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Compact Two-Element MIMO Antenna Based on Half-Mode SIW Cavity with High Isolation

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Abstract—A compact two-element multiple-input-multiple-output (MIMO) antenna with high isolation is proposed in this paper. It is based on a half-mode substrate-integrated-waveguide (SIW) cavity where three edges are shorted by metallic vias, and one edge is opened to radiate cavity energy into free space. Fed by coaxial ports, two antenna elements are constructed in the SIW cavity, and a narrow T-shaped slot is introduced to enhance the isolation between them. High port isolation can be achieved by adjusting the slot length although these antenna elements are connected with each other. A prototype has been fabricated and measured. With the compact cavity size of $0.22\lambda_0 \times 0.44\lambda_0$, the fabricated antenna achieves the operating frequency of 3.51 GHz, enhanced isolation of 18.0 dB, low envelope correlation coefficient of 0.006, peak gain of 5.2 dBi, and high efficiency of 82.6%. Therefore, the proposed MIMO antenna has potential applications for wireless communication.

1. INTRODUCTION

With further requirements of high transmission rate, multiple-input-multiple-output (MIMO) antennas have been widely introduced in current fourth-generation (4G) and forthcoming fifth-generation (5G) wireless communication systems [1]. It can provide multiplexing gain to increase channel capacity and can also offer diversity gain to improve link reliability [2]. However, two major challenges are faced for the design of compact MIMO antennas. One is to minimize antenna elements, and the other is to enhance the isolation between them [3].

Recently, the half-mode (HM) substrate-integrated-waveguide (SIW) cavity has drawn special attention from antenna designers [4–6]. Compared to the conventional SIW cavity, its size is reduced by half, but comparable characteristics are maintained, in terms of resonant frequency, field distribution, and radiation performance [7]. However, two antenna elements constructed in an HM SIW cavity have been rarely studies up to now. On the other hand, a number of techniques have been proposed to enhance the isolation between antenna elements, such as optimization of antenna configuration [8], introduction of isolating elements [9, 10], and utilization of a decoupling network [11]. However, MIMO antennas adopting these methods usually have large overall size, complex structures, and low radiation efficiency [12].

In this paper, a compact two-element MIMO antenna based on a half-mode SIW cavity is proposed. High isolation can be achieved by introducing a narrow T-shaped slot in the cavity although these antenna elements are connected with each other. The S-parameters comparison, electric-field distribution, and parametric study have been discussed to validate effectiveness of the proposed design. The proposed antenna with compact size, high isolation, and good radiation performance is attractive for practical applications.

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2. ANTENNA CONFIGURATION AND ANALYSIS

2.1. Antenna Configuration

The configuration of the proposed antenna is shown in Figure 1. It is composed of a rectangle SIW cavity, a narrow T-shaped slot, and two coaxial feeding ports. Three cavity edges are shorted by a number of metallic vias with diameter d and pitch p, whereas one edge is opened to radiate cavity energy into free space. Hence, this cavity is an HM cavity whose width w_c is only half of cavity length l_c, resulting in compact size. The T-shaped slot has a long stub l_1 and a short stub l_2 with the same width w_1. It is located in the center of the cavity and cut from the opened edge. Two antenna elements are separately excited by port 1 and port 2 where their inner pins (r_1) and outer conductors (r_2) are connected to the top and bottom planes of the SIW cavity, respectively. By moving offset distances (d_h and d_v) from perpendicular shorted edges, good antenna matching can be achieved.

The proposed antenna has been designed and optimized by using ANSYS HFSS. The overall structure is completely printed on a single-layer F4B-2 substrate with relative permittivity 2.5 and thickness 3 mm. Parameters' dimensions are $l_g = 67.5$ mm, $w_g = 45.0$ mm, $l_c = 37.8$ mm, $w_c = 18.9$ mm, $l_1 = 14.5$ mm, $l_2 = 3.6$ mm, $w_1 = 1.5$ mm, $d_v = 4.9$ mm, $d_h = 7.4$ mm, $d = 0.6$ mm, and $p = 1$ mm.

