

An Improvement of Antenna Bandwidth in Microstrip Patch Antenna with the Insertion of PBG Structure

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Abstract-Antenna design has grown more stringent and difficult over the years as the world becomes strictly a wireless environment. In order to overcome the limitations of microstrip antennas such as narrow bandwidth, lower gain, excitation of surface waves etc, a new solution method; using Photonic Band Gap (PBG) materials, as substrates has attracted increasing attention. These periodic structures have the unique property of preventing the propagation of electromagnetic waves for specific frequencies and directions which are defined by the shape, size, symmetry, and the material used in their construction. The aim of this project is to design, simulate and fabricate the new PBG structure operating at 7.5GHz frequency and study the performance of the rectangular microstrip antenna (RMSA) with and without PBG structure.

I. INTRODUCTION

A microstrip antenna (MSA) consists of a conducting patch of any planner or non-planner geometry on one side of a dielectric substrate with a ground plane on the other side. In spite of their various attractive figures like low profile, light weights, low cost, easy fabrication and so on, the microstrip elements suffer from an inherent limitation of narrow impedance bandwidth and low gain in the order of 6dB [1]. So, widening the bandwidth of microstrip elements has become a major branch of activities in this field. Use of the photonic band gap (PBG) structures as antenna substrates is one promising solution to this problem and thus it attracts a large fraction of antenna people to work with PBG [2].

II. PHOTONIC BAND GAP (PBG) STRUCTURE

A. Introduction

Conventionally, in order to achieve small size and broadband operation patch antenna are fabricated on a thick piece of high permittivity substrate. But in this case, unwanted substrate modes begin to form and propagate towards the edges of the substrate, which have a deleterious effect on the antenna radiation pattern. In the 1990s, researches suggested the introduction of a photonic band gap structure into the printed antenna substrate, which saw the capability of removing unwanted substrate modes. This PBG substrate consists of the periodic arrangement of air-columns into the substrates.

B. Formation of surface wave

As a patch antenna radiates, a portion of the total available power for direct radiation becomes trapped along the surfaces of the substrate. This trapped electromagnetic energy leads to

the development of surface waves. In fact, the ratio of power that radiates into the substrate compared to the power that radiates into air is approximately $(\epsilon : 1)$. This is governed by the rules of total internal reflection, which state that any field line radiated into the substrate at angles greater than the critical angle ($\theta_c = \sin^{-1}(\epsilon^{-1/2})$) are totally internally reflected at the top and bottom surfaces. This is illustrated in “Fig. 1”. Therefore, for a substrate with dielectric constant $\epsilon = 10.2$, nearly 1/3 of the total radiated power is trapped in the substrate with critical angle of roughly 18.2 degrees[3].

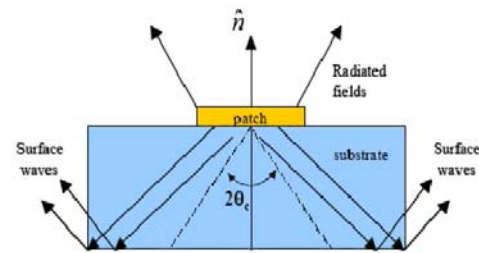


Figure 1. Field lines radiating from a patch antenna; illustrates the formation of surface waves

C. Photonic Band Gap Structure

The first PBG structure conceptualized and manufactured was in 1991 by Eli Yablonovitch, then at Bell Communications Research in New Jersey. Yablonovitch fabricated the crystal structure by mechanically drilling holes a millimeter in diameter into a high dielectric constant material. In most communication applications, a 2-D photonic crystal, the band gap exists within a plane, thereby allowing propagation along one axis of the crystal. This is the ideal scenario for microstrip antenna designs, since the “rejection plane” could be in the plane of the patch to prevent surface wave’s formation.

D. Unit cell of Photonic Crystals

As stated in the American Heritage Dictionary, a crystal is “a homogenous solid formed by a repeating, 3-D pattern of atoms, molecules or shapes, having fixed distances between constituent parts”. This replicating pattern is referred to as the unit cell of a crystal. “Fig. 2” illustrates the unit cell for the triangular crystal lattice. The unit cell contains all the pertinent information of the crystal such as the crystal geometry (shape, thickness etc.), material properties (dielectric or magnetic), and the lattice spacing (shown as the dimension, lattice constant,

‘a’ in the figure) of each individual atom or molecule. It is this replicating unit cell that provides the periodicity in the crystal and controls the location and extent of the bandgap.

