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Sub-6 GHz Band Massive MIMO Antenna System for Variable Deployment Scenarios in 5G Base stations

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Abstract

A compact massive MIMO antenna system with 1x4 (sector) subarray setup working at sub-6 GHz range for 5G base stations has been planned and broke down in different configurations(rectangular, triangular and hexagonal). The limit of a system can be expanded by more than 10 times whereas the energy efficiency can be expanded 100 times utilizing a Massive MIMO system. A limit of 5 sectors has been utilized with every sector containing 1x4 subarray components. Every sector comprises of three layers, in which 1x4 patches is situated on its top layer though it's taking care of organization and ground plane has been set in the base layer and the centre layer individually. The whole system can work in two modes, singular port activity and massive MIMO exhibit activity with shaft guiding abilities. The deliberate data transmission of the framework is 140 MHz that covers the frequencies from 3.36 GHz to 3.50 GHz in sub-6 GHz band. The general component of a unit subarray regarding length, width and tallness was 280.5 x 56.1 x 2 mm³. The gain of an individual port is discovered to be 12.95 dBi and the general addition of a single panel with 5 sectors arranged in rectangular structure is 19.73 dBi. Mutual coupling among all the ports has been kept not exactly - 16 dB. The working frequency of the radio antenna array system is picked in the scope of 3.3 GHz to 3.8 GHz as this band has been assigned and focused across the globe to empower 5G in Sub-6 GHz band.

Key words: Subarray, Massive MIMO, Antenna array, Mutual coupling

1. Introduction

5G is expected to rule the world in the near future due to its ability to support ultrahigh speed broadband connection with minimum latencies in comparison to its old generations including 4G. With increase in demand for autonomous vehicles along with the requirement of smart cities and over the air internet, 5G will be the heart of the wireless communication environment [1]. The above requirements are met using various technologies of 5G like advanced coding techniques, millimetre wave (mmwave) communication, massive MIMO systems etc., [2-4]. Our focus in this paper will be on massive MIMO systems which are believed to have increased data rate, better efficiency in terms of spectrum, energy and reduced interference due to its beamforming capabilities. Also the use of less expensive low power components can be preferred for massive MIMO systems [5-7]. Due to these merits over mmwave in terms of the distance coverage. Even though millimetre wave spectrum supports highest speeds, its limited coverage makes it impossible to deploy with immediate effect. But it can be deployed in selected locations like high traffic areas [8-10]. As per the literature review, very few papers were found in the field of massive MIMO antenna system design. Most of those papers show the design based on arrays operating in the frequency range of 28 GHz to 38 GHz, which falls under millimetre wave

communication. But none of the above work shows tested results based on fabricated prototype [11-14]. The literature survey also shows that the antenna has been designed in low frequency (i.e. in ISM band) and simulation results have been displayed without any test results [15-18]. Also some research works show the design of array antenna in hexagonal or triangular configuration [19]. Few other research works explain the effective use of reflectors and arrays in massive MIMO systems [20]. So, from the above survey, it is evident that no comparison study has been made between two different configurations. In this work, we propose a massive MIMO antenna system design with multiple sectors, each sector comprising of 4 patches in the 1x4 geometry. Different configurations like single sector, 3 sectors in triangular shape and 5 sectors in hexagonal shape has been designed and simulated.

2. Literature Survey

Table 1 Literature review summary

Reference	Band coverage, (GHz)	MIMO order (RF ports)	Single element type	Max. gain (single port)	Geometry	Single sector size	BW (MHz)	Prototype fabrication
[21]	3.6	3x24	2x2 patches	8.5dBi	hexagonal	44.4 cm x29.6 cm	100	yes
[22]	5.8	Single panel	1x4 patches	11 dBi	hexagonal	256 cm x21.5 cm	200	yes
[23]	3.7	Single panel	100 patches	NA	NA	60 cm x120cm	138	yes
[24]	2.4	NA	9x12 Patches	6.5 dBi	nonagon	7.5 cm x25.5cm	200	No
[25]	6–8.5	Single panel	Horn type	NA	NA	70 cm x70cm	2500	yes
[26]	2.6	6x32	1x4 patches	10 dBi	hexagonal	NA	198	No
[27]	2.6	6x4	1x4 patches 9	.2 dBi	hexagonal	NA	120	No
[28]	3.7	3x6x8	2x2 patches	10.5 dB	hexagonal	32.4 cm x8.6cm	160	yes
Design Proposed	3.36-3.5	5x4	1x4 patches	12.95d Bi	Rectangular/ Triangular/ Hexagonal	280.5mmx56.1mm	140	yes

Table 1 gives a reasonable picture about the different research works done by the researchers in the field of massive MIMO antenna plan. The current work includes the reception apparatus configuration is more than one calculation, with the goal that the necessary arrangements can be picked and executed in appropriate organization situation. This gives the current work an edge over others where antenna array configuration is finished by the one geometry which restricts the applications.

