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Dual-Band Frequency Selective Surface Design Using Artificial Hummingbird Algorithm

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***Abstract*—In this work, the design and optimization of an FSS device are presented for dual-band operation in the frequency bands of LTE-2600 and 5G-FR1 cellular communication networks. The proposed FSS device is designed by utilizing a recently introduced swarm-based meta-heuristic, namely the artificial hummingbird algorithm. The obtained numerical results of the proposed FSS device exhibit resonances at the frequency bands of interest, and quite acceptable values of gain and efficiency. Its overall performance makes it a suitable candidate for a receiving module of a rectenna in RF energy harvesting applications.**

I. INTRODUCTION

Frequency Selective Surfaces (FSSs) are featured electromagnetic (EM) devices that exhibit complex characteristics [1]. Based on the frequency of operation, FSSs can reflect, transmit, or absorb the electromagnetic radiation of incident fields [2]. They are designed based on a periodic structure, i.e., the unit cell (or the element) of the FSS geometry [3]. The main features of FSSs that synthesize their complex characteristics in electromagnetic environments are the unit cell geometry, the electrical properties of the substrate material, and the inter-element distance [2], [3].

By exploiting the characteristic of absorptivity, FSSs can be applied in Radio Frequency (RF) Energy Harvesting (EH) applications as the receiving module of a rectenna [4], [5]. However, due to their design complexity, even for simple unit cells, as well as when they are required to operate in more than one frequency band, their geometry cannot be determined analytically. In such cases, the application of an optimization method seems to be a straightforward process to obtain an optimal solution [2].

In this work, we design and optimize an FSS operating in the frequency bands of LTE-2600 (2500 MHz - 2690 MHz) and 5G-FR1 (330o MHz - 3800 MHz) cellular communication networks. To obtain a feasible solution to the given optimization problem, the Artificial Hummingbird Algorithm (AHA) [6] is applied in combination with a high-frequency electromagnetic solver. AHA is a meta-heuristic that is classified to the swarm intelligence algorithms for solving optimization problems.

II. ALGORITHM DESCRIPTION

The terminology of AHA includes three categories, i.e., the hummingbirds, the food sources, and the visit table. The hummingbirds in AHA refer to the population of the optimization method that seeks food. Each hummingbird is related to a specific food source and updates its position based on the position of the selected food source. Food sources are individual sets of flowers that are used by hummingbirds to feed. Food sources represent the solution vector to the optimization problem and the nectar refilling rate is the corresponding value of the fitness function. Finally, the visit table is a matrix that lists the number of visits for each food source from various hummingbirds. It is utilized by the hummingbirds to locate the food sources in the given search space of the optimization problem.

Three distinguished mechanisms are described in AHA, i.e., the guided mechanism, the territorial mechanism, and the migration mechanism. In the guided mechanism, each hummingbird seeks the food source with the highest nectar volume by the corresponding visit table. Three different flight patterns, i.e., omnidirectional, axial, and diagonal, are utilized to visit the selected food source. In the territorial mechanism, each hummingbird seeks a new food source within its own territory. This mechanism represents the local search (exploitation phase) for the population members in the optimization problem. Finally, the migration mechanism is taking place when the assigned food source to a hummingbird lacks food. In this case, the hummingbird needs to seek a new food source, usually at a longer distance. The migration mechanism denotes the exploration phase of the optimization method. Details about the AHA can be found in [6].

III. NUMERICAL RESULTS

In this work, we apply the AHA to obtain a feasible solution to the design of an FSS device. We set the number of population equal to 30 and the number of iterations equal to 1000. The objective function of the given optimization

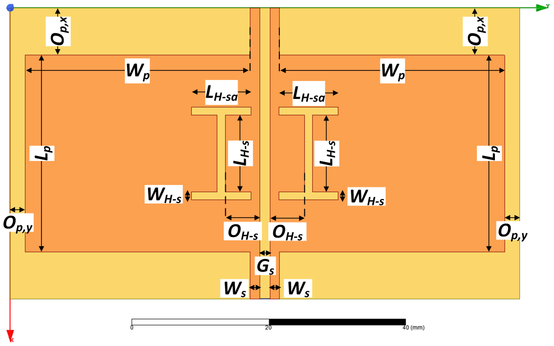


Fig. 1: Proposed unit cell geometry of the designed FSS device (yellow color denotes the substrate, orange color presents the metal foil of unit cell - figure also depicts the geometrical variables of the optimization problem).

