

Investigation of Dual-Band Patch Antennas Based on Photonic Band-Gap Structure

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Abstract: The purpose of this paper is to analyze the influence of Photonic Crystal Band-Gap (PBG) structure to the patch antenna. The method of Finite Difference Time Domain (FDTD) was used, and a dual-band patch antenna was presented. We compared two simulated antennas, one of which is based on PBG structure. By analyzing the antennas' parameters such as S11, Radiation Pattern, and resonant frequency, we found that its directivity and gain were improved by adding the PBG structure. Besides, the characteristics of the resonant frequencies are changed accordingly. Due to these advantages, the application of photonic crystal patch antennas will be extended in various areas such as mobile communication, satellite communication, aviation, et al.

Key Words: PBG, Dual-Band, Patch Antenna, FDTD

1 Introduction

Photonic Crystal Band-Gap structure (PBG) is an artificial periodic structure, which has the characteristic of frequency forbidden band, that is, Electromagnetic (EM) waves in this frequency range can not transmit through it. The PBG structure can be fabricated by adding a periodic material into another material, and can be divided into three kinds by the periodic: 1D, 2D, and 3D. Generally, the higher the dimension is, the more difficult it is for calculating and preparing. The concept of "Photonic Crystal" was put forward firstly by E. Yablonovitch with Bell laboratory and S. John with Princeton University when they were studying how to avoid spontaneous radiation and photon region of dielectric material, respectively^[1-2]. It attracted a great of interest since it was presented, nowadays, many researchers and institutes are studying on the Photonic Crystal structures, and some important development and application are obtained. The PBG structures under study currently mainly have: drilling a periodic pattern of holes in the substrate, etching a periodic pattern of circles in the ground plane, using a triangular or square lattice of metallic pads connected to ground with vias and etching metal units on the layer of the substrate.^[4-7]

Patch antennas were firstly used in early 70s of 20 century, It had extensive application in army, civilian areas after development of decades of years. Its main advantages include: low profile, conformity to planar and nonplanar surfaces, and simplicity, et al, while its disadvantages are: narrow bandwidth and low radiation efficiency. In order to solve the problems

caused by these disadvantages, some researchers thought of utilizing the characteristic of the forbidden band of the PBG structure. The method can improve the patch antenna's gain, broaden the bandwidth, and enhance the radiation efficiency to some extent. Brown, Parker and E. Yablonovitch combined the PBG structure and patch antennas for the first time, and opened a door from PBG structure to patch antennas for antenna study, now, there are many researches of patch antennas based on the PBG structure, and great progress were made.

The paper mainly study the dual-band patch antennas based on etching some periodic patterns in the ground plane. By analyzing the antennas' performance parameters such as return loss, radiation pattern and resonant frequency, we demonstrate the influence caused by PBG structure to the dual-band patch antennas, for example, influence to high harmonic, influence to antenna's gain. Also, different PBG structures are used.

2 Structure design of the antennas

The top views of the antennas are shown in Fig1.

Where the patch's size are: $L=10\text{mm}$ in length, $W=20\text{mm}$ in width; the dimension of the substrate is:

$40\text{mm} \times 40\text{mm} \times 1.5\text{mm}$, the dielectric constant $\epsilon_r=2.27$.

The formula for design of the patch antennas can refer to^[8].

As to the PBG structure's dimension, One theory considered that the period of the PBG structure is about half of the wave length corresponding to the center frequency of the forbidden band, which derived from the reflection condition of the Bragg

in Optics, its original formula is: $2K = K_{\text{Bragg}} = \frac{2\pi}{a}$

Where "a" is the period of the PBG structure, "K" is the wave number of the guided wave, and we know $K = \frac{2\pi}{\lambda_g}$, so

we can get: $a = \frac{\lambda_g}{2}$, where $\lambda_g = \frac{\lambda}{\sqrt{\epsilon_r}}$, and λ is the wave length in free space.

Furthermore, some papers proved that when the period of the PBG structure "a" and the crystal lattice constant "d" satisfy

some conditions, for example, $\frac{d}{a} = 0.5$, a perfect frequency

forbidden band can be obtained.

