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Compact Multi-Band MIMO Antenna with Improved Isolation

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Abstract—Nowadays everyone needs electronic gadgets in compact size, and single device should accomplish all the tasks. A compact MIMO antenna resonating at multi-band of frequencies is proposed in the current research work. The proposed MIMO antenna consists of two elements. The edge to edge separation between the two antennas is $\lambda_0/31$ and still maintains low mutual coupling levels between the two antennas. The proposed MIMO antenna resonates at 4.75 GHz, 5.89 GHz, 6.74 GHz, 8.25 GHz and 9.82 GHz. The mutual coupling is reduced by −23.78 dB at 4.75 GHz, −25.71 dB at 5.89 GHz, −29 dB at 6.74 GHz, −32.79 dB at 8.25 GHz and −21.5 dB at 9.82 GHz, respectively. The performance of the proposed MIMO system was evaluated in terms of S-parameters, Envelope Correlation Coefficient (ECC), Voltage Standing Wave Ratio (VSWR), and Radiation Pattern. The measured and simulated results are presented.

1. INTRODUCTION

In various mobile communication services, Long-Term Evolution (LTE) is one of the widely used communication systems as a fourth-generation wireless service. As each nation or wireless carrier uses different frequency bands, multiband antenna systems are highly desirable. Moreover, the role of multiband antennas has become more important as the carrier aggregation technique of LTE-Advanced communication system was released [1]. In current 4G technology, an increasing demand for multiband antennas capable of receiving multiple services has come into picture. In handheld devices like mobile, Laptop etc. the space for antenna is restricted. When numbers of antennas are placed within small area, mutual coupling dominates the operation of the entire wireless system. The consequences of mutual coupling may result in change of radiation pattern of the antenna and change in antenna matching characteristics. Because of these reasons the performance of the MIMO antenna deteriorates.

It is important to design MIMO antenna with enhanced isolation. For minimizing the mutual coupling in MIMO systems, many techniques are mentioned in the literature. In [2, 3] mutual coupling is reduced by using EBG (Electromagnetic Band Gap) structures. The main disadvantage of EBG structure is its more space occupancy. In [4], mutual coupling is reduced by using frequency selective surface wall. In [5], mutual coupling is reduced by using meta-materials. In [6, 7], mutual coupling is reduced by using parasitic elements. In [8], mutual coupling is minimized by using neutralization lines. In [9], mutual coupling is reduced by using discrete mushrooms. In [10, 11] mutual coupling is reduced by using DGS. In [12], mutual coupling is reduced by using Asymmetrical Coplanar Strip walls.

The motivation of the current research work is to propose a multi-mode multi-functional antenna, and some related works are mentioned in [13–16]. In [13], the multi-mode operation of the antenna is discussed in detail. In [14], a novel triple-layer dual-mode meta-atom where an H-shaped structure is combined with a pair of symmetric patches is proposed. In [15], a general strategy to efficiently and flexibly control the emission beams with dual functionalities, which is realized independently

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by orthogonal excitations, is discussed. The state of art techniques for reducing mutual coupling are discussed in [17, 18]. In [17], Hilbert-shaped magnetic wave guided metamaterials are used for mutual coupling reduction. In [18], MTMs are used for reducing mutual coupling. In [19], an antenna which resonates at five bands 3.13 GHz: S-band (2–4 GHz); 8.89 GHz and 10.69 GHz: X-band (8–12 GHz); 16.79 GHz: Ku-band (12–18); 20.37 GHz and 26.06 GHz: K-band (18–27 GHz); 30.13 GHz and 36.26 GHz: Ka-band (27–40 GHz) is discussed. In [20], the reduction of mutual coupling using parasitic element is discussed in detail.

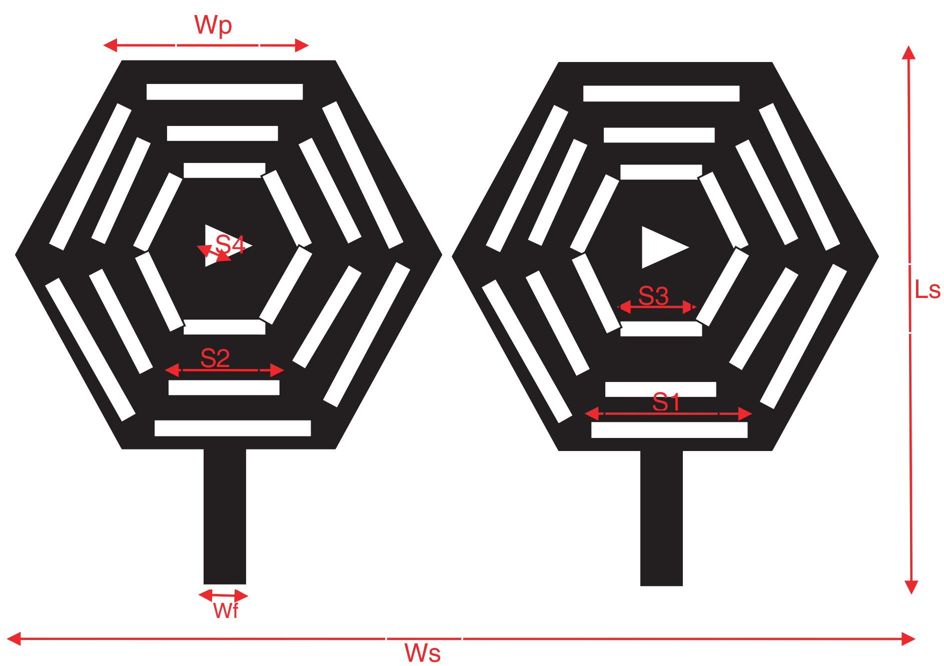
In this paper, mutual coupling between the antennas is minimized by using Defected Ground Structure (DGS) technique. The developed MIMO antenna resonates at 4.75 GHz, 5.89 GHz, 6.74 GHz, 8.25 GHz and 9.82 GHz frequencies with reduced mutual coupling by keeping the edge to edge separation between the two antennas at $\lambda_0/31$ only. This paper is organized into five sections. Section 2 deals with the proposed MIMO antenna design. Section 3 mentions the design procedure and parametric study. Section 4 provides results, and the work is concluded in Section 5.

