Indian Journal of Radio & Space Physics
Vol 50, December 2021, pp 198-203

Extremely compact UWB antenna design with single Notch-Band characteristic

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Received: 14 May 2021; Accepted: 2 September 2021

An extremely compact antenna design for Ultra-wideband (UWB) application has been presented in this paper that successfully displays band-notch characteristics at the WLAN band. The design consists of a truncated radiator supplied by a 50 Ω Coplanar Waveguide (CPW) feedline structure. The antenna has been mounted on a FR4 substrate, and its ground plane has been etched with an inverted-L slot responsible for frequency-notch characteristics at the WLAN band (5.15-5.825 GHz). The ground plane has been defected by engraving a rectangular slot in the ground plane for improving the impedance bandwidth. The antenna has a profile size of 19×9×1.6 mm^3. The performance of the antenna has also been compared with another design having twice the dimensions of the proposed structure (30×26×1.6 mm^3).

Keywords: Ultra-wideband (UWB), Coplanar Waveguide (CPW), Voltage Standing Wave Ratio (VSWR), HFSS v13, Group Delay

1 Introduction

The contemporary era, has been ruled by wireless communication technologies in almost all aspects of life. To accommodate the ever-increasing user demands, limited resources have to be used judiciously. Thus, minimum bandwidth requirements, high data speed, minimum latency, high reliability, and lesser power consumption are some of the key features that have governed the designing of any wireless system. According to Ullah *et al.*[1], the UWB technology (3.1-10.6 GHz) has been offering such features for reliable wireless communication. But, the UWB operation has been somehow limited by interferences caused by various narrow bands that co-exist with the UWB spectrum, such as WLAN (5.15-5.825 GHz), WiMAX (3.3-3.6 GHz), and X-band satellite communication (7.25-8.395 GHz). With advancements in device modeling, various solutions have been offered to solve the above-stated limitation. The use of filters for removing the interfering bands has been one of the initially developed solutions. But this arrangement has resulted in bulky systems with increased cost and high insertion losses[2-3]. A realistic and fruitful way of achieving UWB functionality with desired notch-bands has been to design UWB antennas that can inherently introduce successful notch-bands at desired frequencies. Some of the techniques that have been employed for introducing the notch-bands in a UWB antenna design include Split Ring Resonators (SRR)[4-6], Electromagnetic band gap (EBG) structures[1,7], etching resonant slots in radiating patch or ground plane[8-10] and coupling the parasitic elements with radiating patch[11-12]. With the help of certain optimizations in UWB antenna designs, all these techniques have successfully removed the unwanted interfering bands from the UWB spectrum with substantial sensitivity.

In this work, an extremely low profile UWB antenna has been offered that has utilized a resonant slot (inverted-L slot) in ground plane for achieving a notch at WLAN band.

2 Materials and Methods

The structure of proposed antenna (Design 1) is portrayed in Fig. 1 (a) and the structure for comparative antenna (Design 2) having a profile dimension almost twice of Design 1 is shown in Fig. 1 (b). UWB feature (3.1-10.6 GHz) was achieved in both designs by trimming the lower edges of the radiating patch and feeding the structure with a 50 Ω CPW feedline structure. The band notch feature at WLAN band (center frequency, f_c = 5.5 GHz) was introduced by integrating some narrowband half-wavelength resonant structure (inverted L-slot of length: 18 mm and width: 0.3 mm in Design 1, C-slot of length: 18 mm and width: 0.3mm in Design 2) in the non-notched UWB antenna design. According to Schantz *et al.*[14],at half-wavelength resonant frequency

