Sensors & Transducers, Vol. 172, Issue 6, June 2014, pp. 178-183

www.sensorsportal.com

Sensors & Transducers

http://www.sensorsportal.com

Analysis and Design of a Multi-Frequency Microstrip Antenna Based on a PBG Substrate

YANG Hong, WANG Zhi Peng, SHAO Jian Xing
College of Electrical Engineering, Chongqing University of Posts and Telecommunications, Chongqing 400065, P. R. China
Tel.: 0086-023-62471716, fax: 0086-023-62471719
E-mail: yanghong@cqupt.edu.cn

Received: 11 April 2014 /Accepted: 30 May 2014 /Published: 3 June 2014

Abstract: Based on the C-shaped microstrip slot antenna, a new photonic band gap substrate for multi-frequency microstrip slot antenna is designed. The antenna has a groove been dug below the radiation plate, within which the radiation plate is placed, and air triangular prism column gaps with different height are placed in the substrate periodically. Numerical simulation is performed for the antenna with Ansoft HFSS10.0, which is a kind of simulation software based on Finite Element Method. Comparing with the C-shaped microstrip slot antenna, the resonant frequency of the antenna was reduced by 230 MHz, and the low frequency bandwidth was increased from 12.63 % to 18.95 %, both the radiation and multi-frequency characteristics of this proposed antenna are improved. The result demonstrates that the structure is efficient in improving the antenna gain and radiation directivity by suppressing surface wave of the microstrip antenna.

Keywords: Photonic band gap structure, C-shaped slot microstrip antenna, Surface wave, Gain.

1. Introduction

Recent years there are PBG (photonic band gap) materials, also known as photonic crystals, in improving the antenna performance, increase the gain, reducing the coupling between the microstrip antennas, limit the spread of high-order mode and so have attracted wide attention. The concept of photonic crystals is in 1987 by the University of California Professor E. Yablonovich first proposed [1] which is an artificial periodic dielectric structure that can form in the spectrum band, known as photonic band gap [2]. Based on the new electromagnetic (photonic) crystals, raise in recent years a new area of research [3]. In the field of microwave and millimeter-wave, PBG materials have been used to improve the performance of various antennas, including microstrip patch antenna, resonant antenna. Microstrip antenna as small size, light weight, low profile, easy processing, and easy-to-conformal with the carrier, and so on. In mobile communications, satellite communications, aerospace and other fields has been widely used, however due to the loss of the surface wave existence of the low radiation efficiency, narrow bandwidth and other shortcomings. In order to control surface waves and improve the antenna gain and radiation efficiency, lots of PBG microstrip antenna structure is used. Although the domestic and foreign has base drilling [4], Surface corrosion type [5], High-impedance surface model [6], UC-PBG type [7], Cladding type [8] and Soft-surface model [9] photon crystal patch antenna has carried out research, but these studies remains a lots of issue, such as how to significantly improve the antenna performance indicators, reduce the antenna volume, weight and reduce the costs of processing the antenna.

Aiming at the above problems, also in order to improve the radiation and multi-frequency characteristics of the C-shaped slot microstrip antenna, this paper presents a PBG structure based on small-scale multi-band antennas, proposed new type of PBG microstrip antenna structure is introduction by different highly on substrate with the periodic cylindrical air holes in the Triangle. The antenna is not only maintained a low profile microstrip antenna, simple structure, easy to feed the advantages, but also work with multi-band characteristics, in particular to ensure its excellent radiation performance of broadband RF communication will have a good prospect.

Typically, in the design of photonic crystal, the first step is designed photonic crystal structure and antenna, respectively, and then put them together. This is a more common design idea, but for the final photonic crystal antenna, we should considering the number of antennas and photonic crystal parameters on the overall performance of the antenna.

