Regular Article

Proposal of MIMO Ultra-Wide Band Antenna with Low Mutual Coupling

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Abstract– **In this paper, a new ultra-wide band (UWB) MIMO antenna is proposed. A MIMO antenna set consists of two single ultra-wide band antennas. This simple and compact MIMO antenna, which is designed to work from 3.1 GHz to 10.6 GHz, has a broad bandwidth with the VSWR$\leq$ 2. In addition, MIMO antenna characteristics such as radiation pattern, maximal gain are thoroughly investigated.**

Keywords– **Ultra-Wide Band (UWB), Ultra-Wide Band antenna, printed antenna, planar antenna, MIMO antenna.**

1 Introduction

MIMO (Multi-Input Multi-Output) systems use multiple antennas at both transmitter and receiver sides. As a result, these systems can obtain transmit and receive diversity to improve the system performance or perform transmit as well as receive beamforming to enhance the system efficiency and suppress interferences. Moreover, the system capacity can be significantly improved thank to spatial multiplexing. In MIMO systems, equal numbers of transmit and receive antennas, such as 2×2, 4×4, are often chosen.

The ultra-wide band (UWB) technology was proposed to achieve high data rates in short range communications. To further enhance the data rates and cover ranges of the UWB communication systems, the combination of MIMO techniques and the UWB technology has gain considerable attention recently. A MIMO UWB antenna, however, often uses many radiation elements which have considerable mutual coupling between each other. This phenomenon is considered as a bottleneck in the MIMO UWB systems and should be minimized to improve the stability and radiation efficiency of the whole system. Thus, the designing of a MIMO UWB antenna is not only the designing of its elements but the mutual coupling must also be taken into account.

There have been a number of UWB antennas with different structures and materials including defected ground structure plane radiator [1], UWB monopole antenna with semi-ellipse shaped patches [2], slot UWB antenna with half-wavelength and quarter-wavelength slot on the radiation plane [3], defected ground structure [4], dipole antennas [5, 6], printed antennas [7], printed antennas with defected ground structure [8], slot antennas [9]. In [10], the authors have also proposed an ultra-wide antenna with slotted rectangular radiation plane to achieve small-sized structure.

Some designs of the MIMO UWB antennas with two elements using different structures and materials have also been proposed. In [11], Najam *et al.* proposed a MIMO antenna composed of two rounded antennas with radius $R = 12$ mm, antenna dimensions are of $80 \times 34 \times 0.8$ mm^3 on FR4 dielectric substrate. Compared to this structure, the design in [12] by Li *et al.* has smaller size but more complex structure.

In this paper, a MIMO UWB antenna with small, compact and thin structure, suitable for general structure of UWB equipment, is proposed. The structure of the antenna elements is fabricated on the FR4 substrate with dielectric permittivity of $\varepsilon_r = 4.4$ and loss factor of $\tan\delta = 0.02$. Since the mutual coupling between elements in MIMO antenna always exists, it is necessary to calculate and tune the parameters of the antenna elements, set suitable distance between them and select suitable size of the dielectric substrate so that the proposed MIMO UWB antenna can achieve low mutual coupling while keeping the desired voltage standing wave ratio (VSWR$\leq$ 2), isotropic radiation pattern and good gain. To minimize the mutual coupling between antennas, a stub is placed between two elements in the MIMO antenna. Finally, the prototype was fabricated and its characteristics were measured and compared with simulation results.

2 Design of MIMO UWB Antenna

2.1 Structure of Proposed Antenna

In the first step of designing the MIMO UWB antenna, its single UWB element is calculated. Considering the design in [13] by Kumar *et al.*: a substrate of FR4 with $\varepsilon_r = 4.3$ and $\tan\delta = 0.02$ was used; the dimensions are $60 \times 45 \times 1.6$ mm^3 and ground plane made of copper with the thickness of 35 μm, however, that antenna structure is fairly big. Based on the structure in [13], the authors proposed an antenna with smaller size, more compact and simpler structure that serves as radiation elements for the MIMO UWB antennas.

Based on the working frequency range of the antenna, particularly the wavelength at resonance frequency f_0 and the electric permittivity ε_r, the authors calculated preliminary dimensions of antenna radiation patch.

