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8x8 Massive Multiple Input Multiple Output (MIMO) Antenna Array with Diamond-Ring Slot for 5G and 6G Cellular Applications

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Chronicle

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Abstract

In this research paper, an 8x8 antenna Massive MIMO array, with diamond ring slots elements for 5G and 6G cellular networks, has been designed using Computer Simulation Technology (CST) Microwave Studio Software. The configuration of the design consists of eight double-fed diamond ring slot antenna elements placed at different corners of the printed circuit board (PCB). A low cast FR-4 (lossy) dielectric with an overall dimension of 75x150 mm2 is used as the designed substrate. Moreover, a common ground of copper pure (lossy) metal is also used. For antenna elements, copper annealed material is used to get better results at a very low cost and for easy fabrication. The antenna elements are fed by 50-ohm microstrip feedline. The lower cutoff frequency of the array is almost 3 GHz, while the upper cutoff frequency is almost 4.4 GHz. So, the overall impedance bandwidth, i.e., at S11= -10 dB, of the design is approximately 1200 MHz, which is very efficient for future 5G and 6G cellular communication networks. The characteristics impedance and operation impedance of the design are very close to each other, i.e., 50 ohms, which shows very minute impedance mismatching. The value of the Scattering Parameter or S-parameter in the given bandwidth is around -15 dB, which is an optimum value for this array. The value of the Voltage Standing Wave Ratio (VSWR) also lies in the threshold value of 2. The radiation efficiency of the array is almost 80%, while its total efficiency is equal to 75%. The resonance frequency of the array is 4 GHz, which is very efficient and reliable for future 5G and 6G cellular wireless networks. The farfield directivity of the array is 4.4 dBi while the farfield gain of the array is 3.44 dBi. This array can easily be used for 5G applications. For the combined and collective pattern of the overall structure, the post-processing is applied in CST to achieve a narrow beam in a particular direction. The resultant intense beam can be sent in any particular direction using the beamforming technique.

Keywords: Massive MIMO System, antenna array, diamond ring slot, microstrip feedline, Gain, Directivity, Radiation Efficiency, Total Efficiency, Beamforming.

INTRODUCTION

The issue of achieving high data rates, higher bandwidth, higher gain, greater efficiency, lower latency, and ever-increasing number of users have compelled engineers and researchers to design new types of antennas and initiate new types of cellular technologies (Kumar, Gaur, & Nanthaamornphong, 2024). Currently, available cellular networks such as 2G, 3G, and 4G are not sufficient to overcome these issues (Taufique et al., 2017; Walker et al., 2024). With the increasing numbers of users, the quality of service, coverage, and connectivity in densely populated areas have immensely deteriorated. Researchers have devised several approaches for overcoming all the aforesaid problems but for this purpose high investment, extra infrastructure, and regular maintenance would increase enormously, which is practically not feasible (Xiao, Hao, Zhang, Li, & Wang, 2024). An antenna is an element that is connected to electricity or to a transmitter (Solouma et al., 2023). During transmission mode, an oscillating current is applied to the antenna using a radio transmitter, which creates oscillating electric and magnetic fields around the antenna element (Krivova et al., 2024). These time-spanning fields emit energy from the antenna to space, such as moving in the form of transverse electromagnetic field waves (Blandford, 2015). Conversely, the antenna element is affected by the energy of incoming electromagnetic waves and eventually creates an oscillating current that flows towards the radio receiver (Xiao et al., 2024). The data rate of a massive MIMO array is almost 1000 times greater than that of a 4G LTE network (Balasubramanian et al., 2023).

5G cellular network uses frequency ranging from 20 GHz to 200 GHz, which in turn decreases the size of the antenna array (Zhang et al., 2016; Alsharif & Nordin, 2017). This array uses millimetre-wave (mm-wave) technology with smaller size of antenna elements, with improved data rate and bandwidth (Ghosh & Sen, 2019). Massive MIMO system is almost ninety percent energy efficient than the previously used LTE network (Prasad et al., 2017). The number of antenna elements can be increased to hundreds or thousands of elements depending on the number of User Equipment (UE) and data rate required (Nabil & Faisal, 2021; Shetty, Kumar, & Vijayasarathy, 2023).

RESEARCH METHODOLOGY

In this research work, an 8×8 diamond ring slot, Massive Multiple Input Multiple Output (MIMO) array is designed which will be used in 5G and 6G cellular communication with improved data rate, higher bandwidth, higher spectral efficiency, lower latency, improved energy efficiency, and better multiplexing gain. In this research work, an 8×8 massive MIMO array is designed and simulated using CST Microwave Studio Software. There is a total of eight input-output ports in this array, which is why it is known as massive MIMO array. It can be deployed at a Base Station (BS) as well as in mobile cell phones owing to its smaller size for increasing channel capacity and diversity gain, using spatial multiplexing leading to higher data rates (Chen et al., 2020).

