A New UWB Slot Antenna with Rejection of WiMax and WLAN Bands

J. William and R. Nakkeeran

Department of Electronics and Communication Engineering
Pondicherry Engineering College, Puducherry – 605 014, India
wills.susan@gmail.com, rnakeeran@pec.edu

Abstract ─ This paper presents a compact coplanar waveguide (CPW) fed ultra wideband (UWB) planar slot antenna with the characteristics of dual band rejection. The antenna consists of a rectangular slot with triangular tuning stub. The band notching of WiMax (3.2-3.8 GHz, with VSWR 68 at 3.5 GHz) is achieved by inserting a 'U' slot in the ground plane and band-notching of WLAN 802.11a (5.1-5.9 GHz, with VSWR 14 at 5.5 GHz) is obtained by embedding a 'U' type slot in the triangular tuning stub. The characteristics of the proposed antenna are studied both numerically and experimentally, and the design parameters for achieving optimal operation of the antennas are also analyzed extensively. The size of the antenna is around 28mm (L) × 21mm (W) × 1.6mm (T). The prototype of the proposed antenna is fabricated for its optimal values and tested. The VSWR, radiation pattern and gain are measured and agree well with the simulation results. The proposed antenna is simple, easy to fabricate and can be integrated into any UWB system, which can work without interference from WiMax, WLAN, and HYPERLAN/2 systems.

Index Terms ─ CPW, dual band, slot antenna, UWB.

I. INTRODUCTION

The unlicensed UWB spectrum 3.1 GHz to 10.6 GHz was released in the year 2002 by the Federal Communications Commission (FCC) for commercial purposes. UWB, a short pulse communication system, gets much attention among the researchers due to its inherent properties of low power consumption, high data rate, and simple configuration [1]. With the rapid developments of such UWB systems, a lot of attention is being given to design the UWB antennas. Designing an antenna to operate in the UWB band is quite a challenge because it has to satisfy the requirements such as ultra wide impedance bandwidth, omni directional radiation pattern, constant gain, high radiation efficiency, constant group delay, low profile, easy manufacturing, etc [2]. Interestingly, the planar slot antennas with CPW fed possess the above said features with simple structure, less radiation loss, less dispersion, and easy integration of monolithic microwave integrated circuits (MMIC) [3]. One of the major problems associated with the UWB system is the interference from the other narrow band communication systems, such as WiMax (3.3 GHz - 3.7 GHz), IEEE 802.11a (5.15 GHz - 5.35 GHz and 5.725 GHz - 5.825 GHz), and HYPERLAN/2 (5.15 GHz - 5.35 GHz and 5.47 GHz - 5.825 GHz), which are operated in the portion of UWB band.

To mitigate this effect, many antenna designs have been proposed in the literature [4-10]. Many techniques are, also, used to introduce notch band for rejecting the interference in the UWB slot antennas. It is done either by inserting half wavelength slits, stripes in the tuning stub [11], or inserting stub in the aperture connected to the ground planes [12], or inserting square ring resonator in the tuning stub [13], or inserting 'L' branches in the ground plane [14], or with complementary split ring resonator [15], or inserting strip in the slot [16]. All of the above methods are used for rejecting a single band of frequencies. However, to effectively utilize the UWB spectrum and to improve the performance of the UWB system, it is desirable to design the UWB antenna with dual band rejection. It will help to minimize the interference between the narrow band systems with the UWB system. Some methods are used to obtain the dual band rejection

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of WiMax and WLAN bands in the literature [17-22]. In this paper, a new method is proposed to obtain the dual band rejection of frequency bands for WiMax, WLAN 802.11a, and HYPERLAN/2 systems. The WiMax frequency band is rejected by inserting a half wavelength 'U' slot in the ground plane at a center frequency of 3.5 GHz, and another 'U' type half wavelength slot at a frequency of 5.5 GHz is inserted in the triangular tuning stub to reject the desired WLAN frequency band. The simulation software used for this analysis is IE3D [23].

