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A Monopole Antenna with Notch-Frequency Function for UWB Application

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Abstract

A new Ultra-Wideband Antenna with notched band performance for WiMAX is proposed. The antenna has an extended impedance bandwidth from 3 up to 12GHz (120%). The band-notched can be controlled by adjusting the length of the rectangle slot. In order to obtain Omni-directional wide bandwidth antenna with uniform radiation pattern, rounded corners ground plane with two L-shaped slots are utilized to the antenna. The antenna has a compact size 21×17mm^2, which is printed on an FR-4 substrate with 1mm thickness. The experimental results show that the proposed low cost and compact antenna has a good efficiency in terms of return loss and gain.

1. Introduction

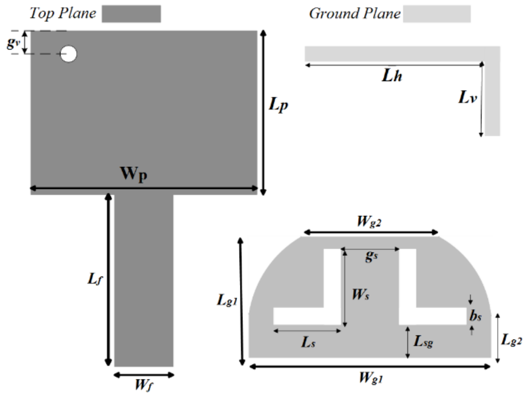
Nowadays, UWB wireless systems and their applications have been developed tremendously. This interest has grown after the establishment of U.S. Federal Communications Commission (FCC) allocation of the frequency band on 3.1–10.6 GHz for commercial use [1]. Due to the set of benefits including simple structure, small size, low cost, high degree of reliability, robustness against jamming, low power consumption, and high data rate transmissions plenty of planar microstrip antennas with various configurations have been experimentally characterized and published in reputable journals [2-4].

One of the major drawback of UWB systems is that the frequency range of 3.1 and 10.6 GHz cause interference to the existing wireless communication systems, such as wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands, IEEE 802.16 for the Worldwide Interoperability for Microwave Access (WiMAX) system operating at 3.3–3.6 GHz. Therefore, new UWB antennas with single and dual notched bands are thought after to minimize the interference with other wireless communication systems. Recently, multiband stopped UWB antennas based on various techniques have been proposed in literature [5–8]. In order to filter the interference frequency bands, there are various techniques and methods such as the fractal structures, shorting pine, slots, Electromagnetic Band Gap (EBG), and so on [9-10]. These aforementioned methods can achieve proper single or dual stop-band properties, but some of them are with large size or complicated design procedure which makes them unsuitable for the UWB antenna candidates.

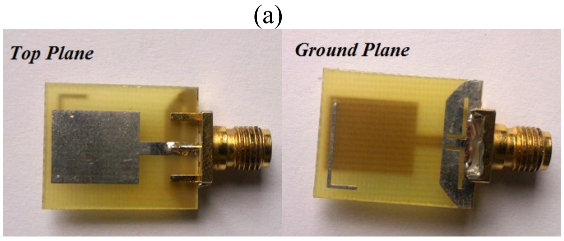
In this paper, a new UWB antenna with notch-frequency property for WiMAX is presented. The antenna has a wide impedance bandwidth from 3GHz to 12GHz and compact size of 21×17mm^2 which is printed on low cost FR-4 substrate. To achieve extended impedance bandwidth, rounded corners are utilized on the ground plane. It has been shown in [11] that gradual increasing of gap space by adopting rounded corners is an advantageous for maintaining a good impedance matching across the UWB band. At the same time, the rounded corners increase the length of the current path from the feed point to the vertices of the ground plane which helps for reducing the antenna size. Also, they can gradually change the electric current direction, which improves the radiation pattern. In order to obtain single notched band in WiMAX, two slots are etched off both of the elliptic patches. The antenna is successfully fabricated and measured and the experimental results show favorable agreement with theoretical analysis and simulations. Section II describes the details of antenna design, discussions on results is presented in Section III followed by conclusive comments in Section IV.

