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Ultrawideband Notch Antenna with EBG Structures for WiMAX and Satellite Application

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Abstract—In this paper, an ultrawide band (UWB) notch antenna with electromagnetic bandgap (EBG) structure for WiMAX and satellite applications is proposed. The proposed design contains an inverted-π model slot and EBG element which create lower and upper notch frequency bands, respectively. The designed antenna is fabricated on a Rogers RT/duroid 5880 with the dimensions of $18 \times 21 \times 1.6\,\text{mm}^3$ which is fed with a $50\,\Omega$ transmission line. The proposed antenna has a frequency range from 2 GHz to 12 GHz, in which lower notch covers 3.3–3.7 GHz (WiMAX), and upper notch covers 5.9–6.9 GHz (satellite uplink application). The simulated and measured proposed antenna results are in good correlation. It has good radiation characteristics in the required frequency bands.

1. INTRODUCTION

Ultrawide band (UWB) communication system becomes popular among researchers, academicians, and industries in recent years. UWB consists of S-band (2 to 4 GHz), C-band (4 to 8 GHz), and X-band (8 to 12 GHz). UWB holds viable applications due to its distribution of unlicensed band between 3.1 and 10.6 GHz [1]. It is an important technique which has large bandwidth, and it needs only less energy than wireless protocols for short range communication purpose [2] and can also be used in applications, such as wireless personal area network (WPAN), worldwide interoperability for microwave access (WiMAX), wireless local area network (WLAN), military communication, ground penetrating radar, and intelligent sensors. Among all the above benefits, frequency interference is focused as a serious problem in UWB. To overcome the aforementioned issue, a bandstop filter is embedded with the UWB antenna to avoid such interfering signals. However, the external embedded filter significantly increases the total dimensions of the antenna [3]. To realize above performance, the planar antenna technique is used which is compact in nature, in low cost, and easy to integrate into modern devices. A number of band stop models have been described to bring down the conceivable electromagnetic noise in UWB antenna [4, 5]. Different types of EBG are embedded in the antenna design to achieve notch characteristics [6–14]. A single notch is created by introducing an inverted-U-type slot on a ground plane of the antenna design [6]. Due to interference of many wireless applications and various standards, the single notch band performance is not sufficient. Multiple notch band antenna design can be used for addressing the current demand. Currently numerous multi-notch band designs are present, which decrease the interference among UWB and narrowband communication systems [7–11]. A three stage capacitive loaded line resonator (CLLR) is embedded on a radiating patch to generate three notch bands for wireless local area networks (WLAN), wideband code division multiple access (WCDMA), and global system for mobile communication (GSM) applications at the frequency range of 2.4 GHz, 2.15 GHz, and 1.78 GHz, respectively [12]. To generate dual notches, a stub loaded ring resonator (SLRR) is embedded on radiating element, and periodic spiral like electromagnetic bandgap

