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Design and Analysis of a Novel and Compact Two Element Modified Circular MIMO Patch Antenna for WLAN and 5G sub 6 GHz Applications

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ABSTRACT: This study proposes a modified circular MIMO antenna design suitable for 5G sub-6 GHz (N77/N78 & N79) and WLAN applications. The antenna is built on an FR4 substrate with a volume dimension of 24 × 36 × 1.6 mm3, a dielectric constant of 4.4, and a loss tangent of 0.02. It operates in the 3.36 to 6.02 GHz range, encompassing the WLAN (5.15–5.85 GHz) and N77/N78 & N79 (3.3–4.2 GHz/3.3–3.8 GHz & 4.4–5.0 GHz) bands, and provides over 20 dB isolation for most of the band. The antenna demonstrates excellent efficiency values of above 87% across the band due to good impedance matching at the ports. The working region achieves peak values of 2.5 to 4.6 dBi. The study evaluates and measures various MIMO performance metrics, including ECC (Envelope Correlation Coefficient) ≤ 0.005, DG (Diversity Gain) ≥ 9.99 dB, TARC (Total Active Reflection Coefficient) ≤ -10 dB, CCL (Channel Capacity Losses) ≤ 0.05 bits/s/Hz, and MEG (Mean Effective Gain) ≤ -3 dB. The simulated radiation patterns are compared with measured results, and the constructed prototype is examined and measured. The parameters of the prototype are compared with simulation results, and the simulated and measured values show good agreement.

KEYWORDS: Modified circular, MIMO, 5G Sub 6: GHz, WLAN, CCL, and TARC**.**

I.INTRODUCTION

The MIMO technology has become essential in modern wireless communication due to its numerous benefits, such as higher data rates, larger channel capacity, and reliable transmission quality. This technology utilizes a large number of antenna elements at both the transmitting and receiving ends, making it highly effective in combating multipath fading in a free space environment [1-4]. With the increasing demand for higher data rates and improved transmission quality, MIMO technology is crucial for 5G cellular wireless communications. The 5G cellular technology offers numerous advantages over previous generations, including 1G, 2G, 3G, and 4G wireless cellular communications. Additionally, 5G sub-6 GHz is an efficient communication method compared to lower 5G and millimeter-wave 5G communications, in terms of coverage area and data rate. By combining 5G and MIMO technology, the current wireless technology has become more effective and efficient [5-8]. While various researchers have proposed different works on MIMO with 5G communications, there is still room for further development in this field.

A microstrip planar antenna designed for 5G mobile station applications is presented **[9]**. Dual element MIMO antenna for dual-band frequencies is designed and developed for 5G sub 6 GHz and another one for WLAN application is presented **[10]**. A compact two-element MIMO structure is presented for future 5G applications **[11]**.

We see that the suggested MIMO antenna is designed to operate in both WLAN and 5G sub-6 GHz applications. It has a frequency range of 3.38 to 6.02 GHz and achieves isolation of over 20 dB throughout most of the band. The structure's

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overall size is 24 × 36 mm2, with a height of 1.6 mm. The antenna's high-efficiency values of above 86% in the entire band and peak gain values of 2.5 to 4.6 dBi are significant benefits. Additionally, this MIMO antenna has a compact design, covers the complete 5G and WLAN band, and easy to design and attains high-efficiency values. The MIMO diversity metrics ECC, DG, TARC, CCL, and MEG values are also calculated and verified with measured results.

II. MIMO ANTENNA DESIGN AND ANALYSIS:

We understand that the proposed MIMO antenna is designed to be used in 5G sub-6 GHz and WLAN applications. The antenna has been designed using a low-cost FR4 material that measures 24 × 36 mm2 and has a height of 1.6 mm. To improve isolation, the antenna consists of two modified circular patches and a T-shaped stub. It operates in the 3.38 to 6.02 GHz frequency range and has an isolation of above 20 dB in most of its working regions. The structure and dimensional parameters of the design are shown in Fig. 1 and Table 1, respectively, and the detailed evolution process of the structure is provided.

