Progress In Electromagnetics Research, PIER 83, 323–333, 2008

COMPACT AND WIDEBAND 1-D MUSHROOM-LIKE EBG FILTERS

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Abstract—A new wideband and compact bandstop filter using one dimensional (1-D) mushroom-like electromagnetic bandgap (EBG) structures is proposed in this paper. Although the proposed structure can not be fabricated as easy as defected ground structure (DGS) filters, it has several winning features such as more compactness, better characteristics and no backward radiation. A 5-cell 1-D mushroom-like EBG filter is compared with 5-cell and 9-cell circular DGS filters. The 1-D mushroom-like EBG filter is found to be more compact as it requires fewer cells for the same characteristics and also as it has 0.44 times shorter cell length. The proposed EBG filter has a 10-dB bandwidth of 39% while the 5-cell and 9-cell DGS filters have 10-dB bandwidth of 20% and 27%, respectively. Also, the 1-D mushroom-like EBG filter is studied for various number of cells and compared with a two dimensional (2-D) structure. The simulated and measured results are found to be in good agreement.

1. INTRODUCTION

Electromagnetic bandgap (EBG) structures are periodic structures that prohibit the propagation of electromagnetic waves at certain frequencies [1–3]. Because of their novel electromagnetic properties, EBG structures have been used in various applications in microwave, antenna, and propagation fields [4–8]. An array of metal protrusions on a flat metal sheet which are connected to the ground plane by metal vias is shown to have EBG properties [1, 2]. The structure can be visualized as a mushroom EBG structure. Mushroom-like EBG structures have been integrated with microstrip antennas to enhance performance by suppression of surface waves [9, 10]. Also, there has been an increasing interest in designing compact mushroom-like EBG structures [11, 12]. In antenna arrays, the distance between adjacent antennas is limited and only a compact EBG wall can be located between them [13]. Due to the electromagnetic bandgap properties, mushroom-like EBG structures can also be used in filter design.

A major method for designing filters is using defected ground structures (DGS) which can be categorized as a kind of EBG structures [14, 15]. DGS filters have attracted a lot of attention in recent years. These structures are widely used for filter design due to their wide stopband with high attenuation. DGS filters are planar structures with periodic patches etched in the ground plane. A microstrip line with such a ground plane exhibits a bandgap in the transmission characteristics when the Bragg condition is satisfied [16]. Comparison between 1-D and 2-D DGS filters shows similar characteristics due to high confinement of fields near the transmission line [17]. Various methods such as using modulated microstrip line in DGS filters are proposed to achieve ultrawide stopband compact filters with high attenuation [18]. Applications of DGS structures are not limited to filter design and these structures can be used in other microwave circuit design such as couplers [19].

As previously mentioned, mushroom-like EBG structures can be used in filter design due to the electromagnetic bandgap feature. In this paper, a 1-D mushroom-like EBG structure is located under a microstrip line and is shown to have high attenuation in its wide stopband and low attenuation in its passband. This filter is then compared with its equivalent DGS filters. For this purpose, a 5-cell mushroom-like EBG structure is designed to have the same bandgap frequency region as a 5-cell and a 9-cell DGS filter. Simulation results show that the mushroom-like EBG filter in comparison with DGS filters is more compact and has wider bandstop. Then, a 1-D EBG filter is studied for various cell numbers. Finally, filtering characteristics of a 1-D EBG filter vs. a 2-D EBG filter is investigated.

2. DGS AND MUSHROOM-LIKE EBG FILTERS

2.1. DGS Filters

Figure 1(a) shows the 3D view of a DGS microstrip filter. As can be seen, a straight microstrip line is located above a substrate with