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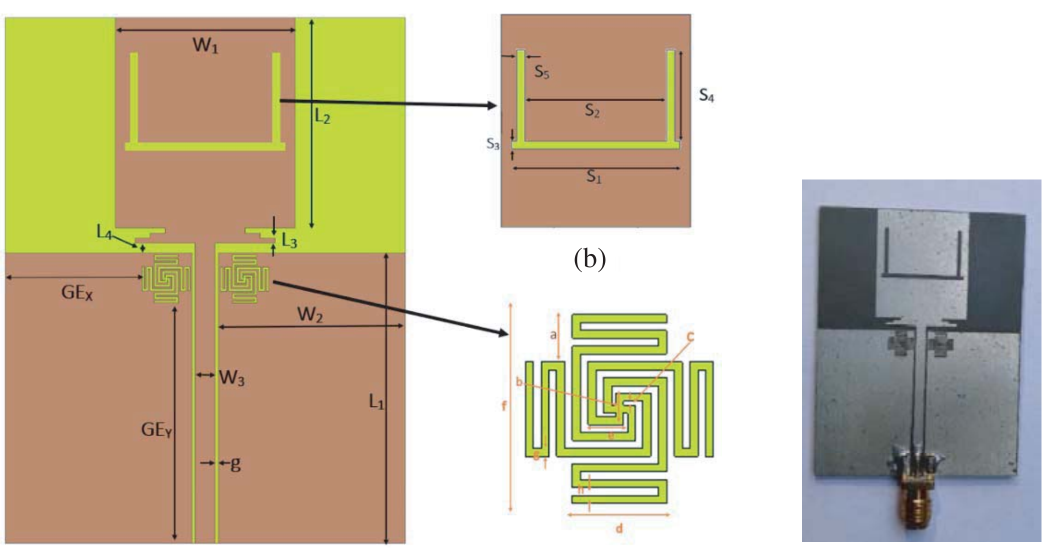
(EBG) arrays are embedded around the radiating patch [13]. Similarly, a circular ring is printed on a monopole antenna with a triangular tapered microstrip feed line (TTMFL), and round cornered finite ground plane (RCFGP) antenna has been offered to generate double notch features [14]. However, to realize dual notch feature, two stub resonators have been used. Most of the existing designs have limitations of multiple resonators and large size, which cause difficulty in implementation [15–21]. A circular dumbbell antenna for WiMAX application is proposed with square and circular shape EBGs, but it offers single notch only. A double notch is achieved by integrating two different EBG designs uniformly embedded near the input line of the UWB antenna [22]. Similarly, double notch band is realized in UWB antenna by designing a mushroom type EBG configuration close to connecting line and adding a complementary split ring resonator (CSRR) on the propagating field. Notch features using EBG model have used a regular mushroom model and the contacts concluded to ground plane through substrate using metal. A few investigators also finalize unipolar EBG close to feed path to get notch features [23]. The above discussed antennas have a drawback of non-self-control resonance, and this can be overcome in the proposed antenna design.

In this paper, a double band UWB antenna with self-control rejection is proposed. Towards realizing lower rejection band, an inverted-π shaped structure is embedded on radiating plane for S-band which operates between 3.3 and 3.7 GHz for WiMAX application. Similarly, the upper rejection band is obtained by embedding a unipolar EBG structure on both sides of ground plane which operates between 5.9 and 6.9 GHz for satellite communication. An inverted-π shaped slot and EBG structure embedded on radiating plane and ground plane control the lower and upper notch bands, respectively. The proposed antenna design has advantages of compact size, dual notch band performance as well as operates independently.

2. ANTENNA CONFIGURATION

The proposed UWB antenna is designed using a Rogers RT/duroid 5880 substrate of thickness 1.6 mm with relative permittivity of $\varepsilon_r = 2.2$ and dielectric loss tangent of 0.0009 as shown in Figure 1(a). The radiating element has the dimensions of $18\,\text{mm} \times 21\,\text{mm}$ along with feed line width of 2 mm to achieve $50\,\Omega$. The radiating element comprise three parallel truncated rectangular slits close to the bottom of radiating element. The geometrical parameters of the proposed antenna design are shown in Figure 1(a). Parameters are $w1 = 18\,\text{mm}$, $w2 = 18.7\,\text{mm}$, $w3 = 2\,\text{mm}$, $L1 = 29\,\text{mm}$, $L2 = 21\,\text{mm}$, $L3 = 0.5\,\text{mm}$, $L4 = 1\,\text{mm}$, and $g = 0.2\,\text{mm}$. The proposed antenna is designed using Ansoft HFSS.



(a) (c) (d)

Figure 1. The proposed UWB anenna. (a) Antenna design, (b) inverted-π section, (c) EBG section and (d) prototype.

