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International Journal of
Electrical and Electronics Research (IJEER)
Research Article | Volume 11, Special Issue NGWCN | Pages 15-19 | e-ISSN: 2347-470X

Defected Ground Based MIMO Antenna for 5G mm Wave Applications

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ABSTRACT- This study provides a novel 4 Port "MIMO antenna" design for "5G mm wave" implementation. This designed antenna operates in mm-wave band and adheres to the 5th generation's specifications. The antenna is described from two perspectives. The array elements appear to be arranged in a rectangular shape from the top view, however the bottom view, which is the view on the substrate, is composed of rectangular and ring-shaped slots to improve the antenna's radiating properties. In general, the study covers all aspects of the MIMO antenna design, including antenna methodology, simulation results and among other things. The antenna equipment supports impending mm-wave 5G applications by operating in the 25.5-29.6 GHz frequency spectrum. Furthermore, the operational frequency band achieves a peak gain of 8.3dBi. Once again, polarization diversity is used between adjacent radiators to achieve great isolation between antenna parts, resulting in low envelope correlation Coefficient.

Keywords: MIMO, Microstrip Antenna, Antenna array, Defected Ground Structure (DGS), 5G mm-wave.

ARTICLE INFORMATION

Author(s): Nelapati Ananda Rao, Lalitha Bhavani Konkyana, Ch Ramesh Babu;
Received: 04/07/2023; **Accepted**: 14/09/2023; **Published**: 30/10/2023;
E- ISSN: 2347-470X;
Paper Id: IJEER NG-WCN-012;
Citation: 10.37391/IJEER.11ngwcn03
Webpage-link:
https://ijeer.forexjournal.co.in/archive/volume-11/ijeer-11ngwcn03.html

Publisher's Note: FOREX Publication stays neutral with regard to jurisdictional claims in Published maps and institutional affiliations.

1. INTRODUCTION

Multiple technological breakthroughs have been recognized in the telecommunications business to increase efficiency and sustainability. The creation of Multiple-In Multiple-Out systems, which have replaced the conventional Single-In Single-Out systems [1-3], is one of the breakthroughs that has been made. Because of the enormous advantages of MIMO technology provides over equivalent systems utilizing single antenna transceivers, most modern communications models, Specifically, manufacturing companies have used it. MIMO system entails using many radiators at the sending and receiving system, results in a signaling degree of freedom not previously available in SISO systems. Normally, the degree of freedom provided by this technology is used for redundancy or multiplexing [4].

Figure 1 push for a 5G network has recently paid off, allowing for a successful step-by-step transition from the previous 4G network. This network's adoption is expected to deliver greater dependability, less power wastage, high speed needs, and to satisfy the large number of connected elements [5]. Various changes have been made to multiple networking devices in order to achieve this. The usage of Multiple Input Multiple Output antennas is one alteration that has been widely embraced. Because of their ability to execute concurrent activities, these antennas have been identified as enabling increased channel capacity, high data rates, and throughput of terabytes per second [6].

Figure 1: 5G spectrum allocation Globally

2. EXISTING DESIGNS

In general, fifth generation MIMO system design model demands a large operating bandwidth for convergent operation as well as a high gain for mm-wave absorption and atmospheric reduction [7-10]. Among all of the antennas developed for 5th generation devices, the most common error has been found to be installing tightly arranged radiator units with greater isolation and low mutual coupling. As a result, current antennas designed for 5G aren't fit for use. Some of those antennas also fail to meet the requisite standards, which suggests they cannot cope with the significant atmospheric as well as propagation losses that occur on the mm-wave frequency.

As a result, current 5G antennae are insufficient. Furthermore, some of these antennas fail to meet established criteria, indicating a lack of ability to handle substantial propagation losses at high frequencies. This paper explains the design of a four antennae MIMO antenna, considering the advantages and disadvantages of existing designs. The design considers not only current 5th generation gadgets, but also those that will be released in the future. (See *figure 2* to *figure 6*, *table 1*)

2.1 Proposed Antenna Design

The design of a double pair 5G MIMO antenna is described in this study. The presence of a double pair of antennae signifies that there are four ports, two for input and two for output. The above work presents a MIMO antenna system of dimensions 30x35x0.76mm3 with four ports. CST software studio suite is used to design and simulate this antenna. (*Figure 2*)

