International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Electromagnetically Coupled MIMO Antenna for 5G Communication

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Submitted:11/03/2024 **Revised**: 26/04/2024 **Accepted**: 03/05/2024

Abstract: This article introduces a quad-port antenna for 5G wireless communications. The antenna is fed by means of aperture-strips electromagnetic coupling. The optimized slots inside the patch induces strong electromagnetic fields which excites the dielectric resonator (DR). The DR is kept above the slits of the patch for induction of resonant mode. The antenna has bandwidth of 3.53% and 256% at 3.39 GHz and 4.68 GHz. The mechanical dimensions of the antenna are 30 mm x 30 mm. The antenna has full ground which works as a reflector and presents higher peak gain in boresight worth 2.95 dBi and 2.42 dBi. The diversity parameters of MIMO are at par with communication requirements.

Keywords: *MIMO diversity; aperture-coupling, planar resonator, EM coupled;*

1. Introduction

Using manifold resonators at both the sender and receiver in wireless systems is called multiple-input multiple-output (MIMO) system. It has become very popular very quickly over the last ten years because it greatly improves performance. Multi-path fading is the main factor that hampers communication in wireless channels. Multipath refers to the phenomenon where a broadcast signal reaches its intended recipient through various angles, time delays, and frequency shifts caused by the dispersion of electromagnetic waves in the surrounding environment. As a result, the power of the received signal varies at different locations (because to the spread of angles), frequencies (due to the spread of delays), and over time (due to the spread of Doppler shifts) because of the random combination of the several paths the signal takes. The quality and dependability of wireless communication can be significantly impacted by this erratic change in signal strength, sometimes referred to as fading. Moreover, the limitations imposed by restricted power and insufficient frequency spectrum present a formidable challenge in the development of wireless communication systems that offer high data rates and reliability. MIMO technology is a significant advancement in the design of wireless communication systems. The system has several advantages that address the difficulties caused by both the limitations in the wireless channel and resource limitations. A key strategy for establishing present and The utilization of multiple antennas at both the sender and receiving terminals is a key aspect of forthcoming wireless communication systems. MIMO technology utilizes multiple channel communication to provide improved data speeds, even in challenging fading settings.

[1] exhibits sub 6 GHz MIMO antenna with square enclosed circular split ring resonators. It describes electrically compact antenna with high efficiency and gain. A metasurface has been employed along with a truncated partial ground plane to achieve targeted antenna parameters. In another technique presented in [2], a CPW-fed antenna with polarization diversity is designed for mobile devices, wherein quad elements of antennas are kept at the farthest angles of the communication device. The design of a uniplanar MIMO antenna with four radiators in the form of loops is presented in [3]. Furthermore, the study investigates how the antenna is affected by a human hand and head. The article [4] presents a concise description of a MIMO antenna with two elements, designed for triple band application. The antenna utilizes a common ground plane and incorporates an inverted H-shaped stub as a decoupling device. [5] offers a dual-band MIMO resonator with a defective ground plane for 5G wireless communication. A resonator element is proposed to have a patch with an F-shaped and an L-shaped conducting lines. An electrically small dual band MIMO with an omnidirectional radiation pattern is described in [6]. Targeted antenna parameters have been achieved using a two-element configuration with a defective ground structure. In [7] integrated patch antenna is defined as a system that supports millimeter Wave 5G MIMO and mid-band MIMO is discussed. It encompasses a range of frequencies for mid-band and 5G-mmWave applications. In order to facilitate 5G smartphone applications, a dual-band MIMO system with 8 elements is suggested in [8]. To minimize the mutual interaction between antenna elements, a radiating element has been positioned on the PCB's bidirectional sides. A four-element MIMO slot antenna is described for 5G tablet computers [9]. To optimize utilization of the tablet's area, multi-element is implemented on the corner edges of the

