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Design and Experimental Analysis of Dual-Port Antenna with High Isolation for 5G Sub 6 GHz: n77/n78/n79 and WiFi-5 Bands Applications

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ABSTRACT
The work details the development of a two-port arc-shaped Multiple-Input-Multiple-Output (MIMO) antenna with enhanced isolation characteristics. The proposed dual-port MIMO provides a wide impedance bandwidth of 3.28–5.93 GHz and a maximum isolation of 27 dB between elements in the operating frequency band. A reduced ground plane is utilized to obtain the wideband characteristics for the proposed antenna. The major applications covered by the antenna include sub-6 GHz: n77/n78/n79 and WiFi-5 bands. The important MIMO parameters such as Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG), Diversity Gain (DG) and Total Active Reflection Coefficient (TARC) are presented to estimate the performance of the developed antenna in the MIMO environment.

KEYWORDS
5G; arc-shaped; defected ground structure; isolation; MIMO; WiFi

1. INTRODUCTION

The current advanced wireless communications need enormous and huge data rates with ease of implementation and high Quality of Service (QoS). The accelerated evolution appertaining to wireless communication systems ameliorates the necessity and demand for antennas of smaller size, multi-band applications. MIMO technology in current modern wireless communications is significant, utilizing propagation in a multipath environment to improve the data rates [1]. The main important objectives of MIMO technology are Quality of Service and improved spectral efficiencies [2]. However, the main design challenge in the MIMO technology is the coupling developed between the antennas, owing to the lesser spacing between the antennas.

Hence, maintaining the device size to be compact and at the same time attaining higher isolation is the most difficult task in any MIMO system. Hence, various procedures are proposed in the present literature to get better the isolation between the antennas and also keep the antenna size compact keep because of the current size-reduced wireless devices. The different ways to nullify coupling or enhance isolation in this technology are neutralization line [3], decoupling methods [4], utilization of meta-materials [5], incorporating pattern diversity [6], utilization of matching network [7], etc.

Most of the current applications require the antennas to be used for multiple applications, thus arising the need for multiband antennas. A multiband antenna is utilized in wireless applications simultaneously without the need for additional circuitry and components. The multiple applications or use of various wireless networks can be done using a single antenna, by designing it as a multiband antenna [8]. The design and development of broadband or wideband antennas is another method to be used for multiband applications [9,10]. In [11], a novel semi-circular antenna with a ground defect structure, developed using characteristic mode analysis (CMA), is presented. The current work focuses on the design and development of a new arc-shaped multi-element antenna with dual-port that can be used to cover various applications such as 5G Sub-6 GHz: n77/n78/n79, WiFi-5 is designed and developed. The antenna gives a reduced coupling of -27 dB making it suitable for present 5G bands. This is achieved by the inclusion of novel elliptical slots on the ground plane and parasitic stubs kept near the radiating elements. Finally, the utility of the antenna in a MIMO environment is evaluated by discussing different parameters such as ECC, CCL, MEG, DGandTARC. Section 2 details the design procedure and antenna development, Section 3 discusses the obtained results, and Section 4 gives the work's conclusion.

