Design of a Multi-Bandpass Filter using Slit-top Mushroom-Like Electromagnetic Band Gap Structures

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Abstract

A multi-bandpass filter using the slit-top mushroom-like on two-layer structure of electromagnetic band gap (EBG) and transmission line is proposed in this paper. The challenge is to design an EBG structure providing variety of bandwidths of the multi-bandpass filter. The proposed structure of filter in this paper is composed of the four units of slit-top mushroom-like EBG, which are cascaded to yield the multi-bandpass characteristic. The differences of dimension and number of slit-tops truncating on the surface of mushroom-like EBG units that influence to the resonant frequency and bandwidth of filter have been shown and compared to the conventional mushroom-like EBG unit. Afterwards, the appropriate slit-top on the classical mushroom-like patches of EBG structure has been considered for the proposed multi-bandpass filter. Finally, the simulated and measured results for transmission characteristics, S21, are investigated to be in good agreement.

Keywords- EBG structure mushroom-like EBG multi-bandpass filter slit-top

1. Introduction

Recently, the electromagnetic band gap (EBG) structures have become one of the most interesting areas of research. The EBG structure has been designed to prevent or enhance the propagation of the electromagnetic wave at a specified band of frequency. The design procedure of the band gap consists of the design of unit cells, which is assigned to characterize a transmission curve, occurred in the required band gap [1]. The general structures of EBG are periodical cells composed of metallic or dielectric elements. However, one of the most important properties of EBG structure is to prohibit the propagation of surface wave [2]. The practical applications of EBG structure usually have the difficulty in accommodating its physical size, because the period of EBG lattices has to be a half-wavelength at the band-gap frequency. This problem had not been solved until the mushroom-like EBG was proposed by Sievenpiper et al. [3]. Later, several novel EBG structures were presented such as uniplanar compact EBG (UC-EBG) [4] and fork-like EBG [5]. These presented structures have several advantages, such as compact size, low loss, and low cost. Moreover, R.Coccioli et al. [6] proposed the filter, which are designed and integrated with an antenna to enhance the gain and reduce the backward radiation by suppressing surface wave and improving efficiency. The challenge is how to produce an EBG structure for providing the desired bandwidth of the multi-bandpass filter.

In this paper, first, the two-layer EBG structure for unit cell based on classical microstrip design and transmission line method will be theoretical presented. Afterwards, the influence of dimension and position of a slit-top truncated on the microstrip patch has been described. When these parameters are found, four elements of one slit-top mushroom-like patch will be cascaded horizontally to form the multi-bandpass filter. In addition, four cascaded elements of two and three slits-top on the same microstrip patches have also been investigated to compare with the first one and the conventional mushroom-like EBG unit and to meet requirement of the proposed multi-bandpass filter. The simulation results by using CST software will show the curves of transmission characteristics, S21, of the filter: multi-band width, stop-band width and pass-band width, which can be improved by varying the number and dimension of slit-top on the microstrip patches. Finally, the experimental results of such filter are measured and validated to the simulation results.

2. Two-Layer EBG Structure Cell Based on Microstrip Design and Transmission Line Method

The mushroom-like EBG structure behaves as a network of parallel resonant LC circuit, which acts as a network of a two-dimensional electric filter to block the flow of current along the sheet. It consists of a lattice of metal patches, connected to a solid metal sheet by vertical conducting vias. While interacting with electromagnetic waves, the electric charges are built up between ends of adjacent patch and the sheet between the top and bottom plate, which can be considered as a capacitance. At the same time, the current flows around the path through the vias and the bottom plate, which results in inductive effect.

As shown in Fig. 1, the equivalent circuit agrees well with the full wave simulation results. Using this equivalent circuit the impedance can be calculated as [7]

$$Z = \frac{1-\omega^2 L_1 (C_1 + C_2)}{j\omega C_1 \left(1-\omega^2 L_1 C_2\right)} \quad . \qquad (1)$$

It can be deduced from (1) that Z becomes zero when frequency is

$$f_1 = \frac{1}{2\pi \sqrt{L_1 (C_1 + C_2)}} \, . \qquad (2)$$

Thus, a short circuit between the microstrip line and the ground has been created. On the other hand Z becomes infinite when frequency [8], [9]

$$f_2 = \frac{1}{2\pi \sqrt{L_1 C_2}} \quad . \qquad (3)$$

3. Effect of Slit-Top Patch

The parameters of the slit-top patch on two-layer compact electromagnetic band gap structure are labeled in Fig. 2 (a) as patch width (w), gap width (g), substrate thickness (h), vias radius (r) dielectric constant (ε_r), length of the slit (l_s), width of the slit (w_s) and distance of the slit to edge (d_s). The slit-top patch is a very important parameter on the band-gap, which affects the equivalent capacitance of the LC resonant circuit of the EBG structure. When the capacitance ratios are decreased, the two resonant frequencies move closer to each other. The change in capacitance ratios can be achieved simply by moving the slit to another position relative to the edge of the top grounded pad by changing d_s. This technique can be used for tuning the band-gap position; furthermore, by combining EBG units with the slits at different positions the band-gap can be enlarged slightly [10].

