Progress In Electromagnetics Research C, Vol. 11, 81–90, 2009

DESIGN OF A NOVEL EBG STRUCTURE AND ITS APPLICATION IN FRACTAL MICROSTRIP ANTENNA

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Abstract—In this paper, a novel electromagnetic bandgap structure (EBGs) is proposed, which is similar to the mushroom-like EBG. By introducing double reverse split rings (RSR) into the square patch, the size of EBG cell is reduced by 30%, and the bandgap achieves bandwidth about 65%. A fractal microstrip antenna is implemented using the EBGs as a ground plane, and the measured results show that the reduction in the surface wave level is remarkable. Compared with the reference antenna at 5 GHz, an approximately 8 dB improvement of the return loss is achieved, and the back lobe is reduced by 10 dB in E plane and 8.73 dB in H plane at the resonant frequency, respectively. The front-back ratios of the antenna have significantly increased from 4.9 GHz to 5.2 GHz.

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1. INTRODUCTION

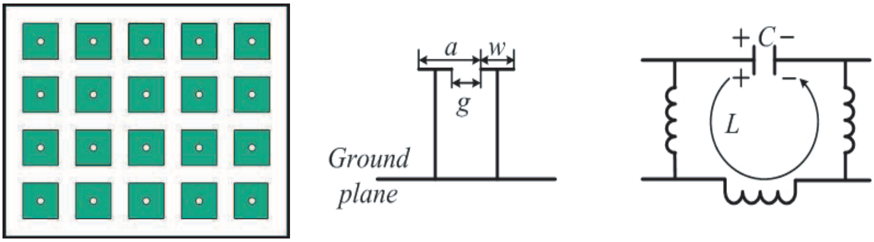
Recently, there has been much interest in investigating electromagnetic bandgap structures or photonic band gap structures (PBGs) [1, 2]. Varieties of EBGs have been proposed and studied, because the EBGs represent some unique characteristics, such as forbidden bandgap, in-phase reflection, etc. [3]. It has been reported that EBGs used in microstrip antenna community can improve characteristics of antennas, such as improving their radiation patterns, enhancing their gain, and minimizing the side and back lobe levels, etc. [4–6]. Since the period of an EBG lattice has to be a half-wavelength at the stopband frequency in early EBG design, the EBGs usually have difficulty in practical applications accommodating its physical size. So many small and compact periodic EBGs have been investigated to solve this problem, such as mushroom-like EBG [7], UC-PBG [8], fork-like EBG [9] and spiral-like EBG [10]. The mushroom-like EBGs known as high impedance surface (HIS) is initially proposed by Sievenpiper, which is made up of metal patches, dielectric substrate, and vias connected with patches and ground plane, as shown in Figure 1. The mushroom-like EBGs have a frequency bandgap and very high surface impedance characteristics, which is generally called in-phase reflection band. This conventional mushroom-like EBGs can be used in antenna design to suppress the propagating of surface wave, but the cell size is still too large to be used in some practical applications. Thereby, it is necessary to investigate the smaller EBGs for widely using in antenna fields.

This paper presents a novel reverse split rings EBGs, which is based on the conventional EBGs. The size of EBG cell is reduced by introducing double reverse split rings into the square patch. Compared with the conventional EBGs, the size of the RSR EBG cell is reduced by 30%, and the bandgap achieves bandwidth about 65%. To verify the deign, two fractal microstrip patch antennas with and without EBGs are constructed and simulated by Ansoft HFSS 11. The results show that the reduction in the surface wave level is remarkable.

2. RSR EBG SUBSTRATE AND CHARACTERIZATION

2.1. Design of the RSR EBG Structure

As it is shown, when the periodicity is small compared to the operating wavelength, the EBGs can be simply modeled as a parallel LC equivalent circuit. The capacitance C is determined by the fringing capacitance between neighboring metal patches, while the current flowing through the via and metal plate, can be considered as inductance L, as demonstrated in Figure 1.



(a) (b)

Figure 1. The mushroom-like EBGs. (a) Geometry of the EBGs. (b) The equivalent circuit model.

