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Design of dual band-notched UWB hexagonal printed microstrip antenna

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Research Paper

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Abstract

This article presents the design and performance analysis of a printed microstrip ultra-wideband (UWB) antenna consisting of the slots in the ground plane and radiating patch. A meandered *S*-shaped slot has been introduced on the patch and an inverted *U*-shaped slot has been incorporated in the ground plane to realize the band-notch effect for WiMAX (3.2–3.8 GHz) and WLAN (5.1–5.8 GHz) bands respectively. The total dimension of the proposed design is 44 $\times$44 mm^2. The fabricated antenna exhibits wide impedance bandwidth of 10 GHz (2.4–12.4 GHz), i.e., 135% of center frequency. The design prototype is fabricated, and the measured results have good agreement with simulated values. The effects of the slots have been analyzed by simulated surface current distribution. The designed antenna shows almost omnidirectional radiation patter and stable gain. The proposed hexagonal antenna may be suitable for UWB applications removing WiMAX and WLAN bands.

Introduction

The current communication scenario around the world is primarily remote-based. Thus, there is a great deal of reliance on wireless communication devices. As a result, demands for broadband and high data rate systems have also been increased. Besides, the IoT has gained interest in different fields, starting with home automation, smart cities, healthcare, etc. Hence the challenge for the research community is to appease these demands. The ultra-wideband (UWB) frequency spectrum (3.1–10.6 GHz) has the potential to mitigate such demands. Currently, the researchers are working on the UWB antenna, which is an essential part of wireless communication systems. However, there is a problem of interference with the existing narrowband applications such as WiMAX (3.2–3.8 GHz) and WLAN (5.1–5.8 GHz). An UWB antenna with low radiation efficiency for these bands is very desirable.

UWB antenna design involves a better understanding of the various system parameters such as gain, fractional bandwidth, radiation characteristics, etc. A detailed knowledge of UWB electromagnetics, components, and system engineering has been well documented in [1] by dividing into various topics which are very beneficial for the research community. Researchers have proposed both planner and non-planner type of antenna structures [2–4] to attain operational bandwidth over entire UWB spectrum with good radiation characteristics. The planner type hexagonal radiator may provide higher average peak gain and better efficiency as compared to other regular planner structure [4]. Many articles have been published on the subject of attaining band-notch properties. Some of those have reported single-band elimination [5–11] characteristics. However, the single notched band would not be sufficient to implement the design for practical applications. So, UWB antennas with dual band-notched properties have also been investigated and designed [12–23]. To attain a single notched band effect, mushroom type EBG structure [5], grounded stub [6], and *C*-shaped stub [7] beside the feedline have been realized. *U*-shaped slot on the patch [8, 9], sorting pin-loaded structure [10], and SRR loaded on the ground plane [11] have also been considered by the researchers to obtain a single notch effect. Furthermore, for achieving dual notched bands, etching of slots having different shapes on the radiating element has been adopted by the researchers. *C*-shaped slots [12, 13], *U*-shaped slots [14, 15], combinations of *C*-shaped and *U*-shaped slots [16], SRR and SIR type slots [17], and *L*-shaped slots [18] have been presented in some literature. Different types of slots on the radiating patch create interference on the surface current, and as a result, the antenna becomes non-responsive at this frequency. In the article [19], combinations of slots both in radiating patch and ground plane are used for notching effects in two different bands. In the article [20], a circular-shaped split-ring parasitic element in the ground plane along with a rectangular split-ring slot on the patch has been used to obtain a band notch for the WiMAX band. The effects of *L*-shaped stubs loaded UWB antenna with a slot on the feed line have been demonstrated [21]. Iron-shaped and inverted *U*-shaped

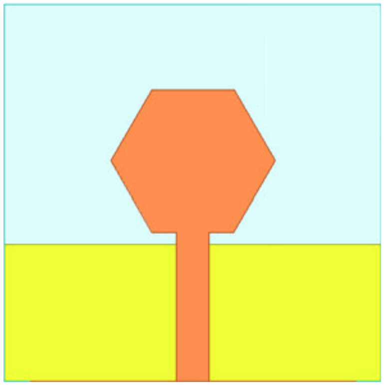

Fig. 1. Structure of the reference antenna.

Table 1. Design parameters of the proposed antenna (units are in mm)

Parameters	Values	Parameters	Values
L_s	44	L_3	4.35
W_s	44	L_4	3.1
L_g	16	L_5	11.5
L_c	8	L_6	4.2
L_f	17	L_7	2.8
W_f	3.8	L_8	9.75
L_h	9.6	L_9	0.8
L_1	7.5	L_{10}	0.95
L_2	4.5	L_{11}	2.5

parasitic resonators in the ground are being used to achieve dual notch properties for a circular UWB antenna [22]. Reconfigurable UWB antenna using pin diode has also been proposed to realize notch characteristics [23]. An overview of different kinds of proposed work on UWB antenna has been well discussed in [24]. It has been observed from some articles that the excitation of the radiating patch has been provided by microstrip line feed or CPW line feed technique with different shapes of radiator such as circular, rectangular, triangular, and hexagonal. Few structures have been modified to realize desired impedance bandwidth.