2. PROCESS OF ANTENNA DESIGN

2.1 Antenna Design

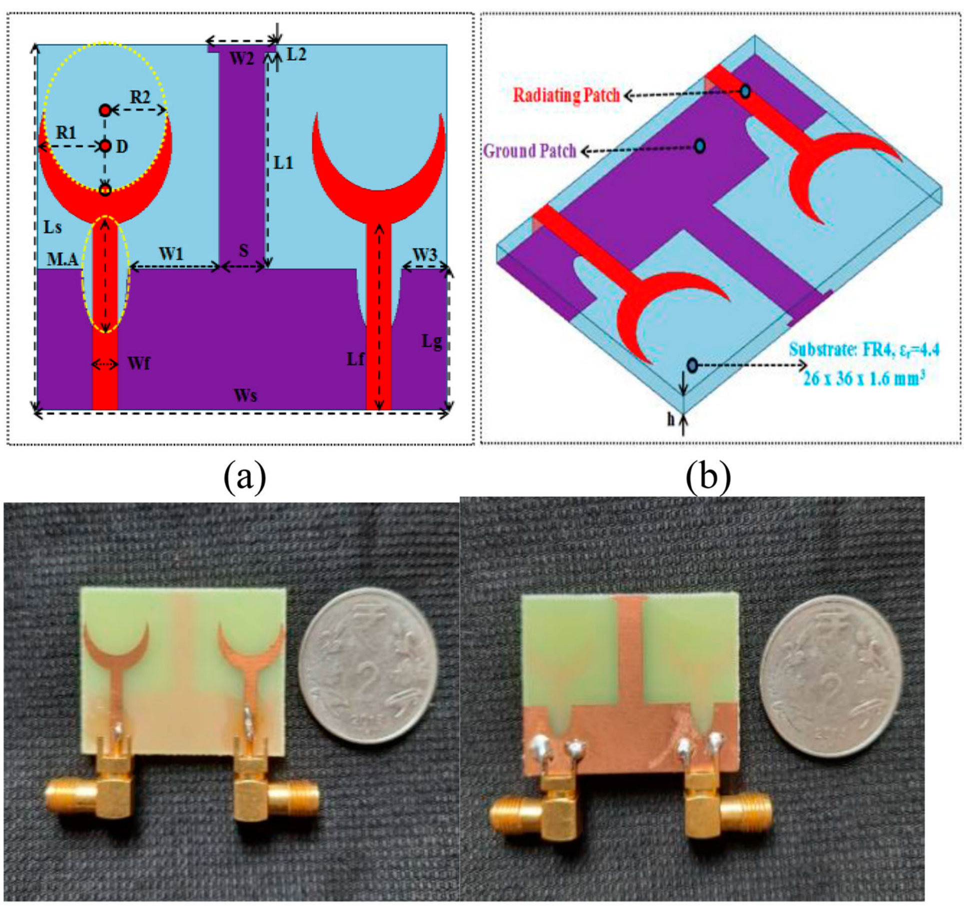
The considered radiating structure is presented in Figure 1. The antenna is arc-shaped and taken on a semi-circular disc. The final radiating element is made by slicing and removing a circular disc of the "R2" radius from one more disc of the "R1" radius. As shown in Figure 1, the antenna is replicated so that a two-port MIMO antenna structure is obtained. The antenna is fed using a microstrip line and its dimension W_f is taken as 2.2 and final device is constructed using a cheaper FR4 substrate of dielectric constant value 4.4 with a height of 1.6 mm. To achieve wide impedance bandwidth and better isolation characteristics, a reduced ground plane is considered with a vertical stub at the centre of the bottom side, as given in Figure 1(a). The length and width of the stub are taken as L_1 and S, respectively. Another patch is added at the top side of the stub with length and width as L_2 and W_2, respectively. At the antenna feed location, the major axis (MA) of an elliptical slot is taken as the length shown in the figure. The angular perspective of the proposed antenna is given in Figure 1(b). The dimensions of various important parts of the considered design are given in Table 1. The upper and bottom sides of the fabricated prototype are presented in Figures 1(c) and (d), respectively.

Table 1: Antenna dimensions

Parameter	Dimension (mm)	Parameter	Dimension (mm)
Ls	26	W1	8
Ws	36	*W2*	6
Lf	13.2	*W3*	4
Wf	2.2	*L1*	15.5
Lg	10	*L2*	0.5
R1	5.9	*S*	4
R2	5.9	*MA*	10
D	8	H	1.6

2.2 Proposed Antenna Evolution

The final design is arrived at by taking different evolution steps, as presented in Figure 2. In the first step of



(a) (b)

(c) (d)

Figure 1: (a) Parameters of the proposed antenna; (b) isometric view of the proposed antenna; (c) & (d) The top and bottom layers of the fabricated prototype