The width of radiation patch is

$$w_3 = \frac{c}{2f_0}\sqrt{\frac{2}{\varepsilon_\rho + 1}}.$$

The length of radiation patch is

$$l_1 = l_{\text{eff}} - 2\Delta l,$$

where

$$\Delta l = 0,412h\frac{(\varepsilon_{\text{eff}} + 0,3)\left(\frac{w_3}{h} + 0,264\right)}{(\varepsilon_{\text{eff}} - 0,258)\left(\frac{w_3}{h} + 0,8\right)},$$

$$l_{\text{eff}} = \frac{c}{2f_0\sqrt{\varepsilon_{\text{eff}}}},$$

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{10h}{w_3}\right]^{-\frac{1}{2}}.$$

With relative permittivity of $\varepsilon_r = 4.4$, frequency of $f_0 = 7.0$ GHz and the thickness of dielectric substrate $h = 1.6$ mm, the length and the width of radiation patch are $l_1 = 11.5$ mm and $w_3 = 13.4$ mm, respectively. These are preliminary dimensions of a narrow frequency band antenna. With broadband antennas, if the width of radiation patch is bigger, frequency range will be widened because of increase in radiation emission and in amplification ratio as a result of increased emission area. Therefore, with UWB antennas, the width of radiation patch should be increased to achieve expected frequency band. When the width of radiation plane is enlarged, its length must also be increased accordingly. In addition, the square hole is pierced and dimensions of the antenna are adjusted to create multi-resonance, which helps to expand the frequency range and reduce the dimensions of the antenna. Finally, the suitable dimensions of the radiation plane are selected as $l_1 = 14$ mm and $w_3 = 15$ mm.

For the purpose of calculating the width of the antenna feeding strip (w_1), the following formula in [14, 15] is used:

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1,41}}\ln\left(\frac{5,98h}{0,8w_1 + t}\right),$$

where Z_0 is the characteristic impedance of the line, set to Z_0 = 50 Ω; ε_r is the relative permittivity; h is the thickness of dielectric substrate; t is the thickness of copper layer.

Based on the formula for Z_0, the width of feeding strip is calculated as $w_1 \approx 3$ mm. From the design of the single element, by using a slow adjustment method to adjust parameters of antenna, the authors have selected suitable MIMO UWB antenna with geometrical parameters given in Table I.

Table I
THE OPTIMAL GEOMETRICAL PARAMETERS (MM)

Parameters	Values	Parameters	Values	Parameters	Values
L	30	l_1	14	w_3	15
W	70	l_2	2	w_4	2
W_g	32	l_3	1	w_5	2
L_g	10	l_4	11	w_6	2
s	5	l_5	1	w_7	0.5
t	0.035	l_6	4	w_8	1
h	1.6	l_7	10	w_9	1.5
d_1	23	w_1	3	w_{10}	3
d_2	6	w_2	8.5	d	38

2.2 Simulation Results

The simulations were performed under the condition that both elements in MIMO antenna are working concurrently. With no stub, the simulated VSWR is shown in Figure 2. In order to reduce the mutual coupling effect between antennas, a copper stub on the plane of the MIMO antenna is added to separate its two elements. The VSWR of the MIMO UWB antenna with attached stub is shown in Figure 3. As can be seen from the figure, in case of using the stub the VSWR is smaller than that of the case of no stub and the VSWR is less than 2 in the whole frequency range for both antenna elements. In the case of no stub between two elements, when one antenna works, it will induce the other, causing a considerable mutual coupling effect between the two elements because the gap between them is not big enough. If a stub is used then when one antenna works, it will induce the stub first, therefore the induction to the other antenna will be reduced. As a result, the mutual coupling effect between two antennas decreases. The induced current on the stub will create a secondary electro-magnetic field which in turn will have an effect on the two antenna elements, this will affect not only the mutual coupling between the two antennas but also their VSWR. Therefore, the dimensions of the stub must be carefully selected. In the proposed MIMO antenna, the authors have selected the stub as shown in Figure 1.

The mutual coupling effect between two antennas is given in the following formula [16]:

$$\begin{aligned}\rho_e &= |r_{12}| \\ &= \frac{\left|S_{11}^*.S_{12}+S_{21}^*.S_{22}\right|^2}{\left(\sqrt{1-|S_{11}|^2-|S_{21}|^2}\right)\left(\sqrt{1-|S_{22}|^2-|S_{12}|^2}\right)}.\end{aligned} \quad (1)$$

In order to ensure that MIMO antennas work properly when the voltage standing wave ratio is less than 2 (equivalent to return loss ratio S_{11} and $S_{22} < 10$ dB) it is required that $\rho_e < 0.5$ [17]; this is equivalent to the fact that S_{12} and S_{21} are less than -15 dB.