In this paper, an UWB antenna with dual-band rejection characteristics has been proposed. The radiating element is hexagonal and poses a wide impedance bandwidth of 10 GHz (2.4–12.4 GHz), i.e., 135% of the center frequency. A meandered *S*-shaped slot has been etched out on the patch, and a notched band from 3.2 to 3.8 GHz has been achieved experimentally, which will be useful to eliminate the WiMAX band. Furthermore, a notched band from 5 to 6 GHz is achieved experimentally after incorporation of an inverted *U*-shaped slot on the ground plane placed below the feed line. Hence it can successfully eliminate the WLAN band. The proposed design of the hexagonal microstrip antenna has been fabricated and measured. The radiation characteristics and reflection parameter of the proposed design have been measured using a vector network analyzer. An acceptable similarity has been observed between the simulated and measured data. A vector network analyzer has been used to measure the parameters of the fabricated antenna, and a good agreement between the simulated and measured results has been observed.

Antenna design and structure

The reference and proposed antenna structures are shown in Figs 1 and 2, respectively. The values of the designing parameters in mm have been depicted in Table 1. It has been designed using electromagnetic solver Ansys HFSS. Arlon AD300A has been chosen as a substrate with dielectric constant $\varepsilon_r = 3$, thickness $h =$ 1.524 mm, and loss tangent 0.002. The radiating element of the proposed design is hexagonal. Initially, the antenna has been designed without any slots or defects on the ground plane and the radiating element. The fabricated structure of the proposed antenna is shown in Fig. 3. The design has been optimized through simulation in multiple stages. The variation of the reflection coefficient (S_{11}) with frequency for different stages of design has been shown in Fig. 4. At stage 1, a simple hexagonal antenna with a partial ground plane has been simulated. Next, on stage 2, a rectangular slot has been etched out in the ground plane below

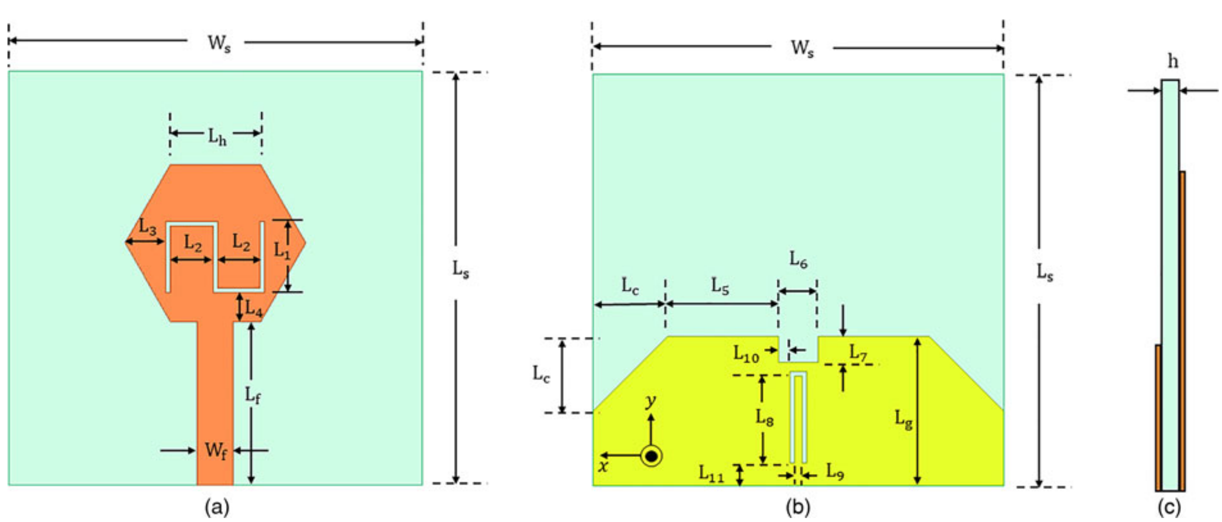

Fig. 2. Structure of the proposed antenna, (a) radiating plane, (b) ground plane, and (c) side view.

