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Compact Band-notched UWB Antenna Design Based On Transmission Line Model

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Abstract – In order to avoid the interference from existing narrowband communication systems, this paper proposes a compact band-notched UWB (ultra wideband) antenna with size of 12mm×22mm ×1.6mm. Transmission line model is applied to analyzing wide impedance matching characteristic of the modified base antenna, which has a gradual stepped impedance feeder structure. The proposed antenna realizes dual band-notched function by combining two biased T-shaped parasitic elements on the rear side with a window aperture on the radiation patch. The simulation current distributions of the antenna reflect resonant suppression validity of the two methods. In addition, the measured radiation characteristics demonstrate the proposed antenna prevents signal interference from WLAN (5.15-5.825GHz) and WiMAX (3.4-3.69GHz) effectively, and the measured patterns show the antenna omnidirectional radiation in working frequencies.

Keywords: UWB antenna, Notched band, Transmission line model, Gradual stepped impedance matching, Parasitic element, Window aperture

1. Introduction

In 2002, UWB was permitted to apply in civil areas with frequencies from 3.1 to 10.6 Hz [1] by the Federal Communication Commission (FCC), so UWB antenna became an important antenna type that covered wider frequency range. However there are several existing narrow wireless communication systems within the UWB bands, such as WLAN (2.4-2.4835GHz) in IEEE 802.11b/g/n standards, WLAN (5.15-5.825GHz) in IEEE 802.11a standard, WiMAX (2.5-2.69GHz, 3.4-3.69GHz, 5.25-5.850 GHz), C-band (3.7-4.2GHz) and X-band (7.25-7.75GHz, 7.9-8.4GHz) satellite communication systems. Microwave band rejection filters can be used at the leading end of UWB antenna device to avoid the interference from the narrow systems. But it will bring in the problems at the aspects of volume, complexity and impedance matching of the system at different levels. Due to the aforesaid reasons, it is important to design a band-notched antenna directly based on UWB antenna. At present the major structures of band-notched antennas have different apertures on radiation patch or ground plane including U-shaped, L-shaped, arc-shaped slots [2-7]. Certain frequency resonance is caused by these apertures to change the radiation performances of UWB antenna. In addition, adding small resonators inside the wide aperture [8, 9] and parasitic elements near the radiation patch [10-12] both realizes band-notched function at specified frequency bands.

A novel dual band-notched UWB antenna structure is presented in this paper. In order to achieve the design of the UWB antenna more effectively, the printed monopole antenna model is advanced by applying gradual conduction band and coplanar waveguide (CPW) feed structure. Based on transmission line theory, the antenna structure is designed and optimized. Finally the designed UWB antenna achieves two rejected bands with biased T-shaped parasitic elements on the rear side and the window slot on the radiation patch together.

2. Design of the Base Antenna

The base antenna is printed on a rectangular FR4 substrate with the thickness h 1.6 mm, the relative permittivity ε_r 4.4 and the loss tangent 0.02 depicted in Fig. 1. Then the effective permittivity is formulated as:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{W}\right)^{-1/2} \tag{1}$$

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

where c is the velocity of light and f_r is the resonant frequency. The value of width W should be less than the result of Eq. (2), or else higher order modes will cause the field distortion. The following formula is to compute antenna length L as:

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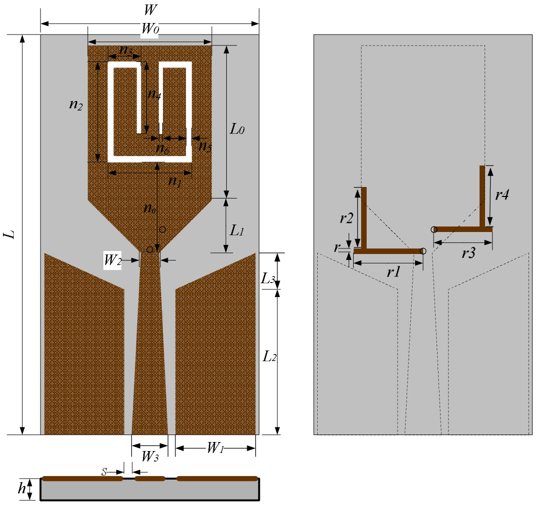


Fig. 1. Geometry of the proposed UWB antenna with two notched bands

$$L \approx \frac{c}{2 f_r \sqrt{\varepsilon_e}} \tag{3}$$

From the above calculations the size of the base antenna is chosen as $12 \times 22\text{mm}^2$ smaller than the common UWB antennas[13-16]. The antenna has the CPW feed structure that is easy to manufacture and suitable for hybrid integrated circuits of the microwave and millimeter wave.

