Development of a Versatile Planar Periodic Structure Simulator in MATLAB

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Abstract. *This article describes development of a versatile periodic structure simulation program. The program is written in Matlab and performs analysis of a planar multilayer frequency selective surfaces by method of moments. Analysis reflection/transmission from a FSS compromised from arbitrarily shaped metal elements and having several dielectric layers is possible. The biggest advantage of the program compared to some commercial EM codes is in easier motif definition of complex structures and is thus suitable for researchers in the area of metamaterials. Due to its design in Matlab most common tasks like parametric design and optimization may be implemented easily.*

Keywords

Periodic structures, frequency selective surfaces, metamaterials, method of moments.

1. Introduction

During last ten years there have been growing interest in the area of metamaterials/periodic structures. Nowadays, several commercial codes may be used to analyze such surfaces (like AnsoftDesigner, CST microwave studio as well as Ansys). However it is not always easy to model complex multilayer periodic structures such as heavily stacked composites. The main problem is not a numerical analysis, which runs fine even for a very complex 3D structures but an ease at which the model of the periodic structure is being created in a computer. Some commercial EM codes do not have an enough powerful and simple scripting language which is being used to build up a physical model of a periodic structure. In some commercial codes it is not also easy to make an optimization or a parametric design. The abovementioned disadvantages were leading us to develop a program within popular Matlab programming environment which would help us in characterization of composite materials as they represent one of main areas we are focusing to in our research.

2. Theory

2.1 Analysis of multilayer FSS

Usually, an analysis of multilayer FSS is performed by a cascading approach. Such an approach has the advantage in reduced computational costs compared to a direct approach presented here.

When analyzed by a cascading approach, scattering on individual metal layers is performed separately. Global scattering matrix for the entire FSS is then assembled with the aid of relations for propagation in layered media. Details about the procedure can be found in [3], or [4].

Direct approach is computationally heavy, however may represent solution for cases which cannot be analyzed by a cascading approach so effectively. For example FSSs with densely stacked metal layers with a strong layer to layer interactions.

A choice of basis domain functions used to represent currents on metal screens may keep number of total unknowns low. Thus the direct approach of analysis of FSS can still ensure fast solution time. Such a statement is true if large domain basis functions (having higher order expansion functions) are being used. Currently the program FSSMR (see Chapter 3) developed for analysis of multilayer FSSs doesn't support that case. However it was written while keeping in mind incorporation of that feature in future.

Let's consider arrangement of a multilayer FSS according to Fig.1 where an example with two dielectric and three metal layers is shown. Metal layers are denoted M0, M1 and M2 respectively. Density of induced currents from in metal layers are denoted as $\mathbf{J}_0, \mathbf{J}_1$ and $\mathbf{J}_2$. Similar notation is used for total scattered electric intensities $\mathbf{E}_0, \mathbf{E}_1$ and $\mathbf{E}_2$ on individual layers. Relation between currents in j^{th} metal layer with respect to the scattered electric intensity $\mathbf{E}_{ii}^{scat}$ on the i^{th} metal layer is given by the impedance matrix $[Z_{ij}]$.

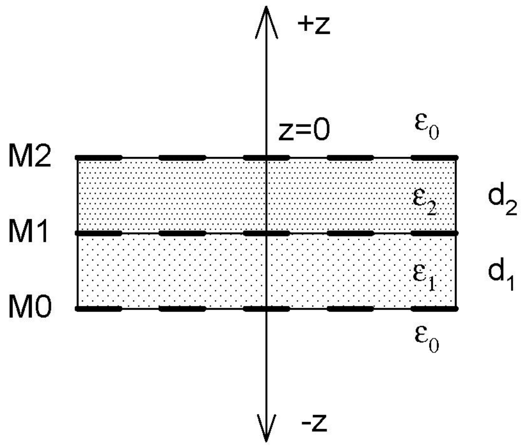


Fig. 1. Multilayer FSS – layer definition.

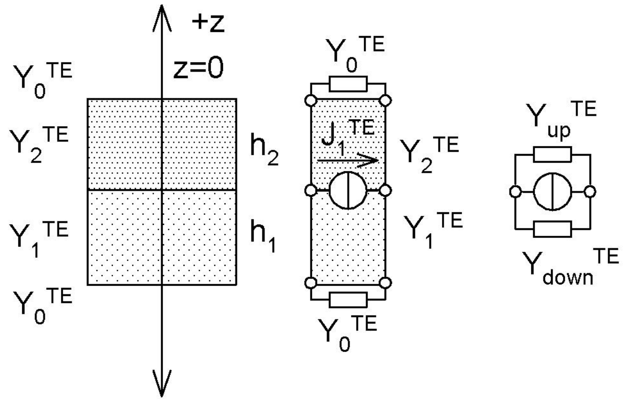


Fig. 2. Propagation of EM waves through the layered media and its equivalent circuit (Figure is valid for the metal layer 11).

