EM Simulations for Radio and Wireless on a PC

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Abstract: *An electromagnetic (EM) computational tool for radio and wireless applications is presented. The generality, versatility, accuracy, and practicality of the method and code are demonstrated on five very diverse, electrically large and complex antenna problems. The examples are: a dipole antenna array backed by an optimal 220-degree inverse corner reflector; an X-band reflector antenna modeled after a bat's ear; a pyramidal horn antenna together with its coax-to-waveguide feed; cylindrical and hemispherical dielectric-resonator antennas; and EM system consisting of a dipole antenna and a human body. The CPU time with a PC Pentium 166 MHz ranges from 2 seconds to 8 minutes for a single-frequency application. A factor of 10-100 average reduction in CPU time is observed when compared to other commercially available EM codes.*

1. Introduction

Electromagnetic (EM) field simulations are nowadays widely used in radio and wireless communication, in design of all kinds of antennas, cellular phones, and pagers, and of RF, microwave and millimeter-wave circuits and components, as well as in solving problems in EM packaging, EMC, EMI, signal integrity, EM interaction with biological tissues, propagation, etc. The new generation of wireless and satellite communication technology, with higher frequencies, higher information capacities, higher mobilities, as well as higher security/privacy, bandwidth, packaging, energy, cost, and health/enviromental demands, leads to the yet more pronounced role of electromagnetics and need for highly efficient, accurate, reliable and general EM simulation tools. In addition, the EM software for radio and wireless engineering must be relatively cheap and intended for usage not only in a few supercomputer centers, but on thousands of standard personal computers (PCs) and moderate-sized workstations at universities, labs, institutes, offices, and homes, as well as on lap-top (note-book) portable computers.

The first applications of the method of moments (MoM) for EM field computations can be traced to the early 1950s. The famous 1968 MoM monograph by R. F. Harrington [1] made it clear that the MoM was a powerful tool for the solution of a wide class of EM field problems. For two decades almost no other method was used for numerical solution of such problems. In recent years the greatest progress in computational electromagnetics has been in the development and application of partial differential-equation methods such as the finite-element (FE) frequency-domain and finite-difference time-domain (FD-TD) methods. The principal shortcoming of these methods is that they *require supercomputers*.

The aim of this paper is to present to a broad radio and wireless audience a *general*, *efficient* and *accurate PC-oriented* MoM for the analysis of 3D EM structures composed of arbitrarily interconnected wires, metallic surfaces (plates), and dielectric bodies. Wires and plates can have any distributed impedance loading. Dielectrics can be lossy and inhomogeneous. Several models of lumped loadings and generators are included. This work has been done at the University of Belgrade, Yugoslavia, as a joint effort with the University of Colorado at Boulder, USA, and it resulted in a *G*eneral *E*lectro*M*agnetic code (*GEM*) [2]. Although further improvements and optimizations of the method/code are certainly to be expected, we believe that even in its present form it can be used as a very powerful *low-cost* tool in radio and wireless applications.

2. Brief Overview of Large-Domain MoM

Our method is based on the integral-equation formulation in frequency domain. It represents a unified large-domain (high-order expansion) MoM. The inhomogeneous dielectric bodies are approximated by trilinear hexahedrons, the plates and surfaces of homogeneous dielectric bodies by bilinear quadrilaterals, and wires by straight-wire segments [3-6]. A trilinear hexahedron (Fig.1) is defined uniquely by its eight vertices, that can be positioned arbitrarily in space. Its edges and all coordinate lines are straight, while its sides (bilinear quadrilaterals) in the general case are curved. Current distribution in the elements is approximated by high-order 3D, 2D, and 1D polynomials in local parametric coordinates, enabling electrically large elements, as opposed to usual small-domain (subdomain) moment-methods, which utilize

This work was funded by NSF under a Presidential Faculty Fellow Award.

0-7803-5454-0/99/$10.00©1999 IEEE

low-order expansions defined in electrically very small geometrical elements. The unknown current-distribution polynomial coefficients are determined by a Galerkin-type solution [1] of a system of coupled integral equations. The principal advantage of our method over the other available methods is its generality combined with a comparatively small number of unknowns required for a given problem.