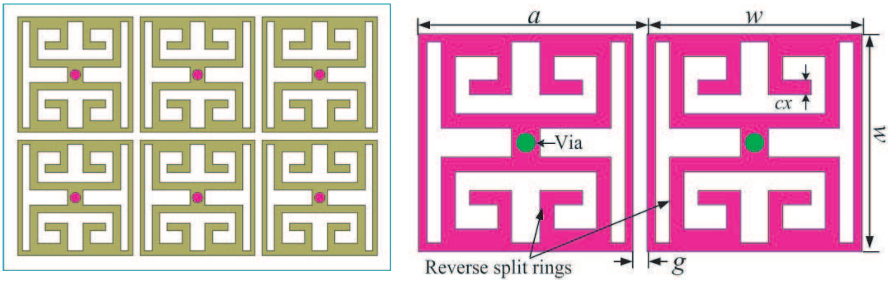
The novel RSR EBGs is designed which is similar to the conventional EBGs. Figure 2 shows the new EBGs which consists of four parts: 1) reverse split rings — like metal patch, 2) a ground plane, 3) a dielectric substrate and 4) connecting via. The reverse split rings are etched on the metal patches.

According to the lumped LC model of the conventional EBGs, the surface impedance equals to the impedance of a parallel resonant circuit, and the resonance frequency of the EBG structure f_0 is calculated as following:

$$Z = \frac{j\omega L}{1 - \omega^2 LC} \tag{2a}$$

$$f_0 = \frac{1}{2\pi\sqrt{Lc}} \tag{2b}$$

From Equations (2a) and (2b), the high impedance could be obtained, and the EBGs do not support any surface waves near the



(a) (b)

Figure 2. The novel RSR EBGs. (a) Geometry of the RSR EBGs. (b) The RSR EBG cells.

resonance frequency, resulting in a frequency bandgap. The inductance L and capacitance C are given by the following equations [11]:

$$L = \mu_0 \mu_r h \tag{2c}$$

$$C = \frac{w\varepsilon_0(1+\varepsilon_r)}{\pi} \cosh^{-1}\left(\frac{a}{g}\right) \tag{2d}$$

where μ_0 and ε_0 are the permeability and permittivity of free space, respectively. The EBG cell is determined by the parameters: a is the grid period; g is the gap width; w is the patch width; h is the thickness of the substrate; ε_r is the relative permittivity. The bandwidth BW of bandgap can be determined by the surface capacitance C and inductance L:

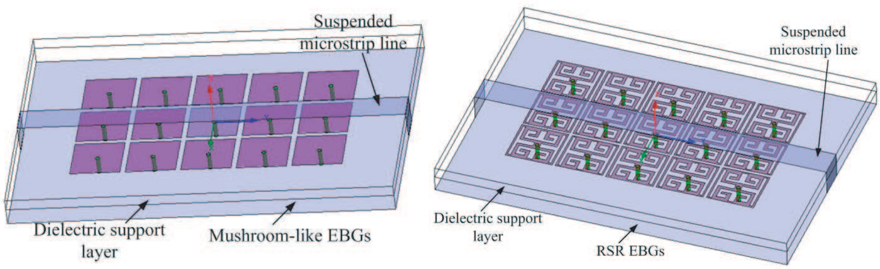
$$\mathrm{BW} = \frac{1}{\eta}\sqrt{\frac{L}{C}} \tag{2e}$$

where η is the free space impedance, which is 120π. In order to increase the equivalent inductance, a new approach is used by etching curves into the metal patches of an EBG surface to introduce additional inductance, similar to the coplanar spiral inductor used in microwave circuits [12]. Thus, the equivalent inductance L is determined by the additional inductance, and the inductance is formed by plated via. In these novel EBGs, the double reverse split rings (RSR) are etched into the square patch to introduce additional inductance. From Equations (2c) to (2e), we know that the inductance formed by plated via is unchanged, once the substrate is defined. So we can change the length of reverse split rings to increase the equivalent inductance L resulting in a lower resonant frequency, reducing the EBG cell size, and improving the bandgap bandwidth.