3. Antenna System Design

3.1 Single Sector Design

The patch antenna has been planned with most extreme consideration by ascertaining the significant boundaries like the working frequency, dielectric constant and height of the substrate utilizing the plan equations portrayed beneath.

$$W = \frac{1}{2F0\sqrt{\frac{\mu0\epsilon0}{\epsilon r + 1}}} \quad (1)$$

$$\epsilon_{reff} = \frac{\epsilon r + 1}{2} + \frac{\epsilon r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{\frac{1}{2}} \quad (2)$$

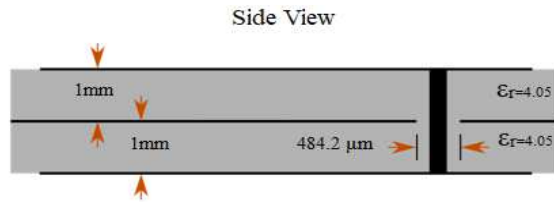
$$L_{eff} = \frac{1}{2f0\sqrt{\epsilon_{reff}}} \quad (3)$$

$$\frac{\Delta L}{h} = \frac{0.412(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad (4)$$

$$L_{eff} = \frac{C}{2f0\sqrt{\epsilon_{reff}}} \quad (5)$$

$$L = L_{eff} - 2\Delta L \quad (6)$$

Using the above conditions 1-5, the length, width and height of the patch is found to be 20.81 x 20.81 x 1 mm³. A solitary area includes a 1x4 fix exhibit made of a three-layer Printed Circuit Board (PCB). The circularly polarized patch antenna is arranged on the top layer of the PCB. The top layer patches are dealt with signals from the bottommost layer through by methods for (hole) along the middle layer. Feed line is engraved in the base layer however focus layer is believed to be the ground plane which will be the reference for both the fix layer and the feed network layer. The substrate used in the arrangement is FR4 with a thickness of 1mm and relative permittivity of 4.05. Fig 1 shows the portrayals of a single sector with four patches. Fig.2 depicts the 3D point of view on the 5-sectorantenna array structure coordinated in hexagonal geometry.



(d)

Fig.1: (a) Top view of unit sector with four patches (b) Top view of single patch (c) Bottom view of unit sector with feeding network and (d) Side view of a single patch showing via through ground plane

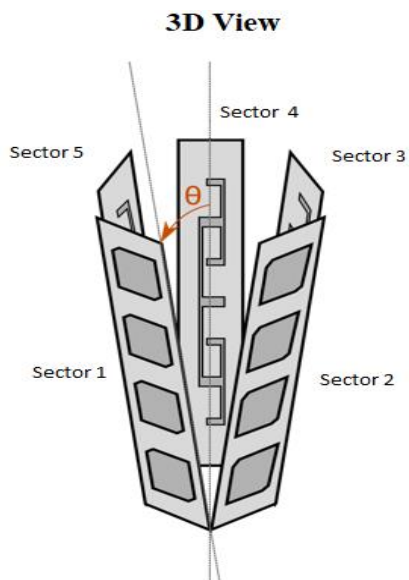


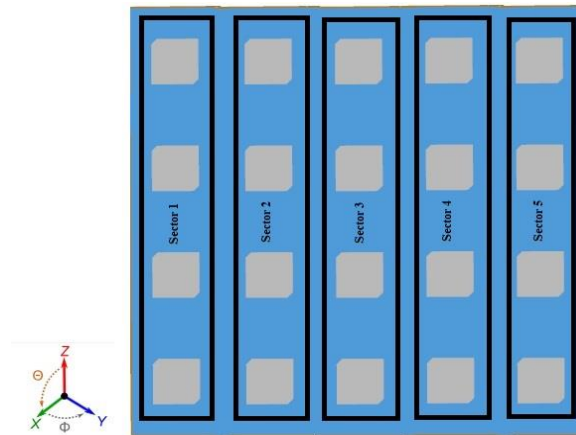
Fig.2: 3D View of 5-sectors antenna array system arranged in hexagonal shape

