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Compact UWB MIMO Antenna with ACS-Fed Structure

Hao Qin* and Yuan-Fu Liu

Abstract—A compact UWB (Ultrawideband) MIMO (Multiple-input multiple-output) antenna with asymmetric coplanar strip (ACS)-fed structure is proposed in this paper. The antenna consists of two modified ACS feeding staircase-shaped radiation elements which are orthogonally placed, and the wideband isolation is achieved through a fence-like stub between them. The effectiveness of the fence-like stub is analyzed. Measured results show that the presented antenna can achieve a broad impedance bandwidth ($|S_{11}| \leqslant -10\,\text{dB}$) of 3.1–11 GHz with good performance in terms of isolation $> 15\,\text{dB}$. Radiation patterns and correlation coefficient (ECC) denote the consistent diversity performance across the entire UWB bandwidth. By introducing the ACS-fed structure, the antenna size can be considerably reduced to $43.5\,\text{mm} \times 43.5\,\text{mm} \times 1.6\,\text{mm}$ compared to the recently published UWB MIMO antennas, which makes the antenna suitable for portable UWB MIMO applications.

1. INTRODUCTION

Ultrawideband (UWB) communication technology has been put into consideration since the Federal Communication Commission (FCC) authorized the frequency band from 3.1 to 10.6 GHz for commercial communication applications in 2002 [1]. The UWB communication systems can perform high-speed communication with speed more than 100 Mbps. However, the conventional wireless communication systems suffers from channel fading due to multipath environment. Moreover, the fading of the UWB signal is more serious because of its low transmit power. This can be improved by using multiple-input multiple-output (MIMO) technology which is one of the effective ways to reduce multipath phenomenon in complex environment and increase range or capacity of the channel [2]. UWB-MIMO system with pattern diversity can efficiently utilize different radiation patterns to make use of the channel fading and improve the transmission quality of the mobile terminals, e.g., orthogonal radiation patterns and symmetrical radiation patterns [3].

UWB-MIMO system requires multiple antennas with a wide bandwidth and good isolation performance between antennas. Several types of UWB MIMO antennas have been studied. As key components of UWB system, high isolation and wide-band characteristics are required for UWB MIMO antennas, which have been studied recently, including inserting decoupling stubs between the radiation elements [4–7], etching a ring slot in the ground plane [8, 9], extending a treelike structure [10] or parasitic meander lines [11] on the ground plane. However, all the reported UWB MIMO antennas listed above have large sizes which are not easy to be integrated. There are still spaces to be further reduced without deteriorating the performances.

In order to further minimize the overall size of the UWB MIMO antenna, the asymmetric coplanar strip (ACS)-fed structure is introduced. Using the ACS-fed structure, the overall size of this antenna can be reduced to about one half of the common coplanar waveguide (CPW)-fed antennas [12–15]. In this paper, a compact UWB MIMO antenna with ACS-fed structure is proposed. The antenna consists of two modified ACS feeding staircase-shaped radiation elements, and the wideband isolation is

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achieved through a fence-like stub placed diagonally between them. Measured results show that across 3.1 to 10.6 GHz (UWB bandwidth), the presented antenna can achieve a broad impedance bandwidth with good performance in terms of isolation > 15 dB. Moreover, the antenna has a compact size of 43.5 mm × 43.5 mm × 1.6 mm, which has been significantly reduced compared with recently published UWB MIMO antennas. Details of the antenna design, simulated and measured results are presented and discussed below.