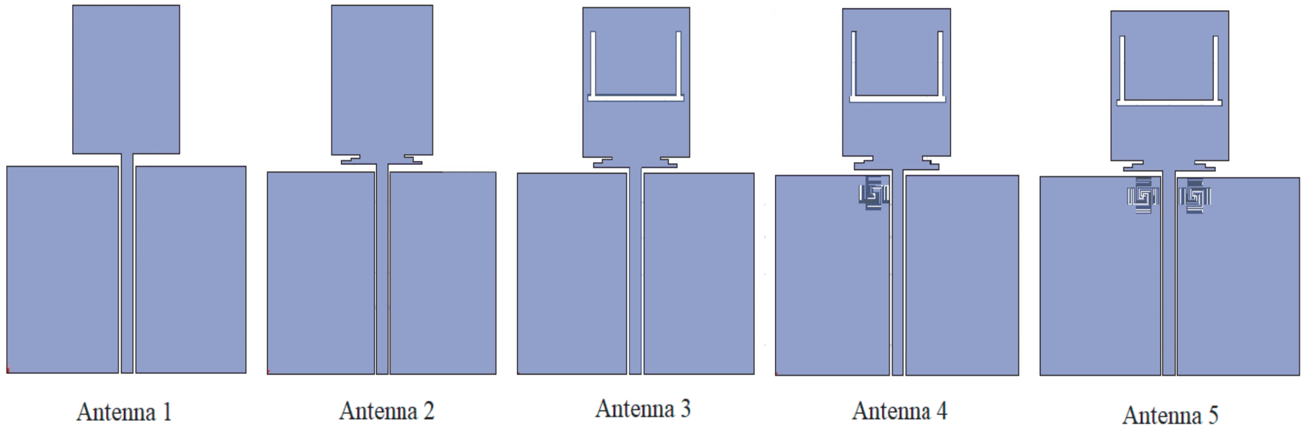


Figure 2. Antenna #1: CPW without UWB, Antenna #2: CPW with UWB, Antenna #3: antenna with UWB and lower band notch, Antenna #4: partial upper band notch with UWB and lower band, Antenna #5:with UWB and dual notch.

The proposed antenna's inverted-π model slot and EBG structures are shown in Figures 1(b) and (c). A design evolution of the proposed antenna is illustrated in Figure 2, in which Antenna #1 represents the CPW without UWB; Antenna #2 denotes the CPW with UWB; Antenna #3 exhibits a UWB antenna with lower notch band; Antenna #4 shows the partial upper notch band with UWB. Finally, Antenna #5 (proposed) represents UWB with dual notch performance.

Antenna #1 has a narrow bandwidth which does not meet the UWB (3.1–10.6 GHz) range. To cover the above, three different size slits are introduced in the rectangular patch (antenna #2). To generate the first notch, an inverted-π model structure is integrated on the propagating plane of the patch antenna which is considered as antenna #3. To generate the second notch along with the first notch, single EBG is embedded in ground plane (antenna #4). To achieve stronger rejection, two EBG cells have been employed symmetrically on both sides of ground plane near the feed line (Antenna #5).

3. ELECTROMAGNETIC BANDGAP (EBG) STRUCTURE ANALYSIS

The periodic structure has an ability to control propagated electromagnetic (EM) waves, and it can create high impedance on a particular frequency which is not available in nature [24]. Various models

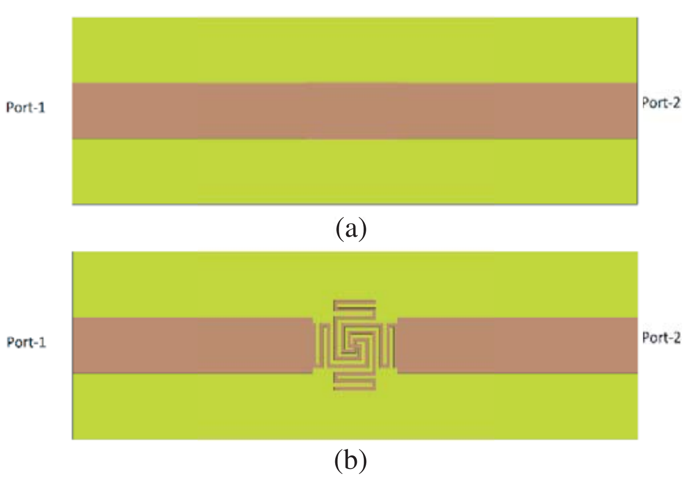


Figure 3. Transmission line analysis. (a) Without and (b) with EBG structure.