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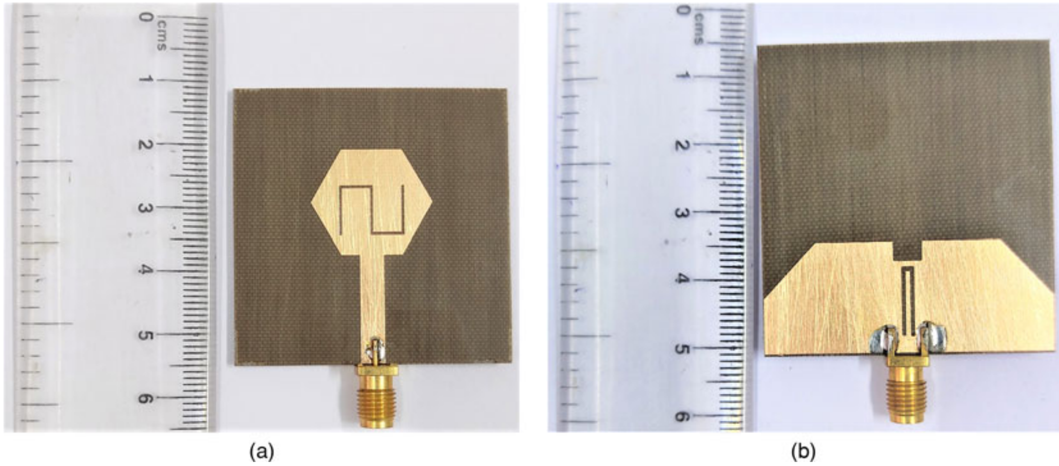

Fig. 3. Fabricated structure of the proposed antenna, (a) radiating patch and (b) ground plane.

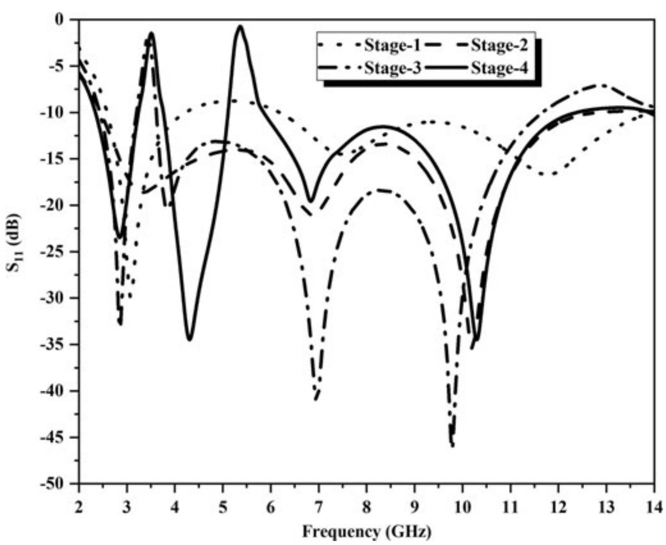

Fig. 4. Simulated reflection coefficient (dB) in different stages of the design.

the microstrip line along with corner chamfering. At stage 3, a meandered *S*-shaped slot on the radiating patch has been utilized. Finally, at stage 4, an inverted *U*-shaped slot in the ground plane under the feedline has been engraved. The structural modification on different stages is depicted in Fig. 5.

In stage 1, the antenna poses a relative impedance bandwidth of 3 GHz over which $S_{11} \leq -10$ dB. The impedance bandwidth has been improved to 11 GHz ($S_{11} \leq -10$ dB) by implementing the modification on the ground plane at stage 2. The antenna covers the frequency spectrum (2.54–12.25 GHz), in which the entire UWB has also been covered. With the addition of a meandered *S*-shaped slot in the radiating element, a notched band from 3.14 to 3.82 GHz has been obtained, which is depicted in stage 3. It is possible to eliminate the WiMAX (3.2–3.8 GHz) band due to this implementation. Lastly, at stage 4, the inverted *U*-shaped slot on the ground plane has produced a notched band from 5.1 to 5.85 GHz, which eliminates the WLAN band (5.2–5.8 GHz) is also possible.

Parametric study

Several parametric studies concerning different designing parameters have been carried out to determine the optimum values of the same such that we would obtain the desired results. The study of the proposed design has been performed using the EM simulator Ansys HFSS. The characterization of the antenna is outlined as follows.

Effect of the variation on slot length L_1

The slot length along the *y*-direction for the meandered *S*-shaped slot on the radiating patch is depicted as L_1. The deviations in the

