Isolation enhancement of four port multiple-input multiple-output antenna for sub-6 GHz 5G communication

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ABSTRACT

For 5G communication, this research suggests a small, broad band, 4-port multiple-input multiple-output (MIMO) antenna with an impedance bandwidth of 2.0 GHz (or 3.0-5.0 GHz). The n77, n78, and n79 bands are covered. The single antenna is realized by inserting the stubs and creating the 'HI' slot on the rectangle patch with the defect in the ground plane, using FR-4 substrate. Next, four MIMO antennas are built utilizing the reference antenna. Due to mutual interaction, implementing MIMO systems presents a substantial challenge: achieving good isolation between antenna parts in the confined space. To increase isolation with decoupling procedures, the four antennas are placed orthogonally to one another. Because the antennas are positioned orthogonally, the MIMO antenna has an isolation of 28.0 dB. The diversity gains (DG) and envelop correlation coefficient (ECC) are used to analyze the recommended antenna's diversity performance characteristics, and the results show that the values are 9.99 dB and 0.0003, respectively. The simulated S-parameters have been compared with orthogonal and adjacent positions of quad port MIMO antenna. Anritsu MS2037C VNA is used to measure the parameters, and HFSS software is used to simulate it.

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1. INTRODUCTION

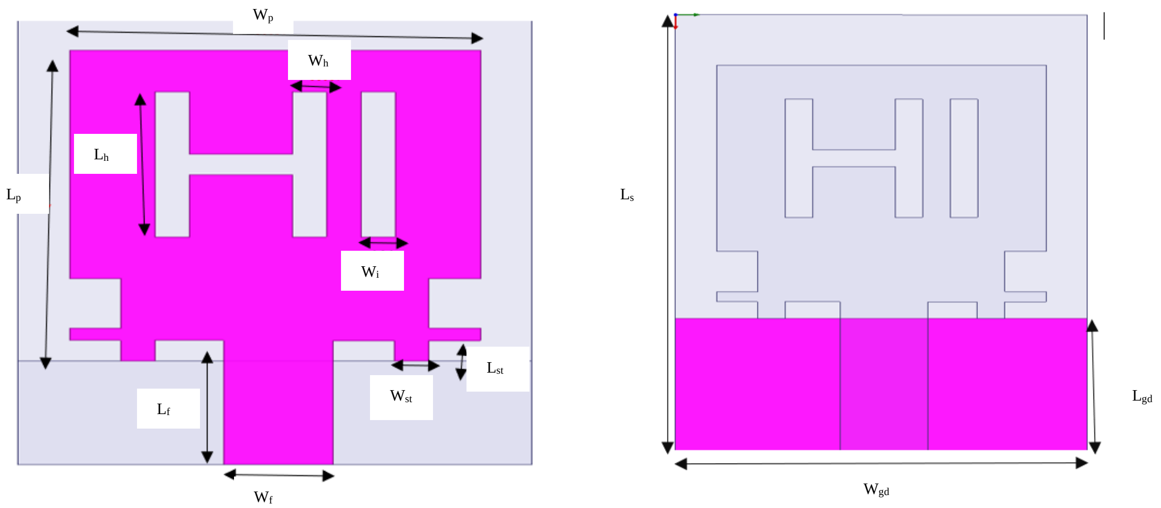
Modern mobile communication systems require high capacity, low latency, and high data rates. These requirements can be fulfilled through 5G technology, which offers significant improvements in network performance. In a 5G system, multiple-input multiple-output (MIMO) antennas are used to attain better throughput [1]. Isolation and envelop correlation coefficient (ECC) reduce the MIMO antenna system's efficiency since mobile terminals are so small. There are few methods to enhance isolation in situations with many antennas, such as electromagnetic band gap (EBG), metamaterials, neutralization lines, and defective ground structure (DGS). The rectangular quad port MIMO antennas are positioned adjacent on a FR4 substrate, and isolation is reduced using the stub method. The stubs are kept between antennas [2]. Slot-coupled microstrip antenna with circular polarization for wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX), and Indian satellite (INSAT) applications [3]. To improve isolation, a hook-shaped antenna and an elliptical slot at the ground plane were combined [4]. The mode cancellation method is used to reduce the synthetic aperture radar (SAR) of 8-port MIMO antenna and it is fed with micro strip line [5].