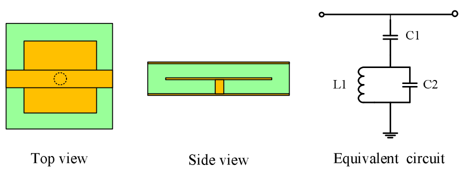


Figure 1. A mushroom like EBG coupled to a microstrip line

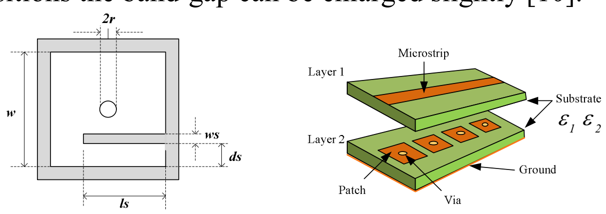
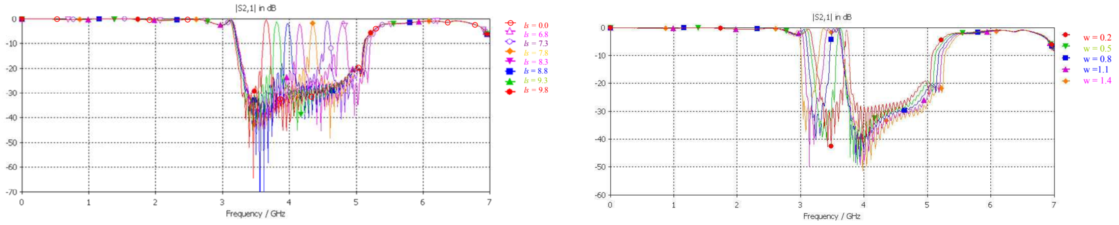


Figure 2. Model of slit-top patch on two-layer compact electromagnetic band gap structure

Figure 3 (a) shows the simulated results for the transmission performance of the band-gap when its width (w_s) is kept constant and the length of the slit (l_s) is varied. The capacitance ratio is varied as well as the values of L and C of the slit. As the length of the slit is reduced, the values of L and C decrease, which is assigned to characterize the transmission curve, occurred in the required band gap. First, the value of w_s is fixed while the value of l_s is varied to study the proper slit length for multi-passband filter. It is noted that, when l_s is shorter than the minimum value at around 6.8 mm (l_s=0 is in case of the conventional mushroom-like EGB structure), the EGB structure loses dual band characteristic because of the second resonance does not occur in the band gap. Besides, we found that the length of l_s *is* related to the position of the second resonant frequency. In Figure 3 (b), the effect of slit width for tuning the width of band gap has been considered by varying w_s from 0.2 mm to 1.4 mm while its length (l_s) is fixed at 0.9 mm. It is found that the bandwidth of passband filter will be increased if the width of slit is enlarged. These properties can be exploited in the design for array of slit-EBG structure to enlarge the band-gap response.

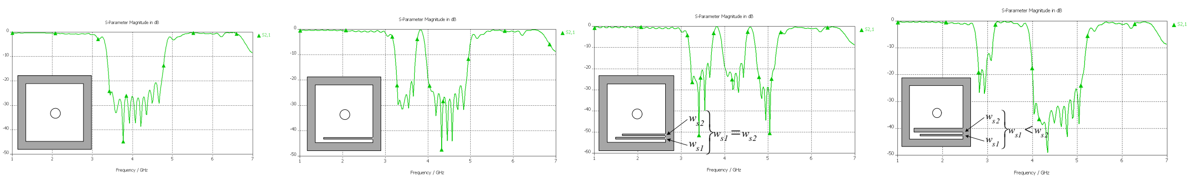


(a) (b)

Figure 3. Transmission curves for tuning the band-gap: w = 10 mm, g = 1 mm, $h_1 = h_2$ = 1.6 mm, r = 1 mm, ε_1 = 2.64, ε_2 = 4.4, (a) l_s is varied from 6.8 to 9.0 mm (d_s=0.5mm, w_s=0.2 mm), (b) w_s is varied from 0.2 to 1.4 mm (l_s=9.0 mm, d_s=0.5 mm)