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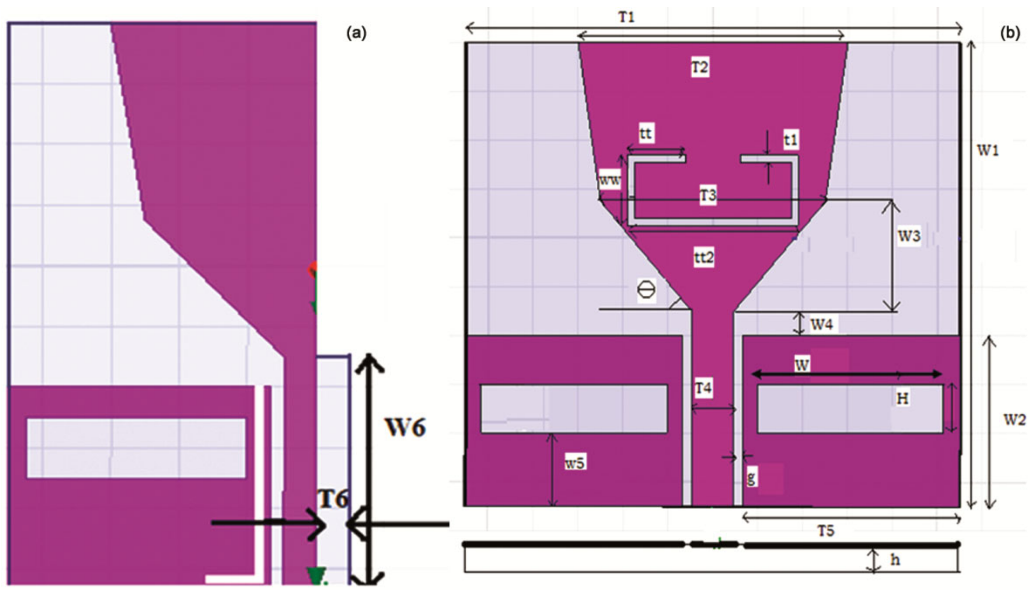

Fig. 1 — (a) Structure of projected antenna, and (b) Structure of comparative antenna[13].

these slot structures results in destructive interference, making the designed antenna non-responsive at that frequency (or the particular frequency appears to be notched). A rectangular slot was engraved in ground plane that offers a supplementary current path. Such arrangement causes variation in inductance and capacitance of input impedance, hence resulting in enhancement of impedance bandwidth. The design factors of required antenna are optimized to attain high impedance bandwidth and high sensitivity. For both antenna designs, the substrate height (h) =1.6 mm, dielectric constant (ε_r) = 4.4 and loss tangent (δ) = 0.02. The optimized values of various design parameters for both Design 1 and Design 2 are provided in Table 1.

Table 1 — Optimized parameter values for Design 1 and Design 2

Parameters	Dimensions of Design 1 (mm)	Dimensions of Design 2 (mm)
T1	9.3	18.6
T2	6	12
T3	5	10
T4	0.93	1.86
T5	7.57	7.57
W1	19	19
W2	7	7
W3	4.5	4.5
W4	1	1
W5	3	3
W	6.5	6.5
H	2	2
G	0.5	0.5
Θ	48°	48°
W6	15.5	
T6	1	

3 Results and Discussion

3.1 RF performance

The various simulation results for proposed antenna wereobtained using HFSS v13 simulation tool. The impedance characteristics for both antenna designs (Design 1 and Design 2) in terms of VSWR are reflected in Fig. 2. Both antennas offered impedance bandwidth of 3.1-10.6 GHz (UWB technology) having VSWR <2. Also, by making use of resonant structures (inverted-L slot: Design 1; C-slot: Design 2), a notch was successfully obtained at WLAN band (5.2 GHz-5.8 GHz) without demeaning the bandwidth of UWB antenna, as seen from Fig. 2. It can also be implied that an almost comparable band-notch trait was achieved with proposed antenna design which attest the competence of the designed low profile antenna.

The sensitivity of designed antenna (Design 1) was further improved by optimizing the design parameters such as W4, W5, Θ and H, as illustrated in Fig. 3.

The competence of the proposed antenna design can also be verified from the gain curve as shown in Fig. 4 (a). It can be examined from Fig. 4 (a) that, the gain values for both designs remained fairly high in order of 3 dBi to7 dBi within the UWB range; except for WLAN notch-band where its value dipped down to almost -3 dBi reflecting the notch characteristic. The group delay curve is represented in Fig. 4 (b). It can be deduced from Fig. 4 (b) that the phase response (group delay) remained appreciably constant with values around 1 ns in the UWB range (desired for pulse communication used in UWB technology), except for notch-band (WLAN) where the group delay value abruptly raised to around 4 ns. Also, a comparatively better performance of proposed antenna can be visualized from Fig. 4 (b).

