Regular paper

BIOELECTROMAGNETIC AND INTERNAL FIELD DOSIMETRY: MODELLING OF DIELECTRIC MATERIALS

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Abstract: Bioelectromagnetic has become very important due to rapid development of electromagnetic applications. A basic knowledge of biological materials, their electrical properties and their variability among living systems may provide a basis for the exploration of EM interaction mechanisms. Numerical techniques for modeling of dielectric materials are presented in this paper, with emphasize on bio-electromagnetic applications.
Keywords: bioelectromagnetic, method of moments, finite difference time domain method, finite element method, specific absorption ratio

INTRODUCTION

The increasing use of wireless equipment has increased the amount of radiation energy to which we expose our bodies, and it is particularly important to avoid radiation into the brain. Since most of biological effects are related with internal fields, dosimetry in this manner considers the measurement or determination by calculation of internal fields, induced current density, and specific absorption rate (SAR) distribution in objects like models (phantoms), animals, humans or even parts of human body. SAR calculations or measurements depend largely on the electrical properties of tissues, especially on permittivity and conductivity. A common property that measures absorbed energy is the SAR value, calculated as

$$E_{SAR} = \sigma \cdot \frac{|E|^2}{\rho} \tag{1}$$

where σ is the conductivity of human tissue, ρ is the density, and |**E**| is the norm of the electric field. The SAR value is an average over a region of either 10 g or 1 g of brain tissue, depending on national rules [2].

Three most widely used numerical methods applied to electromagnetic in general and bioelectromagnetic are [1]:

- Method of Moments (MoM)
- Finite Element Method (FEM)
- Finite Difference Time Domain (FDTD).

METOD OF MOMENTS

Method of Moments relates to an approach that solves complex integral equations by reducing them to a system of simple linear equations, and it is a frequency domain technique. One of the advantages of the MoM is therefore that only the surface of the structure needs to be discretised. First, MoM finds currents or charges on the surface and then integrates these quantities over the entire surface to find fields.

Although is MoM normally associated with the analysis of metallic structures, special formulations of the MoM are used for the analysis of dielectric and magnetic materials. These include problems involving multiple homogeneous dielectric bodies, thin dielectric sheets, planar multilayered media and dielectric coated wires and surfaces [1].

Some of techniques for modeling dielectric materials, used with MoM, are currently [3]:

- surface equivalence principle (SEP),
- volume equivalence principle (VEP),
- special Green's functions,
- thin dielectric sheet approximation,
- dielectric coating for wires.

Surface Equivalence Principle (SEP)

The SEP often uses the PMCHW formulation. The MoM for metallic structures solves for the electric currents on the surface of all objects, to determine other electromagnetic observables. When using the SEP, surfaces of a dielectric are discretised for both the electric and magnetic currents on the surface. Same surface mesh is usually used for both currents. This formulation makes no assumptions and is therefore applicable to arbitrarily shaped bodies. It is possible to model structures with arbitrary embedding and junctions [3].

Considerations: All sides of a dielectric have to be modeled, making a closed solid. When using the SEP, both electric and magnetic currents are modeled. This means that there are now two basis functions for each triangle pair, which correlates to a memory requirement of four times what it would be if the same structure were metallic. Mesh refinement might be required now in places where the magnetic current varies rapidly, as well as regions where the electric current varies rapidly. SEP principle is given on Fig.1 [4].

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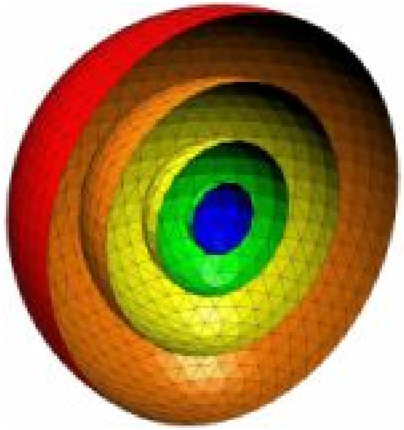

Fig.1 - *SEP: Multiple and nested homogeneous bodies possible*

Volume Equivalence Principle (VEP)

The VEP is implemented for cubical elements. The MoM is used to solve for a set of equivalent currents located at the centre of the cuboids. Similarly to the SEP, the VEP makes no assumptions about the shape of the object, and it is therefore generally applicable. Three basis functions are introduced for each cuboid. Cuboids can either be dielectric or magnetic, but not both. If a material is both, two cuboids should be placed at the same location, one to model the dielectric effect, and the other to model the magnetic effect [3].

Considerations: Because of the type of basis function that a cuboids uses, there is no restriction on connectivity, as in the case of triangular elements. The large number of basis functions introduced for each cuboid, and the fact that three dimensional discretisation must be used, results in high memory requirements for larger structures. Inhomogeneous structures are easily considered, since each cuboid can have unique properties. VEP principle is given on Fig.2 [4].