2. Multi-frequency Microstrip Antenna Design and Simulation

2.1. Simulation Model-frequency Microstrip Antenna Design

This paper designed a working band is 2.0 GHz ~ 5.0 GHz's new multi-frequency slot antenna, the specific indicators are: center frequency of the work are 2.40 GHz, 3.70 GHz, 4.50 GHz, when the return wave loss is less than -10 dB, the antenna relative bandwidth greater than 3%. Which 2.4 GHz is the common country's ISM band, the current WLAN, ZigBee, Bluetooth and other wireless networks are operating in this band. The design specifications required by the antenna in a relatively wide bandwidth, low relative dielectric constant used here Rogers RT / duroid 5880 material (relative permittivity = 2.2, loss tangent $\tan\delta = 0.009$). The basic size of an ordinary microstrip antenna can be obtained through the transmission line model [10]. To achieve multi-band antenna design, this single point through the coaxial probe feed, use an ordinary rectangular patch in the open C-slot patch structure, design a new type of multi-frequency microstrip antenna. The idea is: add-C radiation plate gap, the gap divides the rectangular patch, the current, thereby increasing the current path, the path of the double bending method of the current multi-band effect. Because the center frequency of the traditional microstrip antenna can be achieved by changing the antenna length, the width of slot change can improve the reflection coefficient and port standing wave ratio; width W the size of the antenna directivity function, input impedance, radiation impedance related. In general, the width of the higher efficiency, wider bandwidth, but the radiant panel is easy to produce high-order mode, caused by field distortion. After the above analysis, the final design of microstrip antenna size: radiant panel size; ground plate size; C-type gap width is 1 mm. Designed planar microstrip antenna shown in Fig. 1.

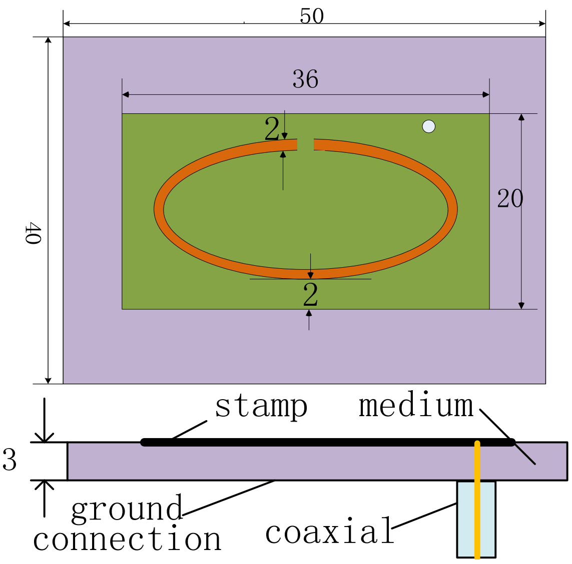

Fig. 1. Top view and side view of the antenna.

2.2. Simulation and Analysis of Frequency Microstrip Antenna

Using Ansoft's electromagnetic simulation software HFSS10.0 on the C-slot microstrip antenna simulation. Antenna return loss graph and the radiation pattern graph are shown in Fig. 2 and Fig. 3.

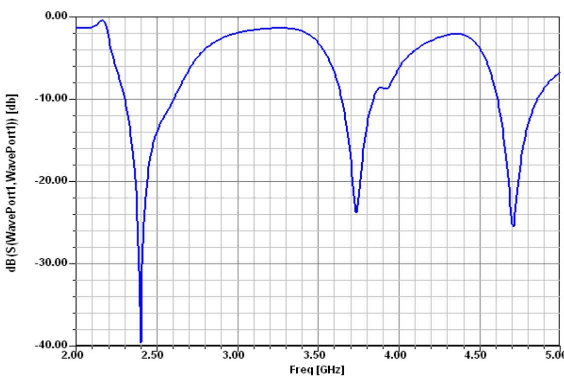

Fig. 2. C-type slot microstrip antenna return loss graph.

It can be seen from Fig. 2, the general C-slot microstrip antenna with multi-frequency performance, the resonance frequencies are 2.40 GHz, 3.73 GHz and 4.71 GHz. When the return wave loss less than -10dB, the antenna bandwidth are 310 MHz (2300 MHz ~ 2610 MHz), 210 MHz

(3640 MHz ~ 3850 MHz) and 250 MHz (4610 MHz ~ 4860 MHz), the relative bandwidth respectively are 12.63 %, 5.61 % and 5.28 %. At the same time, can be seen from Fig. 3, when the frequency is 2.4 GHz, the antenna's main radiation direction of the antenna in the -450~400, 00 when the maximum forward gain is 10.101 dB, the horizontal direction, a gain of -5.777 dB, antenna at this frequency before and after the ratio is 16.134 dB; Antenna resonant frequency is 3.74 GHz at the time of the main radiation direction -450~450, when the antenna has maximum gain decrease of about 7.682 dB, the front ratio about 19.574 dB; and when the frequency attains to 4.71 GHz, the antenna mainlobe split occurred, the antenna's main radiation direction ±450. And the antenna to the direction of radiation and the radiation level is large, the antenna radiation performance is poor, it takes the antenna structural improvements.