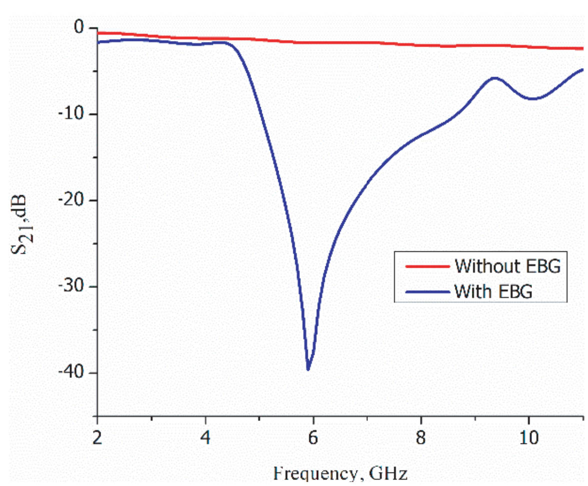


Figure 4. Transmission coefficient for the proposed EBG structure.

are used to form an artificial periodic structure, and generally it is called as electromagnetic bandgap (EBG) structures [25]. The periodic metallic structure has several advantages based on its place of embedding.

Transmission line model analysis is shown in Figures 3(a) and (b). Figure 3(a) represents a 50 Ω line model without EBG structure, and Figure 3(b) shows a 50 Ω line model with EBG structure. From transmission line model, transmission coefficient (S_{21}) values are obtained from the two ports for with and without EBG structures, plotted in Figure 4. Transmission line model without EBG has a value around 0–1 dB along the frequency axis. From this, it is observed that power is effectively transmitted from port1 to port2 without any loss. Transmission line model with EBG structure has a value less than 30 dB around notch band frequency region. From the above analysis, it is inferred that power is not effectively transmitted from port1 to port2 around notch frequency region. So, it is confirmed that the proposed spiral shaped EBG structure creates filtering performance. After confirming the effect of notch band frequency, the EBG structure is embedded in the proposed antenna. A single EBG structure is placed on the left side of the ground plane which creates upper notch band from 5.9–6.9 GHz where it does not meet -10 dB notch range. In order to realize a perfect notch, another EBG structure is placed on the right side of the ground plane where it produces strong notch band performance towards 5.9–6.9 GHz with required dB level.

4. SIMULATED RESULTS AND ANALYSIS

The proposed antenna is obtained after various modifications in design, and their reflection coefficients are shown in Figures 2 and 5, respectively. Conventional CPW antenna (Antenna #1) is designed with the size of $18 \times 21 \times 1.6\,\text{mm}^3$, and its reflection coefficient responses is shown in Figure 5. It has narrow bandwidth (1.8–7.6 GHz) which does not cover the entire UWB region. To cover UWB region, Antenna #1 is modified by introducing three parallel truncated rectangular slits with the dimensions of 8 mm, 11 mm, 14 mm, respectively, which is present close to the bottom edge of radiating element, and it is exhibited as Antenna #2. It covers the frequency range from 2–12 GHz.

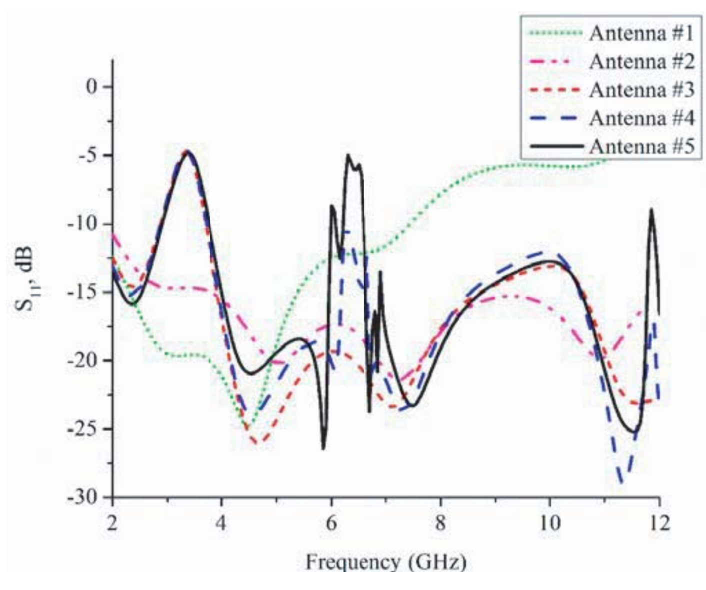


Figure 5. Simulated return loss of Antenna #1 to Antenna #5.

