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Novel UWB microstrip antenna with dual band-notched characteristics for short distance wireless applications

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Abstract. Introduction: In this paper, the design, simulation, and fabrication of a novel compact ultra-wideband (UWB) monopole microstrip antenna with dual band-notched characteristics for short distance wireless applications were explored. **Methodology:** The design of the antenna was carried on FR4 substrate with dielectric constant 4.4, loss tangent 0.02, the thickness of 0.8mm and the size of the proposed antenna is 30×20 mm^2. The rectangular monopole antenna endures a rectangular radiating patch with chamfered bevel slots on the top side and a defective ground plane on the bottom side of the substrate. To realize single, dual-band notch characteristics, inverted V shape slot is created on the patch to achieve the first notch at 4.6 GHz which eliminates INSAT signal, and a pair of symmetrical C shaped slots is created on the ground plane to achieve the second notch at 5.5GHz which eliminates WLAN signal. The proposed antenna is well miniaturized and can be easily integrate with any compact devices. **Result & Conclusion:** The measured result shows that proposed antenna gain a good range of UWB from (2.9 GHz to 16.8 GHz) with dual band notch characteristics. This antenna gains a good harmony between the simulated results and measured results.

Keywords: Rectangular Monopole Antenna, Chamfered Bevel Slots, Inverted V slot, Symmetrical C shaped slots, Ultra Wide Band.

1. Introduction

In wireless communication technology Ultra-Wideband (UWB) is a widely admired and attractive technique used for short-range communication applications. From the past few years, UWB have become the highlight of wireless communication due to advantages of less power spectral density, maximized data rate, low power utilization and many others. Allocation of bandwidth ranging from 3.1 to 10.6 GHz done by the Federal Communication Commission (FCC) In February 2002 to be used for short-range communication purposes, by far the demand for UWB increasing rapidly [1]. UWB antennas are increasingly used in wireless communications at short range because they can transmit a great amount of information across a wide frequency range. It gives a high data rate system at a low cost and with low power.

A lot of research on UWB system brought some challenges including their impedance matching, compact size, low manufacturing cost, etc. which introduced while designing an antenna for UWB applications. The operating frequency of UWB allocated by FCC includes more narrowband wireless

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standards that have been allocated to share some part of this spectrum. These include INSAT 4.6GHz, wireless local area network (WLAN) services 5.5GHz, etc. which interfere with the UWB system. So somewhere its needed an antenna with band-notched property that can diminish the unwanted interferences from these coexisting wireless system rather than by using an additional band stop filter. There are various methods which are helpful for introducing a notch in UWB antenna. The most commonly used technique is by adding different slots on the radiating material or in the ground plane or also on the feed line. Different shapes are used like V-shaped slot is used on the patch to create band notch characteristics [2]. Two short-circuited folded stepped impedance resonators [3]. By etching one quasi complementary split-ring resonator (CSRR) [4]. Etching four u-shaped slots [5]. One angle-shaped parasitic slit is etched out along with the tuning stub, and two symmetrical parasitic slits on ground plane [6]. Etching a c-shaped slot on the radiation patch and extruding an l-shaped stub from the ground plane [7]. Two w-shaped slots etched into the monopole and the truncated ground plane [8]. A modified complementary co-directional split ring resonator (SRR) etched on the radiation patch, which leads to the desired dual notched bands [9]. Adding a meandering slot on the radiation patch and, with adding a pair of symmetrical C-shape strips to the feed-line dual band notched characteristics are achieved [10]. A pair of C-shaped slots and a U-shaped slot placed on the radiating patch [11]. A pair of bended dual- L-shape branches are attached to the slotted ground [12]. The microstrip feed line is placed between two pairs of EBG cells which are designed to act as stop-band filters [13]. A semi-circular parasitic strip located above the circular ring, and a t-shaped stub is located near the inner edge of circular ring [14]. Two resonators of different lengths are employed at the bottom layer to create two notches at the frequency of interest [15]. A T-shaped stub embedded in the square slot of the radiation patch and a pair of U shaped parasitic strips beside the feed line is used [16]. Pair of two slots in the ground plane as well as adding a pair of arc-shaped parasitic strips around the radiating element [17] A modified complementary split-ring resonator (CSRR) is placed inside the inner patch to obtain band rejection characteristics [18]. Inclusion of an additional small radiation patch on the ground plane [19]. W shaped slot integrated on the radiating patch [20].
However, the above designs has larger size of the antenna or limited band notch performance. This paper presents a novel design of UWB monopole microstrip antenna with inverted V shape slot on the radiating patch and a pair of C shaped slots on the ground plane. The proposed antenna covers the full range of UWB and also its capable of rejecting frequencies like INSAT signal and WLAN band. this approach has acceptable band notch performance without increasing size and complexity of antenna and how it is achieved is discussed in the following section.

