Compact Printed Ultra-wide Band Antenna with Band-notched Characteristics

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Abstract— In 2002, the Federal Communication Commission (FCC) set the frequency band of 3.1–10.6 GHz as the operating bandwidth of high-precision distance measurement, metal detection, and wireless communication systems. From then on, ultra-wide band (UWB) antennas have attracted more and more attention. In this paper, a novel low profile compact UWB microstrip antenna was proposed for UWB communication applications. It is shown both numerically and experimentally that the bandwidth of the antenna is wide enough to cover 3.1–10.6 GHz. Moreover, utilizing parasitic strips and gap structures, the characteristic of dual band suppression has been achieved rejecting the frequency band of 5.15–5.825 GHz and that of 3.3–3.8 GHz, in order to exclude the operating bandwidth of wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX).

1. INTRODUCTION

Since the Federal Communication Commission (FCC) approved the frequency band of 3.1–10.6 GHz for the commercial use of ultra-wideband (UWB) communication in 2002 [1–4], the research on UWB antennas has attracted more and more attention for its inherent advantages, such as high data rate, low power consumption and low cost. Nowadays, considerable amounts of UWB antennas have been proposed, covering the bandwidth of 3.1–10.6 GHz [5–8]. Yet, most of them cannot achieve band-notched characteristics. As commonly known, the antenna with band-notched characteristics can reduce the interference between different systems such as WLAN (5.125–5.825 GHz) and WiMAX (3.3–3.8 GHz) [9, 11].

In order to solve the problem above mentioned, a new UWB microstrip antenna was proposed in this paper, which covers the bandwidth of 3.1–10.8 GHz with band-notched characteristics of 5.125–5.825 GHz and 3.3–3.8 GHz, respectively. The radiation part of the antennas consists of a hyperbolic plane fed by a coplanar waveguide structure (CPW) [5]. By adjusting its dimensions, the desired impedance bandwidth of the antenna is achieved. Two U-Shaped slots are etched on the hyperbolic plane, which provide the demanded band-notched characteristics, respectively. Furthermore, we optimize the structure of the antenna by CST Microwave Studio. Finally, CPW with rounded corners provides better impedance performance for the proposed antenna.

2. STRUCTURE OF THE ANTENNA

Figure 1 describes the geometry of the proposed antenna. It is fabricated on a FR4 substrate, with a total area of $30 \times 30 \times 1.1\,\mathrm{mm}^3$, relative dielectric constant of 4.4, and loss tangent of 0.02. The antenna is composed of a hyperbolic plane radiator, fed by CPW, which realizes the UWB characteristics by generating more resonance frequencies. Additionally, two U-shape slots are etched on the radiator providing band-notched properties by destroying the original distribution of the surface currents. Moreover, the rounded corners of the CPW decrease the discontinuities of the antenna structure, which can thus broaden the operating bandwidth of the proposed antenna. The functions of the structure mentioned above will be discussed in detail in Section 3. As shown in Fig. 1, the optimized dimensions are achieved using CST Microwave Studio, and listed as follows: $W_1 = 10$, $W_2 = 8$, $W_3 = 10$, $W_4 = 24$, $W_5 = 27$, $W_6 = 7$, $W_7 = 8.8$, $W_8 = 2.66$, $W_9 = 9.3$, $g_1 = 0.16$, $g_2 = 0.5$, $g = 1$, $R_1 = 2$, and $R_2 = 3$ (all in millimeters).