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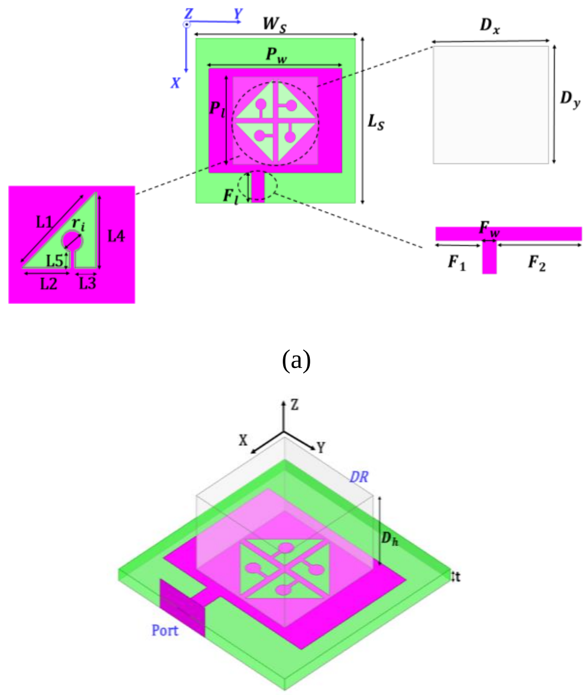
communication device. A full-wavelength strip resonator that is ungrounded is employed to establish separation between the two slot antennas. [10] presents an 8 x 8 dual-band MIMO antenna that operates in the sub-6 GHz region and is intended for 5G MIMO smartphone usage [10]. To lessen mutual coupling, an antenna element made of monopole is symmetrically positioned along the smartphone's long edges and on its corners. For sub-6 GHz applications, a metasurface inspired multi-element resonator for wide bandwidth and strong isolation properties is suggested in [11]. In [12], a proposal is made for a planar 5G MIMO antenna that integrates beamforming antennae. This antenna is designed for potential application in vehicle-to-everything (V2X) networks. Nevertheless, the DRA MIMO antenna for 5G communications is not well-documented in literature. A multi-band CP-DR with a single feed is presented for GPS and WLAN applications [13]. The metallic strip is positioned above the DRA to improve the bandwidth. In [14], a four-port connected ground MIMO antenna inspired by a dielectric resonator is given for WLAN and communication applications using frequencies below 6 gigahertz (GHz) for 5G technology. Through strategically placed triangle slots, the antenna achieves dual band by feeding the rectangular dielectric resonator. [15] presents a CP - RDRA designed focusing on circular polarization based communication applications. The antenna demonstrates enhanced isolation through the utilization of a flawed ground plane structure. A hexagonal DRA with circular polarization, comprising of two dielectric layers, has been presented for 5G Sub 6GHz application in reference [16]. The presence of an S-shaped slot in the ground plane, along with a micro strip line, allows for the production of right-hand circular polarization. Integrating a band pass filter into the feedline enhances the antenna efficiency. The sub-6GHz use of the four-element probe-fed MIMO DRA is illustrated in reference [17]. A compact MIMO Distributed Reconfigurable Antenna (DRA) is introduced in reference [18] specifically tailored for Internet of Things (IoT) use cases. The antenna can work in two different frequency bands. Each antenna is designed to vibrate at two different frequencies and provides a bandwidth that matches those frequencies to make sure that the impedances match up correctly. [19] presents a quad-port DRA that is excited via CPW technique for use in the NR N47 sub-6GHz frequency range. A cross-shaped construction is designed to optimize efficiency and achieve a wideband resonance of around 11% for dual band operation. The ring DRA structure for the CP MIMO antenna is shown in [20]. To enable the HE modes, two probes are placed at right angles to each other. In addition, by adjusting the length of the probes, it is possible to accomplish time phase quadrature between modes. Other MIMO antennas are exhibited in [21-23].

2. Design Outline

The designed unit element is illustrated in Figure 1. A dumbbell shaped slits were optimized and kept beneath the DR for excitation. The patch element's dimensions are 19 mm x 25 mm and dimension of DRA element is 12 mm x 12 mm. The 3-dimensional view is shown in figure b. There is a full ground plane under the substrate. The dielectric resonator antenna has benefit of absence of conducting elements. This helps to reduce the antenna losses and due to which high gain values can be attained. The positioning of the slits is tailored in such a way that optimal coupling between the radiated fields and DR can be achieved. The aperture-coupling has a strong electromagnetic excitation of the DR. The dielectric material polarization alters due to induced electromagnetic fields and because of this the dipole moment gets altered. This shall store the field within the dielectric material and eventually the radiations shall be emitted out of the antennas.