2. ANTENNA DESIGN

The geometry of the proposed MIMO antenna is as shown in Fig. 1, and the detailed dimensions of the antenna are mentioned in Table 1. Two symmetric antennas are arranged on the substrate. The dimensions of a single antenna are $32 \times 35\,\text{mm}^2$. The dimensions of the proposed MIMO antenna are $64 \times 35\,\text{mm}^2$. The proposed MIMO antenna is developed on an FR4 substrate with relative permittivity of $\varepsilon_r = 4.3$. The thickness of the substrate is 1.6 mm. The edge to edge separation between the two elements in the proposed MIMO antenna is $\lambda_0/31$ only. As the antenna structure is symmetric, the two antennas give similar resonant properties. A defect is introduced in the ground plane for minimizing the mutual coupling. The novelty of the design is its simple structure and compactness. The slots are

Table 1. Parameters for the proposed MIMO antenna.

Parameter	W_s	L_S	W_p	S_1	S_2	S_3	S_4	W_{gs}	L_{gs}	W_f
Dimensions (mm)	64	35	15	12	8	6	5.2	30	35	3



(a)

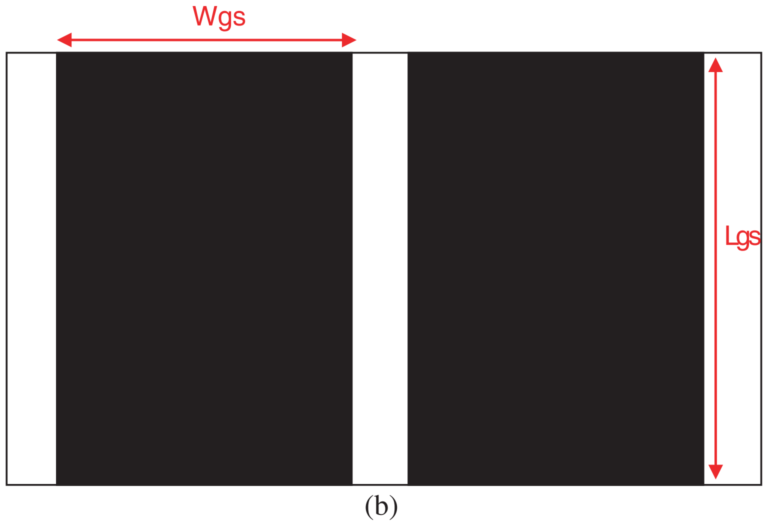


Figure 1. Geometry of the proposed MIMO antenna 1. (a) Top layer 1. (b) Bottom layer.

introduced with uniform spacing thereby altering the current path, which leads to multiband operation. The advantages of this design are compact in size and being used for various applications at different frequency bands.

3. DESIGN PROCEDURE AND PARAMETRIC STUDY

The radiating patch in the proposed antenna is a hexagon with radius of 15 mm. In the first iteration, slots S_1 are introduced, and the results are verified for multi-band operation and for reduced mutual coupling. In the second iteration, slots S_2 are introduced, and the results are observed. In the third iteration, slots S_3 are introduced, and results are verified. Finally, a triangular slot is introduced in the center of the hexagonal patch giving the desired performance. The proposed design is finalized through parametric analysis. The evolution procedure of the proposed MIMO antenna is shown in Fig. 2. In Fig. 3, the simulated S_{11}-parameters are shown using slots S_1 alone, with slots S_1, S_2 and finally the proposed design. The variations in S_{11} parameter by introducing slots S_1 alone, S_1, S_2 and finally S_1,

