USING FDTD AND HIGH FREQUENCY TECHNIQUES IN THE TIME DOMAIN FOR SAR ASSESSMENT IN HUMAN EXPOSURE TO BASE-STATION ANTENNAS

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ABSTRACT

An exact surface integral derived from the Green's theorem in the time domain, combined with the finite-differences time-domain method (FDTD) is used to simulate an actual base-station antenna that illuminates a place where people can stand. Moreover, as large scattering objects can be in the surroundings, near the antenna and/or the person, high frequency techniques in the time domain are used to calculate the scattered field, in the near o resonant region, which reaches the person. By a combination of these techniques with FDTD, specific absorption rate (SAR) is calculated. Results which demonstrate the suitability of this approach are presented.

INTRODUCTION

Due to the widespread use, in the last years, of personal communications systems, great public concern has arisen about the possible dangerous effects of the electromagnetic radiation on the human health coming, mainly, from mobile telephones and base-station antennas. For this reason, dosimetry studies have to be made to assess the risks in all the possible situations where electromagnetic waves from these sources interact with the surrounding environment, specially with buildings and biological tissues. In order to prevent hazards from those radiations, reference levels have to be observed [1,2]. Moreover, in some cases, with the exposition of a critical organ, it can also be necessary to evaluate if basic restrictions —which are given in terms of specific absorption rate (SAR) for the frequencies under study— are fulfilled. Numerical methods are used for evaluating this last parameter in biological tissues.

The finite differences time domain method (FDTD) has been the most used one for SAR calculations [3,4]. It has the advantages that it can represent complex material properties and obtain broadband responses with a single analysis, but it also has some limitations when calculating fields in large regions or when large scatterers are present. In a work by the authors, an exact surface integral derived from the Green's theorem in the time domain, combined with the FDTD method, has been used for calculating electromagnetic fields both in near- and far-zone in the time domain [5], and this combination has demonstrated to be useful for large computational domains. In a complex electromagnetic environment, a mixed FDTD-integral equation approach for the evaluation of the power deposition in a human body model immersed in that environment has been developed in [6], using previously stored FDTD-computed impulse responses of the human body model and integrating them with the complex incident electromagnetic field distribution, that can be measured on site. This approach is versatile and easy of use, but requires storing a large amount of precalculated data and actual on site measurements. A prediction technique for safety assessment in complex electromagnetic environments is also desirable. When large scatterers are involved, asymptotic high frequency techniques, in the frequency domain, have shown to be a good choice, specially with perfectly conducting obstacles [7]. The development of the time domain version of those high frequency techniques enables us to study problems where large scatterers and large domains are involved, and to combine them with FDTD to analyze SAR in the exposed people. In a recent work [8], a combination of the physical optics in the time domain (TDPO) [9] and the physical theory of diffraction in the time domain (TDPTD) [10] has been used for calculating the energy absorbed by a human head exposed to an electromagnetic plane wave in the presence of a reflecting wall.

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Typical real life situations include those where the field at a place where people can stand may also come from reflections and diffractions in an obstacle, in the near or in the far field from the antenna. Because of these different environments, the size of actual base-station antennas and their operating frequency, in most cases the problem is best approached without assuming plane wave illumination from the antenna and considering near scattered field from the obstacle. In this work, the technique developed in [5] is used to simulate an actual base-station antenna that illuminates a place where people can stand, with scattering obstacles in the surroundings. The field from the antenna at a finite distance is not assumed as that of a plane wave but the field corresponding to the actual antenna characteristics. Once this is known, a formulation for TDPO is developed to precisely compute the $\boldsymbol{E}$ and $\boldsymbol{H}$ scattered fields in large scattering objects that can be in the surroundings, near the antenna and/or the person. As the main contributions to SAR come from specular directions, the TDPTD does not improve the TDPO results in this case [8]. These fields are then introduced into an FDTD scheme to compute the SAR inside the exposed part of the body. The problem can match a typical situation in electromagnetic pollution analysis.

FORMULATION

The FDTD method is a well know computational technique in which the time-dependent Maxwell's equations are discretized using a finite differences scheme and implemented for a lattice of cells named the Yee cells [3,4].

