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Design Of Microstrip Patch Antenna For Sixth Generation Frequency Band

A.O. Aldhaibani[1*], A. Ba sharahil[2], S. Bukier[3], M. Ba bukier[4], A. Ba wazir[5], S. Balcauilkh[6]

[1,2,3,4,5,6]Dept. of Electronics and Communications Engineering, College of Engineering & Petroleum Hadhramout Universiyy Almukalla, Yemen

**Corresponding Author: aldhaibani.omar@gmail.com*

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Abstract— The rapid advancement of technology and our growing reliance on it in our daily lives have led to a growing demand from users for higher data transfer speeds. The This work presents the design of rectangular microstrip single patch antennas as well as 1x2, 2x2, and 1x4 array patch antennas for 6G applications that operate in the 100 GHz–300 GHz frequency range. A rectangular patch antenna with copper conductivity material developed using Durod5880 unique substrate materials serves as the centrepiece of this arrangement. The dimensions are calculated using mathematical formulas and software, and this design was optimized and simulated using CST Studio Suite. Therefore, the assessed characteristics—return loss, bandwidth, gain, directivity, sidelobe magnitude, angular breadth (3 dB), input impedance, radiation efficiency, and VSWR—give adequate performance for the specified antennas. The array antenna is used to optimize the designated antenna in order to attain optimal performance.

Keywords— Six Generation, patch antenna, millimeter waves, substrate materials

I. INTRODUCTION

The design of the microstrip patch antenna is one layer. Typically, it consists of three primary parts: the substrate, the patch, and the ground plane. The patch is an extremely thin radiation metal strip (or array of strips) on the other side of a thin, non-conductive substrate (t<<λ_0, where λ_0 is the free space wavelength). The ground plane is the same metal that is present on the opposite side of the substrate. [1,2,[3].

Microstrip patch antennas operate in millimeter waves and are widely used in 5G and 6G networks. The following characteristics of these antennas are advantageous: they are low profile, lightweight, and adaptable to both planar and non-planar surfaces [4]. Additionally, they can be easily and affordably made using current printed circuit technology. They can also be used for a range of wireless communication systems, including mobile devices, satellite communication, radar systems, and Internet of Things applications [5][6]. However, because of the radiation patch's close closeness to the ground plane, patch antennas have several disadvantages, including low efficiency, a small bandwidth of less than 5%, and low RF power (making them unsuitable for high-power applications) [1].

The goal of creating a microstrip patch antenna for the 6G frequency band is to meet the growing need for data transfer and high-speed wireless communication. In addition to lowering latency, which is essential for real-time applications like autonomous driving, remote surgery, industrial automation, and internet of things support, 6G promises to deliver data rates larger than 1 Tbps.

This research describes the design of a microstrip patch antenna for the 6G frequency band utilizing the microwave studio application CST (Computer simulation technology) in the frequency range of 100 GHz to 300 GHz. Due to the current demand for extremely high frequencies and speeds due to the advancement of new technologies, this effort looks for the right frequency with a high gain that will aid in obtaining high speeds for 6G applications.

II. RELATED WORK

In [7], a planar antenna array with high gain and bandwidth at terahertz frequency is suggested for upcoming indoor cellular communication systems. In conclusion, the scientists stated that this antenna design is suitable for cellular communication in the THz band (beyond 5G) at 116.9 GHz in the future generations. It is necessary to conduct experimental validation using prototype THz antenna construction in order to acquire more accurate validation.

An integrated all-silicon 2-D horn antenna working in the WR-3 band, which spans 220 to 330 GHz, was proposed by the authors in [8]. This antenna was designed to be fully integrated with a terahertz frontend that is substrate-less and all-dielectric. Two orthogonal basic modes of guided waves with in-plane and out-of-plane polarizations can be supported by the antenna. With enhanced free-space impedance matching and antenna realized gain, broadband operation with a 40% fractional impedance bandwidth on a tiny footprint is made possible. Realized gains throughout the whole WR-3 band range from 10.5 to 15.0 dBi out-of-plane and from 11.2 to 14.2 dBi in-plane, according to experimental confirmation of the built antenna.