(a)

(b)

Fig. 1: Views of the Antenna (a) From the Top (b) Perspective

Figure 2a illustrates the antenna phase-wise evolution and Figure 2b depicts the reflection coefficient as an outcome of the modifications in the slots. As shown in the illustrated images, the Phase-I has primary cuts within the patch, because of it an antenna resonance was achieved. This response was altered due to the further changes exhibited as Phase-II. Finally, the dumbbell shaped slots were optimized for targeted application response as exhibited in Phase-III. The table 1 tabulates the mechanical property of all the physical parameters of tailored antenna and the elements within it.

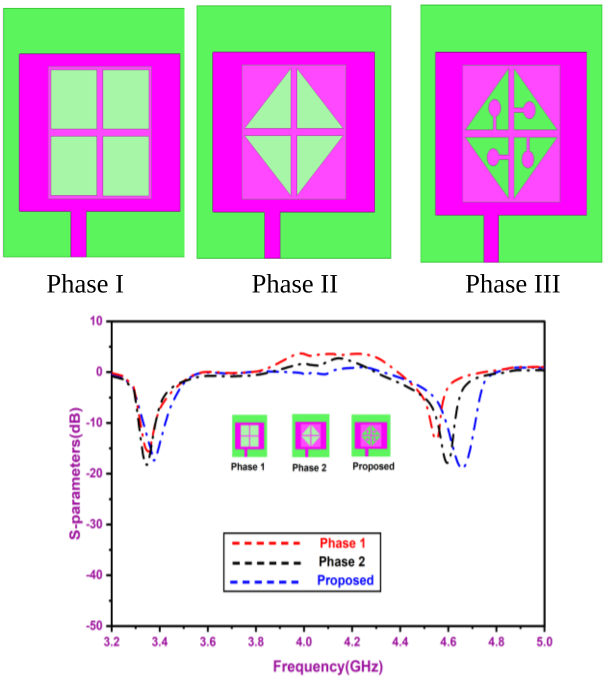


Fig 2 : Phase-Wise Generation of Geometry Reflection Coefficient

Table 1. Geometric specifications of a single-element antenna, with measurements specified in millimeters.

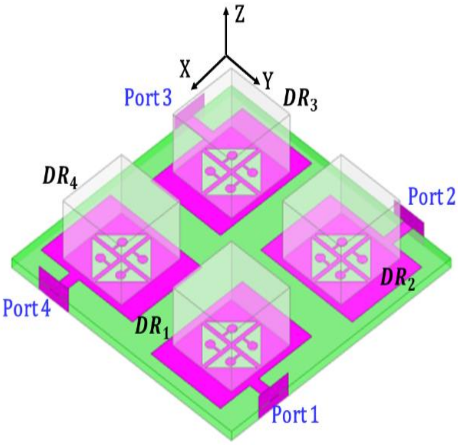
Parameter	*Dimension*	*Parameter*	*Dimension*
Ws=Ls	30	L3	2
Dx=Dy	16	L4	7
Pw	25	L5	1.5
Pl	19	ri	1
Dh	10	G1	3
L1	10.15	G2	3
L2	4.6	Fw	2.4
F1	8	Fl	5.5
F2	14.6	t	1.56
Wm	60	Lm	60