2 Antenna Design Methodology

2.1 Design of UWB antenna without notched bands

First, the basic antenna covering the entire band width of UWB frequency range without any band-notched characteristics is discussed. This antenna is printed on an FR4 substrate with dielectric constant 4.4, loss tangent 0.02, size of 20x30 mm^2 and thickness of 0.8mm. The feed line and the radiating patch is attached to each other, so these are printed on the top of the substrate and the bottom side ground plane is printed. Microstrip feed line width is fixed as 1.5mm to achieve 50-ohm characteristic impedance. The design procedure of radiating patch to achieve UWB with a defective

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ground plane of size 20x13mm^2 has 3 cases as shown in fig. 1(a). In case 1 the design starts with a rectangular monopole antenna, a 10dB return loss bandwidth is obtained by changing the width between the patch and ground plane since for rectangular monopole the ground plane serves as an impedance matching circuit. In case 2 symmetrical bevel slots are etched on the lower edges of the patch, etching of slots looks as steps on the lower side of the monopole radiating patch [19]. This slot with dimensions of W2 and L2 plays the significant role in achieving wider band width. In case 3 the patch was chamfered at the bottom edges of the radiating patch above the bevel slots, this is to create the good impedance matching for the patch and the ground plane. Chamfering the edges (case 3) of slots and increasing the width of slots (case 2) support the traveling wave from the lower frequency to higher frequencies as shown in fig. 1(a). It can also be mentioned that by decreasing the width W1 as shown in fig. 2. the VSWR goes below 1(b).

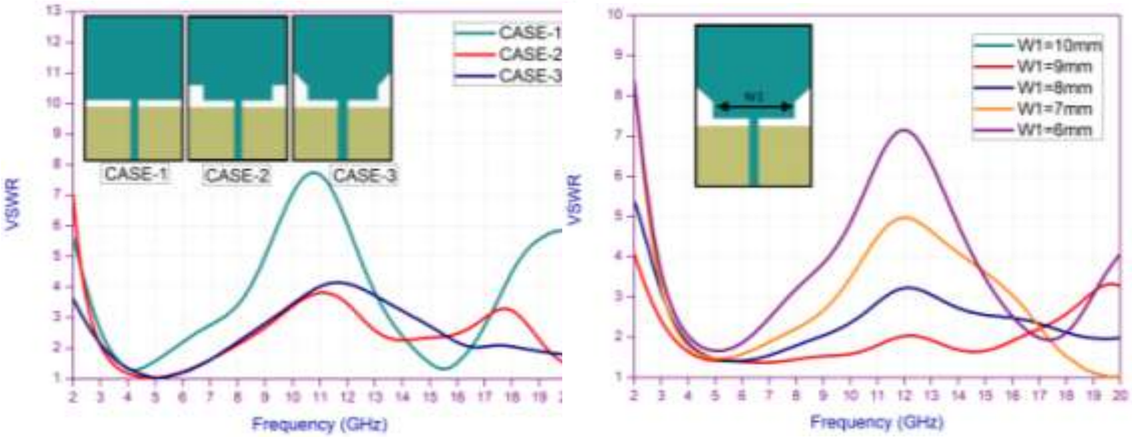

Figure 1. Design procedure of ultra wide band antenna (a) Different Case (b) Variation of W1