It directs the beam towards a specific user, by using the beamforming phenomenon, to save the energy and reduce signal losses. This intense and unidirectional beam cannot be directly affected by multipath propagation and fading (Ziółkowski et al., 2021). The frequency ranges from 2 GHz to 5 GHz and is used to reduce the size of the array, so that it can be deployed in a very small area of a cell phone as well as of a Base Station (BS). In this research paper, a substrate of FR-4 lossy material, a common ground of copper pure lossy metal, and eight antenna elements are connected to a common ground and a common substrate. All of the array elements are fed with microstrip feedline, and they are excited by waveguide port.

Structure of the Array

To design the patch antenna array in the range of 2 GHz to 5 GHz frequencies with the resonance frequency of 4 GHz, different components such as ground, substrate, and microstrip feedline (TL) are used. For this design, FR-4 (Lossy) substrate is used whose value of relative permittivity or dielectric constant is equal to 4.4. Copper (pure), which is a lossy metal, is used in ground as well as in patch antenna elements. After simulation through CST Microwave Studio, its bandwidth is almost equal to 1200 MHz. Figure 1 shows the front view of the 8x8 Massive MIMO array designed in CST.

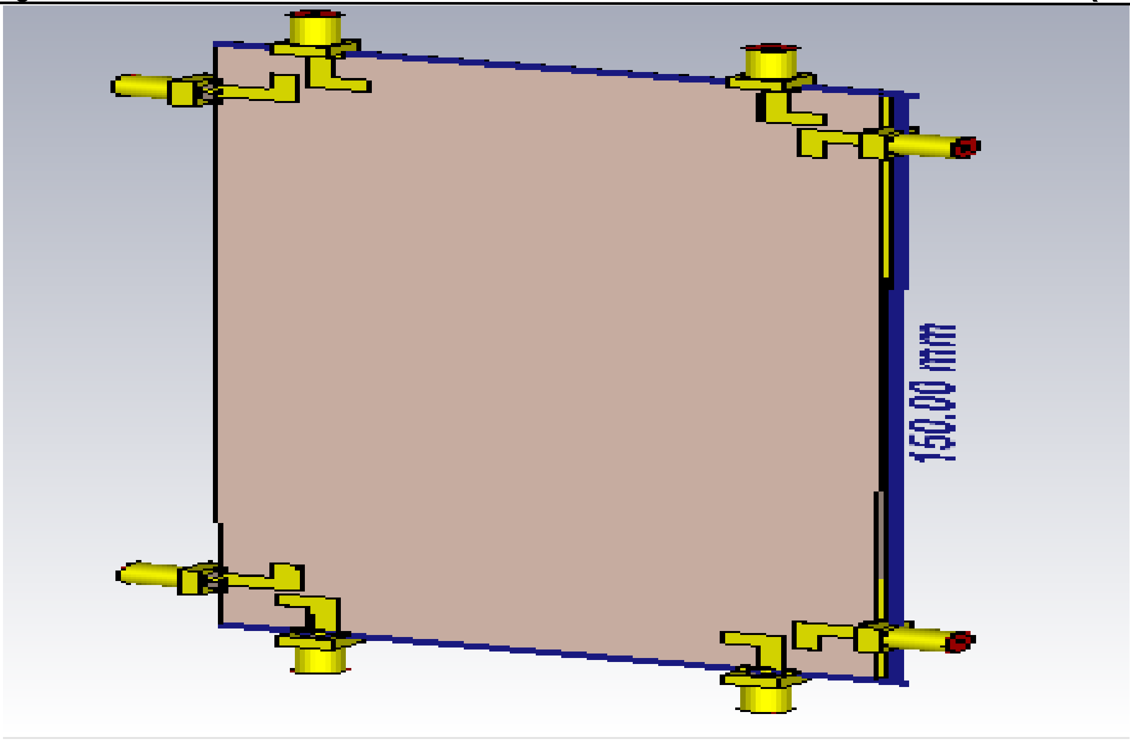

Figure 1.
Front view of 8x8 Massive MIMO array

Design Specifications of the Array

Design Specifications of the array are illustrated in Table 1.

