Combination of the Hybrid$^{(2)}$–Method and the FDTD for Safety Assessment of Human for Base Station Antennas Mounted in Real Environments

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1 Introduction

The Hybrid$^{(2)}$–Method, introduced first in [1], is a very powerful method for solving complex electromagnetic problems consisting of arbitrarily shaped and inhomogeneous objects and electrically large structures. The Hybrid$^{(2)}$–Method is applied successfully to analyze, for example, base station antennas of mobile communication systems embedded in real environments, such as on multi-layered walls, near corners of a building and windows [2, 3, 4, 5]. With the wide acceptance of the mobile telephone there are an increasing risk due to the radiation of the electromagnetic field either from the mobile station or from the base station into the human body. In the past there are many studies on the effects of mobile station antenna on the human body, especially on the human head. Some other studies concerned with the effects of base station antennas [6]. The availability of human models with very fine resolutions from the *Visible Human Project*, that are appropriate as models for the FDTD calculation [7], makes the use of the FDTD the best option. Due to the character of the FDTD as a local numerical method, the FDTD is suitable only for problems with small dimensions. Especially for the study of the scattering problems concerning with base station antennas mounted on buildings, as described above, the use of the FDTD is not efficient or maybe impossible.

The idea developed in this work is to combine the Hybrid$^{(2)}$ method to consider electrically large bodies and also smaller bodies in free space and the FDTD for analyzing human models of best resolution.

Section 2 describes the basic of the computational tool developed. We restricted the explanation only to the necessary things for the understanding, and referred to the given literature list for the completeness of the theory. In section 3 some results are given.

2 Concept of the Computational Tool

The concept of the computational tool introduced in this work is shown in Fig. 1. The antenna is modelled by means of the Finite Element Method (FEM), while the antenna surface is enclosed by the Boundary Element Method (BEM). The effects of the environments of the antenna, for example the building and its parts (windows, corner, etc.), are described ray-optically by means of the Uniform Theory of Diffraction (UTD). At the first step of the calculation we do not consider the finite difference (FD) volume. Instead of this, the electric and magnetic fields of the antenna (direct from the antenna itself and due to the scattering on the environments of the antenna) are calculated on the surface of the FD volume with the help of the following equations

$$\begin{aligned}\vec{E}(\vec{r}\,) &= \iint\limits_A \Big[\overleftrightarrow{G}_J^{E,mod}(\vec{r},\vec{r}\,'\,)\cdot\vec{J}_A(\vec{r}\,'\,) + \overleftrightarrow{G}_M^{E,mod}(\vec{r},\vec{r}\,'\,)\cdot\vec{M}_A(\vec{r}\,'\,)\Big]\; da'\,,\\ \vec{H}(\vec{r}\,) &= \iint\limits_A \Big[\overleftrightarrow{G}_J^{H,mod}(\vec{r},\vec{r}\,'\,)\cdot\vec{J}_A(\vec{r}\,'\,) + \overleftrightarrow{G}_M^{H,mod}(\vec{r},\vec{r}\,'\,)\cdot\vec{M}_A(\vec{r}\,'\,)\Big]\; da'\,.\end{aligned} \tag{1}$$

$\vec{r}$ is observation point on the surface of FD volume ($\partial\Omega$, $\vec{r}\in\partial\Omega$, see Fig. 1). $\vec{J}_A$ and $\vec{M}_A$ are equivalent current densities flowing on the surface of the antenna (Huygens' surface), determined before by the Method of Moment. The convolution of these sources with the Greens' functions, $\overleftrightarrow{G}_J^{E,mod}$ and others, over the Huygens' surface A, results the fields at the observation point. The Greens' functions consist of the Greens' function in the free space $\overleftrightarrow{G}_J^{E,\text{free space}}$ (in absence of the large structures) and the effects of the large structures, due to reflections and diffractions $\overleftrightarrow{G}_J^{E,\text{UTD}}$

$$\overleftrightarrow{G}_J^{E,mod} = \overleftrightarrow{G}_J^{E,\text{free space}} + \overleftrightarrow{G}_J^{E,\text{UTD}}. \tag{2}$$

The electric and magnetic fields calculated on $\partial\Omega$ (closed dashed line in Fig. 1) are then used as excitation for the FD volume (Ω) íncluding the human model.

