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COMPACT SLOT ANTENNA WITH EBG FEEDING LINE FOR WLAN APPLICATIONS

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Abstract—A compact CPW-fed slot antenna is proposed for dual-band wireless local area network (WLAN) operations. In this paper, electromagnetic band gap (EBG) structures with square-shaped lattices have been incorporated into the feed network for harmonic suppression. Experimental results show that EBG structures not only exhibit well-behaved band stop characteristics, but also enhance the bandwidth of the proposed antennas. For the proposed antenna with square-shaped lattices, the −10 dB return loss bandwidth could reach about 38.4% for the 2.4 GHz band and 23.8% for the 5 GHz band, which meet the required bandwidth specification of 2.4/5 GHz WLAN standard.

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1. INTRODUCTION

Coplanar waveguide (CPW) transmission lines have been widely used as feeding networks with slot antennas. CPW lines have many useful design characteristics such as low radiation leakage, less dispersion, little dependence of the characteristic impedance on substrate height, and uniplanar configuration. They also allow easy mounting and integration with other microwave integrated circuits and RF frequency devices. Dual-band operations have become very important in wireless local area network (WLAN) applications. CPW-fed antennas for wireless communications have been discussed by many authors for dual-band operations.

Since WLAN antennas are usually required on broad bandwidth and small antenna size, researchers have studied monopole structures with dual resonant modes [1–3]. Those monopole antennas have the bandwidth with narrow margin at both bands, and their sizes are somewhat large. A microstrip-line-fed ring antenna with compact structure [4] is single band operation only. A rectangular ring with open-ended CPW-fed antenna [5] is capable of providing operating bandwidth for 2.4/5.2 GHz WLAN.

Recently reported CPW-fed dual band antennas have simple structures but large size [6–8]. A compact planar inverted-F antenna (PIFA) has also been presented but has a complex structure and still a large size [9].

Also, bandwidths of higher order modes will increase simultaneously, which may cause a potential problem of the electromagnetic interference and compatibility. To alleviate this serious symptom of the conventional CPW-fed slot antenna, the electromagnetic band gap (EBG) structure is a promising solution in this regard. EBG structures, originating in the optical system and scale for microwave applications, are renowned for the capability to prohibit the propagation of electromagnetic waves along one or more directions within certain bands of frequencies. EBG structures have been utilized to eliminate the harmonic modes in the microstrip patch antennas successfully [10] due to their appealing low-pass filter characteristics [11].

The CPW-fed G-shaped planar monopole antenna with dual band operation is a good choice for WLAN application [12]. For WLAN operations we can use the dual-band slot antenna with compact size [13]; this antenna can be easily integrated with other RF front-end circuits.

A new M-slot loaded patch is presented in [14], with a triangular parasitic patch and a coaxially fed folded patch with shorting walls to provide the required bandwidth as well as reducing the overall antenna size suitable for WLAN application.

The Ref. [15] explains a novel dual-band patch antenna on magnetic substrate for WLAN application. The dual-band operation is obtained by inserting a pair of L-shaped slots.

Using two-tapered patch with different slopes, a slot between them, modified feed and a slot in the ground plane, the impedance band width can be increased [16].

A new CPW-fed T-shaped monopole antenna with a trapeze form ground plane and two parasitic elements for WLAN/WiMAX dual mode operation is investigated in [17].

In this paper, we propose a compact CPW-fed slot antenna with an EBG structure in the feed network for the 2.4/5 GHz WLAN applications. The proposed antenna is suitable for 2.4 and 5 GHz WLAN systems whose frequencies are at 2.4–2.484 GHz for IEEE 802.11b/g and at 5.15–5.35 and 5.725–5.825 GHz for IEEE 802.11a, respectively. Experimental results elucidate that the EBG structure exhibits a good band-stop characteristic; furthermore, the impedance bandwidth of the proposed antenna also becomes wider than that of the original CPW-fed slot antenna without an EBG structure in the feeding network. Details of the antenna design are described, and both simulated and measured results are presented and discussed.

