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Comparison between Various Compact Electromagnetic Band-gap (EBG) Structures for Coupling Reduction in Antenna Arrays

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1. Introduction

Over the last few years, there has been an increasing research interest in electromagnetic band-gap (EBG) structures and their applications in microwave frequencies. The main property of EBG structures is suppression of surface wave propagation in a specific frequency band [1], [2]. This characteristic can lead to noticeable improvement in antenna's performance such as increasing the antenna efficiency and also reducing side lobes and back lobes in radiation pattern of the antenna [3]. Using compact EBG structures in antenna arrays can help to reduce the mutual coupling between elements [4], [5]. In this paper, three compact EBG structures are compared by calculating the transmission coefficient of a suspended strip line over EBG surfaces. The three structures are designed to have their band-gap centre at the same frequency and their bandwidths are compared. Also a parametric study for the spiral EBG structure is presented.

2. Electromagnetic Wave Suppression

One of the main problems of phase array antennas is the mutual coupling among elements due to excitation of surface waves in the structure. A compact EBG structure can be located between elements to block the propagation of electromagnetic waves in its band-gap region. To model this feature, we use a suspended strip line that is located over the EBG surface. This model is shown in Fig. 1a. The Method of Moment is used to simulate the structure (IE3D Package, Zeland Software). The S_{21} parameter is computed for the two input ports connected to the suspended strip line. For frequencies within the band-gap region, the EBG structure will block transmission of power along the strip line [4], [5]. Because of this feature, a noticeable reduction in S_{21} can be observed at a certain frequency band. The band-gap of the EBG structure is defined as the frequency region in which S_{21} is less than -10 dB. Fig. 1b illustrates S_{21} of a 3×3 ordinary mushroom-like EBG surface. Three compact forms of this structure are presented in the next section.

3. Compact EBG Surfaces

3.1 Fork-like EBG Surfaces

Fig. 2a shows one unit cell of a fork-like EBG lattice. As can be seen, each element of this EBG structure is made of a square patch with a slot etched on it and a stretched strip. Each patch is connected to the ground plane by a metal via. A 3×3 array of fork-like patches is built on a 2-mm-thick substrate with a relative permittivity of 2.7. The width of each square patch is 4 mm. Other parameters of the EBG structure are as follow:

$$S = 1 \text{ mm},\ L_p = 3 \text{ mm},\ D = 0.5 \text{ mm},\ L_s = 3 \text{ mm},\ G = 0.5 \text{ mm},\ W + G = 4.5 \text{ mm} \quad (1)$$

The 3×3 fork-like patch array is investigated using the suspended strip line method. Fig. 3a shows the transmission coefficient S_{21} of the structure. In this figure, a band-gap region can be seen with a

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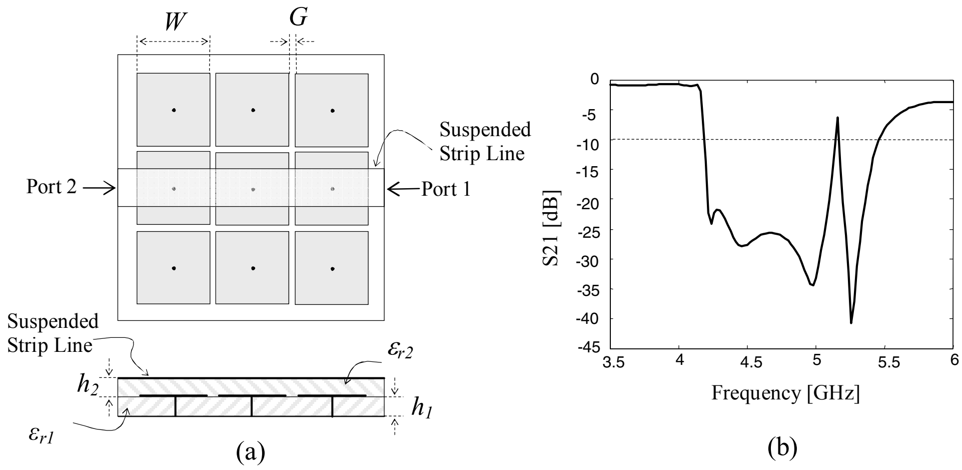


Figure 1: (a) Suspended Strip Line Model (b) Transmission Coefficient of a 3×3 Array of Mushroom-like EBG Surface (W = 4 mm, G = 0.5 mm).