3.2. Feed System

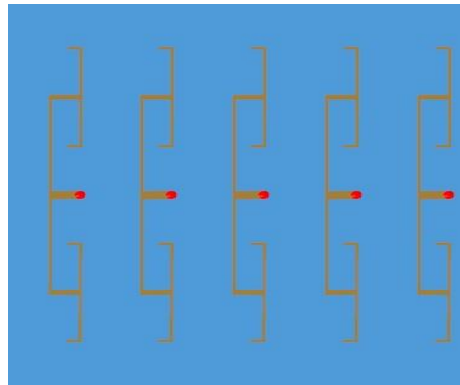
The reduction of false radiation from the feed system should be possible by attaching the corporate feed to the base of the antenna structure so that it is suitable for basic station installation purposes without pre-level undesirable associations. Every component of the sector was associated with the taking care of design underneath the sector with the assistance of by means of through the ground plane. Rather than utilizing some other impedance coordinating organization, impedance can be coordinated by fluctuating the pin-inset distance from the patch edge with significant changes in the corporate feed under the structure. Among the quantity of strategies accessible to take care of a 4 by 1 micro strip patch exhibit structure; this plan fuses the whole co-enraptured reception apparatus took care of from a solitary point underneath. Quarter wave transformer has been joined to permit some degree of impedance coordinating. Efficiency of the antenna array may be affected due to the ohmic and dielectric losses in the resulting feed network. But the use of low loss tangent dielectric can overcome few of the loss mechanisms.

3.3. MIMO Antenna Array System

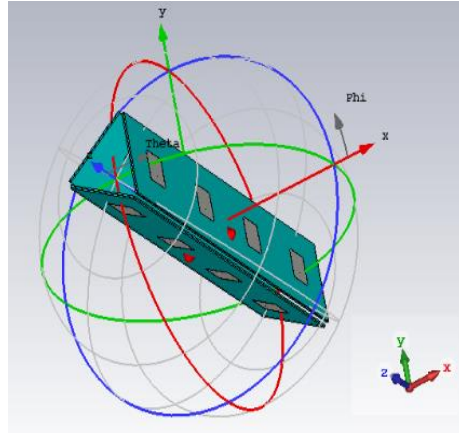
The antenna system works at 3.4 GHz frequency and has a deliberate transmission capacity of 140 MHz. Beam steering can be accomplished when more sectors is $280.5 \times 56.10 \times 3 \text{ mm}^3$.



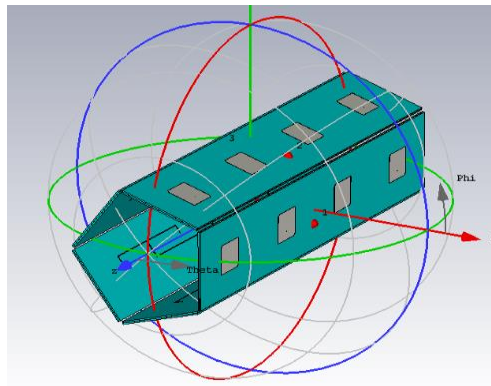
(a)



(b)



(c)



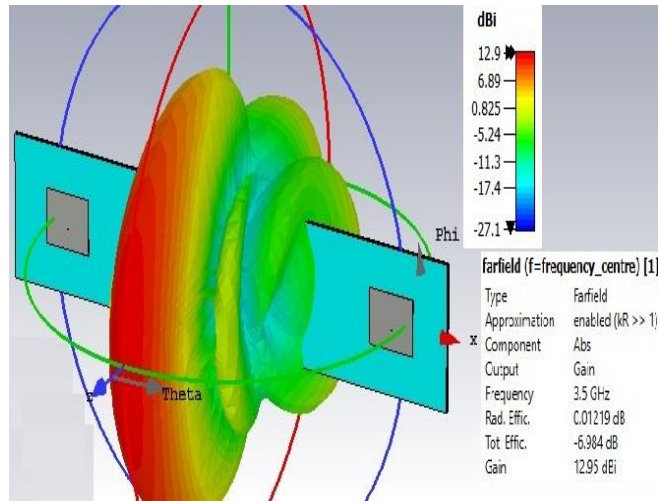
(d)