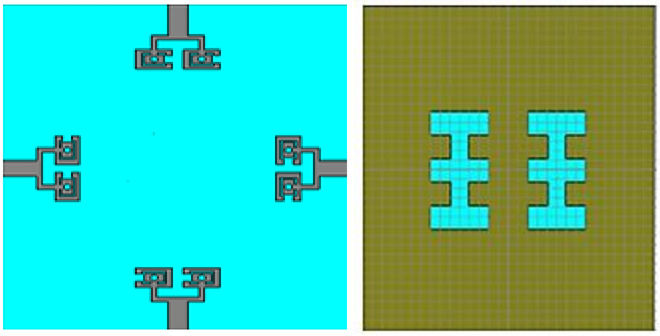

Figure 2: proposed antenna design (a) Top Layer, (b) Bottom Layer

Table 1: Parameters for proposed Design (in millimeter)

Parameter	B	W1	W2	Wi1	WLl	S
Value (mm)	1.5	3	1.66	1.6	0.42	0.8
Parameter	L1	L2	Lil	LLl	r	L
Value (mm)	2	3.4	1.35	1.5	0.3101	35
Parameter	S1	W3	h	Gl	Gw	Gb
Value (mm)	0.2	3.5	0.76	6	2.5	1.8

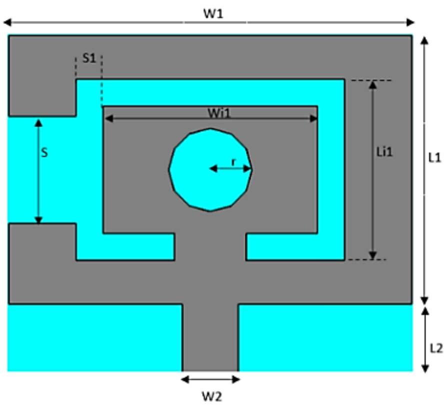

Figure 3: single element antenna

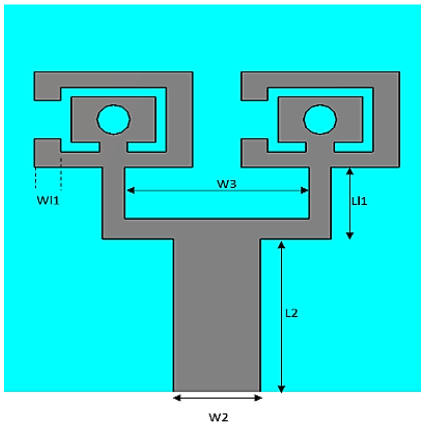

Figure 4: Two element antenna

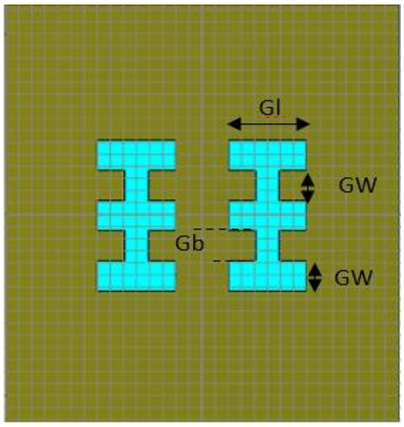

Figure 5: Ground Parameters

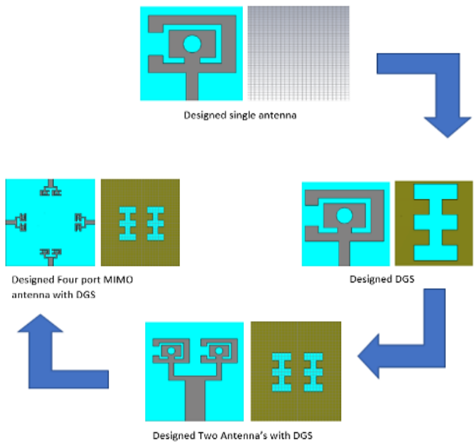

Figure 6: Design procedure of the antenna

2.2 Four Antenna MIMO Configuration

In comparison to single and double element MIMO antennas, the four antennae MIMO device is less complex to construct and performs more reliably. All four antennas for our proposed MIMO device are printed on a 10mil substrate, as illustrated in *figure 2*. The antennas are charged in opposite directions and are equal in size. The only variation between them is the distance between them, which is 6mm along the x-axis and 2.2mm along the y-axis. A 50 Ω microstrip line feeds each of the four antennas, and the dipole antennas radiate down the y-axis.