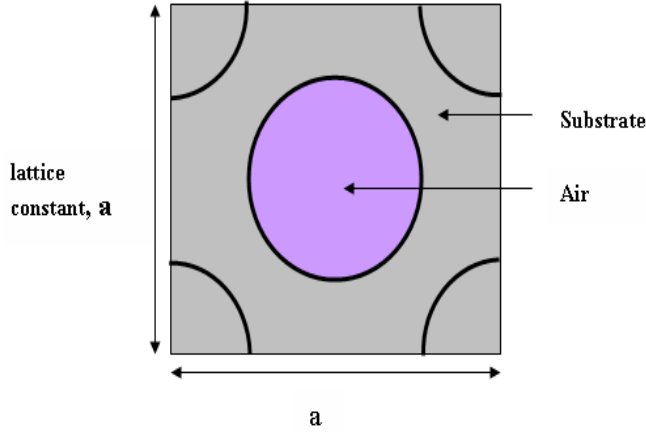


Figure 2. Top view of the unit cell of triangular crystal lattice

E. The Bandgap

As a first order approximation, a bandgap is obtainable in a high dielectric material with integrated photonic crystals when an incident electromagnetic field propagates with a guide-wavelength approximately equal to the lattice spacing of the crystal [4]. This rough approximation locates the center of the bandgap, which can be higher than $\pm 10\%$ of the center frequency for high index materials. Indeed, the formation of the bandgap is dependent on the periodicity of the crystal, but it is also heavily dependent on the refractive index (dielectric constant) ratios between the base material (the substrate) and the impurities that form the crystal. Typically, the refractive index ratio must be at least 2:1 (substrate-to-impurity) ratio for the bandgap to exist [5]. For the 2-D triangular structure, the broadest bandgap is obtainable when the impurities (the cylindrical post) are of air ($\epsilon_r = 1$), while the base material is a high dielectric constant (for example, $\epsilon_r = 10$). A 10:1 dielectric (3.16:1 refractive index) ratio would satisfy the index requirement and form a broad bandgap, with proper crystal spacings. This explains the need for a high dielectric substrate for a patch antennas designed on a photonic crystal substrate.

III. TRANSLIGHT 3.01B (BANDGAP ANALYSIS SHAREWARE)

Numerical evaluation of the location and extent of the bandgap is performed using software called Translight©, a shareware graphic-user interface (GUI) distributed through the Department of Electronics & Electrical Engineering at the University of Glasgow. It was developed by Dr. Andrew L. Reynolds of the same department of the University of Glasgow. The code uses user definable “building blocks” or the unit cells, which are cascade in any direction to form photonic crystals. The software computes the reflection and transmission coefficients as electromagnetic signals are applied, at multiple angles of incidence, to the photonic crystal and output the size of the crystal.

IV. MSA ON PBG STRUCTURE DESIGN

Here a microstrip patch antenna is designed on a 2-D single-period PBG structure. The PBG layer is sandwiched between the patch and the ground plane, as shown in “Fig. 3”. The patch antennas on the single period PBG structure were evaluated using the HFSS (High Frequency Structural Simulator). The conventional patch antenna, which is designed for comparison with the proposed patch antenna on the sandwiched single-period PBG, is shown in “Fig. 4”.

TABLE I

CONVENTIONAL MSA CONFIGURATION

Parameter	Value
Height, h	0.6 mm
Width, W	8.5 mm
Length, L	6.6 mm
Relative Permittivity, Rogers RT/duroid 6010	10.2
Feedline	32.6 mm
Feed width	2.6 mm

Here, in HFSS modeling 7.5 GHz resonance is examined. The substrate dimensions are 72 mm by 96 mm, with the thickness of 0.6 mm, a permittivity 10.2 and a loss tangent 0.0023. The substrate is based on the infinite ground plane on 72 mm x 96 mm platform. The patch dimensions are 6.6 mm x 8.5 mm and an air-box surrounding the antenna providing a radiation boundary is 72 mm x 96 mm x 10.6 mm. The patch is fed by a microstrip feed-line which is excited by a lumped port of 32.6 mm by 2.6 mm and directly unite to patch from its source with an impedance of 50 Ω . Both patch and the feed-line is made of ‘pec’ substrate with bulk conductivity 1e+030 Siemens/m. From the Translight 3.01b software we get the size of the cylindrical crystal is stated below:

