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Triangular Intertwined Frequency Selective Surface

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***Abstract*—This paper presents a frequency selective surface design and simulation using intertwined triangular structures. It has been discovered that by using the proposed tessellated intertwined lattice, the reduction of the resonance frequency of a frequency selective surface can be improved by 22.58% compared with other triangular structures. Additionally, this structure is used as a MEFSS to improve the miniaturization of the structure and obtain a compact, angular stable band-pass filter. The simulations presented in this paper have been obtained using CST Microwave Studio.**

***Index Terms*—Frequency selective surfaces, meta-surfaces, equivalent circuit, Miniaturized element frequency selective surfaces.**

I. Introduction

Frequency Selective surfaces are part of the planar periodic structures and are considered meta-surfaces. These structures are electromagnetic filters whose frequency response depends upon the impinging polarization and angle of incidence of the electromagnetic wave. Some authors have researched different intertwined structures for propagation control applications; for instance, some principal designs are: convoluted cross spiral [1], quadrifilar spiral [2], trifilar spiral [3], hexafilar spiral [3], intertwined Brigid's cross [4], and intertwined hexagonal structure [5]. All previous structures can be used as band band-pass filters (inductive FSS) or band-stop filters (capacitive FSS). The design principles of the intertwined structures are the interleave of the resonant element arms with its neighbors. This interleave increases the equivalent capacitance and inductance of the structure, hence reducing the resonance frequency of the structure and, depending on the resonant element, increasing its fractional bandwidth.

II. Design of the intertwined triangular frequency selective surface

Figure 1 shows the proposed intertwined triangular structure in a continued tessellated fashion and as a stand-alone unit cell. The design consists of triangles placed in a triangular lattice of period p. The sides of each triangle should be $2t+2s$, where t is the thickness of the structure arm, and s is the inter-arm space. Then the sides of each triangle are increased in the form of a protruded arm with thickness t. As the protruded arms extend, and before it meets the neighbor protruded arm, changes its direction forming a hexagonal shape. Finally, the previous process is repeated until the entire structure is entirely tessellated and intertwined.

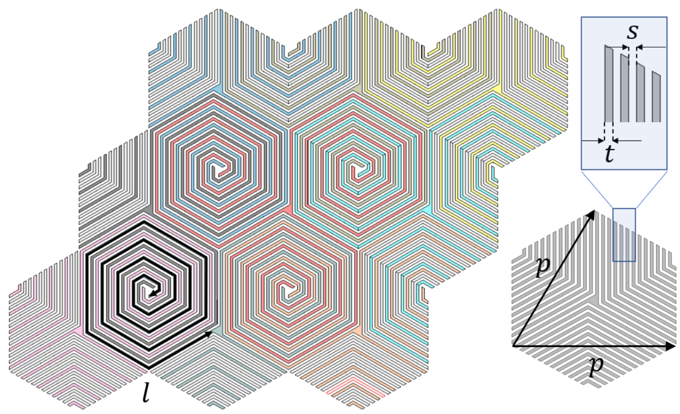

Fig. 1. Intertwined triangular shape. Each unit cell protruded arm is coded in different colors. The period of the structure is defined by p, the arm thickness by t, and the inter-arm spacing by s.

To compare the results obtained in this paper with previous works, the structure will be substrate-less, the period is set $p = 10.8mm$, arm thickness $t = 0.2mm$, and inter-arm spacing $s = 0.2mm$. The transmission coefficient of the structure as a function of the length of the arms is illustrated in Figure 2. It can be seen that the resonance frequency of the structure decreases exponentially as the length of the arms increases up to $40mm$, then it tends to an asymptotic value. This reduction in resonance frequency is due to the rise of the equivalent capacitance and inductance of the structure as the intertwined became denser. On the other hand, the -10 dB bandwidth of the structure shows a significant increase, especially between the length of $10-30mm$, then it softly decreases. Finally, it can be seen that as the length increases, new resonances appear. These resonances repeat by $3\lambda_0/2$ due to the higher-order modes produced by the resonance periodicity of the arms.

