Compact Miniature MIMO Array Antenna Towards Millimeter Wave

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Abstract. Two types of MIMO antenna arrays are proposed, towards millimeter wave technology. The antenna resonances are at 77 GHz. This paper mainly discusses the decoupling of antenna in MIMO system. The first array antenna is microstrip feed patch MIMO antenna which unit is an elliptical patch. A decoupling branch is added in the middle to improve the isolation to less than −15 dB. The second MIMO array antenna is with a resonance frequency at 77 GHz which meets the Chebyshev distribution. We use series resonance feed, and 1 × 16 line array is used as the MIMO antenna unit. We increase the line array space to achieve an isolation of less than −20 dB in the antenna frequency band.

Keywords: MIMO antenna · 77 GHz · Isolation · Decoupling

1 Introduction

In the future, MIMO technology will also become the key technology for 5G communication. A major problem in implementing MIMO technology is the design of MIMO antennas. On the one hand, MIMO antennas will develop in the direction of miniaturization. On the other hand, in order to realize the advantages of the MIMO system, the MIMO antenna needs to have low mutual coupling [1]. Due to the limited space, shortening the antenna size and reducing the antenna distance will inevitably lead to an increase in coupling. Therefore, how to enable more antenna elements to achieve low coupling in a limited space has caused widespread academic research.

Researchers usually add decoupling structures between antenna elements, including parasitic elements, defective ground structures (DGS) and EBG structures to improve the performance of MIMO antennas. For example, an aperture coupled MIMO antenna is designed in [2], and a novel EBG structure is proposed for decoupling between two patches of the MIMO antenna. Coupling effect decreased 16.5 dB at the operating frequency of 2.45 GHz by inserting the EBG structure between the two patches. A MIMO antenna array is proposed in [3] for sub-6 GHz communication applications. The proposed antenna element is a proximity coupling fed split-ring antenna, which is

S. Shi et al. (Eds.): AICON 2020, LNICST 356, pp. 166–176, 2021.
https://doi.org/10.1007/978-3-030-69066-3_16

excited by a 50-Ω microstrip line. The researcher designed two split-rings at the outer of the antenna, a fork-like slot integrated into the middle of the ground and two L-shape-like slot at each side of the ground plane. The results proved that the MIMO antenna can provide a low coupling and a good omnidirectional radiation patterns in the operating sub-6 GHz. A compact planar wide-band MIMO antenna array with high isolation is presented in [4], which consists of four half-circular monopole radiators and four separated ground planes. Four separated grounds are designed to reduce the surface wave coupling, and four ground stubs are etched to reduce the near field coupling. And better port isolation of above 15 dB is obtained.

Therefore, miniaturization, compact layout and high isolation are the current development trends of MIMO. It has become a challenge to design high-speed links, compact, broadband and efficient antenna systems.

With the rapid development of mobile communications, millimeter wave technology has attracted widespread attention. Due to the high frequency band and few interference sources, millimeter wave technology can obviously enhance the channel anti-interference ability. The application of millimeter-wave antennas greatly reduces the size of antennas compared with microwave and realizes the miniaturization of antennas [5].

Based on previous research results, the MIMO antennas designed in this paper work are in the millimeter wave band and the resonance frequencies are all near 77 GHz. The design results in the reducing of the size of the MIMO antenna and achieves good performance of MIMO system. We had a research on MIMO antennas with different radiation units, different feeding methods, and different structures to meet the requirements of miniaturization and high isolation.

2 77 GHz Microstrip Feed Patch MIMO Antenna

2.1 The Structure of MIMO Antenna

In this section, we design a 77 GHz array antenna with microstrip feed, and an elliptical patch used as the antenna unit. We discuss the influence of the distance between the two elements on the performance of the MIMO antenna. Finally, the distance between the two elements is determined to be 0.5 λ. We design the decoupling branches to increase the isolation between MIMO units [6]. The antenna covers a frequency band of 76.4–77.6 GHz. The isolation in the antenna frequency band is less than −15 dB, and the system has a good performance.

