Design of High-Impedance Screens by Using Multilayered Frequency Selective Surfaces

Agostino Monorchio*, Luigi Lanuzza, Giuliano Manara

Department of Information Engineering,
University of Pisa, Via Diotisalvi 2, I-56126 Pisa, Italy.
a.monorchio, l.lanuzza, g.manara@iet.unipi.it

Abstract - In this paper, a multilayered dielectric structure backed by a perfectly electric conducting (PEC) ground plane is investigated for realizing high-impedance surfaces. These surfaces behave like a perfect magnetic conductor (PMC) at a certain frequency range. The inclusion of an FSS in the structure provides an additional degree of freedom which can be exploited to obtain the desired frequency and angular performance. All the presented solutions are derived by using a genetic algorithm-based synthesis procedure. The genetic algorithm (GA) resorts to an electromagnetic solver based on the Method of Moments (MoM) to describe the scattering behavior of the structure. In particular, the GA determines the permittivity and the thickness of each dielectric layer and the shape and the dimensions of the FSS screen. The synthesized structures are discussed with particular reference to the frequency response and to the robustness of the solution with respect to the angle of illumination.

1. Introduction

It is well known that a hypothetical magnetic conductor ground plane might improve the performance of printed dipole antennas, creating their positive image currents; moreover, it could be very useful in a large variety of microwave applications. Recently, photonic bandgap (PBG) structures have been widely investigated for their behavior as perfect magnetic conductors (PMC) at the stopband frequency, considerably reducing the tangential magnetic field. Either three-dimensional [1] or two-dimensional [2] structures have been proposed to realize this goal, both dielectric and metal-dielectric. In particular, a two dimensional structure can be realized by using a frequency selective surface screen inserted in a multilayered dielectric arrangement, backed by a perfectly electric conducting (PEC) ground plane. This configuration is desirable for its low-cost manufacturing and for the easy integration in microwave devices. However, the design of such a complex structure is not an easy matter, because it involves the optimization of many parameters, as for instance, the FSS screen basic periodicity cell shape and dimensions, as well as the dielectric layers thickness and electric properties. Genetic algorithms are global stochastic search methods that are very suitable to this aim [3]. They are able to determine a global minimum (or a maximum) of a multi-variables function representing the problem to be solved, by evolving proper populations of solutions. The chromosomes of the populations are a set of genes, representing coded versions of individual optimization parameters. In this work, some different two-dimensional configurations for realizing high impedance surfaces are discussed. In particular, we show that an improvement in the desired performance can be achieved if a multilayered configuration is employed. At the same time, the inclusion of resonant FSSs can provide better performance in terms of frequency behavior and angular stability of the solution, being this latter an important requirement in practical applications.

2. Genetic Algorithm synthesis

The permittivity and the thickness of each dielectric layer together with the shape and the dimensions of the unit cell have been chosen as the parameters to be optimized. Each parameter has been codified in a binary string to form a chromosome, representing the whole structure. To achieve a realistic design, the permittivities of the dielectric layers were selected from among a set of commercially-available products, together with some hypothetical (but still realistic) exploratory values. The maximum number of different dielectric layers has been fixed to 4, being

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the layers placed indifferently above or below the FSS screen. The basic cell of the FSS is subdivided into elementary pixels coded as 1s or 0s depending on whether they are covered by a printed metal element or not; the choice between symmetric or asymmetric shape is allowed. To evaluate the frequency and angular responses of the surface, an electromagnetic solver based on the Method of Moments (MoM) has been used, which is particularly suited for the analysis of doubly-periodic multi-layer screens. The evaluation criterion of the structure performance has been chosen as the root mean square difference between the actual and the desired electric field reflection coefficient for TE and TM modes; *i.e.,* $\Gamma_{E\,\mathrm{des}} = 1+j0$ for a PMC (this condition has been imposed separately on both real and imaginary part). To improve angular stability, two analyses are performed, one in the frequency domain, and the other by varying the incidence angle at the central frequency of the band. A weighted mean is then performed between the relative fitness data, to get the global fitness value of the structure. A single point *crossover* has been used, with probability *pcross*=80%. The specific GA adopted in this work employs a standard proportionate selection also called the weighted roulette wheel selection scheme. Moreover, to improve the algorithm speed of convergence, a new kind of selection strategy has been introduced with a linear variable mutation probability [4]. In particular, mutation probability *pmut* increases if two successive generations show the same fitness value. In particular, *pmut* increases linearly between a minimum value of 1% to a maximum value of 20% with 1% steps. If an improvement has been observed, *pmut* returns to its lower value.