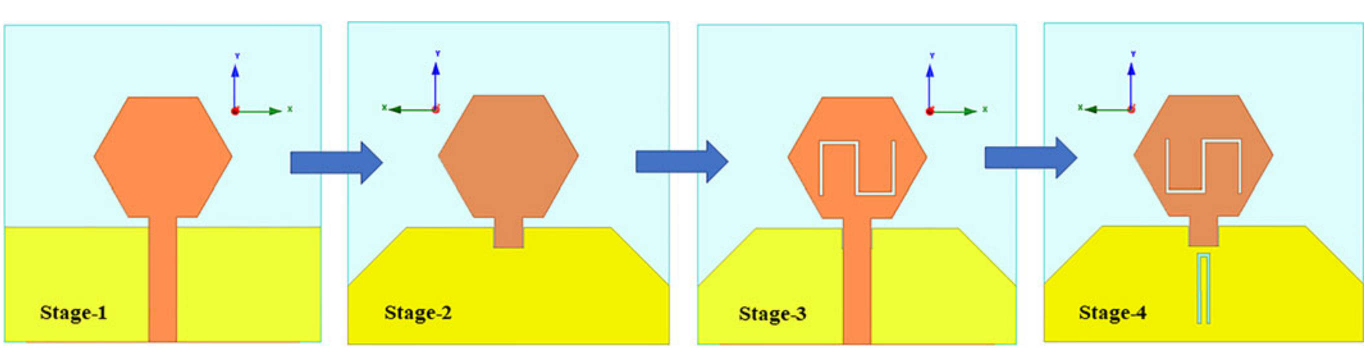

Fig. 5. Structural modification in different stages of the design.

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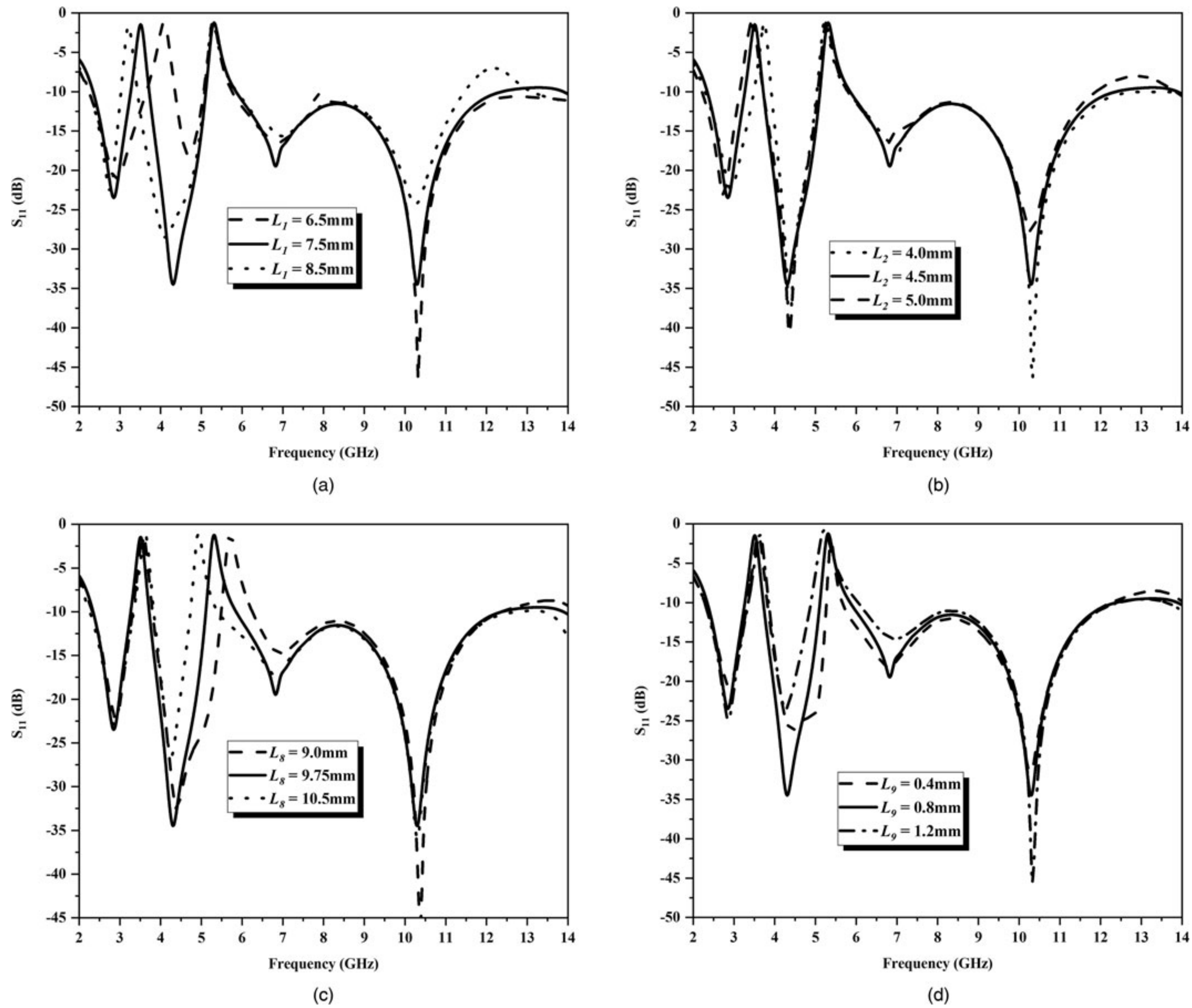

Fig. 6. Simulated return loss (dB) plots with variation of the (a) slot length L_1 of the *S*-shaped slot, (b) slot length L_2 of the *S*-shaped slot, (c) slot length L_8 of the *U*-shaped slot, (d) slot length L_9 of the *U*-shaped slot.

value of L_1 are responsible for shifting the center frequency of the lower notch band. The lower notch band has been obtained for eliminating the WiMAX band. The value of L_1 has been varied between 6.5 and 8.5 mm, and the accepted value is 7.5 mm as per the parametric study shown in Fig. 6(a). Hence, the increment of the value of L_1 shows the shifting of the frequency to the lower side. The value of L_1 is optimized for 7.5 mm to have the desired notched band from 3.2 to 3.81 GHz.

