2.5D Inductive Intertwined Frequency Selective Surface For Pass-Band Applications

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***Abstract*—This paper presents the design of a miniaturized intertwined pass-band inductive frequency selective surface in a 2.5D configuration. In the literature, we have identified that the 2.5D configuration has been described and used only for a capacitive intertwined frequency selective surface; therefore, we describe the design of this structure, taking Brigid's cross as an example that later on can be used as starting point for other types of structures. Moreover, the proposed structure presents high miniaturization capabilities, reaching a period of 0.00967 wavelengths and a fractional bandwidth of 30.856 % without the influence of a substrate. Finally, besides the pass-band capabilities of the structure, it also offers a wide stop-band in upper frequencies with a fractional bandwidth of 73.15 %.**

***Index Terms*—Frequency Selective Surfaces, filters, antennas.**

I. INTRODUCTION

Frequency selective surfaces (FSS) are electromagnetic filters that, compared to conventional filters, not just depend on the operational frequency but also on the polarization and incidence angle. The mechanical structure of the FSS is composed of periodic structures carved on a metallic layer resting over a substrate. However, the previous does not imply that an FSS can be designed only using dielectric or metal. These structures are used in multiple applications; for instance, radomes, dichroic sub-reflectors, electromagnetic interference (EMI) reduction, and angle-selective surfaces applications [1]. However, in the most straightforward design, these planar periodic structures will have one wave-length period, which is a considerable drawback for low-frequency applications. Therefore, its miniaturization has been studied over the last few decades.

One of the techniques used to improve FSS miniaturization is the so-called 2.5D configuration, which consists of using vias to connect two or more FSS layers. As we increase the number of layers, the surface current finds a new path that will increase the inductance, improving the miniaturization, but with reduced bandwidth [2].

Some authors have presented different designs to obtain a pass-band structure at different frequency bands in the literature. E.g., for stop-band applications, authors use knitted structures [3], like square spirals arranged in a 2.5D configuration for one band [4] and two bands [5], tapered meandered lines [6], and multifunctional active FSS [7]. Moreover, other authors use structure extension to increase the physical size of the structure using pins in specific locations to generate stop-band filters with rectangular spiral elements [8], extended cross-dipoles [9], and convoluted interwoven elements [10]. On the contrary, authors have proposed combining two FSS structures to control the zero in the transmission for pass-band applications. For instance, authors use a planar tapered meandering line with a vertical via-based meandering line [9], parallel LC resonators [11], a convoluted square loop with a grid [12], or multiple 2.5D resonators [13].

This paper proposes an intertwined inductive structure in a 2.5D configuration to highly miniaturize a pass-band FSS. To our knowledge, this paper is the first to present a 2.5D intertwined inductive FSS.

II. UNIT CELL DESIGN

To design the 2.5D inductive intertwined Brigid's cross unit cell, illustrated in Figure 1, we have considered the design of a 2.5D capacitive structure as a starting point.

In the capacitive configuration, the current distribution starts in the first layer and is distributed in the next layer. Moreover, the electric conductivity of the structure is only limited to the unit cell and some of the neighbor cells, which means the structure is not self-standing. This can easily be understood by comparing this to the case of a patch FSS, where the elements are not connected electrically to each other.

On the other hand, in the inductive case, the current distribution has to be distributed in the two layers, as in the capacitive one, and also offer electrical conductivity. Therefore, the second layer of the structure has to offer a short circuit to warranty the electrical conductivity in every point of the metallic section. As in the previous case, we can use the analogy with the complementary of a patch FSS, a square grid FSS, where the metallic sections are electrically connected to each other. To accomplish the intertwined inductive configuration, we removed the section that electrically

This work was supported by the Luxembourg National Research Fund (FNR), through the CORE Project (ARMMONY): Ground-based distributed beamforming harmonization for the integration of satellite and Terrestrial networks, under Grant FNR16352790.