3. Numerical Results

Sample of numerical results are presented in this section, comparing three different solutions. Concerning the total value of the fitness function, a weight equal to 65% has been assigned to the angular analysis, while 35% has been assigned to the frequency behavior. The frequency range has been fixed to f=1.71÷1.88 GHz. We used a set of 16 dielectric materials with ε_r ranging from 1.1 to 80, this database containing some commercially-available products, together with other hypothetical exploratory values. The tangent loss of the materials was included in the design. A structure is presented first (design #1) which is composed only by 4 dielectric layers on a PEC ground plane, without any FSS. In this case, we fixed the maximum value of the dielectric thickness to be 0.2 cm. As it can be seen from Figure 1a, this solution presents a bandwidth equal to 21.85%, defined as the relative band in which the phase of the reflected field varies in the range ±90°. Although the angular performance is satisfactory, a problem of this solution may subsist in the possibility of excitation of surface wave in the structure. The GA synthesized layers permittivity and thickness values are ε_{r1}=50, thickn_1=0.133 cm, ε_{r2}=30, thickn_2= 0.196 cm, ε_{r3}=25.0, thickn_3=0.174cm and ε_{r4}=40.0, thickn_4=0.187cm. In the following we show two GA-derived solutions that use an FSS screens; as regards the elementary cell, a symmetric shape together with equal dimensions along the periodicity directions have been chosen, ensuring equal performances for TE and TM polarizations. To achieve a compact design, the maximum value of the unit cell dimensions has been imposed to be 2 cm. In Fig. 2 we show an example of GA synthetized multilayered FSS structure (design #2). As the previous solution, it consists of 4 dielectric layers (three as superstrates and one substrate), with a maximum thickness of 0.2 cm for each layer; the dimensions of the unit cell are $T_x = T_y$=0.391cm. The dielectric layers permittivity and thickness values are ε_{r1}=50, thickn_1=0.186cm, ε_{r2}=6, thickn_2=0.198cm, ε_{r3}=30, thickn_3=0.194cm, and ε_{r4}=80.0, thickn_4=0.161cm for the substrate. The frequency and angular responses of the structure are shown in Fig. 3. The relative bandwidth is equal to 23.6%, this increase depending on the insertion of the FSS screen. The last structure shown here (design #3) is composed by an FSS screen with only one dielectric substrate placed on a PEC ground plane. In this case a maximum substrate thickness of 0.5 cm has been imposed; the ability of limiting surface wave propagation is an additional advantage of this solution. For the unit cell the GA found the dimensions $T_x = T_y$=0.482 cm, a dielectric substrate with permittivity ε_r=50 and a thickness value t=0.495cm. The unit cell shape and a complete view of the resulting FSS screen are shown in Figure 4. As concerns the frequency performance (see Figure 5), the bandwidth is equal to 16.55%. Moreover, the insertion of the FSS screen in an AMC structure causes considerable variations in its properties, allowing more compact solutions ($\lambda/4$=0.591cm when f=1.795GHz, using ε_r=50). Finally, it is worth pointing out that a properly set GA optimization procedure can achieve very robust solutions as concern the variation of the incidence angle; in our case, we obtained very low phase values up to an incidence angle θ=80° in all of the cases shown, both at the central frequency and in the entire design frequency band. Additional results will be shown at the conference to illustrate the effect of the FSS inclusion on the compactness of the final design with particular reference to the geometry of the unit cell.