2.2. Design of UWB antenna with band notch characteristics

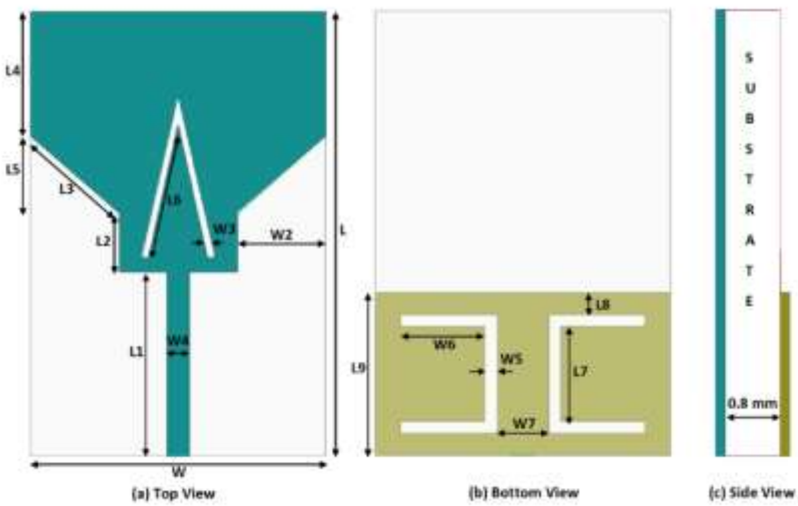

Figure 2. Geometry of Proposed UWB antenna with band notch characteristics (a) Top view (b) Bottom view (c) Side view

Table 1. Optimized parameters for the proposed UWB antenna with dual-band notch characteristics.

Parameter	Size(mm)	Parameter	Size(mm)	Parameter	Size(mm)
L	30	L6	9.5	W2	6
L1	11	L7	6	W3	0.5
L2	4	L8	1.5	W4	1.5
L3	8.92	L9	10	W5	1
L4	8.4	W	20	W6	5.5
L5	6.6	W1	8	W7	3.5

The design of proposed antenna with double notched band characteristics for UWB applications is shown in fig. 2. Initially, the designed antenna covers the full range of UWB with the microstrip feed line width as 1.5mm to achieve 50Ω character impedance. In the presented design inverted V shape slot on the radiating patch and a pair of C shape slot in the ground plane are introduced to achieve notch at 4.6GHz (INSAT signal) and 5.5GHz (WLAN signal). The simulation process of proposed antenna is done on HFSS 13 software. Table 1 shows the optimized dimensions of the antenna.

2.3. Study of slot dimensions

The total length of the inverted V slot and C slot is calculated by the following formulae at center frequency of notched bands

$$L_{inverted\ V\ slot} = \frac{C}{2f_i\sqrt{\varepsilon_{eff}}} \quad (1)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \quad (2)$$

Where c denotes the velocity of light in free space, ε_r is the substrate dielectric constant, ε_{eff} is the effective dielectric constant, and f_i (i = inverted V slot or C slot) is the center frequency of the notched bands. For the inverted V slot of INSAT signal notch band whose center frequency is 4.6GHz the slot lengths theoretically calculated value is $L_{Theoretical}$=19.8mm and practically calculated value is $L_{Practical}$=19mm. For the C slot of WLAN notch band whose center frequency is 5.5GHz the slot lengths theoretically calculated value is $L_{Theoretical}$=16.6mm and practically calculated value is $L_{Practical}$=17mm. Table 2 shows the comparison between theoretical and practical values of slot lengths; there is good agreement between the theoretical and practical values with a minimum logical error.

Table 2. Slot lengths at rejected frequencies.

Slot	Notching frequency	L-Theoretical	L-Practical	Logical error
Inverted V slot	4.6GHz	19.8	19 (L6+L6)	0.8
C slot	5.5GHz	16.6	17 (L7+W6+W6)	0.4

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3. Results and Discussion

The proposed antenna performance with different slots is characterized by Full-wave electromagnetic simulations which were carried out by Ansoft's high-frequency structure simulator (HFSS). To reduce the interference with the INSAT signal, a notched band frequency covering 4.6 GHz is desired. The desired band notch achieved by inner length of inverted V slot. Here the slot creates the capacitance, and the capacitance depends on the length of the slot. Placing such type of slots near to the feeding edges of the patch a frequency filter is formed which characterize first notched band. Noting that for the proposed antenna dimensions can be fixed and the center frequency of notch can be tuned by varying length L6 to achieve the desired INSAT signal notched frequency. Fig. 3. shows the simulated S11 and VSWR characteristics of the proposed antenna for different dimensions of the inner length of inverted V slot L6.

