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Compact 4-Port ACS-Fed UWB-MIMO Antenna with Shared Radiators

Jing-Yi Zhang*, Fan Zhang, and Wen-Peng Tian

Abstract—A compact 4-port asymmetric coplanar strip (ACS)-fed MIMO antenna working in the ultra-wideband (UWB) frequency band with two shared radiators is presented in this paper. The proposed antenna is composed of two radiators, and each radiator is shared by two antenna elements in order to achieve a very compact size of $36 \times 36\,\text{mm}^2$. By etching two I-shaped slots in the radiators and attaching a rectangular patch on the back, the operating band width is broadened, and the isolation between any two antenna elements is enhanced. The stub of the ground also has great effect on the return loss and isolation. The working frequency band of the MIMO antenna covers 3.1–10.6 GHz with isolation over 15 dB between any two antenna elements. Furthermore, the proposed antenna with a simple feeding structure and compact size makes it possible to be used in portable devices.

1. INTRODUCTION

Ultra-wideband (UWB) technology possesses great merits including high data rate, low cost and easy fabrication. Therefore, the UWB antennas have been designed to be used in radar field, microwave imaging and future mobile technologies [1]. However, this excessively researched technology suffers from multipath fading. In order to solve this problem, multiple-input-multiple-output (MIMO) antenna was introduced [2]. Moreover, the communication quality and channel capacity of MIMO antenna can be improved by increasing the number of transmitter antennas and receiver antennas without extra radiation power and spectrum bandwidth [3]. However, when two or more antenna elements work closely to each other, the mutual coupling between the antenna elements becomes strong that the MIMO antenna cannot reach high isolation and wide operating band without taking any method [4]. Some configurations have been studied to ensure small size, broad impedance bandwidth and high isolation. For example, two bent slots in the ground make the isolation higher than 18 dB between the two antenna elements from 2.45–6.55 GHz in [5]. [6] illustrates a MIMO antenna using different patterns and polarization to reach high isolation in its working frequency band (3.1–5.15 GHz), by adding a slot to the ground also further enhance the isolation to -20 dB. [7] introduces a double-layer EBG structure. Three slit-patch structures are inserted in the ground plane between two closely placed UWB monopoles, and the isolation of the whole working frequency band is larger than 15 dB. [8] demonstrates an 5.5 GHz band-notched UWB-MIMO antenna using coplanar waveguide (CPW)-fed to achieve a small size of $48 \times 48\,\text{mm}^2$, and a stub from the ground can enhance the isolation over 15 dB in its operating frequency band, and a compact MIMO antenna whose size is $32 \times 32\,\text{mm}^2$ is presented in [9]. The antenna consists of two open L-shaped slot antenna elements and a narrow slot to ensure the impedance bandwidth larger than 3.1–10.6 GHz and the mutual coupling less than -15 dB.

Asymmetric coplanar strip (ACS)-fed structure has high-performance in decreasing the overall size of antennas because of its half ground identity compared to CPW-fed structure. Moreover, the ACS-fed structure has many advantages such as compactness, single lateral ground-plane, wide impedance

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* Corresponding author: Jing-Yi Zhang (jing1_345@163.com).
The authors are with the Research Institute of Electronic Science and Technology, University of Electronic Science and Technology of China, Chengdu 611731, China.

matching bandwidth and easy integration with modern communication [10]. [11] presents a 2-port MIMO antenna using ACS-fed structure to reach a very compact size of $28.5 \times 28.5\,\mathrm{mm}^2$, in order to raise isolation between the two antenna elements, a stub from the ground is introduced, the impedance bandwidth of the antenna covers UWB with the isolation over 15 dB.