The antenna impedance matching is crucial for broader bandwidth of UWB system. In order to have 50 ohms characteristic impedance the stepped impedance microstrip feeder is selected. The more steps exist, the better characteristic impedance will be. But feeder with too many steps will cause the increase of the total electrical length, which might exceed the calculated size by resonant frequency and cause more difficulties for antenna production. Two stepped impedance construction is generally used for designing UWB antenna [17]. The gradual conduction band antenna model with CPW feeder is applied to satisfy the wider impedance matching characteristic as same as the stepped impedance structure. The novel matching structure makes input impedance vary within a small range in a wider bandwidth.

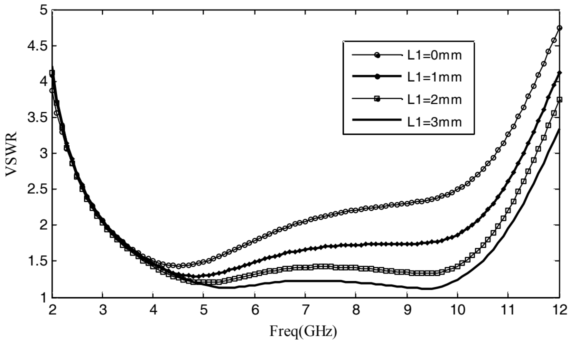


Fig. 2. VSWR of the base antenna with different L1

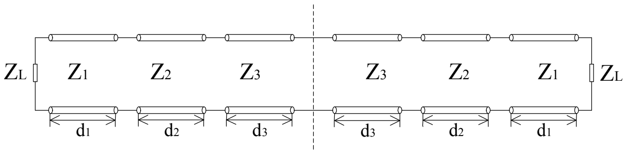


Fig. 3. Corresponding transmission line model

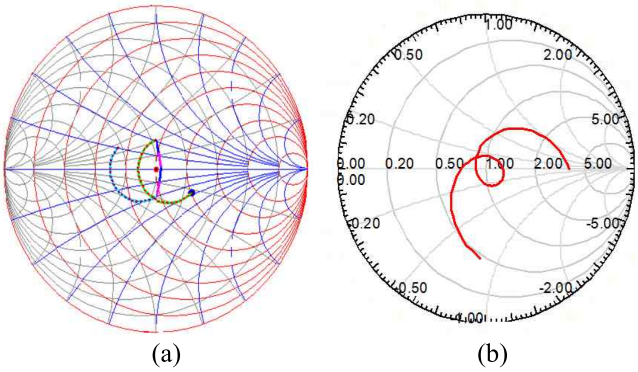
In the beginning, the radiation patch shape of the antenna is designed to be a rectangle shape. Changing the rectangle patch shape into a right angle position could decrease current discontinuity and broaden the frequency range. Fig. 2 depicts the variation bandwidth performance of the base antenna for different values of L1.

Through optimization model parameters of the base UWB antenna are described as below: W_0=7mm, W_1= 4.8mm, W_2=1.1mm, W_3=1.8mm, L_0=8.5mm, L_1=3mm, L_2= 8mm, L_3=1.8mm.

Here transmission line theory is applied to model UWB antenna. Transmission line can be represented by characteristic impedance Z_0 and length d. The radiation part of antenna can be represented by arbitrary loaded impedance. The transmission line is made up of the lower part of the antenna and feeder. So the base antenna can be regarded as a transmission line in Fig. 3.

In transmission line model, characteristic impedance Z_1 and loaded impedance Z_L of the first section depend on half width and length of the original rectangle radiation patch. The beveled square processing corresponds to insertion the second transmission line with parameters Z_2 and $d2$. The gradual stepped feeder reflects the third transmission line parameters Z_3 and $d3$. In fact the improvement in the base antenna structure can be expressed by transmission line model totally. Fig. 4 shows the Smith Chart contrast of transmission line and base UWB antenna.