3.2 Radiation pattern and current distribution performance

The performance of both antenna designs in terms of radiation pattern is demonstrated in Fig. 5. For

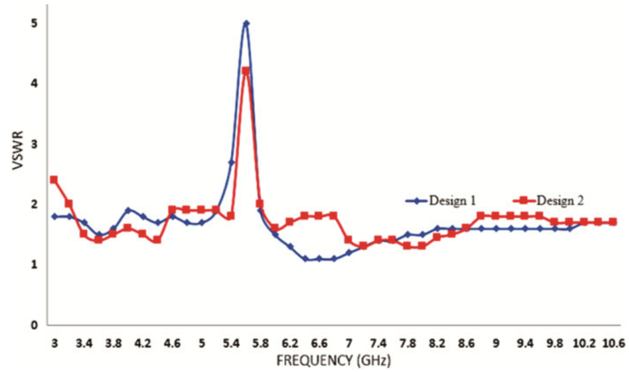

Fig. 2 — VSWR comparison of Design 1, and Design 2.

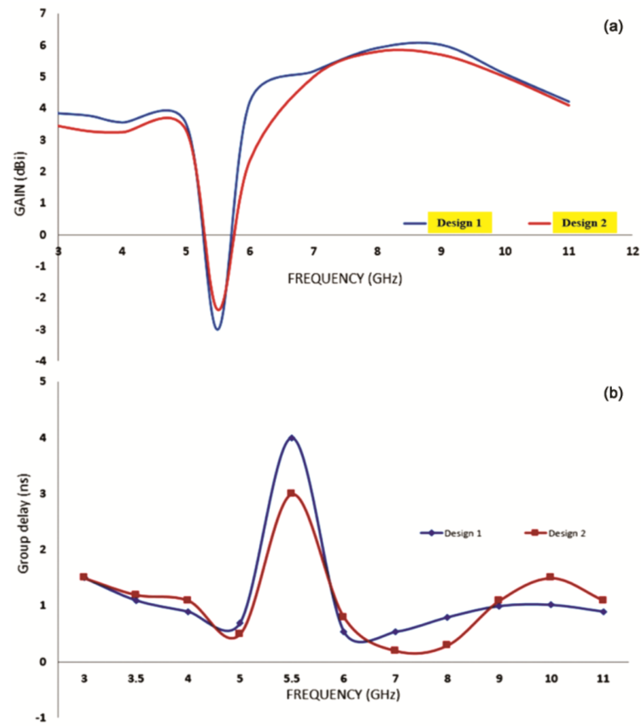

Fig. 4 — Design comparison in terms of (a) gain, (b) group delay.

