Frequency and Time Domain Analysis of Planar UWB Antenna with Controllable WIMAX/WLAN Band-Notched Characteristics

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***Abstract* –** An ultra wideband (UWB) printed monopole antenna with dual band stop characteristics is proposed in this article. Distinctive feature of this antenna is the notched band control ability with improved operating bandwidth. By employing modified λ/2 vertically combined T and U-shaped conductor backed plane, a sharp band notch is achieved with notched band of 3.3–3.7 GHz. In order to obtain another notched frequency band of 5.1-6 GHz, a rectangular spiral shaped λ/4 open stub has been incorporated to the microstrip feed line. Frequency rejection performance can be controlled flexibly by varying various parameters and positions of the corresponding band notched elements. Furthermore, additional resonance at higher frequencies has been generated by introducing a metal loaded complimentary split ring resonator (MLCSRR) to the ground plane, so that it provides enhanced usable fractional bandwidth (2.6-13.9 GHz) more than 136%. The performance of the proposed antenna is analyzed both in frequency and time domain to assess its suitability in UWB communication.

***Index Terms* –** Conductor backed plane, frequency band notch performance, Metal Loaded Complimentary Split Ring Resonator (MLCSRR), ultra wideband.

I. INTRODUCTION

Federal Communication Commission (FCC) has assigned the frequency range from 3.1 GHz to 10.6 GHz for ultra wideband (UWB) communication systems [1]. However, various band notched elements are applied to overcome the electromagnetic interference of WIMAX (3.3-3.7 GHz) and WLAN (5.15-5.825 GHz) in UWB system. Conductor backed plane (CBP) is one of the band notched elements. In previous literatures, different geometries of CBP have been discussed so far such as I-shaped [2], H-shaped [3], W-shaped [4] CBP structures. Introduction of split ring resonator (SRR) at the rear side of patch is the similar approach for band rejection [5]. Another common way of band notch technique is the application of open stub at the edge of the microstrip feed line; ground plane or patch has been discussed in recent investigation [6]. In this paper two different band notch elements are employed for dual band rejection purpose. First one is a vertically combined half wavelength T- and U-shaped conductor backed plane. The main advantage of the new modified CBP geometry is that it can efficiently control the rejection bandwidth of WIMAX frequency band (3.3-3.7 GHz) for deep and sharp rejection. Another stop band element for WLAN frequency band (5.1-6 GHz) is a quarter wave length rectangular spiral shaped open stub in the microstrip feed line. Bandwidth of the WLAN rejection band can be controlled by varying the open stub distance from patch. Moreover, a metal loaded CSRR is introduced to achieve much wider impedance bandwidth, especially at higher band. Metal loading technique with CSRR in ground plane generates additional resonant mode which ensures good impedance matching over the wide range of frequency 2.6-13.9 GHz (VSWR < 2).

II. ANTENNA DESIGN AND CONFIGURATION

The geometry of the proposed design with WIMAX band-notched ability is illustrated in Fig. 1. Antenna is printed on FR4 substrate with $\varepsilon_r = 4.4$ and thickness of 1.6 mm, which consists of a simple rectangular radiating patch, which is excited by a 50Ω microstrip feed line. To generate notch band around 3.5 GHz, a thin half wavelength on the rear side of the patch is electrically separated from the ground plane and patch. The conductor

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backed plane geometry is a vertical combination of T- and U-shaped parasitic elements. The desired centered rejection frequency $f_{notch\text{-}wimax}$ at 3.5 GHz can be approximated as:

$$\mathbf{f}_{\textbf{notch-wimax}} = \frac{c}{2L_{CBP}\sqrt{\epsilon reff}}, \quad (1)$$

where $\epsilon_{reff} = (\epsilon_r+1)/2$, c = speed of light in free space, ϵ_r = relative permittivity of the substrate and $L_{CBP} = (L_1+L_3)/2+L_2+2L_4$. Similarly, to reduce the interference from the WLAN system, a rectangular spiral shaped quarter wavelength open thin stub is inserted to the microstrip feed line corresponding to the rejection frequency at 5.5 GHz. The total length of spiral stub (L_{STUB}) can be calculated by the empirically approximated formula as:

$$\mathbf{f}_{\textbf{notch-WLAN}} = \frac{c}{4L_{STUB}\sqrt{\epsilon reff}}, \quad (2)$$

where $L_{STUB} = X_1+X_2+X_3+X_4+X_5+X_6+X_7-7t$.