2. ANTENNA DESIGN

2.1. Asymmetric Coplanar Strip (ACS) Feeding

In this antenna design, a compact and effective feeding technique is employed. Therefore, the antenna constructed using the Asymmetric Coplanar Strip (ACS)-fed exhibits all the advantages of the CPW-fed antenna together with more compactness [16]. This feeding mechanism is analogous to the CPW-fed except that the ACS-fed has a single lateral ground strip compared to the twin lateral ground strips in the CPW-fed. Furthermore, the ACS-fed antenna exhibits similar radiation patterns to CPW-fed antenna. Figure 1 shows the UWB antenna using ACS and CPW feeding techniques, respectively. These antennas are printed on an FR4 substrate with thickness of 1.6 mm, permittivity of 4.4, and loss tangent 0.02. Using the electromagnetic simulation software Ansoft HFSS V13, the return loss and peak gain characteristics are observed for both ACS and CPW feeding techniques. The ACS and CPW feeding geometries are shown in Figures 1(a) and (b). It can be easily observed from Figure 1 that the radiation part of ACS-fed structure is half the size of the CPW-fed structure. The simulated return loss and peak gain characteristics of ACS and CPW feeding are shown in Figure 2. It can be clearly deduced

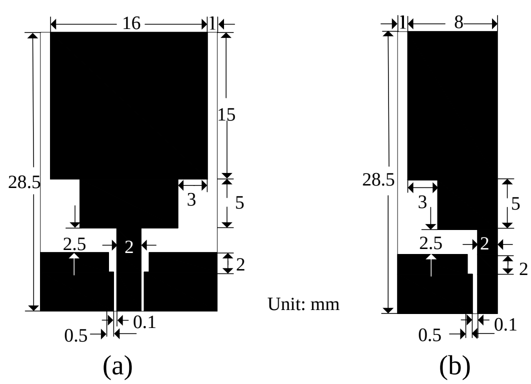


Figure 1. Geometry of (a) CPW-fed antenna and (b) ACS-fed antenna.

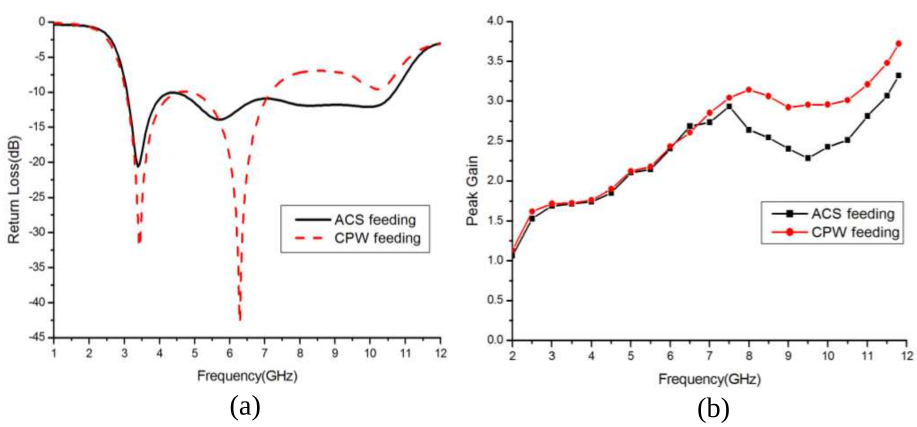


Figure 2. Simulated (a) return loss and (b) peak gain of ACS and CPW-fed antenna.

from Figure 2 that the compact ACS feeding antenna has the return loss and peak gain property similar to the CPW feeding antenna. The design using ACS feeding can be used to miniaturize the antenna structure for size-restricted devices.

2.2. UWB-MIMO Antenna Configuration

Figure 3 illustrates the geometry of the proposed UWB MIMO antenna. The antenna is printed on an FR4 substrate with size of 43.5 mm × 43.5 mm, thickness of 1.6 mm, permittivity of 4.4, and loss tangent 0.02. The antenna consists of two staircase-shaped radiators, and both of them use ACS feeding. The ACS feedline has a signal strip width of 2 mm and a gap distance of 0.1 mm between the signal strip and the coplanar ground plane, corresponding to the 50-Ω characteristic impedance. A one-stage impedance transformer with length of 2 mm and gap of 0.3 mm is incorporated in the ACS line for further impedance matching leading to UWB. A fence-like metal stub located in the middle of the antenna is used to decrease the mutual coupling caused by near-field. Moreover, two slots are symmetrically etched on the ground plane to adjust the impedance bandwidth. The antenna is successfully designed and optimized by using the Ansoft High Frequency Structure Simulator (HFSS V13). The wideband isolation between the two UWB radiators can be efficiently enhanced by a fence-like structure that extends from the ground plane. The effectiveness of this fence-like structure will be shown and analyzed in the next section.

