A UNIQUELY-FED MINIATURIZED ULTRA-WIDEBAND ANTENNA WITH DUAL BAND-REJECTION CHARACTERISTICS

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ABSTRACT— *The presented article exhibits a novel compact sized monopole Ultra-WideBand antenna with dual band-notch characteristic having size of 19x11x1.6mm^3. The antenna is fed using microstrip line on the backside of the substrate and shorted through a 0.5mm radius pin to the patch on top of the substrate. The U-shaped (crescent) slot embedded in the patch and the U-shaped slot in the microstrip feed line are used to reject the WIMAX band (3.3GHz-3.8GHz) and X-band Downlink range (7.25GHz-7.85GHz), respectively. The proposed antenna has been printed on low cost FR4 substrate with relative permittivity of 4.4 and thickness of 1.6mm. Moreover, the fabricated prototype antenna shows good agreement between the simulated and measured results.*

I. INTRODUCTION

Federal Communication Commission's (FCC) allocation of the Ultra WideBand ranging from 3.1GHz to 10.6GHz in 2002 [1] has produced a great influence on commercial uses of this technology. Numerous antenna types have been used to implement this technology amongst which the Microstrip patch antennae are of significant importance because of their several eye-catching characteristics as they are inexpensive, light weight, low profile and above all, quick and simple to manufacture [2]. Regardless of the progressions in designing microstrip antennas for Ultra WideBand technology, the chief issues are the large size, low gain, narrow bandwidth and radiation losses which result in radiation in half plane for the microstrip antennas. To reduce these limitations, several design methodologies have been devised to achieve the UWB using microstrip patch antennas. Some of the noteworthy techniques include aperture coupling [3], stacking [3], slot compact planar design [4], parasitic patch [5] and thickening the substrate.

With the expansions in antenna technology for UWB applications, the interference challenges in the frequency bands are the major ones to be dealt with. Within the Ultra Wideband frequency range there are several other narrow band applications operating, such as World Interoperability for Microwave Access (WiMAX) ranging from 3.3GHz to 3.8GHz and X-band Downlink ranging from 7.2GHz to 7.8GHz, which are reported to cause interference with the UWB systems. Numerous methods have been devised to eliminate the interference in the UWB due to interfering frequency bands which include a rectangular tuning stub entrenched on a circular annular ring [6], a printed UWB antenna with couple slotted elements (H-shaped) [7]. A few of the other approaches towards band-notching include Co-Planar Waveguide (CPW) fed C-shaped slot antenna [8], an antenna with a wide slot [9], a CPW-fed rectangular patch antenna with L-shaped slot in ground plane[10], an inverted U-slot antenna [11], a circular radiating patch with two L-shaped slots in the ground [12], a rectangular patch antenna with an E-shaped slot [13], a CPW resonant cell as narrow stop-band filter in CPW feed-line [14] and a CPW-fed band-notch antenna [15].

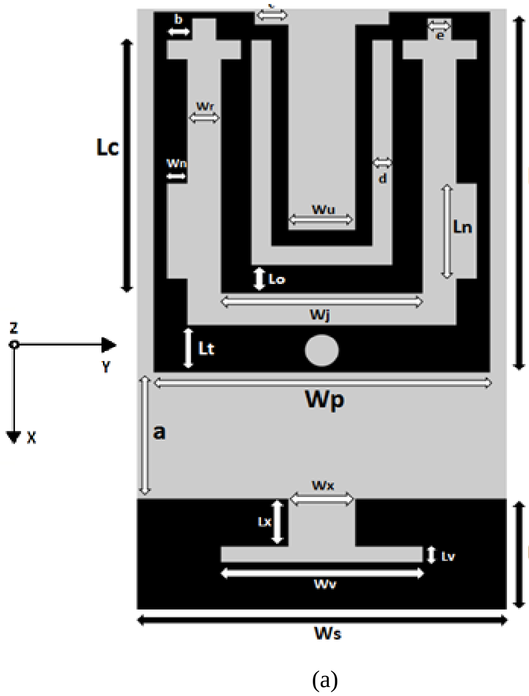
One of the primary issues in the design of the Ultra WideBand systems is the antenna size for portable devices because the size of the antenna has a major effect on the bandwidth and gain. Therefore, the miniaturization of antennas having the ability of providing a wide bandwidth and offering an adequate gain is a challenging job. The presented article exhibits a very small sized Ultra WideBand antenna with dual band rejection feature with a unique feeding technique.

