

# SIW Cavity MIMO Antenna Using Hybrid Boundaries and Anti-Symmetric U-Shaped Slots

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**Abstract**—A substrate-integrated-waveguide (SIW) cavity multiple-input-multiple-output (MIMO) antenna using hybrid boundaries and anti-symmetric U-shaped slots is proposed. Unlike conventional SIW cavities completely shorted by metallic vias, the proposed two cavities possess opened edges. Since shorted and opened cavity edges can be regarded as electrically and magnetically conducting boundaries, respectively, hybrid resonating boundaries are achieved. Excited by coaxial ports, antenna elements can radiate cavity energy through the opened edges. Moreover, antenna isolation can be significantly enhanced by introducing a pair of anti-symmetric U-shaped slots on the top and bottom planes. This design has been validated by experiments. With the overall size of  $0.44\lambda_0 \times 0.44\lambda_0 \times 0.04\lambda_0$ , the fabricated MIMO antenna exhibits operating frequency of 3.51 GHz, high isolation of 20.18 dB, peak gain of 3.15 dBi, and low envelope correlation coefficient of 0.12, which has potential applications for wireless systems.

## 1. INTRODUCTION

Since it was first introduced a decade ago, the substrate-integrated-waveguide (SIW) technology has been extensively applied to antenna design [1]. It can realize cavity antennas in planar substrates with attractive characteristics such as low profile, light weight, and good radiation performance. However, due to the completely-closed structure of SIW cavities, etched slots should be employed to radiate cavity energy into free space. In recent years, SIW cavity antennas using rectangle [2], bow-tie [3], U-shaped [4], crossed-shaped [5], and triangular-ring [6] slots have been reported.

Recently, SIW cavities with hybrid boundaries have attracted significant research interest due to two beneficial features [7]. One is that compared to conventional cavities, their size can be greatly reduced. The other is that different from the former with additional radiating slots, the latter possess opened apertures by their nature. Many excellent antennas have been developed for compact-size [8], frequency-tunable [9], multi-band [10], circular-polarized [11], and high-gain [12] applications. However, SIW cavities with hybrid boundaries have been rarely investigated for designing multiple-input-multiple-output (MIMO) antennas. By employing multiple antenna elements, MIMO systems can drastically improve channel capacity and link quality of wireless communication in multipath and fading environments [13, 14].

In this letter, two SIW cavities with hybrid electrically and magnetically conducting boundaries are proposed to design a MIMO antenna with high isolation. It consists of a single-layer substrate, two metal planes, two coaxial ports, and three metallic via arrays. Moreover, the resonant frequency and antenna isolation can be effectively adjusted by introducing a pair of anti-symmetric U-shaped slots. To validate the proposed design, measured results are compared with the simulated ones in terms of  $S$ -parameters, radiation patterns, antenna gain, and envelope correlation coefficient (ECC).

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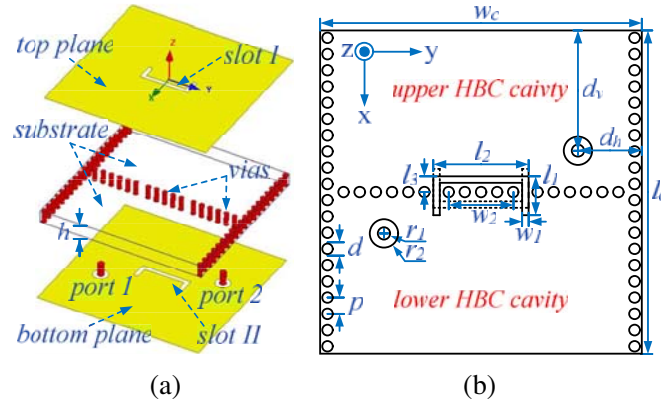
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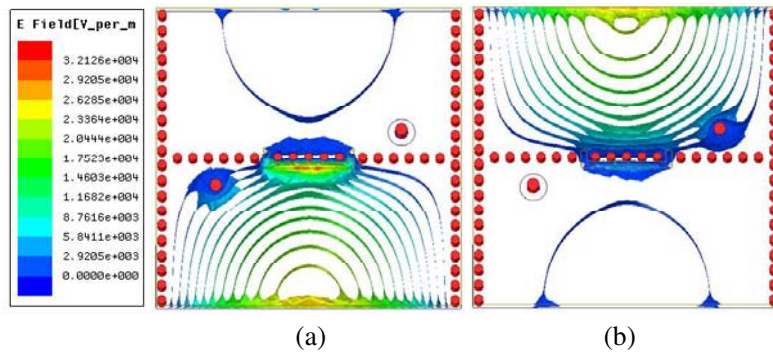
## 2. CONFIGURATION AND DESIGN

