

Compact Ultrawideband (UWB) Slot Antenna with Wideband and High Isolation for MIMO Applications

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Abstract—A compact ultrawideband (UWB) multiple-input-multiple-output (MIMO) antenna with a small size of $22 \times 36 \text{ mm}^2$ is proposed for portable devices. The MIMO antenna consists of two symmetric slot antenna elements with back-to-back separation of 7 mm. Adjusting the open-ended stepped radiator and the position of the microstrip line can realize UWB impedance matching. In order to achieve wideband and high isolation, a cross-shaped decoupling slot and connecting metal line are etched on the ground plane. The cross-shaped slot between the antenna elements is used to decrease the mutual coupling caused by near-fields at middle and high bands. The connecting line can be interpreted as a neutralized line, which produces an additional current path for the ground coupling currents. Measured S -parameters show that the isolation is better than -16 dB across the UWB of 3.1–10.6 GHz. The radiation pattern, gain, and envelope correlation coefficient are also measured. The proposed antenna with a simple structure and compact size achieves good impedance matching and excellent port isolation simultaneously, and is a good candidate for UWB MIMO systems.

1. INTRODUCTION

Ultrawideband (UWB) has become a rapidly growing technology because of very high data rates and low operating power levels [1]. Like other wireless communication systems, UWB systems also suffer from rapidly time-varying environments resulting in multipath fading. It is well known that the multiple-input-multiple-output (MIMO) technology is capable of dramatically increasing the channel capacity and combating multipath fading [2]. However, installing multiple antennas on limited space in portable devices will inevitably cause severe mutual coupling and significantly degrade the diversity performance. Furthermore, it is far more difficult to maintain a low mutual coupling within an ultrawide band than a narrow band. Therefore, the design of UWB MIMO antenna system with compact structure and high port isolation is a challenging topic.

Many studies have been reported to achieve the wideband and high isolation between the elements of a MIMO UWB antenna [3–11]. The neutralized line is a simple decoupling network to improve the isolation and utilized in [3, 4]. However, it usually guarantees at an excellent isolation in a resonant frequency. Ground branches are applied in [5, 6] to achieve low mutual coupling within a narrow frequency band, and the diversity antennas only cover the lower UWB band. To enhance wideband isolation, a multiple-resonance decoupling ground stub is proposed in [7]. The MIMO antenna with a complicated tree-like structure has an isolation higher than -16 dB over the entire UWB band. In [8], a closely-packed MIMO antenna combines monopole antenna and slot antenna to achieve pattern diversity. The antenna elements have distinct polarizations and radiation patterns, and so they can receive signals with low correlation. In [9], there is a compact MIMO antenna design with partial ground plane. The MIMO antenna with asymmetric coplanar strip (ACS)-fed structure is proposed in [10]. Good isolation

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is achieved by inserting fence-like stub and vertical port position. A combination of decoupling ground stub and polarization diversity is investigated in [11] to achieve high isolation. The printed MIMO monopole antenna has a small size of $26 \times 40 \text{ mm}^2$.

To meet the specifications of wide bandwidth, simplicity, and high isolation, a closely-packed UWB MIMO slot antenna is proposed in this paper. The proposed MIMO antenna consists of two symmetric stepped slot antennas with back-to-back separation of 7 mm. With such a compact dimension and simple antenna structure, the -10 dB impedance bandwidth of the antenna covers the band of 3.1 GHz to more than 11 GHz. The cross-shaped decoupling slot and connecting metal line are etched on the ground plane to achieve wideband and high isolation for diversity application. In order to evaluate the effectiveness of the decoupling network, a parametric study is carried out to study the influence of some important parameters. The measured isolation is better than -16 dB in the whole UWB band and -20 dB in most of the band. Moreover, the radiation patterns, gains, and envelope correlation coefficient are also measured. The results show that the proposed antenna with good impedance matching and excellent port isolation is suitable for portable UWB MIMO antenna systems.