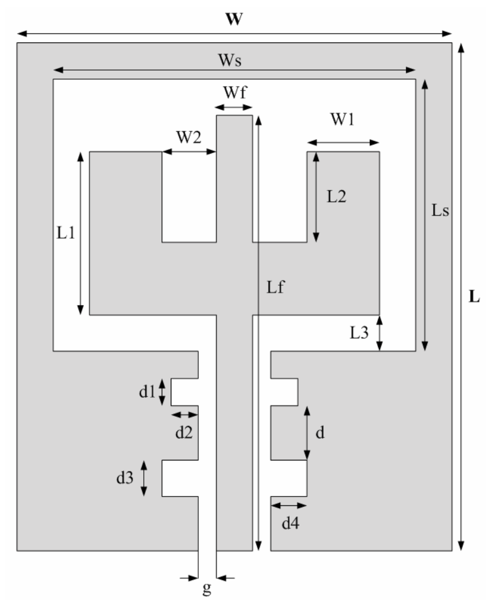


Figure 1. Geometry of proposed antenna.

2. ANTENNA GEOMETRY

In this design, square-shaped lattices have been used to suppress harmonic modes and geometry of the proposed antenna, as shown in Fig. 1.

The antenna is etched on Rogers RO4003 substrate with a thickness of 20 mil (0.5 mm) and dielectric constant of 3.38. The size of the ground plane is $W = 21\,\text{mm} \times L = 25\,\text{mm}$. The slot has a length $L_s = 19.8\,\text{mm}$ and width $W_s = 13.5\,\text{mm}$. The antenna is excited by a $50\,\Omega$ microstrip line with E-shaped tuning stub. The width of the $50\,\Omega$ microstrip line is $W_e = 2\,\text{mm}$, and the gap of the CPW line is $g = 0.12\,\text{mm}$.

The E-shaped tuning stub is located at the center of the slot, where the antenna is symmetrical along the center, x-axis. Dimensions and location of the E-shaped tuning stubs are $L_f = 23.5\,\text{mm}$, $L_1 = 9\,\text{mm}$, $L_2 = 5.5\,\text{mm}$, $L_3 = 1.6\,\text{mm}$, $W_1 = 4.65\,\text{mm}$ and $W_2 = 1.5\,\text{mm}$. Furthermore, the square-shaped lattices are placed on both sides of the ground plane along the feed line. The dimension of the smaller square-shaped lattice is $d_1 \times d_2$ ($0.4 \times 0.4\,\text{mm}^2$), while that of the larger square-shaped lattice is $d_3 \times d_4$ ($1 \times 1.4\,\text{mm}^2$). Moreover, the distance d between two lattices is chosen as 1.5 mm. The photograph of the fabricated antenna is shown in Fig. 2.

As known, the distance between two cells, which is equal to half guided wavelength ($\lambda_g/2$) in [11, 18], determines the cut off frequency of the EBG structure. In this design, the EBG structure used is more compact, since the distance between two cells approximates to $\lambda_g/15$. This compact EBG structure can be easily integrated into a feeding network with a limited size and provides great performance for the suppression of higher order modes.

Figure 2. Photograph of the antenna.

3. RESULTS AND DISCUSSION

The antenna performance was investigated by simulation via HFSS software. Fig. 3 shows the measured and simulated return losses of the proposed antenna. Fig. 3 shows the measurement and simulation frequency responses of the return loss for the proposed antenna with the EBG structure. For the purpose of comparison, the simulation result of return loss of the corresponding antenna without the EBG structure is also shown in Fig. 3.