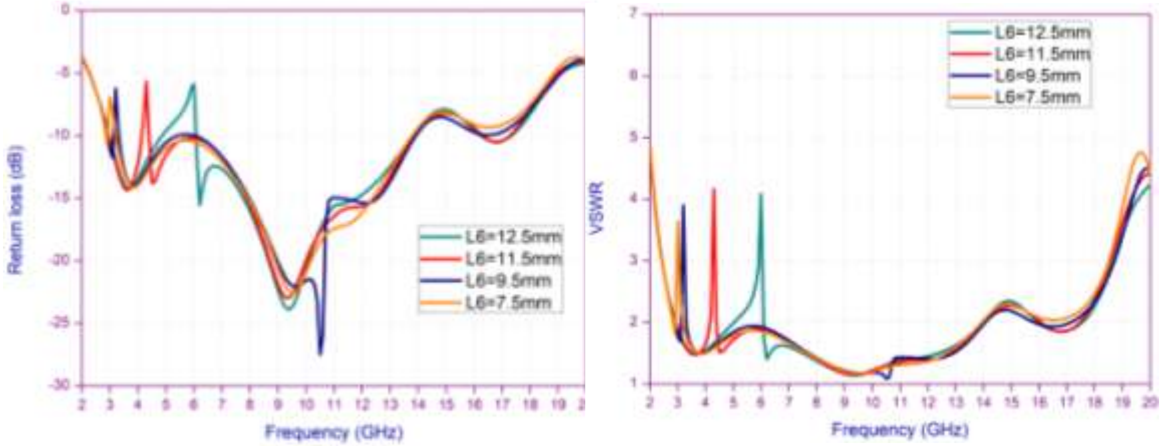

Figure 3. Simulated S11 and VSWR characteristics of proposed antenna with different values of L6

In addition to the INSAT services 4.6 GHz, the commonly used WLAN (5.5 GHz) frequency will also interfere with the UWB band frequency. To minimise the interference in this frequency band, the second notched band is characterized by placing a pair of C slots on the ground plane near to feed line. Fig. 4. shows the simulated S11 and VSWR characteristics of the proposed antenna for different dimensions of the inner length of C slot L7 keeping W6 constant as 5.5mm.

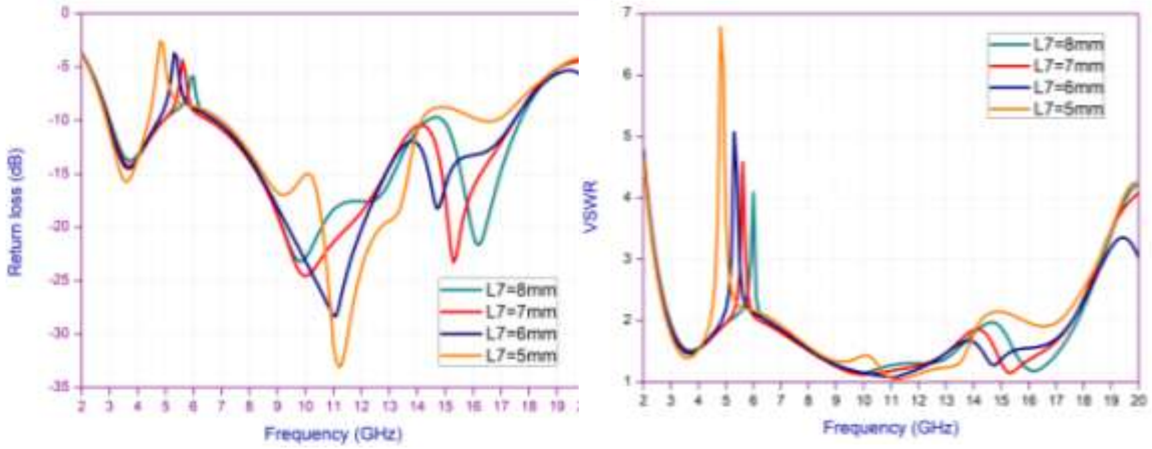

Figure 4. Simulated S11 and VSWR characteristics of proposed antenna with different values of L7

The parametric study was done to investigate the slot dimensions of the proposed monopole antenna. Table 3 shows the variation in the width of inverted V slot for different dimensions. Here the width is taken as 0.5 mm where the centre frequency of first notch is 4.7GHz which is near to 4.6GHz which is proposed center frequency of first notch.

