Power Absorption and Temperature Elevations Induced in the Human Head by Dual-Band Phones

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Abstract — **A numerically efficient way to evaluate SAR deposition and temperature elevation inside the head of a user of a cellular phone equipped with a dual-band helical antenna is proposed. The results obtained for a given radiated power show that, although the maximum SAR value as averaged over 1 g in the brain is higher at 900 MHz than at 1800 MHz, the maximum temperature increase in the brain is higher at 1800 MHz. In fact, at 1800 MHz the thermal diffusion process moves heat from the external layers, where SAR values higher than those obtained at 900 MHz are present, toward the brain.**

I. INTRODUCTION

The ever-rising diffusion of cellular communication systems has determined an increased concern for possible adverse health effects due to the field emitted by the hand-held terminals. The evaluation of the power absorbed in the user's head is a key task that can be efficiently performed numerically. At present, among the numerical techniques, the most often applied in the presence of highly non-homogeneous structures, like the human head, is the finite-difference time-domain (FDTD) method, thanks to its efficiency and ease of implementation [1]. Generally, in FDTD studies, the phone radiating element is simulated as a half-wavelength dipole, a quarter-wavelength monopole, or a whip antenna. All these antenna models, and the last two in particular, can be used as an approximate (quarter-wavelength monopole) or realistic (whip antenna) model of pullout antennas, that were equipping, till some time ago, almost all cellular hand-sets. Nowadays, however, the need for more and more compact terminals and for dual-band operation is arising, and new antenna designs are being used. This is accomplished by using planar integrated antennas [2] or helical antennas [3], [4]. Therefore, the solution of the problem of the electromagnetic (EM) dosimetry for a human head exposed to a hand-held terminal equipped with a helical antenna becomes of primary importance. However, while monopole and planar antennas are easily implementable inside an FDTD code, as confirmed by the many FDTD studies available in literature, modeling of a helix can become a rather difficult task. Some studies of this problem have recently appeared in the literature, but they have evidenced the difficulty of modeling helical structures with the FDTD method. In fact, only rather large structures have been studied employing a pure FDTD scheme [3], while for smaller structures either equivalent sources [4] or a hybrid MoM/FDTD technique [5] have been employed. Since all these techniques show some problems and drawbacks, the applicability of a pure FDTD approach, properly modified to allow the use of a graded mesh, has been investigated [6].

Numerical dosimetry applied to the problem of human head exposure to fields radiated by cellular phones exhaustively answered many questions, but some problems are still open. In particular, one of them is the evaluation of induced temperature increases in the user's head, that can be directly compared with the thresholds for the induction of known thermal effects in the human head. Unfortunately, if much has been done in the field of numerical dosimetry, only a few works are available addressing the em field / human body interaction problem also from a thermal point of view [7], [8]. In particular, in [8] the power deposition and temperature increase in the head of a cellular phone user have been evaluated for cellular phones equipped with linear and planar antennas.

In the present work, the problem of SAR deposition and temperature elevation inside the head of a user of a cellular phone equipped with a dual-band helical antenna is numerically solved by using a graded-mesh FDTD approach for the solution of the dosimetric problem, and a finite-difference implementation of the bio-heat equation (BHE) for the solution of the thermal problem.

II. METHODS

The power deposition in a human head model due to a cellular phone equipped with a helical antenna has been computed by using the FDTD numerical technique [1] with a graded mesh.

The considered head model has been obtained from a tissue-classified version of the "Visible Human Project" data set developed at Brooks Air Force Base laboratories

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[9]. The model has a 3-mm resolution and discriminates 19 different types of tissues/organs. For the electrical characterization of the tissues at the considered frequencies, Gabriel's data [10] have been used (see web site "http://www.fcc.gov/fcc-bin/dielec.sh").

A cellular phone equipped with a dual band helical antenna, similar to one actually available on the market [11], has been considered.

