Particle Swarm Optimization of Square Loop Frequency Selective Surfaces considering a Model of Dielectric Effective Permittivity

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This paper presents the results of a Particle Swarm Optimization Method (PSO) applied in the design of square loop frequency selective surfaces (FSS) via the Equivalent Circuit Model (ECM). In the optimization process, in addition to the FSS geometrical parameters, the thickness and relative permittivity of dielectric material used as support are included as variables in the search space. The effect of dielectric layers is considered in the ECM by using a model of dielectric effective permittivity for square loop FSS developed in our previous work. In the synthesis procedure, we are interested in reducing the FSS unit cell surface and/or the dielectric thickness compared with designs reported in literature for applications in WLAN systems. It is worth noting the low computational cost and acceptable accuracy obtained with the proposed approach. PSO method results were implemented with ECM and compared with those obtained with Ansys HFSS commercial software.

***Index Terms*—Dielectric Effective Permittivity, Equivalent Circuit Model, Frequency Selective Surfaces, Particle Swarm Optimization.**

I. INTRODUCTION

FREQUENCY SELECTIVE SURFACES (FSS) are spatial electromagnetic filters that, due to their electromagnetic behavior, are used to control the propagation of electromagnetic energy in several scientific, industrial and military areas as well as, in recent years, in applications associated with security and efficiency in wireless network communication [1].

The design of FSS with specified requirements (as resonant frequency, bandwidth and incidence angle) generally falls in two categories [2]. The first one is associated to problems in which the pattern of the periodic structure is to be determined. In this case, full wave electromagnetic simulation is used in conjunction with stochastic optimization methods [3], but the high computational cost can make the optimization problem unfeasible [2]. The second category is associated to problems in which the parameters of a given pattern are to be determined. In this second case, it is possible to use less accurate methods to analyze the electromagnetic response of FSS, as the Equivalent Circuit Model (ECM) [1], which combined with stochastic optimization methods can synthetize a FSS with simple algorithms and low computational cost.

Particle Swarm Optimization method (PSO) is a stochastic strategy that mimics the social behavior of insect and bird swarms. It has simple formulation and rapid convergence. PSO was originally proposed by Kennedy and Eberhart [4] and has a great potential in synthesizing and optimizing electromagnetic structures.

In this paper, we present the implementation of the ECM with the PSO in the design of square loop FSS. The main difference with other similar works [2], [5] is the inclusion of an accurate model for dielectric effective permittivity in the ECM equations.

II. METHODOLOGY

The Fig. 1 shows the relevant geometric parameters of a square loop FSS.

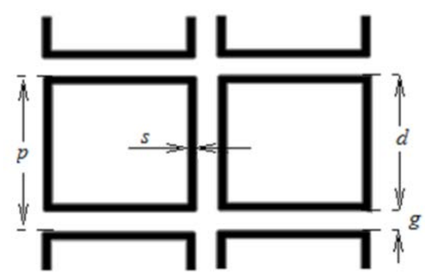

Fig. 1. Geometry of the square loop FSS.

In [6], it was developed a model for the dielectric effective permittivity that complements and particularizes the model proposed in [7]. Specifically, for a square loop FSS, the dielectric effective permittivity was written as [6]:

$$\varepsilon_{eff} = \varepsilon_{rh} + (1 - \varepsilon_{rh}) e^{-\frac{2dt}{p\sqrt{sg}}}, \qquad (1)$$

where ε_{rh} is the asymptotic value of the dielectric effective permittivity, which corresponds to ε_r for a double-sided dielectric configuration and $(\varepsilon_r + 1)/2$ for a single-sided configuration. The variables d, s, g, p are the geometric parameters of the square loop FSS and t corresponds to the thickness of a single dielectric layer.

A PSO tool was implemented for the design and optimization of a square loop FSS. The electromagnetic analysis was performed using the ECM, which includes the model of dielectric effective permittivity developed in [6].

Therefore, in the current design of a square loop FSS, there are five variables in the search space: d, s, g, t and ε_{rh}. In order to take into account different design possibilities, three cases have been considered, as shown in Table I.

