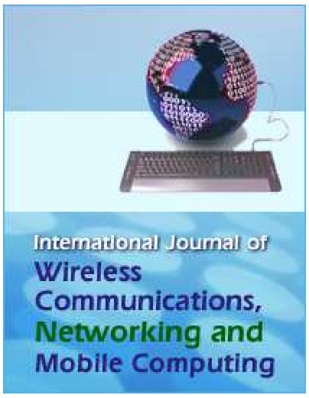
International Journal of Wireless Communications, Networking and Mobile Computing
2014; 1(1): 8-13
Published online September 20, 2014 (http://www.aascit.org/journal/wcnmc)

American Association for Science and Technology



Keywords
Protruded Strips,
Microstrip Antenna,
UWB Application

Received: August 28, 2014
Revised: September 03, 2014
Accepted: September 04, 2014

Application of protruded Γ-shaped strips at the feed-line of UWB microstrip antenna to create dual notched bands

Nasser Ojaroudi

Department of Electrical Engineering, Germi Branch, Islamic Azad University, Germi, Iran

Email address
n.ojaroudi@yahoo.com

Citation
Nasser Ojaroudi. Application of Protruded Γ-Shaped Strips at the Feed-Line of UWB Microstrip Antenna to Create Dual Notched Bands. *International Journal of Wireless Communications, Networking and Mobile Computing.* Vol. 1, No. 1, 2014, pp. 8-13.

Abstract
In this manuscript, a novel design of ultra-wideband (UWB) monopole antenna with dual band-notched characteristic is proposed. The proposed antenna consists of ordinary square radiating patch, modified feed-line with a pair of Γ-shaped strips protruded inside the rectangular slot, and ground plane with a pair of cross-shaped slots. In the proposed design, by cutting a pair of cross-shaped slots in the ground plane, an additional resonance is excited and much wider impedance bandwidth can be produced. To generate single and dual band-notched characteristics, a pair of Γ-shaped strips is protruded inside the rectangular slot at feed-line. The designed antenna has a small size of 12×20×0.8 mm3. The simulated and measured results show that the antenna design exhibits an operating bandwidth (VSWR<2) from 2.9 to 11.5 GHz with 3.3-4.2 GHz and 5-6 GHz rejected bands covering all the 5.2/5.8GHz WLAN, 3.5/5.5 GHz WiMAX and 4 GHz C bands. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. The proposed antenna can be used in UWB systems to reduce interference between UWB and other wireless communication systems such as WLAN, WiMAX and etc.

1. Introduction

There has been more and more attention in ultra-wideband (UWB) antennas since the Federal Communications Commission (FCC)'s allocation of the frequency band 3.1–10.6GHz for commercial use [1]. 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, constant group delay, low profile, easy manufacturing and etc [2]. In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been characterized [3-8].

There are many narrowband communication systems which severely interfere with the UWB communication system, such as the worldwide interoperability microwave access (WiMAX)) operating at 3.3-3.7 GHz and 5.35-5.65 GHz, wireless local area network (WLAN) operating at 5.15-5.35 and 5.725-5.825 GHz, and etc. Therefore, UWB antennas with band-notched characteristics to filter the potential interference are desirable. Nowadays, to mitigate this effect many UWB antennas with various band-notched properties have developed [9-13].

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 in the literature [14-17].

In this paper, a new design of compact UWB monopole antenna with dual band rejection of frequency bands for WiMAX/C/WLAN systems is presented. The antenna is successfully implemented and the simulation results show reasonable agreement with the measurement results. The designed antenna has a small size. Simulated and experimental results show that the proposed antenna could be a good candidate for UWB application.

2. Microstrip Antenna Design and Configuration

The presented antenna fed by a microstrip-line is shown in Fig. 1. The antenna was fabricated on FR4 epoxy substrate with the dielectric constant ε_r= 4.4, h_{sub}=0.8 mm and loss tangent δ=0.02. The radiating patch is connected to a feed line. The proposed antenna is connected to a 50Ω SMA connector for signal transmission. Final values of the antenna design parameters are specified in Table. 1.