2. ANTENNA DESIGN

The geometry of the proposed UWB MIMO slot antenna is shown in Figure 1. The antenna is printed on a $22 \times 36 \text{ mm}^2$ F4B-2 PCB substrate, which has a relative dielectric constant of 2.65, dielectric loss tangent of 0.02, and thickness of 0.8 mm. The MIMO antenna system consists of two symmetric slot elements, and they are fed by Port 1 and Port 2, respectively. The slot antennas are etched on the back ground plane, which denotes as the back areas as shown in the Figure 1. The radiators are excited via $50\text{-}\Omega$ microstrip lines of 2.2 mm width and 17 mm length. The two antenna elements are placed back to back and separated 7 mm from each other. Since the close proximity inevitably causes severe mutual coupling, a novel cross-shaped structure has been inserted between the radiators to efficiently enhance the wideband isolation. Furthermore, a connecting metal line is added in the decoupling slot to improve the isolation at the low band. The EM simulation tool CST Microwave Studio (MWS) is carried out to design and optimize the proposed UWB MIMO antenna, in terms of impedance bandwidth, isolation between the two input ports, radiation pattern and peak gain. The optimized parameters are listed in Table 1. The working mechanism of the proposed antenna will be analyzed and discussed in the

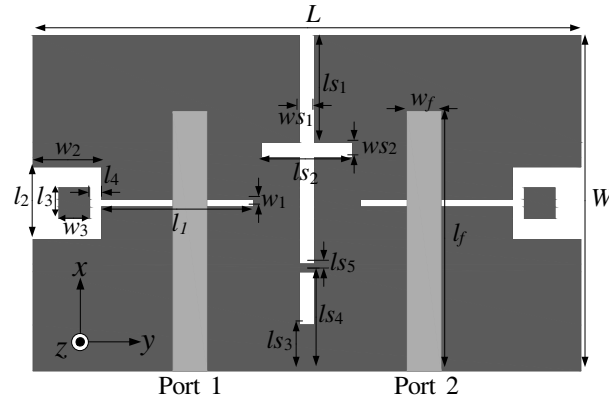


Figure 1. Configuration of the proposed MIMO slot antenna. (The light is top layer and the dark is bottom layer).

Table 1. Parameters of the proposed antenna (unit: mm.)

L	W	l_f	w_f	l_1	l_2	l_3	l_4	w_1
36	22	17	2.2	10	4.8	2	0.8	0.5
w_2	w_3	ls_1	ls_2	ls_3	ls_4	ls_5	ws_1	ws_2
4.5	2	7	6	3	6.5	0.5	1	1

following sections.

2.1. The UWB Slot Antenna

Generally, the radiators with gradient, tapered or stepped shapes can achieve wideband characteristics [12]. An open-ended stepped slot is adopted as the antenna radiator to realize UWB impedance matching and fed through a microstrip line by capacitive coupling. Each slot acts as a resonator, and the resonant frequency mainly depends on the length of the slot, which is about a quarter-wavelength of the resonant frequency. By adjusting the stepped slot, the antenna can realize multiple matching-points (3.3, 4.6, 6.8 and 8.7 GHz, as is depicted in Figure 2) and result in smooth transitions from one resonant mode to another [13]. In addition, these matching-points can be adjusted by tuning the position of the feed line to achieve a wide impedance matching. In order to improve high frequency impedance, a parasitic patch with a size of $2 \times 2 \text{ mm}^2$ is put on the upper edge of the stepped slot.

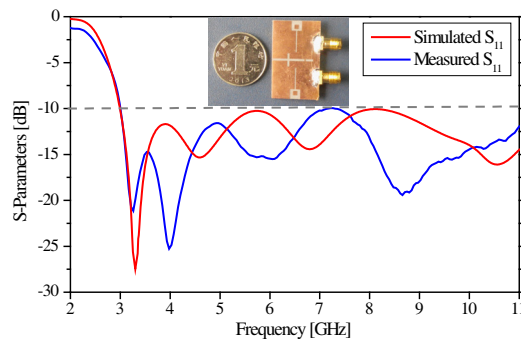


Figure 2. Simulated and measured S_{11} of the UWB slot antenna.