Table 1.
Design Specifications of Single Patch Antenna

Design Parameters	Dimension (mm)
Length of Ground	150
Width of Ground	75
Height of Ground	1.6
Length of Substrate (L)	150
Width of Substrate (W)	75
Height of Substrate (H)	1.6
Length of single Patch (Lp)	3.063
Width of Patch Single (Wp)	4.236
Length of Microstrip Feedline	1.4685
Width of Microstrip Feedline (T)	0.3

RESULTS OF THE ARRAY

Different results of the 8x8 Massive MIMO array are explained below.

Bandwidth of 4×4 MIMO Array

For this 8×8 massive MIMO array, at S_{11}= -10 dB, lower cutoff frequency is 3 GHz and upper cutoff frequency is almost 4.2 GHz, so the total bandwidth of this array is almost equal to 1200 MHz. Figure 2 illustrates the bandwidth of this array.

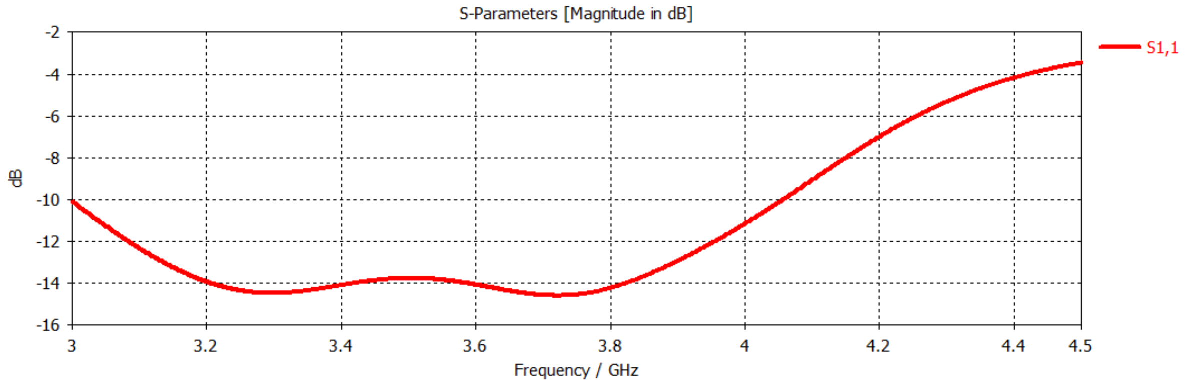

Figure 2.
Bandwidth of the 8x8 MIMO array

S-Parameter of the Array

The value of the S_{11} parameter within the given bandwidth lies below -16 dB. The minimum value of S_{11} is calculated at 3.7 GHz, i.e., at resonance frequency which is equal to -14.4 dB. Figure 3 shows the plot of the S_{11} parameter of the array.

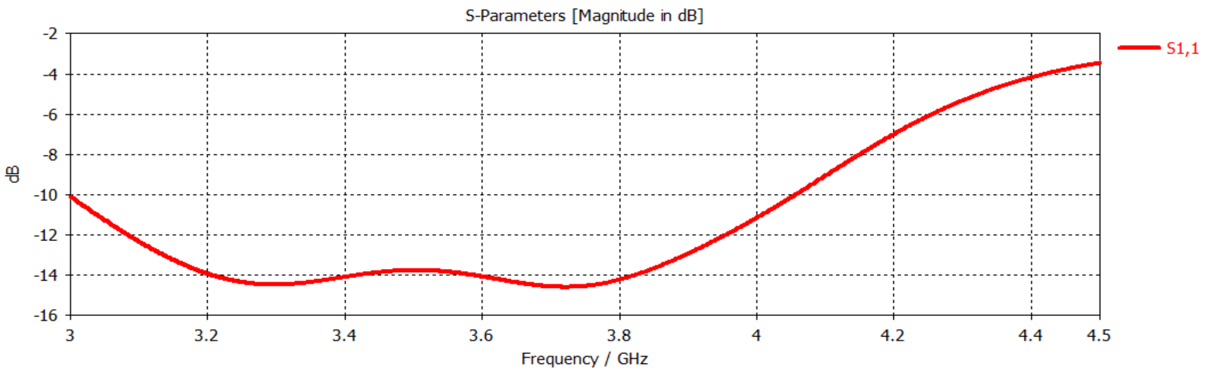

Figure 3.
S_{11} Parameter of the Array

VSWR Of the Array

Voltage Standing Wave Ratio (VSWR) of the array at lower cutoff frequency is equal to 1.8 while for upper cutoff frequency its value is equal to 1.98. The minimum value is 1.35 at resonance frequency. Figure 4 shows the value of VSWR for the array.