In this paper, we design a 4-port ACS-fed UWB-MIMO antenna with shared radiators. Four ports fed by ACS are inserted to ensure the antenna working in the UWB frequency band while reducing the ground size. Additionally, the two radiators are shared by four antenna elements which could further decrease the total size of the MIMO antenna. As a result, the MIMO antenna reaches a very compact size of $36 \times 36\,\mathrm{mm}^2$ which is smaller than most of the 4-port UWB-MIMO antennas. The key parameters which influence the impedance bandwidth and the isolation between any two antenna elements are simulated and discussed in detail. The simulated and measured results both show that the antenna operates from 3.1 to 10.6 GHz with the isolation over 15 dB between any two antenna elements.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

Figures 1(a) and (b) show the configuration of the proposed antenna. The antenna is designed on a low-cost 1 mm-thick FR-4 substrate, with a total size of $36 \times 36\,\mathrm{mm}^2$, a relative permittivity of 4.4 and a loss tangent of 0.02. It contains two quarter-circular radiating elements, and the four ports of the radiators are fed by ACS. The signal strip width is 0.92 mm, and the distance between the signal strip and the coplanar ground plane is 0.17 mm.

Each radiator is etched with an I-shaped slot. By adjusting the length and width of the slots properly, the working frequency band of the antenna reaches UWB and the isolation between port 1 and port 2 (port 3 and port 4) can also be enlarged. We use the High-Frequency Structure-Simulator (HFSS) to quickly study the antenna behaviour, and the optimized parameters of the proposed antenna are given in Table 1.

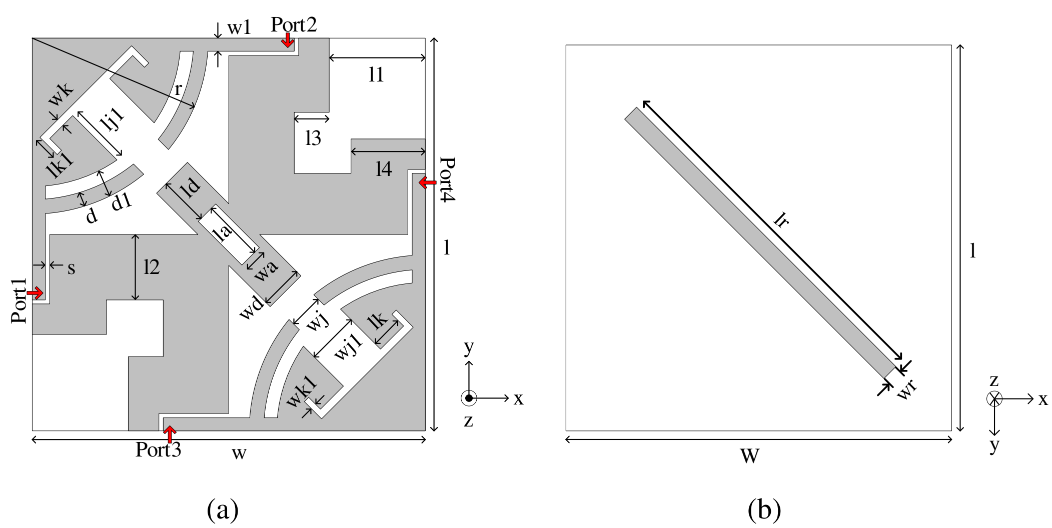


Figure 1. Configuration of the proposed ACS-fed UWB-MIMO antenna with shared radiators. (a) Top view. (b) Back view.

Table 1. Parameters of the proposed antenna.

Parameter	w	l	r	$w1$	s	$l1$	$l2$	$l3$	$l4$	wd	ld	wa
Value (mm)	36	36	17.34	0.92	0.17	10.43	4.88	2.48	7.19	4	4.15	1.96
Parameter	la	d	$d1$	wj	$wj1$	$lj1$	wk	lk	$wk1$	$lk1$	wr	lr
Value (mm)	4.89	1.08	2.42	3.4	4.23	6.87	0.69	3.5	0.78	2.49	1.15	31.23

