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A Compact Rectangular Ultra-Wideband Microstrip Patch Antenna with Double Band Notch Feature at Wi-Max and WLAN

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Abstract

A compact rectangular microstrip-fed Ultra Wideband patch antenna with double band notched feature at Wi-Max and WLAN is offered in this paper. The designed antenna is composed of an ordinary rectangular patch antenna with a partially defective ground structure. For achieving dual notch characteristics a ‘U’ and ‘Reversed U’ slots are embedded in the radiating patch. The partial ground plane structure with U shaped slot in the middle is incorporated for achieving additional resonance and bandwidth enhancement. The proposed antenna has a measurement of 20 × 33 × 1.6 mm^3. First notch created by U shaped slot at frequency 3.5 GHz is for Wi-Max (from 2.9 to 4.5 GHz) and Second notch which is generated by Reversed U shaped slots at frequency 5.4 GHz is for WLAN (from 5.49 to 6.45 GHz). The antenna covers almost complete range of Ultra Wideband (3.1–10.6 GHz). The Simulation analysis of the proposed antenna is carried out using CST-2011 simulation software. The radiation pattern of the simulated antenna is near Omnidirectional and the Gain of proposed antenna is almost stable over the range of UWB excluding notch bands.

Keywords Microstrip antenna · Band-notch · FR-4 substarte · Ultra wideband · X-Band · WLAN · Wi-Max

1 Introduction

Ultra Wideband Wireless Communication has gained remarkable consideration in the last two decades, notably once the Federal Communications Commission has assigned the unlicensed band for commercial applications from 3.1 to 10.6 GHz [1]. As the potential benefits of Ultra Wideband systems like staggeringly low profile, low power utilization, low power spectral density, high radiation power, the fastest data communication rate, low price and wider frequency band; some research has been conducted in each trade, both as an

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industry and as an academic associated with UWB systems. Owing to the easier assimilation with integrated microwave monolithic circuits (MMICs), miniature size and profile, the most commonly used antenna is the printed monopole antenna for ultra-wide applications [2, 3].

The UWB wireless communication band operating at 3.1–10.6 GHz, with very low power emission levels permitted by Federal Communications Commission (FCC) systems, is simply interfered with nearby communication systems such as the 3300–3600 MHz WiMax communication system, the 5150–5820 MHz and 5720–5870 MHz WLAN system, X-band (down link frequency band) between 7250–8400 MHz, Wi-Fi between 5470–5725 MHz and C-band between 3700–4200 MHz. A band stop filter is added to the antenna to avoid the interference of the above-mentioned narrow band communications systems with the existing Ultra wideband system, but the performance increases the complication, size and cost of the system [4]. Band Stop filter is not a right choice to avoid interference with the narrow band applications within the UWB band, antenna having a band notched character is enviable and be achievable by a number of methods.

The traditional ways to realize band-notched function are by printing slots of completely different shapes within the radiating patch or within the ground structure [5–9], or using parasitic (passive) essentials within the aperture region of the antenna [10, 11]or by cutting a slot of different shapes within the feed line of antenna that results in a sharp modification in the electrical phenomenon in the notched band [12, 13]. A split ring resonator type of slot has been incised within the patch to get notch characteristic at Wi-Max and WLAN systems [14]. An Ultra Wideband antenna of 50 × 40 mm^2 size with twin band-notched characteristics acquiring a frequency band ranging from 2.0 to 13.7 GHz, with U-shaped in addition to Π-shaped defected patch arrangement are designed to get the characteristics of band-notched which covers the Wi-Fi and Wi-Max band [15].

An Ultra wideband antenna covering a bandwidth vary from 3.1 to 10.5 GHz and 40 × 38 mm^2 size, with U-shaped defected patch plus Stair-shaped defected patch construction are applied to attain a whole UWB range, are offered in [16]. In [17] the researchers have designed an Ultra wideband coplanar waveguide (CPW) fed monopole antenna of size 45 × 41 mm^2 which has a triple band notch characteristics, band notch at 3.5 GHz and 10.5 GHz is acquired by etching U-shaped slot within the patch and another band notch feature at 5.5 GHz is retrieved by means of L-shaped slots engraved within the ground structure in addition with wide bandwidth covering the frequency which vary from 2.8 to 12 GHz. In [18] the researchers have presented a compact monopole UWB antenna of size 31 × 22 mm^2 with triple band-notched features by means of a couple of C-shaped slots carved out in the ground plane including two round shaped slots etched within the radiator patch whose bandwidth ranging from 3 to 15 GHz.

