A Novel Ultra-wideband Planar Antenna with Rejection of WLAN and ITU Bands

A. Subbarao and S. Raghavan

Department of Electronics and Communication Engineering
National Institute of Technology, Tiruchirappalli, 620015, India
subbarao_ka@yahoo.com and raghavan@nitt.edu

Abstract **─** A novel compact coplanar waveguide-fed ultra wideband (UWB) antenna is proposed with dual band-notched characteristics. The antenna consists of novel tapered patch and is printed on FR4 substrate with compact size of 18×23 mm^2. By inserting a novel parasitic strip in trapezoidal slot and a pair of L-shaped slots in metallic ground, dual band-notched characteristics are obtained. Parametric analysis is performed by studying the effects of geometrical parameters of antenna on various characteristics. The antenna operates from 3.1 GHz to 11.6 GHz with dual-notched bands of 5.1 GHz-6.2 GHz and 8 GHz-8.4 GHz to avoid potential interference from WLAN and ITU bands, respectively. The antenna is analyzed in both frequency and time domains. The measured results show that the antenna has stable radiation patterns, consistent gain over the entire operating band. The time domain group delay of antenna indicates good linear phase response. The main features that make the antenna suitable for UWB applications are compactness, simple configuration, and stable radiation patterns.

Index Terms **─** Dual notched bands, gain, parasitic strip, radiation pattern, trapezoidal slot, and UWB.

I. INTRODUCTION

UWB technology has become popular due to various features such as high speed data transmission of 100 Mbps to 1 Gbps and wide bandwidth. Federal communication commission (FCC) has assigned a frequency band from 3.1 GHz to 10.6 GHz for commercial UWB applications. Hence, design of UWB systems has become more attractive in both industry and academia. UWB antenna is a key component in UWB systems. The UWB antenna is popular for future applications due to ease of fabrication, compact size, and stable radiation characteristics. Small size antennas [1, 2] are required in industrial RF and microwave devices. Conventional compact microstrip antennas with ground plane exist for UWB applications. In microstrip antennas, small ground plane is present on substrate, which is on the opposite side of the patch for size reduction. The surface current on small ground plane is considerable and affects the performance of the antenna [3]. This can be solved by using coplanar waveguide (CPW) with patches such as elliptical [4], crescent [5] because feed structure, radiating patch and ground plane are constructed on the same side of the substrate and single metallic layer is present. CPW has less dispersion, large bandwidth, and low radiation leakage than microstrip line. CPW also offers low power consumption, low profile, and high data speed for transmitter. Since planar slot antennas [6-10] have attractive features such as ease of fabrication, small size and wide bandwidth, they have become popular for the design of UWB antennas. These slot antennas can be easily integrated with monolithic microwave integrated circuits (MMIC) and printed circuit boards. A non planar UWB tapered resistive horn antenna [11] is available in literature, which provides stable beam width.

UWB antenna faces serious interference problems. Several narrow band communication systems such as IEEE 802.11a wireless local area network (WLAN) bands (5.15 GHz - 5.35 GHz and 5.725 GHz - 5.825 GHz) and 8 GHz ITU band (8.025 GHz - 8.4 GHz) overlap with UWB. Hence, it is necessary to design UWB antennas with dual

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band-notched characteristics to avoid interference between WLAN, ITU [12] bands and UWB. To meet these requirements of the UWB antenna, there are several band notched techniques like inserting arc-slot [2], square slot [13], pi-slot [14] in radiating structure, attaching bar [15], and placing parasitic elements near printed monopole [16, 17]. UWB antenna has various applications in ground penetrating radar, indoor multimedia communications, medical imaging, and radio frequency identification.

In this paper, a compact UWB slot antenna with dual band-notched characteristics is presented. By inserting a novel parasitic strip in the trapezoidal slot and a pair of L-shaped slots in the metallic ground, the interfering WLAN and ITU bands can be rejected, respectively. The configuration of the UWB antenna is introduced in section II. The effects of different geometrical parameters on the antenna are investigated and discussed in section III. The measured radiation patterns and gain of the antenna are presented in section IV. The group delay, which represents linear phase response, is analyzed. Time domain characteristics of the antenna are presented with transient behavior in section V. Section VI concludes the paper.

