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MICROSTRIP ARRAY ANTENNA WITH NEW 2D-ELECTROMAGNETIC BAND GAP STRUCTURE SHAPES TO REDUCE HARMONICS AND MUTUAL COUPLING

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Abstract—This paper presents microstrip array antenna integrated with novel shapes of 2D-electromagnetic band-gap structure (2D-EBG). Three different shapes of 2D-EBG are used for harmonic suppression, optimizing the current distribution on the patches and decreasing the mutual coupling between array elements. As a result, the performance of the antenna array is improved. The three novel shapes of 2D-EBG presented are star, H shaped and I shaped slots. Simulated and measured results verify the improved performance of the array antenna compared to the array antenna without EBG as well as antenna array with conventional EBG shapes. The harmonic suppression and reflection coefficients are improved by about 18 dB. Minimum mutual coupling is less than −20 dB, and the antenna size is reduced by 15% compared to the original size.

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1. INTRODUCTION

Microstrip patch antennas are widely used in various applications because of low profile, low cost, light-weight and convenient integration with RF devices. However, microstrip antennas have many disadvantages. One of them is the excitation of surface waves that occur in the substrate layer. Surface waves are undesired because when a patch antenna radiates, a portion of total available radiated power becomes trapped along the surface of the substrate. It reduces total available power for radiation to space wave, and there is harmonic frequency created [1]. For arrays, surface waves have a significant impact on the mutual coupling between array elements [2]. One solution to reduce surface waves is using electromagnetic band-gap (EBG) or photonic band-gap structure (PBG). Recently, there has been an increasing interest in studying the microstrip patch antenna with various periodic structures including electromagnetic band-gap (EBG) [2, 3]. For example, a microstrip patch antenna with 2D-EBG used to control harmonic is reported in [4]. Many shapes of EBG slots have been studied for single element microstrip antenna such as circles, dumb-bells and squares. However, not many have realized in antenna arrays [5, 6]. It has been demonstrated that the EBG structure will lead to a reduction in the side-lobe levels and improvements in the front to back ratio and overall antenna efficiency for the radiation pattern. In [6, 7], the unique capability of the EBG structure to reduce the mutual coupling between elements of an antenna array is demonstrated. The side lobe of the antenna with one patch is caused by surface-wave diffraction at the edges of the antenna substrate, while for antenna array the side lobe is related to the pattern of the individual antenna, location of antenna in the array and the relative amplitudes of excitation. In addition, the mutual coupling between radiators affects the current distribution on an antenna and results in increased side lobes levels [5–10].

In this paper, microstrip patch antenna arrays with three different shapes of 2D-EBG as star, H shaped and I shaped etched on the ground plane are designed, simulated and measured. In this study, harmonic suppression and reduction of the mutual coupling effect are investigated by proposing these new shapes. The obtained results demonstrate that the 2D-EBG not only reduces the mutual coupling between the patches of antenna array, but also suppresses the second harmonic, reduces the side lobe levels and gives results better than conventional 2D-EBG shapes as circle and square. It is also shown that the novel shapes of 2D-EBG on the ground plane increases the gain of the antenna array.

2. CONFIGURATIONS OF 2D-EBG SHAPES

Three different shapes of 2D-EBG are presented in this paper as shown in Figure 1. The three shapes are compared with familiar conventional shapes as circular and square 2D-EBG by using transmission line approach. The proposed EBG units are composed of several rectangular-shape slots (of length L and width W). This EBG cell can provide a cutoff frequency and attenuation pole. It is well known that an attenuation pole can be generated by a combination of the inductance and capacitance elements as given in Figure 2(a) which presents circuit model for the cell for all 2D-EBG structures as that shown in Figure 2(b). Here, the capacitance is provided by the transverse slot and inductance by different shapes slots. For star shape, there are four rectangular slots with $L = 5$ mm, $W = 1$ mm at angles = 0°, 45°, 90° and 135°. The second shape, which is the H shaped slot,