In order to create and analyze such an antenna spanning the whole THz range of 0.1 to 10 THz, [9] introduced graphene material in a variety of possible patch and feedline combinations. Four primary antenna properties were analyzed: return loss, VSWR, gain, and directivity. Additionally, a parametric investigation of substrate thicknesses for silicon, polyamide, and RT5880 was carried out. A wide bandwidth of over 9 THz was obtained as a result of this effort. Furthermore, starting at 2.2 THz for all substrate materials, VSWR is less than 2. By utilizing graphene and silicon as the substrate material, the directivity is increased and can reach 7.45 dBi for a thickness of 4.75 µm. At 0.1 THz, the gain can then approach 34 dBi. In order to increase the gain and directivity, the authors recommend using an antenna array, which will be quite interesting for further research on the sixth generation of telecommunications (6G).

A novel and small-sized MIMO antenna design is presented in [10] for sixth-generation (6G) satellite communication systems that use the D band. The substrate layer of the 2.951× 2.951 × 0.127 mm3 antenna is made of Rogers RT5880 material, which is renowned for having good dielectric qualities. The incorporation of a PIN diode is a crucial component that allows for frequency reconfiguration over six different bands, ranging from 120 GHz to 220 GHz, with a bandwidth of up to 27 GHz. The designed antenna reaches a peak efficiency of 92% and a maximum gain of 8.27 dBi. Robust MIMO performance depends on port isolation of less than −40 dB, coherence coefficients close to zero, and a diversity gain of 10 dB, all of which are guaranteed by its optimization. making it appropriate for current 6G communication networks.

III. SYSTEM DESIGN

The CST Studio Suite 2023 is the software used in this project. The primary component of the microstrip patch antenna design is an extremely thin metallic strip that is positioned only a tiny bit above the ground. In order to obtain a resonant frequency in the range of 6G frequencies, the conventional micro strip patch antenna model for rectangular form is used, and it is optimized by altering the shape, material, and substrate of the metallic strip.

We create an array from the planned patch by selecting the number of antennas and the method of receiving feeds to obtain better results than a one-patch antenna after designing the microstrip patch antenna and getting decent results. The output results of one antenna are compared to the output of that antenna's array in order to continue this research. Moreover, great accuracy guarantees that the outcome will be satisfactory. The final analysis of the microstrip patch antenna design considers the following factors: angular width, radiation efficiency, directivity, bandwidth, gain, preference for return loss, side loop magnitude, input impedance, and VSWR.

This section will cover the paper's goal, which is to build an effective mm-wave Microstrip patch antenna for 6G applications. The design of microstrip patch antenna arrays using copper as the conductance material and distinct substrate materials—Duron5880—in rectangular shape.

A. Material of Antenna

Choosing the patch material has an impact on the patch's diminution, therefore choosing the antenna material will also have an impact on the outcome. this content displayed in Table 1.

Table 1. Material of patch

Metallic Material	**Conductivity**	**Substrate Material**	εr
Copper	$5.8\text{x}10^7$ s/m	Duroid 5880	2.20

B. Design of rectangular Single patch antenna

The next steps are to determine the antenna's shape and compute its dimensions after specified the material of the antenna. The following formulae can be used to estimate the dimensions. [11,12,13]:

Calculating the width (W) of the patch using the formula (1):

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where
W= width of microstrip line
v_0= the free space velocity of light
f_r= resonant frequency
ε_r= relative dielectric constant

i) Calculate the length,

Calculate the effective dielectric constant using the formula (2):

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\,\frac{h}{w}\right]^{-1/2} \qquad \frac{W}{h} > 1 \quad (2)$$

Where
ε_{reff}= effective dielectric constant for microstrip line
ε_r= relative dielectric constant
h = thickness of the substrate layer

Calculate the length by using the following the formula (3):

$$L = \frac{v_o}{2f_r\sqrt{\varepsilon_{reff}}} - 0.824h\left[\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\,\frac{\left(\frac{w}{h}+0.264\right)}{\left(\frac{w}{h}+0.8\right)}\right] \quad (3)$$

Where
L= the actual length of patch
h = thickness of the substrate layer
W= width of microstrip line

