Khurram S. ALIMGEER[1], Shahid A. KHAN[2], Zeeshan QAMAR[3], Syed M. ABBAS[4]

COMSATS Institute of Information Technolgy (1-4), Islamabad, Pakistan

Planar monopole UWB antenna with 5GHz dual notched band characteristics

***Abstract**. These days most of the research work in the area of antenna design is focused on monopole antennas for UWB communications due to their high data rate, precision and low complexity. However, interference effect increases within the Ultra wide Band due to the increasing growth of 802.11a wireless LAN in the frequency band of 5 GHz in many countries. To minimize this closely found in-band interference effect, antennas with closely found notch band characteristics are becoming essential. The idea of band notch is extended in this paper by the placement of parasitic strips at different positions on the bottom of the substrate to achieve dual notches in 5 GHz band. Experimental results show that this technique can be employed to generate sharp controllable notch and/or dual notch bands with reasonable accuracy.*

***Streszczenie.** Przedstawiono projekt anteny do szerokopasmowej komunikacji w paśmie 5 GHz w sieciach bezprzewodowych standardu 802.11a. Właściwości anteny kształtowano przez dodanie dodatkowych pasków w różnych pozycjach. (**Planarna jednobiegunowa antena UWB pracująca w paśmie 5 GHz**)*

Keywords: monopole, Ultra-wide Band, Notched Band, Parasitic Strip.
Słowa kluczowe: antenna szerokopasmowa, antenna planarna

Introduction

High data rate in wireless communication systems is focal feature upon which bunch of research ensue and persist. To enable these features wireless communication systems created momentous demands on antenna designer. The antenna designer has to consider that the antenna should be compact and in ease to integrate with the active devices. In 2002, the FCC authorized to employ Ultra wide band from 3.1 GHz to 10.6 GHz with the limited emission power spectrum [1, 2]. After that, different types of antennas were designed for ultra wide band applications [3-11] and at the same time many challenges cropped up in designing ultra wide band antennas. One of the main problems in ultra wide band is the interference within the band. It is essential to minimize the interference with existing wireless local area network (WLAN) technologies as reported in IEEE 802.11a standard (5.15–5.35GHz and 5.725–5.825GHz) [12]. Many techniques have been developed in minimizing the interference.

One such technique is to use a spatial filter i.e. a frequency selective surface (FSS) above the antenna [13]. This technique is although efficient but requires extensive space. Similarly many antennas were designed for Ultra wide band with band notch characteristics. Some of the approaches are meandered ground Stubs [14], parasitic element for Laptop applications [15], wide slot antenna [16], narrow slit and modified inverted U-slot antenna [17], two monopoles of same size and a strip [18], CPW – fed – Sail boat antenna [19]. A single band rejection characteristic in 5 GHz to 6 GHz is presented in [20, 21]. Single and dual notch bands were created by the help of adding two strips on the main radiator side [22]. However adding the strips on main radiator side increases the dimensions of the patch. The research work presented in this paper extends the idea of dual notches in 5 GHz band by adding three strips at the bottom of the substrate at appropriate places. Closely found dual notch bands are discussed few times in literature because sharp notch bands require larger antenna size. In order to have lesser interference, rejection of undesired bands is challenging issue for the designers.

The placement of the strip with appropriate dimensions and distance from each other enables to control the notch frequency for desired range. Moreover strips at the bottom of the substrate does not require extra space and hence helpful to have compact antenna design. Mathematical model of the notch frequency is obtained using method of least square errors as function of length and distance from the center of antenna is also presented. The antenna is designed using FR-4 Substrate of thickness 1.6mm^2 with ε_r=4.7 and tanδ =0.02.

