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A Case Study for Improving Performance of Frequency Selective Surface through Union of Sub-Sets and Particle Swarm Optimization

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***Abstract*—Frequency Selective Surfaces (FSSs) consist of a repetition of a given pattern in a periodic way; typically, a dielectric substrate supports this arrangement giving rise to a two-dimensional array. Although relatively simple in structure, designing an FSS that exhibits large bandwidth and stable response to oblique incidence is not straightforward and requires special attention and significant computational effort. To address this problem, this study presents a methodology whereby an initial configuration of the FSS pattern is subjected to an optimization method for sizing the geometrical parameters. Consequently, the initial unit cell is first broken down into subsections, specifically as a ”union of subsets”, then particle swarm optimization is used to achieve optimal design parameters that further improves the overall FSS performances. To validate the proposed method, an X-band FSS is proposed and optimized in a commercial simulation environment (Microwave Studio, Dassault Systèmes).**

***Index Terms*—Frequency Selective Surface (FSS), optimization methodology, Particle Swarm Optimization (PSO), Domain Subdivision.**

I. INTRODUCTION

Frequency Selective Surface (FSS) aims to control either the transmited or reflected electromagnetic waves [1], [2] through/from an (usually) periodic metallic pattern positioned on a dielectric layer. This structure is typically used in microwave and millimeter-wave areas for circuits as antennas, reflectors, absorbers and so on [3]. Figure 1 offers a graphical representation of the working principle of an FSS in terms of incident, transmitted and reflected waves.

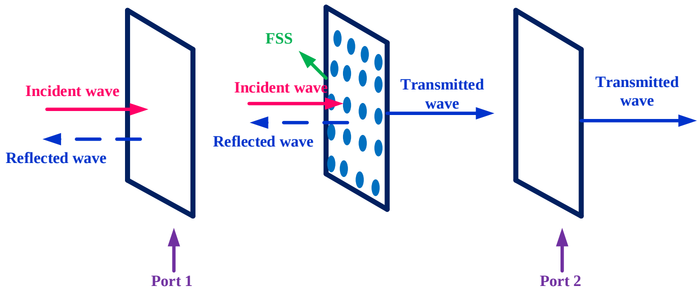

Fig. 1. Representation of different phenomena when an incident wave hits a FSS. Port 1 and port 2 correspond to the observation sections on the two sides of the FSS structure.

FSS structure includes 2-dimensional periodic array of patterns: the most commonly used geometries derives from and are variations of patches and/or loops [1], [4]. In the recent years, various FSS designs have been proposed. Pang et al., present the design of FSS based on the spoof surface plasmon polariton for two passbands [5]. In [6], radar absorbing materials are designed to be used at the 77-GHz frequency band. In another study ([7]) high-order bandpass FSS is designed that results in flat in-band frequency response. In [8], a popup FSS is proposed that has the ability to be tuned; it is constructed by periodic 2-D crossed dipoles. An ultra-miniaturized low-profile angularly-stable configuration is presented in [9] that can be used for shielding in the GSM frequency band.

Considering the multiple applications FSSs fit, their design can present challenging aspects. For this reason, a proper methodology is required for configuring and optimizing the design parameters that describe the geometry and electromagnetic constrains, sequentially. In this work we present a methodology which results in designing high-performance FSS structure described by a high number of degrees of freedom. For this case, *union of sub-sets* method is used for configuring the unit cell where it is used for combining the sub-divisions of large cell. Afterwards the *particle swarm optimization (PSO)* method is employed for providing the optimal design parameters. Overall, one FSS structure that is operating in the X-band frequency is designed for validating the proposed methodology.

The reminder of this paper is as follows: Section II presents the proposed methodology for designing FSS. Section III describes the practical implementation of the FSS structure and then presents the simulation results. Finally, Sec. IV concludes this work.

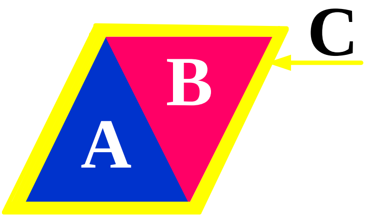

Fig. 2. Graphical representation for *union of sub-sets* concept in the mathematical set theory.