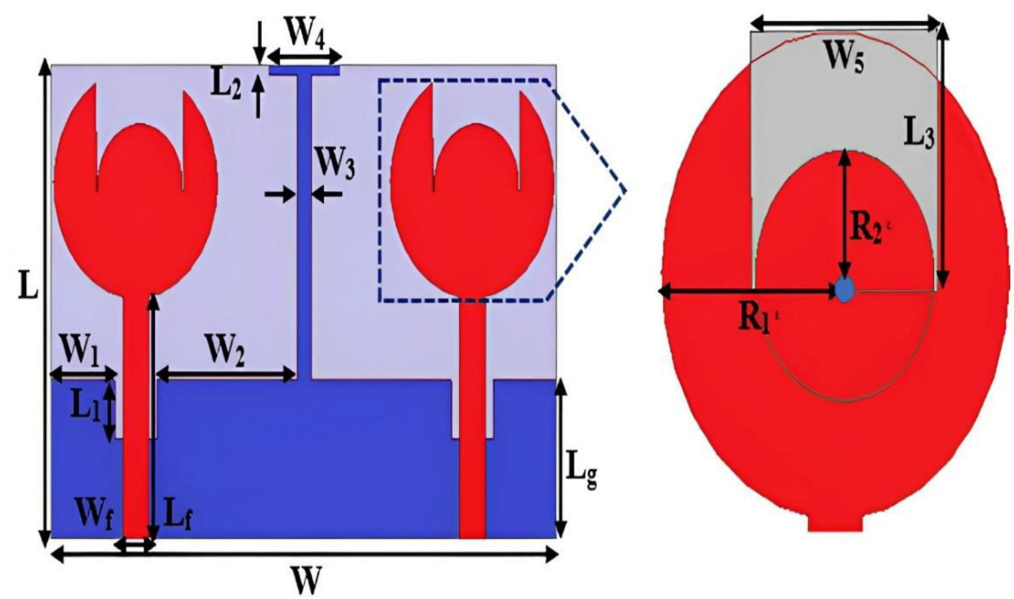

Figure 1: Suggested MIMO Antenna Design and Parameters.

Table 1: Proposed MIMO Antenna Parameters with Values.

Parameter	***L***	***W***	L_1	L_2	L_3
Value (mm)	**24**	**36**	**4**	**0.5**	**6**
Parameter	L_f	L_g	W_1	W_2	W_3
Value (mm)	**15.5**	**8**	**4**	**11.5**	**1**
Parameter	W_4	W_5	W_f	R_1	R_2
Value (mm)	**5**	**6**	**1.8**	**5.9**	**3**

The process begins with the placement of two circular-shaped patches in a two-element MIMO structure for 5G sub: 6 GHz region applications, called **Antenna #1**. To achieve impedance matching, a strip of rectangular shape is removed from the top end of the circular patch. This enhances the reflection coefficient from -18 dB to -27 dB at the 5G sub: 6 GHz region. However, the isolation between the elements is very poor, resulting in -13 dB, and thus, it is named **Antenna #2**. **Antenna #3** is formed by placing a T-shaped stub with optimized dimensions between the elements. The T-shaped stub acts as an isolating element, providing effective impedance balancing between the elements. This antenna operates in the 3.38 to 6.02 GHz region, and in the majority of this region, isolation above 20 dB is achieved. Lastly, an optimized circular patch with a

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radius of 3 mm is placed at the center of the defective circular patch, forming **Antenna #4**. This results in better impedance matching in the 4 to 5 GHz region, and improved isolation at the same region. The evolution stages of this process are represented in **Fig. 2**. Additionally, **Fig. 3 (a)-(b)** demonstrates the s-parameter responses of the suggested MIMO antenna's evolution stages.

