A Modified Hexagonal Shaped Sub-6 GHz 5G Antenna in MIMO Configuration

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***Abstract*—A line-fed Modified Hexagon shaped 2-port planar antenna is presented for 5G application. The MIMO antenna is designed through combining the techniques of a modifying the radiator and defected ground structure. In the MIMO configuration, two replicas of the MIMO element are arranged orthogonal to ensure the pattern diversity. A cross shaped structure is integrated with the ground to enhance interelement isolation. The size and operating bandwidth of the MIMO antenna are 28×56 mm^2 and 2.54 GHz to 5.46 GHz, respectively. This design advantageously offers a wide -15 dB bandwidth from 3.3 GHz to 5.0 GHz with a percentage bandwidth of 40.96% and a peak realized gain of 3.1 dBi at 3.3 GHz. Maximum isolation value of 33.55 dB is achieved while it is never less than 16.85 dB for the frequency of interest. The envelope correlation coefficient (ECC) $<$ 0.003, mean effective gain (MEG) $<$ -3 dB, and diversity gain (DG) approaching to 10 have been achieved. The MIMO design is fabricated and experimentally tested for S-parameter analysis and the results matches satisfactorily. This antenna will be highly suitable for sub-6 GHz 5G communication applications in today's world.**

***Index Terms*—Modified hexagon, MIMO antenna, pattern diversity, connected ground, ECC, wideband.**

I. Introduction

Over the years, the wireless technology has witnessed significant development from first generation (voice calls) to fifth generation (HD data transfer). In the wireless experience, people have sought out greater access rates and less latency. The 3GPP has released new 5G NR specifications namely n77 (3300-4200 MHz), n78 (3300-3800 MHz) and n79 (4400-5000 MHz). However, different countries have their own 5G frequency bands which could be either one or two of them, it is a good approach to design a wideband antenna that covers all 5G NR bands to comply with the specifications in the different countries [1].

Currently MIMO antenna is widely employed for 5G communication. In MIMO antennas the inter-element isolation should be strong with low mutual correlation. In these types of antennas, very low inter-element distance is being maintained between the individual elements. Also, the footprint embodiment engaged by each antenna should be compact which is measured in λ_0^2, which is the wavelength of lowest operating frequency [2], [3].

In the past years researchers have proposed several antennas for sub-6 GHz and 5G NR in [4]–[7]. These antennas utilized rectangular monopole antenna element with total electrical area of 0.592 λ_0^2, two-arm monopole radiator element with total electrical area of 0.613 λ_0^2, fractal shaped antenna element with total electrical area of 0.38 λ_0^2, slotted octagon shaped antenna with total electrical area of 0.335 λ_0^2 respectively. The size of antenna for 5G NR band of interest can be reduced compared to the above literatures.

Reference [8] uses a new kind of mathematically inspired shape by cutting half circles in both side of square from centre, whereas [9] uses a modified Y shaped monopole with defected ground structure. Both the above antennas show comparable performance in terms of size, isolation and ECC. They have moderate gain of 1.0 dBi and 1.5 dBi respectively, which can be increased in a newer design. Also, the improvement can be done in bandwidth as they are not able to operate in all 5G NR bands.

The improvements are accomplished in proposed 2-port MIMO design which reduced the electrical area with radiation efficiency more than 77%, improved peak gain of 3.1 dBi, with low ECC and comparable isolation for full 5G NR sub-6 GHz band. This antenna has -15 dB bandwidth from 3.3 GHz to 5.0 GHz which includes n77, n78 and n79 bands of 5G NR. Here, -15 dB bandwidth is advantageous as reflections are limited to 3.125%. In this way it fulfils the requirement of wide band antenna for the performance, capacity, and adaptability of 5G networks, enabling them to meet the demands of modern communication, such as improved coverage and enhanced capacity even with the variation of regions.

