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A Compact Band-Notched Ultra-Wideband Spatial Diversity Antenna

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Abstract—A compact band-notched ultra-wideband (UWB) spatial diversity antenna is presented in this paper. The antenna is fabricated on an FR4 substrate and consists of two tapered microstrip feeding lines and two radiating elements. The wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.825 GHz band-notched function is achieved by introducing two slits in the radiators as $\lambda/4$ resonators. The simulated and measured results show that the presented antenna has a broadband impedance bandwidth which covers UWB band and also has a band-notched characteristic. Additionally, the antenna has a good transmission coefficient better than -15 dB across the UWB. The radiation patterns, peak gain, and envelope correlation coefficient are measured and discussed.

1. INTRODUCTION

Recently, ultra-wideband (UWB) wireless communications have attracted universal attention for their merits of high data transfer rate, high capacity, and low power consumption [1]. At the same time, UWB technology combined with multiple-input-multiple-output (MIMO) antennas is a good choice to achieve data rates more than 1 Gb/s for wireless communications and to make increased range available through beam forming [2]. Antenna diversity, such as spatial diversity, polarisation diversity, is a well-known technique to combat the multipath fading problem and co-channel interference and thus enhance the performance of MIMO systems [3, 4]. Therefore, UWB antennas with good diversity performance are becoming highly desired for MIMO systems.

Many studies have been carried out to design UWB diversity antennas [5–21]. However, the impedance bandwidth of the antennas in [5–8] cannot cover the whole UWB, and the sizes of the antennas are relatively large in [5, 9–17] which are not suitable for some portable devices' applications. On the other hand, the frequency range for UWB systems between 3.1 to 10.6 GHz will cause interference to the existing wireless communication systems, such as the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.825 GHz, so the UWB diversity antenna with a band-notched function is desired in the design. However, the antennas in [5–21] do not have the band-notched function to avoid the interference. Recently, some antennas with band-notched function have been reported [22–27]. Unfortunately, the size of the antennas is still relative large in [22–27].

In this paper, we present a compact UWB diversity antenna with band-notched function. The antenna is designed on an FR4 substrate with a size of 36 mm × 36 mm × 1.6 mm which is much smaller than most of the antennas in the current literature. The presented antenna consists of two radiating elements for spatial diversity performance and is fed by tapered microstrip lines. By introducing two slits as $\lambda/4$ resonators in the radiating elements, the wireless local area network (WLAN) for IEEE 802.11a operating in 5.15–5.825 GHz can be rejected. The parameters of the slits are studied and the impedance bandwidth, transmission coefficient between two ports, radiation patterns, gain, and envelope correlation coefficient of the proposed antenna are measured and discussed.

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2. ANTENNA CONFIGURATION

The configuration of the proposed UWB spatial diversity antenna with band-notched function is shown in Figure 1. The antenna is fabricated on a 36 mm × 36 mm × 1.6 mm FR4 substrate with a relative permittivity of 4.6. Two radiators including the tapered microstrip feeding lines are symmetrically aligned with respect to the z-axis. The rectangular stub introduced in the middle of the ground plane enhances the isolation between two feeding lines. The semi-circular slots under the radiators adjust the impedance bandwidth of the antenna. Two rectangular slots at the bottom of the reflector not only adjust the impedance bandwidth of the antenna, but also adjust the length of the stub to enhance the isolation.

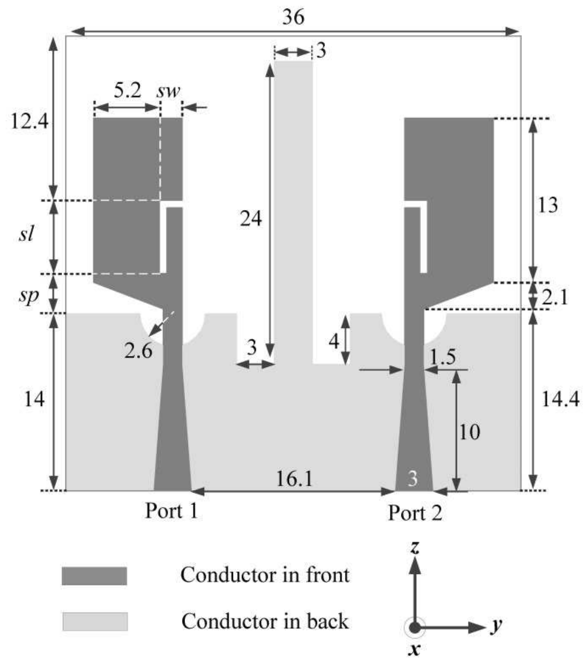


Figure 1. Geometry of the proposed antenna with optimal dimensions. ($sp = 3.8$, $sl = 5.8$, $sw = 1.8$, unit: mm).