2.2. Characteristics of the RSR EBG Structure

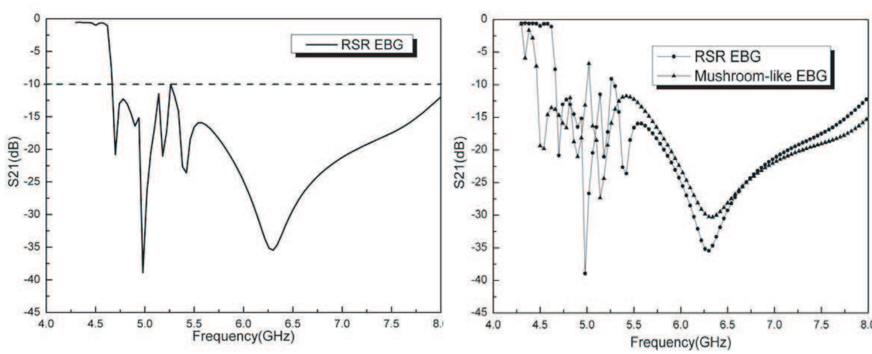
To verify the properties of the proposed RSR EBGs, the EBGs are constructed on a 2 mm thick substrate with the relative permittivity of 2.55. For the parameters of the EBG cells: the square patch size is $w = 4.5$ mm; the RSRs width is $cx = 0.3$ mm; the gap between the neighboring cells is $g = 0.3$ mm; the via radius is $r = 0.2$ mm, so the period is $w + g = 4.53$ mm. A 3×5 conventional EBGs and RSR EBGs have been simulated using method of suspended microstrip line, which is proposed by Fan to measure the bandgap characteristic of the EBGs, as shown in Figure 3 [13]. The operating frequency is setting at 5 GHz, and the 50 Ohm microstrip line is placed on a dielectric support layer with the thickness of 0.5 mm.

The simulated result of the transmission coefficient S_{21} is shown in Figure 4(a). The bandgap is centered at 5.0 GHz and 6.35 GHz, and the bandgap bandwidth is from 4.72 GHz to 8.0 GHz ($S_{21} < -10$ dB), achieved the bandgap bandwidths about 65%. As shown in Figure 4(b), the bandgap range of RSR EBGs is approximately the same as the conventional EBGs, while the size of square patch of the conventional EBGs is $w_1 = 6.4$ mm, with the preservation of the other parameters. Therefore, the cell size of RSR EBGs is reduced about 30%, which is smaller than that of the conventional EBGs at the same operating frequency.



(a) (b)

Figure 3. Geometry of 3 × 5 EBG arrays. (a) The mushroom-like EBG array. (b)The RSR EBG array.

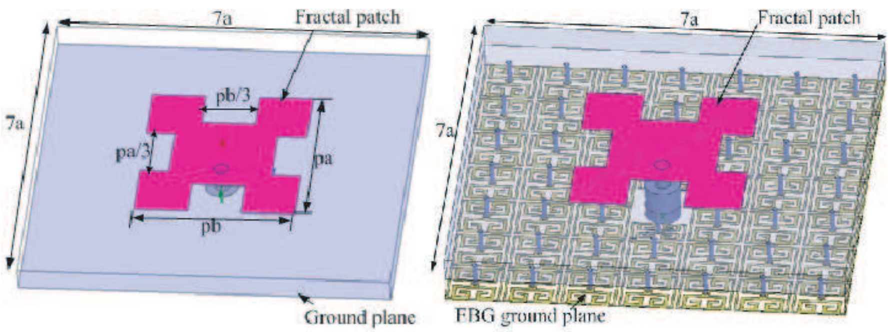


(a) (b)

Figure 4. Simulated S_{21} of the two EBGs. (a) The novel RSR EBGs. (b) Comparison of simulated results of the EBGs ($w = 4.5$ mm, $w_1 = 6.4$ mm).

