Three-dimensional Loaded Dipoles for Applications in Frequency Selective Structures

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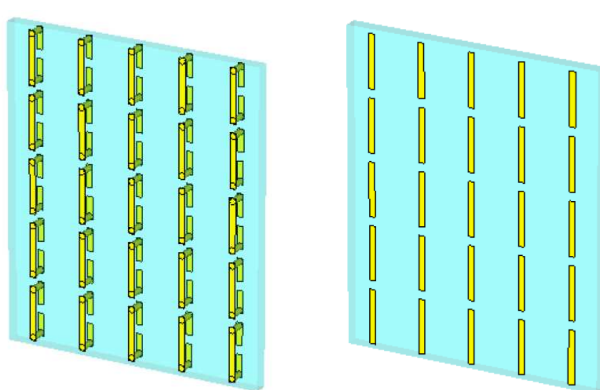
Abstract— A three-dimensional (3-D) frequency selective structure (FSS) is proposed, which consists of a two-dimensional (2-D) periodic arrays of loaded strip dipoles. These strip dipoles are loaded along the thickness of the FSS, which leads to certain advantages compared to the conventional 2-D loading. Unit-cell period is greatly reduced, and a relatively stable frequency response is achieved under even a large variation of the angle of incidence

1. INTRODUCTION

Conventional frequency selective surfaces consist of two-dimensional (2-D) unit-cell shapes like dipoles, loops, etc. [1, 2]. A number of variations to earlier simple shapes have been proposed over the last three decades, which lead to an advantage in certain applications [3–5]. This quest for finding the best shape continues till date, and more recently, a few three-dimensional unit-cell shapes have also been considered [6, 7]. Freedom of variation in third dimension actually offers more flexibility in designing innovative unit-cell geometries. It appears prudent to efficiently use the third dimension (thickness) of a frequency selective structure (FSS) in order to obtain improved performance of certain parameters. Based on that, it may be useful to reconsider the conventional FSS shapes, and modify them to utilize the freedom of third dimension. This may lead to better and interesting FSS designs, which may also be easy to analyze and fabricate with the present computational and manufacturing technology.

Dipole constitutes one of the earliest shapes used in FSS designs [1]. It has been a preferred choice for application in linearly polarized FSSs. A number of other FSS shapes have actually been derived from a dipole unit-cell, and they include loaded-dipoles [3], meander-lines [4], crossed-dipoles [8], Jerusalem cross [9], tri-poles [10], etc.. These modified forms basically lead to more compact shapes, which can also be applied in dual-polarized FSS.

We study an FSS consisting of a 2-D periodic array of strip dipoles, which have been loaded along the third dimension (thickness) of FSS. This scheme leads to a compact unit-cell geometry, which is actually desirable to improve the angular performance of an FSS [1, 2]. The proposed structure is easy to fabricate on a two-layer printed circuit board (PCB).



(a) (b)

Figure 1: (a) Conventional 2-D array of printed dipoles, (b) proposed array of three-dimensional loaded dipoles.

2. DESCRIPTION OF THE STRUCTURE

A perspective view of the proposed structure is shown in Fig. 1(a). A conventional FSS consisting of 2-D unloaded strip dipoles is also given as Fig. 1(b). Our proposed dipole consists of strips and two conducting cylinders. The two cylinders represent the two via-holes, which connect the opposite sides of a printed circuit board (PCB) where strips are printed. Fig. 2 shows detailed views of a unit-cell of this structure. Vertical period and horizontal periods are denoted by p_y and p_x, respectively. Length of the dipole as seen in the top view is represented by a. Width of the strips and the diameter of the via-hole are kept identical, and they are given by w. Strips are printed on a substrate of height d, dielectric constant ε_r. Gap between strips on the back side of the PCB is denoted by g.

The perspective view of a unit-cell (Fig. 2) shows a case of normal incidence when the incident electric field is parallel to the printed strip. However, we also study this structure under oblique incidence under both parallel (transverse electric) and perpendicular (transverse magnetic) polarizations, following the convention given in [1]. Based on that, the incident angle θ is defined with respect to the positive z-axis.