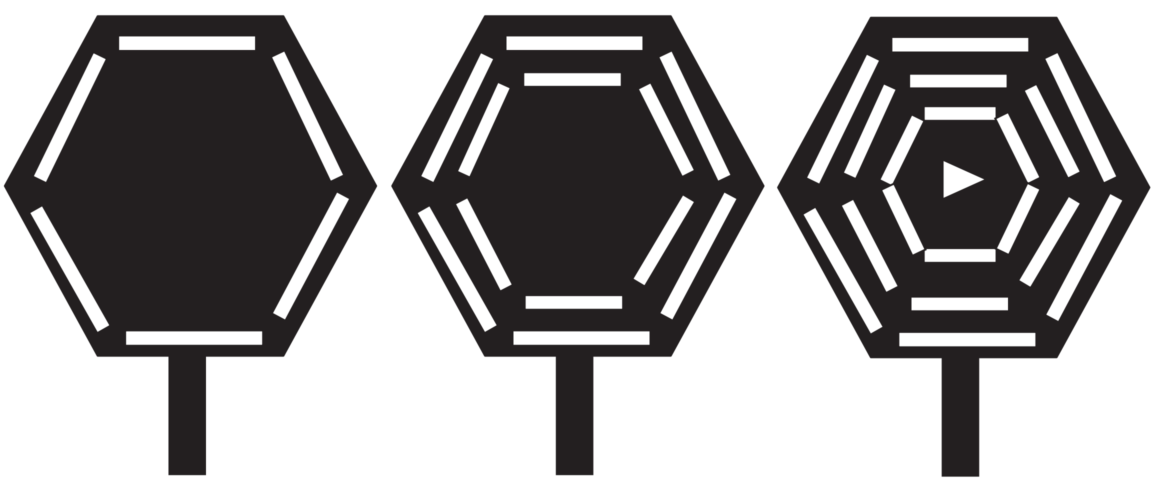


Figure 2. Evolution procedure of proposed MIMO antenna.

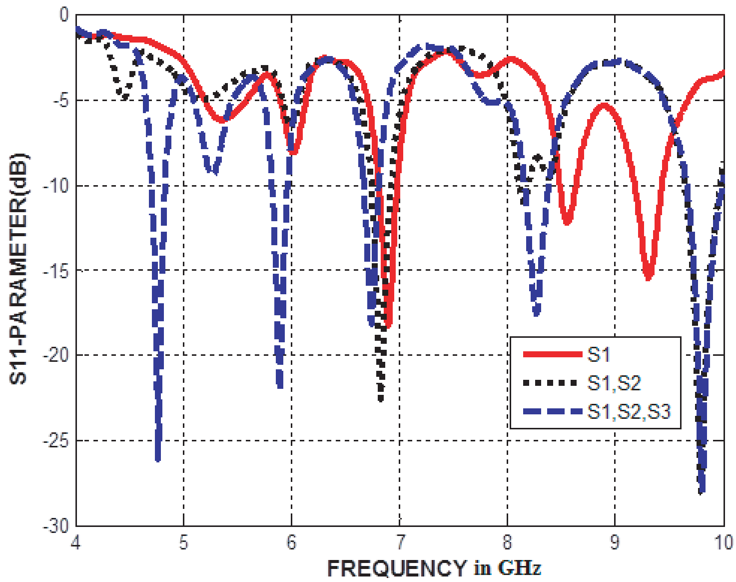


Figure 3. Variation in S_{11} with S_1, S_2, S_3.

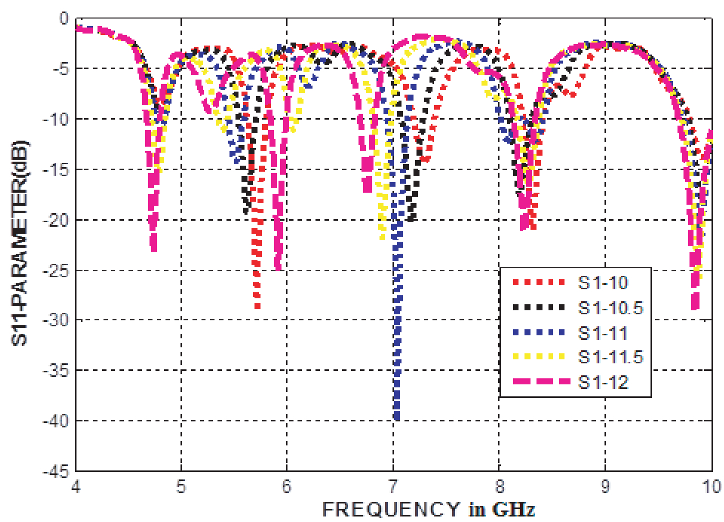


Figure 4. Parametric analysis of S_{11} with variation in slot length S_1.

S_2, S_3 are observed. The variations in S_{11} and S_{21} with variation in slot length S_1 are shown in Fig. 4 and Fig. 5. The variations in S_{11} and S_{21} with variation in slot length S_2 are shown in Fig. 6 and Fig. 7. After multiple iterations, satisfactory results are obtained as shown in Fig. 8 and Fig. 9. In MIMO antenna, the important parameter is mutual coupling, and it should be maintained as minimum as possible. The design is finalized with $S_1 = 12$ mm, $S_2 = 8$ mm, $S_3 = 6$ mm, $S_4 = 5.2$ mm, and as long as these dimensions are fixed, the resonating frequency bands of the antenna are also consistent.