II. ANTENNA GEOMETRY AND DUAL BAND-NOTCHED DESIGN

The structure of the antenna is shown in Fig. 1. The antenna is printed on FR4 dielectric substrate with relative dielectric constant of ε_r = 4.4 and loss tangent of tanδ = 0.02. The antenna has tapered tuning stub at the centre, which is fed by CPW. The CPW feed has conductor width W_4 = 2 mm and dielectric height h = 2.4 mm. The CPW feed has a 50 Ω characteristic impedance and it is terminated by subminiature version A (SMA) connector. Pentagon on tapered structure indicates novel radiating patch and each side of the pentagon is 5 mm. The antenna has a compact size of 18 × 23 mm^2. It has small size when compared to [1-6, 8, 12-14, and 16-17].

A pair of L-shaped slots is inserted in the metallic ground to avoid potential interference from ITU band as shown in Fig. 1. When the length of the each L-slot is nearly equal to ¼ th of the guided wavelength λ_{g1}, the slot resonates at corresponding notch frequency $f_{ITU\text{-}notch}$ and acts like short circuit in parallel with input impedance of the antenna. This leads the pair of L-slots to behave like resonant structure and provides band-notched characteristic for proposed antenna by rejecting the band from 8 GHz to 8.4 GHz.

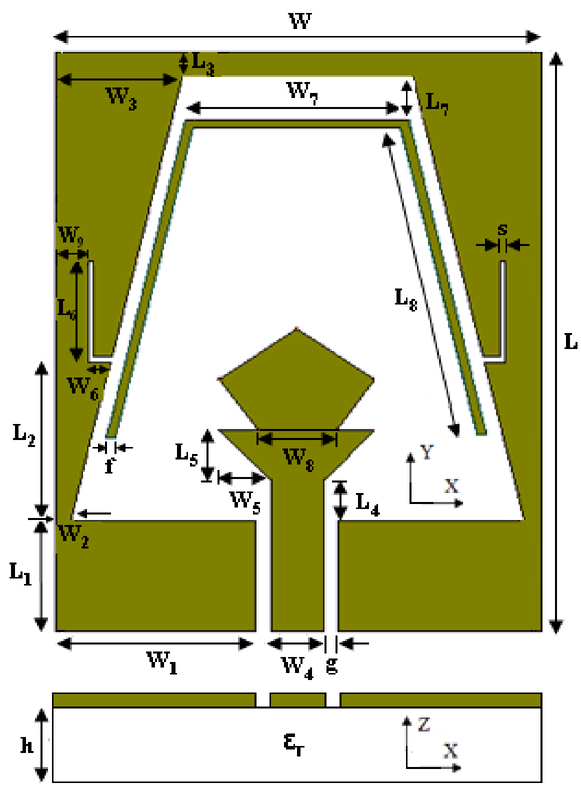

Fig. 1. Geometry of the proposed UWB antenna.

The total length of each L shaped slot is obtained by,

$$L_{L-slot} = \frac{\lambda_{g1}}{4} = \frac{c}{4 f_{ITU-notch}\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

where λ_{g1} is the guided wavelength corresponding to the notch frequency of $f_{ITU\text{-}notch}$, c is the speed of light, and ε_r is the dielectric constant of FR4 substrate. Initially, a pair of L-slots is designed to resonate at $f_{ITU\text{-}notch}$ = 8 GHz by taking the total length of each L-slot nearly equal to $L_{L\text{-}slot}$ specified by equation (1). Practically, total length $L_{L\text{-}slot}$ of each L-slot is taken as 0.22 λ_{g1} and is represented in geometrical parameters of the antenna as $L_{L\text{-}slot} = W_6 + L_6$. Hence, the pair of L-slots are responsible for rejection of 8 GHz - 8.4 GHz band. The ITU band-notched characteristic is obtained by properly tuning geometrical parameters of the antenna around each L-slot.

Another band notched characteristic is obtained by inserting novel parasitic strip in the trapezoidal slot of the antenna to avoid interference from WLAN band. The total length of the parasitic strip is given by equation (2)

$$L_{strip} = \lambda_{g2} = \frac{c}{f_{strip-notch}\sqrt{\frac{\varepsilon_r + 1}{2}}}, \quad (2)$$

where λ_{g2} is the guided wavelength corresponding to the notch frequency of $f_{strip\text{-}notch}$. In this design, $f_{strip\text{-}notch}$ is 5.5 GHz. The total length L_{strip} is practically represented in parameters of the antenna as L_{strip} = $W_7 + 2\ L_8$. When L_{strip} is equal to λ_{g2} as specified in equation (2), destructive interference takes place, which makes antenna non responsive in the 5.1 GHz - 6.2 GHz band. Hence, WLAN band is rejected.