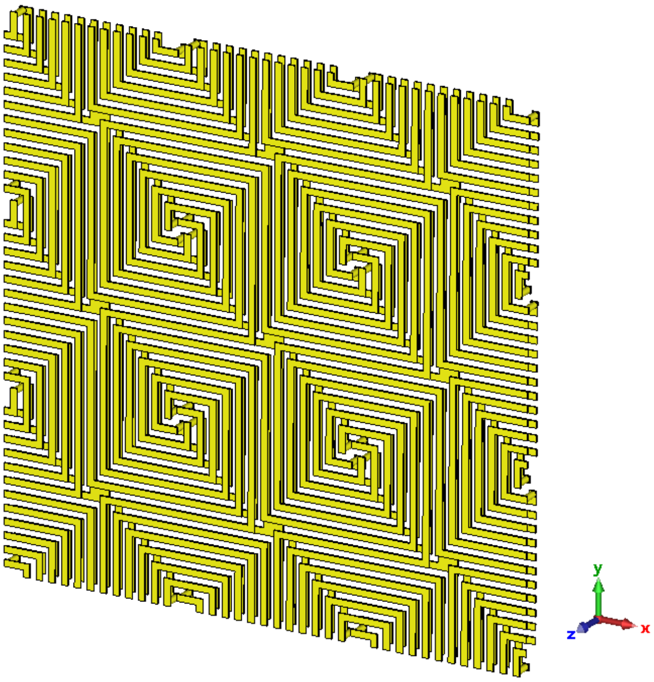

Fig. 1: 2.5D Inductive intertwined Brigid's cross with 6 intertwined stages.

interconnects the unit cells in the first layer. However, in the second layer, we used a capacitive structure, which has in its center a Brigid's cross, to interconnect the unit cells, as illustrated in Figure 2. Most intertwined structures found in the literature use a unit cell with a period $p = 10.8$ mm, arm width $w = 0.2$ mm, inter-arm space $s = 0.2$ mm, and no substrate; in this paper, we continue this scheme for a matter of fair comparison. The structure has 25 intertwined stages distributed in both layers, which are separated $t = 1$ mm.

III. Simulation Results

The simulated structure's results are based primarily on the TE- and TM-mode S-parameters using CST Microwave Studio, where the frequency domain solver is configured in the 0 - 2 GHz frequency range using a suitable meshing tolerance. By analyzing the S-parameters of the structure shown in Figure 3, we can locate the fundamental resonance frequency when the structure is operating as a pass-band at $f_{0_{BP}} = 0.2687$ GHz. This operational frequency gives a unit cell period of $p = 0.00967\lambda_0$ or, what is the same, a figure of merit $\lambda_0/p = 103.378$. This result shows the high miniaturization capabilities of the structure. The fractional bandwidth at the pass-band regime is $FBW_{BP} = 30.856\%$, which can be further improved by using substrates. A second pass-band is generated due to the current distribution ins the structure, and it is located at $f_{1_{BP}} = 1.717$ GHz, with a narrower fractional bandwidth compared to the first one.

If we consider the stop-band properties of the structure, we can see that for TE- and TM-mode, the central frequency, where the structure shows ground plane behavior, is located at $f_{0_{BS}} = 0.9214$ GHz, with a fractional bandwidth $FBW_{BS} = 73.15\%$. This three-band behavior allows the structure to have multiple applications, such as RCS, dichroic structures, and propagation control inside buildings, to name a few.