To achieve the notch band in the UWB region, an inverted-π shaped slot (Antenna #3) with dimensions of $S1 = 16$ mm, $S2 = 14$ mm, $S3 = S5 = 0.75$ mm, and $S4 = 9$ is introduced in the radiating element of Antenna #2 which produces a lower notch band at 3.3–3.7 GHz for WiMAX application. In order to produce another notch band effect, an EBG structure is introduced in the left side ground plane of Antenna #3 to create a higher band frequency range from 5.9–6.9 GHz, but the notch does not

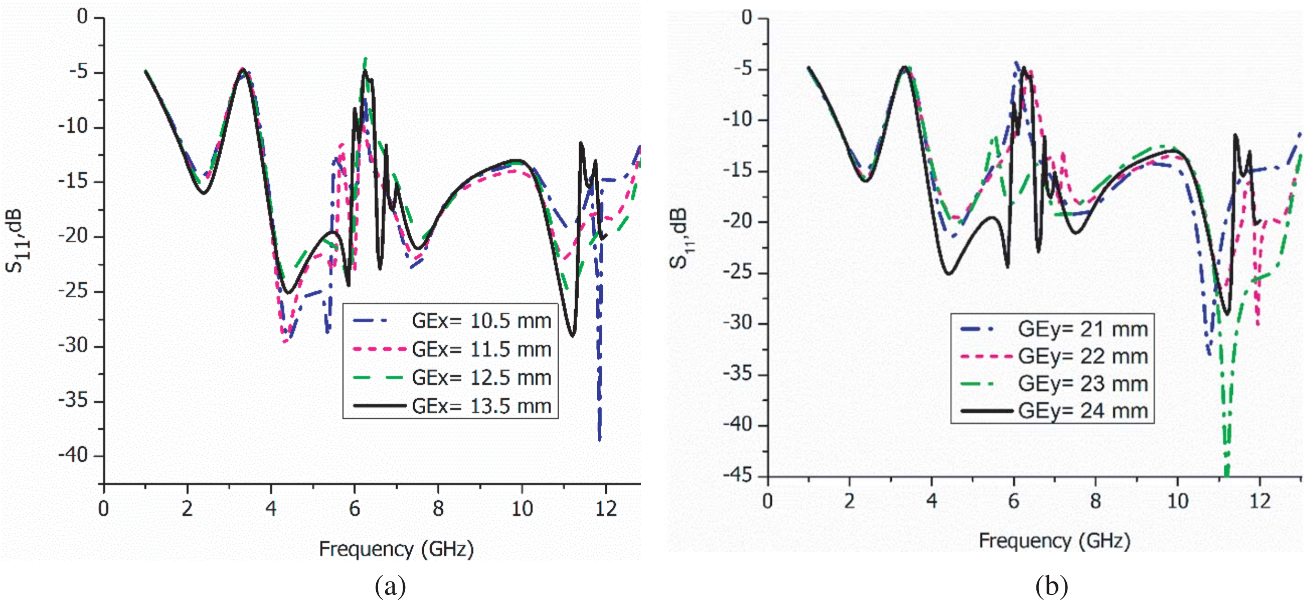


Figure 6. The proposed antenna EBG position. (a) Along X-axis GEx and (b) along Y-axis GEy.

meet -10 dB range (Antenna #4). In order to meet the band rejection, another EBG is embedded on the right side of ground plane (Antenna #5), which helps for strong band rejection from 5.9 to 6.9 GHz (satellite uplink application) along with lower frequency from 3.3 to 3.7 GHz. Here EBG structures help to achieve notch for higher range of frequency without disturbing lower band. Both EBG and inverted-π work independently without disturbing each other's response. From the above design analysis, Antenna #5 is fixed as the proposed antenna. In Antenna #5, EBG structures are used to create notch band effect at 6.3 GHz. The position of the EBG structure is fixed based on the parameter study which is shown in Figures 6(a) and 6(b).

