Spurious Modes Reduction in a Patch Antenna Using a Novel DP-EBG Structure

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Abstract— A novel dual planar electromagnetic bandgap (DP-EBG) microstrip structure with wide stopband and flat passband is presented. It is demonstrated that the proposed structure achieves a Ultra-Wide stopband and excellent passband performance within a compact circuit area. And the DP-EBG structure is employed in the feed line of patch antenna with the aim of suppressing harmonics and other spurious modes. Simulated and measured results indicate that the application of this DP-EBG structure not only drastically diminishes spurious radiations of 2nd $\sim$ 6th harmonics in a broad frequency band, but also overcome some shortages of other EBG microstrip antennas introduced in previous research.

1. INTRODUCTION

The active integrated antennas play an important role in the framework of modern wireless communication systems [1]. The evolution of communication systems, demand antennas with specific operational features and create the necessity to develop advanced new methods to design them in order to fulfill the imposed technical requirements. So more and more new technologies are utilized in the modern antennas. One of them, being choice for many antenna engineers, is the EBG (Electromagnetic Band Gap) technology [2].

The electromagnetic band-gap (EBG) structure exhibits a bandstop behavior over a certain frequency range, in which the propagation of electromagnetic waves is prohibited [3]. Recently, some papers have proposed the employment of EBG structures for the improvement of the antennas' radiating features. For example, the EBG structure has been developed to reduce the spurious harmonic radiation of the patch antenna. For microstrip patch antenna with proximity coupled feeding line, the second and third harmonics are eliminated by adjusting the length of feed line and introducing one resonant cell [4]. A CPW-fed circular slot antenna with an arc-shaped slot inserted on the ground conductor was designed for achieving four-frequency band notch characteristic in the range of $2 \sim 10$ GHz [5].

In this paper, a novel dual planar electromagnetic bandgap (DP-EBG) microstrip structure is proposed. Wide stopband and compact size are realized with asymmetric defected ground structure (ADGS). Furthermore the new structure is utilized to suppress harmonics and other spurious modes of the patch antenna. Both simulated and measured results demonstrate that the patch antenna which adopt the new structure obtains better performance than that of other designs in previous references in view of harmonic signal suppression and radiation patterns.

2. NOVEL DP-EBG STRUCTURE DESIGN AND ANALYSIS

As shown in Fig. 1, the novel dual planar electromagnetic bandgap (DP-EBG) microstrip structure is achieved with a combination of two one-dimensional (1-D) EBG structures, namely the asymmetric defected ground structure (ADGS) and the microstrip line type electromagnetic bandgap (ML-EBG) structure. According to [6], The ADGS circuit not only provides deeper stopband but also decreases the physical dimensions when compared with the microstrip line type EBG structure due to its highly-resonant characteristics. Hence, if we superpose the microstrip line type EBG structure and the ADGS section into a double-plane configuration, this assembled configuration may be expected to realize better stopband and low-pass band performance than that of any other single type EBG structure.

Based on this idea, we propose a novel compact dual planar electromagnetic bandgap (DP-EBG) microstrip structure as shown in Fig. 1, in order to achieve minimization, only one unit cell are etched underneath the adjacent EBG square patches. In addition, the proposed DP-EBG microstrip structure using a FR4 substrate with 0.8 mm thick and a dielectric constant of 2.65. The line width w for all models is chosen to be 2.2 mm (equal to the width of microstrip 50 ohm line). And other correlative structural dimensions are calculated and shown in Table 1.