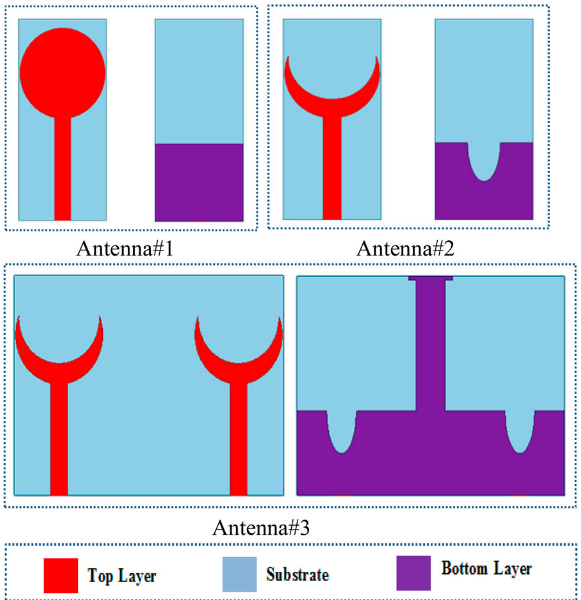


Figure 2: The proposed antenna evolution process

the design process, a complete circular disc with a defective ground structure and microstrip feed arrangement is considered and this antenna is defined as Antenna 1. A semi-circular arc-shaped antenna is developed from the complete circular disc Antenna 1 and also elliptical slot is incorporated at the bottom side of the antenna leading to a second evolution antenna known as Antenna 2. The MIMO version of the proposed antenna with a central stub is named Antenna 3 and is depicted in Figure 3. The S-parameters of both steps are provided in Figure 3, indicating that Antenna 1 gives a narrow band in the bandwidth of 4.5–7 GHz. Antenna 2 operates from 3.8 to –5.1 GHz, still which is not the desired band. The final proposed antenna with a stub at the centre of the bottom plane, which is termed Antenna 3 resonates from 3.28 to –5.93 GHz. The mutual coupling of the final designed antenna is also given in Figure 3, which is well below -20 dB throughout the band and a minimum coupling of -27 dB is observed at 4.5 GHz.

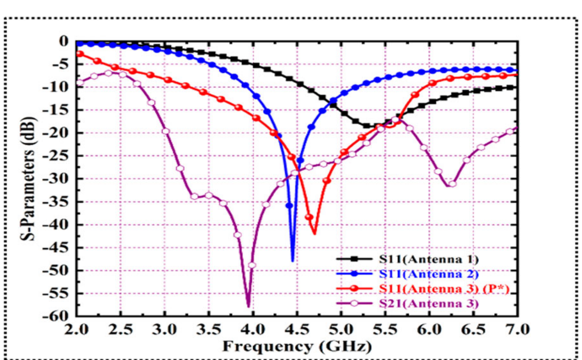


Figure 3: S-Parameters of the proposed antenna evolution process

2.3 Parametric Analysis

The antenna performance mainly depends on the dimensions of the parameters that are chosen in the design of the proposed structure. The operational performance of the designed antenna is dependent on various antenna

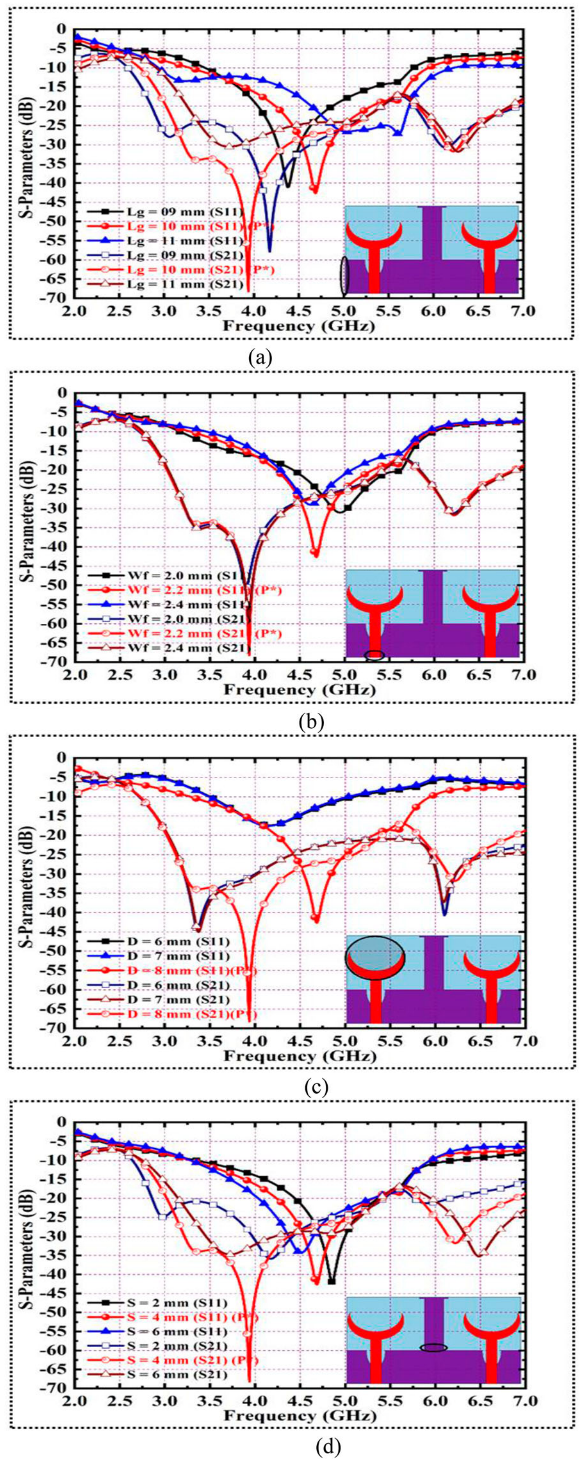


Figure 4: Parametric analysis of the proposed antenna: (a) Ground length (Lg); (b) Feed width (W_f); (c) Subtracted distance (D) and (d) Stub width (S).

