

MIMO ANTENNA SYSTEM WITH DUAL POLARIZATION UTILIZING CIRCULAR RING APERTURE FOR 5G APPLICATIONS

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ABSTRACT: This study presents a dual-polarized MIMO antenna system tailored for 5G networks operating at frequency 3.5 GHz. The design incorporates a circular ring aperture antenna, where orthogonal modes are excited through a 50-ohm dual-port microstrip feed line. A non-contact feed mechanism improves port isolation at the 3.5 GHz operating frequency. The 2x2 MIMO configuration, featuring 8 ports, is fabricated on low-price FR4 dielectric material with a compact footprint of $52 \times 52 \times 1.6$ mm³. The antenna illustrates high efficiency and favorable gain characteristics. Additionally, the envelope correlation coefficient (ECC) and channel capacity loss (CCL) remain low across the target frequency band, making the system well-suited for MIMO and diversity applications.

INDEX TERMS Antenna, ECC, Dual-Polarization, sub-6, 5G, MIMO, 3.5 GHz, FR-4.

I. INTRODUCTION

THE 5G technology has been implemented in multiple regions around the world, providing faster speeds, greater coverage, and improved latency and congestion in comparison to 4G. While both sub-6.0 GHz and millimeter wave bands are suggested for 5G, the majority of nations have initially adopted sub-6 GHz bands for better network accessibility. For instance, countries such as India, Europe, and Australia are using bands in the range of 3.4-3.8 GHz, while the outside countries like USA is using bands in the range of 3.10-3.55 GHz and 3.7-4.2 GHz [1-4]. Demand is really high for indoor 5G base station antennas that can explore the two new licensed sub-6 GHz bands and the existing 2G/3G/4G bands. To enhance communication channel capacity and minimize multipath fading, dual-polarization is often implemented. Patch antennas and crossed dipole antennas are typically employed in wireless communication systems for this purpose because they offer unidirectional radiation patterns, high efficiency, and decoupled ports. In indoor scenarios, antennas that are low-profile, easy to manufacture, and cost-effective are preferred due to their quick and simple installation [3,5-10].

In base station antennas, polarization diversity techniques commonly involve the use of patch antennas, slot antennas, and cross dipole antennas. Dual polarization antennas are highly preferred for base station antennas as they help to overcome multipath fading and improve channel capacity.

Different types of dual polarization antennas used for base station antennas include bow-tie antennas in orthogonal orientation, and two crossed bow-tie dipoles. The evolution of 5G networks is focused on multiplexing data streams through multiple-input multiple-output (MIMO) antenna systems to increase data throughput. For MIMO functionality, multiple port antennas with highly isolated ports, independent radiation patterns, and low Envelope Correlation Coefficient (ECC) are required. Achieving high isolation between ports is a critical consideration, particularly in confined spaces where multiple-port solutions are installed. Various methods have been utilized to increase isolation, X-shaped isolators in [7] including the use of a decoupling element in [11-13], a neutralizing transmission line in [14-15], multiple etched/slot-coupled patch antennas in [16], and different defense application for Frequency selective surfaces for band rejection and acceptance [17, 24-29].

In recent decades, base station antennas have garnered significant attention, leading to the development of diverse antenna types and structures [3,18]. The most common types of base station antennas include patch antennas, slot antennas, and crossed dipole antennas. Polarization diversity techniques have become increasingly prevalent in the design of base station antennas, with dual polarization antennas being a preferred choice due to their unique ability to overcome multipath fading and improve channel capacity [3,8,13]. Examples of dual polarization antennas that have

been developed for base station applications include bow-tie antennas in orthogonal orientation [3,8,12], cross-dipoles fed with balun [15,19], crossed stripped liptic-H slots [16], two connected pairs of folded radiation,dielectric tetraskelion-shaped antenna [20] and two crossed bow-tie dipoles [13]. Also RF domain with applications like frequency selective surfaces for improvement in the performance of antenna can be utilizes [24-26].