The paper is organized as follows: Section II brings out the geometry of the antenna. Simulation results and analysis are presented in Section III. In Section IV, obtained experimental results are given. Section V concludes the paper.

II. ANTENNA GEOMETRY

The structure of the antenna is shown in Fig. 1. The antenna consists of a rectangular slot with width 'W_1' and length 'L_1'. The tuning stub comprises a triangular patch with height 'H'. The distance between the tuning stub and the feed line is 'd', 'W', and 'L' are the overall width and length of the antenna respectively. In this study, the dielectric substance (FR4) with thickness of 1.6 mm with relative permittivity of 4.4 is chosen as substrate to facilitate printed circuit board integration. The 50 Ω characteristic impedance CPW feed is designed with fixed feed line width of 2.4 mm and 0.5 mm ground gap. The proposed antenna is designed to cover the entire UWB band with dual band rejection capability. The effective length of the rectangular slot introduced in the ground plane is approximately 0.5 λ_{eff} at the desired notch center frequency of 3.5 GHz.

The length 'L_2' of the slot in the ground plane is

$$L_2 = \frac{\lambda_{\text{eff}}}{2} = \frac{c}{2f_{n1}\sqrt{\varepsilon_{eff}}}, \quad \varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2}, \tag{1}$$

where 'f_{n1}' is the centre frequency of the WiMax frequency band.

The length L_3 of the slot in the tuning stub is,

$$L_3 = \frac{\lambda_{\text{eff}}}{2} = \frac{c}{2f_{n2}\sqrt{\varepsilon_{eff}}}, \tag{2}$$

where 'f_{n2}' is the centre frequency of the WLAN frequency band.

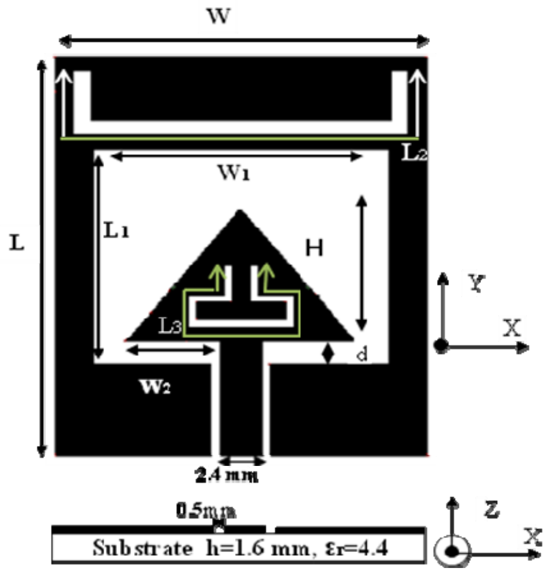


Fig. 1. Geometry of the proposed dual band notch slot antenna.

III. SIMULATED RESULTS AND ANALYSIS

The analysis and performance of the proposed antenna is explored by using IE3D for better impedance matching. The detailed parametric analysis of the UWB antenna is carried out and presented in our paper [24]. In order to evaluate the performance of the proposed antenna with dual band slots, the optimal parameter values of the antenna (without slot) suggested in that paper are considered. The final optimal parameter values of the antenna are listed in Table 1.

Table 1: Optimal parameter values of the antenna

Parameter	Description	Values
L	Length of the Antenna	28mm
W	Width of the Antenna	21mm
L_1	Length of the Slot	15mm
W_1	Width of the Slot	16.8mm
d	Feed gap Distance	1.6 mm
H	Height of the tuning stub	9.3 mm

However, to study the impact of the slots in the ground plane and in the tuning stub, the slot lengths 'L_2' and 'L_3' are varied and the simulated VSWR results of the proposed antenna is shown in Fig. 2. It clearly indicates that the rejection of dual bands of 3.2 GHz -3.8 GHz and 5.1 GHz- 5.9 GHz are achieved by inserting slots at appropriate length in the ground plane and in the tuning stub. The current distribution, gain and group delay are, also, studied.