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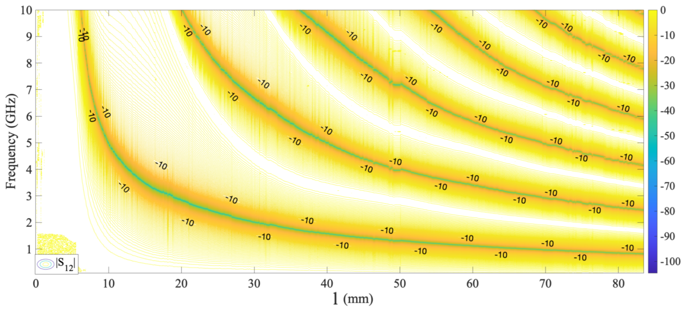

Fig. 2. Transmission coefficient as a function of the arm length l and frequency of the structure presented in Figure 1.

A. Intertwined triangular MEFSS

The concept of MEFSS can also be applied to intertwined structures to generate a band-pass frequency selective surface to reduce even further the resonance frequency. As is known, the equivalent circuit of a capacitive PPS that represents the fundamental resonance frequency due to fundamental modes is a series LC circuit parallel to another capacitor. This circuit has a significant capacitive component. Suppose this circuit is placed in parallel to other where the inductive component is predominant. In that case, we can obtain a band-pass structure whose resonance frequency is lower than the alone structure. We can use the proposed structure in this paper (predominantly capacitive) and the inductive trifilar structure (predominantly inductive), separated a certain distance, to obtain the MEFSS band-pass structure, as illustrated in Figure 3.

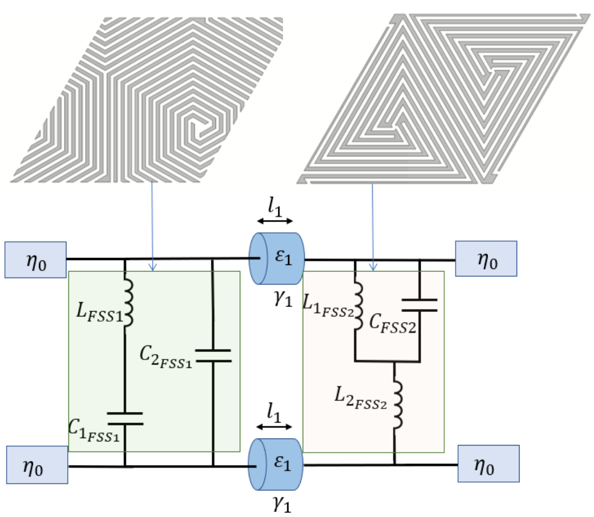

Fig. 3. Equivalent circuit of the proposed intertwined MEFSS.

The full-wave simulation results obtained by using the comparison dimensions described before and a separation distance between structures of 0.5 mm, are illustrated in Figure 4. It can be seen that the resonance frequency at $\theta = 0^\circ$ is drastically reduced, and the effect of high order resonances is mostly suppressed due to the inductive structure impact. An additional advantage of this structure is its excellent angular stability, which can be evaluated by the shift of the resonance frequency, in this case around zero for angles as high as $\theta = 80^\circ$. A comparison table with previous intertwined triangular FSS works is presented in Table I.

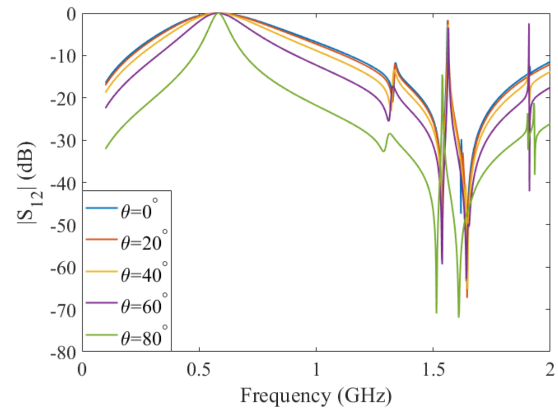

Fig. 4. Transmission Coefficient of the proposed intertwined MEFSS at different angles of incidence.

TABLE I
FIGURE OF MERIT AND FRACTIONAL BANDWIDTH COMPARISON BETWEEN INTERTWINED TRIANGULAR STRUCTURES.

Type	λ_0/p	Fractional bandwidth (%)
Trifilar spiral [3]	34.72	17.98
Hexafilar spiral [3]	26.94	69.91
Intertwined Hexagonal [5]	18.617	90.2
Intertwined Triangular	**34.8**	**55**
Intertwined Triangular (MEFSS)	**47.9**	**28**

III. CONCLUSIONS

In this paper it has been introduced an intertwined triangular FSS, which has improved miniaturization 22.58% compared with other triangular structures. Additionally its use has been proposed as MEFSS, which shows higher miniaturization and good angular stability.

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