

Band notched UWB circular monopole antenna with inductance enhanced modified mushroom EBG structures

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Abstract Circular monopole antenna for ultra-wide band applications with notch band transition from WLAN to WiMAX is presented. The proposed antenna rejects WiMAX band (3.3–3.8 GHz). Antennas utilises modified mushroom-type electromagnetic band gap (EBG) structures to achieve band-notched designs. The proposed inductance enhanced modified EBG structures are 34 % compact than the conventional mushroom EBG structures. The band notched antenna designs using EBG structures have advantages like notch-frequency tuning, antenna design independent approach and omnidirectional radiation pattern. The step wise effect of inductance enhancement and tuning of notch from WLAN band (5–6 GHz) to WiMAX band is shown. Effect of variation of EBG structure parameters on which notched frequency depends is investigated. The proposed antenna has been fabricated on low cost FR4 substrate with overall dimensions as $(42 \times 50 \times 1.6)$ mm³. Measured results are in good agreement with simulated ones.

Keywords Modified mushroom electromagnetic band gap (EBG) structure · Notch band · Inductance enhancement · Ultra-wide band (UWB) antenna

1 Introduction

The Federal Communications Commission (FCC)'s [1] allocation of the frequency range of 3.1–10.6 GHz for UWB systems causes interference with existing standards like worldwide interoperability for microwave access WiMAX band (3.3–3.8 GHz) and wireless local area network WLAN band (5–6 GHz). So UWB antennas with a single or dual band-stop performance is required. The planar UWB patch antenna is extensively used in wireless communications because of its ease of fabrication, light weight and low cost. It has been demonstrated in [2] that the optimal design of this type of antenna can yield an ultra-wide bandwidth with satisfactory radiation properties over the whole bandwidth. To generate frequency band-notches, several techniques have been proposed. The simple and prominently used approach is to incorporate slots into the radiating elements, such as a U-shaped slot [3–5], V-shaped slot [6], an arc-shaped slot [7], square-slot [8] etc., mostly $\frac{\lambda}{2}$ resonator structures. Other techniques being used to obtain notches includes using tuning stub [9], putting parasitic elements near patch [10, 11], using resonant cells in microstrip feed line [12]. In [13] the band-notches are realized by adding controllable strips for notch frequency tuning and to adjust width of the band-notches. Recently, using similar to above mentioned techniques triple notch antennas are proposed by various authors in [14–18]. The problems with these methods are design specific approach as technique used with one antenna may

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not be used with other antenna design and poor notch frequency controlling. Furthermore, radiation pattern of antenna and time domain behaviour of antenna gets affected using alterations in radiating patches.

Researchers in [19, 20] proposed notched UWB antenna with one or two notches with mushroom EBG structures. EBG structures can be used to obtain notches with most of UWB antenna designs without effecting antenna behaviour substantially. The authors in [19] used four mushroom EBG structures to obtain single notch. In [20] ELV-EBG structures are used to replace the conventional EBG but no significant size reduction is achieved. Hence realising compact EBG structures is now important requirement for applications in electromagnetic and antenna community [21–23]. Due to sudden increase in EBG structure’s applications various compact EBGs are proposed. Different techniques used to achieve compactness includes spiral shaped EBGs [24], using Hilbert curve [25] and complementary designs [26]. EBG structures that have polarization-dependent reflection phase are discussed in [27]. Tuneable EBG structures using varactor diodes and other active elements are proposed in [28, 29]. EBG structure optimization techniques like genetic algorithms [30] and particle swarm optimization are reported so as to analyse these structures easily.

The high bandwidth provided by UWB results in high data rate. It can provide hundreds of Mbps to several Gbps in 1–10 m range. It makes UWB technology finds applications in wireless networking [31], wireless telemetry, wireless speakers, wireless sensor networks telemedicine [32]. UWB technology has best time resolution and ranging capabilities. This allows its usage in positioning and tracking applications, collision avoidance radars in vehicles and guided parking etc. UWB material penetration capabilities make its use in radar imaging, ground penetration radars, medical imaging [33] and surveillance systems.

This paper begins by designing a simple planar Circular UWB monopole antenna with mushroom EBG structures to

obtain notch in WiMAX band. Then effect of purposely Inductance Enhancement with modified EBG structure is shown and step wise notched frequency is tuned from WLAN to WiMAX band thereby reducing the size of conventional Mushroom EBG structure up to 34 %. Lastly, parameters of EBG structures are varied and their effects on notched frequencies are shown.

2 Selective band gap formation with EBG structures for propagating surface waves

EBG structures are a kind of frequency selective surface also known as High Impedance Surface (HIS) or Artificial Magnetic Conductor (AMC). EBG structures acts like band stop filters in a particular frequency band, at the same time provides very high impedance hence also given the name High Impedance Surface [34–37]. Mushroom EBG structures constitutes metallic patches and shorted pins named via that connect patches into the ground planes. The operation of EBG can be seen as equivalent to a LC filter where L is due to current flow through via and C is due to gap effect between adjacent patches. The various parameters of EBG are formulated in Eq. (1–5) [35].