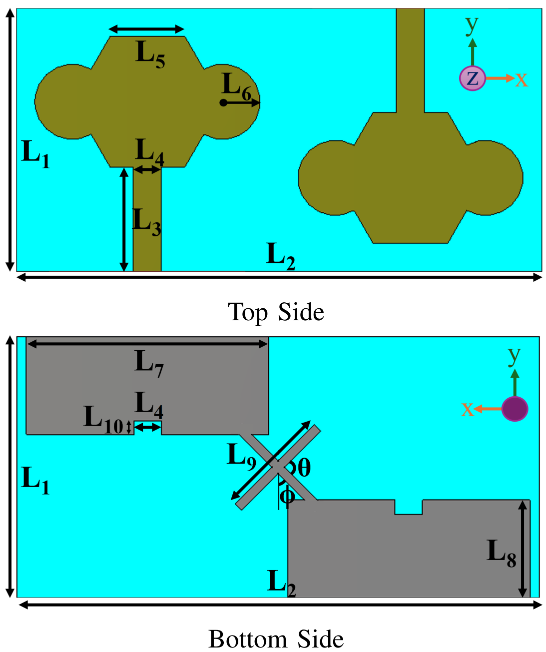

Fig. 1. 2-port MIMO antenna configuration with details of dimensions.

TABLE I
DIMENSIONS OF MIMO DESIGN

Parameter	Dimensions	Parameter	Dimensions
L_1	28.00 mm	L_7	26.00 mm
L_2	56.00 mm	L_8	10.50 mm
L_3	11.12 mm	L_9	12.00 mm
L_4	03.00 mm	L_{10}	01.50 mm
L_5	08.00 mm	Φ	45.00°
L_6	04.00 mm	θ	90.00°

II. PROPOSED 2 × 2 MIMO ANTENNA

In Fig. 1, the schematic diagram with dimensions of proposed 2-port modified hexagonal shaped antenna is presented. The design is etched on a standard FR-4 substrate with a thickness of 1.6 mm due to its low cost and ease of availability. The cross-section of the structure is 28 × 56 mm^2 and the elements are fed via a 3 mm broad microstrip feed line with a reference impedance of 50 Ω. All the dimensions of the proposed 2-port antenna represented in Fig. 1 are given in Table I. The desired frequency of interest, available substrate for antenna prototyping, and degree of freedom inherited within the geometrical shape of the antenna are the critical factors behind the selection of the particular antenna structure. Hexagonal antenna offers unique benefits, such as compact size and improved bandwidth, as they provide greater freedom in antenna performance analysis. However, there are some challenges in the said geometry, such as gain variability, size constraint, and complexity in the design fabrication. Using modern simulation tools improved bandwidth and flexibility in the applications achieved by carefully examining the geometrical modifications and antenna miniaturization.

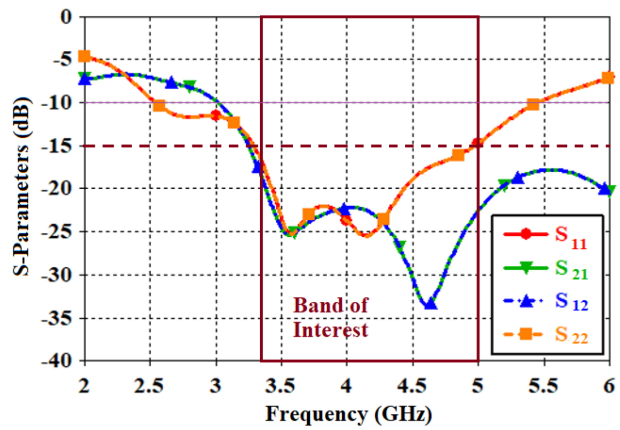

Fig. 2. Variation of simulated S-parameters with frequency.

A. Design Procedure

The design presented in Fig. 1 is made using 2 single elements of modified hexagons with defected ground structure on back side. The hexagon is modified by placing 2 circles of radius L_6 on both side vertices. At the top middle portion of the ground in each element, a rectangular cut is made to improve the transition. Both the grounds are connected with a 0.5 mm thick copper line at an angle of 45° from the central vertical line. At the central point another decoupling line is placed with length L_9 at an angle of 90° from the connecting ground line. The final design is optimized for full 5G NR sub-6 GHz bandwidth using parametric analysis on the radius of circle (L_6), length (L_7) of ground plane, width (L_8) of ground plane, length (L_9) and width (0.5 mm) of decoupling line as well as connecting line, angle Φ and angle θ. After completing the analysis the values of these parameters have suitably chosen for the band of interest with satisfactory performance on other results.

