A Bowtie Slotted Quad-Band Notched UWB Antenna with Defected Ground Structure

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Abstract **─** A novel compact bowtie slotted circular patch antenna with quad-band notched characteristics is demonstrated in this work. The presented prototype is ascertained on FR-4 substrate. Initially, an Ultra-Wideband (3.1-10.6 GHz) antenna is achieved. Later, undesirable bands between 3.55-5.16, 5.52-5.73, 6.44-6.78 and 7.61-10.6 GHz are eliminated by incorporating slots in the patch. By proper optimization of the patch as well as ground plane, four resonant bands are achieved between 2.56-3.53, 5.22-5.5, 5.7-6.4 and 6.81-7.53 GHz supporting LTE2500, WiMAX, WLAN, and X-band applications. For good impedance matching, the antenna employs a very unique bat-shaped defected ground plane structure. The peak gain of 3.7 dB is obtained by the proposed radiator. A good agreement is observed between the measured and simulated results.

Index Terms **─** Bowtie slotted antenna, defected ground structure (DGS), notched bands, WiMAX, WLAN, X-band.

I. INTRODUCTION

In recent years, a lot of attention is acquired by UWB systems for commercial applications. For Ultra-wideband (UWB) systems, the band between 3.1-10.6 GHz is allocated by FCC (Federal communication commission) which has attracted the researchers from the academic and industrial background for current and future small range wireless applications. Recent works exhibit intensive research on UWB antennas due to features such as low cost, high data throughput, low power consumption, and small size. [1-6]. In order to design an UWB antenna, there are certain challenges which antenna designers have to deal with. As the operating range of the UWB antenna is wide so there is a possibility of interference of different frequency bands such as LTE 2500, Wi-Max at 3.5/5.5 GHz (3.3 to 3.7 GHz and 5.15-5.85 GHz), WLAN2 systems at 5.2/ 5.8 GHz (5.15-5.35 and 5.725-5.825 GHz), and X-band at 660 MHz/7.10-7.76 GHz [7-9]. To mitigate this problem, rather than using an extra filter, UWB antennas with inherent band notch characteristics are deployed which reduces the area, complication and cost of an UWB system.

Recent work reports several UWB antennas with one or more notch bands [10-18] by using different band notching techniques. A fork shaped antenna with a total size of 42×24×1.6 mm^3 and a defective ground structure (DGS) is demonstrated for ultra-wideband applications with triple notch bands [10]. A J and U-shaped slotted antenna with an overall substrate size of 47×40×1.6 mm^3 is reported with WLAN and WiMAX band notch function [11]. In [12], a dual band-notched antenna consisting of half ring-shaped resonator and a trapezoidal ground is presented. A rectangular notched-band antenna with overall dimensions of 48×50×1 mm^3 with electromagnetic bandgap structures on CPW feed-line is presented [13]. A UWB antenna featuring triple notch bands using a C-shaped and U-shaped inversion slots and a modified ground plane with L-shaped slot is reported [14]. In [15], an UWB antenna with two split ring resonators (SRRs) to obtain notch filters in 5-6 GHz WiMAX/WLAN bands is demonstrated with a substrate size of 44.6×78 mm^2. A diamond-shaped SIR (stepped impedance resonator) ultra-wideband antenna with CPW-feed with dual rejected bands is reported [16]. By inserting a rectangular slot in the radiation patch and a slot in the feedline, a UWB antenna with a compact size of 33×32×1.5 mm^3 is

Submitted On: February 10, 2019
Accepted On: July 14, 2019

obtained with suppression of the dual bands [17]. A 30×40×1.6 mm^3 circular UWB antenna with WLAN band rejection characteristic is proposed by engraving rectangular split ring resonators (RSRRs) structure in the radiator [18].

In this work, a miniaturized microstrip-fed circular notched band antenna is presented and realized. The quad notched bands are obtained by incorporating bowtie and U-shaped slots in the circular patch. A bat shaped defected ground and a rectangular structure at the bottom layer of the substrate also contributes in obtaining the notch bands. By modifying and optimizing the size and the positions of the slots, the band-notched characteristics of the antenna can be achieved to reject the complete operating bands of the 3.55-5.16, 5.52-5.73, 6.44-6.78 and 7.61-10.6 GHz. The proposed antenna thus rejects the WLAN, WiMAX, X-band and 8 GHz ITU bands.