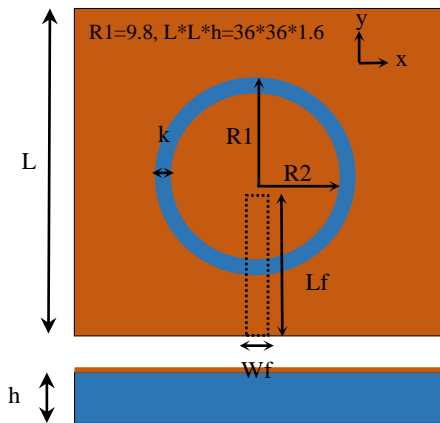
The primary objective in designing base station antennas is to enhance channel capacity and mitigate the effects of multipath fading by utilizing diversity in polarization. With the advancement of 5G networks, multiplexing is becoming more and more important. Data streams can be transmitted simultaneously through Multiple Input Multiple Output (MIMO) antenna systems by utilizing distinct time or frequency resources. For indoor 5G base stations, boosting data throughput with MIMO necessitates antennas with multiple ports, high port isolation, and distinct radiation patterns, ensuring a low Envelope Correlation Coefficient (ECC) between them.

II. ANTENNA DESIGNING AND ANALYSIS

A. ANTENNA MINIATURIZATION

In this work, we need to designed compact size antenna for 5G MIMO applications. Figure 1(a) is the geometry of circular shaped ring aperture antenna termed as (CRAA)

designed on FR4 ($\epsilon_r=4.3,\tan\delta=0.025$). The designed parameters of antenna can be calculated at 3.5 GHz for first resonance frequency using following equations [21]



(a)

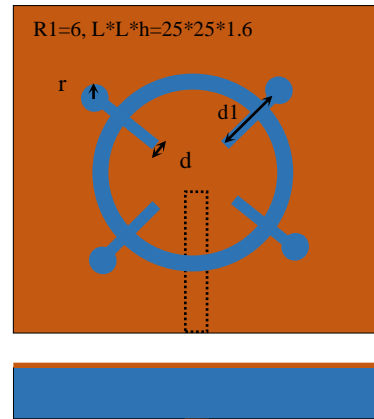


FIGURE 1. (a) Initial antenna-1 design, (b) miniaturized antenna-2 design.

$$f_r \approx \frac{300}{2\pi R_1 \sqrt{\epsilon_{eff}}} \quad \epsilon_{eff} = \frac{2\epsilon_r}{1+\epsilon_r} \quad (1)$$

Where, ϵ_{eff} is the dielectric materials' effective dielectric constant.

For FR4, $\epsilon_{eff} = 1.62$, So

$$R_1(f_r = 3.5 \text{ GHz}) \approx \frac{300}{2\pi f_r \sqrt{\epsilon_{eff}}} = 10.72 \text{ mm}$$

The width (W_f) of 50Ω feed line can be calculate using Transmission line method.The antenna is used to design by CST Studio EM simulation tool using theoretical calculated parameters. The simulated designed parameters of antenna-1 are $R_1=9.8 \text{ mm}$, $R_2=8.8 \text{ mm}$, $w_f=3\text{mm}$, $h=1.6 \text{ mm}$, $k=1 \text{ mm}$, $L=36 \text{ mm}$. So total volume of antenna is $36*36*1.6 \text{ mm}$ for 3.5 Ghz resonance frequency.

Figure 1(b) illustrates the miniaturized antenna-2 that has been modified from antenna-1. To achieve miniaturization, The antenna's effective electrical length has been increased without altering its physical length. In the modified antenna-2, four circular and rectangular slots have been incorporated on the antenna structure's upper side. The antenna's effective electrical length at 3.5 GHz is increased by these slots.The antenna's surface current distribution can be analyzed using the plot depicted in Figure 2(a, b).The first antenna-1's surface current distribution is displayed in Figure 2(a).The current shows half of lambda, which is approximately equal to $2R_1$ at 3.5 GHz. However, in Figure 2(b), the surface current distribution is diverted due to the presence of circular and rectangular slots.This diversion of current extends the total current path beyond $2R_1$, effectively increasing the antenna's electrical length.Figure 3 depicts the S11 plots of both antennas, of which resonate at 3.5 GHz. Compared to antenna-1, antenna-2's bandwidth is slightly less. However, other methods of miniaturization reduces more bandwidth after miniaturization [3,7].

