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# A NOVEL DESIGN APPROACH FOR DUAL-BAND ELECTROMAGNETIC BAND-GAP STRUCTURE

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**Abstract**—A novel compact dual-band electromagnetic band-gap (EBG) structure is proposed in this paper. The major contribution to this dual-band design is using cascaded mushroom-like units which operate at different frequencies. The position of via is moved off the center of the metal patch to get a lower resonant frequency and the effects of the radius of via are considered at the same time. The method of suspended microstrip is utilized to measure the band-gap characteristics of the EBG structures. Several dual-band EBG structures are designed and compared. Results show that this novel cascaded structure offers additional flexibility in controlling the frequencies of the stopband over a wide range. The cascaded dual-band EBG structure has potential application to dual-band antenna and circuit.

## 1. INTRODUCTION

In recent years, there has been a growing interest on investigating electromagnetic band-gap structures, and various kinds of EBG structures have been suggested at microwave frequencies for applications in the electromagnetic and antenna community [1, 26]. EBG structures are periodic structures which can suppress the propagation of electromagnetic waves in particular frequency bands. The mushroom-like EBG structure with square patches connected to a dielectric substrate ground by vertical posts or metal-plated via was first developed by Sievenpiper in 1999 [1]. The physical mechanism of the mushroom-like EBG structure can be simply explained from the viewpoint of an LC parallel resonant circuit. Then some new techniques, which were mostly to increase the inductance or capacitance, were utilized to improve the characteristics of EBG structures [2–10].

With the growing interest in designing multi-antennas in wireless communications system, the investigations on compact and multi-band EBG structure has been attractive to many researchers [19–30]. In [11], a rabbet EBG structure which consists of concave and convex patches with insert spiral braches was introduced and analyzed. A multi-band structure by utilizing for S-shaped corrugated arms or spiral arms connected to the edge of a square patch was presented in [12] and a dual-band 1-D EBG was analyzed in [13]. Recently, cascaded structure with different radius of via was presented to enlarge the bandwidth of the stopband [14].

In this article, two kinds of mushroom-like EBG unit are cascaded to form a novel dual-band structure. The effects of the position of via on the unit resonant frequency are discussed with the method of suspended microstrip [15, 16]. Furthermore, the radius of via is important to take effect on the band-gap. The resonant frequency is decreased when the position of via is moved off the center of patch or the radius of via is reduced. Several new EBG structures with 10 elements are proposed and compared. A unique feature of the proposed structure is the realization of tuning two stopband positions without changing the size of the EBG patch unit. By adjusting the position and radius of via simultaneously, the stopband frequency can be tuned easily over a wide range.

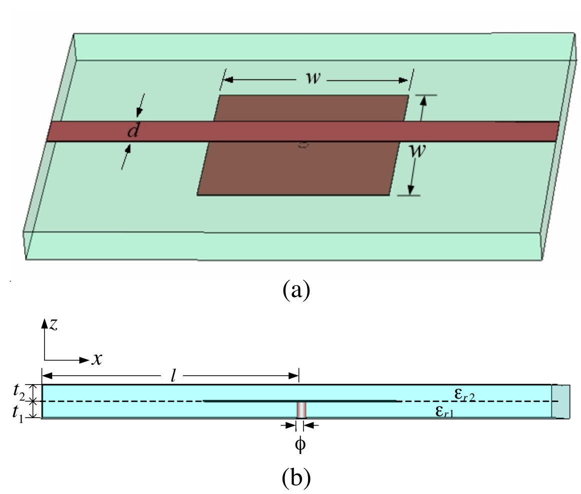


**Figure 1.** Geometry of suspended microstrip over an EBG unit. (a) 3D view. (b) side view.

## 2. UNIT MODEL AND EQUIVALENT CIRCUIT

To analyze the band-gap characteristic of EBG structure with finite unit number, the method of suspended microstrip is utilized. Geometry of the suspended microstrip line over a mushroom EBG cell is shown in Fig. 1. The EBG structure is designed on a substrate with relative permittivity $\varepsilon_{r1} = 7.5$ and height $t_1 = 0.25\,\text{mm}$. The edge length of the square patch is $w = 3\,\text{mm}$. The center of the pad is connected to the ground plane by a thin metal via with a diameter of $\phi = 0.15\,\text{mm}$. The distance between the microstrip line and the metal patch of EBG is $t_2 = 0.25\,\text{mm}$. The relative permittivity of the supporting material is $\varepsilon_{r2} = 7.5$ and the width of $50\,\Omega$ microstrip line is $d = 0.6\,\text{mm}$.