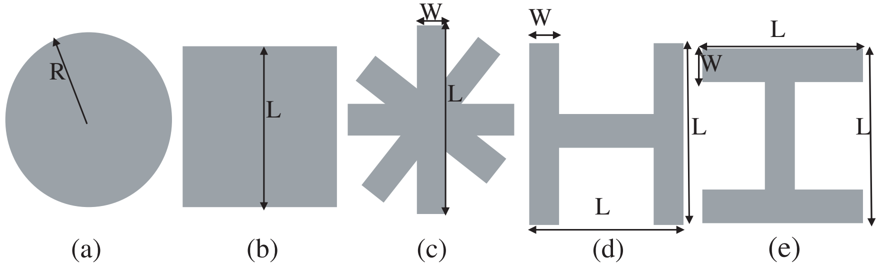


Figure 1. The different shapes of one unit cell of 2D EBG: (a) Conventional circle, (b) conventional square, (c) star, (d) H shape and (e) I-shape.

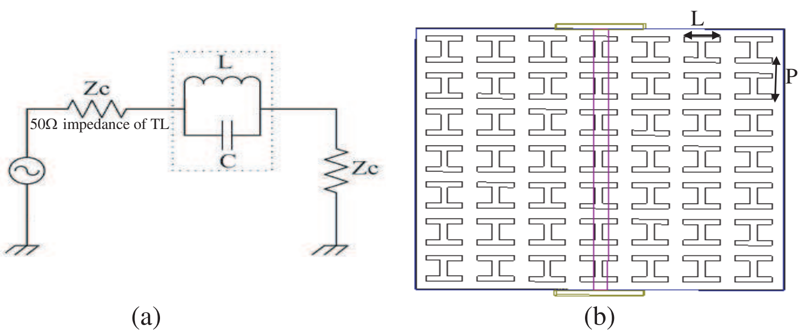


Figure 2. (a) Equivalent circuit of the one cell of 2D-EBG under the proposed microstrip line, (b) ground plane with all 2D-EBG structure.

consists of three rectangular slots with the same dimensions (5 mm × 1 mm). The third shape is the I shaped slot, which is obtained by rotating H shape by 90°. The substrate with a dielectric constant of 10.2, loss tangent of 0.0019 and thickness of 2.5 mm is considered here. The microstrip feeding line on top plane has a width $W_f = 2.3$ mm, corresponding to 50 Ω characteristic impedance. 2D-EBG cells are etched on the ground plane with periodicity $P = 7$ mm and ratio $L/P = 0.7$ [6]. Then the reflection and transmission coefficients (S_{11} and S_{21}) are calculated using the high frequency structure simulator (HFSS).

3. ANTENNA ARRAY DESIGN

Consider an ordinary antenna array with two elements, as shown in Figure 3(a). At 5.2 GHz, the dimensions of the patches are patch width $W_p = 8$ mm, patch length $L_p = 7.5$ mm and microstrip feed line with length L_f, $L_s = 20$ mm, 13 mm, respectively. Width $W_f = 2.3$ mm and the distance between the patches is $d = 19$ mm ($0.44\lambda_g$) where λ_g is guided wavelength at 5.2 GHz resonant frequency. It can be seen that the antenna will radiate energy at a harmonic frequency of 7.5 GHz. In order to suppress such harmonics, the band-stop characteristic of the EBG structure may be used. In this paper, the 2D-EBG shown in Figure 3(b), which is simply 2D-EBG cells, are etched on the ground metal sheet. The two separate array elements are also studied to measure the mutual coupling between the two patches in MIMO arrays as shown in Figure 3(c).