dimensions, which can be predicted using parametric analysis. Parametric analysis is used to determine which dimensions or parameters of the proposed antenna affect the radiating and resonant characteristics of the antenna. In Figure 4(a), the ground length Lg varies for different dimensions and the antenna operates for Lg = 10 mm in the desired operating frequency range, i.e. 3.28–5.93 GHz, and also better insulation characteristics are observed. In Figure 4(b), the feed width W_f varies for different values and $W_f = 2.2$ mm, a better reflection coefficient value with the required frequency range of operation is obtained.

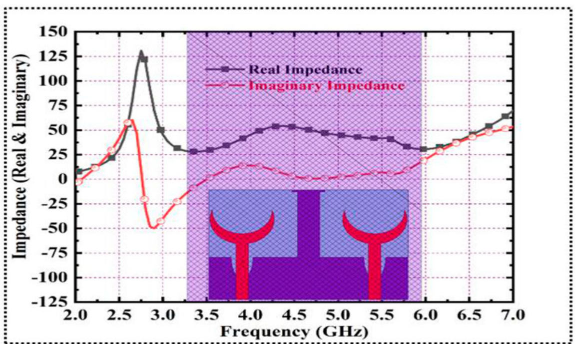


Figure 5: Impedance characteristics of the proposed antenna

Another important parameter for which the parametric analysis is performed is the disc diameter parameter "D" as shown in Figure 4(c), and the desired reflection coefficient values are obtained for D = 8 mm. Also, for this specific value of the diameter, the isolation value is better than the other values of the diameter. Another parameter, taken for the parametric analysis is the stub width "S", as shown in Figure 4(d) and S = 4 mm gives the desired operating band and better return loss values than the other selected values.

The real and imaginary impedances of the considered design are given in Figures 5 and 6, from which it is identified that the real value of the impedance is near 50 Ω and the imaginary impedance is near 0 Ω in the operating band of the antenna. This clearly shows the good impedance matching properties of the antenna in the band 3.2–5.9 GHz.

2.4 Surface Current Distribution

The surface current distributions of the proposed antenna at various frequencies, viz; 3.8, 4.8, 5.2 and 5.6 GHz are given in Figure 6, and it is observed that in the entire desired bandwidth of the antenna, a major portion of the current is distributed on the upper layer of the antenna, which ensures that the developed antenna is a

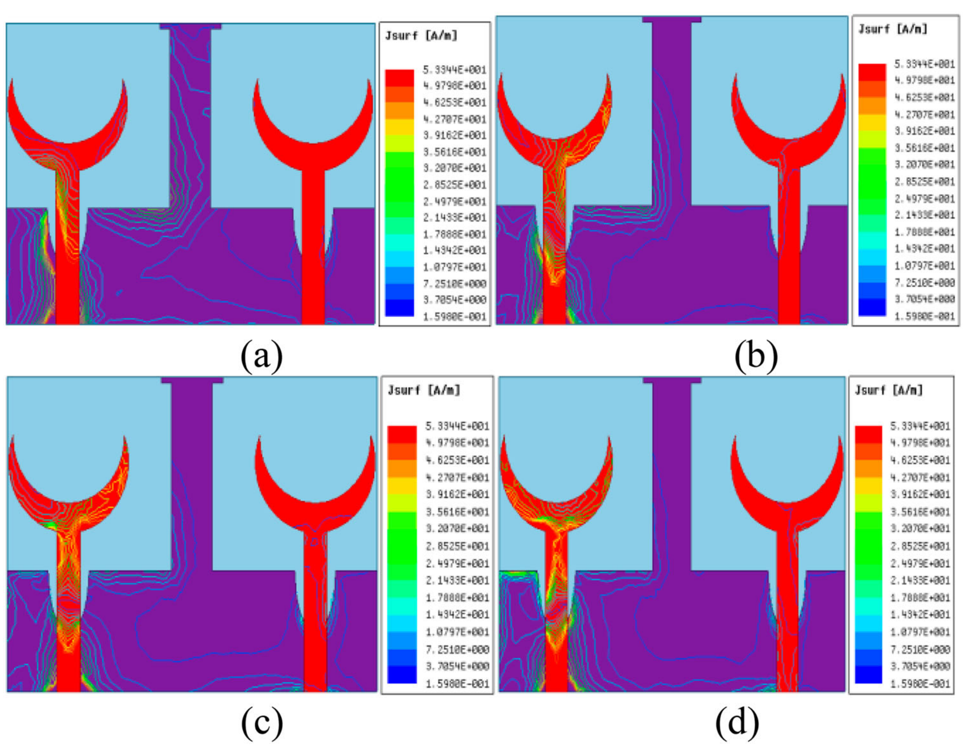


Figure 6: Surface current distribution of the proposed antenna when Port 1 is excited; (a) at 3.8 GHz; (b) 4.8 GHz; (c) at 5.2 GHz and (d) at 5.6 GHz

