Lecture Notes in Networks and Systems 826

Noredine Gherabi
Ali Ismail Awad
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Proceedings of I2ST'23

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Preface

This book offers a comprehensive reference and cutting-edge knowledge on Intelligent System and Smart Technologies. This book is composed of theoretical foundations for Intelligent System and Smart Technologies. The book discusses significant issues relating to machine learning, smart technologies, and data analytics. Further, in-depth reading can be done from the detailed bibliography presented at the end of each chapter. The book will be divided into two sections, Foundations and Applications, which will provide a complete source of information for the book theme. Furthermore, the chapters will include concepts, algorithms, figures, graphs, and tables that will increase the readability of the book. The target audience of this book includes researchers, practitioners, and postgraduate and graduate students who developing artificial intelligence algorithms or using these algorithms in different applications.

The book will address a wide spectrum of topics that cover both algorithms and applications of Intelligent System and Smart Technologies. The book has the following topics that will span different chapters:

- AI & Intelligent Systems
- Smart Technologies
- Communications and Networking
- Software Engineering and Web Applications
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- Software Engineering and Web Applications

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About This Book

This book is a collection of high-quality peer-reviewed research papers presented at The International Conference on Intelligent Systems and Smart Technologies (I2ST'23) held at the Faculty of Science and Technology of Hassan First University, Morocco, on January 17–18, 2023.

I2ST'23 is a forum for presenting new advances and research results in the fields of information, communication, and smart technologies. The book discusses significant issues relating to machine learning, smart technologies, and data analytics.

The main and distinctive topics covered are I) AI & Intelligent Systems, II)Smart Technologies, III) Communications and Networking, IV) Software Engineering and Web Applications, V) Information Technology, and VII) Software Engineering and Web Applications.

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A New Design of 5G Planar Antenna with Enhancement of the Gain Using Array Antenna

A. Bellekhiri, N. Chahboun, J. Zbitou, Y. Laaziz, and A. El Oualkadi

Abstract In this paper, an antenna array with 32 radiating elements was designed, analyzed, and simulated using ADS and using CST Microwave Studio electromagnetic solvers so as to investigate the effects of various factors on the antenna's radiation characteristics. The square patch antenna is printed on Rogers RT5880 substrate, with a relative dielectric permittivity of 2.2, a loss tangent of 0.0009, and a thickness of 0.508 mm. The dimensions of the single element are 28.1 × 28.1 mm^2. The results obtained present a good matching of input impedance around 3.5 GHz, a reflection coefficient of −23 dB, a high gain of 20.5 dBi, and a directional radiation pattern. The effect on the antenna parameters due to the increase in antenna elements (array) is observed in the antenna gain and directivity. This structure offers good performances which makes it suitable for sub-6 GHz wireless communication technologies of the mobile fifth generation (5G).

Keywords Antenna array · Gain · 5G

1 Introduction

The microstrip antenna plays a very important role in the wireless communication system, presenting many advantages due to their lightness, their miniaturized structure, the ease of realization by the technique of the printed circuit, the low manufacturing cost, and the small footprint. Despite these advantages they have a number of considerable disadvantages, such as low gain and narrow bandwidth. This