II. ANTENNA GEOMETRY

The pictorial representation of the proposed antenna is shown in Figure 1. The antenna is designed on an inexpensive FR4 substrate of thickness 1.6mm, relative permittivity of 4.4 and dielectric loss tangent of 0.02. The antenna is fed by shorting the 50Ω microstrip line at the bottom of the substrate to patch on top of the substrate by using a 1mm diameter hole. The effective permittivity is formulated as shown in equation (1). In equation (1), 'f_r' is the resonant frequency and 'c' is the speed of light. The value of W must be lesser than that calculated in equation (2) otherwise the higher modes will result in field distortion. The size of the antenna is chosen to be 19x11mm^2 which is smaller than the existing UWB antennas [2-22]. The inverted T-shape in the ground plane and U-shape in the patch of the substrate are the primary contributors to broadening the bandwidth. The microstrip line at the bottom of the substrate has length of 9.0mm and is 2.0mm wide having the shorting pin inserted at 0.3mm from top of the microstrip line. The detailed parameters of the antenna geometry are described in Table I. Other parameters which contributed in the impedance matching include 'a'= 4.0mm, 'b'= 0.75mm', 'c'=1.0mm, 'd'=0.6mm and 'e'=0.7mm.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2} \quad \textbf{(1)}$$

$$W = \frac{c}{2 f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \quad \textbf{(2)}$$



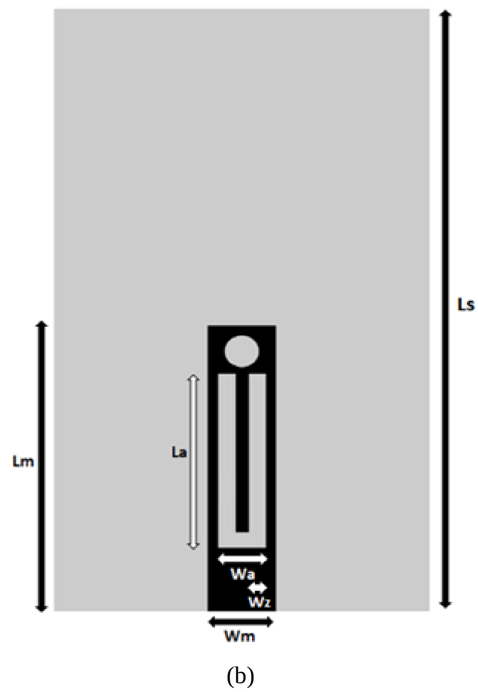


Fig. 1. Geometry of Proposed Antenna (a) Front (b) Back

Table I Design Parameters of the proposed Antenna

Symbol	Size (mm)	Symbol	Size (mm)	Symbol	Size (mm)
Ls	19	**Lx**	1.5	**Ln**	3
Ws	11	**Wx**	2.0	**Wn**	0.6
Wv	6	**Lg**	3.5	**Wj**	6
Lv	0.5	**Lc**	7.1	**Wu**	2
Wp	10	**Lt**	1.5	**Wr**	1
Lp	11.4	**Lo**	0.9	**Wa**	1.5
Wm	2.0	**Lm**	9.0	**La**	5.5