II. ANTENNA STRUCTURE

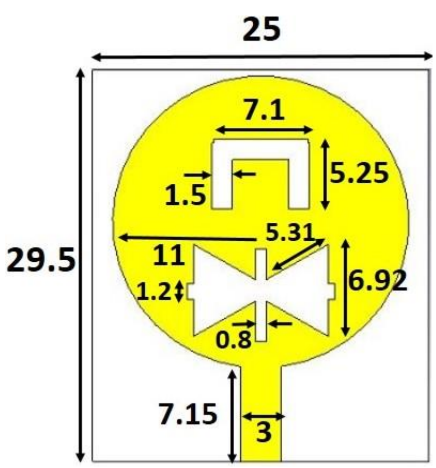
Figures 1 (a) and (b) show the layout of the proposed antenna. CST®MWS® is used for design and simulation purposes. A circular radiating patch of radius, a=11 mm fed by 50 Ω microstrip feeding line is proposed. The circular radiating structure consists of optimized bowtie and inverted U-shaped slot. A bat like defected structure is incorporated at the ground plane. The antenna also employs a rectangular optimized structure above the bat-shaped ground plane, whose placement and size is adjusted. The following equations are used to design the antenna [19]:

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}}, \quad (1)$$

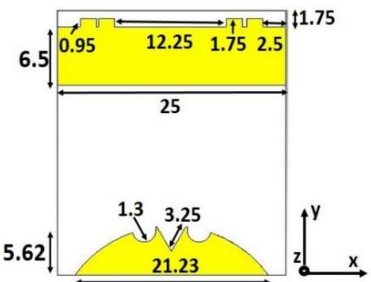
$$F = \frac{8.791\times10^9}{f_r\sqrt{\varepsilon_r}}, \quad (2)$$

$$a = a\left\{1+\frac{2h}{\pi a\varepsilon_r}\left[ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\right\}^{1/2}, \quad (3)$$

$$(f_{re})_{110} = \frac{1.8412V_o}{2\pi a_e\sqrt{\varepsilon_r}}. \quad (4)$$



(a)



(b)

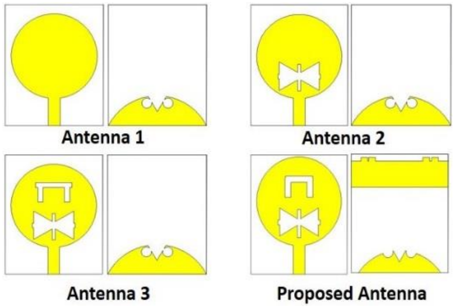
Fig. 1. (a) Top and (b) bottom (all dimensions are in mm).

In the above equations, the radius of the radiating patch is represented by a, height of the substrate by h, the relative permittivity of the substrate by εr whereas the resonant frequency is denoted by f_r. The proposed design with overall dimensions of 29.5×25 mm^2 is realized on 1.59 mm thick FR4 substrate with εr=4.3 and tan δ=0.025.

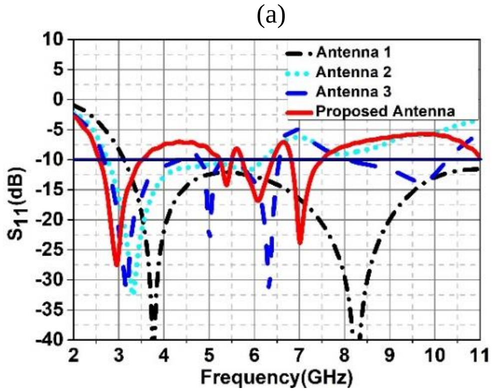
III. DESIGN CONFIGURATION AND WORKING MECHANISM

Figure 2 (a) shows the step by step progression of the proposed prototype. Figure 2 (b) illustrates the S_{11} for all the stages of the design to understand the working mechanism of the proposed antenna.