A microstrip line fed printed plaque monopole Ultra Wideband antenna featured with triple band-notch are recommended in literature [19], the proposed antenna (size 30 × 30 mm^2) is customized to maintain band rejection at the WLAN using an inverted U-shaped slot within the radiating patch to produce band-notch at Wi-Max (3.25–3.75 GHz) and two U-Shaped slots are engraved within the radiating patch for achieving band notch at X-band (7.25–7.75 GHz) (down link) communication system. A printed Ultra wide- band monopole antenna of size 27 × 25 mm^2 which covers 2.9 to 10.9 GHz frequency bandwidth including triple notched bands is proposed in [20], the characteristics of band notched are acquired by engraving two round shaped slots within radiating patch and a couple of rotated V-shape slot in the partial ground plane.

In [21] a conventional rectangular microstrip patch antenna of size 20 × 20 mm^2 with partial defected ground plane is fabricated. A strip of T-shape is formed in the ground plane and an inverted L-shaped slot is grafted into the radiator patch. By means of inverted Ω and L-shaped slots, band notched functions at Wi-Max and WLAN are achieved whereas the strip of T-shape produces the notch for the microwave frequency X-band satellite communication (Up-link). The proposed antenna extends from 2.39-18 GHz excluding notched bands.

The paper [22] presents the triple band notched featured Ultra Wideband antenna through two U-shaped slots of different dimensions one over the other within the patch and a small reversed U slot ($\Pi - shape$) in microstrip feed line with a metallic reflector below the radiator patch. The proposed configuration gives broader bandwidth which varies from 2.71 to 12.92 GHz for which VSWR < 2 including three Wi-Max, WLAN and X-band (VSWR > 2) rejection bands. The simulated gain near to 9.9 dBi at 7.4 GHz for the projected antenna is achieved.

A compact design UWB antenna of smaller size 26×25 mm^2 with triple-band notched feature is offered in [25]. By engraving U-shaped slot, L-shaped stubs, and nesting semi-elliptic slots on the ground plane with a rectangular slot and a hexagonal patch fed by a coplanar waveguide, the triple notched wide bands were acquired. 3The simulated outcome reveals the antenna achieves an impedance bandwidth from 2.7 to 10.7 GHz with three notched bands of 3300–3800 MHz, 4750–5900 MHz, and 7250–8400 MHz for return loss (S11) < 10 dB are obtained. The surface current measurements at the working and the said notch frequencies can be obtained to validate the antenna's design process and theory. The mutual intervention between Wi-MAX / WLAN/ 5G / X-band satellite network narrow-band channels and UWB communication system can be greatly minimized.

In [26] a novel, high performance, low-profile configuration and compact size of $39 \times 39 \times 1.6$ mm^3 four-element ultra-wideband MIMO antenna is offered. The suggested antenna is constructed using symmetric form, orthogonal architecture, four- staircase- decoupling, multiple slots and slits techniques with a novel integration technology. Through adding the symmetrical orthogonal and independent four-directional staircase-shaped structure the reciprocal couplings between the antenna components are greatly the. Additionally, by embedding various form slots and slits on the square radiating elements, the default ground structure, and the decoupling system, the proposed antenna attains triple band-notched functionality. As a whole, the antenna receives a larger frequency of 2.30–13.75 GHz with the 3250–3750 MHz, 5080–5900 MHz, and 7060–7950 MHz notched frequencies. The three notched bands are fine compatible with the current Wi-MAX, WLAN and X-band interference systems. However, the suggested antenna also has lower coefficient of mutual coupling, lower envelop correlation coefficient, high multiplexing efficiency, stable gain, and quasi-omnidirectional radiation patterns. As well as a better performance trade-off for the proposed antenna is received.

The paper [27] introduces the design and implementation of a compact UWB antenna having size of $16 \times 25 \times 1.52$ mm^3. The antenna's ultra-wide-band (UWB) capability is accomplished by cutting down the lower ends of the rectangular microstrip patch, and the notch characteristics are gained by using two metallic rectangular conductors mounted on the back of the radiator, which are attached to the patch by short pins. The result also shows that the bandwidth and frequency of the rectangular notch band could be regulated according to the applications for the on-demand rejection band. The simulated and evaluated results show that the suggested antenna has a 3.1–12.5 GHz working bandwidth with a 5–6 GHz rectangular notch band, thus refusing WLAN band signals, and consistent gain and radiation patterns. A compact, circular shaped ultra wideband fractal antenna with triple-notch rejection bands at Wi-MAX, WLAN and X band is recommended in [28]. The fractal structure suggested is composed of a simple circular patch with circular fractal iterations. The average size of the antenna is compacted to 21×25 mm^2 which is 53 percent of traditional circular monopole antenna, using the concept of fractals in the area. The antenna being suggested has an operating bandwidth of 3.1–10 GHz. The reconfigurability is accomplished by constructing slots and split ring resonators with the attached PIN diodes at appropriate frequencies. Furthermore, multiple bands may be inserted or discarded by adding diodes to the above specified slots and designating the on / off diodes. In conclusion, the properties of the antenna are measured in anechoic chamber, and the results agree with the findings of simulation.