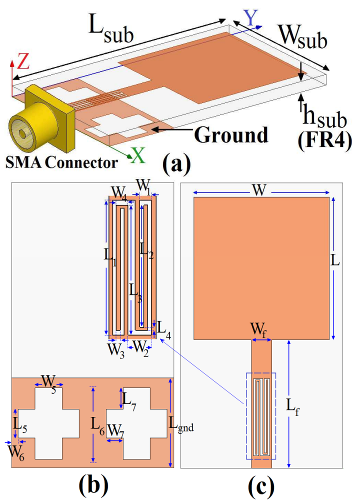


Fig. 1. Geometry of proposed antenna, (a) side view, (b) top layer and (c) bottom layer.

One of the essential parameters for the design of a microstrip antenna is the operation frequency (f_0). As the ultra-wideband (UWB) uses the frequency range from 3.1-10.6 GHz, hence the antenna designed must be able to operate in this frequency range. The resonant frequency selected for antenna design is 4.5 GHz (lower resonance frequency). The dielectric material selected for antenna design is FR4 which has a dielectric constant of the substrate (ε_r) of 4.4. A substrate with high dielectric constant and height of dielectric (h) has been selected since it reduces the dimensions of the antenna. So, the essential parameters for the design are: f_0= 4.5 GHz, ε_r = 4.4 and h = 0.8 mm. The dimensions of the radiating patch along its length have now been extended on each end by a distance ΔL, which is given as:

$$\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)}{(\varepsilon_{eff}-0.258)}\frac{\frac{W_{sub}}{h_{sub}}+0.264}{\frac{W_{sub}}{h_{sub}}+0.8} \quad (1)$$

where h_{sub} is the height of dielectric, W_{sub} is the width of the microstrip monopole antenna and $\varepsilon_{r\,eff}$ is the effective dielectric constant.

Then, the effective length (L_{eff}) of the radiating patch can be calculated as follows:

$$L_{eff} = L + 2\Delta L \quad (2)$$

For a given resonant frequency f_0, the effective length is given as:

$$L_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} \quad (3)$$

For a rectangular microstrip antenna, the resonance frequency for any TM_{mn} mode is given by as:

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2}\frac{(\varepsilon_r-1)}{2}\frac{1}{\left(1+12\frac{h}{w}\right)^{\frac{1}{2}}} \quad (4)$$

The width W of microstrip antenna is given

$$W = \frac{C}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (5)$$

This work started by choosing the dimensions of the design parameters. These parameters including the substrate is $W_{sub}\times L_{sub}$=12×20 mm^2 or about 0.15λ×0.25λ at 4.5 GHz (the first resonance frequency of the ordinary monopole antenna). We have a lot of flexibility in choosing the width of the radiating patch. This parameter mostly affects the antenna bandwidth. As W decreases, so does the antenna bandwidth, and vice versa. This parameter is approximately $\lambda_{lower}/4$, where λ_{lower} is the lower bandwidth frequency wavelength. λ_{lower} depends on a number of parameters such as the radiating patch width as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated.

The last and final step in the design is choosing the length of the resonance and filter elements. In this design, the optimized length of $L_{resonance}$ is set at $0.25\lambda_{notch}$, where

$L_{resonance}$=0.5 (L_3+W_3) +L_2+W_4, for 10.8 GHz (extra resonance frequency). Also L_{notch1}=0.5 (L_1+W_1+W_2) +L_2+W_4 for 5.5 GHz and L_{notch2}=0.5 (L_3+W_3) +L_2+W_4, for 3.9 GHz notched frequency and L_{notch2}=0.5 (L_1+W_1+W_2) +L_2+W_4 corresponds to the first band-notched frequency (3.9 GHz) and second band-notched frequency (5.5 GHz), respectively.