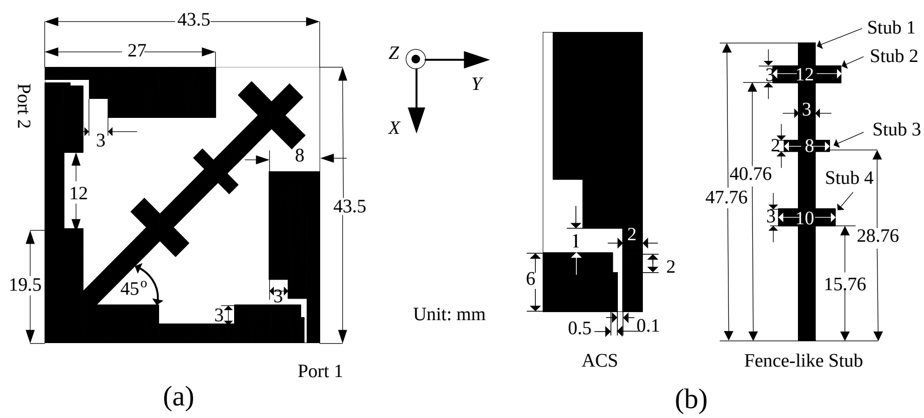


Figure 3. Configuration and parameters of the UWB MIMO antenna (unit: millimeters).

2.3. Studies on the Fence-Like Strip

Wideband isolation can be achieved with the fence-like stub mainly due to two mechanisms. One is that stub 1 [see Figure 3] can be viewed as a reflector, which can reduce the wideband mutual coupling by separating the radiation patterns of the two radiators. In this paper, we increase the number of cross stubs, and the mutual coupling can be further weakened. The other mechanism is that as the number of cross stubs increases, more resonances will be introduced, and each of which is provided by a monopole of one stub. The length of the stubs can be obtained by (1)

$$l = \frac{c}{2f * \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Here f is the frequency of resonance, ε_r the dielectric constant, and c the speed of the light. With properly chosen length and position of each stub, the wideband isolation can be efficiently enhanced as the resonances are in different frequency ranges.

Figure 4 shows S-parameters of the proposed antenna when the total number of the stubs varies. As depicted in Figure 4(a), when stubs 1–4 are inserted in the antenna, the path of the surface current is lengthened, and the middle frequency of the operating band thus shifts from 7.5 GHz to 6 GHz. In Figure 4(b), we can see the improvement of the isolation across the operating band as the total number