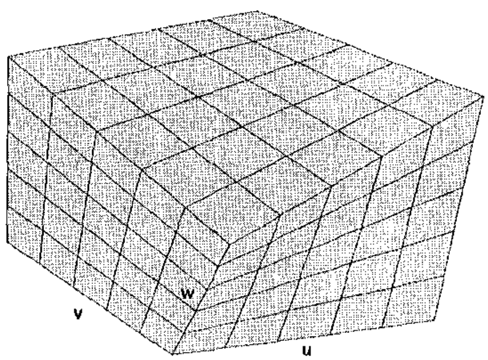


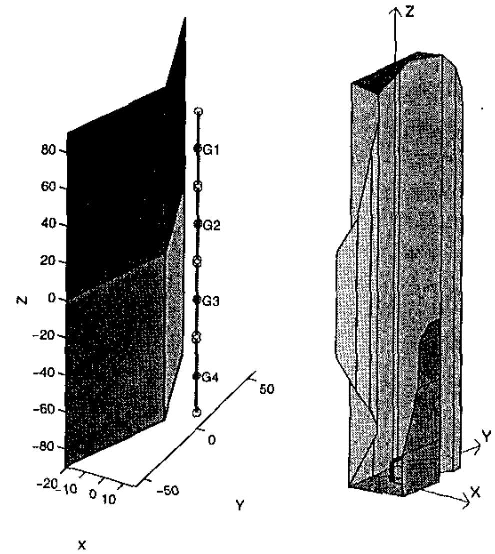
Fig.1. Trilinear hexahedron.

3. Practical Examples of Analysis and CAD

We present five very diverse practical examples, which are of interest to radio and wireless communication designers. All results were obtained on a relatively modest personal computer (**PC Pentium 166 MHz** with 16 MB RAM memory). In all cases, data on the number of unknowns, N_{unkn}, and CPU time, T_{CPU}, at the highest frequency considered (if more than one) are given, so that interested readers may compare the efficiency of our code with other available codes.

3.1. Dipole Array Backed by an Unconventional Optimal Inverse Corner Reflector

The first example is a linear array of four second-resonance dipoles driven in phase, backed by a synthesized optimal 220-degree inverse corner reflector (instead of the usual 90 or 180 degrees). The simulated geometrical model consists of 12 elements (8 wire segments and 4 bilinear surfaces), as shown in Fig.2a (N_{unkn} = 81, T_{CPU} = **2 seconds**). The array is designed to provide a wide horizontal beam with a relatively high gain of over 10 dBi. Fig.3 shows the simulated radiation pattern in the horizontal plane. Dipoles operated at the second resonance are used because of their high impedance (approximately 350 Ω), so that four dipoles connected in parallel have an impedance that is easy to match to 50 Ω over a relatively wide frequency range (440-470 MHz). The antenna was fabricated and has been operating successfully in the survey of a system of water-wells in a 140-degree horizontal range near the border between two European countries. A similar antenna was designed for a PCS basestation operating around 1.86 GHz.



(a) (b)

Fig.2. Simulated geometrical model of (a) dipole antenna array backed by a 220-degree inverse corner reflector (dimensions are in centimeters) and (b) bat-ear antenna.

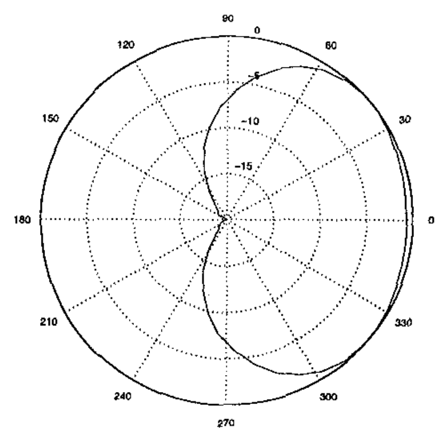


Fig.3. Simulated radiation pattern in the horizontal plane of antenna array in Fig.2a.

