Enhanced Performance of a Microstrip Patch Antenna using a High Impedance EBG Structure

M. Fallah-Rad* and L. Shafai
Department of Electrical and Computer Engineering
The University of Manitoba
Winnipeg, Manitoba, Canada, R3T 5V6
mehran@ee.umanitoba.ca shafai@ee.umanitoba.ca

I. Introduction

Recently, there has been extensive research on electromagnetic band gap structures (EBG's) and their applications in microstrip antennas and transmission lines. 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. Some EBG structures include drilled holes in dielectrics, patterns etched in the ground plane, and metallic patches placed around microstrip structures. The structure studied in this paper consists of metallic patches with center vias connecting the patches to the ground plane. The properties of this 2D structure are studied using the Ansoft Ensemble simulator which is based on the method of moments (MOM). The effects of the EBG on the gain, radiation pattern, and resonant frequency of a patch antenna are investigated. It is shown that by placing a single layer of EBG around a patch antenna, significant improvements in the gain and radiation pattern can be achieved. Additionally, the back radiation due to the finite ground plane can be reduced significantly.

II. The EBG Structure

The geometry of the two-dimensional EBG structure is shown in Fig. 1. If the dimensions of this structure are small compared with the wavelength, the impedance of the structure can be modeled by an equivalent parallel resonant LC circuit [1]. The inductance of the circuit is due to the shorting vias, while the capacitance is due to the spacing between the adjacent metal patches. At resonant frequency, the surface impedance becomes very high and this is associated with the band gap of the structure [1]. In order to find the band gap of this geometry, Ansoft Ensemble was used to measure the reflection vs. frequency, due to an incident wave on the structure. At resonance, one would expect reflection of the incident wave due to the high surface impedance. For the EBG design, we are interested in the stopband of the TM surface mode, which propagates along the surface of the dielectric and has no cutoff frequency [2]. The surface waves are generated from the patch antenna and hence there is a power loss associated with them. By placing the EBG structure around the patch, the surface waves are forced to radiate. However, the radiated fields from the EBG must add co-phasally to the patch radiation to improve the gain or lower the side and back radiations. The relative placement of the EBG with

0-7803-7846-6/03/$17.00 ©2003 IEEE

respect to the patch is therefore important and investigated in this study. The dielectric material used here for the simulation of the EBG's has a permittivity of 3.2 and a thickness (h) of 1.59 mm. An example of the radar cross section of the TM mode for two different EBG structures is shown in Fig. 2. The first case uses metal patches of dimensions 6 mm by 6 mm and the second uses patches of dimensions 8 mm by 8 mm. For both cases, the spacing between the edges of the adjacent patches is 0.2 mm and the vias used have a radius of 0.6 mm. The radar cross sections (RCS) shown are for the TM modes looking in the same direction as the incident wave, i.e. the back scattering cross section. As it can be seen, the RCS for the design with dimensions of 6 mm by 6 mm has peak reflections between 6.25 to 8.5 GHz, and another peak between 10.25 to 14.75 GHz. As expected, the structure with metal patches of size 8 mm by 8 mm has peak reflections occurring at lower frequencies due to the increase in capacitance of the structure. For the 8 mm by 8 mm patch, the first reflection peak occurs between 4.75 to 6.25 GHz, and second between 8 to 11.75 GHz.

III.Application of the EBG Structure in a Microstrip Patch Antenna

Since, the RCS of the 8 mm by 8 mm EBG structure has a peak reflection between 4.75 and 6.25 GHz, the fabricated patch was designed to operate at 5.6 GHz. The patch is probe fed and has dimensions L = 14 mm, W = 20. The dielectric material has a permittivity of 3.2, and a thickness of 1.59 mm. The ground plane is finite for this patch and has dimensions 80 mm by 80 mm (1.5λ). The measured gain pattern of the fabricated reference antenna in the E and H-planes are shown in Fig. 3a and 3b respectively. As it can be seen from the gain plots, the co-polar E-plane pattern is wider than the co-polar H-plane pattern and has a dip at $\theta = 0$ which, is due to the size of the finite ground plane. There is also a large amount of back radiation caused by the diffraction from the finite ground plane edge. The back radiation levels reach as high as -4 dBi at $\theta = 100$ degrees.