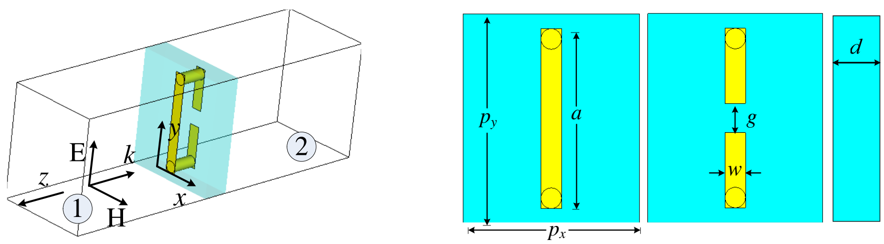


Figure 2: Different views of a unit-cell of the proposed structure.

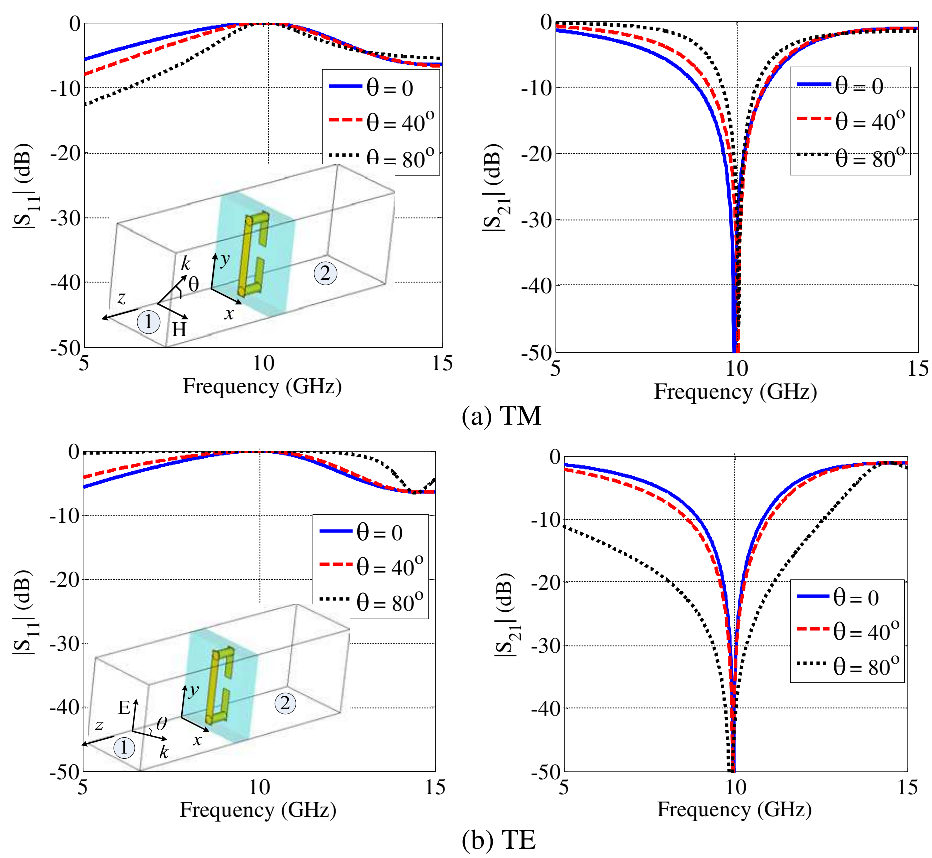


Figure 3: Scattering parameters of the proposed structure under oblique (a) TE and (b) TM incidence ($p_x = 6$ mm, $w = 0.7$ mm, $d = 1.6$ mm, $\varepsilon_r = 2.2$, $p_y = 7.1$ mm, $a = 6.1$ mm, $g = 1$ mm).