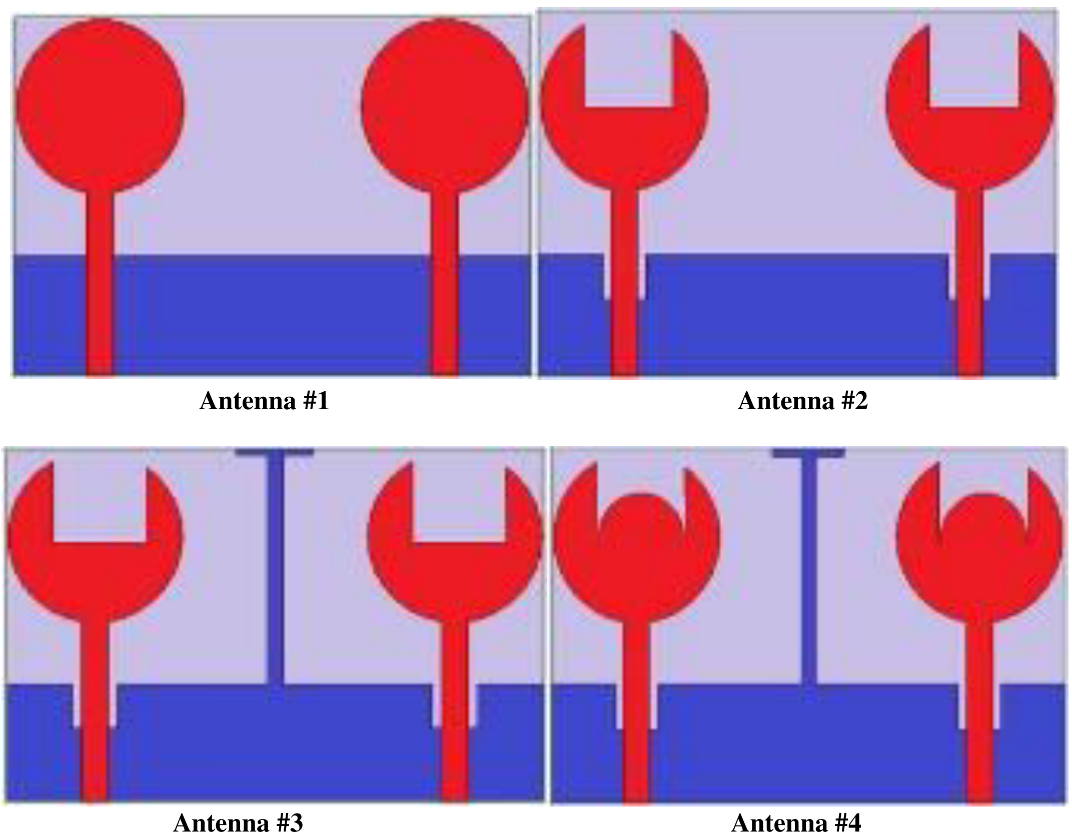

Figure 2: Suggested MIMO Antenna Evolution.

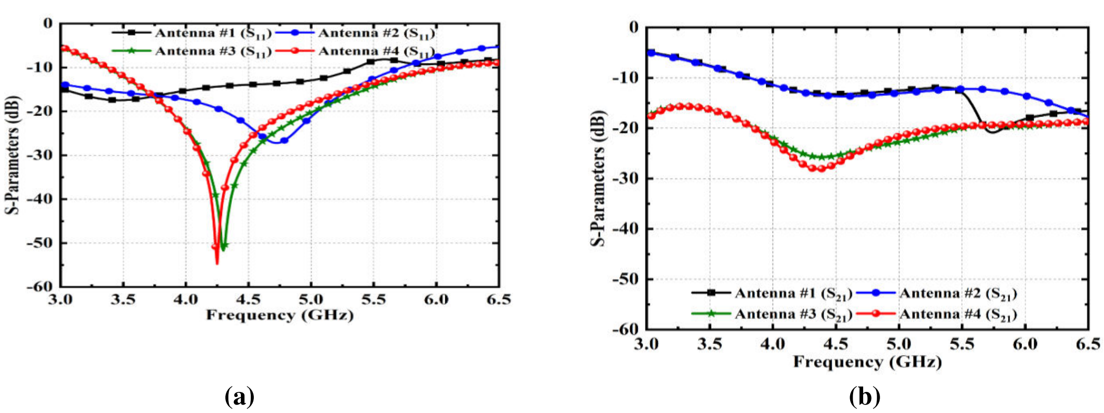

Figure 3: Suggested MIMO Antenna Evolution Results; (a) S_{11} and (b)$S_{21.}$

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III. RESULTS AND DISCUSSIONS

(i) S-Parameters:

The S-parameters are very essential parameters for whether the antenna is working in a particular band of a region or not. Evaluated, and its S-parameter values were measured for the suggested MIMO antenna. The measured S-parameter values are checked with simulated ones. Both are in good agreement except for a small deviation at mid-band frequencies. These deviations are due to the tolerances at soldering ports.

(ii) Radiation Performance:

The suggested MIMO antenna's radiation performance is evaluated in an anechoic chamber. The constructed MIMO antenna that is being suggested is placed underneath the testing antenna, with the reference horn antenna. The radiation patterns E & H fields are measured at 3.38 GHz, 4.50 GHz, 5.00 GHz, and 5.50 GHz. The measured patterns from the proposed MIMO antenna almost exactly match the predicted outcomes. The main advantage of the suggested MIMO antenna is boring sight patterns are attained along with Omni directional patterns. The comparison of field patterns is represented in **Fig. 4**.