Next, a single layer of EBG was placed around the patch antenna (Fig. 4a). This provided the highest gain compared with a multilayered structure. The use of the EBG around the patch caused a shift in the resonant frequency of the patch as shown in Fig. 4b. This change in the resonant frequency can be adjusted by moving the EBG structure away from the antenna and leaving a gap between the antenna and the shorted metal patches. The EBG structure shown in Fig. 4 has metal patches of dimensions 8 by 8 mm and spacing of 0.2 mm with the RCS shown in Fig. 2. The E and H-plane patterns of the EBG patch antenna are shown in Fig. 5a and 5b. The gain of the patch is increased from 4.1 dBi to 7.54 dBi, and the radiation pattern of the co-polar E-plane has improved significantly. Unlike the pattern for the reference patch shown in Fig 3, the E-plane co-polar pattern is narrower than the H-plane co-polar pattern for the EBG patch antenna, and the dip at $\theta = 0$ degrees has disappeared. In addition, the back lobe radiation in the E-plane has dropped significantly to -14 dBi compared with -4 dBi at $\theta = 0$. The slight change in the H-plane cross-polar levels of the EBG antenna can be adjusted by moving the EBG structure away from the patch in the x-direction without affecting the over all gain. By moving the EBG structure away from the patch in the y-direction, the gain of the antenna drops and the resonant frequency shifts down as expected. Table 1 shows a comparison of the simulated and fabricated reference and EBG antennas. The slightly lower gain values of the fabricated antennas are due to the loss tangent, tanδ = 0.01, of the substrate used in fabrication. Overall, good agreement between the simulated and fabricated results is observed.

Table 1. Comparison of the fabricated and simulated reference and EBG antennas

EBG Antenna	*f_r (GHz)*	*Gain at θ=0 (dBi)*		*Reference Antenna*	*f_r (GHz)*	*Gain at θ=0 (dBi)*
Fabricated	5.72	7.54		Fabricated	5.46	4.09
Simulated	5.78	7.76		Simulated	5.6	4.3

IV.Conclusion

In this paper, the properties of an EBG structure consisting of metal patches with grounding vias were studied. The implementation of the EBG structure in the design of a patch antenna showed a significant improvement in the gain values. An increase of 3.4 dBi in the gain value was obtained while the back lobe radiation level was reduced significantly.

References

[1] D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-Impedance Electromagnetic Surfaces with a Forbidden Frequency Band", IEEE Transactions on Microwave Theory and Technique, VOL. 47, NO. 11, November 1999.
[2] D. M. Pozar, "Microwave Engineering", John Wiley and Sons, Inc. 2nd edition, 1998.

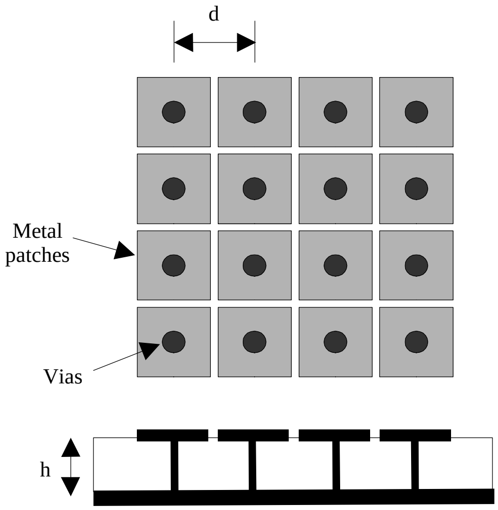


Fig. 1 Geometry of the EBG structure

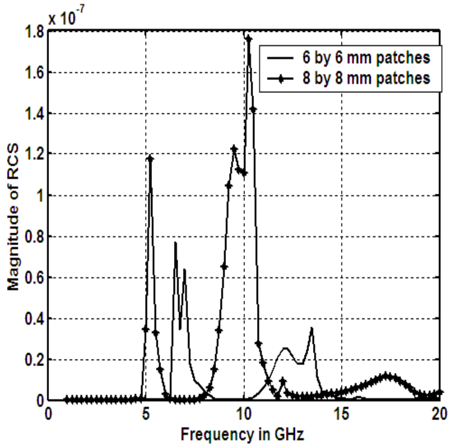
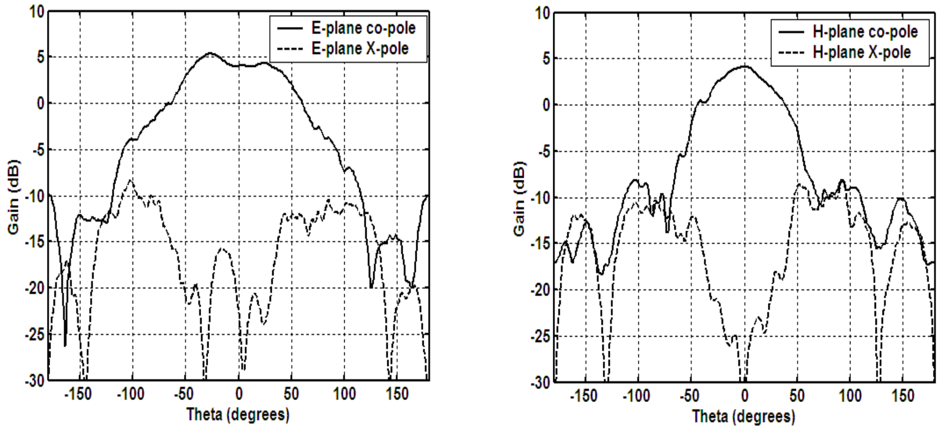


