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Analysis and Design of Compact Triple Band Notched Circular Monopole Antenna Using Mushroom EBG Structures and Compact Spiral Slotted EBG Structures

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Abstract**: *This work presents analysis and design of a low profile multi band notched UWB circular monopole antenna. Multi band rejection characteristics of the proposed antenna can be achieved by placing the EBG structures in the proximity of the feed line. To avoid the interference with narrow bands with frequency ranges from (3.2-4.0) GHz – WiMAX, (5.0-5.9) GHz – WLAN and (7.1-8.4) GHz – X-Band (both uplink and downlink), it is essential for any antenna operating in UWB to have band rejection features. The proposed antenna has the dimensions of 46x26x1.6 mm^3. The simulation was carried out through HFSS.***

Index Terms**: *EBG structure, Multi Band-Notch, UWB antenna.***

I. INTRODUCTION

Ultrawide band spectrum ranging from 3.1 GHz to 10.6 GHz is declared as an unlicensed band by the 2002 Federal Communication Commission (FCC) report. Due to the advantages like low cost, low power consumption and higher bandwidth there has been an increase in use of UWB antennas. Many antennas were proposed with different notching techniques to eliminate the interference due to narrow band wireless technologies like WLAN, WiMAX and X band that share the same bandwidth of UWB technology.

Naveen Jaglan, Binod K. Kanaujia, Samir D. Gupta, and Shweta Srivastava designed a printed UWB antenna with notches at dual-band. To obtain rejection in dual band, EBG cells are placed along the feed line to provide two stop band filters with mid frequencies of 3.5 GHz and 5.5 GHz [1].Dual band rejection characteristics in WiMAX (3.3 - 3.6 GHz) and WLAN (5.1-5.8 GHz) is obtained by placing CSRR slot on the patch and an inverted L shape EBG structure adjacent to the radiating patch [2]. A modified electromagnetic-band gap (MEBG) structure is used to generate dual notched bands in a common UWB antenna. The M-EBG consists of two L-shaped strips with different dimensions. The dual notched bands WiMAX and WLAN are achieved by varying the dimensions of the M-EBG [3]. In [4] to obtain dual notch-band properties, a slotted mushroom type EBG structure is used for reduction in mutual coupling. Hao Liu and Ziqiang Xu [5] proposed a dual band notch UWB antenna for WiMAX and satellite applications in X-band. To achieve, dual Band notch characteristics, a complementary hexagonal SRR is placed on the patch fed by a microstrip line with a partial ground plane. F. Mouhouche, A. Azrar, M. Dehmas and K. Djafri [6] proposed a WLAN band notched characteristic antenna. The notched characteristics are obtained by inserting two rectangular mushroom shaped EBGs on either side of the feed line. In order to avoid interference in UWB region for Bluetooth and WLAN bands, a monopole antenna with stepped geometry has been considered in [7]. Here the band notch has been achieved by using a modified mushroom type EBG which has a square patch with additional two complementary L-slots embedded in it and a metallic via which connects the ground plane to the patch. In [8] dual notch band UWB antenna with Defected Ground Compact Electromagnetic Band Gap structures (DG-CEBG) is designed to notch WLAN band. In [9] a circular shaped UWB monopole antenna was designed with which the WiMAX, WLAN, X-Band downlink satellite communication bands have been notched using uniplanar and mushroom type EBGs.

The above papers provided single, dual and triple band notches at WiMAX, WLAN, X-band downlink satellite communications.

This paper proposes a very low profile circular monopole radiator with mushroom type EBGs and compact spiral slotted EBG to provide triple notched bands at WIMAX, WLAN and satellite communications (both uplink and downlink) operating in X-band.

II. ANTENNA CONFIGURATION

The designed Multi- notch strip fed monopole antenna's structural configuration and dimensional details are shown in Fig 1. The proposed antenna comprises of FR-4 substrate which has ε_r of 4.4 and δ= 0.024.