We use microstrip feed, and the antenna unit is an oval patch. The dimensions are as follows: $a = 7.2$ mm, $b = 1.55$ mm, $c = 1.9$ mm, $d = 1.5$ mm, $e = 0.15$ mm, $f = 2.68$ mm, $g = 0.54$ mm, $h = 1.41$ mm. The distance between the two units is 0.5 λ. Blue structure is a metal radiation patch, and the yellow structure is a 0.1 mm thick FR4 dielectric board [7]. MIMO antenna has a resonance frequency of 77 GHz. The isolation within the antenna band is less than −15 dB. A decoupling branch is added between two units, and its dimensions are as follows (the unit is mm) (Fig. 2):

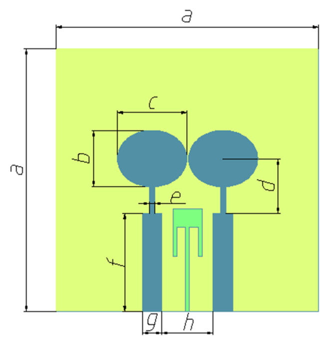

Fig. 1. MIMO antenna structure

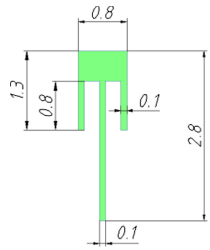

Fig. 2. Decoupling structure

2.2 Design of MIMO Antenna

As shown in Fig. 3, assuming that the unit spacing is a, here we analyze the return loss and the isolation of the MIMO antenna with a ranging from 1.948 mm (0.5 λ) to 3.986 mm (λ), which are shown in Fig. 4 and Fig. 5. The results show that the isolation increases with distance.

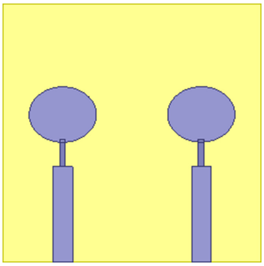

Fig. 3. MIMO antenna structure

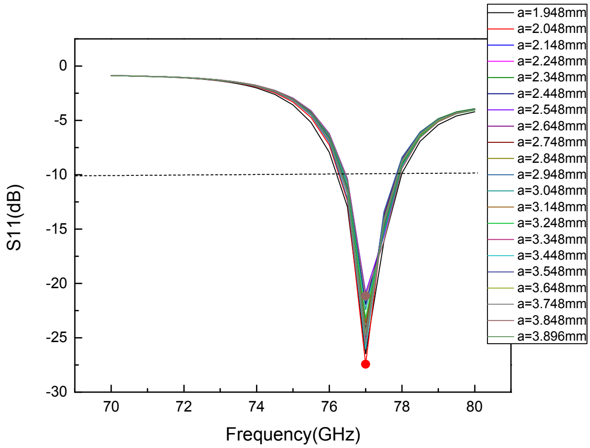

Fig. 4. The effect of the distance on S11

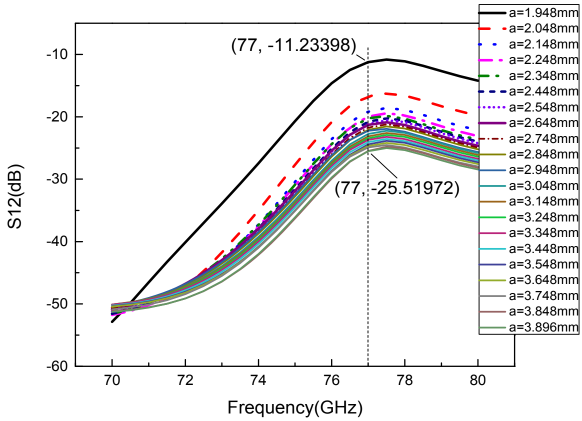

Fig. 5. The effect of the distance on S12

When a = 0.5 λ, S12 = −11.2 dB, the isolation does not meet the requirements. Increasing the distance of the MIMO antenna unit can increase the isolation, but this article uses the method of adding decoupling branch [8], as shown in Fig. 1. The comparison is shown in Fig. 6.