Based on the above theory, there are many methods can be used to design and fabricate the PBG structure, and mostly, two

ways are used: one is to drill the periodic holes in the substrate; the other is to etch the periodic patterns in the ground plate, which is very easy to implement, process, and fabricate. The

latter was used by our study, and $\frac{d}{a} = 0.5$ was taken. We

designed three PBG patch antennas with different patterns in the ground plate: (1) 5×5 rectangular lattice with circular pattern, whose diameter and period are $d=3\text{mm}$, $a=6\text{mm}$, respectively, as shown in Fig1(b); (2) 7×7 rectangular lattice with circular pattern, whose diameter and period are $d=2\text{mm}$, $a=4\text{mm}$, respectively, as shown in Fig1(c); (3) 5×5 rectangular lattice with square pattern, whose length is 3mm , the center distance is 6mm , as shown in Fig1(d).

During the simulation of the antennas, the absolute absorbing condition was chosen. In order to get the characteristic of the PBG's forbidden band, we employed the 7 layers PML condition as the boundary condition. The antennas are excited by the gauss source through the microstrip feed, the microstrip's dimension is $15 \times 2.6\text{mm}$

3 Simulation results and analysis

The method of FDTD was used to simulate and analyze the above antennas, and the corresponding performance parameters were attained, the return loss of the antennas are shown in Fig2, the radiation patterns are shown in Fig3. The concerned parameters are summed up in table1.

We can see from Fig2 that the antennas' resonant frequencies shift when adding the PBG structure in the substrate, compared to the conventional patch antennas, and the frequency shift is different corresponds to different PBG structures, that is, the frequency shift is concerned with the PBG's pattern and dimension. The main reason for the shift is that the transmission's guide wavelength decrease when adding the PBG structure, while the dimension of the antenna keeps unchanged, so the resonant frequencies will decrease accordingly. From Fig2 or table1, we can also find that the PBG antennas' return loss become better at the first resonant frequency, but worse at the second resonant frequency, it indicates that the PBG structure has the effect of restraining the second-order harmonic, in fact, it has the effect of restraining high harmonics. The reason is that, when the EM waves are transmitted in the periodic structure, and if the period and wave length are at the same measure stage, multiple scattering would happen, which would lead to discontinuity in the distribute of the wave's energy. The stable energy state will be divided by the unstable energy state (for example, forbidden band), and the energy band structure are formed, the EM waves in the forbidden band are restrained to propagate.

The radiation patterns are shown in Fig3. The gain of the conventional antenna is about 7.67dB , as shown in Fig3(a), and there is an increment of about 0.4dB in gain for the PBG antennas, showing that the PBG structure can improve the antenna's gain. On the other hand, the PBG structure in the ground plate will increase the back radiation at the same time, as shown in the Fig3. The main reason is that the periodic holes in the ground plate will also radiate EM waves, and its radiant

intensity corresponds to the hole diameter, the smaller the hole is, the less the back radiation has, and the fewer the ability to restrain the high harmonic is, it can be seen in Fig3(b) and Fig3(c), it is a conflict, it must split the difference in real application.

4 Conclusion

By etching the periodic structure(PBG) in the ground plane of the dual-band patch antenna, the calculation results indicate that two-order and high harmonics can be restrained, the antenna's gain can be improved, and the return loss at the first resonant frequency will be better, therefore, the antenna's radiation efficiency will be increased. It makes it possible to use the dual-band patch antennas in some areas with special request, especially for these multi-frequency devices. Furthermore, the working frequency will shift because of the PBG structure. For the problem that PBG structure will increase the back radiation, that's what we must study in future.

