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Triple Band Notched UWB Antenna Design Using Electromagnetic Band Gap Structures

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Abstract—A circular monopole antenna for ultra wideband (UWB) applications with triple band notches is proposed. The proposed antenna rejects worldwide interoperability for microwave access WiMAX band (3.3 GHz–3.8 GHz), wireless local area network WLAN band (5.15 GHz–5.825 GHz) and X-Band downlink satellite communication band (7.1 GHz–7.9 GHz). The antenna utilises mushroom-type and uniplanar Electromagnetic Band Gap (EBG) structures to achieve band-notched designs. The advantages of band-notched designs using EBG structures such as notch-frequency tuning, triple-notch antenna designs and stable radiation pattern are shown. The effect of variation of EBG structure parameters on which notched frequency depends is also investigated. Fabricated and measured results are in good agreement with simulated ones.

1. INTRODUCTION

Features such as low profile, inexpensive manufacture and compatibility with monolithic microwave integrated circuits (MMIC) design have made microstrip antenna considerably useful while the major concern of such antennas is low bandwidth. Since 2002, when the Federal communication commission (FCC) released the bandwidth 3.1 GHz–10.6 GHz, there has been increasing interest in the use of UWB systems because of their low power consumption, low cost, precise positioning and promising for short-range high-speed indoor data communications [1–3]. Planar circular monopoles [4] have been found as a good example for UWB applications due to their merits such as easy fabrication, acceptable radiation pattern, and large impedance bandwidth. However, some narrowband systems also operate in frequency such as WiMAX (3.3 GHz–3.8 GHz), WLAN (5.15 GHz–5.825 GHz) and X-Band satellite downlink satellite communication band (7.1 GHz–7.9 GHz), which cause interference in UWB range. To overcome any interference with these systems, it is desirable to design a UWB antenna with band-notch characteristics. Various methods have been proposed for band-notch designs such as cutting slots in patch/ground plane [5–8], putting parasitic elements near the patch [9, 10], using tuning stub [11], embedding resonant cells in microstrip feed line [12] and putting filter structures in the ground planes or in antenna feed [13]. In [14], notch bands around WiMAX, WLAN, and the X-band frequencies are obtained by etching out two elliptic single complementary split-ring resonators (ESCSRRs) of different dimensions from the radiating patch of the antenna and split-ring resonators near the feed line — patch junction of the antenna. In [15], the band-notched characteristics are obtained by introducing quarter-wavelength band-rejected elements in the planar UWB antenna. In [16], to create a multi-band antenna, several narrow strips, acting as resonance paths, can be integrated with the DSP (diamond shaped patch) antenna. In [17], by employing a hook-shaped defected ground structure (DGS) in each side of the ground plane, embedding an Ω-shaped slot on the radiating patch as well as adding a

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semi-octagon-shaped resonant ring on the back side of the antenna, triple-notched frequency bands are achieved. In [18], the proposed antenna uses three open-ended quarter-wavelength slots to create triple band-notched characteristics. In [19], a straight, open-ended quarter-wavelength slot is etched in the radiating patch, and three semi-circular half-wavelength slots are cut in the radiating patch to generate a triple-notched antenna. Extending similar concepts, triple-notch antennas are proposed by various authors in [20–23].

The problems with these methods are design-specific approach and poor notch width controlling. Furthermore, the radiation pattern and time domain behaviour of an antenna are affected by perturbations in radiating elements. Researchers in [24, 25] proposed UWB antenna with one or two notches with EBG structures but within a WLAN band only. The authors in [24] used four EBG patches to obtain a single notch. This paper presents a triple-notch UWB circular monopole antenna with notches in WiMAX, WLAN and X-Band downlink satellite communication bands. The paper begins by designing a simple circular UWB monopole antenna with mushroom and uniplanar EBG structures. Lastly, key parameters of EBG structures are varied, and their effects on notched frequencies are shown.