1.1 Problem Statement

Placing the slots in a radiating patch or ground plane irregularly in a dynamic arrangement complicates the job of positioning the slots in the system and introduces iteration time to the simulation method, causing the system slow. Consequently, designing optimal bandwidth enhancement with the band-notching technique in a small size region is still a challenging task. One of the most promising prospects for UWB implementation is the monopole antenna sort among the planar UWB antenna designs in the recent literature.

1.2 Proposed Method

In the present article, a compact rectangular Ultra Wideband microstrip line fed patch antenna beveled at bottom with double band notched features is offered. The proposed structure of microstrip antenna is simulated on the inexpensive FR4 substrate which has a dielectric constant of $(\epsilon_r) = 4.4$ and t = 1.60 mm thick with entire size of 20×33 mm^2. The proposed antenna impart a wider bandwidth of 2.75 to 10.1 GHz including double-band notched characteristics by etching a 'U-Shaped' in the radiating patch and 'Inverted/Reversed U' shape slot just over the 'U-Shaped' slot engraved within the radiator patch and a very small U-shaped slot in the partial ground structure. Each slot's effect was optimized and discussed in detail. For the entire UWB, the proposed antenna shows an almost Omni-directional radiation pattern in the H-plane and a dipole-shape pattern in the E-plane.

2 Antenna Layout and Configuration

The geometric layout of the projected antenna is shown by a Fig. 1. The antenna is simulated on a low-priced FR4 substrate of thickness h = 1.60 mm, relative permittivity of $(\epsilon_r) = 4.4$, and loss tangent of $(tan\delta) = 0.02$. The presented antenna of size 20×33 mm^2 is compact structure and is supplied with a 50Ω microstrip feed line. Initially, the proposed structure of an antenna will consist of a rectangular radiator patch with two bevels at the base. The antenna is fed by microstrip feed line of dimensions $L_f = 35$ mm height and $W_f = 3$ mm width. The antenna is now modified with two slots A (Inverted/Reversed U Shaped) and B (U Shaped) embedded on a radiating patch for achieving dual-band notch characteristics and a partial ground plane of length $L_g = 16.5$ mm and $W_g = 20$ mm on the backside of the substrate with a small U shaped in the middle just beneath the microstrip feed line for achieving wide impedance bandwidth. The simulation was performed by a CST Microwave Studio-3D EM simulation (2011) software. The final optimized antenna dimensions are mentioned in Table 1.

Table 1 Optimized parameters for the final proposed UWB antenna

Parameters	Length (in mm)	Parameters	Length (in mm)
L_{sub}	33	L_{p1}	3.25
W_{sub}	20	W_{p1}	11
L_r	9	L_{p2}	7
W_r	12	W_{p2}	10.4
L_f	35	W_{t1}	0.75
W_f	3	W_{t2}	1.75
L_d	3	L_{d2}	4
L_g	16.2	L_a	6
W_g	20	W_a	3

To recognize the influence of both the slots A and B within the patch and a small U-cut in the middle of the partial ground plane, the VSWR pattern of the proposed antenna is compared with the VSWR of the conventional microstrip patch antenna in Fig. 2.

2.1 Conventional Antenna

Initially designed an antenna using a simple rectangular patch fed by a 50Ω microstrip feed line which we called as conventional antenna. The geometry and configuration of the conventional antenna is shown in Fig. 1(a), (b). The VSWR vs. frequency curve as shown in Fig. 2 by red dotted line shows that the steeped red line has VSWR less than 2 (VSWR<2) in the ultra wideband range which results to cover a little more from the range of UWB (3.1-10.6 GHz).

2.2 Characteristics of First Band

To get the required notch at 3.5 GHz central frequency a U-Shaped slot (Slot-B) is etched within the radiator patch as revealed in Fig. 1(c) for Wi-Max application. The slot length can be calculated by using a quarter wavelength technique. The slot working as a band stop filters to eliminate some specific frequency band. In Fig. 2 the VSWR shown by blue dotted line indicates the band notched at 3.5 GHz after adding Slot B within the radiating patch. As observed from the Fig. 2 the band notched at 3.5 GHz for Wi-Max applications has been created.

2.3 Characteristics of Second Band

In order to achieve another band notched function for WLAN band at 5.4 GHz, an inverted U-Shape or Slot-A is etched just above the Slot-B (U-Shaped slot) in the radiating patch as shown in Fig. 1(d). The simulated VSWR for the second band notched at 5.4 GHz is shown in Fig. 2 by green dotted line. By the adjustment of different geometrical parameters of this slot, the band notch at desired frequency has achieved. The length of each slot is just about half the guided wavelength given.

The center frequency for band-notched is given approximately by the expression [23, 24].