The size of the patch is 15 × 15 mm^2 printed on a substrate of dimension 30 × 35 mm^2 which is partially grounded i.e. 30 × 12.5mm^2. The geometrical structure and the current distribution of the antenna with three parasitic strips on the bottom of the substrate besides the ground plane is discussed. The paper is organized in sections, as follows:

Design and simulation of the antenna with one parasitic strip

Geometrical structure of top and bottom of designed antenna with parasitic strip is shown in the Fig. 1 and the parameters of the antenna are listed in Table 1. Addition of each upper and lower step in the geometry of the antenna, increases the bandwidth and hence helpful in achieving the UWB characteristics by affecting the coupling between the main radiator and the ground plane. The step size listed in Table 1 is achieved by the fine-tuning of dimensions of step size through iterative process to obtain the wide band impedance matching.

Table 1. The parameters of designed antenna

Parameters	Size (mm)	Upper and Lower steps of Antenna	
L_p	15	Step 1, 6	1x13mm^2
W_p	15	Step 2, 7	1x11mm^2
L_{feed}	13	Step 3, 8	1x9mm^2
W_{feed}	3	Step 4, 9	1x7mm^2
L_{sub}	35	Step 5, 10	1x5mm^2
W_{sub}	30		
L_{gnd}	12.5		

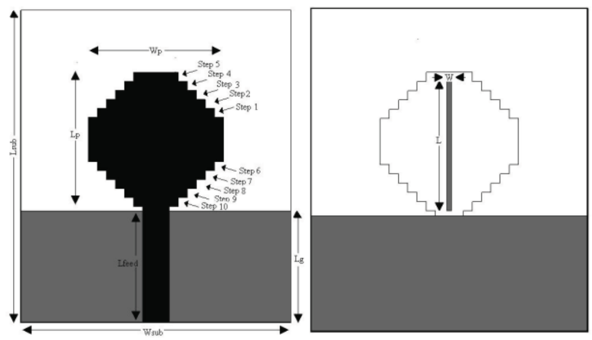

Fig. 1. Configuration of the band-notch UWB antenna (a) top view (b) bottom view.

Geometrical structure

One parasitic strip of width 0.5 mm at the bottom layer of substrate near to the ground plane is introduced in order to achieve notch band characteristics. The width of the parasitic strip is kept constant and the length of the strip is used to tune the notch band. The variations of the width of parasitic strip have negligible effect on the notch frequency. The strip is positioned in the center of the patch as shown in Fig. 1b.

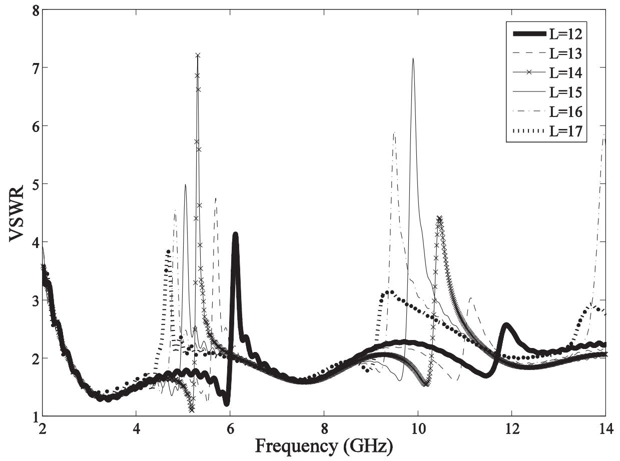

Fig. 2. Simulated VSWR Vs Frequency with constant width of 0.5 mm and variable length of 12 mm to 17 mm for single strip.

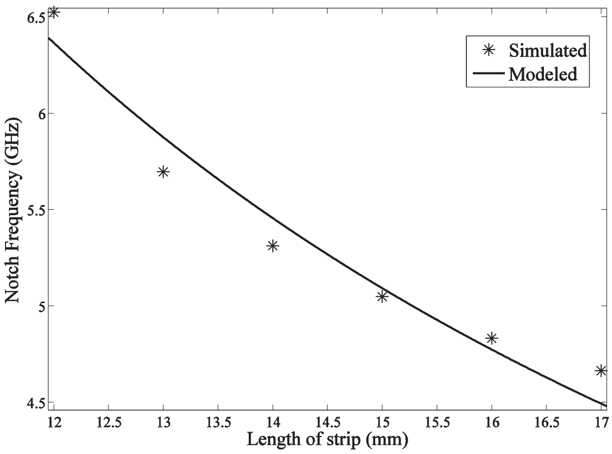

Fig. 3. Notch frequency as a function of Strip length at constant strip width of 0.5 mm.