2. MUSHROOM ELECTROMAGNETIC BAND GAP STRUCTURES

Mushroom EBG structures are frequency selective surface and also known as Artificial Magnetic Conductor (AMC) or High Impedance Surface (HIS) [26–29]. The electrical equivalent of EBG structures is an LC filter where L accounts for current flow through via, and C is due to a gape between adjacent structures. The relation of physical parameters to electrical parameters for mushroom EBG structures is formulated in Eqs. (1) to (3).

$$L = 0.2h\left[\ln\left(\frac{2h}{r}\right) - 0.75\right] \tag{1}$$

$$C = \varepsilon_0\varepsilon_r\frac{w^2}{h} \tag{2}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{3}$$

where L and C define the inductance and capacitance values associated with mushroom EBG structures. W is the width of mushroom EBG patch, h the height of via, r the radius of via for mushroom EBG structures, ε_0 the absolute permittivity, ε_r the relative permittivity of the material and ω_0 the resonant frequency.

3. PROPOSED UWB MONOPOLE WITH TRIPLE NOTCHES

A circular monopole microstrip antenna with a defected ground plane is known as common UWB planar antenna structure. This antenna acts as a basic structure for notched antenna design, and only EBG unit cells are placed in the vicinity of microstrip line without affecting the dimensions of basic structures.

The proposed antenna is designed on a low cost substrate FR-4 with dielectric constant (ε_r) 4.4, height = 1.6 mm and loss tangent 0.02. The antenna design parameters are shown in Table 1.

$$f_r = \frac{1}{2\pi\sqrt{L_1\left(C_1 + C_0\right)}} \tag{4}$$

When there exist three interference bands in the UWB operating range, UWB with three notches is required. Hence the EBG unit cells can be placed in the vicinity of microstrip feed to obtain the desired notch. Figure 1 shows the dimensions of prototype UWB antenna with three EBG cells. EBG Cell 1, EBG Cell 2 and EBG Cell 3 [30] denote the different EBG structures used to obtain notches in WiMAX, WLAN and X-Band downlink satellite communication band, respectively. In recent years, there has been rapid development in EBG technology with emphasis on compact and uniplanar EBG structures. Like mushroom EBG structures, the surface impedance of uniplanar EBG is frequency sensitive since it also forms a distributed LC network with a specific frequency band. At the stop band, the equivalent LC network behaves as a high-impedance surface, forms 2-D electric filter and stops the propagation

Table 1. Dimensions of the proposed antenna.

Antenna Parameters	Value (mm)
Radius of circular disc monopole (R)	12
Length of conducting ground plane (L_1)	20
Width of dielectric substrate (W)	42
Length of dielectric substrate (L)	50
Width of Microstrip feed line (W_f)	3
Gap between ground and circular disc (h)	0.3
Radius of via of EBG 1 and 2 structures (r)	0.5
Gap between antenna feed and EBG 1 (g_1)	0.75
Gap between EBG 1 and EBG 2 (g_2)	0.55
Gap between antenna feed and EBG 3 (g_3)	0.15
Gap between feed line and EBG 1 (d_1)	0.1
Gap between feed line and EBG 2 (d_2)	0.25
Gap between feed line and EBG 3 (p_1)	0.2
EBG 3 cell edge length (d_3 and d_6)	15
EBG 3 cell dimension (d_4)	2.5
EBG 3 cell dimension (d_5)	1
EBG 3 cell dimension (d_7)	0.5
EBG 3 cell dimension (d_8)	2.5
Edge length of Square EBG 1 (W_1)	5.6
Edge length of Square EBG 2 (W_2)	9.25