Fig.3: (a)Top view of a5-sector panel in a single side (b)Bottom view of a5-sector panel in a single side (c) 3 sector in triangular configuration and (d)5 sector in hexagonal configuration

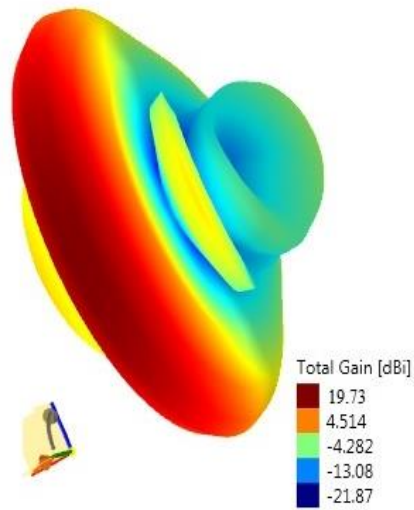
Fig. 3 shows the pictorial portrayal of the relative multitude of three configurations in rectangular, triangular and hexagonal calculations. In triangular and hexagonal calculations, the hole between singular sectors is kept up as same with disconnected ground plane between all sectors.

4. Simulated and Measured Parameters

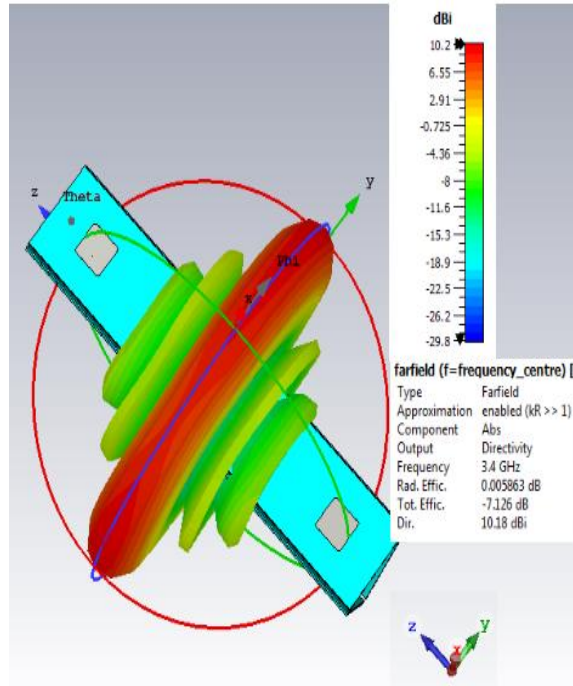
Simulation of the antenna has been performed using 3D EM simulation software CST 2019. Tested results versus simulated results will give a better picture on the performance of the antenna system in different configurations. So, suitable configurations can be proposed for varying deployment scenarios.



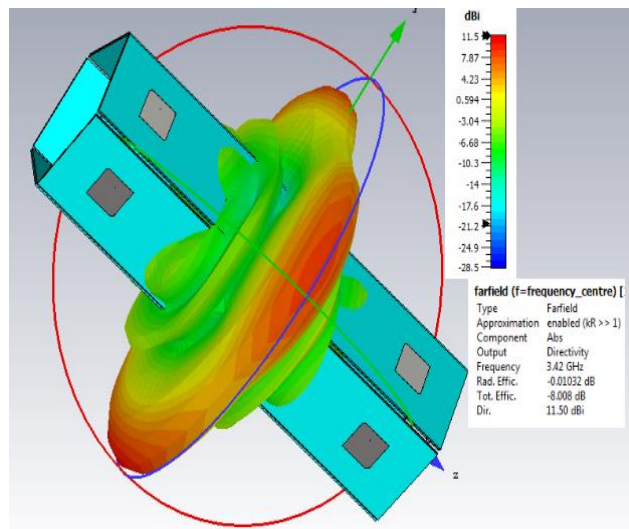
(a)



(b)



(c)



(d)