Table 3. Variation in width of inverted V slot for different dimensions (W3).

width of V slot (W3)	bandwidth of antenna			bandwidth of notch for inverted V slot			notch frequency
	F_L(GHz)	F_H(GHz)	band width	F_L(GHz)	F_H(GHz)	band width	
0.5	2.95	13.39	10.44	4.4	4.81	0.41	4.7
1	2.99	13.62	10.63	4.18	4.59	0.41	4.49
1.5	2.95	13.35	10.4	3.94	4.2	0.26	4.11
2	2.99	13.8	10.81	3.79	3.97	0.18	3.89

Table 4. Variation in length of inverted V slot for different dimensions (L6).

length of V slot (L6)	bandwidth of antenna			bandwidth of notch for inverted V slot			notch frequency
	F_L(GHz)	F_H(GHz)	band width	F_L(GHz)	F_H(GHz)	band width	
5	2.99	13.78	10.79	5.17	7.68	2.51	7.55
6	2.96	13.77	10.81	5.01	7.05	2.04	6.95
7	2.98	13.73	10.75	4.81	6.08	1.27	5.98
8.1	3	13.31	10.31	4.29	4.77	0.48	4.65
9	2.99	13.64	10.65	4.26	4.61	0.35	4.52
10	2.86	13.7	10.84	2.96	3.2	0.24	3.02

Table 5. Variation in width of C slot for different dimensions (W5).

width of C slot (W5)	bandwidth of antenna			bandwidth of notch due to C slot			notch frequency
	F_L(GHz)	F_H(GHz)	band width	F_L(GHz)	F_H(GHz)	band width	
0.4	2.99	15.03	12.04	4.94	6.53	1.59	5.27
0.8	2.97	17.23	14.26	4.88	6.56	1.68	5.37
1.2	2.99	17.46	14.47	4.85	6.6	1.75	5.86
1.4	2.99	17.63	14.64	4.96	6.73	1.77	6
1.8	3.02	17.66	14.64	4.98	7.08	2.1	6.45

Table 6. Variation in length of C slot for different dimensions (L7).

length of C slot (L7)	bandwidth of antenna			bandwidth of notch due to C slot			notch frequency
	F_L(GHz)	F_H(GHz)	band width	F_L(GHz)	F_H(GHz)	band width	
7	3.02	17.68	14.66	4.91	6.8	1.89	5.95
8	2.99	17.47	14.48	4.94	6.55	1.61	5.62
8.3	2.96	17.44	14.48	4.78	6.71	1.93	5.58
9	2.96	17.44	14.48	4.73	6.77	2.04	5.34
10	2.92	14.11	11.19	4.36	6.96	2.6	4.82

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Table 7. Variation in distance between C slot and feed line in dimensions (W7).

distance in mm (W7)	bandwidth of antenna			bandwidth of notch due to C slot			notch frequency
	F_L(GHz)	F_H(GHz)	band width	F_L(GHz)	F_H(GHz)	band width	
0.5	2.99	18.36	15.37	5.02	6.84	1.82	5.68
1	2.98	17.49	14.51	4.88	6.56	1.68	5.62
1.2	3	17.46	14.46	4.75	6.88	2.13	5.59
1.4	2.97	17.37	14.4	4.8	6.59	1.79	5.51
1.5	3.02	17.06	14.04	4.81	6.52	1.71	5.41

Table 4 shows the variation in length of inverted V slot for different dimensions. Here the length is taken as 8.1 mm where the center frequency of first notch is 4.65GHz which is required to eliminate INSAT signal. Table 5 shows the variation in width of C slot for different dimensions. Here the width is taken as 0.8 mm where the center frequency of second notch is 5.37GHz which is near to 5.5GHz. Table 6 shows the variation in length of C slot for different dimensions. Here the length is taken as 8.3 mm where the center frequency of second notch is 5.58GHz which is required to eliminate WLAN signal. Table 7 shows the variation in distance between C slot and feed line for different dimensions. Here the length is taken as 1 mm where the center frequency is 5.62GHz.