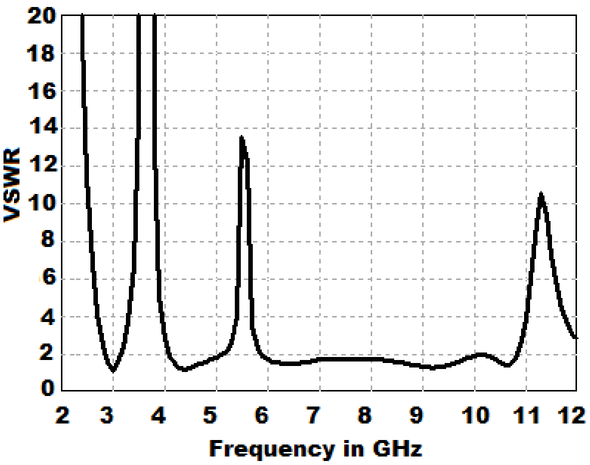


Fig. 2. Simulated VSWR of the proposed antenna.

A. Effect of 'U' slots

The effect of variation of the slot lengths is studied in this section. The length 'L_2' of the ground slot is varied by keeping tuning slot length 'L_3' as constant and the response is shown in Fig. 3. It is noticed that the variation of length 'L_2' changes the notch center frequencies of the first rejected band. The optimal value chosen for this case is 28 mm.

The response curve for different slot lengths 'L_3' in the tuning stub is shown in Fig. 4, which clearly indicates that slot length variation gives an impact on the variation of the notch center frequency for the second rejected band. The optimal value of 'L_3' is 19 mm.

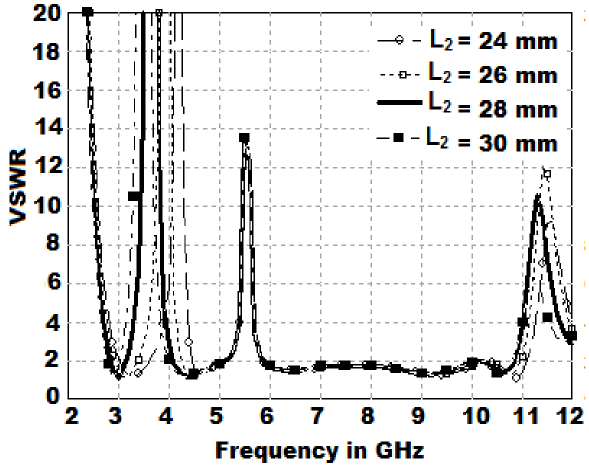


Fig. 3. Simulated VSWR for different ground slot lengths 'L_2'.

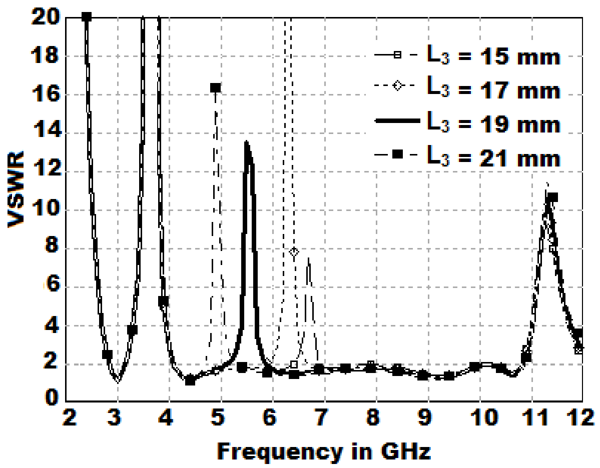


Fig. 4. Simulated VSWR for tuning stub slot lengths 'L_3'.