3. Results And Discussions

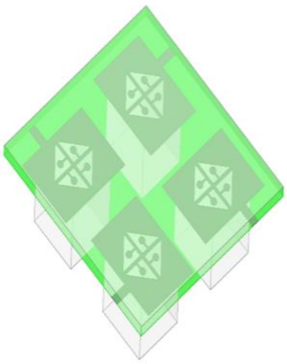
The MIMO design is presented in figure 3. The substrate was extended further to accommodate all the quad-antenna elements. In order to achieve the MIMO antenna's diversity parameters, the element gap is chosen rather carefully. If they are kept nearby then it is very likely that there shall be coupling between the elements, due to which it is very difficult to achieve the required diversity parameters. Also, the physical dimensions are not kept too big so that electrical length of the antenna becomes too big. It becomes cumbersome to fit the extremely large antenna within the 5G communication module and hence it is extremely necessary to limit the physical dimensions of antenna. The MIMO antenna has footprint of 30 mm x 30 mm. The dielectric material of DR was fixed with the patch antenna by means of conducting paste material. The resonator reflection coefficient simulation and measurement are presented in figure 6. The mechanical model was manufactured to compare simulation results with the hardware results. The measurements were carried out by P5004A streamline vector network analyzer. This is a table-top analyzer of the antenna. The antenna has dual band at 3.39 GHz and 4.68 GHz as exhibited in figure 4.

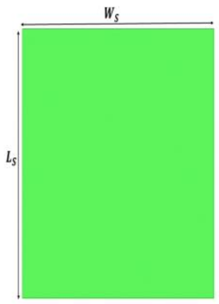
The bandwidth of the antenna depends on multiple factors. The patch antennas have very low bandwidth. Due to patch slots, the fields get altered and the bandwidth of the antenna increases with increase in multiple nearby resonance. It is possible to generate the higher order resonating modes for dielectric resonators however many antenna parameters get comprised. However, it is most relevant to utilize the DR wherever there is a requirement of high gain. The bandwidth of the antenna is 3.53% and 2.56% respectively. The impedance matching between the port and antenna is crucial for improved reflection coefficient. The dual-band has reflection coefficient of -17.23 and -19.57 was achieved by using the best values of the feed. The higher the matching lower the return loss as the signals gets good termination in the load. The strip of the antenna feed was modified multiple times through HFSS simulation to get the load near to 50 Ω.

The orthogonal alignment of the conducting elements and DR was to attain the diversity parameters. The linear-polarization shall co-inside with another linear-polarization. The vertical polarization along with horizontal polarization shall have lesser mutual coupling effect and hence diversity shall be accomplished. There are also other orientation techniques viz. mirror arrangement on opposite side of the substrate, two opposite mirror arrangement etc. However, these shall not be able to give polarization diversity. The farthest ends of the substrate have been selected to obtain spatial diversity of the MIMO resonator. There is a tradeoff between the dimensions against MIMO antenna diversity.



(a)





(b) (c)

Fig. 3: MIMO Antenna (a) Upper (b) 3D Lower (c) Ground

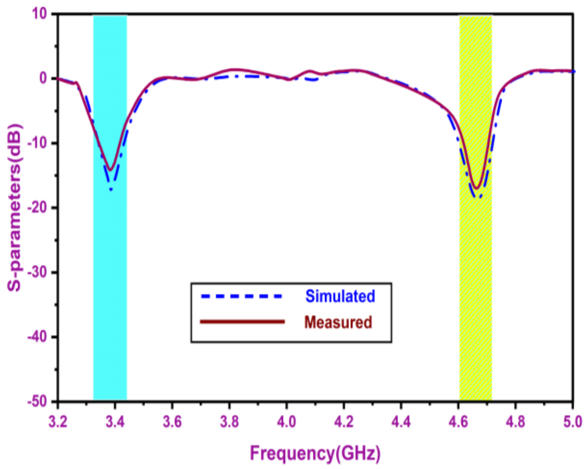
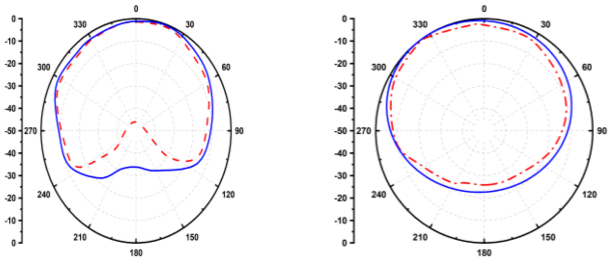
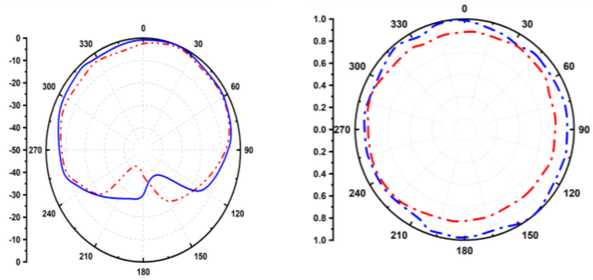


