OPTIMIZATION OF EBG STRUCTURES BY USE OF GLOBAL OPTIMIZATION ALGORITHMS

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Dielectric electromagnetic bandgap structures (EBGs, photonic crystals) are periodic dielectric structures preventing electromagnetic wave propagation in some band. They enable to design reflectors, resonators or to suppress surface wave on the planar antennas. The article presents way of the planar EBG design for planar antennas design by use of global optimization algorithms.

Planar dielectric EBG structures are formed by two-dimensional periodic dielectric inclusions in the dielectric slab. The main design parameters forming the frequencies of stopband are the shape of inclusions and their size, kind of slab it is formed in, lattice constant and both slab and inclusions permittivity constant. While there does not exist a general way how to determine the stopband existence of certain parameter setup analytically it must be simulated by use of numerical methods.

To be able to reach the best performance in such nonlinear optimization problem, two algorithms – Particle Swarm Optimization (PSO) and representative of Genetic Algorithms (GA) applied to the problem of the bandgap fitting to the planar patch antenna will be presented. MATLAB is there used as tool to design both global optimization algorithms while the calculations are done by freely available simulation tool. The verification of results and the final patch design are done in CST Microwave Studio (CST MWS). The whole procedure is intended to serve as practice in the antenna design course on our department.

1 Introduction

Planar antennas have become very popular in recent years due to their small size low profile and manufacturing costs. However, planar antennas also exhibit relatively small bandwidth, low gain and efficiency. The efficiency of the antenna can be further decreased by surface wave radiation effect that occurs especially if thick or high permittivity substrates are used [1].

Surface waves of patch antennas can be effectively suppressed using electromagnetic band gap (EBG) structures in the form of substrates or superstrates. EBG structures are based on the wave interference caused by pattern periodicity in one or more dimensions. Exploiting constructive respectively destructive interference, the electromagnetic waves flow of TE respectively TM band can be controlled [2]. However if multiple bands should be covered, the design is more complicated.

Two-dimensional dielectric EBGs could be in the simplest case formed by a dielectric slab with some inclusions of the same shape formed in a periodic lattice. The desired gap occurs if two neighbour bands can be separated in dispersion diagram. For the applications several demands occur:

a) the bandgap bandwidth covering all desired bands to prevent unintentional wave propagation,

b) sufficient suppression level of parasitic wave provided by bandgap with sufficient attenuation. To achieve the desired state several parameters can be set: type of planar lattice (square, triangular, hexagonal), lattice constant, the inclusion shape and size, and permittivity of the dielectric slab or of the inclusions respectively. The simplest way how to fulfill the designers demands is to cover all bands in one large bandgap if all of them are sufficiently close to each other which implies the optimization goal set to maximize the gap bandwidth. One way how to design EBG structure comprises of finding some convenient bandgap in yet calculated and published diagrams (gap maps) and recalculating them to desired permittivity and operational frequency. Unfortunately this procedure can not be used to design more complex structures or for tuning of defects in the periodic lattice. As the gap width need not to be monotonic function and generally depends nonlinearly on permittivity, global optimization algorithms can be used for searching several input variables space to find a solution close to aforementioned requirements.

2 Design procedure

As an example of EBG capabilities, dualband patch antenna matched on 5 GHz respectively 10 GHz was designed (Fig. 1) with the use of approximate equations with radiation diagram (Fig. 2a, 2b) showing parasitic surface wave propagation thanks to high permittivity constant of the slab. In the second step the bandgap width is maximized by optimizing the unit cell geometry to cover at least the selected band and finally the whole structure is simulated and the dimensions are recalculated for the desired central frequency. Third step consists of tuning the size of unperturbated space surrounding the patch to resonate near to the selected central patch operational frequency. The final step – patch optimization together with EBG does not require optimization of the EBG itself but is needed to compensate the reduced size of unperturbed dielectrics surrounding the patch. For the simulation of simple EBGs freely available simulation tool using FDTD numeric method - mpb [4] aimed to the simulation of modes in periodic dielectrics was selected and optimized by our own PSO algorithm implementation in Matlab. The same problem was optimized in real coded Mean Adaptive Genetic Algorithm (MADGA) presented in [8, 9]. The efficiency of both algorithms was compared before [7] on bandgap maximization problem. MADGA proved here statistically slightly better ability to find minimum and faster convergence. As it was mentioned, this work is intended to serve as an exercise in an introductory course aimed to the antenna design. Therefore PSO is selected as a global optimization technique easy to understand by beginner students and easy to be implemented. MADGA was used only for the purpose of verification of sufficiently optimized results.