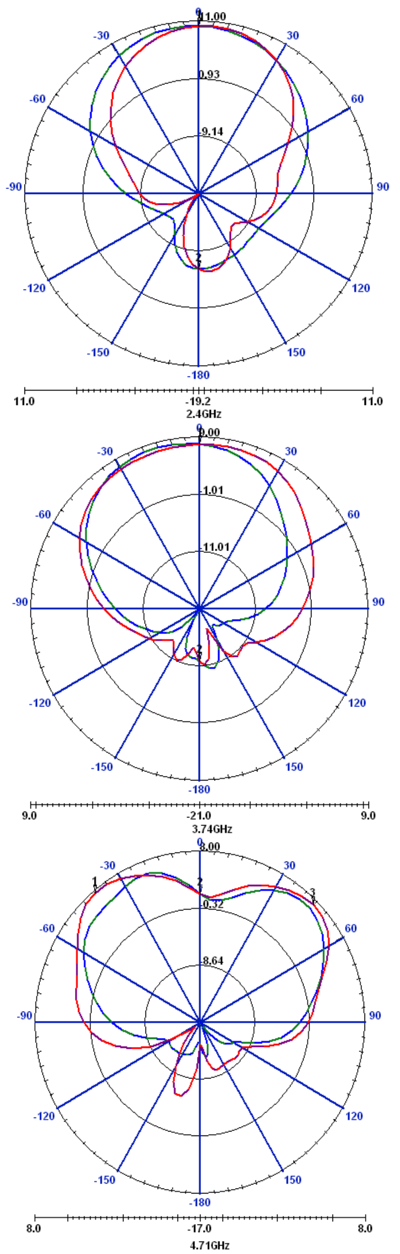

Fig. 3. C-type slot antenna radiation patterns microstrip.

3. PBG Microstrip Slot Antenna's Design

3.1. PBG Antenna Structure's Design

In source microstrip patch antenna, microstrip antenna is not only a radiator, but also a resonator, since the antenna integrated directly with the source devices, source devices are also nonlinear harmonics generated by the antenna radiation out the formation of harmonic radiation antenna, the traditional tuning method is to increase the slip in the short-circuit microstrip branch to achieve, but this will increase the circuit area. To avoid the area increasing, we can use the PBG of the band-stop characteristics make the antenna operating frequency of the harmonic generation, thereby reducing the surface waves and inhibit basal energy loss and improve the antenna radiation efficiency. PBG structure currently used mainly in drilling the base type, ground corrosion, high impedance surface structure and so on, we use the base type of PBG structure drilling program. As the PBG structure will be directly applied to the dielectric substrate of the microstrip antennas, this will not to increase the size of the antenna.

The traditional type of base drilling, that is, the media surrounding the antenna radiation plate substrate to introduce a two-dimensional PBG structure, usually in the substrate can be used in a number of periodic holes drilled (such as round holes, oval holes, square holes etc.) to implement the structure. The properties of photonic band gap crystals with grid constant a, filling factor r / a and dielectric constant and other factors. TM photonic crystals can map to proper selection of the band gap r, a value, so that the antenna operating frequency in the band gap of photonic crystal structures within the substrate to suppress the surface wave antenna to improve the overall performance of the antenna. Gonzalo base through regular periodic air holes drilled in the structure, making the hole-type photonic crystal substrate patch antenna. Gonzalo, who proved that the design of surface wave suppression is very obvious, and weakened the antenna sidelobe back flap, increasing the gain of the forward radiation, but this design likely to cause the base size is too large, the antenna weight increase, so this antenna applications in miniaturization difficult to promote [11].