3.2. X-Band Bat-Ear Antenna

Fig.2b shows the simulated geometrical model of a X-band (10 GHz) reflector antenna designed after the external right-ear geometry of a bat species (*Plecotus auritus*). The motivation was to benefit from the accuracy and sensitivity of bat biosonar systems in the design of direction-finding radar. The model consists of 23 elements (2 wire segments and 21 bilinear surfaces) and is about $11\lambda^3$ large at X band ($N_{unkn} = 988$, $T_{CPU} =$ **8 minutes**). The simulated and measured look (main-beam) directions in the zenith-plane (plane $\phi = 0°$), $\theta_{simulated} = 37°$ and $\theta_{measured} = 36°$, were in excellent agreement, and also in good agreement with the acoustic measurements at 50 kHz ($\theta_{acoustic} = 31.4° \pm 4°$ [7]).

3.3. General Radio Pyramidal Horn Antenna

As the next example, consider a 6-7 GHz, 50 Ω, General Radio pyramidal horn antenna together with its coax-to-waveguide feed. Fig.4 shows a half of the simulated geometrical model consisting of 15 elements (1 wire segment and 14 bilinear surfaces). The antenna is about $27\lambda^2$ large at 7 GHz ($N_{unkn} = 617$, $T_{CPU} =$ **3 minutes**). The simulated VSWR was between 1.02 and 1.39 with respect to 50 Ω in the specified frequency range.

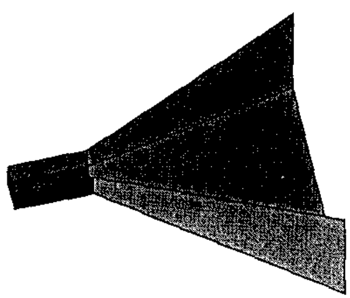


Fig.4. Half of the simulated geometrical model of a pyramidal horn antenna and its coax-to-waveguide feed.

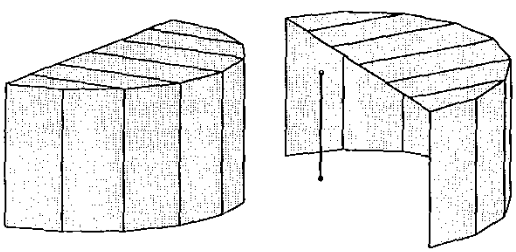


Fig.5. Half of the simulated geometrical model of a cylindrical dielectric resonator antenna.

3.4. Dielectric-Resonator Antennas

Shown in Fig.5 is one half of the simulated geometrical model of a cylindrical dielectric resonator antenna (CDRA), with radius $a = 2.75$ cm, height $h = 2.6$ cm, and dielectric relative permittivity $\varepsilon_r = 12$, excited by a vertical wire-monopole probe. The horizontal PEC ground plane is considered infinite and taken into account by applying image theory. The model consists of a wire segment and 28 dielectric bilinear surfaces ($N_{unkn} = 104$, $T_{CPU} =$ **7 seconds**). Fig.6 shows the simulated and measured [8] antenna impedance as a function of frequency. We see an excellent agreement between the two sets of results.

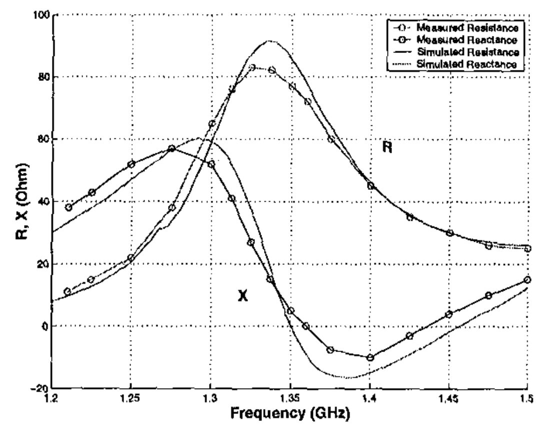


Fig.6. Simulated and measured [8] impedance of the antenna in Fig.5.

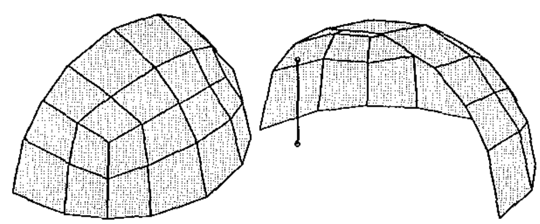


Fig.7. Half of the simulated geometrical model of a hemispherical dielectric resonator antenna.