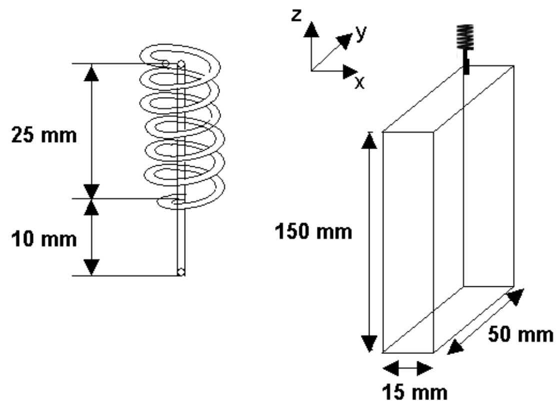

Fig. 1. Cellular phone model considered.

The phone helical antenna operates in normal mode and is constituted of a helix mounted on a straight metal connection and of a monopole placed inside the helix (see Fig. 1). The diameter, pitch, and length of the helix are 5.5, 4.4, and 27 mm, respectively, and the straight metal connection is 10 mm long. All dimensions are chosen to achieve resonance at 900 MHz. The monopole is 25 mm long and, together with the straight metal connection, is tuned to operate at 1800 MHz. The wire radius is equal to 1 mm. The helix is mounted on the right-hand corner of a metallic case, in the far end with respect to the side of the earphone. The phone metal case is 15×50×150 mm wide and a 3-mm thick lossless dielectric shell (ε_r = 2.7) encloses it.

In the FDTD analysis of the considered phone, the section of the wire has been modeled, within the fine-resolution region of the graded mesh, with a five-cell cross. The size of the cells in the high-resolution region has been chosen equal to 0.55 mm. The largest cell size has been chosen equal to 3 mm and the grading factor equal to 2. The antenna has been fed, at the connection between the metallic case and the straight wire, with a gaussian pulse, thus exploiting the capability of FDTD to perform a wide-band analysis of the structure. The simulation has been interrupted when the current at the antenna feed point was reduced at least of three orders of magnitude with respect to the peak value.

To describe the temperature distribution $T = T(\mathbf{r},t)$ inside the user's head the bio-heat equation has been used [8]. This equation describes the different ways through which heat is transferred, produced, or removed inside the tissues, and precisely: heat transfer through internal conduction, metabolic heat production, exogenous heat deposition, and heat exchange mechanism due to capillary blood perfusion. The BHE can be adopted to study the temperature increase induced inside subjects exposed to EM fields, after that a dosimetric analysis has been performed. In fact, the power absorption induced by the EM-field exposure can be represented as an exogenous heat deposition term inside the BHE. This exogenous heat deposition is responsible for the alteration in temperature profiles inside the biological tissues with respect to the unexposed situation. This term, which represents a volumetric heat deposition, can be directly derived from the SAR distribution, simply multiplying SAR by the tissue mass density ρ [8].

III. RESULTS

First of all, a simulation has been performed to study the free-space radiating properties of the phone. The outputs of this simulation have been the antenna return loss (RL) over the 0.8÷2 GHz band and the radiation pattern at the operating frequencies of 900 and 1800 MHz. In particular, antenna radiation impedance (from which RL is derived) has been computed as the ratio between the fast Fourier transforms of the voltage and current signals recorded at the antenna feed point. The radiation pattern, instead, has been evaluated through a discrete Fourier transform of the near field components and by applying a near-to-far field transformation. Fig. 2 shows the behavior of antenna RL as a function of frequency. The obtained results follow quite well those measured and simulated in [11]. In particular, the two frequencies of operation, where the RL has a minimum, are clearly evident.