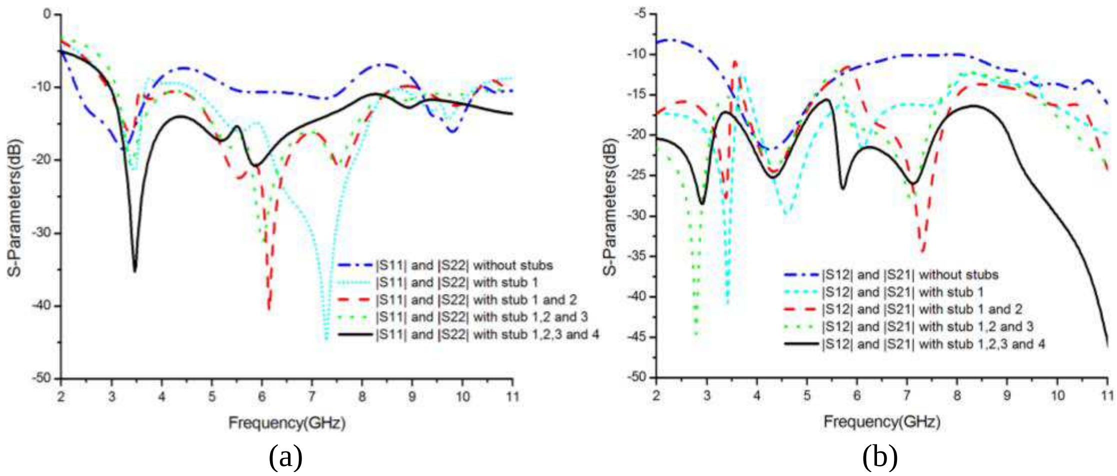


Figure 4. Simulated S-parameters when the total number of the stubs varies (a) $|S_{11}|$ and $|S_{22}|$, (b) $|S_{12}|$ and $|S_{21}|$.

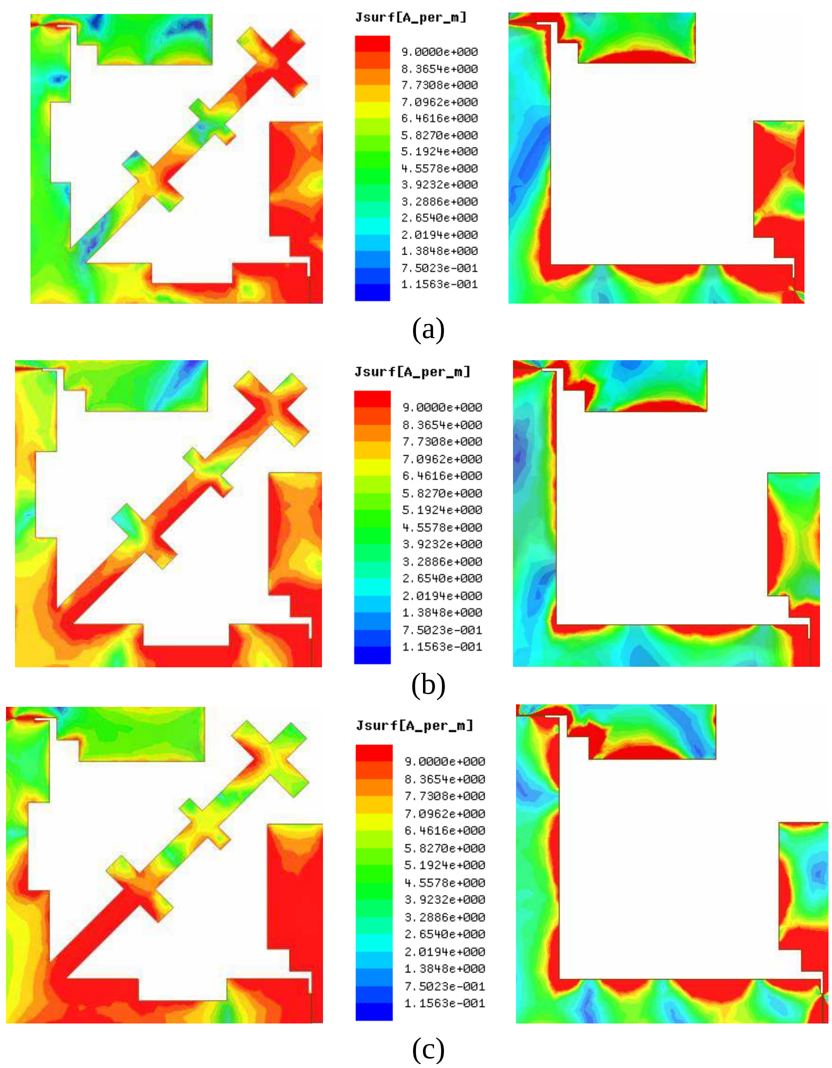


Figure 5. Surface current distributions with Port 1 excitation: (a) 3.5, (b) 6.5, and (c) 9.5 GHz.