Method of moments based IE3D electromagnetic solver is used to optimize the antenna. The genetic algorithm in the solver is used to obtain the optimized values for various parameters of the proposed antenna. The optimized values of the proposed antenna are W = 18 mm, W_1 = 7.4 mm, W_2 = 0.5 mm, W_3 = 4.7 mm, W_4 = 2 mm, W_5 = 2 mm, W_6 = 0.82 mm, W_7 = 9 mm, W_8 = 5 mm, W_9 = 1 mm, L = 23 mm, L_1 = 4.4 mm, L_2 = 6.2 mm, L_3 = 0.5 mm, L_4 = 1.6 mm, L_5 = 2 mm, L_6 = 4 mm, L_7 = 2.2 mm, L_8 = 12.5 mm, g = 0.6 mm, s = 0.2 mm, and f = 0.3 mm. The voltage standing wave ratio (VSWR) of the proposed antenna is measured with Agilent E8362B network analyzer. The behavior of the antenna is specified with VSWR curve by considering lumped load at the end of the feed line. The comparison between the simulated and measured VSWR responses of the antenna is shown in Fig. 2. Both IE3D and finite element method based high frequency structure simulator (HFSS) are used to obtain VSWR curves. There is reasonable agreement between the simulated and measured VSWR responses except that there is slight difference between the curves beyond 10 GHz. The difference between the measured and simulated curves is mainly due to manufacturing tolerance of the radiating patch and imperfect soldering at the junction of the SMA connector to CPW line. The measured VSWR indicates that the impedance bandwidth of the antenna for VSWR < 2 is from 3.1 GHz to 11.6 GHz with dual notched bands of 5.1 GHz - 6.2 GHz and 8 GHz - 8.4 GHz. The measured antenna has three resonant frequencies 3.78 GHz, 4.98 GHz, and 7.2 GHz. The overlapping between these resonant frequencies leads to ultra-wide bandwidth. Good impedance matching and radiation characteristic of the antenna are obtained by proper selection for the dimensions of the novel patch and surrounding ground plane. The photograph of the fabricated antenna is shown in Fig. 3.

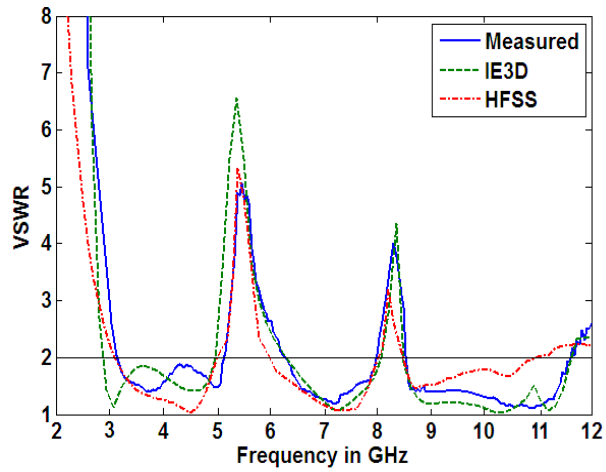

Fig. 2. Simulated and measured VSWR of the proposed antenna.

Fig. 3. Photograph of the fabricated antenna.

III. PARAMETRIC ANALYSIS

The effects of different geometrical parameters on various characteristics of the antenna are studied for the proposed antenna. This helps to design antenna with ultra-wide bandwidth. The performance of the antenna is analyzed with IE3D electromagnetic solver. The analysis is obtained by varying one parameter and keeping the other parameters constant. The effects of most critical geometrical parameters of the antenna on different characteristics are presented here.

A. Effect of intrusion depth L_4

The intrusion depth L_4 is the most critical parameter of the antenna. This parameter leads the problem of impedance mismatching when L_4 is 0.6 mm as shown in Fig. 4. This impedance mismatching is mainly due to capacitive and inductive effects due to improper coupling between the radiating patch and the ground plane. This parameter was optimized to provide proper coupling from feed line to patch. As L_4 increases from 0.6 mm, the impedance matching is improved and the first resonant frequency almost remains constant. The second resonant frequency shifts left and the third resonating frequency also changes. The impedance bandwidth also changes. At L_4 = 2.6 mm, the bandwidth of the notched WLAN band is 5.1 GHz - 6.7 GHz, which is not desired. The antenna has good impedance matching and desired notched WLAN bandwidth of 5.1 GHz - 6.2 GHz at optimized value of L_4 = 1.6 mm.

