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Compact 8-port EMSIW MIMO antenna with high isolation for sub-6 GHz communication systems

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Abstract

A compact 8-port eighth-mode substrate-integrated waveguide (EMSIW) multiple-input multiple-output (MIMO) antenna is presented in this paper. It consists of eight EMSIW cavities placed side by side sharing their open-ended edges which are separated by rectangular slots. High isolation (>22 dB) between the antenna elements over the entire operating band is obtained by the strategic placement of rectangular slots and vias. The open-ended region of EMSIW cavity resonator and the edges of the diagonal slots help in the excitation of TE_{110} mode at 5.5 GHz. The simulated bandwidth of MIMO antenna is 180 MHz, while the measured bandwidth is 220 MHz. The proposed MIMO antenna system has potential applications for sub-6 GHz communication systems.

Introduction

In order to improve the communication quality and increase the channel capacity in modern communication systems, multiple-input multiple-output (MIMO) technology is one of efficient and essential methods [1]. In MIMO technology, highly isolated multiple transmitting and receiving antennas are employed. Several techniques are used to obtain high isolation among the different ports of antennas. Decoupling methods, neutralization line methods, polarization, and pattern diversities are name a few [2]. Owing to various inherent advantages such as low loss, good inter-port isolation, low profile, and ease of integration with planar circuits, substrate-integrated waveguide (SIW) technology is gaining much more attention from the researchers nowadays [3]. Several 2-port and 4-port MIMO antennas [4–7] based on SIW technologies are reported in the literature. A full-mode SIW (FMSIW) cavity backed slot MIMO antennas utilizing TE_{110} mode for lower WLAN band (2.4 GHz) is presented in papers [5, 6]. To design the compact antenna systems, several miniatured versions of SIW such as half-mode SIW (HMSIW), quarter-mode SIW (QMSIW), eighth-mode SIW (EMSIW) are also reported [7–9]. In paper [8], 2-port and 4-port EMSIW-based MIMO antennas are presented. Several 8-port MIMO antennas for 5 G communication systems have been reported in the literature [9–15]. In paper [9], an 8-port MIMO antenna with tightly coupled pairs for 5G applications is presented, while in paper [10], dual-polarized MIMO slot antenna system is designed and developed. Eight-element MIMO antenna arrays for sub-6 GHz is presented in papers [11,12]. In paper [13], a 5-GHz eight-element-based MIMO antenna system for IEEE 802.11ac devices is presented. Recently, an 8-port $\pi/8$ SIW cavity-based MIMO antenna for 6.1 GHz is demonstrated that utilizes TE_{220} mode of the rectangular SIW cavity [14]. Due to the usage of higher order mode, the overall size of the antenna is increased. Thus, designing a compact 8-port MIMO antenna with good isolation among the ports is a great challenge.

In this paper, an 8-port MIMO antenna based on EMSIW cavities for sub-6 GHz communication systems is presented. The open-ended region of EMSIW cavity resonator and the edges of the slots help in the excitation of TE_{110} mode. High isolation among the EMSIW resonator is due to the strategic placement of diagonal slots and vias. The detailed working mechanism of the proposed MIMO antenna is also demonstrated.

Antenna configuration

Figure 1 represents top view of the proposed miniaturized 8-port EMSIW MIMO antenna. The designed antenna comprises eight EMSIW cavities which are individually excited through eight inset-fed 50-Ω microstrip feedlines. The EMSIW MIMO antenna is designed on RT/Duroid 5880 substrate ($\varepsilon_r = 2.2$, $h = 0.508$ mm, $\tan\delta = 0.0004$).

Unit element of the MIMO antenna

Figure 2 shows the evolution of the unit element of the proposed MIMO antenna. In FMSIW cavity resonator, the TE_{110} mode is the dominant mode, in which there is one half wavelength variation along the x-axis, one half wavelength variation along the y-axis and no variation of the fields along the z-axis. These electric fields are symmetrical along the plane AA'. The FMSIW cavity resonator can be bifurcated through the magnetic wall concept along the symmetrical plane to obtain the HMSIW cavity resonator. The HMSIW cavity resonator can be further bifurcated along the symmetrical plane BO to obtain QMSIW cavity resonator. These bifurcations not only preserve the modal characteristics of TE_{110} mode, with maximum intensity of fields at the open-ended edges, but also facilities the size miniaturization. The QMSIW cavity resonator is further bifurcated along symmetrical plane CO to obtain an EMSIW cavity resonator. As can be visualized from the figure, the maximum intensity of fields at the open-ended edges is observed which ensures the preservation of the modal characteristics of TE_{110} mode. The EMSIW cavity resonator is inset-fed by a microstrip feedline. It can be visualized from the electric field distribution; this structure also supports TE_{110} mode with maximum intensity of fields at the open-ended edges. Thus, it is seen that from the evolution of the unit element that it supports TE_{110} mode with maximum intensity at the open-ended edges.