of the cross stubs increases from one to four. The simulation results show that branches 2, 3, and 4 mainly affect low, middle and high frequencies, respectively. To further investigate the effect of the fence-like structure, the surface current distributions at 3.5, 6.5, and 9.5 GHz are shown in Figure 5. The case of an antenna system without the decoupling structure in between is also shown in Figure 5 for comparison. When port 1 is excited, the current from the radiator tending to couple to port 2 is blocked by the fence-like structure and cannot flow to the other radiator through the common ground plane at all these frequencies. The effect is the same when port 2 is excited. It is shown that the proposed fence-like structure can efficiently enhance the isolation between the radiators across the whole UWB.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Impedance Performance

Based on the optimal dimensions in Figure 3, a prototype of the ACS-fed UWB MIMO antenna is designed, fabricated, and experimentally investigated. Figure 6 shows a photograph of the fabricated antenna. S-parameters of the UWB MIMO antenna is measured by the Agilent E8363B vector network analyzer (VNA). Figure 5 shows the simulated and measured S-parameters of the proposed antenna. As indicated in Figure 7(a), the reflection coefficients are almost identical for the two ports in the simulation due to the symmetry of the structure. The discrepancies are mainly caused by the mismatching between the connector and the antenna feedline. According to the measured results, the impedance bandwidth (defined by $|S_{11}| \leqslant -10\,\text{dB}$) is from 3.1 to 11 GHz which can cover the whole UWB applications. As observed in Figure 7(b), the measured isolation is better than 15 dB in the whole band and 20 dB in most of the band within the UWB. These results indicate that this antenna is suitable for MIMO systems.

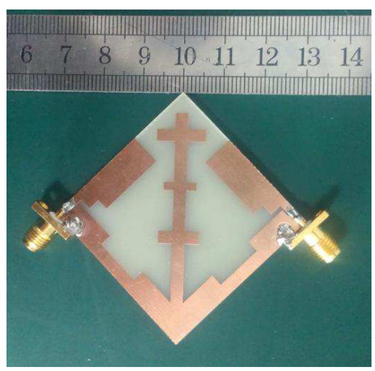
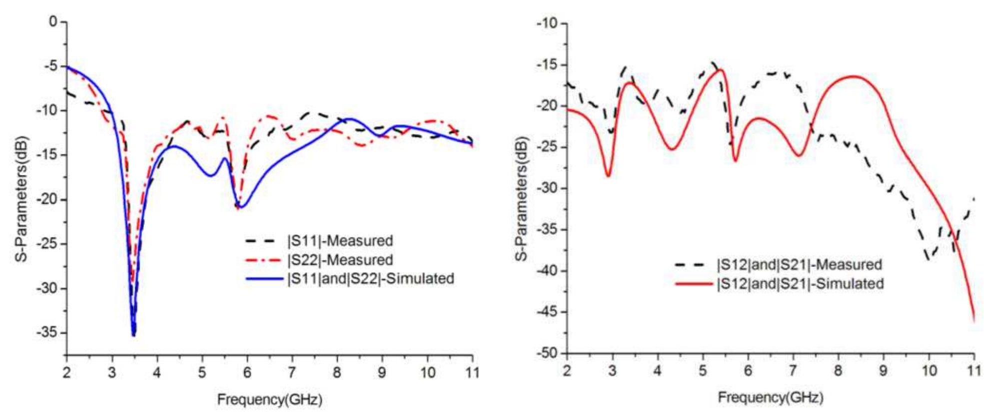


Figure 6. Prototype of the proposed antenna.



(a) (b)

Figure 7. Measured and simulated (a) reflection coefficients and (b) transmission coefficients of the proposed antenna.

