

Using MATLAB to Model Inhomogeneous Media in Commercial Computational Electromagnetics Software

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Abstract — This paper presents a new method to model inhomogeneous media in commercial electromagnetics software, especially FEKO. In this method, the inhomogeneous medium is fragmented to some homogeneous pieces. If the size of these pieces is chosen correctly, then the electromagnetic behaviors of them and inhomogeneous medium are the same. Since creating these homogeneous pieces in FEKO manually is very difficult and time consuming, MATLAB is employed to create these pieces in FEKO.

Index Terms — FEKO, inhomogeneous media, MATLAB.

I. INTRODUCTION

These days, the computational electromagnetic software products, like FEKO [1], become essential tools for any electromagnetic design procedure. These products can simulate a various type of electromagnetic media and devices such as antennas, waveguides, filters, couplers, radomes and so on. So, many designers use them to verify their designs. But most of them cannot model the inhomogeneous media in a user-friendly way.

On the other hand, the usage of inhomogeneous media is quickly increasing due to their enormous applications. For example, the inhomogeneous media are used as antenna radome, substrate of microstrip devices and device coating [2-4]. And also, they are used to design microwave filters [5] and frequency selective surfaces [6].

This paper presents new toolboxes to model inhomogeneous media in computational electromagnetics software. These toolboxes are based on MATLAB [7] which is a powerful numerical computing environment and is widely used for research, academic and industrial purposes. A toolbox that is based on MATLAB has some advantages, e.g., the user can utilize the general-purpose functions of MATLAB to customize it.

In this paper, modeling of inhomogeneous medium in FEKO is presented, but the proposed method can be

easily applied to other commercial computational electromagnetics software, such as CST [8], HFSS [9].

II. DESIGN PROCEDURE

In the presented method, the inhomogeneous medium is fragmented to N homogeneous pieces and the inhomogeneous medium is estimated by these homogeneous pieces. If the dimensions of pieces are very smaller than wavelength or the inhomogeneous medium parameters are about constant in each piece, then the electromagnetic behavior of fragmented medium is similar to the one for inhomogeneous medium. In other words, the inhomogeneous medium is modeled by some homogeneous pieces, which their sizes are depended on the simulation frequency and inhomogeneous medium parameters.

In this method, a large number of homogeneous media should be created in FEKO to model inhomogeneous media. But creation of these pieces in FEKO manually is very difficult, time consuming and almost impossible and it is necessary to automate it.

To solve this problem, FEKO is controlled by using MATLAB [8] and a toolbox is created in MATLAB in which inhomogeneous medium is estimated to some homogeneous small pieces and create these pieces in FEKO. The output of this toolbox is a FEKO file that contains modeled inhomogeneous medium.

A. Using MATLAB to create media in FEKO

FEKO in addition to having a CAD environment for modeling various types of media and geometries, has a scripting interface for advanced users which is named Edit FEKO. In Edit FEKO environment, user can utilize all the capabilities of FEKO by using known and defined commands.

Considering this particular capability of FEKO, any structure can be created in FEKO by using MATLAB. To do this, MATLAB must write all necessary Edit FEKO commands to an ASCII file that its suffix is PRE. This file could be opened in Edit

FEKO and any other commands can be added to it depending on user needs. After simulation by FEKO, the modeled structure and its results are available in POST FEKO.

B. Inhomogeneous media modeling

There is two ways in FEKO to model a homogeneous medium in Cartesian coordinate. The first is to use QU command to create cubical dielectric elements. This is the simplest way to model a dielectric or magnetic cube in Edit FEKO, but periodic boundary conditions cannot be applied to the media which are created by this command. Hence, this way is useful to model finite inhomogeneous media.

Another way is to use BP and ME commands. The BP command creates a flat parallelogram which its type is determined by using ME command. So, dielectric media can be created by combining these two commands. Periodic boundary condition can be applied to the media which are created by the second method. So, this method is useful to model infinite inhomogeneous media. Two toolboxes are presented in this paper. The first toolbox can be modeled infinite inhomogeneous media and the second one is used to model finite inhomogeneous media.

C. Infinite structures

To model and simulate infinite inhomogeneous structures in two dimensions, as discussed above, the inhomogeneous medium is fragmented to several homogeneous media using MATLAB as shown in Fig. 1.