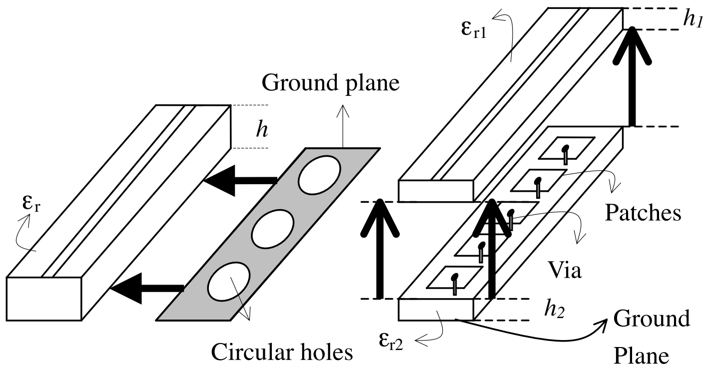


Figure 1. (a) DGS filter with circular holes in the ground (b) 1-D mushroom-like EBG filter.

circular holes in the ground plane. The substrate has a relative permittivity of ε_r and a thickness of h. The width of the microstrip line is $w_{m,DGS}$. In this structure, coupling between the microstrip line and the ground plane is reduced due to the circular holes in the ground plane. When the Bragg condition is satisfied [16], the 1-D planar DGS structure exhibits a bandgap. Period of the structure, a, is defined as the distance between the centers of two adjacent circular holes. Regarding the Bragg condition, the period a should be half of the guided wavelength (λ_g). The radius of circular holes is represented by r. It has been shown that in a planar DGS filter with circular holes and uniform distribution, the large filling ratio (r/a) introduces wide and deep bandstop but also enhances the ripples in the passband. The optimal value for the ratio (r/a) is 0.25 [16].

2.2. 1-D Mushroom-like EBG Filters

The 3D view of a 1-D mushroom-like EBG filter is shown in Fig. 1(b). In this structure, a straight microstrip line is located above a mushroom-like EBG structure with rectangular patches. The upper and lower substrates have dielectric constants with relative permittivity of ε_{r1} and ε_{r2} and thicknesses of h_1 and h_2, respectively. The width of microstrip line is represented by $w_{m,EBG}$. The patches in mushroom-like EBG structure have a width of w and are connected to the ground plane with vias with radius of r_{via}. The width of gap between two adjacent patches is g.

In this structure, the propagating power along the transmission line is coupled to the EBG patches and is suppressed because of electromagnetic bandgap property of the mushroom-like EBG structure.

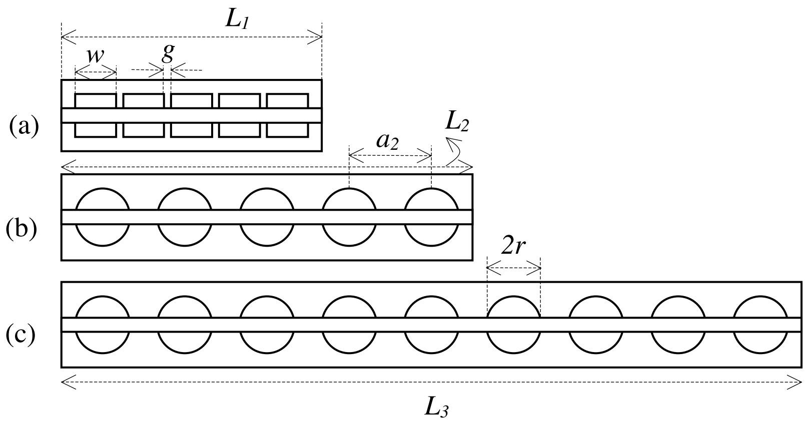
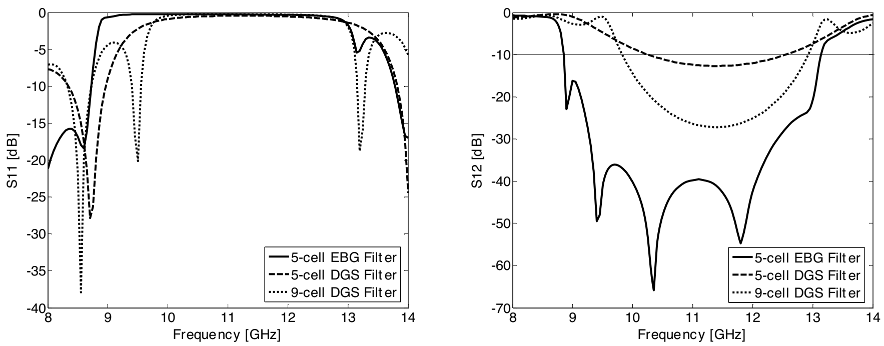


Figure 2. Top view of (a) 5-cell 1-D mushroom-like EBG filter (b) 5-cell circular DGS filter (c) 9-cell circular DGS filter.