Now the length calculated, which completes the computation of the rectangular patch dimensions.[14,15] Calculate the effective wavelength using the formula (4):

$$\lambda_{eff} = \frac{v_0}{f_r}\sqrt{\varepsilon_{reff}} \qquad (4)$$

Calculate the width of ground using the formula (5):

$$W_g = \frac{\lambda_{eff}}{4} \times 2 + W \qquad (5)$$

Use the formula (6) to Calculate the length of ground:

$$L_g = \frac{\lambda_{eff}}{4} \times 2 + L \qquad (6)$$

ii) Calculate the transmission line feed

To determine the approximate dimensions of line feed the quarter wave transformer method chosen to match the impedance of the patch with the transmission feed line by using the following equations:

a) the impedance of the patch is given by:

$$z_a = 90\frac{\varepsilon r^2}{\varepsilon r - 1}\left(\frac{L}{w}\right)^2 \qquad (7)$$

b) The transition section's characteristic impedance has to be:

$$z_T = \sqrt{50 \times Za} \qquad (8)$$

c) The transition line's width is determined by:

$$z_T = \frac{60}{\sqrt{\varepsilon reff}}\, ln\left(\frac{8d}{w_T} + \frac{w_T}{4d}\right) \qquad (9)$$

d) The following formula can be used to determine the width of the 50Ω microstrip feed:

$$z_o = \frac{120\pi}{\sqrt{\varepsilon reff}\left(\frac{w}{h}+1.393+0.667\, ln\left(\frac{w}{h}+1.44\right)\right)} \qquad (10)$$

e) The transition line's length is one-fourth the wavelength.:

$$l = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon reff}} \qquad (11)$$

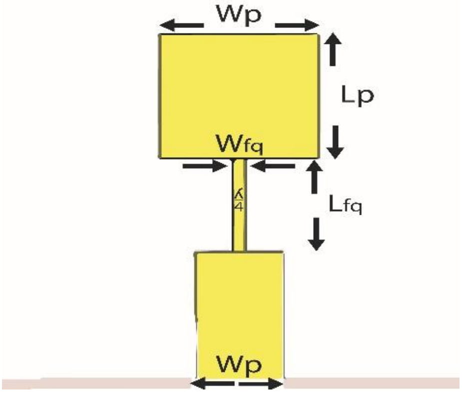


Figure.1 The design of single microstrip patch antenna

C. *Results of single microstrip patch antenna*

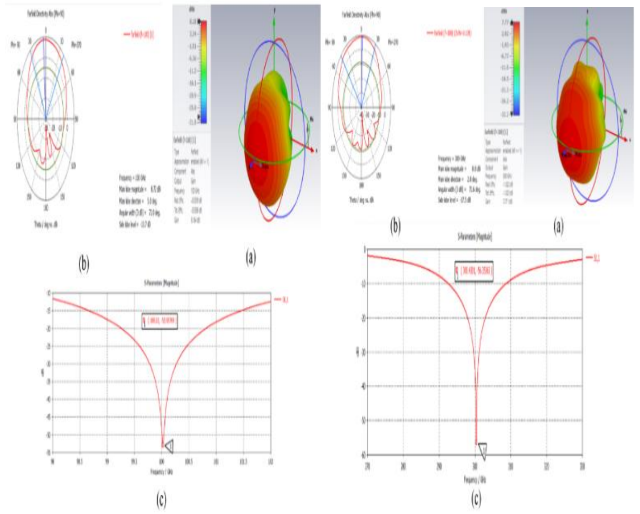
In this paper, the CST Studio Suite Version 2023 selected. The focus will be on some antenna parameters that play a crucial role in the design and performance of antenna such as S-Parameters, Bandwidth, Gain, Directivity, Side lobe magnitude, Angular width (3dB), Input Impedance, Radiation Efficiency and VSWR. Table 2, represent the approximate mathematical measurements for the patch antenna design at frequencies (100GHz & 300GHz) respectively, so, from the previously specified equations, noted that the dielectric constant ε_r is the primary controller in calculating all dimensions, for this reason, the difference between antenna dimension measurements appears with the Duroid 5880 (2.2). In addition, as the operation frequency increase, the dimension of the antenna design decrease. And based on the related literature research, the thickness of the conductive material (copper) is selected. From Table 3. And Figure 2., It is evident that at 100 GHz, the patch's mathematical dimensions are fewer than its simulation dimensions in terms of width and length, while at 300 GHz, the converse is true. According to CST simulation results, there is less return loss at 300 GHz than at 100 GHz. Directivity and VSWR, however, are nearly identical at both frequencies.