Effect of the variation on slot length L_2

The slot length along the *x*-axis of the meandered slot on the radiating element has been denoted as L_2. Though the very nominal variation in the lower notch band has been observed, the value of L_2 has been taken as 4.5 mm to achieve the desired result. The parametric study regarding the variation of the *S*-parameter with the variation of L_2 has been shown in Fig. 6(b). The value of L_2 has been varied between 4 and 5 mm.

Effect of the variation on slot length L_8

The length of the inverted *U*-shaped slot toward the negative *y*-axis is marked out as L_8, as shown in Fig. 2(b). Due to the variation of L_8, the second notch-band center frequency is varying, keeping other resonant frequencies unaffected. The higher notch band is responsible for eliminating the WLAN band. The value of L_8 has been varied from 9 to 10.5 mm, for which the notch-band center frequency has been varied from 4.8 to 5.5 GHz. It has been observed from the study shown in Fig. 6(c) that the notched band has been shifted lower side with the increasing length of L_8. To achieve the desired response, i.e., the elimination band for 5.1–5.85 GHz, the length of L_8 has been fixed to 9.75 mm.

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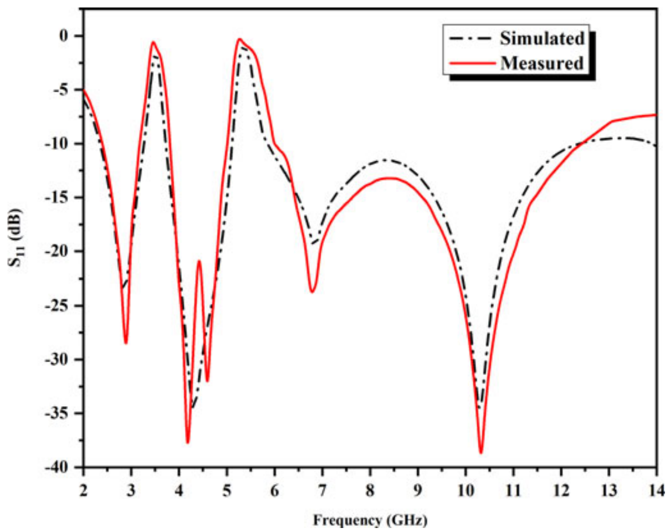

Fig. 7. Variation of reflection coefficient with frequency of the proposed antenna.

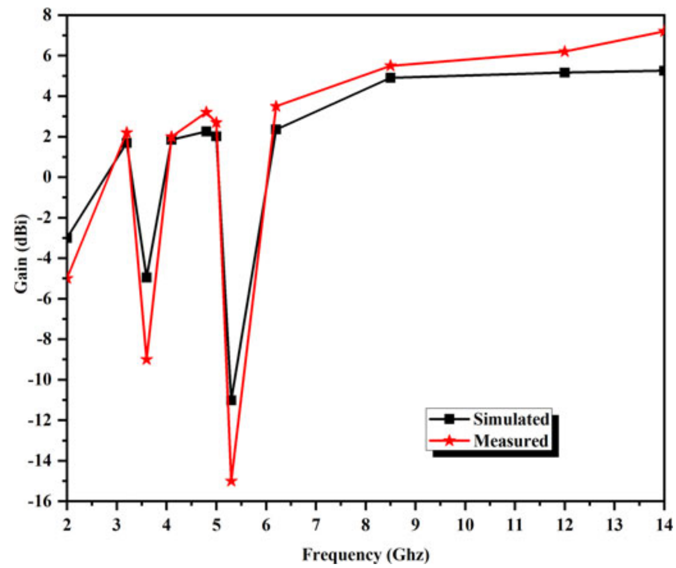

Fig. 8. Variation of the gain with frequency of the proposed antenna.

Effect of the variation on slot length L_9

The slot length along the x-axis of the inverted U-shaped slot is marked as L_9, as depicted in Fig. 2(b). Due to the deviation of the value of L_9, there is a noticeable change in the bandwidth of the second notched band. With the increasing value of L_9, the width of the elimination band has also been increased, which is depicted in Fig. 6(d). So, the optimum value of L_9 has been taken as 0.8 mm to eliminate the 5.1–5.85 GHz band, which has been allocated for WLAN.