Another cost-effective MIMO antenna system is designed for smartphones. This system is made from FR4 substrate with 0.8 mm thick. This design encourages pattern variation [6] for isolation reduction. The characteristics modes method is used for reduction of mutual coupling [7]. In [8], the utilization of split ring resonators (SRRs) in ultra-wideband (UWB) antenna design is explored. An initial UWB antenna designed for the 2.30–11.50 GHz frequency band is modified by incorporating two square SRR cells. Optimized for maximum efficiency is an eight-element MIMO antenna system [9] operating at 3.50 GHz monopole inverted L-shaped with a 450 MHz measured bandwidth.

A 4-port MIMO antenna array [10] with two identical two-element arrays that are excited by a T-junction power combiner/divider is intended for 5G applications. The array elements use rectangular slotted patch antennas, and defective structures with zigzag, circular, and rectangular slotted patterns are present on the ground plane to improve radiation characteristics. By mm-wave 5G requirements, the design operates efficiently in the 25.50–29.60 GHz frequency band and achieves a peak gain of 8.30 dBi. Significantly, by reducing the ECC, polarization between neighboring radiators guarantees good isolation. The industrial, scientific and medical (ISM) band four-element MIMO antenna [11], on the other hand, is designed to function in the 2.40–2.48 GHz frequency range. The design also incorporates a cross-shaped radiator slot, an expanded ground branch, and electromagnetic band gaps to promote isolation between antenna sections. Time-averaged simultaneous peak SAR is a novel metric that was presented in [12] to assess exposure to electric fields in MIMO operations where there may be large changes in the electric field phase and power allocation from various antennas. Using machine learning and artificial intelligence approaches, massive MIMO antenna is created with superior performance than traditional design methods [13], [14]. The design achieved dynamic polarization diversity with high purity by utilizing branch-line couplers, integrated baluns, and orthogonally positioned printed dipoles [15]. Quad port M-array MIMO antenna is designed using split ring resonators [16].

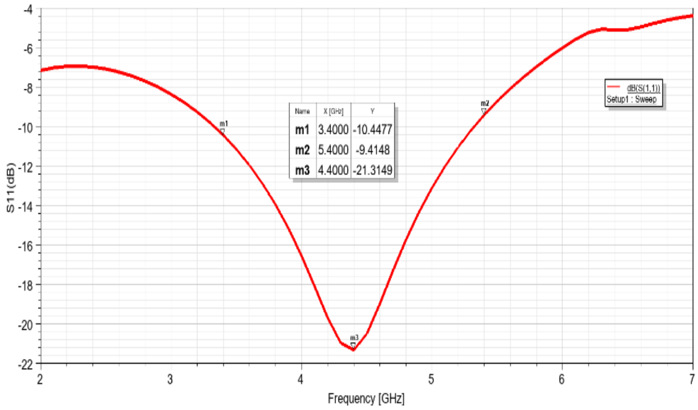
2. SINGLE ANTENNA DESIGN

A rectangular microstrip antenna is first built with an FR-4 substrate, 1.60 mm thickness, and a relative permittivity of ε_r=4.40. It has two 1×1 mm^2 identical stubs attached to it [17]. The single patch antenna measurement is 23×15×1.6 mm^3 and has a 15×5 mm^2 partial ground. The front, rear, and partial ground views of a single patch antenna are displayed in Figures 1(a) and (b). It is energized by using a microstrip feedline. The H and I slots improve the electrical length of patch and reduce the patch size. Figure 2(a) shows a single-element antenna's simulated reflection coefficient (S_{11}), which is -20.7 dB. Flow chart of proposed antenna is shown in Figure 2(b). It resonates between 3.4 and 5.4 GHz with an impedance band width in the range of 2.0 GHz using a -10 dB reference. Table 1 displays the optimum design parameters of reference antenna. MIMO uses multipath propagation to boost communication efficiency, and data throughput without using more bandwidth or transmit power.