Table 8. Variation distance between C slot and feed line in dimensions (W7).

width of C slot (W7)	bandwidth of antenna			bandwidth of notch due to inverted V slot			first notch freq. (GHz)	bandwidth of notch due to C slot			second notch freq. (GHz)
	F_L (GHz)	F_H (GHz)	band width	F_L (GHz)	F_H (GHz)	band width		F_L (GHz)	F_H (GHz)	band width	
0.4	2.95	17.63	14.68	4.25	4.75	0.5	4.62	5.29	6.76	1.47	5.61
0.7	2.93	17.62	14.69	4.32	4.84	0.52	4.73	5.31	6.84	1.53	5.74
1	2.91	17.61	14.7	4.01	4.38	0.37	4.26	5.08	6.04	0.96	5.54
1.4	2.93	17.49	14.56	4.35	4.96	0.61	4.85	5.29	6.22	0.93	5.7
1.5	2.88	17.51	14.63	3.42	3.63	0.21	3.52	4.88	6.36	1.48	5.71

Table 9. Variation in width of C slot for different dimensions (W5).

width of C slot (W5)	bandwidth of antenna			bandwidth of notch due to inverted V slot			first notch freq. (GHz)	bandwidth of notch due to C slot			second notch freq. (GHz)
	F_L (GHz)	F_H (GHz)	band width	F_L (GHz)	second notch	band width		F_L (GHz)	F_H (GHz)	band width	
0.8	2.95	15.03	12.08	3.47	second	0.23	3.56	4.82	6.64	1.82	5.2
1	2.97	16.88	13.91	4.25	4.71	0.46	4.61	5.24	6.36	1.12	5.57
1.2	2.92	17.58	14.66	4.01	4.38	0.37	4.26	5.06	6.1	1.04	5.54
1.4	2.95	17.58	14.63	4.42	5.09	0.67	4.97	5.4	6.22	0.82	5.68
1.8	2.95	17.69	14.74	4.29	4.87	0.58	4.75	5.43	7.01	1.58	6.35

The table (3,4,5,6,7) values are individual and not depending on each other, individual slots are considered and the values have been noted. After adding both slots the result is shown in table 9 and 10. In the combined results the Center frequency of first notch and center frequency of second notch

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is varied so the variation in distance between C slot and feed line is done in table 8 and Table 9 Shows the accurate values of center frequency of first (4.6GHz) and second (5.5GHz) notches. Here the variation is done for the width of C slot initially the width is taken as 0.8 mm now the width is taken as 1 mm.

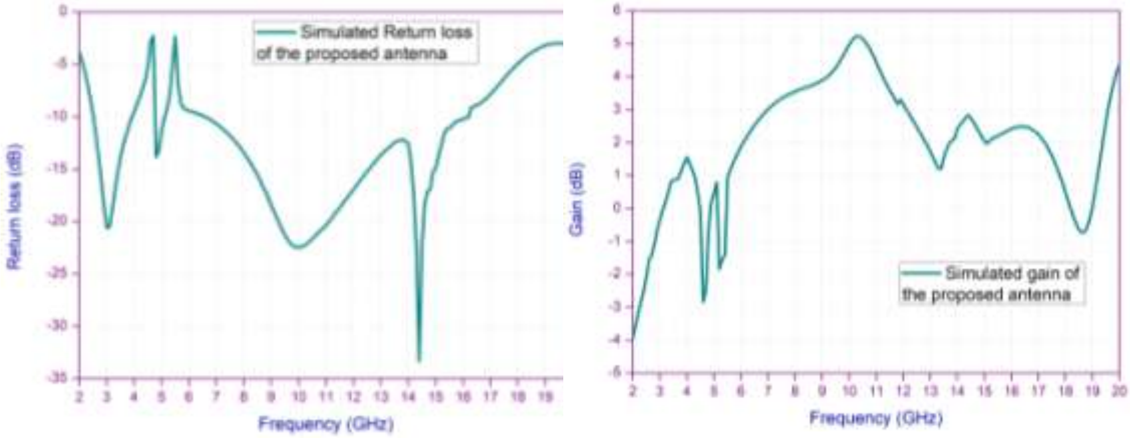


Figure 5. Simulated S11 and Gain values of proposed dual band notched UWB antenna

Fig. 5. shows the simulated S11 and gain of the proposed dual band notch ultra wide band antenna. the proposed antenna has a gain below 0dB up to 2.9GHz and the gain increases with frequency. It is observed that the antenna gain is decreased with the use inverted V slot in the patch and the pair of C shaped slots on the ground plane of the antenna. Notice that a sharp decrease of gain below 0dB is shown at first notched band frequency band of 4.6GHz and second notched band of 5.5GHz. The gain of the antenna outside the notched frequency bands is above 0dB and the maximum gain of 5dB is achieved at 10.5GHz.