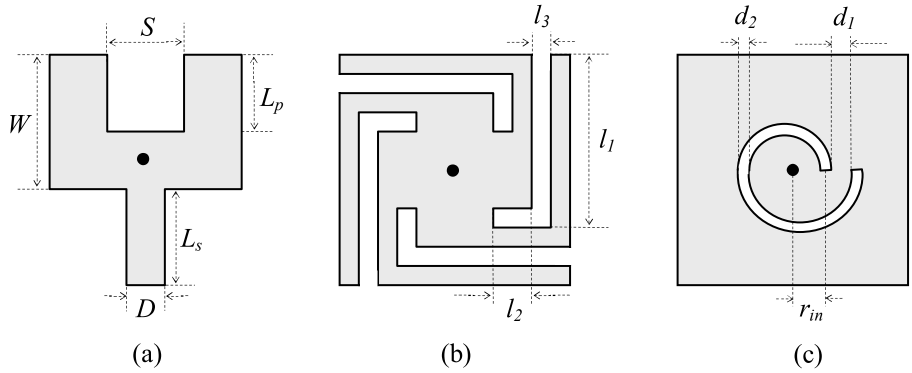


Figure 2: Compact EBG Surfaces: (a) Fork-like (b) Slotted patch (c) Circular Spiral.

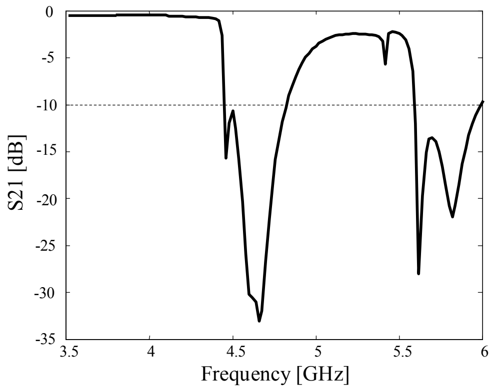
centre frequency of about 4.7 GHz and a bandwidth of 8.6%. In comparison with the mushroom-like EBG surface, this structure has 28.5% width reduction.

3.2 Slotted Patch EBG surfaces

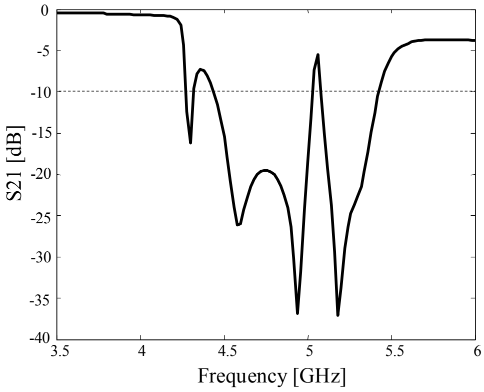
A unit cell of a slotted patch EBG surface is demonstrated in Fig. 2b. To design a compact EBG structure, four identical L-shape slots are cut on a square patch [6]. The width of each patch is the same as the previous compact design and is equal to 4 mm. Therefore, this design has the same width reduction, 28.5%, compared to the mushroom-like EBG structure. The width of slots is l_3 = 0.2 mm. The lengths of slots are selected in order to have band-gap with a centre frequency of about 4.7 GHz. This occurs if $l_1 + l_2$ = 4.2 mm. In this case, the bandwidth of band-gap region is equal to 12.5% which is more than the bandwidth of the fork-like EBG structure.

3.3 Circular Spiral EBG surfaces

A rectangular spiral patch EBG structure has been introduced in [5] and is demonstrated to be a compact EBG structure in comparison with ordinary mushroom-like EBG structures. In Fig. 2c, a circular spiral EBG structure has been depicted. This structure has the same substrate and patch width as the two previously investigated compact EBG structures. There is a spiral slot cut on each patch. The number of spiral turns, T = 0.75*,* is chosen in order to have the band-gap region with a centre frequency of about 4.7 GHz. For $r_{in} = d_1 = d_2$ = 0.2 mm, the transmission coefficient S_{21} of the structure is shown in Fig. 4. The bandwidth of this structure is equal to 19.7%.



(a)



(b)

Figure 3: (a) Transmission Coefficient of a 3×3 Array of Fork-like EBG Surface (b) Transmission Coefficient of a 3×3 Array of Slotted Patch EBG Surface.