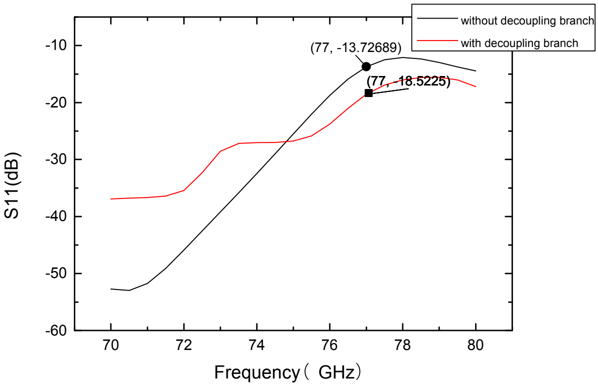

Fig. 6. Comparison of S11

It can be seen that the decoupling branch greatly improves the isolation between MIMO units, and the isolation in the antenna frequency band is less than −15 dB. Figure 7 shows the MIMO antenna gain, which reaches 5 dB.

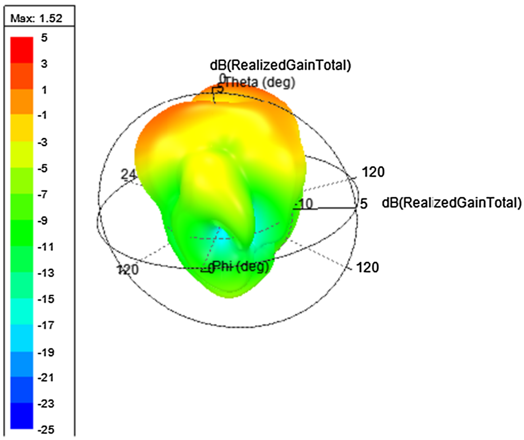

Fig. 7. 3D gain of the antenna

3 77 GHz Series-Fed MIMO Antenna for Chebyshev Distribution

3.1 The Structure of MIMO Antenna

In this section, we design a series-fed microstrip array antenna that meets Chebyshev distribution [9]. The antenna array consists of two 1 × 16 series feed units [10].

The influence of the slotting and folded T-shaped coupling branches are studied. The antenna covers a frequency band of 76.1 GHz–79.4 GHz. There are two resonance frequencies of 77 GHz and 78.5 GHz in the frequency band. The gain is 19.4 dB and the isolation is greater than 20 dB (Fig. 8).

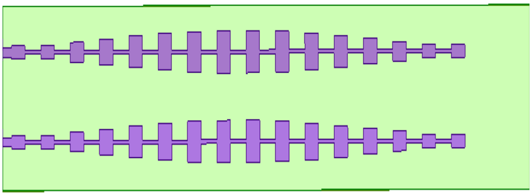

Fig. 8. Structure of MIMO antenna

A 1 × 16 array is used as the MIMO antenna unit. Blue structure is a metal radiation patch, and the green structure is a 0.254 mm thick RO3003 dielectric board. The excitation amplitude of each array element obeys Chebyshev distribution by adjusting the width of each array element to meet the Chebyshev distribution [11]. The MIMO antenna covers the frequency band of 76.1–79.4 GHz with the gain of 19.44 dB, and the isolation reaches −35.2 dB.

3.2 Design of MIMO Antenna

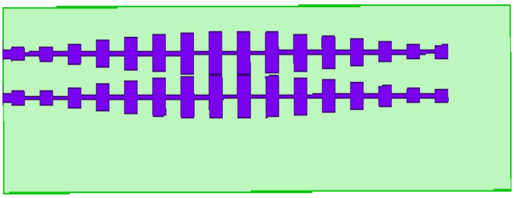

Fig. 9. MIMO antenna structure

As shown in Fig. 9, two array elements are placed in parallel on a RO3003 dielectric board with the area of 6 × 36.5 mm and thickness of 0.254 mm. Distance between two elements is 0.36 λ. S12 parameters of the MIMO antenna is shown in Fig. 10. At 77 GHz, the coupling of the MIMO antenna does not achieve the desired effect.