3 EBG design and optimization

The optimization problem was specified as the bandgap width maximization for dielectric EBG slab with given permittivity (ε_r = 20) high enough to produce surface wave and drilled air holes (ε_r = 1) organized in triangular lattice. This setup provides sufficiently high dielectric contrast to enable EBG stopbands. As criterial function ratio of maximum bandgap width of all present bandgaps to the central bandgap frequency in particular input parameter setup was considered. The mpb package is able to calculate bands propagating in periodic dielectrics and can therefore be used for calculation of bandgaps. It also enables two-dimensional calculation that provides faster way how to optimize EBG than three-dimensional CST MWS. Every EBG simulation setup in the optimization process was simulated as two-dimensional infinite periodic structure with 32x32 meshcells. The model is very fast to be calculated because it is only elementary cell that is simulated. Comparing to COMSOL Multiphysics (CM) mpb makes it possible to evaluate directly gap sizes.

The PSO algorithm was implemented according to [6] with absorbing walls, 40 iterations and 20 individuals. MADGA was taken from [8, 9] with parameters described in [7]. As the results of both algorithms were comparable with 3% difference PSO was found to be sufficiently efficient for the purpose of the exercise.

As a result the EBG working in TE band on the central frequency 10 GHz with holes of radius r = 7.2 mm organized to triangular slab with lattice constant a = 18 mm was designed by use of mpb. The existence of suppression effect was then verified for by fullwave two-dimensional simulation in COMSOL Multiphysics (see Fig. 4)-.

4 Patch antenna design and optimization

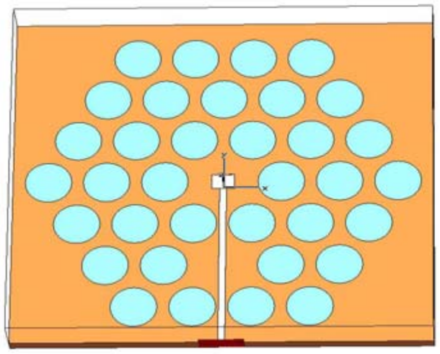

Fig. 1: The dualband patch antenna layout.

In the fullwave model containing patch antenna together with EBG substrate was modeled as set of air holes drilled conventional planar substrate. The thickness of this substrate was set to 5 mm and the upper side of the patch was surrounded by air region. Then, basic parameters of the EBG substrate were obtained by of optimization of the triangular lattice because of significant TE stopband, with lattice constant of 18 mm and with radius of the air holes equal to 7.2 mm. The antenna and the EBG substrate were optimized for central bandgap frequency 10 GHz (bandgap width to central bandgap ratio approximately 55%). In the pictures Fig. 2a and Fig. 2b, radiation patterns of the antenna on the conventional substrate and on the EBG substrate at the frequency of 10 GHz are depicted. It is obvious, that surface waves are suppressed, the radiation pattern is concentrated to the main lobe direction and the gain is increased by 3 dB at this frequency. Strong attenuation in bandgap frequency region can be observed from the reflection coefficient graphs (see Fig. 3a, 3b). However, the surface waves were not suppressed at 5 GHz, hence the radiation patterns at this frequency are not presented. These facts are going to be our future work.