III. SINGLE BAND-NOTCH STRUCTURE

In the design of this antenna the Ultra Wideband is achieved by placing slots (U-shaped) in the patch as well as the ground plane of the antenna. The WIMAX band-notch is achieved by embedding a U-shape slot (crescent shape) in the patch of the antenna. Figure 2 shows the effect on VSWR for the parametric variation of the parameter 'Wr'. It can be seen from the figure that the 'Wr' has a primary role to handle the WIMAX band notch. The antenna operates in the UWB range (3.1GHz to 10.6GHz) and the WIMAX band is completely notched when 'Wr' is 1.0mm wide. For Wr= 0.9mm and 1.1mm the antenna is rejecting the frequencies between 10.34GHz to 10.76GHz and 10.26GHz to 10.88GHz, respectively, which is not acceptable as it doesn't cover the Ultra WideBand completely. For these values of 'Wr', the antenna is unable to reject the WIMAX band (3.3GHz to 3.8GHz) completely as well. Therefore the optimum value of 'Wr' chosen in order to reject the WIMAX band is 1.0mm on which the antenna operates from 2.76GHz to 11.78GHz covering the entire UWB (3.1GHz to 10.6GHz) and rejecting from 3.20GHz to 3.96GHz which covers the undesired WIMAX band (3.3GHz to 3.8GHz).

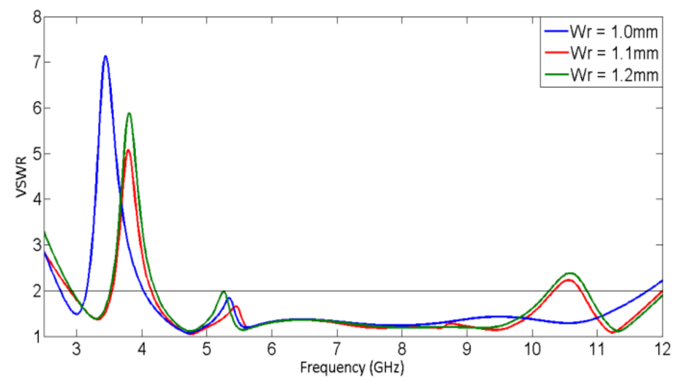


Fig. 2. Frequency vs VSWR varying Wr for WIMAX Band-Notch

IV. DUAL BAND-NOTCH STRUCTURE

After achieving the Ultra Wideband and rejecting the WIMAX band using a U-shape slot in the patch of the substrate, a U-shaped slot is inserted in the microstrip line on the bottom of the substrate to reject the X-band downlink frequency range as it can be seen in Figure 3. Figure 3 shows the parametric analysis by taking several values of 'Wz'. It can be seen from the figure that as the value of the parameter 'Wz' increases the notching range shifts towards higher frequencies. The optimum value of 'Wz' which rejects the entire X-band Downlink frequency range is 0.5mm.

The resonant frequency of this antenna can be postulated using equation (3). In equation (3), c is the speed of light, ε_{eff} is the effective dielectric constant and L is the total effective length of the resonator. Equation (3) was taken into consideration for both the band rejections and later the results were optimized to achieve the optimum solution.

