A New Design of a Planar High Gain Base Station Antenna Array for 5G Cellular Communication

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Abstract— **In this paper, we present the fabrication of a 64-element patch antenna array optimized for 5G applications. The initial step involved constructing an individual antenna element, using a 0.035 mm-thick perfect conductor on a Rogers RT 5880 substrate with a dielectric constant of 2.2, a thickness of 0.252 mm, and a loss tangent of 0.009. Subsequently, this design was replicated to form a uniform array of 64 identical elements. Using an electromagnetic solver based on the finite integration technique, we meticulously simulated this compact antenna array. Our simulations revealed promising results: a commendable reflection coefficient of around -20.270dB, a gain of 17.588 dB at 3.5 GHz, and a distinct radiation pattern.**

Keywords—Patch Antenna, Antenna array, 64 elements, Gain, Radiation pattern, Reflection coefficient.

I. INTRODUCTION

The fifth generation (5G) has successfully met various requirements in the field of telecommunication technology, marking a significant milestone in the current era. Introduced in 2020 [1], 5G brings numerous advantages, including higher bit rates, reduced latency, increased reliability, massive device connectivity, cost reduction, and improved energy efficiency [2]. The state of the art for 5G technologies encompasses a range of cutting-edge advancements that are shaping the future of wireless communication. Here are key aspects of the state-of-the-art 5G technologies: Massive MIMO (Multiple-Input Multiple-Output): Massive MIMO technology has emerged as a foundational element of 5G networks. By utilizing a large number of antenna elements at the base station [16,18], Beamforming and Beam Management, Network Slicing, Cloud-Native Architecture, Edge Computing Integration, Network Automation, and Orchestration of millimeter Wave (mmWave) Spectrum [3][9]17].

Although the millimeter wave (mmWave) band is considered the fundamental aspect of 5G technology, many researchers have focused on this topic by proposing several antennas [4]-[7]. Despite this, 5G technologies also operate at lower frequencies, such as the 3.5 GHz frequency band been thought of as the 5 G band for most countries [10][11], which we found in [12] simulating the design of a massive MIMO antenna, a 12-patch antenna that operates at 3.5 GHz. In [13] has proposed 1 × 8 array antenna delivers a high gain of 6.938 dBi at 3.5 GHz. Another noteworthy design involves an arc-shaped antenna with high gain for next-generation base station applications, operating between 2.5-3.9 GHz [14]. In [15], a new Bluetooth bow-tie antenna array operates in three frequency bands: 2.27–2.68, 3.25–3.92, and 4.14–6 GHz, while [14] designed a rectangular patch antenna for WiMAX application at 2.5 GHz. In the context of a 64-element antenna network for 5G Kerim Kibaroglu et al [20] proposed a 28 GHz 5G communication link using a 64-element (8x8) phased array, it has a high data rate at the longest link distance demonstrated in a 28 GHz 5G array in base station applications, a 64-element array at 28 GHz, a 256-element array at 28 GHz [21][22], and a 144-element array at 60 GHz [23] have been designed and verified.

As a result, the 64-element antenna network for 5G at 3.5 GHz represents a cutting-edge approach to maximizing the potential of the 5G spectrum, supporting a multitude of use cases ranging from mobile broadband to IoT, and paving the way for transformative applications in the era of ultra-fast and ultra-reliable connectivity. So, after considering that all this research shows that the array antenna has an important role in developing communications in general. Therefore, in this paper, we will work on an antenna array that operates at exactly 3.5 GHz with 64 identical elements to obtain high throughput. In the first section, we will begin by designing one antenna, whose dimensions and immunity will be calculated to adapt to 3.5 GHz frequencies, and then we will simulate the coefficient of reflection and gain. In the second section, we will design a 64-element array structure. The paper concludes with the presentation and discussion of simulation results.