For $i = j$ a self impedance matrix $[Z_{ii}]$ is obtained, while the case with i and j different is described by a mutual (interlayer) impedance matrix $[Z_{ij}]$. First index (i) always means number of destination layer, while the second one (j) describes the source layer.

Self impedance matrix $[Z_{ii}]$(resp. mutual impedance matrix $[Z_{ij}]$) are written as

$$[Z_{ii}] = \begin{bmatrix} G_{xx}^{ii} & G_{xy}^{ii} \\ G_{yx}^{ii} & G_{yy}^{ii} \end{bmatrix} \qquad [Z_{ij}] = \begin{bmatrix} G_{xx}^{ij} & G_{xy}^{ij} \\ G_{yx}^{ij} & G_{yy}^{ij} \end{bmatrix}. \qquad (1a,b)$$

Evaluation of G-elements (they represent components of Dyadic Green's functions) of $[Z_{ii}]$and $[Z_{ij}]$ can be found in [4]] and is based on the immitance approach [1], where propagation of EM waves through the multilayer dielectric structure can be modeled by the equivalent transmission lines (separately for TE and TM polarizations). Elements in matrixes $[Z_{ii}]$ and $[Z_{ij}]$ are then expressed according to equations well known from a transmission line theory. As an example, Fig 2 is given where the total impedance connected to the current source (represents induced currents in the metal layer M1) work to a total load admittance Y_{up}^{TE} and Y_{down}^{TE}.

If all sub-matrixes $[Z_{ij}]$ are arranged together, a global impedance matrix $[Z]$ can be written.

$$[Z] = \begin{bmatrix} Z_{00} & Z_{01} & Z_{02} \\ Z_{10} & Z_{11} & Z_{12} \\ Z_{20} & Z_{21} & Z_{22} \end{bmatrix} \qquad (2)$$

Global impedance matrix then links all currents on metal layers and total scattered electric intensities $\mathbf{E}_{ii}^{S}$ on these layers. Then electric field integral equation (EFIE) in the spectral domain is written. Unknown current density is expressed as a sum unknown functions and Galerkin procedure is applied to find current expansion coefficients.

2.2 Reflection and transmission from FSS

As soon as currents on all metal layers are known, total electric intensity $\mathbf{E}_{ii}^{tot}$ on any i^{th} metal layer can be evaluated. The intensity has two parts. First one becomes from currents from all metal layers (scattered electric intensity). While the second one, corresponds to the reflection/transmission of EM waves in the layered dielectric with metallizations being removed. This second part is calculated separately from the moment solution. Tangential components of intensity $\mathbf{E}_{ii}^{tot}$ are then used for definition of reflection and transmission coefficients. Corresponding equations can be found in [4].

3. Analysis of the FSS in Matlab

Two programs in Matlab were written. First one, called FSS1R is capable to analyze reflection/transmission from the FSS having arbitrarily shaped patches. The code uses uniform mesh of rectangular cells to approximate surface currents on the patch. FSS can consist from one dielectric one and metal layer. Currents on metal layers are approximated by rooftop basis functions and reflection/transmission is solved by the spectral domain method of moments.

The FSS1R is a fast code (with fast MoM matrix fill using pre-computed moment tables). Solution time for large problems is dominated by the inverse of a matrix of coefficients arising in MoM solution. Typically analysis of a problem having 1000 unknowns runs in 20 seconds per frequency (CeleronM 1.6GHz/Matlab6.5). First stage of solution with MoM table generation and matrix assembly is always fast and takes just 1 or 2 seconds. Rest of the time is a matrix inverse. Usually much smaller problems are being analyzed. Thus even parametric studies/designs of the FSS can be performed quickly. The code FSS1R has its own graphical interface which allows easy EM structure definition and subsequent analysis for a desired frequency range. Example from the run of the code is given in Fig. 3 and Fig. 4.

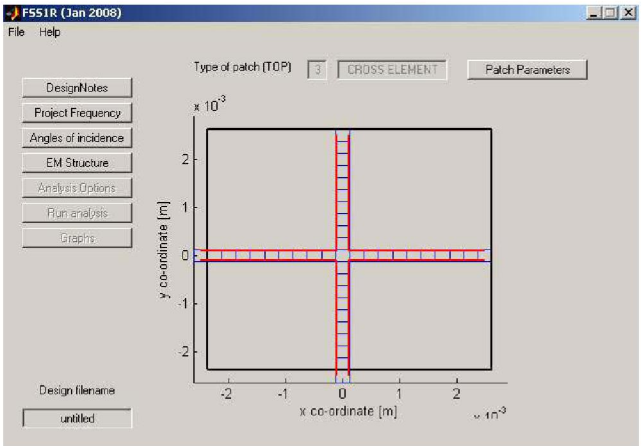


Fig. 3. FSS1R program – GUI (right part shows a periodic cell for the FSS consisting from infinite 2D grid of wires)