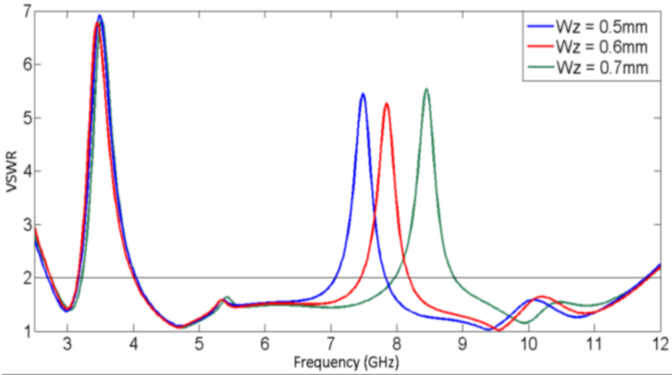


Fig. 3. Frequency vs VSWR varying Wz for X-Band Downlink Band-Notch

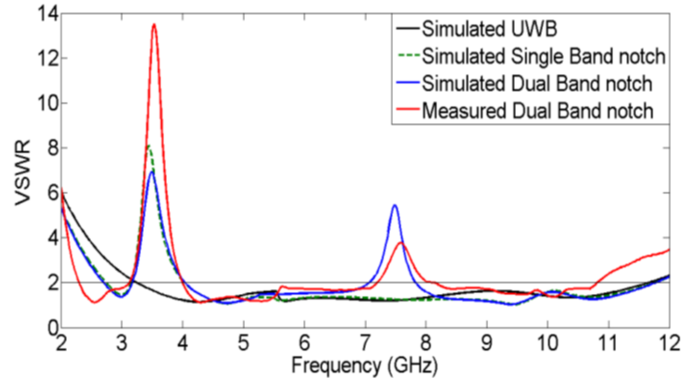


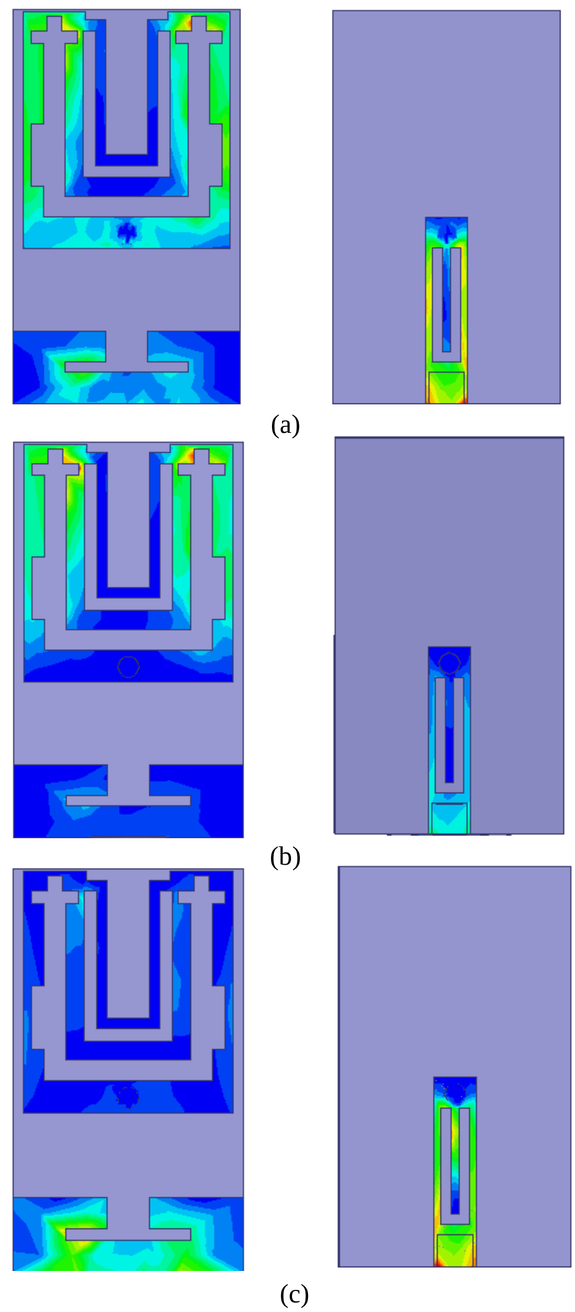
Fig. 4. Frequency vs VSWR with and without Band-Notch simulated and measured

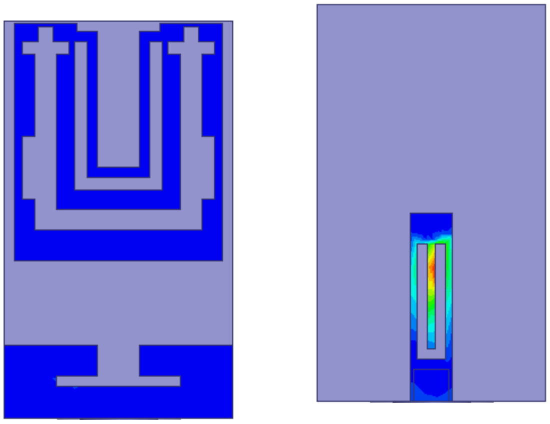
$$f_{notch} = \frac{c}{2L\sqrt{\varepsilon_{eff}}} \qquad (3)$$