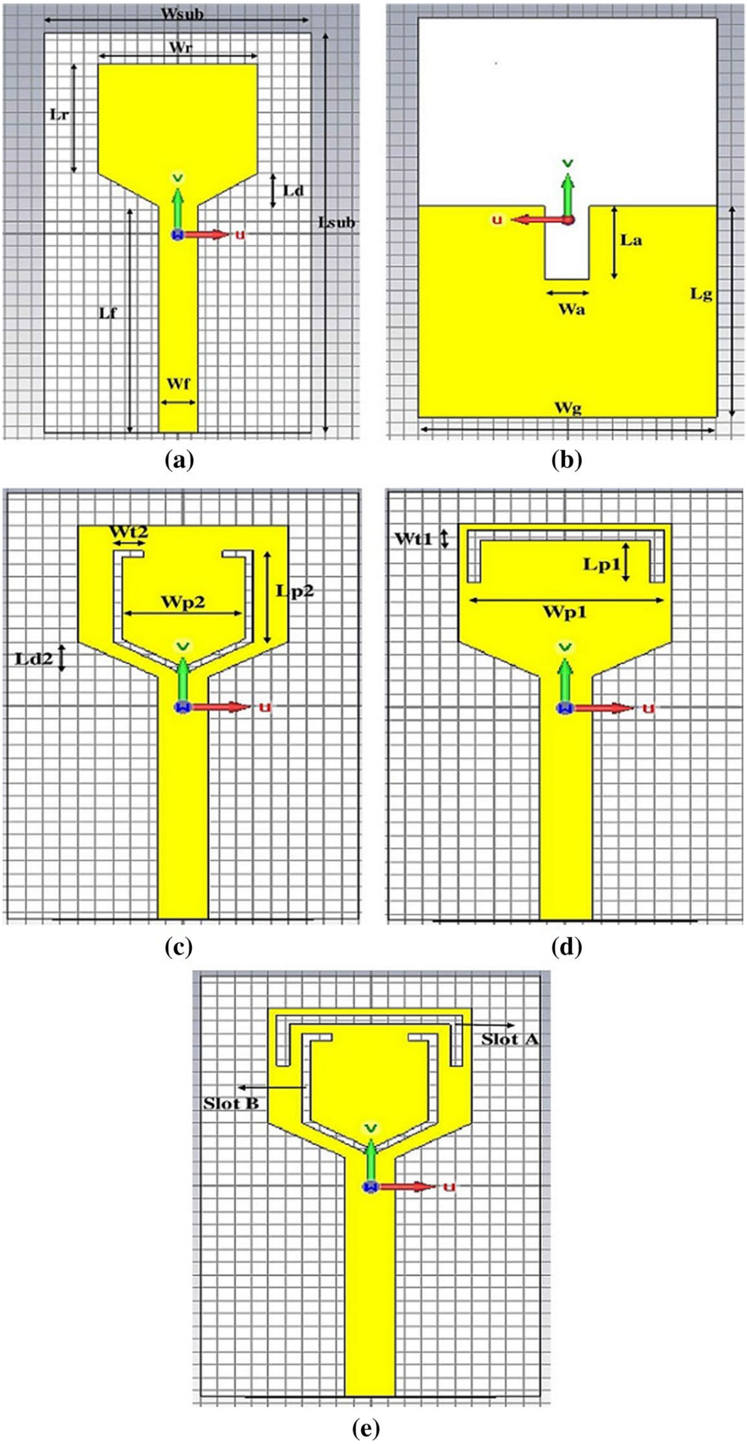


Fig. 1 Schematic diagram of the (**a**) conventional antenna, (**b**) back view of the proposed antenna, (**c**) U-slot in radiating patch, (**d**) inverted U-slot in radiating patch, (**e**) Final proposed antenna front view

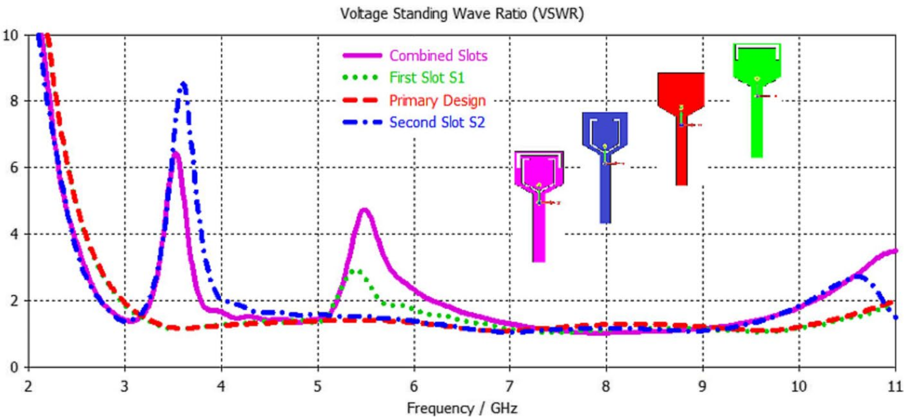


Fig. 2 Comparison of conventional and proposed antenna VSWR versus frequency (GHz) curve

$$f_{notch} = \frac{c}{2L_T\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{2}$$

where L_T is the entire length of the U-shape, c the speed of the light, ϵ_{eff} is the effective dielectric constant and ϵ_r is the dielectric constant of the substrate.