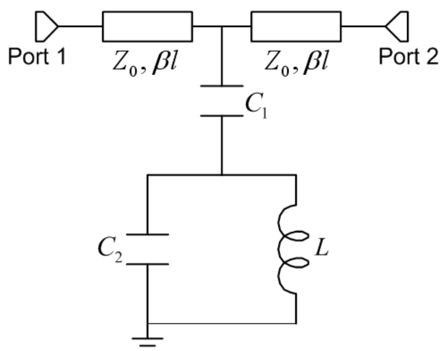


**Figure 2.** Equivalent circuit of suspended microstrip over an EBG unit.

Figure 2 shows the equivalent circuit of this structure [17, 18]. The coupling between the microstrip line and the patch generates a capacitance $C_1$, the coupling between the patch and the ground plane creates a capacitance $C_2$, and the metal via yields an inductance $L$. The characteristic impedance and the phase constant of the transmission line are $Z_0$ and $\beta$ respectively. $l$ is the distance between the port and the center of via. The shunt admittance can be given as

$$Y = \frac{j\omega C_1 \left(1 - \omega^2 L C_2\right)}{1 - \omega^2 L \left(C_1 + C_2\right)} \tag{1}$$

The total ABCD matrix can be derived by cascading one admittance $Y$ and two transmission lines

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\beta l & jZ_0 \sin\beta l \\ jY_0 \sin\beta l & \cos\beta l \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \begin{bmatrix} \cos\beta l & jZ_0 \sin\beta l \\ jY_0 \sin\beta l & \cos\beta l \end{bmatrix} \tag{2}$$

Generally, $S$-parameters can be calculated by the following equations:

$$S_{11} = \frac{A + B/Z_0 - CZ_0 - D}{A + B/Z_0 + CZ_0 + D} \tag{3a}$$

$$S_{21} = \frac{2}{A + B/Z_0 + CZ_0 + D} \tag{3b}$$

The equivalent circuit can be validated by comparing the $S$-parameters of equations with the full wave analysis. 3D EM simulator CST Microwave Studio is used to obtain the $S$-parameters of full wave analysis. Using the parameters extraction technology, the corresponding equivalent circuit of the EBG unit can be determined as follows: $C_1 = 0.29\,\text{pF}$, $C_2 = 0.24\,\text{pF}$, $L = 0.86\,\text{nH}$. It is seen from Fig. 3 that there is a good agreement between the $S$-parameters responses of equivalent circuit and the results from full wave simulation.

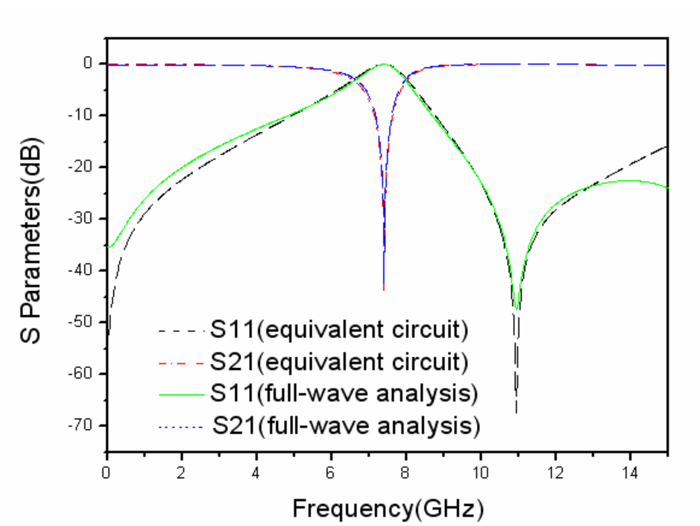


**Figure 3.** Comparison of equivalent circuit with full-wave analysis.

The conventional method used to decrease the resonant frequency of an EBG unit is enlarging the dimension of the patch to increase the equivalent capacitance, or decreasing the radius of the metal via to increase the equivalent inductance. Here we use another way to decrease the unit resonant frequency: changing the position of the metal via. The resolution of the distance between via and the center of the metal patch into x- and y-components is possible, which can be written as $dx$ and $dy$. The position of via changing, the distribution of electric field on the patch will change as well. By adjusting the relative position of via, the center frequency can vary in a special range. The center frequency of the EBG unit cell varies with the distances of via from the center of the patch as shown in Fig. 4. It is observed that the center of the stopband moves to lower frequency with $dx$ or $dy$ increasing. The resonant frequency is 7.8 GHz in the normal structure with via at the center of the patch. When the position of via is moved off the center of the patch, for example, $dx = dy = 1.4$, the resonant frequency is reduced to 4.75 GHz. Further more, the variation of center frequency in the $y$-direction is more significant than that in the $x$-direction.