4. RESULTS

The effect of mutual coupling on radiation pattern and matching characteristics of the antenna are investigated in this paper. The scattering parameters of the proposed MIMO antenna are S_{11}, S_{22}, S_{21}, and S_{12}. Since structure is symmetric, S_{11} is same as S_{22}, and S_{21} is same as S_{12}. The S_{11}-parameter for

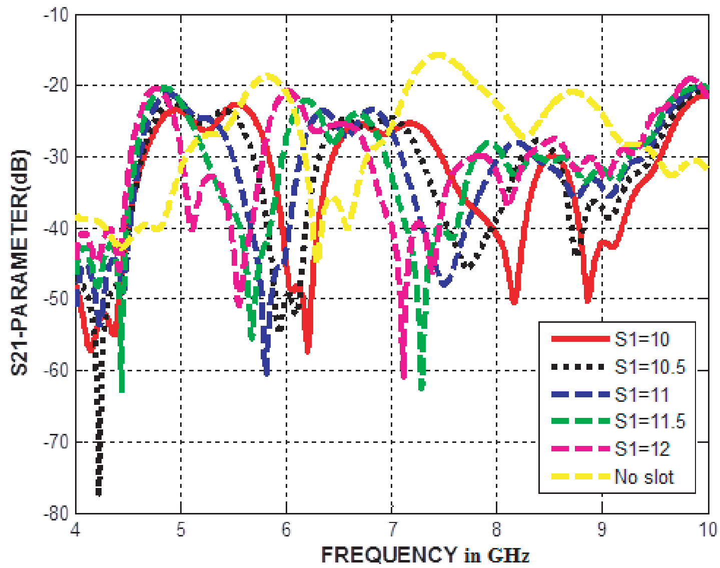


Figure 5. Parametric analysis of S_{21} with variation in slot length S_1.

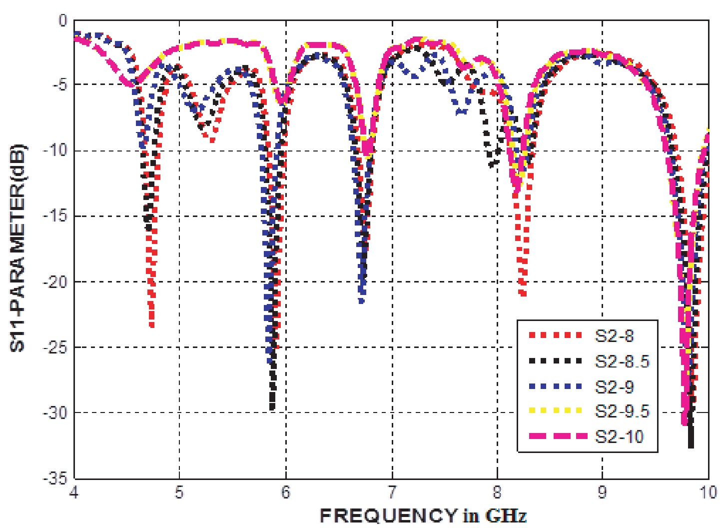


Figure 6. Parametric analysis of S_{11} with variation in slot length S_2.

the proposed MIMO antenna is shown in Fig. 8. The MIMO antenna resonates at five bands: 4.75 GHz, 5.89 GHz, 6.74 GHz, 8.25 GHz and 9.82 GHz.

In the ground plane, a slot is introduced to reduce the mutual coupling (DGS technique). When a slot is introduced in the ground plane, it prevents the surface currents propagating from one element to another thereby reducing the mutual coupling. The mutual coupling (S_{21}) for the proposed MIMO antenna is as shown in Fig. 9. The mutual coupling is reduced by −23.78 dB at 4.75 GHz, −25.71 dB at 5.89 GHz, −29 dB at 6.74 GHz, −32.79 dB at 8.25 GHz and −21.5 dB at 9.82 GHz.

Envelope Correlation Coefficient (ECC) is a key parameter for MIMO. ECC determines the diversity gain of the MIMO antenna. ECC can be calculated from Eq. (1). The ECC for the proposed MIMO antenna is 0.0005 at 4.75 GHz, 0.0004 at 5.89 GHz, 0.0005 at 6.74 GHz, 0.0004 at 8.25 GHz and 0.0005 at 9.82 GHz. The diversity gain and ECC are inversely related. For the proposed MIMO antenna, ECC

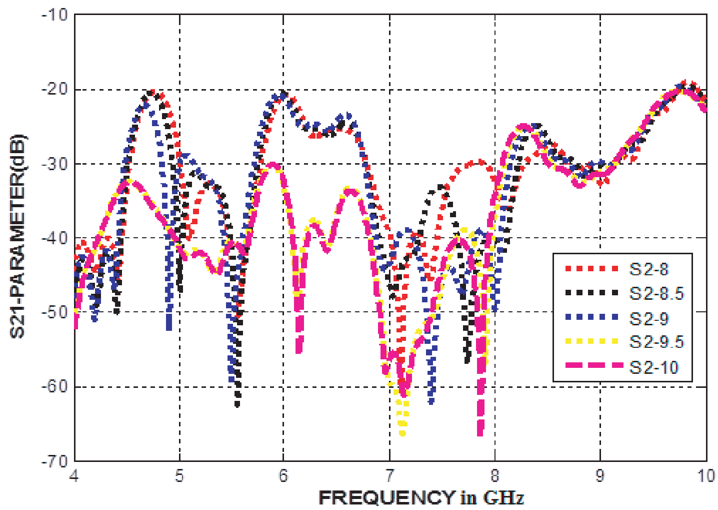


Figure 7. Parametric analysis of S_{21} with variation in slot length S_2.