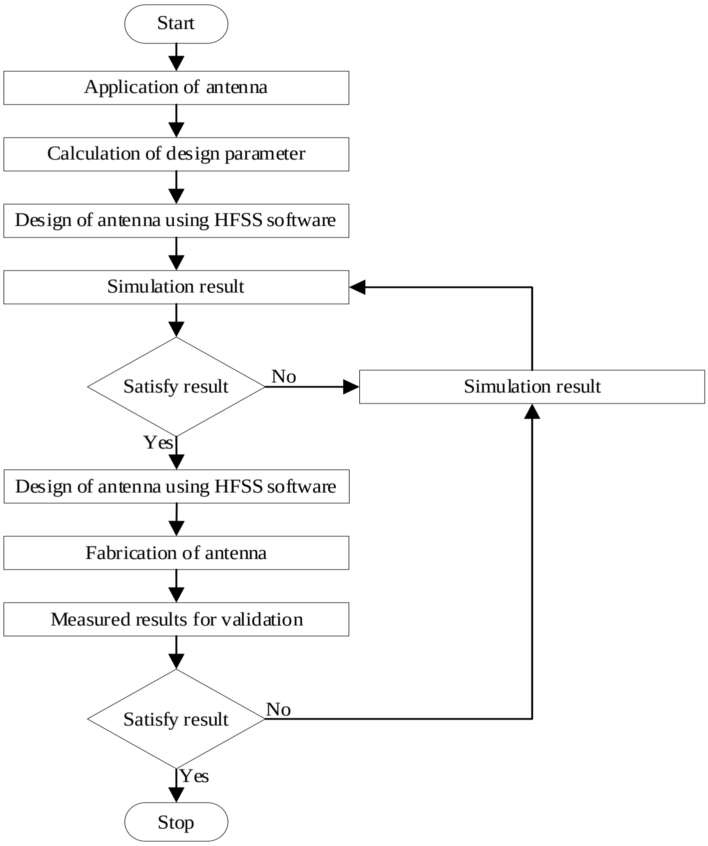


(a) (b)

Figure 1. Geometry of single antenna; (a) front and (b) rear view



(a)



(b)

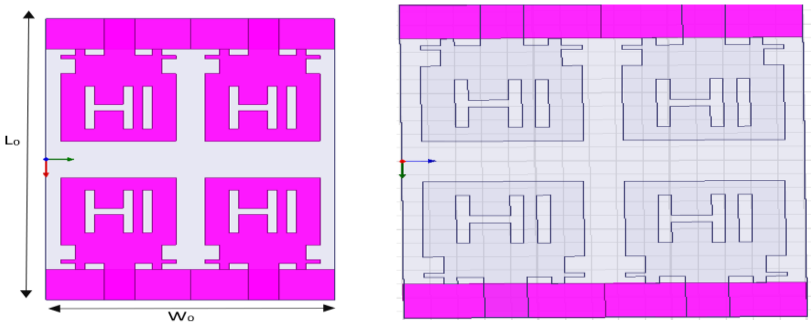
Figure 2. Reference antenna; (a) S_{11} and (b) flow chart

Table 1. Reference single patch antenna dimensions (mm)

Parameter	L_p	W_p	W_h	L_h	L_f	W_i	L_{st}	L_s	W_{st}	W_{gd}	W_f	L_{gd}
Value (mm)	14	12	1	7	6	1	1	23	1	15	3	5

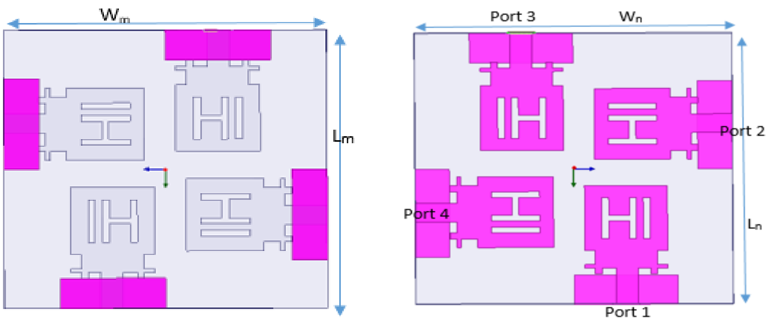
3. MULTIPLE-INPUT MULTIPLE-OUTPUT ANTENNA DESIGN WITH FOUR PORTS

The quad port MIMO antenna with an HI slot was designed using the FR-4 substrate, which has a height of 1.60 mm is shown in Figure 3 without orthogonal. Figure 3(a) displays the substrate dimensions of the MIMO antenna without an orthogonal position, which are L_o=46 mm and W_o=30 mm. The orthogonal position of MIMO antenna is shown in Figure 4. Figure 4(a) displays the substrate dimensions with the orthogonal position, which are L_m=46 mm and W_m=46 mm. In both of the scenarios depicted in Figures 3(b) and 4(b), the defective ground is of the same size.