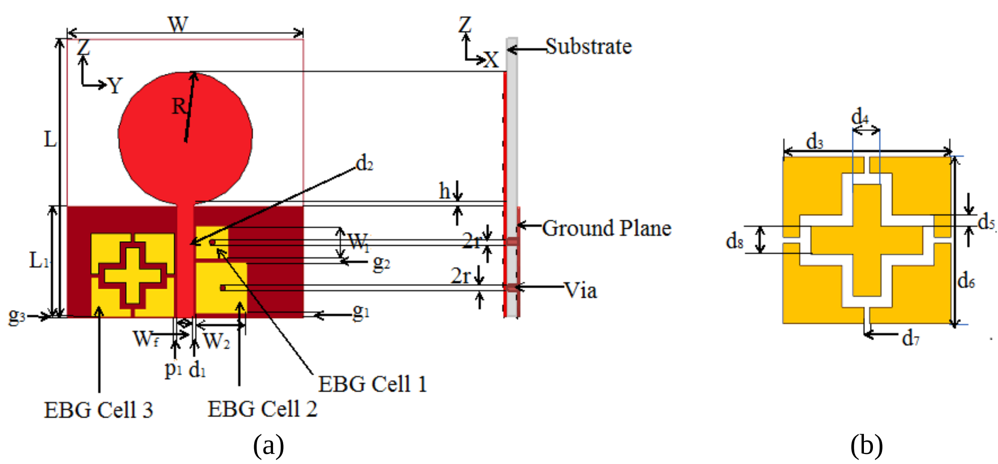

Figure 1. (a) Geometry of circular UWB monopole antenna with uniplanar and mushroom EBG, (b) EBG cell 3 dimensions.

of surface wave. In uniplanar EBG, inductor L results from thin connecting lines of EBG cell, and capacitance C results from gaps within the cell and b/w cell and feed. EBG Cell 3 used here in this paper is a typical example of uniplanar EBG. Figure 2 shows the equivalent circuit of Mushroom EBG cell [25] in the vicinity of microstrip line, and Eq. (4) gives the resonant frequency which is analogous to Eq. (3). Different EBG structures will have different currents distributed over them at different frequencies with maximum currents in their respective bandgaps.

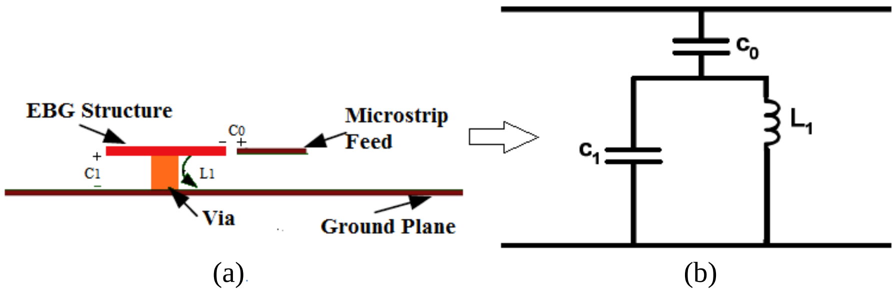

Figure 2. (a) EBG structure in the vicinity of transmission line, (b) equivalent circuit.

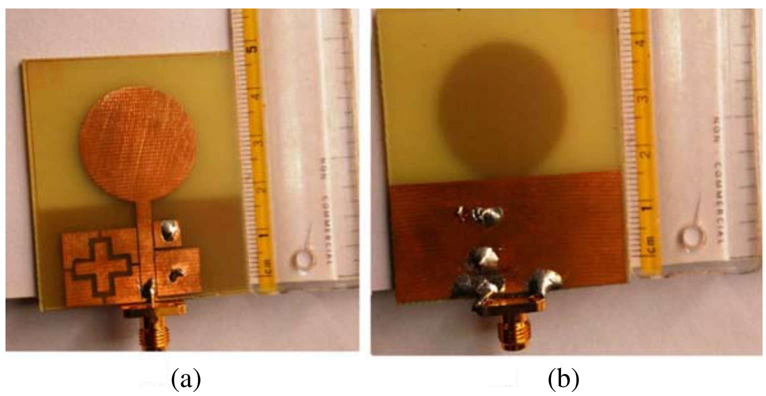

Figure 3. (a) Top View, (b) bottom view of fabricated prototype of antenna.

Figure 3 shows a fabricated prototype of the antenna. The VSWR of the fabricated antennas are measured using Agilent$^{\mathrm{TM}}$ Network Analyzer PNA-L series. All simulations are carried out using Ansoft HFSS v.14. The radiation mechanism of the antenna can be understood from input impedance vs frequency. In the band gap of EBG structures, there is a high mismatch in both real and imaginary parts of Input impedance of antenna. Hence input power does not get transmitted to antenna, and no radiation takes place.