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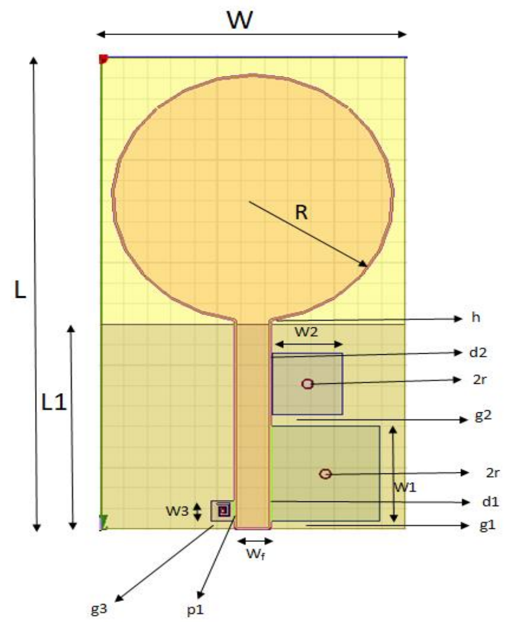

Fig 1: Dimensions of proposed antenna structure.

The proposed antenna structure has a circular patch fed by a microstrip feedline.

As the dimension is considered to be a circular loop, the actual radius of the patch is calculated by

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

$$F = \frac{8.791\ x10^9}{f_r\sqrt{\varepsilon_r}}$$

The effective radius of patch is calculated by

$$a_e = a\left\{1 \frac{2h}{\pi \varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h}\right) 1.7726\right]\right\}^{1/2}$$

The resonant frequency is given by

$$(f_r)_{110} = \frac{1.8412\, v_0}{2\pi a_e\sqrt{\varepsilon_r}}$$

Three Mushroom EBG structures which are frequency selective surfaces are placed in the proximity of feed line for providing notched bands. The equivalent circuit of EBG structure consists of a *LC* filter where *L* indicates the current flow through via, and *C* is because of the gap between adjacent structures. The physical parameters of the mushroom EBG structures can be related with the electrical parameters and can be formulated as follows.

$$L = 0.2h\left[\ln\left(\frac{2H}{R}\right) - 0.75\right]$$

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

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

Here *C* and *L* represent the capacitance and inductance values for the mushroom EBG structures.

W represents the width of mushroom EBG structure, *H* is the height of via, *R* is the radius of via for mushroom EBG structures, ε_0 represents the free space permittivity, ε_r representsthe relative permittivity of the material and $\omega 0$ represents the operating frequency.

The antenna has defected ground structure and its dimensions are found by using the following equations.

$$L(g) = 6h + L$$

$$W(g) = 6h + w$$

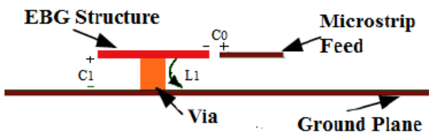

Fig 2: Mushroom EBG.

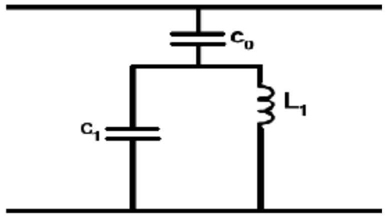

Fig 3: Equivalent circuit of Mushroom EBG structure.

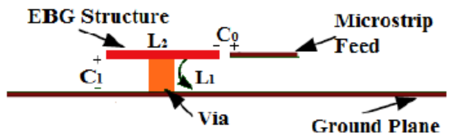

Fig 4: A compact spiral slotted EBG (CSS-EBG) structure.

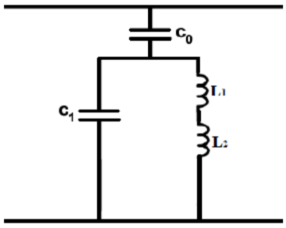

Fig 5: Equivalent circuit of CSS-EBG structure.

In the mushroom EBG structures and CEBG structure inductor L_1 is obtained from the thin connecting plates of the EBG cell and capacitance C_0 is obtained because of the gap between conducting plate & feed, capacitance C_1 results from the gap between EBG conducting plate and ground plane. In CEBG structure, L_2 represents the inductance in series with L_1 due to the spiral slot structure in the top plane of CEBG cell which can be observed in figure 5.

The optimized dimensions of the proposed structure are provided in the table 1 below.