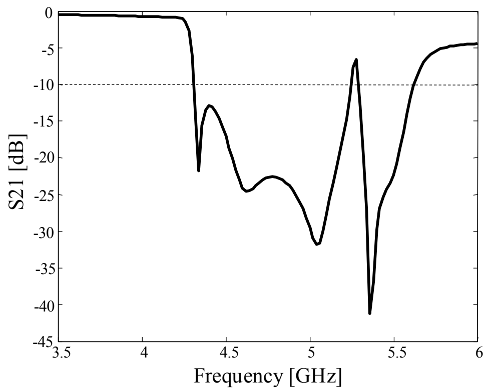


Figure 4: Transmission Coefficient of a 3×3 Array of Circular Spiral EBG Surface.

Table 1: Comparison between Four Different EBG Structures. $f_c \sim 4.7$ GHz.

EBG Structure	Lattice Constant	f_L [GHz]	f_H [GHz]	BW (%)
Square	6.3 mm	4.19	5.14	20.4
Fork-like	4.5 mm	4.42	4.82	8.6
Slotted	4.5 mm	4.44	5.03	12.5
Spiral	4.5 mm	4.31	5.25	19.7

Table 1 sum up four EBG structures with information about their lattice constants, band-gap frequency regions and fractional bandwidth. It is obvious that the circular spiral EBG structure has a better surface wave suppression characteristics than the other two compact EBG structures.

4. Parametric Study on Spiral EBG Structure

It is possible to decrease the centre frequency of band-gap region by cutting slots on the patches of the EBG structure. Reduction in the centre frequency usually is followed by reduction in the fractional bandwidth. In other words, it is possible to have more compact EBG structures but with the cost of lower bandwidth. In a circular spiral EBG structure shown in Fig. 2c, there are four parameters that can cause reduction in the centre frequency of the band-gap region. The major parameter that can control the centre frequency of the band-gap region is the number of spiral turns. In Table 2, the effect of this parameter on the centre frequency and fractional bandwidth of the structure is investigated. Increasing the number of spiral turns results in lower centre frequency and reduction in the bandwidth. Also, in Table 2, the effect of inner radius of spiral, r_{in}, is investigated. This parameter causes just a little change in the characteristics of the structure. Table 3 exhibits the effect of separation width, d_1, and slot width, d_2, on the centre frequency and bandwidth of the structure. In both cases, increasing the parameter results in reduction in centre frequency and bandwidth of the structure.

Table 2: Effects of Spiral parameters on the Centre Frequency of the Band-gap and Bandwidth of the Structure: (a) Number of Turns (b) Inner Radius of Spiral (c) Separation Width of the Spiral (d) Slot Width of the Spiral.

Spiral Turns (T)	f_c [GHz]	BW (%)
1	3.32	22.4
1.25	2.86	20.0
1.5	2.44	16.8
1.75	2.11	13.7

($r_{in} = d_1 = d_2 = 0.2$ mm)
(a)

Spiral inner Radius (r_{in})	f_c [GHz]	BW (%)
0.2 mm	3.32	22.4
0.4 mm	3.22	22.2
0.6 mm	3.14	21.4
0.8 mm	2.94	17.1

($d_1 = d_2 = 0.2$ mm, T = 1)
(b)
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Separation width (d_1)	f_c [GHz]	BW (%)
0.2 mm	2.86	20.0
0.4 mm	2.62	18.3
0.6 mm	2.53	17.0
0.8 mm	2.42	16.1

($r_{in} = d_2 = 0.2$ mm, T = 1.25)
(c)

Spiral Slot width (d_2)	f_c [GHz]	BW (%)
0.2 mm	2.86	20.0
0.4 mm	2.60	18.0
0.6 mm	2.49	16.8
0.8 mm	2.37	15.9

($r_{in} = d_1 = 0.2$ mm, T = 1.25)
(d)

5. Conclusions

In this paper, three different compact EBG structures, i.e. fork-like, slotted patch and circular spiral, are compared. It is shown that for a specific patch width and specific band-gap centre frequency, the circular spiral EBG structure has largest bandwidth. The circular spiral EBG structure has been investigated for different values of its parameters. Noticeable decrease in the centre frequency of the band-gap region can be achieved by increasing the number of spiral turns.

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