Compared with the traditional base drilling PBG structure, this paper proposed a PBG structure, which mainly is drill the dielectric substrate that under the PBG antenna radiation board, in order to form the triangular periodic distribution of cylindrical air holes, and the radiant panel grooves dug beneath the dielectric layer, so that including the introduction of photonic crystal defect, and the antenna patch on the bottom of the groove, through the rational design cycle grid size and pore size to obtain the wide band gap, and make the design of the antenna operating frequency falls we calculate photonic crystal within the band, this design in addition to surface wave suppression, can also be seen from Fig. 4, the electromagnetic wave radiation to space the band gap of the photonic crystals will also be the presence of inhibition, so this structure can better focus the radiation, allowing the radiation of space than the patch antenna on the photonic crystal surface on the microstrip antenna to be small.

Based on the above analysis and calculations, we get the results, which is when the triangle side length of cylindrical air gap is 4.33 mm, horizontal distance between the two air band's distance is 10.75 mm, the vertical spacing of 8.25 mm, the antenna's overall performance is good, when the antenna structure shown in Fig. 4 follows (Note: Figure in a radiant panel cylindrical air holes in the bottom of the triangular plate obscured by radiation but not displayed).

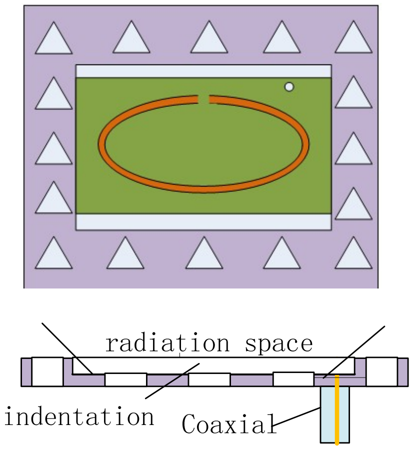

Fig. 4. PBG antenna top view and front view.

3.2 PBG Antenna Simulation

Again simulate the antenna with HFSS10.0, PBG structures can be the antenna return loss of microstrip antenna radiation pattern diagram and are shown in Fig. 5 and Fig. 6 (Note: C-type slot antenna and the PBG structure of the radiation plate antenna size, then the floor size, and thickness of dielectric substrate materials are the same, the specific dimensions described above.)

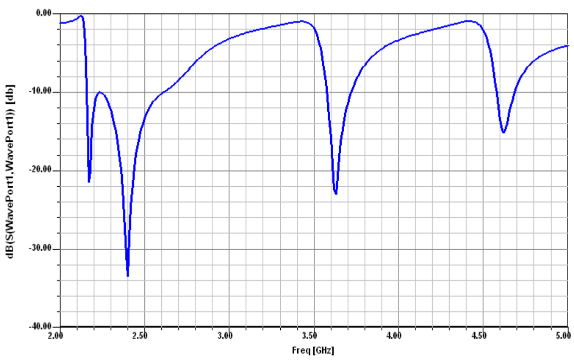

Fig. 5. PBG structure of the antenna return loss graph.

It can be seen from Fig. 5, the introduction of the C-gap PBG structure the resonant frequency of the antenna are 2.17 GHz, 2.40 GHz, 3.63 GHz and 4.62 GHz, respectively, of its -10 dB bandwidth of 450 MHz (2150 MHz ~ 2600 MHz), 140 MHz (3580 MHz ~ 3720 MHz) and 110 MHz (4580 MHz ~ 4690 MHz). It is thus clear, as the PBG structure was added to the C-type slot antenna, the patch antenna return loss has significantly improved. Besides, the low frequency bandwidth was increased to 18.95 %, comparing to 12.63 % of the common C-type slot antenna, and the antenna bandwidth increase by 6.32 %, all of these results achieve the broadband performance of the antenna; at the same time, the resonant frequency of the antenna was reduced by 230 MHz, in order to achieve miniaturization of the antenna miniaturization performance.