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

$$C = \epsilon_0 \epsilon_r \frac{w^2}{h} \tag{2}$$

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

$$BW = \frac{1}{\eta} \sqrt{\frac{L}{C}} = \frac{\Delta\omega}{\omega_0} \tag{4}$$

where $\eta = 120 \pi$ is the free space impedance. Frequency dependence of surface impedance may be written as

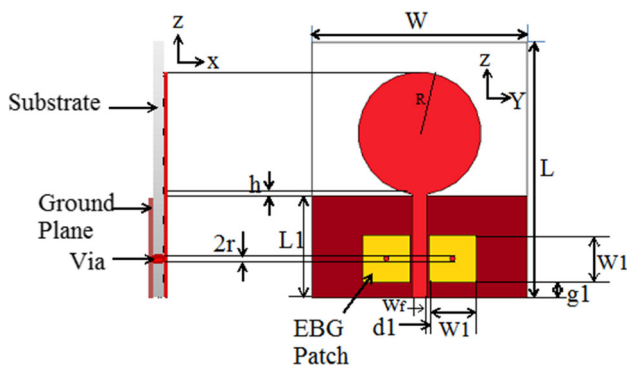


Fig. 1 Geometry of notched circular UWB monopole antenna (antenna 1)

Table 1 Antenna 1 design parameters in mm

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 EBG structure via (r)	0.5
Gap between antenna feed and EBG structure (g_1)	3.05
Gap between feed line and EBG structure (d_1)	0.3
Edge length of square EBG structure (W_1)	9.25

Fig. 2 a EBG structure in the vicinity of transmission line. b Equivalent circuit

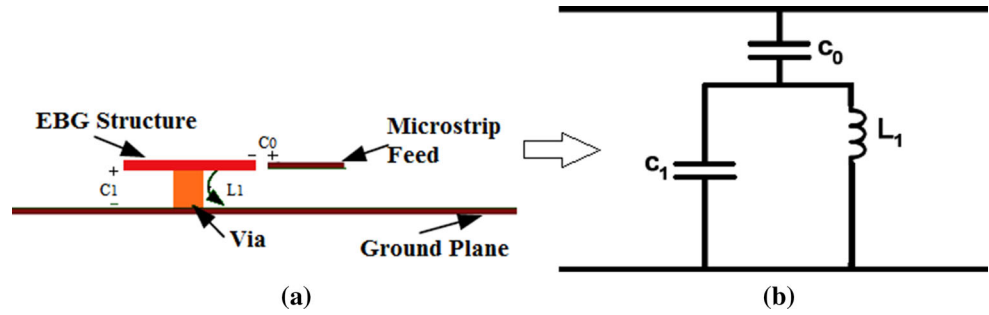


Fig. 3 Surface current distribution of UWB antenna with EBG for notch in WiMAX band

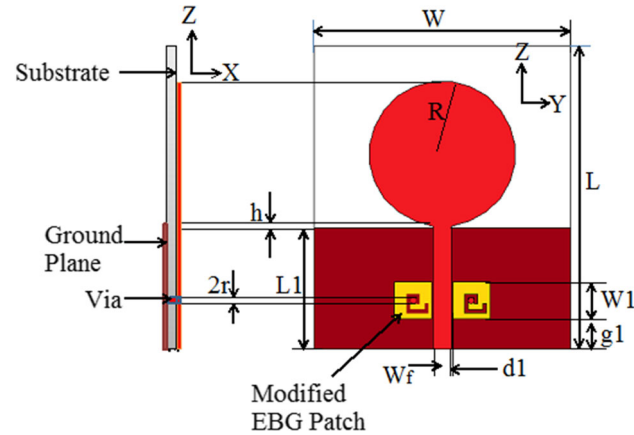
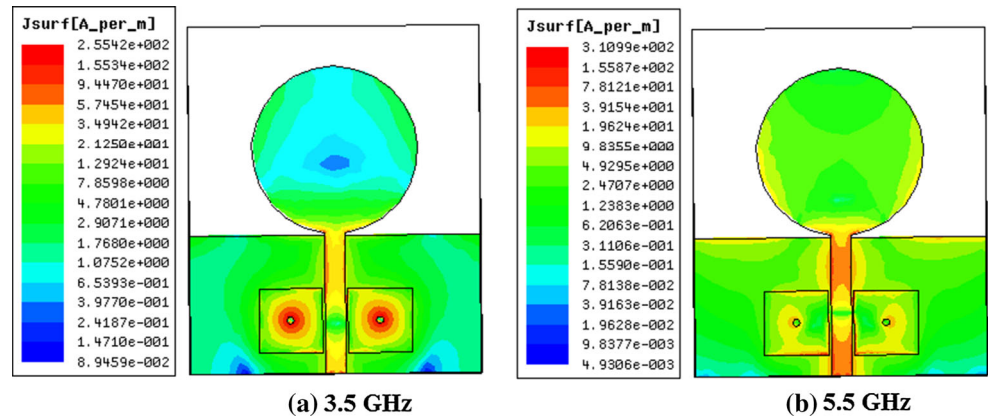


Fig. 4 Geometry of proposed circular UWB monopole antenna with modified mushroom EBG (antenna 2)

$$Z_s = \frac{j\omega L}{1 - \omega^2 LC} \tag{5}$$

3 Conventional UWB monopole with notch in WiMAX

The conventional planar UWB patch 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.