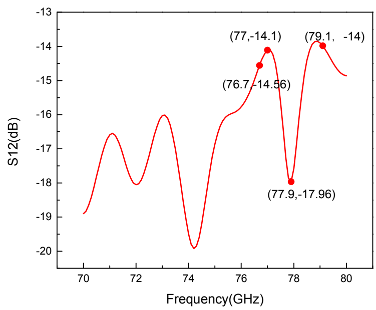

Fig. 10. S12 result of MIMO antenna

In order to reduce the coupling between the two units, the method of slotting and adding decoupling branches in the vicinity of the feed port are shown in Fig. 11 and Fig. 12 [12]. The result of S11 (as is shown in Fig. 13) is good. Figure 14 increases the resonance point of 77 GHz and increases the bandwidth by 20%.

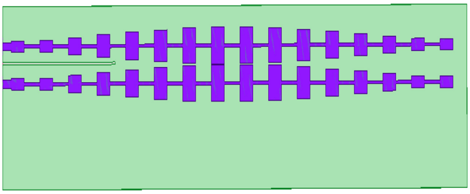

Fig. 11. The slotted MIMO antenna

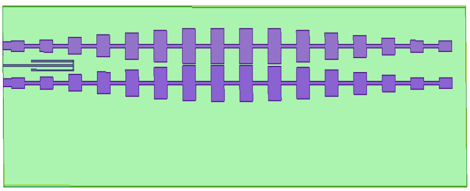

Fig. 12. MIMO antenna with decoupling branches

The S12 results are shown in Fig. 15 and Fig. 16. Figure 15 shows that slotting does not reduce the coupling. As for Fig. 16, in the 70–80 GHz frequency band, the S12 value decreases significantly near the three resonance frequencies of 70.5 GHz, 72.8 GHz, and 75.8 GHz. Because we concern the frequency of 77 GHz, the decoupling branches have not achieved the desired effect.