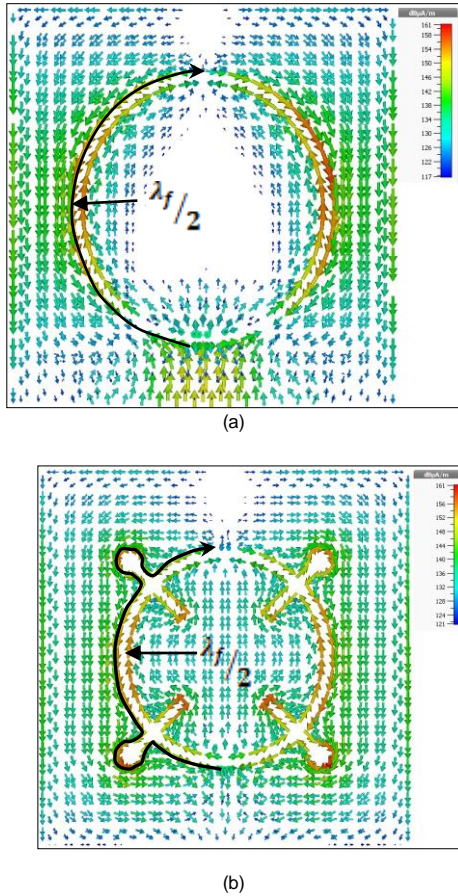


FIGURE 2.(a) Initial antenna-1 design, (b) miniaturized antenna-2 design

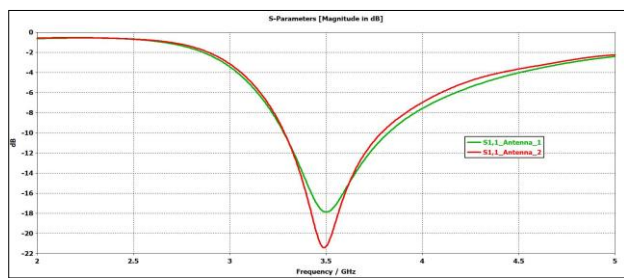


FIGURE 3.(a) Initial antenna design, (b) miniaturized antenna design

B. DUAL POLARIZED ANTENNA DESIGNING

Dual polarization means that two distinct polarizations can be transmitted and received concurrently by the antenna, typically vertical and horizontal. The polarization is determined by the orientation of the antenna elements and is typically achieved by using orthogonal antennas or feeding mechanisms. Two orthogonal feed are required to achieve dual polarization characteristics of antenna. Figure 4(a,b) shows the dual orthogonal micro strip feed antenna. In this orthogonal modes are excited with dual microstrip lines.

Dual polarization relates to the capability of an antenna to transmit and receive two different polarizations simultaneously, typically vertical and horizontal. The polarization is determined by the orientation of the antenna

elements and is commonly achieved through the use of orthogonal antennas or feeding mechanisms. Two orthogonal feeds are necessary to achieve dual polarization characteristics. Figure 4(a,b) illustrates a dual orthogonal microstrip feed antenna that uses dual microstrip lines to excite the orthogonal modes. In order to maintain orthogonal polarization purity, the coupling between the orthogonal ports should be minimized. However, in antenna-3, the coupling between port1 and port2 is greater, as shown in figure 5's S21 plot. Because both the micro strip feed lines are close at center of antenna, that why the field coupling between ports are more.

To ensure minimal field coupling between ports, the space between ports must be maintained. In order to maintain the minimum amount of coupling between ports, the feed lines are modified. The antenna-4 exhibits an improved feed with the incorporation of two arc-shaped parasitic elements, as illustrated in the figure4(b, c). The improved S21 plots shown in figure 5 for antenna-4, it has low coupling with comparison of antenna-3. Because the spacing between feed lines are enhanced. The efficiency and gain of antenna-4 are desirable for 5G applications , which are represented in figure 6 and figure 7 respectively.