Fig. 4: S_{11} Parameters

Figure 5 shows a representation of the radiation pattern that the antenna emits at dual-frequencies. The structure of the antenna has full-ground plane profile owing to which a radiation occurs in unidirectional mostly in the boresight direction of the antenna. The electric field pattern of dual-band presents this phenomenon. The magnetic field pattern of the antenna shall be omni-directional due to its electrical properties. The magnetic field patterns as exhibited in figures exhibits this phenomenon. Since the radiation of the antenna shall be in one direction, it possesses higher directivity. The gain is dependent on the directivity and antenna losses. As the utilized material for the antenna is dielectric, overall losses are quite less due to which high gain was achieved.



(a)



(b)

E-plane H-plane

Fig. 5: Radiation Patterns (a) *f1 (b) f2*

The gain plot is exhibited in figure 6 wherein the gain values are 2.95 dB and 2.42 dB. The figure 7 illustrates the efficiency of the antenna which around 89.28% and 87.92% at both the bands respectively.

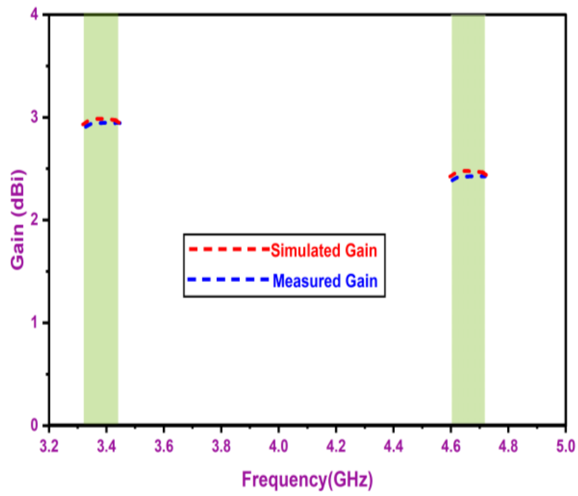


Fig. 6: Gain

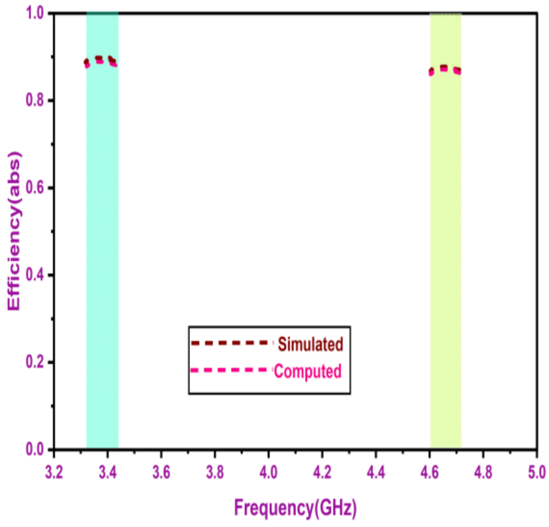


Fig 7: Efficiency

4. Diversity Parameters Of MIMO:

Achieving the benefits of MIMO systems requires careful consideration of the diversity values. The multi-channel transmission and reception shall enable significant reduction in noise and substantial improvement in communication Quality of Service (QoS). Due to this an enhanced data-rate can be obtained irrespective of the channel environment. The MEG power ratio, TARC reflection coefficient and CCL losses were examined for MIMO diversity parameters. As exhibited in Figure 8, MEG power ratio is examined for the MIMO antenna. MEG provides the reference power in context to isotropic antenna. Due to structural composition of the antenna, MEG power ratios are near to one. The ratio is taken between all four ports. Figure 9 illustrates TARC values. The TARC is lower than -20 dB for both the frequencies. It is expected that TARC values should be lesser than -17 dB for optimized performance of MIMO antenna. Figure 10 displays the CCL (co-channel interference level) of the MIMO antenna. The allowable values for the CCL are around 0.5 bits per second per Hertz. The designed antenna has CCL of values better than this values.

