

FDTD implementations for electromagnetic shields

S.Ursache¹, M. Branzila¹, C. Bratescu¹, R. Burlacu¹

¹ *Technical University of Iasi, Faculty of Electrical Engineering, Bd. Profesor Dimitrie Mangeron, nr. 51- 53, 700050 Iasi, Romania, Tel/Fax: +40-232-237627; E-mail: sursache@ee.tuiasi.ro*

Abstract- This paper is a brief presentation of FDTD numerical method usable for simulation of electromagnetic shields behavior. The presentation is focused on this method that is appropriate for high frequency shields. A new class of auxetic materials, a hexachiral honeycomb structure with good mechanical properties, is investigated through computer simulation. Some simulation results are also presented in the final part of the paper.

I. Introduction

The continuing growth of computing resources is changing how we think about, formulate, solve, and interpret problems. In electromagnetics as elsewhere, computational techniques are complementing the more traditional approaches of measurement and analysis to vastly broaden the breadth and depth of problems that are now quantifiable. Computational electromagnetics may be broadly defined as that branch of electromagnetics that intrinsically and routinely involves using a digital computer to obtain numerical results.

Electromagnetics is the scientific discipline that deals with electric and magnetic sources and the fields these sources produce in specified environments. Maxwell's equations provide the starting point for the study of electromagnetic problems, together with certain principles and theorems such as superposition, reciprocity, equivalence, induction, duality, linearity, and uniqueness, derived therefore. While a variety of specialized problems can be identified, a common ingredient of essentially all of them is that of establishing a quantitative relationship between a cause (forcing function or input) and its effect (the response or output), a relationship which we refer to as a field propagator, the computational characteristics of which are determined by the mathematical form used to describe it.

II. Modeling as a Transfer Function

The foregoing relationship may be viewed as a generalized transfer function (see Fig.1) in which two basic problem types become apparent. For the analysis or the direct problem, the input is known and the transfer function is derivable from the problem specification, with the output or response to be determined. For the case of the synthesis or inverse problem, two problem classes may be identified. The easier synthesis problem involves finding the input, given the output and transfer function, an example of which is that of determining the source voltages that produce an observed pattern for a known antenna array. The more difficult synthesis problem itself separates into two problems. One is that of finding the transfer function, given the input and output, an example of which is that of finding a source distribution that produces a given far field. The other and still more difficult is that of finding the object geometry that produces an observed scattered field from a known exciting field. The latter problem is the most difficult of the three synthesis problems to solve because it is intrinsically transcendental and nonlinear.

Electromagnetic propagators are derived from a particular solution of Maxwell's equations, as the cause mentioned above normally involves some specified or known excitation whose effect is to induce some to be determined response (e.g., a radar cross section, antenna radiation pattern). It therefore follows that the essence of electromagnetics is the study and determination of field propagators to thereby obtain an input-output transfer function for the problem of interest, and it follows that this is also the goal of CEM.

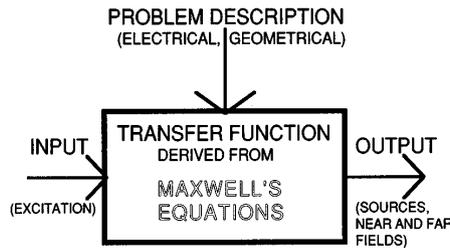


Fig. 1 The electromagnetic transfer function relates the input, output, and problem

A. Classification of Model Types

It is convenient to classify solution techniques for electromagnetic modeling in terms of the field propagator that might be used, the anticipated application, and the problem type for which the model is intended to be used, as is outlined in Table 1. Selection of a field propagator in the form, for example, of the Maxwell curl equations, a Green's function, modal or spectral expansions, or an optical description is a necessary first step in developing a solution to any electromagnetic problem.

Table 1

Field Propagator	Description Based on
Integral operator	Green's function for infinite medium or special boundaries
Differential operator	Maxwell curl equations or their integral counter parts
Modal expansions	Solutions of Maxwell's equations in a particular coordinate system and expansion
Optical description	Rays and diffraction coefficients
Application	Requires
Radiation	Determining the originating sources of a field and patterns they produce
Propagation	Obtaining the fields distant from a known source
Scattering	Determining the perturbing effects of medium inhomogeneities

B. Development of a Computer Model

Development of a computer model in electromagnetics or literally any other disciplinary activity can be decomposed into a small number of basic, generic steps. These steps might be described by different names but would include at a minimum those outlined in Table 2. Note that by its nature, validation is an open-ended process that cumulatively can absorb more effort than all the other steps together. The primary focus of the following discussion is on the issue of numerical implementation.