II. Proposed Methodology

Providing a proper initial structure of FSS is fundamental, since its response represents a first guess for the desired optimisation. For this case, we firstly present the proposed method of configuring the unit cell of FSS and then we employ the optimization method namely as 'PSO' for achieving the optimal design parameters. This section devotes to present the proposed methodology for designing the complex structure of the FSSs.

A. *Union of sub-sets*

Mathematically, *union of sub-sets* is the method of collecting set of sub-divided elements as Fig. 2 presents. As this figure shows, 'A' and 'B' are the sub-sets of big set named as 'C'; formally it can be presented as C=A∪B. The union of sets is typically used in set theory and it is analogous to arithmetic addition where it includes all the elements presented in the largest set. The methodology is akin to the domain decomposition paradigm, but in the opposite direction; instead of braking down the initial domain, here it is constructed by grouping.

B. *Particle swarm optimization*

Computationally, similarly to the genetic algorithm, PSO method is based on the stochastic optimization technique [10]. In particular, PSO method targets to improve solutions related to the fitness function [11], [12]. The candidate solution will be improved in iterative way aiming to achieve the given measure of quality. The comprehensive view for the basic PSO method is presented in Fig. 3 [13]. Velocity and position vectors are updated at each step, till the cost function reaches the pre-set threshold.

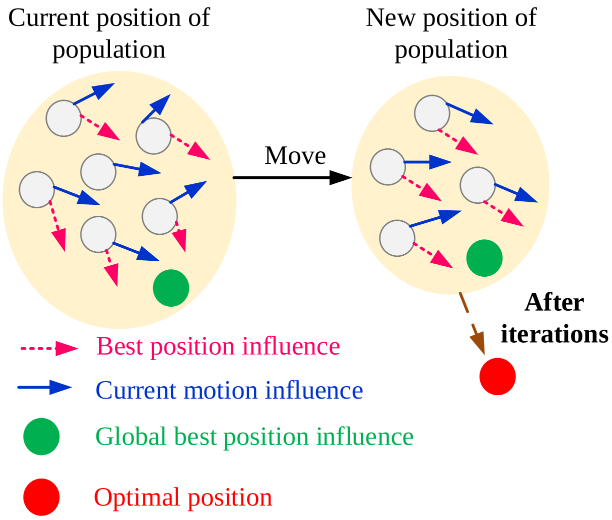

Fig. 3. Graphical representation of the working principle of the PSO method.

III. Practical Implementation of the Proposed Method

This section presents the employed methodology for configuring and sizing the FSS structure; afterwards simulation results are provided. In this study, to design and optimize an FSS operating on the X-band is targeted.

A. *Design procedure of FSS through proposed methodology*

The design of FSS starts with a circular patch [14], and then develops in generating sub-sections of circular shapes (**Step-①**). Afterwards, the generated shape with sub-sets are dividend in two sections where the union of them will produce the initial structure in Step-① and the final structure will be named as "expanded" (**Step-②**). After generation of the extended structure, the PSO method is employed for extracting the optimal geometric parameters (here the radii of the circle) (**Step-③**). Figure 4 presents the methodology for generating the structure of FSS in a comprehensive fashion. The in detail structure with design parameters are depicted in Fig. 5 and the optimal values of parameters are presented in Tab. I. The distance between the central point of the two units is 17.5 mm, corresponding to the periodicity of both the initial and expanded structures.

TABLE I
Optimal values of FSS structure parameters in Fig.5

parameters	**value (mm)**	**parameters**	**value (mm)**
W_1	12.0	W_7	1.0
W_2	11.0	W_8	2.0
W_3	8.80	W_9	6.0
W_4	7.80	W_{10}	8.0
W_5	4.0	W_{11}	9.80
W_6	3.0	W_{12}	10.80

B. *Simulation results*

The designed and optimized FSS structure presented in Sec. III-A is simulated in the Microwave Studio (Dassault Systèmes). The FSS structure is designed on FR-4 with relative permittivity ε_r=4.1 and of thickness of 0.5 mm. The related simulation results are discussed in this section.