The geometric configuration of the proposed SIW cavity MIMO antenna is shown in Figure 1. It is printed on a single-layer F4B-2 substrate with the relative permittivity of  $\epsilon_r = 2.5$  and thickness of  $h = 3$  mm. There are metal planes (i.e., top plane and bottom plane) with a length  $l_c$  and a width  $w_c$  on both sides of the substrate. A pair of anti-symmetric U-shaped slots (i.e., slot I and slot II) with a narrow width  $w_1$  is etched on the top and bottom planes. To form SIW cavities, some edges are shorted by metallic vias with the diameter of  $d$  and center-to-center pitch of  $p$ . In especial, a via array is introduced along the symmetry axis of the structure to divide the whole SIW into upper and lower cavities. Since three shorted edges can be regarded as electrically conducting boundaries and one opened edge can be considered as a magnetically conducting boundary [15], two hybrid-boundary-condition (HBC) SIW cavities are constructed. Moreover, two coaxial feeding ports with the inner pin of  $r_1$  and outer conductor of  $r_2$  are adopted to excite MIMO antenna elements. Their locations (i.e.,  $d_v$  and  $d_h$ ) are carefully adjusted such that proper impedance matching can be achieved at the desired frequency.

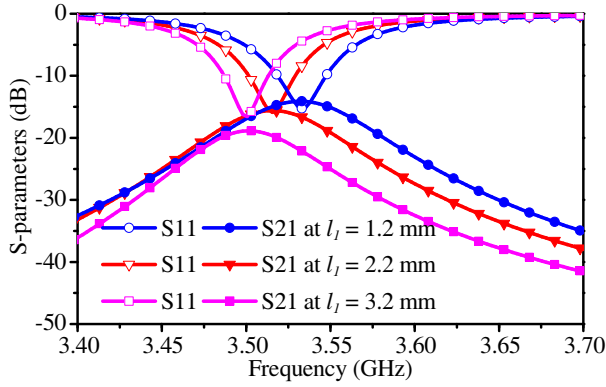


**Figure 1.** Configuration of proposed SIW cavity MIMO antenna. (a) Side view and (b) top view.

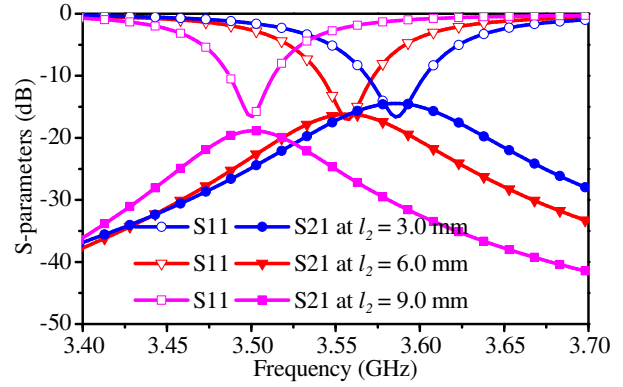
To understand the operating principle of the proposed MIMO antenna, distributions of the electric-field magnitude are plotted in Figure 2. When port 1 is excited, electric field has a maximum magnitude in the opened edge of the lower SIW cavity while keeping a minimum value in three shorted edges, which indicates that an HBC cavity mode is resonating. A similar distribution can also be observed when port 2 is excited. In addition, it is interesting that cavity energy of one HBC mode is little leaked to the other although these two SIW cavities are contacted with each other. This is because most of electromagnetic wave inputted by one port is radiated into air through the opened edge, resulting in high isolation between antenna elements.



**Figure 2.** Distributions of electric-field magnitude inside HBC SIW cavities. (a) When port 1 is excited and (b) when port 2 is excited.