Table 2

Step	Activity
Conceptualization	Encapsulating observation and analysis in terms of elementary physical principles and their mathematical descriptions
Formulation	Fleshing out of the elementary description into a more complete, formally solved, mathematical representation
Numerical implementation	Transforming into a computer algorithm using various numerical techniques
Computation	Obtaining quantitative results
Validation	Determining the numerical and physical credibility of the computed results

III. Finite difference time domain method (FDTD)

FDTD is a popular computational technique. It is considered easy to understand and easy to implement in software. Since it is a time-domain method, solutions can cover a wide frequency range with a single simulation run. Maxwell's equations (in partial differential form) are modified to central-difference equations, discretized, and implemented in software. The equations are solved in a leapfrog manner: the electric field is solved at a given instant in time, then the magnetic field is solved at the

next instant in time, and the process is repeated over and over again. The basic FDTD space grid (Fig.2) and time-stepping algorithm trace back to a seminal 1966 paper by Kane Yee in IEEE Transactions on Antennas and Propagation [1].

In order to use FDTD a computational domain must be established. The computational domain is simply the physical region over which the simulation will be performed. The E and H fields are determined at every point in space within that computational domain. The material of each cell within the computational domain must be specified by its permeability, permittivity, and conductivity.

Once the computational domain and the grid materials are established, a source is specified. The source can be an impinging plane wave, a current on a wire, or an applied electric field, depending on the application. Since the E and H fields are determined directly, the output of the simulation is usually the E or H field at a point or a series of points within the computational domain. The simulation evolves the E and H fields forward in time.

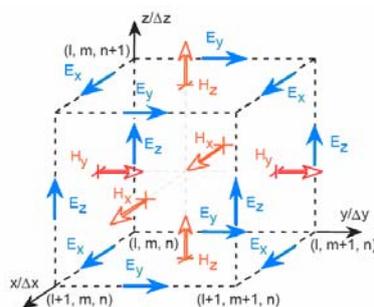


Fig.2 Three-dimensional Yee cell showing the staggered positions of the field component samples.

IV. Computer simulation

A. Test details

The structure used in tests was a fiber reinforced polymer [5] (figure 3). The structure is a hexachiral honeycomb, each of the equally spaced cylinders being connected with strings to 6 of his neighbors.

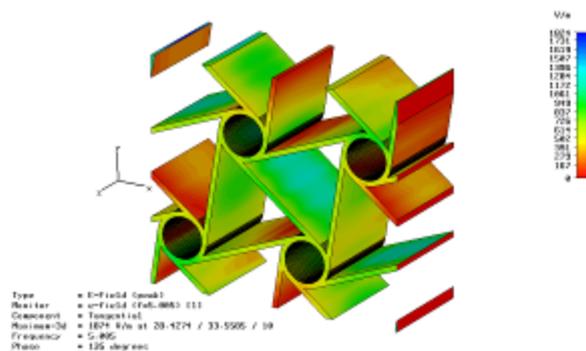
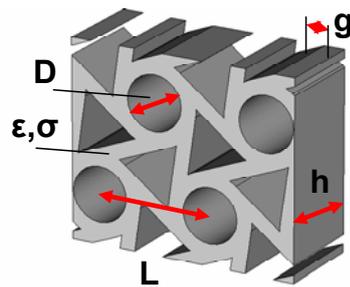


Fig.3 Hexachiral honeycomb

In order to limit the dimensions of the model, the periodicity of the structure has been investigated, the rectangular unit cell is showed in figure 2, the length and width being equal to $2 \cdot L$ (x direction) and $L \cdot \sqrt{3}$ (y direction) respectively (where L is the cylinder separation). The typical dimensions used in tests were those of the prototype mentioned above, also shown in figure 2.