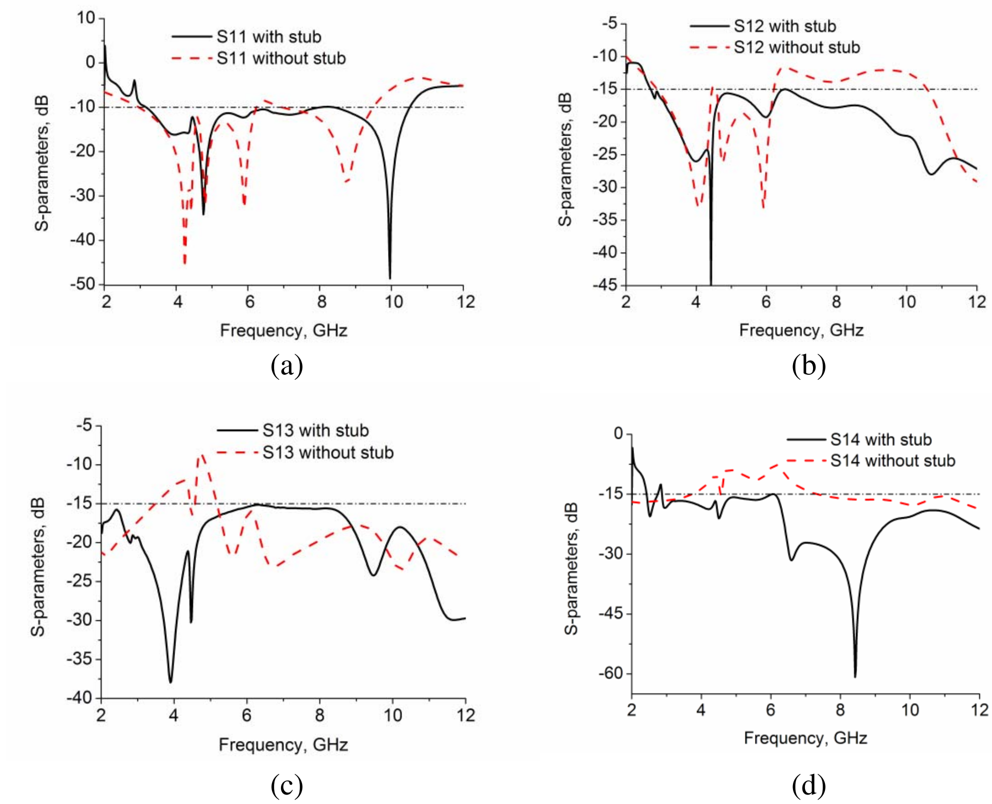


Figure 2. Simulated S-parameters of antenna when the stub varies. (a) S_{11}. (b) S_{12}. (c) S_{13}. (d) S_{14}.

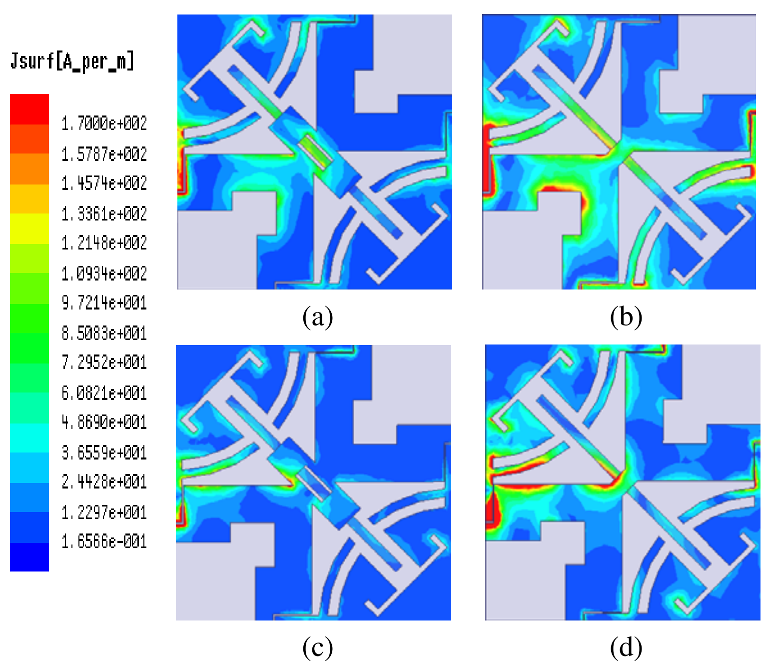


Figure 3. Simulated surface current distribution of the proposed antenna. (a) With the stub at 4.7 GHz. (b) Without the stub at 4.7 GHz. (c) With the stub at 10 GHz. (d) Without the stub at 10 GHz.