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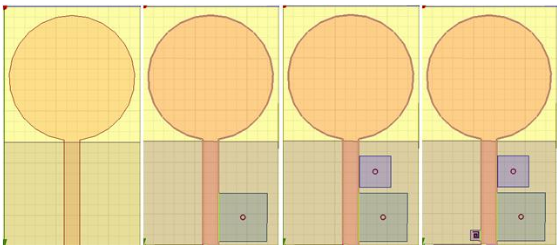
Table 1: Dimensions of the proposed antenna structure

Antenna Parameters Value (mm)	Value(mm)
Radius of circular disc monopole (R)	12
Length of conducting ground plane (L_1)	20
Width of dielectric substrate (W)	26
Length of dielectric substrate (L)	46
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
Radius of via of EBG 3 structure (r_1)	0.25
Gap between antenna feed and EBG 1 (g_1)	0.75
Gap between EBG 1 and EBG 2 (g_2)	1.15
Gap between antenna feed and EBG 3 (g_3)	0.75
Gap between feed line and EBG 1 (d_1)	0.1
Gap between feed line and EBG 2 (d_2)	0.2
Gap between feed line and EBG 3 (d_3)	0.05
Edge length of Square EBG 1 (W_1)	9.25
Edge length of Square EBG 2 (W_2)	6
Edge length of Square EBG 3 (W_3)	2

III. EVOLUTION OF PROPOSED ANTENNA STRUCTURE

Different stages involved in the evolution of proposed antenna for obtaining band notches in the desired bands are shown in fig 6.



Stage1 Stage2 Stage3 Stage 4

Fig 6: Evolution of the proposed antenna structure.

Stage 1 comprises of a circular monopole fed by a microstrip line with defected ground. In stage 1, the antenna operates in entire UWB.

In addition to Stage1, Stage 2 consists of mushroom EBG cell 1.This provides a band notch at 3.5 GHz with a bandwidth of 0.8 GHz.

In addition to Stage2, Stage 3 consists of mushroom EBG cell2. EBG cell2 provides a band notch at 5.5 GHz. Stage 3 provides a two band notches at 3.5 GHz and 5.5GHz with a bandwidth of 0.9 GHz.

In addition to Stage 3, Stage 4 consists of DG compact EBG cell3. EBG cell3 provides a band notch at 8 GHz. Finally Stage 4 provides a three band notches at 3.5 GHz, 5.5 GHz and 8 GHz with a bandwidth of 1.8 GHz.

The simulated results for different stages of proposed antenna are depicted in fig 7.

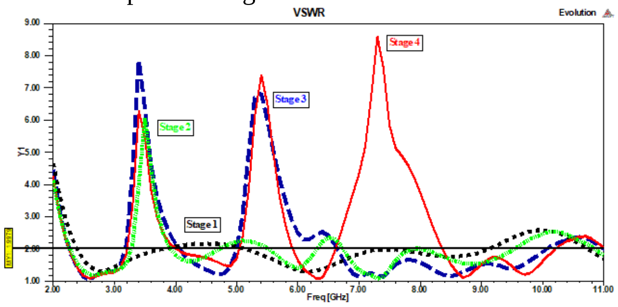


Fig 7: VSWR plots for four stages in the evolution of the proposed antenna.

The gap between the feed line and EBG structures is varied to achieve desired band notch. It is observed that by decreasing the gap (d2) between EBG 2 and feed line the mutual coupling between the elements is increased and a strong band notch is obtained, an increase of band width is observed in the band rejected corresponding to EBG 2 as shown in fig 8 and 9.

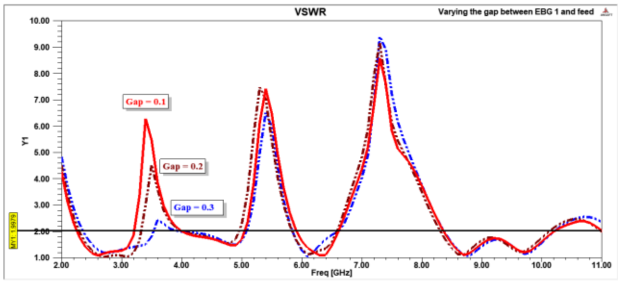


Fig 8: Optimetrics for the parameter d1.