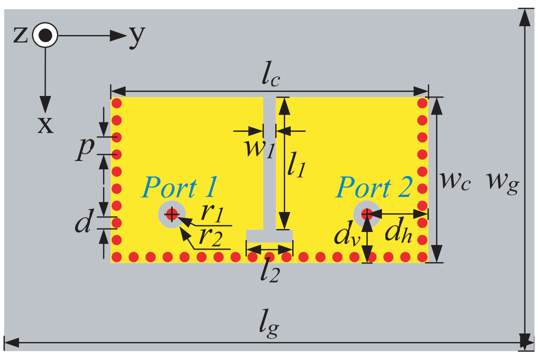


Figure 1. Configuration of the proposed two-element MIMO antenna based on a HM SIW cavity.

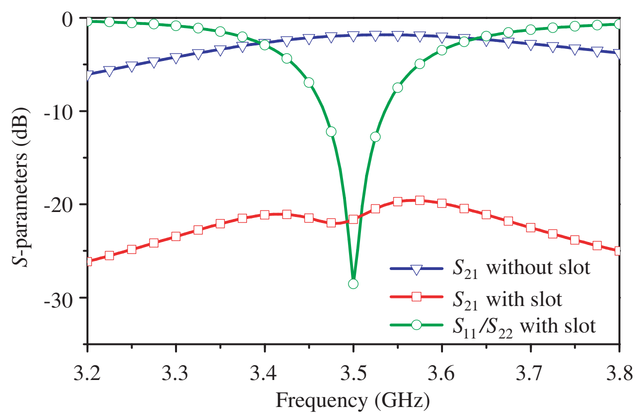


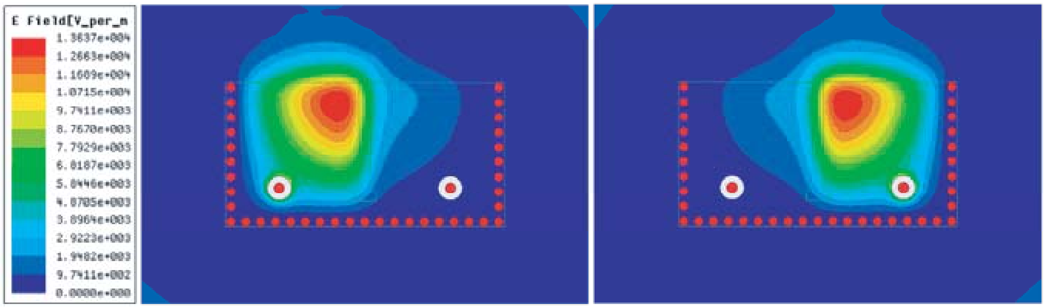
Figure 2. Simulated S-parameters with and without the narrow T-shaped slot.

2.2. Operating Principle

High port isolation is crucial for MIMO antennas. In the proposed design, the narrow T-shaped slot can serve as the isolating element and reduce the mutual coupling between antenna elements. The simulated S-parameters with and without the slot are shown in Figure 2 for a comparison. Owing to a symmetrical structure, S_{11} is the same as S_{22}, resonating at 3.5 GHz with 10-dB bandwidth of 70 MHz. As can be seen, before adding the isolating slot, the mutual coupling between antenna elements is quite high within the frequency of interest. By introducing the slot, the port isolation S_{21} is significantly enhanced to better than 19.8 dB, satisfying the requirement of typical MIMO antennas. Therefore, although these two antenna elements are constructed in an HM SIW cavity and contacted with each other, high isolation can be achieved in the proposed design.

To investigate the operating principle of the proposed MIMO antenna, electric-field distributions on the bottom plane of the SIW cavity are plotted in Figure 3. When port 1 is excited, strong field is concentrated in the left part of the cavity while negligible field is distributed in the right part. A similar distribution can also be observed when port 2 is excited. It can be concluded that cavity energy input by one port is little transmitted to the other port, but mainly radiated into free space through the opened edge and narrow slot.

To provide a better understanding about the function of the T-shaped slot, Figure 4 shows simulated port isolation S_{21} by varying l_1 while keeping the other parameters unchanged. It is seen that the



(a) (b)

Figure 3. Electric-field distributions on the bottom plane of the SIW cavity. (a) When port 1 is excited. (b) When port 2 is excited.