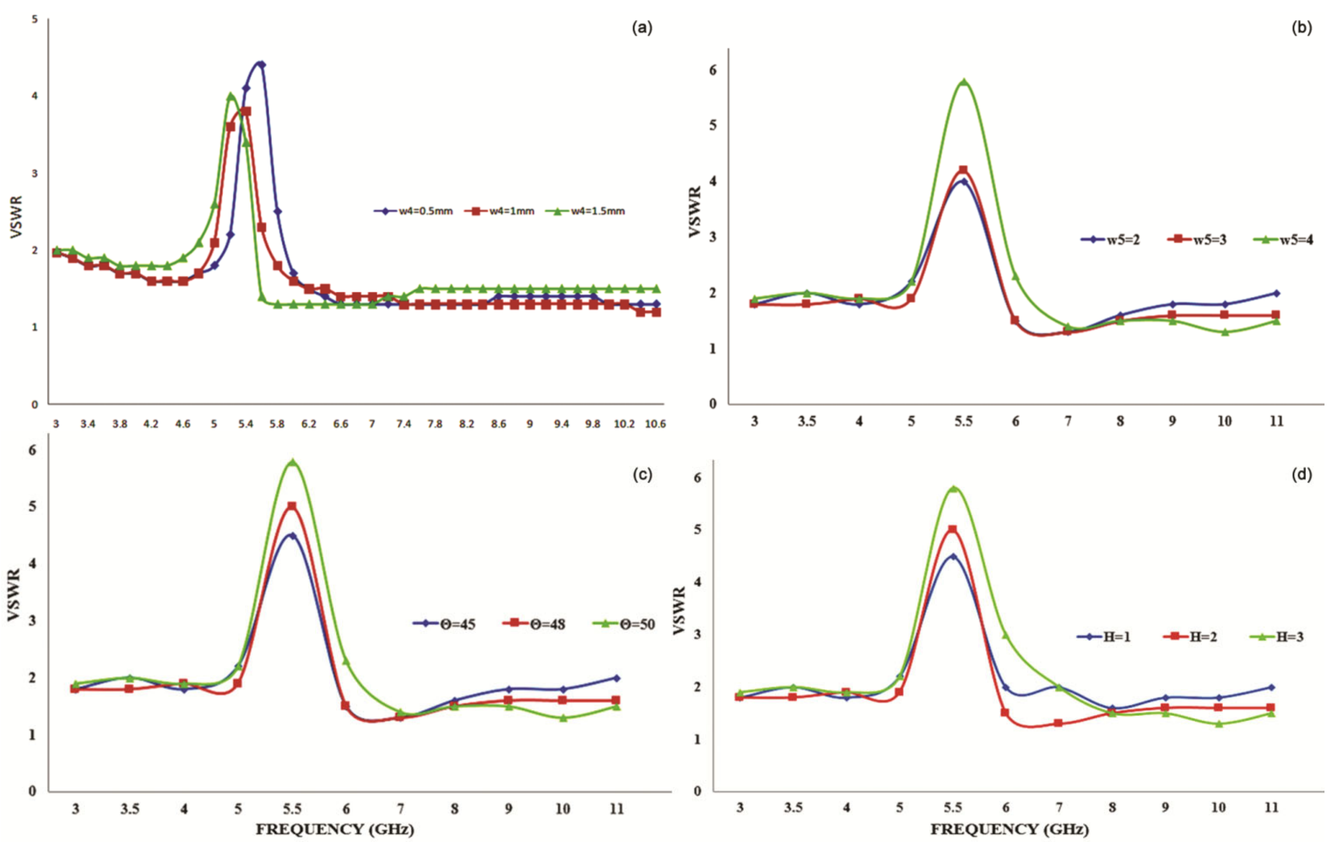

Fig. 3 — VSWR for Design 1 with variation in (a) W4, (b) W5, (c) Θ, and (d) H.