References

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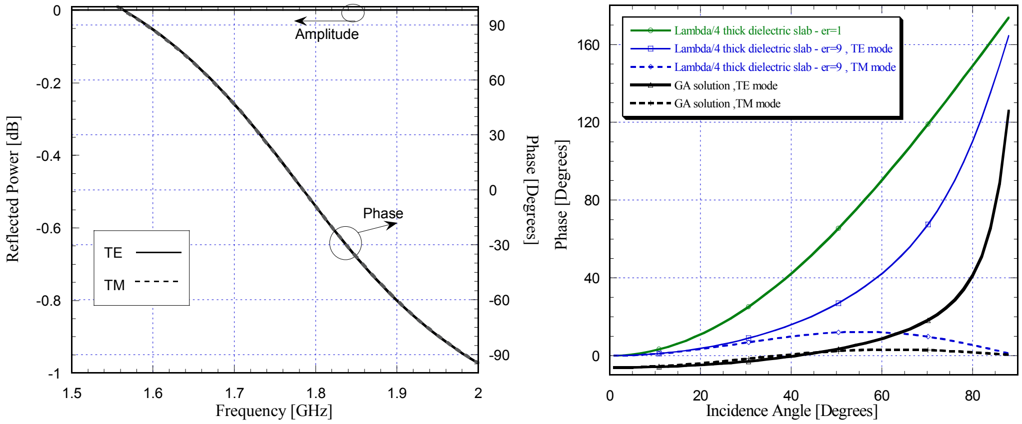
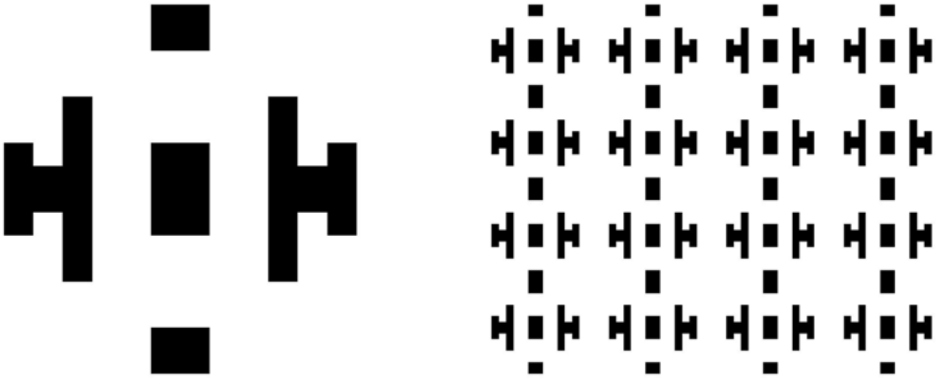


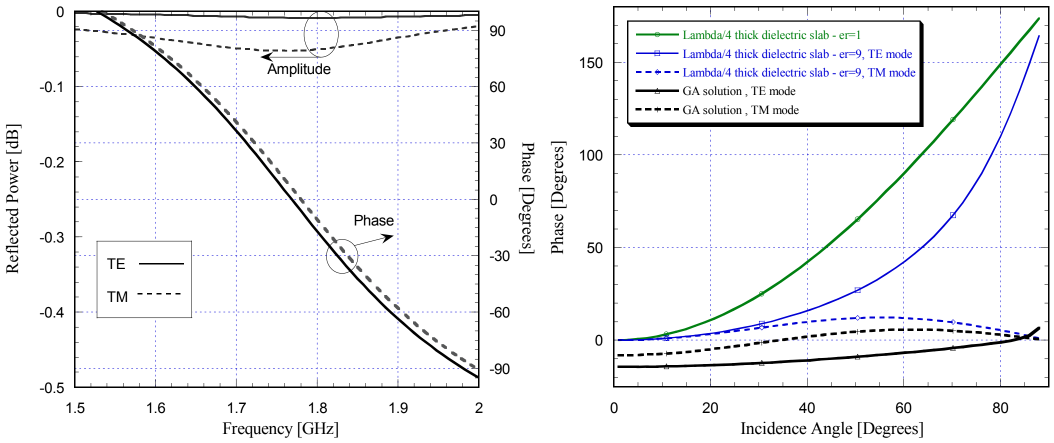
(a) (b)

Figure 1 - Frequency (a) and angular properties (b) of the multilayered structure without FSS (design #1). Frequency analysis is performed close to normal incidence, angular analysis is performed at the design central frequency of the band (f=1.795GHZ).