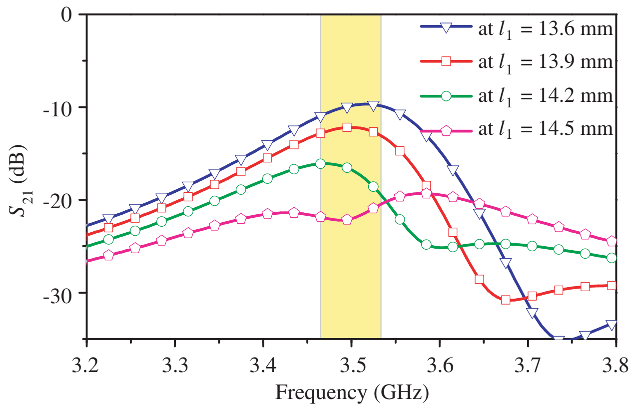


Figure 4. Simulated port isolation S_{21} by varying l_1.

isolation between antenna elements is determined by the slot length. As l_1 increases from 13.6 mm to 14.5 mm, S_{21} is enhanced from 9.7 dB to 19.8 dB. This simple and effective technique of isolation enhancement makes the proposed design attractive for practical applications.

3. EXPERIMENTAL VERIFICATION

As shown in Figure 5, an antenna prototype has been fabricated to validate the proposed design and analysis. The cavity size is $0.22\lambda_0 \times 0.44\lambda_0$, which is very compact. The S-parameters of the fabricated

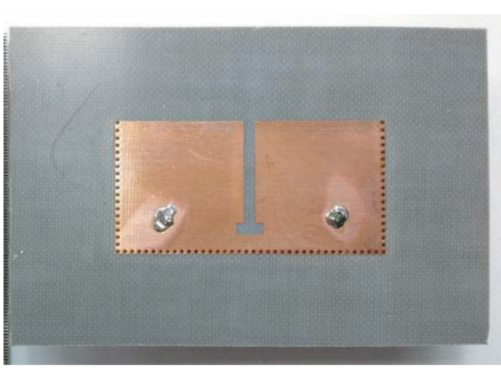


Figure 5. Fabricated prototype.

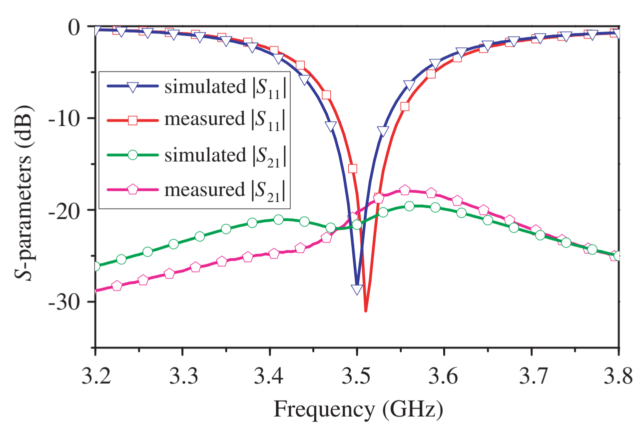


Figure 6. Simulated and measured S-parameters.

antenna were measured by a Keysight vector network analyzer while the radiation performance was tested by a Satimo anechoic chamber system.

The measured S-parameters are shown in Figure 6, compared with the results from the full-wave simulation. A good agreement between them is observed, and slight differences are mainly due to fabrication errors. The measured operating frequency is at 3.51 GHz with impedance matching of −31 dB. The measured isolation is better than 18.0 dB, which is enough for MIMO applications [12]. It is important to point out that there two antenna elements are constructed in an HM SIW cavity and connected with each other.

The simulated and measured total-gain radiation patterns are shown in Figure 7. Owing to the symmetrical structure of the proposed design, only port 1 is excited while port 2 is terminated with a 50 Ω load. The measured patterns are in a good agreement with the simulated ones in two orthogonal cut planes. For this antenna element, xoz-plane is the E-plane with a tilted unidirectional pattern, and yoz plane is the H-plane with maximum radiation in the broadside direction.

In order to evaluate the MIMO performance of the proposed antenna, the envelope correlation coefficient (ECC) has been calculated from 3-D radiation patterns with the assumption of a uniform incident wave environment [12]. As shown in Figure 8, both the simulated and measured ECCs are below 0.006 over the entire operating band, which is acceptable for MIMO operation.