First of all, antenna 1 is designed which is a simple circular patch above the substrate. The initial structure of the antenna is designed to achieve the UWB (3.1-10.6 GHz) as demonstrated in Fig. 2 (b). The ground located at the substrate's bottom-layer is modified to a bat like structure to attain UWB and to enhance wideband impedance matching. Afterwards, the required notch bands are achieved by further optimization. Antenna 2 is obtained by inclusion of a bowtie-shaped slot in the circular patch to obtain notch band at X-band. The notch band achieved at this step is depicted in Fig. 2 (b). The dimensions and placement of the bowtie slots are optimized to get the desired results along with sustaining good impedance matching. In the next step, a U-shaped slot is subtracted from the patch, thus obtaining antenna 3. The incorporation of U-shaped slot in addition to previously obtained antenna 2 provides two notches at WLAN and WiMAX bands. Shifting of notch bands is observed at the inclusion of slots due to mutual coupling between existing and newly incorporated slots. Finally, the proposed antenna is achieved by adding a rectangular structure above the defected bat-shaped ground structure. The structure is modified to obtain the desired notch bands thus stopping the X band and 8 GHz ITU band. It is clear that proposed antenna has quad notch bands ranging from 3.5-5.2 GHz, 5.5-5.7 GHz, 6.45-6.7 GHz, and 7.6-11 GHz, thus filtering out potential interference from WiMAX, WLAN, X band and 8GHz ITU bands.



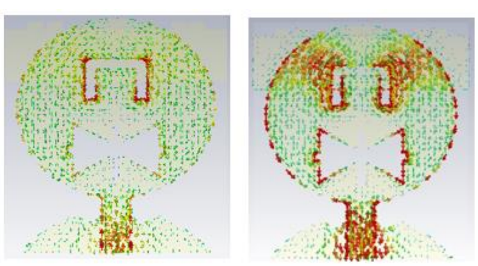
(a)



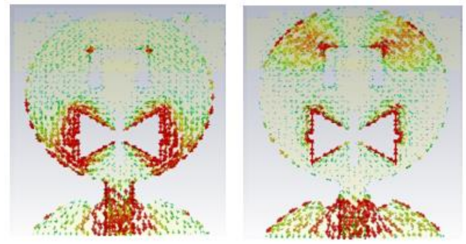
(b)

Fig. 2. (a) Stepwise progression of the proposed antenna, and (b) S-plot (S_{11}).

In order to demonstrate the working technique of proposed antenna, the surface current density at four notch frequencies, i.e., 4.3, 5.6, 6.5 and 9.1 is shown in Figs. 3 (a)-(d). It is clearly evident in Fig. 3 (a) that current density is around the U-shaped slot at 4.3 GHz. Figure 3 (b) illustrates the major current distribution around the rectangular structure for 5.6 GHz. Current is mainly centered at the bowtie slot and ground structure for 6.6 GHz frequency as shown in Fig. 3 (c). Figure 3 (d) depicts that at 9.1 GHz notch frequency, the concentration of current is at the rectangular structure, ground plane and around the edges of the bowtie slot.



(a) (b)



(c) (d)

Fig. 3. Current distribution at: (a) 4.3 GHz, (b) 5.6 GHz, (c) 6.6GHz, and (d) 9.1 GHz.

IV. RESULTS AND DISCUSSION

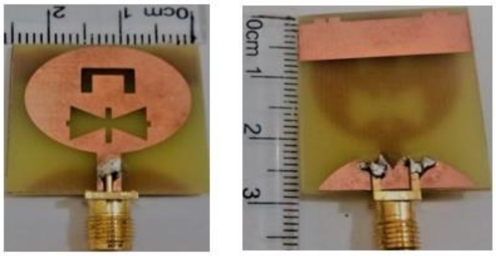
According to the optimized parameters of the prototype the proposed antenna is fabricated and measured to validate the performance. Figure 4 illustrates the top and bottom view of the prototype. Measured results are obtained by the Agilent (Key sight) Technologies PNA-E8362 Vector Network Analyzer.

A. S-parameters

The S_{11} plots for measured and simulated results of the presented antennae are shown in Fig. 5. A suitable consistency is perceived between measured and simulated results; nevertheless, dissimilarities also exist because of the unpreventable usage of SMA-connector and coaxial-cable for measurement purposes [20]. Substrate losses and fabrication imperfections also contribute to the dissimilarities.