The gap between edge of the ground and the EBG position along the X-axis is represented as GEx which is varied from 10.5 mm to 13.5 mm, and its reflection coefficient is illustrated in Figure 6(a). At 10.5 mm and 11.5 mm, a notch is present towards lower frequency band, and due to this it does not cover the entire notch band. To cover the entire bandwidth, the position of GEx is increased to 12.5 mm where the notch is obtained at the desired frequency, but it has very narrow bandwidth. When GEx is 13.5 mm, it produces better performance than other positions and effectively notches the wanted frequency band at 5.9–6.9 GHz. From the above analysis, GEx position is fixed as 13.5 mm for the proposed antenna. Similarly, GEy represents the distance between the bottom of the ground plane and EBG structure along the Y-axis. GEy parameter is varied from 21 mm to 24 mm, and its reflection coefficient is shown in Figure 6(b). By varying the position of EBG in the Y-axis, notch effect has been realized when the EBG is fixed at 24 mm distance from the bottom of the ground plane.

5. EXPERIMENTAL RESULTS ANALYSIS

This section discusses simulated and measured reflection coefficients of the proposed antenna which is illustrated in Figure 7.

The antenna has lower notch band due to the inverted-π section on radiating element for the frequency range from 3.3 GHz to 3.7 GHz, and for upper notch EBG structure is embedded on both sides of the ground plane of the antenna for the frequency range from 5.9 GHz to 6.9 GHz. Simulated results are in good match with the measured ones in lower band while in upper band there is a deviation due to dielectric loss. The fabricated prototype of the proposed antenna is shown in Figure 1(d), and it is validated using Agilent vector network analyzer NA9901 as illustrated in Figure 8. Lower and upper notch bands of antenna can be used for notching WiMAX and uplink satellite communication application, respectively. The radiation pattern for the proposed UWB notch antenna is illustrated in

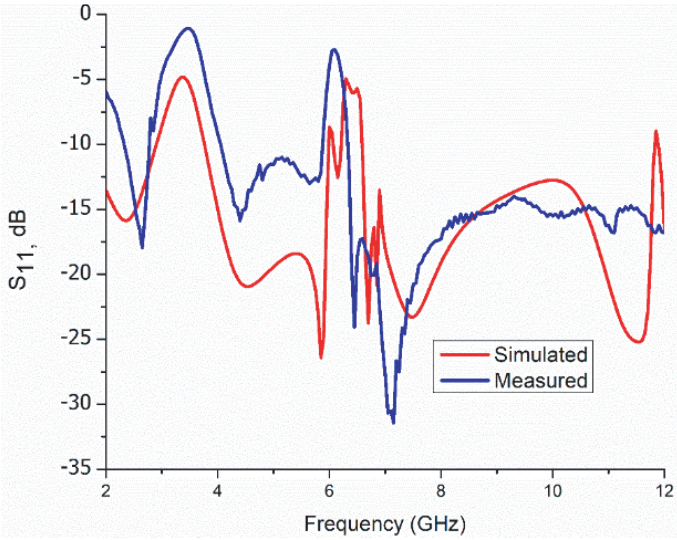


Figure 7. Return loss: simulated vs measured.

Figure 8. Antenna measurement using VNA.