Table 1. *Dimensions of the designed antenna parameters*

Parameter	W_{sub}	L_{sub}	h_{sub}	L_g	L_f	W_f	L
(mm)	12	20	0.8	6	9	1.5	10
Parameter	W	L_1	W_1	L_2	W_2	L_3	W_3
(mm)	10	5.4	0.4	5.1	0.6	5.2	0.2
Parameter	L_4	W_4	L_5	W_5	W_6	L_6	L_7
(mm)	0.1	0.4	2	2	0.5	5	1.5

3. Results and Discussions

In this section, the presented microstrip antenna with various design parameters was constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The analysis and performance of the proposed antenna is explored by using Ansoft simulation software high-frequency structure simulator (HFSS) [18], for better impedance matching.

The structure of the various antennas used for simulation studies was shown in Fig. 2. VSWR characteristics for the ordinary monopole antenna [Fig. 2(a)], the antenna with a pair of cross-shaped defected ground structures (DGS) [Fig. 2(b)], and the proposed antenna [Fig. 2(c)] structures are compared in Fig 3.

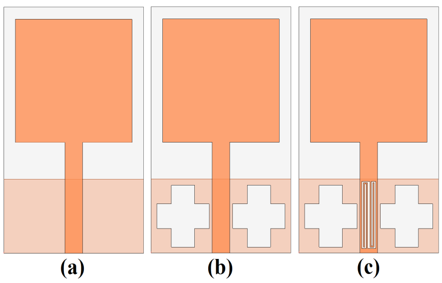


Fig. 2. *(a) Basic structure, (b) monopole antenna with a pair of cross-shaped slots, and (c) the proposed antenna structure.*

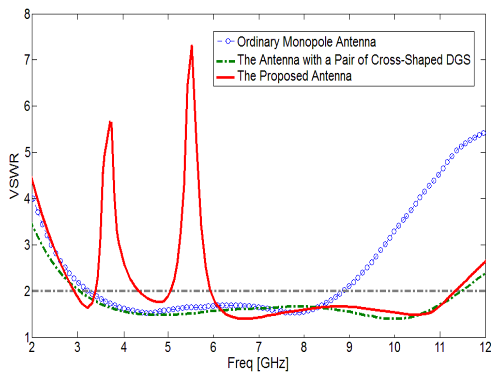


Fig. 3. *Simulated VSWR characteristics for the various antenna structures shown in Fig. 2.*

As illustrated in Fig.3, by cutting the pair of cross-shaped slots in the ground plane, a new extra resonance at higher frequencies (10.8 GHz) is generated and the usable upper frequency of the antenna is extended from 8.8 GHz to 11.5 GHz. To generate the dual band-notched function, a rectangular slot with a pair of protruded Γ-shaped strips at the feed-line is used. The created notched bands covers all the 3.5/5.5GHz WiMAX, 4GHz C-band and 5.2/5.8 GHz WLAN bands.

The simulated current distribution for the proposed antenna at the notched and resonance frequencies of 3.8, 5.5 and 10.8 GHz are presented in Fig. 4. As shown in Fig. 4(a), at the notched frequencies, the current flows are more dominant around of the Γ-shaped strips at feed-line. As a result, the desired high attenuation near the notched frequencies (3.8 and 5.5 GHz) can be produced [19-21]. Also it can be observed in Fig. 4(b), at the extra resonance frequency (10.8 GHz), the current concentrated on the edges of the interior and exterior of the cross-shaped slots in the ground plane.

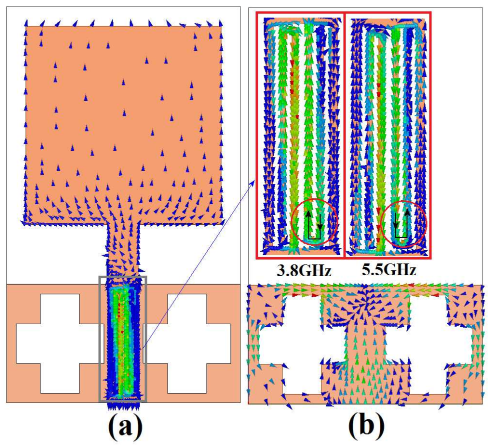


Fig. 4. *Simulated surface current distributions for the proposed antenna at (a) notched frequencies, and (b) resonance frequency.*

Fig. 5 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna has the frequency band of 2.9 GHz to 10.5 GHz with two notched bands around of 3.3-4.2 GHz and 5-6 GHz.