Figure 2 shows S-parameters of the proposed DP-EBG microstrip structure. Regarding Fig. 2, the most important feature of the proposed DP-EBG microstrip structure is about -20 dB stopband

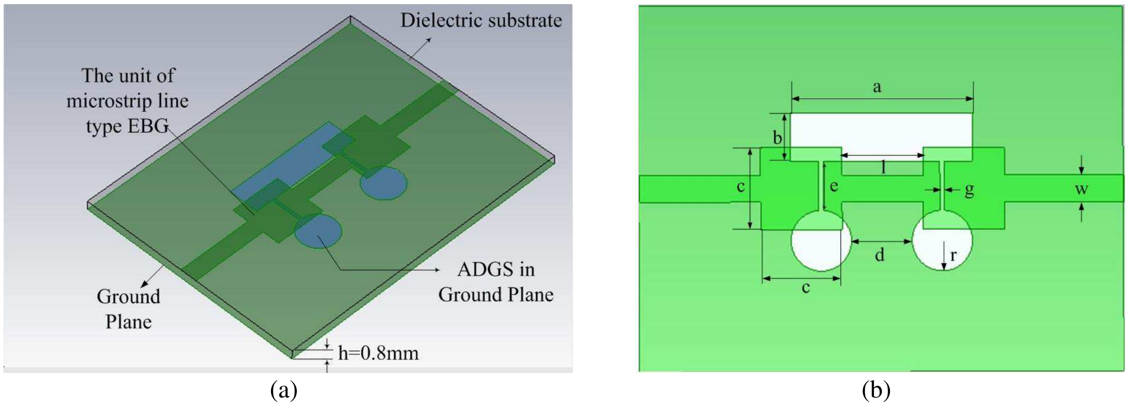


Figure 1: Schematic of the novel DP-EBG microstrip structure. (a) 3-D view. (b) Top view.

Table 1: Structural dimensions.

Parameters	d	a	b	c	r	g	e
Value (mm)	4	14	4	6.7	2.5	0.4	4.5

from 3.5 GHz to 13 GHz (In other words, the relative bandwidth is over than 115%) in addition to the negligible insertion loss which is less than 0.3 dB throughout the passband. These favorable results are profit from the fact that the longitudinal resonant modes of the microstrip line type EBG structure and the transverse resonant modes of the ADGS are strongly coupled through the DGS gap fields so that the passband and stopband characteristics are effectively improved by these multiple resonant modes. By virtue of the highly resonant mechanism, this novel DP-EBG structure has relatively wider stopband characteristics and smaller required circuit size than that of the new EBG structure proposed in [7, 8] which satisfies the Bragg reflection condition.

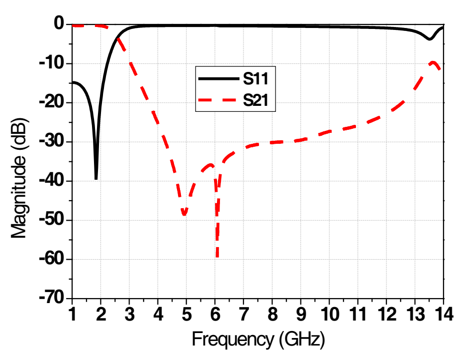


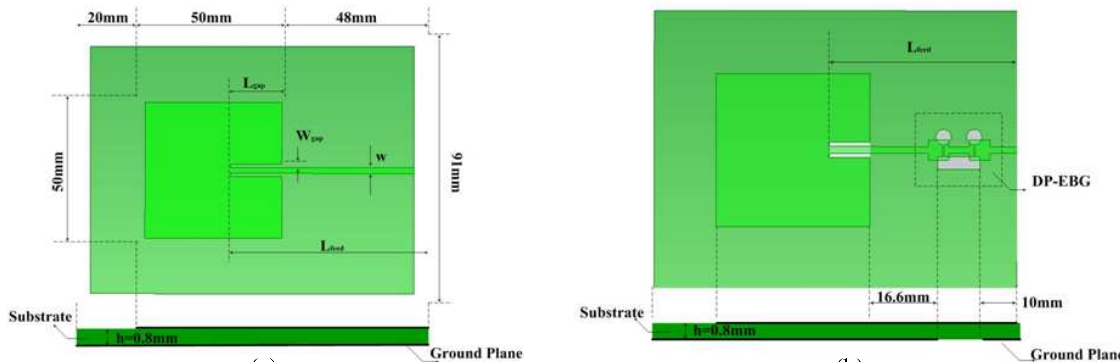
Figure 2: S-parameters of the proposed DP-EBG microstrip structure.