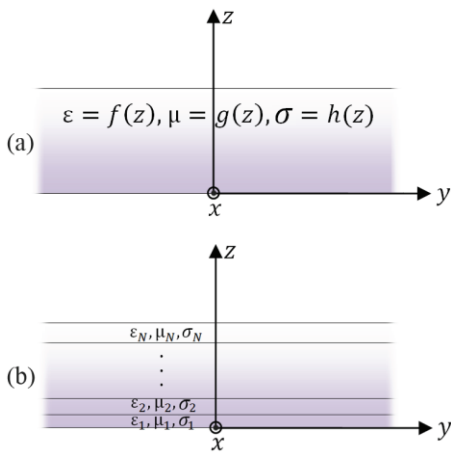


Fig. 1. (a) A typical infinite inhomogeneous medium, and (b) its estimation by some homogeneous media.

The medium parameters of each homogeneous piece are estimated by the average weights of inhomogeneous parameters as given in equations 1, 2 and 3:

$$\epsilon_n = \frac{1}{\alpha_n - \alpha_{n-1}} \int_{\alpha_{n-1}}^{\alpha_n} f(\alpha) d\alpha, \quad (1)$$

$$n = 1, 2, \dots, N$$

$$\mu_n = \frac{1}{\alpha_n - \alpha_{n-1}} \int_{\alpha_{n-1}}^{\alpha_n} g(\alpha) d\alpha, \quad (2)$$

$$n = 1, 2, \dots, N$$

$$\sigma_n = \frac{1}{\alpha_n - \alpha_{n-1}} \int_{\alpha_{n-1}}^{\alpha_n} h(\alpha) d\alpha. \quad (3)$$

$$n = 1, 2, \dots, N$$

In these equations, ϵ_n , μ_n and σ_n are medium parameters of n^{th} piece and α_{n-1} and α_n are its start and end position, respectively.

It is remarkable that in this toolbox, while the variations of inhomogeneous medium parameters are more severe, more fragmentation is done and vice versa. So, it needs shorter time to simulate.

Figure 2 shows the toolbox for infinite media. Inputs of this toolbox are ϵ_r , μ_r and σ of inhomogeneous medium, the direction of homogeneity and its range, minimum fragmentation size, variation tolerance and the address of output file.

More fragmentation is generated if minimum fragmentation size is decreased. If difference of medium parameters of two nearby pieces is less than variation tolerance value, then these two pieces will be merged together.

In the right side of toolbox window, the fragmented media and parameters of each section are shown.

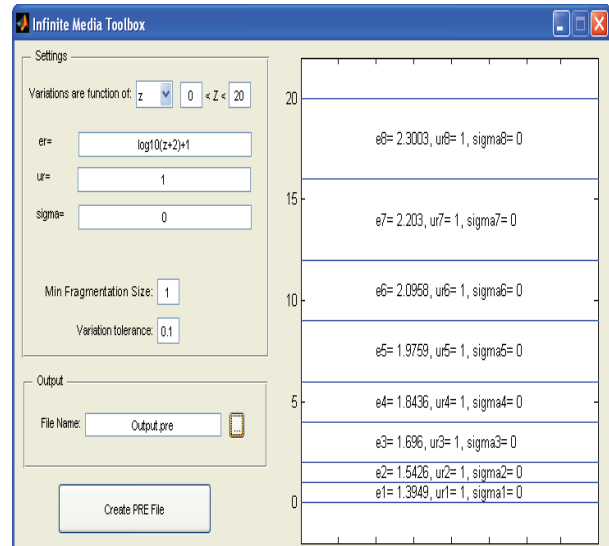


Fig. 2. Presented toolbox to model infinite inhomogeneous media.

In order to verify the proposed method, an infinite inhomogeneous medium is modeled in FEKO by presented toolbox. The parameters of the modeled medium are $\epsilon_r(z) = 4e^{5z}$, $\mu_r = 1$, $\sigma(z) = 0$ and its thickness is 20 cm along z axis. The medium is infinite along x and y axes.