The stub of the ground has great effect on both bandwidth and mutual coupling. Figure 2 shows different conditions between with and without the stub. In Figure 2(a), we notice that when the stub is introduced, the operating band width is enlarged to meet UWB. Figure 2(b) to Figure 2(d) present that the stub can make the S-parameters drop so as to achieve the expected isolation. In order to better convey the influence of the stub, the surface current distribution of the antenna at the two resonant frequencies of 4.7 GHz and 10 GHz are shown in two forms: with and without the stub in Figure 3. As can be seen from Figure 3, the stub blocks the surface current flowing from port 1 to port 2, 3, 4, thus the stub can reduce the mutual coupling. Moreover, the absorbed surface current of the stub helps expanding the operating bandwidth of the antenna. To better enhance the isolation, we introduced a rectangular slot in the stub and the influence of the slot can be seen from Figure 4. The slot does improve the isolation in 5.6–7.1 GHz frequency band between port 1 and port 3 obviously.

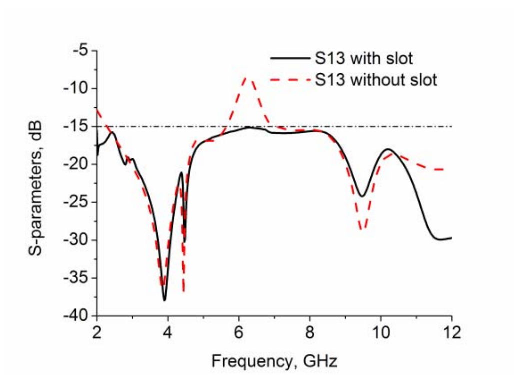


Figure 4. Simulated S_{13} of antenna when the rectangular slot varies.

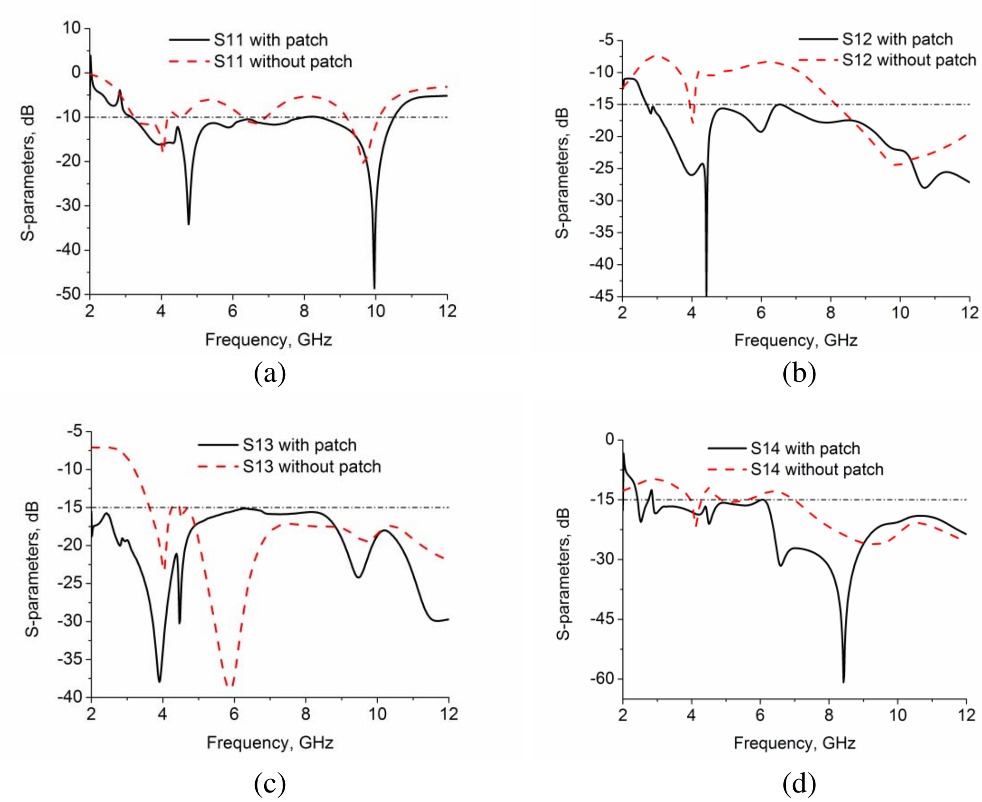


Figure 5. Simulated S-parameters of antenna when the patch varies. (a) S_{11}. (b) S_{12}. (c) S_{13}. (d) S_{14}.