Simulation results

Simulation result of the antenna is shown in Fig. 2. The length and width of the parasitic strip act as filter to reject the certain frequency [22]. It is observed from simulation results that strip length variation creates momentous effect on the notch frequency. Hence the length of the strip is believed to be a major factor to tune band rejection in case of single strip. However the antenna has poor performance in the range of 9 GHz - 11 GHz. Notch frequencies are decreasing with the increase in length of strip keeping the constant width of 0.5mm as shown in Fig. 3, and also described in 1.

(1) $$f_{\text{notch}} = \frac{C}{2L\sqrt{\varepsilon_{eff}}}$$

where f_{notch} is the frequency in GHz and L is the strip length in mm. It is observed that there is a slight variation in the f_{notch} and it follows the model as described in the 2.

(2) $$f_{\text{notch}} = \frac{a \times C}{2L\sqrt{\varepsilon_{eff}}}$$

where a = 0.0011 and obtained through the method of least square errors.

Frequency of operation as a function of strip length is shown in Fig. 3. The model given in 2 found appropriately fitting the simulated results.

Design and simulation if the antenna width

Two parasitic strips

In previous section it is observed that the length of the parasitic strip plays major role to tune band rejection. Multiple parasitic strips are also employed to achieve similar results with more accuracy. However, because current distribution in multiple parasitic strips is quite complex, reasonable confidence has not yet been placed in analytical methods for determining exact position of parasitic strips on substrate. Therefore, greater reliance has been placed on experimental procedure. Thus by varying distances between two strips the undesired frequency bands have been rejected. Adding two parasitic strips will create capacitive effect [22] not only with the main radiator but also with each other. This interaction is responsible for band notch at certain frequency.

Geometrical structure

Two parasitic strips are introduced on the bottom layer of the substrate in order to create band notch filter. The filter is tuned by varying the distance between the strips. Appropriate positioning of the parasitic strips is found experimentally while keeping their lengths and widths constant (14 mm and 0.5 mm respectively) as shown in Fig. 4.

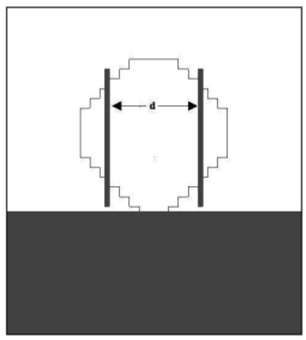

Fig. 4. Geometrical structure of designed antenna with two parasitic strips.

Simulation results

The simulated VSWR with different distances between the strips verses different frequencies is shown in Fig. 5. It is evident from Fig. 5 that band rejection can be achieved and controlled by varying the distance between parasitic strips. The band notch frequency is increasing linearly by increasing the distance between the two strips as shown in Fig. 6. Following relation of notch frequency as a function of distance between the strips and it is mathematically formulated through the method of least square errors:

(3) $$f_{\text{notch}} = \frac{C(d \times a + 1)}{2L\sqrt{\varepsilon_{eff}}}$$

where f_{notch} is the frequency in GHz, d is the distance between the strips in mm and a = 0.07 is the scaling factor found out through mean square error method. The simulated gain plot is shown in Fig. 7 with length and width of each strip kept constant at 14 mm and 0.5 mm respectively and the distance between strips is 6 mm. It shows that there is minimum gain at the notch frequency.