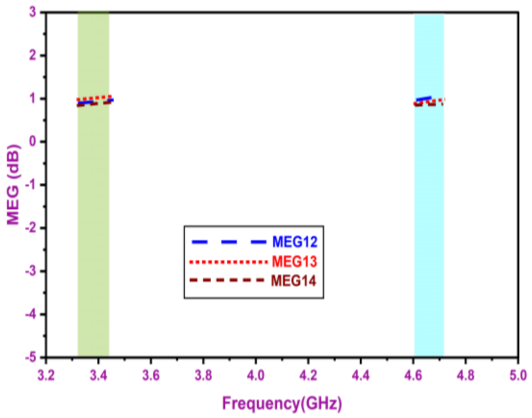


Fig.8: MIMO MEG

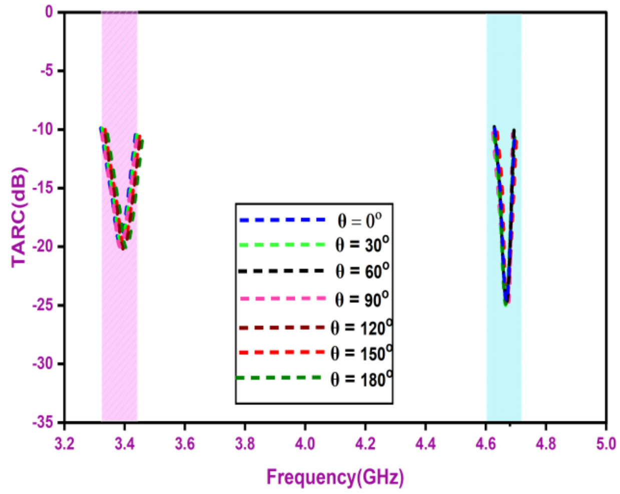


Fig. 9: MIMO TARC

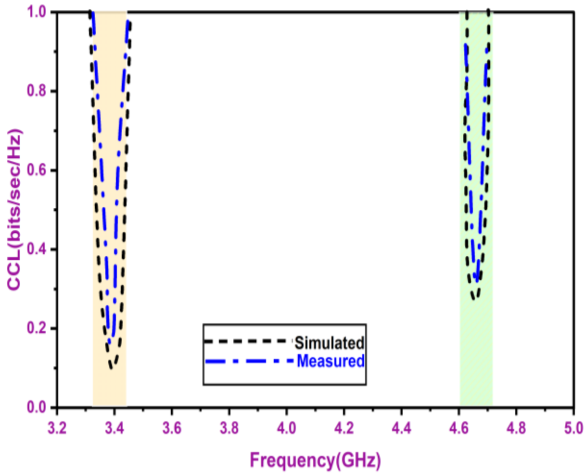


Fig. 10 : MIMO CCL

5.Conclusion:

The paper presents a MIMO antenna with four ports that utilizes a dielectric resonator. The antenna operates in dual-mode due to the optimized electromagnetic coupling between the fields produced by the dielectric material and patch resonators. It offers a notable gain of 2.95 dBi at 3.32 GHz and 2.42 dBi at 4.6 GHz, respectively. The antenna's diversity performance fulfills the intended communication requirements.

5.1 Acknowledgment

No funding was received for the research.

5.2 Author contributions

Arpita Patel.: Conceptualization, methodology, literature review, data curation, and analysis.

Arpita Patel: Investigation, validation, visualization, and writing.

Arpita Patel:Visualization, Investigation, Writing-Reviewing and Editing.

Arpita Patel: Investigation, Writing-Reviewing and Editing.

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