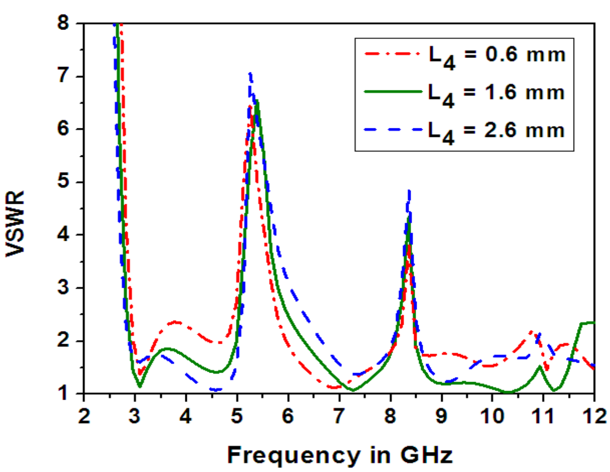

Fig. 4. Simulated VSWR curves of the antenna for different intrusion depths L_4.

B. Effect of the height L_6 of the L-slot

If L-slot height L_6 is increased from 3.5 mm to 4.5 mm, the total length of L-slot increases and the notch frequency $f_{ITU\text{-}notch}$ of ITU band decreases from 8.6 GHz to 7.9 GHz as shown in Fig. 5. The main reason is that the notch frequency $f_{ITU\text{-}notch}$ is inversely proportional to the total length of the slot $L_{L\text{-}slot}$ according to equation (1). When L_6 is 4 mm, the pair of L-slots resonates at notch frequency 8.3 GHz, which is desirable. At this frequency, ITU band is fully rejected. As L_6 changes from 4 mm, the ITU band is not fully avoided as shown in Fig. 5. The notch frequency of WLAN band is little influenced due slight interaction between L-shaped slots and parasitic strip. Hence, the notch frequency of ITU band is controlled by the slot height L_6.

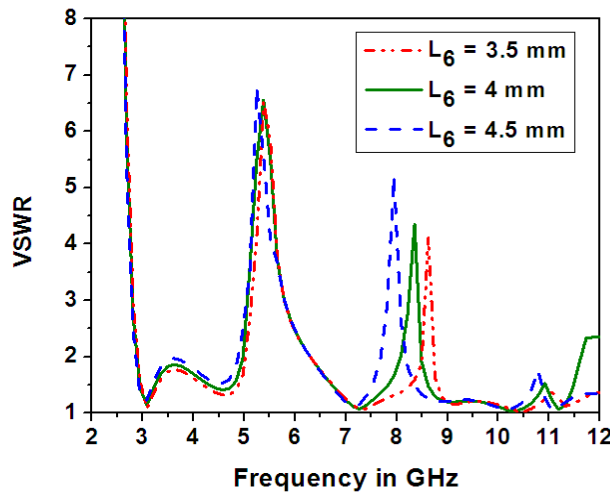

Fig. 5. Simulated VSWR curves of the antenna for different heights L_6 of the L-shaped slot.

C. Effect of the height L_8 of the parasitic strip

The parasitic strip length L_8 has significant effect on the notch frequency $f_{strip\text{-}notch}$ of WLAN band. As L_8 decreases from 13.5 mm to 11.5 mm, the total length of the strip decreases and the corresponding notch frequency $f_{strip\text{-}notch}$ increases from 4.98 GHz to 5.85 GHz as shown in Fig. 6. The desired notch frequency 5.5 GHz of WLAN band is obtained at L_8 = 12.5 mm. The notch frequency of ITU band is slightly affected. Hence, this parameter plays important role in obtaining the desired notch frequency to reject the interference from the WLAN band.

IV. RADITION PATTERNS AND GAIN

The radiation patterns of the proposed antenna are measured in anechoic chamber using double ridge horn as transmitting antenna and the proposed UWB antenna as the receiving antenna. Figures 7 and 8 present the radiation patterns of the proposed UWB antenna in both E- and H-planes at the measured resonant frequencies 3.78 GHz, 4.98 GHz, and 7.2 GHz. In the E-plane, the antenna has a bi-directional radiation patterns at all resonant frequencies. In the H-plane, the antenna has nearly omni-directional radiation patterns, which indicates that it can receive the signals from all directions.