Table 2 Antenna design parameters of antenna 2 in mm

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 EBG structure via (r)	0.5
Gap between antenna feed and EBG structure (g_1)	5
Gap between feed line and EBG structure (d_1)	0.2
Edge length of square EBG structure (W_1)	6.1

Proposed antenna is designed on low cost substrate FR-4 with dielectric constant (ϵ_r)4.4, substrate height of 1.6 mm and loss tangent of 0.02.

Figure 1 shows the geometry of prototype UWB antenna with mushroom EBG cells. Antenna 1 design parameters are listed in Table 1. Figure 2 shows the equivalent circuit of Mushroom EBG cell [19] in the vicinity of microstrip line and Eq. (6) gives the resonant frequency which is analogous to Eq. (3). The simulated current distribution of antenna 1 is shown in Fig. 3. It can be seen easily from Eq. (3) that different EBG structures have different current distributions at different frequencies

Fig. 5 Development of Inductance enhanced modified mushroom EBG cells

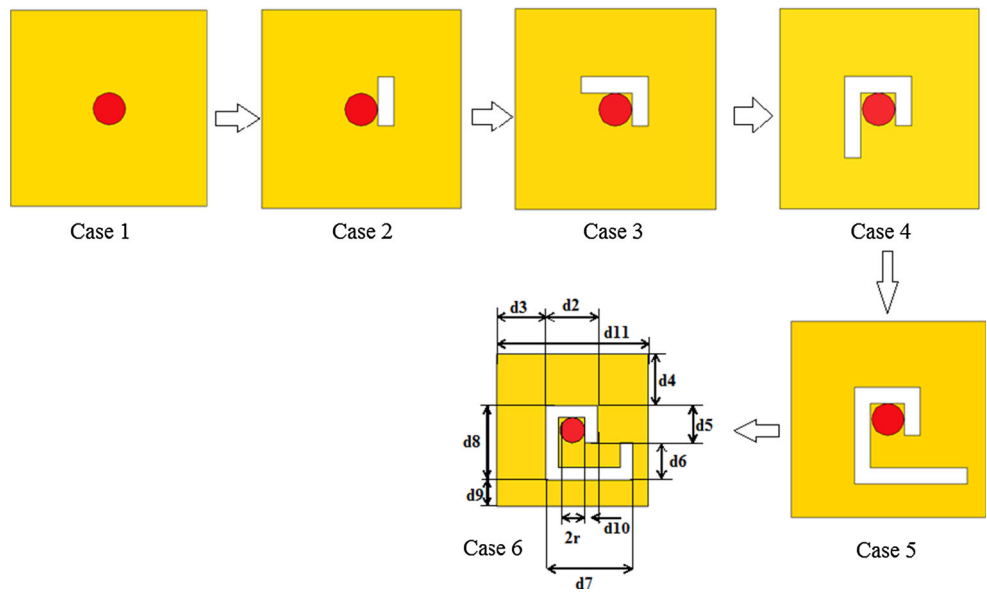


Fig. 6 **a** Modified EBG structure in the vicinity of transmission line. **b** Equivalent circuit

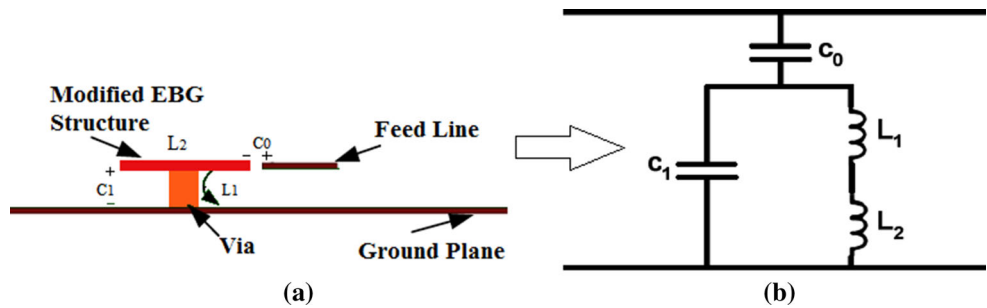


Fig. 7 Surface current distribution of UWB circular monopole antenna with EBG for Notch in WiMAX band

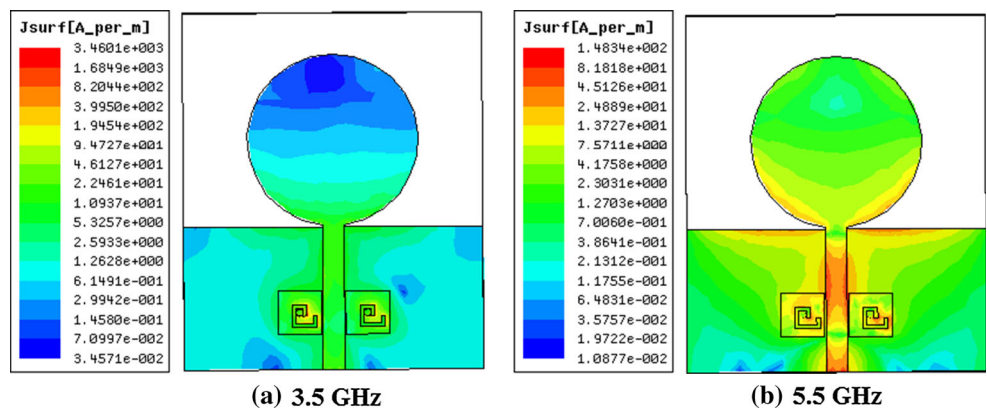


Table 3 Design parameters in mm of inductance enhanced modified EBG structures

2r	d ₂	d ₃	d ₄	d ₅	d ₆	d ₇	d ₈	d ₉	d ₁₀	d ₁₁
1	2.05	2	2.05	1.5	1.5	3.5	3	1.05	0.5	6.1

with maximum currents in their respective bandgaps. The Mushroom EBG structures have maximum current accumulated over them at 3.5 GHz and thereby creating a notch at this frequency.

