ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

DEVELOPMENT AND SIMULATION OF MICROSTRIP PATCH ANTENNAS FOR 5G WIRELESS CONNECTIVITY

NEERU MALIK[1], SHRUTI VASHIST[2], AJAY N. PAITHANE[3], MUKIL. ALGIRISAMY[4]

[1]Asso. Professor, Department of Electronics & Telecommunication, Pimpri Chinchwad University, Pune, India & Research fellow at Manav Rachna University, India
[2]Professor, Department of Electronics & Communication, ManavRachna University, Faridabad, India
[3]Asso. Professor, Department of Electronics & Telecommunication, D. Y. Patil Institute of Engineering, Management & Research, Pune, India
[4]Asso.Professor, Lincoln University College Wisma Lincoln, No. 12-18, Jalan SS 6/12, 47301 Petaling Jaya, Selangor DarulEhsan, Malaysia

E Mail:[1]neeru1508@gmail.com, [2]deanacademics@mru.edu.in, [3]ajay.paithane@dypiemr.ac.in, [4] mukil.a@lincoln.edu.my

ABSTRACT

This study introduces a microstrip patch antenna designed to support 5G communication technology. It operates effectively at central frequencies of 38GHz and 54GHz, offering respective bandwidths of 1.94GHz and 2GHz. The antenna design prioritizes compactness, affordability, and suitability for miniature devices. It consists of an FR4 epoxy substrate, patch, and ground. The substrate boasts a dielectric constant of 3.8, a minimal loss tangent of 0.02, and adheres to a standard thickness of 1.57mm. The substrate measures 6mm x 6.25mm, and the patch's dimensions are 2mm x 2mm, employing the microstrip-line feeding technique.For mobile applications within the millimeter-wave spectrum, including frequencies of 38.6GHz, 47.7GHz, and 54.3GHz, accompanied by bandwidths of 3.5GHz, 2.5GHz, and 1.3GHz, this research also proposes an antenna array comprising four components, spaced at 4mm intervals. The overall antenna size is 6mm x 6.25mm x 0.578mm. The proposed antenna design undergoes rigorous simulation using HFSS software for performance validation.

Keywords: *5G, Microstripline,Antenna Array, Taperedline Feeding, HFSS Software***.**

I. INTRODUCTION

The surge in wireless and radio communication network advancements has heightened the demand for antenna designs featuring enhanced attributes. These include antenna size, bandwidth, gain, power efficiency, traffic capacity, and data rate. In response to this demand, numerous antenna designs have emerged, aiming to strike a balance between factors such as design efficiency, high gain, minimal power loss, compact size, extensive bandwidth, radiation efficiency exceeding 70%, millimeter wave technology effectively utilizes the spectrum, particularly within the 20-90GHz band, specifically earmarked for 5G applications [2]. The selection of frequencies at 28GHz, 38GHz, and 72GHz, each accompanied by respective affordability, and achieving high data rates [1-9]. This demand is driven by the distinctive characteristics of 5G technology, characterized by its high data rates, wide bandwidth, and remarkable capacity.

The foundation of the fifth generation (5G) technology is rooted in millimeter wave radio frequencies, which harness the previously untapped spectrum ranging from 3GHz to 300GHz. In fulfilling the requirements of 5G,

bandwidths of 500 MHz, 1 GHz, and 2 GHz, serves the purpose of 5G antenna design, primarily owing to their suitability for low-latency and high-data-rate systems [3]. These frequencies, characterized by their narrow beam width and exceptional

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

obstacle sensitivity, prove to be well-suited for applications in the realm of cell phones [4].

Numerous substrate materials are available, with FR4 epoxy emerging as the preferred choice for millimeter-wave applications. Its optimal characteristics, characterized by minimal dispersion and low dielectric loss, render it exceptionally well-suited for ultra high frequencies (UHF) [10,11]. FR4 epoxy substrate exhibits advantageous traits such as minimal water absorption, low electric loss, and minimal moisture absorption, making it an ideal selection for a variety of applications [10,11].