(a) (b)

Figure 3. Four ports MIMO without orthogonal (antenna 1); (a) front and (b) rear views

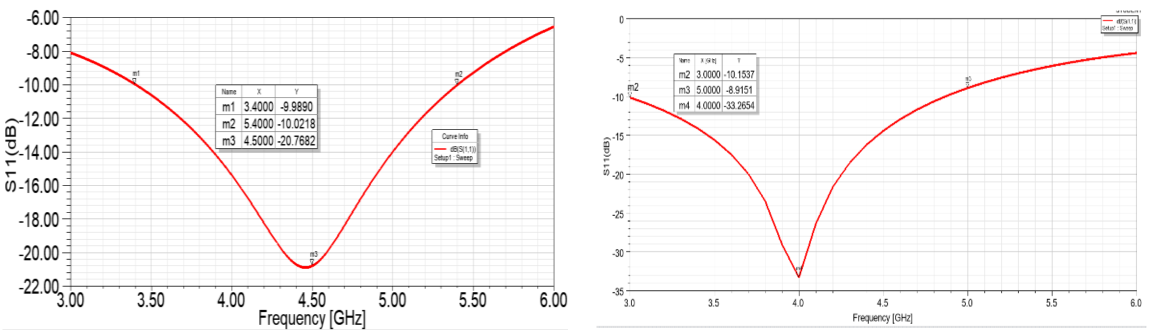


(a) (b)

Figure 4. MIMO antenna with orthogonal (antenna 2); (a) front and (b) back views

4. RESULTS AND DISCUSSION

In quad port MIMO antenna, the four antennas are arranged adjacent to each other, and they resonate from 3.4 to 5.4 GHz; the maximum S_{11} value is -20.7 dB at 4.5 GHz, according to Figure 5(a). The MIMO antenna S_{11} is illuminated in Figure 5(b) in an orthogonal position, and it resonates between the 3-5 GHz frequency band with a maximum reflection coefficient of -33.2 dB at 4 GHz. Orthogonal positioning guarantees that there is little interaction between the surface currents on the ground plane. There is less scattering and near-field influence.

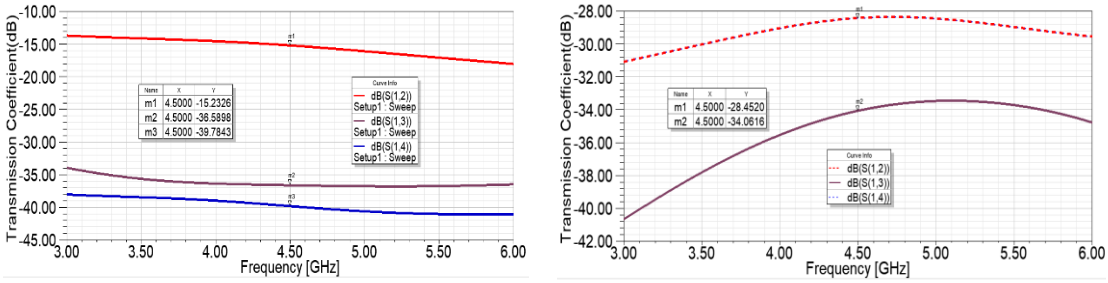


(a) (b)