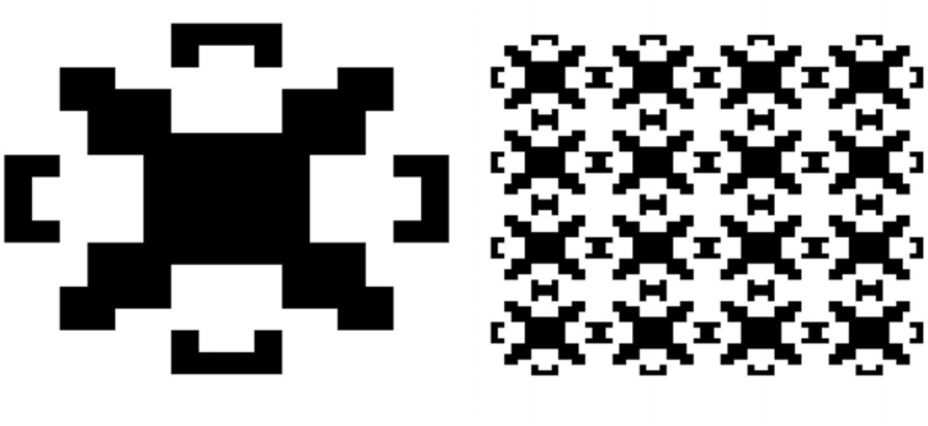
(a) (b)

Figure 2 – Ga synthesized unit cell (a) and FSS screen (b) for the design #2. Dark areas correspond to conducting printed elements.



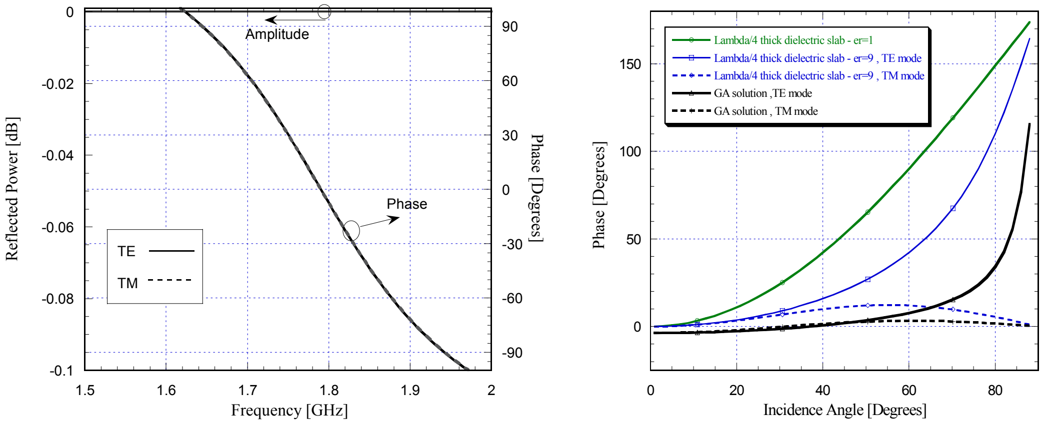
(a) (b)

Figure 3 - Frequency (a) and angular properties (b) of design #2



(a) (b)

Figure 4 – Design #3: a) GA synthesized basic periodicity cell; b) Complete view of the FSS screen. Dark areas correspond to conducting printed elements.



(a) (b)

Figure 5 - Frequency (a) and angular (b) properties of design #3.