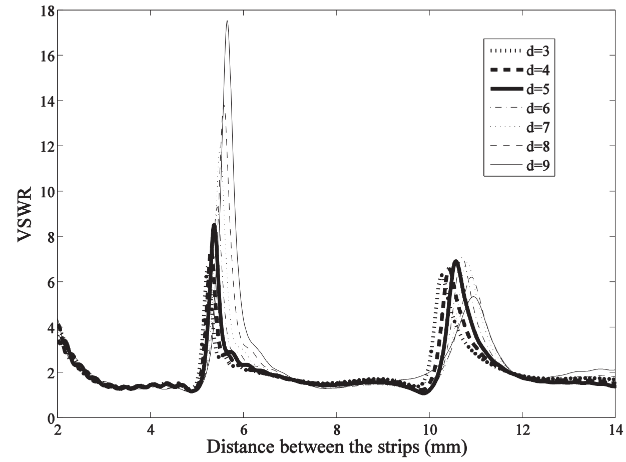

Fig. 5. Simulated VSWR Vs Frequency with the variation of distance between the two strips.

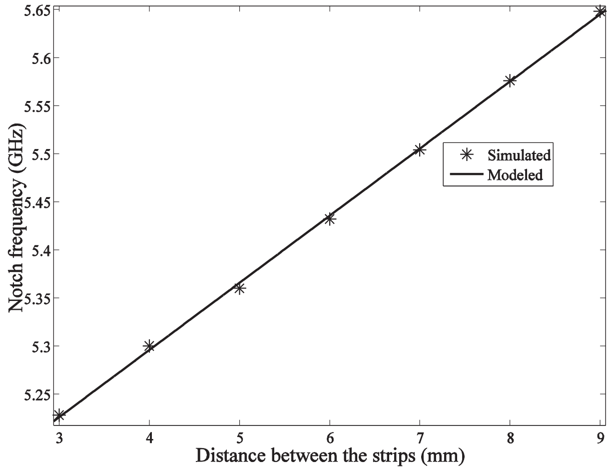

Fig. 6. Notch frequency as a function of distance between the strips.

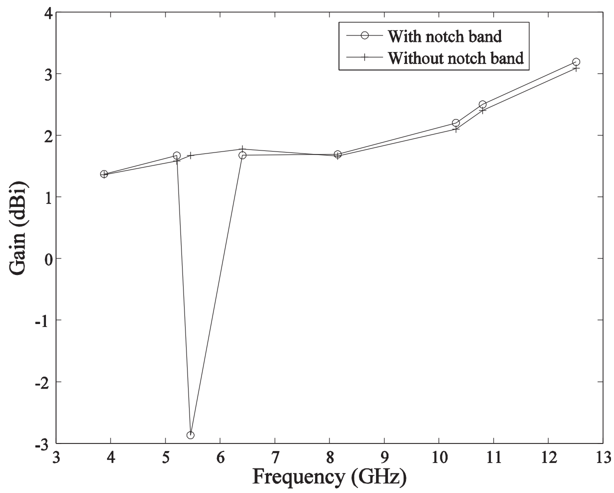

Fig. 7. Gain of antenna with and without notch band for 6 mm distance between the strips.

Design and simulation of the antenna width Three parasitic strips

According to IEEE, 802.11a WLAN there exists two frequency bands i.e. 5.3 GHz and 5.8 GHz that offer less congestion and higher speeds. 5 GHz range is mostly used by high end users especially in corporate and educational type of environments. 5.3 GHz has 8 channels and 5.8 GHz has 4 channels hence total of 12 non-overlapping channels, each of 20 MHz, exists in this range. Moreover card-less phones operates mostly in the range of 5.8 GHz range. As these two bands are heavily in use and causes interference in the UWB band so high interference level in this frequency spectrum leads to the idea of creating an antenna that inherently notches these frequency bands. The proposed structure using three strips at the bottom of substrate, is very useful in creating dual band rejection at such closely found bands. An attempt is made to achieve dual notch band at 5.3 GHz and 5.8 GHz by introducing three parasitic strips of suitable dimensions and at appropriate distance central strip at the bottom of the substrate. The idea of adding strips on bottom of the antenna does not increase the size of antenna.

Geometrical structure

Three parasitic strips are introduced on the bottom layer of the substrate. By using this technique, we obtained the dual notched band. The dimension of the parasitic strips are same i.e. 14 × 0.5 mm^2. The antenna with three parasitic strips is shown in Fig. 8.

