INTERACTION BETWEEN SMALL THIN-WIRE ANTENNAS AND THE HUMAN HEAD STUDIED WITH THE ADI-FDTD/MoMTD HYBRID METHOD

F. J. García Ruiz [1], **R. Godoy Rubio, S. Gonzalez Garcia, M. Fernández Pantoja, A. Rubio Bretones, R. Gómez Martín**

All authors are with the Dpt. of Electromagnetics and Matter Physics, University of Granada, Spain.

[1] Email: franruiz@ugr.es

ABSTRACT

The design of electrically small antennas is a topic of current interest connected with the growing development of mobile-communication devices that require their components to be even smaller and lighter. From the designers' point of view, apart of seeking antennas with the appropriate radiation characteristics, it is critical both to know how the presence of the head affects the performance of antennas, as well as how much energy is absorbed by the head in front of the antenna in order to meet the maximum Specific Absorption Rate (SAR) directives. In this work this mutual interaction of small thin-wire antennas in front of the human head has been studied.

The thin-wire small antennas considered were genetically optimized (GA) monopoles with either prefractal or Euclidean (zigzag or meander) geometries (M. F. Pantoja et al., "GA design of wire pre-fractal antennas and comparison with other euclidean geometries", *IEEE Antennas and Wireless Propagation Letters*, 2, 2003. pp. 238-241). In the first part of this work we study how the presence of the head modifies the resonance frequency and the input impedance of these antennas depending on the specific geometry, showing that the resonance frequency has greater variation in the prefractal antennas than in their non-fractal counterparts. In the second part, we focus our attention on the calculation of the SAR of a human head in front of those antennas, and show that the SAR maps are almost identical for all of them, since the main radiation actually comes from the excitation point. In order to meet the recent IEEE recommendation on SAR calculation (Std. C95.1-1999, Std. C95.3-2002), we have developed a new algorithm managing the average volume to be exactly a 1gram cube.

A biologically realistic model of a human head, obtained from a Magnetic Resonance Image (MRI) has been employed. The head is divided into 122x133x155 voxels 2 mm side, specifying for each one the constitutive parameters (permittivity, permeability and conductivity) at 900 MHz from a Debye model. The novel Alternating Direction Implicit Finite Difference Time Domain (ADI-FDTD) method has been used to simulate the head and the free-space around the antenna, and the Method of Moments in Time Domain (MoMTD) to simulate the thin-wire antenna. Making use of Huygens' principle, the hybridization of ADI-FDTD with MoMTD (R. G. Martín et al. Time-domain hybrid methods, in *Time Domain Techniques in Computational Electromagnetics*. Pp. 133-172. WIT press) yields a tool which permits to simulate the full problem of the antenna in front of the head, thus overcoming the well-known inability of FDTD techniques to accurately handle arbitrarily-oriented thin wire structures. The use of this hybrid tool was crucial to get accurate results due to the intricate shapes of the antenna geometries considered.

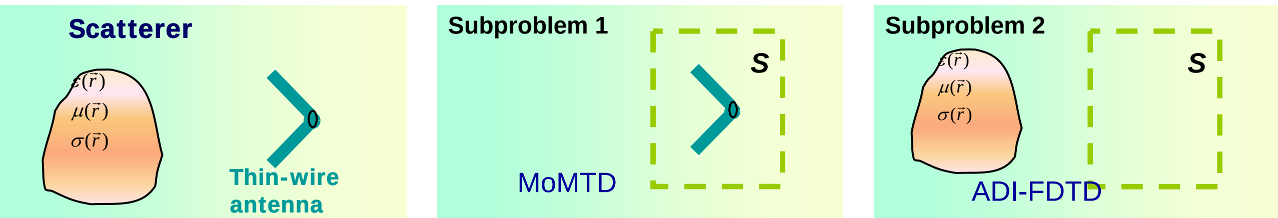
The employment of ADI-FDTD, instead of the classical Yee-FDTD, allows us to overcome the conditional stability limit of the latter while keeping its ability to treat general inhomogeneous bodies. Thus, the time increment can be increased over this limit, independently of the space increment, to reduce the computation time. Furthermore the hybrid code ADI-FDTD/MoMTD has proven to reduce the apparition of the late-time instabilities which, under some circumstances, arise in the hybrid Yee-FDTD/MoMTD code.