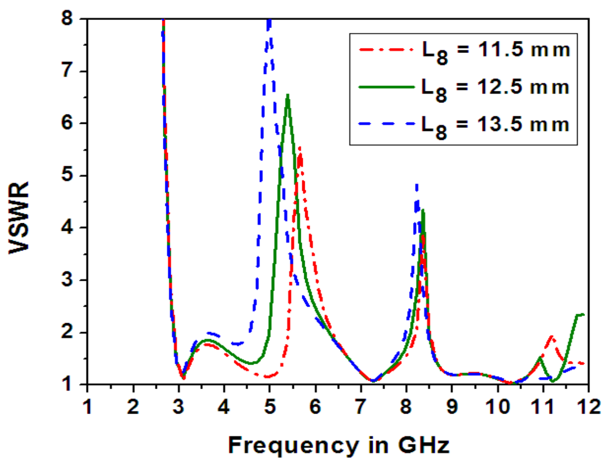

Fig. 6. Simulated VSWR of the antenna with different heights L_8 of the strip.

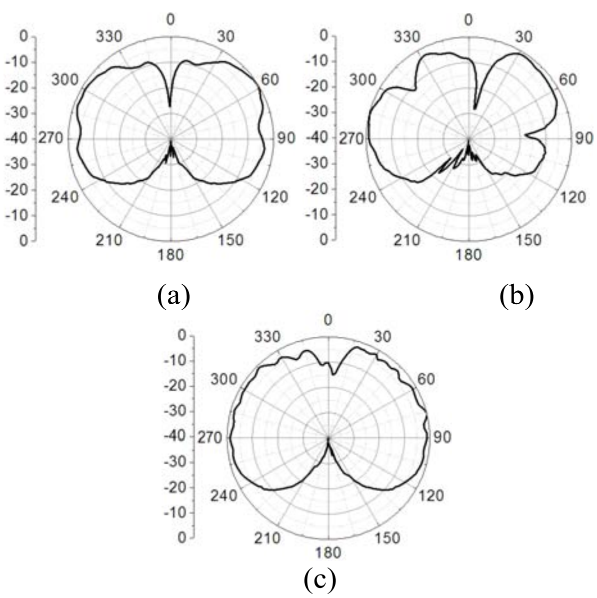

Fig. 7. Measured radiation patterns of the proposed antenna in the E-plane at (a) 3.78 GHz, (b) 4.98 GHz, and (c) 7.2 GHz.

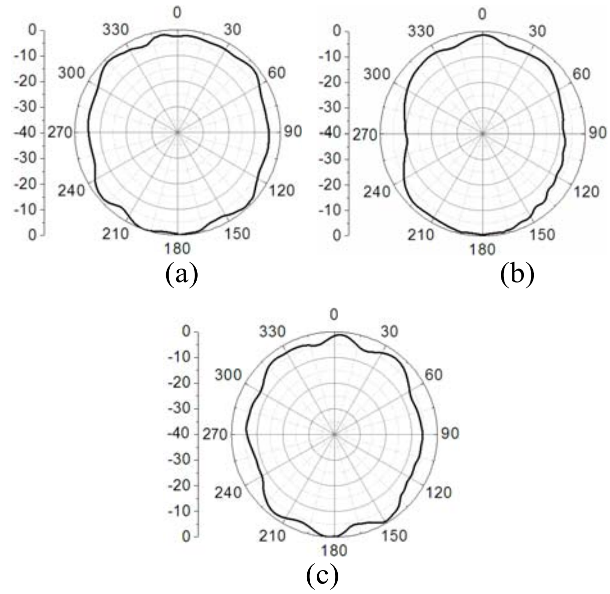

Fig. 8. Measured radiation patterns of the proposed antenna in the H-plane at (a) 3.78 GHz, (b) 4.98 GHz, and (c) 7.2 GHz.

Figure 9 represents measured gain of the antenna against frequency. The antenna has consistent gain that varies between 2.1 dBi to 4.2 dBi in the operating band. The antenna gain falls sharply to -4 dBi in WLAN band and it falls to -3.3 dBi in the ITU band. Hence, the gain curve is in good agreement with the VSWR curve, which indicates the rejection WLAN and ITU bands.