B. Antenna far-field results

The proposed bowtie slotted antenna's E (yz) and H (xz) plane radiation patterns are depicted Figs. 6 (a)-(d). The gain, current-densities, and the S_{11} are well explaining the band-rejection features. The radiation patterns are presented only for substantiation of the UWB characteristics at 2.9, 5.37, 6.09 and 7.02 GHz. The radiation pattern in E plane is bidirectional while in H-plane omnidirectional pattern is obtained. It can be seen that the cross-polarization level is less than -20 dB over the E-plane of the four frequency bands and for the H-plane the cross-polarization level is less than -20 dB for the lower frequency bands i.e. 2.94 GHz and 5.37 GHz but for the upper frequency bands i.e. 6.09 GHz and 7.02 GHz, the cross polarization level is between -20 dB and -10 dB. Thus, it is apparent from the radiation patterns of the proposed design, a stable behavior is obtained for the resonating frequencies.



(a) (b)

Fig. 4. Fabricated prototype: (a) top and (b) bottom

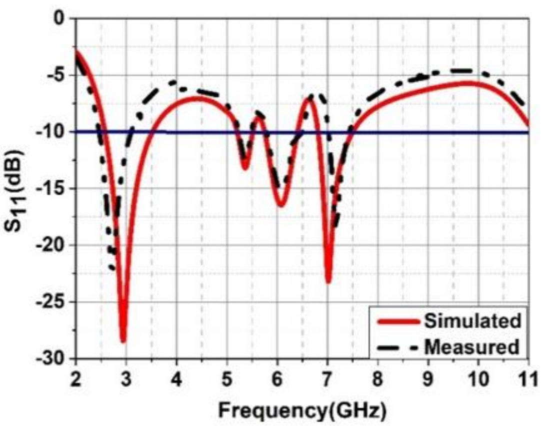


Fig. 5. Simulated and measured S_{11}

C. Antenna gain

The gain of the proposed notched band UWB antenna is illustrated in Fig. 7. It provides clear evidence that the peak gain of 3.7 dB is obtained for the resonant bands. Therefore, the proposed bowtie slotted antenna can deliver a reasonable gain over the entire range of ultra-wideband except at the notched bands.

V. SUBSTRATE ANALYSIS

The proposed antenna’s performance is analyzed by changing the substrate’s material. The analysis is depicted in terms of S_{11} plots in Fig. 8. The substrates used for the analysis purpose are Rogers RT Duriod 5880, Rogers RT6010 and FR-4. The thickness of all the substrates is kept same that is 1.6 mm. The detail of the substrate analysis in term of permittivity, no. of achieved notch bands and maximum gain achieved has been presented in Table 1. After the complete analysis of the outcomes, it can be seen that the working of the proposed antenna on FR-4 substrate is much reasonable as compared to the other substrates with a peak gain of 3.7 dB and quad notch bands. Rogers 5880 with permittivity of 2.2 has achieved 2 notch bands. Whereas for Rogers RT6010, the number of notch bands is 3.

