Particle Swarm Optimization of Frequency Selective Surfaces for the Design of Artificial Magnetic Conductors

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Introduction

The particle swarm optimization (PSO) is a population-based optimization algorithm, inspired by concepts as the swarm intelligence and the learning process of the human cognition. The PSO was originally proposed by Kennedy and Eberhart [1] and it has recently found interesting applications within the electromagnetic community [2-4]. In PSO, each member of the swarm represents a codified solution which traverses a multidimensional space. Each dimension of this space is a parameter of the problem to be optimized. During its excursion in the solution domain, each particle in the swarm looks for the best location and changes its position with time. During the flight, each agent in the swarm is attracted towards two different places related to its own experience and those of the other members. The former is the best position reached by the single particle and it is commonly referred as the “cognitive rate”, since it determines how much the agent is affected by the memory of the best position he has found. The latter is the best location found by the rest of the swarm and it is called the “social rate”, which indicates the influence the swarm has on the single particle. Following these two types of stochastic attractions, the velocity of each member is updated and the swarm is driven towards the best overall location.

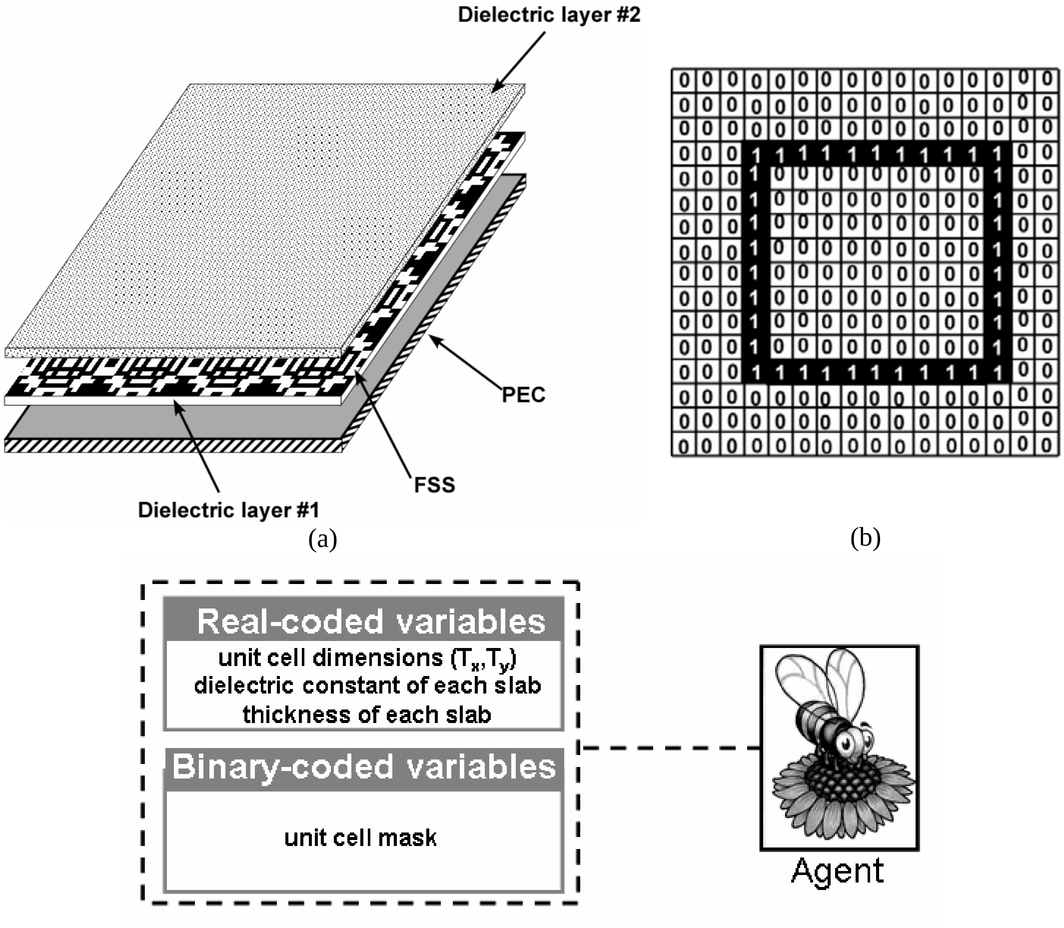
In recent years, the design of Artificial Magnetic Conductors (AMC) has been the object of many investigations, and is considered to be very appealing for a large variety of applications, especially in the field of low-profile antennas [5-7]. In fact, the zero -phase reflection coefficient at the resonance frequency allows placing the source very close to the magnetic ground plane without any detriment to the radiation pattern, offering the possibility of shrinking the total dimension of the device. In order to realize an AMC ground plane, it is possible to exploit a planar architecture which incorporates a high impedance Frequency Selective Surface (FSS) into the design. As shown in Fig. 1(a), once the number and the configuration of the dielectric layers has been chosen, it is necessary to optimize the shape and dimensions of the FSS unit cell, and the values of dielectric constants as well as the thickness of each dielectric slab in order to obtain the AMC behaviour at the desired frequency. Our aim is to describe how this task is accomplished by using the PSO algorithm. The proposed optimization strategy is validated through a set of numerical tests, which also demonstrate its effectiveness and reliability.

