PERFORMANCE IMPROVEMENT OF SMALL ARRAYS OF MICROSTRIP ANTENNAS ON PHOTONIC BAND GAP SUBSTRATES

T SUDHA AND T S VEDAVATHY

Electrical Commn. Engg. Dept., Indian Institute of Science, Bangalore, India

E-mail: sudha@protocol.ece.iisc.ernet.in, veda@ece.iisc.ernet.in

Patch antennas have some limitations such as restricted band -width of operation, low gain and a potential decrease in radiation efficiency due to surface wave losses. In this paper, the ability of a Photonic Band Gap (PBG) substrate to minimize the surface wave effects is analyzed for a high ϵ_r substrate. Instead of the conventional PBG, a metallodielectric structure is employed. A two element linear array and a four element planar array on the PBG substrate are found to give reduced levels of side lobe radiation, increased directivity and a better front-to-back ratio.

1 Introduction

A common property of most microstrip antennas is that the antenna element launches surface wave modes, in addition to the fields radiated into the space. For finite-size substrates, the surface wave power will diffract from the edges of the substrate, resulting in disturbance of the radiation pattern. The excitation of the surface waves also results in increased mutual coupling between antenna elements. Suppression or reduction of surface waves improves antenna efficiency and reduces side lobe level. Other favorable effects brought by surface wave suppression are the reduction of unwanted mutual coupling between array elements and interference with on-board systems.

Photonic crystals (PC) can offer a real solution to the surface wave problem [1-3]. PCs are a class of periodic metallic, dielectric or composite structures that exhibit pass and stop bands in their frequency response. Because of this they offer the property to forbid the propagation of the electromagnetic waves whose frequency is included within their stop band-so called Photonic Band Gap (PBG). Hence if the substrate is periodically loaded to create a PBG crystal in such a way that the frequency of the substrate mode overlaps the stop band frequency of the crystal, the excited substrate mode exponentially decays thus reducing the energy lost into the substrate. Thus an increased amount of radiated power couples to space waves and this mechanism has the effect of reshaping the antenna pattern [2-3]. From large-scale study made regarding the influence of the lattice shape, size and shape of the atoms, large circular holes on a triangular lattice found to give a large PBG, common for both TE and TM polarization. The triangular lattice is chosen because it has proved capable, in the simpler case of a 2-D PBG, of providing a stop band for any in plane ($\beta_z=0$) direction of propagation due to the high symmetry of the Brillouin zone (BZ) associated to it. While a PC structure, such as a substrate with holes, could be thought of as a non-isotropic medium, the anisotropy is introduced into the equations through the positional dependence of the dielectric constant, ϵ :

$$\mathbf{D}(\mathbf{r}) = \epsilon(\mathbf{r})\mathbf{E}(\mathbf{r}), \quad (1)$$

where $\mathbf{D}$ is the electric flux density and $\mathbf{E}$ is the electric field. The Brillouin zone for the triangular lattice is a hexagon (Fig.1). A band gap in the dispersion curves will show up at the BZ boundary, $\beta \cdot \mathbf{a} = q$ where ' β ' is the propagation vector and ' $\mathbf{a}$ ' is the lattice constant of the crystal. If we consider the two directions of propagation corresponding to the edges ΓK and ΓM of the Brillouin zone, the gaps should appear at the vertexes M and K. Since the values of the ratio of the radius of the hole(r) to the lattice constant is usually high for getting good band gap, the frequencies corresponding to β at M or K can be estimated by resorting to the concept of effective dielectric constant, ϵ_{eff} of the perforated substrate. Using the quasi-static volumetric principle for the case of triangular lattice, ϵ_{eff} is given by

$$\epsilon_{eff} = \epsilon_i [1 - 2\pi r^2 / \sqrt{3} a^2] \quad (2)$$

The values of ' $\mathbf{a}$ ' providing a stop band centered on f_0 for propagation for the two directions are given by [4]

$$a = 4\pi/3\beta(f_0) \text{ along } \Gamma K \quad (3)$$

$$a = 2\pi/\sqrt{3}\beta(f_0) \text{ along } \Gamma M \quad (4)$$

Fig. 1 Brillouin Zone of

Since lowest mode surface wave is present along the ΓM direction we can take that value as a starting value of 'a'. It can be optimized for maximum band gap by studying the transmission characteristic of the PBG structure. Conventional PCs are made of two different dielectric materials, arrayed in a periodic lattice. Wide crystal variety can be added to existing structures by introducing both dielectric and metal components in a unit cell thus making them metallodielectric photonic crystals. A theoretical study of a PBG structure in 2-D metallodielectric PC that consists of square arrays of dielectric and perfectly conducting cylinders is reported in [5]. It is showed that introducing metallic cylinders in dielectric crystals can generate PBG, even when the dielectric PC exhibits no full band gap. Metallic implants also help surface wave mode elimination in all directions. Because of its large imaginary dielectric constant metallic core reflects radiation very efficiently at least at microwave and millimeter-wave frequencies, if it is surrounded by loss less dielectric. This enhances the rejection in the stop band. One of the best features of microstrip antennas is the ease with which they can be formed into arrays and a wide variety of arrays have been designed using microstrip elements. Most of the PBG applications reported are for single antennas and very little effort is devoted to arrays of microstrip antennas. It is clear that PBG structures offer promising potential applications in array configurations, increasing the antenna efficiency together with the suppression of its mutual coupling through the substrate material. In this work, the improvements in the radiation characteristics are studied for a 2-element linear array and a 4-element planar array, made on a 50mil thick substrate with ϵ_r of 10.2 and loss tangent 0.0023 loaded with a 2D triangular lattice of cylinders. With the conventional dielectric PC here a two dimensional metallodielectric PC is also used to obtain the band gap. The results showed reduced surface wave propagation along the PBG substrate resulting in improved gain and an increase in bandwidth. It is also established that introducing metallic cylinders in dielectric crystals is more effective in suppressing side lobe radiation.