Since Port 2 has the same impedance response S_{22} as that of Port 1, Figure 2 just shows the simulated and measured S_{11} with a fabricated antenna photograph displayed in the inset. In simulation, the waveguide ports are utilized for the two antenna elements, since the results they achieve better reflect the measurement than those produce using discrete ports. The antenna is measured by an Agilent E5071C network analyzer, and the measured results have a good agreement with the simulated one. It is observed that the wide bandwidth from 3.1 GHz to 10.6 GHz is attributable to the four resonances, which are excited with a good impedance matching. The measured bandwidth of the slot antenna is from 3.0 GHz to more than 11 GHz. Therefore, this kind of slot antenna has the advantages of small size, wide bandwidth and good directional property.

2.2. Isolation Mechanism

For MIMO applications, it is crucial for the closely-spaced antenna array to offer low mutual coupling. In the proposed MIMO antenna, three decoupling mechanisms work together to achieve the wideband and high isolation between the two antenna elements.

2.2.1. Angle Diversity

Antenna 1 is a UWB slot antenna that is directional, and its main beam points in the direction of negative y -axis. Since the two antenna elements are back to back, the radiation pattern of Antenna 2 always has a null pointing in the direction of negative y -axis. Hence, the two antenna elements can realize angle diversity to certain extent in their radiation patterns.

2.2.2. Decoupling Slot

The decoupling slot technique has been studied in the closely-spaced narrowband PIFAs [14]. The cross-shaped slot can be interpreted as a reflector of electromagnetic wave, which separates the radiation

patterns of the two slot antennas to reduce the unwanted mutual coupling resulted from the near-field. Furthermore, it also introduces a resonant structure. As the number of the decoupling stub slot increases, more resonances will be introduced, each of which is provided by the open-ended quarter-wavelength slot. With a proper length and position of each stub slot, the wideband isolation can be efficiently enhanced as the two resonances are in different frequency ranges.

In order to investigate the working mechanism of this decoupling method, a parametric study is conducted to design and optimize the cross-shaped slot. Figure 3 depicts the simulated port isolation S_{21} of the MIMO antenna with different l_{s1} . The results show that the slot length l_{s1} mainly influences the isolation at high band. As the length l_{s1} decreases from 8 mm to 5 mm, the poles of the port isolation at the frequencies near 10.3 GHz can be enhanced.

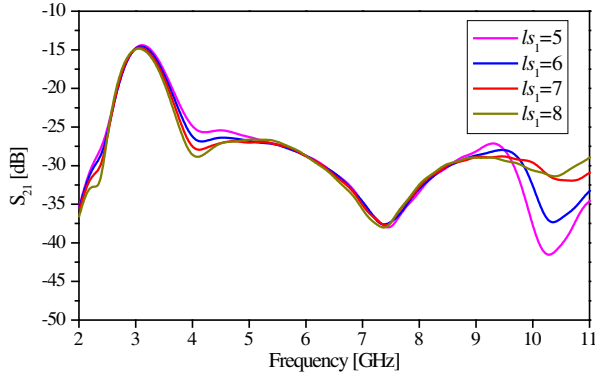


Figure 3. Simulated S_{21} with different slot length l_{s1} .

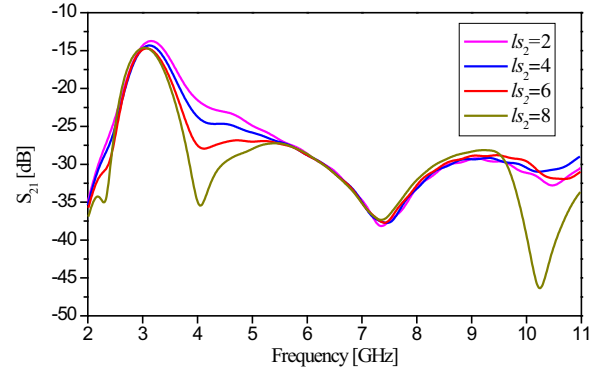


Figure 4. Simulated S_{21} with different slot length l_{s2} .

The effects of the stub slot length l_{s2} on the S_{21} are shown in Figure 4. As length l_{s2} increases from 2 mm to 8 mm, the port isolations at the frequencies near 4.3 GHz vary greatly. The results show that the stub slot with a size of $l_{s2} \times w_{s2}$ mainly influences the isolation at middle band.

