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Design and Optimization of a 4×4 Patch Antenna Subarray for 5G Applications

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Abstract. Fifth-generation (5G) technology is a cell phone system that aims to make wireless networks much faster and more responsive. In fact, 5G makes it possible to significantly increase the amount of data transmitted by the wireless system, with increased bandwidth and advanced antenna technology. According to an expanded bandwidth spectrum and advanced antenna technology. This article presents the development and simulation of rectangular microstrip patch antennas for wireless transmission at a frequency of 3.5 GHz. We simulated two varieties of antennas utilizing Computer Simulation Technology (CST) software. The design approach commenced with the development of a singular element, and then evolved into 4×4 element arrays. Microstrip feedlines feed the proposed 4×4 element arrays antenna, facilitating directed radiation, beneficial for the base station to ensure excellent quality, high-capacity network connectivity. The finalized antenna had a significant gain of 10.7 dB at a frequency of 3.5 GHz. The accumulated antenna results confirm that the proposed patch antenna is suitable for massive MIMO use in 5G applications.

Keywords: Subarray; Massive MIMO; CST; 5G.

1 Introduction

In the dynamic context of 5G, optimizing antenna systems is essential to meet increased performance requirements. The patch antenna, or microstrip antenna, is a key component due to its compactness and ease of integration into various devices [1]. The design and improvement of patch antennas for MIMO massive (Multiple Input Multiple Output) use is an active area of research, aimed at maximizing 5G capabilities.
The adoption of MIMO technology in 5G networks makes it possible to significantly enhance the quantity of radio frequency chains between antenna element and the radio entity, thereby improving base station capacity, user bandwidth and the overall experience [2]. For patch antennas, this means optimizing the design to improve characteristics such as bandwidth, gain and directivity [3].

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In our design, we use two FR-4 substrates with advantageous dielectric characteristics, with a 1.6 mm thickness, a loss tangent of 0.025, and a dielectric constant of 4.3. These characteristics enhance antenna performance regarding bandwidth, directivity and gain [4]. The suggested patch antenna was developed to resonate at a frequency of 3.5 GHz, that is presently used in modern wireless systems. This frequency has been chosen to ensure compatibility with available spectrum bands and to provide extensive coverage.
The design adopted aims to transform the patch antenna structure into 4×4 subarrays usage in massive MIMO. Massive MIMO systems exploit an immense number of antennas to significantly increase network capacity and improve overall system performance [5]. In our case, a single antenna port consists of a subarray of 4×4 patches, allowing us to take advantage of spatial diversity and constructive interference to increase transmission capacity and enhance signal quality [6].
In the remainder of this article, a full description of the patch antenna design is given, focusing on key antenna dimensions and parameters. We will also discuss the configuration of the 4×4 subarray and its potential advantages in terms of capacity and performance. Finally, the result obtained presents a simulation using CST (Computer Simulation Technology) software to evaluate the performance of the designed patch antenna.

2 Antenna design and methodology

This approach was first developed by computing the singular patch at the given frequency. CST was employed to model the design. Fundamental antenna parameters, including frequency, resonance, bandwidth, return loss, gain, and directivity, must be considered in antenna design. The design procedure for the antenna array is now finalized.

2.1 Antenna specifications

The parameters, which was based on a frequency of 3.5 GHz, is displayed for prototype evolution. In this structure, the FR-4 substrate using a dielectric substance ($\mathcal{E}_r = 4.3$) which has a dielectric loss tangent of 0.025 and a substrate height (h) used 1.6 mm. To construct the patch antenna with two FR-4 substrates using CST software.

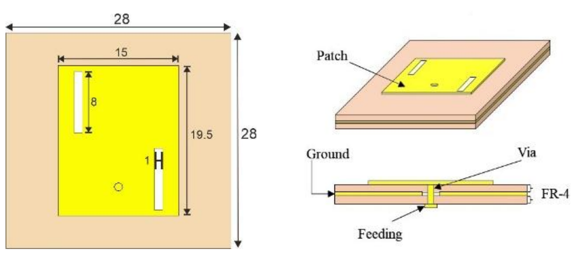


Fig. 1. Modeling our antenna in CST (all dimensions are in mm)

2.2 Antenna design process

This section delineates the model of an individual antenna element with an overall dimension of $28 \times 28 \times 3.2\ mm^3$, using a microstrip patch form.
The antenna was developed at a resonant frequency of 3.5 GHz. The relevant equations are employed to calculate the components of the radiating patch, but always depending on the shape of the patch, whether it is triangular, rectangular, or circular. In this study, a rectangular

patch is the basic starting design. The formulas for determining the dimensions of rectangular patches are as follows [7] :
The resonant frequency (f_r) of a patch antenna can be determined using the subsequent formula:

$$f_r = \frac{c}{2 \times L \times \sqrt{\varepsilon_r}} \tag{1}$$

Where
c : is the speed of light,
L : the length of the patch,
ε_r: is the dielectric constant of the substrate
The patch's width can be determined using the formula provided below:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{2}$$

Where
V_0 : is the speed of light in free space.

$$L = \frac{v_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{3}$$

Where
ε_{reff} : Effective dielectric constant
h : Dielectric substrate height
ΔL: Length extension.