2 Antenna Design & Analysis

The array geometry consists of rectangular patch elements designed to work at 9GHz on a finite grounded substrate of 50 mil thick and having ϵ_r of 10.2. The patch elements are excited with opposite feed locations in the H-plane and same locations in the E-plane. The radiation characteristics of this antenna on a $2.1\lambda_0 \times 2.2\lambda_0$ ground plane at 9GHz for element spacings of $\lambda_0/2$ is analyzed on the PBG substrate. The substrate is made to a PBG structure by drilling triangular lattice of air holes in it. The lattice constant (a) is selected as 1.38 cm, which is already proved to give a gap at approximately 9GHz[1]. The radius of the holes is selected such that $r/a=0.48$ for getting maximum gap. This substrate is later converted as a metallodielectric PBG structure by introducing triangular array of air and perfectly conducting cylinders (PEC) in it. The antenna analysis is done with normal and PBG substrates, the later consist of air holes only and having air and perfectly conducting cylinders, with all the dimensions of the structures exactly the same. HFSS- a full-wave em simulator based on FEM in association with proper absorbing boundary conditions is used to analyze the structure. Convergence and minimization of errors is obtained by ensuring that enough iterations are used.

3 Simulation Results

3.1 Two element array

The geometry of the antenna is shown in Fig.2 and the return loss characteristics in fig.3.

Fig. 2 PBG 2-element Antenna Array

Fig. 3 Return Loss Characteristics

From Fig.3 it is seen that the bandwidth for $VSWR < 2$, is improved from 2.72% to 3.64%. The radiation pattern of the array is shown in Fig.4 (a) and (b). It is clear that the metallodielectric PBG (PBG2) shows more surface wave suppression than air PBG (PBG1). With bigger ground planes the back lobe level can be further improved, but the side lobe remains at about the same level.

Fig.4. (a) Comparison of E-Plane Patterns
(b) Comparison of H-Plane Patterns

3.2 Four element array

The geometry of the antenna is shown in Fig.5 and the return loss characteristics in fig.6.

Fig. 5 PBG Antenna Array

Fig. 6 Return Loss Characteristics

There is a bandwidth improvement from 2.75% to 3.32%. The radiation patterns of the array are given in Fig. 7. With the PBG2 antenna the side lobes are reduced in both the planes. Table. 1 shows the results of the investigations for both arrays. It is seen that PBG, thus helps to reduce all the unwanted effects of surface waves and at the same time improves the directivity and gain of the antenna.

Fig. 7 (a) Comparison of E-Plane Patterns
(b) Comparison of H-Plane Patterns

Antenna Parameters	2-Element Linear Array			4-el		
	Normal Substrate	Air	Metallo-dielectric	Normal Substrate	Air	Metallo-Dielectric
Directivity(dB)	8.61	9.09	9.72	12.11	12.49	12.90
Gain(dB)	8.11	8.65	9.37	11.52	11.9	12.48
B-W (%) (VSWR<2)	2.72	3.6	3.64	2.75	3.26	3.32
Sidelobe(dB) E-plane	-11	-13	-16	-11	-13	-16
H-plane	-13	-13	-14	-20	-20	-24
Backlobe(dB) E -plane	-20	-22	-22	-22	-25	-25
H-plane	-24	-24	-25	-21	-24.5	-24.5

Table 1: Comparison of the parameters of antenna arrays on normal and PBG substrates

4 Conclusion

It is observed from the results that the radiation characteristics of an array on PBG substrate are remarkably improved as compared to a conventional array and this is attributed to the surface wave reduction by introducing PBG. Thus the use of PBG is advantageous for integrating antenna on high ϵ_r substrates without losing performance. It also reduces unwanted coupling between nearby systems since it reduces back radiation and surface waves along antenna substrate. The results show introducing metallic cylinders in dielectric crystals is more effective in suppressing side lobe radiation than a structure having only dielectrics. Future applications in array configurations are under study for beam steering and gain enhancement.

References

- [1] J D Joannopoulos, R D Meale, J N Winn, "Photonic Crystals: Modeling the flow of Light," Princeton University Press, New Jersey, 1995
- [2] Y Qian, R Coccioli, D Sievenpiper, V Radisic, E Yablonovitch, T Itoh, "Microstrip patch antenna using novel PBG structures," Microwave Journal, Vol. 42, No. 1, pp. 66-76, Jan 1999
- [3] Ramon Gonzalo, Peter de Maagt, Mario Sorrolo, "Enhanced Patch antenna performance by suppressing surface waves using PBG substrates," IEEE trans. Microwave Theory & Tech., Vol. 47, No. 11, pp. 2131-2138, Nov. 1999
- [4] Roberto Coccioli and Tatsuo Itoh, "Design of photonic band-gap substrates for surface waves suppression," IEEE MTT-S Digest, pp. 1259-1262, 1998.
- [5] Toshio Suzuki and Paul K.L. Yu, "Existence of photonic band gaps in two dimensional metallodielectric photonic crystals," Electromagnetics, pp. 321-335, 1999