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A Compact Dual-Band Self-Diplexing MIMO Patch Antenna for ISM and X-Band Communications

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***Abstract*— A compact, dual-band, and self-diplexing MIMO patch antenna with a shared aperture is presented for Industrial scientific medical (ISM) band and X-band communications. The structure consists of two orthogonal feed lines and a rectangular slot in a square patch. The size of the FR4 substrate is 50 x 50 x 1.6 mm^3. The designed structure operates at 5.8 (ISM) and 8 GHz (X-band) frequencies independently with a simulated peak gain of 5.46 and 3.59 dBi respectively. A 13 dB of isolation is obtained for the two orthogonal ports. The obtained frequency ratio range is 1.20-1.33 over the reflection bandwidth. The design structure is fabricated and validated experimentally. The compactness and promising performance in terms of low ECC (Envelope Correlation Coefficient) (<0.1), high peak gain can make the proposed antenna a choice for current wireless devices.**

***Index Terms*—** Self-diplexing MIMO patch antenna, dual-band, frequency ratio, ISM & X-bands

I. INTRODUCTION

The demand for compact RF front-end components is increasing in modern transceiver communication systems. Recently, the context of the self-diplexing concept is gaining much interest to get compactness. The use of self-diplexing antennas have been increasing, in which two feed lines are excited with high isolation. This concept will reduce the need for a diplexing network for transmitter and receiver operation. Which improves the compactness and performance efficiency, while operating at two independent frequencies. The realization of self-diplexing using a microstrip patch antenna provides low cost, low profile, and easy fabrication [1]. Thus, the self-diplexing patch antennas with MIMO provide a high data rate, low-cost transceiver systems.

Several research works are reported on self-diplexing antennas in literature. These works are mostly on two layers [2], different feeding positions [3], adopting metamaterial concepts [4], tunable diplexers [5], single layer structures with various slots, and SIW structures [6]-[10]. Among these, multilayer structures are not suitable for compact portable wireless devices due to incompatibility with other RF components and the complexity of fabrication. For single-layer structures with orthogonal feeding, the isolation between ports becomes challenging, when the frequency ratio is (>1). The narrow bandwidth of resonance is another problem with single layer independent port excitement,

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which is unwanted for current wireless devices. Recently, only a few designs on single-layer structures with compact size and performance are reported by adopting the SIW technique [11]-[17].

In this work, a compact and single layer self - diplexing MIMO antenna with a rectangular slot on a square patch. The designed patch structure is excited with two orthogonal feed lines that make two independent resonant bands at 5.8 (ISM) and 8 GHz (X-band). The isolation between the two ports is 13 dB at both operating frequencies. The MIMO parameters are also analysed and obtained with the low ECC value <0.1, which is a much-required one. The design concept, working principle, and experimental validation of the fabricated prototype are also described. The simulation of the design and analysis of the work is carried out using CST MWS software.

II. Design and Analysis

A. Design Layout

Fig. 1 shows the design model of the self- diplexing MIMO patch antenna with geometry. FR4 is used as a substrate with properties r=4.3 and tanδ=0.025. The dimensions of the substrate are 50x50x1.6 mm^3. A square patch with two orthogonal feed lines for two-port excitations as a radiating structure with the full ground. A rectangular loop slot in the middle of the patch and slits across both sides of the feed line is inserted on the patch structure. The geometry parameters of the design are tabulated in Table I.

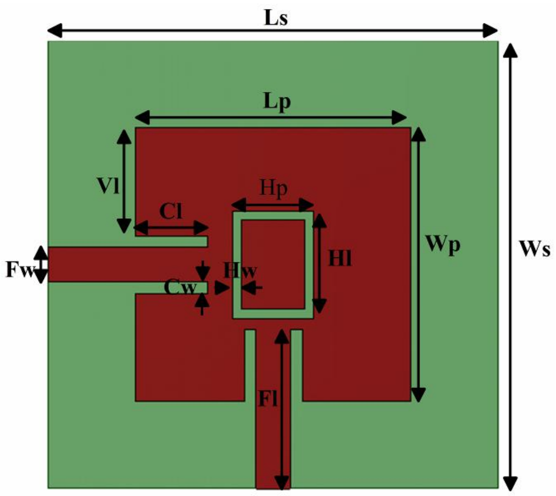

Fig. 1. Design Topology.