This work mainly focuses on the following two issues:

i) Proper control of filter bandwidth of rejection bands;
ii) Enhancement of impedance bandwidth using metal loaded CSRR type defective ground structure.

Sharpness of the rejection mechanism completely depends on the quality factor (Q-factor). Coupling gap (d_C) between horizontal arm of CBP and ground plane acts as resonator and introduces capacitive effect which offers series resonance band notch function around 3.5 GHz. Inductive reactance is offered by narrow metallic strip of CBP and the capacitive effect of coupling gap (d_c) is termed of equivalent series RLC resonance circuit. Strong coupling effect due to closer separation between the horizontal arm of CBP and the ground plane produces high capacitance value that conversely degrades that Q-factor and enhances the rejection bandwidth around 3.5 GHz. On the other hand, closer gap between the vertical arms of CBP significantly improves the capacitance value which leads to high Q-factor and sharp rejection around 3.5 GHz. At rejection frequency (5.5 GHz), the open circuited stub draws more current by presenting low impedance at its anchor. In case of increasing separation, both equivalent capacitance and Q-factor decrease which leads to the rejection bandwidth enhancement around 5.5 GHz. Regarding the defective ground structure (DGS), a rectangular complimentary split ring resonator has been loaded to the inner periphery of the ground plane with metal loading. In previous literature, several DGS geometries have been presented. In this work, an asymmetrical modified DGS is depicted by using a thin metal shorting strategy on single rectangular CSRR type DGS configuration. Additional current path in ground plane due to the metal loaded CSRR type DGS creates a resonance circuit. The combination of current path due to metal shorting effect and the presence of defect in the region of high electromagnetic fields lead to smaller equivalent inductance and capacitance; hence, higher resonance frequency can be obtained. This effect in turn leads to the enhancement of the impedance bandwidth.

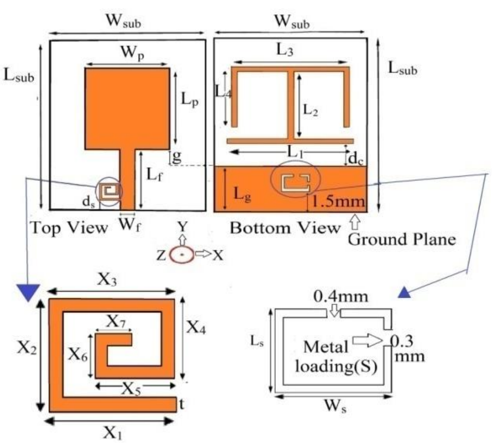

Fig. 1. Configuration of the proposed antenna.

III. FREQUENCY DOMAIN RESULTS

A parametric study of the frequency domain characteristics has been done by using Ansys HFSS simulator.

A. Effect of d_C & d_S in rejection band controlling

Figure 2 shows the effect of d_c and d_S in controlling of the bandwidth of individual rejection band around 3.5 GHz and 5.5 GHz.

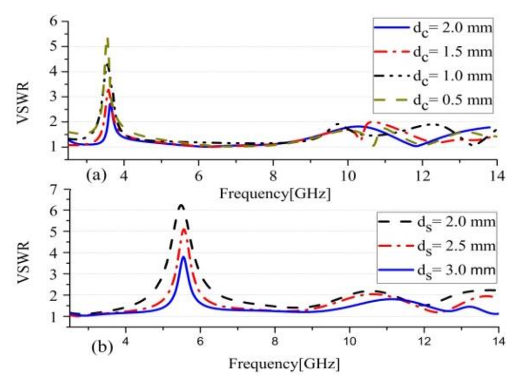

Fig. 2. Simulated VSWR for different value of: (a) d_c for controlling WIMAX rejection band, and (b) d_s for controlling of WLAN rejection band.