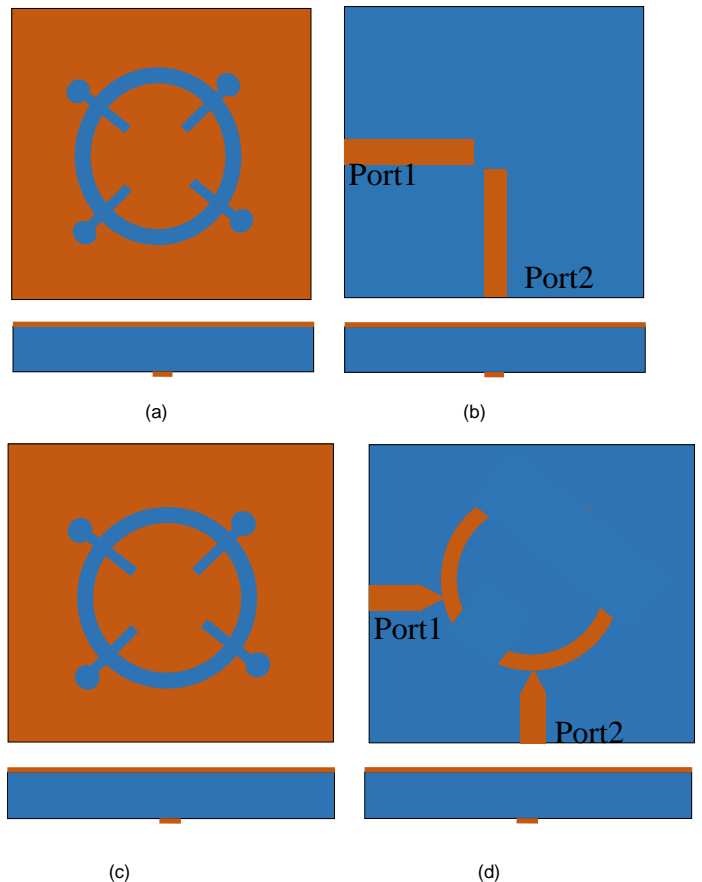
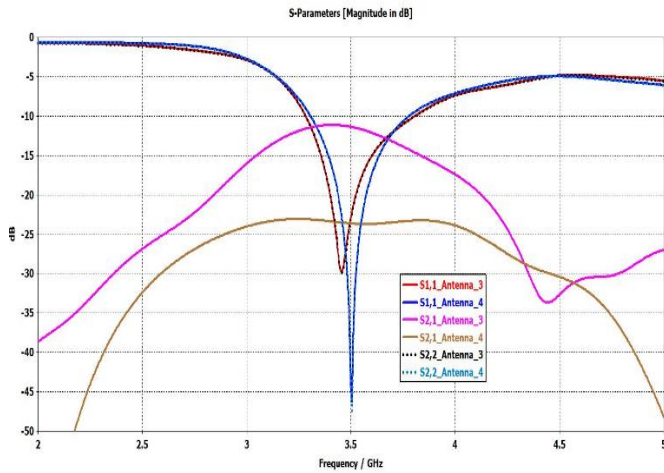


FIGURE 4.(a) Initial antenna design, (b) miniaturized antenna design, (c-d) two arc-shaped parasitic elements

III.MIMO ANTENNA DESIGNING

A detailed perspective of the suggested 2x2 MIMO antenna intended for usage in 5G operating at sub-6 GHz is given in Figure 8. It has an overall geometry size of proposed element is $52 \times 52 \times 1.6 \text{ mm}^3$ and displayed on a dielectric



substrate made of FR4 that has a relative permittivity of 4.3 and loss tangent of 0.025. The MIMO antenna utilizes two 50Ω micro-strip inputs to excite each of the two antenna elements, enabling dual polarization. In order to operate the 2x2 MIMO antenna, a total of 8 ports are required. Figure 9 displays the MIMO antenna's scattering characteristics, which shows all S-parameter reflection result for all 8 ports. The 3.5 GHz is the resonance frequency of antenna and operates within range of the 3.2 to 3.8 GHz for sub-6 5G bandwidth. Figure 10 depicts the mutual coupling parameters between antenna ports, specifically from port 1 to port number 2, 3, 4, 5, 6, 7 and 8 respectively.