Table 2. A) Simulation Results using CST .and B) Mathematical and Simulation Dimensions Results at 100 GHz &300 GHz in mm for Single microstrip patch antenna

A			**B**				
Parameters name	**Simulation Results using CST**		**Parameters name**	**Mathematical Dimensions Results**		**Simulation Dimensions Results**	
	100 GHz	**300 GHZ**		**100 GHZ**	**300 GHZ**	**100 GHZ**	**300 GHZ**
Return loss (dB)	-52.9	-56.35	Width of ground	3.29	1.105	5	2
Bandwidth (GHz)	5.26	16.26	Length of ground	3.012	0.990	5	2
Gain (dBi)	8.18	7.77	Conductor thickness	0.035	0.035	0.035	0.035
Directivity (dBi)	8.72	8.79	Substrate thickness	0.158	0.05	0.1588	0.05
Side lobe level (dBi)	-13.7	-17.5	Width of patch	1.185	0.4	1.181	0.4
Angular width (3dB)	72	72.6	Length of patch	0.905	0.304	0.861	0.2853
Input Impedance (Ω)	50	50	Width of quarter transmission line	0.133	0.013	0.1	0.0234
Radiation Efficiency (%)	88.3	79.03	Length of quarter transmission line	0.534	0.168	0.534	0.17
VSWR	1.05	1.003	Width of 50Ω transmission line	0.473	0.087	0.453	0.128

Table 3. Mathematical Dimensions Results of (1x2 & 1.4 & 2x2) in mm

A			**B**				
Parameters name	**Simulation Results using CST**		**Parameters name**	**Mathematical Dimensions Results**		**Simulation Dimensions Results**	
	100 GHz	**300 GHZ**		**100 GHz**	**300 GHZ**	**100 GHz**	**300 GHZ**
Return loss (dB)	-52.9	-56.35	Width of ground	3.29	1.105	5	2
Bandwidth (GHz)	5.262	16.26	Length of ground	3.0125	0.9903	5	2
Gain (dBi)	8.18	7.77	Conductor thickness	0.035	0.035	0.035	0.035
Directivity (dBi)	8.72	8.79	Substrate thickness	0.1588	0.05	0.1588	0.05
Side lobe level (dBi)	-13.7	-17.5	Width of patch	1.1858	0.4	1.1815	0.4
Angular width (3dB)	72	72.6	Length of patch	0.9059	0.3043	0.861	0.2853
Input Impedance (Ω)	50	50	Width of quarter transmission line	0.1334	0.0136	0.1	0.0234
Radiation Efficiency (%)	88.39	79.03	Length of quarter transmission line	0.5341	0.1685	0.5341	0.17
VSWR	1.05	1.003	Width of 50Ω transmission line	0.4739	0.0876	0.4535	0.128



(100 GHz) **(300 GHz)**

Figure 2. Simulation results in CST at 100GHz &300GHz, for (a)3D radiation pattern for gain, (b) 2D radiation pattern for directivity and (c) S_{11}

D. *Design of Array patch antenna*

Following the computation of the feed line and patch antenna dimensions, the rectangular patch dimensions were chosen for the array patch construction. The corporate feeding approach is selected to feed the array elements in order to imitate the line feed dimensions. finding the patch array feedlines impedance by Using the next formulas [16]. In communication systems, the array of antenna is used to enhance the performance of the antenna like increasing directivity, gain, and other functions that are difficult to get with a single antenna. By using, one of the three ways of feeding techniques series feed as shows in Fig.3, Fig.4 and corporate feed as in Fig.5 or both of them to design the antenna array [17]:

- calculate the distance between the patch's by:

$$d = \frac{\lambda}{4} = \frac{\lambda_o}{4\sqrt{\varepsilon reff}} \qquad (12)$$

- calculate the transconductance of patch by:

$$G_e = 0.00836\frac{w}{0.8\lambda} \qquad (13)$$

- calculate the edge impedance of patch by:

$$R_{in} = \frac{1}{2G_e} \qquad (14)$$

After calculate the edge impedance, we substitute the value of R_in the equation (8), (9) and (10) to get the value of the width of 50 Ω, 70.07 Ω, 100 Ω and 120 Ω feedlines.