II. THEORY AND DESIGN

A. *The choice of substrate for the Rogers RT 5880*

Designing an antenna involves selecting a substrate material with specific characteristics that match the requirements of the application. Rogers RT5880 substrate is commonly chosen for its excellent electrical properties, such as low dielectric loss, high thermal conductivity, and stability over a wide temperature range.

The choice of specific dimensions for the substrate depends on several factors: Frequency of Operation, Antenna Size, Beamwidth and Directivity, the manufacturing process, Array Geometry, Array Factor and Radiation Pattern, and Inter-element Coupling. [25].

In summary, the choice of substrate material and dimensions for designing an antenna and an antenna array is driven by a combination of electrical, mechanical, and manufacturing considerations to achieve the desired performance characteristics for the specific application.

B. *DESIGN AND PATCH RADIATOR*

In this study, we began by designing a rectangular patch antenna structure to validate an antenna at 3.5 GHz, printed on an RT 5880 substrate. Various equations were utilized to calculate the parameters of the proposed antenna [19].

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

$$L = \frac{1}{2f_r\sqrt{2\varepsilon_{reff}\sqrt{\mu_0\varepsilon_0}}} - 2\Delta L \quad (2)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}} \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_r+1)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

L: The length of the rectangular patch antenna

W: The width of the rectangular patch antenna

f_r : The resonant frequency of the antenna

μ_0 *et* ε_0: Permeability and permittivity in free space,

ΔL: The extension of the patch length around the slots

ε_{reff} : The dielectric effective permittivity

h: The height of the substrate.

The geometry of the proposed antenna is illustrated in Figure 1.

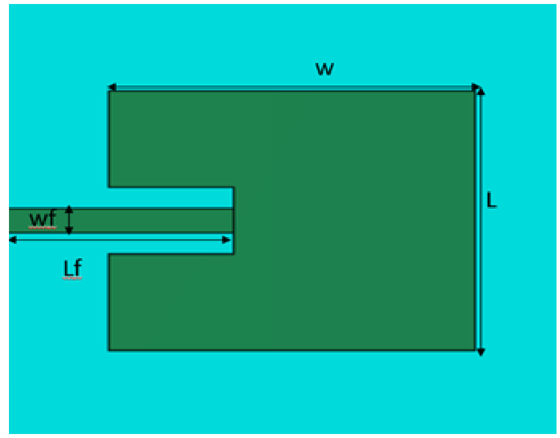

Fig.1. Geometry of the proposed antenna

The optimized parameters of the antenna are shown in Table I.

TABLE I. The optimized parameters of the rectangular patch antenna

Parameters	Values
W	29.35 mm
L	27 mm
Lf	18 mm
Wf	2.5 mm

After optimizing various parameters, the final patch antenna is simulated. As we can see from Figure 3, the antenna presents a good matching at 3.5 GHz with a coefficient reflection of -34.695 dB. The simulated antenna has a gain of 6 dBi (Fig.4) and a good radiation pattern (Fig. 5) for the radiation performances.

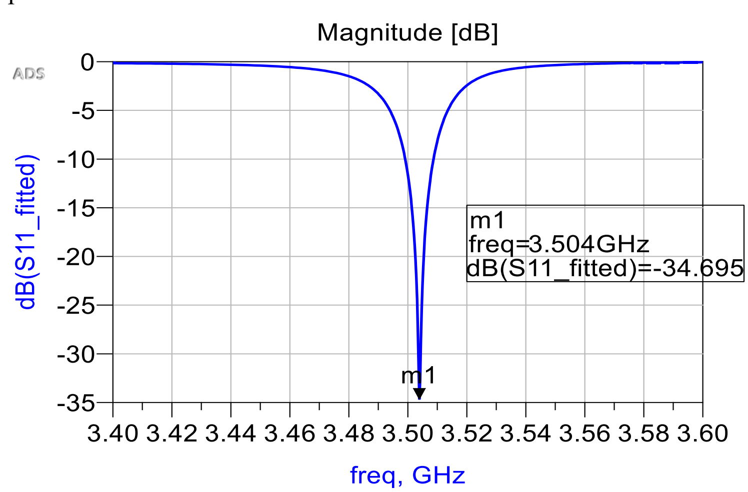

Fig.3.a Simulated reflection coefficient S11 in ADS

We also simulated the same antenna in CST Studio Suite and obtained almost the same results as shown in Figure 3.b.