TABLE I. GEOMETRY VARIABLES

Parameters	Values(mm)	Parameters	Values(mm)
ls	50	**cl**	8
ws	50	**cw**	1.3
lp	30.5	**hl**	9
wp	30.5	**hp**	5
h	1.6	**hw**	1
fw	3.8	**vw**	1
fl	13	**vl**	12

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The excitations are applied to the two orthogonal feed lines with a shared patch aperture that produces two independent resonances. The reflection characteristics of the proposed antenna at two ports is shown in Fig.2. At port1, it produces a resonance at 5.8 GHz for ISM band applications with a bandwidth of 1.67 GHz (5.47-7.08 GHz). At Port2, the structure is resonating at 8 GHz (X-band) with a bandwidth of 1.24 GHz (7.28-8.54 GHz). The frequency ratio(f_h/f_l) of the design lies between 1.20-1.33.

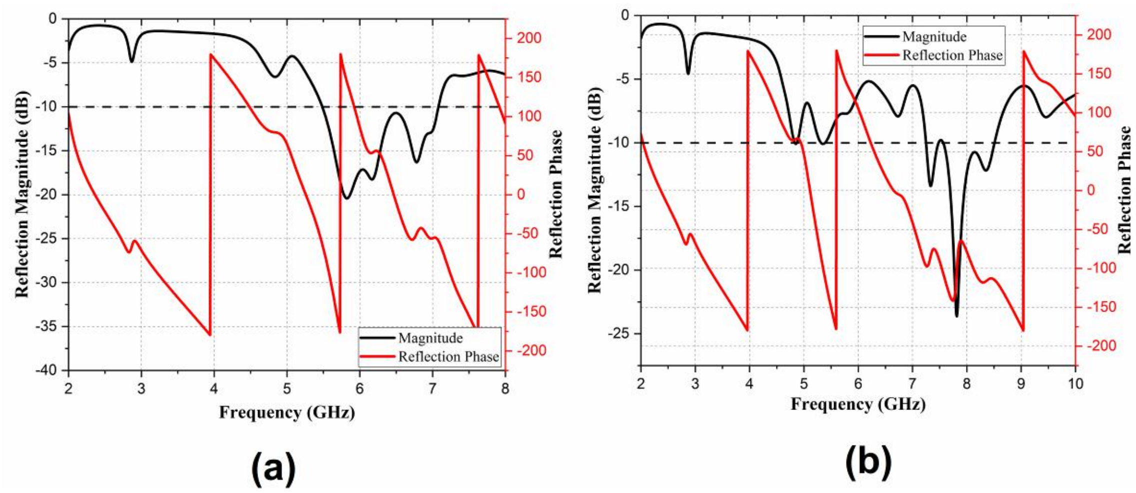

Fig. 2. Reflection Properties: (a) S_{11}- Magnitude & phase at Port1, (b) S_{22}- Magnitude & Phase at Port-2.

B. Principle of operation

The diplexing operation of the proposed structure is illustrated using distribution of surface current. The surface current distribution of the structure at individual ports is shown in Fig 3. Fig 3(a) shows the current distribution for port1 excitation, it is observed that current intensity is mostly distributed at 5.8 GHz resonance on the patch.