A technique based on the Green's integral combined with FDTD can be used in order to obtain accurate field values at several distances from the source without enlarging the computational domain. This method has demonstrated its validity when calculating electromagnetic fields at finite distances including near, resonant and far field regions [5]. Briefly, the field components outside the FDTD computational domain are obtained by integrating the expression (1) over a surface enclosing the sources of fields:

$$u(\boldsymbol{r},t) = \frac{1}{4\pi}\oint_{S_i} \frac{1}{R}\cdot \boldsymbol{n}'\cdot\left[\nabla' u\,(\boldsymbol{r}',t') - \frac{\boldsymbol{R}}{cR}\frac{\partial u\,(\boldsymbol{r}',t')}{d\,t'} - \frac{\boldsymbol{R}}{R^2}u(\boldsymbol{r}',t')\right]da' \quad , \tag{1}$$

where $\boldsymbol{r}'$ denotes the position vector of a point on the integration surface, S_i, $\boldsymbol{r}$ is the position vector of the observation point, c is the light speed in vacuum, the integrand is evaluated at the retarded time $t' = t - R/c$ with $\boldsymbol{R} = \boldsymbol{r} - \boldsymbol{r}'$, and u represents any component of the electrical or magnetic fields.

The TDPO and TDPTD have been used to obtain far scattered fields from an obstacle and compute SAR when combined with the FDTD method [8]. In this section, we introduce the formulation used in order to apply TDPO to compute scattered fields in points located in the near field of an obstacle.

Using the vector-potential solution to Maxwell's equations for $\boldsymbol{H}$ and $\boldsymbol{E}$ fields [4], and the physical optical approximation, that assumes

$$\boldsymbol{J} = \begin{cases} 2\boldsymbol{n}'\times\boldsymbol{H}_{inc} & \text{lit region} \\ 0 & \text{shadow region} \end{cases} \quad , \tag{2}$$

where $\boldsymbol{J}$ denotes the current density, $\boldsymbol{n}'$ is the unit vector normal to the surface and $\boldsymbol{H}_{inc}$ is the incident magnetic field, we can write

$$\boldsymbol{H}(\boldsymbol{r},t) = -\frac{1}{4p}\int_S \left(\frac{\boldsymbol{R}\times\boldsymbol{n}'\times\frac{\partial}{\partial t}\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)}{cR^2} + \frac{\boldsymbol{R}}{R^3}\times\boldsymbol{n}'\times\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)\right)dS' \quad , \tag{3}$$

where the integral is extended over the lit surface S of the scattering object. From Maxwell's equations, the corresponding expression for the electric field is

$$\boldsymbol{E}(\boldsymbol{r},t) = -\frac{1}{4p}\sqrt{\frac{m}{e}}\int_S \left[\frac{1}{cR}\frac{\partial}{\partial t}\left(\boldsymbol{n}'\times\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)\right) - \frac{1}{cR^3}\left(\boldsymbol{R}\frac{\partial}{\partial t}\left(\boldsymbol{n}'\times\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)\right)\right)\boldsymbol{R} \right.$$
$$-\frac{3}{R^4}\boldsymbol{R}\cdot\left(\boldsymbol{n}'\times\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)\right)\boldsymbol{R} + \frac{\boldsymbol{n}'\times\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t-R/c\right)}{R^2} \tag{4}$$
$$\left. -\frac{3c}{R^5}\boldsymbol{R}\left(\boldsymbol{n}'\times\int_{t_0}^{t-R/c}\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t'\right)dt'\right)\boldsymbol{R} + \frac{c}{R^3}\cdot\boldsymbol{n}'\times\int_{t_0}^{t-R/c}\boldsymbol{H}_{inc}\left(\boldsymbol{r}',t'\right)dt' \right] dS' .$$

RESULTS

Several computations have been made for different scattering obstacles of different sizes in order to test the TDPO near field formulation for a wide range of frequencies. As an example the results obtained by applying the above equations for calculating the scattered fields from a perfectly electric conducting (PEC) square plate are presented in Fig. 1 and compared with those obtained by direct FDTD computation. The incident plane wave, in the direction f = 180º, q = 10º, is a Gaussian pulse with an amplitude of 1 kV/m, a width of 616.32 ps and E_f polarization. The plate is placed in the *XY*-plane, with its edges parallel to the axis and its edge size is 1.2 m. For the FDTD simulation, cubic cells with an edge of 1 cm have been used. The field is computed at a distance of 0.5 m from the plate in the direction of specular reflection, f = 0º, q = 10º.

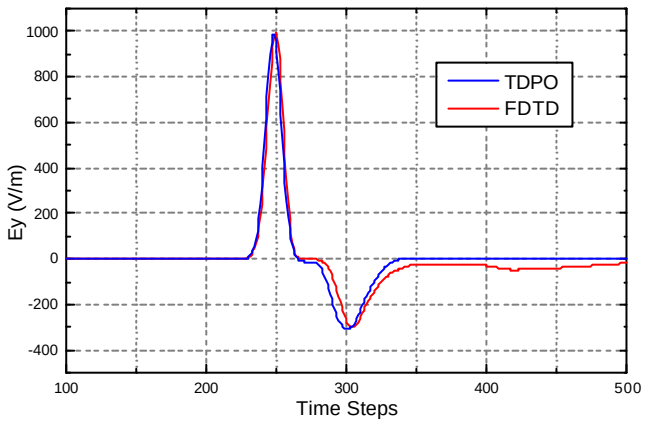

Fig 1. Comparison between TDPO and FDTD techniques. Reflected field 50 cm apart from a 1.2 side square plate. Incident field: Gaussian pulse with E_f polarization; amplitude 1 kV/m.