Formulation

Since we have to deal with not only with real parameters, such as, for instance, the unit cell dimensions (T_x and T_y) and the characteristics of the dielectric substrates (permittivity and thickness), but also with binary ones (Fig. 1(b)), we have implemented a PSO algorithm which can handle both real and binary parameters. In this case, each agent (Fig. 1(c)) moves in a space whose dimensions are determined by the number and the kind of the parameter set at the beginning of the optimization process. For example, the value of the permittivity, as well as its thickness, can be chosen from a predefined database (integer parameter) or can be a real value. The shape of the FSS unit cell is a binary parameter and, since the discretization adopted by our MoM code [7] is 16×16, the number of binary parameters is 256 which can be reduced to 64 if the cell is forced to have a quarter-fold or to 36 if the cell has an eight-fold symmetry. It is worth noting that, while in the case of optimization of real and integer parameters the velocity of the particle can be associated with a physical meaning, dealing with binary ones this concept loses its physical interpretation and provides the value of a probability. In fact, the position of the particle in the part of the multidimensional solution space which is related to the binary parameters can be either 0 or 1. Then, the velocity represents the probability of changing for the value of that bit. Consequently, the higher is the velocity along that direction, the larger is the possibility of that bit to be changed. To evaluate the performance of the structure, and the “goodness” of the location occupied by the agent, we have adopted the root mean square difference between the actual electric field reflection coefficient (Γ_E) and the desired one ($\mathrm{Re}\{\Gamma_{AMC}\}=1$, $\mathrm{Im}\{\Gamma_{AMC}\}=0$), as an indicator for both TE and TM modes.

Numerical results

The PSO has proved to be a fast and reliable tool for the design of Artificial Magnetic Conductors. In Fig. 2, we show the unit cell and the FSS screen, synthesized by the PSO to behave as an AMC at 2.5 GHz. For this case, we identified as optimization parameters the dielectric permittivity as well as the thickness of the substrate between the PEC ground plane and the FSS. The period of the unit cell is 4.9 cm, and the PSO yields a dielectric permittivity of 2.5 and a thickness of 0.1 cm. The optimization process required less than 30 minutes on a 3.0 GHz Pentium IV with 4 GB of RAM and involved a number of agents that can be considered quite small when compared with the standard dimension of a genetic algorithm (GA) population. Indeed, in our experience the (GA) requires larger runtimes, suggesting that the PSO seems to provide better convergence rates.