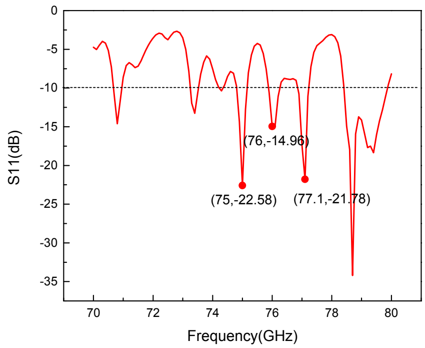

Fig. 13. S11 result of MIMO antenna after slotting

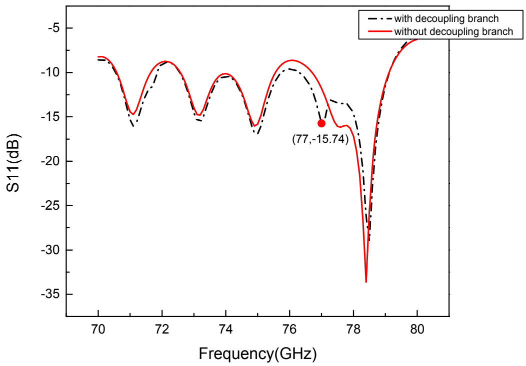

Fig. 14. Comparison of S11 before and after adding branches

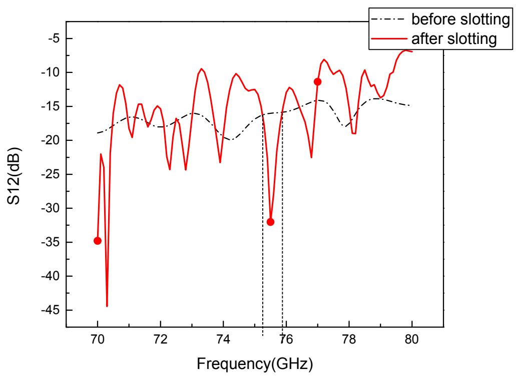

Fig. 15. Comparison of S12 before and after slotting

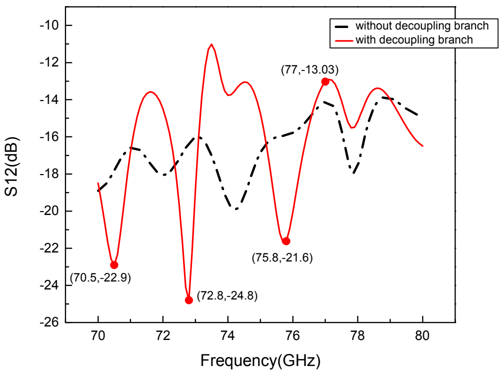

Fig. 16. Comparison of S12 before and after adding branches

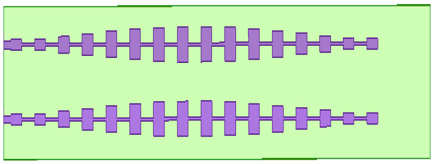

Fig. 17. MIMO antenna structure with increased unit distance

Finally, we increase the isolation by increasing the distance between the antenna elements. As shown in Fig. 17, we adjust the space between the two line arrays to 0.75 λ.

The simulation results are as follows: Fig. 18 shows the S11 parameters of the MIMO antenna with a bandwidth of 3.3 GHz. Compared with the line array spacing of 0.36 λ, the frequency band is widened. Figure 19 shows the S12 results of the MIMO antenna. The coupling between the linear arrays is greatly reduced. Figure 20 shows the 3D gain of the MIMO antenna, which reaches 19.4 dB. Compared with the linear

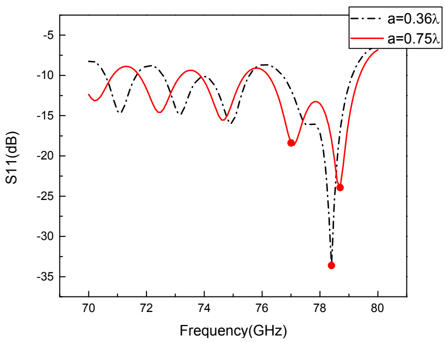

Fig. 18. Antenna S11 results with increased unit distance

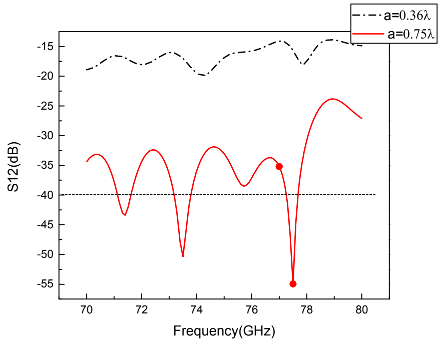

Fig. 19. Comparison of S12 before and after increasing unit distance

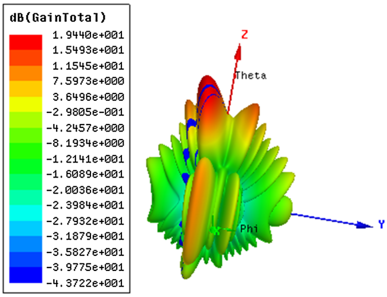

Fig. 20. 3D gain after increasing the unit distance

arrays spacing of 0.36 λ, the gain is further improved. MIMO system has a good performance.

4 Conclusion

This article focuses on the issue of millimeter-wave MIMO antennas. A MIMO array antenna with 77 GHz microstrip feed is designed. The antenna unit is an elliptical patch. We mainly discussed the influence of the unit spacing on the performance of the MIMO antenna. The distance between the two units is determined to be 0.5 λ. A decoupling branch is added in the middle to improve the isolation between MIMO units. At a result, the isolation in the antenna band is less than −15 dB, and the MIMO system has better performance. Further more, a MIMO array antenna with a resonance frequency at 77 GHz that meets the Chebyshev distribution is designed. We use series resonance feed, and 1 × 16 line array is used as the MIMO antenna unit. Slotting and decoupling branches didn't improve the isolation of the antenna.Finally we increased the line array spacing to achieve an isolation of less than −20 dB in the antenna frequency band.

Acknowledgement. This work is supported in part by the Youth Innovation Promotion Association CAS and the National Natural Science Foundation of China (No. 61831002 and 41861134010).

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