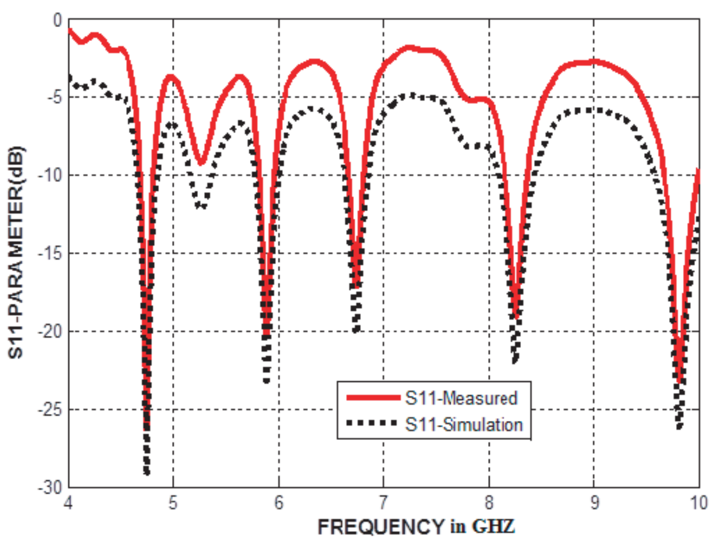


Figure 8. Scattering parameter S_{11} for the proposed MIMO antenna.

is very small as shown in Fig. 10.

$$\rho = \frac{\left|s_{11}^* s_{12} + s_{21}^* s_{22}\right|^2}{\left(1 - |s_{11}|^2 - |s_{21}|^2\right)\left(1 - |s_{22}|^2 - |s_{12}|^2\right)} \tag{1}$$

VSWR indicates amount of reflection at the two input ports. It actually represents the matching between microstrip feed and antenna. VSWR is generally less than 2. For the proposed MIMO antenna, VSWR is 1.6 at 4.75 GHz, 1.62 at 5.89 GHz, 1.65 at 6.74 GHz, 1.5 at 8.25 GHz and 1.4 at 9.82 GHz as shown in Fig. 11. Photographs of the fabricated MIMO antenna are shown in Fig. 12.

The proposed MIMO antenna resonates at five frequencies, and the surface currents at these frequencies are shown in Fig. 13. According to Eq. (2), the resonant frequency is determined by the length of the current path. If the length of current path is longer, frequency is lower. If the length of current path is shorter, frequency is higher. From Fig. 13, it can be observed that, at 4.75 GHz resonant frequency, the length of the current path is longer compared to the resonant frequency 9.82 GHz, where

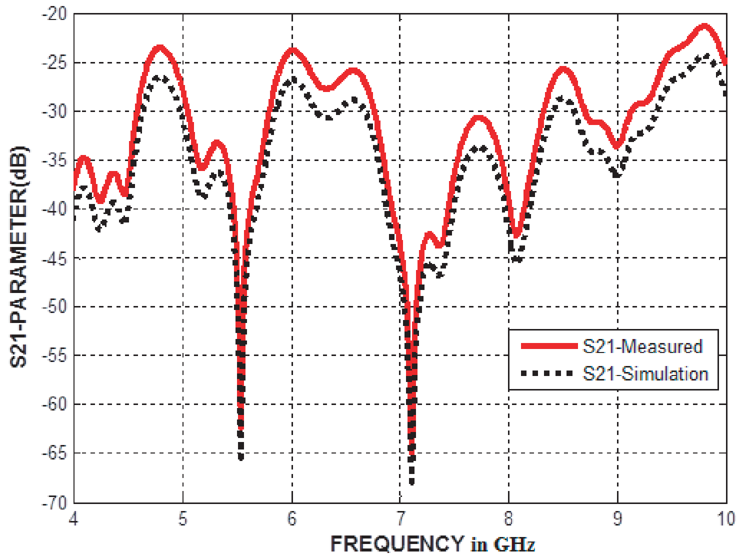


Figure 9. Mutual coupling (S_{21}) for the proposed MIMO antenna.

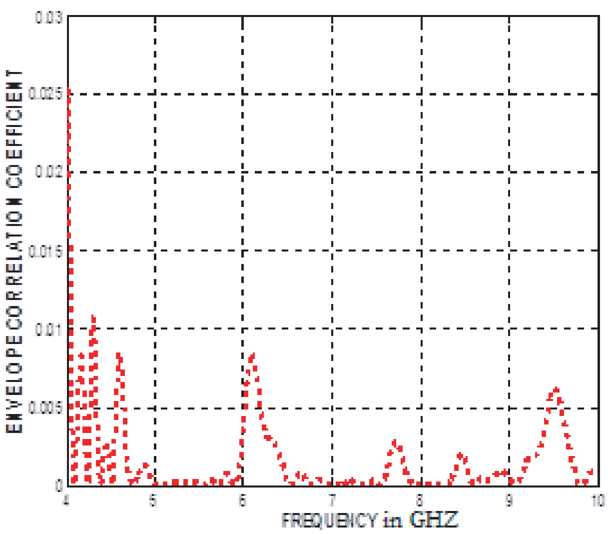


Figure 10. Envelope correlation coefficient for the proposed MIMO antenna.