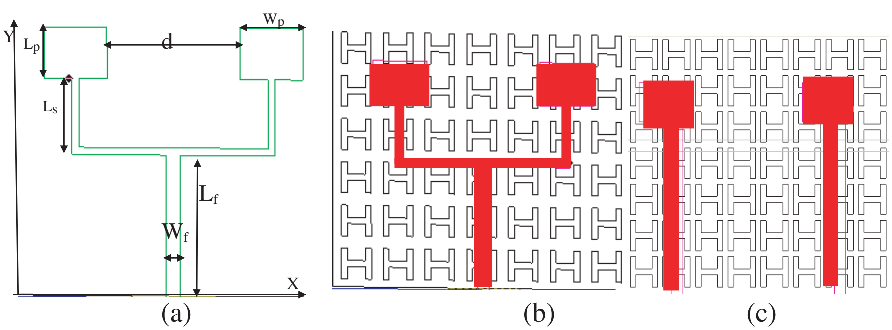


Figure 3. (a) Two-element MPAA, (b) MPAA with 2D-EBG, and (c) two separate array elements.

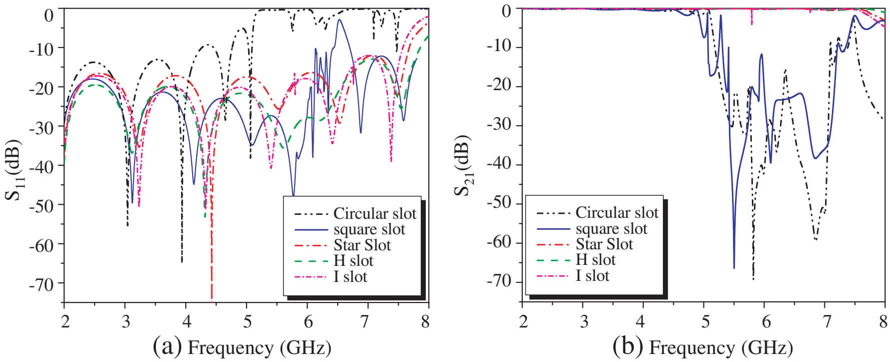


Figure 4. (a) The reflection, and (b) transmission coefficients for different 2D-EBG shapes.

4. RESULTS AND DISCUSSION

The first step of the design is obtaining the transmission and reflection coefficients responses of the ground plane which has 2D-EBG as shown in Figure 4. The response presents both conventional shape as circular and square 2D-EBG as well as the three new shapes. The second step is applying these shapes to the ground plane of two element array antenna. Figure 5 shows the reflection coefficient of the two patches array antenna with 2D-EBG structures. The results indicate that the harmonic at 7.5 GHz is indeed suppressed as well as reducing the electrical array antenna size by about 7.5% for H-shape, 8% for star-shape and reaches 15% for I-shape. The techniques for designing these shapes is using small rectangular strip that redistributes the surface current regard less on the isolation of the ground plane. According to the characteristics of EBG, the surface wave can also be suppressed. For effective suppression of the harmonics and surface waves, a periodic structure surrounding the patches, in addition to one underneath the patches, is necessary. The array performance of the conventional 2D-EBG and the three new shapes of 2D-EBG are given in Table 1.

From Table 1 and Figure 5, one notices that I shape gives maximum reduction in resonant array frequency than other shapes so reduces the electrical array size, and star shape gives maximum average antenna gain and minimum mutual coupling while H shape gives larger antenna bandwidth than others.

The 2D-EBG structure on the ground plane changes the current distribution on the patches and consequently the antenna gain. The

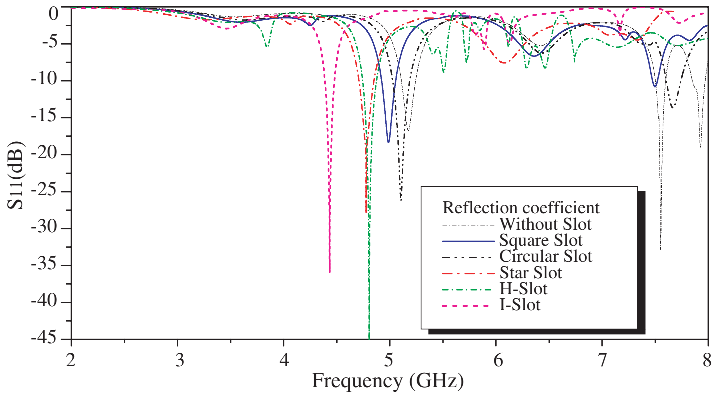


Figure 5. The reflection coefficient for different MPAA with 2D-EBG.