Comprehensive simulations using CST-2011 software package are carried out to optimize the entire size of the U-shaped slot with its location within the radiating patch to assign the rejection frequency band to Wi-Max and WLAN applications.

3 Parametric Results for Different Parameters

In this section, a parametric study of various antenna parameters is conducted to investigate the stimulation of various key antenna performance parameters as well as the antenna characteristics. The individual effects of various slot parameters such as slot length, width and position were examined. Parametric study of variations of both the slots (Slot A and Slot B) are given in Table 2.

3.1 Impact of Length Variation (Slot-A)

Figure 3 shows the simulated VSWR with frequency performance for distinct values of slot-A length. The response exemplifies that as the slot length value varies from a lower value of 16.5 mm to 18.5 mm, the notch frequency is shifted left side of the characteristics. So far for achieving band notch characteristics at 5.4 GHz (WLAN) the optimal length of slot A should be 17.5 mm as shown in figure below.

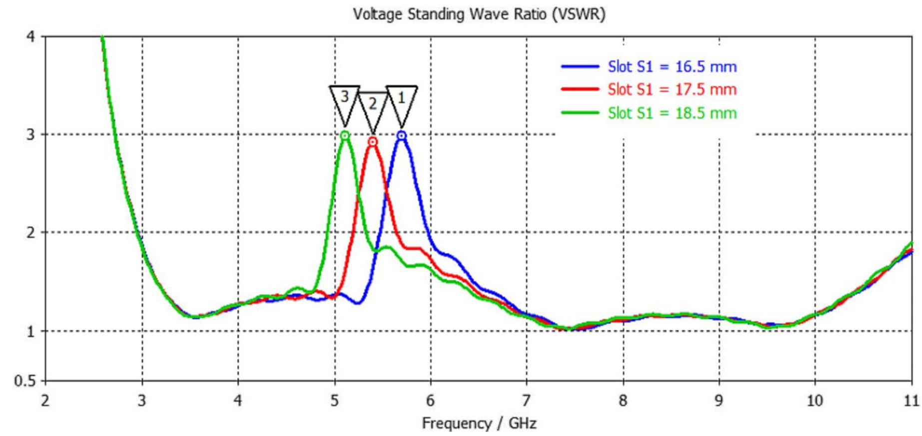


Fig. 3 Simulated VSWR versus frequency (GHz) curve for different values of slot-A length

Table 2 Parametric study of variations of both the slots (Slot A and Slot B)

Slot	Length (mm)	Impedance bandwidth (GHz)	Notch Frequency (GHz)
A	16.5	5.47–5.97	5.70
	17.5	5.18–5.64	5.40
	18.5	4.92–5.32	5.11
B	22.5	3.51–4.47	3.90
	23.5	3.37–4.22	3.74
	24.5	3.24–4.00	3.58

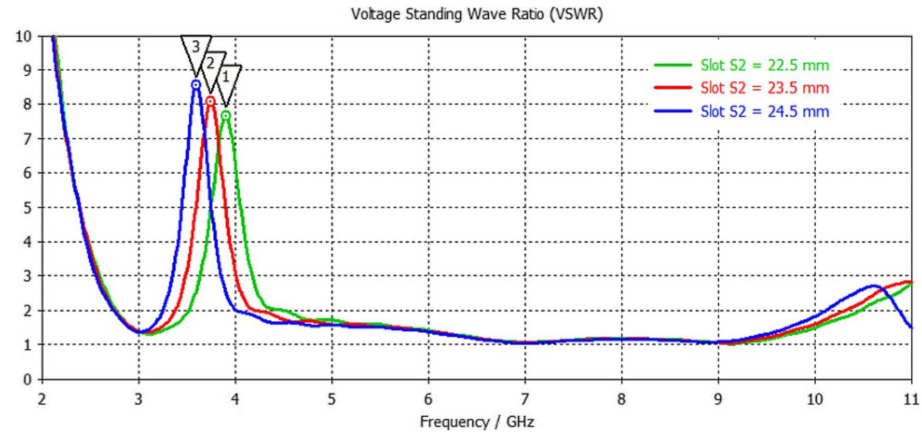


Fig. 4 Simulated VSWR vs. frequency (GHz) curve for different values of slot-B length

3.2 Impact of Length Variation (Slot-B)

Figure 4 displays the simulated VSWR with frequency for various values of slot-B length. The response exemplifies that as the slot length value varies from lower value say 22.5 mm to 24.5 mm, the notch central frequency is shifted left side of the characteristics. So far for achieving band notch characteristics at 3.5 GHz (Wi-Max) the optimal length of slot B should be 23.5 mm as shown in figure below.