For the calculation of the FD volume the Finite Difference Time Domain (FDTD) procedure is used and the FD volume

is bounded by $\partial\Omega$ modeled as a Perfectly Matched Layer (PML). Due to the availability of very fine human model up to resolution 1 mm, the FDTD is a very powerful method for the analyzing of the safety assessment of radiating structures into the human body.
Based on these boundary conditions, PML on the outer boundary of the FD volume and equivalent current densities $\vec{J}_{FD}$

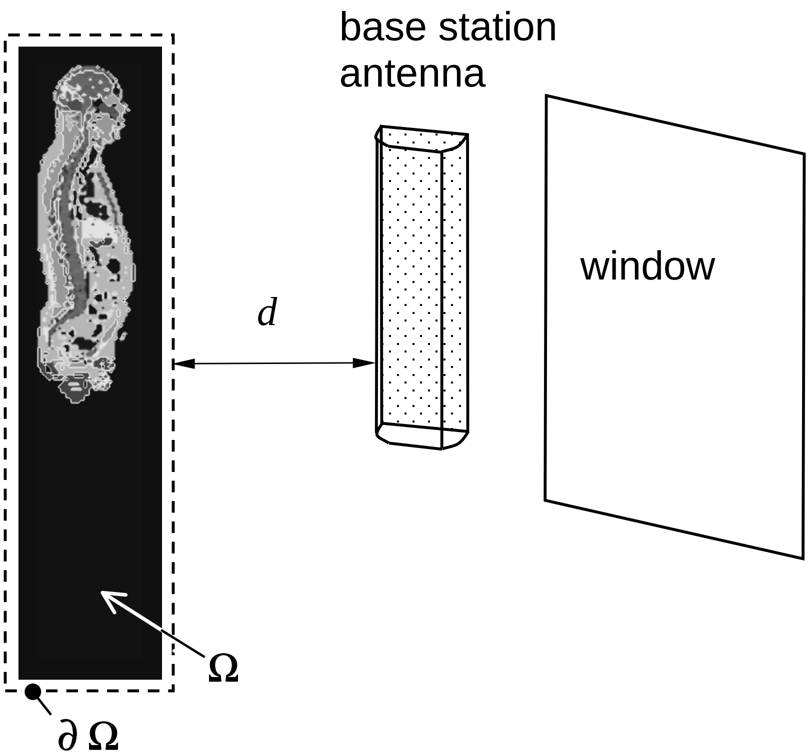

Figure 1: Configuration FD volume with human body model at a distance d in front of a base station antenna mounted on a house wall near a window.

and $\vec{M}_{FD}$ on the same boundary produced via the equivalence principle due to the electric and magnetic fields from the antenna

$$\vec{J}_{FD} = \vec{n}(\vec{r}) \times \vec{H}(\vec{r})\Big|_{\vec{r}\in\partial\Omega} \tag{3}$$

$$\vec{M}_{FD} = -\,\vec{n}(\vec{r}) \times \vec{E}(\vec{r})\Big|_{\vec{r}\in\partial\Omega} \tag{4}$$

the FD volume is then analyzed by the FDTD.
The field distribution on $\partial\Omega$ at the steady state can be again converted back to equivalent current densities with the help of equivalence principle. On the other hand, these current densities radiate electromagnetic fields outside the FD volume. The fields can be then considered in order to take into account the effects of the FD volume on the primer source (the base station antenna), that can change the current distribution on the antenna. To do this, these new current sources are considered as impressed sources (i.e. incident waves for the antenna), and we start the same Hybrid$^{(2)}$ procedure at the second time but now with these additional sources. After that we repeat the FDTD for the FD volume, and so on. The iterative procedure is stopped, if there are no changes of the current distribution on the antenna.