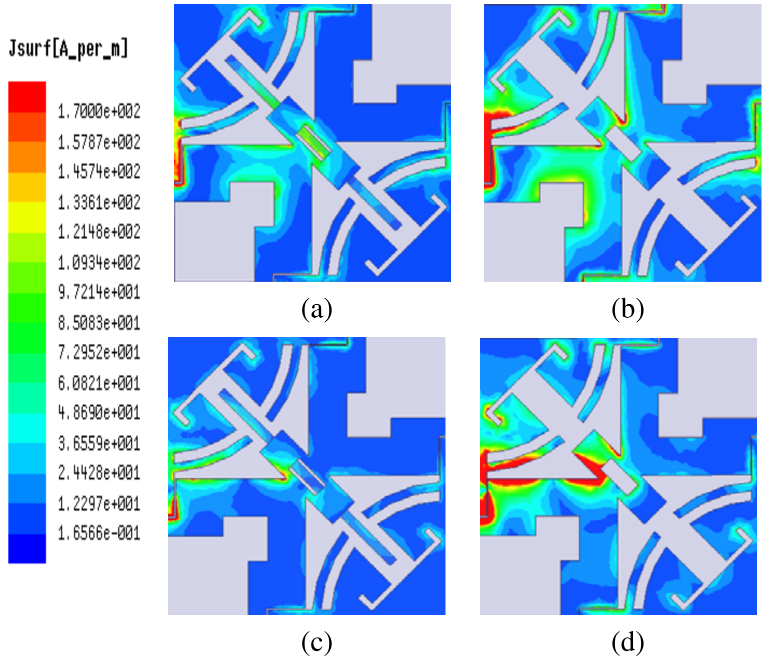


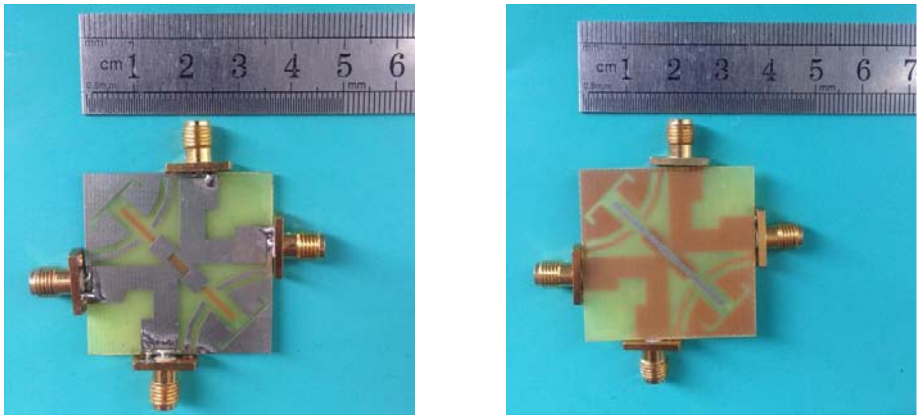
Figure 6. Simulated surface current distribution of the proposed antenna. (a) With the patch at 4.7 GHz. (b) Without the patch at 4.7 GHz. (c) With the patch at 10 GHz. (d) Without the patch at 10 GHz.

Another key structure is the rectangular patch which acts as a reflector on the back of the substrate. Firstly, we introduce this patch between each two antenna elements and find that the patch impacts the antenna on both impedance bandwidth and mutual coupling. The different simulated results between with and without the patch is shown in Figures 5(a) to (d). Secondly, different current distributions of the proposed antenna in two conditions: with and without the patch, are studied, as shown in Figures 6(a) to (d). We can notice that the patch works as a reflector and enhances the isolation in the lower frequency band. From Figure 5(a) we can conclude that the patch impacts the antenna on −10 dB impedance bandwidth in the following frequency band: 3.1–9.1 GHz. Thirdly, we found the proper size of the patch after optimization by using HFSS.