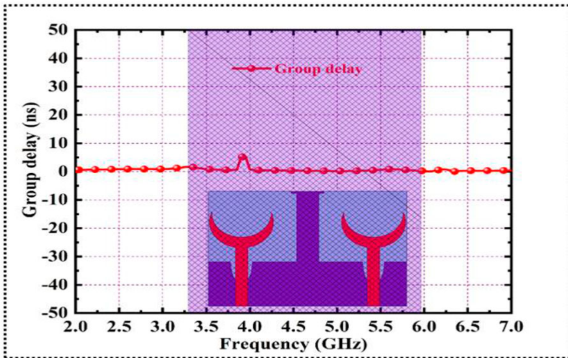


Figure 7: Group delay characteristics of the proposed antenna

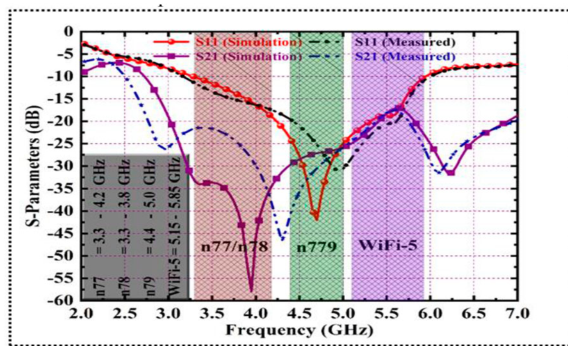


Figure 8: Simulation and measured S-parameters of the proposed antenna

good radiator in the considered frequency band. Also, a minimum amount of surface current is observed on the bottom plane of both antennas. This is very much required to control the coupling between the two antennas, as the current on the bottom plane is the primary factor in influencing the isolation characteristics between the proposed or designed antennas [12]. The stub on the ground plane plays a key role in controlling the surface current on the ground plane, which obstructs the surface current flow from one antenna to the other.

2.5 Time Domain Analysis

Group delay characteristics of the developed antenna are plotted in the frequency range 2–7 GHz, as given in Figure 7. Figure 7(a) gives the input transmitted time pulse and Figure 7(b) gives the time analysis at different frequencies. From the obtained curves, it is observed that a minimum delay around 5 nS is observed near 4 GHz band and in the entire remaining band almost no delay is observed.

3. RESULTS AND ANALYSIS

3.1 S-Parameters

Figure 8 gives the simulated and measured S-parameters of the proposed model, whose values are in good agreement. The final designed MIMO model operates in the frequency band of 3.28–5.93 GHz. This obtained frequency range covers the aimed 5G sub-bands with good reflection coefficient and isolation characteristics. For n77/n78 bands, the simulated isolation is 33 dB, whereas the measured isolation is more than 23 dB. Similarly, for band n79, the isolation values exceed 26 dB for both simulated and measured results. The observed isolation values are far better than 17.5 dB for the WiFi band, as presented in the Figure. Table 2 contains the complete values.

Table 2: Comparision between simulation and measured results of the proposed antenna

Simulation (or) Measured /Parameters		Proposed Antenna (Simulation)	Proposed Antenna (Measured)
Impedance Bandwidth S_{11} *(GHz)*		**3.28–5.93**	**3.11–6.01**
Isolation │ ***S21*** │ ***(dB)***	***n77/n78 (3.3 - 4.2 GHz)***	**≥ 33**	**≥ 23**
	n79(4.4 - 5.0 GHz)	**≥ 27**	**≥ 26**
	WiFi-5(5.15 - 5.85 GHz)	**≥ 17.5**	**≥ 18**
MIMO Performance	***ECC***	**≤ 0.01**	**≤ 0.01**
	DG (dB)	**≥ 9.99**	**≥ 9.99**
	MEG (dB)	**≤ −3.1**	**≤ −3.2**
	TARC (dB)	**≤ −10**	**≤ −10**
	CCL (bits/s/Hz)	**≤ 0.025**	**≤ 0.020**