III. RESULTS AND DISCUSSION

This section presents and discusses the simulated results for S-parameters, measured results for S-parameters, analysis of antenna performance as radiation pattern, gain, efficiency, surface current etc. and analysis of MIMO performance measured in terms of MEG, DG and ECC for the proposed design. All the simulated results presented in this paper are produced with CST 2019.

A. Simulated S-parameter Results

Fig. 2 shows the simulated S-parameters of the above 2-port design. As presented in figure, above antenna operates at 4.0 GHz with -10 dB bandwidth from 2.54 GHz to 5.46 GHz. It is expressed in Fig. 2 as S_{11} as well as S_{22} which expresses the reflection coefficient. Also, for the sub-6 GHz 5G NR band, it gives -15 dB bandwidth from 3.3 GHz to 5.0 GHz. For the band of interest the mutual coupling is always less than 16.85 dB which is represented by S_{12} and S_{21}. The above results shows that this MIMO configuration can be used in n77, n78 and n79 bands of 3GPP 5G specifications.

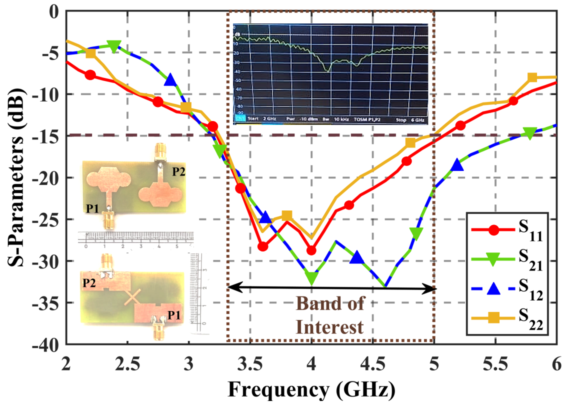

Fig. 3. Variation of measured S-parameters with frequency, hardware prototype (inset), and measurement screen (inset).