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Research Article | Volume 11, Special Issue NGWCN | Pages 15-19 | e-ISSN: 2347-470X

3. EXPERIMENTAL RESULTS

It is found that one element for the suggested network resonates in the mm wave spectrum between 26.8 to 29.6 GHz when compared to MIMO antennas. The bandwidth immediately improves when switching from a single element to a dual element, which is a considerable improvement. The double array's bandwidth is 3.5Ghz, which covers the same frequency range as the single array. (See *figure 7*)

It is usually necessary to identify the antenna's radiation behavior before using it. This is mostly accomplished by employing any measurement device, such as the ORBIT/FR far-field measurement system, to conduct radiation measurements. The radiation behavior of a system can be measured in either plane, depending on its architecture. The far-field measurements for the four -port system should always be obtained in the XZ as well as YZ planes, with the theta angle ranging from -90 to 90degrees. An illustration of radiation pattern measurements is presented. (See *figure 8*)

The predicted peak gain of the suggested design is 8.45dB, whereas the observed peak gain is 8.3dBi. While being tested, the antenna has a gain that is essentially constant and a gain bandwidth of 3dB from 26 to 29.97 GHz. On the other hand, when diversity methods are used to the module in this MIMO configuration, the diversity gain displays the loss in transmission power. For the 4-port MIMO antenna, the diversity gain is determined to be 10dB throughout the whole band. This guarantees that the antenna performs well in terms of diversity. (See *figure 9*)

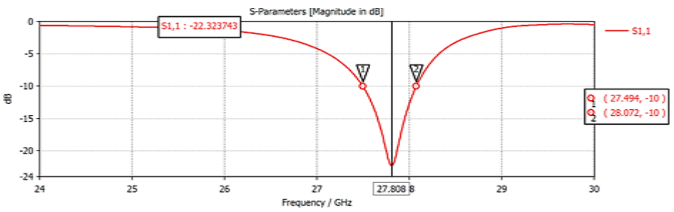

Figure 7: S-Parameters [Magnitude in dB]

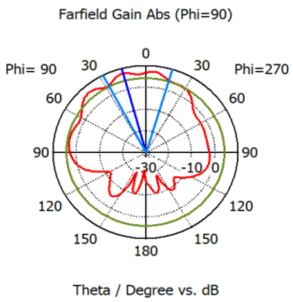

Figure 8: Far-field gain abs (Phi=90)

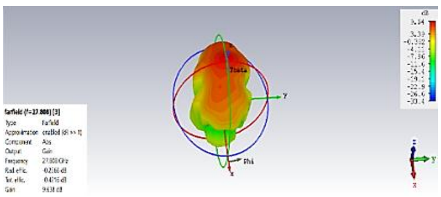

Figure 9: Radiation pattern and gain

4. MIMO PERFORMANCE

To investigate the implementation of MIMO system, there are several specifications like DG, MEG, ECC and CCL which are highly important. These specifications for the developed antenna's design are examined.

4.1 ECC& DG

Figure 10 ECC of a MIMO antenna finds the interrelationship across the different antenna units with regard to their specific features. This *equation 1* is utilized to obtain ECC.