4. RESULTS AND DISCUSSION

Figure 4 shows VSWR of the antenna. The notch in WiMAX band is centred at 3.45 GHz with VSWR value of 4.6, in WLAN band the notch centred at 5.55 GHz with VSWR value of 5.2 and in X-Band satellite downlink satellite communication band the notch centred at 7.6 GHz with VSWR of 6.88. The measured values of VSWR shown in Figure 4 at 3.45 GHz, 5.55 GHz and 7.6 GHz are found to be 4.93, 4.72 and 5.87, respectively. Figure 5 shows VSWR vs frequency plots when single EBG structures are placed in the vicinity of microstrip line. Figure 6 shows VSWR vs frequency plot when different combinations of EBG cells are placed near microstrip line. To a large extent, each EBG unit cell is responsible for a notch in its band gap though some mutual coupling is also present among different EBG cells. Figures 7, 8 and 9 show the variation in VSWR and frequency when p_1, d_1 and d_2, i.e., gaps between EBG structures and microstrip line, are varied. It is observed that as the gap decreases the mutual coupling between microstrip feed and EBG structures increases, and a strong band notch is obtained. Figure 10 shows variation of VSWR with variations of size of mushroom EBG patch which is used for WiMAX notch applications. It is shown that as the size of EBG patch (W_2) increases, the approximate capacitance associated with it increases using Eq. (2) and thereby decreasing the resonant frequency (f_r) given in Eq. (4). This happens because Eq. (2) shows a direct relation between EBG structure width (W) and capacitance (C), and Eq. (4) shows inverse relation between resonant frequency

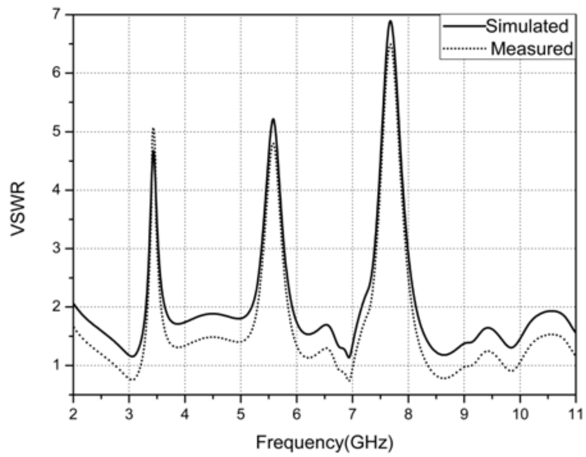

Figure 4. Simulated and measured VSWR of proposed antenna.

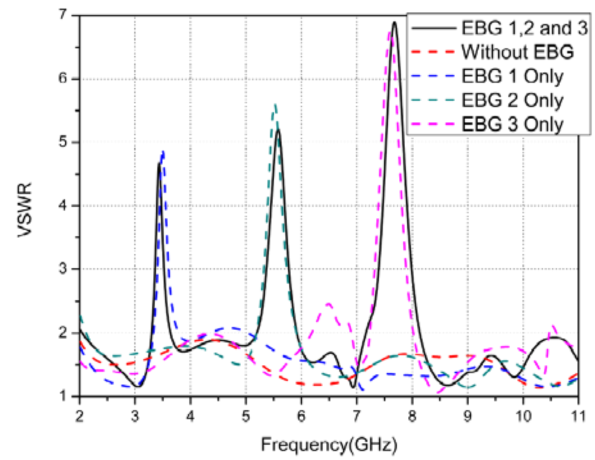

Figure 5. Proposed antenna with different EBG structures.

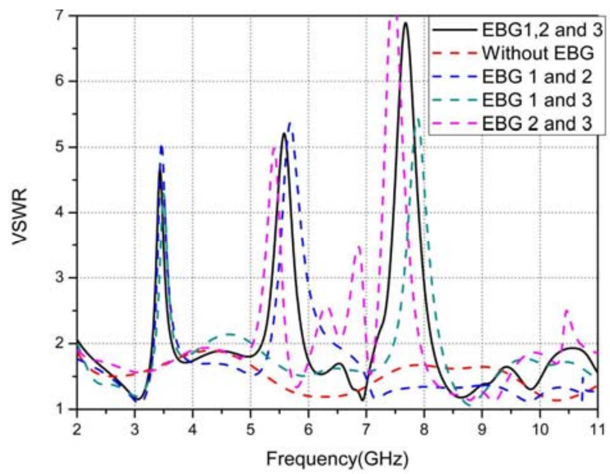

Figure 6. Proposed antenna with combination of different EBG structures.