FIGURE 5. S11/S21 Plots for Antenna-3 and antenna-4

FIGURE 7. Gain of antenna-4

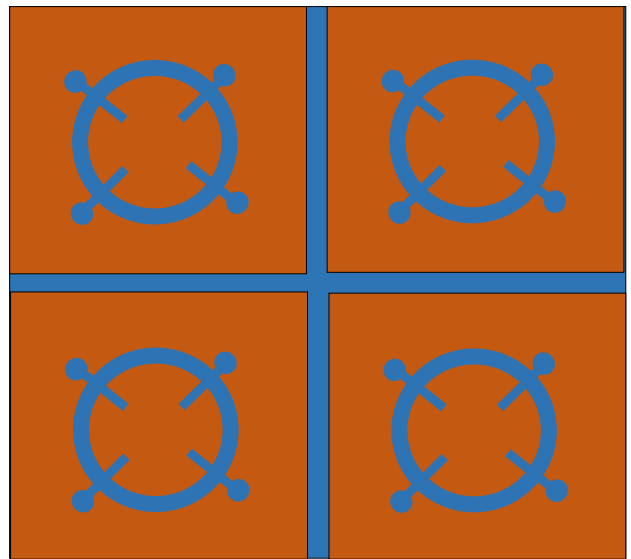


FIGURE 8. 2x2 MIMO Antenna designed Using Antenna-4

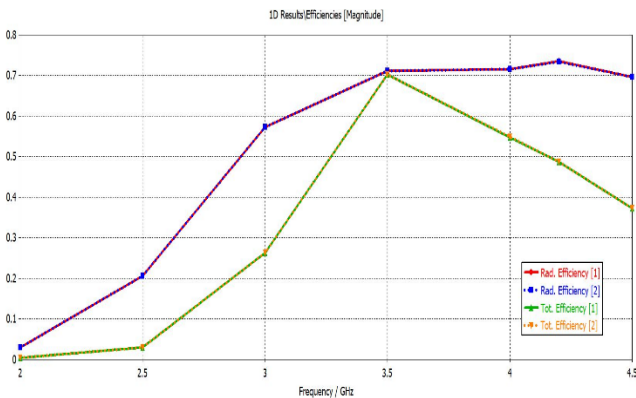


FIGURE 6. Antenna-4 radiation and overall efficiency

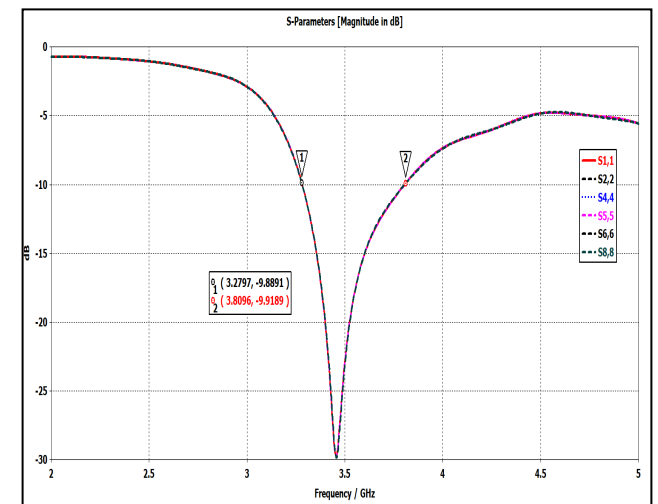
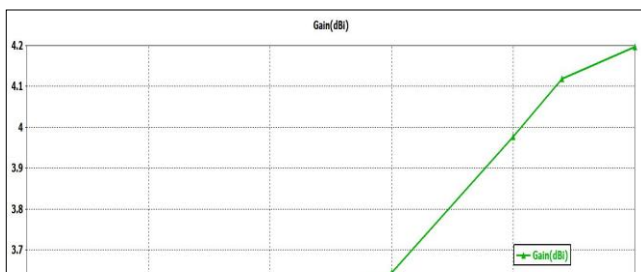


FIGURE 9. S11 Plots for MIMO antenna

The proposed 2x2 MIMO antenna designed for sub-6 5G usage is shown in detail in Figure 8. It has an overall

geometry size of 52 x 52 x 1.6 mm³ and The FR4 dielectric substrate on which it appears has a loss tangent of 0.025 and a relative permittivity of 4.3. The MIMO antenna consists of two elements, each driven by dual 50 Ω microstrip feeds to accomplish dual polarization. The 2x2 MIMO antenna requires 8 ports for operation. Figure 9 presents the scattering parameters, highlighting the reflection (S-parameters) for all 8 ports. The antenna is tuned to resonate at 3.5 GHz and functions efficiently within the 3.2 to 3.8 GHz range, conforming to 5G applications' sub-6 GHz spectrum. Figure 10 demonstrates the coupling between antenna ports through S-parameter analysis.