B. Gain

The simulated maximum gain of the proposed dual band notched UWB antenna is shown in Fig. 5. It is observed that there is a drop in gain at the notched frequencies of 3.5 GHz and 5.5 GHz.

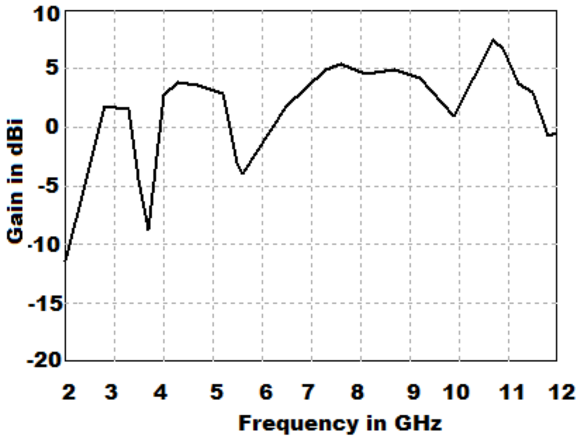
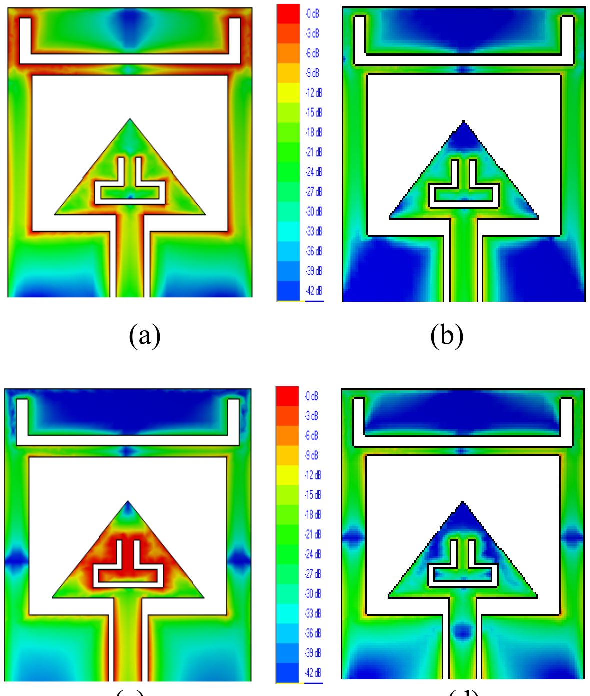


Fig. 5. Simulated maximum gain response.

C. Current distribution

The simulated current distribution at two designed notch center frequencies is presented in Fig. 6; as shown in this figure, the current distribution, at a frequency of 3.5 GHz, is mainly around the slot in the ground plane. This current distribution around the slot in the ground plane, which gives destructive disturbance to the radiating slot current distribution, is responsible for the notch in the particular frequency band.

Similarly at the notch center frequency of 5.5 GHz, the current distribution of the radiation slot is disturbed by the tuning stub slot which causes notching in the specific band. The current distribution for other operating frequencies 4.5 GHz and 9 GHz are, also, plotted, which confirms that on these frequencies current distribution is mainly around the slot and the tuning stub which is responsible for the better radiation at these frequencies.



(a) (b)

(c) (d)