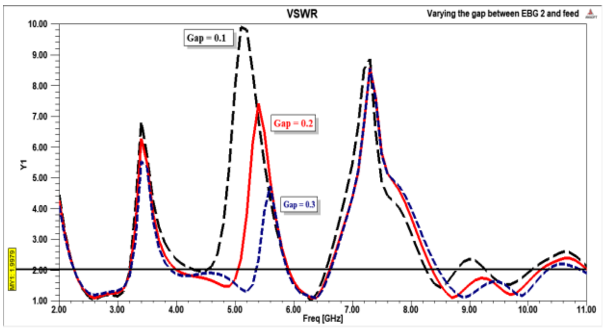


Fig 9: Optimetrics for the parameter d2.

The plots of VSWR and S11 of proposed antenna are shown in figures 10 and 11.

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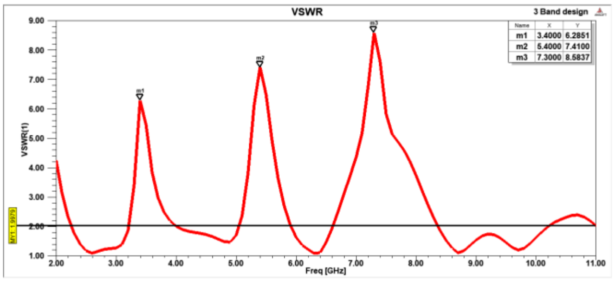

Fig 10: VSWR plot.

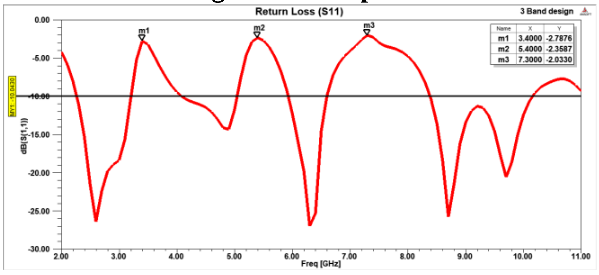

Fig 11: S_{11} plot.

There is interference from three narrow bands i.e. due to WLAN, WiMAX, X-band satellite communications in the UWB operating range. Hence an UWB antenna needs to overcome the interference due to these bands while operating in the entire UWB. To achieve notched bands at these three frequencies, three EBG cells are placed in the proximity of the feed line.

EBG cell 1 and EBG cell 2 are mushroom type EBG structures which are conducting patches with shorted vias which connects this conducting patch and the ground plane. EBG 3 is a compact spiral EBG structure. The spiral shaped slots present in the CEBG structure increases the total series inductance between the EBG and ground plane making the structure compact.

The band notch at WiMAX and WLAN are obtained due to EBG cell 1 and EBG cell 2 respectively. At these bands, the EBG cell 1 and EBG cell 2 having equivalent circuit as LC network as shown in fig 3 acts as a surface which has high impedance, forms an electric filter that attenuates the propagation of surface waves. The current distribution is shown in the figures 12 and 13.

The band notch at X-Band is obtained due to EBG cell 3. At this band, the EBG cell 3 having equivalent circuit as LC network that is shown in fig 5 acts as a surface which has high impedance, forms an electric filter that attenuates the propagation of surface waves. The current distribution is shown in the fig 14.

Different EBG structures that are placed near the feed line will have maximum currents in their corresponding band gaps and minimum current at other frequencies.

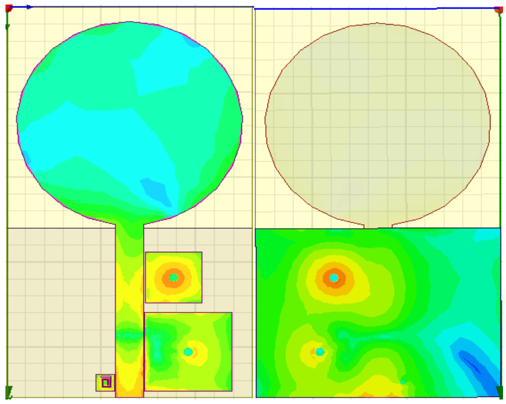

Fig 12: Current distribution in the radiating plane and ground plane at 3.4 GHz.