Comparing their effects on the Smith chart, both transmission line model and base UWB antenna have analogous rotation traces. The loop near the matching point shows, a new resonate frequency is added to extend frequency range and that improves matching performance of the UWB antenna.



(a) (b)

Fig. 4. Smith chart for two models: (a) transmission line model; (b) base UWB antenna

3. Design of Notched Bands

To avoid the potential interference from WLAN and WiMAX systems, parasitic elements and apertures methods are applied to generate band-notched performance base on above UWB antenna model. The specific notched geometry is shown in Fig. 1.

3.1 Parasitic elements

According to the analysis of the field structure, two analogous T-shaped parasitic elements, named biased T-shaped parasitic elements as below, are placed on the rear side of the antenna to realize the notched band of 5.15-5.825GHz. They are connected to the radiation patch via two cylindrical pins. The length of biased T-shape parasitic element l_{n1} has a relationship with notched resonate frequency f_{n1}.

$$f_{n1} = \frac{c}{4 l_{n1} \sqrt{\varepsilon_e}} \tag{4}$$

In practice the effective permittivity of the antenna can be simplified as:

$$\varepsilon_e \approx \frac{\varepsilon_r + 1}{2} \tag{5}$$

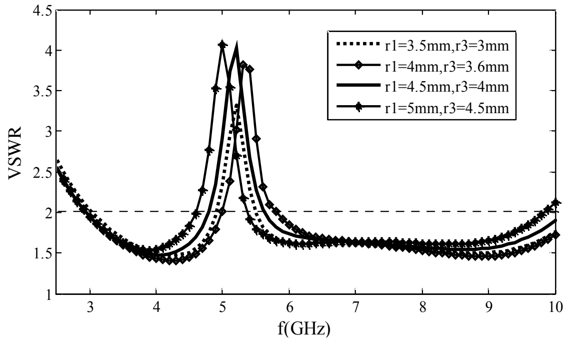


Fig. 5. VSWR of the band-notched antenna with different r1 and r3

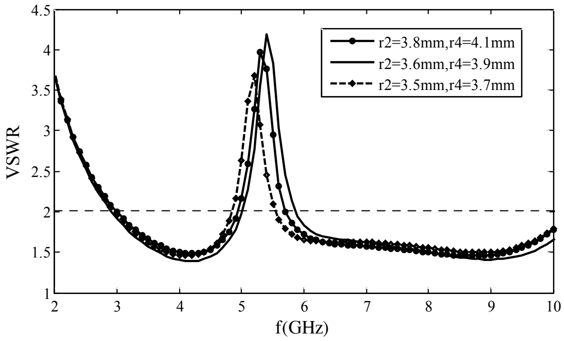


Fig. 6. VSWR of the band-notched antenna with different r2 and r4

Because the dimension of the base antenna is smaller and compact, parasitic elements must bend to reach the requirement of notched frequency. Two biased T-shaped parasitic elements are approximately equal in size.

$$l_{n1} \approx \mathrm{r1} + \mathrm{r2} \approx \mathrm{r3} + \mathrm{r4} \tag{6}$$

The VSWR curves of one notched band antenna with various r1 and r3 are illustrated in Fig. 5. When r1 is 3.5mm and r3 is 3mm, the shape of parasitic elements turns to be L-shape and the performance of notched function is worse than others. Therefore biased T-shape structure is better than L-shape. Fig. 6 shows different values of r2 and r4 impact on the notched centre frequency. The reason for chosen dual T-shaped structure is that they produce resonance effects simultaneously, increase the value of VSWR on the notched center frequency, and improve the notched ability of the antenna with one T-shaped parasitic element.

3.2 Window aperture

To gain the second notched band of 3.4-3.69GHz, another band-notched method-slotting window on the radiation patch is used. The length of the window aperture l_{n2} has a relationship with the second notched resonate frequency f_{n2} as Eq.(4). Comparing with the first notched band, f_{n2} is smaller and l_{n2} is longer, so l_{n2} should be bent at multiple positions.

In order to avoid the inference on the first notched band, the window aperture should be placed on suitable location of patch. The value of n_0 is the distance from the window aperture to patch bottom which influence the dual band-notched characteristic depicted in Fig. 7. When n_0 is 1mm or 2 mm, the window aperture coincides with biasd T-shaped parasitic elements at the vertical view the notched antenna. The overlap makes the fist notched band almost disappear. When n_0 is 5 mm, the second notched band has the least influence on the first band and the characteristics of two notched bands are more independent.