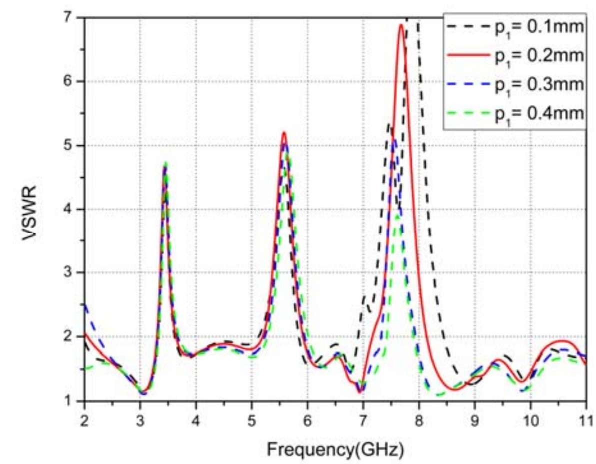

Figure 7. Effect of variation of gap between feed line and EBG structure (p_1).

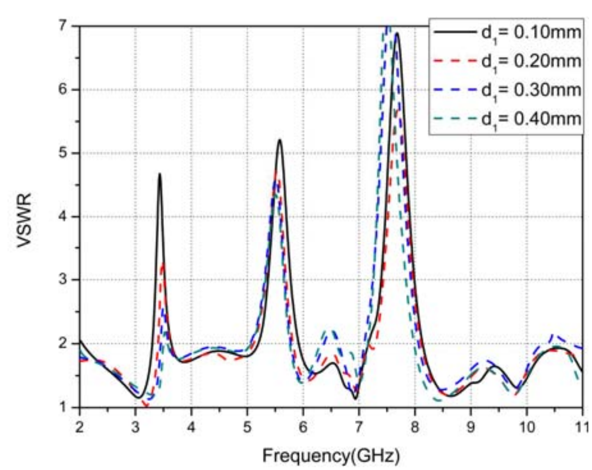

Figure 8. Effect of variation of gap between feed line and EBG cell 1 (d_1).

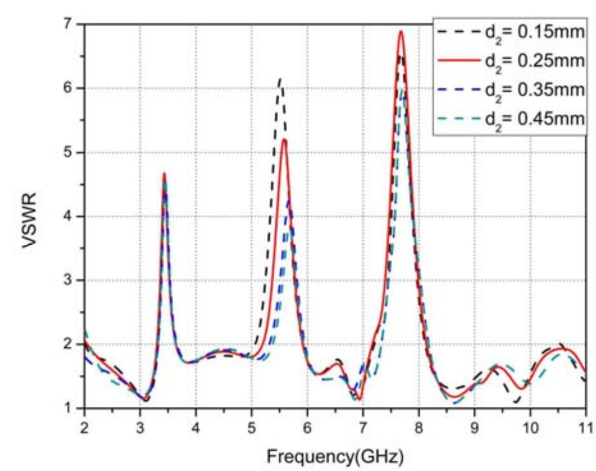

Figure 9. Effect of variation of gap between feed line and EBG cell 2 (d_2).

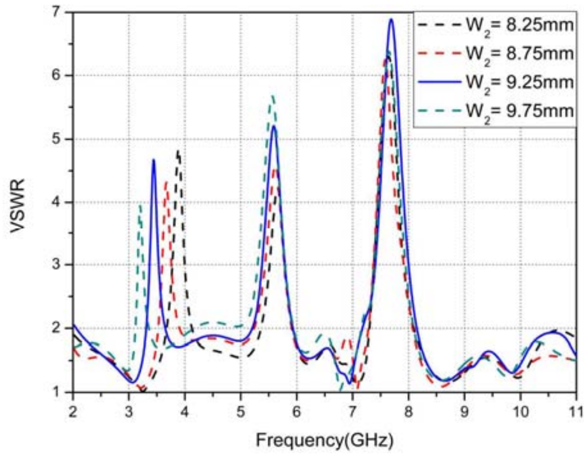

Figure 10. Effect of variation of edge length of mushroom EBG cell 2 (W_2).