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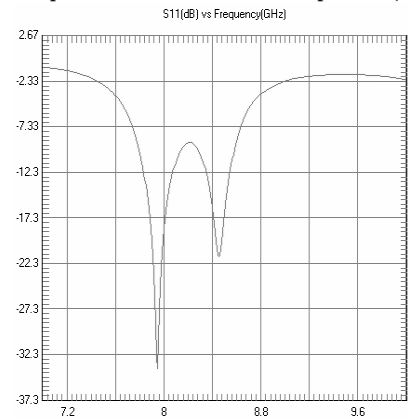
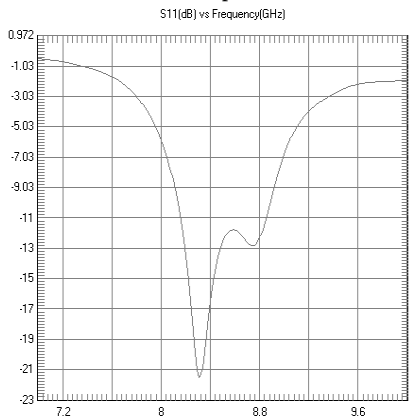
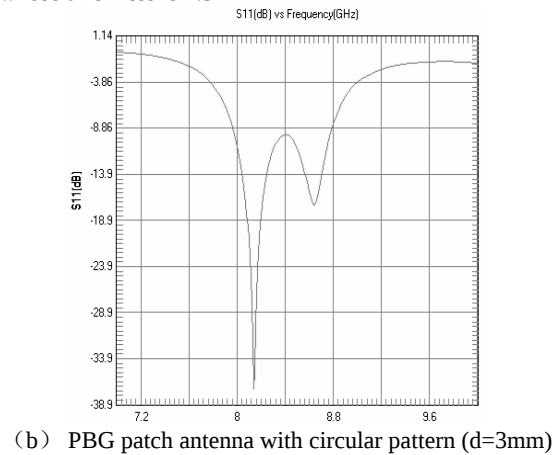
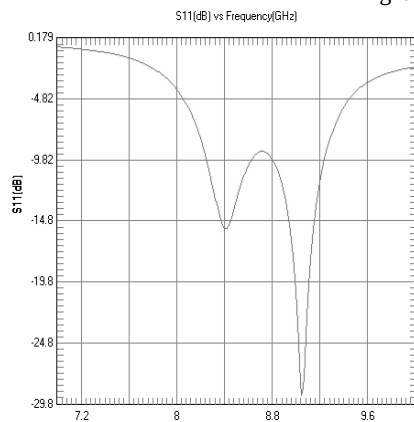
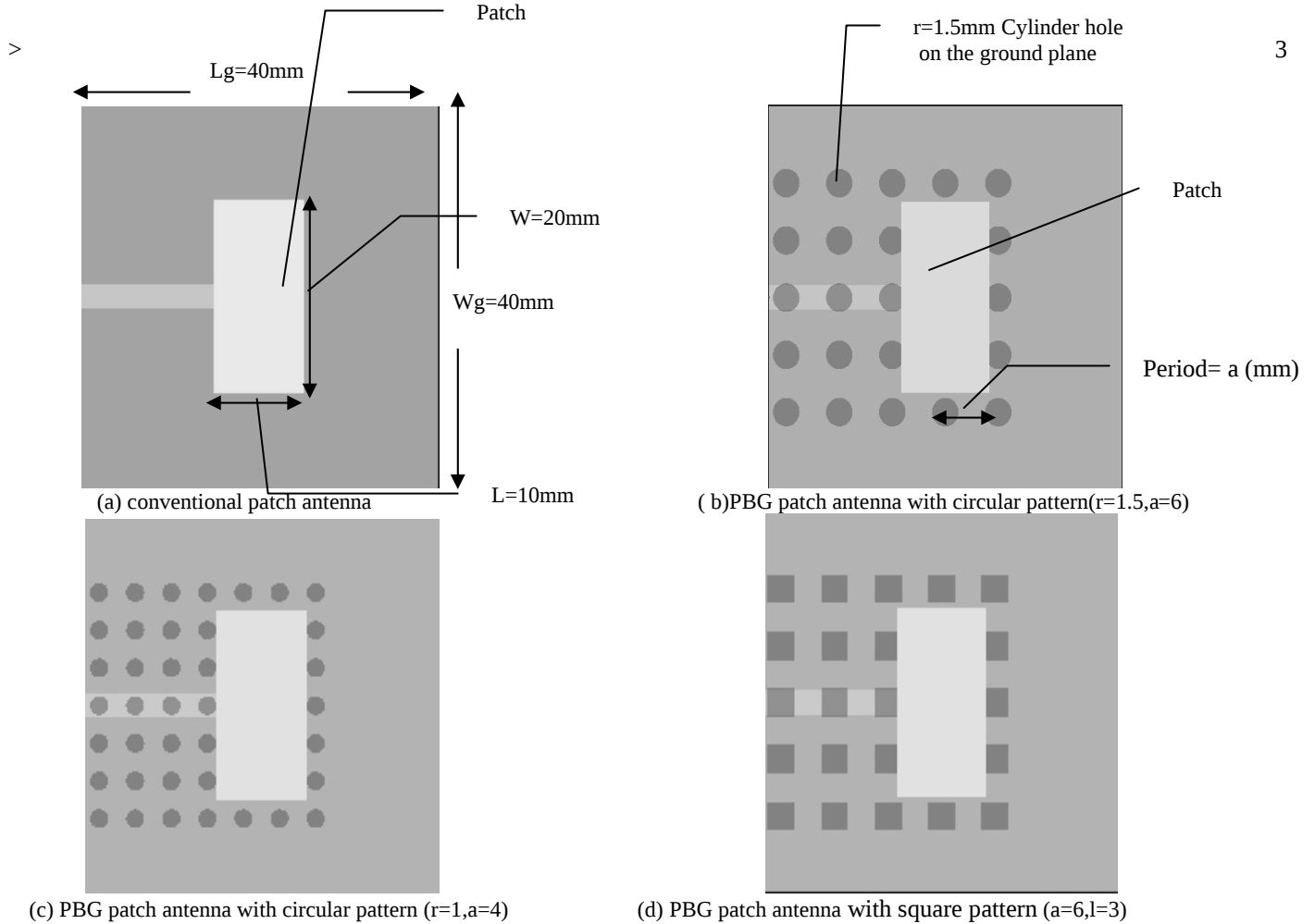
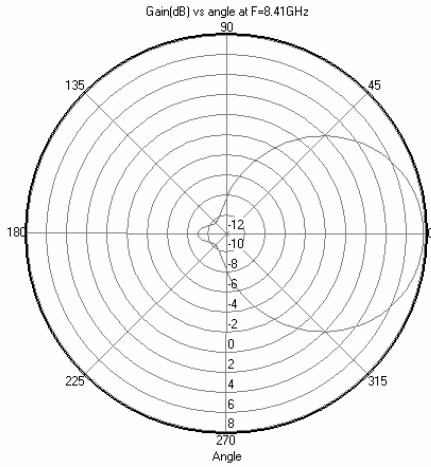
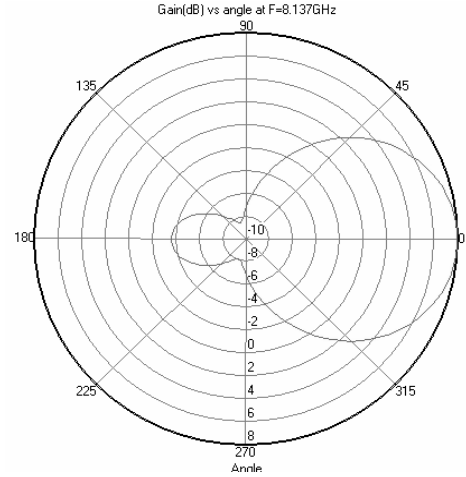