2. Antenna Design

The geometry of the proposed antenna is exhibited in Figure 1(a). The antenna is printed on an FR-4 substrate of 21×17×1mm^3, symmetrically, with relative permittivity $\varepsilon_r = 4.4$. The printed monopole antenna with a basic rectangular patch with dimensions of 12×10mm^2 on the top of the substrate is connected to a 50Ω microstrip feed line. The optimal design parameters obtained by parametric study for the proposed antenna are shown in Figure 1. The parameters values are summarized in Table 1. In order to obtain a required impedance matching, the rounded ground corners and couple of inverted L-shaped slots are etched on the partial ground as shown in Figure 1(a). Figure 1(b) exhibits photograph of fabricated antenna. One L-shaped strip printed on the bottom of substrate is depicted in Fig. 1(a). By connecting this parasitic element to the patch, through via pins with diameter of 0.5mm, filtering capability is added to the full band antenna. The horizontal section of the L-shaped strip is constant and the width of all strips is 2mm. Details of the antenna design with simulation and experiment results are presented in the next section.



(a)



(b)

Figure 1. (a) Geometry of the proposed antenna, (b) Photograph of fabricated antenna.

Table 1. Parameters values of fabricated antenna (in mm)

L_p	W_p	L_f	W_f	W_{g1}	W_{g2}	g_v
12	10	8	1.9	17	11	1
L_{g1}	L_{g2}	L_s	W_s	L_{sg}	b_s	g_s
4.5	1.4	5.5	2.5	1.5	0.5	1

3. Results and Discussion

The performance of the antenna at parametric studies has been investigated to find optimized parameters using Ansoft High Frequency Simulation Structure (ver.13) based on the finite element method (FEM). Figure 2 shows the design procedure of the antenna with their return-loss characteristics. In Figure 2. Ant. 1 (labeled as First) consists of partial rectangular ground and a radiating patch in the form of simple rectangle which is connected to the 50Ω feed line. In Ant. 2 (labeled as Second) two over corners of the ground plane are rounded. In addition, Ant. 3 (labeled as Third) has a couple of two L-shaped slots in its ground plane which have an important role on the impedance matching in comparison with the first and second antenna. The truncated ground plane creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly pure resistive input impedance it can be observed from these three antennas that the ground plane geometry and L-shaped slots account the main reasons for such wide bandwidth.

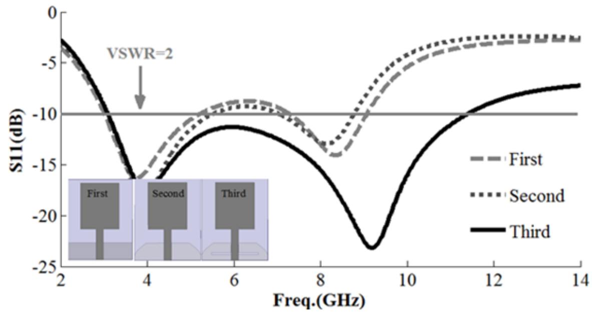


Figure 2. The return loss of the proposed antenna over the band.

In order to generate single stop band at center frequency at 3.5 GHz, one inverted L-Shaped strip with the width of 0.5mm and the length of $\lambda/4$ at the desired center frequency of the rejection band is connected to rectangular patch through a via hole. Since the resonator is connected to ground through 'via', it can be referred as a quarter-wavelength resonator. To estimate the center frequencies at which the rejected band is achieved, one may use the following formulas.

$$f_r = \frac{c}{4(l_1+l_2+h_b)\sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\sqrt{\varepsilon_{eff}} = \sqrt{\frac{\varepsilon_r+1}{2}} \cong 1.64 \tag{2}$$

Where l_1 and l_2 are horizontal and vertical strip length respectively and h_b is the substrate height.

The effect of via in VSWR characteristics can be studied in Figure 3. As it is apparent in Figure 3 by applying via, the notched frequency band edge is decreased from approximately 5.8GHz to 3.5GHz. As a result, it can be utilized to narrower notched band without increasing antenna size.