$$f_r = \frac{1}{2\pi\sqrt{L_1(C_1 + C_0)}} \tag{6}$$

4 Proposed UWB monopole with notch in WiMAX using modified EBG structures

Figure 4 shows the proposed antenna with Inductance Enhanced EBG structures. The EBG structures used here are compact then the conventional mushroom type EBG structures used in Fig. 1.

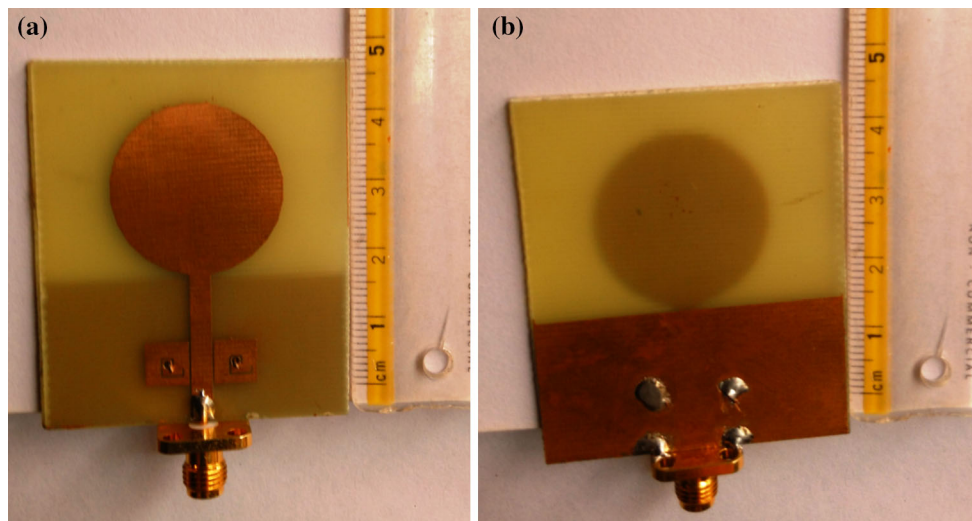


Fig. 8 a Top view, b bottom view of fabricated prototype of antenna 2

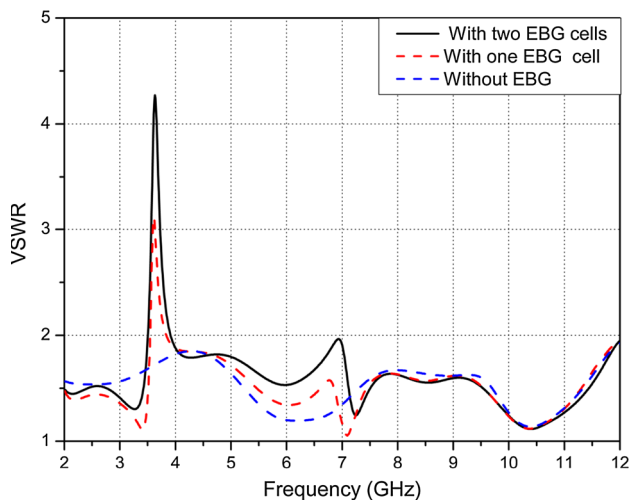


Fig. 9 VSWR of antenna 1 with notch in WiMAX bands with one and two EBG cells

Proposed antenna design parameters are listed in Table 2. Figure 5 shows the development of Inductance enhanced EBG cell. A spiral shaped slot is made in the EBG structure to increase the inductance and different cases represents incremental inductance enhancement. The spiral slot length and width are selected purposely to achieve the objective of notch transition from WLAN to WiMAX. The circular dot in the centre of EBG structures denotes conducting vias. Figure 6 shows the equivalent circuit of inductance enhanced modified mushroom EBG structure placed in the vicinity of antenna feed.

$$f_r = \frac{1}{2\pi\sqrt{(L_1 + L_2)(C_1 + C_0)}} \quad (7)$$

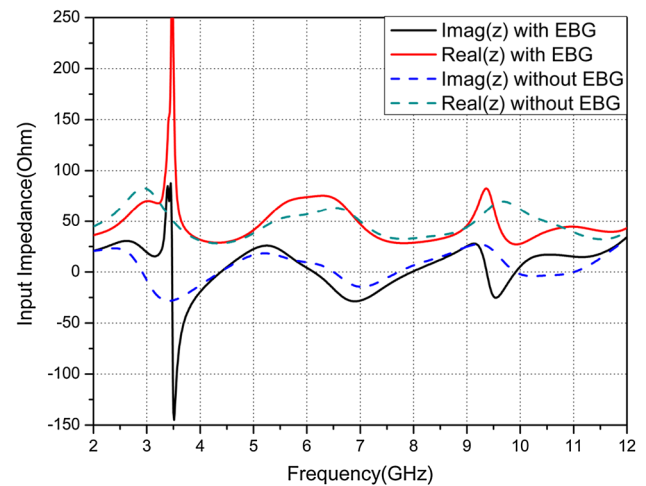


Fig. 10 Variation of Input impedance of proposed antenna with and without EBG structures

Figure 7 shows the equivalent circuit of Inductance enhanced modified mushroom EBG cell in the vicinity of microstrip line and Eq. (7) gives the resonant frequency which is analogous to Eq. (3) with increased inductance value. Table 3 represents the modified mushroom type EBG design parameters.