Figure 5. S_{11} of four-port MIMO antenna; (a) antenna 1 and (b) antenna 2

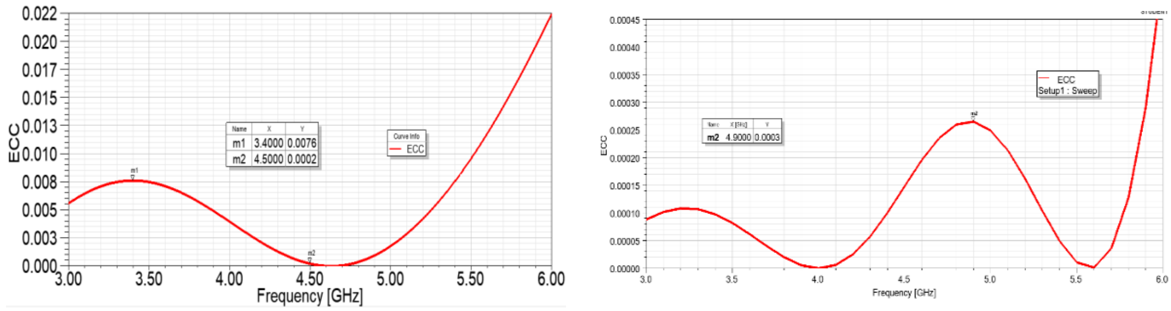
The four port MIMO antenna 1 isolation parameters are S_{12}=15.2 dB, S_{13}=36.5, and S_{14}=39.7, at 4.5 GHz, as illustrated in Figure 6(a). The Figure 6(b) demonstrates the transmission coefficients of the 4-port MIMO antenna 2. The S_{12} and S_{14} are almost equal; their isolation value is 28.0 dB, and for S_{14}, the isolation value is 34.0 dB at 4.5 GHz, respectively. The antennas are positioned orthogonal to each other, so high isolation occurs. The suggested frequency band's ECC value of less than 0.0076 is displayed in

Figure 7(a) (antenna 1). Regarding the anticipated 3 to 5 GHz frequency range, the quad port MIMO antenna with orthogonal position (antenna 2), shown in Figure 7(b), shows that the ECC value is less than 0.0003.



(a) (b)

Figure 6. Transmission coefficient of; (a) antenna 1 and (b) antenna 2



(a) (b)

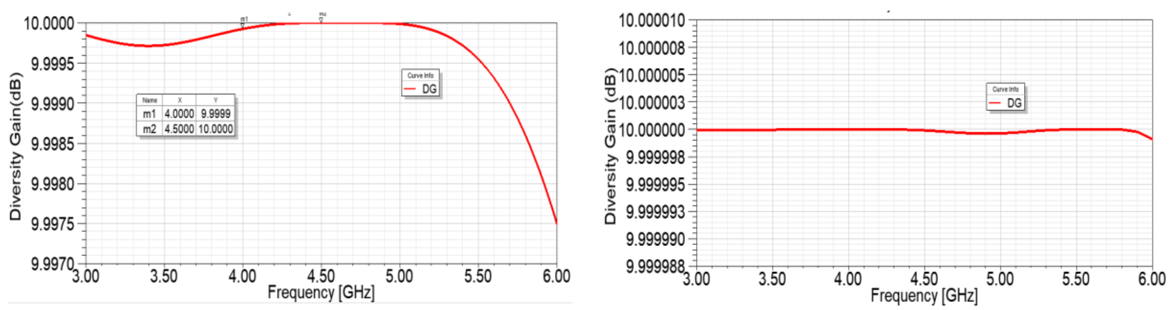
Figure 7. ECC of; (a) antenna 1 and (b) antenna 2

This section examines the diversity performance of the suggested MIMO antenna using a number of performance measures, including the channel capacity loss (CCL), diversity gain (DG), ECC, and total active reflection coefficient (TARC) [18], [19].

$$ECC = \frac{|S_{ii}*S_{ij}+S_{ji}*S_{jj}|^2}{(1-|S_{ii}|^2-|S_{ji}|^2)*(1-|S_{jj}|^2-|S_{ij}|^2)} \quad (1)$$