Lattice Constant, $a = 12$ mm

Crystal diameter, $d = 6$ mm

Crystal height = 0.59 mm

Number of the crystal = $(8 \times 6) = 48$

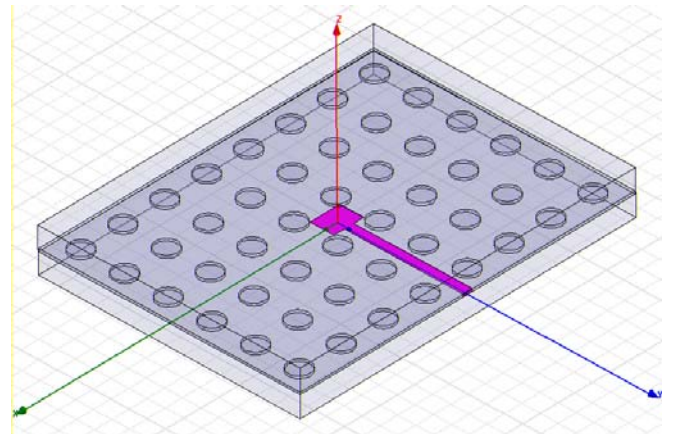


Figure 3. 3D View of PBG structured MSA

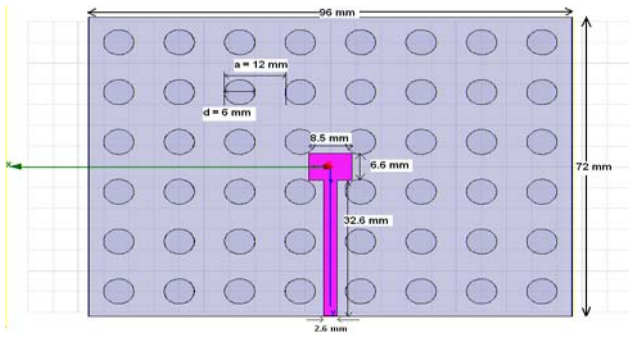


Figure 4. Top View of PBG structured MSA

V. RESULT ANALYSIS AND DISCUSSION OF CONVENTIONAL MSA

From frequency sweep, in “Fig. 5”, plotting the S_{11} versus frequency reveals the 7.42 GHz resonance at a return loss of -11.75dB. If we consider the return loss of -6dB we get 190MHz bandwidth and if we consider the return loss of -10dB we get 80MHz bandwidth from the conventional patch antenna