problem can be expressed as

$$\begin{aligned} \text{Minimize } OF(\mathbf{v}) = max\big(S_{11}^{2.6\text{GHz}}(\mathbf{v}), S_{11}^{3.55\text{GHz}}(\mathbf{v})\big) \\ +\Xi \times max\big(0, S_{11}^{2.6\text{GHz}}(\mathbf{v}) - T\big) \\ +\Xi \times max\big(0, S_{11}^{3.55\text{GHz}}(\mathbf{v}) - T\big) \end{aligned} \quad (1)$$

where $OF(\mathbf{v})$ is the objective function, $\mathbf{v}$ is the decision variables vector, i.e., the geometrical design parameters of the FSS device, S_{11}^{i} ($i = \{2.6\text{GHz}, 3.55\text{GHz}\}$) is the magnitude of the reflection coefficient, T is the threshold in dB for the acceptance (or not) of the solution at each iteration, and Ξ is a factor (e.g., equal to 1000) that gives a positive value in the objective function when the difference between the magnitude of the reflection coefficient S_{11}^{i} and the threshold T is larger than zero.

Fig. 1 displays the proposed unit cell geometry of the FSS device that is designed on a Rogers 4003C substrate material (relative permittivity: 3.55, dielectric loss tangent: 0.0027, substrate thickness: 1.524 mm). A total number of 10 design parameters is required to thoroughly describe the geometry of the obtained unit cell. The obtained FSS device consists of 4 × 2 unit cells, having an overall size of 170.28 mm × 146.64 mm.

Fig. 2 illustrates the magnitude of the reflection coefficient for the obtained FSS device as a function of frequency. From the presented graph we can conclude that the proposed FSS resonates at the desired frequency bands of LTE-2600 (-28.54 dB at 2.604 GHz) and 5G-FR1 (-30.55 dB at 3.548 GHz) mobile communication networks.

Finally, Fig. 3 portrays the realized gain of the proposed FSS device at the tuning frequencies of operation. From the presented graphs we can conclude that the maximum gain of the designed FSS device reaches the value of 5.29 dBi at 2.604 GHz, having an efficiency of 76.6%, and the value of 6.04 dBi at 3.548 GHz, having an efficiency of 67%.

IV. CONCLUSION

In this work, a dual-band FSS, operating in the frequency bands of LTE-2600 and 5G-FR1 cellular communication networks, has been designed and optimized by applying the AHA optimizer. The proposed FSS device resonates at the frequency bands of interest and exhibits quite acceptable results in terms of its gain and efficiency. Its overall performance renders it a promising candidate for a receiving module in a rectenna system for RF EH applications. Future work comprises the fabrication and the experimental validation of the designed FSS in a real environment.

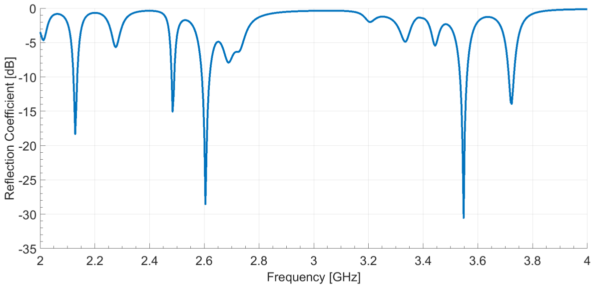
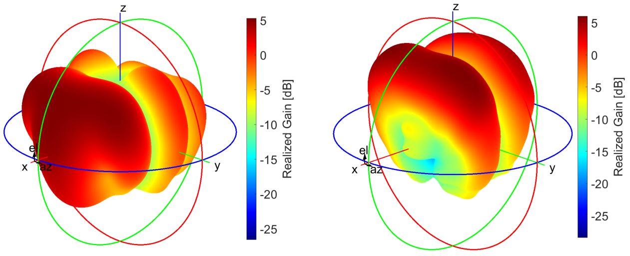


Fig. 2: Reflection coefficient of the obtained FSS device versus frequency.



(a) (b)

Fig. 3: Realized gain of the obtained FSS device at the frequency of (**a**) 2.604 GHz (LTE-2600) and (**b**) 3.548 GHz (5G-FR1).

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