Fig. 2 Magnitude of RCS vs. frequency for the two different metal patch sizes (wave incident horizontally)



(a) (b)

Fig. 3 Radiation patterns of the fabricated reference antenna with L = 14 mm,W = 20 mm, $\varepsilon_r = 3.2$, h = 1.59 mm at 5.45 GHz (a) E-plane patterns (b) H-plane patterns

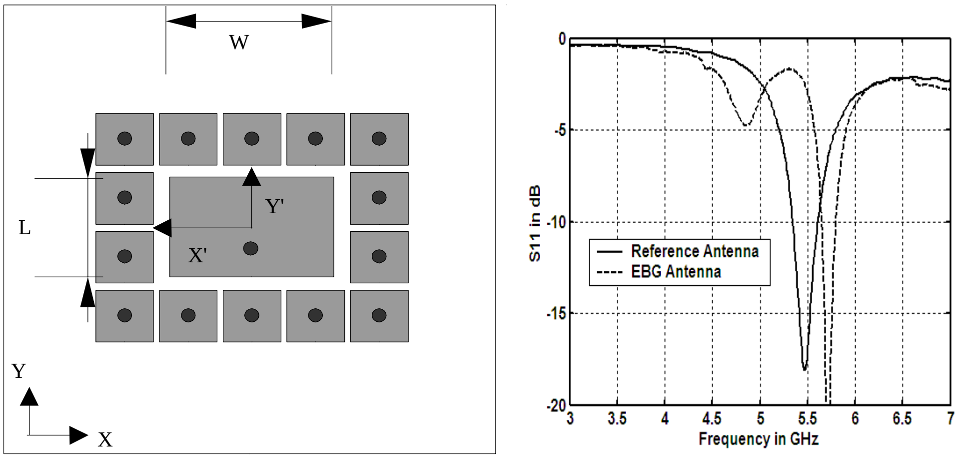
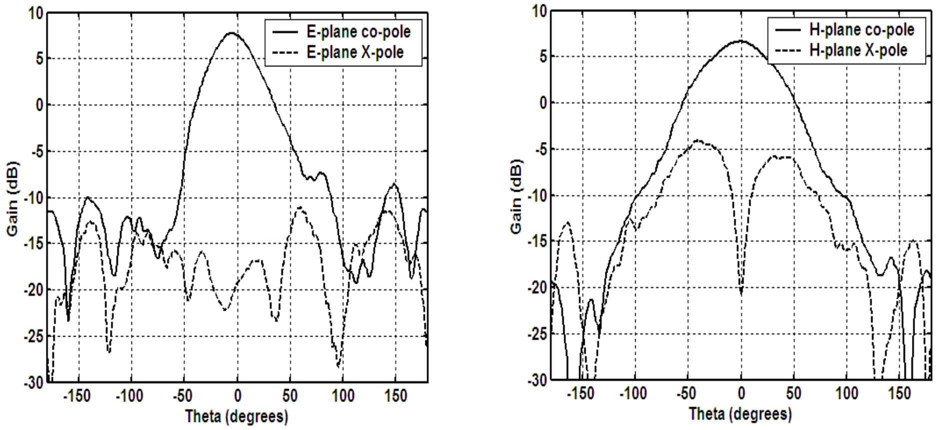


Fig. 4(a) Geometry of the EBG antenna (b)The return loss of the reference and the EBG antenna



(a) (b)

Fig. 5 Radiation patterns of the fabricated EBG patch with L = 14 mm,W = 20 mm, $\varepsilon_r = 3.2$, h = 1.59 mm, X′ = 12.4 mm , Y′ = 8.3 mm at 5.75 GHz (a) E-plane patterns (b) H-plane patterns