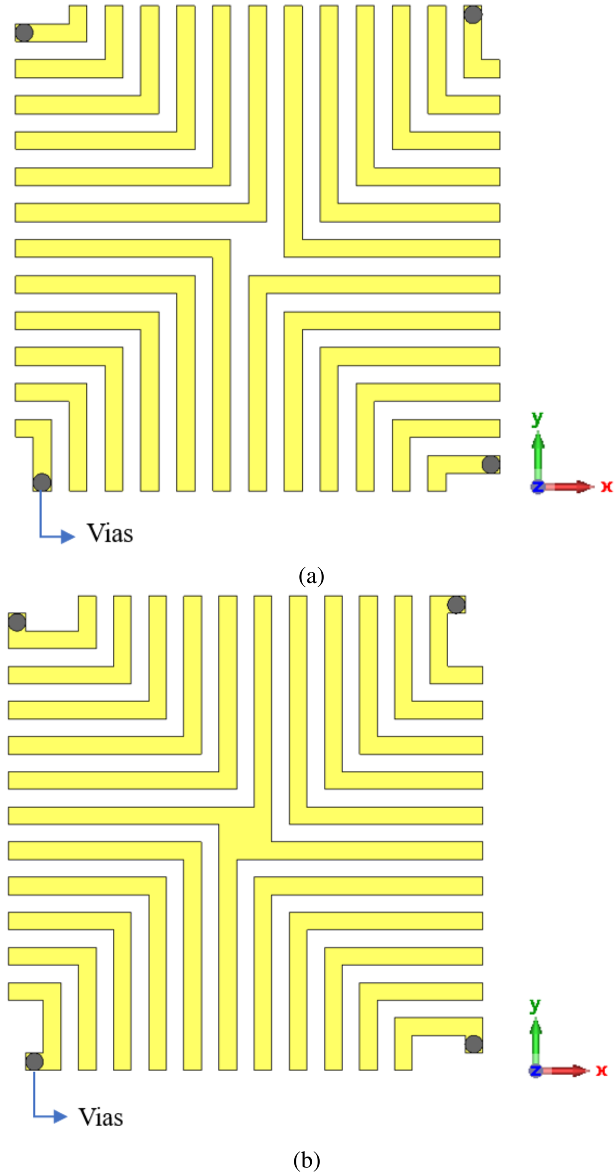

Fig. 2: 2.5D Inductive intertwined Brigid's cross (a) Top view; (b) Bottom view.

Acknowledgment

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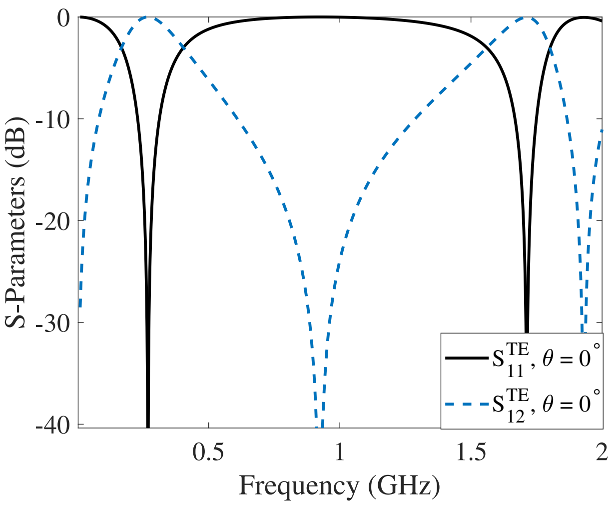
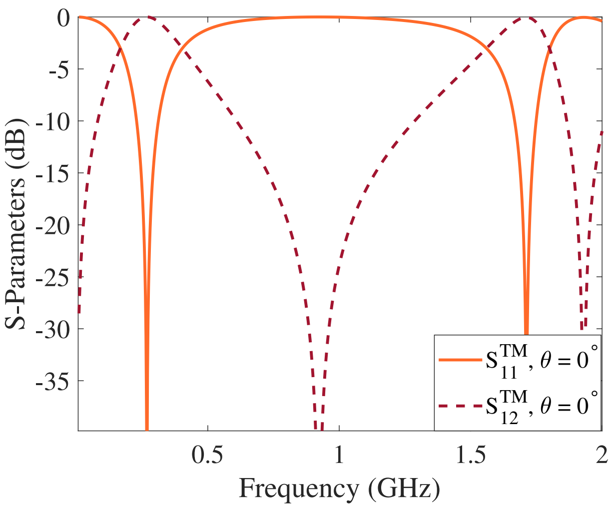
IV. Conclusions

This paper has described the design of an inductive intertwined pass-band structure in a 2.5D configuration. The structure allows high miniaturization by extending the surface current from the top layer to the bottom layer due to the



(a)



(b)

Fig. 3: S-Parameters of the proposed 2.5D Inductive intertwined Brigid's cross (a) S-Parameters in TE-Mode; (b) S-Parameters TM-Mode.

interconnection through vias. Furthermore, due to the first harmonic generated by the current distribution, the structure also presents wide-bandwidth in the stop-band frequency range. Finally, it is worth mentioning that this structure will have improved miniaturization and bandwidth enhancement by placing a substrate between layers, which has to be included in the manufacturing stage.

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