Figure 4 shows the simulated values of S_{12} and S_{21} of MIMO antenna in two cases: with and without the stub. To keep the mutual coupling effect between elements low, it is required that S_{12} and S_{21} are less than -15 dB. From Figure 4 it is apparent that in the case of using the stub, S_{12} and S_{21} are less than -15 dB in the whole investigated frequency range while without the stub, S_{12} and S_{21} are greater than -15 dB in the frequency range from 3 GHz to 5 GHz.

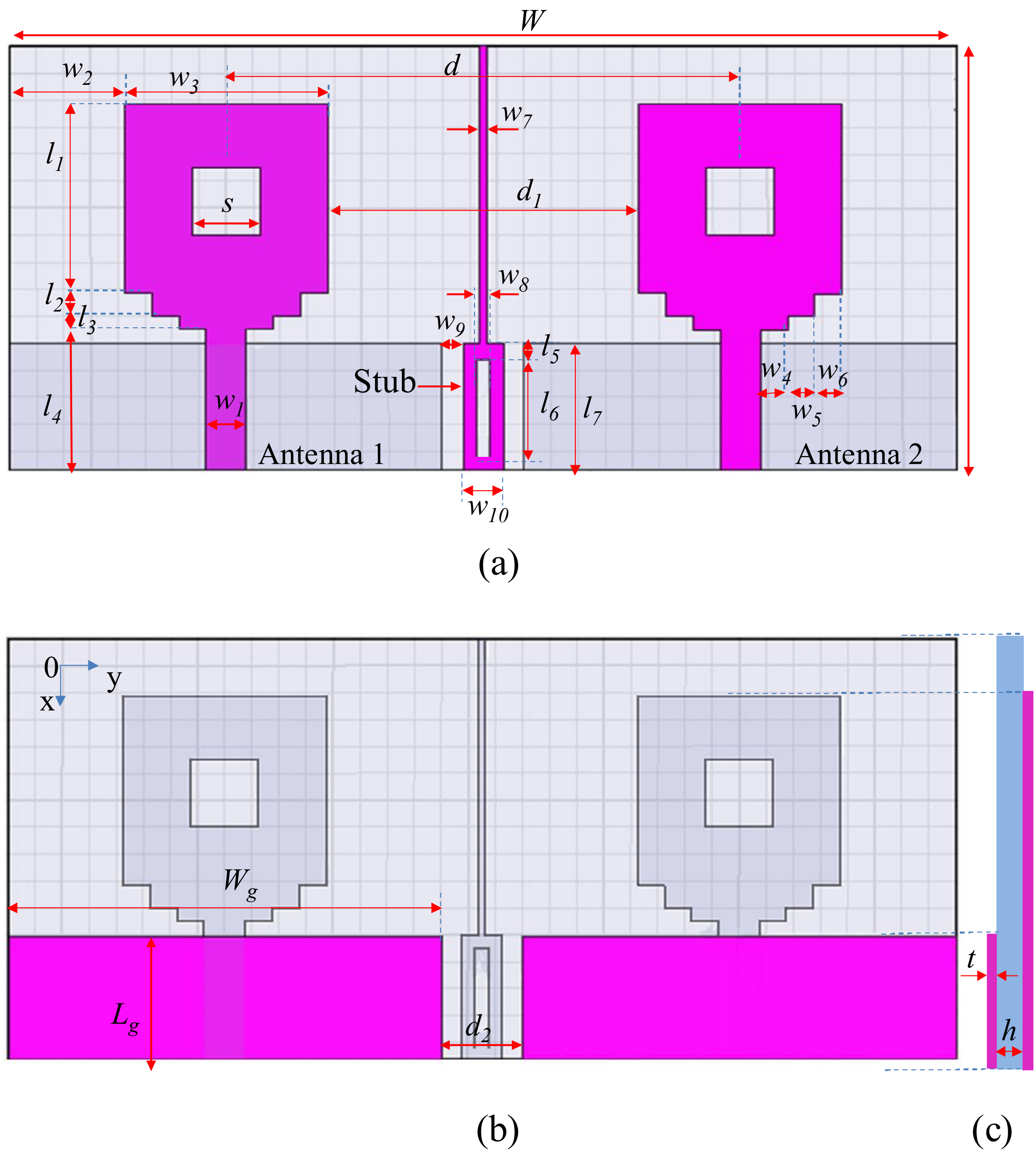


Figure 1. Configuration of MIMO antenna: (a) top view; (b) bottom view; (c) side view.

