NUMERICAL EVALUATION OF HUMAN EXPOSURE

TO RADIO BASE STATION ANTENNAS

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ABSTRACT

The exposure of a subject to the field emitted by a typical base station antenna has been studied. Pure FDTD, hybrid RT / FDTD or MR / FDTD, together with a detailed model of the human body, have been used. With reference to the exposure of general population, field and SAR values well below limits proposed in protection standards have been obtained in all studied situations. Similarly, with reference to workers, at a distance of 1 m from the antenna the obtained SAR data are well below the corresponding limits. Some conclusions have been drawn on the relation between local field levels and induced SAR values.

INTRODUCTION

The presence of a large number of radio base stations in densely populated areas makes evaluation of compliance distances from the antennas of these base stations, on the basis of safety standards, an important issue. In particular, compliance distances for a safe exposure must be established both for the general population and for technical personnel working close to the antennas for the maintenance of the base station apparatuses.

Safety of base stations, with respect to human exposure, is currently assessed by comparing the field value, averaged on a surface equivalent to the vertical body section, with reference levels suggested by exposure guidelines [1]-[2]. However, in the vicinity of the base station, where occupational exposure can occur, the incident field is far from being uniform due to the high directivity on the vertical plane of typical base station antennas. General population exposure, instead, generally takes place far from the antenna, in a region where the field emitted by the antenna would be locally uniform but, due to environmental reflections, such as those produced by buildings and ground, field non uniformities arise again. As a consequence, it is not obvious that compliance of the average field level with reference levels ensures that basic limits on the power absorbed per unit of mass (SAR) are respected. This is true in particular for local SAR values, which are expected to be influenced by spatial peaks of the exposure field.

In order to characterise the exposure to the field emitted by a base station antenna, both for general public and for workers, typical urban environment exposure situations together with exposure in close proximity of the antenna must be studied. Therefore numerical tools, able to quantify human exposure for a wide range of distances from the antenna and in the presence of multi-reflection environments, are required.

The finite-difference time-domain (FDTD) method is currently applied to a large number of electromagnetic (em) scattering and antenna problems like those encountered in dosimetry [3]. However, for great distances between sources and scattering objects, numerical requirements become prohibitive due to the accuracy criterion of FDTD (cell size must be less than 0.1 lambda). On the other hand, field propagation in large environments can be efficiently studied by using Kirchhoff's integral (KI) or ray-tracing (RT). KI is a time-domain near-field to near-field transformation that can be derived starting from Green's theorem and Maxwell's equations. RT is a frequency domain technique based on geometrical optics and the uniform theory of diffraction (UTD), able to study field propagation both in free space and in the presence of reflecting surfaces and diffracting edges. Both KI and RT can easily evaluate field distribution produced by sources radiating in free space but are unsuitable to predict field distribution in the presence of scatterers of arbitrary shape. A way to overcome the problems and drawbacks specific to each method is to use hybrid techniques combining FDTD, for the evaluation of the field in confined volumes containing the antenna and/or scattering objects, and KI or

RT, for the modelling of field propagation in the empty space between these volumes. Following this approach, the hybrid multiple-region / FDTD (MR / FDTD) [4-5] and ray-tracing / FDTD (RT / FDTD) [5-6] techniques have been developed.
In this paper the exposure of a subject to the field emitted from a typical urban base station antenna has been studied, both with reference to the exposure of the general population, and to the exposure of workers. To this end, pure FDTD, RT / FDTD and MR / FDTD techniques have been implemented and used, together with a detailed model of the human body.