-Two element (1x2), (1x4)& (2x2) patch arrays

The design of rectangular array antenna made in three shapes. The Fig.3 shows the (1x2) patch arrays, Fig. 4 display the (1x4) patch arrays while Fig.5 shows the (2x2) patch arrays

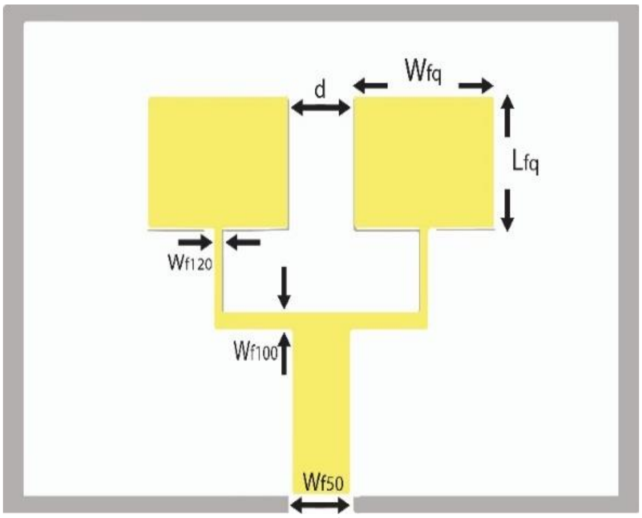


Figure 3. The design of (1x2) patch arrays

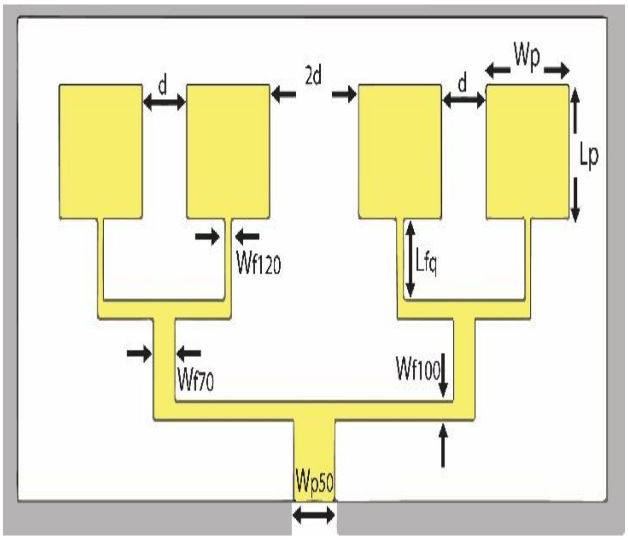


Figure 4. The design of (1x4) patch arrays

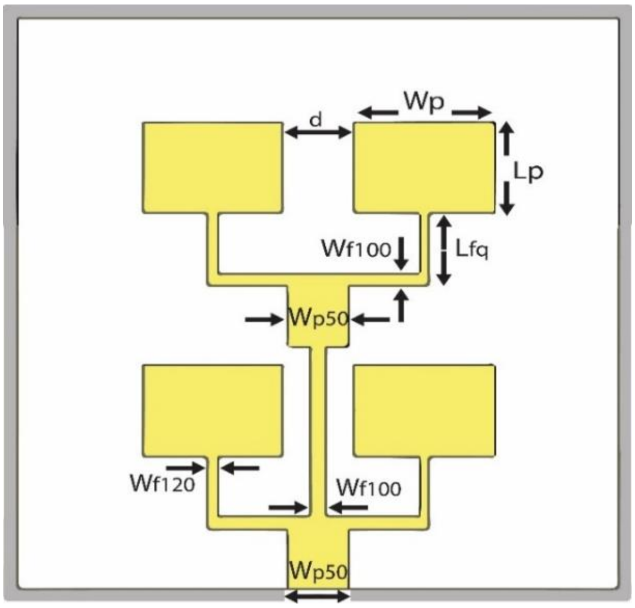


Figure 5. The design of (2x2) patch arrays

E. Results of Array patch antenna

Following the determination of the patch's dimensions using the Duriod 5880 material.based on multiple expermintal, we evident that the Duriod 5880 material yields the best Return loss values, and that the Duriod 5880 material also yields a higher gain than Polyimide material. Thus, the Duriod 5880 material produced good results in terms of either return loss or gain. So, the Duriod 5880 chosen in whole calculation in this work. Tables 4 and 5 provide the array patch's dimensions based on simulation and mathematical conclusions. It is evident that for every type of array (1x2, 1x4, and 2x2), the dimensions of the array patches' length and width have somewhat greater mathematical values than simulation values. having a tiny degree of width or length tolerance. Therefore, the array patch's dimensions are almost the same as the single patch's..

Table 4. Mathematical Dimensions Results of (1x2 & 1.4 & 2x2) in mm

Antenna name	**1x2**		**1x4**		**2x2**	
	100 GHz	**300 GHz**	**100 GHz**	**300 GHz**	**100 GHz**	**300 GHz**
Width of ground	3.29	1.105	3.29	1.105	3.29	1.105
Length of ground	3.0125	0.9903	3.0125	0.9903	3.0125	0.9903
Conductor thickness	0.035	0.035	0.035	0.035	0.035	0.035
Substrate thickness	0.1588	0.05	0.1588	0.05	0.1588	0.05
Width of patch	1.1859	0.4	1.1859	0.4	1.1859	0.4
Length of patch	0.9059	0.2853	0.9059	0.2853	0.9059	0.2853