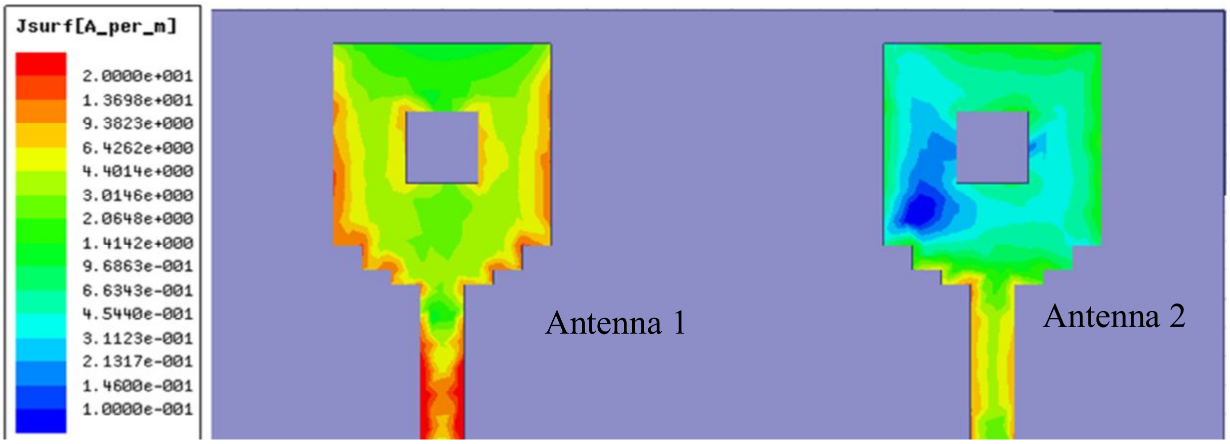
In the case of using the stub, after completing the simulation and calculation based on formula (1), we got the graph showing the values of ρ_e in working frequency range in Figure 5. From Figure 5, it is clear that the mutual coupling ratio between two antennas is small, this satisfies the requirement for the two elements of the proposed MIMO UWB antenna to work properly.

To better understand the mutual coupling effect between the two elements in the MIMO antenna, the surface current distribution is investigated in the case when antenna 1 works while antenna 2 does not. The current distribution is shown in Figure 6, in which one can see if the stub structure is not used, the current of antenna 1 induces that of antenna 2. However, when the stub structure is used between 2 antennas, the induced current between the two antennas decreases significantly. Instead, the induced current will be distributed mainly on the stub.

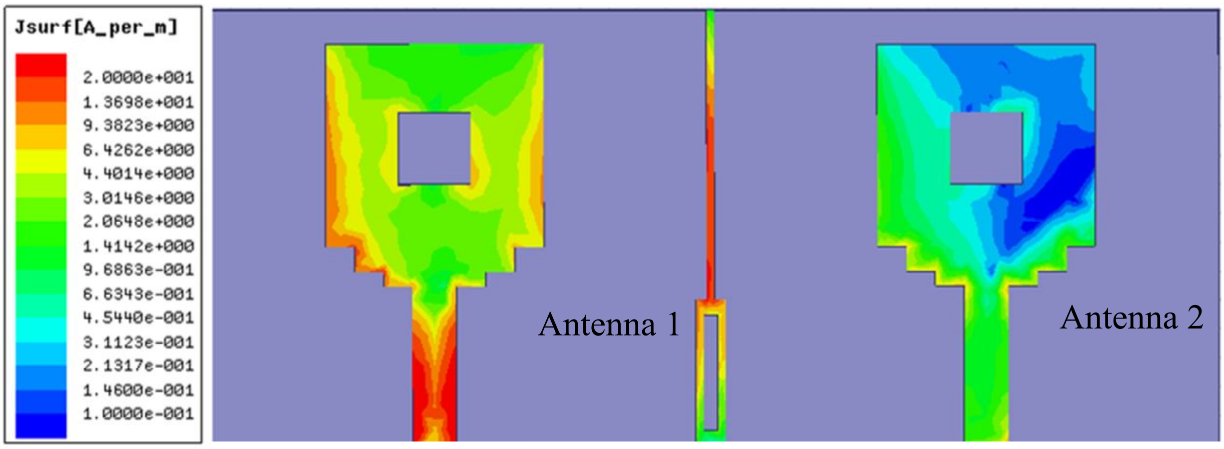
Thus, when the two antennas are placed at distance of $d = 38$ mm $= 0.38\,\lambda_{\max}$ (with $\lambda_{\max} = c/f_{\min}$) from each other, the use of the additional stub helps these antennas work properly with little mutual coupling effect.

It is clear that the use of the stub can reduce mutual coupling effect between the two elements in the proposed MIMO antenna, we therefore will use this structure and investigate other parameters of the MIMO antenna.

