTD consists in using different cell sizes over different areas of the computational volume. Thereby, the cellphone and the ear region may be described with a fine spatial resolution, whereas the rest of the head is coarsely meshed. The communication between each subregion implies interpolations and extrapolations of the field components at the interface. Unfortunately, those mathematical operations might generate undesired instabilities when computing the solution [5]. Moreover, the finely discretized area has the same accuracy all along the simulation whatever the magnitude of the field, which can be viewed as a waste of computation time.

Expanding-grid (EG), also called graded mesh, has also been proposed [7], [8]. In that case, the spatial resolution is nonuniform all through the volume, which reduces the computation time. However, the mesh generation must fulfil several requirements to ensure a good accuracy since the nonuniform grid leads to first-order error locally and nonuniform numerical dispersion [7].

Previous studies have demonstrated the use of truncated head to perform SAR assessment [8]–[10]. One way is to consider two simulations of a truncated head that are sequentially run to obtain SAR results in this truncated region only [8], [9]. A faster method resides in using perfectly matched layer (PML) absorbing layers [10]. It is shown that only one third of the head model and one FDTD simulation are required to compute accurate SAR values at 835 MHz. However, this approach does not enable the radiation patterns to be directly calculated unless half of a head is considered.

We propose in this letter to apply the dual-grid finite-difference time-domain (DG-FDTD) method, already introduced by the authors in [11], to the simulation of a cellphone next to a human head.

II. DG-FDTD Principle

As reported in [11], the DG-FDTD method consists of two FDTD simulations that are sequentially run. Fig. 1 presents the two steps of the DG-FDTD method when it is applied to the simulation of a classical dosimetry problem.

As shown in Fig. 1(a), the first step of the DG-FDTD resides in a fine FDTD simulation of the cellphone and a truncated head. The truncation is performed by immersing the tissues into PML layers [12]. This FDTD simulation is stopped when all the EM energy has been radiated outside the computational volume. Actually, this first step only differs from the

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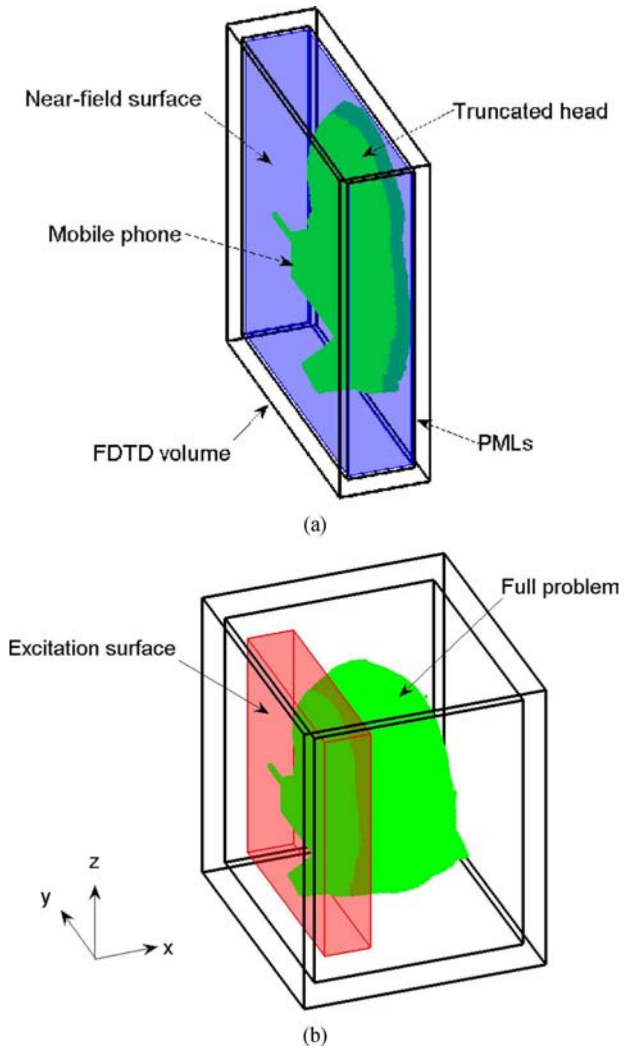

Fig. 1. DG-FDTD decomposition of a classical dosimetry problem. (a) First step: fine FDTD simulation. (b) Second step: coarse FDTD simulation.

simulation performed in [10] by considering a near-field surface [in blue in Fig. 1(a)] that enables the radiated near-field in the time-domain, also called "primary" radiation, to be saved in a data file.