2.2.3. Connecting Metal Line

To further reduce the mutual coupling at the low band of 3–4.5 GHz, a metal strip with a size of $l_{s5} \times w_{s1}$ is applied by the proposed UWB MIMO antenna shown in Figure 1, which electrically connects the decoupling slot together. Figure 5 depicts the simulated S_{21} of the proposed MIMO antenna. With the aid of the metal strip, the isolation at the low band is significantly improved, and the port isolation at 3.1 GHz increases from -12 dB to -15 dB.

The surface current distributions for the UWB MIMO antenna with or no connecting metal line are displayed in Figures 6(a) and (b), respectively. It is worth noting that the feed line is terminated with a standard 50- Ω SMA connector. Compared to the MIMO antenna without short strip, there is a little current on the ground plane around the right radiator and the decoupling slot blocks more coupling currents from the no excited Port 2 to the excited Port 1. In fact, the connecting metal line behaves similar to a neutralized line, which produces an additional current path for the coupling ground currents and the current path picks up a part of coupling currents [15].

Based on the mechanisms described above, wideband and high isolation can be achieved, despite the two elements being placed very close to each other. The simulated and measured port isolation S_{21} are in a good agreement as shown in Figure 7. The slight difference between the results is mainly contributed from permittivity variation and the soldered SMA connector, which deteriorate impedance matching. Usually the isolation less than -15 dB is considered adequate for a good diversity performance [6]. The isolation between two ports in the whole UWB is lower than -16 dB and even better than -20 dB above 4 GHz.

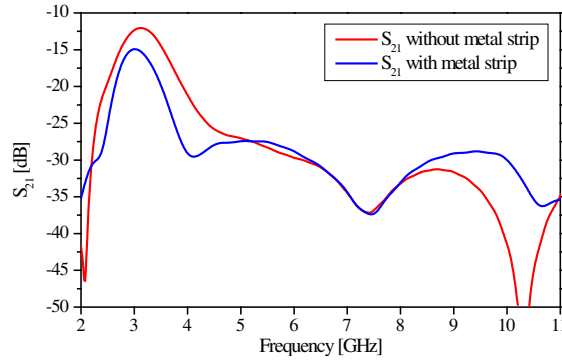


Figure 5. Simulated S_{21} with/without connecting metal line.

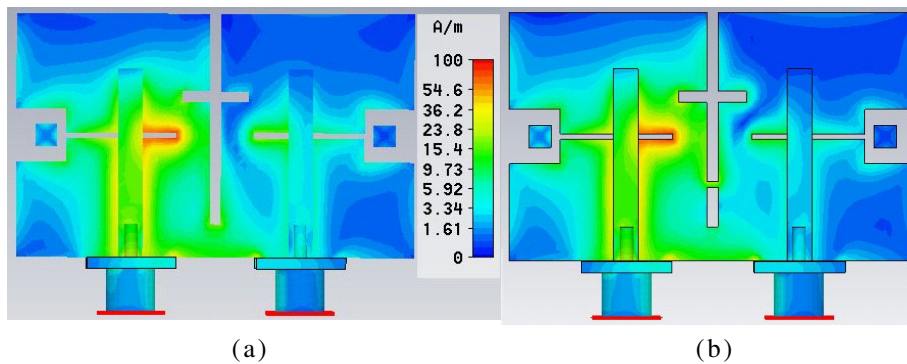


Figure 6. Surface current distributions with Port 1 excitation at 3.1 GHz.

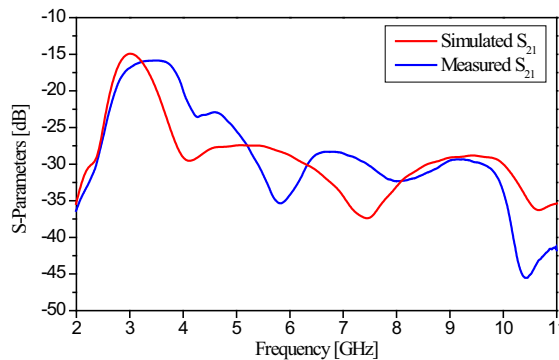


Figure 7. Simulated and measured mutual coupling S_{21} of the UWB MIMO antenna.