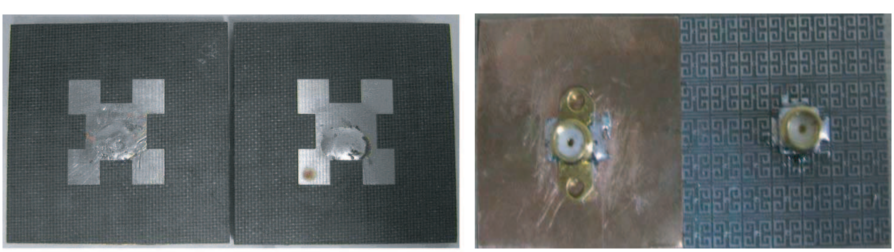
3. APPLICATION TO PATCH ANTENNAS

A fractal microstrip patch antenna is designed as the reference antenna, which is on a classical ground plane, as shown in Figure 5(a). The fractal patch is printed on a dielectric substrate with a relative permittivity of 2.65, thickness of $h = 2\,\mathrm{mm}$ and size of $7a \times 7a\,\mathrm{mm}^2$. Figure 5(b) shows another fractal antenna which is designed with RSR EBGs replacing the conducting ground plane. In the EBG antenna design, the RSR EBGs are inversed to get significant effect, which is proved in the research process. For comparison purposes, all parameters of the proposed antennas are consistent. The resonant frequency at 5 GHz is set within the surface wave bandgap of the RSR EBGs. To effectively suppress the surface waves, seven rows of EBG cells are used in the design. It is worthwhile to point out that the



(a) (b)

Figure 5. Structures of the fractal patch antennas. (a) The reference antenna with PEC ground. (b) The antenna with EBG ground plane. ($p_a = 14.5\,\mathrm{mm}$, $p_b = 15.8\,\mathrm{mm}$).



(a) (b)

Figure 6. The fabricated antennas. (a) The conventional and EBG ground planes. (b) The fractal patches of two antennas.

novel EBG cell is very compact. Therefore, the ground plane size is the same as that of the reference antenna. The fabricated antennas are shown in Figure 6 and measured with a vector network analyzer Agilent N5230A.

Figure 7 demonstrates the simulated and measured S_{11} of the two proposed antennas. The simulated results indicate that the S_{11} is -22.86 dB for the reference antenna and -31.35 dB for the EBG fractal antenna. It indicates that the latter is about 8.49 dB less than

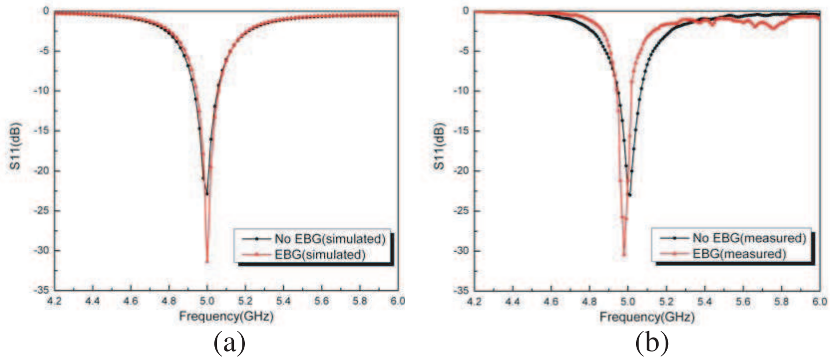


Figure 7. S_{11} of the proposed antennas. (a) Simulated S_{11} of the proposed antennas. (b) Measured S_{11} of the proposed antennas.