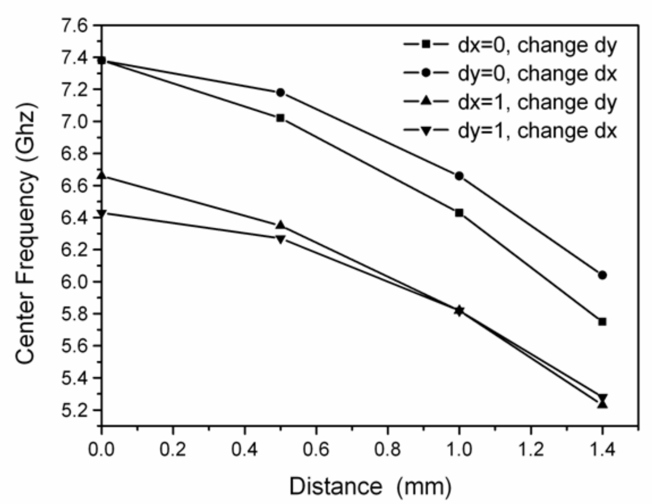


**Figure 4.** Center frequency changes with the position of via.

The radius of via is important to take effect on the band-gap, which is not considered in the parallel resonant LC circuit formulation. Here we investigate the resonant characteristics of an EBG unit with different radius of via, which is shown in Fig. 5. In the EBG unit, via is at the center of the metal patch and the radius of via is increased from 0.075 mm to 0.3 mm while other parameters are unchanged. It is seen that the stopband moves to higher frequency with the radius of via increasing. When the radius of via is increased, the effective area between the patch and bottom metal sheets is reduced. So the equivalent capacitance between the sheets diminishes, and the resonant frequency becomes higher. Further more, the bandwidth of the stopband is enlarged because it is proportional to $\sqrt{L/C}$, where $L$

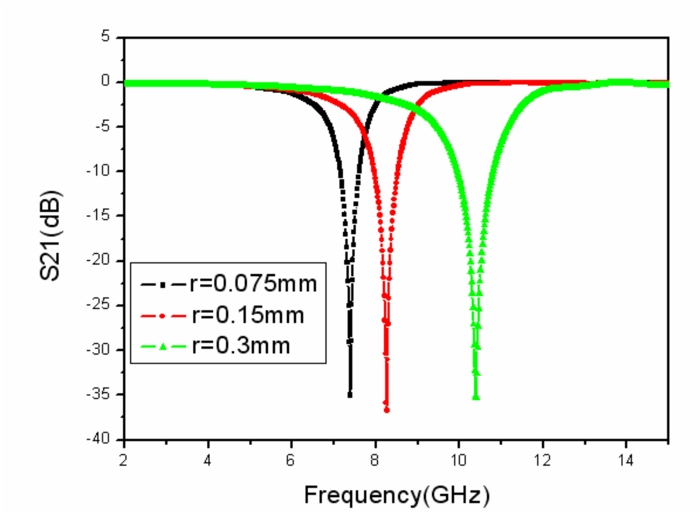


**Figure 5.** Center frequency changes with the radius of via.

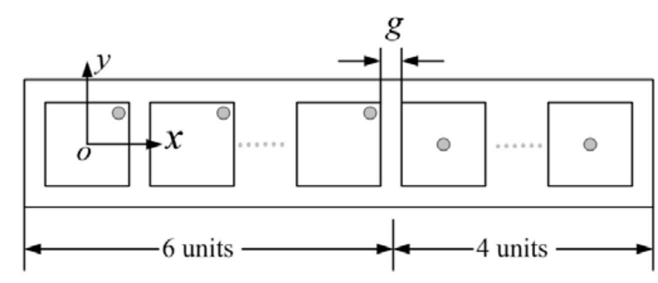


**Figure 6.** Configuration of the proposed cascaded structure.

is the equivalent inductance and $C$ is the equivalent capacitance in an EBG unit.

## 3. PROPOSED STRUCTURE

On the basis of the fact that the EBG structure behaves like a stopband filter which can be seen from Eqs. (3a) and (3b), it is expected that a dual-band EBG can be achieved when two different kinds of EBG unit are cascaded. As mentioned earlier, the bandwidth of the stopband will be decreased when the resonant frequency becomes higher. We choose six units whose position of via is moved off the center of the metal patch and four units whose via are at the center of the patch. The ten units which have the same patches and radius of via are arranged along the $x$-direction to form a cascaded structure, as shown in Fig. 6. The distance between the adjacent patches is $g = 0.5$ mm, so the period of the lattice is $w + g = 3.5$ mm. In the first kind of EBG unit, The distance between via and the center of the patch is $dx = dy = 1.3$ mm.