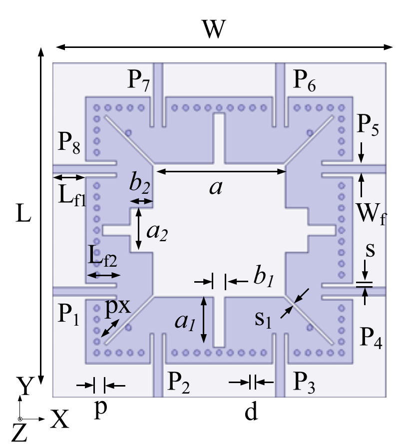

Figure 1. Geometrical sonfiguration of proposed 8-port EMSIW MIMO antenna [L = 60, w = 60, lf1 = 5, lf2 = 5.5, wf = 1.45, s = 0.7, s1 = 0.5, a1 = 9, b1 = 2, a2 = 8, b2 = 4, a = 24, px = 5, p = 2, d = 1 (all are in mm).].

Design stages of the proposed MIMO antenna

In this subsection, the design stages of the proposed EMSIW MIMO antenna is demonstrated in Fig. 3. Stage-I consists of eight EMSIW cavities placed side by side sharing the open-ended side walls as depicted in Fig. 3(a). Each of the EMSIW cavities is inset-fed through a microstrip feedline. The MIMO antenna in Stage-I radiates at 3.50 GHz with a mutual coupling between the Port P_1 and Port P_2 ($|S_{21}| = -12.5$ dB). While the mutual coupling between the others ports are below −15 dB. It can be also verified by illustrating its electric field distributions.

Further to enhance the isolation, a square slot of dimensions $a \times a$ is introduced at the center of the EMSIW MIMO antenna [Fig. 3(b)]. This square slot not only improves the impedance matching but also introduces extra capacitance that in turn shifts the operating frequency of MIMO antenna to 5.2 GHz. The isolation among all the ports is improved and it is better than 18.5 dB. In order to observe the effect of square slot on the operating frequency, a parametric study is performed on the design parameter a. Figure 4 shows the S-parameters of the MIMO antenna in Stage-II for the different values of a. It is clear from the figure that as that value of a increases the operating frequency of the MIMO antenna in Stage-II shifts to higher value.

For satisfactory MIMO operation, the mutual coupling among all the ports should be less than 20 dB [2]. The MIMO antenna in Stage-III is obtained with the introduction of four vias of diameter d in second, third, sixth and seventh EMSIW cavities [Fig. 3(c)]. These vias shifts the resonant frequencies of corresponding second, third, sixth and seventh EMSIW cavities to higher value of 5.5 GHz, while the resonant frequencies of first, fourth, fifth and eighth EMSIW cavities remain unaltered at 5.2 GHz. The isolation is better than 20 dB among all the ports of the MIMO antenna in Stage-III.

To design a MIMO antenna at 5.5 GHz, i.e. for sub-6 GHz communication systems, all the antenna elements must radiate at the same frequency. To increase the operating frequencies of first, fourth, fifth, and eighth EMSIW cavities, a pair of short square slots are engraved between them [Fig. 3(d)]. These short square slots increase the operating frequencies of first, fourth, fifth and eighth EMSIW cavities to 5.5 GHz. The asymmetrical structure not only facilitates the radiation of all the ports of designed MIMO antenna