Width of 50Ω transmission line	0.4535	0.128	0.4535	0.128	0.4535	0.128
Width of 100Ω transmission line	0.1214	0.038	0.1214	0.038	0.1214	0.038
Width of 121Ω transmission line	0.6573	0.021	0.6573	0.021	0.6573	0.021
length of 121Ω transmission line	0.534	0.18	0.534	0.18	0.534	0.18
Distances between patch	0.534	0.18	0.534	0.18	0.534	0.18

Table 5. Simulation Dimensions Results for array patch by using CST in mm

Antenna name	**1x2**		**1x4**		**2x2**	
	100 GHz	**300 GHz**	**100 GHz**	**300 GHz**	**100 GHz**	**300 GHz**
Width of ground	4.9	1.78	8.1	2.68	4.9	1.58
Length of ground	3.57	1.08	2.14	0.99	5.42	1.78
Thickness of the conductivity	0.035	0.035	0.035	0.035	0.035	0.035
Thickness of the substrate	0.1588	0.05	0.1588	0.05	0.1588	0.05
Width of patch	1.1815	0.4	1.1815	0.4	1.1815	0.4
Length of the patch	0.849	0.2713	0.849	0.2713	0.849	0.2713
Width of 50Ω transmission line	0.4535	0.128	0.4535	0.128	0.4535	0.128
Width of 100Ω transmission line	0.1214	0.038	0.1214	0.038	0.1214	0.038
Width of 121Ω transmission line	0.0637	0.016	0.0637	0.016	0.0637	0.016
Length of 121Ω transmission line	0.5341	0.18	0.5341	0.18	0.5341	0.18
Distances between patch	0.5341	0.18	0.5341	0.18	0.5341	0.18

The patch array antenna findings are shown in Table 6. The outcomes were displayed at both 100 GHz and 300 GHz for all design variants. Table 6 and the following Figures(6,7,8) make it evident that, at 300 GHz, the 2x2 array has the best directivity (13.5 dBi) and gain (13.1 dBi) compared to the other two types; in contrast, the 1x4 has the best return loss (-39.3 dB) and the 1x2 has the best radiation efficiency (91.5%). Table 5.show the CST simulation results for the 1x2, 2x2, and 1x4 arrays. At 100GHz, the 2x2 array outperforms the others in terms of gain (13 dBi) and directivity (13.4 dBi); conversely, the 1x2 array has a better return loss (-41.6 dBi) and radiation efficiency (93.3%).