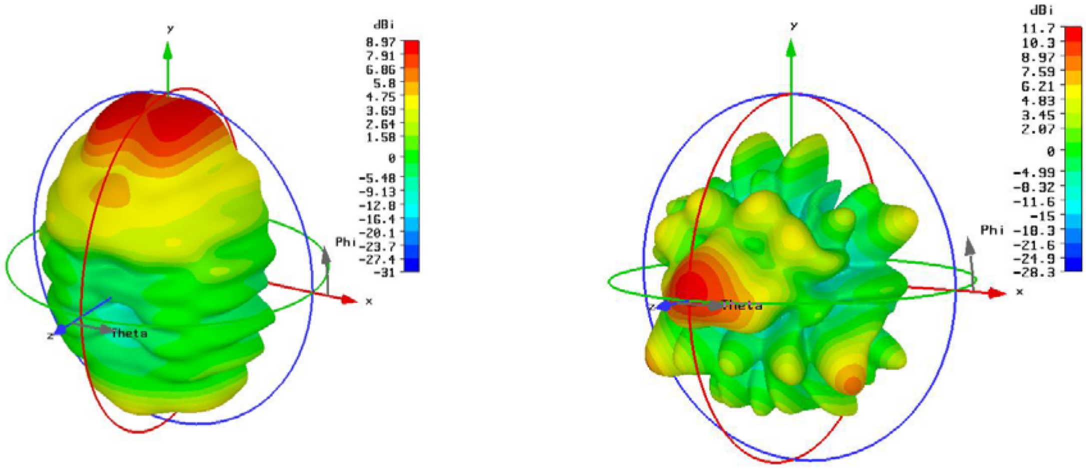

Fig. 2a, 2b: Radiation patterns for designed dualband patch antenna for 10GHz without (left) and together with EBG substrate calculated in CST MWS.

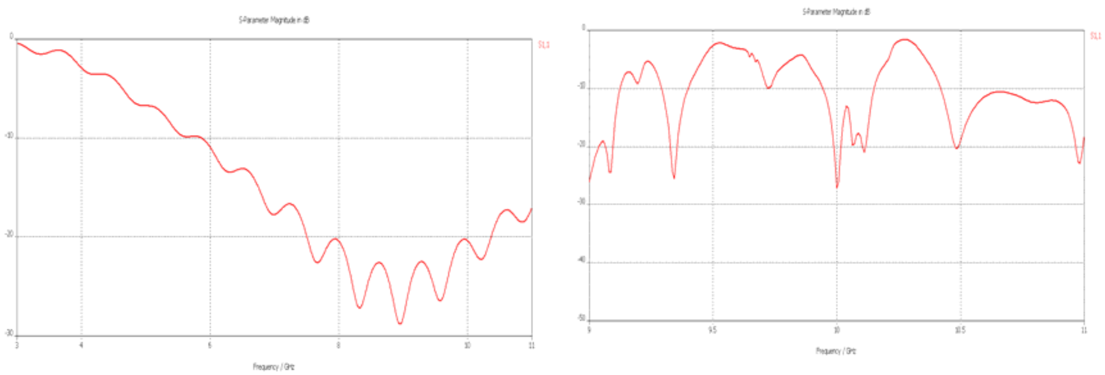

Fig. 3a, 3b: Reflection coefficient for designed dualband patch antenna for 10GHz without (left) and together with EBG substrate calculated in CST MWS.

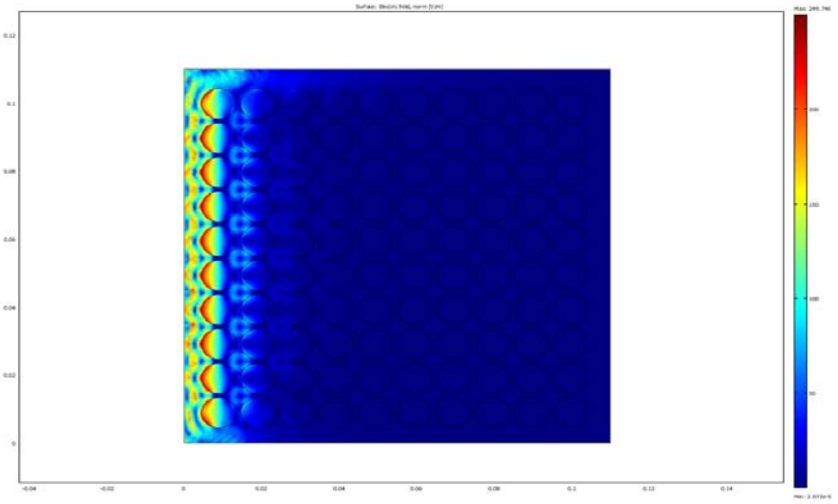

Fig. 4: Fullwave verification of simulated EBG structure for TE mode on 10 GHz in COMSOL Multiphysics.

5 Conclusion

Simple procedure of designing EBG structure on the patch antenna substrate was designed to suppress parasitic influence of surface wave together with simple bandgap width optimization procedure was presented. The EBG structure was then used to suppress the surface wave on the high permittivity substrate produced by patch antenna in 3D simulation. The whole procedure was designed using freely available simulation tool mpb, COMSOL Multiphysics as two-dimensional validation tool, CST MWS as three-dimensional fullwave simulation tool and MATLAB as scripting language primarily to serve for introduction to new ways of the surface wave suppression techniques in the bachelors antenna design course.

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