Results and discussion

The return loss characteristics and the radiation parameters of the fabricated antenna have been measured using the vector network analyzer and standard microwave test bench setup. Both measured and simulated results are showing good harmony between them. The minimal deviation between the measured and simulated results may be due to the simulation error, loss of cables and connectors during the measurements, and tolerance in manufacturing. The measured and simulated reflection coefficients of the proposed antenna are shown in Fig. 7 and Table 2.

The fabricated antenna with the slots on the radiating patch and the ground exhibits dual notch bands of 3.2–3.8 and 5–6 GHz as per the measured results. The simulated and measured gain of the proposed antenna has been shown in Fig. 8. The simulated and measured radiation patterns of E-plane co-polarization at 2.85, 4.25, and 9.2 GHz, respectively, have been shown in Figs 9(a)–9(c). In order to witness the significance of the slots in getting the band notches, the simulated vector current distribution in the radiating patch and the ground plane of the proposed antenna at the center frequencies, 3.48 and 5.48 GHz of two notched bands, has been shown in Figs 10(a) and 10(b).

In the proposed design, the meandered slot on the patch has been utilized to obtain the notch band in the frequency range 3.2–3.8 GHz (WiMAX) and the inverted U-shaped slot has been introduced to achieve the notch band in the frequency range 5–6 GHz (WLAN). The total length of the slots has been calculated approximately as half guided wavelength at the center notch frequency. From the simulated current distribution of the designed antenna shown in Fig. 10, the center notch frequency for both the slots may be predicted by the equation [9],

$$f_{Notch} = \frac{c}{2L_s\sqrt{\frac{\varepsilon_r + 1}{2}}}, \quad (1)$$

where c is the speed of light in free space, ε_r is the dielectric constant of the substrate, and L_s is the total calculated slot length.

The total slot length of the meandered slot has been calculated as $L_{s1} = 31.5$ mm, shown in Fig. 11(a), and for which the center notch frequency has been approximated as 3.37 GHz, and the total slot length of the inverted U-shaped slot has been found as $L_{s2} = 20.3\ mm$, shown in Fig. 11(b), using which the approximated second notch center frequency has been calculated as

Table 2. Simulated and measured results of the proposed antenna

	Bandwidth (GHz), %	Lower elimination band (GHz)	Higher elimination band (GHz)
Simulated	10.01 (2.36–12.37), 136%	3.26–3.7	5.1–5.85
Measured	10 (2.4–12.4), 135%	3.2–3.8	5–6

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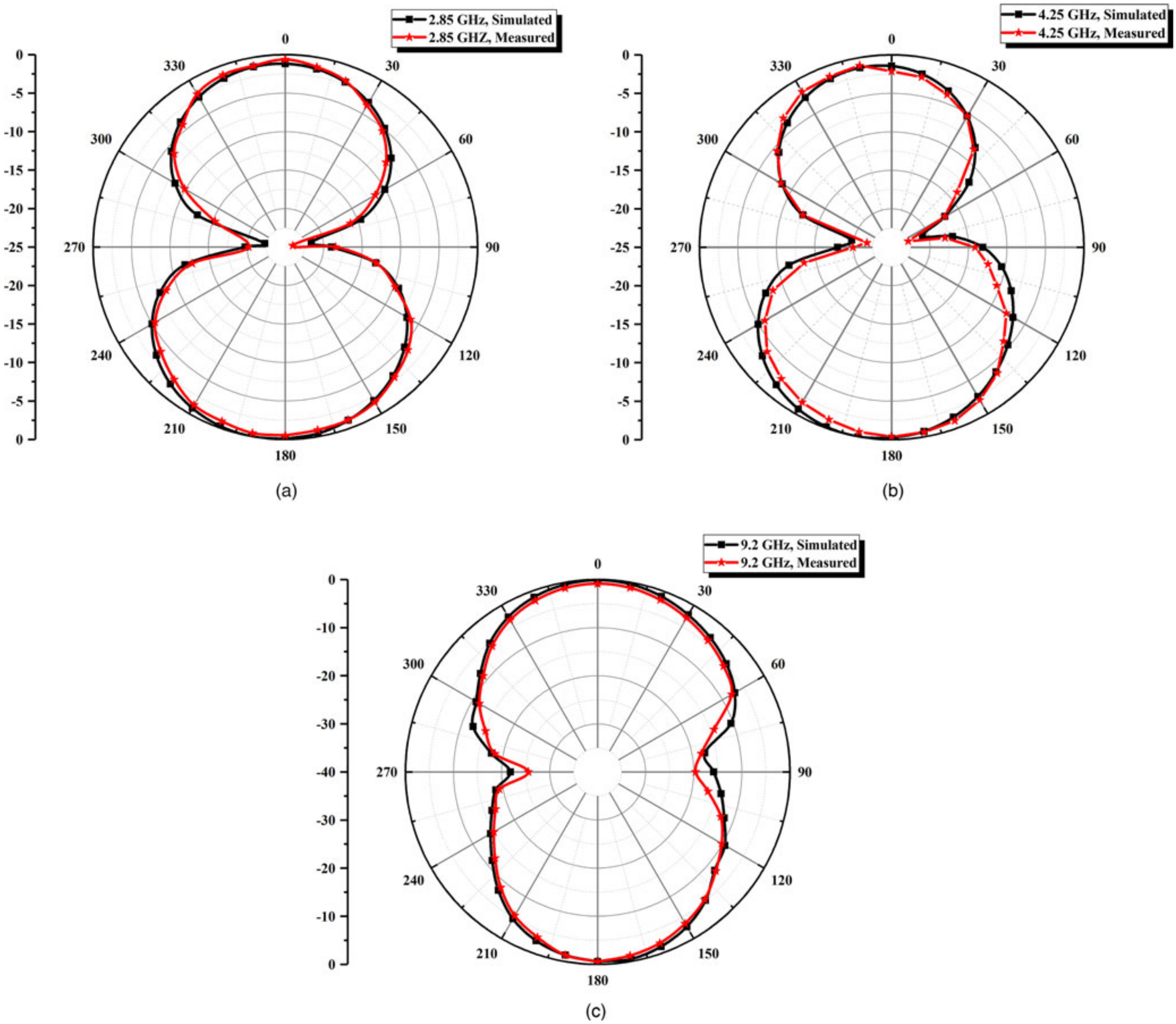