3. APPLICATION OF THE NOVEL DP-EBG STRUCTURE IN MICROSTRIP ANTENNA

3.1. The Novel EBG Microstrip Antenna Design

In order to validate the validity of the novel DP-EBG structure in the usage of suppressing spurious radiations of patch antenna, a normal microstrip patch antenna that serves as the reference antenna and operates at 1.83 GHz is designed firstly. Fig. 3(a) shows the configuration of the reference antenna. A $50 \times 50\,\text{mm}^2$ square patch is fabricated on the FR4 substrate with the physical size of $118 \times 91 \times 0.8\,\text{mm}^3$ and the relative permittivity of $\varepsilon_r = 2.65$. A 50 ohm microstrip feed line is used for antenna excitation. Inset cut with the length (L_{gap}) of 18.8 mm and the width (W_{gap}) of 1.2 mm is also adopted for a good impedance design for the reference antenna. Additionally, other structural parameters are evaluated and shown in Fig. 3(a).

Then, the proposed DP-EBG structure shown in Fig. 1 was constructed in the feed line of the microstrip patch antenna, and it is apparent from the schematics shown in Fig. 3(b) that this



(a) (b)

Figure 3: Sketch of the printed antennas. (a) The reference patch antenna. (b) The proposed EBG patch antenna.

novel EBG microstrip antenna has the same dimensions as that of the reference antenna except a modulated microstrip line on top of a perturbed ground plane etched with ADGS.

The above models are fabricated and measured experimentally to confirm the theoretical analysis with respect to the reflection coefficients and radiation properties. All the simulation is carried out by HFSS. The reflection or transmission coefficients of all the fabricated prototypes are measured using an Anritsu ME7808A vector network analyzer while the radiation patterns are measured inside an anechoic chamber with an AV3635 antenna measurement system.

4. SIMULATION AND EXPERIMENTAL RESULTS

It is shown in Fig. 4 that the simulation and measurement return loss of the two antennas has been depicted. Reasonable agreement is observed between the measurements and the simulated data over the entire frequency span. The difference in the value of input return loss could be due to the number of sampling points taken while the slight shift in frequency could be attributed to the variation of the actual dielectric constant and the machining error. From the measured result shown in Fig. 4(a), the dominant resonant frequency of the reference antenna is 1.85 GHz, slightly shifting from the simulated one and its −10 dB bandwidth is about 16 MHz. The reference antenna also resonates at many harmonic frequencies along with other surface wave modes. However, for the EBG antenna, these harmonic resonances as well as other surface wave modes are totally suppressed within a wide frequency band except the fundamental as shown in Fig. 4(b). It is also easily found by comparing the measured S_{11} of both antennas that the proposed EBG antenna has the same fundamental frequency (i.e., 1.85 GHz) as that of the reference antenna, and the bandwidth and the reflection coefficient roughly remain unchanged. Therefore, the proposed EBG antenna obtains a number of attractive features, which include the following.

I. The operating frequency is not shifted away from the original resonance of the reference antenna, even though the patch size of the EBG antenna remain unchanged. Unlike other designs introduced in the references [4, 9–11], where the fundamental frequencies of EBG antenna were always shifted more or less if they have the same patch size as that of the normal one. This character can be attributed to two reasons. Firstly, the low-pass characteristics of the feed line constructed with the proposed DP-EBG structure is so well that the propagation loss is small and can be comparable to that of a conventional microstrip line. On the other hand, the distance between the patch's bottom edge and the DP-EBG structure's top side is enough long (i.e., 16.6 mm, which is longer than $\lambda_g/10$, where λ_g is the wavelength under the substrate corresponding to 1.85 GHz), so the electromagnetic field in the vicinity around the patch is not disturbed by the DP-EBG structure, making the fundamental frequency of the EBG antenna be stable. So, the method in this letter can be utilized to design an EBG patch antenna operating on any required fundamental frequency and reducing spurious modes over a wide band even though the patch size is calculated by using the conventional procedure applied to the normal microstrip patch antenna.