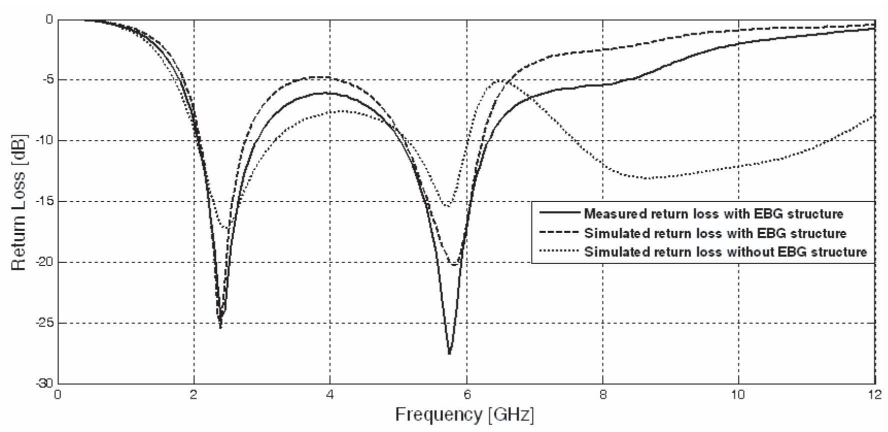


Figure 3. Simulated and measured return loss of the proposed antenna.

The obtained −10 dB impedance bandwidths are 950 MHz (2–2.95 GHz) and 1350 MHz (5–6.35 GHz), corresponding to an impedance bandwidth of 38.4% and 23.8% with respect to the appropriate resonant frequencies. Obviously, the achieved bandwidths can cover the WLAN standards in the 2.4 GHz (2.4–2.484 GHz), 5.2 GHz (5.15–5.35 GHz) and 5.8 (5.725–5.825) GHz bands. Although the bandwidth at the upper frequency band of the original antenna reaches almost 800 MHz (5.2–6 GHz) which is about 14.3% with respect to the center frequency of 5.6 GHz, the proposed antenna with the EBG structure of square shapes in the feed network could reach 1350 MHz (5–6.35 GHz), which is about 23.8% with respect to the center frequency of 5.675 GHz. Also, the referenced CPW-fed rectangular slot antenna at the upper frequency band could cover only 5.8 GHz standard bands. In order to overcome this problem, an EBG structure is incorporated into the feeding network. It is observed that the EBG structure demonstrates a band stop characteristic, which is enough to thoroughly eliminate the high order mode. The EBG structure not only successfully suppresses higher order modes, but also increases the impedance bandwidth.

These dimensions are obtained after performing and optimization. In order to provide design criteria for this antenna, the effects of each geometrical parameter are analyzed. The antenna dimensions (L_2, L_f and W_2) are chosen to be (5.5, 23.5 and 1.5 mm), respectively, and one parameter is changed at a time while the others are kept constant. Fig. 4 to Fig. 6 show the effect of changing L_2, L_f and W_2, respectively.

As L_2 and L_f are increased, second resonant frequency moves

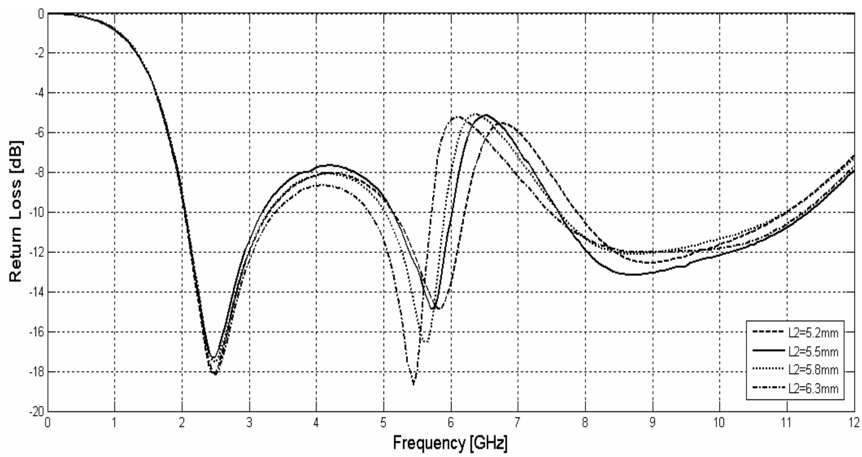


Figure 4. The effect on return loss due to the change of L_2.