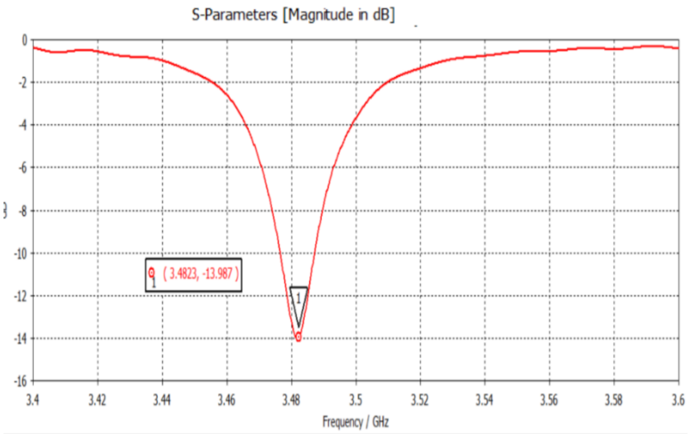

Fig.3.b. Simulated reflection coefficient S11 in CST

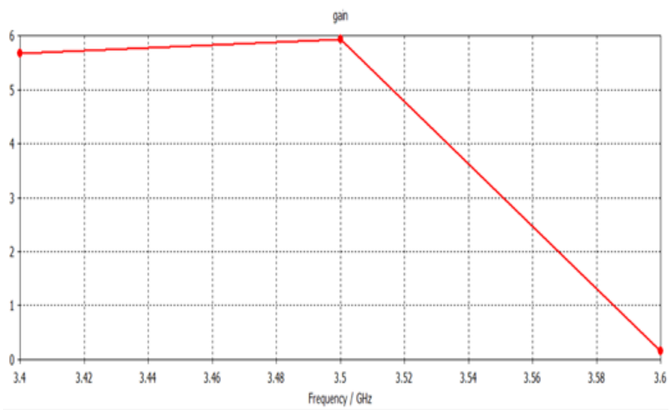

Fig.4.Simulated gain in dBi

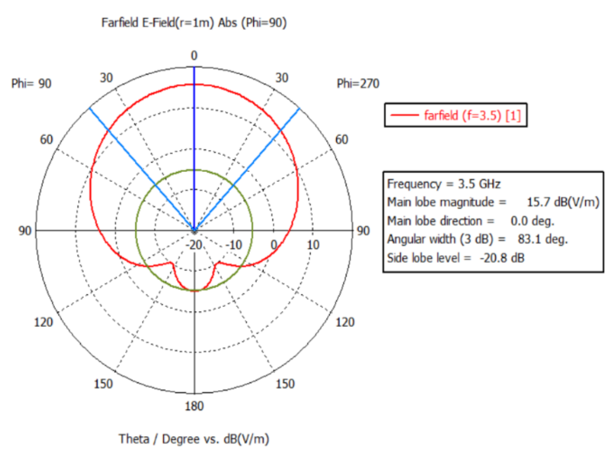

Fig.5. The radiation pattern of the proposed antenna

C. THE PROPOSED ANTENNA ARRAY

Utilizing the proposed antenna design, we proceeded to create a patch antenna array comprising 64 radiating elements, as depicted in Figure 6 utilizing the proposed antenna design, we proceeded to create a patch antenna array comprising 64 radiating elements, as depicted in Figure 6. The space between every radiating element is 50 mm in the same row. 100 Ω, 50 Ω lines, and quarter-wave transformers are used to connect the patches. The 90° bends in the network are mitered.