4 Results and Discussion

As seen, the slots defined above are situated at different positions and are not overlapped with each other in the radiating structure, therefore it was decided to put them as one within the patch geometry. The slots are optimized for their position and different slot length to minimize the effect of coupling. The optimized dimensions of 'inverted/Reversed U-shape' slot as exposed in Fig. 1(d) are $L_{p1} = 3.25$ mm, $W_{p1} = 11$ mm and $W_{t1} = 0.75$ mm that produces the band notch characteristics corresponds to WLAN (from 5.49 to 6.45 GHz) system at central frequency of 5.4 GHz.

The optimized length parameters of the 'U-shaped' slot as revealed in Fig. 1(c) are $L_{p2} = 7$ mm, $W_{p2} = 10.4$ mm, $W_{t2} = 1.75$ mm and $L_{d2} = 4$ mm that produces the band notch characteristics intended for Wi-Max (from 2.9 to 4.5 GHz) systems with central frequency at 3.5 GHz. A defected ground structure with U slot cut in the middle and just behind the feed line having a dimension of $L_a = 6$ mm, $W_a = 3$ mm which has shown in Fig. 1(b) and it used to increase the impedance bandwidth of the proposed antenna. In the above approach, each of the slots inserted in the Ultra Wideband antenna fed by a microstrip feed line functions autonomously and offers separate band-notch features as can be seen in Fig. 2. Figure 1(b) and (e) are combined together and are called as proposed antenna. The variations of simulated VSWR with frequency for projected antenna (with combined slots) which exhibits double band notched characteristics are displayed in Fig. 5. The simulated antenna's result presents a wider bandwidth which varies from 2.70 GHz to 10.15 GHz for which VSWR < 2 covers almost complete Ultra wideband range including

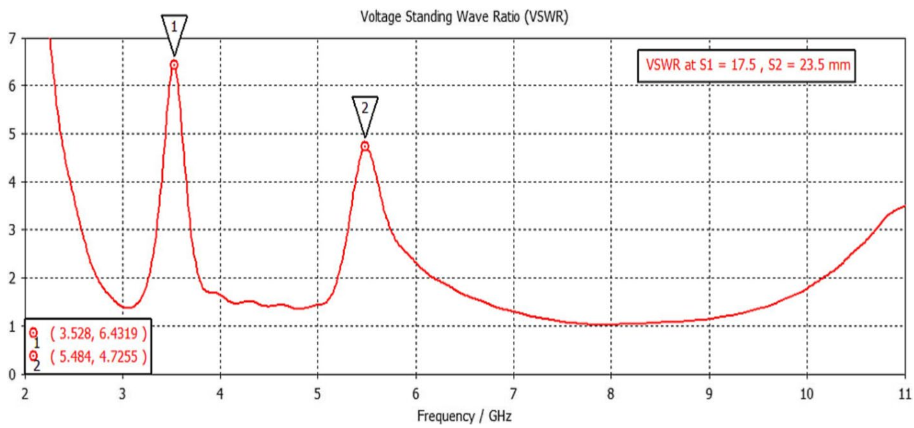


Fig. 5 VSWR vs. frequency (GHz) curve for proposed antenna

double band notch feature in the frequency ranges from 2.9 to 4.5 GHz and from 5.49 to 6.45 GHz for which VSWR > 2.

Figure 6(a)–(d) show the simulated far-field radiation patterns for the projected antenna at particular frequencies of 3.5, 4.5, 5.5 and 7.5 GHz. Cross polarization (X-pol) levels at the notch band frequency are observed, which shows that cross polarization levels at stop band frequencies are increased compared to passband frequencies. It has been ascertained that the projected antenna's radiation patterns deliver better Omnidirectional radiation patterns within the H-plane and dipole-shape patterns within the E-plane at stop (3.5 and 5.5 GHz) and pass band (4.5 and 7.5 GHz) frequencies.