METHODS AND MODELS

In the MR / FDTD method the simulation domain is divided into smaller sub-domains surrounding the em structures to be considered (e.g. sources and scatterers). The sources that contribute to the field in each sub-domain are both those internal to the domain itself and those external whose effect is taken into account by using the equivalence principle. This principle is applied dividing each sub-domain in two regions separated by an equivalence surface (S): the inner total-field domain and the outer scattered-field domain. The discontinuity between total and scattered fields is sustained by equivalent currents flowing on S, which are obtained by using KI formula computed over a surface S' located in the scattered field region of the other sub-domains. In the RT / FDTD technique, the FDTD technique is used only for the computation of the field in a sub-domain surrounding scatterers while sources and field propagation are modelled through RT. In RT / FDTD, the sources that contribute to the field in the scattered sub-domain are only external to the sub-domain itself and, similarly to MR / FDTD, they are taken into account by using the equivalence principle with the total-field scattered-field formulation. In this case the incident em field required for the evaluation of equivalent currents flowing on the equivalence surface (S) is computed through ray tracing. This technique allows considering the presence of fields reflected from planar surfaces applying, for example, image theory [6].
A panel antenna operating at 947.5 MHz (central frequency of the GSM base station transmit band) has been considered. It consists of four elements, constituted by a parallel pair of vertical dipoles, aligned on a vertical axis. At the back of this array is mounted a metallic flat reflector whose dimensions are 25 x 129 cm. For this antenna the Fraunhofer distance is equal to about 5.3 m. The radiation pattern at 947.5 MHz of the antenna has been obtained with the FDTD method by using a near-to-far-field transformation [3]. The obtained radiation pattern shows a -3 dB aperture on the horizontal plane of about 82°, and a -3 dB aperture of about 13° on the vertical plane. The maximum gain is 14.6 dBi.
To study the interaction of the radiated field with an exposed subject, a heterogeneous model of man has been used. This model has been obtained from a tissue-classified version of the "Visible Human Project" data set developed at Brooks Air Force Base laboratories [7]. The original model had a 1 mm resolution and has been down-sampled to obtain a final resolution of 5 mm. At the considered frequency of 947.5 MHz, in the tissue with the highest permittivity, this cell dimension corresponds to about one tenth of the wavelength, resulting in a good accuracy for the FDTD simulations. The body model has a total height of 180 cm and 31 different types of tissues/organs have been evidenced. In particular, due to the cell dimension used, the most external layer of the model has been associated with an average tissue made of 1/2 skin and 1/2 fat. For the electrical characterisation of the tissues at the considered frequency the data reported in [8] have been used.

RESULTS AND DISCUSSION

Initially the exposure of the human model to the field radiated by the above described base station antenna mounted on a rooftop has been evaluated using the hybrid RT / FDTD method. Three typical exposure conditions have been considered. In all cases the radiated power is 30 W, corresponding to a typical value for a four transmitters base station in urban area. In the first situation (case I), the subject stands on the building roof at a distance of 8 meters from the six meter high trestle where the antenna is mounted. The chosen distance allows the use of the Fraunhofer region approximation for the considered antenna. The subject is placed within the beam of the first lateral lobe of the radiation pattern. In the second situation (case II), the subject stands on a balcony in front of the building where the antenna is mounted at a distance of 30 meters. The subject position corresponds to the pointing direction of the antenna. In the third situation (case III) the subject stands on the street beneath the building (30 meters high) where the antenna is mounted, and another building is present at his back. The subject is positioned within the beam of the last lateral lobe of the radiation pattern.
The obtained results show that, due to the high directivity on the vertical plane of the base station antenna considered, the highest field levels are not obtained on the roof of the building where the antenna is located, but rather on the nearby building placed in the direction of the maximum antenna radiation. Differences between maximum (EIMAX) and

average (EIAVE) values of the exposure field up to 50% have been obtained, evidencing the non-uniformity of the field distribution. As expected, the lowest field levels are experienced by the subject standing in the street due to the high distance from the antenna and to the angled position with respect to the antenna pointing direction.
Fig. 1 reports field and SAR distributions obtained for the subject positioned on the balcony in front of the building where the antenna is located. In particular, Fig. 1 shows the field distribution on the vertical plane containing the antenna maximum radiation direction in the absence of the subject (a), in the presence of the subject (b), and the SAR distribution inside the subject in the same plane (c).
Exposure field and SAR values well below reference levels and basic limits proposed in the main international protection standards [1, 2] have been obtained in all the situations.
A relevant point to investigate is the influence of the environment on incident field levels and on power absorption. To get some insight into this issue, the simulations performed for case II, which is the "worst case", have been repeated neglecting the presence of the two reflecting walls (free space condition). The EIMAX and EIAVE values found show that the field distribution becomes more uniform with the maximum field level decreasing by about 33%, while the average value remains almost unchanged. The SAR values evaluated in this last case of free space condition, compared with those obtained in case II, show that both the average field level and the SAR values remain almost unchanged.
In order to characterise occupational exposure, the human model placed in front of the base station antenna in the direction of maximum radiation, at distances around 1 m, has been also studied by using both FDTD and MR / FDTD. Table 1 presents SAR values averaged over the whole body, and peak SAR values averaged over 1 g and 10 g of tissue mass evaluated for different distances (around 1 m) between antenna and body model, with pure FDTD and MR /FDTD. The antenna radiated power is equal to 30 W.