3 Results

As an example, Fig. 2 shows on the left side a base station antenna mounted on a 25 cm thick wall ($\underline{\varepsilon}_r = 3.0 - j\,0.01$, $\underline{\mu}_r = 1$) near a window (1.0 m $\times$ 1.0 m). The antenna has a radiated power $P_{\text{Gen}} = 50$ W. In this work we studied the effects of the base station antenna on a human standing inside the building in the middle of the window facing the

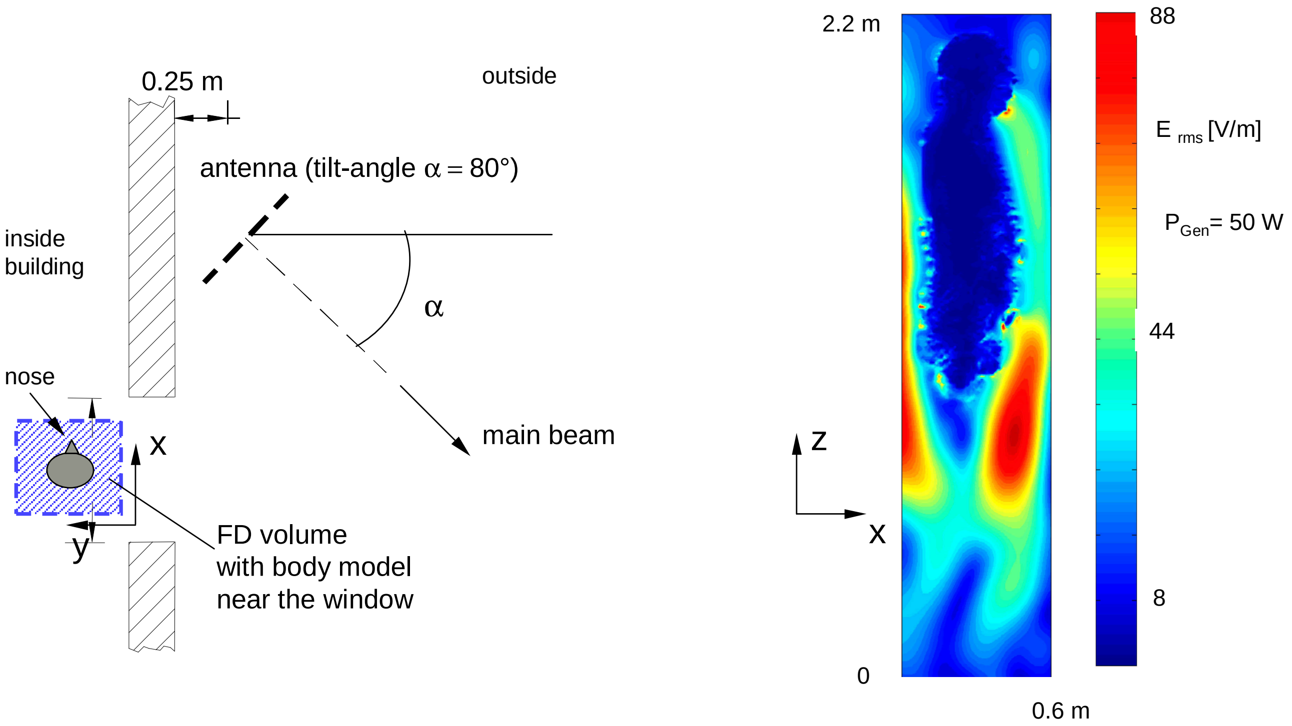

Figure 2: left: base station antenna mounted on a wall near a window, right: electric field distribution in FD volume (Ω).

positive x-axis (hatched box on the left side of the Fig. 2). On the right side the electric field distribution in the FD volume (through the human) is shown. In this calculation we neglected the effects of the FD volume on the current distribution on the antenna, that means, we performed the procedure only once. This approximation is certainly acceptable, since the human body is located far away from the antenna.
Based on the field distribution inside the human body we calculated the specific absorbtion rate (SAR). Fig. 3 shows the local SAR distribution in the human model. Table 1 shows the SAR averaged over the whole-body and over 10 g. The

	Whole-body SAR [W/Kg]	localized SAR [W/Kg]
this work	0.012	0.26
basic restriction [8] for public exposure	0.080	2.00

Table 1: Comparison the SAR calculated in this work and the restrictions given by ICNIRP [8].

comparison with the restriction released by the ICNIRP [8] reveals that the values calculated in this work lie with the factor 7 less than the maximal allowed SAR.