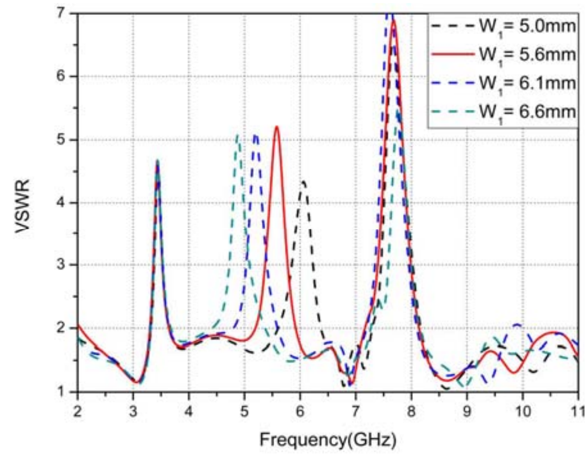

Figure 11. Effect of variation of edge length of mushroom EBG cell 1 (W_1).

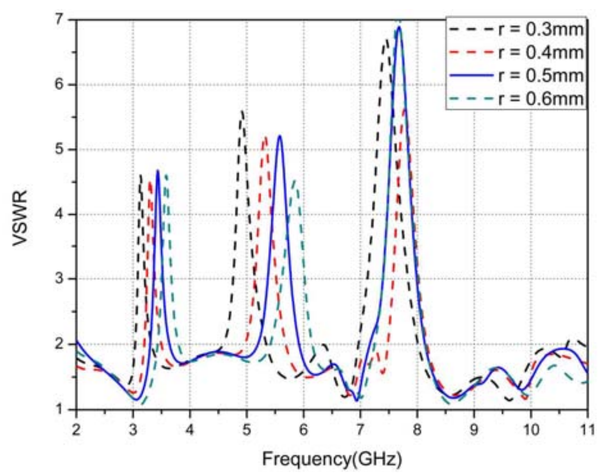

Figure 12. Effect of variation of radius (r) of via of EBG cells 1 and 2.

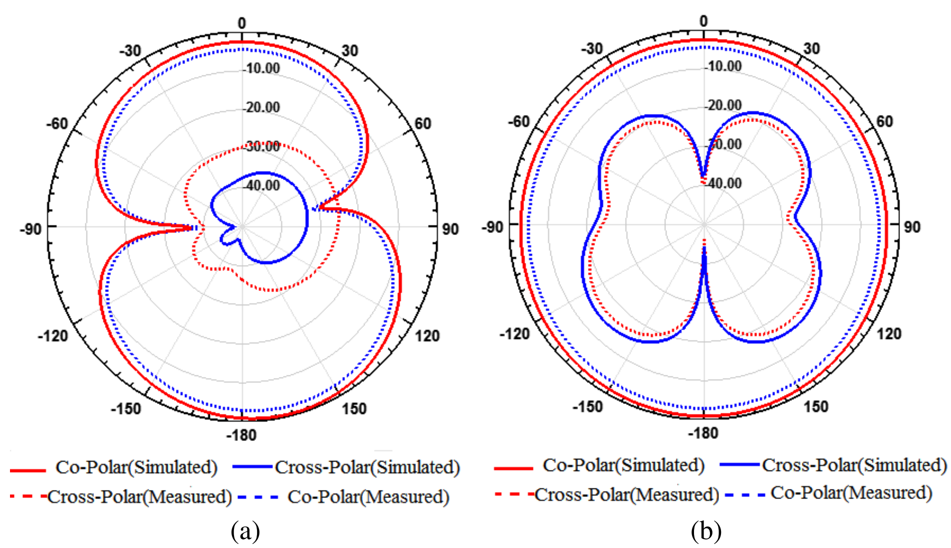

Figure 13. E-plane and H-plane radiation pattern of proposed antenna at 3.1 GHz.