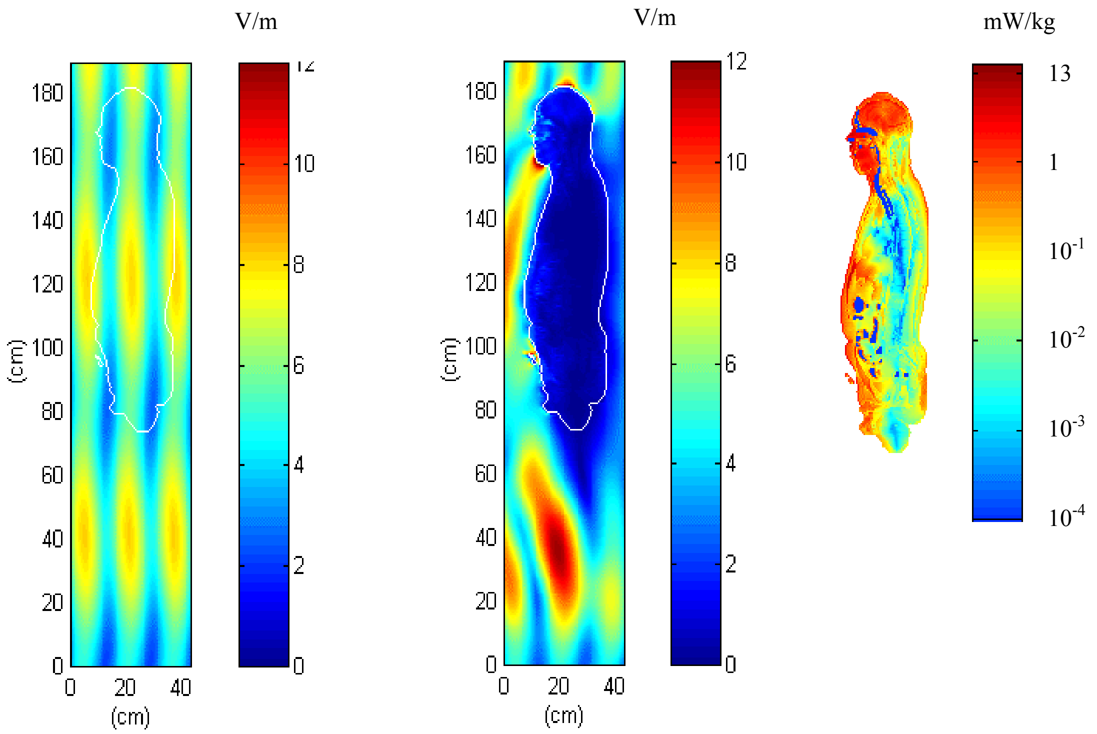

Fig 1 Field and SAR distributions, on the vertical plane containing the antenna maximum radiation direction, for the subject positioned on the balcony in front of the building where the antenna is located.
(a) Field distribution in the absence of the subject,
(b) in the presence of the subject,
(c) SAR distribution inside the subject in the same plane.

Table 1 SAR data for different distances between the human model and the base station antenna

Distance (cm)	FDTD			MR / FDTD		
	SAR_{wb} (W/kg)	**SAR_{1g} (W/kg)**	**SAR_{10g} (W/kg)**	**SAR_{wb} (W/kg)**	**SAR_{1g} (W/kg)**	**SAR_{10g} (W/kg)**
75	0.062	3.21	2.01	0.065	3.24	2.00
100	0.051	3.00	1.92	0.052	3.09	1.89
120				0.043	2.79	1.71

From the Table, the good agreement between the two used techniques can be noted. When distances greater than 1 m are considered, the pure FDTD method requires an excessively high amount of memory, so that the analysis has been carried out only with the MR / FDTD method. Still from the Table, it can be noted that, for all the considered distances, the SAR data are well below the limit values considered for workers by international protection standards [1-2]. If the limit for the general population are concerned, whole body averaged SAR is below the basic restrictions [1-2] for all the considered distances. Instead, the SAR_{10g} almost reaches the limit value of 2.00 W/kg [2] at the shorter distance, and the SAR_{1g} is always above the 1.6 W/kg limit [1].

In the exposure situation corresponding to a distance of 1 m between antenna and human body model, the rms value of the exposure field, averaged on a 40x180 cm surface, equivalent to the vertical left-to-right body section, is about 50 V/m, while the maximum rms field level on the same surface is about 78 V/m. For investigating the effects of these field non-uniformities, a reference plane wave exposure situation has been also studied. In this case, a rms amplitude equal to the average value previously found has been chosen for the incident field. Analysis of the obtained results, in terms of SAR values, suggest that, when field non uniformities due to antenna directivity are present, only the whole-body averaged SAR value is dependent on the field level averaged over a surface equivalent to the vertical body section. Instead, local SAR values appear to be more correlated to the maximum field impinging over the exposed subject.

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