Fig. 6 shows the radiation pattern of PBG structure antenna at the resonant frequency. It can be seen from Fig. 6, that after the introduction of PBG structure, the antenna radiation in the work on the consistency of a good band, with and without the introduction of PBG structure compared to the antenna radiation characteristics, antenna gain of the first to have improved. When the operating frequency of 2.17 GHz, the antenna forward gain achieves to 10.382 dB, then the horizontal gain of -20.360 dB, the antenna can be seen in the low frequency side-lobe has been greatly suppressed, and the backward radiation of the antenna is quit small, the front-to-back ratio is around 18.774 dB; antenna at the resonant frequency of 2.40 GHz, it has the coincident radiation pattern with the ordinary slot antenna at the same resonance frequency, in the mean time, the forward gain antenna was increased to 10.533 dB, the front-to-back ratio is about 14.650 dB. Seen after the introduction of PBG structure, the gain of microstrip antennas have a more significant improvement, because the media had a surface wave PBG structure on the inhibition, so that power is no longer part of the strengthening of the back-propagation to the front, thereby reducing the side lobe and back lobe radiation, and enhance the main direction of radiation intensity. However, in the high frequency, the antenna's resonant frequency has decreased, when the frequency is 3.63 GHz, the antenna at -300 when the maximum antenna gain prior to 9.011 dB, and the front-to-back ratio of 22.697, but when the frequency of high frequency 4.62 GHz, the main beam splitting of microstrip antenna which not loaded C-shaped slot can be improved, then the antenna's main radiation direction of -600 to 600, -350 when the maximum antenna gain is 7.810 dB, the ratio is around 16.511 dB. PBG can be seen in the high frequency antenna gain and directivity of radiation have been effective in improving the same time, and after the radiation has also been reduced. Although the whole of the PBG antenna proved effective in the inhibition of surface waves, increase the gain directional antenna radiation and improve the effectiveness and other properties, but the high frequency antenna in the direction of the radiation level has not been inhibited. This is mainly around the PBG structure of radiant panel caused by periodic small. Therefore, to inhibit the substrate in all directions in the surface wave is necessary to introduce the ideal three-dimensional PBG structure.

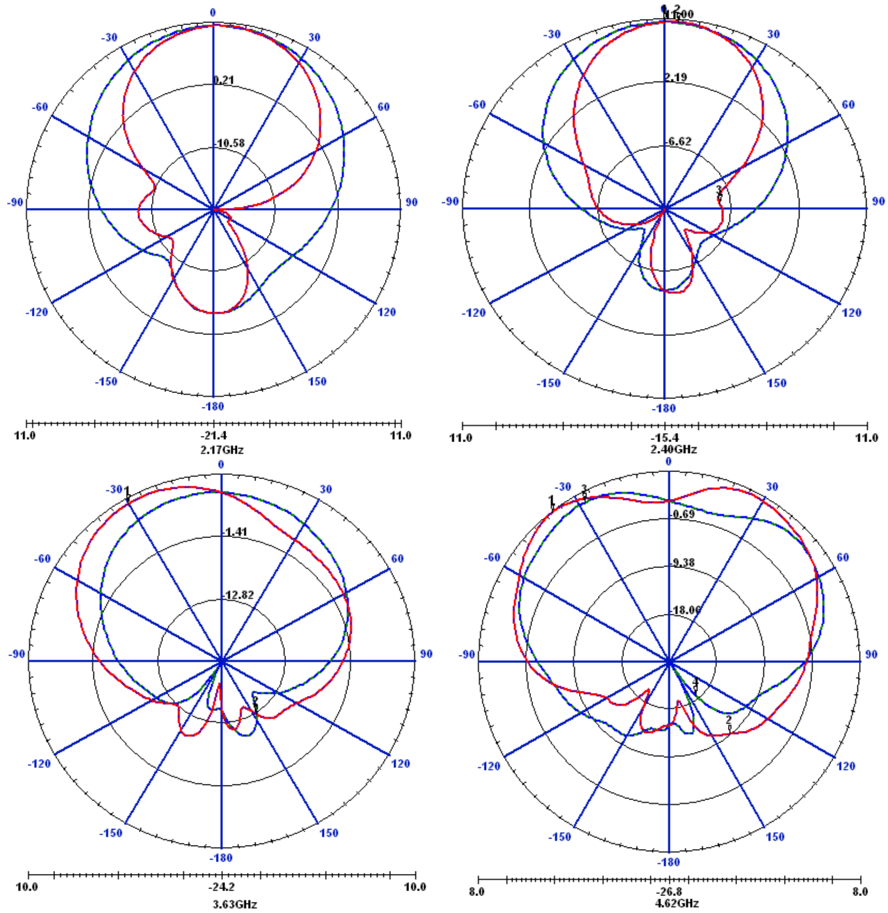

Fig. 6. PBG structure of the antenna radiation's direction.