V. RESULTS AND DISCUSSION

This section describes the experimental and simulated results of the proposed antenna. Different parameters of proposed antenna are discussed. Figure 4 shows the simulated frequency versus VSWR plots with and without the U-shaped slots along with the measured results with the U-shaped slots in the patch and microstrip line. The measurement of frequency vs VSWR was performed using Vector Network Analyzer. The simulated results show that the antenna has VSWR<2 from 2.70GHz to 11.76GHz. In between this frequency range it rejects the WIMAX band from 3.20GHz to 3.98GHz and X-band downlink range from 7.10GHz to 7.87GHz. Whereas it can be seen from the measured results that the antenna is operating from 2.30GHz to 10.80GHz with band rejections ranging from 3.13GHz to 3.94GHz and 7.20GHz to 8.12GHz. The measured results shows that the antenna is also operating in the Bluetooth frequency band (2.4GHz) and 2GHz WLAN range (2.412GHz to 2.484GHz).

The surface current distribution, determined by HFSS simulations, on ground plane along with radiating patch on top side and the microstrip feed line on bottom side of the substrate is shown in Fig 5 at 3.1GHz, 3.5GHz, 5.5GHz and 7.5GHz. In Figure 5(a), it is observed that the current is distributed over the patch, ground plane and microstrip feed line on bottom plane which results the Ultra Wideband starting from 3.1GHz. In Figure 5(b), it can be clearly noticed that there is significant amount of current accumulated around U shaped slot with the parameter Wr (U-shaped crescent) causes the first notch at 3.5GHz. It can be seen from Figure 5(c) that the maximum current concentrates over the ground plane on top side and microstrip feed line on bottom side of the substrate at 5.5GHz which exhibits Ultra WideBand characteristics of the proposed antenna. Figure 5(d) shows the second band notch at 7.5GHz can be seen at the bottom side as the current accumulates around the U-shaped slot in the microstrip feed line.





(d)

Fig. 5. Current Distribution plot of dual band-notched antenna (a) 3.1GHz (b) 3.5GHz (c) 5.5GHz (d) 7.5GHz

Plot of peak gain over the entire range of frequencies (2.9GHz to 11GHz) for Ultra WideBand applications with two band notch, 3.3GHz to 3.9GHz and 7.2GHz to 7.8GHz, is shown in Fig 6. As described in the figure that the gain values drastically drop down in the WIMAX and X-band Downlink range where the desired bands are rejected. Except the notched bands, the antenna exhibits satisfactory gain and reaches as high as 6.6 dBi, presenting the stable gain over the entire range of UWB frequency.

Table II shows the other parameters of the antennas calculated at different frequencies of the proposed dual band rejected antenna.

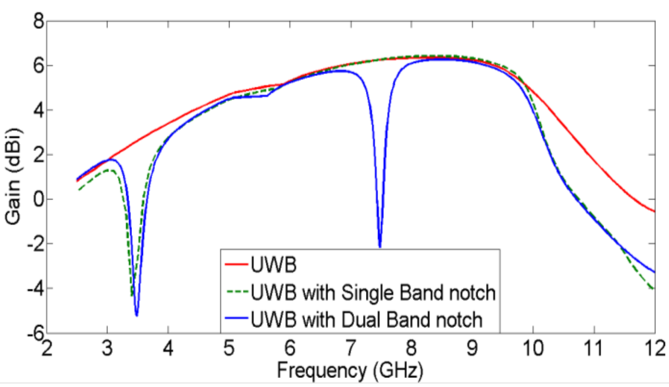
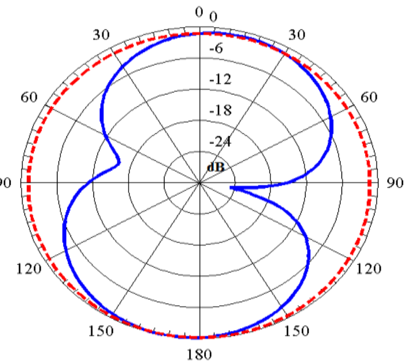