As can be observed the agreement with the FDTD method is very good, so this technique yields good results for predicting scattered fields near the obstacles, saving time and computational resources when large scattering obstacles are present.

For SAR assessment in high frequency human exposure to base-station antennas, we can use (3) and (4) to obtain the ***E*** and ***H*** fields in points immediately outside the exposed body (or a part of it), including the effects of the scattering from a obstacle nearby. Those field values can be used to calculate the plane-wave equivalent and then include it into a FDTD scheme to accurately compute the SAR inside the body.

In practical situations the exposed person may not be in the far field region, so it is necessary to compute the radiation at finite distances from the source. As an example, (1) has been used to calculate de radiation pattern of an actual base station antenna model used in cellular communications. As emitting antenna we have used a 6 x 2 dipole vertical array antenna backed by a finite-size (171 x 35 cm) metal reflector placed at a distance of $0.25l$ behind the dipoles. Its radiation at distances of 6 and 10 meters, so as its far field radiation pattern, are shown in Fig. 2. A high-fidelity human head model, considered as the most exposed part of the body in this example, is located at 6 m in front of the 6 x 2 antenna, 10º degrees below the maximum gain direction, and a 1.2 m side PEC square plate has been situated 50 cm behind the head. The total radiated power from the antenna is 250 W, and the operating frequency is 900 MHz. In Fig. 3 a contour plot of the 1-gram averaged SAR in the head exposed to both incident and scattered field is shown.

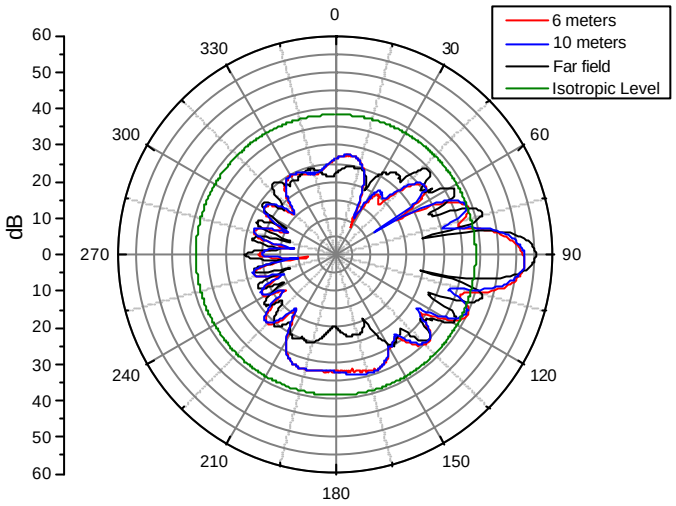

Fig 2. Vertical radiation pattern of the 6 x 2 half-length dipoles antenna. Antenna height 1.71 m.

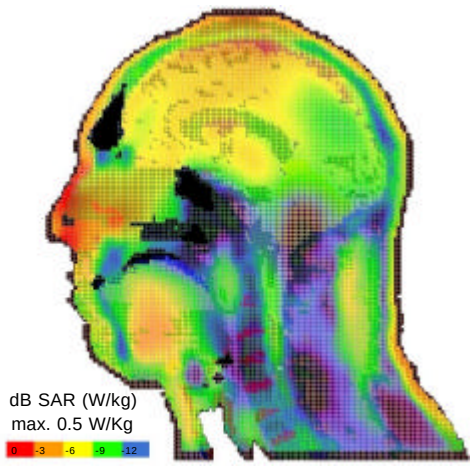

Fig. 3. 1-gram averaged SAR in human head model. Frequency: 900 MHz. Direct + scattered field

CONCLUSIONS

We have shown that the combination of the FDTD method and high-frequency techniques in the time domain is suitable for safety assessment in human exposure to base-station antennas in complex environments. The use of an exact surface integral derived from the Green's theorem in the time domain, combined with the FDTD method allows us to easily simulate the radiation of actual antennas at finite distances without enlarging the FDTD computational domain and, in addition, the scattered fields in large obstacles near the body of a person exposed to that radiation can be accurately computed by TDPO and introduced into a FDTD computer code to predict the SAR. In the example shown it can be noted that due to scattering in the obstacle, appreciable SAR levels are obtained in parts of the head not directly exposed to the antenna radiation. However, although the power density at the point where the head model is located is near the limit of the reference level, the maximum SAR is below the basic restrictions.

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