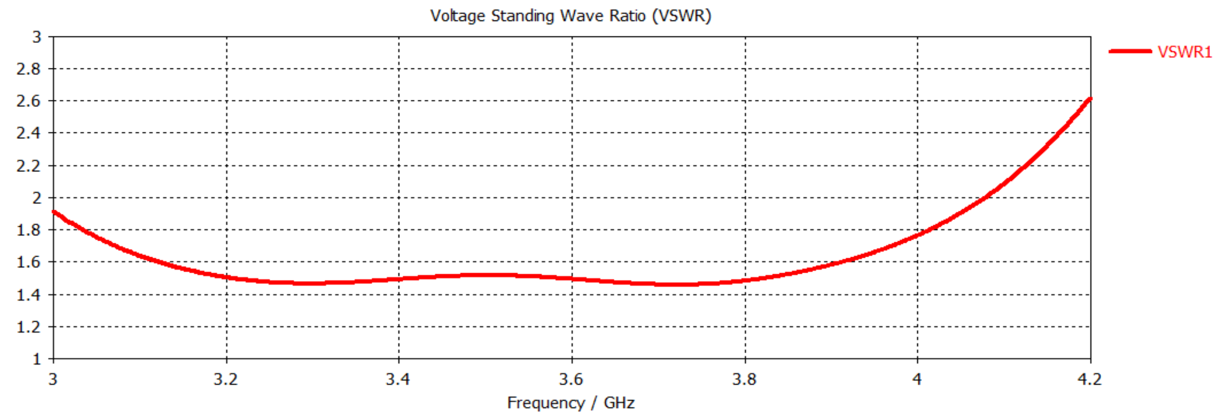

Figure 4.
VSWR of the Array

Z-Parameter of the Array

Z_{11} parameter at lower cutoff frequency is nearly equal to 46 ohms while at upper cutoff frequency, its value is equal to 49 ohms, which is near to the characteristic impedance of the array. Figure 5 depicts the plot of the Z_{11} parameter of the array.

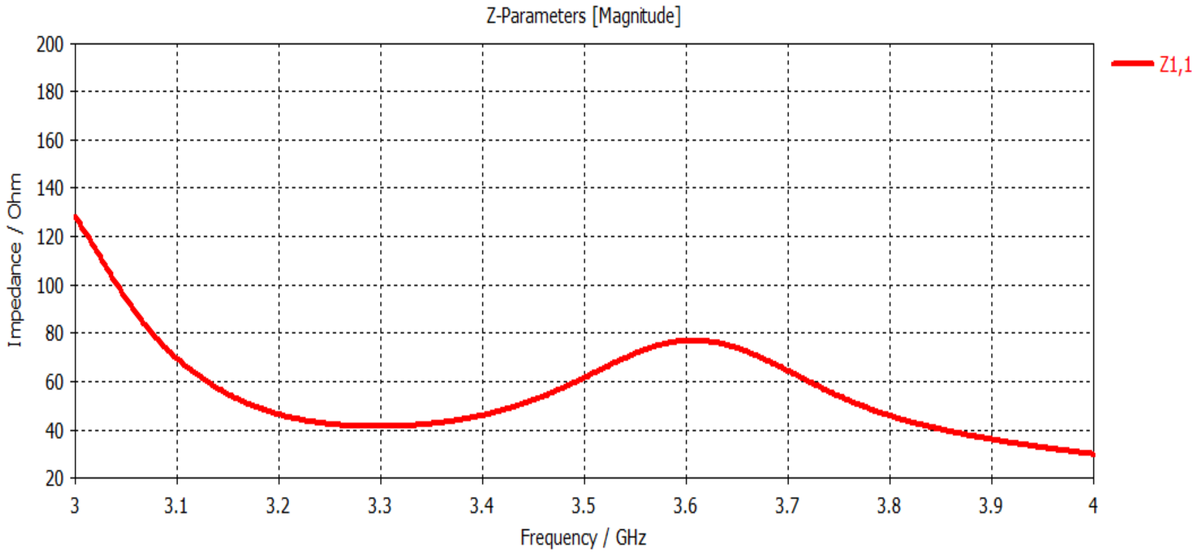

Figure 5.
Z-Parameters of the Array

Fairfield Gain of the Array

Farfield gain of the array at resonance frequency i.e., at 4 GHz frequency, the magnitude of main lobe is equal 3.37 dB. Figure 6 demonstrates a polar plot of the farfield gain of the array.