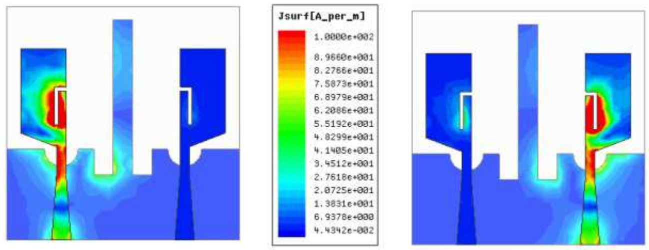
The band-notched function in the proposed antenna is achieved by two slits etched in the radiators. Each slit can be viewed as a $\lambda/4$ resonator that shorts the antenna at the relevant frequency. The length of the slots is about $\lambda/4$ at the center frequency of the notched band and can be calculated by (1) and optimized by High Frequency Structure Simulator (HFSS) software, Version 15.

$$L = sl + sw = \frac{\lambda}{4} = \frac{c}{4f_0 \cdot \sqrt{(\varepsilon_r + 1)/2}} \tag{1}$$

where c is the speed of the light, ε_r is the relative permittivity of the substrate, and f_0 is the center frequency of the desired notched band. For example, the center frequency of WLAN is about 5.5 GHz. Figure 2 shows the simulated current distributions of the proposed antenna with port 1 and port 2 excited respectively at the frequency of 5.5 GHz. It is clearly shown that the current is concentrated around the slits, thus the band-notched function is successfully achieved.

3. PARAMETRIC STUDY

A numerical parametric study is carried out to evaluate the performance sensitivity to the design parameters and to obtain the optimal values. For the sake of brevity, we only simulate the effects of three important geometrical parameters on the reflection coefficient and isolation of the proposed



(a) (b)

Figure 2. Surface current distributions of the proposed antenna with port 1 and port 2 excitation: (a) port 1 excitation; (b) port 2 excitation.

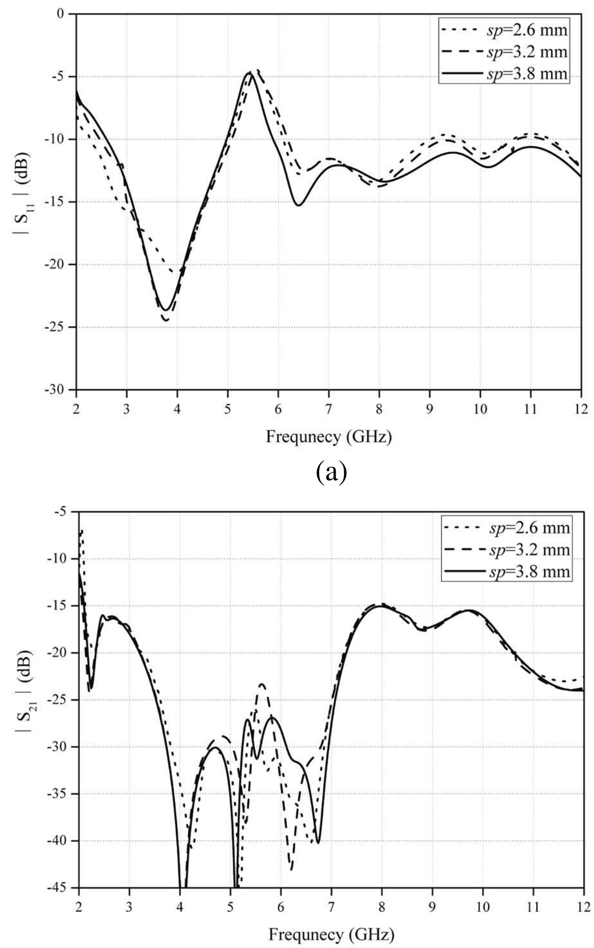


Figure 3. Simulated S-parameters value for the proposed antenna with different value of sp ($sl = 5.8$ mm, $sw = 1.8$ mm). (a) $|S_{11}|$, (b) $|S_{21}|$.