3 Results and simulation:

3.1 Reflection coefficient:

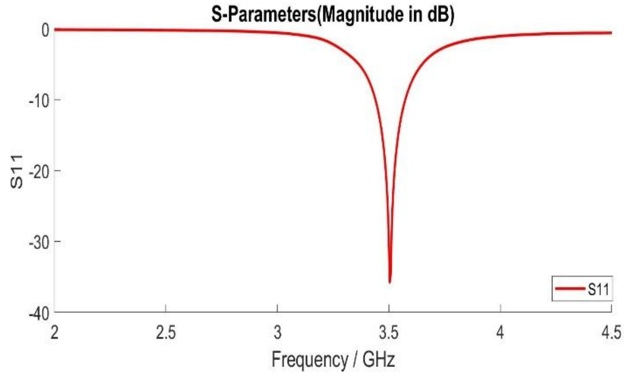


Fig. 2. S-Parameters

Parameter S11, where is the input antenna reflection coefficient, expresses the energy transfer to the antenna. The value of this parameter varies with frequency. To ensure a good match in the desired frequency band.
Figure 2 illustrates the S11 parameter curve as a function of frequency for the patch antenna utilizing a FR-4 substrate. In the (3.43 - 3.57) GHz band we see a reflection coefficient of (-35.78dB) with a -10 dB bandwidth of (140 MHz) around the desired resonant frequency (3.5 GHz).

3.2 Radiation pattern:

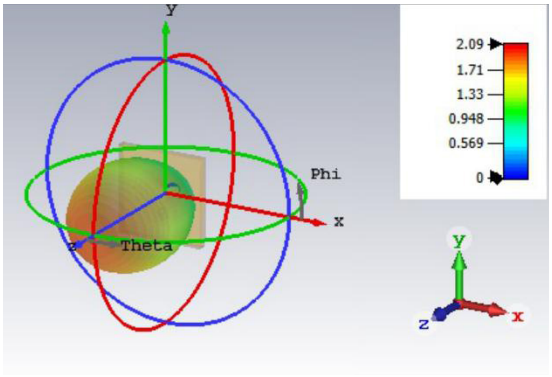
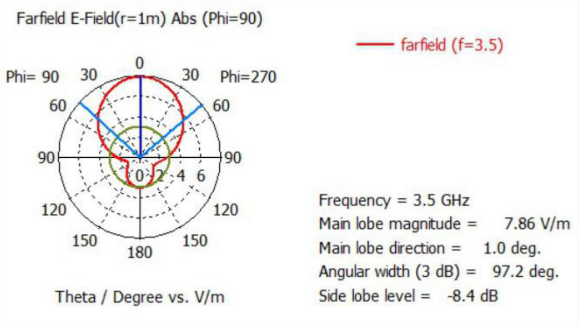
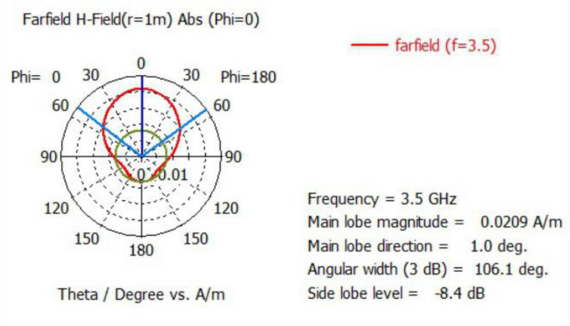


Fig. 3. Realised Gain

The antenna's 2D and 3D radiation patterns are illustrated in Figures 3 and 4, respectively. From the pattern we can see that the maximum gain achieved is 2.09 dB, giving a directivity D = 3.68 dB. To visualize the lobes of the radiation pattern, we've represented it in polar coordinates in the H and E planes. As shown in figure 4, the pattern is identical in both planes, with one main lobe, which means that our antenna's pattern is directive.



(a)



(b)

Fig. 4. Results of the radiation pattern in (a) E-Field, (b) H-Field

4 Design of a 4×4 subarray for massive MIMO use:

After the antenna has been designed and optimized, a 4×4 antenna patch subarray is designed with two FR-4 substrates in CST. As shown in figure 5, the 4×4 antenna subarray is composed of sixteen radiating elements of identical size, positioned with spacing to avoid interference between them.