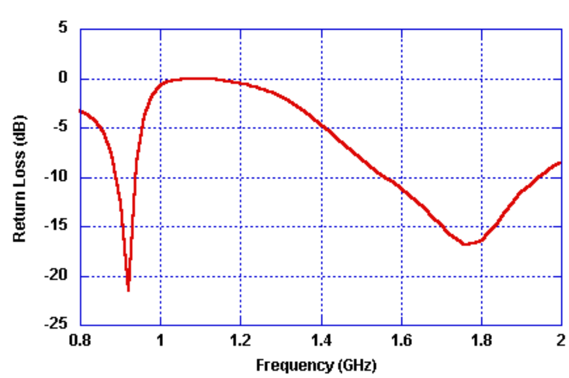

Fig. 2. Return loss as a function of frequency

The normalized radiation patterns on the z-y plane of Fig. 1, at the two frequencies of 900 and 1800 MHz, are reported in Fig. 3 and Fig. 4, respectively. The two figures show that the considered antenna operates in normal mode with a 30° down tilting (the maximum gain is obtained for θ ≈ 240°). At the frequency of 1800 MHz the radiation pattern shows many lobes with respect to the typical monopole pattern, due to the presence of the helical structure.

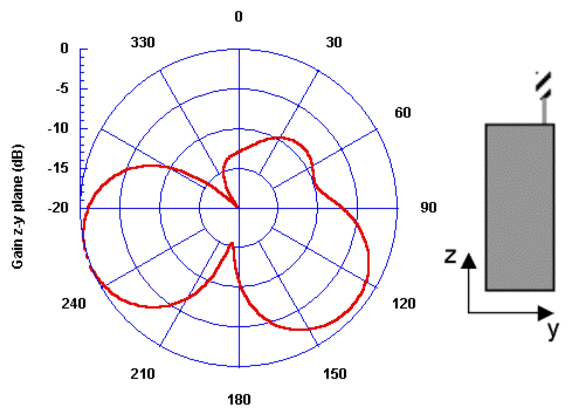

Fig. 3. Normalized radiation pattern at 900 MHz.

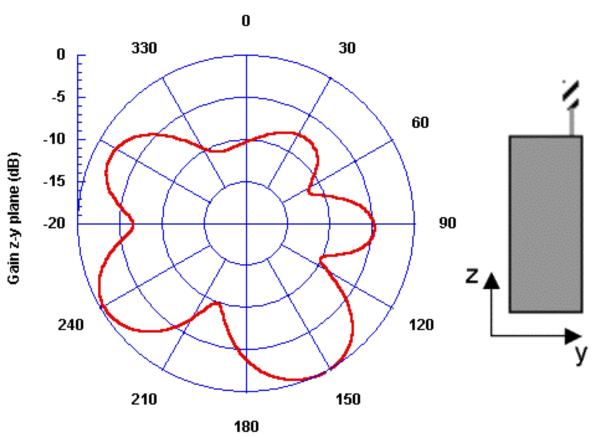

Fig. 4. Normalized radiation pattern at 1800 MHz.

The interaction between the considered phone model and the human head model has been studied at the two frequencies of operation. A discrete Fourier transform of the electric field inside the head has been used to evaluate the field amplitude from which the SAR distribution has been derived. Fig. 5 and Fig. 6 show the SAR distributions evaluated on the coronal vertical plane passing through the point where the maximum SAR is located. Both figures refer to a radiated power of 1 W. The figures evidence the higher penetration depth at 900 MHz, and the higher superficial SAR values obtained at 1800 MHz. In particular, at the frequency of 900 MHz about 800 mW are absorbed inside the head, while the SAR_{1g}, SAR_{10g} and $SAR_{1gBRAIN}$ are equal to 8.24 W/kg, 4.77 W/kg and 1.29 W/kg, respectively. At the frequency of 1800 MHz, about half of the radiated power (500 mW) is absorbed inside the head, while the SAR_{1g}, SAR_{10g} and $SAR_{1gBRAIN}$ are equal to 14.46 W/kg, 6.93 W/kg and 0.93 W/kg, respectively. In conclusion, at 1800 MHz the SAR averaged over 1 g and 10 g increases with respect to the 900 MHz situation, while the SAR in the brain and the power absorbed in the head reduces. Similar results have been obtained by Dimbylow [12] and Gandhi [13].