TABLE I
CONSIDERED CASES FOR PSO IMPLEMENTATION

Case Number	**Fixed Parameters**	**Variable Parameters**
1	t, ε_{rh}	d, s, g
2	ε_{rh}	d, s, g, t
3	–	d, s, g, t, ε_{rh}

III. Results

The proposed method was applied in the design of a square loop FSS and the obtained results were compared with some results reported in literature. The selected FSS corresponds to a square loop described in [1] and referenced as UNII, designed for controlling propagation of WLAN signals, with a resonant frequency of 5.8 GHz.

The geometric parameters of the square loop FSS referenced as UNII are shown in Table II.

TABLE II
GEOMETRIC PARAMETERS OF UNII FSS

p (mm)	***s (mm)***	***d (mm)***	***g (mm)***
21.0	4.0	20.0	1.0

In the PSO implementation, we chose a number of swarm particles equal to 100, with 500 iterations. Additionally, considering the dispersion in results for each execution of the optimization process, the presented results correspond to the average of 50 successive PSO executions.

Table III shows the range of optimization parameters for each case considered in Table I.

TABLE III
PARAMETERS RANGES IN PSO OPTIMIZATION

Case Number	***d (mm)***	***s (mm)***	***g (mm)***	***t (μm)***	ε_{rh}
1	5 – 10	0.5 – 1	0.1 – 0.5	20	4
2	5 – 10	0.5 – 1	0.1 – 0.5	20 – 50	4
3	5 – 10	0.5 – 1	0.1 – 0.5	0 – 50	1 – 4

Table IV shows the PSO results for the three considered cases. Additionally, the ratio of the UNII surface unit cell to the surface unit cell calculated with the parameters determinate by PSO process is presented in the last column. This parameter was called "surface unit cell ratio" (SUCR). We can observe that the unit cell for the PSO design is much smaller than that of the FSS UNII. This is an advantage because smaller cells allow an improvement in the angular response. In addition, small cells simulate better an infinite surface in reduced areas, which improve the FSS operation.

TABLE IV
RESULTS OF PSO DESIGNS

Case Number	***s (mm)***	***d (mm)***	***g (mm)***	***t (μm)***	ε_{rh}	**Comput. Time (s)**	**SUCR**
1	0.6709	9.5	0.1754	20.0	4	47.63	4.71
2	0.6997	9.3	0.2142	36.332	4	61.12	4.87
3	0.6632	9.5	0.2015	36.189	3	63.97	4.68

Figure 2 shows the transmission coefficient as a function of frequency (for normal incidence and double-sided dielectric configuration) for three cases: green and black curves correspond to Case 1of Table IV analyzed with HFSS and with the ECM, respectively; the red curve corresponds to ECM results obtained for UNII [1].

It is worth noting the low computation time of the synthesis process using PSO via ECM compared to PSO in conjunction with full wave methods, obtaining also acceptable accuracy in ECM versus HFSS simulation results. As reference data, a computation time of 35 hours was reported in [8] for the synthesis of 7 geometric parameters (with constant relative permittivity and dielectric thickness) of a dual square loop FSS. By using our approach, the computation time, in the largest search space (i.e., Case 3 in Table I), is about 63.97s for the synthesis of 5 parameters.

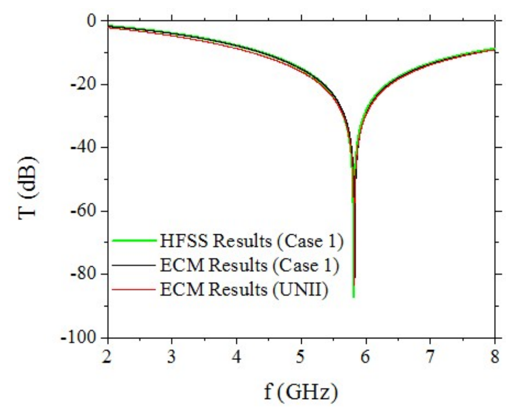

Fig. 2. Transmision Coefficient as a function of frequency.

In the extended version of this paper, we will present more details in PSO implementation and show the results for other square loop FSS referenced in literature.

IV. References

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