The S-parameter performance for normal incidence of the proposed FSS is presented in Fig. 6 where the well matched bands are as follows: 5.705-5.925 GHz, 7.234-7.52 GHz, 8.246-8.708 GHz, 9.104-9.599 GHz, 10.23-11.05 GHz, and 13.57-13.757 GHz, respectively. As it can be observed many of them are in the X-band. Moreover, the transmission coefficient exhibits additional resonances for the expanded case. Depending on the design constrains one can choose between wide band or multi band responses. Radiation pattern at 9.2 GHz, 11 GHz ,and 13 GHz are reported in Fig. 7, Fig. 8 and

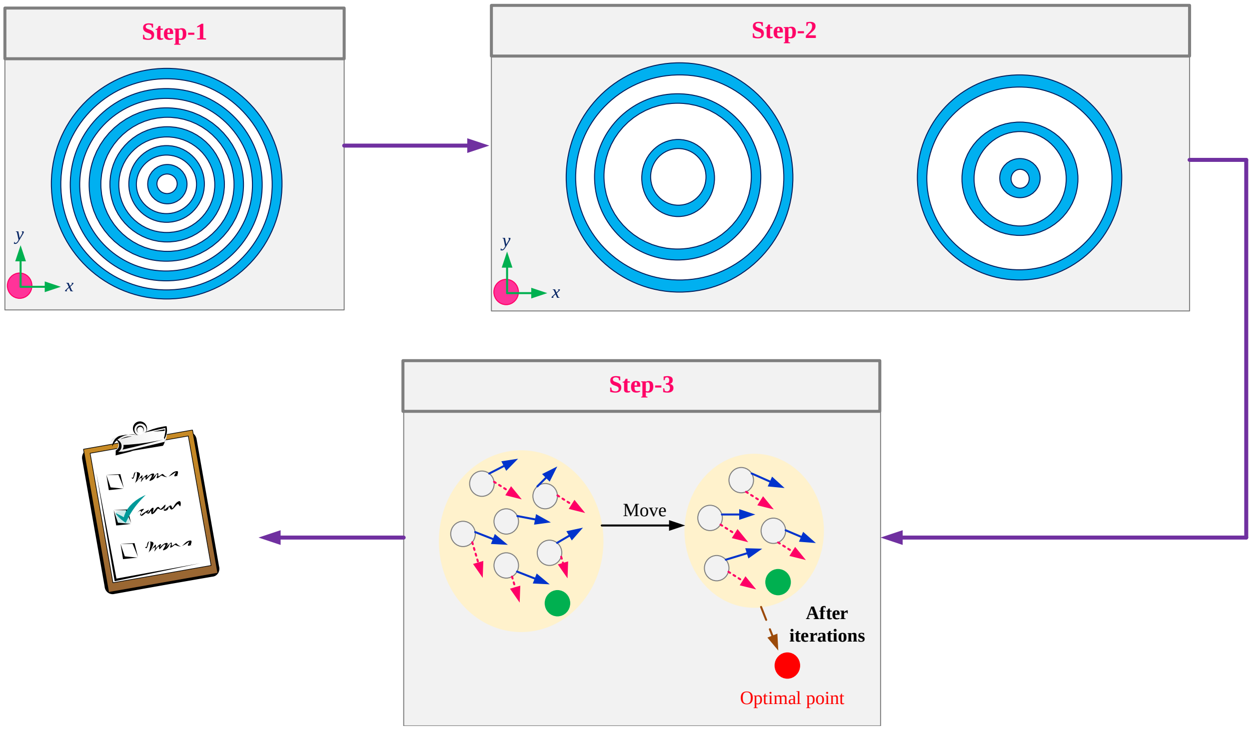

Fig. 4. Proposed 'union of sub-sets' method for configuring the structure of thye FSS.

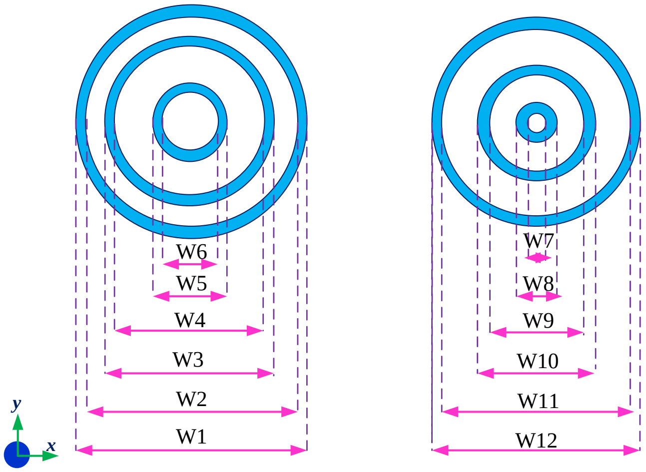

Fig. 5. The generated FSS unit cell structure in Step-2.