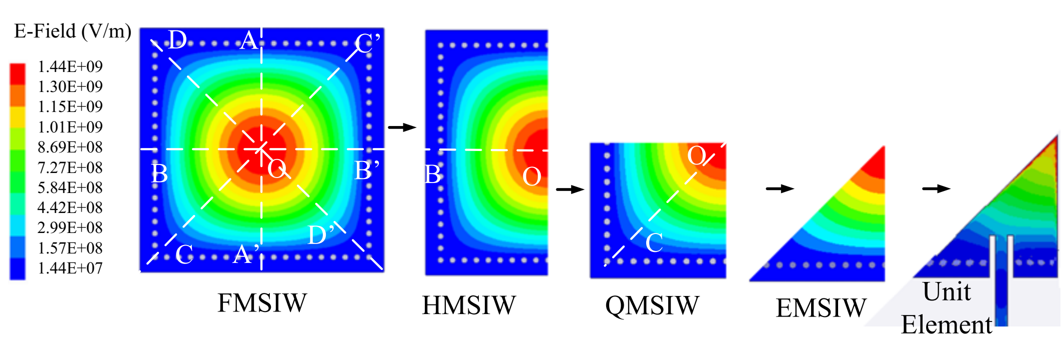

Figure 2. Evolution of the unit element of the proposed MIMO antenna.

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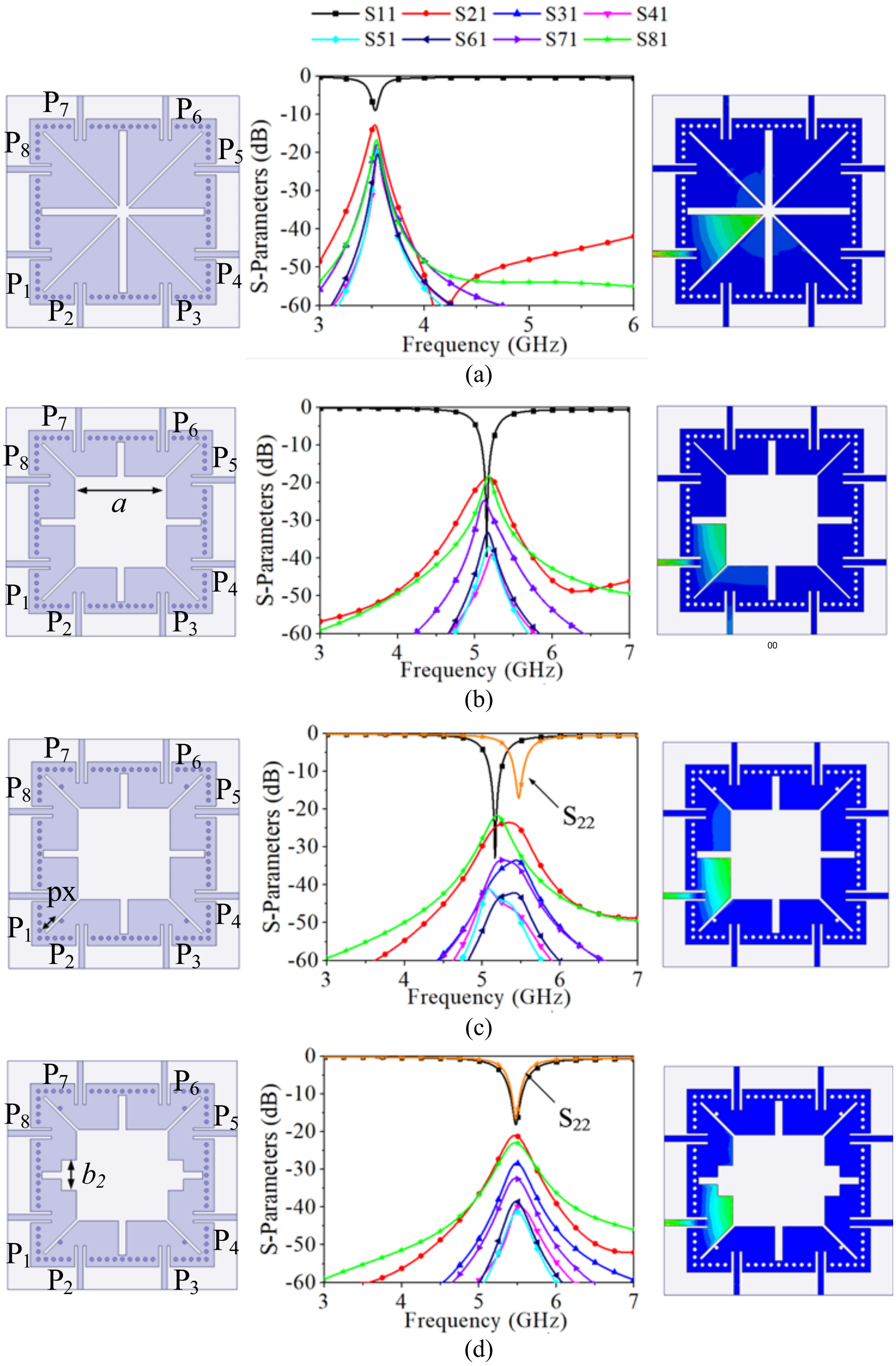

Figure 3. Different stages of proposed 8-port EMSIW MIMO antenna. (a) Stage-I, (b) Stage-II, (c) Stage-III, (d) Stage-IV.

at 5.5 GHz but also enables the high inter-port isolation. The inter-port isolation of the proposed 8-port EMSIW MIMO antenna is better than 22 dB.