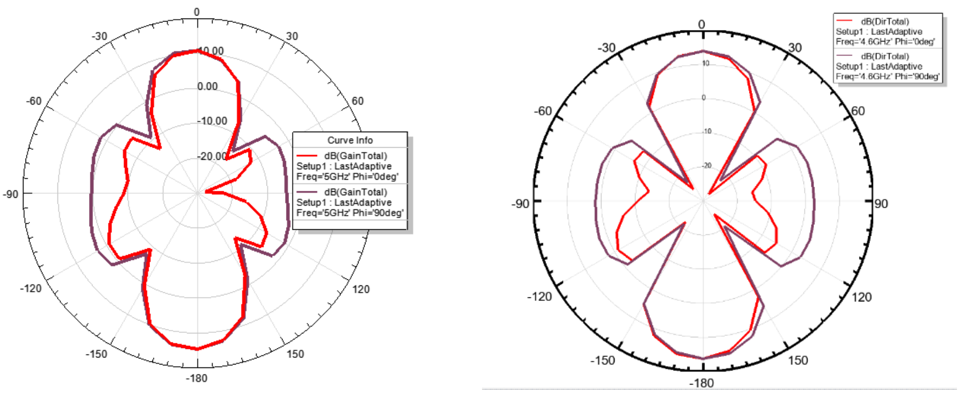
$$DG=10 * \sqrt{1-ECC^2} \quad (2)$$

Figure 8(a) illustrates the DG of 9.99 of the 4-port MIMO antenna without an orthogonal, and Figure 8(b) illustrates the DG of almost 10 dB with an orthogonal for the specified frequency band. The radiation pattern of the proposed MIMO antenna at 5.0 GHz and 4.6 GHz with and without an orthogonal position is shown in Figures 9(a) and (b), respectively. Figures 10(a) and (b) show the surface current distribution of a quad-port MIMO antenna at 4.6 GHz with and without the antennas oriented orthogonally.



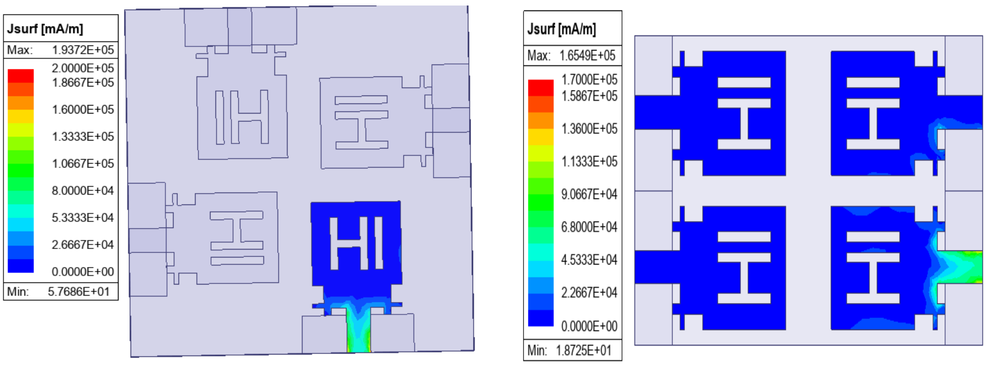
(a) (b)

Figure 8. DG of; (a) antenna 1 and (b) antenna 2



(a) (b)

Figure 9. Radiation pattern of a MIMO; (a) antenna 1 and (b) antenna 2



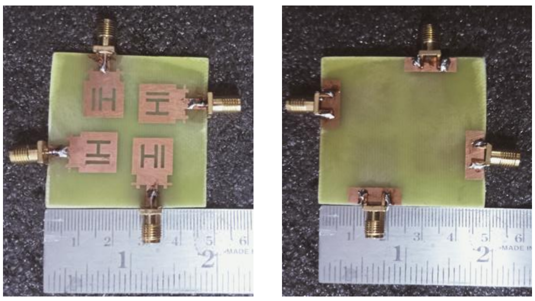
(a) (b)

Figure 10. Current distribution of; (a) antenna 1 and (b) antenna 2

Table 2 presents a comparison between a 4-port MIMO antenna configured with orthogonal antenna positions and the same antenna without orthogonal positioning. Figure 11 illustrates the fabrication of the four antennas that are oriented orthogonally to one another. The four-port MIMO antenna with faulty ground is visible from the rear. Figure 12(a) displays the orthogonally positioned four-port MIMO antenna's measured and calculated S characteristics at various ports, S_{11}, S_{22}, S_{33}, and S_{44}. S_{11} is seen in the anechonic chamber in Figure 12(b). In the target frequency range (3.0 to 5.0 GHz), every port resonates. At 4.0 GHz, the reflection coefficient is less than -30 dB at every port.