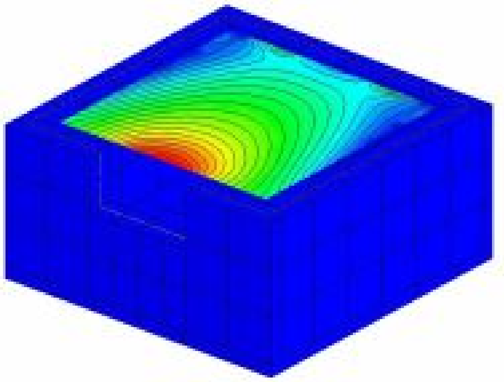

Fig.2 - *VEP: Cubical elements*

Special Green's Functions

A Green's function describes the response in space to a point excitation or source. The simplest form of a Green's function is the free space Green's function, which is used in the default MoM implementation. It is possible to use special Green's functions to incorporate features of the propagation space into the model. This means that properties of the structure are modelled implicitly, which is very computer resource efficient, but is limited to a few special cases. special Green's function formulation takes care of the different dielectric regions and they do not have to be discretised Fig.3 [4]. It is however required to discretise the conducting surfaces and wires inside the different layers. Special Green's functions are implemented to model layered dielectric spheres, and multi-layer substrates [3].

Considerations: When using multi-layer substrates, it is important to remember that the substrate is modelled as if it were infinite in extent. This can cause some problems if one was analyzing, for instance, a printed end-fire antenna. If a ground plane is included in the Green's function, it too is modelled as if it were infinite in extent. It is possible to model a finite ground plane explicitly using triangular elements.

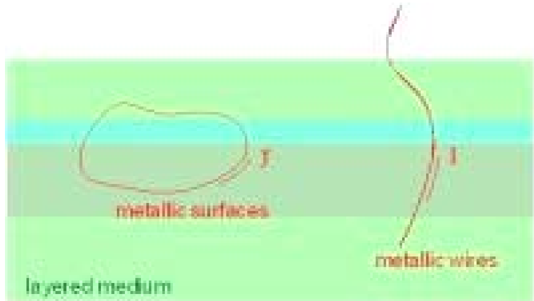

Fig.3 – *Special Green's functions: Dielectrics not discretised*

FINITE ELEMENT METHOD

FEM requires complete volume of the configuration to be meshed as opposed to surface integral techniques, which only require surfaces to be meshed. Each mesh element can have different material properties from those of neighboring elements. The corners of the elements are called nodes. The aim of the FEM analysis is to determine the field quantities at the nodes. The drawback of this method is that for complicated bodies it will be very difficult and sometimes impossible to carry out the integration procedure over the entire body [1].

FINITE DIFFERENCE TIME DOMAIN

The FDTD method belongs to the general class of differential time domain numerical modeling methods. It involves the discretization of the differential form of Maxwell's equations in time and space using second order accurate central differences. The resulting difference equations are then solved in a time marching sequence by alternately calculating the electric and magnetic fields on an interlaced Cartesian grid. Together with MoM and FEM, FDTD is one of the most popular modeling techniques currently used for EM interactions and SAR analysis. Since it is time domain technique it can cover a wide frequency range with a single simulation run. However, it may unexpectedly cause serious errors due to inappropriate modeling of radiation source and inadequate setting of calculation conditions [1].

HYBRID FEM/MOM

The hybridization of the MoM with the FEM exploits the benefits from both techniques, the efficiency of the FEM for the treatment of inhomogeneous dielectric bodies, and the efficiency of the MoM for the treatment of open boundary radiating structures. The FEM/MoM hybrid enables solving certain classes of electromagnetic problems with optimal efficiency. A prime example of this application is the simulation of the exposure of humans to mobile phone base stations antennas [4].

The FEM formulates the electromagnetic problem in terms of the electric field inside the FEM region, and equivalent electric and magnetic currents on the boundary of the FEM region. The standard MoM is formulated in terms of the electric currents on metallic wires and surfaces Fig.4 [4].

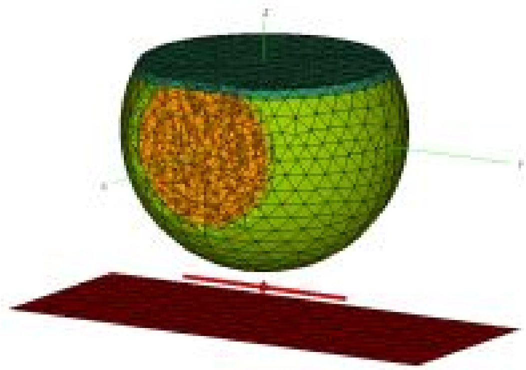

Fig.4 – *FEM/MoM: Hybrid MoM/FEM with full coupling between the MoM and the FEM.*

BIOELECTROMAGNEIC

Highly Inhomogeneous Bodies

Volume discretisation techniques such as the Finite Difference Time Domain (FDTD) or Finite Element Method (FEM) are most suitable, and therefore popular, for the analysis of highly inhomogeneous dielectric bodies.

The hybrid MoM/FEM is particularly suitable for cases where there is a free space region of arbitrary size between the antenna and the dielectric body. The advantage offered by the MoM/FEM hybrid is that the free space between the MoM region (antenna) and the FEM region (dielectric body) does not have to be discretised leading to a reduction in memory and runtime requirements.