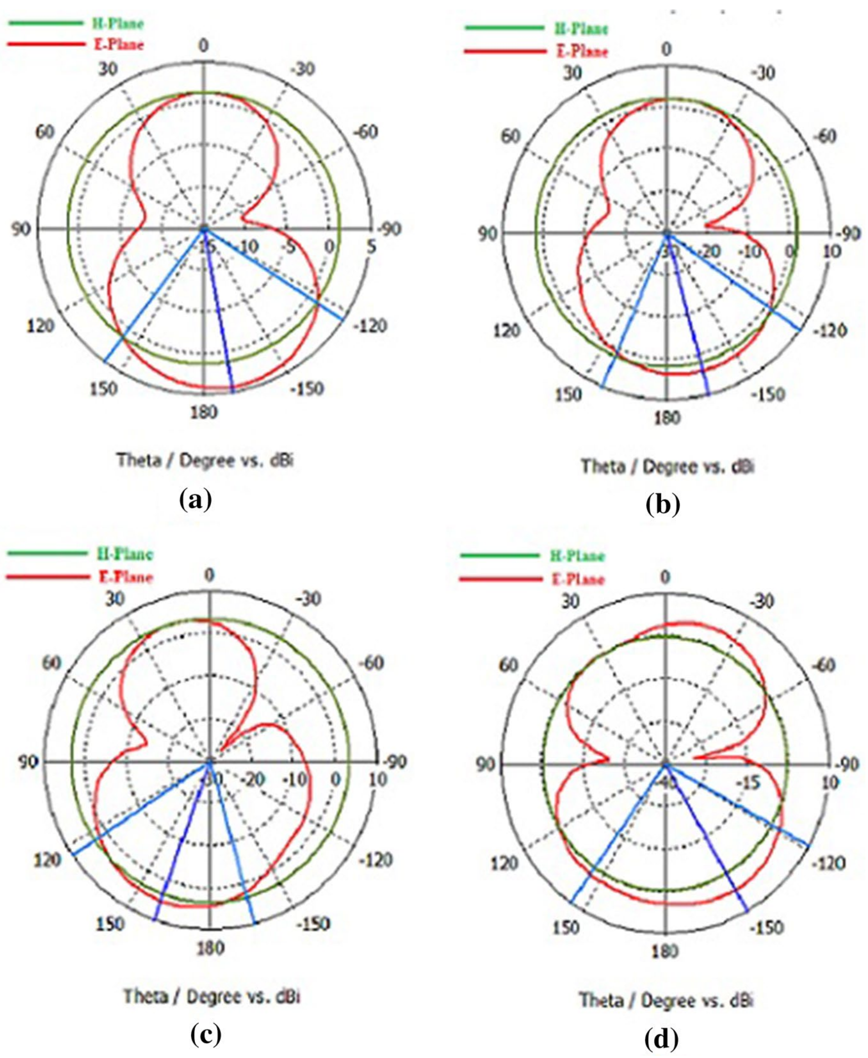
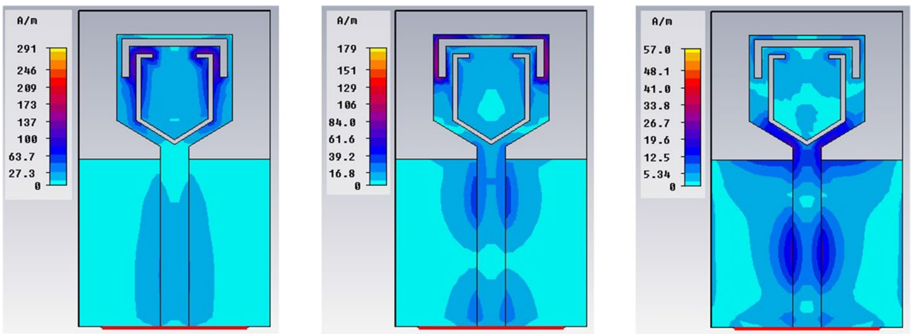


Fig. 6 Simulated far-field radiation patterns for the proposed antenna at (**a**) 3.5 GHz, (**b**) 4.5 GHz, (**c**) 5.5 GHz and (**d**) 7.5 GHz

Table 3 Comparison of performance of the antenna introduced in previous literature's with the current multiple band antenna

Published Antenna	Bandwidth BW (GHz)	Antenna Size (mm^3)	Gain (dBi)	Notched Band (GHz)	Radiation Pattern
Ref. [7]	2.45–10.65	19 × 24 × 1.2	3.45–4.5	3.2–3.7 4.8–6.3 7.0–8.15	Perfect Omnidirectional
Ref. [11]	2.8–11.3	28 × 21 × 1.6	NA	3.1–3.9 5.0–6.1 7.2–7.78	Nearly Omnidirectional
Ref. [14]	3.03–11.4	30 × 25 × 1.5	2.9–5.5	4.85–5.35 5.65–6.08	Nearly Omnidirectional
Ref. [15]	2.0–10.6	40 × 30 × 1	0–7.5	3.27–3.83 4.60–5.90	Nearly Omnidirectional
Ref. [24]	3.33–13.71	30 × 20 × 1.59	1.98–3.86	4.74–6.15	Nearly Omnidirectional
Ref. [26]	2.30–13.75	39 × 39 × 1.6	1.4–4.6	3.25–3.75 5.08–5.90 7.06–7.95	Quasi Omnidirectional
Present Antenna	2.70–10.15	20 × 33 × 1.6	− 2–1.5	2.9–4.5 5.49–6.45	Perfect Omnidirectional