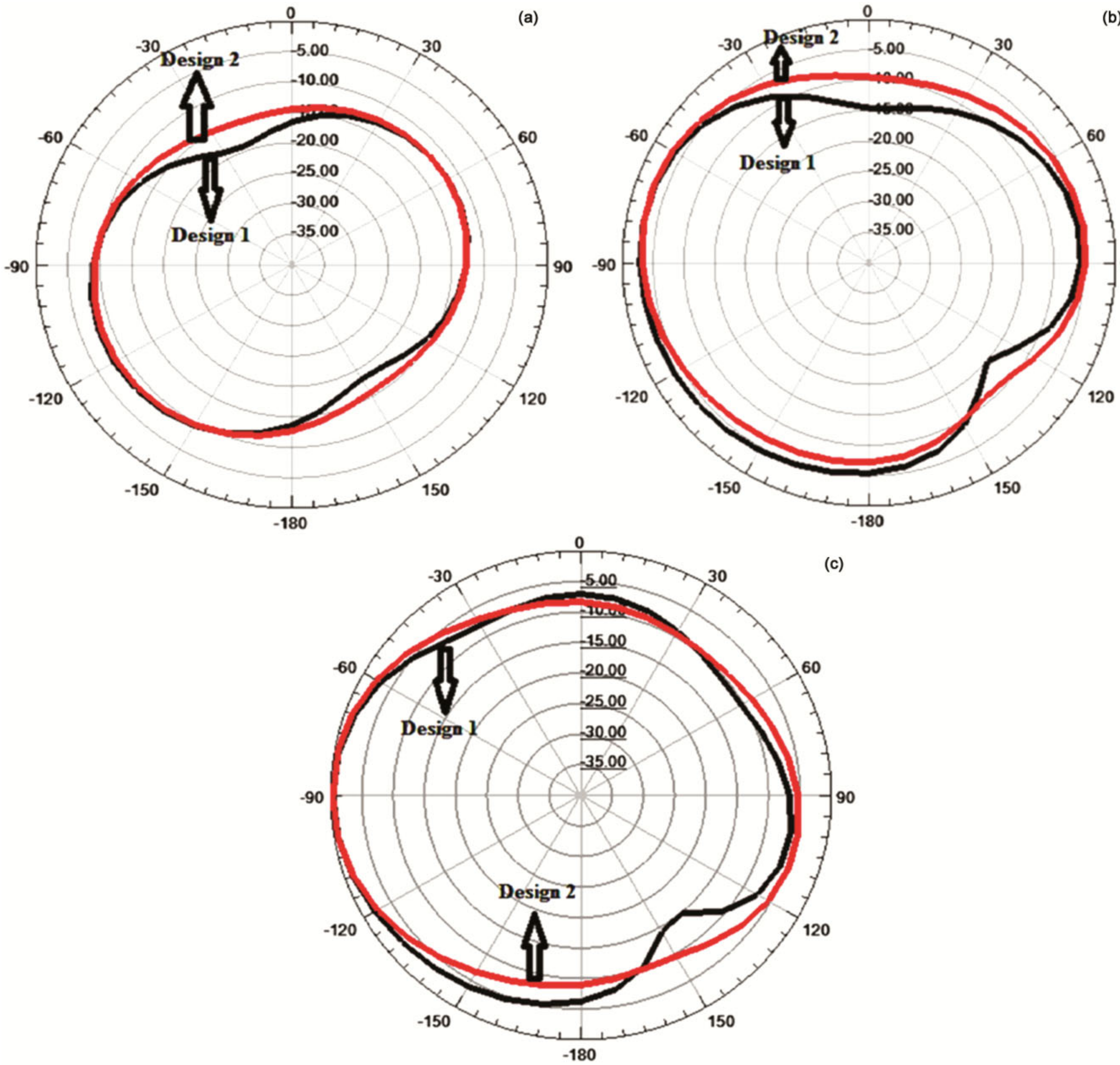

Fig. 5 — Far-field radiation patterns for Design 1 and Design 2 (a) at 3.5 GHz, (b) at 8 GHz, and (c) at 10 GHz.

briefness, only three E-plane radiation patterns are presented at three variable frequencies (3.5 GHz, 8 GHz and 10 GHz). It can be examined that the radiation patterns for both designs remained reasonably omni-directional which was comparable to a conventional wideband monopole antenna. This reassures the efficiency of designed antenna for UWB applications.

The current distributions for both designs, at three variant frequencies (3.5 GHz, 5.5 GHz and 8 GHz), are illustrated in Figs (6 and 7) respectively. It can be noted that for frequencies in non-notched UWB (3.5 GHz and 8 GHz), the pattern of current distribution were prominently concentrated along the transmission line and rectangular slot in ground plane and negligible current distribution was present across the resonant structures (inverted-L slot and C-slot), showing high impedance matching feature at these frequencies that was needed for UWB technology. Conversely, for 5.5 GHz frequency the current distribution was completely restricted to areas of resonant structures for both Design 1 and Design 2 (namely inverted-L slot and C-slot respectively). Such current distribution caused destructive interference, thereby, resulting in non-responsiveness of designed antenna at this frequency. The impedance also varied abruptly causing large back reflections and the 5.5 GHz frequency was notched successfully without affecting impedance matching at other frequencies.

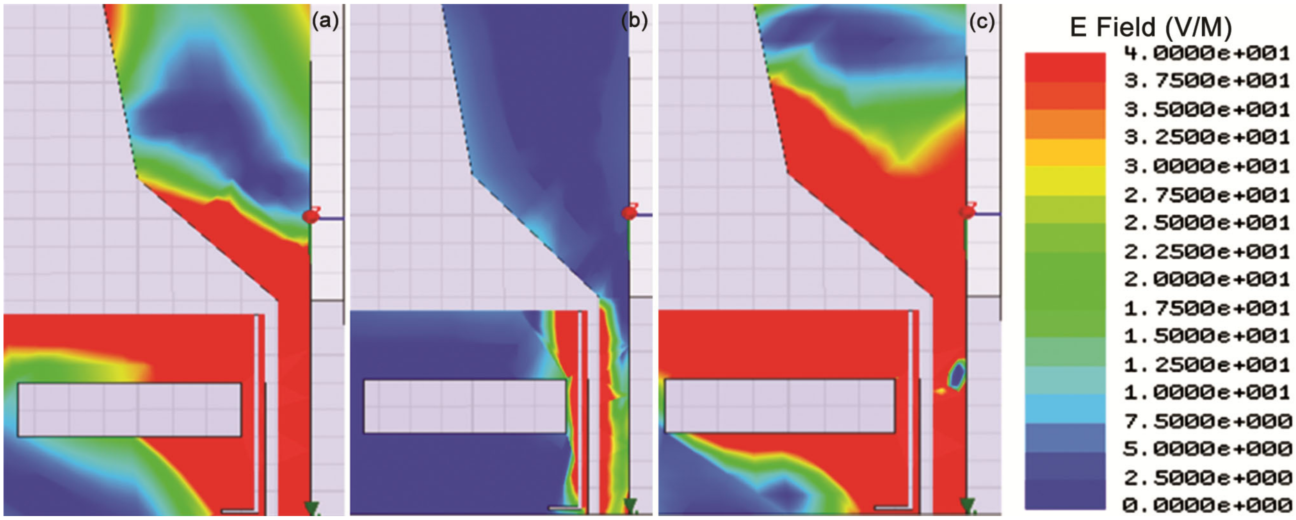

Fig. 6 — Current distributions for Design 1 (a) at 3.5 GHz, (b) at 5.5 GHz, and (c) at 8 GHz.