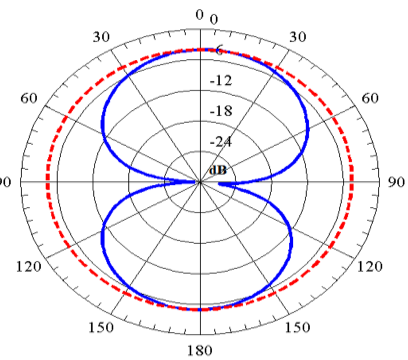
Fig. 6 Frequency vs Gain plot of UWB with and without band-notches

Table II Computed Parameters of UWB Dual band-notched antenna

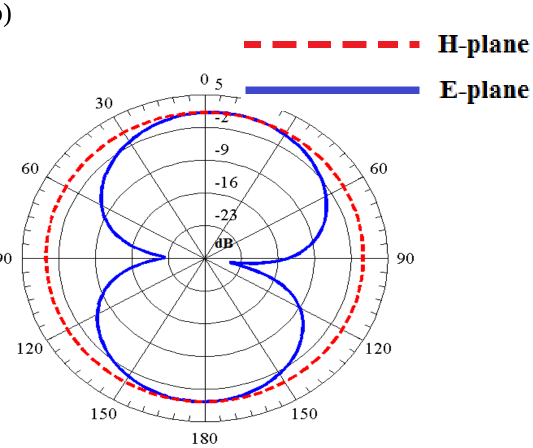
Parameter /Frequency	*3.5GHz*	*5.5GHz*	*7.5GHz*	*9.0GHz*
Maximum U (W/Sr)	0.00616	0.0932	0.0168	0.197
Peak Directivity	0.795	1.408	1.948	2.674
Peak Gain (dBi)	-5.015	3.571	-2.774	6.142
Radiation Efficiency	0.221	0.866	0.207	0.934
Front to Back Ratio	1.842	1.320	1.278	1.3641



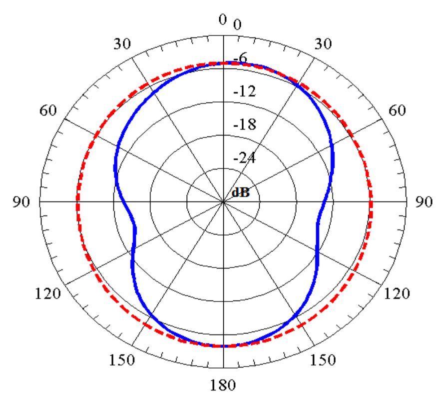
(a)



(b)



(c)



(d)

Fig. 7. Radiation pattern of dual band-notched antenna (a) 3.1GHz (b) 3.5GHz (c) 5.5GHz (d) 7.5GHz

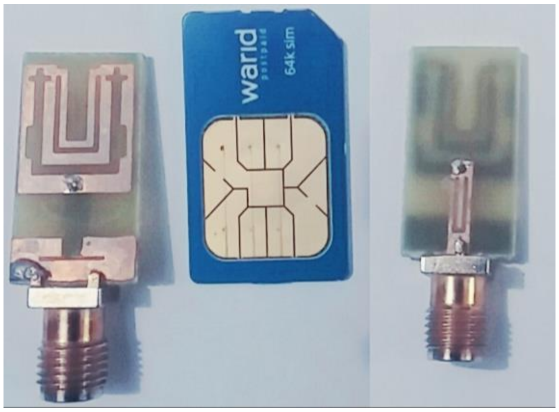


Fig. 8. Size comparison of front (left) and back (right) sides of Prototype UWB dual band-notch antenna with USIM (middle)

VI. CONCLUSION

In this paper, a novel low cost miniaturized monopole Ultra WideBand antenna printed on FR4 substrate is presented with dual band rejection capabilities. The proposed antenna is fed using a shorting pin connecting the microstrip line on the back side of the substrate to the patch on the front of the substrate. The simulated results show that the antenna covers the entire UWB with WIMAX and X-band downlink band notches. The measured results are in complete agreement with the simulated results covering an additional band of Bluetooth and 2.4GHz WLAN band as well.

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