Fig.4: (a) 3D realized gain pattern of a unit sector

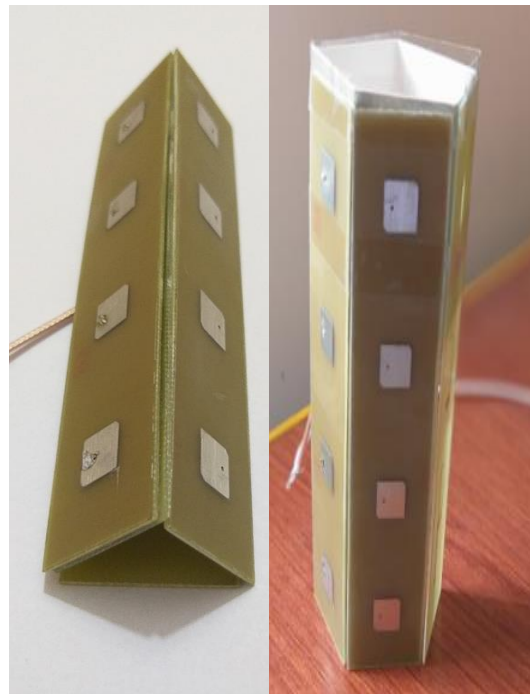
(b) 3D gain pattern of a 5 sector in one panel

(c) 3D gain pattern of a 3-sector unit

(d) 3D gain pattern of a 5-sector unit



(a)



(b)

(c)

Fig.5: Fabricated prototype and measurement setup

- (a) Top view of a5-sectorsingle panel prototype
- (b) Top view of a3-sector prototype
- (c) Top view of a5-sector prototype

Fig.4 and Fig.5 shows the simulation model as well as the fabricated prototype model for measurement. The above results show that the maximum total gain of 12.95 dBi can be achieved for each unit sector, whereas the total gain of the panel comprising of all 5 sectors is found to be 19.73 dBi. Fig.6a & 6b shows the measurement setup using VNA. The simulated and measured reflection coefficient of a unit sector is shown in Fig. 7a, and Fig.7b. Depicts the reflection coefficient of the unit port is real VNA format.



(a)



(b)

Fig.6.(a) and (b) Measurement setup using VNA

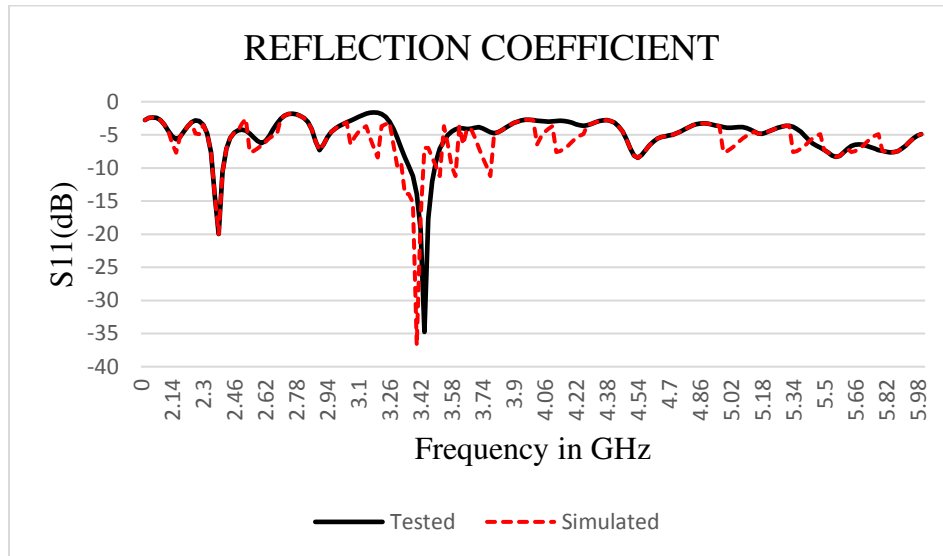


Fig.7:(a) Reflection coefficient of the unit port

The frequency band supported by the designed massive MIMO array is from 3.36 GHz to 3.50 GHz, which clearly fits into the sub-6 GHz band and is the targeted and allocated band for 5G wireless communication across the world for immediate deployment.