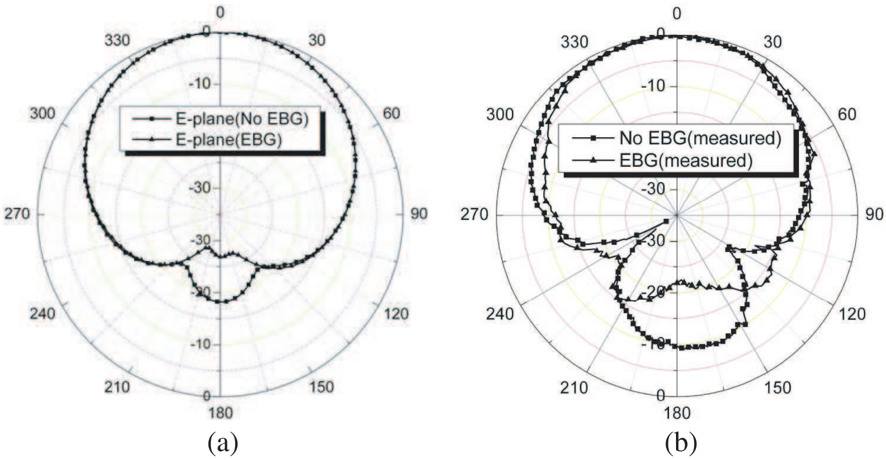
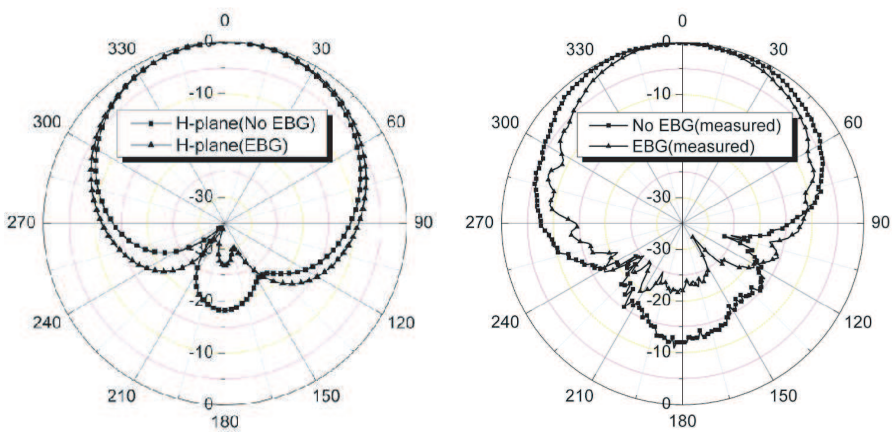


Figure 8. Radiation patterns of the proposed antennas with EBG and without EBG at 5 GHz. (a) Simulated results in E plane. (b) Measured results in E plane.

the former. The results of the measurement are in good agreement with the simulation ones. The measured results show that the S_{11} of EBG antenna and reference antenna are -30.67 dB and -23 dB, respectively. The resonant frequency f_0 of the EBG antenna shifts slightly from 5 GHz to 4.98 GHz. Figure 7 illuminates that the EBGs are used to the antenna ground plane, reducing the antenna input impedance loss and improving the antenna radiation power.

Figure 8 and Figure 9 show the simulated and measured radiation patterns of the proposed antennas with and without EBG in both planes E and H at 5 GHz. The reference antenna shows large radiation in the backward direction, and the fractal antenna on RSR EBG ground plane produces a lower back lobe, with less power wasted in the backward direction. All the measurement results obtained approximately confirm the simulation results. As shown in Figure 8 and Figure 9, in the E-plane pattern of the fractal antenna with EBG, the back lobe is reduced by 10 dB, and the back lobe is reduced by 8.73 dB in the H-plane pattern. The radiation pattern of the antenna is improved effectively.

Table 1 shows the measurement results of the front-back ratios in H plane. The front-back ratios of the EBG antenna are improved significantly from 4.9 GHz to 5.2 GHz, although the front lobe is approximately the same for the two proposed antennas. Therefore, the surface waves, which propagate away from the antenna and radiate from the ground, are suppressed by using high-impedance ground



(a) (b)

Figure 9. Radiation patterns of the antenna with EBG and without EBG at 5 GHz. (a) Simulated results in H plane. (b) Measured results in H plane.

planes, and the radiation pattern of the antenna is improved greatly.

Table 1. Measurement results of the proposed antennas with and without EBG in H plane.

Frequency (GHz)	Front-back Ratio (dB)		Improved (dB)
	EBG	No EBG	
4.9	23.349	24.276	5.692
5.0	17.657	18.802	8.727
5.1	26.953	29.4563	5.474
5.2	18.226	19.803	9.6263

4. CONCLUSIONS

This paper designs novel electromagnetic band-gap RSR EBGs. The size of EBG cell is reduced by introducing double reverse split rings into the square patch. The bandgap bandwidth achieves about 65%. Using the EBGs as the ground plane of a fractal microstrip antenna, the surface waves are suppressed effectively. Compared with the reference antenna at 5 GHz, an approximately 8 dB improvement of the return loss is achieved, and the back lobe is reduced by 10 dB in E plane and 8.73 dB in H plane, respectively. The front-back ratios of the EBG antenna are improved significantly from 4.9 GHz to 5.2 GHz. Therefore, the performances of the antenna are improved greatly. The novel EBGs with wide bandwidth can be used in the microstrip antenna design.

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