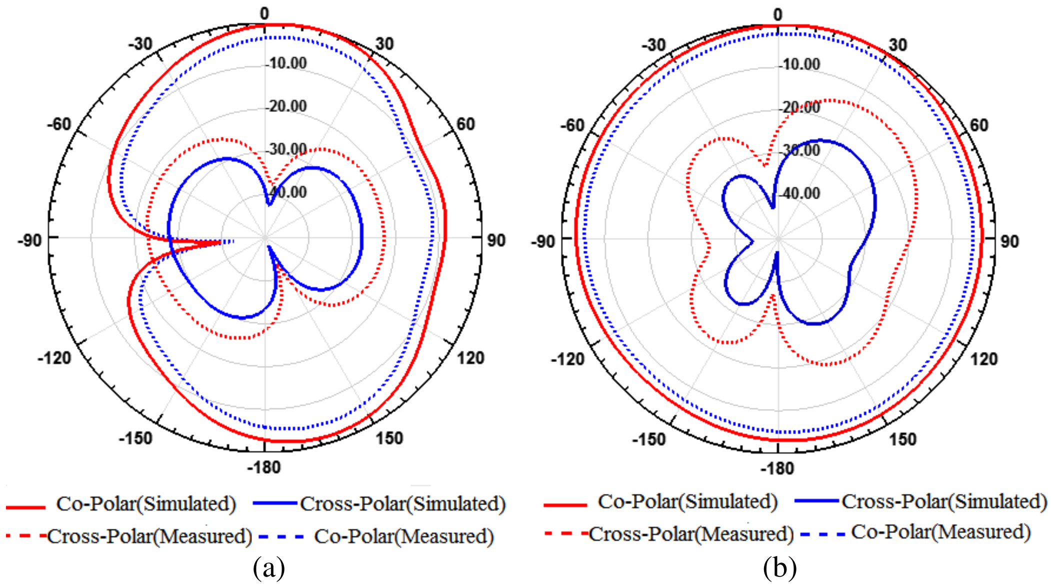

Figure 14. E-plane and H-plane radiation pattern of proposed antenna at 10 GHz.

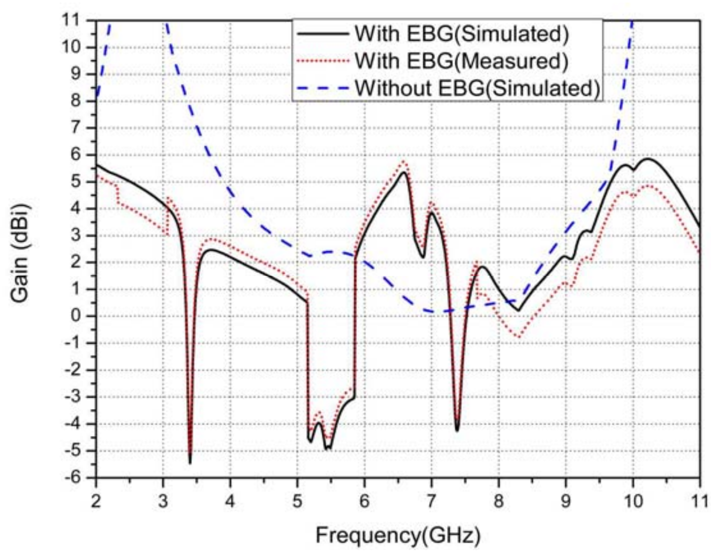

Figure 15. Variation of gain with frequency for proposed antenna.

(f_r) and capacitance (C). Similarly, Figure 11 shows the effect of variation of size of EBG structure (W_1) for WLAN notch-band applications. Figure 12 shows that as the radius of via decreases the centre frequency of notched band shifts at lower frequency. This can be easily verified using Eqs. (1) & (4), i.e., as the radius of via (r) decreases the inductance associated with it (L) increases which thereby decreases the resonant frequency (f_r) given in Eq. (4). The radiation pattern of the antenna is shown at 3.1 GHz and 10 GHz in Figure 13 and Figure 14, respectively. The radiation patterns in E-plane are roughly dumbbell-shaped, and the patterns in H-plane are quite omnidirectional, as expected. Figure 15 shows that gain of the antenna becomes negative at the notched frequencies.

5. CONCLUSION

In this paper, a triple-notch UWB circular monopole antenna with notches in WiMAX, WLAN and X-band downlink satellite communication bands is presented. The proposed antenna rejects worldwide interoperability for microwave access WiMAX band (3.3 GHz–3.8 GHz), wireless local area network WLAN band (5.15 GHz–5.825 GHz) and X-band downlink satellite communication band (7.1 GHz–7.9 GHz). It is also shown that up to a large extent, each EBG unit cell is responsible for a notch in its band gap though some mutual coupling is also present among different EBG structures. The technique discussed for obtaining triple notches is antenna design independent and can also be applied to other antennas without compromising antenna performance. The measured results are found in good agreement with simulated ones.

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