3. RADIATION AND DIVERSITY PERFORMANCE

3.1. Radiation Performance

The radiated patterns are measured in a SATIMO StarLab microwave anechoic chamber. During the measurements, Port 1 is excited, while Port 2 is terminated with a 50-Ω load. The measured radiation patterns for the proposed MIMO antenna on the x - z plane (E -plane) and y - z plane (H -plane) at 3.26 GHz, 4.0 GHz and 5.82 GHz are shown in Figures 8(a) and (b), respectively. The radiation patterns are relatively stable across the UWB. The angle diversity can be clearly observed by the asymmetric patterns in H -plane which can help to reduce the mutual coupling caused by near-field. Thus, the proposed MIMO slot antenna shows good pattern diversity characteristic.

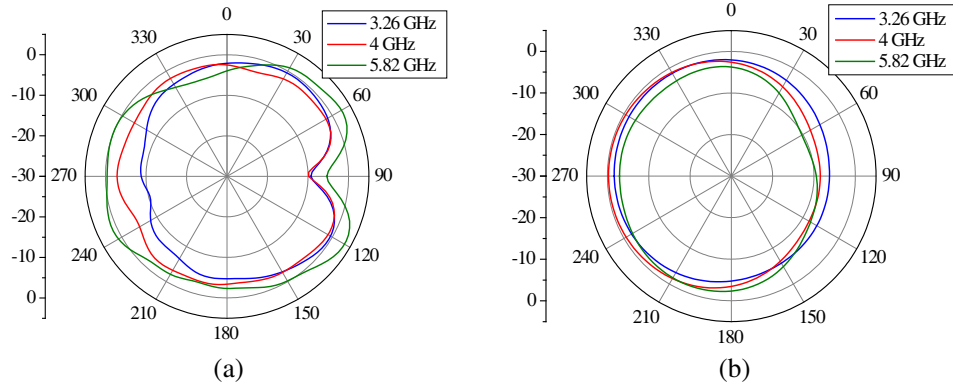


Figure 8. Measured radiation patterns: (a) x - z plane, (b) y - z plane.

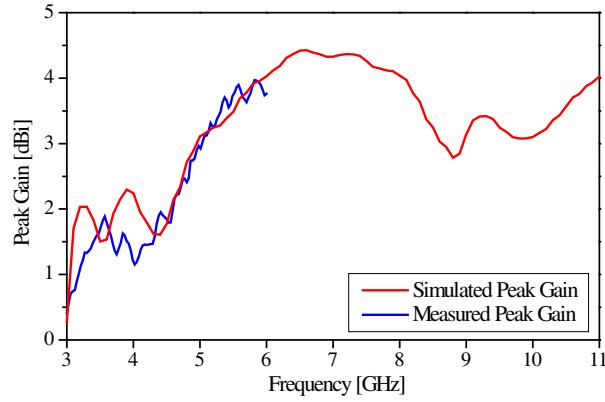


Figure 9. Simulated and measured antenna peak gain for Port 1.

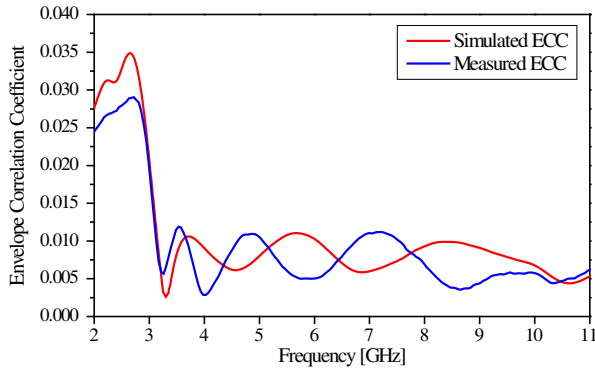


Figure 10. Envelope correlation coefficient.