Table 6. Simulation Results for (1x2, 2x2 & 1x4) by using CST

Antenna Parameters	**1x2**		**2x2**		**1x4**	
	100GHz	**300GHz**	**100GHz**	**300GHz**	**100GHz**	**300GHz**
Return loss (dB)	-41.6	-33.8	-35.1	-21.9	-29	-39.3
Bandwidth (GHz)	12.8	70.8	7.08	19	10.9	39.3
Gain (dBi)	10.5	10.6	13	13.1	13.1	12.9
Directivity (dBi)	10.8	11	13.4	13.5	13.4	13.4
Side lobe level (dB)	-23.1	-21.3	-9.11	-9.2	-19.1	-16.4
Angular width (3dB)	66.2	65.6	32.7	33.4	68.1	65.9
Input Impedance (Ω)	50	50	50	50	50	50
Radiation Efficiency	93.3	91.5	91	90.6	92.2	90
VSWR	1.02	1.04	1.04	1.173	1.07	1.05

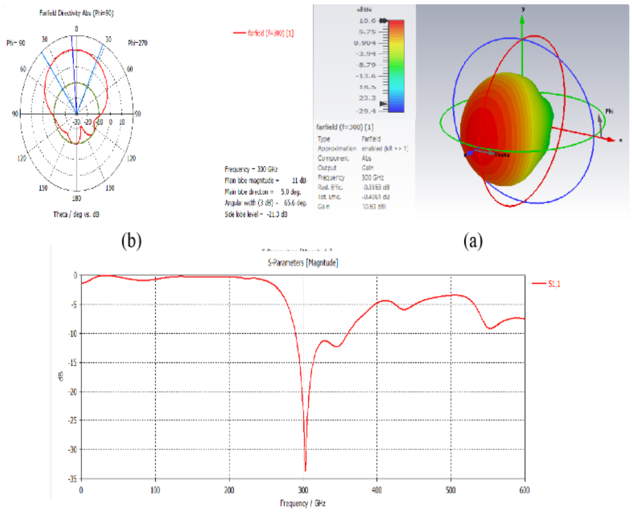


Figure 6. Simulation results for 1x2 patch antenna array at 300GHz in CST for 3D radiation pattern for gain (a), 2D radiation pattern for directivity (b) and S_{11} (c)

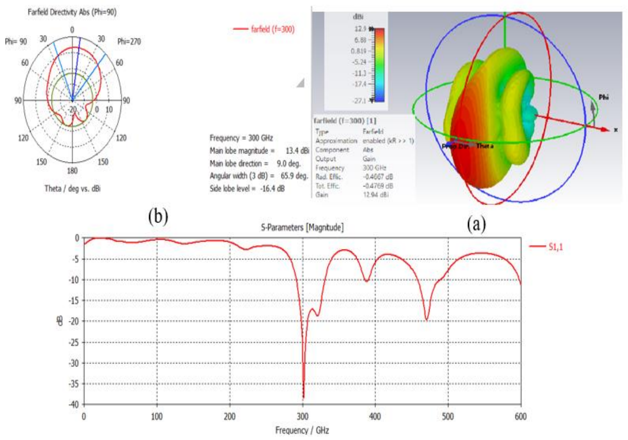


Figure 7. Simulation results for 1x4 patch antenna array at 300GHz in CST for 3D radiation pattern for gain (a), 2D radiation pattern for directivity (b) and S11 (c)

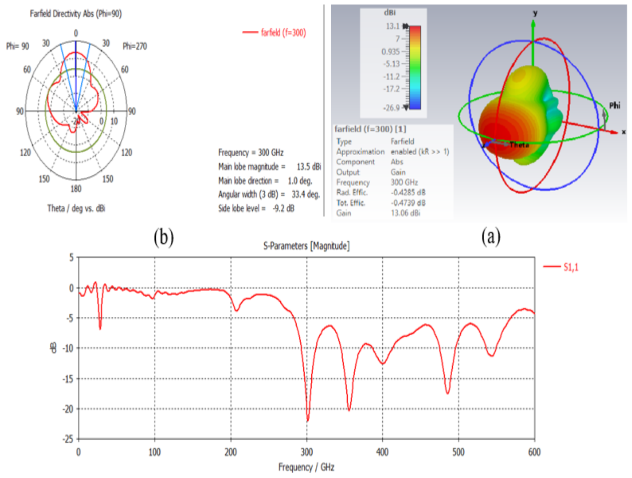


Figure 8. Simulation results for 2X2 patch antenna array at 300GHz in CST for 3D radiation pattern for gain (a), 2D radiation pattern for directivity (b) and S11 (C)