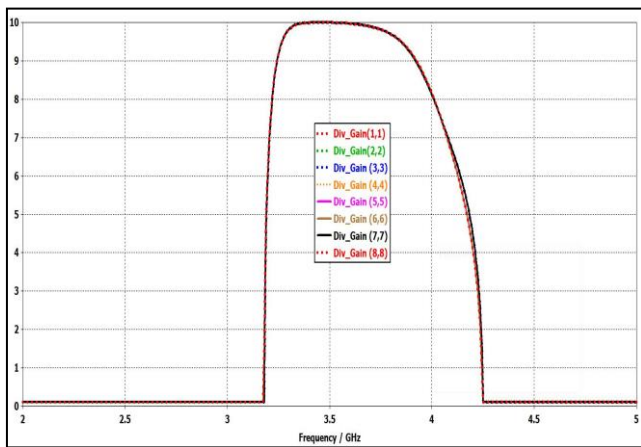


FIGURE 10. Transmission Coefficient of MIMO antenna

A. DIVERSITY PERFORMANCE

Here the isolation and antenna radiation patterns are crucial for assessing MIMO antenna performance, yet they alone do not offer a comprehensive evaluation. Diversity performance, including ECC (Envelope Correlation Coefficients), CCL (Channel Capacity Loss), and DG (Diversity Gain) also plays a pivotal role. This section explores diversity performance in these aspects.

B. ENVELOPE CORRELATION COEFFICIENTS (ECCS)

The suggested MIMO antenna's envelope correlation coefficients (ECCs) were calculated using equation (2) from the simulated scattering parameters. Figure 11 illustrates the simulated ECC characteristic of the 2x2 MIMO system, showing that the ECCs are consistently below 0.001 throughout the entire bandwidth [22]

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

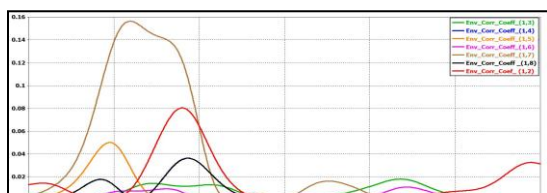


FIGURE 11. Shows envelope correlation coefficients of MIMO antenna

C. DIVERSITY GAIN (DG)

The improvement in signal-to-noise ratio over a single antenna system is known as the MIMO antenna's diversity gain (DG). It is determined using Equation (3) from [16] and visualized in Figure 12. Simulation results indicate that the DG reaches nearly 10 dB.

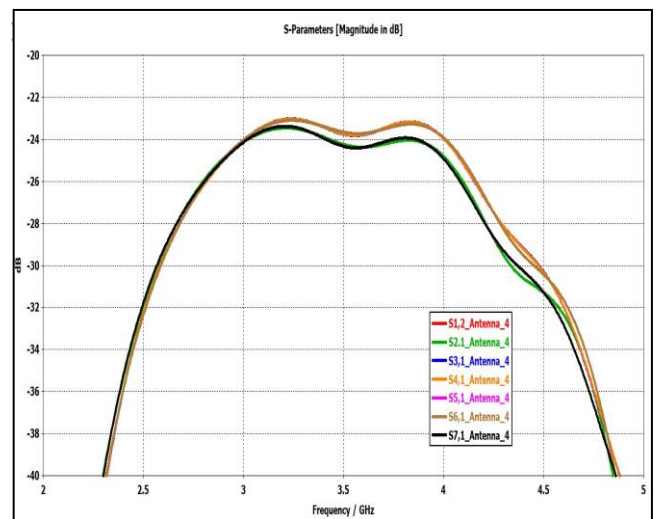


FIGURE 12. Shows Diversity gain of MIMO antenna

D. CHANNEL CAPACITY LOSS (CCL)

In the analysis seen like, A MIMO system's antenna count increases, its capacity increases. But, more antennas also raise the correlation among antenna elements, leading to higher channel capacity losses. Channel capacity loss (CCL) quantifies the capacity reduction due to antenna element correlation. Lower CCL indicates superior performance. Equation (4) computes CCL, aiming for values below 0.4 (bits/s/Hz) to optimize MIMO diversity performance, as referenced in [23]. The calculated CCL from the simulated shown in Figure 13. It reveals that the CCL values is 0.013 bits/sec/Hz.