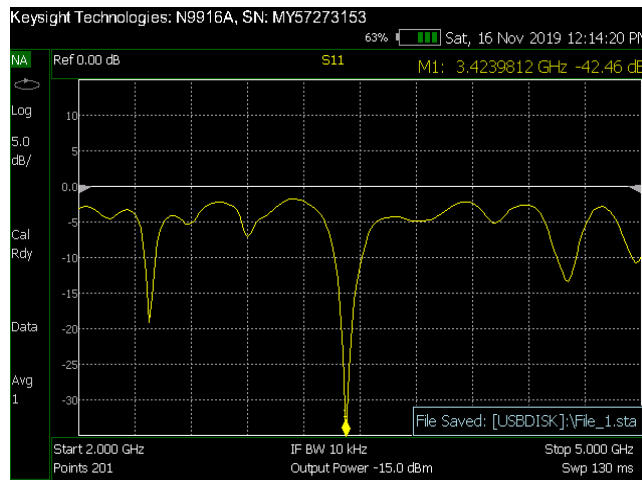


Fig.7: (b) Reflection coefficient of the unit port in real VNA format

Fig.7(c) shows the reflection coefficients of all the five sectors in log magnitude scale when measured with Vector Network Analyser. All the five sectors seem to be in close vicinity in terms of performance. Envelope Correlation Coefficient is generally calculated using the mathematical formula given below.

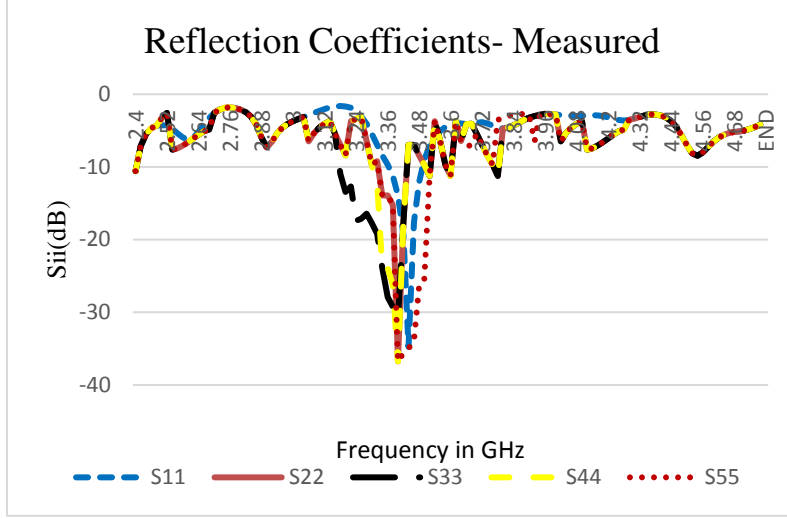


Fig.7. (c) Reflection coefficients of all five sectors in log magnitude scale

$$\frac{\left| \iint_{4\pi} [\vec{F}_1(\theta, \varphi) * \vec{F}_2(\theta, \varphi)] d\Omega \right|^2}{\iint [\vec{F}_1(\theta, \varphi)]^2 * [\vec{F}_2(\theta, \varphi)]^2 d\Omega} = \rho_e \quad (7)$$

Where $\vec{F}_1(\theta, \varphi)$ is the radiation pattern of the antenna system when port ‘i’ is excited. Computation of correlation coefficient using the above-mentioned formula requires the simulated or measured radiation patterns of the antenna. Moreover, this approach is time consuming as well as hard to measure

$$\frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))(1 - (|S_{22}|^2 + |S_{12}|^2))} = \rho_e \quad (8)$$

Instead it will be appropriate to use the S-parameter characterization for the calculation of correlation between antenna elements in an array antenna. This is a much simpler method since it does not require the antenna radiation pattern of the arrays. The main advantage of this method is the fast analysis and broadband analysis of correlation results. However, this method will be under the assumption that all antennas are lossless along with uniformly distributed incoming waves.