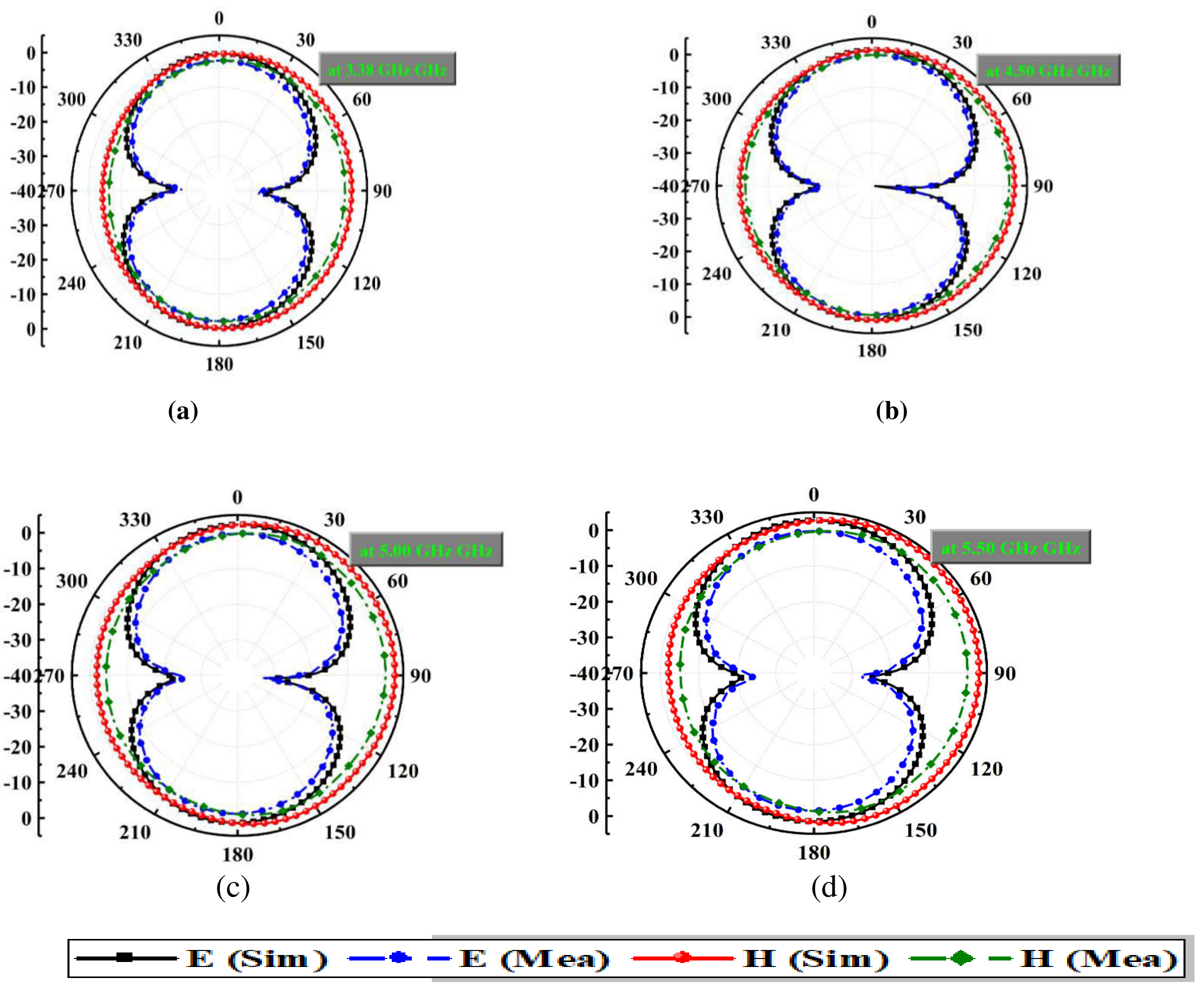

Figure 4: Suggested MIMO Antenna 2-D Radiation Performance; (a) at 3.38 GHz; (b) at 4.5 GHz; (c) at 5.00 GHz and (b) 5.50 GHz.