3. RESULTS AND DISCUSSION

In order to get a better impedance bandwidth performance, several aspects should be taken in to consideration. Firstly, the structure of the CPW should be adjusted strictly, including dimensions of the rounded corners and gaps between the ground plane. Through simulations, we find that when $R_1 = 2$, $R_2 = 3$, $W_2 = 8$, and $g = 1$, the antenna can match well with the $50\,\Omega$ feeding line. Secondly, the shape of the radiator affects the bandwidth performance as well. As it is known,

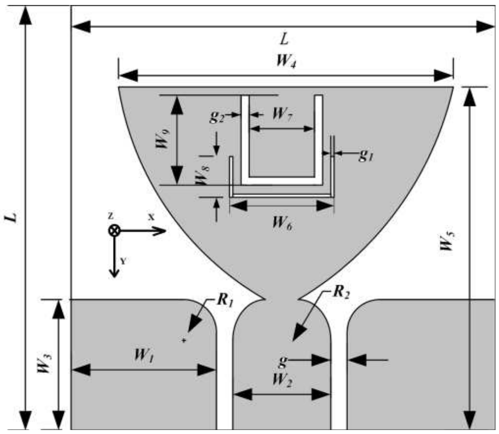

Figure 1: Configuration of the antenna.

it is better to choose curvatures without abrupt discontinuities as the shape of the antenna radiator to achieve a good impedance bandwidth. As we can see in Fig. 1, the radiator is a kind of curved surface based on the hyperbolic function, which is $x^2 = 2py$ ($p = 4$). The reason we choose the hyperbolic curve is that the antenna can cover a wider impedance bandwidth, which is 2.5–14.43 GHz. It should be noted that a smaller p makes a better impedance performance at low frequencies. However, a smaller p will unfortunately make the antenna size larger. Therefore, a suitable value of the parameter p should be chosen by compromising between the antenna compactness and the broadband requirements. With the aid of simulation, we set the value of p as 4. The effects of the parameter p on return-loss can be seen in Fig. 2.

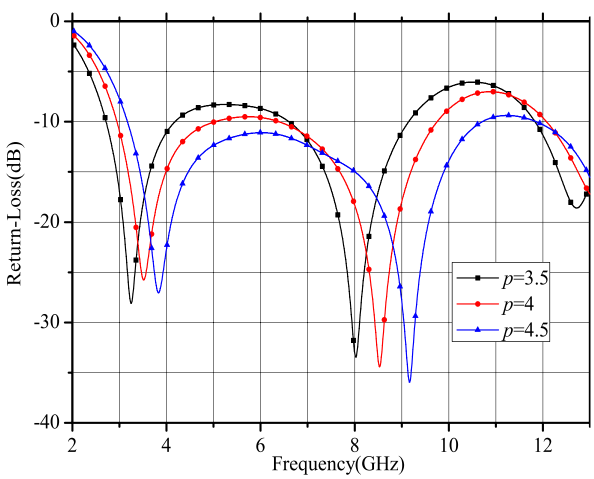

Figure 2: Simulated return-loss with different p.

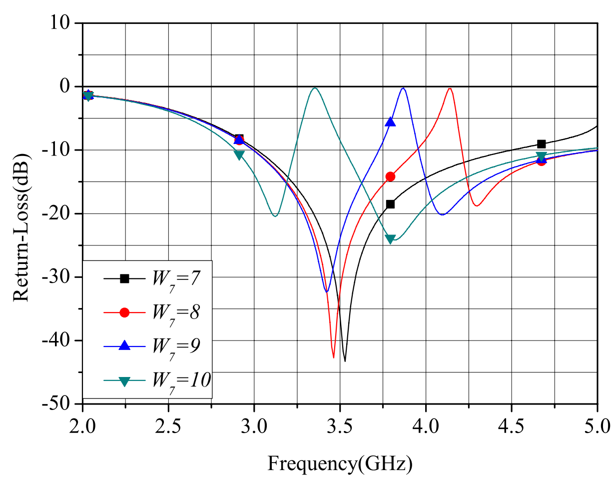

Figure 3: Simulated return-loss with different W_7.

Thirdly, as its most important property, we concentrate on the band-notched characteristics of the antenna. For the proposed antenna, two U-shaped slots are constructed to inhibit electromagnetic waves of specific frequency ranges by disturbing the surface current distribution. The suppressed frequency band has a close relationship with the length and the width of the slot. The length of the slot follows the function:

$$w = \frac{c}{f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{1}$$

where c is the free space light speed, f_r is the center operating frequency, and ε_r is the relative dielectric constant of the substrate [12]. In order to keep the antenna dimension unchanged, a straight slot can be bended to a U-shape with the same effective length.