3. RESULTS AND DISCUSSION

The proposed antenna is fabricated, and its paragraph is shown in Figure 7. As shown in the figure, the ACS-fed ports are linked with four 50-Ω SMA connectors. We use Agilent E8363B vector network analyzer to measure return loss and isolation of the presented antenna. When port 1 is excited, port 2, port 3 and port 4 are terminated with 50 Ohm loads, and vice versa. The simulated and measured S-parameters are presented in Figure 8. From the figure we can conclude that the simulated and measured results show reasonable agreements, and the antenna operates at the UWB frequency band (3.1–10.6 GHz) while the isolation between any two ports is over 15 dB. There are some differences between the simulated curves and the measured curves possibly due to the fabrication error.

The measured radiation patterns in the E- (port 1 & 4: YZ-, port 2 & 3: XZ-) planes and H- (port 1, 2, 3 & 4: XY-) planes at 3.5, 6.5, and 9.5 GHz are shown in Figures 9(a)–(c). In H-planes, the radiation patterns are shown as nearly omnidirectional patterns, and the radiation patterns in the E-planes are shown as likely bidirectional patterns over the desired operating bands. It can be seen that the radiation pattern deteriorates slightly at the higher resonant frequency due to the fact that the presented asymmetric ground plane is half of the CPW-fed antennas. Moreover, the coaxial line which connects the antenna with the spectrometer has higher insertion loss at 9.5 GHz than that of 3.5 and 6.5 GHz.



(a) (b)

Figure 7. Photograph of the UWB-MIMO antenna. (a) Top view. (b) Back view.