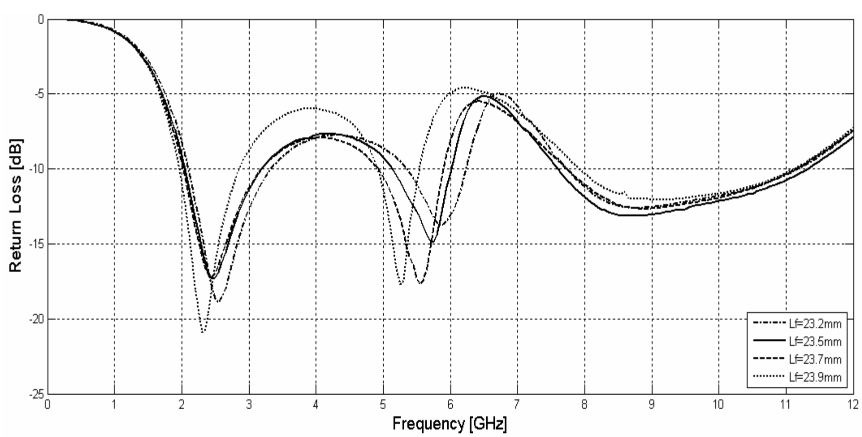


Figure 5. The effect on return loss due to the change of L_f.