3. COMPARISON BETWEEN MUSHROOM-LIKE EBG AND DGS FILTERS

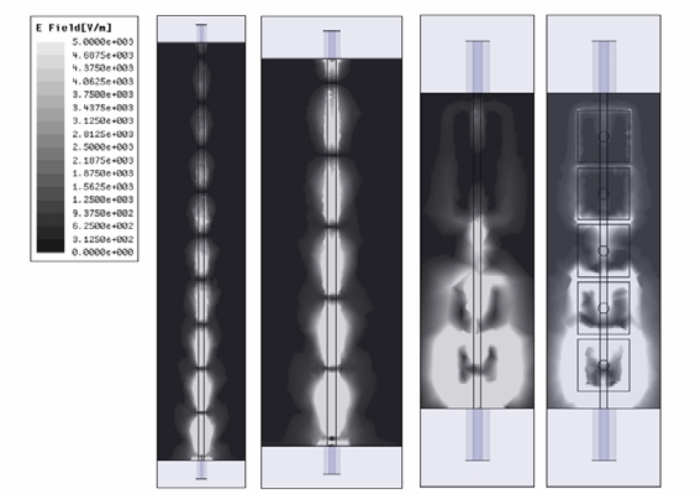
In this section, the proposed 1-D 5-cell mushroom-like EBG filter is compared with 5-cell and 9-cell circular DGS filters. Fig. 2 shows the top view of the three filters. In Fig. 2(a), the patch width is $w = 2\,\text{mm}$ and the gap between two adjacent patches is $g = 0.2\,\text{mm}$. The period of this structure is $a_1 = w + g$ and the total filter length, without considering the required space for input and output connections, is $L_1 = 5a_1$. Other parameters of this filter are $\varepsilon_{r1} = \varepsilon_{r2} = 10.2$, $h_1 = 0.254\,\text{mm}$, $h_2 = 0.381\,\text{mm}$, $w_{m,EBG} = 0.25\,\text{mm}$, and $r_{via} = 0.2\,\text{mm}$.

Figure 2(b) shows the 5-cell DGS filter with a period of $a_2 = 5\,\text{mm}$ and a filling ratio of $r/a_2 = 0.25$. The total length of this filter is $L_2 = 5a_2$. The substrate has a dielectric constant of $\varepsilon_r = 10.2$ and a thickness of $h = 0.635\,\text{mm}$. The width of the microstrip line is $w_{m,DGS} = 0.6\,\text{mm}$. Fig. 2(c) shows a 9-cell DGS filter with a period of $a_3 = a_2 = 5\,\text{mm}$ and the same filling factor of $r/a_3 = 0.25$. Total length of this filter is $L_3 = 9a_3$. The 9-cell DGS filter has the same substrate and microstrip line as the 5-cell DGS filter.



(a) (b)

Figure 3. (a) S_{11} and (b) S_{12} parameters of the 1-D 5-cell mushroom-like EBG filter in comparison with 5-cell and 9-cell DGS filters.



(a) (b) (c) (d)

Figure 4. Magnitude of electrical field on the top surface of (a) 9-cell DGS filter (b) 5-cell DGS filter (c) 5-cell mushroom-like EBG filter (d) 5-cell mushroom-like EBG filter on the EBG plane. The scaling factors for (a)–(d) are not the same. $f = (12\,\text{GHz})$.

The three filters are implemented and simulated using the Ansoft HFSS software. The reflection (S_{11}) and transmission (S_{12}) of all three filters are plotted in Fig. 3. As can be seen, the 5-cell Mushroom-like EBG filter has better characteristic in comparison with the DGS filters as its bandstop region is wider and deeper. Table 1 summarizes various characteristics of the three filters. As shown in this table, the mushroom-like EBG filter has better characteristics while its unit cells are 0.44 times more compact than unit cells of the other two filters. Another advantage of the proposed filter is that it requires fewer cells as can be seen in Fig. 4. Figs. 4(a)–(c) illustrate the electric field distribution on the top surface of the three filters and Fig. 4(d) demonstrates the electric field distribution on the middle surface of the EBG filter. It is obvious that filtering in EBG structure is mainly occurred in the first and the second cells while in DGS filters the propagation is suppressed through all cells. Also, it should be noted that etching holes in the ground plane of DGS structures degrades the isolation characteristic of the ground plane, while EBG structures have no backward radiation.