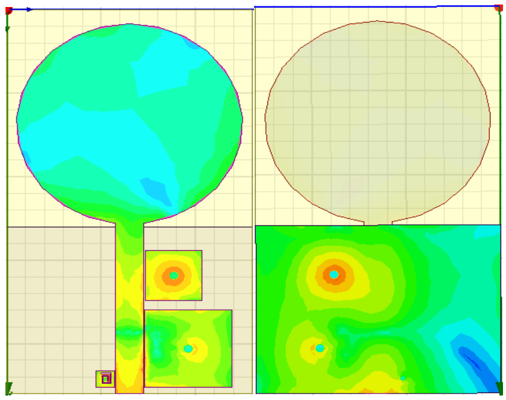

Fig 13: Current distribution in the radiating plane and ground plane at 5.4 GHz.

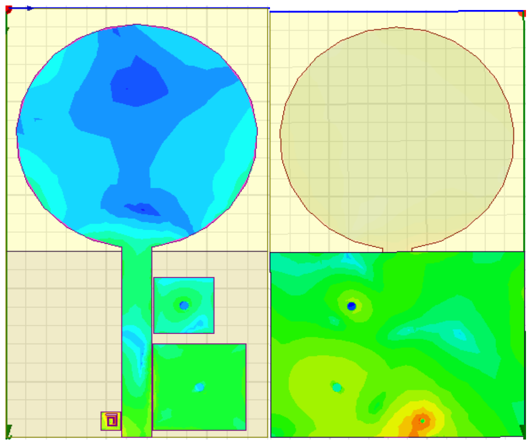

Fig 14: Current distribution in the radiating plane and ground plane at 7.3 GHz.

The gain plot of the proposed antenna is shown in fig 15.

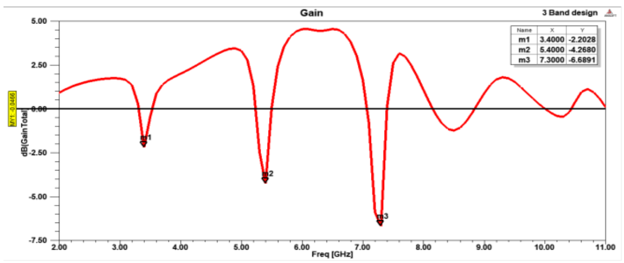

Fig 15: Gain plot of the proposed antenna.

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The elevation and azimuthal plane patterns at notched frequencies are shown in the following figures 16, 17 and 18.

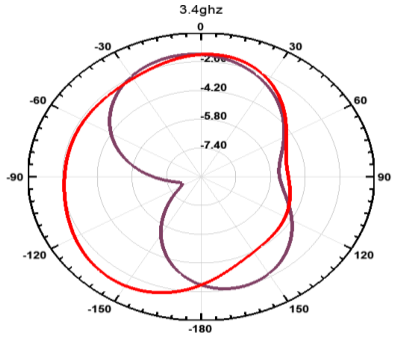

Fig 16: E-plane and H-plane Radiation pattern at 3.4 GHz.

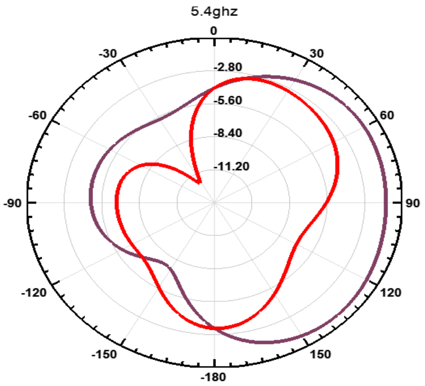

Fig 17: E-plane and H-plane Radiation pattern at 5.4 GHz.

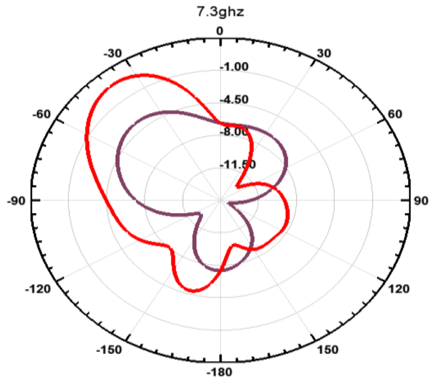

Fig 18: E-plane and H-plane Radiation pattern at 7.3 GHz.