We construct a larger U-shape slot on the antenna and adjust slot length and position to produce a notched-band with the center frequency at 3.55 GHz. The relationship between the slot length and the center frequency of the notched band is shown in Fig. 3. Another U-shape slot is etched on the radiator in order to produce the other notched-band with the center frequency at 5.475 GHz according to Equation (1). What we should notice is that two slots may have mutual coupling effects on each other. As a result, the parameters of these two U-shaped slots need to be adjusted slightly through simulation.

To better understand the relationship between the shape of the antenna and its impedance bandwidth. Surface current distributions on the radiator and the ground plane of the proposed antenna were simulated by CST. Fig. 4 shows that the surface current at 3.1 GHz, 6.7 GHz, and 10.6 GHz. It is shown that currents on the bottom of the radiator contribute to the low frequency part of the bandwidth, while those on the top of the radiator contribute to that of high frequencies. These can also guide us to find the optimal position to etch the slot in order to achieve specific band-notched characteristics.

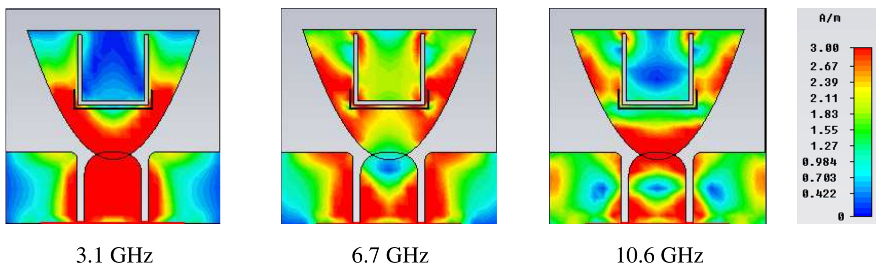

Figure 4: Surface current distributions of the proposed antenna.

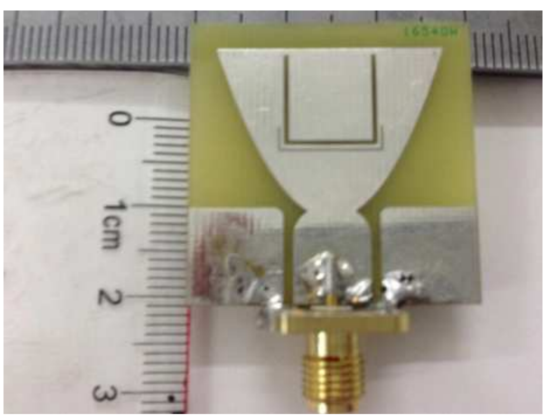

Figure 5: Photography of the UWB antenna.

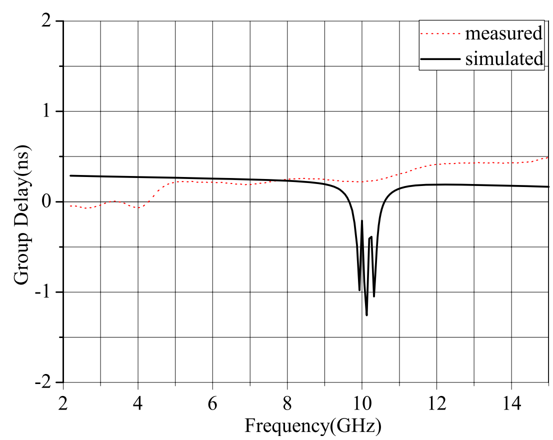

Figure 6: Simulated and measured group delay.