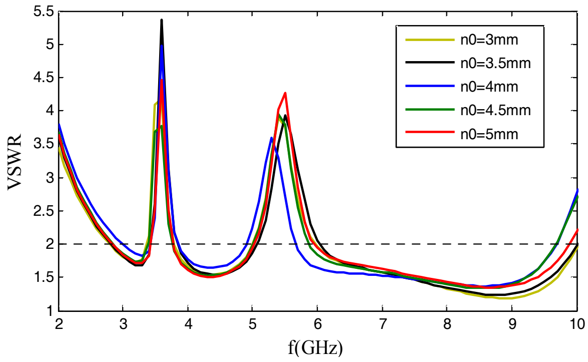


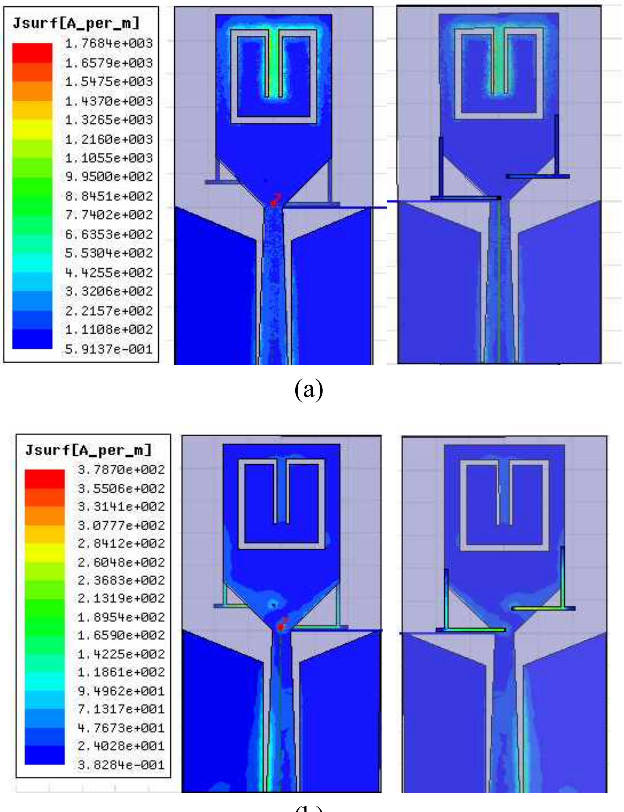
Fig. 7. VSWR of the dual band-notched antenna with different n_0

4. Experimental Results and Discussion

All the reasonable sizes of the notched UWB antenna are determined by designing and optimizing the structures of parasitic elements and window aperture. The fabricated band-notched UWB antenna is shown in Fig. 8, which filters 3.43-3.77GHz and 5.05-5.95GHz.

Fig. 9 shows the simulated surface current density over the proposed antenna and proves the correctness of the notch structures. At the first notch center frequency 5.5GHz, the strongest currents exist around the biased T-shaped parasitic elements. But the current distribution concentrates around the window aperture at the center frequency of the second notch 3.6GHz.

Fig. 8. Geometry of the fabricated band-notched UWB antenna



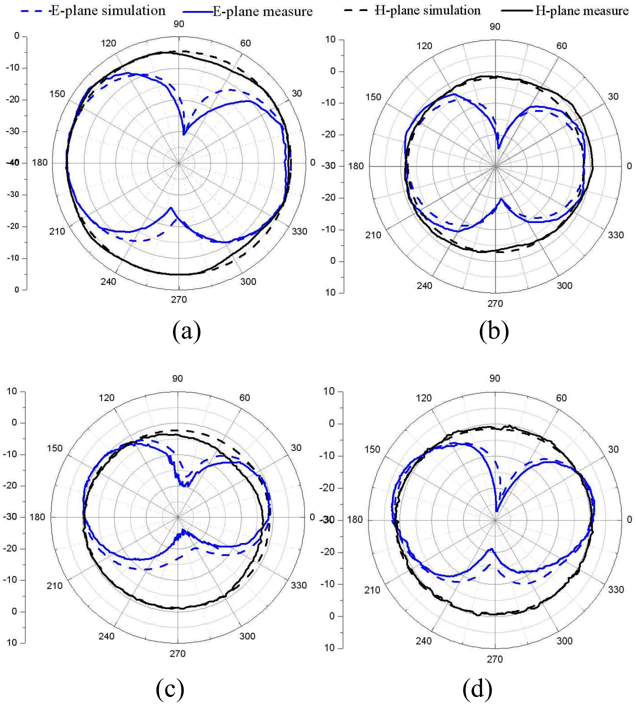
(a)