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has prompted researchers to consider proposing various techniques to enhance the performance of microstrip patch antennas in terms of gain, frequency band, and directivity of radiation. As found in papers [1, 2], that the proposed structures offering a gain improvement of 6.84 dB, to 12.8 dB, and an improvement of 4.25–11.5 dBi by adopting an antenna array configuration containing four elements. Another technique used in the paper [3], including the application of a metamaterial structure in a MIMO antenna array operating at 5.8 GHz, causes a gain improvement of up to 9.2 dBi. We also found a MIMO antenna which was proposed to have a maximum gain of 7.1 dBi and 7.9 dBi at 28 GHz and 38 GHz, respectively [4]. We also find a four-element (MIMO) antenna array giving a bandwidth between 23 and 40 GHz, with a reduction of mutual coupling up to 20 dB, and a gain of 10.58, 8.87 and 11.45 dB at frequencies of 28, 33, and 38 GHz, respectively [5]. In the article [6] the average gain can reach a value of 17.3 dBi, when designing the 4 × 4 antenna array, can also reach 11.5 dBi and 9,019 dB thanks to the design of a four-element array radiating [7, 8]. In [9, 10] we have a slotted SIW cavity planar antenna array with high gain for mmW applications is proposed and designed. In [11], two antenna arrays made up of 64 and 256 radiating components each are used to achieve the large bandwidths of 25.8% and 23.8%, with gains of 27.5 and 33.8 dBi and radiation efficiencies of around 90% and 80%, respectively. Another technique was used to obtain a gain of 6 dBi in the range of frequencies between 3.2 and 5.4 GHz (51%), by uniformly placing meta-columns around the dipole's ring-shaped perimeter [12]. A new form of an array has been designed, containing 16 rectangular elements driven from a single port, via a Y-junction power divider to achieve a gain of 17.1 dB with a radiation efficiency of 92% [13]. In [14] a TSIW multibeam antenna array operating at 30 GHz composed of eight SIW monopoles offers a gain of 12 dBi at the resonant frequency. A conical recessed mass is introduced below the conventional 60 GHz microstrip antenna array. The bandwidth of the CMPA network is improved by 11.84% and the gain is improved by 1.97 dB at 60 GHz [15].

The major goal of this work is to design a compact antenna array to have an improved gain, operating at 3.5 GHz for sub-6 GHz wireless communication systems of the fifth generation (5G). To supply the proposed network we adopt the supply in series, and the supply in parallel under the pretext that they are simpler to implement since they can be on the same layer of the network allowing an optimization of the weight, the thickness and antenna costs. In the first section we will present a square antenna operating at 3.5 GHz, presenting the S11 reflection coefficient, the gain, and the radiation pattern. In the second section an antenna array containing 4 radiating elements, are moved in series and printed on the same substrate, to mention its influence on gain improvement compared to the reference antenna, then an antenna array 4 × 4, and finally the design of the 8 × 4 network containing 32 elements. CST Microwave Studio and Advanced Design System (ADS) software are used to simulate these structures. The Table 1 illustrates the allocation in the sub-6 band for 5G [16].

Table 1 Spectrum allocation for 5G sub-6 GHz applications in different countries

Countries	3–4 GHz range	4–5 GHz range	5–7 GHz range
United States	3.45–3.7, 3.7–3.98	3.49–4.99	5.9–7.1
Canada	3.47–3.65, 3.65–4.0		
Korea	3.4–3.7, 3.7–4.0		26.5–28.1
India	3.4–3.6		26/28
Australia	3.5		27.5–28.35
Italy	3.6–3.8		
EU	3.4–3.8		5.9–6.4
Japan	3.6–4.1	4.5–4.9	
China	3.3–3.6	4.5–5	

2 Design Methodologies

2.1 A Conventional Square Patch Antenna's Design

We started by designing a square-shaped micro-strip patch antenna, operating at 3.5 GHz, fed by a microstrip line. The purpose of this work is to provide a novel strategy to enhance the antenna's radiating performance. The first step was the calculation of the dimensions of the patch using the Eqs. (1) and (2) [17]:

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

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

- f_r: the resonant frequency of the antenna.
- μ_0 et ε_0: Permeability and permittivity in free space.
- ε_r: The relative permittivity of the dielectric material.
- ΔL: The extension of the patch length around the slots.

The dielectric effective permittivity (ε_{reff}) can be determined using the Eq. (3).

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

The height of the substrate is referred to as 'h,' and ΔL may be computed using the following Eq. (4):

Table 2 The optimized parameters of the conventional patch antenna

Parameter	Value (mm)	Parameter	Value (mm)
Wp	28.1	Wf	0.41
Lp	28.1	Lf	16.28
Ws	55	h	0.508
Ls	60	t	0.035

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

The feed widths of different impedances can be calculated using the Eq. (5) [17].

$$\frac{w_f}{h} = \left\{\begin{array}{ll} \frac{8e^A}{e^{2A} - 2}, & \frac{w_0}{h} \le 2 \\ \frac{2}{\mu}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\}, & \frac{w_0}{h} \ge 2 \end{array}\right\} \tag{5}$$

where

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1}(0.23 + \frac{0.11}{\varepsilon_r})$$
$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