A plane wave with TE^z polarization is illuminated to it and the angle of incidence is θ^i . The frequency of plane wave is 1 GHz and its electric field strength is 1 V/m. The reflection and transmission coefficients of this structure are obtained by simulation. Figure 3 shows this modeled structure with periodic boundary condition in FEKO.

This structure has analytical solution [9]; therefore, the results of simulation can be compared with analytical results. Figure 4 depicts the simulation and analytical results for assumed structure.

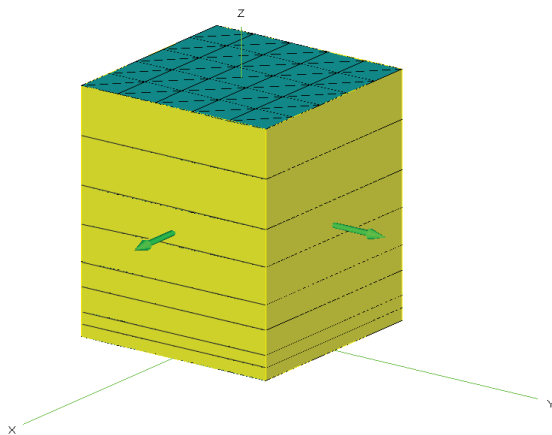


Fig. 3. The estimated model of mentioned structure in FEKO.

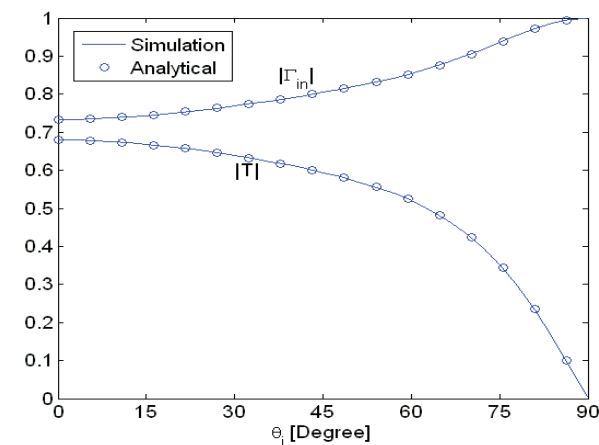


Fig. 4. The amplitude of transmission and reflection coefficient obtained from analytical solution and simulation.

As can be seen in Fig. 4, the proposed method acts as expected and its results have exact agreement with analytical results.

Another slab with constitutive parameters $\epsilon_r(z) = 4 + 5z/d$, $\mu_r = 1$, $\sigma(z) = 0$ is modeled by the proposed toolbox. The thickness of slab is 20 cm. A plane wave impinges normally on the slab and the reflection and transmission coefficient of the slab are simulated and the results are compared to an analytical solution [10] that is plotted in Fig. 5. As shown in this figure, the simulated and analytical results are in full compliance.

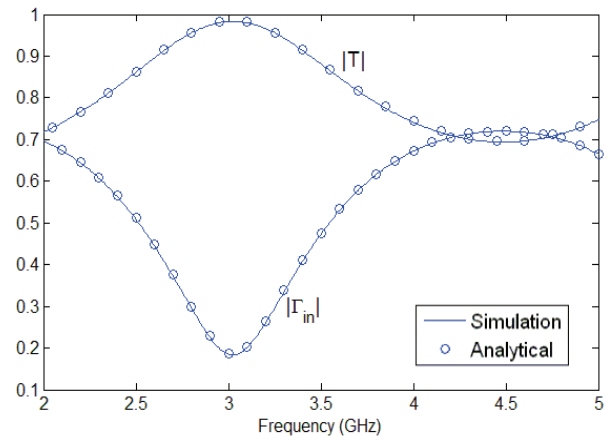


Fig. 5. The amplitude of transmission and reflection coefficient obtained from analytical solution and simulation.

D. Finite structures

To model finite inhomogeneous structures in FEKO as discussed above, the inhomogeneous medium is divided to several homogeneous cubes using MATLAB as depicted in Fig. 6.