In this research, we utilize a substrate featuring a ground layer on one side and a radiator patch on the opposite side, employing metal for both components. The choice of employing the M-line feeding technique is driven by the imperative in mobile communication to achieve a 12dB gain, which can be effectively attained through antenna arrays. Notably, the central frequency for this study is set at 38GHz, falling within the Ka-band spectrum, which spans from 27GHz to 40GHz [11].

Microstrip patch antennas are a favorable choice for various surfaces, thanks to their compact and lightweight design, cost-effectiveness, ease of construction, and small footprint. Employing antenna arrays enhances both gain and efficiency [12], and the proposed antenna design incorporates an array structure to harness these advantages.

In a prior study cited in reference [3], the researchers utilized a PIFA antenna known for its wider bandwidth to cover the frequencies of 28GHz and 38GHz. In another referenced paper [5], transformer coupling was applied to enable operation at 28GHz and 38GHz. The reported antennas in these studies achieved an efficiency of 83.03% and a gain of 9.05dB.

In the research described in paper [13],investigations were conducted at 60GHz frequency using H-slot and E-slot configurations. The results revealed a gain of 5.48 dB and a return loss of -40.99 dB.

The suggested antenna demonstrates impressive characteristics, including a broad bandwidth, efficient radiation, and substantial gain while functioning effectively at both 38GHz and 54GHz frequencies. Additionally, the antenna configuration consists of an array of four elements operating at central frequencies of 38.6 GHz, 47.7 GHz, and 54.8 GHz, with a gain of -12dB.

Table 1 below presents a comparison between the proposed antenna and the relevant prior research.

Table 1: Contrast With Analogous Research.

Reference paper	Patch size(mm)	Bandwidth(GHz)	Resonance Frequency(GHz)	Return loss(dB)	Gain(dB)
[3]	1.3×1.2	3.34, 1.39	28, 38	-43, -18	3.75, 5.06
[15]	1.3×1.83	0.7,0.38	28, 38	-45, -20	0.7, 0.38
This work	1×1	1.94, 2.05	38,54	-15.5, -12	1.94, 2.05

A. ANTENNA DESIGN AND PRINCIPLES

(a) DESIGNING 5G ANTENNAS

Figure 1 illustrates the substrate dimensions (Ls×Ws) of the microstrip patch antenna. The substrate, composed of FR4 epoxy material with a dielectric constant of 3.8 and a loss tangent of 0.02, has a height of 0.78mm. The substrate dimensions measure 6mm×6.25mm. The proposed microstrip patch antenna utilizes M-line feeding, with the feed having a width (Wf) of 0.2mm and a length (Lf) of 2.15mm.

The selected dimensions for the radiating patch (Lp×Wp) are 2mm×2mm. The dimensions for the proposed antenna are computed using established microstrip patch antenna formulas, as illustrated below.

Here are some key equations [16] and parameters used in the design of microstrip patch antennas:

1. Resonant Frequency (f0): The resonant frequency of a microstrip patch antenna can be calculated using the following equation: $f_0=c/2\sqrt{\varepsilon_r}\sqrt{L/(L+2W)}$
Where:
- f_0 is the resonant frequency (in Hertz).
- c is the speed of light in free space (approximately 3 x 10^8 m/s).
- ε_r is the relative permittivity of the substrate material.
- L is the length of the patch (in meters).
- W is the width of the patch (in meters).
2. Effective Dielectric Constant (ε_{eff}): $\varepsilon_{eff}= (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2\ (1+ 12h/W)^{-1/2}$
Where:
- εeff is the effective dielectric constant.
- εr is the relative permittivity of the substrate material.
- h is the height of the substrate (in meters).
- W is the width of the patch (in meters).
3. Patch Length (L) for Resonant Frequency: To achieve the desired resonant frequency, you can rearrange the resonant frequency equation to solve for L: $L=c/2\sqrt{\varepsilon_r} f_0\sqrt{L/(L+2W)}$
4. Patch Width (W) for Resonant Frequency: Similarly, we can solve for W to achieve the desired resonant frequency: $W=c/2\sqrt{\varepsilon_r} f_0\sqrt{L/(L+2W)} - L$
5. Radiation Pattern and Directivity: The radiation pattern and directivity of the microstrip patch antenna can be determined using the following equations[17]:
- Directivity (D) = $4\pi/\Omega$
- Radiation Pattern = $\cos^n(\theta)$, where n depends on the type of patch antenna (e.g., n=1 for a simple patch).
6. Input Impedance (Zin): The input impedance of the microstrip patch antenna can be calculated using the following formula: $Zin=Rr+jXr$ Where:
- Rr is the real part of the input impedance.
- Xr is the imaginary part of the input impedance.
7. Microstrip Line Width (Wm): To feed the microstrip patch antenna with a transmission line, we need to calculate the width of the microstrip line, which can be found using various methods like the transmission line theory.