Table 1. The effect of different 2D-EBG shapes on the antenna performance.

Shape of 2D-EBG	Antenna Gain dB @5.2 GHz	Mutual Coupling $\vert S_{21}\vert$	Harmonic level dB	Reflection Coefficient	BW %	Defect Geometry, Periodicity *X* direction /*Y* direction
Without	10	−16 dB	−35	−17 dB	3	
Square	13.5	−18.5 dB	−10	−17.5 dB	4	Side dimension 4mm, 6 mm, 6 mm
Circular	13	−19 dB	−15	−20 dB	5	Radius 2 mm, 2 mm, 2 mm
Star	13.75	−30 dB	−9	−30 dB	5	Side length 1× 4 mm^2, 6 mm, 6 mm
H	12.75	−20 dB	−10	−40 dB	5.1	Side length 1×5 mm^2, 6 mm, 6mm
I	11	−20 dB	−7	−45 dB	5	Side length 1×5 mm^2, 6 mm, 6 mm

surface current distributions for the various shapes are shown in Figure 6. Figure 6(a) shows that the surface current on the ground plane for the MPAA without 2D-EBG structure is concentrated under the patches. By using conventional shapes as circular and square EBG, as shown in Figures 6(b) and 6(c), the concentration surface current decreases but not eliminated. However, for the three investigated shapes, the surface current decreases more on the ground plane especially when using H shape as shown in Figures 6(d), 6(e) and 6(f).

The gain of the two-element array antenna is also studied for

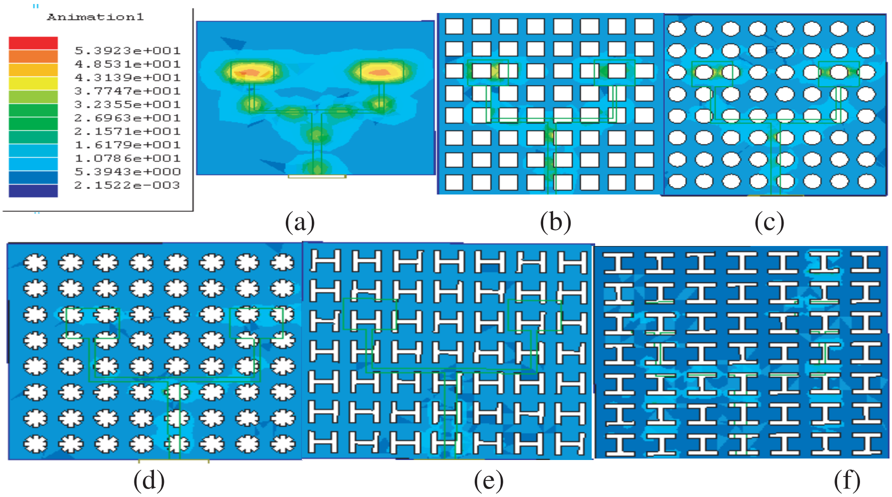


Figure 6. Surface current distribution for different shapes of EBG.

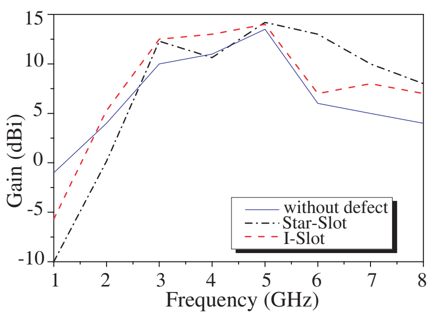


Figure 7. The gain response for different shapes of MP array antenna with 2D-EBG shapes.

different array antennas with and without 2D-EBG. Figure 7 shows that the antenna gain at lower frequencies for the antenna without 2D-EBG is slightly better than that with EBG because it is out of band-gap. However, at higher frequencies the antenna gain with 2D-EBG is better than that without EBG by about 9 dBi maximum difference and 3 dBi in average over the entire antenna band which verifies the harmonic suppression behavior.