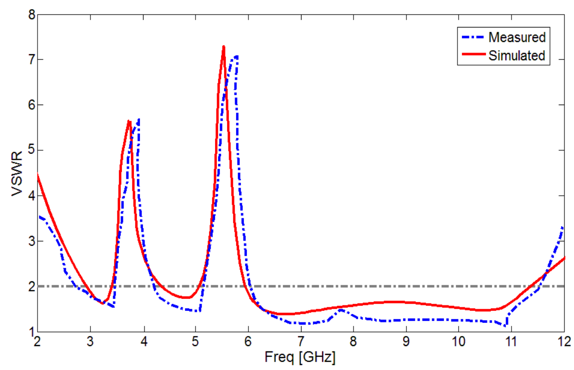


Fig. 5. *Measured and simulated VSWR characteristics of the proposed antenna.*

Fig. 6 depicts the measured radiation patterns including the co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that nearly omnidirectional radiation pattern can be observed on x-z plane over the whole UWB frequency range, especially at the low frequencies. The radiation patterns on the y-z plane are like a small electric dipole leading to bidirectional patterns in a very wide frequency band. With the increase of frequency, the radiation patterns become worse because of the increasing effects of the cross polarization [22-23].

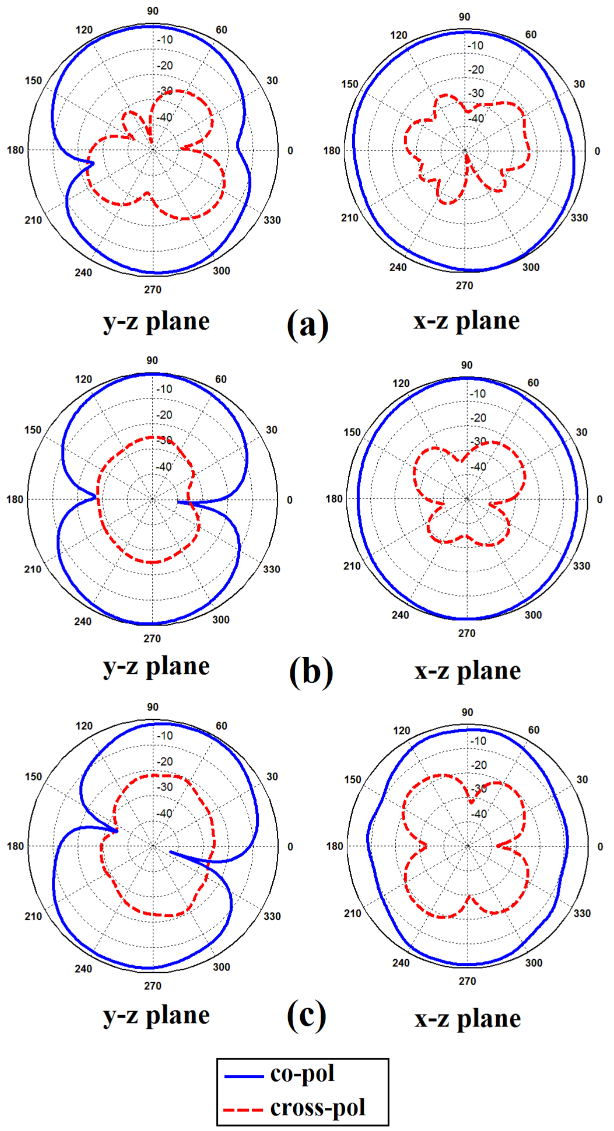


Fig. 6. Measured radiation patterns of the proposed antenna, (a) 4.5 GHz, (b) 7 GHz, and (c) 11 GHz.