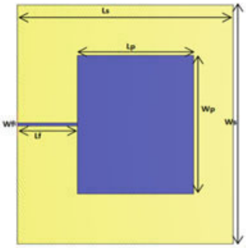
After validating the dimensions of the patch element allowing having a resonance frequency of 3.5 GHz, we associated the quarter wave to adapt the input impedance to 50 Ω. The patch antenna is printed on a Rogers RT 5880 type substrate, with a relative permittivity ε = 2.2, a loss tangent tan(δ) = 0.0009, a height of 0.508 mm, and a size of 60 × 55 mm^2. The optimized square antenna parameters are shown in Table 2.

The geometry of a single radiating element is mentioned in Fig. 1a, and after the simulation, a good input impedance match at 3.5 GHz, a gain of 6.89 dBi, and a radiation pattern that is stable in the frequency band are obtained, (see Fig. 1b–d). As you can see, we have a good agreement between the two software, comparing the results obtained with the ADS and CST software.

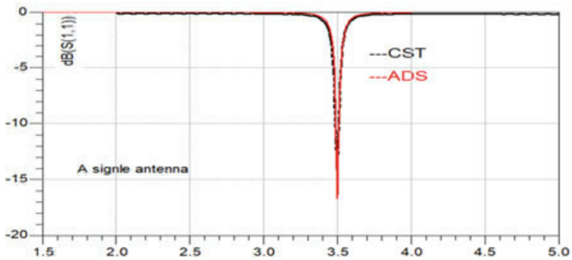
2.2 *Design of a 1 × 4 Antenna Array Containing 4 Radiation Elements*

To further improve the antenna gain, a 1 × 4 antenna array is designed as can be seen in Fig. 2a. The linear antenna array is designed so that the distances between each two consecutive elements of the array are equal $\frac{\lambda}{2}$. The square shape of antenna is

Fig. 1 **a** Basic antenna geometry, **b** return loss (CST vs. ADS), **c** gain versus frequency, **d** 3D radiation pattern



(a)



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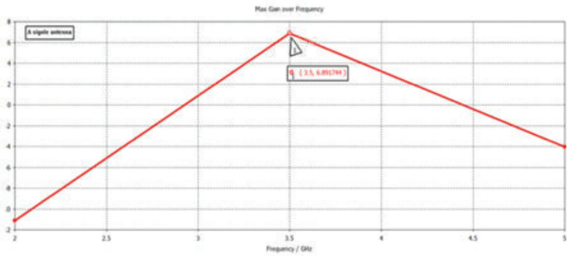
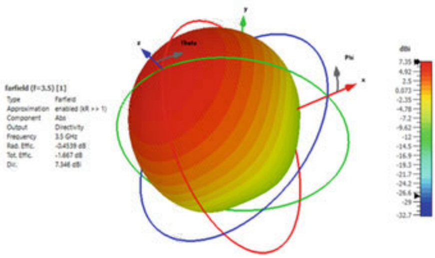
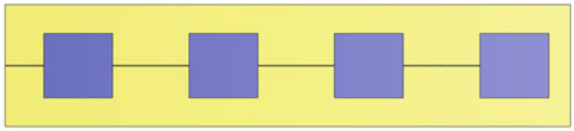


(c)

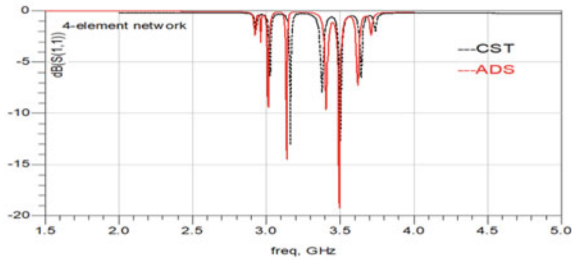


(d)

Fig. 2 **a** 1 × 4 antenna array geometry, **b** return loss (CST vs. ADS), **c** gain versus frequency, **d** 3D radiation pattern



(a)