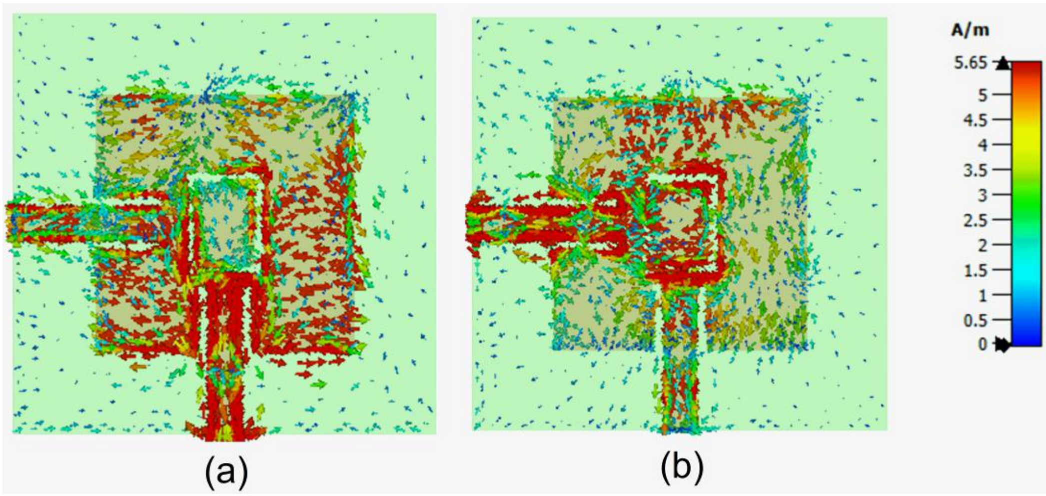

Fig. 3. Surface current density distribution: (a) 5.8 GHz at port-1 (b) 8 GHz at port-2.

Whereas, for port-2 excitation, the high current intensity is located across the slot and feed line itself at 8 GHz resonance. As a result, it provides two independent frequencies, with different polarization and radiation patterns. The isolation between the two ports is an important consideration

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for the self-diplexing MIMO antenna. Fig. 4 shows the isolation characteristics of the antenna. It provides 13 dB of isolation between two ports.

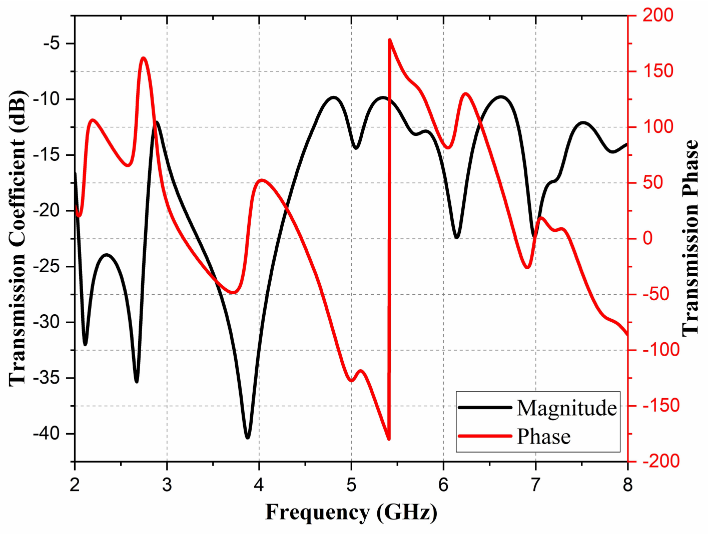

Fig. 4. Isolation properties-S_{21}.

The obtained isolation between the two ports at operating bands provides the MIMO performance for the design. The simulation results and MIMO-performance analysis is presented in the next section.

C. Simulated results and MIMO Performance

The simulated far-field results are obtained using CST MWS simulation software. The 3D far-field results for 5.8 GHz at port -1 and 8 GHz at port-2 are shown in Fig. 5. The peak gain obtained at the two ports is 5.46 and 3.59 dBi, respectively. The bidirectional radiation patterns are obtained for the two frequencies.