3.2. Radiation Performance

Figure 8 shows the radiation patterns (measured with anechoic chamber SATIMO StarLab) of the proposed antenna at 3.5, 6.5, and 9.5 GHz when port 1 is excited, and port 2 is terminated with 50-Ω load, and vice versa. Owing to the location of the radiators, it is observed that the XY-planes of port 1 and port 2 are almost rotated 90°, and the XZ-plane (YZ-plane) of port 1 is similar to the YZ-plane (XZ-plane) of port 2. These results indicate that this antenna is suitable for diversity systems.

Figure 9 gives the radiation efficiency and peak gains of the proposed UWB MIMO antenna. It can be seen that the peak gains are stable with the variation within 3 dBi in the UWB. Across the entire

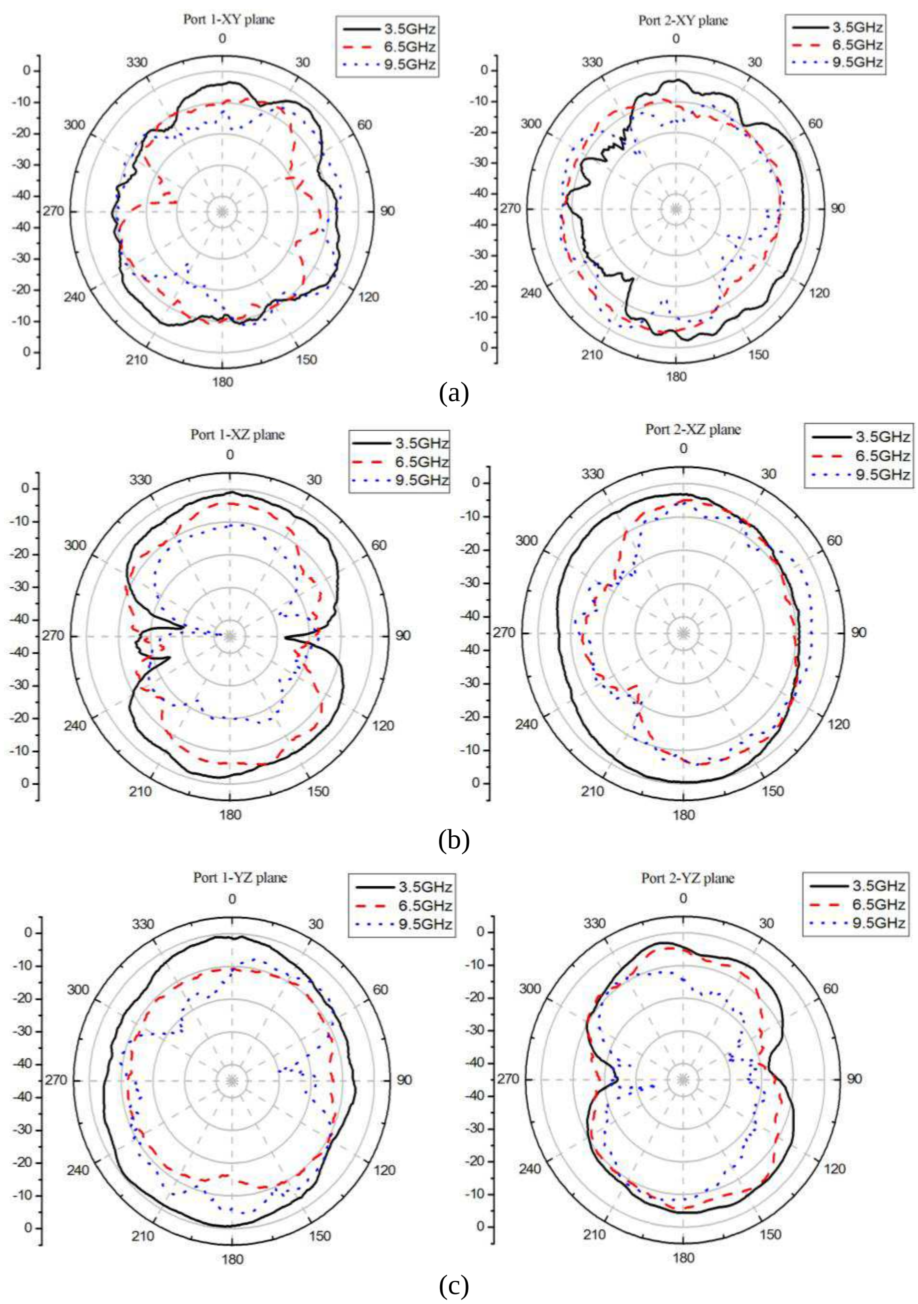


Figure 8. Measured radiation pattern of the proposed antenna at 3.5, 6.5, 9.5 GHz: (a) XY plane, (b) XZ plane, (c) YZ plane.

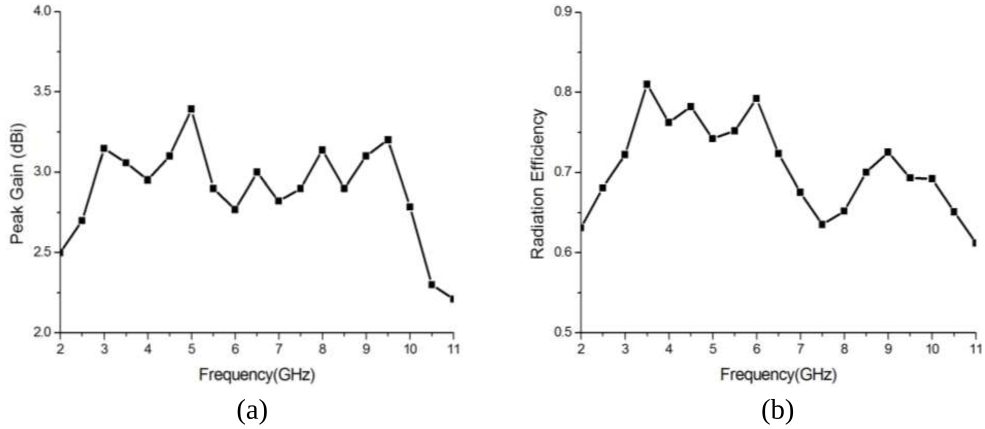


Figure 9. Measured (a) peak gains and (b) radiation efficiencies of the proposed UWB MIMO antenna.

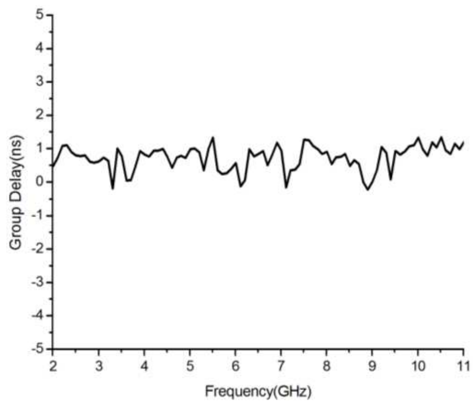


Figure 10. Measured group-delay.

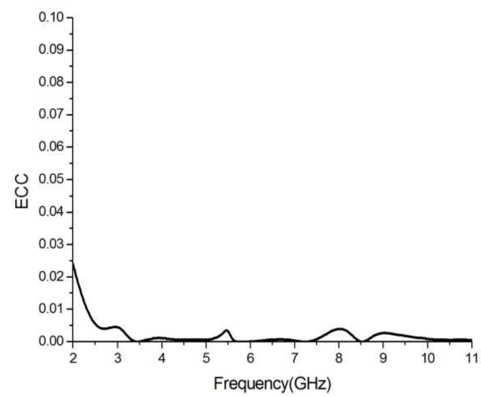


Figure 11. Measured envelope correlation coefficient.

operating band, the proposed antenna has radiation efficiencies of 60%$\sim$90% while the peak gains keep stable and reach 2.2$\sim$3.5 dBi.