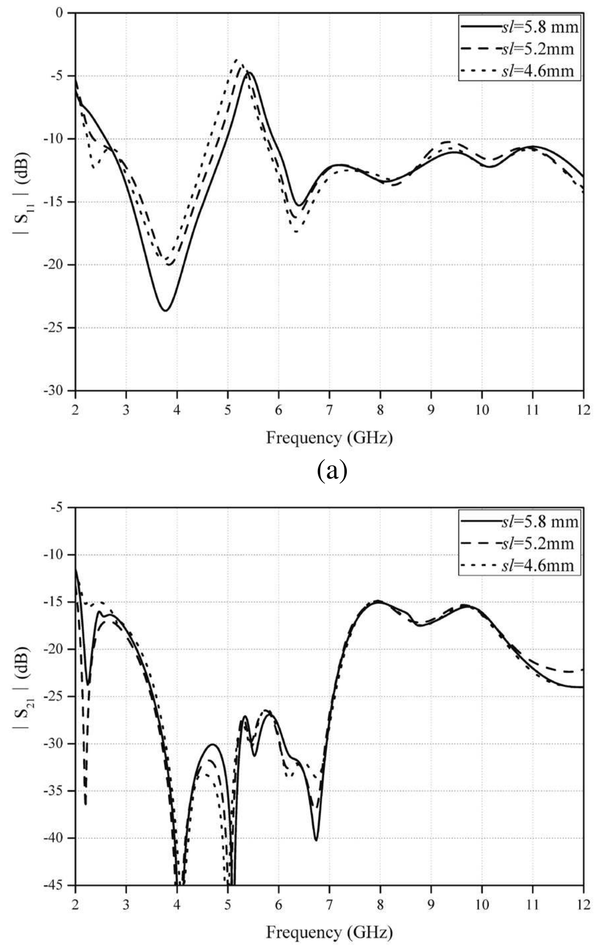


Figure 4. Simulated S-parameters value for the proposed antenna with different value of sl ($sp = 3.8$ mm, $sw + sl = 7.6$ mm). (a) $|S_{11}|$, (b) $|S_{21}|$.

antenna. These parameters are position sp, length sl, and width sw of the slits respectively as shown in Figure 1. The simulated results are plotted in Figure 3 to Figure 5. We can observe in Figure 3(a) that the notched frequencies are shifted from 5–6.1, 5.08–6.18, and 4.98–5.9 GHz with sp of 2.6, 3.2, and 3.8 mm, respectively. The results indicate that the notched frequencies can cover the WLAN band but are decreased when sp is increased. To achieve less signal losses out of the WLAN band, the