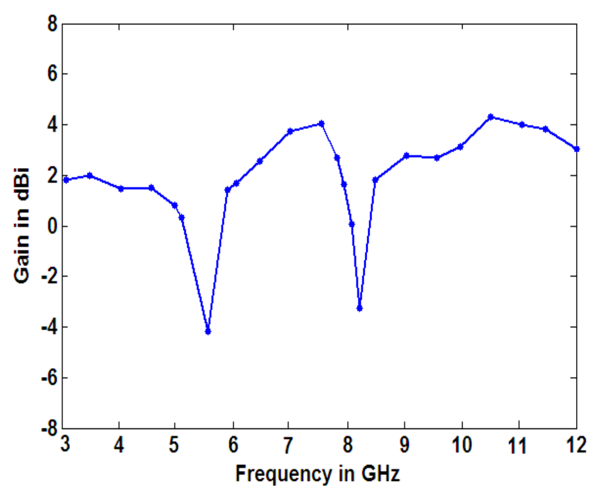

Fig. 9. Measured gain of the proposed antenna.

V. TIME DOMAIN ANALYSIS

Even though UWB antenna has large bandwidth, it does not guarantee good pulse handling capability. To analyze this, time domain response of the antenna is required. Since group delay represents far-field phase linearity, it indicates the quality of the UWB pulse. Hence, group delay measurement is performed by placing two identical antennas at a distance of 20 cm in the far-field region. The antennas are placed in face to face orientation. The time domain group delay characteristic is shown in Fig. 10. The graph shows that the group delay variation is less than one nano second in UWB except for the notched band. This indicates linear phase response and good pulse handling capability for the proposed antenna. Hence, the antenna is useful in the UWB impulse radio and microwave imaging.

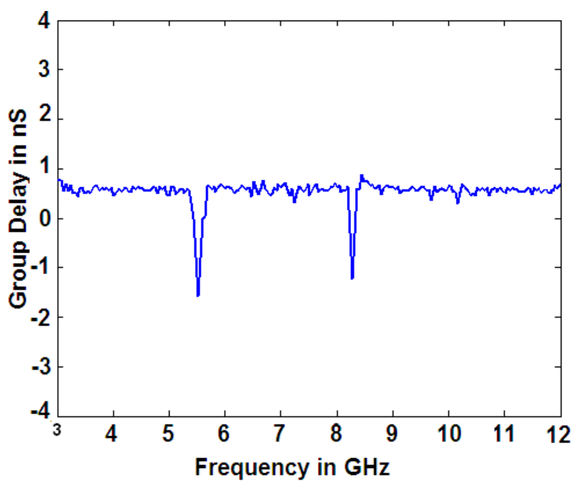

Fig. 10. Measured group delay of the proposed antenna.

Since information is transmitted through short pulses in the UWB systems, it is important to study the behavior of the transmitted pulse. The transient response of the antenna is obtained by using transfer function *H(ω)* [18] of the system. The channel is considered as linear time invariant (LTI) system for the transmission and reception of narrow pulses. The transmission co-efficient S_{21} is measured when two identical antennas are placed in face to face orientation in the far field. The transfer function *H(ω)* is computed using S_{21} parameter of the antenna as given by equation (3),

$$H(\omega)=\sqrt{\frac{2\pi R c S_{21}(\omega)e^{j\omega R/c}}{j\omega}} \qquad (3)$$

where c is the speed of light, ω is the angular frequency and R is the distance between two identical antennas. The co-sine modulated pulse is taken as input pulse with pulse width T = 228 picoseconds, centre frequency f_c = 6.85 GHz and an amplitude factor A = 1. Figure 11 shows that the proposed antenna fulfills the requirement of UWB indoor emission mask specified by the FCC. The time domain input pulse *i(t)* is represented by equation (4),