In addition, the average efficiency of the array is also studied over the operating band. The average array efficiency with conventional 2D-EBG is lower than that without by about 15% while the average area of three new shapes is lower by 10%.

To study the harmonic suppression and reduction of mutual coupling between antenna elements in microstrip array antenna, two separate patches of the array with separation distance $\mathbf{d} = 19\,\mathrm{mm} \approx 0.44\lambda_{5.2\,\mathrm{GHz}}$, as shown in Figure 3(c), are used. S_{11} and S_{21} for the various shapes are shown in Figure 8, which indicates that the mutual coupling of the array antenna with 2D-EBG is better than that without 2D-EBG. The I-shaped 2D-EBG gives the best performance. Finally, the two element array antennas are fabricated by using photolithographic techniques at HCAC center and measured by using E8364A vector network analyzer. The comparisons between measured and simulated reflection coefficients are shown in Figures 9 and 10 for the star and I shapes, respectively. The difference between the simulation and measurement results is, in average, about 10%, and it

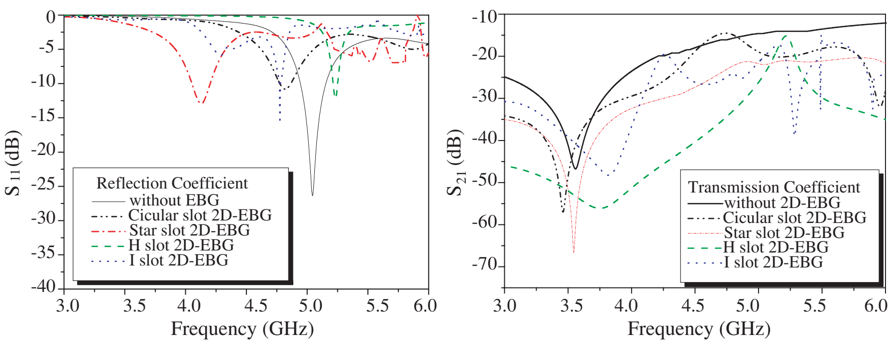


Figure 8. The reflection and transmission coefficients of two separate elements.

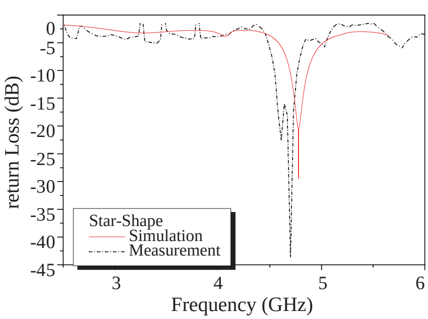


Figure 9. Comparison between measurement and simulated reflection coefficients for star-shaped slot 2D-EBG.

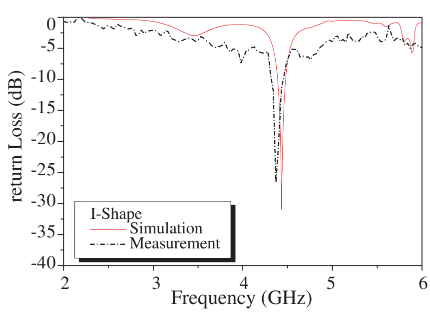
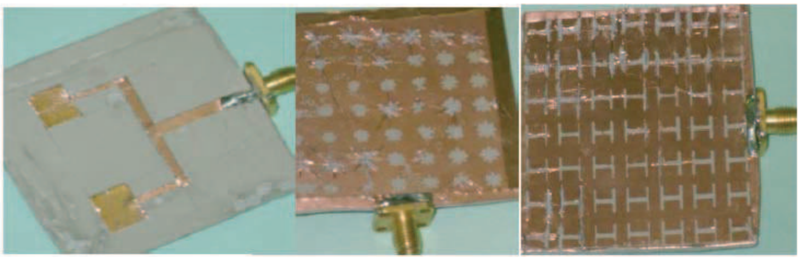


Figure 10. Comparison between measurement and simulated reflection coefficients for I-shaped slot 2D-EBG.