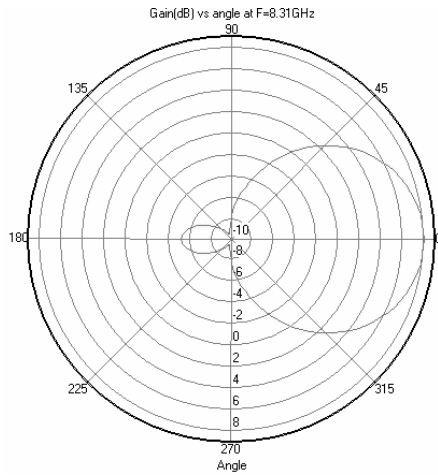
Fig2. Return loss of the antennas with and without PBG



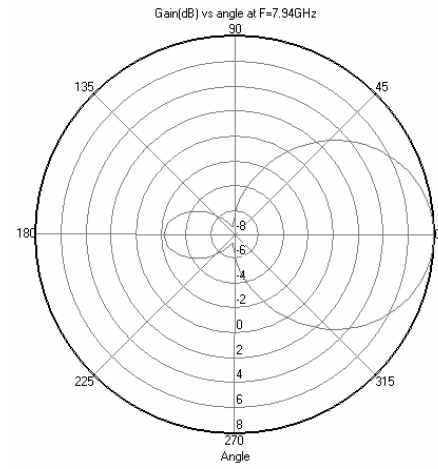
(a) conventional patch antenna



(b) PBG patch antenna with circular pattern (d=3mm)



(c) PBG patch antenna with circular pattern (d=2mm)



(d) PBG patch antenna with square pattern (l=3mm)

Fig.3 Radiation patterns of the antennas with and without PBG

Table.1 parameters of antennas with and without PBG

	S11(fundamental wave)dB	S11(2th harmonic)	Gain (dB)	Resonant frequency(GHz)
Conventional antenna	-15.48	-29.1	7.67	8.41/ 9.02
PBG patch antenna with circular pattern (d=3mm,a=6mm)	-37.16	-17.10	8.0	8.14/ 8.64
PBG patch antenna with circular pattern (d=2mm,a=4mm)	-21.53	-12.85	8.02	8.31/ 8.75
PBG antenna with square pattern (d=3mm,a=6mm)	-32.53	-21.32	7.96	7.94/ 8.45