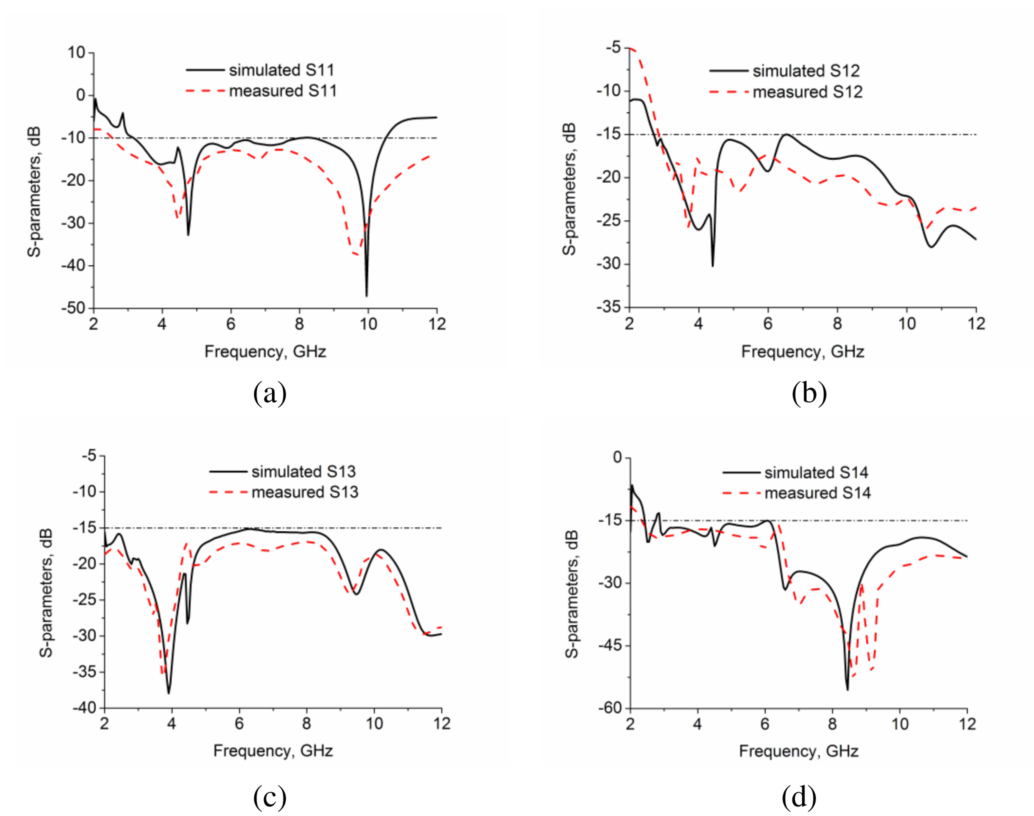


Figure 8. Simulated and measured S-parameters of the proposed antenna. (a) S_{11}. (b) S_{12}. (c) S_{13}. (d) S_{14}.

Figure 10 shows the measured peak gains and radiation efficiency of the four ports against the frequency. The curves of the peak gains are almost constant in the whole band (3–11 GHz). It can be seen that the antenna shows reasonable gains, and the measured radiation efficiency of the four ports are all above 58% across the UWB.

The envelop correlation coefficient can be calculated using measured S-parameters by the format referred in [8]. The measured envelop correlation coefficient between antenna elements is all below 0.02 as shown in Figure 11. From the figure we can conclude that the proposed antenna provides good diversity performance.