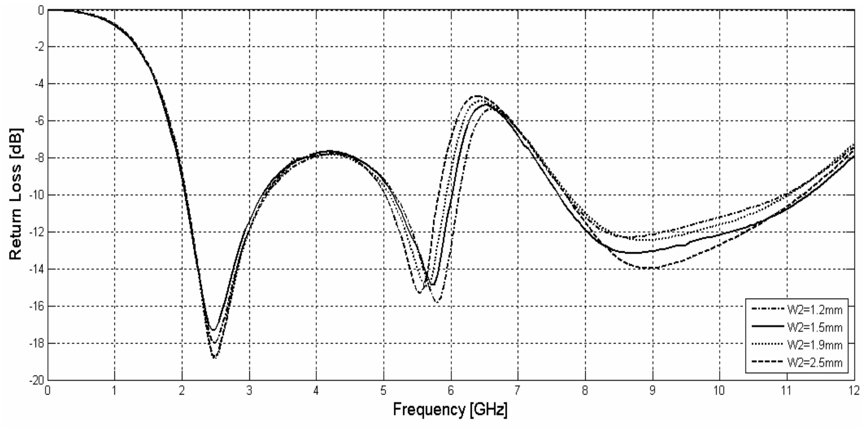
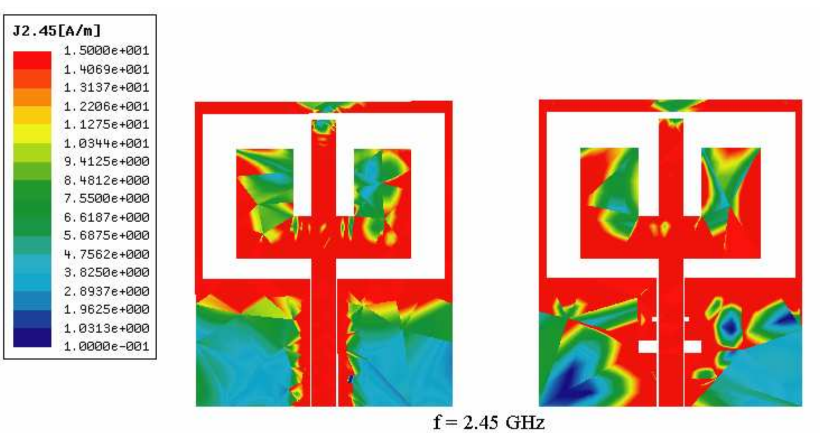
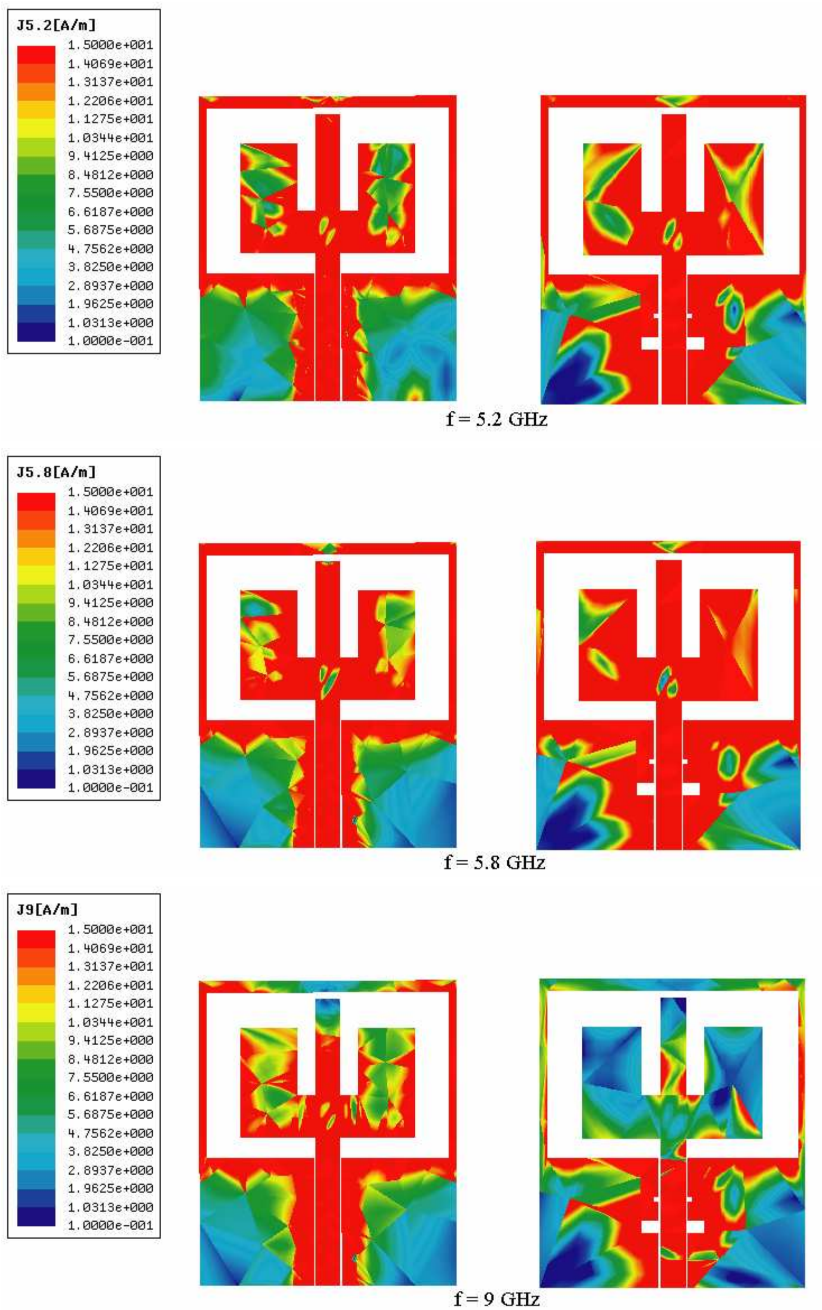


Figure 6. The effect on return loss due to the change of W_2.

towards lower frequencies and cannot cover 5.8 GHz. By reducing W_2 and L_f, on the other hand, second resonant frequency moves towards upper frequencies and cannot cover 5.2 GHz. Fig. 7 shows the HFSS simulated current distributions of the antenna at 2.45, 5.2, 5.8, 9 and 10 GHz with and without EBG structures. Without the EBG structures it is just an ultra wideband antenna which entirely covers 3–11 GHz and more. EBG structures act like an LC filter which rejects any undesired frequency range. This behavior is studied more in Fig. 7. The electric current distribution over the substrate is plotted in presence of the EBG structures and compared with the case of its nonappearance.