**Figure 3.** Simulated  $S$ -parameters with different  $l_1$ .



**Figure 4.** Simulated  $S$ -parameters with different  $l_2$ .

Serving as important elements of the proposed design, anti-symmetric U-shaped slots are studied in detail.  $l_1$  and  $l_2$  denote the slot lengths along the  $x$ -axis and  $y$ -axis, respectively. Their effects on the  $S$ -parameters are shown in Figures 3 and 4. It can be found that increasing slot lengths results in the decrease of the resonant frequency and simultaneous enhancement of port isolation. Therefore, introducing anti-symmetric slots gives us the benefits of size reduction and MIMO performance improvement. When  $l_1 = 3.2$  mm and  $l_2 = 9.0$  mm, the proposed antenna operates at 3.50 GHz with high isolation of 18.76 dB. The final geometrical parameters optimized by CST Microwave Studio are listed in Table 1.

**Table 1.** Geometrical parameters of the proposed design.

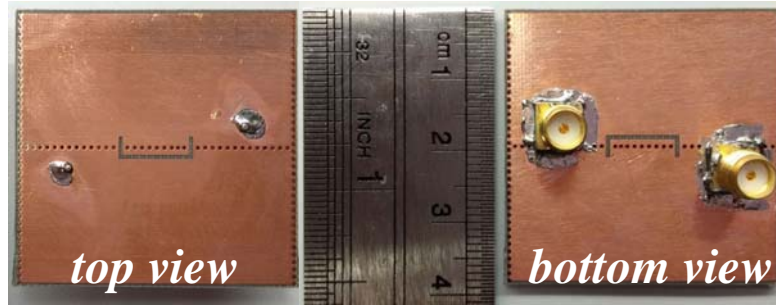
Parameters	$l_c$	$w_c$	$l_1$	$l_2$	$l_3$	$w_1$	$w_2$
Value (mm)	38.0	38.0	3.2	9.0	1.5	0.5	7.7
Parameters	$d_v$	$d_h$	$r_1$	$r_2$	$d$	$p$	$h$
Value (mm)	15.9	7.0	0.7	1.65	0.6	1.0	3.0

### 3. EXPERIMENTAL VERIFICATION

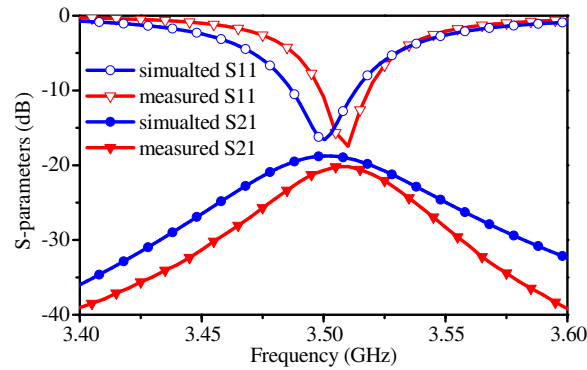
To validate the simulated performance, the proposed SIW cavity MIMO antenna has been fabricated by a low-cost printed-circuit-board process. Its photographs are shown in Figure 5. The size of  $0.44\lambda_0 \times 0.44\lambda_0$  is compact, and the profile of  $0.04\lambda_0$  is low. SMA connectors are utilized for experiments, where their inner pins and outer conductors are soldered to the top and bottom of the antenna, respectively. It has been measured by an Agilent network analyzer and a Satimo microwave chamber.

The measured  $S$ -parameters are shown in Figure 6, compared with the simulated ones. A good agreement between these results is achieved. The measured operating frequency is 3.51 GHz. The impedance matching at above frequency is better than 15.0 dB. Moreover, the measured isolation between two antenna elements is below 20.18 dB, which is good enough for MIMO applications. Therefore, high isolation has been confirmed by both the simulation and measurement.

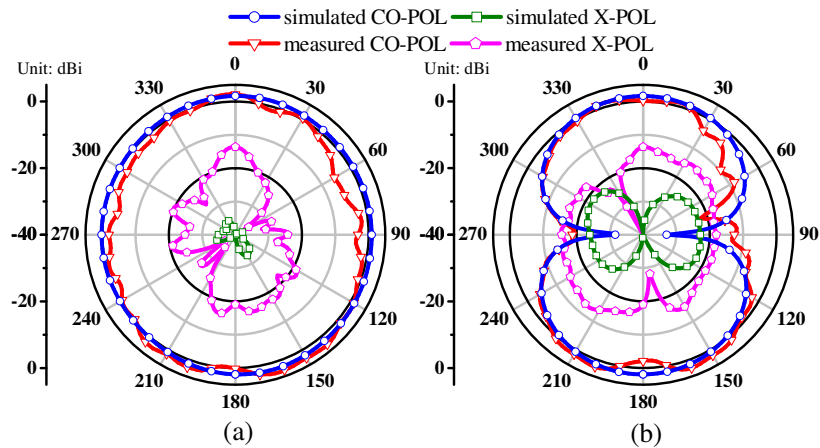
The simulated and measured radiation patterns in two principal cut planes are shown in Figure 7. When one port is excited, the other port is terminated with a matching load. The antenna element excited by port 1 demonstrates omni-directional radiation in the  $E$ -plane and provides a dumbbell-shaped pattern in the  $H$ -plane. In addition, measured cross-polarization levels are lower than  $-13$  dB, which are worse than the simulated results of  $-32$  dB. The simulated and measured radiation gain and efficiency are shown in Figure 8. The measured peak gain and maximum efficiency are 3.15 dBi and 67.55%, respectively, which are slightly different from the simulated results. This discrepancy may be