INTRODUCTION

The analysis of the interaction between mobile handset antennas and the human head has become one of the most covered topics in the electromagnetic investigation during the last few years. Anyway, to the best of our knowledge, no work has been done on the behaviour of small thin-wire antennas in the presence of the head, and their mutual interaction. This interaction has two different effects to be considered: the effect that the presence of the human head has over the antenna parameters, and the energy absorption produced in the head due to the electromagnetic fields radiated by the antenna and the near fields present around it. In this paper both effects have been studied and will be presented after a brief description of the hybrid ADI-FDTD/MoMTD method employed for the computational simulation.

THE HYBRID ADI-FDTD-MoMTD METHOD

The simulation of the transient excitation of permeable bodies is a problem of current interest in areas such as: Ground Penetrating Radar (GPR), breast tumor detection, or SAR prediction. The problems include the modelling of radiating elements in the presence of inhomogeneous bodies, which are close to the antennas, and therefore influence their radiation characteristics. Appropriate numerical methods able to accurately analyze these complex problems should be used. However, it is not always possible to find a single numerical technique appropriate to deal with the whole configuration, and then it is necessary to resort to hybrid methods. This is, for example, the case when thin-wire antennas are chosen as radiating elements, which is relatively frequent due to their simplicity and flexibility.
The hybrid FDTD-MoMTD [1] has been successfully employed to address the above mentioned problems. Its formulation is quite general but since it employs the traditional explicit FDTD algorithm, the time increment cannot exceed the Courant stability limit. Furthermore, in some cases, the hybrid FDTD-MoMTD technique leads to unstable results.
The Alternating Direction Implicit Finite Difference Time Domain (ADI-FDTD) method [2-4] is a powerful alternative to the traditional FDTD method. Its unconditional stability permits to choose the time increment independently of the space increment, which may lead to significant CPU time reductions for a number of practical cases.
It has been demonstrated [5] how the hybridization of the ADI-FDTD with the Method of Moments in time domain (MoMTD) permits to build a robust simulation tool that can be applied to solve complex problems. A main advantage of the ADI-FDTD-MoMTD is that it has exhibited a stable behaviour in the problems where the FDTD-MoMTD becomes unstable.
The hybridization technique is based upon the use of the Huygens' Principle, as it follows. First, the original problem of a thin-wire antenna located in the area surrounding an inhomogeneous dielectric body shown in Fig. 1*a* is divided into two subproblems (Figs. 1*b* and 1*c*), and each one is treated by the most appropriate method. Both subproblems are interconnected through a Huygens' surface, *S*, where equivalent sources replace the antenna and are used as the excitation to advance the ADI-FDTD problem in the whole space. Next, the scattered fields inside the Huygens' surface previously obtained are added to the excitation of the antenna and used to advance the MoMTD procedure, and so on.



1*a* 1*b* 1*c*

Fig. 1. Division of the original problem into two subproblems, each of which can be treated choosing appropriate method.

MODEL DESCRIPTION

A biologically realistic model of a human head, obtained from a Magnetic Resonance Image (MRI) has been employed. The head is divided into 122x133x155 voxels 2 mm side and its constitutive parameters (permittivity, permeability and conductivity) are approximately constant in the 850-950 MHz range, and calculated at 900 MHz from the Debye model.

SMALL THIN-WIRE ANTENNAS NEAR THE HUMAN HEAD

As reducing the electrical size of an antenna is at the expense of other parameters such as bandwidth and efficiency, antenna-miniaturization techniques require a compromise among all the parameters involved. This fact makes optimization techniques such as Genetic Algorithms (GA) an appropriate tool for the design of such antennas. With this aim, we have applied a Multiobjective Genetic Algorithm (MOGA) to the optimization of wire antennas in terms of bandwidth, efficiency and electrical size [6].
In this work several antennas designed with this technique have been tested when they are situated close to the human head. Table 1 shows the variation on the resonance frequency and input resistance of the three antennas shown in Fig. 2 when they are placed by the head. It is noteworthy that the prefractal Koch-type antenna suffers from a greater variation in terms of its resonance frequency that their non-fractal counterparts.

Table 1. Characteristics of small thin-wire antennas with and without head.