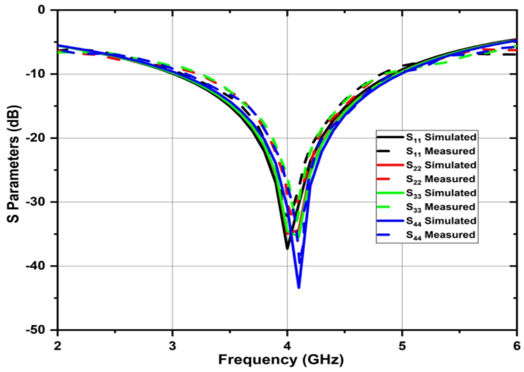
Table 2. Comparasion of simulated results for antenna 1 and 2

Parameters	S_{11} (dB)	S_{12} (dB)	DG (dB)	ECC
Adjacent ports	-20.7	15.0	10	0.007
Orthogonal ports	-33.2	28.0	10	0.0003



(a) (b)

Figure 11. Fabrication of MIMO antenna 2; (a) front and (b) back view



(a)

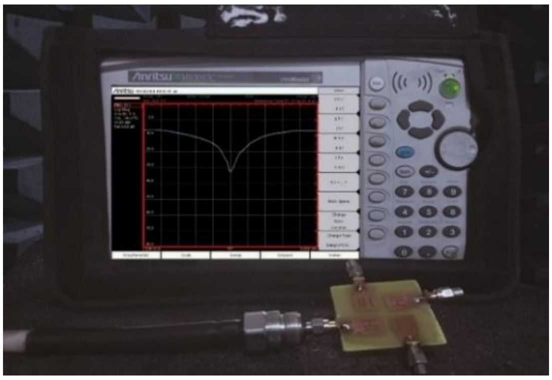

(b)

Figure 12. MIMO antenna 2; (a) S-parameters and (b) anechoic chamber

The isolation between different ports at S_{12}, S_{13}, and S_{14} are shown in Figure 13. The measured and simulated isolation is less than 28.4 dB at all ports. The mesured results are justifies the simulated results. For the intended frequency (3.0 to 5.0), the orthogonal positioned 4 port MIMO antenna exhibits a measured ECC value of less than 0.0003, a DG of almost 10 dB, and a gain of less than 13 dB asdepicted in in Figures 14 to 16. 97% efficiency is shown in Figure 17.