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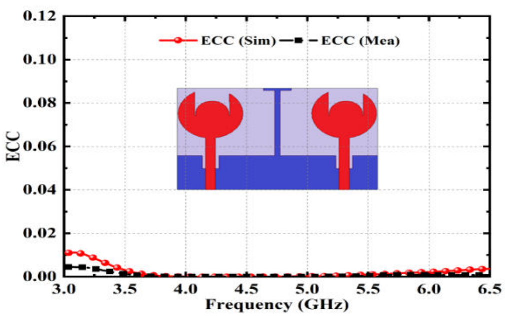
(iii) MIMO Performance:

For analysis of the diversity performance of any MIMO structure, the MIMO diversity metrics ECC, DG, TARC, CCL, and MEG are significant. The MIMO antenna structure's ECC parameter describes the relationship between any two channels. The ECC is represented here using S-parameters and it is represented in **equation (1) [18-19]**. **Fig. 5** demonstrates the contrast between ECC values for simulation and measurement. The diversity gain (DG) is calculated using the ECC parameter and these are represented in **equation (2)**. Fig. 6 illustrates a comparison of measured and simulated DG. The suggested MIMO antenna's ECC and DG values are below 0.005 and above 9.99 dB throughout the entire band, respectively.

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

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



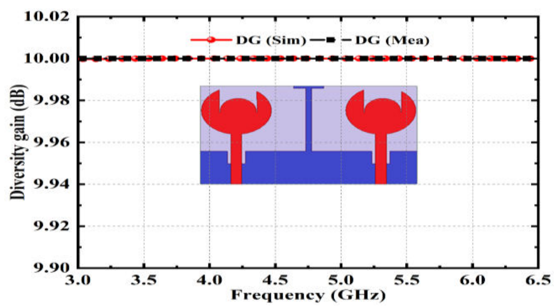


Figure 5: Suggested MIMO Antenna ECC Results (Simulation and Measured).

Figure 6: Suggested MIMO Antenna DG Results (Simulation and Measured).

The parameter TARC is also essential in MIMO antenna diversity performance analysis. It takes into account how the coupling of the elements has an impact on changes in self and mutual impedances. The self and mutual impedances are altered by the mutual coupling between the MIMO structure's components. The acceptable TARC in MIMO structure is ≤0 dB as practically. The suggested MIMO antenna TARC values are below -10 dB in the entire working region. **Equation (3)** represents the TARC values after being calculated with S-parameters **[20]**. **Fig.7** describes the TARC values comparison of the proposed MIMO antenna with Fabricated prototype results.

$$TARC = \sqrt{\frac{\left|(S_{11}+S_{12}e^{j\theta})\right|^2+\left|(S_{21}+S_{22}e^{j\theta})\right|^2}{2}} \quad (3)$$

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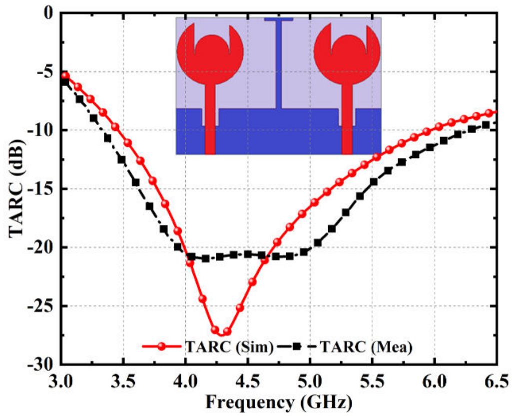

Figure 7: Suggested MIMO Antenna TARC Results (Simulation and Measured).

While transmitting the signal from source to destination, some of the bots will be lost due to the coupling between the elements in MIMO structures. The parameter CCL deals with the number of bits that will be lost while transmitting and is represented in terms of bits/s/Hz. The practical considerable values of CCL are 0.4 bits/s/Hz. The suggested MIMO antenna CCL simulated and measured value comparison is shown in **Fig. 8**. Equation (4) **[21]** represents the CCL in terms of S-parameters. The MEG parameter determines the receiver's ability to receive signals from various routes in a multipath environment. The MEG values are clearly shown in **Fig. 9** and these are maintained -3 dB values in the entire working band. Equation (5) describes the MEG in terms of S-parameters **[22-23]**. The suggested MIMO antenna's performance in comparison to others is shown in Table 2.