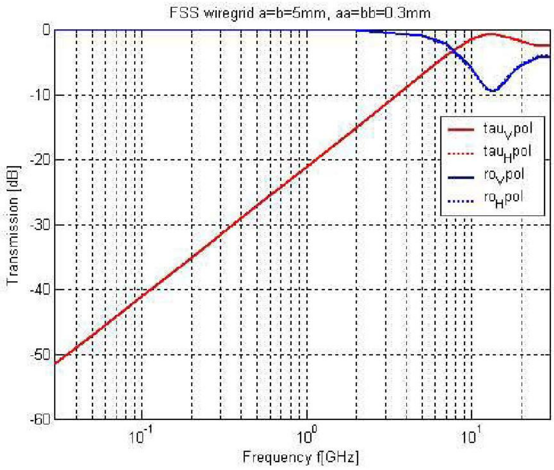


Fig. 4. Reflection/transmission properties of a composite material consisting of horizontal and vertical wires etched on a 1.57mm FR4 substrate (permittivity of 4.0 was assumed). Grid period 5mm, and width 0.3mm.

Second code FSSMR is more versatile. It also uses mesh of rectangular cells. Arbitrary non-uniform mesh is possible. Due to the mesh non-uniformity, the code is slower. However the great advantage is that the FSSMR is a true multilayer code allowing up to 5 metal and 4 dielectric layers. Layers can be lossy if necessary. Since the code uses a direct approach to solve multilayer FSS, there's no limitation on electrical thickness of any dielectric layer. Thus, an extremely dense layer stack up is possible. At the moment the FSSMR code has no GUI.

4. Simulated results

In order to verify correct function of both codes comparison with results available in the IEEE AP papers was performed. Verification of both single and multilayer cases were performed on printed cross dipole analyzed in [5]. See Figs. 5 and 6. Both examples assumed incidence $\vartheta^I = 1^\circ$, $\varphi^I = 0^\circ$ and maximum number of Floquet harmonics $M = N = 18$.

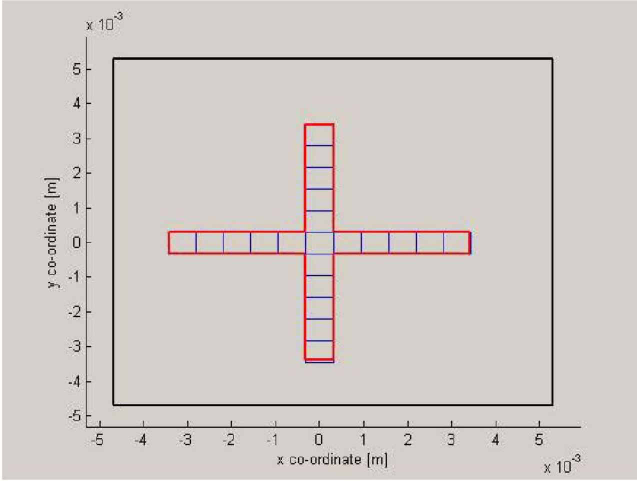


Fig. 5. FSS with cross elements – an elementary cell with meshed crossed element

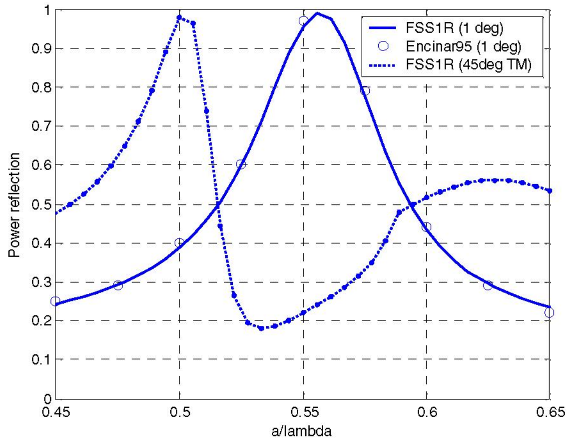


Fig. 6. Power reflection coefficient versus frequency - comparison of results produced by FSS1R code and results in paper [5] – Encinar95 (FSS with single dielectric and single metal layer, Cell period a=b=10mm, Length of cross dipole a'=b'=6.8mm, Width of cross dipole wx=wy=0.625mm, 16x16 grid), Substrate thickness d=3mm, Relative permittivity was 2.0.