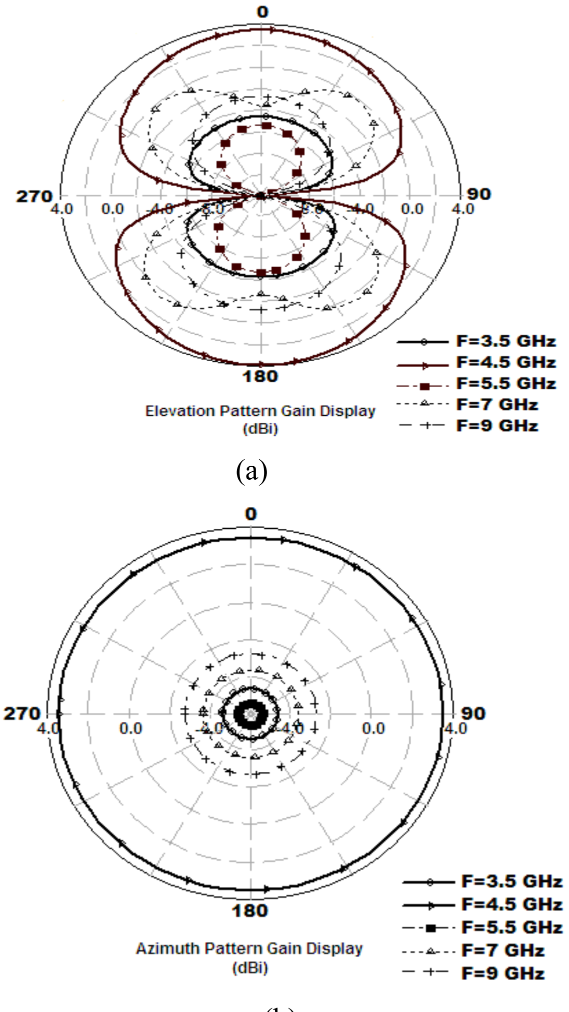
Fig. 6. Simulated current distribution at a) 3.5 GHz, b) 4.5 GHz, c) 5.5 GHz, and d) 9 GHz.

D. Radiation pattern

The radiation pattern for the E plane and H plane at frequencies 3.5, 4.5, 5.5, 7, and 9 GHz are simulated and displayed in Fig.7, which discloses that the directivity gain of the radiation pattern is reduced at the notch frequencies without affecting the shape of the radiation pattern. In the E plane, it is the bidirectional pattern and in the H plane, it is the omni directional pattern.

E. Group delay

The group delay ‘τ’ of the antenna is calculated from the phase of the computed ‘S_{21}’ by using the following equation and plotted in Fig. 8,



(a)

(b)

Fig. 7. Radiation patterns of the proposed antenna at 3.5, 4.5, 5.5,7, and 9 GHz: a) E-Plane (yz-plane) and b) H-Plane (xz-plane).

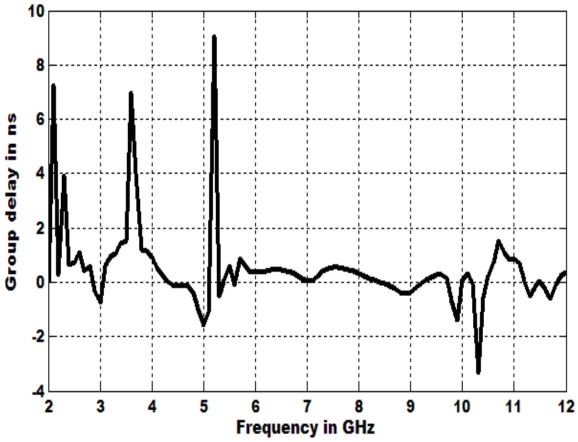


Fig. 8. Simulated group delay.

$$\tau = -\frac{d\phi}{df}, \qquad (3)$$

where 'ϕ' is phase of S_{21} in radians /sec and 'f' is frequency in GHz. From Fig. 8, it is noticed that the variation in the group delay for the antenna is around 2 ns for the frequency range from 3.1 GHz to 10.6 GHz. There is a variation in the group delay response at the notch band which is due to notch behavior of the antenna.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype of the proposed antenna shown in Fig. 1 was fabricated for its optimal values and tested, which is depicted in Fig. 9. Using Hewlett Packard Network Analyzer (HP8757D) the VSWR is measured and plotted. The gain and radiation pattern of the antenna is measured by using VNA Agilent HP 5230A.