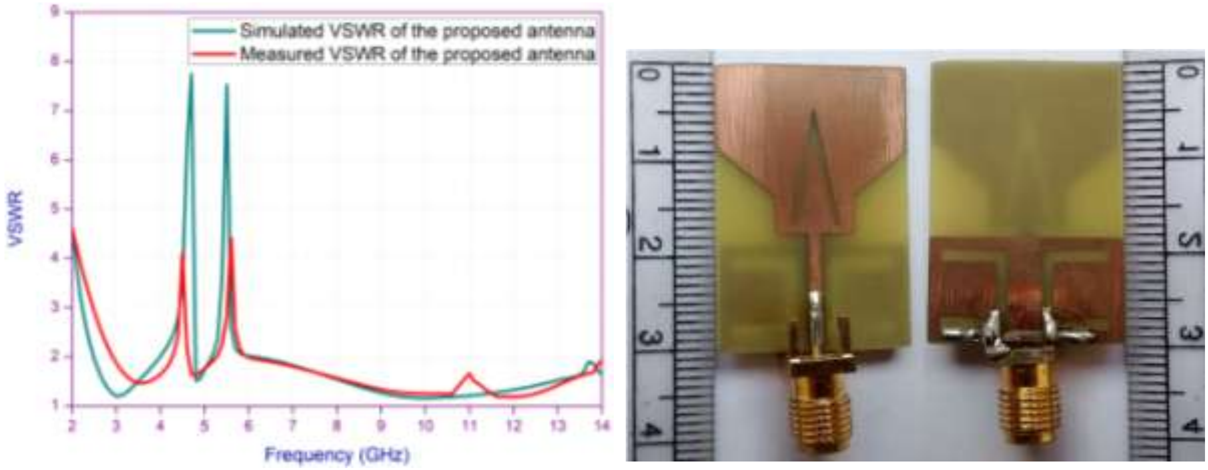
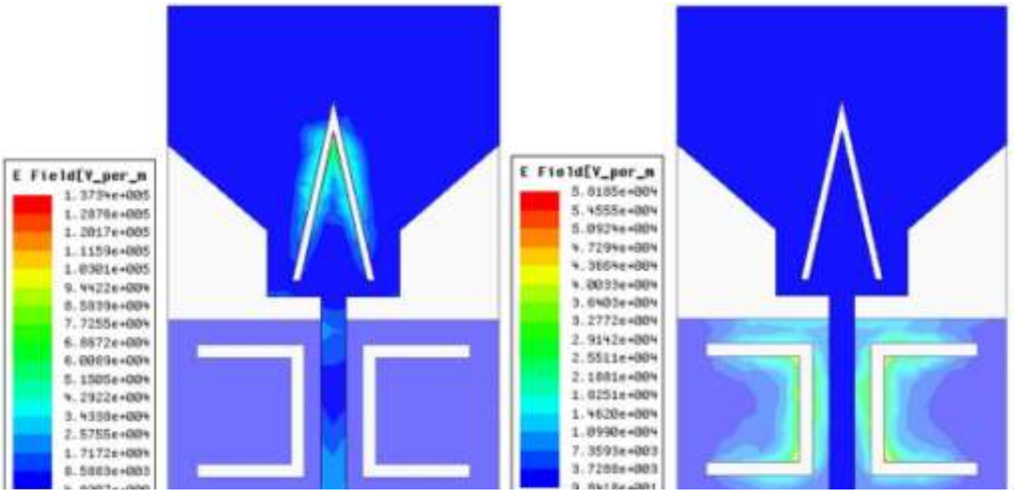


Figure 6. Comparison of Simulated and measured VSWR values with photograph of proposed UWB antenna

Fig. 6. shows the simulated and measured VSWR values of the proposed dual band notch ultra wide band antenna. The simulated and measured values for VSWR gives a matching of the notched bands at 4.6GHz and 5.5GHz. The frequency performance of the antenna demonstrates the two rejection bands with S11 < -10dB and VSWR > 2 covering both the INSAT and WLAN applications, while

maintaining s11 > -10dB and VSWR < 2 at out of the rejection bands. A very good agreement between measured and simulated results is observed. Slight discrepancies could be attributed to the effects of the SMA connector, which is not considered in our simulation. To understand the phenomenon of dual band-notch performance, the simulated current distributions on the radiating patch is shown in Fig. 7. from Fig. 7. one can find that the current is mainly concentrated in the inner and outer edges of the inverted V slot and C slots at 4.6 and 5.5 GHz, respectively.