Partly homogeneous dielectric bodies, which can also be nested within each other (e.g. eyes and a brain inside a head volume), can be solved using the Surface Equivalence Principle Fig.5 [4]. The SEP is however not efficient for highly inhomogeneous models and the FEM should therefore be used Fig.6 [4].

Homogeneous Bodies

For many applications, it is not essential to take the inhomogeneous nature of the dielectric body into account (for example radiation patterns and input impedance calculations). SAR compliance measurements are also normally done in phantoms filled with a homogeneous liquid simulating the human head. Simulations should therefore be done using a homogeneous body in order to have proper comparison between the measurement and simulation environments.

Applications

A typical application is the analysis of the exposure of humans to the EM fields (i.e. bioelectromagnetics) from mobile phones and mobile phone base station antennas.

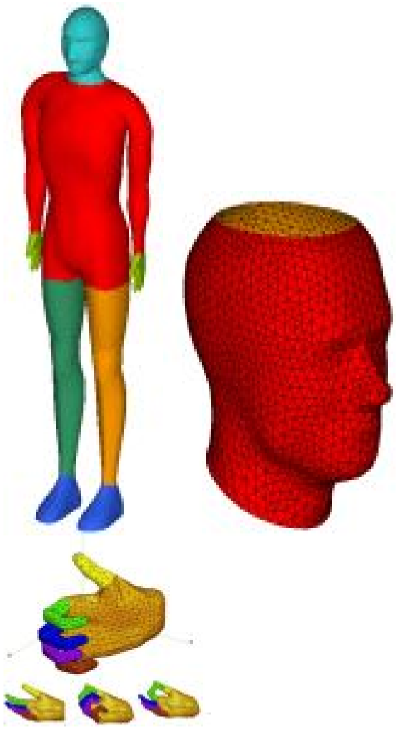

Fig.5 – *Surface Equivalence Principle*

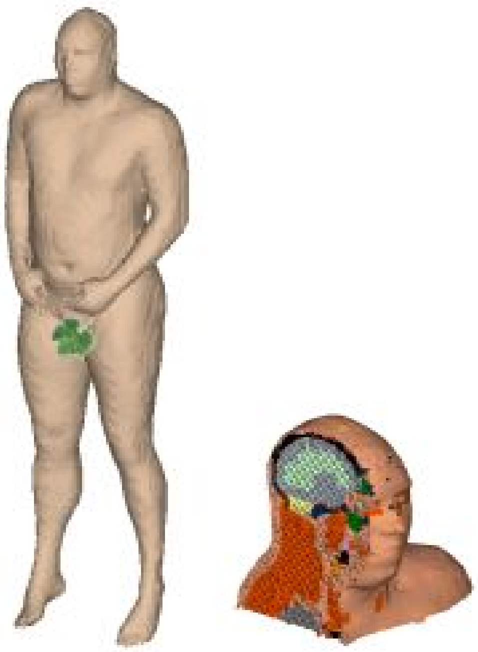

Fig.6 – *Finite Element Method*

Example

Example explains interaction between a heterogeneous anatomically correct model of the human head exposed to a normal-mode helix monopole operating at 1710 MHz mounted on the top of a metal box representing a realistic mobile communication terminal. The study of both canonical and realistic exposure problems includes computations of specific absorption rates (SARs) inside the human head, total power absorbed by the head and assessment of antenna performance. Emphasis is placed on the comparative dosimetric assessment between adults and children head models. Table 1 gives SAR calculation results using Green/MoM and FDTD technique simultaneously. Complete calculation is given in [5].

Table 1:
Peak SAR values and absorbed power in homogeneous and three-layer spherical head models exposed to normal–mode helical dipole antenna at 1710 MHz. The total radiated power is 125 Mw. Results produced with Green/MoM and FDTD (Y) Techniques

Local SARmax			1 gr SARmax (W/kg)	10 gr SARmax (W/kg)	Absorbed power (mW)
Homogenous	Adults	24.73 (25.32)	14.39 (13.80)	5.38 (6.01)	114.84 (114.94)
	Child	24.31 (25.34)	13.98 (14.02)	5.49 (6.09)	112.75 (113.54)
Three - layered	Adults	14.09 (15.17)	6.97 (6.42)	3.42 (3.83)	117.27 (116.95)
	Child	13.88 (15.51)	7.70 (7.21)	4.41 (4.82)	119.01 (117.63)

CONCLUSION

Each of presented techniques has certain applications that it is better suited to. The optimal technique to use is often not immediately evident to the inexperienced user.

Some dielectric problems, e.g. inhomogeneous or electrically large dielectric bodies, cannot be solved efficiently with either of these MoM based techniques due to the scaling properties of the MoM. The FEM, in contrast, is very well suited for modelling inhomogeneous dielectric bodies. The tetrahedral elements used in the volume discretization for the FEM allow for accurate geometrical representation of volumes with curved surfaces, and the formulation furthermore allows for the variation in the material properties from tetrahedral element to tetrahedral element.

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Dr.Mićo Gaćanović was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production.

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