4. Analysis on Transmission Coefficients of Compact Multi-Band High-Impedance EBG Structure

In this section, the transmission coefficients of three different types of slit-top mushroom-like EBG structures are compared to the transmission coefficients of the conventional mushroom-like EBG structure. The normal parameters of microstrip patches for two-layer compact electromagnetic band gap structure are given as follows: w = 10 mm, g = 1 mm, $h_1 = h_2$ = 1.6 mm, r = 1 mm, ε_1 = 2.64 , ε_2 = 4.4. While the dimension of slit-top, l_s and w_s are varied, d_s is neglected, and number of slit-top patches for cascading is four elements. Figure 4 (a) shows that the transmission coefficient (S21) of the classical mushroom-like EBG structure has a single stop band. There is a band-gap between the frequencies 3.42 GHz to 4.75 GHz with the criteria of –20dB, in which the electromagnetic wave cannot be propagated. In Figure 4 (b), the mushroom-like patches with one slit-top provide the dual band of 3.28 GHz to 3.75 GHz and 4.00 GHz to 4.92 GHz, which perform the characteristic of dual bandpass filter. Figure 4 (c) shows the characteristic of two slit-top patches. It is noted that l_s is longer than l_s in case of one slit-top patches while the width of w_s must not be different to produce more than one passband. The case of Fig 4 (d) is the design of the two slit-top patches (l_s) and $w_{s1} < w_{s2}$, to widen the bandwidth of the transmission coefficients of passband that has bandwidth of 756 MHz.

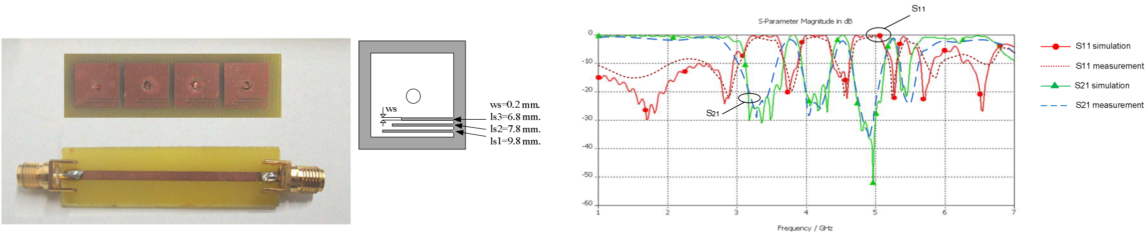


(a) (b) (c) (d)

Figure 4. Transmission coefficients (S21) of mushroom-like patches: (a) conventional patch (b) one slit-top patch (c) two slits-top patch when $w_{s1} = w_{s2}$ (d) two slits-top patch when $w_{s1} < w_{s2}$

5. Design and Experimental Results

In order to improve each bandwidth of multi-passband filter, the third slit-top has been added on the surface of mushroom-like patches as shown in Fig. 5 (a). The design parameters of this filter are given as follows: w = 10 mm, g = 1 mm, $h_1 = h_2$ = 1.6 mm, r = 1 mm, ε_1 = 2.64 , ε_2 = 4.4, l_{s1} = 9.8 mm, l_{s2} = 7.8 mm, l_{s3} = 6.8 mm and w_s =0.2 mm. The width and length of microstrip line on layer1 is 2 mm and 48 mm, respectively. The simulated and measured S21 parameters of three slits-top mushroom-like EBG filter are illustrated in Fig.5 (b). As can be seen, the bandwidths of three pass bands are 250 MHz (at -10 dB), approximately, at 3.800 GHz, 4.525 GHz, and 5.280 GHz, respectively. Also, it can be observed from Fig.5 (b) that simulated results are in good agreement with measurements.



(a) (b)

Figure 5. (a) A photograph of the fabricated multi-bandpass filter and (b) comparison of simulated and measured *S*21 parameters of the proposed multi-bandpass filter

6. Conclusion

This paper proposed a slit-top mushroom-like unit for two-layer EBG structure used in multi-band operation of filter. The main idea is that this structure utilizes the resonator coupled to the microstrip to provide a distinguished bandgap property. We have also investigated the structure and discussed the influences of the tunable geometric parameters on its resonant characteristics. Based on the structure simulation and equivalent circuit, some useful design examples are developed. The proposed structure and its equivalent circuit provide a new idea for designing the microwave devices, such as filters, diplexer, and other passive circuits. However, the results from this research can be modified to the other desired frequency bands. Furthermore, if this slit-top mushroom-like unit is cascaded with other mushroom-like unit, which is assigned to the required band gap (stop band) and pass band, it has a potential application in multiplexer or demultiplexer circuits.

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