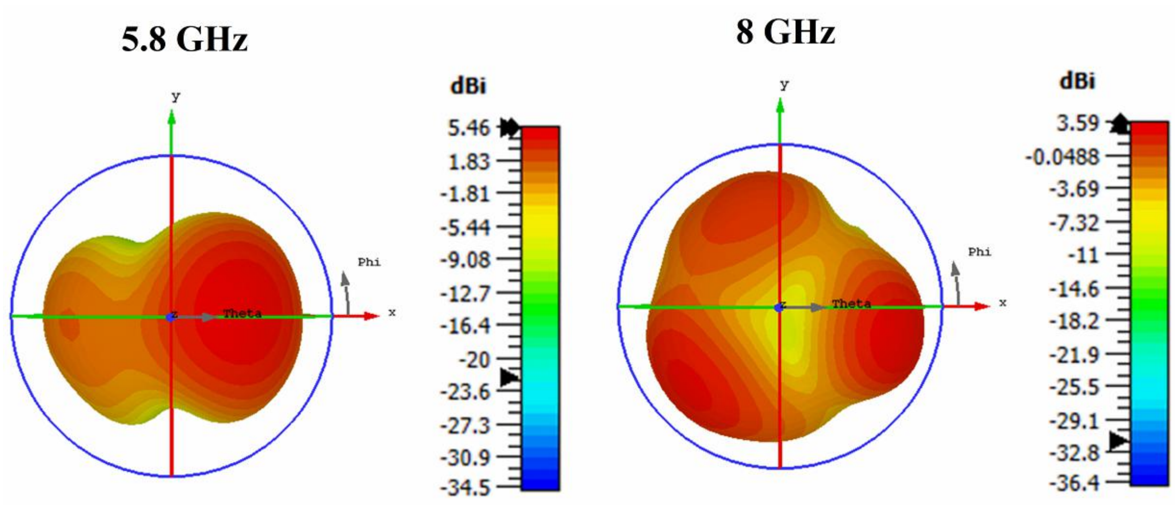

Fig. 5. 3D Far-field Patterns for 5.8 & 8 GHz at Phi=0^0.

The MIMO -performance of the self-diplexing MIMO antenna is assessed in terms of the ECC (Envelope correlation coefficient) and DG (Diversity gain). The ECC gives the correlation between polarization, radiation pattern type, and phase relation between two elements. The ECC can be

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derived from the S-parameters using the relationship given in equation 1[1]. For the MIMO performance, ECC must be less than 0.5. The simulated ECC over the frequency is shown in Fig. 6. It is observed that the value is less than 0.1 at both frequencies.

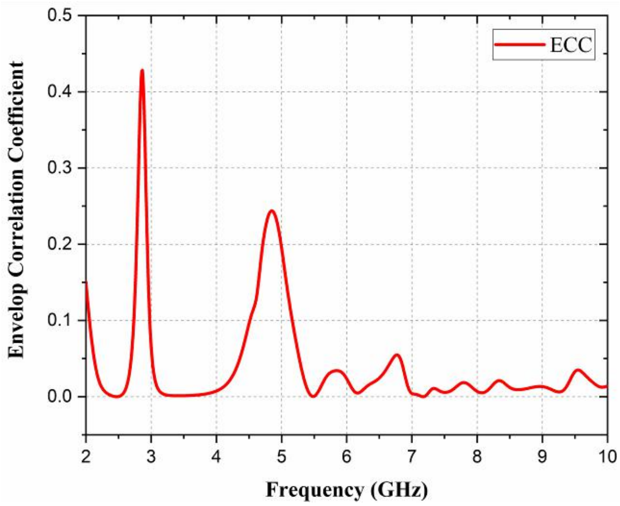

Fig. 6. Simulated ECC Result over frequency.

$$ECC = \frac{|s_{11} \cdot s_{12} + s_{21} \cdot s_{22}|}{(1 - |s_{11}|^2 - |s_{21}|^2)(1 - |s_{22}|^2 - |s_{12}|^2)} \tag{1}$$

Diversity gain is another important parameter for MIMO antenna. It can be derived from the ECC using the mathematical relation in equation 2 [1]. For better performance, the nominal value of Diversity Gain is maintained at > 9.5. The simulated DG of the self-diplexing MIMO antenna is shown in Fig 7. The designed antenna satisfies the DG limits.

$$\text{DG} = 10.\sqrt{(1 - (ECC)^2)} \tag{2}$$

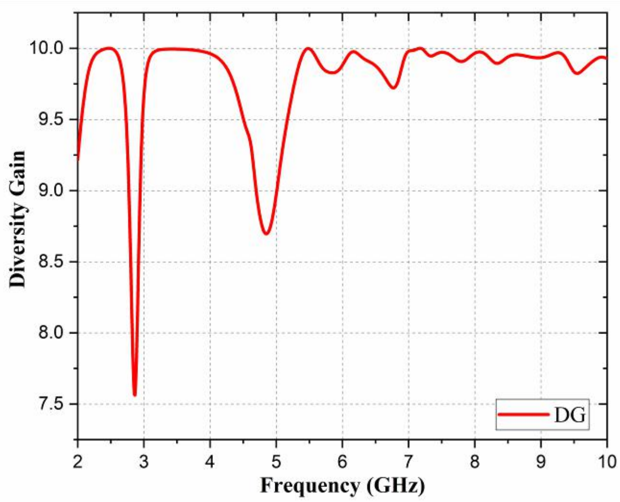

Fig. 7. Simulated DG.