	Without head		With head		
	f_o (MHz)	R_{in} (Ω)	f_o (MHz)	R_{in} (Ω)	f_o var (%)
Koch-type	880.7	46.08	852.8	28.57	3.17
Meander	890.7	45.58	879.5	26.70	1.25
Zigzag	890.8	39.26	876.9	30.77	1.56

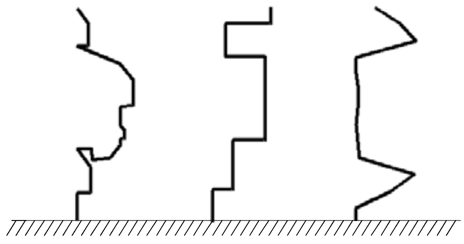


Fig. 2. Small thin-wire antennas.

STUDY OF THE POWER DEPOSITION IN THE HUMAN HEAD

SAR Estimation Algorithm

Normative [7] establishes a limit for exposure to electromagnetic fields in terms of a whole body SAR (Specific Absorption Rate) of 0.08 W/Kg and a maximum localized SAR of 2 W/Kg, averaged in a 1 gram cubic volume. One of the main difficulties when obtaining the SAR with FDTD-like codes is what strategy to choose exactly 1 gram cubic volume cells, since in general it is not always possible to ensure the existence of a cubic volume centered in any cell and with a whole number of cells around it with the required mass ([8] describes a region growing algorithm for this).
Moreover extra difficulties arise when the volume include air cells. A recent recommendation by the IEEE [9] gives some practical norms overcoming this inconvenient. Nevertheless, a direct extension of the algorithm proposed in [8] would lead to difficulties in those cases, because of its cubic centered strategy. In this work we employ a novel algorithm allowing the cubic volume to be centered on the exterior surface, and growing to any direction, so that it automatically finds the 1 gram suitable volume according to the IEEE normative.

Calculus of the SAR in the Human Head due to Small Antennas

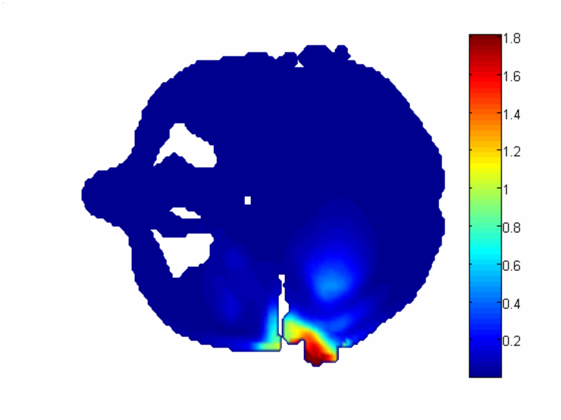
The same small thin-wire antennas presented in Fig. 2 were simulated in order to estimate the SAR in a human head model. The maximum value of the averaged SAR is presented in Table 2, where it can be seen that the behaviour of all the antennas is similar, although the SAR is slightly reduced in the Koch-type antenna. In all cases, the values are near or just above the limit of the above referred normative. Fig. 3 shows SAR maps for the three antennas in the horizontal plane closest to the feeding point of the antennas and a cut of the human head model in the same plane. It is noteworthy that the zone of the head that suffers a greater absorption is just beneath the ear. It can be seen that the maps are almost identical for the three antennas, which confirms, as expected [10], the fact that the main radiation comes from the point where the antenna is excited.

Table 2. Maximum averaged SAR obtained within the human head model due to small thin-wire antennas.

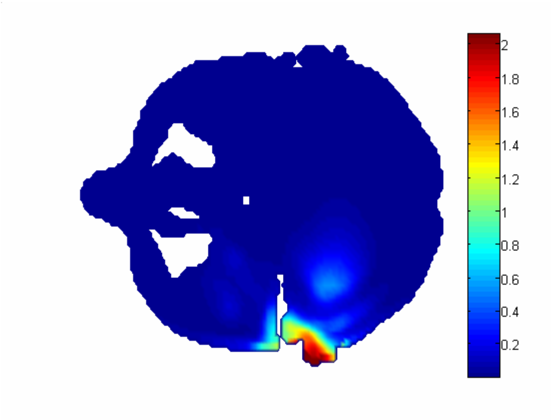
Antenna	SAR
Koch-type	1.81
Meander	2.05
Zigzag	1.98