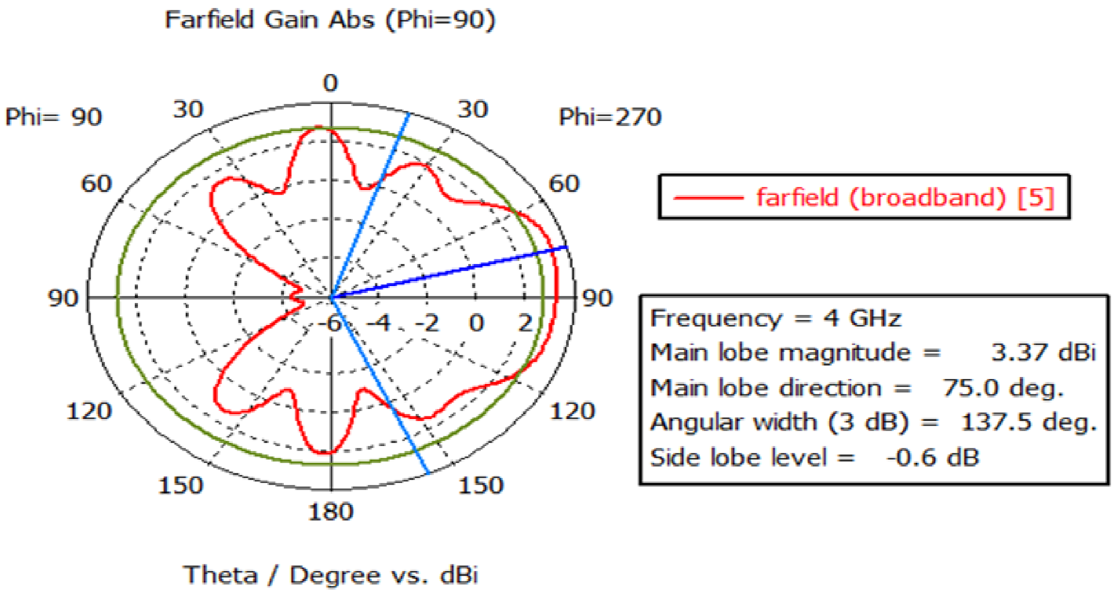

Figure 6.
Farfield Gain Polar Plot of the Array

Farfield Directivity of the Array

The farfield directivity of the array at resonance frequency, i.e., at 4 GHz frequency, the magnitude of main lobe is equal 4.55 dB. Figure 7 demonstrates the polar plot of the farfield directivity of the array.

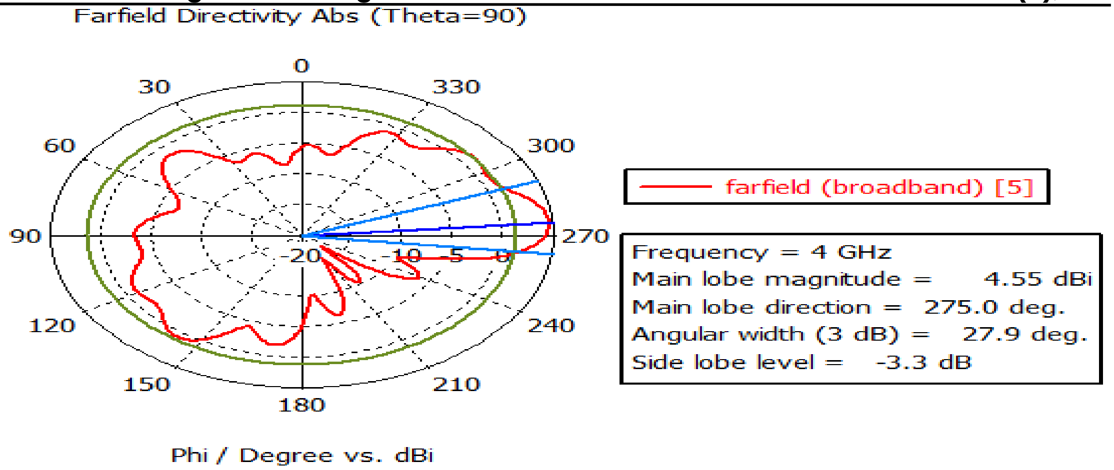

Figure 7.
Farfield directivity polar plot of the array

CONCLUSION AND FUTURE WORK

In this proposed research work, an 8x8 Massive MIMO array is designed using CST Microwave Studio Software, and it was found that it can be used for any planner surface. In this research work, an 8×8 massive MIMO array is designed for increasing gain and directivity in the range of 2 to 5 GHz frequencies. The lower cutoff frequency of this array is equal to 3 GHz, while the upper cutoff frequency is nearly equal to 4.2 GHz. So, the total bandwidth is almost equal to 1200 MHz. Gain is calculated at 3.7 dBi, and farfield directivity is also recorded at 4.55 dBi. This design can be used in 5G cellular networks with low cost, smaller maintenance, and low energy consumption. The data rate and bandwidth can further be improved by increasing the number of antenna elements and partial ground techniques.

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