- Patch width
$w= c/f_0\sqrt{2/s_r+1}$ (1)
- Patch length
$L=L_{eff}- 2\triangle L$(2)
Where L_{eff} can be calculated by formula as stated below
$L_{eff}= c/2f_0\sqrt{S_{reff}}$(3)
ϵ_r =Dielectric constant of the substrate

$S_{reff}= S_r+1/2 + S_r-1/2 \times \sqrt{1+(12h/w))}$ (4)
- $\triangle L= 0.412 \times h \times [(S_{reff}+ 0.3) (w/h +0.26)] / [(S_{reff}+ 0.253) (w/h +0.8)]$ (5)

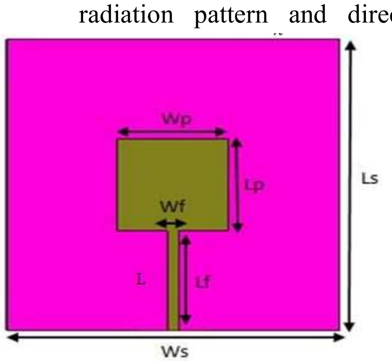


Figure 1: Geometry Of The Antenna For The Envisioned Microstrip Feed

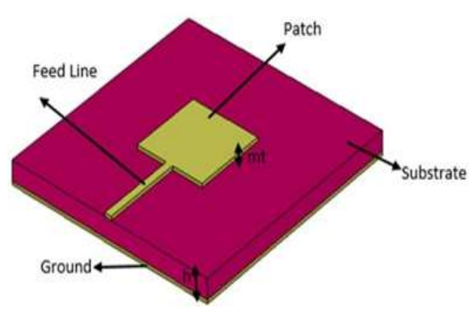


Figure 2: Three-Dimensional Representation Of The Envisioned Microstrip Feed Antenna.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

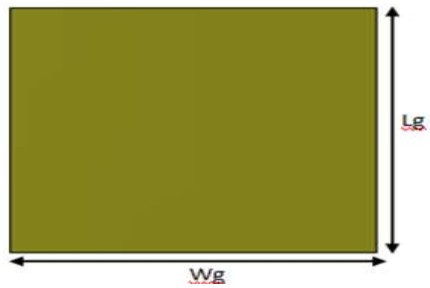


Figure 3: Rear View (Ground Plane) Of The Envisioned Microstrip Feed Antenna.

Table 2: Values Of Parameters For The Proposed 5G Antenna

Antenna Characteristics	Attributes	Measurement in Millimeters
L_s	Substrate length	6
W_s	Substrate width	6.25
H	Substrate height	0.78
L_p	Patch length	2
W_p	Patch width	2
M_t	Patch height	0.035
W_f	Feed line width	0.2
L_f	Feed line length	2.15
W_g	Ground width	6.25
L_g	Ground length	6

(a) DESIGNING A 5G ANTENNA ARRAY

In this research, it is proposed to utilize a 1×4 element array configuration to achieve a significant 12dB gain suitable for mobile applications. The elements within the array are separated by a distance denoted as "d," measuring 4mm. The array is fed through a tapered line feeding mechanism, and the structure of the 4-element array is visualized in Figure 4.