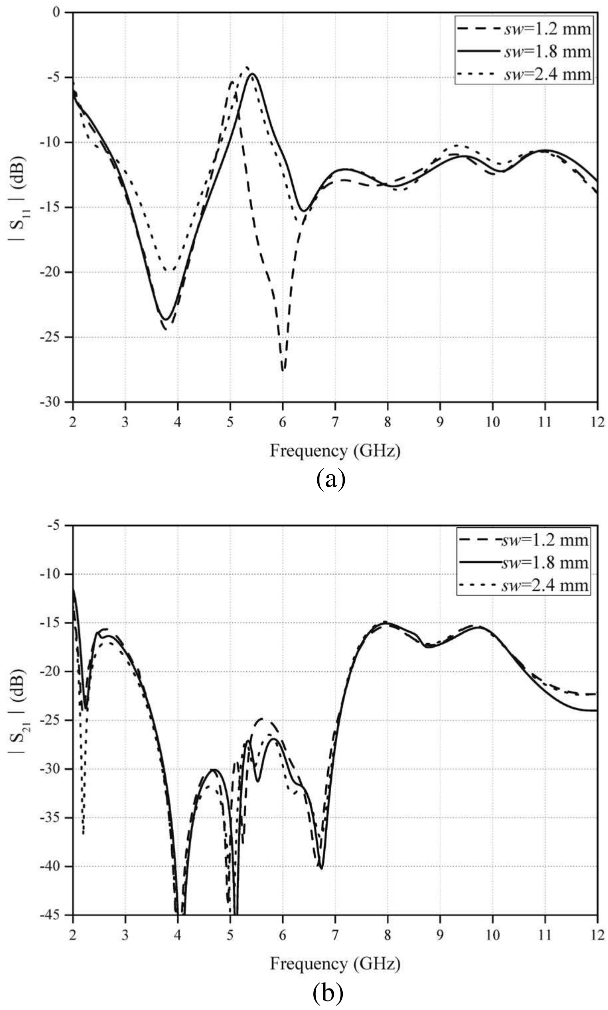


Figure 5. Simulated S-parameters value for the proposed antenna with different value of sw ($sp = 3.8\,\text{mm}$, $sw + sl = 7.6\,\text{mm}$). (a) $|S_{11}|$, (b) $|S_{21}|$.

value of sp is optimized as 3.8 mm. Figure 4(a) plots the simulated S-parameters for the proposed antenna with different values of sl. We can observe that upper edge of the notched band is shifted toward lower frequency, and the notched frequency will not cover the WLAN band when sl is decreased. Figure 5(a) plots the simulated S-parameters for the proposed antenna with different values of sw. It can be observed from Figure 5(a) that the notched frequencies will not cover the desired band when the width of the slits sw is too long or too short. It can also be observed from Figures 3(b), 4(b), and 5(b) that the transmission coefficient between two feeding lines is not influenced significantly with different values of sp, sl, sw. Based upon the discussion in this section, the optimal values of sp, sl, sw are as follows: $sp = 3.8\,\text{mm}$, $sl = 5.8\,\text{mm}$, $sw = 1.8\,\text{mm}$.

Figure 6 plots the simulated S-parameters of the proposed antenna with or without the slits. We can observe that the impedance bandwidth of the proposed antenna without the slits can cover the UWB band, and a band-notched function is achieved when the slits are introducing in the radiators, and the slits have less influence on the transmission coefficient.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Based upon the optimised dimensions shown in Figure 1, the proposed UWB diversity antenna was fabricated as shown in Figure 7, and was measured, analysed as follows.

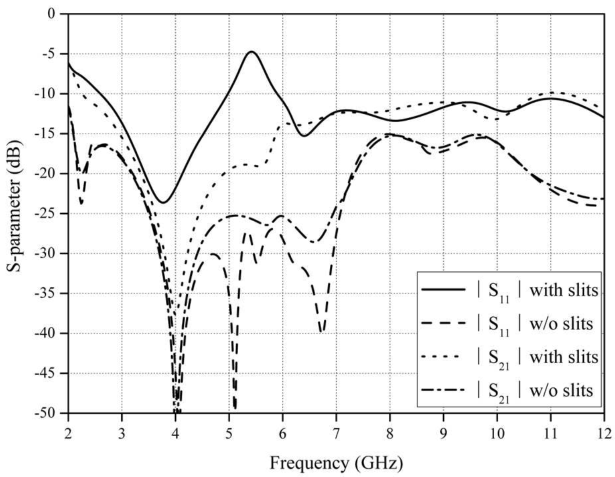
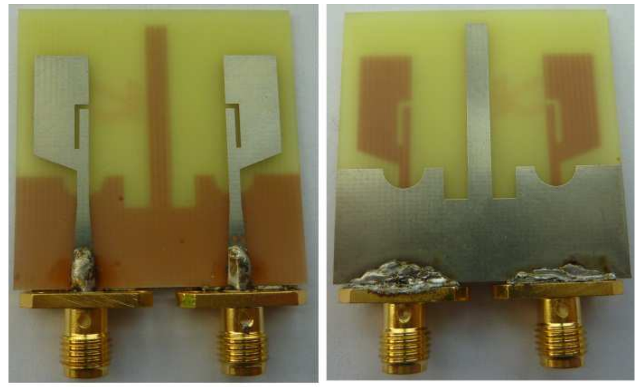


Figure 6. Simulated S-parameters value for the proposed antenna with or without the slits.



(a) top view (b) back view

Figure 7. Photograph of the proposed antenna.