Form the simulated results, it is observed that the proposed design provides a small ECC (<0.1), significant DG value >9.5, and isolation of 13 dB across two ports with the shared aperture. Hence the self-diplexing antenna design offers compact size with significant MIMO performance.

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III. Experimental Results and discussions

To validate the simulated design of the self-diplexing MIMO antenna, a prototype is fabricated. The fabricated sample front view and the back view are shown in Fig. 8.

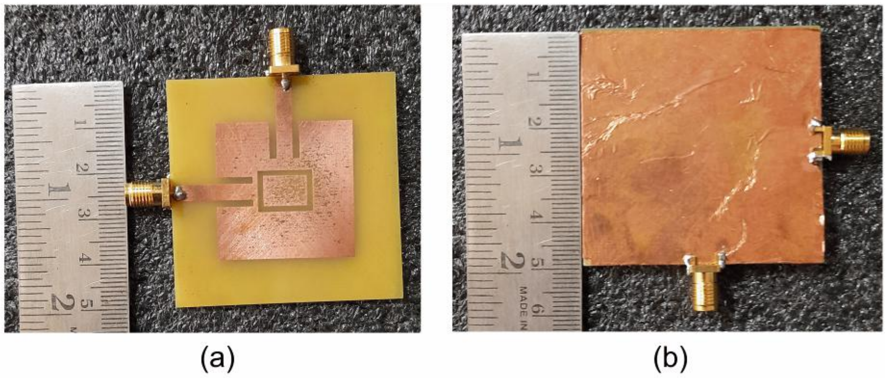

Fig. 8. Design prototype (a) Front view (b) Back view.

The characterization of the prototype is done using the measurement setup shown in Fig. 9. Anritsu MS2037C Vector Network Analyzer is used in the measurement setup. The self-diplexing operation is validated by getting individual reflection responses at each port which the other port is matched with the 50-ohm load. Fig. 9 (a), (b), and (c), depict the setup for S-parameter response at port1,2 and isolation between the two ports.

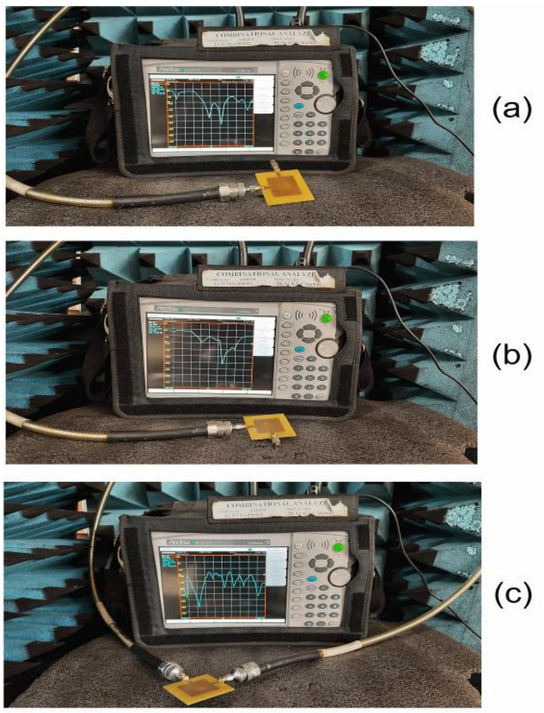

Fig.9. Measurement setup for Reflection characteristics: (a) S_{11} at Port -1; (b) S_{22} at Port 2; (c) S_{21} between two ports.