II. The proposed EBG antenna achieves the goal of notably diminishing resonances of 2nd $\sim$ 6th harmonics and other surface wave modes over a wide frequency range extending from 2 GHz up to 9 GHz, so this proposed EBG antenna obtains better performance than that of other designs in references [4, 5, 9–11] with regard to the frequency bandwidth of harmonic suppression. Moreover, the total length of the two EBG units is about 21.4 mm, less than 1/7 of the free space wavelength at

1.85 GHz. There is no increase in the size of the antenna while the other features are not degraded.

In addition, the radiation patterns at the fundamental frequency are simulated and measured for both antennas as depicted in Fig. 5 and Fig. 6. These power levels are normalized by the maximum level of the reference antenna at the dominant resonant frequency. The experimental co-polarization patterns agree well with simulated ones except some discrepancies which can be attribute to the fabrication inaccuracy. It is easily seen from the measured results that both antennas have almost identical and quite stable co-polarization pattern characteristics in both plane at the fundamental frequency. The EBG antenna radiates broadside, and maintains a cross-polarization level similar to that of the reference one, which is not presented here and remain below −20 dB in the E-plane and H-plane respectively. The realized gain of the EBG antenna is similar to that of the reference antenna (the reference antenna: 6.0 dB; the EBG antenna: 6.0 dB), satisfying the requirements for engineering applications. And there is no energy leaking in our designed EBG antenna, which can be studied from the Fig. 6 that the front-to-back ratio is only a little lower than that of the reference one because the DP-EBG structure constructed in the feed line cannot resonate effectively as an antenna and results in a negligible radiation loss at the operating frequency. Besides that, there is also no beam squint in the fundamental radiation pattern, which is different from the case presented in [9] where the DGS operating with some energy letting out is so close to the patch's bottom edge that its radiation disturbs the antenna's main radiation pattern. Therefore, this proposed EBG antenna in this paper obtains better radiation performance at the fundamental frequency in comparison with some designs in former references.

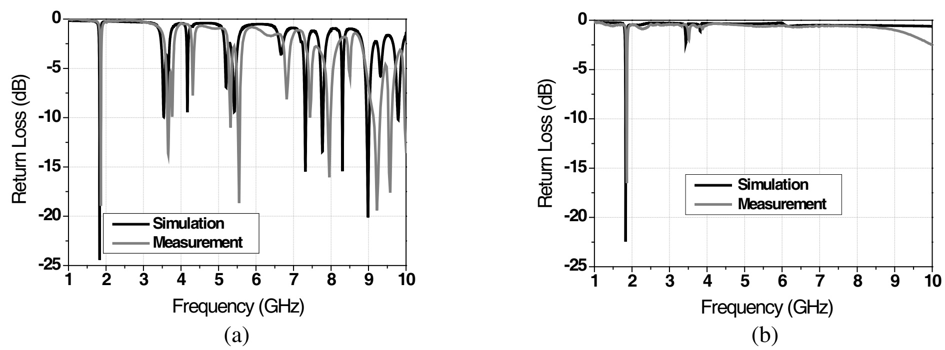


Figure 4: (a) Calculated and measured return losses for the normal antenna and (b) the proposed EBG antenna.