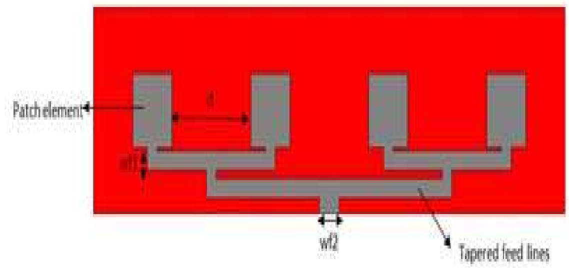


Figure 4: Array Configuration Comprising 1×4 Elements

Table 3 :Values Of Parameters For The Proposed Antenna Array

Characteristics	Attributes	Measurement in Millimeters
D	The gap between two adjacent elements.	4
Wf1	100 Ω impedance line width	0.5
Wf2	100 Ω impedance line width	1

2. FINDINGS AND DISCOURSE

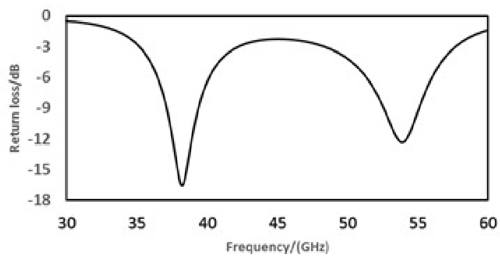
(a)Plot of Return Loss:

The S-Parameter chart depicts the relationship between input and output ports. Return loss is specifically represented by S(1,1). In the case where S(1,1) is at 0dB, it indicates that all power is reflected. For proper antenna operation, S(1,1) should be less than -10dB, as anything lower than this value would result in the transfer of 3dB of total power to the antenna while losing 7dB as reflected power.

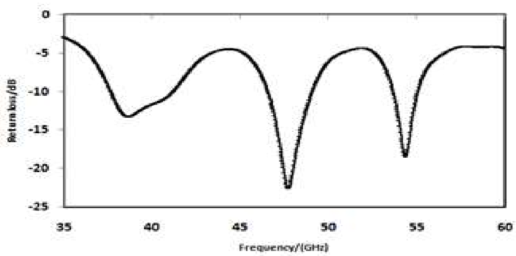
In the context of the proposed antenna, at 38GHz and 54GHz, the return loss is observed to be -15.5dB and -12dB, respectively, as illustrated in Figure 5(a) for the 5G antenna. Similarly, for the relevant frequencies of 38.6GHz, 47.7GHz, and 54GHz, the return loss is -13.6dB, -22.5dB, and -18dB, as shown in Figure 5

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

(b) for the 5G antenna array.



(a)



(b)

Figure 5:Return Loss (A) For The 5G Antenna And (B) For The 5G Antenna Array.

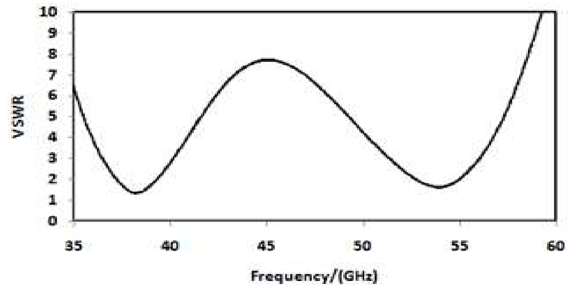
Table 4: Return Loss Of Proposed Model

Antenna	5G Antenna		5G Antenna array		
Frequency of Resonance (GHz)	38	54	38	47.7	54
Return Loss S(1,1) in Decibels (dB)	-15.5	12	-13.5	-22.5	-18

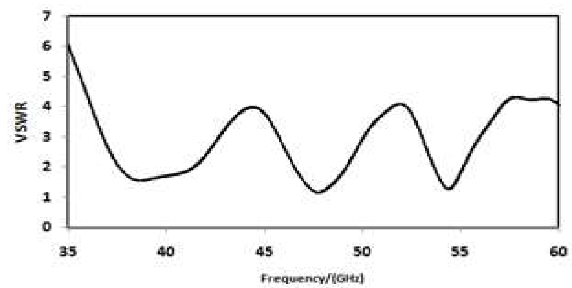
(b) VSWR:

VSWR, or Voltage Standing Wave Ratio, offers detailed insights into an antenna's power reflection characteristics. It's essential for VSWR values to be real and positive numbers. Enhanced antenna performance is achieved with lower VSWR values.