5 Results and discussion

The simulated current distribution of proposed antenna is shown in Fig. 7 for further investigations. It can be seen easily that in the band gap of EBG structure at 3.5 GHz less current is distributed over the radiating element. Figure 8 shows the fabricated prototype of antenna 2. The

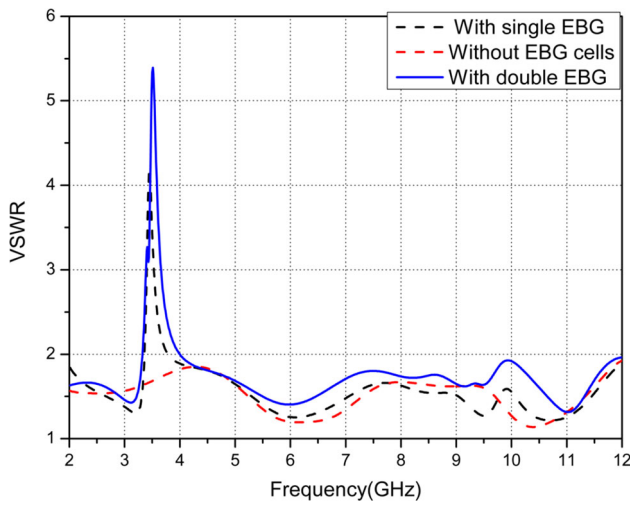


Fig. 11 VSWR of antenna 2 with notch in WiMAX bands with one and two EBG structures