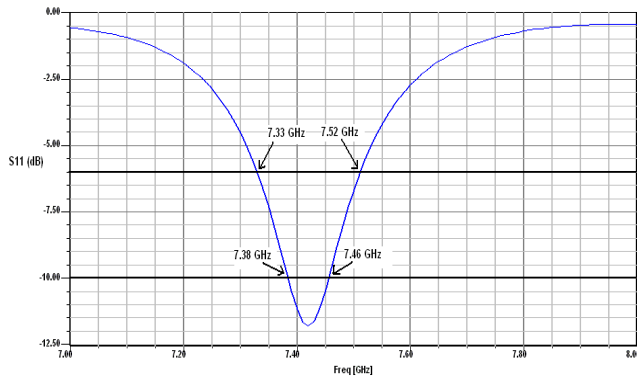


Figure 5. S_{11} – Freq Graph of Conventional MSA

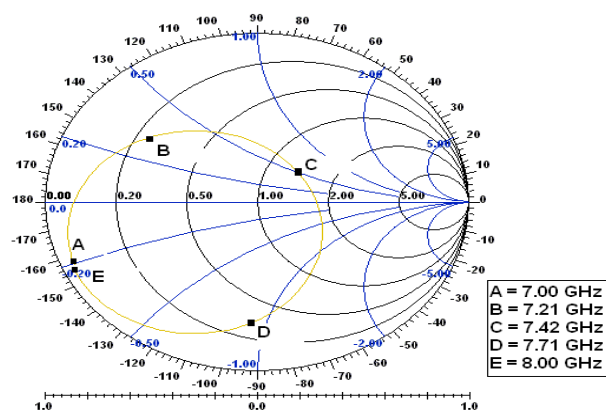
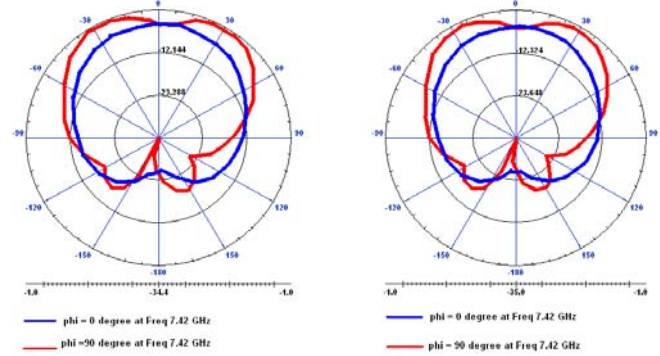


Figure 6. Smith Chart of Conventional RMSA

design. The S_{11} is plotted on the Smith Chart in “Fig. 6”, and the frequency where the impedance becomes purely resistive is the resonant frequency of the patch. “Fig. 6” also shows the

VSWR is 1.692 and the Q factor is 0.396. The normalized impedance of the antenna is $1.318+j0.522$.



(a) Directivity (H-plane in blue and E-plane in red) of conventional RMSA at 7.42 GHz (b) Gain (H-plane in blue and E-plane in red) of conventional RMSA at 7.42 GHz

VI. RESULT ANALYSIS AND DISCUSSION OF PBG STRUCTURED MSA

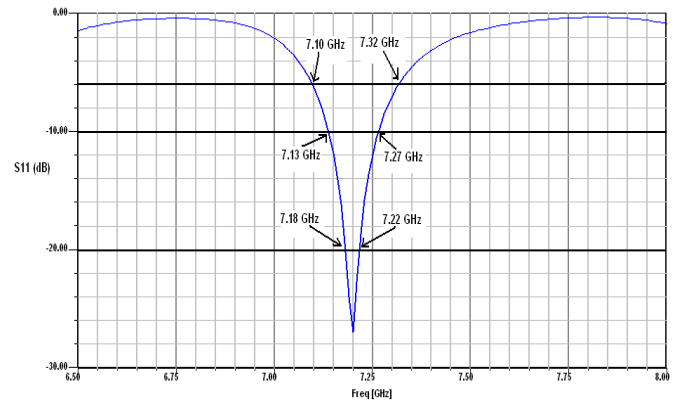


Figure 8. S_{11} – Freq Graph of PBG structured MSA

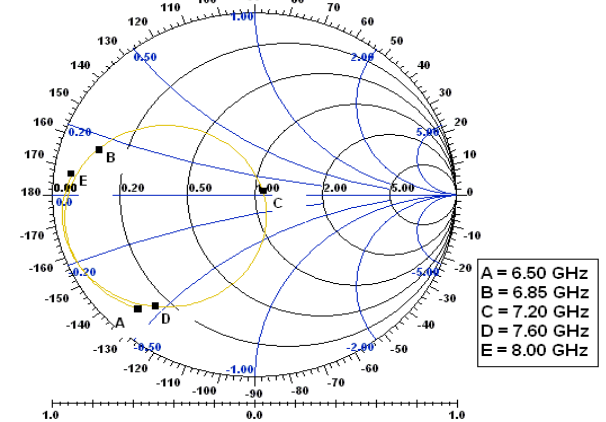


Figure 9. Smith Chart of PBG structured MSA

From frequency sweep, in “Fig. 8”, plotting the S_{11} versus frequency reveals the 7.20 GHz resonance at a return loss of -27dB. If we consider the return loss of -6dB we get 220MHz bandwidth and if we consider the return loss of -10dB we get 140MHz bandwidth and if we consider the return loss of -20dB we get 40MHz bandwidth from the PBG structured patch antenna design. The S_{11} is plotted on the Smith Chart in “Fig. 9” and the frequency where the impedance becomes purely resistive is the resonant frequency of the patch. “Fig. 9” also shows the VSWR is 1.093 and the Q factor is 0.011. The normalized impedance of the antenna is $1.092 + j0.012$.