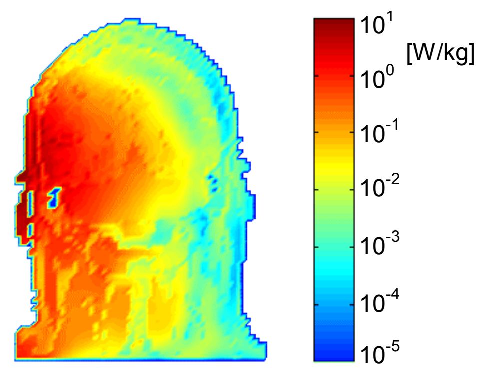

Fig. 5. SAR distribution at 900 MHz for a radiated power of 1 W.

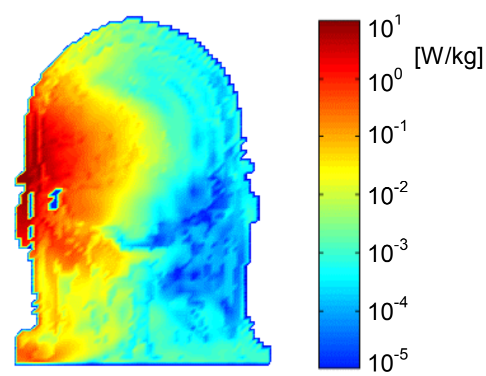

Fig. 6. SAR distribution at 1800 MHz for a radiated power of 1 W.

With reference to the temperature increase (ΔT), Fig. 7 and Fig. 8 show the ΔT distributions at 900 and 1800 MHz, respectively. From the figures, it can be noted that the maximum temperature rises (ΔT_{MAX}) are always obtained in the ear. A comparison between the two frequencies used reveals that at 1800 MHz higher values are obtained with respect to the 900 MHz situation, as expected from the SAR results. In particular, the ΔT_{MAX} obtained in the ear region are equal to 0.93 °C and 1.28 °C

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at 900 MHz and 1800 MHz, respectively. A temperature rise of 0.26 °C (900 MHz) and 0.31 °C (1800 MHz) is present in the external part of the brain close to the phone ($\Delta T_{MAXbrain}$). It is worth noting that in the brain the ΔT_{MAX} is higher at 1800 MHz with respect to the 900 MHz exposure, thus reversing the SAR behavior. This is due to the thermal diffusion process that moves heat from the external layers, where high SAR values are obtained, toward the brain.

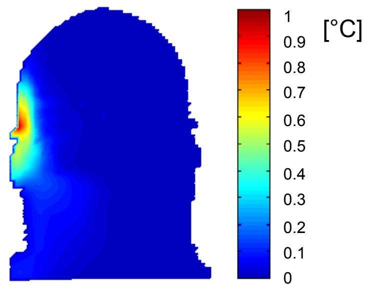

Fig. 7. Temperature increase distribution at 900 MHz for a radiated power of 1 W.

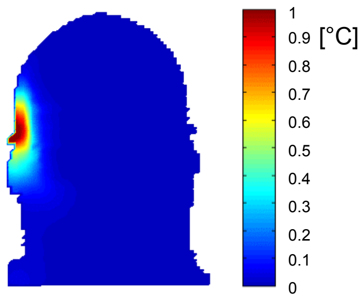

Fig. 8. Temperature increase distribution at 1800 MHz for a radiated power of 1 W.

V. Conclusions

SAR distributions and temperature increases have been evaluated in a head model exposed to the field radiated by a cellular phone, equipped with a helical antenna operating at 900 and 1800 MHz. The obtained results confirm the importance of performing a thermal analysis together with the dosimetric one. At the same levels of radiated power, operation at 1800 MHz results in higher SAR and temperature increases with respect to 900 MHz. It must be noted that all the discussed results refer to a free space radiated power of 1 W. However, the new digital generation of GSM cellular phones is characterized by a mean radiated power of 250 mW at 900 MHz and 125 mW at 1800 MHz. This means that, for extrapolating the safety of the exposure, the reported results should be decreased by a factor of 4, at 900 MHz, and 8, at 1800 MHz. If these reduction factors are considered, the calculated temperature increases become about 40 times lower than those indicated in the literature as thresholds for the induction of thermal damage [8].

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