Since the frequency range is very wide, the radiation



(a)



(b)

Figure 6. Current allocation at frequency 4.0 GHz (a) without the stub; (b) with the stub.

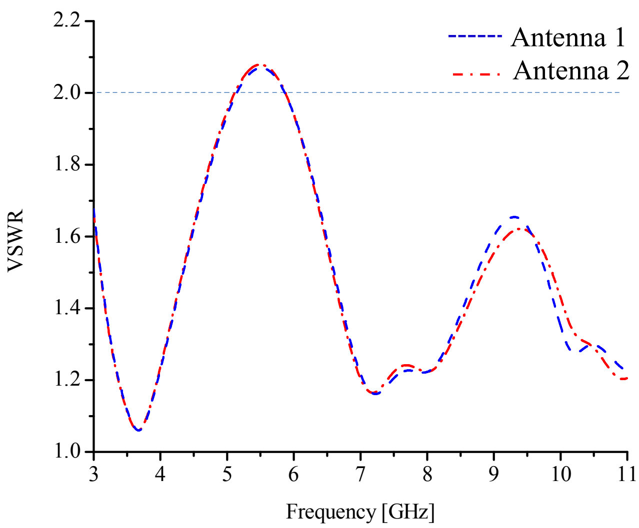


Figure 2. VSWR of MIMO elements without the stub.

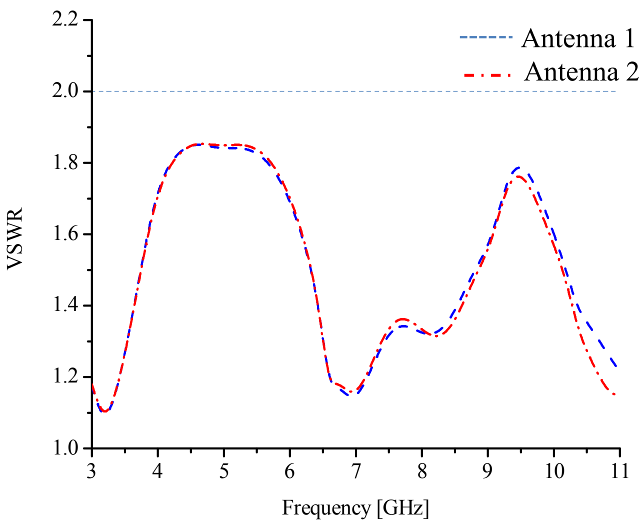


Figure 3. VSWR of MIMO elements with the stub.

pattern of the antenna needs to be simulated at different frequencies. The radiation pattern of MIMO antenna with both elements working is shown in Figure 7. The patterns at the frequencies of 3.1 GHz, 5.0 GHz, 7.0 GHz, 9.0 GHz and 10.6 GHz are shown on Figures 7(a), (b), (c), (d), (e), respectively. In particular, solid line shows the pattern in the xoz plane, the dashed line shows the pattern in the yoz plane. From Figure 7, it can be seen that the radiation pattern of the MIMO antenna is nearly isotropic and varies within the frequency