(a) (b)

Figure 7. HFSS-Predicted surface current distributions at each notched frequencies (a) 4.6GHz (b) 5.5GHz

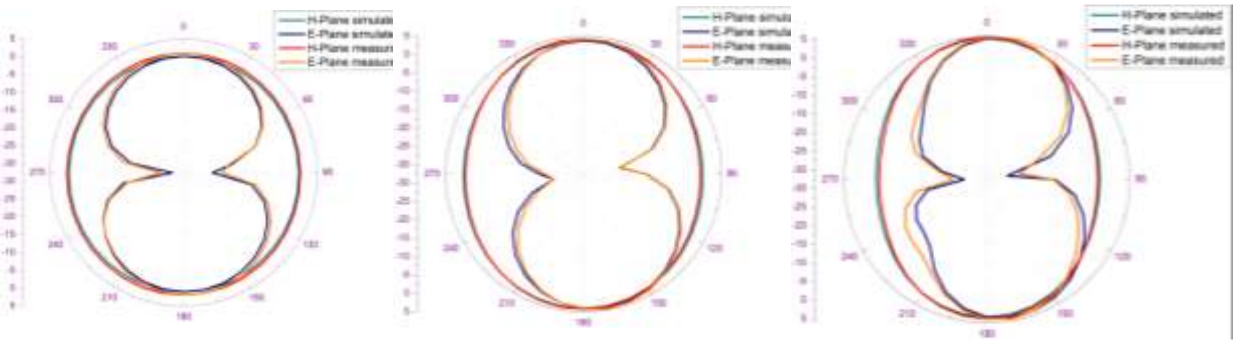


Figure 8. Simulated and measured, E-Plane and H-Plane Radiation pattern for proposed UWB antenna at (a) 4GHz (b) 7GHz (c) 9GHz

Table10. Comparison of proposed UWB antenna with reported antennas

Property	Proposed work	Ref.[12]	Ref.[5]	Ref.[11]	Ref.[10]
Dielectric constant	4.4	4.4	4.4	4.4	4.4
Substrate size in mm	30*20	40*30	37*34	32*28	30*24
Thickness (mm)	0.8	1.2	1	1.6	1.2
Bandwidth (GHz)	2.9-16.8(Tunable)	3-11	3.1-10.6	3.1-10.6	3.1-10.6
First notch band (GHz)	4.2-4.7(Tunable)	3.5	3.3-3.8	3.24-3.78	3.5
Second notch band (GHz)	5.2-6.3(Tunable)	5.5	5.1-5.9	5.13-6.32	5.5

The simulated and measured radiation patterns of the proposed antenna at 4GHz, 7GHz and 9 GHz are shown in Fig. 8. It is observed that the antenna in its H-plane have an omnidirectional radiation pattern, and in E-plane it have a dipole-like radiation pattern. In table 10, the characteristics of the previously reported band notched UWB antennas are compared with this work. Proposed antenna have a good band width of 13.9 GHz. Which can be tunable without increasing the size of the antenna as shown in fig. 1. Which covers entire UWB (3.1 to 10.6GHz) region and even better band width is achieved for future UWB applications. The notch frequencies are also tunable based on lengths (L6 and L7) as shown in table 3 and Table 4.

4. Conclusion

This paper presents a compact UWB microstrip monopole antenna with dual band notched characteristics, which covers the frequency range from 2.9 to 16.8 GHz (Tunable). By introducing an inverted V shape slot on the patch and a pair of C shape slots on the ground plane, dual notch band center frequency at 4.6 GHz (Tunable from 3.02GHz to 7.55GHz as shown in table 4) and 5.5 GHz (Tunable from 4.82GHz to 5.95GHz as shown in table 6) are obtained which rejects INSAT signal and WLAN signal. The designed antenna shows maximum gain of 5dB at 10.5GHz. The proposed antenna is simple, compact, and gives excellent performance so these antennas are used in various UWB systems for short distance wireless telecommunication applications.

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