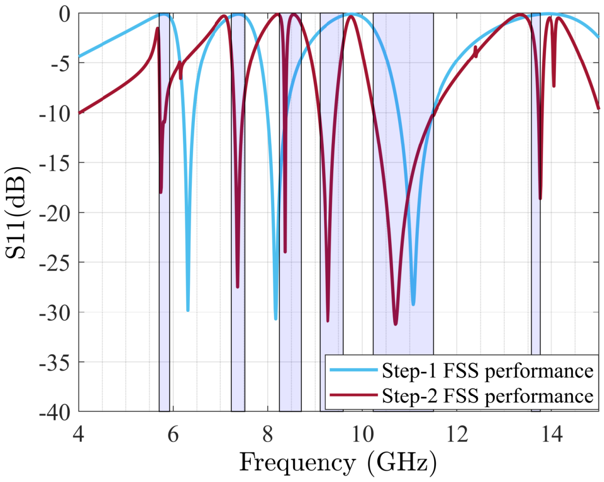

Fig. 6. S_{11} performance of proposed FSS in this study.

Fig. 9 for the initial and expanded cases. The frequency values have been chosen to put in evidence the different matching: Fig. 7 (the extended structure is matched and the initial one is not), Fig. 8 (same value of the S_{11} for matched case) and Fig. 9 (mismatch for both cases). Results for oblique incidences are similar (not reported).

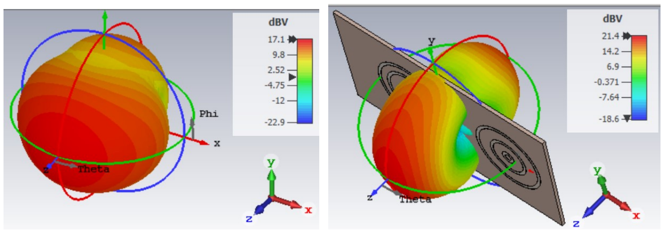

Fig. 7. Radiation pattern of the initial (left) and expanded (right) optimized FSS at 9.2 GHz.

IV. CONCLUSION

Designing circuits operating in at high frequency is not straightforward and requires additional efforts. Nevertheless their relatively simple structure FSSs are still subject to special attention when wide bandwidth and angular stability are requested. In this framework, a new methodology for configuring and optimizing the FSS structure leading to generate wide-band FSS structure is presented here. Hence, firstly subsets of large cell are combined together to provide a wider (here

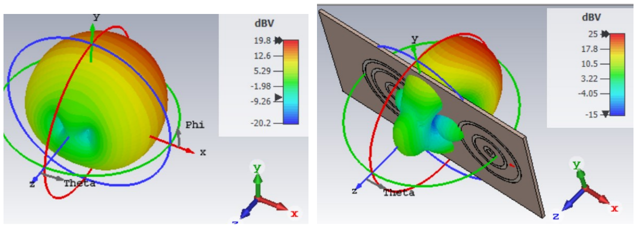

Fig. 8. Radiation pattern of the initial (left) and expanded (right) optimized FSS at 11 GHz.

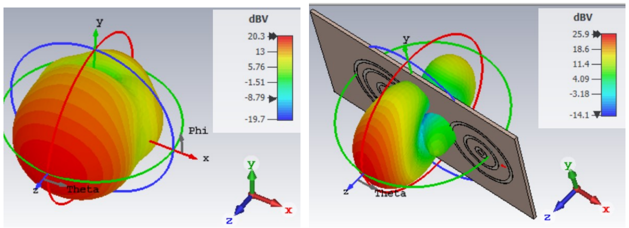

Fig. 9. Radiation pattern of the initial (left) and expanded (right) optimized at 13 GHz.

double) extension unit cell, and then the PSO method is employed to find the optimal design parameters. For validating the proposed method, one FSS structure consisting of circular patches is presented that is working on the X-band. This methodology expands the degree of freedom for controlling the electromagnetic response in different frequency bands, and in turn designing high-performance FSS configurations. The sub-sets of even larger units can have various possibilities of combination. For the future work, we will consider all these possibilities and also employ intelligent-based optimizations for determining the optimal configuration using proper optimisation techniques.

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