Parameter	Value
D	18.58 mm
H	19.75 mm
L	24.72 mm
g	3.3 mm
ε	2.5 (4)
tg δ	0 (0.1-0.5)

Fig.4 Rectangular unit cell and typical dimensions

We investigate the interaction between a plane wave and an infinitely large sheet of auxetic material, at normal incidence. The boundary conditions are set to electric wall (both walls on x directions) and magnetic wall (y direction walls). An input wave port is placed at some space from the structure; the second (exit) wave port is added only when losses inside the structure are taken into account.

The results of the simulation show the S parameters for the structure. The typical shielding parameters reflectance, transmittance and absorption are connected to the S parameters like in equations 1-3.

$$R = |S_{11}|^2 \quad (1)$$

$$T = |S_{21}|^2 \quad (2)$$

$$A = 1 - R - T = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (3)$$

B. Parametric analysis

Analysis shows that the chiral structure has almost identical properties (figures 5, 6) with a homogenous layer from the same material, so the mechanical and thermal advantages provided by the structure do not affect the electromagnetic properties in the bandwidth considered (0.1-10 GHz).

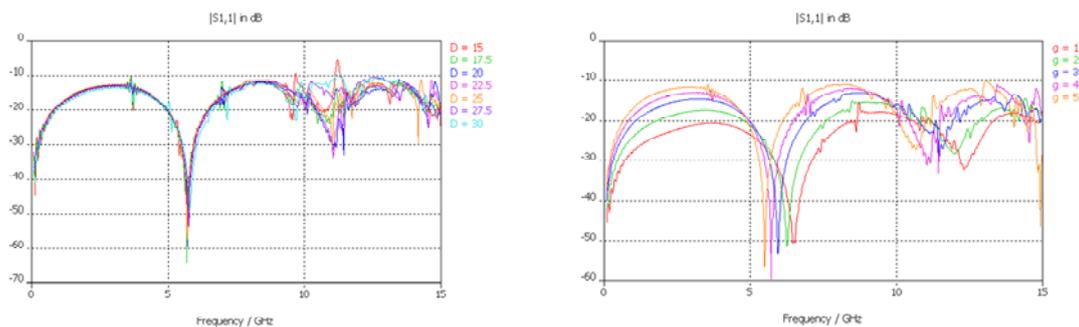


Fig. 5 Internal cylinder diameter (D - left) and string width (g - right) influence over S_{11}

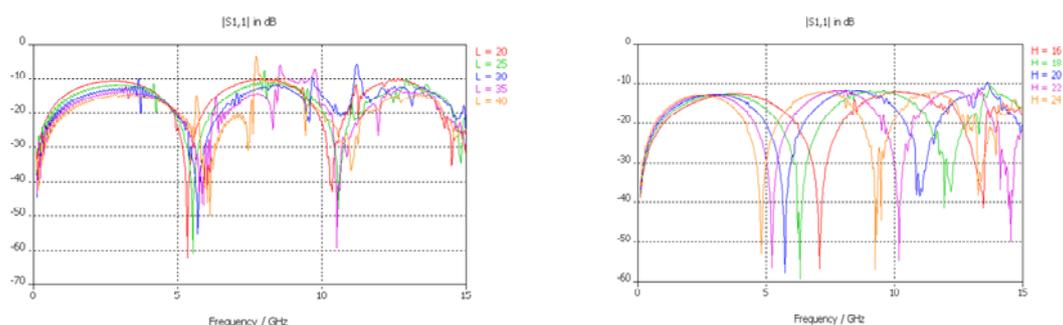


Fig 6. Cylinder separation (L - left) and layers' height (h - right) influence over S_{11}

Parametric studies investigated the effect of the dimensions (L, D, h, g) and material properties (ϵ , σ , $\text{tg } \delta$). Figures 5-6 show the influence of D, g, L, h (in this order) for the lossless dielectric over the reflection coefficient (S_{11}),

V. Conclusions

Because of the high complexity of electromagnetic shields optimisation problems, we used numerical techniques (FDTD) to simulate shields. For validation, we have chosen to optimize some well known shields. The results show that the performance of the hexachiral structure is equivalent to a homogenous dielectric layer, some of the properties being influenced by the specific geometry of the structure. The same structure which offers good mechanical and thermal behavior gives access to some improvement techniques. This allows us to use numerical techniques for optimisation of more complex shields such as composite honeycomb materials.

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