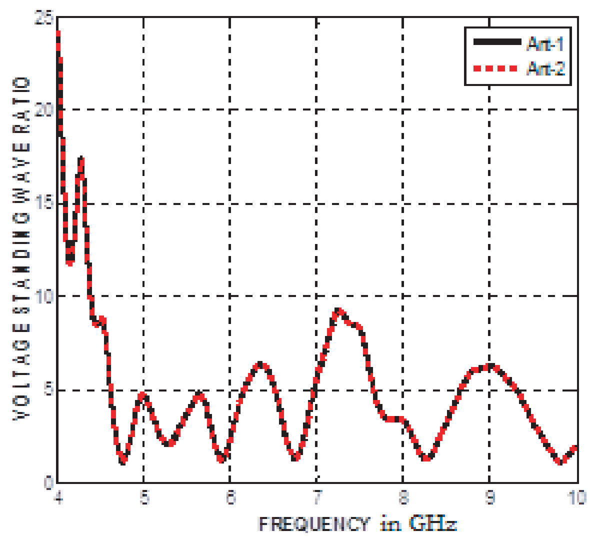
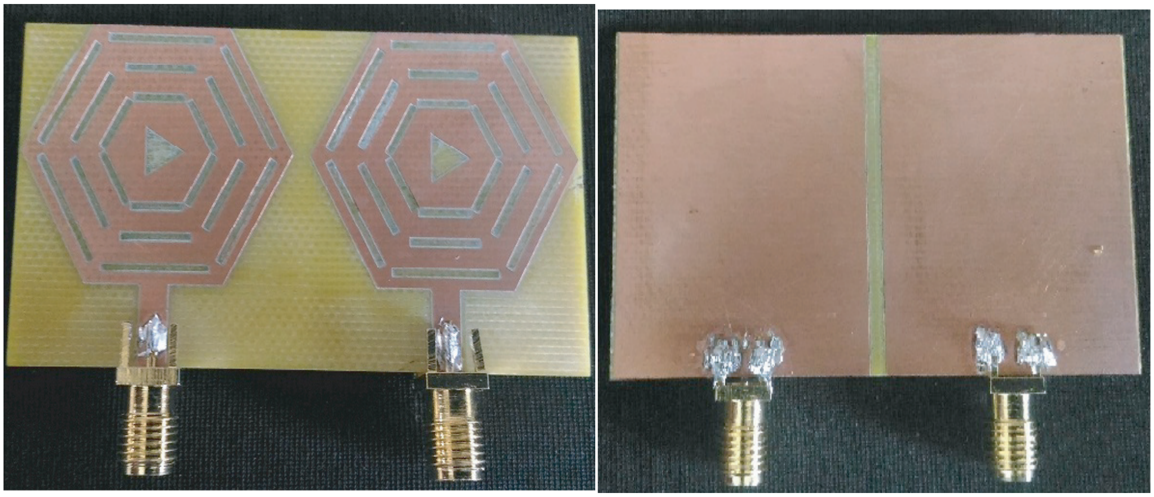


Figure 11. VSWR for the proposed MIMO antenna.

the length of the current path is shorter.

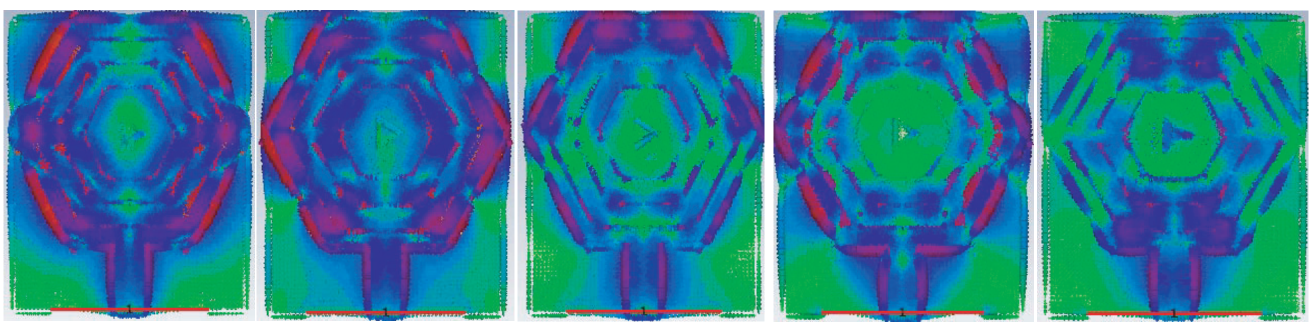
$$\text{Frequency } f = \frac{c}{2 \times L \times \sqrt{\varepsilon_r}} \tag{2}$$

The co-polarization plot indicates radiation in the desired direction, and cross-polarization indicates radiation in the direction perpendicular to co-polarization. The co-polarization and cross-polarization patterns of the proposed MIMO system at five resonating bands are shown in Fig. 14. The radiation patterns of the individual single antenna and the same antenna in the proposed MIMO system are observed to be similar. At 8.25 GHz, the cross-pol component in the E-plane is increased. The performance of the proposed antenna is compared with some existing antennas in the literature as mentioned in Table 2.