(a)

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0
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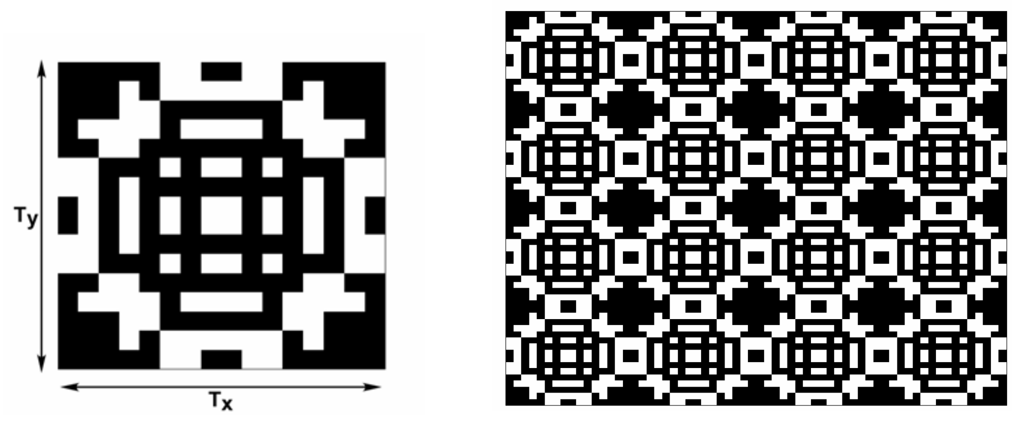
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(b)

(c)

Fig. 1 – Optimization of an AMC: (a) Geometrical configuration; (b) Unit cell is binary encoded (1 means presence of PEC while 0 means absence of conductive surface); (c) Agent structure determined by the design parameters.



(a)

(b)

Fig. 2 – Results of the PSO in terms of the shape of the unit cell (a) synthesized cell; (b) Complete view of the FSS screen. (dark areas correspond to printed metallic elements).

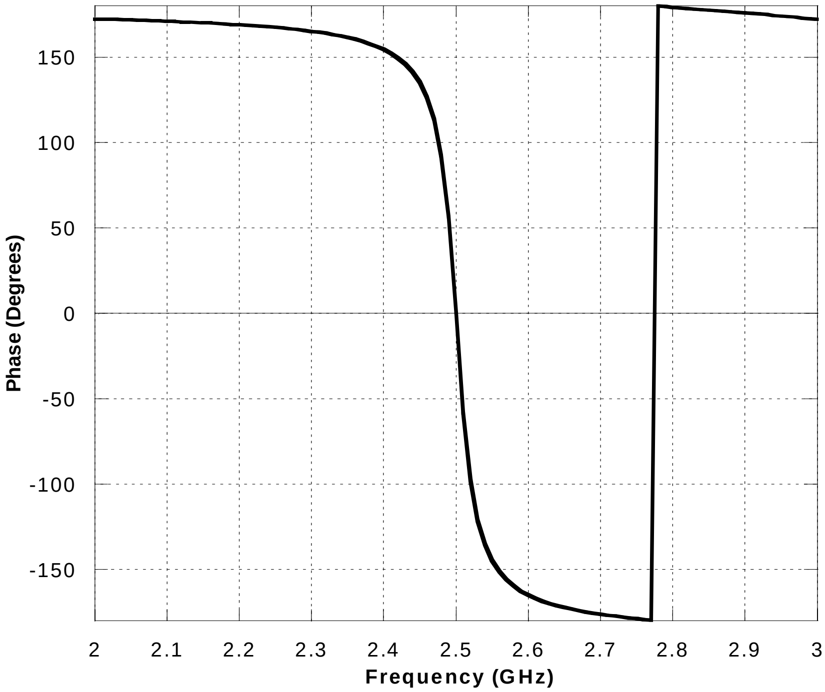


Fig. 3 – Reflection coefficient phase vs. frequency for the synthesized structure shown in Fig. 2. The analysis is performed at normal incidence.

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