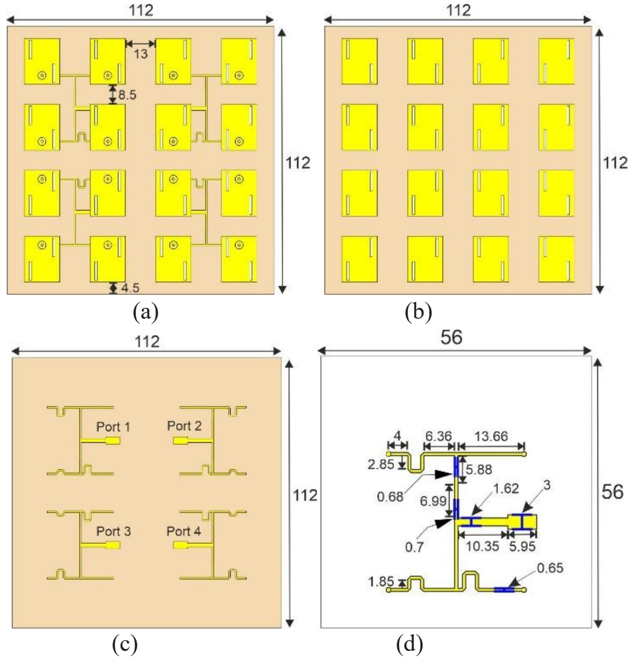


Fig. 5. Geometries of the proposed antenna design (a): Board design stackup displaying the layers (b): 4×4 patches (top) subarray (c): Feeding network (bottom) subarray (d): Network feeding for a single port (all measurements in millimeters)

4.1 Reflection coefficient:

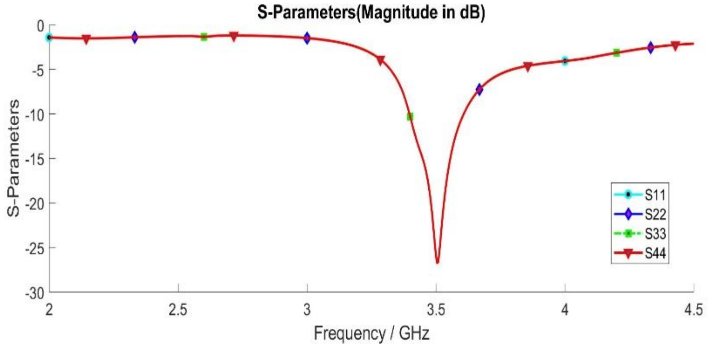


Fig. 6. S-Parameters

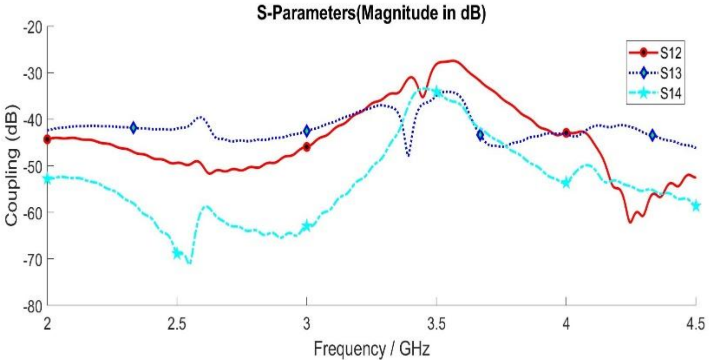


Fig. 7. Coupling between port 1 and its adjacent ports

In this section, the simulation results after simulating the four-port 4x4 subarray antenna's design are presented. From Figure 6, it can be seen that the band supported by this subarray is 3.39 to 3.60 GHz, giving a bandwidth of 210 MHz , the reflection coefficients obtained show a good adaptation.
In the band of interest, The highest coupling between ports is -28 dB. As shown in Figure 7, this means low coupling, because it reduces interference between ports and improves signal separation. This optimizes beamforming and improves signal quality. To ensure efficient communication and reduce interference.