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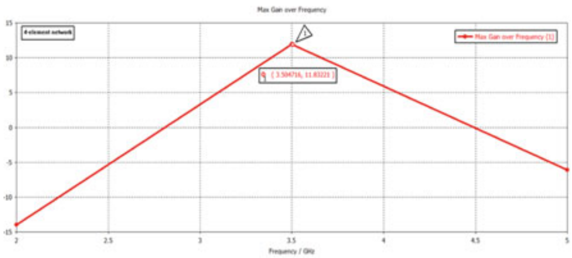

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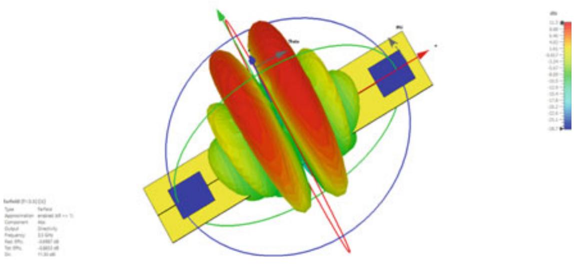


(d)

adopted to have the same input impedance at two sides of the patch designed under the pretext of facilitating the calculation of the dimension of the feed line linking two successive patches in the antenna array, i.e. with the square antenna we can use the same quarter wave which is used in the conventional antenna.

Figure 2b shows that the 1 × 4 antenna array exhibits a good matching of input impedance around 3.5 GHz of −17 dBi, with a significant improvement in gain at 3.5 GHz reaching 11.8 dBi (see Fig. 2c), and an improvement of a radiation pattern (see Fig. 2d).

2.3 Design of a 4 × 4 Antenna Array Containing 16 Radiation Elements

Wilkinson divider is a power divider that isolates output ports from each other while maintaining impedance matching on all ports to minimize crosstalk [18–22]. The 4 × 4 and 8 × 4 antenna arrays designed, including the 1 × 4 sub-arrays which are fed in parallel to a source of feeding network using micro-strip lines of widths 100′ Ω, 70.7′ Ω and 50′ Ω [23–25].

After a simulation of a 4 × 4 antenna array, we find a good adaptation of the reflection coefficient S_{11} at 3.5 GHz, by generating other frequency bands (Fig. 3a), with increased gain (Fig. 3b), and a more directive radiation pattern (Fig. 3c).

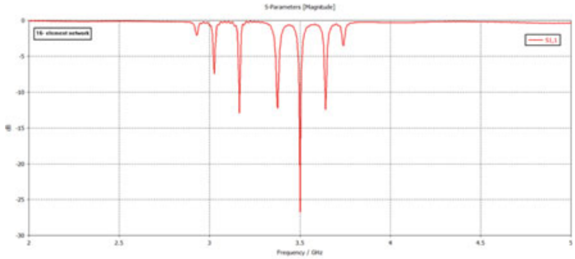
2.4 Design of a 8 × 4 Antenna Array Containing 32 Radiation Elements

After a simulation of an 8 × 4 antenna array containing 32 elements (Fig. 4a), we find a good match of reflection coefficient S_{11} at 3.5 GHz, by generating other frequency bands (Fig. 4b), with a gain increase that reaches a value of 20 dBi (Fig. 4c), and a more directional radiation pattern (Fig. 4d).

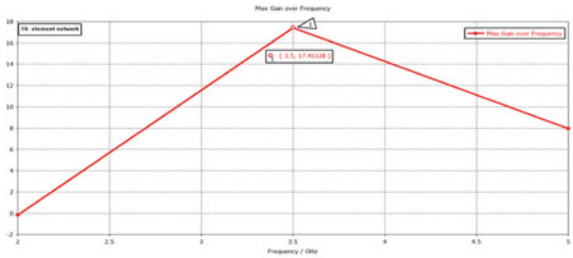
The gain, and the radiation diagram which are obtained using ADS software are in agreement with the results obtained using CST software (see Fig. 5).

After the validation of the suggested array antenna in terms of radiation pattern, matching of input impedance, and gain, Table 3 shows the comparison between the proposed array antennas with some structures validated in the literature. As a result of Table 3, the proposed array antenna exhibits good performances.