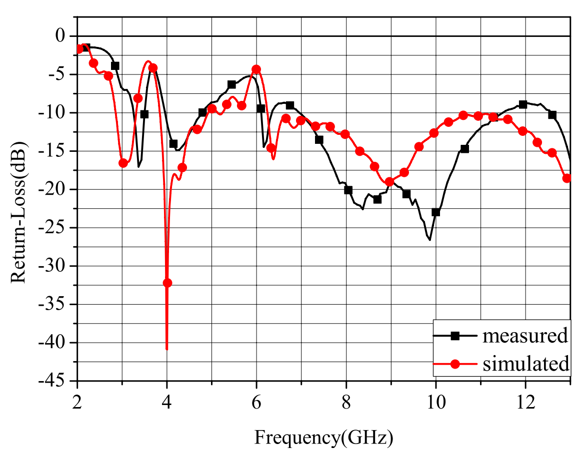

Figure 7: Simulated and measured return-loss of the proposed antenna.

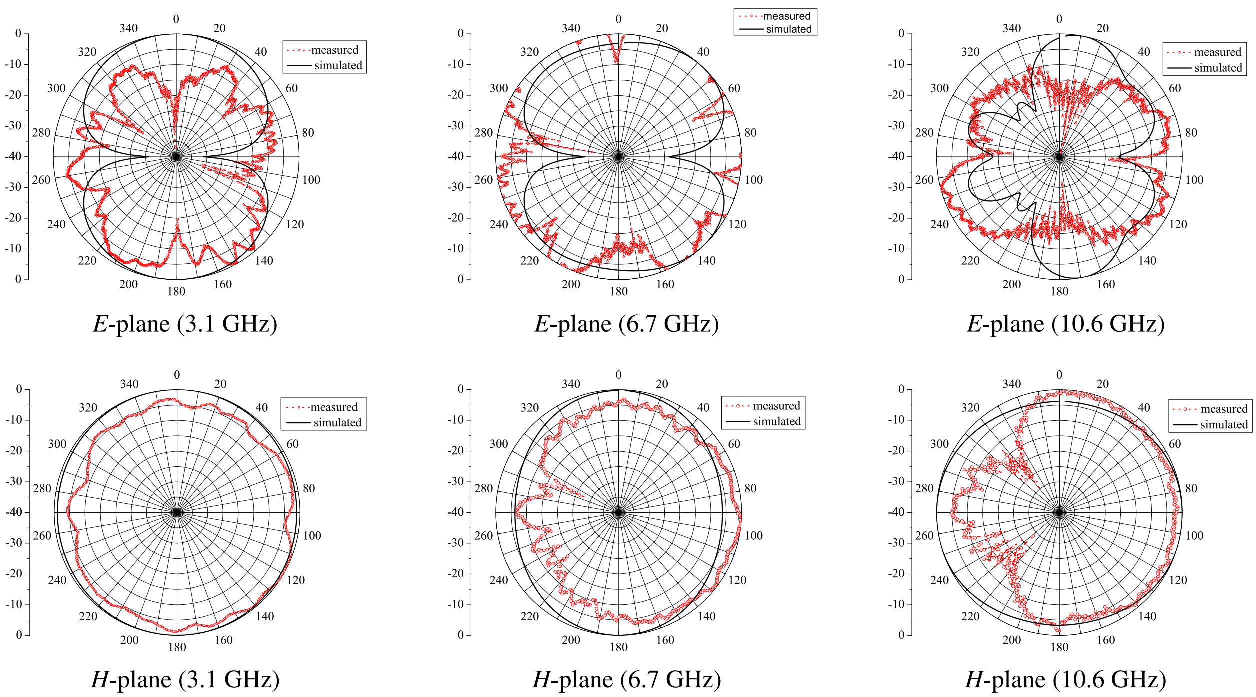

Figure 8: Simulated and measured radiation patterns.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The prototype of the proposed printed compact UWB antenna is shown in Fig. 5. Fig. 6 presents the simulated and the measured results of its group delay. We can see that the group delay of the antenna over the operating bandwidth fluctuates smoothly, smaller than 1 μs. It indicates that the antenna has a good time domain performance, and is capable of transmitting and receiving broadband signals without distortion.