**Figure 5.** Photographs of fabricated prototype.



**Figure 6.** Simulated and measured  $S$ -parameters.



**Figure 7.** Simulated and measured radiation patterns. (a)  $E$ -plane ( $xoz$ -plane) and (b)  $H$ -plane ( $yoz$ -plane).

caused by fabrication errors and SMA connectors.

In order to characterize the MIMO performance of the proposed design, the ECC has been calculated by using far-field radiation patterns of each antenna element with the assumption of a uniform incident wave environment [16]. From Figure 9, it can be found that both the simulated and measured values are below 0.12 within the operating band, indicating good MIMO performance of the proposed antenna. Performance comparisons of the reported and proposed antennas are listed in Table 2. With advantages of compact size, two antennas, high isolation, omni-directional pattern, the proposed design is a good candidate for MIMO applications.

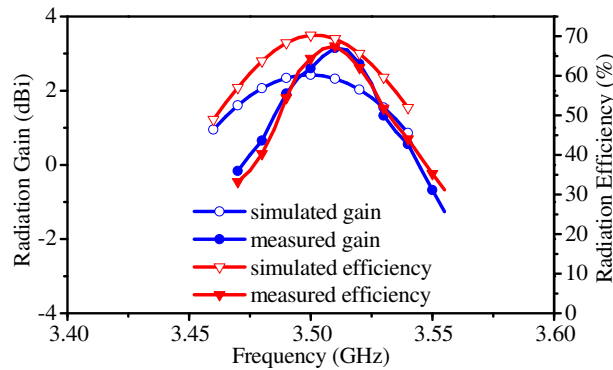


Figure 8. Measured gain and efficiency.

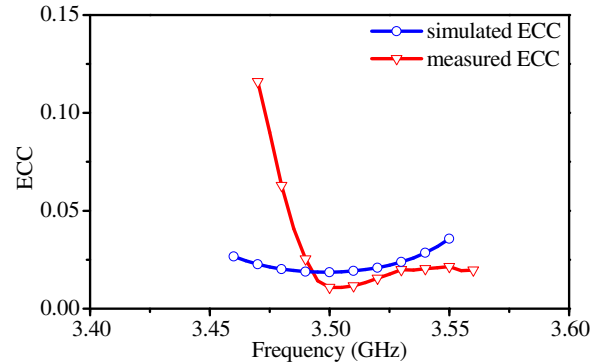


Figure 9. Simulated and measured ECC.

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

	[2]	[3]	[4]	[5]	This work
Size ( $\lambda_0$ )	$0.48 \times 0.48$	$0.55 \times 0.61$	$0.53 \times 1.11$	$0.88 \times 0.88$	$0.44 \times 0.44$
Antenna Quantity	One	One	One	Two	Two
Frequency (GHz)	3.45	10.26	5.92	8.55/9.77	3.51/3.51
Isolation (dB)	-	-	-	18.0	20.18
Radiation Pattern	Bi-directional	Uni-directional	Bi-directional	Uni-directional	Omni-directional

#### 4. CONCLUSION

A SIW cavity MIMO antenna with hybrid boundaries and anti-symmetric slots is presented. Two antenna elements resonate at SIW cavity modes under the condition of hybrid boundaries, where three electrically conducting boundaries are offered by shorted metallic vias, and one magnetically conducting boundary is provided by an opened edge. Moreover, the resonant frequency and antenna isolation are significantly affected by introducing a pair of anti-symmetric U-shaped slots. Measured results of a fabricated sample are in good agreement with the simulated ones.

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