$$C_{Loss} = -log_2 det(\alpha^R) \tag{4}$$

Where,

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

$$\alpha_{ii} = 1 - \left(|S_{ii}|^2 + |S_{ij}|^2\right); \qquad \alpha_{ij} = -\left(S_{ii}{}^*S_{ij} + S_{ji}{}^*S_{jj}\right);$$

$$\alpha_{ji} = -\left(S_{jj}{}^*S_{ji} + S_{ij}{}^*S_{ii}\right); \qquad \alpha_{ii} = 1 - \left(|S_{jj}|^2 + |S_{ji}|^2\right).$$

$$MEG_i = 0.5\eta_{i,rad} = 0.5\left[1 - \sum_{j=1}^{M} |S_{ij}|^2\right] \tag{5}$$

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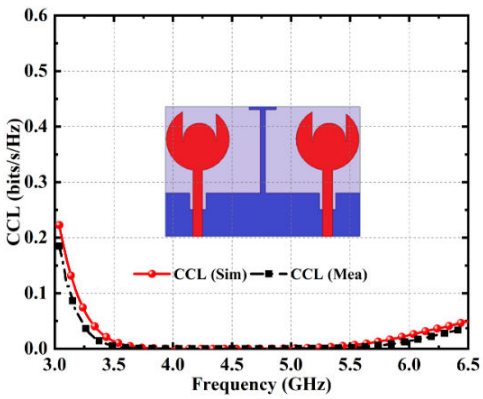

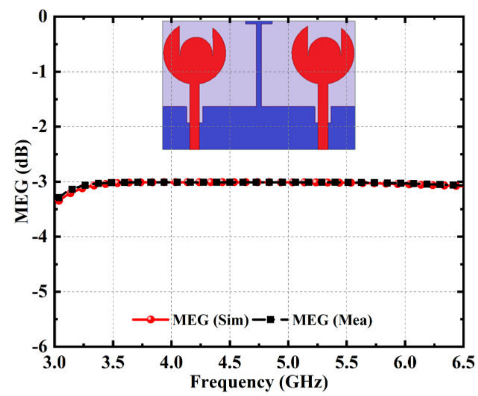

Figure 8: Suggested MIMO Antenna CCL Results (Simulation and Measured).

Figure 9: Suggested MIMO Antenna MEG Results (Simulation and Measured).

Table 2: Comparison of Suggested Work with Other Literature Works.

Ref. No, No of Elements	**Antenna Size (mm^2)**	**IBW (GHz)**	**S_{21} (dB)**	**Peak gain (dBi)**	**Radiation Efficiency (%)**	**CCL (bits/s/Hz)**	**TARC (dB)**
[9], 1	135 × 80	0.75, 2.7-3.5, 4.5-5.0	---	1.66, 4.72, 4.52	60, 42, 41	---	---
[10], 2	46 × 30	1.8-3.6, 5-7.9	17.2, 22.4	4.31, 4.62	71, 70	0.35	≤ -10
[11], 2	30 × 6.75	4.9-5.06	20	1.95	79.5	---	---
[12], 1	100 × 100	2.45, 3.5	---	7.64	64.5	---	---
[13], 8	192 × 76	1.3-3.8	15	13.8	83.6	---	---
[14], 2	35 × 50	4.6-4.9	15	1.8	45	0.5	≤ -10
[15], 4	160 × 70	5.4-5.6	18	5.6	85	---	---
[16], 8	22 × 22	3.3-7.1 (-6 dB)	12	4.6	48	0.3	≤ -30
[17], 2	23 × 19	3.3-3.6 & 4.8-5.0	25	---	---	---	---
P*, 2	**24 × 36**	**3.38-6.02**	**20**	**4.6**	**86**	**0.05**	**≤ -10**

IV.CONCLUSION

The presented work deals with the modified circular-shaped MIMO antenna for 5G sub: 6GHz and WLAN applications. The antenna's operating range is 3.38 to 6.02 GHz, with isolation of more than 20 dB for the vast majority of the band. The construction is created and developed on a 24 x 36 mm^2 low-cost FR4 substrate. Efficiency (86%), peak gain (2.5-4.6 dBi), and field patterns are used to examine the radiation performance of the suggested MIMO antenna. Bore sight patterns are attained with properly designed parameter values. The MIMO diversity metric are ECC, DG, TARC, CCL, and MEG

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values are simulated and checked with measured results of the fabricated prototype. All of the observed values and the findings of the simulation coincide fairly well. Because of its compactness, the suggested MIMO antenna is the best suitable portable wireless device applications.

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