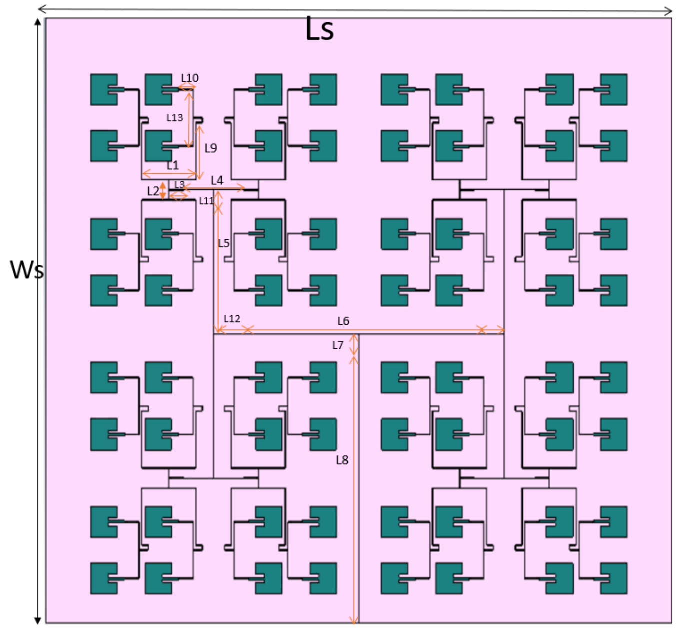

Fig.6. The proposed patch antenna array (64 elements).

Table I shows the majority of dimensions for antenna array parameters. The ones we did not mention are identical to those in the table. As for displaying these parameters, we relied on 100 Ω, 50 Ω, and 70.70 Ω lines.

TABLE I. The dimensions of parameters of the antenna array.

Parameters	Values in (mm)
Ws	533.990
Ls	693.84
L1	59.6
L2	17.4
L3	15.73
L4	67.06
L5	110.8
L6	289.74
L7	16
L8	239
L9	50
L10	16

L11	15.8
L12	16
L13	49.6

After modeling this identical 64-element patch antenna array using ADS, we obtained the reflection coefficient S11 shown in Figure 7. a. As we can see, we have achieved a good result. The S11 value is -21,270dB

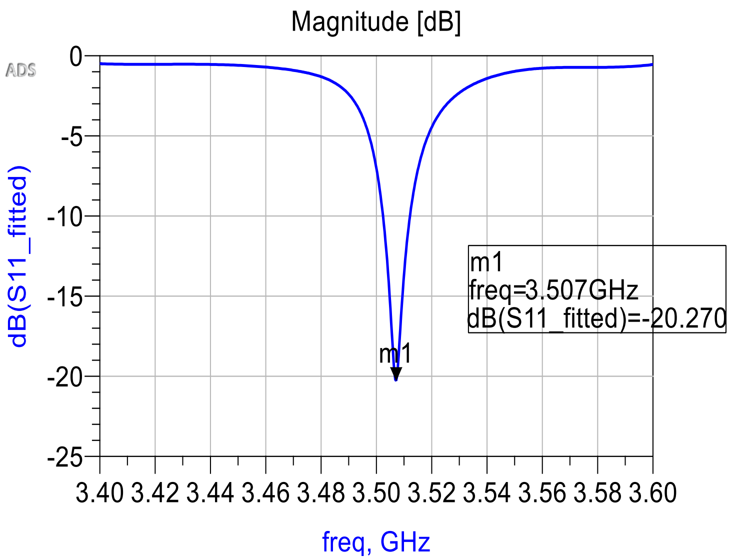

Fig.7.a.Simulated reflection coefficient S11in ADS

We also simulated the same antenna in CST Studio Suite and obtained almost the same results as shown in Figure 7. b.