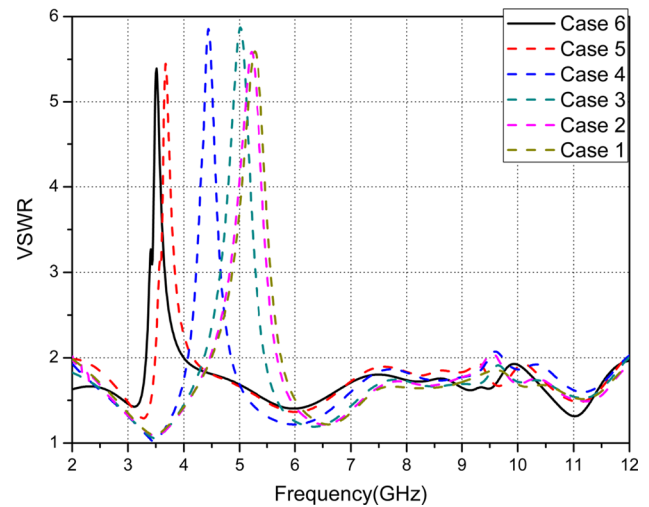


Fig. 13 Effect of inductance enhancement on notch with double EBG cells

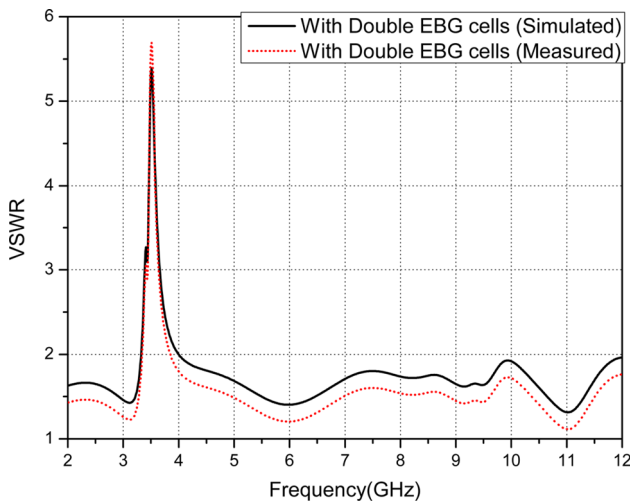


Fig. 12 Simulated and measured VSWR of proposed antenna

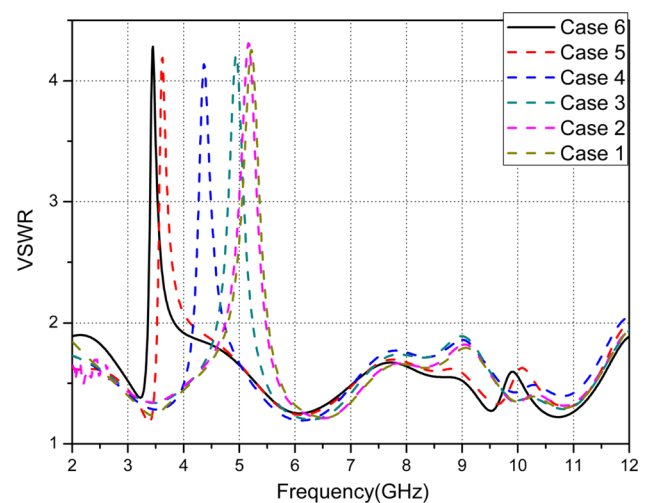


Fig. 14 Effect of inductance enhancement on notch with single EBG cell

VSWR of fabricated antenna is measured using Agilent™ Network Analyzer PNA-L series. All simulations are carried out using Ansoft HFSS v.14. The VSWR of antenna 1 with single and double EBG cells are shown in Fig. 9 and it is verified that strong magnitude notch is obtained with double EBG cells. The edge length of conventional EBG structures used with antenna 1 for notch in WiMAX band is 9.25 mm which is reduced to 6.1 mm in proposed inductance enhanced modified EBG structures used with antenna 2, giving nearly 34 % compactness over conventional mushroom structures. Figure 10 shows the high impedance mismatch of antenna 2 in WiMAX band. The real and imaginary parts of input impedance of antenna in the WiMAX band gap are 300.10 and 87.65 Ω at 3.48 and 3.45 GHz respectively. The real and imaginary part of

antenna without EBG's lies around 50 and 0 Ω respectively. The radiation mechanism of antenna can be understood from input impedance versus frequency plots. In the EBG band gap of there is a high mismatch in both real and imaginary parts of antenna, hence input power does not get transmitted to antenna and no radiation takes place. The VSWR of antenna 2 with single and double EBG cells are shown in Fig. 11 and it is verified that strong magnitude notch is obtained with double EBG cells.

Figure 12 shows the VSWR of antenna 2, the notch in WiMAX band is centred at 3.49 GHz with VSWR value of 5.85, the measured values of VSWR is found to as 5.43. Figures 13 and 14 show the VSWR of antenna 2 with incremental inductance enhancement with double and single EBG cells respectively. Case 1 in Fig. 5 represents

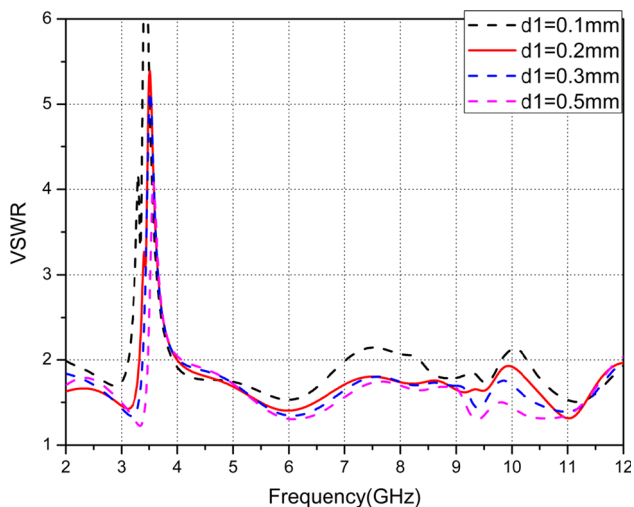


Fig. 15 Effect of variation of gap between feed line and EBG structure (d_1)

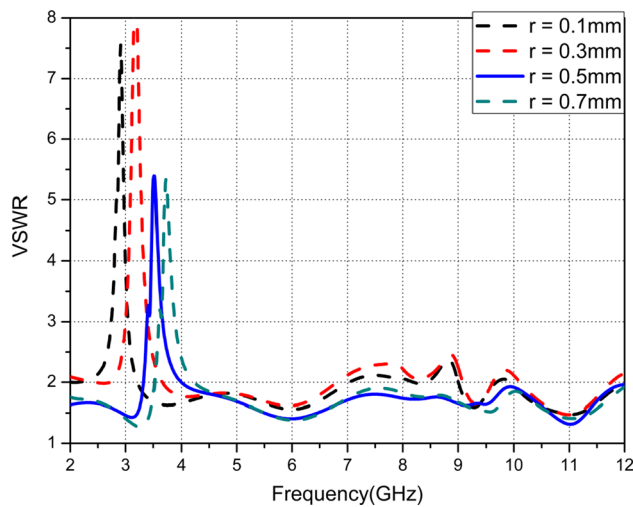


Fig. 17 Effect of variation of radius of EBG structure via

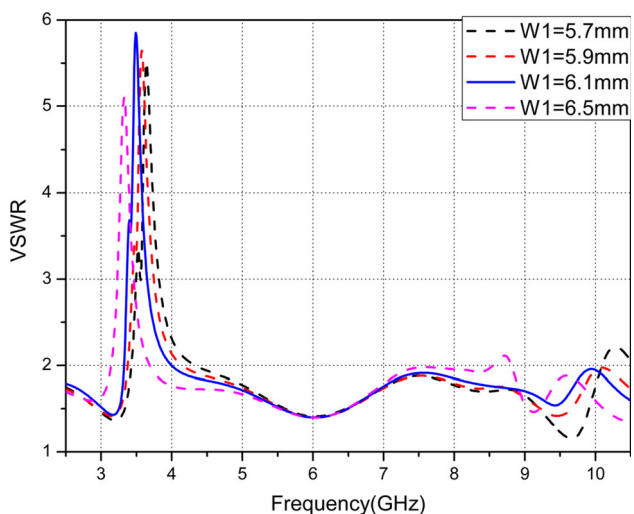


Fig. 16 Effect of variation of edge length of square EBG structure (W_1)