Fig. 9. Normalized *E*-plane co-polarization radiation pattern of the proposed antenna for (a) 2.85 GHz, (b) 4.25 GHz, (c) 9.2 GHz.

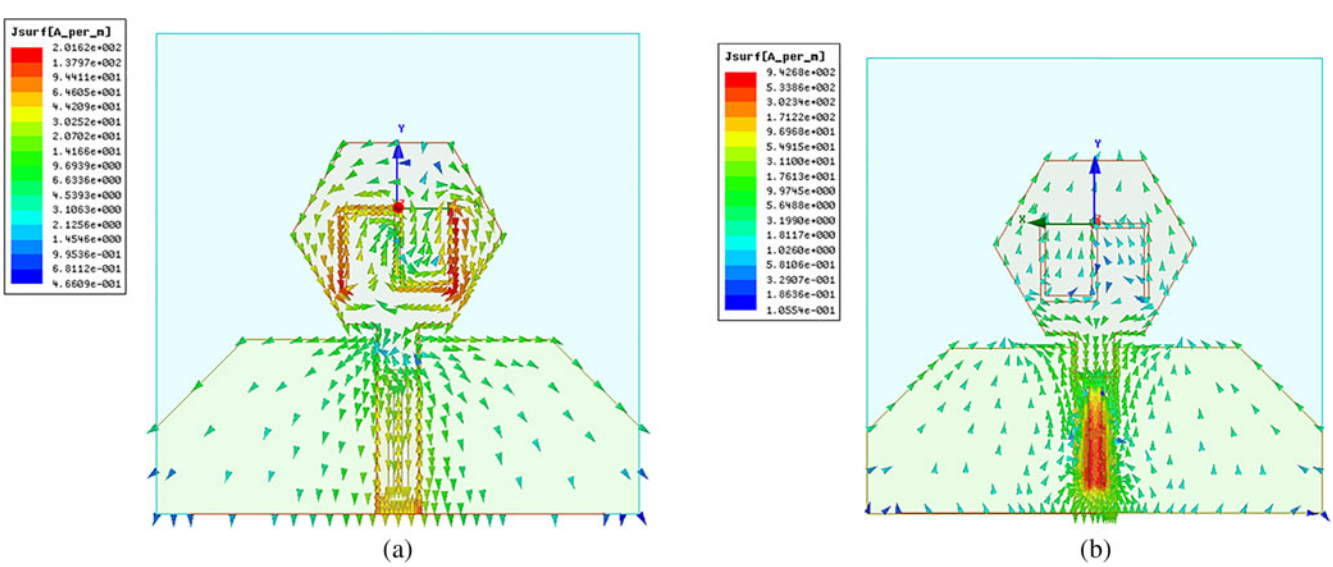

Fig. 10. Simulated current distribution of the proposed design at (a) 3.48 GHz, (b) 5.48 GHz.