4.1. Input Characteristic

The simulated and measured S-parameters of $|S_{11}|$ and $|S_{21}|$ versus frequency of the proposed UWB diversity antenna are shown in Figure 8. Due to the symmetric structures of the proposed antenna, the simulated and measured $|S_{22}|$ and $|S_{12}|$ are almost the same as $|S_{11}|$ and $|S_{21}|$, and they are not shown in the figure for the sake of brevity. As shown in Figure 8(a), the obtained impedance bandwidth defined by $|S_{11}| < -10$ dB can cover the whole UWB of 3.1–10.6 GHz except in the notched band. In other words, the WLAN band operating in 5.15–5.825 GHz is successfully notched as desired. In addition, across the UWB, a transmission coefficient less than -15 dB is achieved as shown in Figure 8(b) which indicates that the proposed antenna has a good isolation between two feeding lines. The discrepancy between simulated and measured results is mainly caused by certain unexpected tolerance in fabrication.

4.2. Radiation Patterns

The radiation patterns at 3, 7, and 10 GHz were measured in an anechoic chamber. The radiation patterns for the proposed antenna on x-y (H-plane), x-z (E-plane), and y-z planes with port 1 excited and port 2 terminated by a 50 Ω load are plotted in Figure 9. As shown in Figure 9, the radiation patterns of the proposed antenna are relatively consistent in the UWB. In addition, due to the symmetric configuration of the proposed antenna, when port 2 is excited, with port 1 terminated, the patterns in x-z plane are similar to those in Figure 9, but the patterns in x-y and y-z planes are mirror transformations about x-z plane of those in Figure 9. In other words, the radiation patterns tend to cover complementary space regions, which provide spatial diversity for the system operation.

The measured peak antenna gain for port 1 excitation with the gain comparison method is shown in Figure 10. Due to the symmetric structures of the two elements, the measured peak antenna gain for port 2 excitation is about the same and not shown in the figure. The result shows a gain level about 6.8 dBi with gain variations less than 4.7 dBi except at the notch band, where the gain drops up to -4.9 dBi.

4.3. Envelope Correlation

The envelope correlation calculation using S-parameters provides a good estimation of the diversity performance of diversity antennas. The measured S-parameters can be used for calculating the envelope correlations of this antenna using (2) [28].

$$\rho_e = \frac{\left|S_{11}^* S_{12} + S_{21}^* S_{22}\right|^2}{\left(1 - \left(|S_{11}|^2 + |S_{21}|^2\right)\right)\left(1 - \left(|S_{22}|^2 + |S_{12}|^2\right)\right)} \tag{2}$$

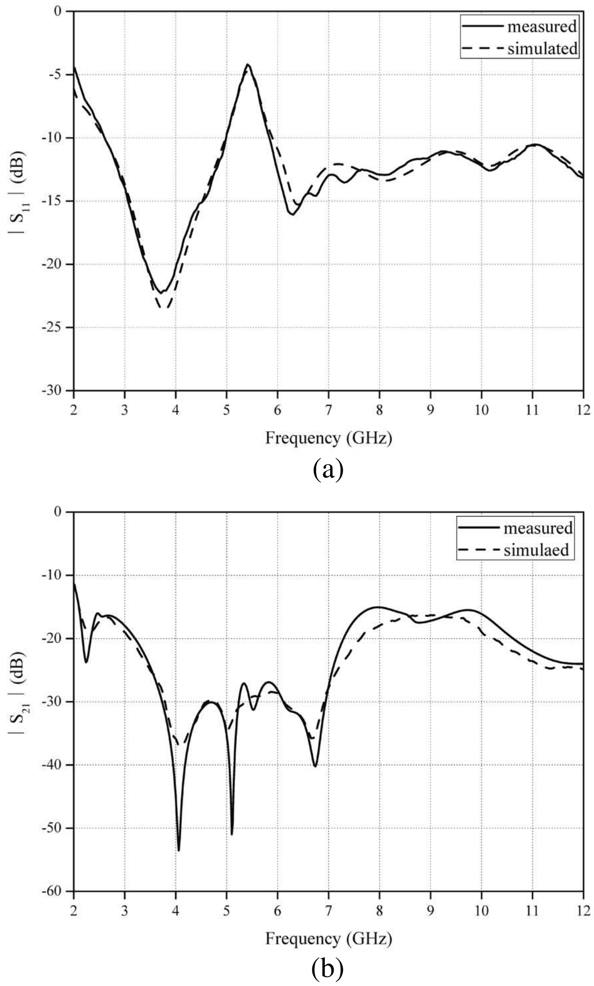


Figure 8. Simulated and measured S-parameters versus frequency of the proposed antenna. (a) $|S_{11}|$, (b) $|S_{21}|$.

