A 2×2 MIMO Antenna Design with High Isolation and Steady Radiation Performances

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Abstract. This paper introduces a new high-isolation 2×2 multi-input multi-output antenna array design. The antenna array adopts multi-objective optimization method and fragment structure to achieve better performance. The results show that the isolation structure of this design can reduce the mutual coupling between different units of the antenna array. Compared with the traditional mutual coupling suppression technology in the microstrip array antenna, the isolation structure also improves the front-to-back ratio of the array.

1. Introduction

In the fifth generation of mobile communication systems (5G), multiple-input multiple-output (MIMO) technology can be used to increase rates of data and the capacity of network compared to previous systems [1]. However, there is strong mutual coupling between closely-spaced antenna elements, which makes it difficult to design a compact MIMO antenna. Without affecting the radiation performance of the antenna, designing the isolation structure in a compact MIMO antenna system with small antenna element spacing is a huge challenge in the field of antennas.

In order to diminish the mutual couplings of antennas, many techniques have been proposed, including electromagnetic band-gap (EBG) structures [2], specific ground structure [3], split-ring resonator structure [4], slotting on the ground plane [5, 6], the neutralization technique [7], coupling elements [8], and so on [9-11]. In this paper, fragment-type isolation structures [12] will be used to diminish the mutual couplings among antenna elements.

![Figure 1. Fragment-type isolation structure.](image)

In the fragment-type isolation design, the design area is divided into several grids, and then 0 and 1 are used to represent the state of each grid respectively. The antenna structure with specific electrical
performance can be obtained by flexibly adjusting the number of 0 and 1. As shown in Fig. 1, the white and gray grids in the figure represent different states with 0/1 values, respectively. White means that there is no metal layer attached, and gray means that there is metal layer attached. The distribution of "1" and "0" forms a flexible design matrix that can be optimized for certain system requirements, such as isolation, gain, bandwidth, etc. For MIMO antenna design, the isolation between different elements can be improved to some extent.

In the paper, a compact 2×2 MIMO Antenna that has high isolation among four antenna elements at 3.42-3.5 GHz will be reported. 3.42-3.5GHz is part of the operation band of fixed satellites and mobile phones. In this design, isolation structures are designed on the front of substrate, which not only greatly increases the front-to-back-ratio, but also well controls the main-beam angle. Besides, isolation structure and four antenna elements are designed on the same plane.

2. 2×2 MIMO Antenna Design

2.1. Antenna Configuration

The structure of the 2×2 PIFAs antenna for design is shown in Fig. 2. The material of substrate is FR4, the thickness is 1.6mm, and $\varepsilon_0$ is 4.4. The sizes are $L = 86\, \text{mm}$, $g = 43\, \text{mm}$, $a = 35\, \text{mm}$, $b = 8\, \text{mm}$, $d_1 = 1.8\, \text{mm}$, and $d_2 = 2.7\, \text{mm}$. The four elements are on a common plane. In addition, center-to-center distance between two elements is $d = 20\, \text{mm}$. The distance between PIFAs metal arms is only 0.144 wavelengths in free space at 3.46GHz, the design space is two rectangles of $17.5\text{mm} \times 11\text{mm}$, and it is composed of a square metal attachment layer with a side length of 0.6mm.

![Figure 2. 2×2 multi-input multi-output antenna array.](image)

2.2. Objective Functions

Multi-objective optimization can be used to design antenna isolation structure and improve optimization efficiency [12], which is expressed as

$$\min F(x) = (f_1(x), f_2(x), ..., f_m(x)),$$
subject to $x \in \Omega$.  

(1)
Where $m$ represents antenna performance parameters, such as isolation, realized gain, axial ratio. $\Omega$ represents the space of decision, $x$ as a variable plays a role in defining the isolation structure. 

To obtain the great isolation $Q$ (in dB) and return loss meeting requirements of antennas in this work, the optimization objectives of this design are defined as:

\[
f_i(x) = \max \left( 10 \cdot \min_{\omega \in [\omega_1, \omega_2]} |S_{1i}|_\text{dB}, 0 \right) \quad (i = 1, 2) \tag{2}
\]

\[
f_2(x) = \max \left( Q - \min_{\omega \in [\omega_1, \omega_2]} |S_{21}|_\text{dB}, 0 \right) \tag{3}
\]

\[
f_4(x) = \max \left( Q - \min_{\omega \in [\omega_1, \omega_2]} |S_{31}|_\text{dB}, 0 \right) \tag{4}
\]

Where $[\omega_1, \omega_2]$ is operating frequency, $|S_{1i}|_\text{dB}$ , $|S_{21}|_\text{dB}$ and $|S_{31}|_\text{dB}$ (in dB) represents the return loss, isolation among feed1 and feed2 and isolation among feed1 and feed3.
2.3. Design Results

In this 2×2 MIMO antenna design, MOEA/D-GO [12, 13] plays a role of an optimizer. Neighborhood size and Population size in MOEA/D-GO are respectively set as 8 and 55.

After 34 iterations of MOEA/D-GO, an antenna design scheme with good performance is obtained, which is shown in Fig. 3(a) and Fig. 3(b). $|S_{11}|_{\text{dB}}$, $|S_{21}|_{\text{dB}}$ and $|S_{31}|_{\text{dB}}$ are shown in Fig. 3(c). Because the distance between port 2 and port 1 is much larger than that between port 3 and port 1, $|S_{31}|_{\text{dB}}$ is much smaller than $|S_{21}|_{\text{dB}}$. The simulated results agree well with the measured results. It can be clearly seen that the results of simulation and test are basically in agreement. Small errors may be caused by the slight difference between fabrication process, measurement environment and ideal state. There is no isolation structure in the antenna before optimization, and isolation structure is added to the antenna after optimization. Fig. 3(d) shows the gain before and after antenna optimization. Besides, the front-to-back ratio of antenna after optimization is 9.12. In addition, as shown in Fig. 3(d), the beam angles keep at about 10° before and after optimization at 3.46GHz.

3. Analysis

In this design, the fragment isolation structure is designed at the front of substrate, which maintains the stability of antenna pattern. Besides, two shorting pins are added to the antenna, which is in the center of PIFAS. As seen from Fig. 4(a), Fig. 4(b) and Fig. 4(c), the addition of shorting pins makes the current density of isolation structure increase. In addition, it can be seen from Fig. 4(d), isolation performs better when the shorting pins and the fragment structure are added. The isolation at 3.46GHz could achieve 10.5dB, 31.2dB and 37dB, respectively.
Figure 4. (a) Original Current distribution  (b) current distribution with fragment structure but without shorting pins, (c) current distribution after adding shorting pins (d) $|S_{11}|_{db}$, $|S_{21}|_{db}$ and $|S_{31}|_{db}$ of the antenna before and after optimization.
4. Conclusion

In this work, the fragment isolation structure is designed at the front of substrate, which maintains the stability of antenna pattern and increase the front-to-back ratio of antenna. Besides, the shorting pins make the current density of isolation structure increase. A 2×2 MIMO array operating at 3.42-3.5GHz is designed through this new method. By comparison, the antenna designed in this paper has stable main beam and great front-to-back ratio while improving isolation.

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