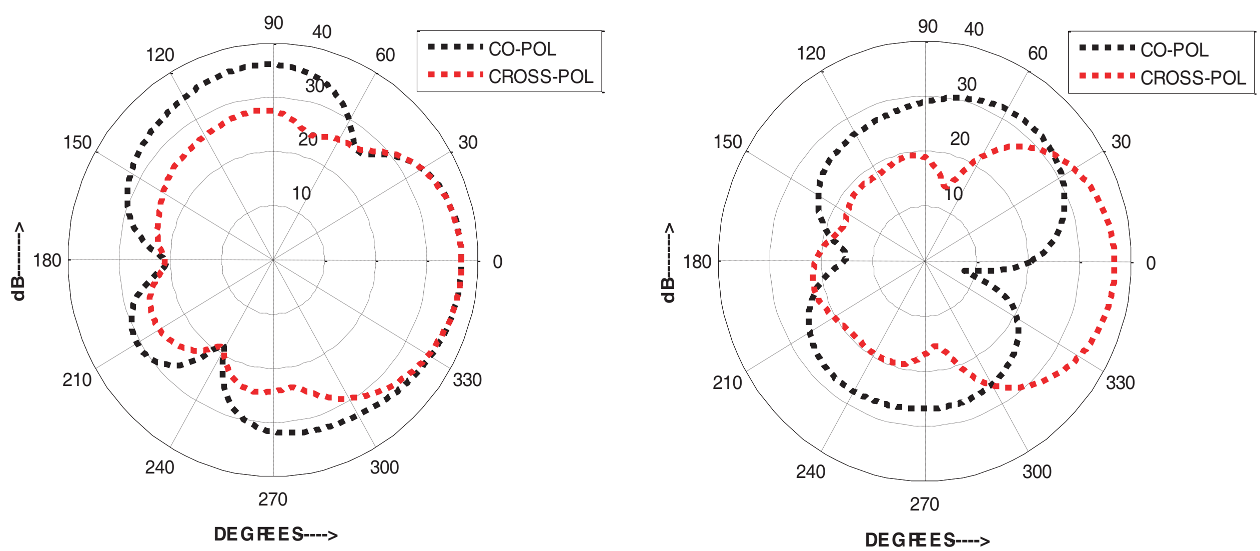
(a) (b)

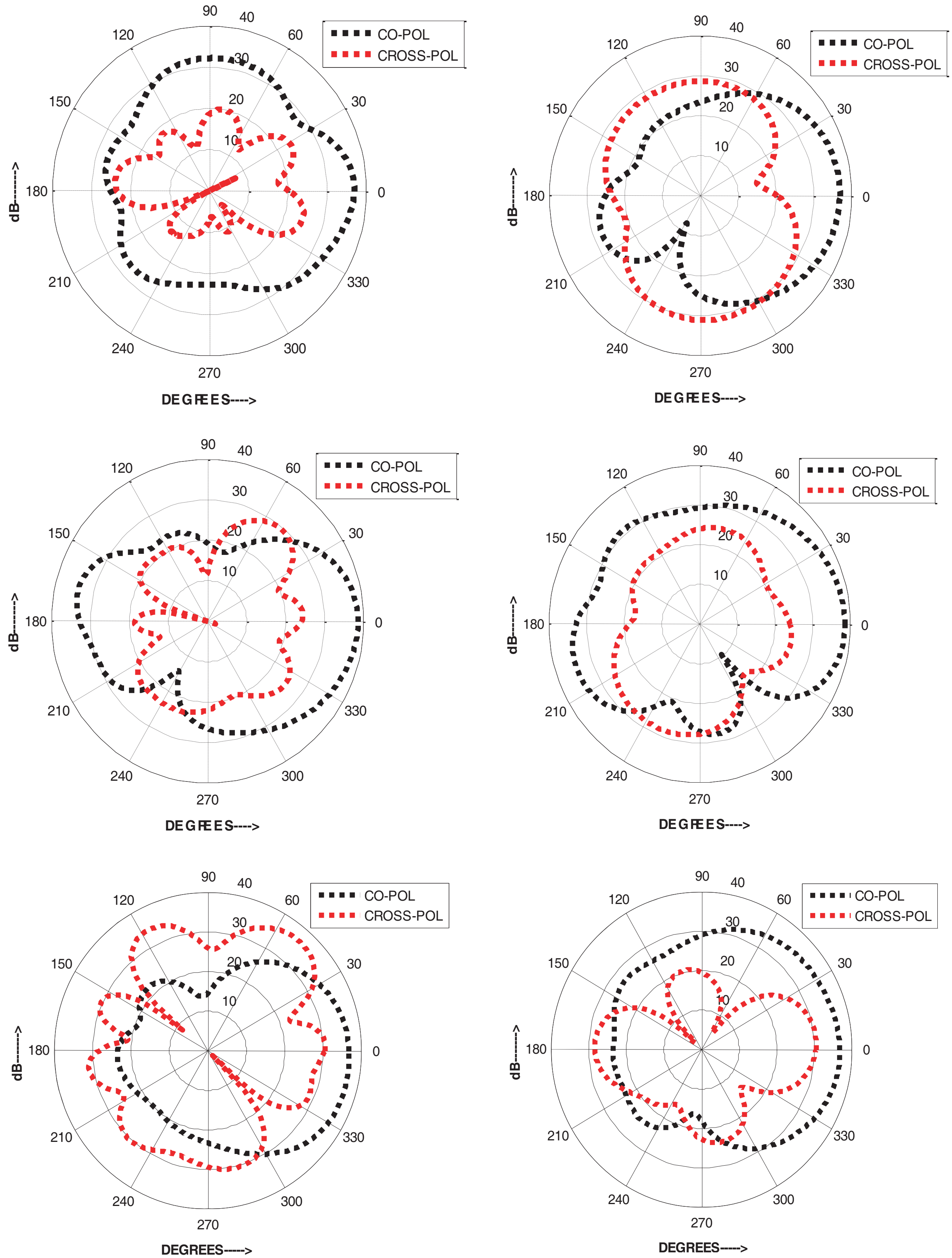
Figure 12. Photograph of the fabricated MIMO antenna. (a) Top layer. (b) Bottom layer.