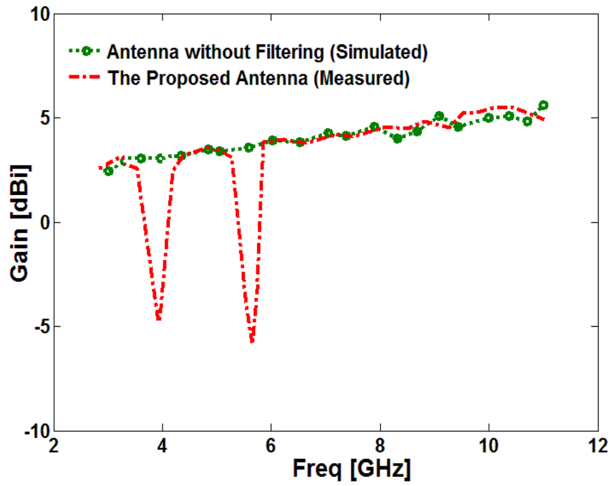


Fig. 7. Measured and simulated maximum gain versus frequency for the proposed antenna w/o notched property.

Measured and simulated maximum gain of the proposed antenna w/o notched property was shown in Fig. 7. Two sharp decrease of maximum gain in the notched frequencies (3.8 and 5.5 GHz) are shown in Fig. 7. For other frequencies outside the notched frequencies, the antenna gain with the filters is similar to the antenna gain without them. As illustrated, the antenna has sufficient and acceptable gain levels in the operation bands [24].

In UWB systems, it is important to study the temporal behavior of the transmitted pulse. The communication system for UWB pulse transmission must limit distortion, spreading, and disturbance as much as possible.

Group delay is an important parameter in UWB communication, which represents the degree of distortion of pulse signal. The key in UWB antennas design is to obtain a good linearity of the phase of the radiated field because the antenna should be able to transmit the electrical pulse with minimal distortion. Usually, the group delay is used to evaluate the phase response of the transfer function because it is defined as the rate of change of the total phase shift with respect to angular frequency (6). Ideally, when the phase response is strictly linear, the group delay is constant.

$$group\ delay = -\frac{d\theta(w)}{dw} \tag{6}$$

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. As expected before, the groups delay variation at notch bands from 3.3 GHz up to 4.2 GHz and 5 GHz up to 6 GHz WiMAX/C/WLAN, with respect to other frequencies is more. Therefore, the proposed antenna is suitable for modern UWB communication systems [25-27].

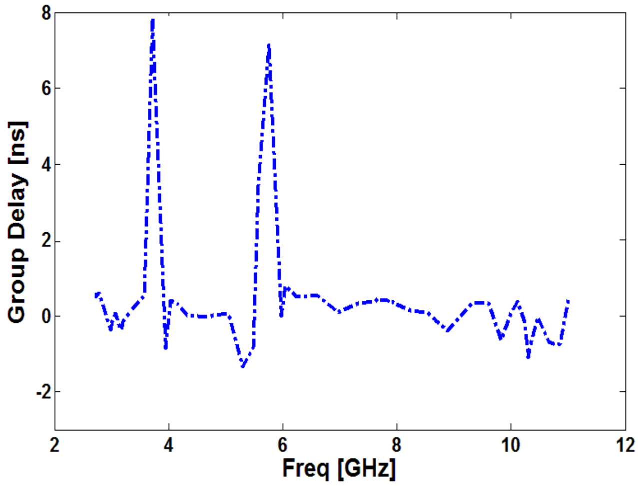


Fig. 8. *Group delay characteristic of the proposed antenna.*

4. Conclusion

In this paper, a new antenna structure is proposed that provides double stop-band notches for various UWB applications. Main novelty of the proposed design is the application of protruded Γ-shaped strips at the feed-line as resonator to create single and double band-stop characteristics. The fabricated antenna has the frequency band of 2.9 to over 11.5 GHz with two rejection bands around 3.3-4.2 GHz and 5-6 GHz covering all the 3.5/5.5 GHz WiMAX, 4 GHz C-band and 5.2/5.8 GHz WLAN systems. The antenna has an ordinary square radiating patch, therefore displays a good omni-directional radiation pattern even at higher frequencies. The proposed antenna has a simple configuration and small size. Simulated and measured results are presented to validate the usefulness of the proposed antenna structure for microwave imaging system applications.

Acknowledgment

The author is thankful to Microwave Technology (MWT) Company staff for their beneficial and professional help (www.microwave-technology.com).

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