Figure 5 shows the electric field distribution of the designed MIMO antenna with each port excitations. During the excitation of the respective port, the remaining ports are terminated with 50 Ω matched loads. It is clear from the figure that all the EMSIW resonators have field configuration similar to dominant TE_{110} mode. Also, when one of the ports is excited, negligible fields are present on the other resonators which guarantee high inter-port isolation.

Experimental results

To demonstrate the effectiveness of present design approach, a prototype of the designed 8-port EMSIW MIMO antenna is

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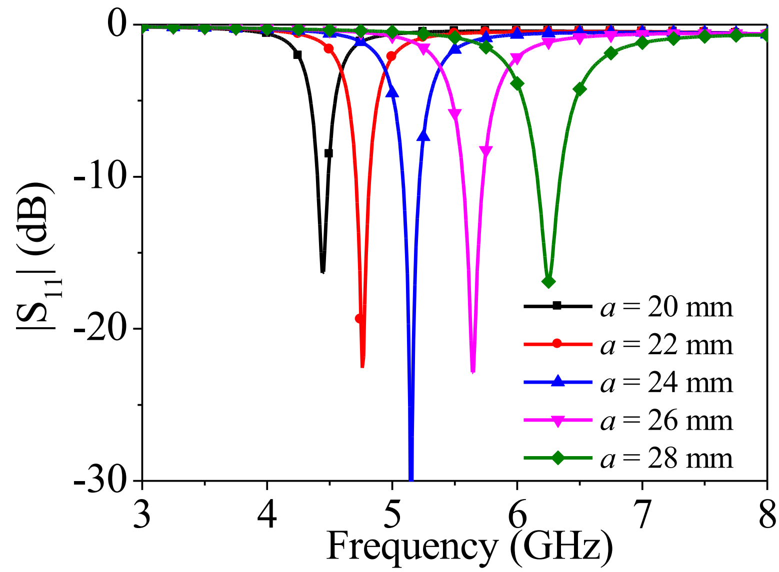

Figure 4. Parametric analysis for the design parameter *a* in stage-ii.

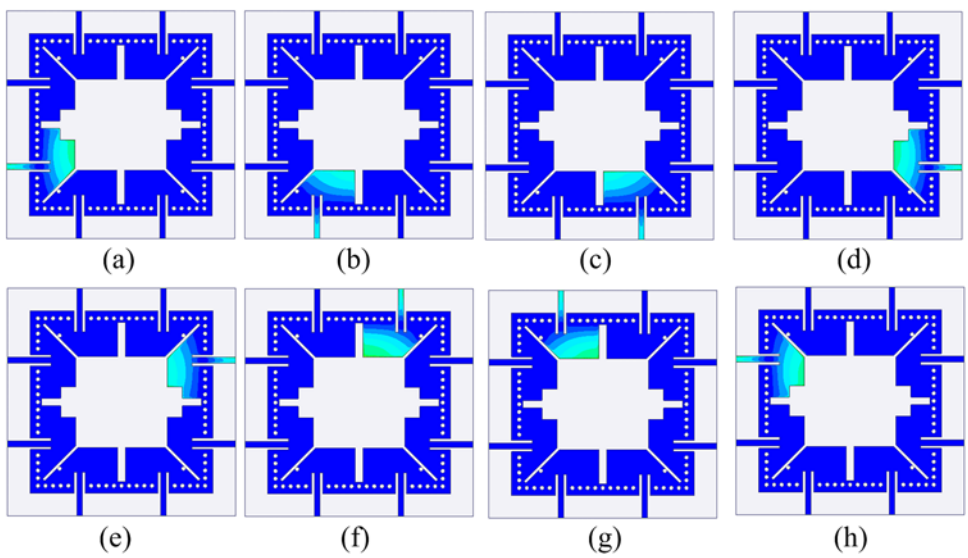

Figure 5. Electric field distribution at (a) P_1 ON, (b) P_2 ON, (c) P_3 ON, (d) P_4 ON, (e) P_5 ON, (f) P_6 ON, (g) P_7 ON, and (h) P_8 ON.