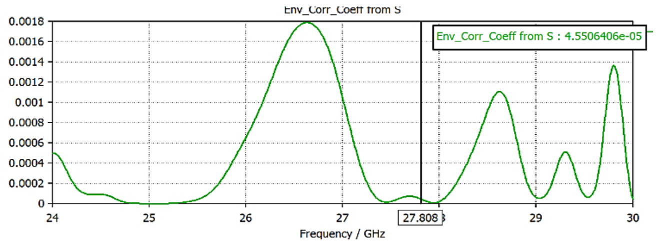

Figure 10: ECC

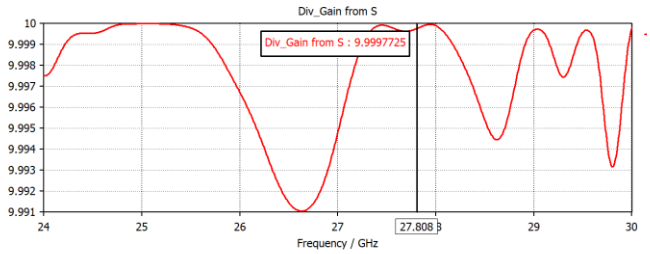

Figure 11: DG

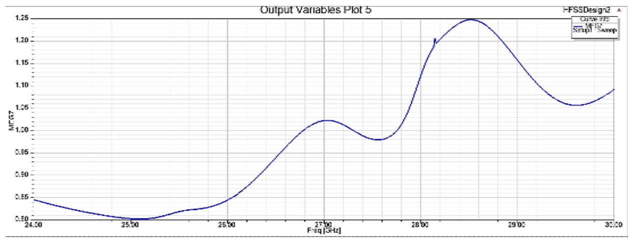

Figure 12: MEG

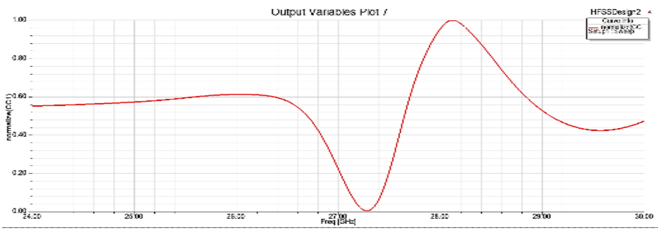

Figure 13: CCL

$$\rho_{ec.ij} = \frac{\left|S_{ii} * S_{ij} + S_{ji} * S_{jj}\right|^2}{\left(1-\left|S_{ii}\right|^2 - S_{ij}{}^2\right)\left(1-\left|S_{ji}\right|^2 - S_{jj}{}^2\right)} \quad (1)$$

While is the transmission coefficient for elements and whereas is the reflection coefficient of radiator. The graphical representation of ECC of the suggested design is illustrated in *figure 10*. It evidently exhibits that the resulted values are much less than the practically reasonable value and the value observed is 0.5 for radio system.

In the similar manner, one more essential MIMO performance metric is diversity gain. It indicates that the amount of reduced transmitted power subsequently using a diversity scheme. Diversity Gain $_g$ is derived from *eq.2* and shown in *fig. 11*.

$$D_{iG} = 10\sqrt{1-\left|\rho_{ec.ij}\right|^2} \quad (2)$$

4.2 MEG

Another notable feature to study the working of MIMO system is “Mean Effective Gain”. The ratio of incident power to average received power is shown. The formula used to represent the value for MEG as it is currently stated *eq. 3*.

$$MR_f G \frac{1}{2}\left(1-\sum_{j=1}^{k} S_{ij}\right) \quad (3)$$

For optimal diversity performance, the "Mean effective gain (MEG)" standard value should be *eq. 4*.

$$-3dB \le MR_f G \le -12dB \quad (4)$$

4.3 Channel Capacity Loss (CLL)

Generally, the channel capacity in a MIMO system increases along with the number of antenna elements. As a result of the correlation between the MIMO links, CCL calculates the channel's capacity loss. *eq. 5* and *6* can be used to calculate CCL.

Where a_k is correlation Matrix.

$$a_k = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} \quad (5)$$

$$C(loss) = -\log_2 \det(a_k) \quad (6)$$

Considering that the MIMO system's array units σ_{ii} *and* σ_{ij} have correlation coefficients of ii and ij, respectively. *Figure 13* shows the CCL for the proposed MIMO architecture. It is amply demonstrated that across the operational band, CCL is less than the practically acceptable value of 0.4 bit/s/Hz. As a result, the suggested system's high throughput is established.

4.4 Comparison with the Related Work

A comparison between the suggested antenna design and the published literature works is made using the DGS Structure, mentioned in *table 2*.

When compared to the most recent literature works, it is seen that the suggested antenna design has higher gain. These MIMO Structures, on the other hand, had four elements and come with MIMO analysis.

Table 2: Comparison with existing models

Reference	Frequency	Board Size (mm^3)	Bandwidth (GHz)	Gain (dB)	ECC, DG
[7]	28	41.3 x 46 x 0.5	3.35	10.95	0.24, >9.6
[8]	28	20 x 20 x0.25	0.85	8	0.13, 9.9
[9]	30	48 x 21 x0.13	1	7.5	<0.4, 9.7
[10]	28	30 x 35 x0.76	4.1	8.3	<0.01, >9.8
This work	28	30 x 35 x0.76	0.5	9.638	<0.01, >9.96

5. CONCLUSION

This paper presents an improved version of the log transformation model of image enhancement by including a hyperbolic tangent transformation with the logarithm image processing model. The algorithm is tested and compared with state-of-the-art methods for multiple metrics and visual analysis. The approach was assessed and evaluated in terms of various metrics and compared with four existing methods, and it was observed that experimental results yielded superior results in all aspects. The analysis concludes that this approach is more suitable for low-illuminated, night-exposure images, medical images and video based wireless communication sequences that aim to be enhanced with high quality before transmission. Experimental results proved that the proposed algorithm improved the processed image details and enhanced the overall visual quality. Moreover, the proposed method is robust to different image characteristics and computationally efficient. Thus, it is qualified for real applications. However, this method also suffers from instability for a few images where the condition of break point does not converge, leading to more processing time. So, in future, this work may be carried out further in dealing with this limitation and employ supervised algorithms for improving the metrics.

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