Figure 7(a)–(c) show the distribution of surface current at separate stop and pass frequencies. The strong distribution of surface currents at stop bands has been detected around the U-slot boundaries, however the current's direction are opposite in nature. For this reason, the currents eliminate each other's impact and prevent the antenna from radiating at above stop band frequencies. It shows that the near field radiation counteracted at the notch frequency, whereby high energy is reflected rear to the input port and the band stop characteristics attained. This performance of the surface currents defines the creation



(a) (b) (c)

Fig. 7 Simulated surface current distributions for the projected antenna at (**a**) 3.5 GHz, (**b**) 5.5 GHz and (**c**) 7.5 GHz of the various band-notches within the far-field region, which are shown in Fig. 7(a), (b) respectively. Also, the current principally concentrates on the feed line at a functioning band frequency of 7.5 GHz, which might be seen in Fig. 7(c). This implies that the U-slots don't have much influence on the performance characteristics of such a resonant frequency.

Figure 8 represents the simulated gain in respect of frequency for the projected antenna. It is ascertained that the antenna demonstrates adequate gain consistency with the exception of two band notches wherever the gain stridently drop, which indicate the impact of the band notch characteristic of the antenna proposed. The gain over the entire band is steep except at the two rejected. The gain of proposed antenna at low frequencies is a little high and is good tolerable with the wide bandwidth attained. The radiation efficiency of antenna is probably to be small with regard to the antenna dimensions at low frequencies. It is observed that very sharp gain suppression occurs up to 8.1 dBi in notch bands.

Lastly, the performance of proposed antenna is compared with some previous literature multiple band notched antennas in terms of their size, impedance bandwidth, notch-band bandwidth, Gain and far-field radiation pattern (Table 3). More or less all the antennas are large and have complicated geometries. The antenna offered in [14, 15, 26] are very large but has a good and more gain over the pass-band frequencies also its covers the entire UWB range while the antennas reported in [7, 11, 24] present the advantages of smaller in size but has lower gain over the pass-band frequencies as compared to previous said antennas. In short, the proposed antenna excels the current multi notch band ultra-wideband antennas, based on its simple design and compact size, as well as the controllable frequency of the notch band, which covers the whole UWB.

5 Conclusions

The research paper presented the design and simulation of the compact Ultra Wideband microstrip patch antenna with double-band notched features and enhanced gain. The overall measurement of the presented patch antenna was $20 \times 33 \times 1.6\ mm^3$ and is accomplished on cheap FR-4 substrate which has dielectric constant (ϵ_r) of 4.4. The redesigned antenna engraved with two 'U' shaped slots (one on the patch and one on the ground plane)

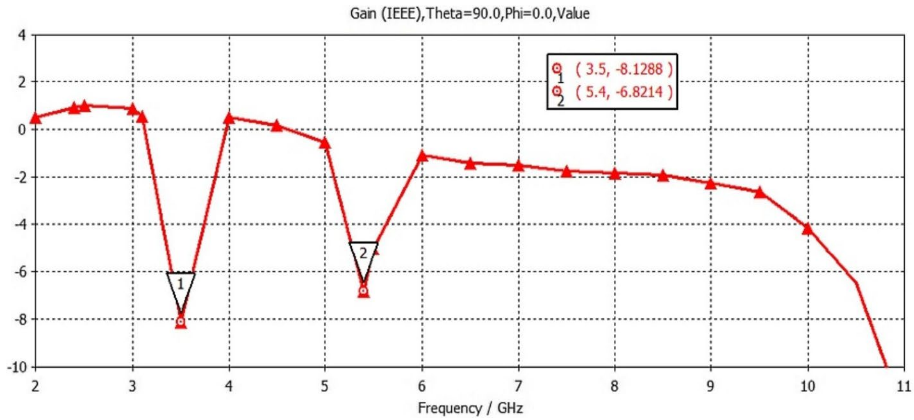


Fig. 8 Simulated gain curve with frequency of proposed antenna

and an 'Inverted/Reversed U' slot within the patch is presented. The insertions of above three slots of completely distinct size and at different positions either in the patch or in the ground plane have acquired rejection bands. The designed antenna has been tested for VSWR, efficiency, surface current distribution, radiation patterns and gain. A sharp decline in gain and antenna radiation efficiency is defined in the known frequency bands with the exception of 3.5 GHz Wi-Max and WLAN 5.4 GHz systems, which could be a significant configuration for present Ultra wideband communication. In fact, the proposed antenna handles the bandwidth somewhat from 2.70 GHz to upto 10.15 GHz with a voltage standing wave ratio (VSWR) < 2 except for the notch bands defined above. With the proposed geometry, a stable gain, improved direction and fair radiation patterns are obtained in the desired frequency range. The antenna proposed has an almost Omnidirectional pattern of radiation. The compact size, simple structure and good performance validate that the antenna presented is appropriate for Ultra Wideband applications where frequency interference from several other implied technologies such as WLAN and Wi-Max can be reduced.

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