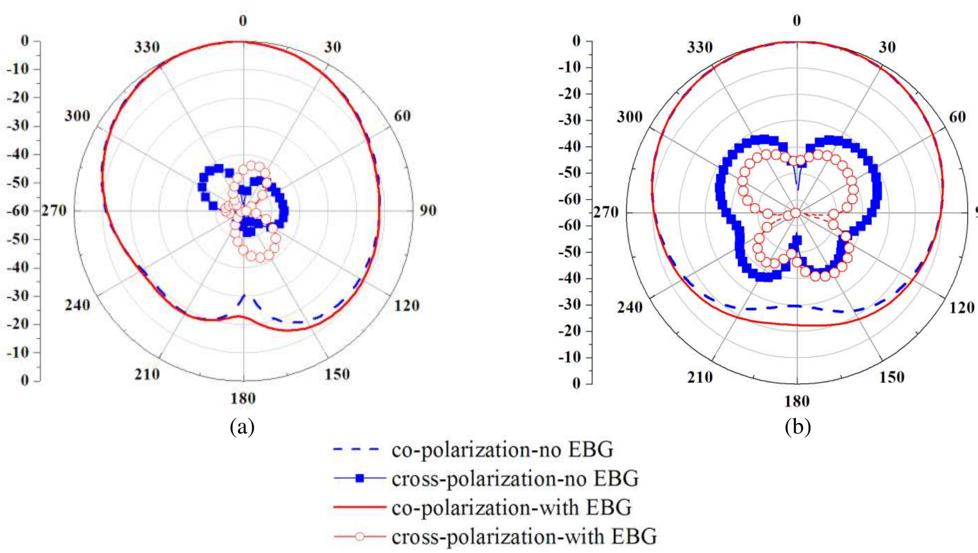
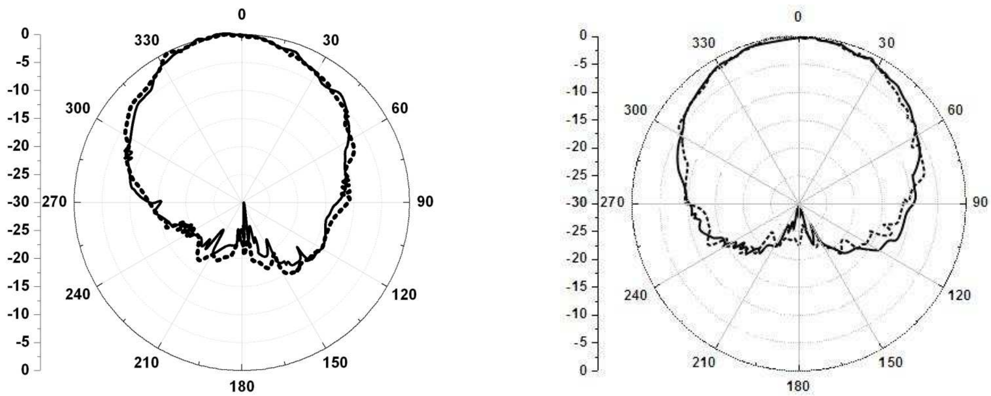


Figure 5: Simulated radiation patterns for the reference antenna and the EBG antenna. (a) E-plane. (b) H-plane.



(a) (b)

Figure 6: Measured co-polarization radiation patterns for the reference antenna (rigid line) and the EBG antenna (broken line) at the dominant resonant frequency. (a) E-plane. (b) H-plane.

5. CONCLUSIONS

A patch antenna with a novel DP-EBG structure constructed in the feeding network has been studied in this letter. It is demonstrated that the usage of the novel DP-EBG microstrip structure in the patch antenna leads to a perfect removal of multiple harmonics and other spurious resonances over a wide frequency range, while improvements in radiations at the fundamental frequency is more significant as compared to other designs given in the previous research. By modulating the separation between DP-EBG structure inserted in the feed line and the patch's bottom edge at a moderate distance (i.e., longer than $\lambda_g/10$), we realize the goal of making the fundamental frequency of the EBG antenna unchanged when compared with the normal one even though the patch sizes of two antennas are identical. Therefore, the design of the EBG patch antenna operating at any certain frequency and reducing spurious modes over a wide band can be simplified by using the method proposed in this paper since the patch sizes can be calculated through the conventional evaluating procedure. Further more, due to the small dimension of the DP-EBG structure, compact feed network is achieved. Therefore, the proposed EBG antenna in this letter is quite effective for the suppression of spurious signals, and may find applications in compact active circuit system and modern wireless communication realm.

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