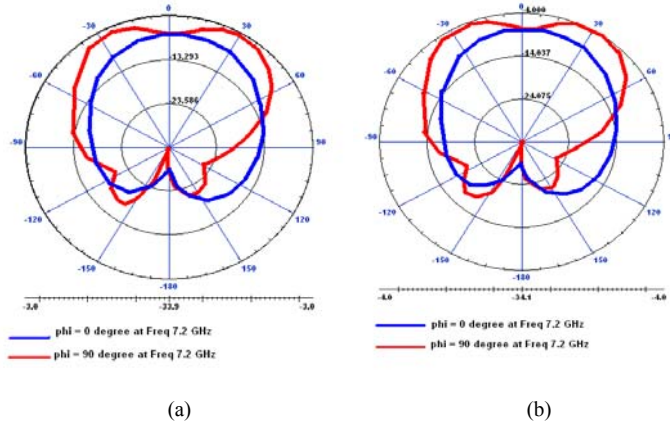


Figure 10. (a) Directivity (H-plane in blue and E-plane in red) of PBG structured MSA at 7.2 GHz (b) Gain (H-plane in blue and E-plane in red) of PBG structured MSA at 7.2 GHz

VII. RESULT COMPARISON BETWEEN CONVENTIONAL AND PBG STRUCTURED MSA

From the Table II it is clearly shown that in PBG structured MSA BW enhancement occurred at $S_{11} < -6\text{dB}$ is 15.8% and at $S_{11} < -10\text{dB}$ is 75% than in conventional MSA. At $S_{11} < -20\text{dB}$ the PBG structured MSA has 40 MHz while the conventional MSA doesn't have that at all. Of course, there is no significant Directivity enhancement but Gain enhancement is 2.38%. Q factor lowering is 97.22% which is very remarkable. In both case, VSWR is 1.692 in conventional MSA and 1.093 in PBG structured MSA shows second one has better impedance matching.

TABLE II
OUTPUT COMPARISON OF CONVENTIONAL AND PBG STRUCTURED MSA

	Without PBG at 7.42 GHz	PBG at 7.20 GHz
BW, $S_{11} < -6\text{dB}$	(7.52-7.33) GHz = 190 MHz	(7.32-7.10) GHz = 220 MHz
BW, $S_{11} < -10\text{dB}$	(7.46-7.38) GHz = 80 MHz	(7.27-7.13) GHz = 140 MHz
BW, $S_{11} < -20\text{dB}$	N/A	(7.22-7.18) GHz = 40 MHz
Directivity	21 dBi	21 dBi
Gain	21 dBi	21.5 dBi
Q factor	0.396	0.011
VSWR	1.692	1.093
Impedance (Normalized)	$1.318 + j 0.522$	$1.092 + j 0.012$

VIII. CONCLUSION

This type of antenna mostly used in modern mobile communication in microwave backbone transmission. The number of array element probably five or nine or more. From the design view point the PBG structured MSA is certainly wider the bandwidth than the conventional MSA.

ACKNOWLEDGEMENT

This paper is written from my M.Sc. research on bandwidth enhancement techniques in MSA where my supervisor Professor Dr.Md. Ruhul Amin has immense contribution. The simulation and the results are analyzed in HFSS simulator of Ansoft corporation and Translight freeware by Dr. Raynolds of University of Glasgow.

REFERENCES

- [1] R. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, “Microstrip Antenna Design Handbook”, Artech House, 2001.
- [2] Y. Horii, and M. Tsutsumi, "Harmonic control by photonic bandgap on microstrip patch antennas," IEEE Microwave and Guided Wave Lett. , vol. 9, No.1, pp. 13-15, Jan.1999.
- [3] C.Y. Huang, J.Y. Wu, C.F. Yang, and K. L. Wong, “Gain-enhanced compact broadband microstrip antenna,” Electronic Letters., vol. 34, pp. 138-139, Jan. 1998.
- [4] Radisic and Qian, “Novel 2-D Photonic Bandgap Structure for Microstrip Lines.” IEEE Microwave and Guided Wave Letters, vol. 8, 1998.
- [5] Parker and Charlton, "Photonic Crystals," Physics World, 2000.
- [6] Keith C. Huie, “MSA: Broadband Radiation Pattern; Using Photonic Crystal Substrates”, Virginia Tech, Blacksburg, VA, USA.
- [7] Girish Kumar and K.P. Ray, “Compact and Broadband Microstrip Antenna”, Artech House, 2005.