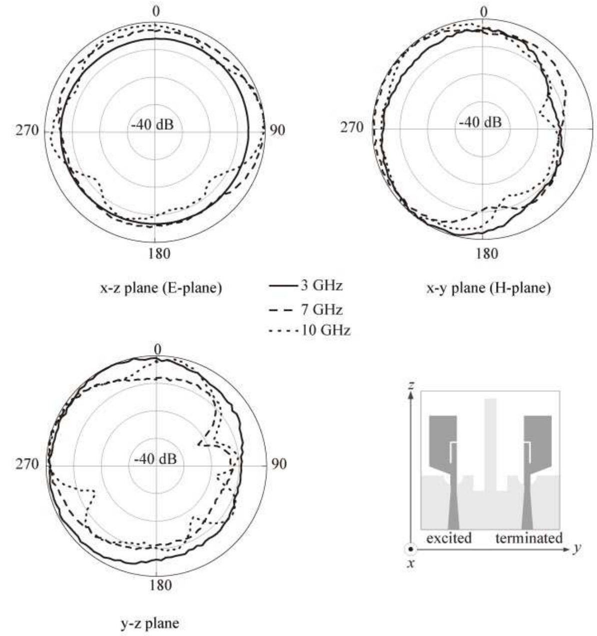


Figure 9. Measured radiation patterns of the proposed antenna with port 1 excited and port 2 terminated by a 50 Ω load.

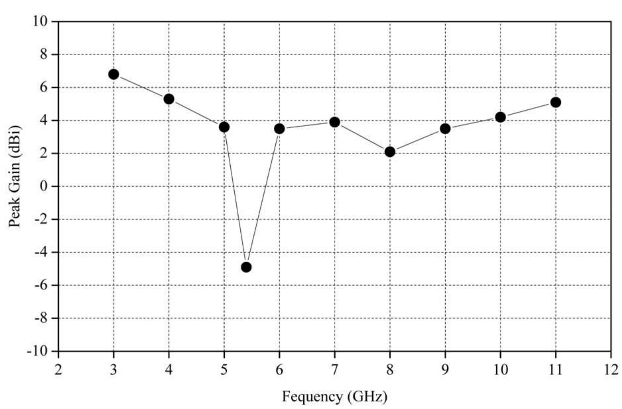


Figure 10. Measured peak gain across the UWB of the proposed antenna with port 1 excited.

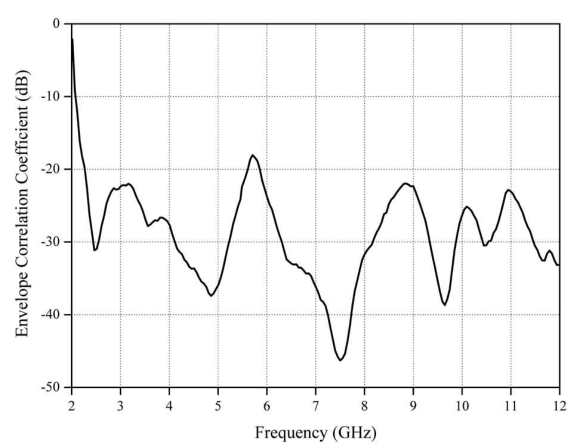


Figure 11. Measured envelope correlation coefficient versus frequency of the proposed antenna.

The envelope correlation coefficient for the proposed UWB diversity antenna, calculated from the measured S-parameters and (2), is plotted in Figure 11. As shown in Figure 11, we can observe that the envelope correlation is below $-17\,\mathrm{dB}$ across the whole UWB of 3.1–10.6 GHz. This indicates that our designed antenna has a good MIMO/diversity performance.

5. CONCLUSION

A compact planar UWB spatial diversity antenna with band-notched function is proposed in this paper. The band-notched function is achieved by etching two slits in the two radiating elements. The parametric study has provided antenna engineers with useful information about the design and optimization of such antennas. The antenna has been successfully designed, constructed, and measured. Results show that the antenna has broadband impedance bandwidth covering the whole UWB, single band-notched function at WLAN band, good isolation between two feeding lines, stable radiation patterns and peak gain, spatial diversity performance and low envelope correlation. These results indicate that the proposed antenna can be a good candidate for some portable MIMO/diversity applications.

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