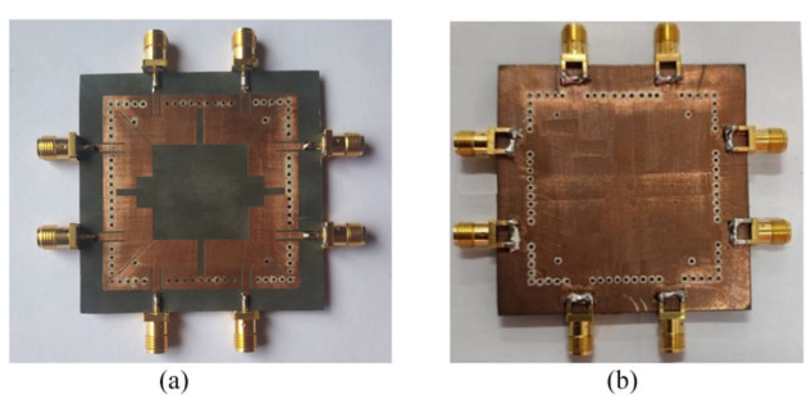

Figure 6. Photograph of fabricated prototype. (a) Top view and (b) Bottom view.

fabricated using standard Printed Circuit Board fabrication techniques and Sub-Miniature Version A connectors are connected for measurement purposes. Figure 6 shows the top and bottom views of the fabricated prototype. The overall dimensions of the designed MIMO antenna is $1.1\lambda_0 \times 1.1\lambda_0 \times 0.009\lambda_0$, where λ_0 is the free space wavelength at the operating frequency. The S-parameters are measured using Agilent E5071C VNA. Figure 7(a) shows the simulated and measured $|S_{11}|$ of the

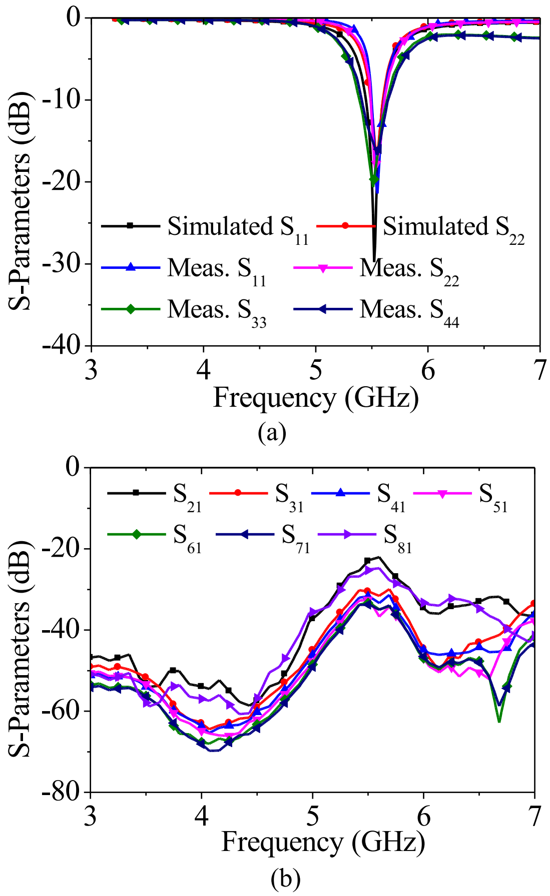

Figure 7. S-parameters of proposed 8-port EMSIW MIMO antenna. (a) Simulated S_{11}, S_{22} and measured S_{11}, S_{22}, S_{33}, S_{44} parameters and (b) measured S_{21}, S_{31}, S_{41}, S_{51}, S_{61}, S_{71} parameters.

designed MIMO antenna. The simulated impedance bandwidth is 180 MHz while the measured impedance bandwidth is 220 MHz. The isolation between the ports of the antenna element is plotted in Fig. 7(b). The isolation between the ports is better than 22 dB in all the cases, that is good enough for MIMO applications.