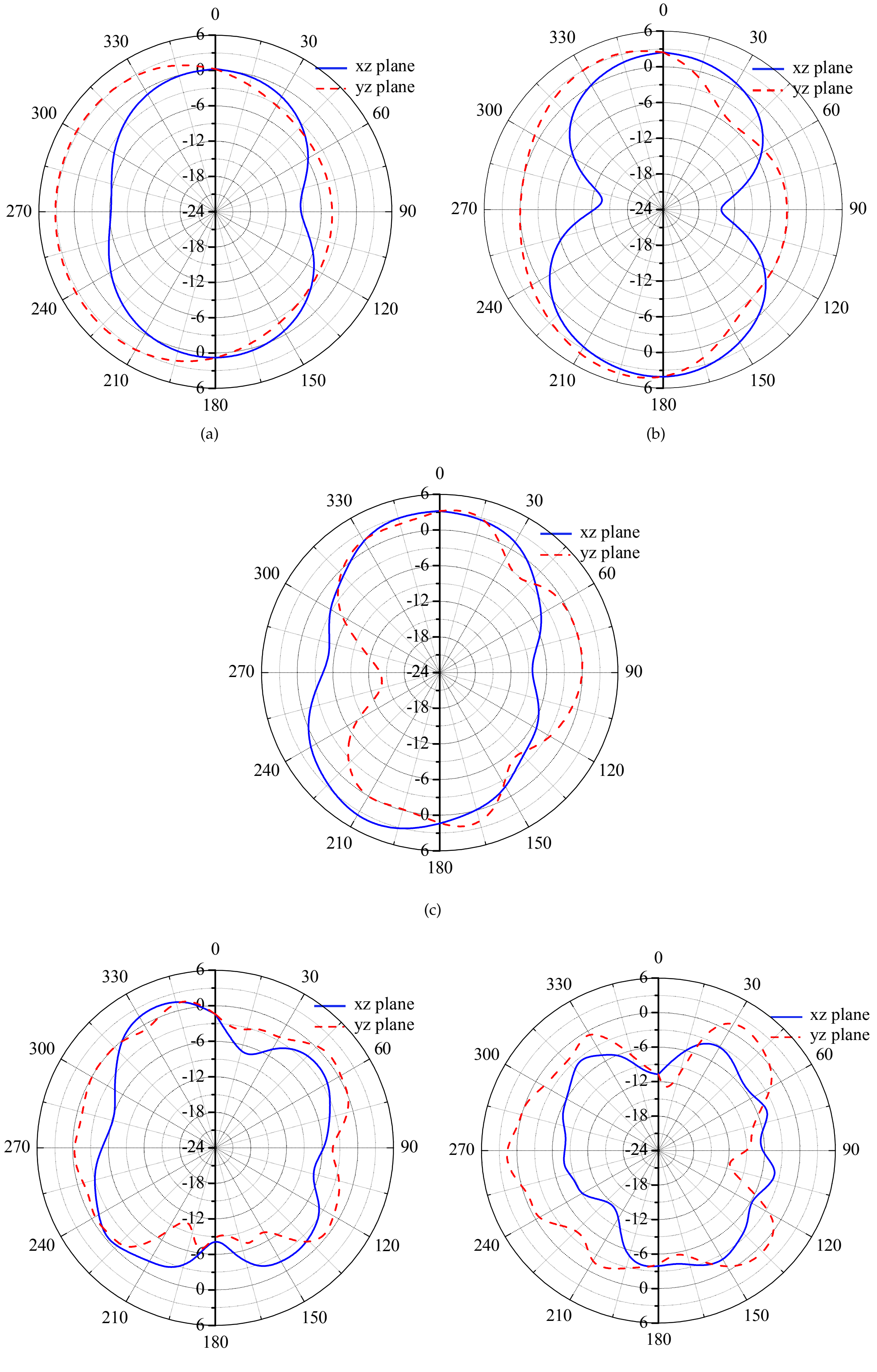


Figure 7. Radiation patterns of the antenna: (a) at 3.1 GHz; (b) at 5.0 GHz; (c) at 7.0 GHz; (d) at 9.0 GHz; (e) at 10.6 GHz

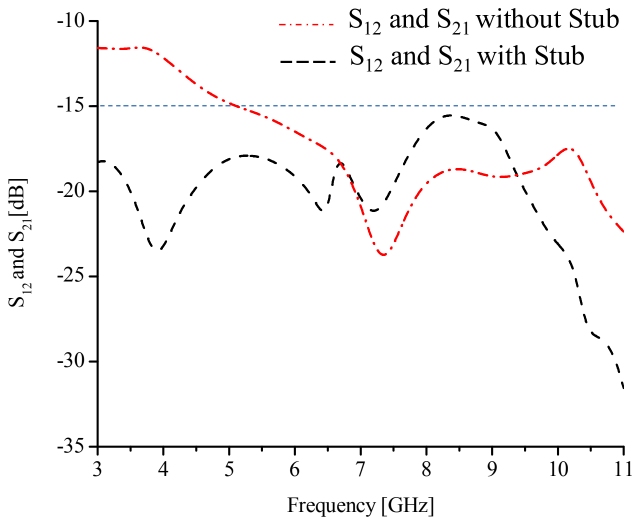


Figure 4. S_{12} and S_{21} of MIMO antennas.

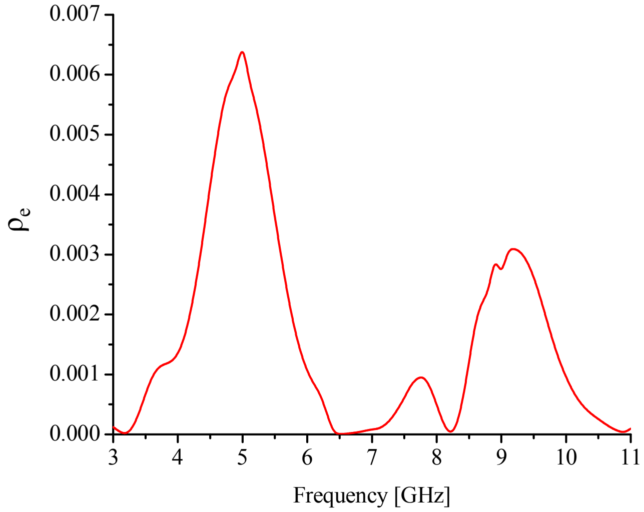


Figure 5. Mutual coupling ratio between two antennas in MIMO.

range; however, it still satisfies the requirements for a MIMO UWB antenna.

