Miniaturized inverted ultra-wideband multiple-input multiple-output antenna with high isolation

Jing-Chang Nan, Ming-Huan Wang, Ming-Ming Gao, and Jing Liu

The Key Laboratory of Wireless Communication Circuit System and Artificial Intelligence of the School of Electronics and Information Engineering, Liaoning Technical University, Huludao, Liaoning, 125105, People’s Republic of China

E-mail: 944959060@qq.com

For the ultra-wideband (UWB) transmission requirements in wireless communication systems and better miniaturization of mobile terminal antennas, a compact UWB multiple-input multiple-output (MIMO) antenna with higher isolation between units is proposed. The MIMO antenna consists of two semi-circular antenna units and a defective ground structure. By improving the structure of the ground plane, the antenna units are placed upside down by taking advantage of the inherent directional radiation characteristics of the antenna units, thereby achieving higher isolation. The proposed antenna size is 15 × 22 × 1.6 mm³. The measurement results show that the proposed UWB MIMO antenna satisfies the port reflection coefficient S11 < -10 dB in the 3.6–12.9 GHz band, and the isolation is all greater than 25 dB, which has high isolation. The allowable limit of the envelope correlation coefficient ensures good MIMO performance, which can meet the requirements of UWB wireless communication in practical engineering applications.

Introduction: In recent years, with the rapid development of wireless communication technology, ultra-wideband (UWB) technology has been widely studied in mobile wireless communication systems due to its low cost and high data transmission rate. However, traditional UWB technology faces the problem of multipath fading. To address this problem and improve the quality of the communication channel, a multiple-input multiple-output (MIMO) antenna system has been proposed in modern communications. MIMO technology is widely used in the field of wireless communication, which can improve the system capacity and overcome the deterioration caused by multipath fading. The combination of UWB technology and MIMO technology can effectively eliminate the effects of multipath fading. With the continuous development of technology, various mobile terminal devices are becoming more and more integrated and smaller in size. Therefore, the UWB MIMO antenna of the mobile terminal must also meet the demand for miniaturization. However, the miniaturized antenna will lead to the coupling between the ports of multiple antenna units and reduce the signal uncorrelated. To improve the MIMO behaviour of the system, several decoupling structures are proposed. In reference [1], a UWB MIMO antenna structure using a shared radiation patch with a size of 26 × 26 mm² is proposed. By etching an I-shaped groove on the radiation patch and attaching a rectangular patch on the back, the isolation in the working frequency band is greater than 15 dB. Reference [2] uses a fractal structure with a hexagonal molecular shape as the radiating element, and the antenna elements are placed orthogonal to each other so that the isolation in the operating frequency band is greater than 20 dB. In reference [3], in order to achieve high isolation, antenna elements are placed vertically with each other, and a T-shaped strip is added between radiation elements as a decoupling structure to suppress the mutual coupling between antenna elements (S11 < -15 dB). In reference [4], a four-port two-sided UWB MIMO antenna with a size of 30 × 30 mm² is proposed. The isolation (S21 < -20 dB) is improved by loading the electromagnetic band gap (EBG) structure. A coplanar waveguide (CPW) UWB MIMO antenna with a size of 26.75 × 41.5 mm² is proposed in reference [5]. The isolation between antenna elements is greater than 20 dB by using Minkowski fractal defective ground structure (DGS) and adding parallel rectangular bars at the back. In reference [6], the isolation in 3.1–5 GHz is greater than 22 dB by adding a broadband neutral line between the radiation patches. None of the above structures can achieve the requirement of a small UWB MIMO antenna with high isolation. Therefore, it is necessary to design a small UWB MIMO antenna with high isolation.

In this paper, a semi-circle UWB MIMO antenna is proposed to improve the isolation by changing the ground structure and inverting the antenna radiation unit. The change of the ground structure can effectively reduce the coupling current between the ports. Besides, placing the two antenna elements upside down has the same polarization and opposite directions, resulting in weaker E-field interaction between the antenna elements, thereby further reducing mutual coupling between the antenna elements. Finally, in order to verify the reliability of the simulation results, the antenna model is processed and tested. The test results show that the MIMO antenna has higher isolation (S21 < -25 dB). Also, the antenna has a wider bandwidth (3.4–12.9 GHz) and a smaller size (15 × 22 mm²), which is very suitable for modern miniaturized communication equipment.

Antenna design: The antenna is a planar UWB MIMO antenna fed by two identical 50 Ω microstrip lines with semi-circular radiation patch and DGS. The antenna structure is shown in Figure 1. The final design of the UWB MIMO antenna is shown in Figure 2. The antenna is printed on an FR-4 substrate with a thickness of 1.6 mm, a size of 15 × 22 mm², a relative dielectric constant of 4.4, and a loss tangent angle of 0.02. The antenna dimensions are shown in Table 1.