3. RESULTS

Figure 3 presents a design example of the proposed structure operating at 10 GHz. Horizontal and vertical periods are set as 6 mm and 7.1 mm, respectively. Since these periods are much smaller than the operating wavelength at 10 GHz, an excellent angular stability of scattering parameters is seen, as expected. For the purpose of fair comparison, we have designed another FSS based on conventional printed dipoles shown in Fig. 1(b). Results of this design example are given in Fig. 4. Horizontal periods of the two designs have been kept identical. Similarly, the gap between two adjacent shapes along the vertical direction ($p_y - a$) has also been set as the same for the two designs. Both are fabricated using on identical substrates. For resonance at 10 GHz, the vertical period of the conventional design turns out to be 14 mm, which is almost twice as large as that of the proposed three-dimensional dipole. For this reason, a relatively poor angular performance of the 2-D FSS is expected, and it is verified from the results of TM incidence shown in Fig. 4(a). Comparison of Fig. 3(a) and Fig. 4(a) is easily understandable from the theory of conventional frequency selective surfaces [1, 2].

Figures 3(b) and 4(b) show the scattering parameters response under TE incidence. It is again seen that the proposed 3-D structure performs superior to the conventional 2-D FSS. Based on these comparisons, it appears clear that 3-D dipole forms an attractive candidate for FSS applications, especially those where high degree of angular stability is required.

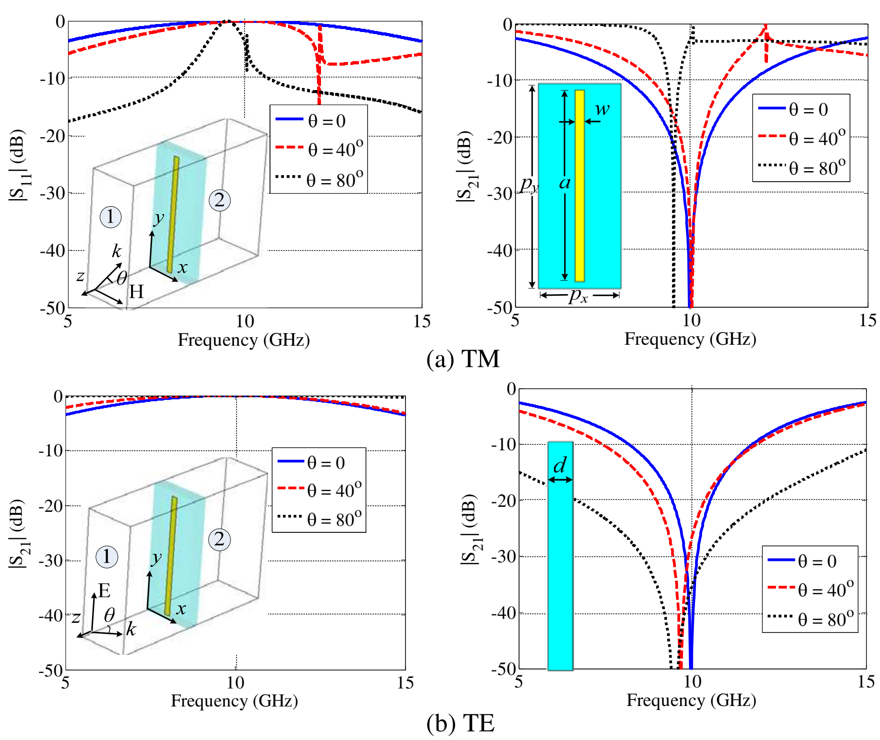


Figure 4: Scattering parameters of a conventional 2-D array of printed dipoles under (a) TM and (b) TE incidence ($p_x = 6$ mm, $w = 0.7$ mm, $d = 1.6$ mm, $\varepsilon_r = 2.2$, $p_y = 15$ mm, $a = 14$ mm).

4. CONCLUSIONS

A new 3-D FSS has been proposed, which consists of a 2-D periodic array of folded/loaded strip dipoles. The proposed structure exhibits stable frequency response even under a large variation of the angle of incidence. It is expected that this new 3-D FSS may find many useful practical applications, especially where 2-D strip dipoles were previously used.

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