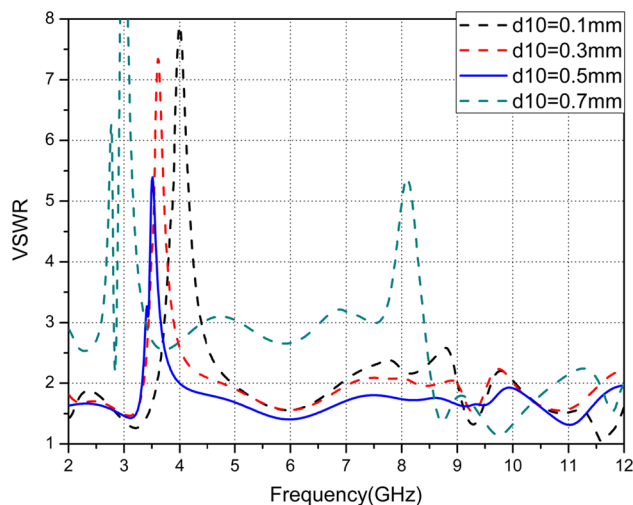


Fig. 18 Effect of variation of variation in slot width of EBG structures (d_{10})

no slot is made on EBG patch and case 6 represents a spiral slot is created on EBG patch, thus enhancing the inductance. The effect of adding extra inductance is reflected in equivalent circuit shown in Fig. 6 and corresponding Eq. (7) in terms of L_2 .

Case 1 EBG cell of Fig. 5 can be used for obtaining notch in WLAN band (5–6 GHz) and case 6 EBG cell is used to obtain notch in WiMAX band. Antenna 1 uses squared EBG cell with edge length equal to 9.25 mm and antenna 2 uses squared EBG with edge length 6.1 mm to obtain notch in the WiMAX band. Thus using the proposed method 34 % reduction in size of EBG structure and thereby transition in notch from Wlan to WiMAX band is shown. Figure 15 shows the variation in VSWR

and Frequency when d_1 i.e. gap between EBG 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 16 shows variation of VSWR with variations of size of square EBG structure which is used for WiMAX notch applications. It is shown that as the size of EBG patch (W_1) increases the approximate capacitance associated with it increases using Eq. (2) and thereby decreasing the Resonant frequency (f_r) given in Eq. (7). Figure 17 shows that as the radius of via decreases the Centre frequency of notched band shifts at lower frequency band. This can be easily verified using Eqs. (1) and (7) i.e. as the radius of via (r) decreases the