3.2 Radiation Characteristics

Important parameters such as radiation efficiency and gain are essential in evaluating the radiation characteristics of the proposed design in the intended frequency band. The attained gain and efficiency of the MIMO model are plotted in Figure 9. The MIMO model designed in the current work gives a peak efficiency of 98% in the operating range and also a peak gain of 4.1

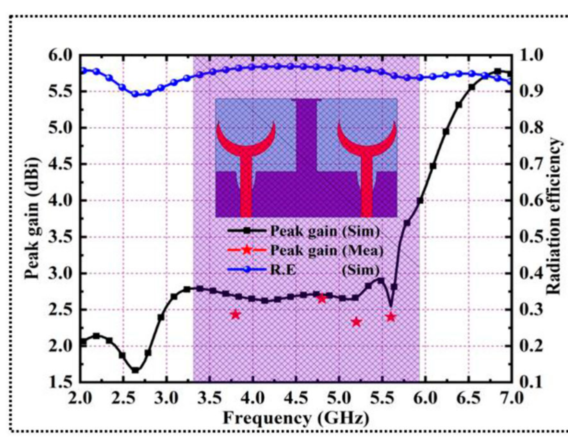


Figure 9: Radiation efficiency and peak gain of the proposed antenna

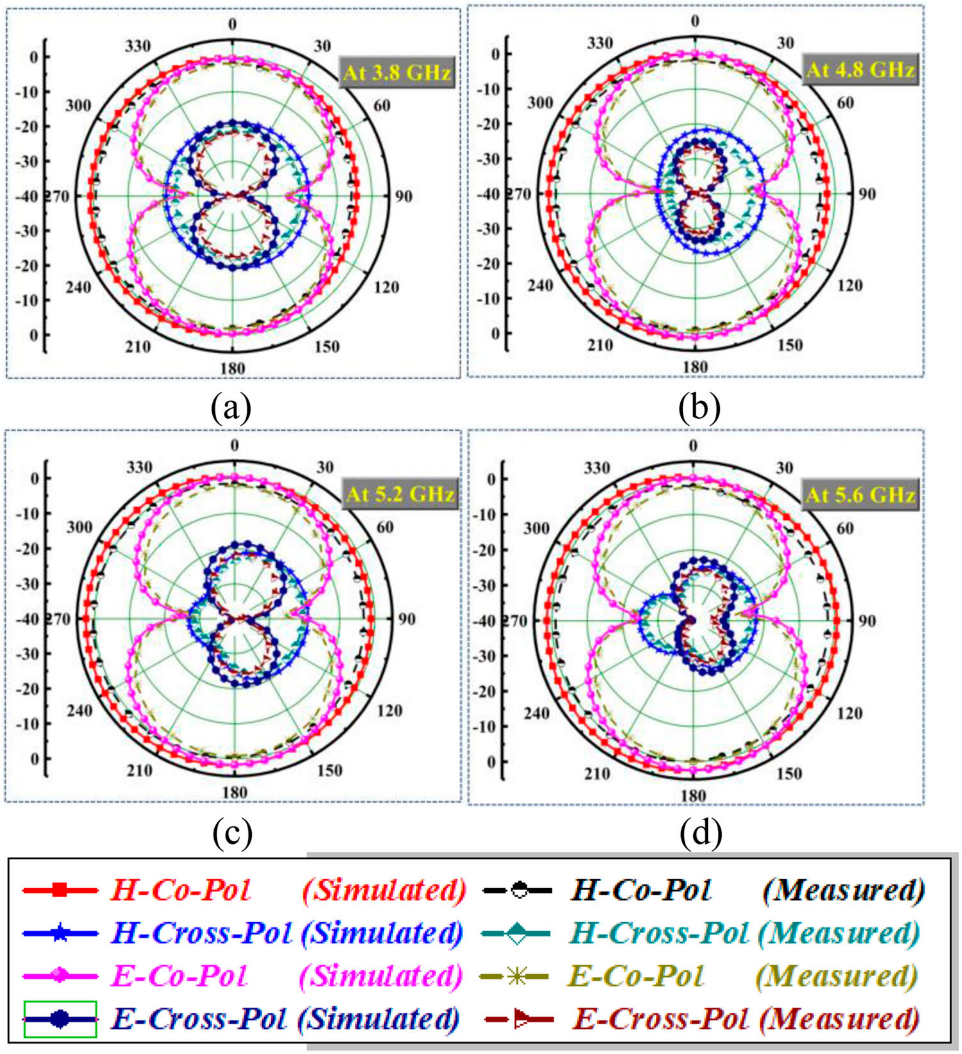


Figure 10: Simulation and measured H & E far-filed patterns at various frequencies of the proposed antenna.

dBi. The obtained gain and efficiency values make the antenna suitable for the defined 5G sub-6 GHz applications. Almost flat gain is observed in the operating range 3.5–5.5 GHz, which is another important feature of the proposed antenna. The radiation patterns of the MIMO model at 3.8, 4.8, 5.2 and 5.6 GHz are presented in Figure 10. The snapshots of the reflection coefficient and radiation pattern measurement are given in Figure 11. The radiation patterns obtained on H-plane are observed to be omni-directional, whereas dumbbell-shaped patterns are observed on the E-plane and also the patterns are seen to be stable in the intended operating frequency of the antenna.