J5.2[A/m]
1.5000e+001
1.4069e+001
1.3137e+001
1.2206e+001
1.1275e+001
1.0344e+001
9.4125e+000
8.4812e+000
7.5500e+000
6.6187e+000
5.6875e+000
4.7562e+000
3.8250e+000
2.8937e+000
1.9625e+000
1.0313e+000
1.0000e-001
f = 5.2 GHz
J5.8[A/m]
1.5000e+001
1.4069e+001
1.3137e+001
1.2206e+001
1.1275e+001
1.0344e+001
9.4125e+000
8.4812e+000
7.5500e+000
6.6187e+000
5.6875e+000
4.7562e+000
3.8250e+000
2.8937e+000
1.9625e+000
1.0313e+000
1.0000e-001
f = 5.8 GHz
J9[A/m]
1.5000e+001
1.4069e+001
1.3137e+001
1.2206e+001
1.1275e+001
1.0344e+001
9.4125e+000
8.4812e+000
7.5500e+000
6.6187e+000
5.6875e+000
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f = 9 GHz

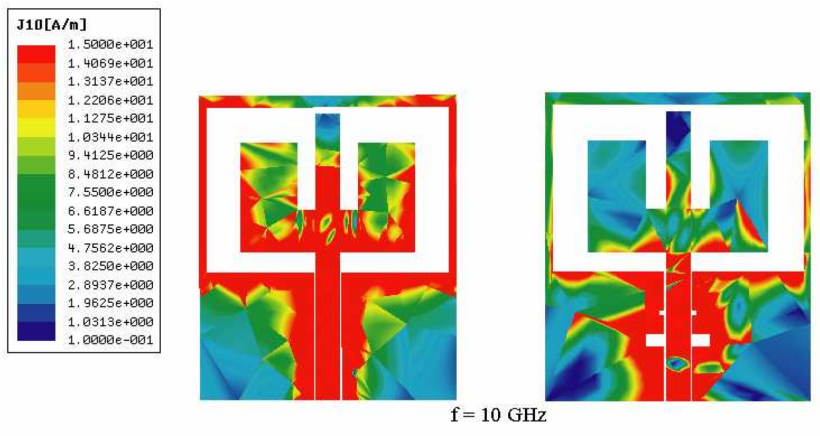

Figure 7. Electric current distribution over the substrate surface.

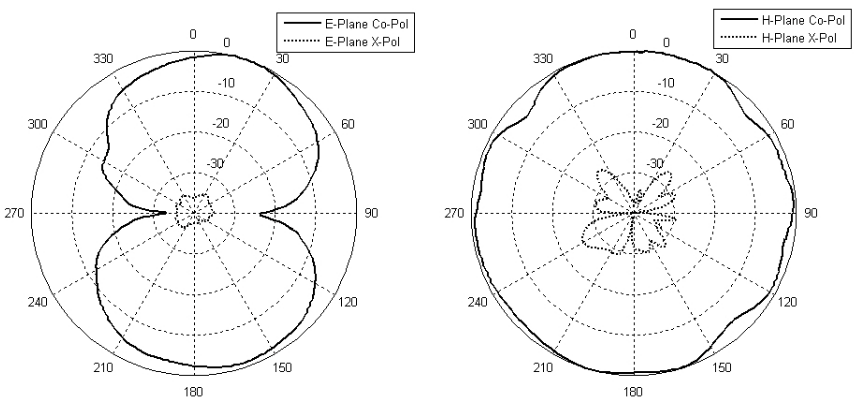

Figure 8. Measured radiation patterns of proposed antenna at 2.45 GHz.