B. Enhancement of the impedance bandwidth

Figure 3 indicates the effect of CSRR with and without metal loading. It is observed that when a narrow metal strip is appropriately loaded with CSRR at optimum position, additional resonance at 11.7 GHz along with 10.6 GHz produces much enhanced bandwidth extended by approximately 3 GHz.

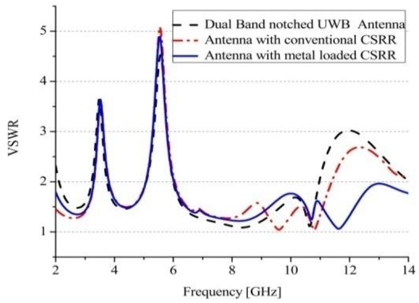

Fig. 3. Simulated VSWR characteristics for the antenna with and without metal loaded CSRR.

C. Variation of conductor backed plane parameter and stub length

The WIMAX band rejection can be tuned by changing the dimension of L_1, L_2, L_3 and L_4 independently as shown in Fig. 4. Similarly, WLAN rejection band can be controlled by varying the effective stub length L_{stub}, as shown in Fig. 5. It is worthwhile to mention that there is a low mutual coupling at two rejected frequencies indicating that each rejection frequency can be controlled independently.

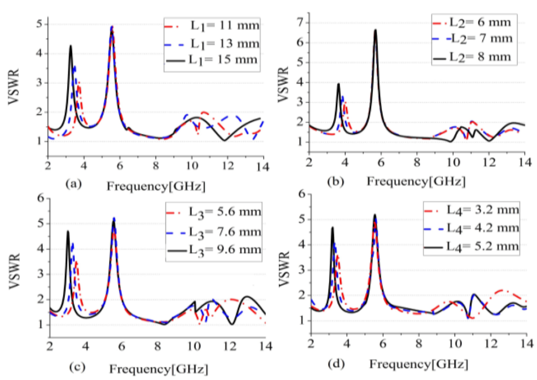

Fig. 4. Simulated VSWR with varying parameters: (a) L_1, (b) L_2, (c) L_3, and (d) L_4, (L_{stub}=10.4 mm).

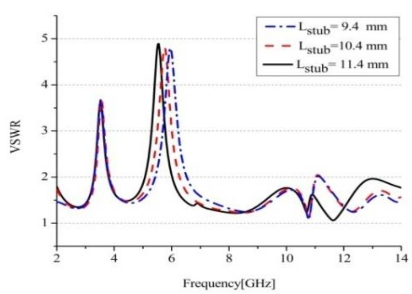

Fig. 5. Simulated VSWR for different value of L_{stub} (L_1=13 mm, L_2=7 mm, L_3=7.6 mm, L_4=4.2 mm).

D. Experimental result for VSWR

Figure 6 illustrates the prototype of proposed UWB band notched antenna with optimized dimension given in mm: L_{sub}=20, W_{sub}=20, L_f=7.5, W_f=2, L_P=12, W_P=10, Lg=4, L_1=13, L_2=7, L_3=7.6, L_4=4.2, g=3.5, d_c=0.5, d_g=2.5, X_1=2, X_2=2.5, X_3=1.7, X_4=1.7, X_5=1.2, X_6=1.2, X_7=6, t=3.

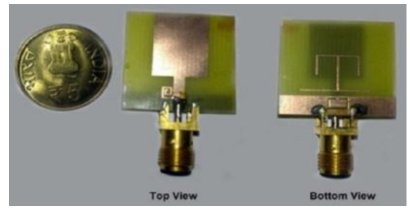

Fig. 6. Prototype of proposed antenna.