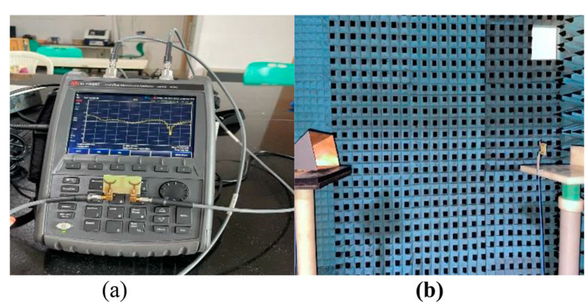


Figure 11: Snapshots of measurement of (a) return loss (b) radiation pattern

3.3 MIMO Characteristics

Antenna diversity performance will be understood by looking at diversity parameters such as ECC, DG, MEG, CCL and TARC as they play a key role when engaged in the MIMO environment. For standard MIMO systems, the ECC can be calculated using Eq. (1) and its preferred value is below 0.5 in a multi-antenna environment. The value of the correlation coefficient is observed well below 0.01 in the working band as shown in Figure 12(a), which is a very good value for the antennas deployed in MIMO devices. Also, from the figure, it is observed that the measured ECC well matches the simulated ECC. The Diversity Gain (DG) of the antenna is almost near 10 dB as depicted in Figure 12(b), thus making the MIMO model a good candidate in a diversified element environment.

MEG of the developed MIMO model can be computed using Eq. (2) and its value is far less than −3 dB in the intended band for the considered antenna as given in Figure 12(c). Similarly, the CCL value must be well below 0.4 b/s/Hz for improved performance under MIMO conditions, which can be calculated using Eq. (3) and for the considered MIMO antenna, the simulated value is less than 0.025 b/s/Hz as depicted in Figure 12(d) and the measured value is less than 0.020 b/s/Hz in the intended band of the antenna. TARC is another parameter, relating to the overall reflected power and input applied power in a multi-element model, which can be computed using Eq. (4) [11]. The TARC values are $<$ 10 dB in the considered frequency band as shown in Figure 12(e), which is the same case for both simulated and measured results hence the proposed antenna is one of the most suitable antennas in the MIMO environment. A detailed comparison of theoretical and measured values is given in Table 2.

$$ECC_{S-Parameters} = \frac{|S_{ii}^{*}S_{ij} + S_{ji}^{*}S_{jj}|^2}{(1-(|S_{ii}|^2+|S_{ij}|^2))\,(1-(|S_{jj}|^2+|S_{ij}|^2))} \tag{1}$$

$$MEG_i = 0.5\eta_{i,rad} = 0.5\left[1-\sum_{j=1}^{M}|S_{ij}|^2\right] \tag{2}$$

$$C_{Loss} = -log_2 det(\alpha^R) \tag{3}$$

where

$$\alpha^R = \begin{bmatrix}\alpha_{ii} & \alpha_{ij}\\ \alpha_{ji} & \alpha_{jj}\end{bmatrix}$$

$$\alpha_{ii} = 1-(|S_{ii}|^2+|S_{ij}|^2);$$

$$\alpha_{ij} = -(S_{ii}{}^{*}S_{ij}+S_{ji}{}^{*}S_{jj});$$

$$\alpha_{ji} = -(S_{jj}{}^{*}S_{ji}+S_{ij}{}^{*}S_{ii});$$

$$\alpha_{ii} = 1-(|S_{jj}|^2+|S_{ji}|^2).$$

$$TARC = \sqrt{\frac{|(S_{11}+S_{12}e^{j\theta})^2| + |(S_{21}+S_{22}e^{j\theta})^2|}{2}} \tag{4}$$

The designed MIMO performance in terms of antenna size, impedance bandwidth (IBW), obtained isolation, maximum gain, ECC, and TARC is compared with different types of available antennas in the existing literature and is presented in Table 3. References [13] to [22] presented in Table 3 represent various MIMO antennas with different sizes, isolations values and gain values.