The simulated and measured antenna gains excited by port 1 are shown in Figure 9. The measured peak gain is 5.2 dBi, which is slightly less than the simulated value about 0.3 dB. This discrepancy may

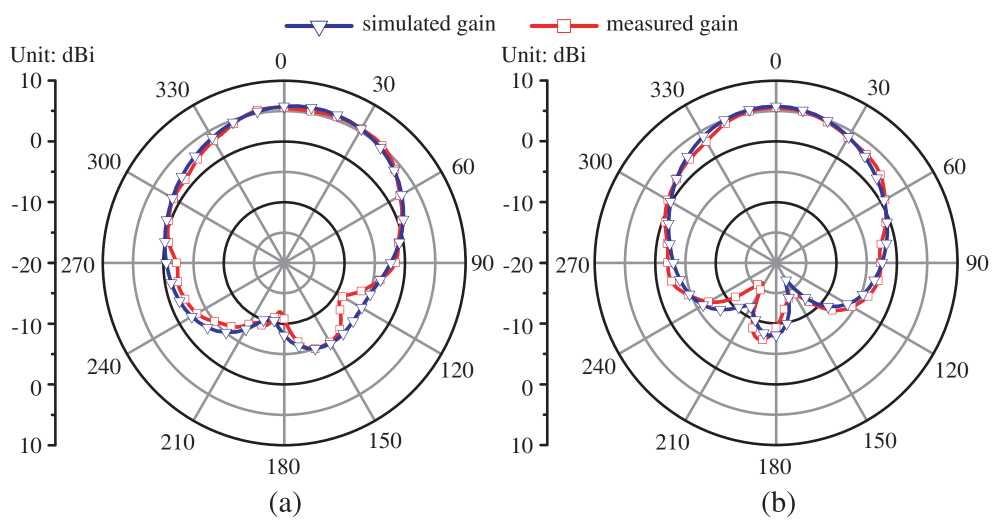


Figure 7. Simulated and measured total-gain radiation patterns at (a) xoz-plane and (b) yoz-plane.

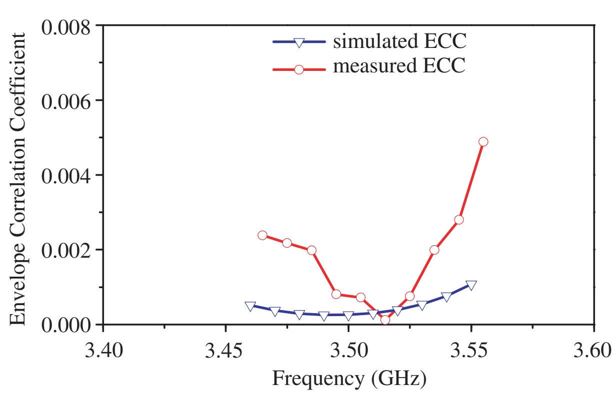


Figure 8. Simulated and measured ECC.

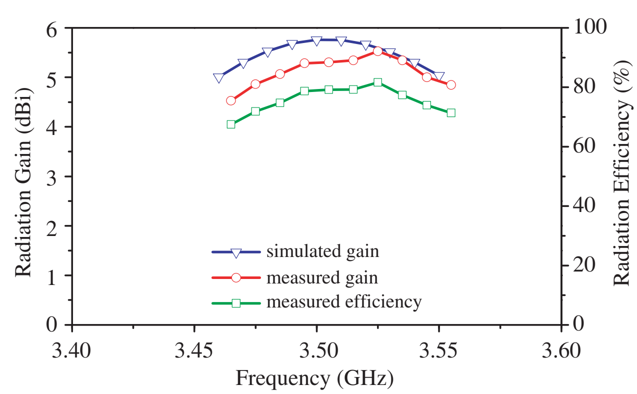


Figure 9. Measured gain and efficiency.

be attributed to the additional loss of SMA connectors. In addition, radiation efficiency has also been measured by calculating the receiving radiation power with the angular sampling interval of 2 deg over the input power [13, 14]. The measured efficiency has the highest value of 82.6% at 3.52 GHz.

4. CONCLUSION

A compact MIMO antenna with high isolation is presented. It consists of a rectangle HM SIW cavity, a narrow T-shaped slot, and two coaxial feeding ports. The isolation between antenna elements can be easily enhanced by adjusting the slot length. This simple and effective method of isolation enhancement makes the proposed design attractive for practical applications. According to measured results, the proposed two-element MIMO antenna based on an HM SIW cavity exhibits attractive characteristics of compact size, enhanced isolation, unidirectional pattern, low ECC, and high radiation performance.

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