NUMERICAL SIMULATION OF METAMATERIALS WITH ACTIVE AND NONLINEAR ELECTROMAGNETIC PROPERTIES

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Abstract – The techniques for calculating electromagnetic parameters of metamaterials containing components with non-linear and active properties are considered. The techniques are based on the method of minimum autonomous blocks. The results of computational experiments are presented.

I. NUMERICAL MODELLING OF COMPOSITES AND METAMATERIALS ON THE BASIS OF THE METHOD OF MINIMUM AUTONOMOUS BLOCKS

The design procedure of electromagnetic properties of composites and metamaterials based on a the method of minimum autonomous blocks was developed (MAB) [1]. The MAB method is based on the description of the electromagnetic parameters of subdomains using the apparatus of the scattering matrix. This method has been successfully used for the simulation of electromagnetic processes in structurally inhomogeneous media and to describe their electromagnetic properties [2,3]. Algorithms of realisation of the MAB method are considered. Models of absorbing boundary conditions for external electrodynamic problems are described. Models of local and remote sources are presented. It is established that the techniques developed on the basis of the MAB method provide a full cycle of modeling: including an estimation of average electromagnetic parameters of metamaterials and calculation of optical and microwave systems.

Features of modeling of interaction of electromagnetic radiation with the metamaterials possessing active, nonlinear and combined properties are considered. For calculation of electromagnetic properties of active metamaterials, especially as a part of resonant systems, it is appropriate to use the recomposition algorithm of realisation of the MAB method.

Nonlinear metamaterials are modeled by use of iterative algorithm of the MAB method allowing on each iteration to spend correction of effective electromagnetic parameters depending on amplitudes of channel waves, exciting blocks. Methods of increase of iterative process stability, including use of secondary decomposition of MABs and hybrid algorithms are considered. The models for describe the effects of harmonic generation using a system of related decomposition schemes are proposed.

II. THE ELECTRODYNAMIC ANALYSIS OF THE METAMATERIAL FROM CUBIC DIELECTRIC ELEMENTS

Efficiency of the developed techniques is illustrated by results of calculation of interaction of the plane linearly polarized electromagnetic wave with a flat layer of the metamaterial consisting of cubic elements, located in knots of a square periodic lattice.

The size of the block is 10 mm and the distance between the faces of the neighboring blocks is 4 mm. Plane wave is normally incident on the layer of metamaterial as is shown in Fig. 1. Frequency dependences of reflection and transmission coefficients were presented for the three-layer lattice in Fig. 2 (active metamaterial), and in Fig. 3 (nonlinear metamaterial).

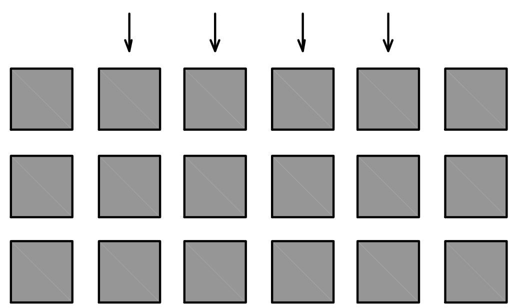

Figure 1 – Flat layer of the metamaterial containing cubic dielectric elements.

To set the active properties of the metamaterial the following values of permittivity and permeability of the material filling cubic elements were used: $\varepsilon = 25 + j2.5,\ \mu = 1 + j0$. Nonlinear material properties were specified as follows: $\varepsilon^{m}(i,j,k) = \varepsilon_{1}(i,j,k) + \alpha \max_{n}(|C_{p}^{m}(i,j,k,n)|^{2})$;

where (i, j, k) – coordinates of the block in the decomposing scheme; n – channel number; m – iteration number; $\varepsilon_1 = 25$ – stationary part of dielectric permeability; α – nonlinearity factor; $C_p^m(i,j,k,n)$ – complex amplitude of the wave falling on the block in the channel n on iteration with number m.

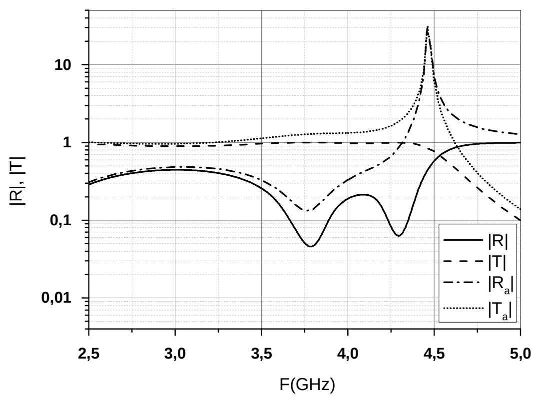

Figure 2 – The frequency dependence of reflection and transmission coefficients for the layer of active metamaterial

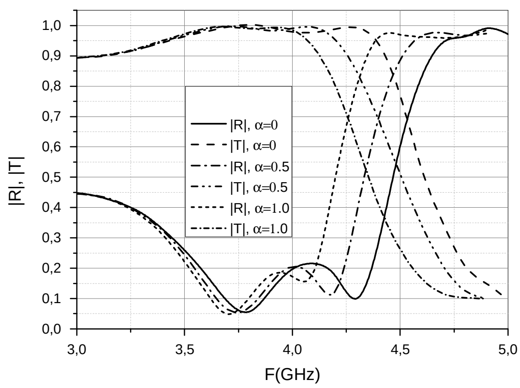

Figure 3 – The frequency dependence of reflection and transmission coefficients for the layer of nonlinear metamaterial

Analysis of simulation results show that the maximum amplitudes of the transmitted and reflected fields correspond to the own resonant frequency of cubic elements. The presence of non-linearity leads to a frequency shift of the curves, with the greatest influence on the reflection and transmission coefficients of the nonlinear properties of materials cubic elements provides at the same resonant frequencies.

III. Conclusion

Techniques for electrodynamic analysis of interaction of electromagnetic radiation with metamaterials are developed. Techniques allow to consider active and nonlinear properties of metamaterials. Results of modelling of a metamaterial with cubic elements confirms adequacy and computing efficiency of the developed techniques.

References

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