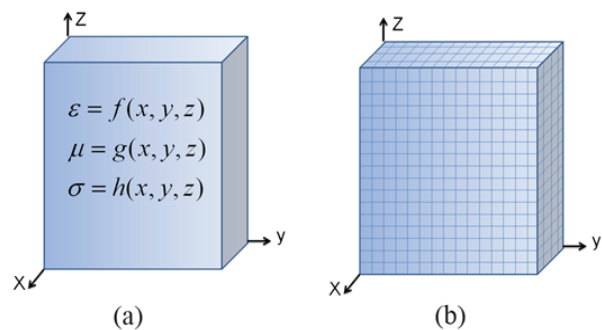


Fig. 6. (a) A typical finite inhomogeneous medium, and (b) its estimation by some homogeneous cubes.

Figure 7 shows the toolbox for finite inhomogeneous media. Its inputs are medium

dimensions in x, y and z axes, ϵ_r , μ_r and σ functions, the size of small homogeneous cubes and the address of output file which its type is PRE file.

A finite inhomogeneous medium with $\mu_r = 1$, $\epsilon_r = \log(x^2 + y^2 + z^2 + 1) + 1$ and $\sigma = 0$ is modeled by proposed toolbox. The dimensions of medium are equal in three axes and are equal to 20 cm. The modeled medium is depicted in Fig. 8.

A plane wave with TE^z polarization is illuminated to the issued structure at $\theta^i = 135^\circ$ and $\phi^i = -135^\circ$. The frequency of plane wave is 1 GHz and its electric field strength is 1 V/m.

The radar cross section (RCS) of issued structure is simulated and plotted in xy-plane as shown in Fig. 9.

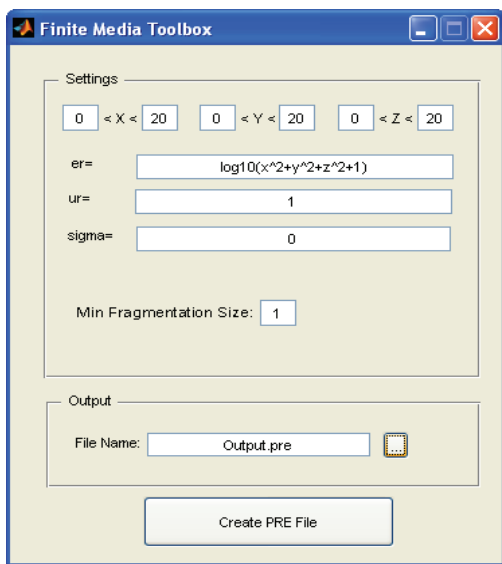


Fig. 7. Presented toolbox to model finite inhomogeneous media.

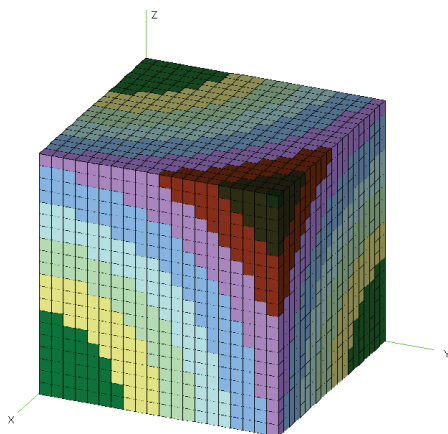


Fig. 8. The estimated model of mentioned structure in FEKO.

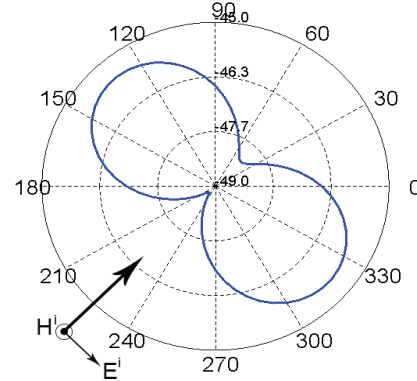


Fig. 9. Radar cross section of proposed finite structure.

III. CONCLUSION

In this paper, a new method is presented in which inhomogeneous media are modeled in FEKO by using MATLAB. In this method, inhomogeneous medium is fragmented to some homogeneous pieces and these pieces are created in FEKO by MATLAB. Two toolboxes are presented in this paper to implement this method for finite and infinite inhomogeneous media. To verify the proposed method, a structure which has analytical solution is modeled by this method. The simulation results and analytical solutions have exact agreement.

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