The measured and simulated VSWR of the proposed antenna with dual band notch characteristics are shown in Fig. 7. The measured frequency range covers the UWB range from 2.6 GHz-13.9 GHz with stop bands 3.3-3.7 GHz and 5.1-6 GHz, which cover the entire WIMAX and WLAN frequency band.

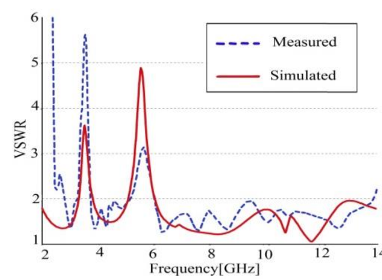

Fig. 7. Measured and simulated VSWR for the proposed antenna.

E. Measured radiation pattern and peak gain

The normalized measured far field radiation patterns are shown in Fig. 8. It is observed that H-plane patterns are fairly omni-directional over the entire frequency band and E-plane patterns are monopole like.

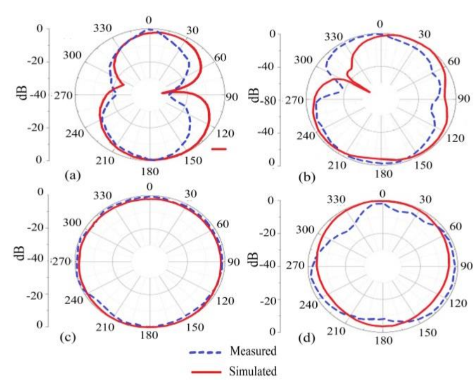

Fig. 8. Simulated and measured radiation pattern for the proposed antenna at: (a) E-plane 7 GHz, (b) E-plane 11 GHz, (c) H-plane at 7 GHz, and (d) H-plane at 11 GHz.

The measured peak gain of the proposed band notched antenna is shown in Fig. 9. It is noted that the proposed antenna exhibits gain variation from 0.2 dBi to 3.3 dBi, except two sharp dips at 3.5 GHz and 5.5 GHz.

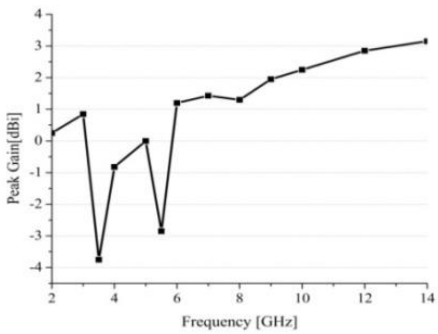

Fig. 9. Measured peak gain for the proposed antenna.

IV. TIME DOMAIN STUDY

Figure 10 illustrates the magnitude of transfer function and group delay characteristics between two identical antennas placed 30 cm apart in face to face and side by side orientation. In pass band, the group delay variation is less than 1 ns and the magnitude of transfer function is almost flat, which indicates the phase linearity between two antennas. However, large variation of group delay can be observed in stop bands with the sharp decrease in transfer function magnitude $|S_{21}|$, which is due to the band rejection characteristics.

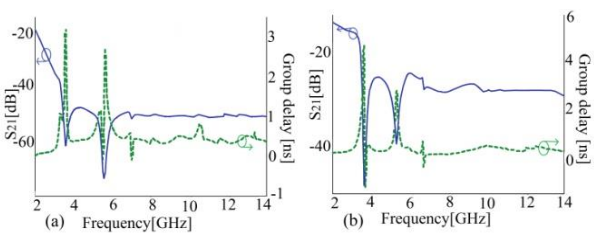

Fig. 10. Measured magnitude of the transfer function and group delay: (a) face-face and (b) side by side mode.

V. CONCLUSION

A monopole UWB antenna with enhanced impedance band width has been investigated and realized with controllable frequency rejection band centered at 3.5 GHz and 5.5 GHz. Metal loaded complimentary split ring resonator (MLCSRR) to the ground plane provides much wider impedance band width (2.6–13.9 GHz). The proposed antenna demonstrates superior performance in terms of frequency and time domain and therefore, it can be applicable in near future UWB wireless applications.

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