The electromagnetic simulation software is used to model, simulate, and optimize the antenna. To illustrate the design approach of this paper, three antennas of different configurations are simulated and compared. The S-parameters of the three antenna structures are shown in Figure 3. It can be seen from Figure 3 that the bandwidth of Ant. 1 with DGS is 4.4–12.6 GHz without any decoupling structure, and the isolation is greater than 9.6 dB, which does not meet the application requirements of UWB MIMO antenna and the high isolation requirements of this paper. Therefore, by improving the floor structure of Ant. 1, the coupling area between the floor and the radiating unit is increased, and the loop of the resonance current becomes longer, the corresponding resonance frequency is reduced, and the radiation intensity of the antenna at this frequency is reduced.
frequency point is correspondingly increased. The return loss of the antenna at this frequency point is reduced. At this time, the bandwidth of Ant. 2 is expanded to 3.7 GHz at the low-frequency point, and the isolation within the operating bandwidth is greater than 16 dB. Finally, the two antenna units are placed upside down in the Ant. 2 structure without adding any branches, and the isolation of Ant. 3 in the 3.5–13.3 GHz frequency band is greater than 25 dB. The design evolution process from Ant. 1 to Ant. 2 shows that by enlarging the area of the defect ground structure, the band stop filter can be used at the corresponding frequency, and the coupling of the surface wave in the two units is suppressed. At the same time, the changed surface current distribution affects the bandwidth of the antenna. In order to further study the principle of high isolation by the inverted placement of antennas, the 3-D radiation pattern of each antenna element under different port excitation at 8.3 GHz is shown in Figure 4. From Figure 4a,b, it can be concluded that the antenna unit of port 1 and the antenna unit of port 2 have the same polarization, but the direction is opposite, which leads to a weak E-field interaction between the two antenna elements and achieves higher isolation.

To understand the working mechanism of the antenna more intuitively, Figure 5 shows the current distribution of Ant. 1, Ant. 2, and Ant. 3 at 8.3 GHz. The antenna unit on the left is connected to the excitation source, and the antenna unit on the right is connected to 50 Ω load. As can be seen from Figure 5, Ant. 1 in Figure 5a without any decoupling structure has a large amount of current flowing from the left antenna unit to the right antenna unit. Ant. 2 with an enlarged floor area in Figure 5b concentrates most of the current from the left antenna unit to the right antenna unit at the edge of the expanded floor, which reduces the current coupled to the right antenna unit and improves the impedance matching accordingly. The inverted antenna element in Figure 5c makes the current coupling from the left port to the right port significantly less than that of Ant. 2. Through the comparison and analysis of the antenna current distribution, it is concluded that the $S_{21}$ of Ant. 1, Ant. 2, and Ant. 3 at 8.3 GHz is $-13.1$, $-18.7$ and $-30.5$ dB, respectively.

**Simulation and measured S-parameter results:** In order to further verify the working performance of the UWB MIMO antenna, machining and testing are carried out according to the final optimized size. The actual effect picture of PCB finally processed by the MIMO antenna is shown in Figure 2. The reflection coefficient and isolation of the antenna are measured by a vector network analyser. SMA-K connector is welded at the feed end of the antenna. High-frequency coaxial cable is used to connect the antenna and the test system. The antenna pattern is measured in the microwave anechoic chamber.

Figure 6 shows the measured and simulated $S$-parameters of the UWB MIMO antenna. It can be seen that the measured operating bandwidth is 3.4–12.9 GHz, and the isolation within the entire operating bandwidth is greater than 25 dB. The measured and simulated results are basically consistent. The accuracy of antenna processing, SMA joint welding technology (sharp or large welding point), and the quality of the dielectric plate can lead to the deviation of measured and simulated results.

**Radiation characteristics:** Figure 7 shows the simulation and measured patterns of the excitation of port 1 at 4.5, 6.5, and 8.5 GHz. The antenna shows good omnidirectional radiation characteristics on the H plane, and the E plane shows an “8” shape similar to the traditional
monopole antenna. However, with the increase of frequency, the wavelength of the antenna decreases and is no longer much larger than the size of the antenna, and the antenna no longer has the characteristics of an electrically small antenna. Therefore, the radiation pattern of the antenna changes. However, it is still conducive to the antenna to receive and transmit signals from all directions, to realize the multi-input and multi-output function.

Diversity characteristics: For MIMO antennas, the envelope correlation coefficient (ECC) is used to describe the correlation between MIMO antenna elements. A lower ECC represents a higher diversity gain [7]. The ECC calculated using S-parameters (Equation (1)) is approximated to an ideal uniform scattering environment. In general, the ECC of the antenna is required to be less than 0.5. As can be seen from Figure 8, the ECC of the antenna is less than 0.35 in the operating frequency band, which means that the designed MIMO antenna has low correlation and high diversity gain.

\[
\epsilon_{cc} = \frac{|S_{11}^*S_{12} + S_{21}^*S_{22}|^2}{(1 - |S_{11}|^2)(1 - |S_{21}|^2)(1 - |S_{22}|^2)}
\]  

(1)

To highlight the novelty of the design of this article, Table 2 lists the performance comparison of the antennas proposed in this article and the references. It can be seen from the table that among all the dual-port UWB MIMO antennas described, the antenna proposed in this paper not only achieves a wider bandwidth but also achieves high isolation and small size.

Conclusion: A compact two-element UWB MIMO antenna with a size of 15 × 22 × 1.6 mm³ is proposed. The experimental results show that the proposed UWB MIMO antenna has high isolation (S₂₁ < −25 dB) in the working bandwidth (3.4–12.9 GHz) by changing the ground structure and using the inherent directional radiation characteristics of the antenna unit, which provides a good choice for portable UWB communication system. In addition, the lower ECC (<0.35) indicates that the antenna has a good diversity performance.

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