Perusing currents distribution, it can be understood that with or without EBG structure, antenna has same current distribution at 2.45, 5.2 and 5.8 GHz but at higher frequencies such as 9 and 10 GHz using EBG structure, we decrease current distribution, reduce antenna's radiation capability, and eliminate unwanted band.

The radiation characteristics of the proposed antenna have also been studied. Fig. 8 to Fig. 10 show the measured radiation patterns for the E- and H-plane pattern including both co- and cross-polarization at 2.45, 5.2, and 5.8 GHz for the proposed antenna.

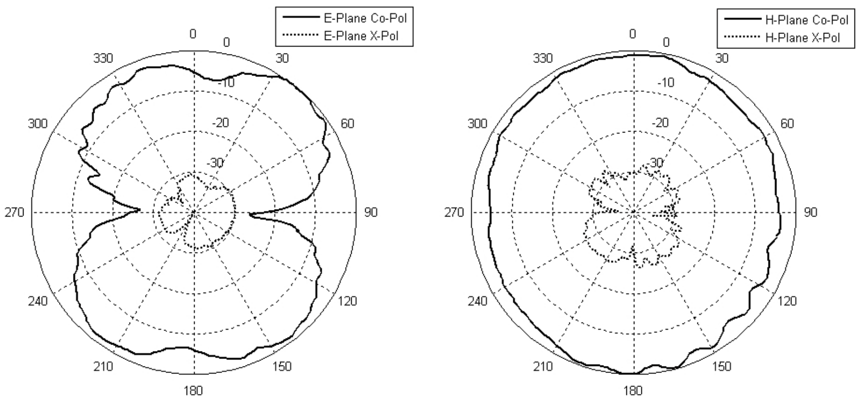

Figure 9. Measured radiation patterns of proposed antenna at 5.2 GHz.

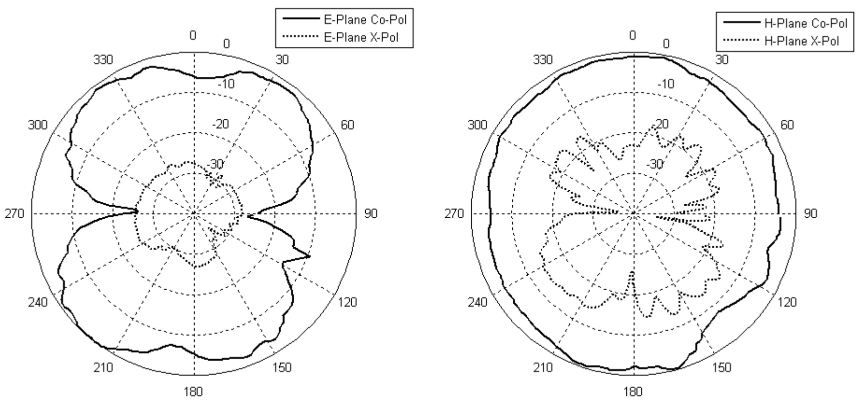

Figure 10. Measured radiation patterns of proposed antenna at 5.8 GHz.

The simulated antenna gains for operating frequencies across the two bands are shown in Fig. 11. The simulated average gains are 1.2 dB (0.5–1.4 dB) and 2.2 dB (1.8–2.4 dB), respectively, within the bandwidths of 2.4 and 5 GHz operating bands. Fig. 12 shows the HFSS simulated electric field distributions of the antenna at 5.2 and 10 GHz with and without EBG structures. As can be observed, at 5.2 GHz frequency, electric field distribution is approximately the same both with and without EBG structure, but at 10 GHz frequency the distribution is decreased with EBG structure.