Table 1. Comparison between the proposed 1-D mushroom-like EBG filter and the 5-cell and the 9-cell circular DGS filters.

	EBG Filter $n = 5$	DGS Filter $n = 5$	DGS Filter $n = 9$
Period of structure	2.2 mm	5 mm	5 mm
Total length	12.1 mm	27.5 mm	47.5 mm
10 dB S_{12} BW	39%	20%	27%
Cutoff freq.	8.84 GHz	10.24 GHz	9.82 GHz

4. STUDY OF A 1-D MUSHROOM-LIKE EBG FILTER WITH VARIOUS NUMBER OF CELLS

In this section, we investigate the filtering characteristics of a mushroom-like EBG filter when different number of cells is used. As shown before, this filter requires fewer cells in comparison with circular DGS filters. Fig. 5 shows the top view of four 1-D mushroom-like EBG filters with 2, 3, 4, and 5 cells. Fig. 6 exhibits the S_{11} and S_{12} parameters of the four filters. As anticipated, decreasing the number of cells would result in losing the wide and deep stopband. Table 2 presents the comparison of the four 1-D mushroom-like EBG filters.

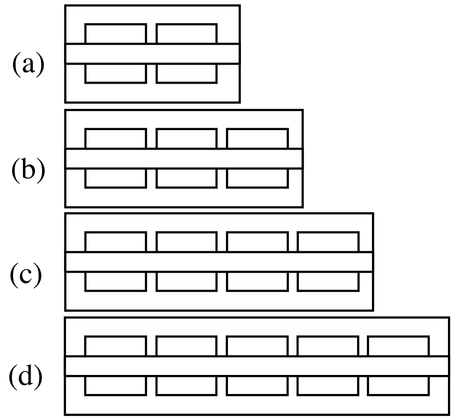


Figure 5. Top view of (a) 2-cell, (b) 3-cell, (c) 4-cell, and (d) 5-cell 1-D mushroom-like EBG filters.

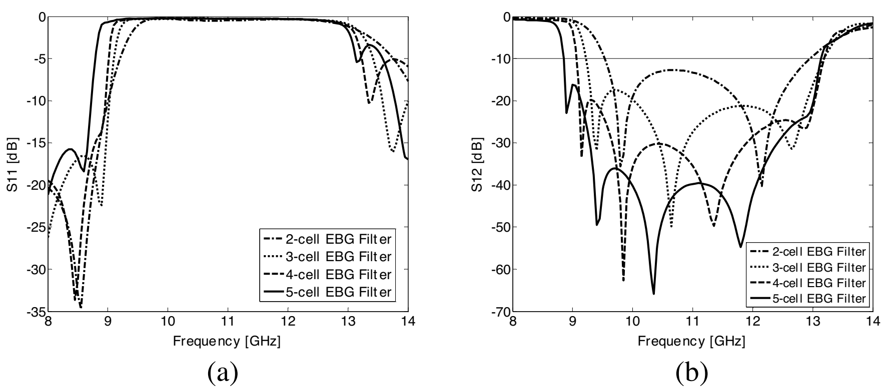


Figure 6. (a) S_{11} and (b) S_{12} parameters of the 1-D EBG filter for various number of EBG cells.