$$CCL = -\log_2 [\det(\psi^R)] \quad (4)$$

$$\psi^R = \begin{bmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{bmatrix}, \text{ and}$$

$$\varphi_{11} = 1 - (|S_{11}|^2 + |S_{12}|^2)$$

$$\varphi_{22} = 1 - (|S_{22}|^2 + |S_{21}|^2)$$

$$\varphi_{12} = S_{11}^* S_{12} + S_{21}^* S_{12}$$

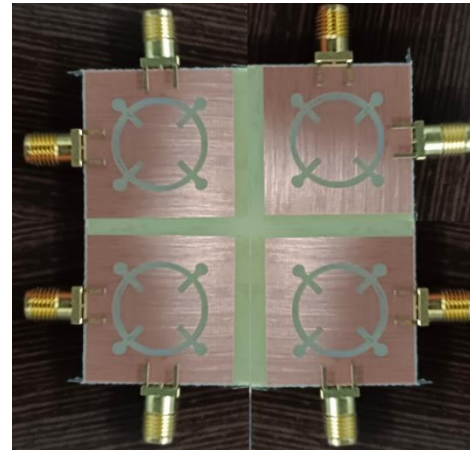
$$\varphi_{21} = S_{22}^* S_{21} + S_{12}^* S_{21}$$

(a)

Figure 14. presented the fabricated MIMO antenna prototype with top and bottom view. Where connector is been connect to all the 8 ports.

Table I Previous MIMO antennas Comparisons

Ref	Frequency Band (GHz)	Port Isolation	ECC	Size(mm ³)	(Material)
4	1.55-6	16	0.500	129.5*129.5*28.2	R04003C
5	2.35-4.25	28.65	0.027	125.2*125.2*18	FR4
7	4.9-6	20	0.300	30*30*13	RT5880
8	1.32-2.82	30	NA	110*110*38.4	FR4
9	3.14-3.92	28	NA	110*110*11.1	FR4
11	3.5-4.9	20	NA	60*60*19.5	FR4
12	3.45-3.55	21	0.119	74*74*1.524	RO4350B
This work	3.2-3.8	24	0.01	52*52*1.6	FR4



(b)

FIGURE 14. Fabricated propotype of proposed MIMO antenna (a) Top View (b) Bottom view

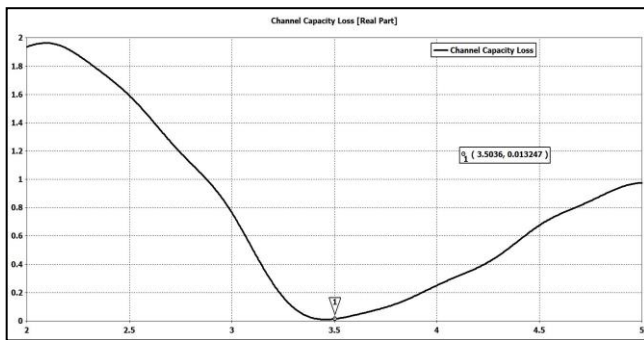
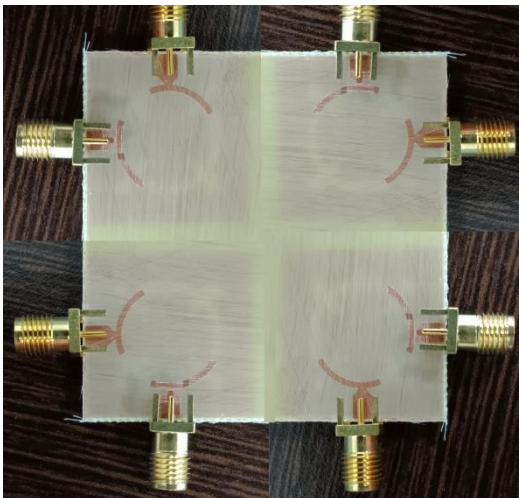


FIGURE 13. Shows Channel capacity loss of MIMO antenna



IV. CONCLUSION

This article presents MIMO antenna system designed for sub-6 GHz applications, operating across the range of 3.2–3.8 GHz. The design includes a non-contact i.e. capacitive feed to minimize mutual interaction between the antenna ports, along with the addition of two arc-shaped parasitic elements. This configuration enhances isolation to less than 24 dB across the entire operating range. This system utilizes an affordable and widely available FR4 substrate, ensuring cost-effectiveness and practicality. The antenna was designed using CST Studio Suite, following a comprehensive analysis of its non-contact feed, structure, and other components. The system's Diversity Gain (DG) is evaluated at 10 dB, and its Envelope Correlation Coefficient (ECC) is measured at 0.001. Channel capacity loss (CCL) across the entire bandwidth is improved i.e. below 0.013 bits/s/Hz, while vertical and horizontal gains approximate 3.5 dBi.

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