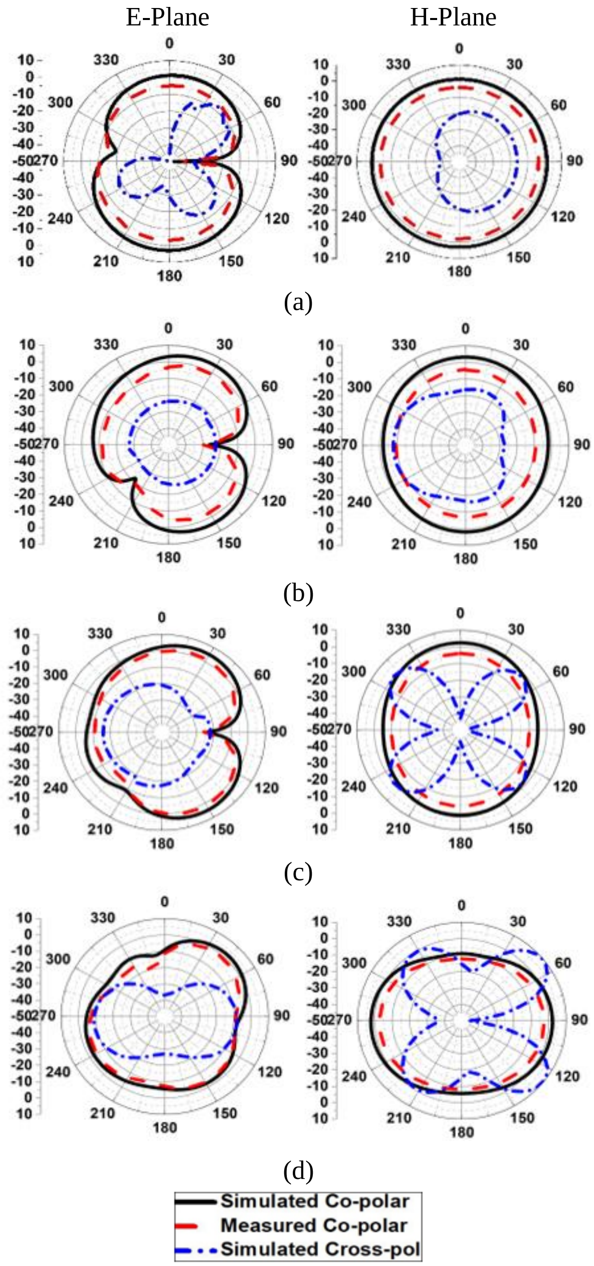


Fig. 6. Measured and simulated radiation patterns at: (a) 2.94, (b) 5.37, (c) 6.09, and (d) 7.02.

Table 2 provides the comparison with the related work. It is evident that the presented work exhibits better performance in terms of compactness, notch bands achieved, and gain.

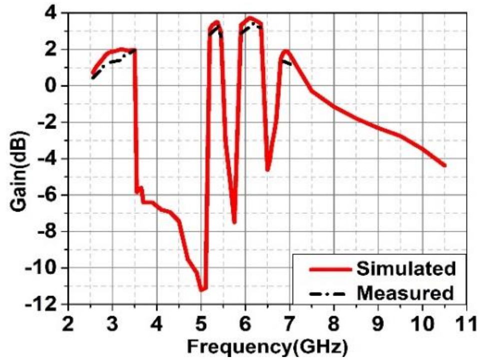


Fig. 7. Simulated and measured gain.

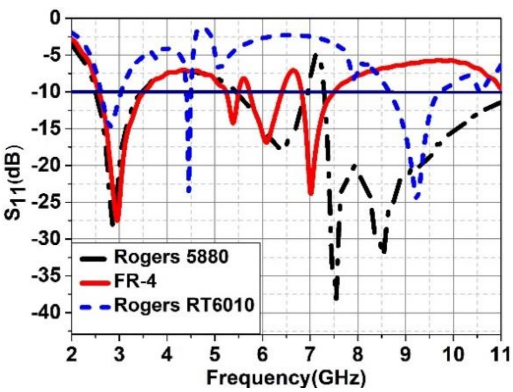


Fig. 8. Substrate analysis of the proposed antenna.

Table 1: Parameters of substrates

Substrate	Permittivity	Notch Bands	Peak Gain (dB)
Rogers 5880	2.2	2	3.505
FR4	4.3	4	3.7
Rogers RT6010	10.2	3	3.37

Table 2: Comparison with related work

References	Size (mm)	Notch Bands	Peak Gain (dB)
[8]	24×42	3	3.6
[12]	25×30.2	3	4
[16]	30*40	1	2
[19]	30*35	2	3.2
Proposed	25*29.5	4	3.7

VI. CONCLUSION

This work presents the design of a compact bowtie slotted circular patch antenna with the quad band-notched characteristics. Good impedance matching of the antenna is accomplished by using a very unique bat-shaped defected ground structure. The undesirable bands between 3.55-5.16, 5.52-5.73, 6.44-6.78 and 7.61-10.6 GHz have been eliminated by incorporating slots in the patch. Thus WiMAX, WLAN and X-band are rejected. A peak gain of 3.7 dB is attained. A reasonable agreement is achieved between simulated and measured results.

ACKNOWLEDGMENT

This work was financially supported by Vinnova through the Vinn Excellence Centers Program and ACTSENA Research Group Funding, respectively.

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