4.2 Radiation pattern:

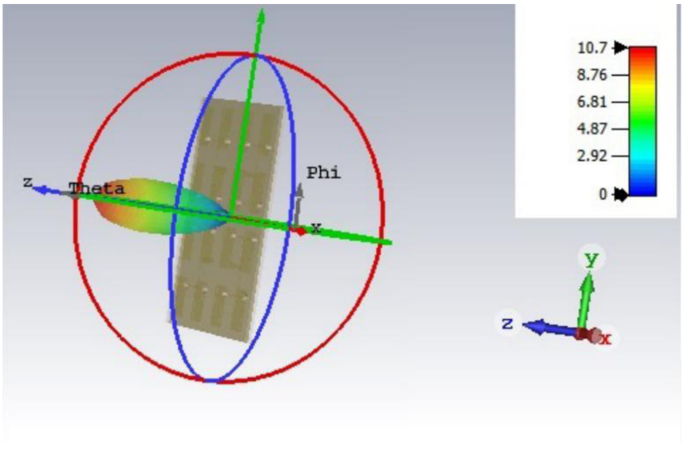
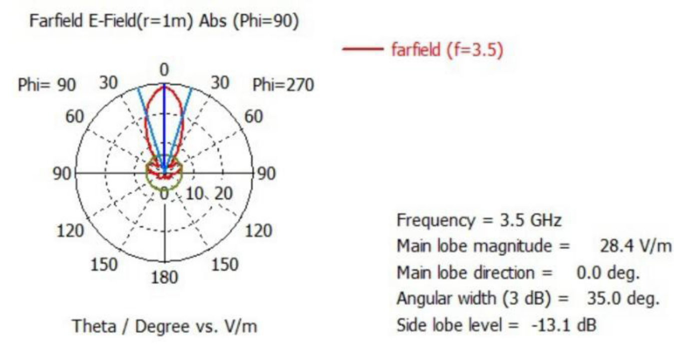
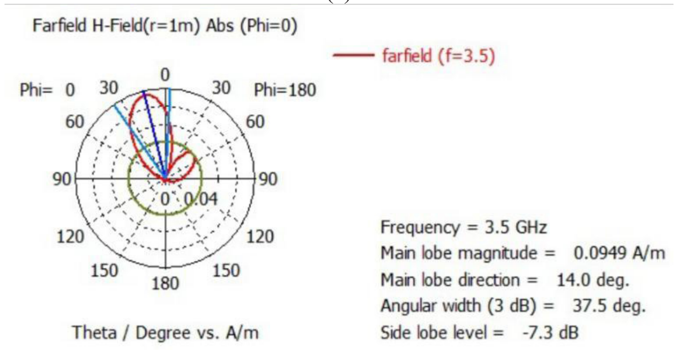


Fig. 8. Realised Gain of 4×4 Subarray



(a)



(b)

Fig. 9. Radiation pattern results of 4×4 subarray (a) E-Field, (b) H-Field

The following parameter to be examined in this article is antenna gain. Gain is a crucial component to assess, as the objective is to develop a high-gain antenna array suitable for 5G applications [8]. As illustrated by figure 8 we can see that our antenna subarray is directive and has a gain of 10.7 dB, and a directivity D = 21.4 dB.
Simulation was used to determine the result in terms of the radiation pattern., The 4×4 antenna subarray is directional, indicating that, as Figures 8 and 9 illustrate, radiation is concentrated in a single direction rather than propagating in all directions. The main beam in the radiation pattern is around 0°, demonstrating that this array is suited for 5G applications because it is large and has good radiation characteristics in its working bands [9].

5 Comparison with other research work

This comparative study, detailed in Table 1, will enable us to evaluate and validate the results of our research. From this approach, we can see that our antenna is better than that of the article in terms of gain, which is too high in our design.

Table 1. Comparison between our research and the referential study

Parameters	Results from [10]	Our results (4×4 subarray)
Resonance frequency	3.5 GHz	3.5 GHz
Antenna type	Patch antenna subarray	Patch antenna subarray
Substart	FR-4	FR-4
Reflection coefficient	-12.45 dB	-26.72 dB
Substrate height	1.6 mm	1.6 mm
Max gain	6.93 dB	10.7 dB
Directivity	11.33 dB	21.4 dB
Bandwidth	-	210 MHz
Dimensions	200×160×1.6 mm^3	112×112×3.2 mm^3

6 Conclusion

In this study, the rectangular patch antenna's design using FR-4 substrates is presented, with a frequency of resonance at 3.5 GHz, with the aim of transforming it into 4×4 sub-arrays for massive MIMO use, the overall performance of the antenna offering improved bandwidth, increased directivity D=21.4 dB and optimized gain of 10.7 dB These favorable characteristics were essential in the design of the antenna to meet the requirements of modern wireless systems.
By transforming the patch antenna structure into 4×4 subarray for massive MIMO use, spatial diversity and constructive interference can be exploited to increase transmission capacity and improve signal quality. This approach opens up new possibilities for wireless communication systems, offering increased capacity, better coverage and improved Capability. The proposed antenna might work as a viable alternative for 5G wireless networks.

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