Fig.10 (a) and (b) presents the comparison of the measured and simulation reflection/transmission properties at the two ports, which shows that the consistency in the measured results. The deviation observed is because of fabrication error, which can be mitigated. Hence, the satisfied MIMO parameters can also be obtained as it depends on S-parameters. The measured frequency ratio is also

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reaching a nearer value of 1.20-1.33. The realized S-parameter results show the self-diplexing operation with good bandwidth and an isolation of 13 dB.

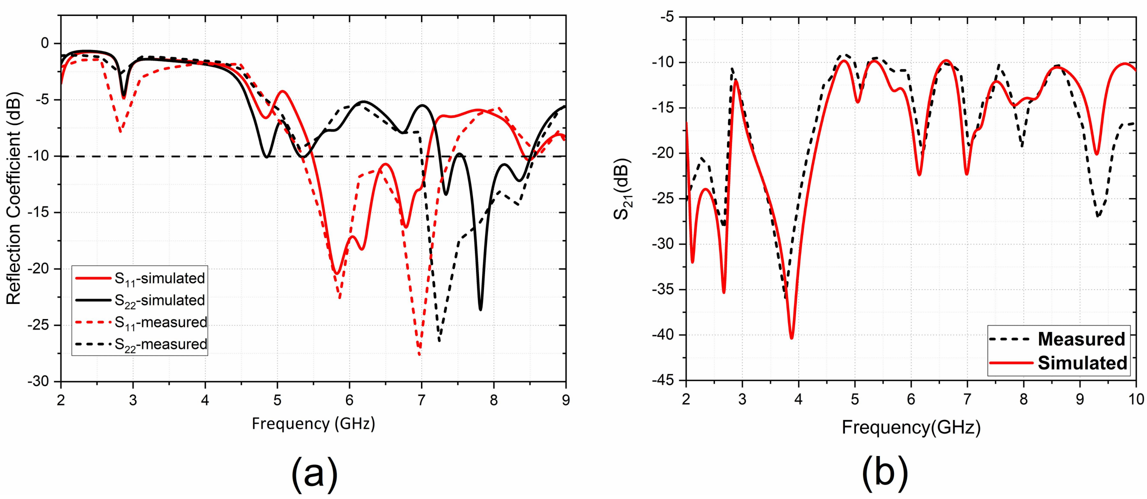

Fig. 10. Simulated and measured results comparison: (a) S_{11}(dB); (b) S_{21}(dB).

Fig.11 depicts the simulated and measured radiation patterns of the designed antenna at 5.8 GHz and 8 GHz frequencies for realized gain values. The radiation patterns obtained are unidirectional with low sidelobe levels. The measurements for far-field patterns are carried out in a shielded anechoic chamber with the setup shown in Fig.12. The individual port radiation patterns are measured while terminating the other with 50 ohms matched load.