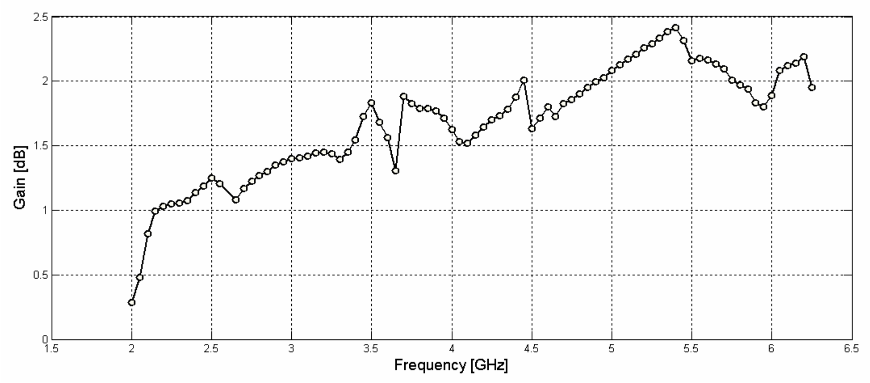

Figure 11. Simulated antenna gains for proposed antenna.

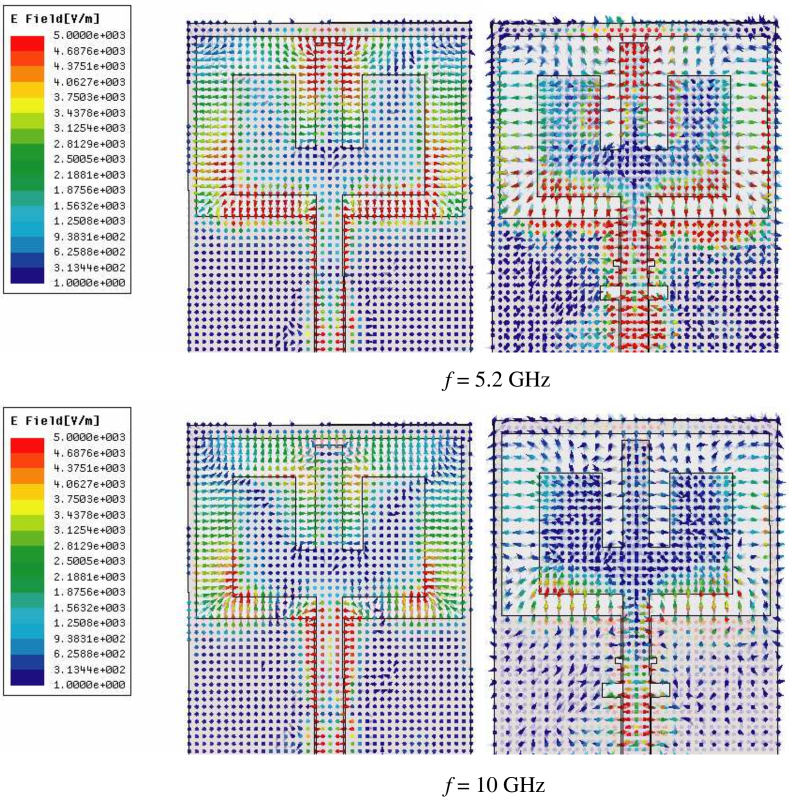

Figure 12. Electric field distribution of the antenna at 5.2 and 10 GHz.

4. CONCLUSION

A CPW-fed rectangular slot antenna incorporated with the EBG structure of square shapes in the feed network has been proposed for the 2.4/5 GHz dual-band WLAN operations. The EBG structure with square-shaped lattices utilized to eliminate unwanted higher-order modes has been integrated into the feeding network, which shows excellent characteristics of harmonic suppression and wider impedance bandwidth. The two operating frequencies of the presented antenna have the same polarization planes and similar radiation characteristics. The measured impedance bandwidths are 38.4% at the lower frequency band of 2.4 GHz and 23.8% at the upper frequency band of 5 GHz for the desired bands. The antenna has characteristics of compact size, simple structure and good omni-directionality.

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