Figure 8 depicts the peak gain of the MIMO antenna within the investigated frequency range. It is apparent that although the antenna peak gain varies with frequencies, it is still higher than 3.8 dBi within the frequency range from 3.1 GHz to 10.6 GHz. The antenna gain achieves its peak value of 6.8 dBi at the frequency of 11.0 GHz.

3 Measured Results and Discussions

Based on the simulated results, a prototype has been fabricated as shown in Figure 9.

The VSWR of the two elements were measured and compared with simulation results as shown in Figures 10 and 11. From these figures, it can be seen that the actual and simulated VSWR are less than 2 in the whole investigated frequency range. This shows that the proposed MIMO antenna satisfies the requirements

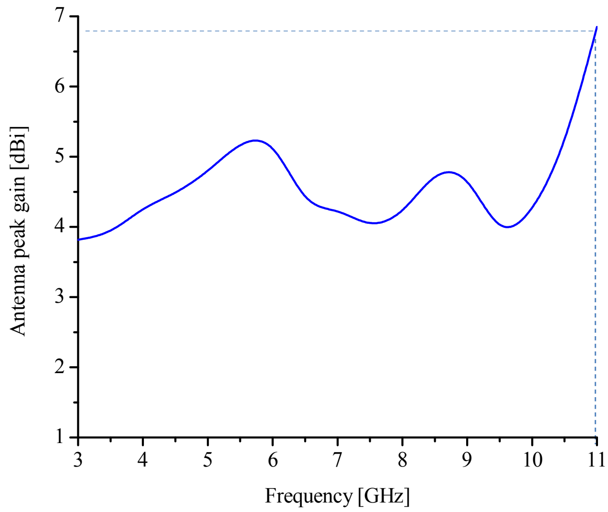
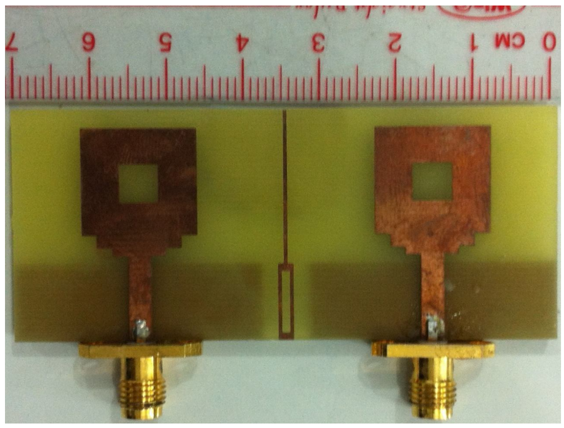
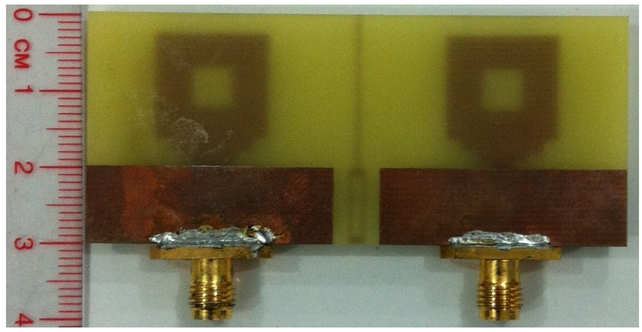


Figure 8. Antenna peak gain versus frequency.



(a)



(b)

Figure 9. Photograph of the fabricated MIMO antenna (a) top view; (b) bottom view.

of MIMO UWB antennas.

In order to evaluate the mutual coupling effect between two antennas, the parameters S_{12} and S_{21} were investigated. Since the two elements in the MIMO antenna have the same structure parameters, S_{12} and S_{21} have the same values. Measurement results and simulation results of S_{12} and S_{21} are shown in Figure 12.