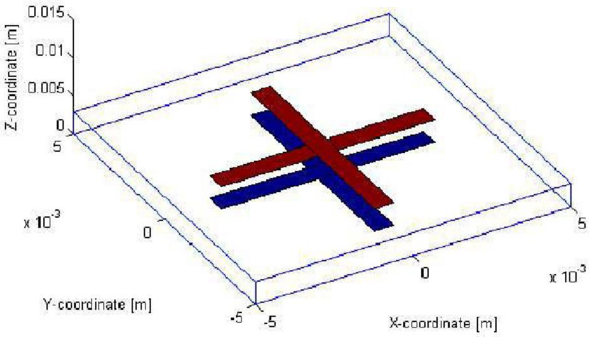


Fig. 7. FSS with cross elements – (FSS with single dielectric and two identical metal layers from Fig 5.

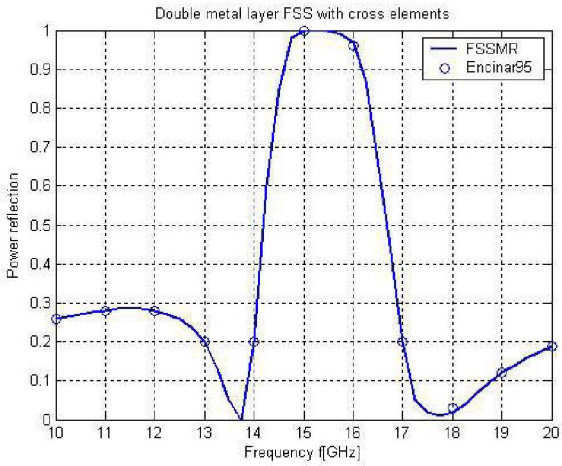


Fig. 8. Power reflection coefficient for the FSS from Fig 7. Solid curve results produced by FSSMR code. Circles correspond results in [5] – Encinar95

5. Motif definition

This chapter explains original procedures used in FSSMR (or FSS1R) codes to accelerate motif definition.

Techniques described below are useful when modeling multilayer geometries which contain predominantly wires (thin flat conductors) placed in several layers and crossing each other. One typical application may be analysis of R/T properties of composites with periodically distributed fibers (see. Fig.9a). Another practical problem includes analysis of composites with carbon fibres. Each fibre consists from many thin carbon wires arranged in a tow (Fig. 9c).

Modeling of standard geometries within written simulator is done in a similar manner as in user friendly planar EM simulators. For example motifs consisting from arbitrarily shaped polygons can be created in FSSMR with the same easy and interactivity as in Microwave office.

New procedures used in motif definitions

=Geometries with moderate complexity (drawn by hand)

- instead of drawing individual metal traces as flat conductors these traces are drawn by their central lines (either with fixed co-ordinates or parametrically). To define position of lines easily, pick points on the boundary of a elementary cell are being used.

- as the second step function (WIRE_TO_FLAT_CONDUCTOR) is called. The function converts wires to polygons with a predefined width. Polygons exceeding boundaries are automatically trimmed.

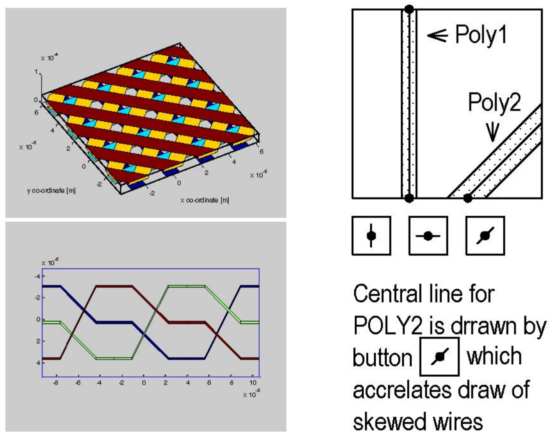
- to draw most common geometries e.g. ones with horizontal, vertical and skewed wires a set of quickbuttons is available (Fig.9b). In this case only one pick point on the boundary is necessary. As in previous case conversion from wire to flat conductor and necessary trimming is performed too.

=Complex geometries

- Motif of the patch is created by execution of a script file (Matlab m-function) written by an user. Typically script file consists from a sequence of commands which create polygons executed within a loop. As an example, one tow consisting from three carbon wires is given (see. Fig.9c).

It is clear that motif definition for all of these "special geometries" may be only accomplished by a custom written EMstructure editor that was exactly our approach to tackle specific needs arising in modeling of composites.

a) b)



c)

Fig. 9. a) Composite material with periodically distributed fibers b) Fast motif definition via wires and speedbuttons c) A tow of three carbon fibres (created by a script file).

6. Conclusions

A versatile Matlab program for analysis of multilayer FSSs having arbitrarily shaped elements was presented and its advantages in analysis of composites were explained.

References

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