Consider next a hemispherical version of the dielectric-resonator antenna. The simulated geometrical model of a HDRA (with radius $a = 2.54$ cm and dielectric parameters $\varepsilon_r = 8.9$ and $\tan\delta = 3.8 \times 10^{-3}$), was constructed from a wire segment and 48 dielectric bilinear surfaces, as shown in Fig.7 ($N_{unkn} = 98$, $T_{CPU} =$ **37 seconds**). The computed resonant frequency, $f_{simulated} = 1.85$ GHz, is in excellent agreement with the experimental result, $f_{measured} = 1.87$ GHz [8].

3.5. EM Coupling Between a Cellular-Phone Antenna and a Human Body

As the last example, consider the influence of a person on the impedance of the antenna of a cellular phone at $f = 840$ MHz. The antenna is approximated by an equivalent symmetrical center-fed wire dipole without the phone box. The adopted model of the person is 178 cm high, and is made of a homogeneous lossy dielectric of parameters $\varepsilon_r = 51.6$ and $\sigma = 1.56$ S/m. It is constructed with 12 trilinear hexahedrons, as sketched in Fig.8. Table1 shows the impedance of the dipole-antenna for a few different distances, d, between the antenna and the face of the person ($x_g = 173.5$ cm). Our simulated results (T_{CPU} = **3 minutes**) are in a satisfactory agreement with the results obtained by a small-domain MoM [9], which required 30 minutes with a CRAY-2 computer.

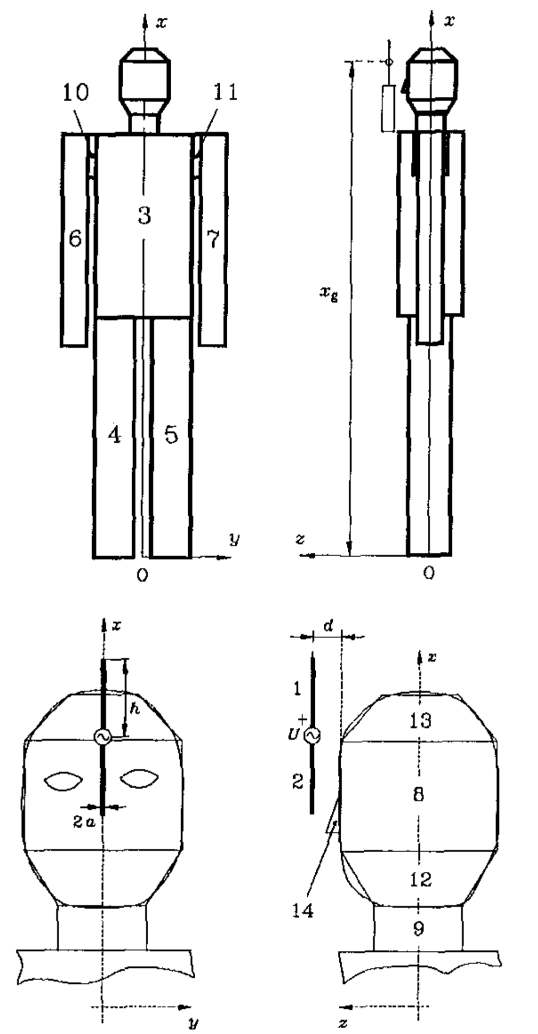


Fig.8. Analysis of the EM coupling between a dipole antenna and a human body – simulated geometrical model of the structure.

4. Conclusions

This paper presents a new numerical EM-field method and emphasizes its applicability to radio and wireless. We have carefully chosen five very diverse, electrically large and complex antenna problems, which illustrate the generality, versatility, accuracy, and practicality of the method and code. The CPU time with a PC Pentium 166 MHz ranges from 2 seconds to 8 minutes for a single-frequency calculation. We thus roughly observe a factor of 10-100 average reduction in the CPU time when compared to other available EM methods and codes.

Table.1: Impedance (Ω) of a dipole antenna near a model of man in Fig.8.

	$d\to\infty$	d=3cm	d=1cm
GEM	76+j7.7	58.6+j35.3	51.9+j34.8
Ref.9	75+j1.3	62+j35	60+j23

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