The impedance bandwidth of the proposed antenna is measured by Aglient network analyzer. Fig. 7 compares the simulated and the measured return-loss of the antenna. As indicated in Fig. 7, the measured return-loss has a good agreement with the simulation results. The antenna has a measured impedance bandwidth from 3.1 to 10.6 GHz (return loss < -10 dB), except for the frequency band from 3.3 to 3.8 GHz and that from 4.8 to 6.2 GHz.

Figure 8 shows the radiation patterns at 3.1, 6.7, and 10.6 GHz. It is demonstrated that stable omni-directional H-plane radiation patterns are achieved in the whole operating frequency band. It should be noticed that the radiation patterns in E-plane become imbalanced as frequency increases. The differences between the measured results and the simulation ones may cause by the fabrication and the measurement errors. The imbalanced radiation pattern is attributed to the imbalance of the current distribution at the high frequency.

5. CONCLUSION

In this paper, a novel compact UWB antenna with improved dual band-notched characteristics is proposed. Two U-shape slots are imported to realize the dual band-notched characteristics, covering the WLAN and the WiMAX bandwidth. The area of the antenna is $30 \times 30 \times 1.1\,\mathrm{mm}^3$, with $S_{11} \leq -10$ dB and stable omni-directional H-plane radiation in the frequency band from 2.5 to 14.625 GHz. Good time domain performance is achieved in the whole operating frequency band, enabling the proposed antenna a good candidate for UWB wireless communication applications.

REFERENCES

1. Lin, Y. C. and K. J. Hung, "Compact ultrawideband rectangular aperture antenna and band-notched designs," *IEEE Transactions on Antennas and Propagation*, Vol. 54, 3075–3081, 2006.
2. Su, S. W., K. L. Wong, and F. S. Chang, "Compact printed ultrawideband slot antenna with a band notched operation," *Microwave and Optical Technology Letters*, Vol. 45, 128–130, 2005.

3. Nguyen, T. D., D. H. Lee, and H. C. Park, "Design and analysis of compact printed triple band-notched UWB antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 403–406, 2011.
4. Li, C. M. and L. H. Ye, "Improved dual band-notched UWB slot antenna with controllable notched bandwidths," *Progress In Electromagnetics Research*, Vol. 115, 477–493, 2011.
5. Chu, Q., C. X. Mao, and H. Zhu, "A compact notched band UWB slot antenna with sharp selectivity and controllable bandwidth," *IEEE Transactions on Antennas and Propagation*, Vol. 61, 3961–3966, 2013.
6. Lin, D. B., I. Tang, and Y. J. Wei, "Compact dual bandnotched CPW fed wide slot antenna for WLAN and WiMAX applications," *Microwave and Optical Technology Letters*, Vol. 53, No. 7, 1496–1501, 2011.
7. Ryu, K. S. and A. K. Ahmed, "UWB dielectric resonator antenna having consistent omnidirectional pattern and low cross-polarization characteristics," *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 4, 1403–1408, 2011.
8. Shilpa, J. and M. Kumar, "Compact planar UWB patch antenna with integrated bandpass filter & band notched characteristics," *IEEE International Conference on Communication Systems and Network Technologies*, Rajkot, India, 2012.
9. Rezaul, A., M. T. Islam, and A. T. Mobashsher, "Design of a dual band-notch UWB slot antenna by means of simple parasitic slits," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 1412–1415, 2013.
10. Hong, C.-Y., C.-W. Ling, I-Y. Tarn, and S.-J. Chung, "Design of a planar ultrawideband antenna with a new band-notch structure," *IEEE Transactions on Antennas and Propagation*, Vol. 55, 3391–3397, 2007.
11. Peng, G., S. He, X. Wei, Z. Xu, N. Wang, and Y. Zheng, "Compact printed UWB diversity slot antenna with 5.5-GHz-band-notched characteristics," *IEEE Antenna and Wireless Propagation Letters*, Vol. 13, 376–379, 2014.