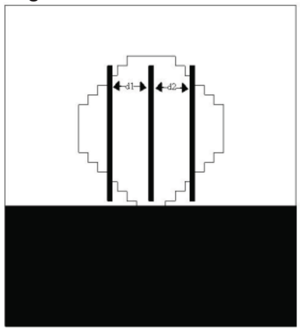

Fig. 8. Geometrical structure of designed antenna with three parasitic strips.

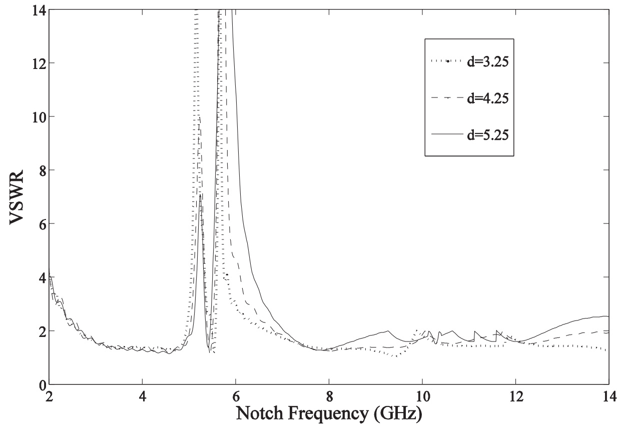

Fig. 9. Simulated VSWR Vs notch frequency with the increasing distance in lateral parasitic strips keeping middle strip at center of the patch.

Simulated and measured results

The simulated VSWR with different distances between the strips verses different frequencies is shown in Fig. 9. The rejected bands for VSWR=2 and 2.5 are tabulated in table 2. The results listed in table 2, clearly demonstrates the dual band rejection behavior of the antenna with three parasitic strips placed on the bottom of substrate at appropriate positions found experimentally. The antenna is then tested using Agilent PNA-X Series Network Analyzer Model- N5242A and compared with the simulated results and shown in Fig 10. Furthermore, Gain of the antenna is presented in Fig. 11. It is clear that there are two notches at the frequency of 5.25 GHz and 5.6 GHz with the lateral strips kept at distance of 3 mm each from central strip. The gain plot is given in Fig. 11 for strips at the distance of 5.2 mm each, from the center strip. The measured radiation patterns are also generated using three strips. The lateral strips are placed at the distance of 3 mm from the central strip. The radiation pattern is shown in the Fig. 12.

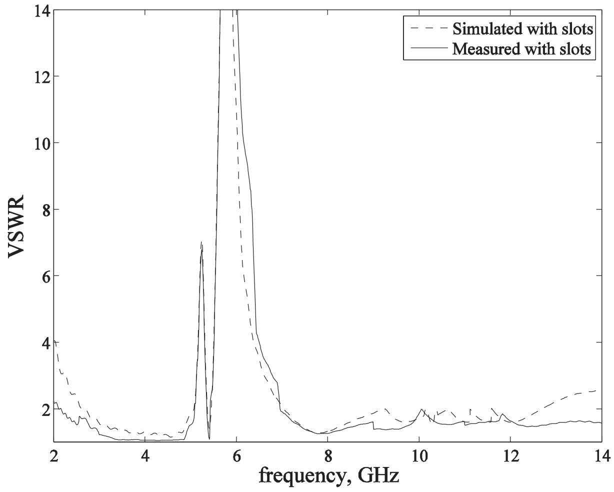

Fig. 10. Simulated Vs Measured return loss with lateral slots at distance of 5.25 mm from central strip.

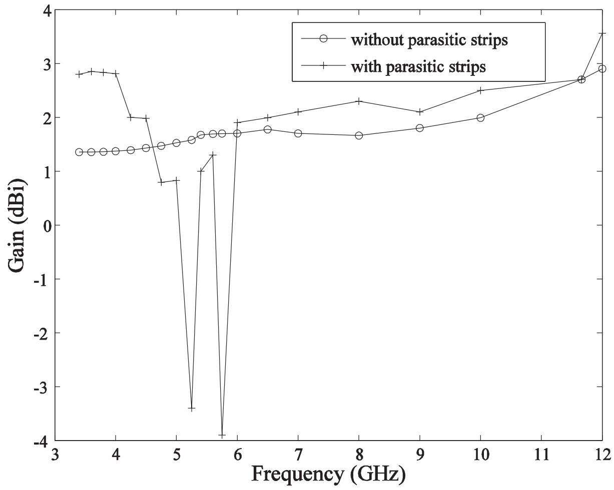

Fig. 11. Gain Vs Frequency for three strips with lateral strips at a distance of 5.25 mm from central strip.