For the designed MIMO antenna, under the individual excitations of ports P1 and P2, $\phi = 45^\circ$ is the E-plane and $\phi = 135^\circ$ is the H-plane. Whereas, under the individual excitations of ports P3 and P4, $\phi = 135^\circ$ is the E-plane and $\phi = 45^\circ$ is the H-plane. The simulated and measured radiation patterns for *xz*- and *yz*-planes of the designed MIMO antenna at its operating frequency is plotted in Fig. 8. For brevity, only the radiation pattern of first four ports are shown in this paper. The *x*-pol levels are better than 15 dB in all the cases in the broadside direction. High cross-polarization is observed because of the different directions of the two open sides of the EMSIW resonators and its asymmetric excitation.

Figure 9 shows the peak realized gain and radiation efficiency of the proposed MIMO antenna. The peak gain of the designed antenna is approximately 4.62 dBi, while the radiation efficiencies are above 80%.

The MIMO performance of the designed antenna is evaluated in terms of envelope correlation coefficients (ECC) and channel capacity loss (CCL). Figures 10 and 11 show the ECC and CCL of the proposed MIMO antenna, respectively. The ECC and CCL of the MIMO antenna are within the acceptable limits of 0.5 and 0.4 bits/Hz/s, respectively.

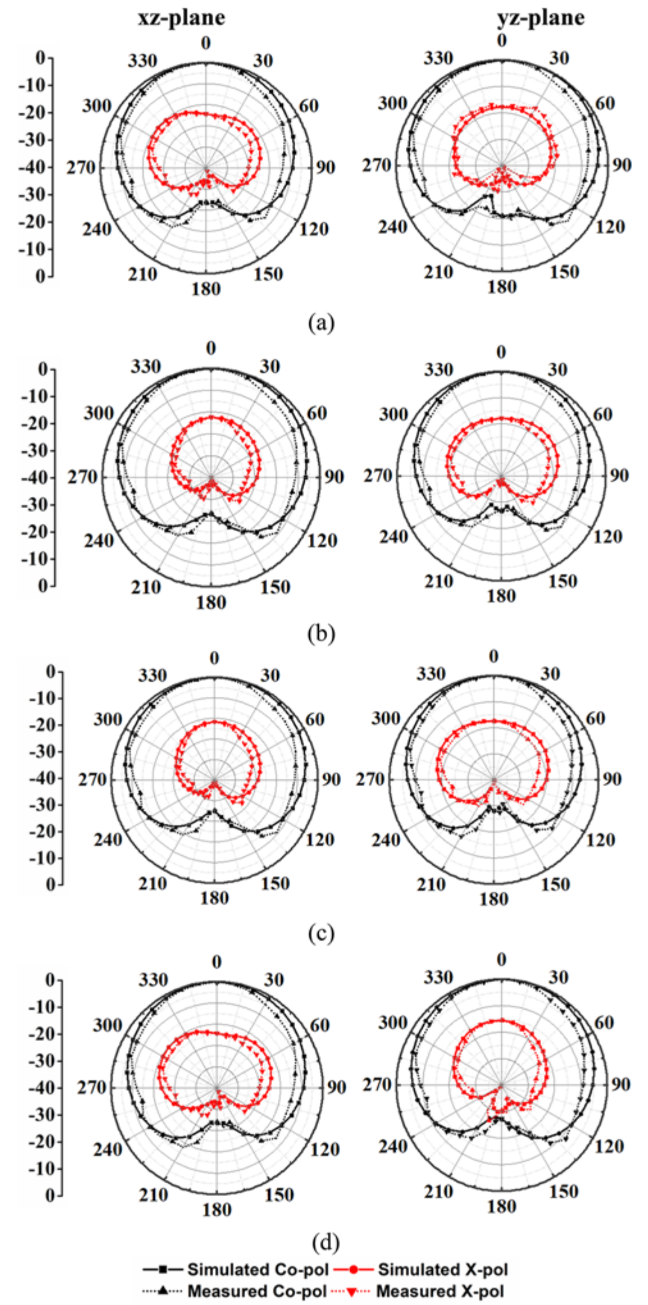

Figure 8. *xz*- and *yz*-plane radiation patterns under (a) P_1 ON, (b) P_2 ON, (c) P_3 ON, and (d) P_4 ON. Other ports are terminated with 50 Ω matched loads excitation.