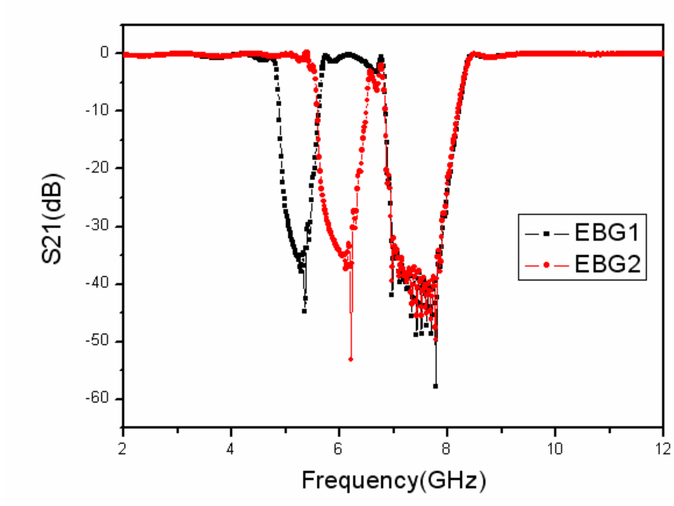


**Figure 7.** Two cascaded structures with different position of via.

The band-gap plotted in Fig. 7 validates our expectation that two stopbands are observed with the central frequency of 5.23 GHz and 7.45 GHz. When the frequency of electromagnetic wave is between 4.94 GHz and 5.52 GHz, the propagation is prohibited by the EBG units whose via are moved off the center of the patch. The second kind of EBG units works when the frequency is between 6.87 GHz and 8.03 GHz. The frequency of the two stopbands can be easily tuned by changing the position of via. When the position of via in the first kind of EBG unit is changed to $dx = dy = 1$ mm, the corresponding band-gaps are centered at 6.02 GHz and 7.45 GHz. It provides an additional degree of freedom to control the position of one stopband while the other keeps the same. To study the effects of the radius of via, two cascaded EBG structures are simulated and the radius of via are 0.075 mm and 0.15 mm respectively. Other parameters such as the position of via in the two kinds of EBG unit, are kept the same as in previous design EBG1. The band-gap moves to higher frequency region with the radius of via increasing, as shown in Fig. 8.

Another cascaded EBG structure whose stopband can be tuned over a wider range is designed. In this structure, the position and

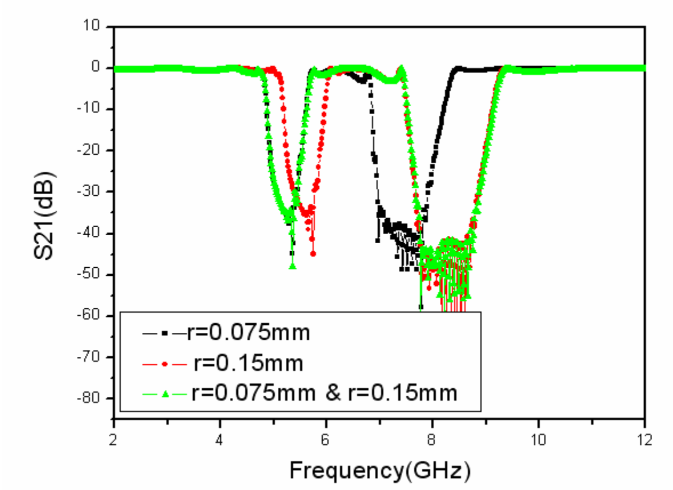


**Figure 8.** Comparison of cascaded structures with different radius of via.

radius of via are changed at the same time. In the first kind of EBG unit, the position of via is $dx = dy = 1.3\,\mathrm{mm}$ and the radius of via is 0.075 mm. The parameters in the second kind of EBG unit are $dx = dy = 0\,\mathrm{mm}$ and 0.15 mm while other parameters are unchanged. Two distinctive stopbands have been observed with the central frequency of 5.23 GHz and 8.28 GHz. It is seen that the frequency range of band-gap is greatly broadened by this combination. The simulated results coincide with the prediction of the equivalent LC circuit.

## 4. CONCLUSION

A new kind of dual-band EBG structure using cascaded mushroom-like structure is introduced in this paper. The method of suspended microstrip is used to simulate the transmission coefficients of the EBG structure. The unit equivalent circuit is given, further more the effects of the position and radius of via on the resonant frequency are discussed in detail. Several cascaded EBG structures with 10 cells are designed and compared. The frequency of stopband can be tuned easily by changing the position of via. The band-gap moves to higher frequency region with the radius of via increasing. By adjusting the position and radius of via at the same time, the stopband frequency can be tuned over a wider range. This dual-band EBG structure will have attractive application in various wireless communication areas, such as multi-antennas and circuit.

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