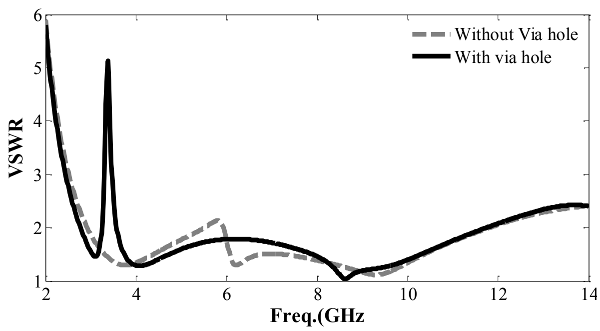


Figure 3. The comparison of VSWR characteristics for two cases of the antenna with via and without via.

The length L of the stripline ($L = L_v + L_h$) is mainly great effect on the stop band of the antenna. In this study L_h is fixed at 11mm while L_h varies between 1 to 7mm.The simulated VSWR for different values of L_h are shown in Figure 4. As illustrated in Figure 4, an increase in length L of the stripline from 1 to 7mm, the center frequency of the rejected band shifts downward from 3.8 to 3.3GHz. Also the band-stop filter can be electrically tuned by changing the length of the L strip.

Regarding to defected ground structures (DGS), the creating slots in the ground plane provide an additional current path. Moreover this method changes the inductance and capacitance of the input impedance which in turn leads to change in the bandwidth. The DGS applied to a microstrip line causes a resonant character of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot. Therefore, by inserting two L-shaped slots at the ground plane and carefully designing its parameters, much enhanced impedance bandwidth is achieved. As shown in Figure 1, these slots are symmetrical with respect to the longitudinal directional and distance of 1 mm (about $0.5W_f$) from the ground's center line. The simulated input impedance of the antenna with and without the L-shaped slots is provided on a Smith chart in Figure 5. It is clearly seen that two resonant modes are excited with good impedance matching in the antenna with L-shaped slots compare without them.

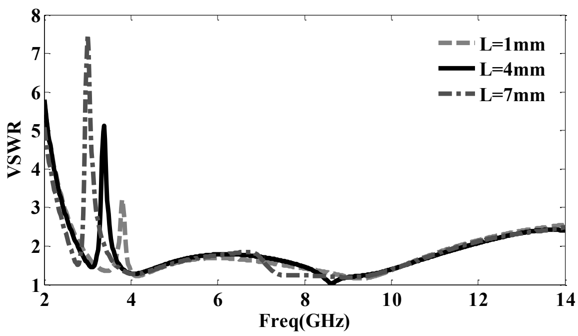


Figure 4. Simulated antenna with L_h is fixed at 11mm while L_h varies between 1 to 7mm.

In UWB systems, the information is transmitted using short pulses. Therefore, it is crucial 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 antenna 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. Ideally, when the phase response is strictly linear, the group delay is constant [6].

$$\text{group delay} = \frac{-d\emptyset(\omega)}{d\omega} \tag{3}$$

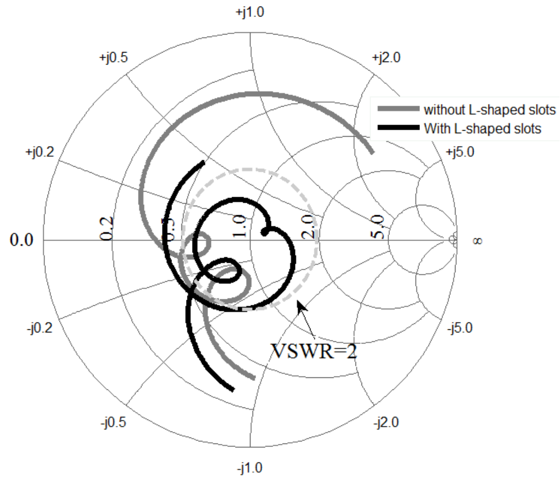


Figure 5. Simulated input impedance of the antenna with and without the L-shaped slots.

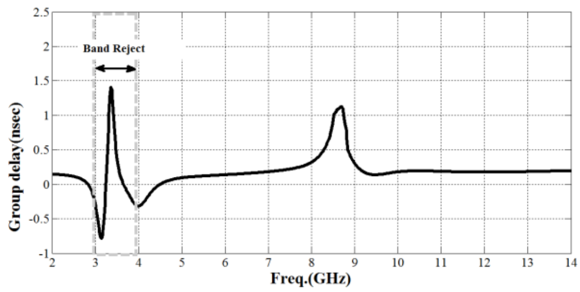


Figure 6. Group delay of the proposed antenna.