4. Concluding Remarks

This paper presents a new base drilling photonic crystal substrate patch antenna. Simulation results show that the performance of the PBG structure which we designed is not only to suppress surface wave propagation, to a certain extent, an increasing of the antenna gain, but also increasing the antenna bandwidth in the low frequency by 6.32 %, t same time of improve directionality of the antenna a. This result is better than not only the common C-shaped slot microstrip antenna, but also the author's previous study [12] and some similar design [13]. In addition, the designed PBG structure size relative to the traditional drill-based PBG structure the base, such as reference [14] is smaller, more use of the antenna to achieve miniaturization of photonic crystals. The simple design of the antenna structure, good performance, in the wireless mobile communication system has a good prospect. However, we also note that the high frequency antenna work in a narrow band, and the poor performance of high frequency, so the next step we should focus on produce antenna model, and on how to improve the high frequency of the antenna radiation performance's issue get in depth study.

References

[1]. E. Yablonovitch, Inhibited spontaneous emission in solid state physics and electronics, *Physical Review Letters*, Vol. 58, Issue 20, 1987, pp. 2059-2062.

[2]. D. N. Elsheakh, H. A. Elsadek, and E. A. Abdallah, Investigated new embedded shapes of electromagnetic band gap structures and via effect for improved microstrip patch antenna performance, *Progress in Electromagnetics Research B*, Vol. 20, 2010, pp. 91-107.

[3]. Zhu Fang Ming, The development of novel patch antenna using photonic band-gap structures, *Zhejiang University*, 2008.

[4]. R. Gonzalo, B. Martinez, P. De Maagt, et al, Improved patch antenna performance by using photonic bandgap substrates, *Microwave Optical Technology Letters*, Vol. 24, 1999, pp. 213- 224.

[5]. D. N. Elsheakh and M. F. Iskander, Microstrip array antanna with new 2D-electromagnetic band gap

structure shapes to reduce harmonics and mutual coupling, *Progress in Electromagnetics Research C*, Vol. 12, 2010, pp. 203-213.

[6]. H. R. Cheng and Q. Y. Song, Design of a novel EBG structure and its application in fractal microstrip antenna, *Progress in Electromagnetics Research C*, Vol. 11, 2009, pp. 91-107.

[7]. Guo Yong, Li Yi Mei, Huang Liang, A new patch antenna using UC-PBG substrate, *Chinese Journal of Radio Science*, Vol. 21, No. 5, 2006, pp. 768-770.

[8]. M. Qin, S. He, High-directivity patch antenna with both photonic bandgap substrate and photonic bandgap cover, *Microwave Optical Technology Letters*, Vol. 30, No. 1, 2001, pp. 41-44.

[9]. Z. Ying, R. S. Kidal, Improvement of dipole, helix, spiral, microstrip, patch and aperture antenna with ground planes by using corrugated soft surfaces, *IEEE Transactions on Microwave and Antennas Propagation*, Vol. 143, Issue 3, 1996, pp. 244-248.

[10]. Zhang Jun, Microstrip antenna theory and engineering, *National Defence Industry Press*, 1988, pp. 112-118.

[11]. R. Gonzalo, Peter de Maagt, Mario Sorolla, Enhanced patch antenna performance by suppressing surface waves using PBG substrates, *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, Issue 11, 1999, pp. 2131-2138.

[12]. Yang Hong, Chen Yi Fen, Shao Jian Xing, Analysis and design of an Φ-shaped compact multi-frequency microstrip antenna, *Journal of Chongqing University of Posts and Telecommunications*, Vol. 23, Issue 3, 2011, pp. 315-319.

[13]. Hou Wei Na, Shao Jian Xing, Liu Xiang Mei, A new microstrip antenna design based on photonic band-gap structure, *Journal of Chongqing University of Posts and Telecommunications*, Vol. 21, Issue 6, 2009, pp. 754-756, 763.

[14]. Lin Ruo Bo, Liao Xing Zhan, Chen Xu Wen, Optimizating microstrip antenna based on photonic crystal PBG structure, *Journal of Chongqing University of Posts and Telecommunications*, Vol. 24, Issue 4, 2012, pp. 431-43.