3.3. Diversity Performance

3.3.1. Time Domain Performance

Figure 10 shows the measured group delay of the proposed UWB MIMO antenna, face to face with distance of 30 cm. It can be seen that the maximum variation of the group delay is within 1 ns over the operating band which indicates that the antenna has a good time domain performance.

3.3.2. MIMO Characteristics

Envelope correlation coefficient (ECC) is an important parameter to measure the diversity gain of a MIMO system. Generally, low envelope correlation always leads to high diversity gain [17]. For a two-antenna system, we can use a simple formula to calculate ECC [18], which is shown in Eq. (2).

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

The calculated result for the proposed antenna is given in Figure 11. The desired operating bands of the proposed antenna have an ECC less than 0.005, which means that the antenna has good diversity gain at the operating bands.

3.4. Performance Comparison

Comparisons of the proposed antenna with those presented in [4–11] on antenna dimensions are given in Table 1. Significant reduction in size has been achieved with our antenna design. Besides, other characteristics such as type of substrate, port position and isolation are studied as well. It can be clearly seen from Table 2 that the proposed paper has a vertical port position which can bring good diversity performance, and substrate FR4 is cheap in price and common in use. Moreover, the bandwidth ratio of $|S_{21}| < -20\,\mathrm{dB}$/UWB bandwidth is 64%, ranking in the middle among Refs. [4–11], which means that the proposed antenna has a good isolation performance.

Table 1. Comparisons of antenna size among proposed antenna and other compact antennas.

Published literature	Antenna purpose	Size comparison (proposed/literature)
Ref. [4]	UWB MIMO	56.25%
Ref. [5]	UWB MIMO	69.57%
Ref. [6]	UWB MIMO	78.84%
Ref. [7]	UWB MIMO	82.13%
Ref. [8]	UWB MIMO	29.57%
Ref. [9]	UWB MIMO	29.57%
Ref. [10]	UWB MIMO	39.42%
Ref. [11]	UWB MIMO	34.4%

Table 2. Comparisons of antenna characteristics among proposed antenna and other compact antennas.

Published literature	Type of substrate	Port position	Bandwidth ratio of $\lvert S_{21}\rvert < -20\mathrm{dB}$/UWB bandwidth
Proposed paper	FR4	Vertical	64%
Ref. [4]	Rogers RT/Duroid 6035HTC	Parallel	30.67%
Ref. [5]	FR4	Parallel	73.33%
Ref. [6]	FR4	Parallel	33.33%
Ref. [7]	FR4	Vertical	74.67%
Ref. [8]	air dielectric	Vertical	49.33%
Ref. [9]	air dielectric	Vertical	62.67%
Ref. [10]	FR4	Parallel	100%
Ref. [11]	FR4	Parallel	80%

4. CONCLUSION

A compact UWB MIMO antenna with ACS-fed structure is presented. The antenna, characterized by a simple structure and compact size of $43.5\,\mathrm{mm} \times 43.5\,\mathrm{mm} \times 1.6\,\mathrm{mm}$, satisfies the 10-dB reflection coefficient requirement for UWB applications (3.1–10.6 GHz). The measured isolation is better than 15 dB in the whole band and 20 dB in most of the band within the UWB. The high port isolation performance is achieved by introducing a fence-like strip diagonally between the ACS-fed staircase-like radiation elements. Besides, the compact size of the antenna is achieved by introducing the ACS-fed structure. The radiation patterns, antenna gain, efficiency, group-delay and envelope correlation coefficient have also been measured. The measurement results show that the proposed antenna system is very suitable for portable MIMO/diversity applications.

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