From Figure 12, it can be seen that the measurement result line has the similar shape to that of the simulation

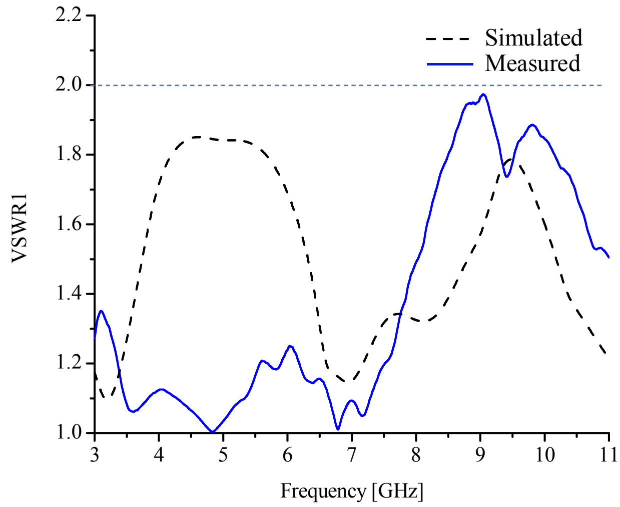


Figure 10. Comparison between measurement results and simulation results of antenna 1 (VSWR).

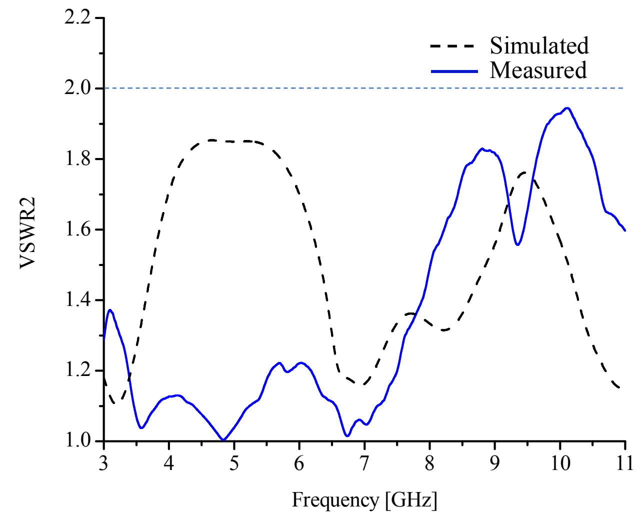


Figure 11. Comparison between measurement results and simulation results of antenna 2 (VSWR).

result. In spite of minor differences, it is still clear that S12 and S21 are less than −15 dB in the whole frequency range. This again satisfies the requirements for MIMO UWB antennas to get low mutual coupling effect and work stably within the desired frequency range.

To sum up, the measurement results of the prototype of proposed MIMO UWB antenna agree well with the simulation results. This affirms that all parameters of the proposed antenna satisfy the technical requirements for MIMO UWB antennas with a small size and a low mutual coupling effect.

4 Conclusion

This paper has proposed a MIMO UWB antenna with a small size and low mutual coupling, which has some following advantages:

i) The antenna structure is small, compact, simple,

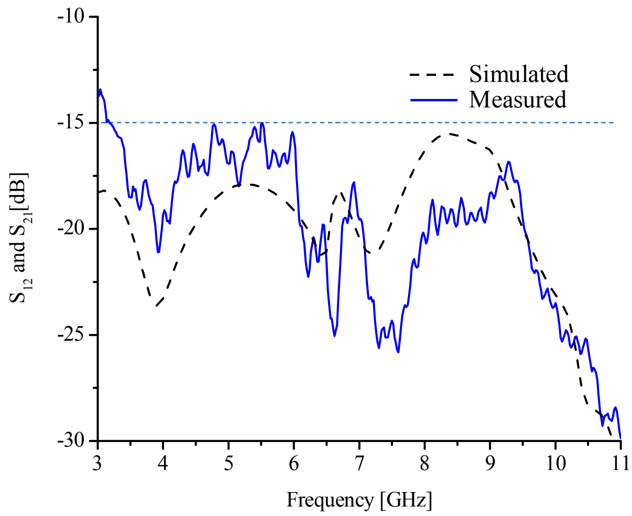


Figure 12. Comparison of measurement results and simulation results of S_{12} of MIMO antennas.

thus it is convenient for fabricating by printed circuit technology.

ii) The VSWR is less than 2 in the whole investigated frequency range from 3.0 GHz to 11.0 GHz, which corresponds to 116.8% of the center frequency.

iii) In spite of ultra-wide frequency range, radiation pattern in the whole frequency range can be considered isotropic.

iv) The peak gain that the antenna achieves in the overall UWB frequency range varies from 3.8 dBi to 6.8 dBi.

v) The mutual coupling effect between antennas is relatively small, ensuring its stability.

vi) Measurement results of proposed antenna prototype are similar to simulation results, showing that the proposed antenna meets the requirements for MIMO UWB antennas.

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