Consequently, array patch antennas outperform single patch antennas in terms of gain, directivity, side lobe level, and radiation efficiency. Together with an excellent return on loss.

IV. CONCLUSION

Every iteration of communication systems aims to achieve lower latency and more spectrum and energy efficiency. 6G networks are expected to include land, air, and sea communication. They are expected to have ultra-low latency, high device support, and increased reliability.

In this paper, single and array microstrip patch antenna designed with rectangular shape for 6G frequency band operating at 100 GHz & 300 GHz. Initially, the dimensions of a single patch antenna computed by using standard equations. CST software is used to evaluate the operational frequency, return loss, radiation pattern, directivity, gain, bandwidth, side lobe level, angular width and VSWR for single antenna and different antenna arrays (1 × 2, 1 × 4 and 2 × 2 patches) with Duroid5880 material as a single and array patch. As a result, a good performance introduced for designed antennas when the parameters evaluated. The results shows that the rectangular array patch antenna give good performance compared with other single patch antenna. In particular, the radiation efficiency increased and the gain and directivity decreased along with the Sid loops level. When comparing different types of antennas, the 1 × 2 design at 100 GHz has the best return loss, followed by the 2 × 2 patch design. On the other hand, the 1 × 4 design has less loss at 300 GHz when compared to other designs at the same frequency. However, the best array patch designs give a gain and directivity are the 2 × 2 and 1 × 4 patch antenna, which are 13 dBi and 13.5 dBi respectively for both frequencies. Additionally, the radiation efficiency is slightly better at 100 GHz and nearly the same at 300 GHz for all array patch types. However, the VSWR has a good value that is nearly constant across all designs. In conclusion, even in terms of return loss, gain, and directivity, the 1 × 4 patch antenna design operating at 300 GHz performs well when compared to other designs. It also obtains favorable results for other parameters. Moreover, this design can be used for higher data rate speed applications because to its high frequency operation.

Data Availability

Not applicable

Conflict Of Interest

There exists no conflict of interest.

Funding Source

No funding was provided for the research work.

Author's Contribution

Dr. A. Aldhaibani provided guidance and technical writing for this paper. His knowledge and perceptions were crucial to the project's accomplishment.

A.Ba sharahil,, layed a significant role in generating and analyzing the result by using CST software.

S. Bukier played role in data analysis, model development,

M. Ba bukier participated in the creation of models and data analysis.

A. Ba wazir and **S. Balcauilkh** helped in literature review, arrangement and gathering of data

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Not Applicable

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Authors Profile

Abdullah O. Aldhaibani, did a postdoc fellow in University of Technology Malaysia (UTM) in the experimental propagation channel of 5G networks at the real field (Kuala Lumpur Area). He obtained his PhD degree in communication Eng. from The University Malaysia Perlis, Malaysia, 2015, and MSc from University of Technology Malaysia (UTM) 2012. Currently, he is working as assistance professor at Hadhramot University. He has been working in the field of optical wireless technologies solution for 4G networks, computer networking, passive optical networks (PON), wireless sensors network and fiber wireless (FiWi), both in experimental and academically research valued work. He participates in many international exhibitions around the world and he awarded a lot of medals. He has authored and co-authored a number of Science Citation Index (SCI) journals and conference papers. He has also participated as a reviewer and a committee member of a number of SCI/ISI journals and conferences.

Ahmed. Ba sharahil earned a Bachelor of Science in Electronics and Communications Engineering from Hadhramout University in 2024. In 2019, he obtained an International English Language Testing System (IELTS) certificate from the IDP-Subing Jaya Center in Malaysia.