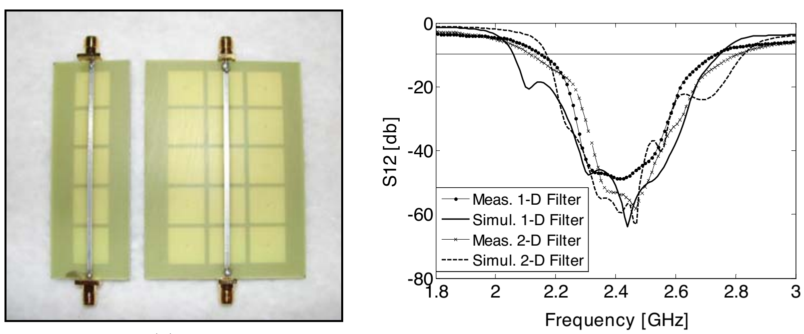
5. 1-D VS. 2-D MUSHROOM-LIKE EBG FILTERS

In this section, a 1-D mushroom-like EBG filter is compared with a 2-D mushroom-like EBG structure. Also, the two filters are fabricated and their transmission characteristics are measured. For sake of easy fabrication and measurement, the parameters of the 1-D mushroom-like EBG structure are considered as $\varepsilon_{r1} = \varepsilon_{r2} = 4.4$, $\tan\delta = 0.02$, $h_1 = h_2 = 1\,\text{mm}$, $w_{m,EBG} = 1.9\,\text{mm}$, and $r_{via} = 0.5\,\text{mm}$.

The 2-D mushroom-like EBG filter has the same parameters as the 1-D case but it consists of a 3×5 array of patches and

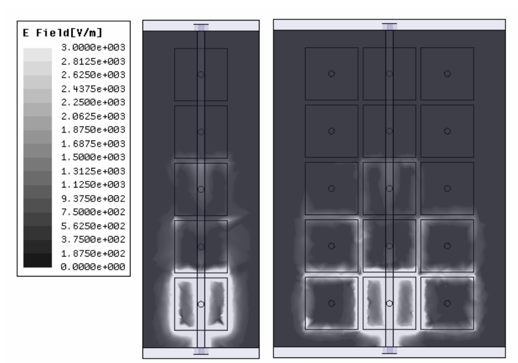
Table 2. Comparison between the 1-D mushroom-like EBG filters with different number of cells.

	2-cell	3-cell	4-cell	5-cell
Period of structure	2.2 mm	2.2 mm	2.2 mm	2.2 mm
Total length	5.5 mm	7.7 mm	9.9 mm	12.1 mm
10 dB S_{12} BW	31%	35.5%	37.4%	39%
Cut off freq.	9.52 GHz	9.22 GHz	9.03 GHz	8.84 GHz



(a) (b)

Figure 7. (a) Fabricated 1-D and 2-D mushroom-like EBG filters (b) Measured and simulated S_{12} parameters of 1-D and 2-D EBG filters.



(a) (b)

Figure 8. Magnitude of the electric field on the EBG surface for (a) 1-D mushroom-like EBG filter and (b) 2-D mushroom-like EBG filter ($f = 2.4$ GHz).

vias. Fig. 7(a) exhibits the fabricated structures. The simulated and measured S_{12} parameters of the 1-D and 2-D mushroom-like EBG filters are illustrated in Fig. 7(b). As can be seen, the transmission characteristic of the 1-D mushroom-like EBG structure is similar to that of the 2-D EBG filter. The filtering characteristic of both 1-D and 2-D EBG filters can be visualized by the electric field distribution of the two filters in Fig. 8. Also, it can be observed from Fig. 7(b) that simulated results are in good agreement with measurements.

6. CONCLUSION

In this paper, a new 1-D mushroom-like EBG filter is proposed and compared with DGS filters. It is observed that the proposed EBG filter is ultra compact as it requires fewer number of EBG cells and also as it has more compact cells. As shown in the paper, a wide and deep stopband can be obtained using this filter. In addition, the proposed structure has an isolating ground as no holes are etched in the ground plane. Different number of cells is investigated for a 1-D mushroom-like EBG filter. It is shown that with the cost of losing wide and deep bandstop, it is possible to have more compact EBG filters by reducing number of cells. Also, a 1-D EBG filter is compared with a 2-D EBG filter and it is shown that the compact 1-D EBG structure and the 2-D one has similar characteristics. For both the 1-D and 2-D EBG filters, the simulated results are in good agreement with the measurements.

ACKNOWLEDGMENT

The authors acknowledge the support of the Iran Telecommunication Research Center (ITRC).

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