To ensure the potential candidacy of the designed MIMO antenna, a comparison with the existing 8-port MIMO antennas in terms of size, isolation, gain, and MIMO performance is presented in Table 1. As compared to the other reported 8-port MIMO antennas, the novel features of the proposed MIMO antenna are as follows: (i) To the best of authors' knowledge, this is the first instance where EMSIW cavity resonator-based MIMO antenna is reported. Moreover, π/8 partial SIW is the only 8-port SIW-based MIMO antenna [13] is reported. However, the proposed MIMO antenna has compact dimension, better gain, better isolation, and

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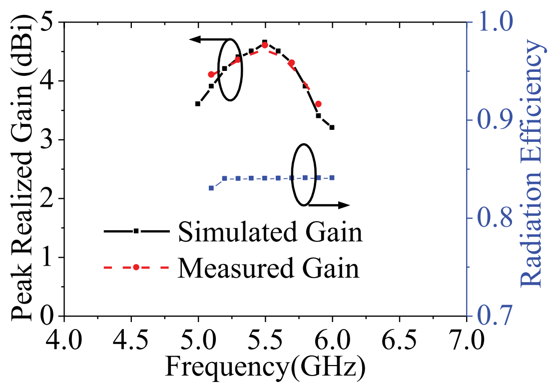

Figure 9. Peak realized gain and radiation efficiency of the proposed MIMO antenna.

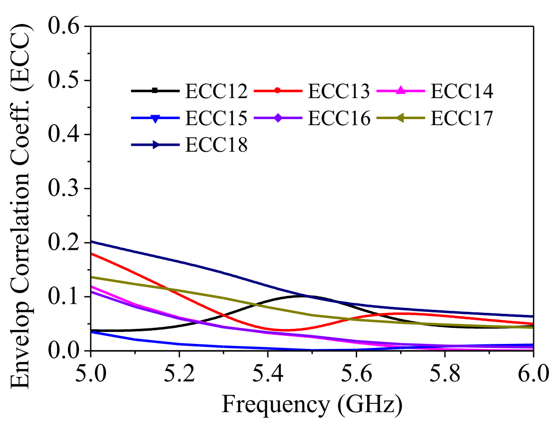

Figure 10. Envelope correlation coefficient (ECC) of the proposed MIMO antenna.

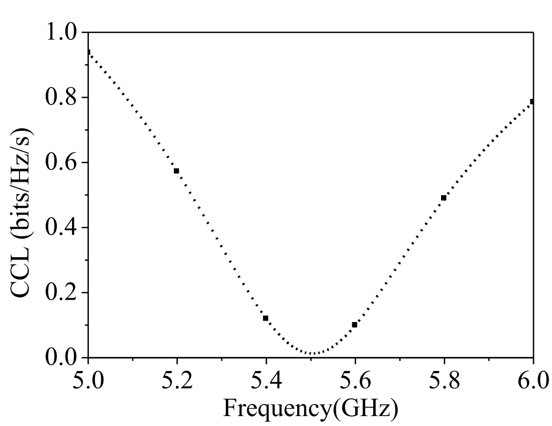

Figure 11. Channel capacity loss (CCL) of the proposed MIMO antenna.

more bandwidth compared to [13]. (ii) Moreover, the proposed EMSIW MIMO antenna, in comparison to papers [12–15], has the flexibility to redesign it for any frequency that lies between 4.4–6.4 GHz without changing its overall dimensions. (iii) In spite of using miniaturized version of FMSIW, i.e. EMSIW resonator, good isolation among the closely placed antenna elements is obtained.

Table 1. Comparison with other 8-port MIMO antennas

Ref.	Freq (GHz)	Size (λ_0^3)	BW (MHz)	Mutual coupling	Gain (dBi)
[12]	5	0.018	80	<−10.5	−0.8
[13]	6.075	0.112	137	<−21	4.72
[14]	3.5	0.014	200	<−10	NM
[15]	3.5	0.024	200	<−20	NM
This work	5.5	0.033	180	<−22	4.62

Note: λ_0 is the wavelength at the operating frequency. NM = not mentioned.

Conclusion

In this paper, an 8-port MIMO antenna for sub-6 GHz communication systems is presented. The compactness of the MIMO antenna can be attributed toward the usage of miniaturized EMSIW cavity as an antenna element. The asymmetricity in the antenna structure is responsible for good isolation among all the ports of the antenna elements without affecting its impedance bandwidth. The designed MIMO antenna has an impedance bandwidth of 180 MHz, 22 dB inter-port isolation, 4.62 dBi peak gain, and excellent MIMO performance which makes it a suitable candidate for sub-6 GHz communication systems.

Competing interests. The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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