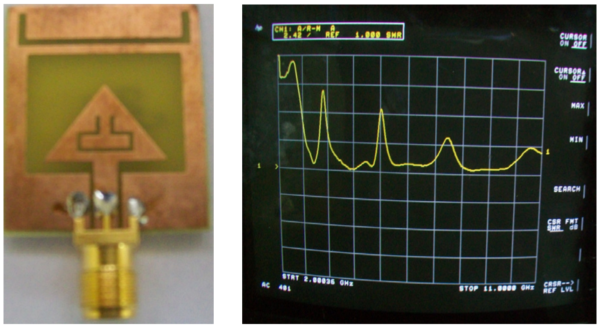


Fig. 9. Fabricated antenna and its measured results.

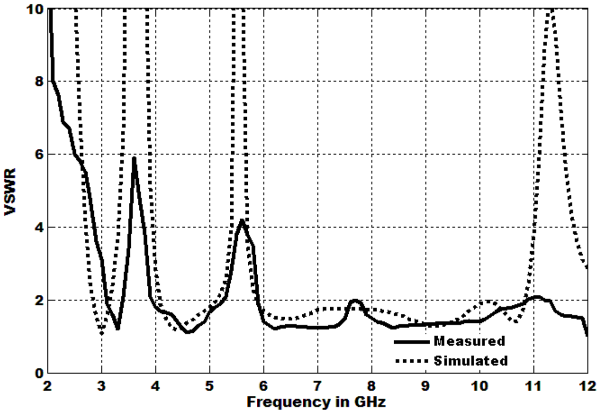


Fig. 10. VSWR comparison of the proposed antenna.

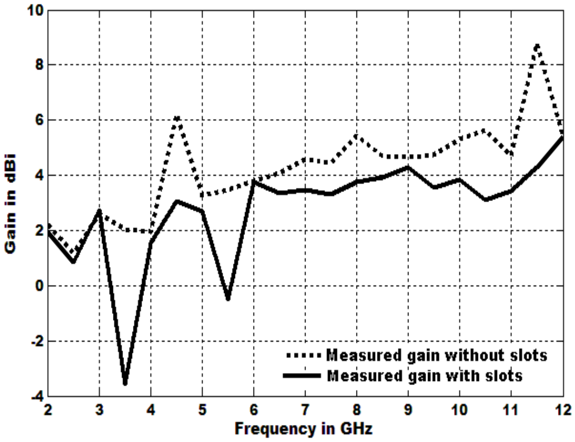
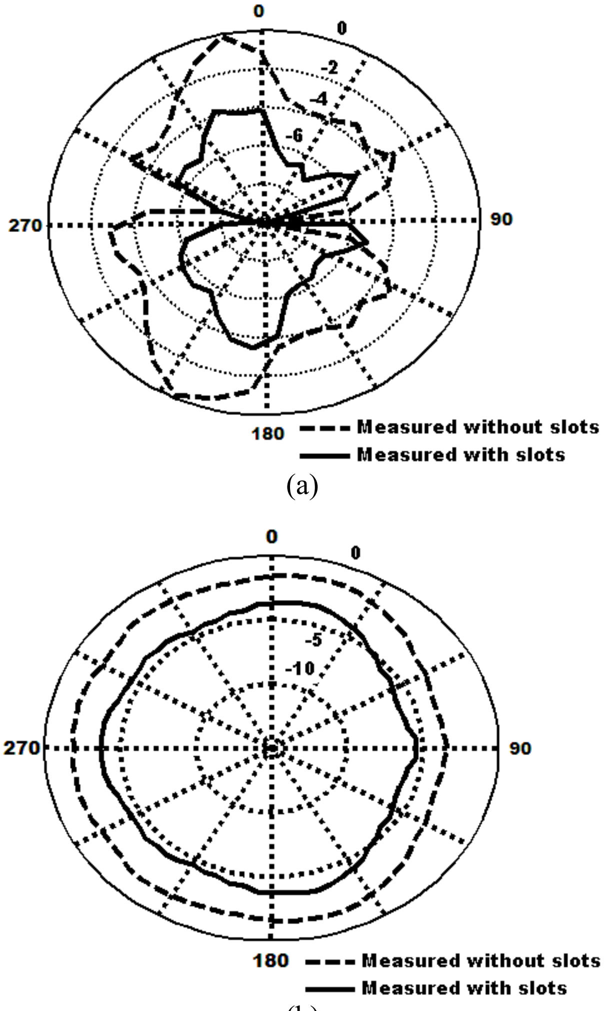