For the proposed antenna, the VSWR values at 38GHz and 54GHz are 1.3dB and 1.64dB, respectively, as depicted in Figure 6(a) for the 5G Antenna. In the case of the 5G Antenna array, the VSWR values are 1.55dB, 1.16dB, and 1.2dB for 38.6GHz, 47.7GHz, and 54GHz, respectively, as shown in Figure 6(b).



(a)



(b)

Figure 6: VSWR (A) For The 5G Antenna And (B) For The 5G Antenna Array.

Table5 :VSWR Of Proposed Model

Antenna	5G Antenna		5G Antenna array		
Frequency of Resonance (GHz)	38	54	38.6	47.7	54
VSWR	1.3	1.64	1.55	1.16	1.2

Table 6 presents the key parameters of the proposed antenna, encompassing operating frequencies, return loss, directivity, gain, bandwidth, and efficiency.

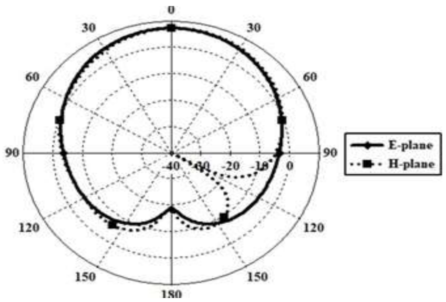
Table6 :Parameters Characterizing The Proposed Model

Antenna	Frequency of Resonance (GHz)	Return Loss in Decibels (dB)	Directivity in decibels isotropic (dBi)	Gain in Decibels (dB)	Frequency Bandwidth (GHz)	Efficiency Percentage (%)
5G Antenna	38	-15.5	7.2	6.9	1.94	93.5
	54	-12	8.2	7.4	2	82.7
5G Antenna Array	38.6	-13.6	12.12	12.12	3.5	99.5
	47.7	-22.5	11.6	11.6	2.5	99.3
	54	-18	12.4	12.1	1.3	93

3. PLOTS OF GAIN:

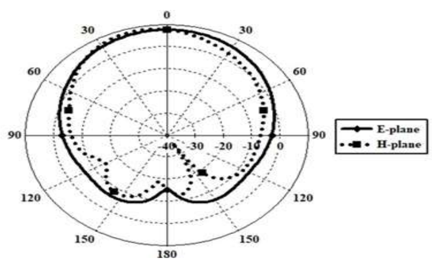
5G ANTENNA

Figure 7 displays the Gain Plots for the microstrip patch antenna.



(a)

Figure 7(A): Gain At A Frequency Of 38 Ghz



(b)

Figure 7(B): Gain At A Frequency Of 54 Ghz

A. 5G ANTENNA ARRAY

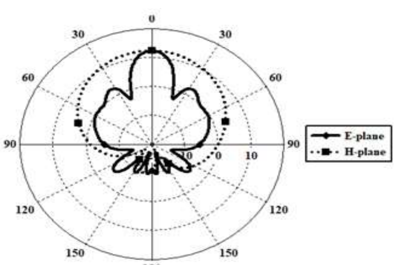


Figure 7(C): Gain At A Frequency Of 38.8 Ghz

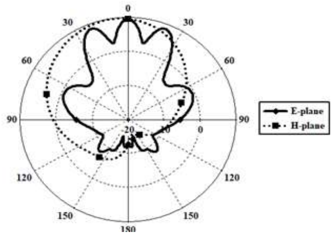


Figure 7(D): Gain At A Frequency Of 47.7 Ghz.

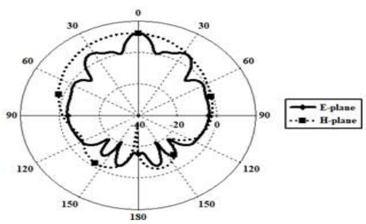


Figure 7(E): Gain At A Frequency Of 54 Ghz.

DISTRIBUTION OF SURFACE CURRENT:

5G ANTENNA

Figure 8(a) and Figure 8(b) illustrate the surface current distribution for the microstrip patch antenna employed in 5G applications.

