Synthesis of High-Impedance FSSs Using Genetic Algorithms

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Abstract - In this paper, a genetic algorithm-based technique for synthesizing high impedance surfaces is presented. These surfaces behave like a perfect magnetic conductor (PMC) in a certain frequency range; to achieve this result, a multilayered dielectric structure in conjunction with an FSS screen and a perfectly electric conductor (PEC) ground plane have been used. The genetic algorithm (GA) uses an electromagnetic solver based on the Method of Moments (MoM) to evaluate transmission and reflection properties of the structure. In particular, the GA determines the shape and the dimensions of the FSS screen, the permittivity and the thickness of each dielectric layer. To improve the speed of convergence of the GA, new selection and mutation strategies have been applied. The synthesized structures show the desired frequency properties and reveal robust as concerns the stability of the solution with respect to the angle of illumination.

1. Introduction

It is well known that an 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 bidimensional [2] structures have been proposed to realize this goal, both dielectric and metal-dielectric. In particular, a bidimensional 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, as shown in Fig.1. 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. 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, new selection and mutation strategies have been developed, to achieve a faster algorithm convergence.

2. Genetic Algorithm strategy

The shape and the dimensions of the unit cell together with the permittivity and the thickness of each dielectric layer 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, as shown in Fig.1. 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 8, being the layers placed indifferently above or below the FSS screen. However, satisfactory results have been found by using only 3 dielectric layers over the FSS screen and only one substrate between the screen and PEC ground plane. The basic cell 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 properties 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., \( \Gamma_{\text{des}} = 1 + j0 \) 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 band central frequency. 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 [3]. Moreover, to improve the algorithm speed of convergence, a new kind of selection strategy has been introduced. It is well known that best results are usually found if GA starts from a good initial population; in our case, we build the initial population by using the best chromosomes of several trial populations; once the evolution has started, the next generations are created by inserting only new chromosomes showing fitness values lower then the older ones. In this way, overlapping generations are involved, resulting in an hybrid scheme between generational and steady-state GAS [4]. A faster convergence might result in a loss of 'genetic information', prematurely removing overall unfit chromosomes, which however might contain good genes. To obviate this problem, a linear variable mutation probability has been applied. The mutation operator is rarely present in the initial evolution stages, when crossover acts maximally to achieve a fast improvement of the populations, while it begins to act when the fitness value settles. In our implementation, mutation probability \( pmut \) increases if two successive generations show the same fitness value. In particular, \( pmut \) increase 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

Some numerical results are shown in this section. The design specifications call for a positive unit reflection coefficient for the electric field, implying in phase
total reflection for an incident plane wave. The frequency range has been fixed to 1.74 + 1.88 GHz, and a symmetric shape for the FSS unit cell has been chosen. The FSS structure is composed by four dielectric layers as shown in Fig. 1; concerning the total value of the fitness function, a weight of 65% is assigned to the angular analysis while 35% is assigned to the frequency behavior. In Fig. 2 we show a sample of the results obtained. The dimensions of the unit cell are \( T_x = 6.747 \) cm, \( T_y = 7.611 \) cm. The dielectric layers permittivity and thickness values are \( \varepsilon_{11} = 10.2, \) \( \text{thick}_{1} = 0.37485 \) cm, \( \varepsilon_{2} = 10.2, \) \( \text{thick}_{2} = 0.3302 \) cm, \( \varepsilon_{3} = 2.8, \) \( \text{thick}_{3} = 0.40915 \) cm and \( \varepsilon_{4} = 3.0, \) \( \text{thick}_{4} = 0.36635 \) cm for the substrate. In Fig. 3 we show the frequency and angular characteristics of the structure. The relative band (defined as the frequency range in which the phase of the reflected field varies in the range ±30°) is equal to 10.97%. The structure also shows a good angular stability, with very low phase values up to an incidence angle of about 80°, at the central frequency (Fig 3b). Finally, it is worth pointing out that introducing the new selection strategy, the GA is able to reach convergence in 100-150 generations on the average.

References


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**Fig. 1** Structure used for realizing the high-impedance surface and corresponding chromosome set.
Fig. 2 a) GA synthesized basic periodicity cell; b) Complete view of the FSS screen.

Fig. 3 - Frequency (a) and angular (b) properties of the synthesized structure. Frequency analysis is performed for normal incidence. In (b), a comparison is made between GA solution and two dielectric slabs with different permittivities backed by a PEC.