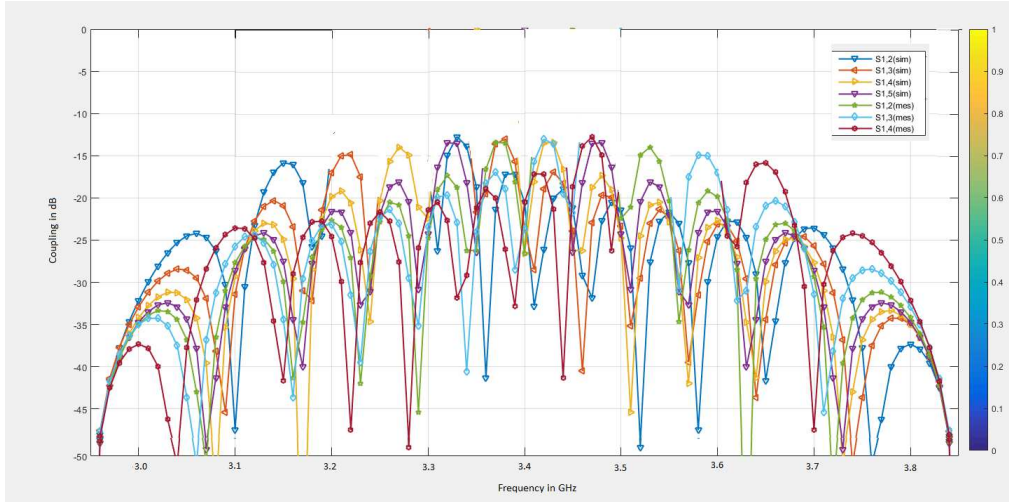


Fig.8:Coupling Coefficients between port 1 and other ports in rectangular configuration

Fig.8 shows the coupling coefficient between port 1 and the remaining ports in rectangular array configuration. In Fig.9 shows the coupling between various ports in the all-important hexagonal geometry

Table 2Comparison between 3 different Configurations (Geometries)

Array Geometry	Frequency band (GHz)	Coupling dB	Gain 1 port dBi	Total Gain dBi
Rectangular	3.36-3.50	-12.3	12.95	19.73
Triangular	3.36-3.50	-14.2	12.95	13.45
Hexagonal	3.36-3.50	-13.9	12.95	14.37

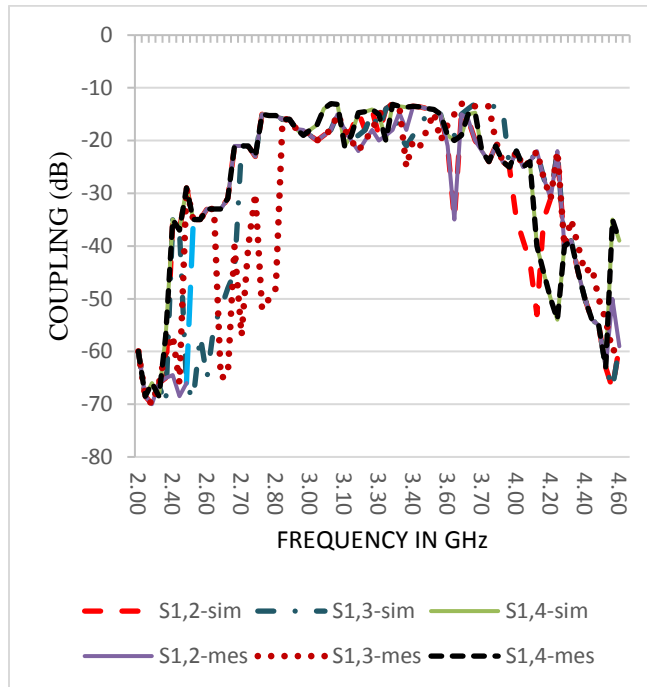


Fig.9: Coupling Coefficients between port 1 and other ports in hexagonal configuration

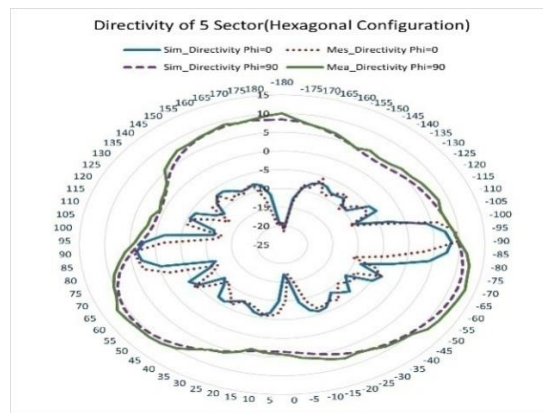


Fig.10: Directivity of Hexagonal Configuration

Table 2 shows the comparison between three different configurations of the array in rectangular, triangular and hexagonal geometries. Maximum coupling between ports has been found to be -12.3 dB for rectangular array with 5 sectors (subarray) and -14.2 dB for triangular array with 3 sectors with 1 sector in single side of the panel in the desired band at which the array has been designed. The maximum coupling between the sectors is found to be -13.9 dB for hexagonal array geometry in the desired frequency band.