(b)

Fig. 9. Current distributions at band-notched frequency: (a) 3.6GHz; (b) 5.5GHz

The simulated and measured E-plane and H-plane radiation patterns of the proposed antenna are shown in Fig. 10 for four sampling working frequencies. As observed, H-plane patterns have omnidirectional radiation characteristic, and E-plane patterns are toroidal, as expected for this type of UWB antenna. The measured patterns at 8.5GHz are nearly similar to the simulations because the frequency point is far away from two notched bands. However, as frequency points(3GHz, 4.5GHz and 6.5GHz) are close to the notched bands, the patterns are slightly asymmetric and inevitably deviate from simulation patterns.

Agilent E8362B vector network analyzer is applied to experiment the antenna characteristics. The measure and simulation results are shown in Fig. 11. Processing technology would lead to some errors, but the measure



(a)

(b)

(c)

(d)

Fig. 10. Simulated and measured radiation patterns of the proposed antenna: (a) f=3GHz; (b) f=4.5GHz; (c) f=6.5GHz; (d) f=8.5GHz

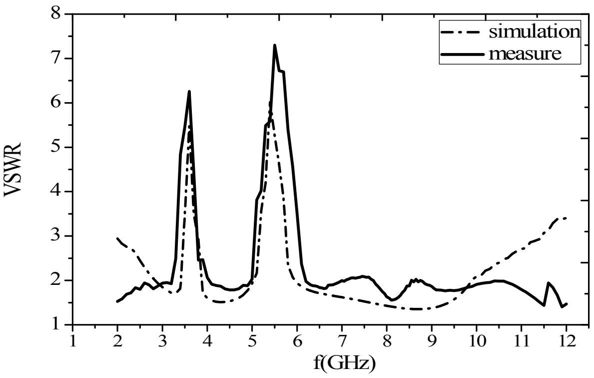


Fig. 11. Simulated and measured VSWR of the antenna

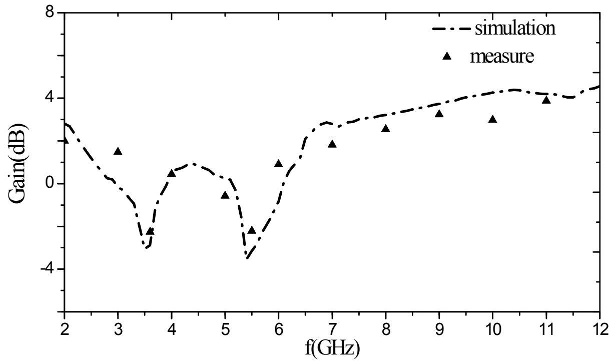


Fig. 12. Simulated and measured gain of the proposed antenna with two notched bands

result nearly coincides with the simulation. The two notched bands avoid interference from WLAN and WiMAX systems successfully.

Fig. 12 shows the gain simulation and measurement results of the proposed UWB antenna. Compared with simulation curve, the measurements keep the same variation trend at the selective frequency points. The expected inference suppression is confirmed in the notched bands because the gain reduction occurs at 3.6GHz and 5.5GHz. Outside the two reject bands, the average gain is practically not attenuated with range from 1.4dB to 3.7dB, which is good for an omnidirectional UWB antenna.

5. Conclusion

A compact UWB antenna with dual notched bands is proposed. The proposed antenna filters the narrow signal from WLAN(5.15-5.825GHz) and WiMAX(3.4-3.69GHz). The simulation and experimental results show the antenna has better filtering function in the notched bands and omnidirectional radiation performance in the working bands. Meanwhile, transmission line model is applied to antenna effectively. Design of UWB antenna translates into the application of broadband matching technique using transmission line. The method can be used without numerical values, but the Smith Chart can analyze the effects of changes in the UWB antenna. The proposed antenna geometry has many advantages such as simple structure, small size, and easiness of fabrication and integration.

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