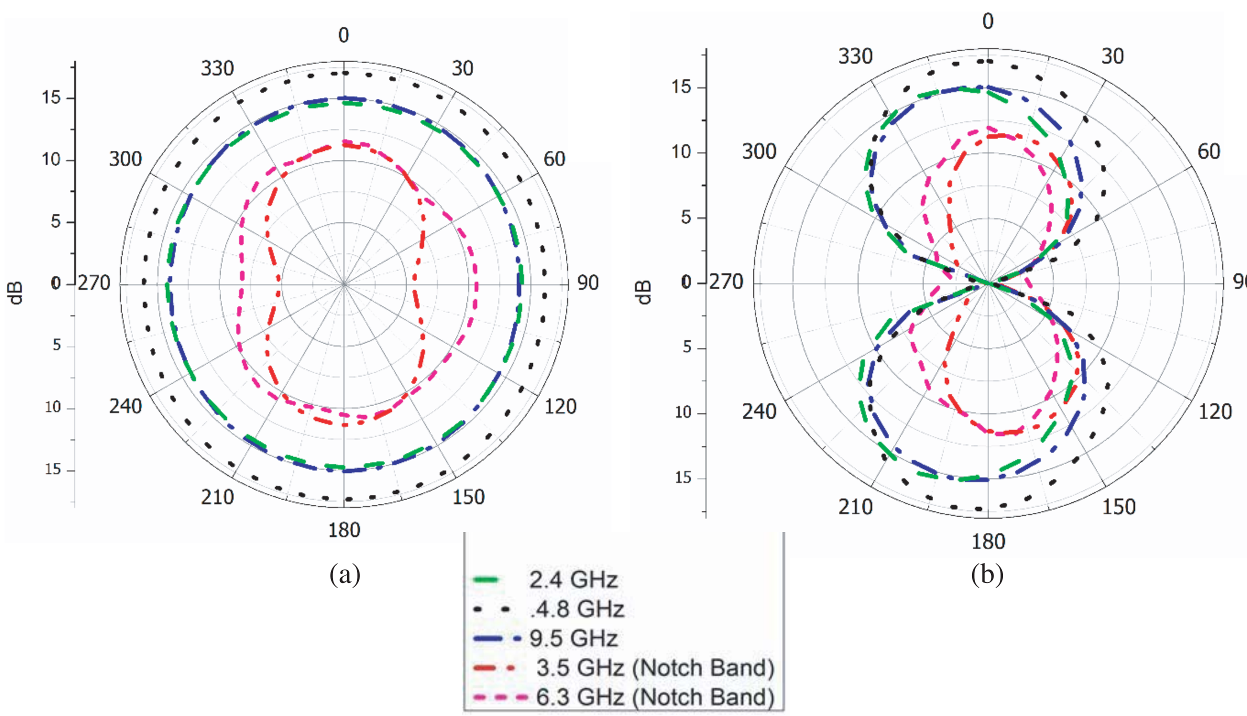


Figure 9. Radiation pattern of the proposed antenna for different frequencies. (a) *H*-plane and (b) *E*-plane.

Figures 9(a) and (b), and it exhibits *E*-plane and *H*-plane radiation characteristics for 2.4 GHz, 4.8 GHz, 9.5 GHz, 3.5 GHz, and 6.3 GHz where the antenna has dumbbell and omnidirection shaped radiation patterns. The frequencies at 2.4 GHz, 4.8 GHz, and 9.5 GHz represent out of notch frequency bands.

Here, power transmission is high in these frequencies in which the shape of the pattern is maintained. The frequencies at 3.5 GHz and 6.3 GHz represent notch bands. Here, the power level of proposed antenna is reduced around 7 dB due to antennas' notch effect. It is inferred that UWB notch antenna performs well in the notch frequency bands as well as out of notch frequency bands.

6. CONCLUSION

In this paper, an ultrawide band (UWB) coplanar waveguide (CPW) antenna is designed with dual notch bands. The proposed antenna design has been concluded after several iterations. An inverted-π section slot is used for achieving lower notch frequency range 3.3–3.7 GHz for WiMAX application and EBG structures used to realize higher notch band frequency range 5.9–6.9 GHz for satellite uplink application. The proposed antenna design has advantages of compact size, and both EBG structures work independently, and frequency tuning can be controlled easily. This antenna structure could be used for reconfigurable antennas for creating notch band frequencies due to its independent tuning feature.

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