(a) (b) (c)

Figure 11. Photo of the fabricated antenna (a) radiator, (b) star slot and (c) I slot.

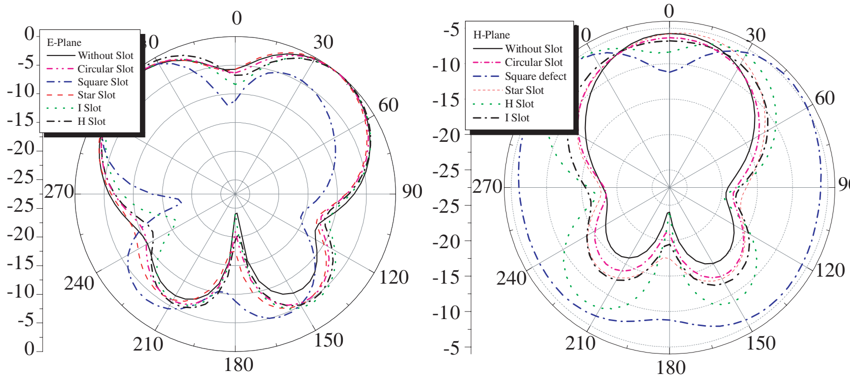


Figure 12. The simulated E-plane and H-plane radiation patterns for the five shapes of 2D-EBG.

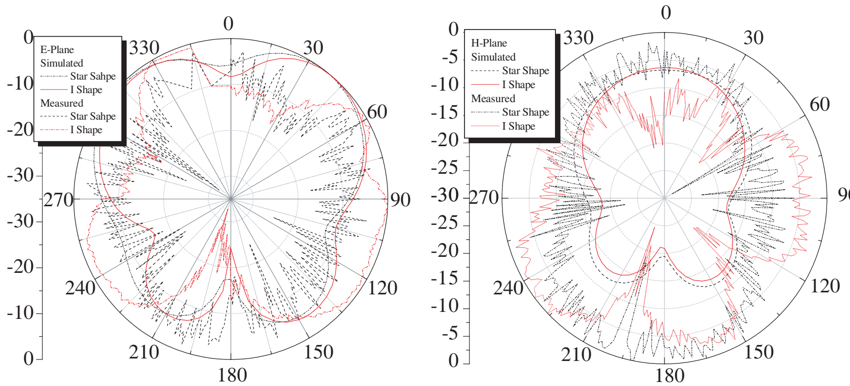


Figure 13. Comparison between measured and simulated E- and H-plane radiation patterns for star and I shaped 2D-EBG.

is may be attributed to some fabrication tolerances especially in the etched slots as well as soldering discontinuities effect. The photos of the fabricated 2D-EBG antennas are shown in Figure 11. The simulated E- and H-plane radiation patterns for the five shapes of the 2D-EBG are shown in Figure 12. The comparison between measured and simulated E- and H-plane radiation patterns for star and I shaped 2D-EBG are shown in Figure 13.

5. CONCLUSION

In this paper, a two-element microstrip array antenna integrated with 2D-EBG on the ground plane has been investigated. Three new 2D-EBG shapes, namely star, H-shape and I-shape, have been compared with conventional 2D-EBG shapes (square and circular). The 2D-EBG reduces the coupling between patches of the array and, hence, is useful in decreasing the maximum side-lobe level of antenna array without a change in the distance between the patches. Consequently, increase in array radiated power and gain have been achieved. The results demonstrate that the radiation properties of the antenna with 2D-EBG are improved compared to the antenna without 2D-EBG or with other conventional shapes as circular and square. The mutual coupling between array patches decreases to less than -20 dB. The MPAA is fabricated easily, and gain enhancement by 3 dBi in average is obtained. The array size is reduced by 15% compared with the original as well as with the conventional shapes of 2D-EBG.

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