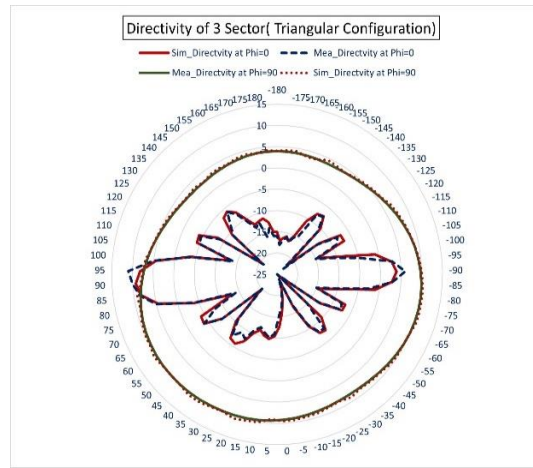


Fig.11:Directivity of Triangular Configuration

Fig.10 and Fig.11 show estimated and simulated aftereffects of directivity of 5 area (hexagonal arrangement) and 3 sectors (triangular configuration) at $\phi=0$ and at $\phi=90$ degree. Table 3 shows the coupling factor between sectors in hexagonal calculation with various point of tendency (θ) between the sectors as addressed in Fig.2. It has been perceived from the gotten results that the shared coupling addressed in dB diminishes with increment in the point of tendency between the areas. It should be perceived that the previously mentioned values in Table 3 is for corner ports just, as the change of angle(θ) will have impact with corner ports just and not for different ports. Any remaining contiguous ports will stay consistent as -12.3 dB regardless of various calculations. The benefits of varying the angle (θ) is that the point of the pillar controlled towards the client can be changed with decreased coupling. Indeed, even without varying angle (θ) the coupling between the various areas is discovered to be good.

Table 3Coupling factor between sectors in hexagonal geometry

Array Geometry	Frequency Band(GHz)	Angle of inclination(θ) degrees	Number of Sectors	Coupling dB
Hexagonal	3.36-3.50	0	5	-13.91
Hexagonal	3.36-3.50	5	5	-14.72
Hexagonal	3.36-3.50	10	5	-15.54
Hexagonal	3.36-3.50	15	5	-17.67

4. Testing and Validation

The proposed multi sector massive MIMO exhibit model is created by Zeta Printed Circuit Services fabrication unit, Chennai, India. A triple layer PCB has been utilized for the plan of array antenna with FR4 substrate. Plan and manufacture were finished with the utilization of Gerber records got from the recreation programming. Here, patches lie on the top layer while ground layer and feed network lie on the centre layer and base layer, separately. Testing of the fabricated antenna array system was done using Keysight Vector Network Analyser, model 9916A located at the Keysight Centre of Excellence Laboratory, Department of Electronics and Communication Engineering, Kumaraguru College of Technology, Coimbatore, India. It is learned from the present work that, if the angle of inclination is increased from 0 degree to 15 degrees, the coupling between the sectors decreases drastically and also the beam steering angle of the arrays from the base station tower towards the user in ground level will be much improved.

5. Conclusion

The 5G Mass MIMO single base station antenna systems for sub 6 GHz band operation are well designed, simulated, fabricated and measured. The 5-port antenna system is designed for the 1x4 antenna subarray. In this thesis a mass MIMO antenna array system is designed and analysed in three different configurations, namely H. rectangular, triangular, hexagonal geometries. The maximum gain can be subjected to a single 12.95 dBi port. Also, the bandwidth obtained in the system is 140 MHz. Above all, the analysis of the hexagonal geometry with all sectors inclined at 5 degrees to 15 degrees shows that the angle of radiation can be varied based on demand. The results of the tutorial were found to include the antenna arrangement of the three figures, which can be used in many different application scenarios. Finally, it is a simple design which is more flexible where faulty antennas can be easily replaced by a spare one without interfering the operations of the entire array system.

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Declaration:

I declare that all the information I have given in the manuscript is true.

1. Conflict of Interest:

I have no Conflict of Interest.

2. Funding:

I have no Funding.

3. Data availability:

I have no Data Availability

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