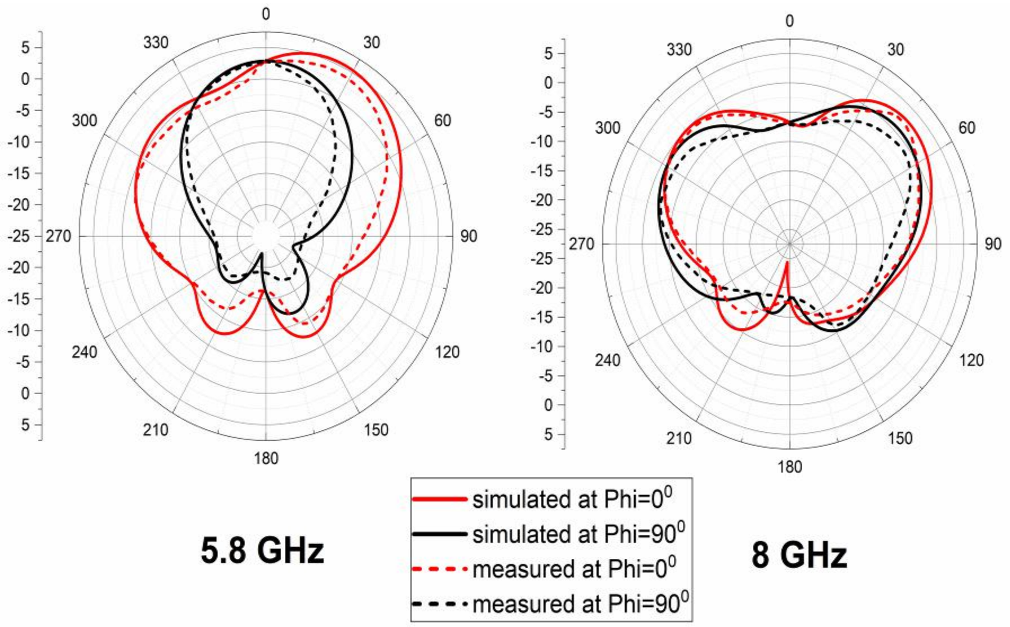

Fig. 11. Realized gain-based Radiation patterns at 5.8 and 8 GHz.

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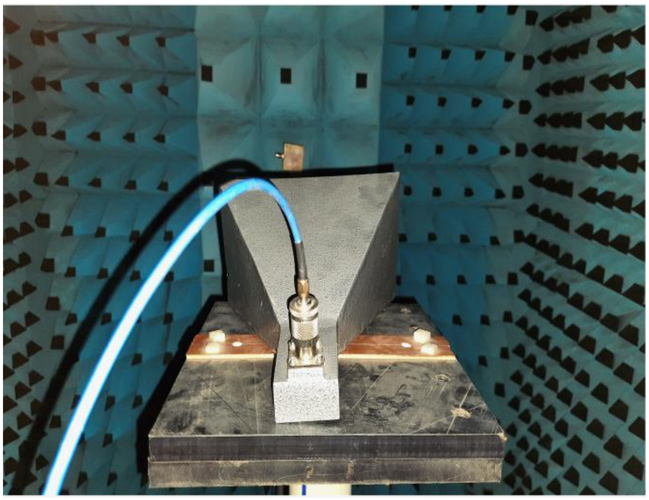

Fig. 12. Far-field Measurement setup in the Anechoic Chamber.

The present work is compared with some of the existing works as shown in table II. The designed antenna shows self-diplexing characteristics with gain of 5.46 and 3.59 dBi at operating frequencies. An isolation of 13dB, compact size, simple structure and MIMO performance makes the design suitable for compact and high-performance self-diplexing MIMO systems.

TABLE II. COMPARISON WITH SELF-DIPLEXING PATCH ANTENNAS

Ref. No.	**Size (mm^3)**	**Substrate/ε_r**	**No. Ports**	**Center Frequency (GHz)**	**Gain (dBi)**	**Isolation (dB)**	**Frequency ratio**
[5]	38×38×1.96	F4B/2.55	2	4.37 4.63	3.82 4.48	32	1.37
[13]	50×24×1.6	FR-4 epoxy/4.4	4	5.1 5.7	2.02 2.96	15	1.62
[14]	100×100×2.9	Rogers 4003C/3.38	2	7.55 8.14	10 10.5	27	1.08
[15]	50×50×1.75	FR4/4.4	1	2.45 5.5	1.9 4.4	25	1.3-3
[16]	50×50×2.62	RO 4003/3.38	2	4.7 6	10.2 12.5	30	1.27
Proposed work	50×50×1.6	FR-4 lossy/4.3	2	5.8 8	5.46 3.59	13	1.20-1.33

IV. CONCLUSION

A simple and compact structure for designing a dual-band self-diplexing MIMO patch antenna with a shared aperture is presented. The proposed antenna provides simplicity in design, compactness, easy fabrication, and integration flexibility, due to its planar structure and simple microstrip feeding method than other i.e., and patch type and SIW based diplexers. The simulated peak gain of 5.46, 3.59 dBi is obtained at 5.8 and 8 GHz, respectively. The design is experimentally validated with consistency between simulated and measured results is achieved.The frequency ratio of 1.20-1.33 and

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the unidirectional radiation patterns, make the proposed antenna suitable for X-band and ISM band communications. The designed antenna provides performance mainly in terms of ECC < 0.1, DG > 9.5, which makes it potential for the MIMO system.

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