The second step of the DG-FDTD involves a coarse FDTD simulation of the whole problem [Fig. 1(b)]. Now, the excitation is performed by means of an excitation surface [in red in Fig. 1(b)] that has the same physical position and dimensions as the previous near-field surface. Actually, this excitation surface uses the total field/scattered field decomposition principle [3] to inject the primary radiation. Obviously, the antenna generator has to be switched off since the incident power is already present in the primary radiation. We also note that a coarse description of the cellphone and the truncated head is included in order to guarantee that all coupling effects are taken into account.

To sum up, if the SAR in the ear region is the only required data, the first step of the DG-FDTD simulation is sufficient and in fact equivalent to [10]. The second step of the DG-FDTD simulation provides the SAR in the rest of the head as well as the radiated far-field. The radiated far-field is computed using a near-to-far-field transformation based on the Huygens principle and a Huygens surface that includes the whole problem. It is important to notice at that point that the DG-FDTD method is strictly equivalent to a classical FDTD simulation if the same cell sizes are involved during the two steps of the DG-FDTD simulation.

The dual-grid FDTD method has the significant advantages to remain stable and to be easy to implement [11]. Moreover, as we can see in Fig. 1, dielectric material may go through the near-field and excitation surfaces without any special treatment. It should be noted, however, that the DG-FDTD will not work properly if one does not pay attention to the decomposition of the problem. Indeed, the fine FDTD region must be large enough to include the objects that are in the near-field region of the antenna, namely where the antenna strongly interacts with its environment.

TABLE I
FDTD AND DG-FDTD PARAMETERS

	Fine FDTD	DG-FDTD	
		First step	Second step
Spatial steps $dx = dy = dz$	1 mm	1 mm	2 mm
Time step dt	1.828 ps	1.828 ps	3.656 ps
Observation time T_{obs}	15 ns	15 ns	15 ns
Volume size $N_x \times N_y \times N_z$	$255 \times 294 \times 322$	$80 \times 278 \times 306$	$147 \times 167 \times 181$

III. Numerical Example

The accuracy of the DG-FDTD method is evaluated by simulating a homogeneous head with a cellphone placed next to it. The head is made up of one homogeneous material with $\epsilon_r = 41.5$ and $\sigma = 0.9$ S/m. The electromagnetic field is produced by a simple mobile phone standardized in IEEE SCC34/SC2/WG2 that delivers 1 W at 835 MHz. It is represented by a dipole antenna mounted on a dielectric box that includes a metallic ground plane. The whole problem has been proposed by France Telecom R&D has a test case for the SoftLAB activity within the Antenna Centre of Excellence (ACE) project [13].

The first step of the DG-FDTD uses a 1 mm resolution in each direction. This fine spatial sampling is required to correctly represent the cellphone and the ear region geometry. According to [10], only one third of the head is considered for the truncated fine FDTD simulation. The truncation is performed using a 10-cell thick PML layer. The size reduction of the first step depends on both the required SAR accuracy and the considered frequency. More details on the relationship between the truncation and the SAR accuracy can be found in [10]. The second step of the DG-FDTD involves a coarser resolution that is equal to 2 mm in each direction. In addition to the DG-FDTD simulation, a classical fine FDTD simulation is carried out and considered as the reference. Table I sums up the FDTD and DG-FDTD parameters.