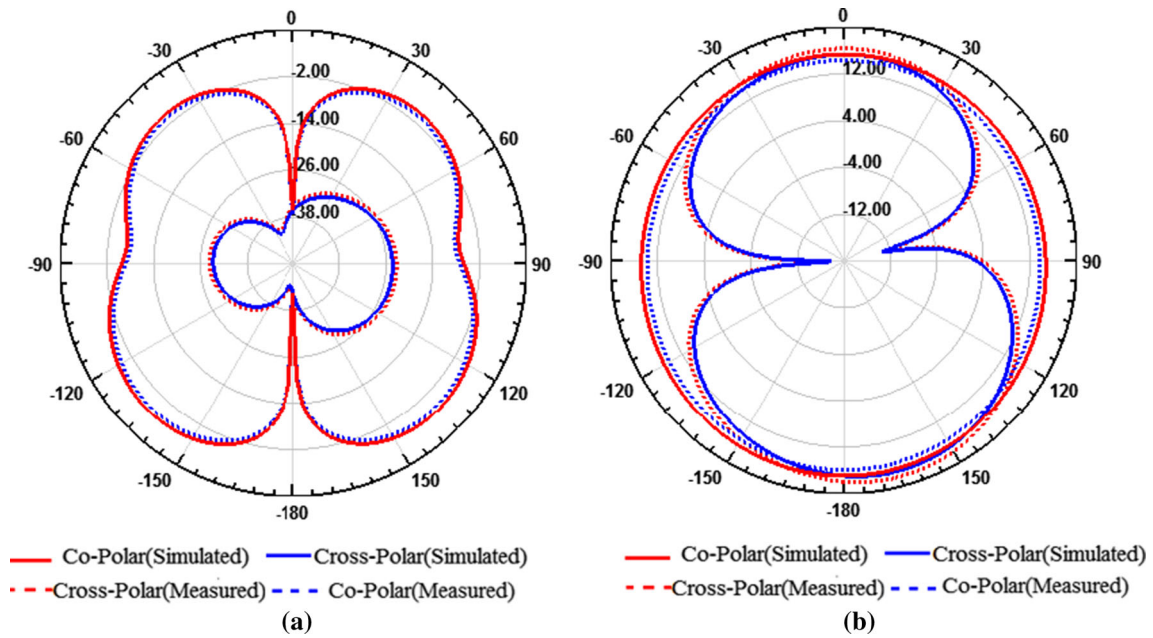


Fig. 19 E-plane and H-plane radiation pattern of proposed antenna at 3.1 GHz

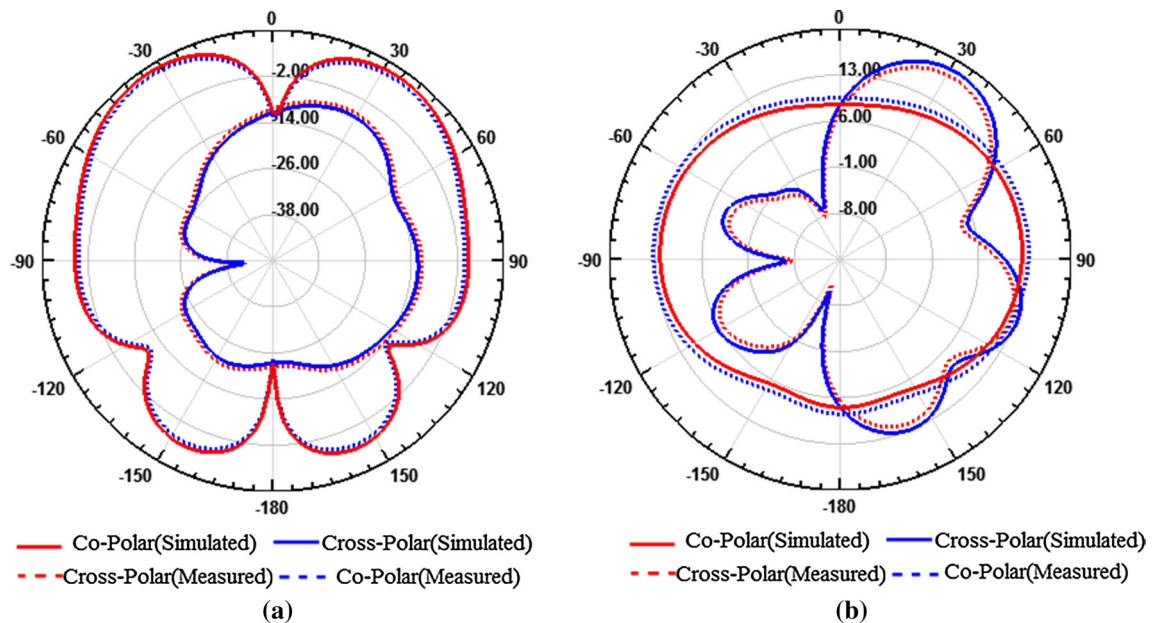


Fig. 20 E-plane and H-plane radiation pattern of proposed antenna at 8 GHz

inductance associated with it (L) increases which thereby decreasing the resonant frequency (f_r) given in Eq. (7). Figure 18 shows the variation in slot width (d_{10}) that is used to create inductance enhancement in proposed EBG structures. An optimum value of d_{10} equals to 0.5 mm is chosen to achieve the objective of paper. The radiation

pattern of antenna 2 is shown at 3.1 and 8 GHz in Figs. 19 and 20 respectively. Generally speaking, the radiation patterns in E-plane are roughly a dumbbell shape and the patterns in H-plane are quite Omni-directional, as expected. Figure 21 shows that gain of proposed antenna becomes negative at the notched frequencies.

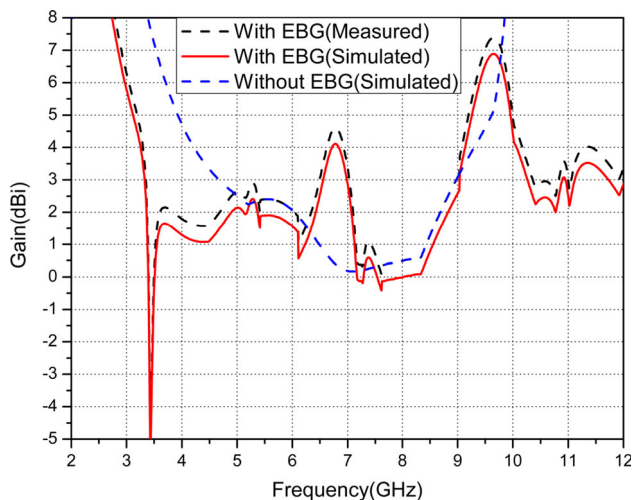


Fig. 21 Variation of gain with frequency for proposed antenna

6 Conclusion

In this paper a notch UWB circular Monopole antenna with notch in WiMAX is presented. The proposed antenna rejects worldwide interoperability for microwave access WiMAX band (3.3–3.8 GHz). It can also reject wireless local area network WLAN band (5–6 GHz) if spiral slot is not made on EBG structures used in antenna 2. A spiral shaped slot is made on the EBG structure to increase the inductance and different cases represents incremental inductance enhancement. With incrementing inductance value the notch is also shown shifting from WLAN to WiMAX band. The proposed technique for obtaining notch is antenna design independent and can be applied to most of other antennas also without compromising antenna performance. Measured results are found in good agreement with simulated one.

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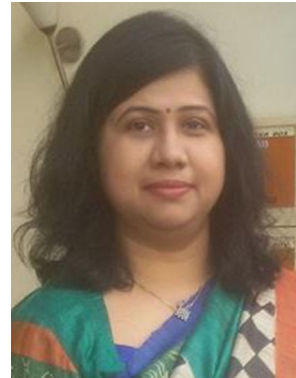
under gone number of professional courses, some of them notably are course on solid state devices at I.I.T. Kharagpur, First and Second line servicing course on Mirage-2000 Aircraft at Gwalior, Air Staff course from Defence Service Staff College, Wellington, Microwave and millimetre wave systems and application course at Institute of Radio Physics and Electronics, Kolkata, and Portable Laser Designator System course at M/s ELOP Industries Ltd, Israel.



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