4.75GHz 5.89GHz 6.74 GHz 8.25GHz 9.82GHz

Figure 13. Surface current distribution at various resonant frequencies.




CO-POL
CROSS-POL
90
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30
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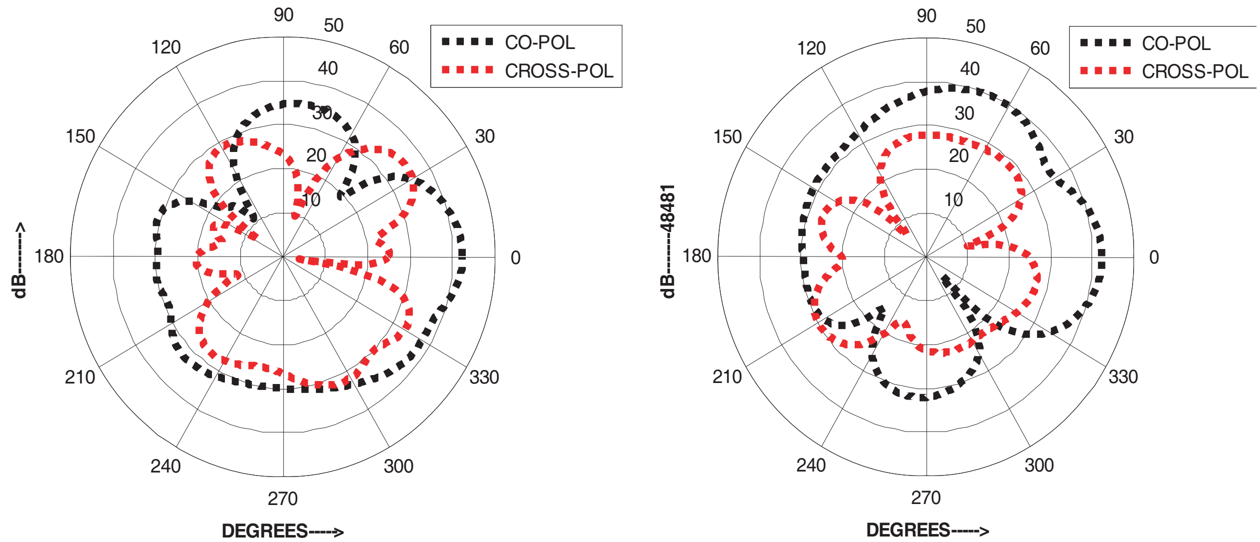

(a) E-plane (b) H-plane

Figure 14. Co polarization and cross polarization patterns of the proposed MIMO antenna at 4.75 GHz, 5.89 GHz, 6.74 GHz, 8.25 GHz and 9.82 GHz.

Table 2. Comparison with existing antennas in the literature.

Reference	**Dimensions in mm**	**Distance between the elements**	**Mutual coupling in (dB)**
Ref. [21]	66×66	$0.1\lambda_o$	-33
Ref. [22]	35×38	$0.05\lambda_o$	-16
Ref. [23]	50×13	$0.25\lambda_o$	-15
Ref. [24]	60×50	$0.53\lambda_o$	< -20
Ref. [25]	60×40	$0.07\lambda_o$	< -20
Proposed	64×35	$0.032\lambda_o$	-32.79

5. CONCLUSION

In this paper, a compact multi-band MIMO antenna is proposed. The proposed MIMO antenna resonates at 4.75 GHz, 5.89 GHz, 6.74 GHz, 8.25 GHz and 9.82 GHz. The mutual coupling is reduced by −23.78 dB at 4.75 GHz, −25.71 dB at the resonant bands 5.89 GHz, −29 dB at 6.74 GHz, −32.79 dB at 8.25 GHz and −21.5 dB at 9.82 GHz, respectively. It is suitable for Radar system applications, WLAN applications, and UWB (Ultra Wide Band) applications. The key parameter for evaluation of MIMO antenna is ECC. This parameter is calculated, and results are good. The performance of the proposed MIMO antenna is verified in terms of VSWR, reflection coefficient and mutual coupling and radiation pattern.

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