Fig. 11. Measured gain comparison.



(a)

(b)

Fig. 12. Measured radiation pattern at 6.5 GHz:
a) E-Plane (yz-plane) and b) H-Plane (xz-plane).

The measured result is shown in Fig. 10 which ensures that the measurement result is in good agreement with the simulation. The discrepancy between the measured and the simulated result seen in Fig. 10 might be due to the effect of soldering or fabrication tolerance. The simulation results have been obtained by assuming coplanar input port, whereas practically a SMA connector was used, the imperfect transition between a SMA feed to coplanar would introduce losses [25]. However, the measured bandwidth is 7.7 GHz (3.1-10.8 GHz), which is moderately close to the simulated impedance bandwidth, 8G Hz (2.8 - 10.8 GHz).

The maximum gain of the proposed antenna is measured and compared with the gain for an antenna without slot. The comparison is shown in Fig. 11, which implies that there is a variation in the gain at the notch frequency bands due to the introduction of the slots in the design.

The radiation pattern of the designed antenna at a frequency 6.5 GHz is measured and plotted in Fig. 12. The figure shows the measured radiation pattern with slot and without slots. The E plane and H plane radiation patterns with slot show a drop in gain when compared to patterns without slot; this may be due to the effect of introduction of the slots in the design.

V. CONCLUSION

In this paper, a planar UWB slot antenna with dual band rejection is presented. Dual band rejection of WiMax and WLAN is achieved by inserting slots at appropriate lengths in the ground plane and in the tuning stub. The antenna was fabricated using FR4 substrate, characterized by measuring VSWR, radiation pattern and gain, and compared with the simulation results. The measurement results are in good agreement with simulation. The proposed antenna achieves good impedance bandwidth covering frequency range from 2.8 GHz to 10.8 GHz with VSWR < 2 except the bands of WiMax and WLAN 802.11a. This type of antenna configuration would be quite useful for UWB indoor applications with no interference from WiMax, WLAN, and HYPERLAN/2 systems when they coexist with a UWB system.

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J. William received his B.E. degree in Electronics and Communication from Bharathidasan University, Tamilnadu, India, and the M. Tech. degree in Communication Systems from the National Institute of Technology (N.I.T), Trichy, India, in 1991 and 2006, respectively. He is currently working towards the Ph.D. degree at Pondicherry Engineering College, Pondicherry, India. He is a life member of ISTE and IE (I) and a member of IEICE and EurApp. His current research interest is in the area of coplanar waveguide feed antennas and printed slot antennas for UWB.

R. Nakkeeran received his B.Sc. Degree in Science and B.E. degree in Electronics and Communication Engineering from the Madras University in 1987 and 1991, respectively, and his M.E. degree in Electronics and Communication Engineering (diversification in Optical Communication) from the Anna University in 1995. He received his Ph.D. from Pondicherry University in 2004. Since 1991, he has been working in the teaching profession. Presently, he is Assistant Professor at Pondicherry Engineering College. He is a life member of IETE, ISTE, OSI, and IE (I). Also, he is a member of OSA, SPIE, and IEEE. He has published seventy five papers in National and International Conference Proceedings and Journals. He has co-authored a book, published by PHI. His areas of interest are optical communication, networks, antennas, electromagnetic fields, and wireless communication.