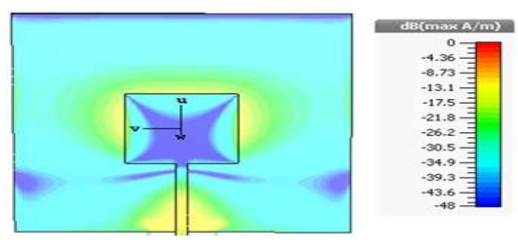


Figure 8(A): Current Distribution At A Frequency Of 38 Ghz.

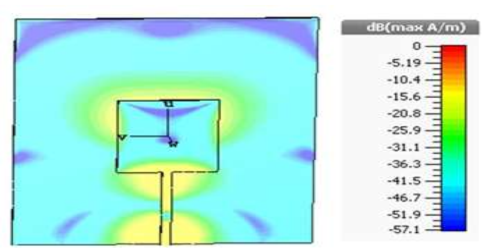


Figure 8(B): Current Distribution At A Frequency Of 54 Ghz.

5G ANTENNA ARRAY

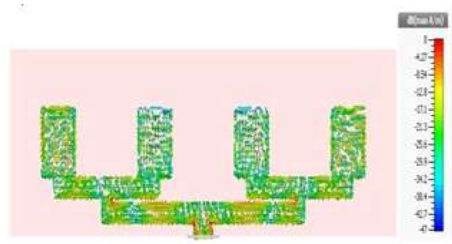


Figure 8(C): Current Distribution At A Frequency Of 38.6 Ghz.

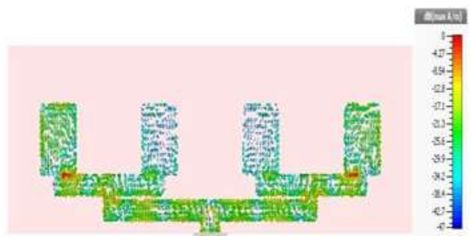


Figure 8(D): Current Distribution At A Frequency Of 47.7 Ghz.

Figure 8(E): Current Distribution At A Frequency Of 54 Ghz.

Three-Dimensional Plots:

A. 5G ANTENNA

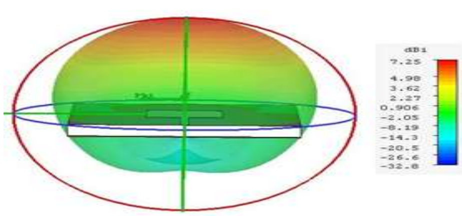


Figure 9(A): Three-Dimensional Pattern At A Frequency Of 38 Ghz.

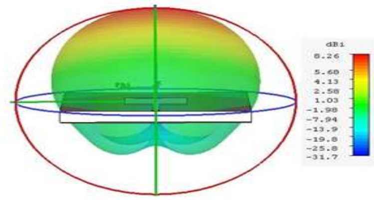


Figure 9(B): Three-Dimensional Pattern At A Frequency Of 54 Ghz.

B. 5G ANTENNA ARRAY

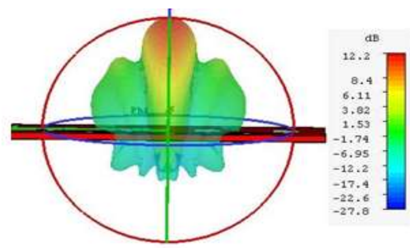


Figure 9(C): Three-Dimensional Pattern At A Frequency Of 38.6 Ghz.

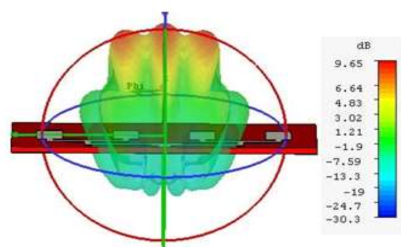


Figure 9(D): Three-Dimensional Pattern At A Frequency Of 47.7 Ghz.