The comparison between the FDTD and DG-FDTD methods is shown as the error distribution of the total electric field [Fig. 2(b)] inside the ear region [Fig. 2(a)] at 835 MHz. We observe a good agreement between both methods. The maximum

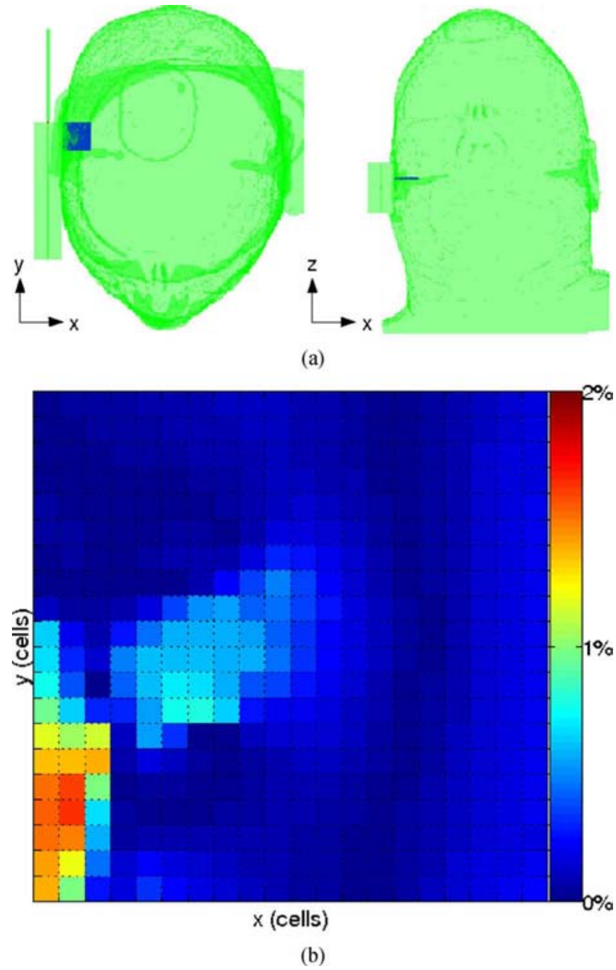

Fig. 2. Error distribution of the total electric field inside the ear region at 835 MHz. (a) Observed cross section. (b) Error distribution.

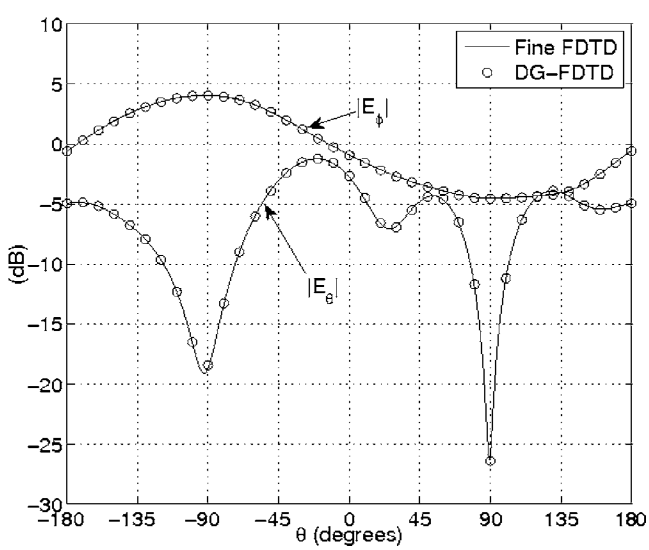

Fig. 3. Simulated far-field in the (xOz) plane at 835 MHz.

error inside the ear region is equal to 1.6% which agrees well with [10].

Fig. 3 presents the simulated far-field at 835 MHz for the FDTD and DG-FDTD methods. The agreement between the dual-grid FDTD and the FDTD results is excellent. Both methods show the modification of the omnidirectional pattern due to the presence of the human head.

Concerning the execution time and the memory occupation, the classical fine FDTD simulation lasts 5 h and 55 min and requires 1270 Mbytes. The DG-FDTD simulation only takes 2 h and 48 min (2 h and 18 min for the first step and 30 min for the second step), that is to say a reduction in execution time by a factor of 2.3. It requires 397 Mbytes (397 Mbytes for the first step and 255 Mbytes for the second step) or a 3.2 reduction of the memory requirements.

IV. Conclusion

In this letter, the DG-FDTD method has been proposed for the fast and accurate analysis of dosimetry problems. The DG-FDTD implies two FDTD simulations with different spatial and time resolutions that are sequentially run. The DG-FDTD approach exhibits a reduction in computation time and memory requirements by a factor of 2.3 and 3.2, respectively, when compared with a classical FDTD scheme.

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