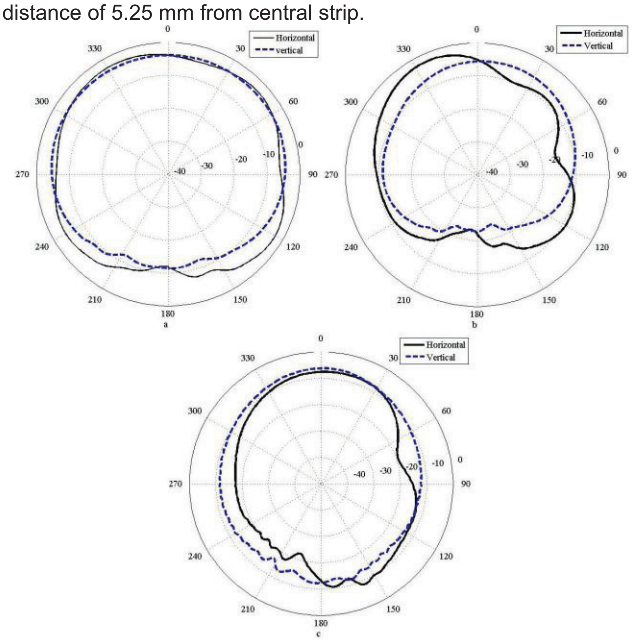

Fig. 12. Measured radiation pattern of three strip antenna at a) 3.99 GHz b) 5.25GHz c) 7.5 GHz

Conclusion

A patch antenna of size 15 × 15 mm^2 printed on partially grounded FR-4 substrate of dimension 30 × 35 mm^2 with 1-3 parasitic strips on the bottom layer of the substrate is designed for UWB applications with single and dual band notched characteristics. The simulated VSWRs with and without parasitic strips are presented and analyzed. Analysis of the results presented show that the undesired frequency band/bands can be rejected by introducing parasitic strip/strips on the bottom layer of the substrate at appropriate positions found experimentally. Closely found dual band rejection in 5GHz band is believed to play a major role in minimizing the in-band interference experienced during UWB communications.

Table 2. Rejected bands for VSWR>=2 and VSWR>=2.5

Distance (mm) and d1=d2=d	Frequency (GHz)			
	VSWR>=2		VSWR>=2.5	
2.75	*4.8–5.55*	*5.6 –6 .58*	*4.94–5.46*	*5.61 – 6.01*
3.25	*4.94 – 5.5*	*5.6 – 6.58*	*5.0 – 5.46*	*5.58 – 6.17*
3.75	*5.0 – 5.43*	*5.5 – 6.76*	*5.0 – 5.42*	*5.54 – 6.38*
4.25	*5.0 – 5.39*	*5.5 – 6.81*	*5.0 – 5.37*	*5.52 – 6.48*
5.25	*5.1 – 5.36*	*5.45 – 7.0*	*5.1 – 5.34*	*5.46 – 6.78*
5.75	*5.0 – 5.36*	*5.41 – 7.1*	*5.1 – 5.33*	*5.44 – 6.91*

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***Authors**: Ph.D. Student Khurram Saleem Alimgeer, Prof. Shahid A Khan, M.S. Student Zeeshan Qamar, Ph.D. Student Syed Muzahir Abbas, COMSATS Institute of Information Technology, Department of Electrical Engineering, RF Communication Lab, Antennas and Microwave Engineering Research Group, Islamabad, Pakistan, 44000, email: khurram_saleem@comsats.edu.pk*