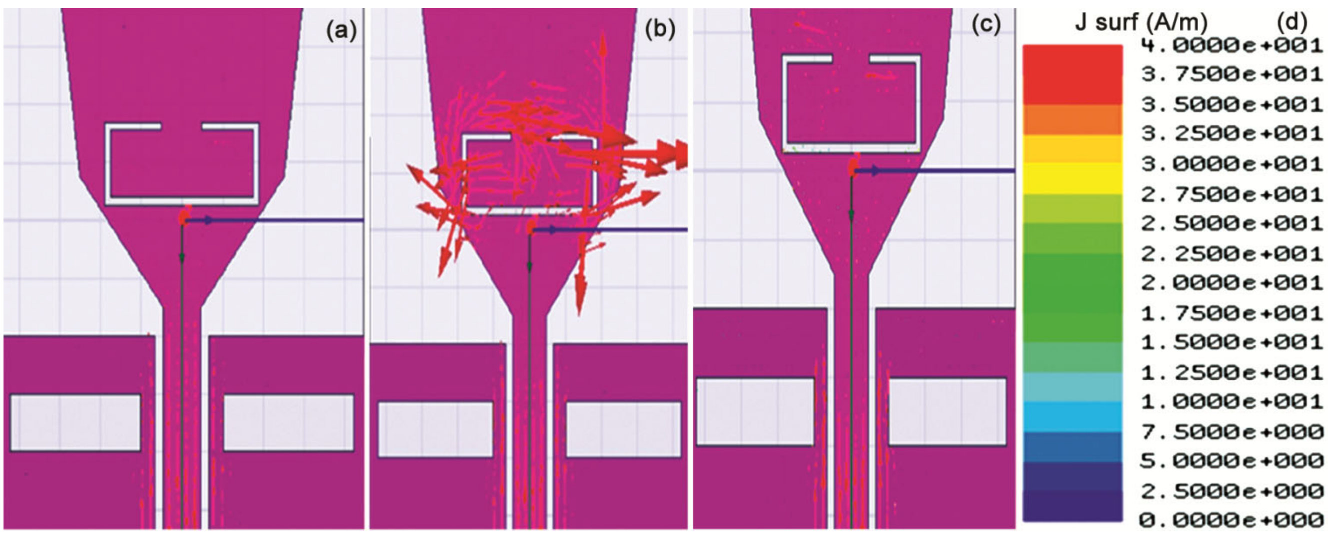

Fig. 7 — Current distributions for Design 2 (a) at 3.5 GHz, (b) at 5.5 GHz, and (c) at 8 GHz.

4 Conclusion

An extremely compact UWB antenna design with a frequency notch at the WLAN band (5.2 - 5.8 GHz) has been presented in this paper. Two antenna designs have been considered, one of proposed antenna ($19\times9\times1.6$ mm^3), and another of comparative antenna ($30\times26\times1.6$ mm^3) that has almost twice the profile size of the proposed antenna and has been used for highlighting the performance characteristics of the proposed antenna. UWB characteristics have been obtained in both designs by trimming the lower edges of the radiating patch. Unwanted frequencies (WLAN band) have been notched by utilizing resonant structures (inverted-L slot in proposed antenna and C-slot in comparative antenna). For improving the impedance bandwidth of the designed antenna, the ground plane has been engraved with a rectangular slot, and for enhancing the sensitivity of the antenna design, various design parameters (W4, W5, Θ, and H) has been optimized on HFSS v13 platform. The simulation results obtained in terms of VSWR (signifying impedance bandwidth), gain, group delay, current distribution, and radiation pattern have verified the effectiveness of the designed antenna as a UWB antenna with a successful notch at desired WLAN band. Comparative analysis of simulation results for both antenna designs have shown that almost comparable results have been obtained with much compact size of the proposed antenna. The designed antenna can be used for both ultra-wideband and narrowband applications.

Acknowledgement

The work presented in this paper was carried out under the guidance of my mentor Dr. Pawan Kumar Singh. A special gratitude is offered to Dr. Tejbir Singh for his valuable suggestions throughout the work.

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