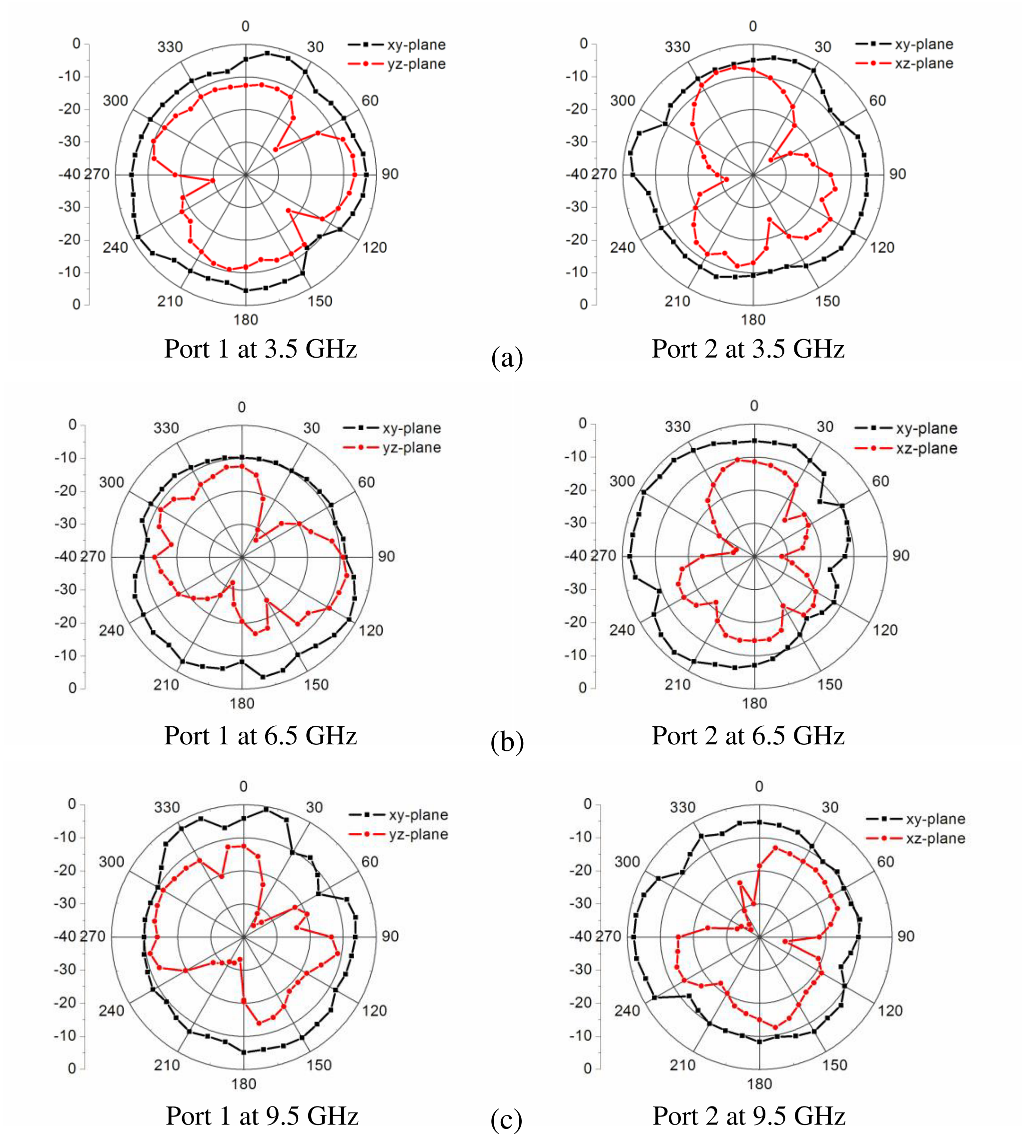


Figure 9. Measured radiation patterns of the proposed antenna. (a) 3.5 GHz. (b) 6.5 GHz. (c) 9.5 GHz.

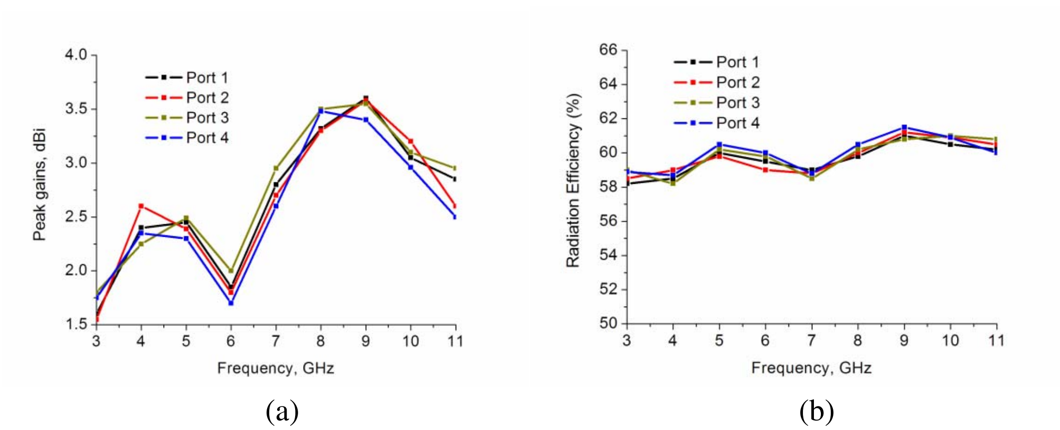


Figure 10. Measured peak gains and radiation efficiency of the proposed antenna. (a) Peak gains. (b) Radiation efficiency.

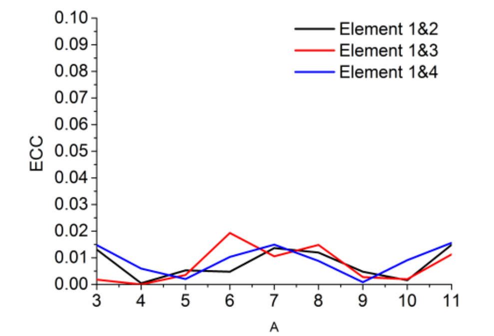


Figure 11. Measured envelop correlation coefficient.

4. CONCLUSION

A compact 4-port ACS-fed UWB-MIMO antenna with shared radiators is designed, fabricated, and measured. The proposed antenna has a very compact size of $36 \times 36\,\text{mm}^2$ which makes it possible to be used in portable devices. By etching two I-shaped slots in the radiators and attaching a rectangular patch on the back, the operating bandwidth is broadened, and the isolation between any the two antenna elements is enhanced. The stub from the ground also has great effect on the $-10\,\text{dB}$ impedance bandwidth and mutual coupling. The simulated and measured results show consistency that working frequency band of the MIMO antenna covers 3.1–10.6 GHz with the isolation over 15 dB between any two antenna elements.

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