$$i(t)=A\cos(2\pi f_c t).e^{(-t/T)^2}\ . \qquad (4)$$

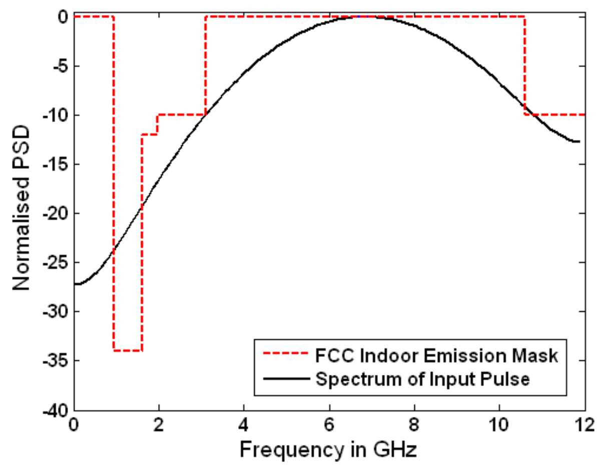

Fig. 11. FCC indoor emission mask and spectrum of the input pulse.

The received output pulse *o(t)* is generated by the inverse Fourier transform of the product of *H(ω)* and the spectrum of the input signal *I(ω)* and is given by the novel equation shown below,

$$o(t) = F^{-1}\,(H(\omega).I(\omega)). \qquad (5)$$

The time domain input and output pulses are displayed in Fig. 12. The slight ringing effect in the received pulse is mainly due to the transmission characteristics of the system. The received pulse indicates that the antenna has less pulse distortion and good time domain response. Hence, the antenna is useful for UWB communications.

VI. CONCLUSION

A novel compact UWB antenna is presented with dual band-notched characteristics. By inserting a novel parasitic strip in the trapezoidal slot and a pair of L-shaped slots in the metallic ground, the interference from WLAN and ITU bands are avoided. The antenna has impedance bandwidth from 3.1 GHz to 11.6 GHz with rejected bands of 5.1 GHz - 6.2 GHz and 8 GHz - 8.4 GHz. The effect of various parameters on the impedance bandwidth and impedance matching are investigated. The antenna has consistent gain and stable radiation patterns. The time domain group delay indicates good pulse handling capacity. The transient response of the presented antenna satisfies indoor emission criteria of the FCC. The antenna can be easily integrated with RF and microwave circuits, which makes the antenna suitable for UWB applications.

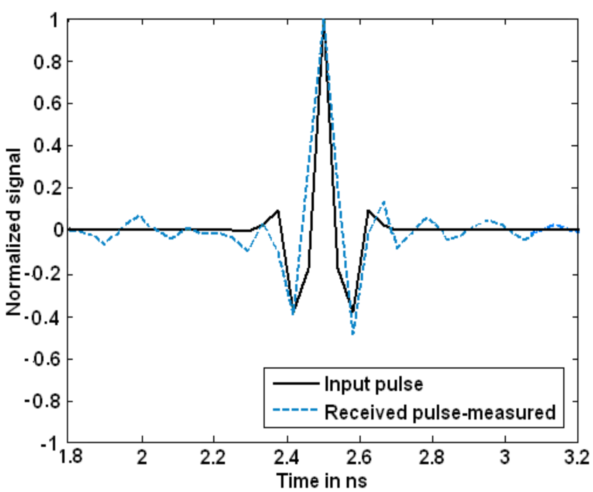

Fig. 12. Comparison of the input and output pulses.

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A. Subbarao received the B.Tech. degree in Electronics and Communication Engineering from Nagarjuna University and M.Tech. degree in Instrumentation and control from JNTU University. He obtained his Ph.D. degree in the area of design and analysis of Ultra wide band Antennas. He has 10 years of teaching experience in a reputed engineering college. His research interest includes microwave/millimeter-wave circuits and devices, microwave integrated circuits, planar antennas, EMI/EMC, computational electromagnetics. He has published 24 research papers in various national, international journals and conferences. He is a student member in the IEICE.

S. Raghavan has 30 years of experience in teaching and research at National Institute of Technology, Tiruchirappalli, India as a Senior Professor. He completed his doctoral programme in the field of Microwave Integrated Circuits from I.I.T., Delhi, India under the guidance of Prof. Bharathi Bhat and Prof. S. K. Koul. He is a Senior Member of IEEE in MTT and EMBS, Life Fellow in BES, Fellow in IETE and IE, Life member in ISSS, MRSI, ISTE, EMC/EMI, IELTS and ILA, referee for MTT journal. His research interest includes microwave/millimeter-wave integrated circuits, antennas and microwaves in biomedical applications. He has contributed more than 40 international, national journal papers and 100 papers in international conferences. He has conducted more than 10 IEEE pre-conference tutorials.