The three dimensional polar plots at the notched frequencies are shown in figures 19, 20 and 21.

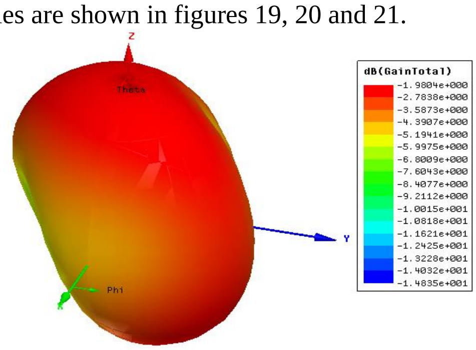

Fig 19: 3-D polar plot at 3.4 GHz.

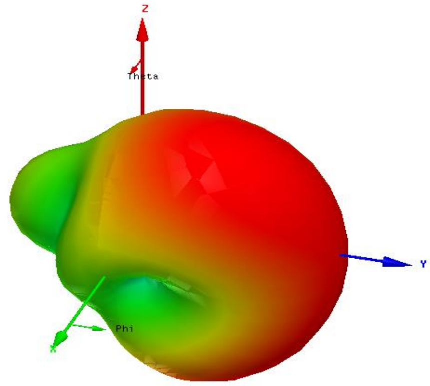

Fig 20: 3-D polar plot at 5.4 GHz.

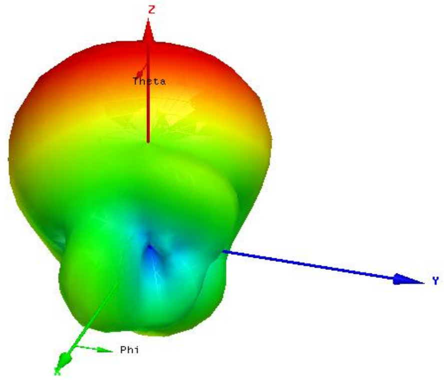

Fig 21: 3-D polar plot at 7.3 GHz.

Table II: Comparison of size of antenna cited in the references

Number of Bands rejected	Band rejection	Size of antenna (mm)
Two Bands [1]	3.375 – 3.875 5.325 – 6.150	42.5 × 34 × 1.6 = 2312mm³
Two Bands [2]	3.3 – 3.6 5.1 -5.8	30 × 30 × 1.6 Volume = 1440
Two Bands [3]	WiMAX WLAN	40 × 30 × 1.6 Volume =1920
Two Bands [4]	WiMAX WLAN	40 × 38 × 1.6 Volume =2432
Two Bands [5]	3.3 – 3.95 7.3 – 8.25	26 × 20 × 1.6 Volume =832
One Band [6]	WLAN	32 × 26 × 1.6 Volume =1331.2
Single Band [7]	WLAN	40 × 30 × 1.6 Volume =1920
Two Bands [8]	3.3 – 3.6 5 – 6	42 × 50 × 1.6 Volume =3360
Three Bands [9]	WiMAX WLAN X – band downlink	42 × 50 × 1.6 Volume =3360
Three Bands (Proposed antenna)	3.2 – 4 5 – 5.9 6.8 – 8.4	46 × 26 × 1.6 Volume =1913.6

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The proposed antenna structure is found to have a low profile among the reference antennas cited above.

IV. CONCLUSION

A triple-notched band circular monopole antenna at WiMAX, WLAN & X-band satellite communication bands is designed. The proposed antenna provides notches for worldwide interoperability for microwave access WiMAX band (3.2 GHz – 4.0 GHz), WLAN band (5.0 GHz - 5.9 GHz) and X-band satellite communication band (7.1 GHz – 8.4 GHz). The benefit of using EBG structures is investigated. It is shown that every EBG unit structure is accountable for providing a notch in its corresponding band gap. The procedure presented for obtaining notches is independent of the antenna structure and can be extended to other antenna designs without affecting performance of the antenna.

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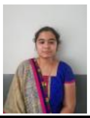

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