As depicted in Figure 6, the group delay variation for the proposed antenna is presented which its variation is approximately constant and less than 0.3ns over the frequency band of interest except notched frequency band (WiMAX), 3.5 GHz, which ensure us pulse transmitted or received by the antenna is not distort seriously and retain its shape. The measured VSWR of the fabricated antenna is shown in Figure 7 and the measured radiation patterns at 4, 8.5GHz are depicted in Figure 8. It can be seen that the antenna has a nearly omnidirectional radiation pattern in the H-plane (y-z plane) and a dipole-like radiation pattern in the E-plane (x-z plane). Another point is that difference between co and cross polarizations is nearly 20dB that it can be acceptable. Measured gain of the proposed antenna is apparent in Figure 9. A sharp drop of gain is displayed in the notched frequency band at 5.5GHz. For other frequencies outside the notched frequency band, the antenna gain is almost flat and it fluctuates from 1 to 2dB. It should be noted that the low gain of the antenna is to the result of compact size of the antenna ($21 \times 17 mm^2$).

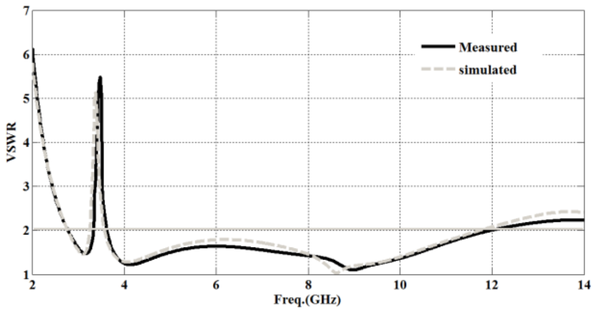
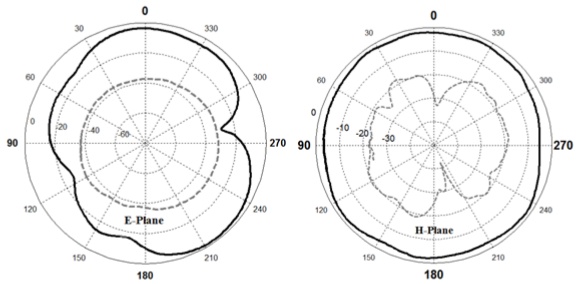
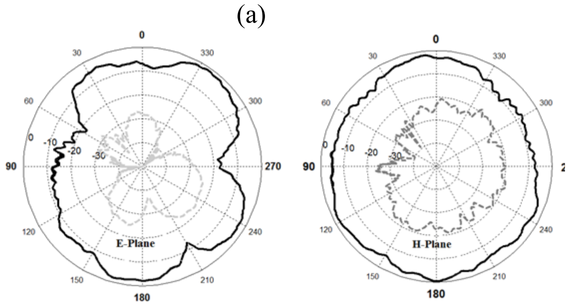


Figure 7. Simulated and measured VSWR characteristics.



(a)



(b)

Figure 8. Measured radiation patterns of the proposed antenna at (a) 4GHz and (b) 8.5GHz.

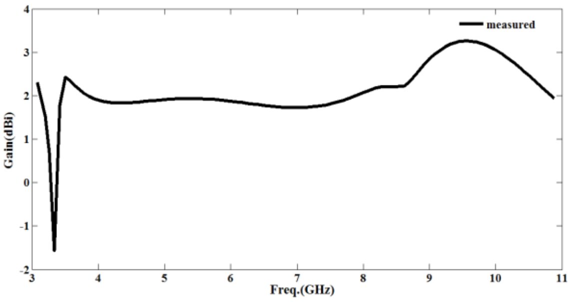


Figure 9. Measured gain for the proposed antenna.

4. Conclusion

A new UWB planar antenna with single notched band on WiMAX of 3.5GHz has been presented. The antenna is able to cover impedance bandwidth form 3GHz to 12 GHz (120%). Meanwhile, the antenna has a compact size as small as $21\times17mm^2$ which is less than the area of the presented antennas in [2-3, 5-11] and it has the maximum bandwidth regarding its small size. The experimental results for VSWR, Radiating pattern, Gain were presented in this letter indicating the proposed antenna is a good candidate for UWB communication systems.

5. References

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