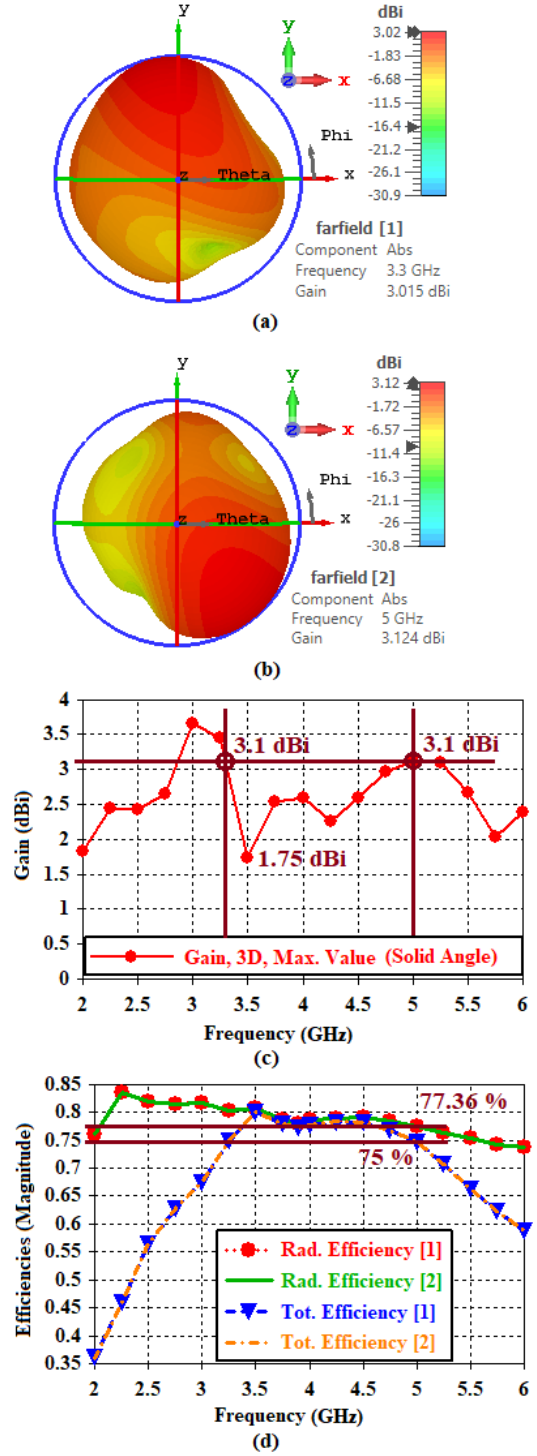

Fig. 4. 3-D Radiation patterns for (a) Port-1 at 3.3 GHz and (b) Port-2 at 5 GHz, (c) Gain versus frequency and (d) Efficiencies versus frequency plots.

B. Measured S-Parameter Results

The above antenna prototype is fabricated in laboratory and S-parameter measurements have been performed on vector network analyzer VNA-ZNB40. The measured S-parameters are presented in Fig. 3. It also shows the hardware prototype, and the measurement screen inset. The measured S_{11} also provide the full bandwidth range for n77, n78 and n79 bands and the mutual coupling is always below -18 dB. These results show satisfactory matching with simulated results presented in Fig. 2.

C. Antenna Performance Parameters

- Fig. 4(a) and 4(b) illustrate the radiation pattern (3-D) for the presented design when port-1 and port-2 are excited respectively. These patterns express the information of radiation in terms of gain.
- The peak gain of this antenna is 3.1 dBi at 3.3 GHz in the sub-6 5G NR band which is maintained always above 1.75 dBi. This is also presented in Fig. 4(c).
- Fig. 4(d) shows the radiation efficiency with the variation of frequency. The radiation efficiency is always above 77.36% whereas the total efficiency is always above 75% in the band of interest which shows that the antenna is good enough in terms of efficiency.
- Fig. 5 shows the surface current distribution for the presented design. In this configuration both the radiating elements are excited one by one, and the other element is terminated with 50 Ω load respectively. When port-1 is excited, maximum surface current flows from element-1 whereas on exciting port-2 maximum current flows through element-2 as shown in Fig. 5. This happens due to the flow of coupling current to full ground through the connecting ground lines. Due to this both the elements separately contribute in the performance of the antenna, even though they have a common ground plane, which shows their isolation characteristics.

D. MIMO Performance Parameters

- To measure the correlation between radiation patterns of nearby antenna elements, ECC is used, and it can be find using Eq. 1 [9].

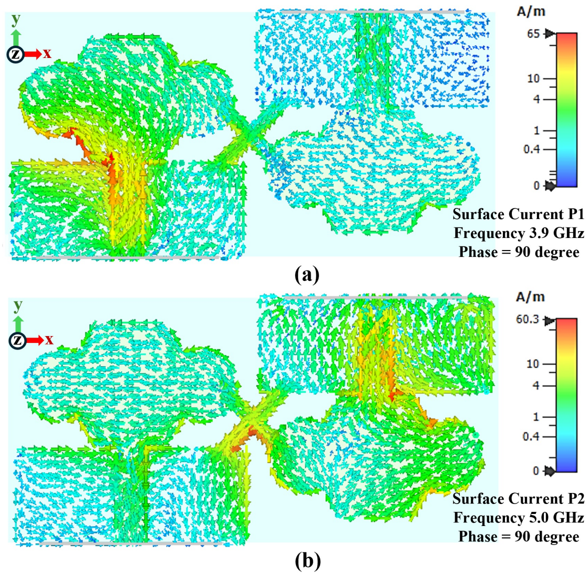

Fig. 5. Surface current distribution for (a) Excitation on port-1 at frequency 3.9 GHz and (b) Excitation on port-2 at frequency 5.0 GHz.