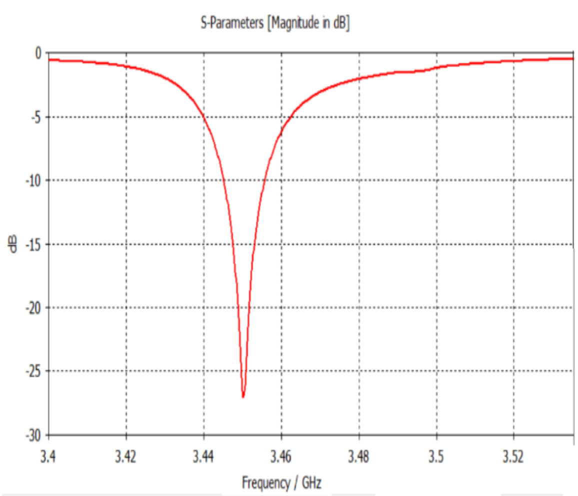

Fig.7.b.Simulated reflection coefficient S11in CST

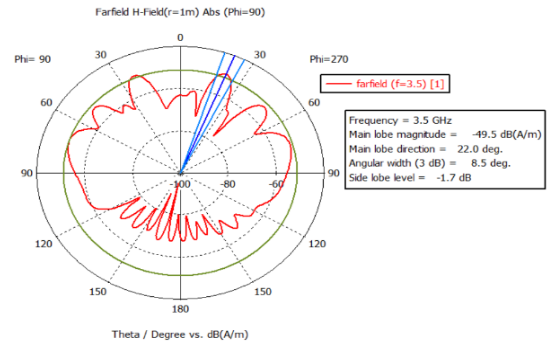

Fig.8. The radiation pattern of the antenna array

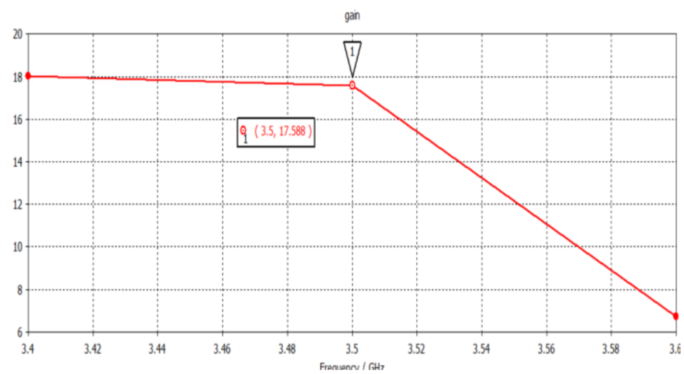

Fig.9.Simulated gain of antenna array

Up on analyzing the obtained results, it's evident that the patch antenna array presents a good matching at 3.5 GHz with S11 of -20.270 dB (Fig7.a). The simulated antenna has a gain of 17.588 dBi (cf. Fig.9) and a good radiation pattern (cf. Fig. 8) for the radiation performances.

D. *Comparison of the proposed antenna with other works*

TABLE III. comparison of the antenna array

Ref	Frequency (GHz)	Number of elements	reflection coefficient	Gain in dB
[13]	3.5	10	−18	6.938
[12]	3.5	12	-21,41	9,176
[24]	3.5	3	-20.60	3.49
This work	3.5	64	-20.270	17.588

Table III shows a comparison of some previous work on the same topic, where it becomes clear that we have developed an array patch antenna and raised the level of gain performance.

III. Conclusion

In This paper we have validated the design of a patch antenna array operating at 3.5 GHz. The initial phase involves designing a single patch antenna, printed on a Rogers RT 5880 substrate with a height of 0.252 mm and a relative dielectric permittivity of 2.2. Subsequently, we employed 100 Ω and 50 Ω microstrip lines, along with quarter-wave transformers, to arrange 64 radiating elements and form the array patch antenna. This proposed array holds significant potential for applications in 5G.

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