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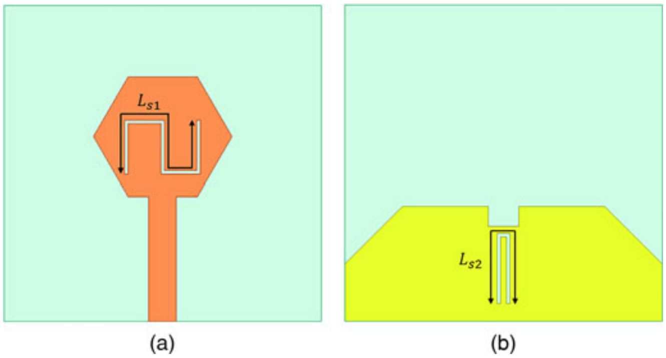

Fig. 11. Current path length for the elimination band centered at (a) 3.48 GHz and (b) 5.48 GHz.

Table 3. Center frequencies of the elimination bands for proposed antenna

	Simulated (GHz)	Measured (GHz)	Calculated (GHz)
Lower elimination band	3.48	3.5	3.37
Higher elimination band	5.48	5.5	5.22

5.22 GHz. Slot length dimensions have been exhibited in Fig. 2, and values have been given in Table 1. The predicted notch frequencies from equation (1) have been found very close compared to both the simulated and measured results which have been depicted in Table 3.

The comparison studies have been obtained and presented in Table 4. From the given comparison studies, it has been observed that the proposed antenna in this literature has been found as the best suitable one for wireless communication

Table 4. Comparison study of proposed antenna with the cited literature

Ref.	Notch characteristics	Shape of the radiating element	Nature of modification	Notch frequency bands (GHz)	Peak gain (dBi)	Size (mm^3)
[5]	Single	Parabolic	Mushroom type EBG on radiating plane	5.62–6.31	5.7	38 × 40 × 1
[6]	Single	Parabolic	Grounded stubs on radiating plane	5.18–6.23	5.5	30 × 40 × 0.76
[7]	Single	Hexagonal	*C*-shaped open stub	4.5–5.85	3.6	21.25 × 33.5 × 1
[8]	Single	Hexagonal	Inverted *U*-shaped slot	5.15–6.17	5.8	25 × 52 × 1.59
[9]	Single	Circular	Stubs on radiating plane and slit on the patch	5.0–5.8	5.7	30 × 28 × 0.8
[11]	Single	Circular	SRR loaded ground plane	4.96–6.15	2	50 × 50 × 1.575
[12]	Dual	Rectangular	*C*-shaped slots on the patch	3.3–3.8, 5–6	4.6	26 × 30 × 1.6
[13]	Dual	Rectangular	*C*-shaped slots on the patch	5.2–5.96, 7.84–8.4	—	26 × 32 × 0.762
[14]	Dual	Hexagonal	*U*-shaped slots on the patch	3.3–3.7, 5.1–5.9	6.4	36 × 42 × 1.59
[15]	Dual	Rectangular	*U*-shaped slots on the patch	3–3.9, 5–5.9	4.5	26 × 27 × 1.6
[16]	Dual	Modified rectangular	*C*-shaped slot on the patch and inverted *U*-shaped slot on the ground	3.2–4.1, 5.2–5.96	2.3	31 × 31 × 1.6
[17]	Dual	Circular	Nested SRR and SIR on the patch	4.1–5.8, 8.2–9.3	5	24 × 32 × 1.6
[20]	Dual	Triangular	*C*-shaped slot on the patch and split-ring parasitic at ground	3.49–3.81, 5.24–6.22	3.2	18 × 20 × 1.6
[21]	Dual	*V*-shape	Parasitic stubs and inverted *U*-shaped slot on the radiating element	3.17–3.8, 7.38–9.1	6.14	23 × 32 × 1.62
[22]	Dual	Circular	Parasitic strips in the ground plane	5–5.35, 7.85–8.4	4.47	24 × 32 × 0.76
[23]	Dual	Octagonal	Slots and SRR with pin diode	3.20–3.67, 32–5.81	3.7	27.1 × 37.8 × 1.6
[Proposed]	Dual	Hexagonal	*S*-shaped slot on the patch and inverted *U*-shaped slot in the ground	3.2–3.8, 5–6	6.9	44 × 44 × 1.524

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systems with perfect elimination bands for WiMAX and WLAN applications.

Conclusion

In this literature, a hexagonal UWB microstrip patch antenna with dual band-notched characteristics has been designed and practically implemented. The proposed design can be useful to eradicate interference issues between the UWB system to the widely used narrowband systems such as WiMAX and WLAN. The design layout has been simulated using full-wave EM simulator Ansys HFSS and experimentally validated. The proposed antenna has attained an impedance bandwidth of 10 GHz (2.4–12.4 GHz), i.e., 135% of center frequency for $VSWR \leq 2$. The realized gain and radiation patterns have also been figured out and found quite admissible for the entire UWB range 3.1–10.6 GHz. The effects of slots on the radiating element and the ground plane have been investigated through several parametric studies presented in this paper. Optimum dimensions have been noted to realize desired elimination bands for 3.2–3.8 GHz (WiMAX) and 5–6 GHz (WLAN) bands.

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Conflict of interest. None.

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