Fig. 3 **a** Return loss, **b** gain versus frequency, **c** geometry 4 × 4 antenna array and 3D radiation pattern



(a)



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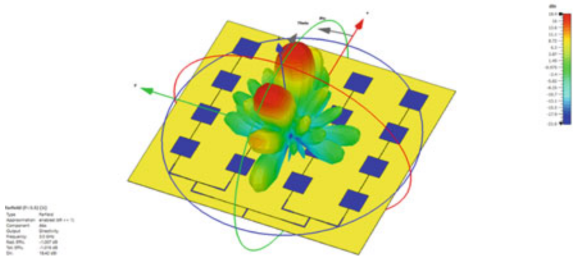

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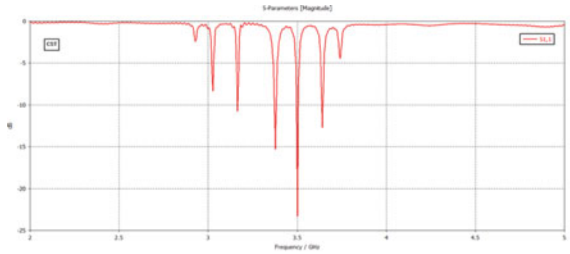
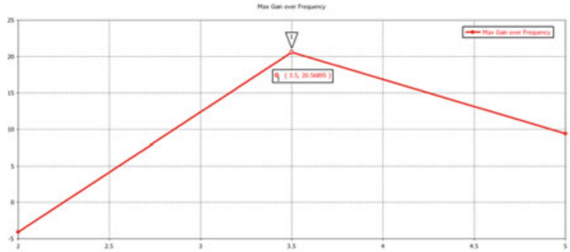
3 Conclusion and Perspectives

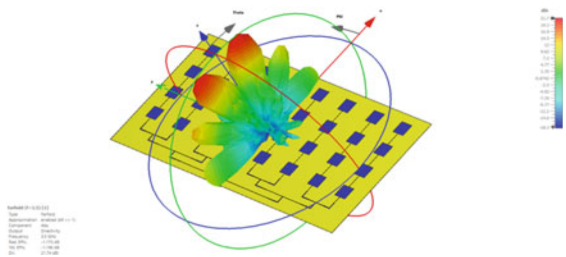
In the current study, we have simulated, optimised and validated an antenna array that is matched for 5G applications operating at 3.5 GHz. The gain had reached a value of 6.89 dBi for a single radiating element and 20.5 dBi for an 8 × 4 antenna array containing 32 elements. For 5G mobile applications, this suggested antenna has been approved. To further increase the gain of the structure, we are considering loading the meta-materials to these designed structures.



(a)



(b)



(c)

Fig. 4 **a** Return loss, **b** gain versus frequency, **c** 4 × 4 antenna array geometry and 3D radiation pattern

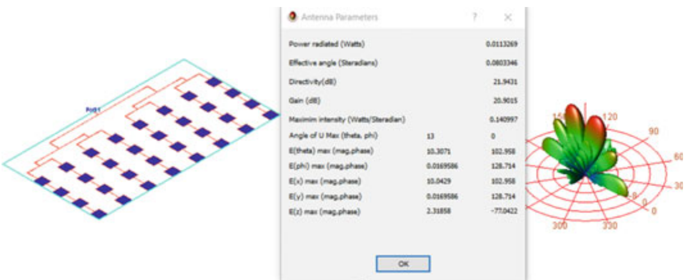


Fig. 5 The gain, and 3D radiation pattern are obtained using ADS software

Table 3 Comparison between the proposed array antenna and some published array antennas

Ref	Size (mm^3)	No. of elements	Freq. (GHz)	G_{max} (dBi)
03	137 × 77 × 3.04	2 × 2	5.8	9.22
16	80 × 80 × 1.575	2 × 2	3.5	8.3
25	374 × 374 × 1.15	4 × 4	3.5	8.76
26	115 × 118 × 1.52	4 × 4	8.15	11.2
27	200 × 200 × 32	4 × 4	3.4	7.63
28	184 × 340 × 3.15	8 × 4	3.5	19.5
Pr.	316 × 660 × 0.515	8 × 4	3.5	20.5

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