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

Where ρ_e represents ECC computed from S-parameters. Using far-field it can be calculated using Eq. 2 [10].

$$\rho_e = \frac{\left|\oint E_1.E_2^* d\Omega\right|^2}{\left|\oint E_1.E_1^* d\Omega \times \oint E_2.E_2^* d\Omega\right|} \quad (2)$$

In Fig. 6 the variations of ECC is presented through S-parameter computation as well as Far-field computation and both are matching satisfactorily. For the proposed antenna the value of ECC is always less than 0.0024 for 3GPP 5G NR band and 0.073 for the entire band

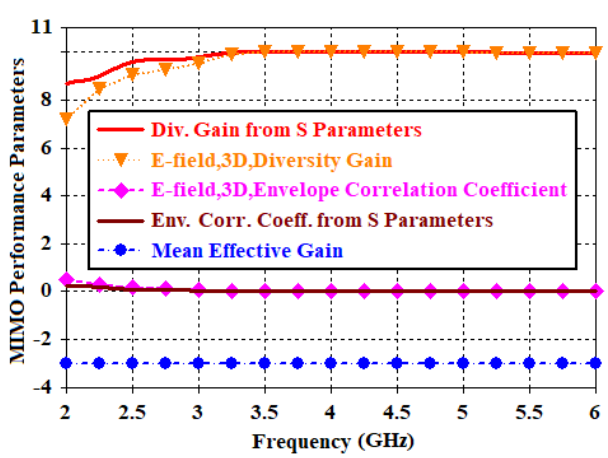

Fig. 6. Variation of ECC, DG and MEG with respect to frequency.

TABLE II
COMPARISON OF PROPOSED ANTENNA TO PREVIOUS LITERATURE

Ref. No.	No. of Ports	Electrical Area (λ_0^2)	Frequ- -ency (GHz)	Isola- -tion (dB)	ECC	Peak Gain (dBi)
[4]	2	1.09×0.543	2.0–3.71	20	0.002	7.5
[5]	4	0.783×0.783	3.0-4.12	20	0.005	4
[7]	2	0.696×0.481	3.1-4.5	20	0.004	-
[8]	2	0.240×0.490	1.5-2.10	17	0.005	1.0
[9]	2	0.235×0.469	3.9-5.0	17.75	0.003	1.5
Prop.	2	0.308×0.616	3.30-5.00	16.85	0.0024	3.1

of operation which satisfies the requirement of ECC less than 0.5 as discussed in [10].

- Fig. 6 also express that the value of diversity gain (DG) always approaches to 10 which completes the requirement of MIMO antenna. DG measures the increase in signal to interference ratio for a certain diversity scheme. Eq. 3 can be used to calculate the DG [10].

$$DG = 10\sqrt{(1 - |ECC|^2)} = 10\sqrt{(1 - |\rho_e|^2)} \quad (3)$$

- MEG compares the average power received to the average power incident at an antenna while accounting for environmental factors at the time of measurement and usages. It can be calculated using Eq. 4.

$$MEG_i = 0.5(1 - \sum_{j=1}^{K} |S_{ij}|) \quad (4)$$

In Fig. 6 it is depicted that the value of simulated result for MEG is the average MEG ranges between -3 dB to -6 dB which is as per requirements suggested in [11].

IV. CONCLUSION

A modified hexagonal shaped 2-port MIMO antenna having a footprint of 0.18973 λ_0^2 for sub-6 GHz 5G NR applications is reported in this article. It provides peak gain of 3.1 dBi with efficiency greater than or equal to 75%. A redesigned radiator, line feeding, and a defective common ground structure are used to obtain wide bandwidth of 40.96% (3.3–5.0 GHz) with a -15 dB loss. A cross-shaped decoupling structure between the ground elements is combined to increase the isolation over 16.85 dB within the intended bandwidth of 3.3-5.0 GHz, which improves up to 33.55 dB. Also, it is always greater than 22 above 3.4 GHz advantageously. The MIMO performance parameters fall within the acceptable limits as discussed in results viz. ECC less than 0.0024, DG approaching to 10 and MEG below -3. The prototype of the above antenna configuration is fabricated and experimentally tested in laboratory. The measured S-parameter analysis agrees well with the simulated results. Comparing the suggested design to existing recent designs in the literature's referred in this paper, demonstrates an appropriate MIMO performance parameter set, a compact physical size, and bandwidth that is either equivalent or better, as depicted in Table II. The proposed design is appropriate for sub-6 GHz n77, n78 and n79 band 5G NR applications.

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