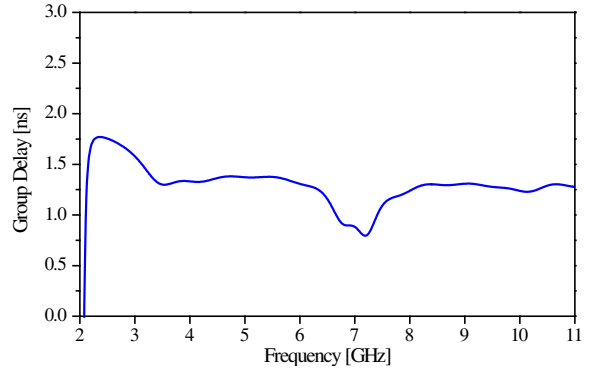


Figure 11. Group-delay.

The antenna gain has also been measured and plotted in Figure 9 at the lower UWB band of 3.1–6 GHz. Due to the symmetry of antenna structure, only the gain for Port 1 is presented. It can be seen that the simulated and measured results agree quite well. The discrepancy comes from feeding cables, particularly at low frequencies. In this case, the antenna ground becomes electrically small, and the current flows back from the antenna to the outer surface of the feeding cable resulting in power loss. The measured gains range from 0.75 dBi to 3.9 dBi at lower UWB band, and the simulated gains are larger than 1.5 dBi across the whole UWB band from 3.1–10.6 GHz.

Table 2. Performance comparisons of the proposed and reference antennas.

Reference	Antenna purpose	Size comparison (proposed/reference)	Port position	Bandwidth ratio of $ S_{21} < -20$ dB/UWB
This Work	UWB MIMO	-	Parallel	88%
Ref. [5]	UWB MIMO	47.5%	Parallel	100%
Ref. [6]	UWB MIMO	29.1%	Parallel	73.3%
Ref. [7]	UWB MIMO	56.5%	Parallel	81.3%
Ref. [8]	UWB MIMO	79.2%	Vertical	100%
Ref. [9]	UWB MIMO	22.9%	Parallel	74.6%
Ref. [10]	UWB MIMO	41.8%	Vertical	64%
Ref. [11]	UWB MIMO	76.2%	Vertical	60%

3.2. Diversity Performance

The envelope correlation coefficient (ECC) is used to measure the degree of similarity between the beam patterns of two antennas and a critical parameter for evaluating the MIMO performance. The low correlation implies that there is little overlapping between the two beam patterns. The envelope correlation coefficient ρ_e can be calculated using S -parameters as shown by (1) [16]. The simulated and measured ρ_e are plotted in Figure 10. It is clearly seen from the figure that the measured envelope correlation coefficient is lower than 0.015 across the whole UWB band.

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

The correlation at low band, which is usually much high, is still very low in the proposed MIMO slot antenna system. It benefits from the good impedance matching and high port isolation, which are due to the stepped slot radiator and the effective decoupling network. In addition, Figure 11 shows the simulated group delay of the proposed UWB MIMO antenna, face to face with distance of 300 mm. 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. Performance Comparison

Comparisons of the proposed antenna and the recently reported MIMO antennas [5–11] on the dimension and isolation performance are listed in Table 2. Though this MIMO antenna has a parallel port position, the bandwidth ratio of $|S_{21}| < -20$ dB/UWB bandwidth is 88%, which means that the proposed antenna has a good isolation performance. In addition, the proposed UWB MIMO slot antenna achieves significant reduction in size. Therefore, the results show that the proposed antenna with compact size and high isolation is a good candidate for MIMO system applications.

4. CONCLUSION

A compact MIMO slot antenna system has been proposed for ultrawideband wireless communication applications. The wideband and high isolation can be achieved through a cross-shaped decoupling slot and connecting metal line on the ground plane. The effectiveness of the decoupling network has been investigated in detail. The stepped slot antenna element can cover the whole UWB band of 3.1–10.6 GHz. Within the UWB, the measured isolation is better than -16 dB in the whole band and -20 dB in most of the band. In addition, the correlation coefficient has been calculated to evaluate the diversity performance of the proposed MIMO antenna. The results show that the proposed antenna is a good candidate for UWB MIMO antenna systems.

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