4 Conclusion

The combination of two powerful methods, the Hybrid$^{(2)}$ method and the FDTD, opened a new possibility to solve problems, that cannot be tackled by other methods. This combination method is capable of solving scattering problems involving open and large structures and at the same time one or several region with very fine resolution have to be taken into account.

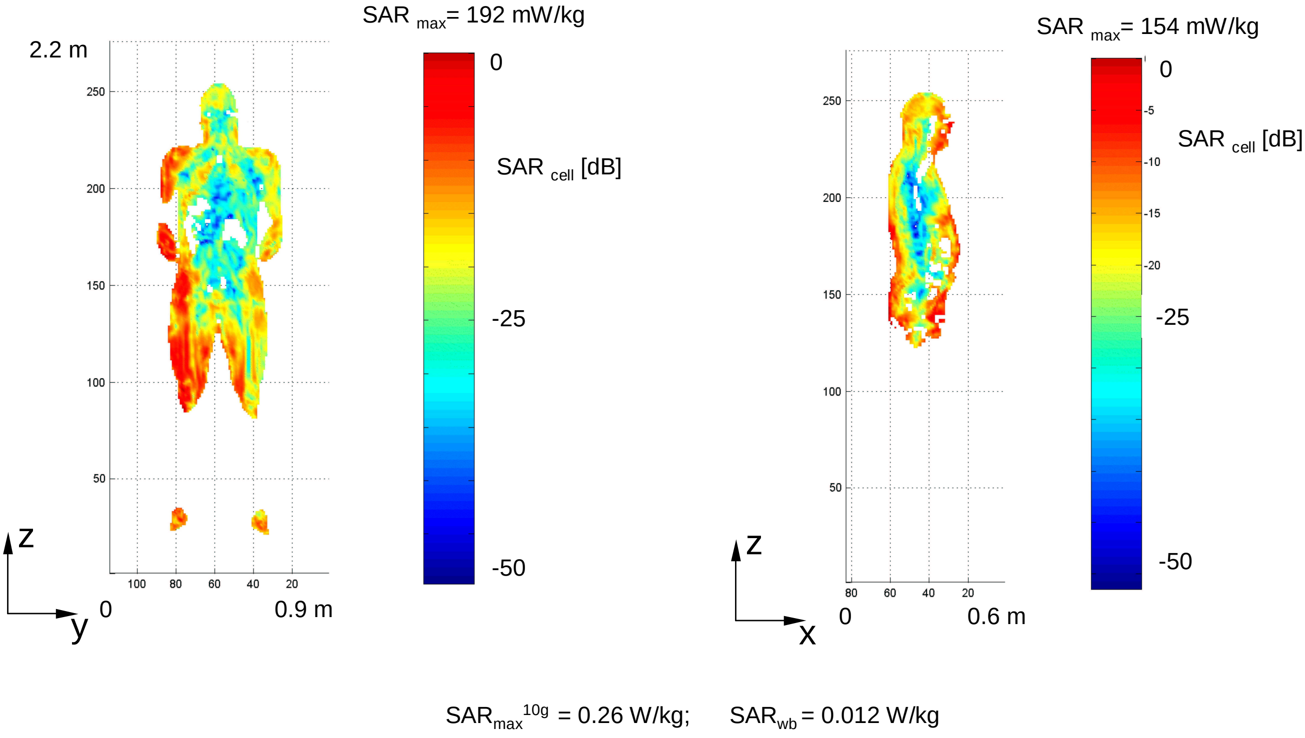

Figure 3: Local SAR distribution inside the human body model for a radiated power of 50 W at 890 MHz. The maximal SAR averaged over 10 g tissue is about 0.26 W/Kg and the SAR averaged over the whole body is 0.012 W/Kg.

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