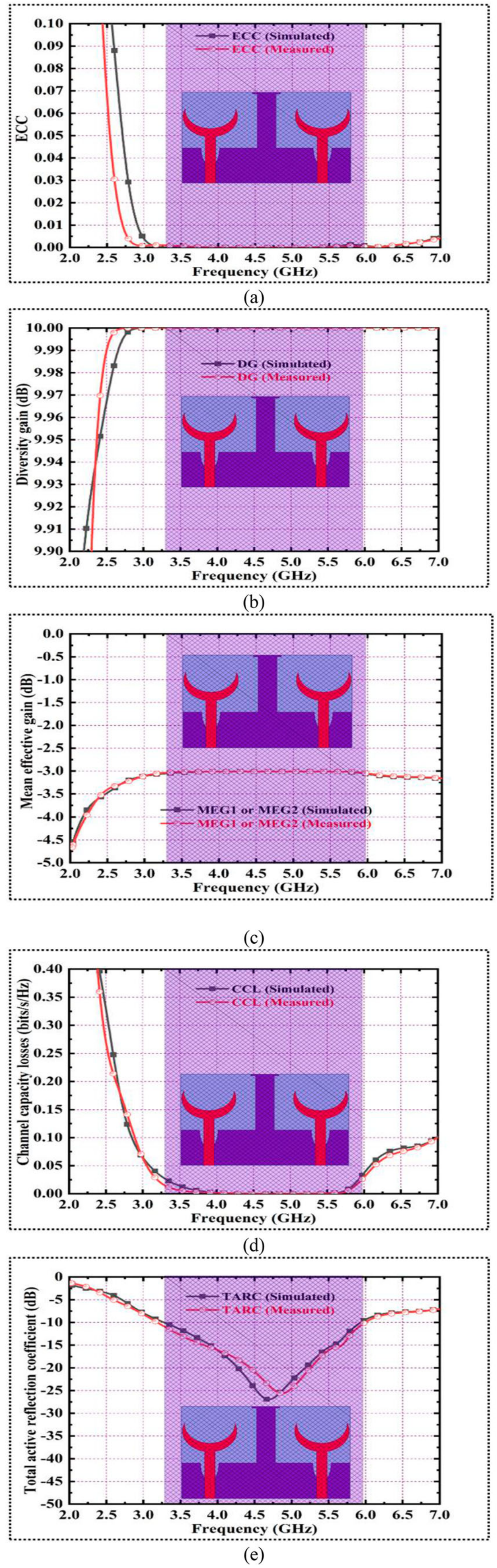


Figure 12: Simulation and measured diversity performance characteristics of the proposed antenna; (a) ECC; (b) DG; (c) MEG; (d) CCL and (e) TARC

Table 3: Comparison with available antennas in the literature

Ref. No	Antenna size (mm^2)	IBW (GHz)	Isolation (dB)	Peak gain (dBi)	ECC	TARC (dB)
#13	70 × 46	1.7 −3.8	> 15	2–5	< 0.02	NA
#14	50 × 50	2.25 −6.3	> 16	4.0	< 0.005	< −10
#15	50 × 25	3.22-5.64	> 20	NA	< 0.1	NA
#16	32 × 22	3.0-7.7	> 20	3	< 0.04	< −10
#17	37 × 30	3.3-4.2	> 20	3	< 0.1	< −15
#18	40 × 40	4.7-5.1	> 25	2.8	< 0.1	NA
#19	68 × 136	3.4–3.6	> 35	2.4	< 0.01	< −40
#20	95 × 2	3.3-5.0	> 15	3.3	< 0.2	NA
#21	40 × 47.5	2.1-2.9 5.13-5.84	> 20	4.7	< 0.01	NA
#22	38 × 25	3-6.5	> 35	6.2	< 0.01	< −10
#*P*∗	36 × 26	3.28-5.9	> 20	4.1	< 0.01	< −10

Compared to the existing antennas in the literature, the proposed MIMO model gives better IBW and isolation and at the same time with smaller dimensions.

4. CONCLUSION

The paper describes the development of an arc-shaped dual-port MIMO antenna. The proposed antenna gives enhanced isolation in the operating band 3.28 GHz to 5.93 GHz without using any matching network, neutralization line or decoupling structure. The developed MIMO model is well suited to the current 5G sub-6 GHz wireless services owing to its enhanced isolation with better reflection coefficient, efficiency and peak gain values. Moreover, the dimensions of the designed antenna are very compact so that it can be simply integrated into wireless gadgets and devices without occupying much space.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the author(s).

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