ACKNOWLEDGMENTS

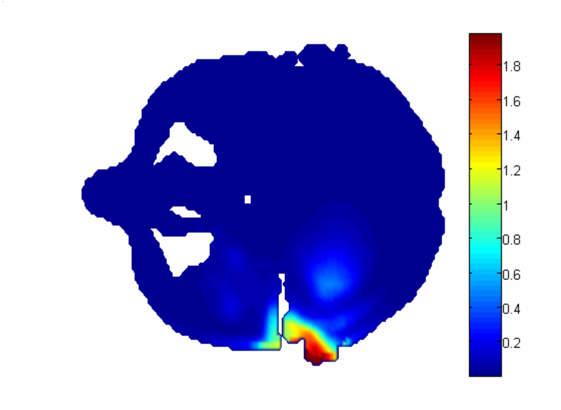
This work was supported in part by the Spanish Projects TEC-2004-06217-C02-01 and TEC-2004-04866-C04-03.



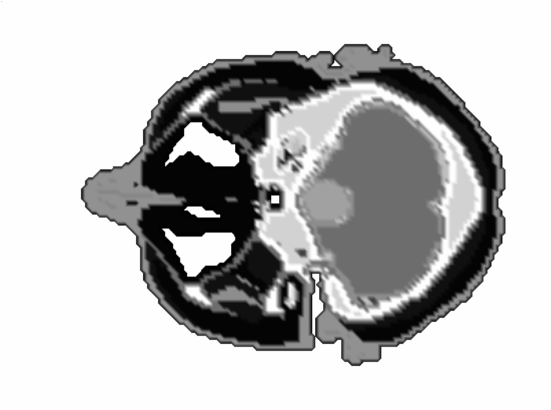
3*a*



3*b*



3*c*



3*d*

Fig. 3. SAR maps of the human head when radiated with a prefractal Koch-type antenna (3*a*), a meander antenna (3*b*) and a zigzag antenna (3*c*). The head model in the same plane is represented in 3*d*.

REFERENCES

[1] A. Rubio Bretones, R. Mittra, R. Gómez Martín. “A new hybrid method combining the method of moments in the time domain and FDTD”. *IEEE Microwave Guided Wave Letters*, vol. 8, pp. 281-283, 1998.

[2] T. Namiki. “A New FDTD Algorithm Based on Alternating-Direction Implicit Method”. *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 10, pp. 2003-2007, 1999.

[3] F. Zheng, Z. Chen, J. Zhang. “A Finite-Difference Time-Domain Method without the Courant Stability Conditions”. *IEEE Microwave Guided Wave Letters*, vol. 9, no. 11, pp. 441-443, 1999.

[4] S. Garcia, A. Rubio Bretones, B. G, Olmedo, R. Gómez Martín. New Trends In FDTD Methods In Computational Electrodynamics: Unconditionally Stable Schemes, in *Recent Res. Development in Electronics*, Transworld Research Network (India), 2005 (to appear).

[5] R. Gómez Martín, A. Rubio-Bretones, A. Monorchio, M. F. Pantoja, S. G. García. Time-domain hybrid methods, in *Time Domain Techniques in Computational Electromagnetics*. Poljak, D., editor, pages 133-172. WIT Press.

[6] M. Fernández Pantoja, F. García Ruiz, A. Rubio Bretones, R. Gómez Martín, J.M. González-Arbesú, J.Romeu, J.M. Rius. “GA Design of Wire Pre-Fractal Antenas and Comparison with Other Euclidean Geometries”. *IEEE Antennas and Wireless Propagation Letters*, 2, 2003. pp. 238-241.

[7] *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz–300 GHz*. IEEE Std. C95.1 -1999.

[8] K. Caputa, M. Okoniewski, M. A. Stuchly. “An Algorithm for Computation of the Power Deposition in Human Tissue”. IEEE Antennas and Propagation Magazine, vol. 41, no. 4, pp. 102-107, 1999.

[9] *IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz*. IEEE Std. C95.3 -2002.

[10] R. Gómez Martín, F. García Ruiz, M. Fernández Pantoja, S. G. García, A. Rubio Bretones. “Some thoughts about the design of small thin-wire antennas”. *Asia Pacific Microwave Conference*, New Delhi, India, 2004.