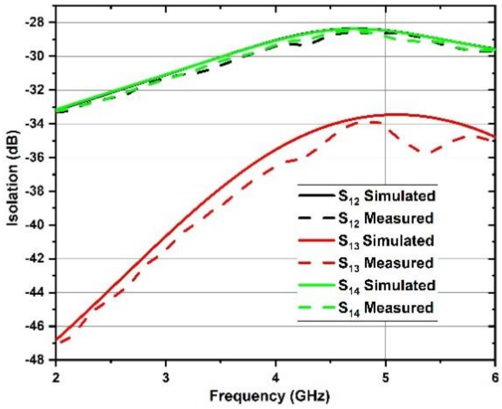


Figure 13. Isolation of orthogonal position MIMO antenna

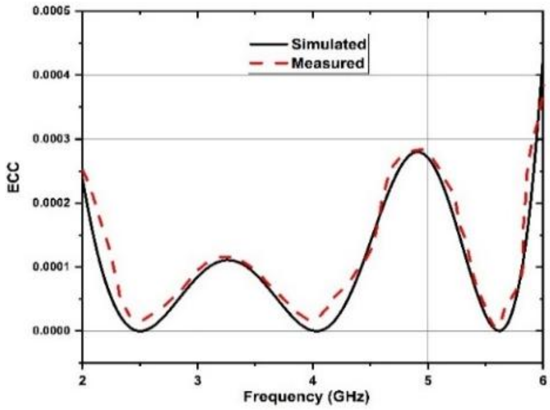


Figure 14. Measured ECC of orthogonal position MIMO antenna

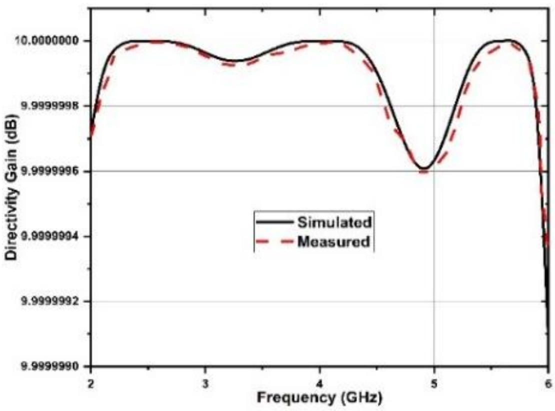


Figure 15. Measured DG of orthogonal position MIMO antenna

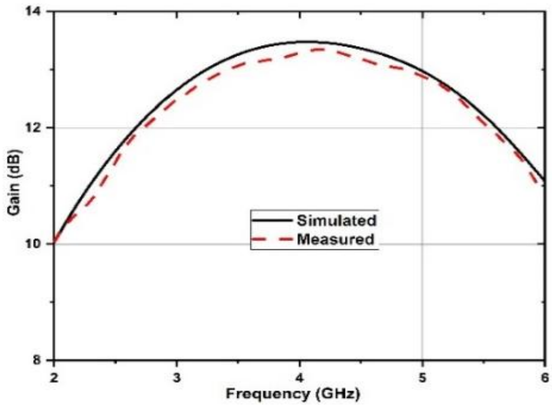


Figure 16. Measured gain of orthogonal position MIMO antenna

Figure 18 displays the measured and computed radiation pattern of an orthogonally positioned four port MIMO antenna at phi=00,900. The suggested antenna and many MIMO antennas [20]-[27] are contrasted in Table 3.

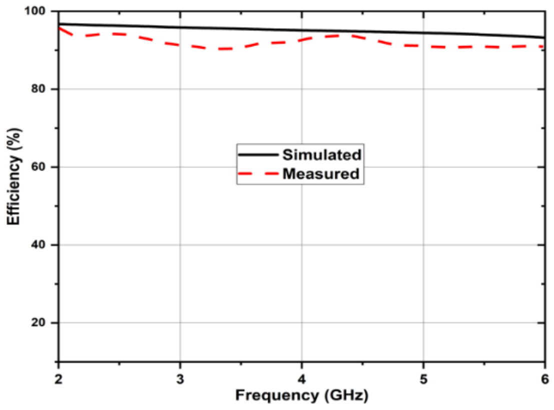


Figure 17. Measured efficieny of orthogonal position MIMO antenna

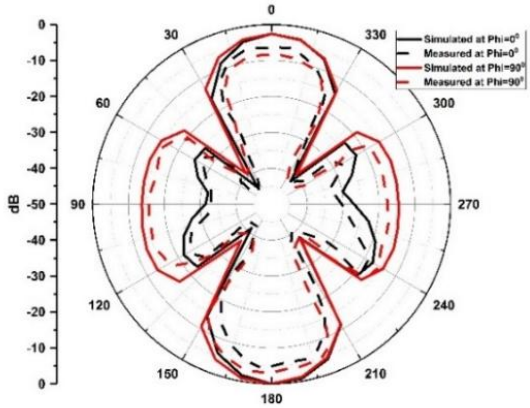


Figure 18. Radiation pattern of orthogonal position MIMO antenna

Table 3. Comparison of different MIMO antennas

Ref.	No. of ports	Frequency range (GHz)	Isolation (dB)	ECC	Decoupling techniques
[20]	4	1.66-2.17	>12	0.23	No decoupling
[21]	4	4.4-6.4	>13	0.04	Orthogonal ports
[22]	4	2.34-2.56	>14	0.01	Parasitic elements
[23]	4	2.7-5.1	>17	0.002	Orthogonal ports
[24]	4	3.2-5.7	>15	0.002	Orthogonal ports
[25]	4	3.4-5.4	>15	0.007	Adjacent ports
[26]	4	3.1-11.5	>15	0.015	Orthogonal ports
[27]	4	3.56-5.28	>22	0.05	Orthogonal ports
Proposed antenna	4	3.0-5.0	>28	0.0003	Orthogonal ports

5. CONCLUSION

The 6 GHz sub band of 5G communication is intended for use with the quad-port wideband MIMO antenna. The suggested quad port MIMO antenna covers 5G NR bands like n77, n78, and n79 and resonates from 3.0 to 5.0 GHz with orthogonal, varying from 3.4 to 5.4 GHz without orthogonal. Here, -10 dB is a reference line for impedance bandwidth 2.0 GHz. The orthogonal antenna orientation improved isolation from 15.0 to 28.0 dB. The DG is almost 10 dB, and the value of the ECC is enhanced from 0.0038 to 0.0003 for a given frequency band (3.0 to 5.0 GHz). The parameters are measured between port 1 and 2. The simulated values are validated by measured results. In future, MIMO antenna designed for wearable application.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ramesh Manikonda	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
Annapantula Sudhakar		✓				✓		✓	✓		✓	✓		
Govindarao Tamminaina	✓		✓	✓			✓		✓		✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analysed in this study.

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