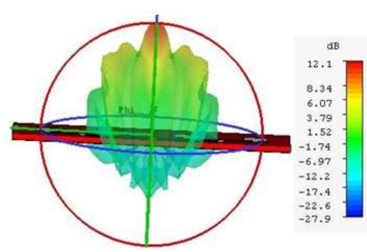


Figure 9(E): Three-Dimensional Pattern At A Frequency Of 54 Ghz.

4. CONCLUSION

In this study, both a basic microstrip patch antenna and a 4-element array configuration have been employed in the context of 5G wireless

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

communication. The microstrip patch antenna provides dual-band reception, while the array extends this capability to three frequency bands, all vital for 5G communication. The microstrip patch antenna covers frequencies at 38GHz and 54GHz, whereas the array spans 38.6GHz, 47.7GHz, and 54GHz. Comparatively, the microstrip patch antenna yields a gain of 6.9dB at 38GHz and 7.4dB at 54GHz. The 4-element linear array, on the other hand, exhibits a gain of 12.2dB at 38.6GHz, 11.6dB at 47.7GHz, and 12.1dB at 54GHz, demonstrating the array's capacity to achieve notably higher gain. As depicted in Table 6, this antenna configuration excels in terms of gain, bandwidth, radiation efficiency, and directivity, positioning it as an excellent choice for 5G communication applications.

REFRENCES:

[1] "Microstrip Antenna for 5G Broadband Communication: Overview of Design Issues," in 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, pp. 2443–2444. David Alvarez Outerelo, Ana VazwuezAlejos, Manuel Garcia Sanchez, and Maria Vera Isasa.

[2] "Design considerations of ultra dense 5G network in millimeter wave band," in Ninth international Conference on Ubiquitous and Future Networks (ICUFN), 2017, pp. 141–146. Naser Al-Falajy and Omar Y.K. Alani.

[3] "Small form factor dual band (28/38 GHz) PIFA antenna for 5G applications," by Waleed Ahmad and WasifTanveer Khan. International Conference on Microdevices for Intelligent Mobility (ICMIM), 2017 IEEE MTT-S, pp. 21–24.

[4] Tin-Yu Wu and Tse Chang, "Interference Reduction by Millimeter Wave Technology for 5G Based Green Communications," IEEE Journals & Magazines, 2016, number 4, pages 10228–10234.

[5] "Multiband millimeter wave antenna array for 5G communication," 2016 International Conference on Emerging Trends in Electrical Electronics & Sustainable Energy Systems (ICETEESES), pp. 102-105.

[6] X.-P. Chen, K. Wu, L. Han, and F. He, "Low-cost high planar antenna array for60-GHz band applications", IEEE Trans. Antennas Propag., vol. 58, no. 6, pp. 2126-2129, June 2010.

[7] "Optimized micro strip antenna arrays for emerging millimeter wave wireless applications", B. Biglarbegian, M. Fakharzadeh, D. Busuioc, M. R. N. Ahmadi, S. S. Naeini. IEEE Trans. Antennaspropagation, May 2011, Vol. 59, No. 5, pp. 1742–1747.

[8] Wideband high-gain 60-GHz LTCCL probe patch antenna array with a soft surface, L. Wang, Y.-X. Guo, and W.-X. Sheng, IEEE Trans. Antennas Propag., vol. 61, no. 4, pp. 1802-1809, April 2013.

[9] Mi Li and K.-M Luk, "Low-Cost Wideband Micro strip Antenna Array for 60-GHz Applications", IEEE Transactions on Antennas and Propagation, vol. 62, no. 6, June 2014, pp. 3012-3018.

[10] Daniel H. Scnaubert and David M. Pozar, "Microstrip Antenna: The Analysis and Design of Microstrip Antenna and Array". Sponsor: IEEE antenna and propagation society.

[11] Rupak Kumar Gupta, T. Shanmuganantham, and R. Kirthika, "A Staircase Hexagonal Shaped Microstrip Patch Antenna for Multiband Applications".ICCICCT 2016, pp. 298–303, International Conference on Control, Instrumentation, Communication and Computational Technologies.

[12] NavreetKaur and ShivaniMalhotra, "A review on significance of design parameters of microstrip patch antennas" in 2016 IEEE Conference publications, pages(1-6).

[13] "Design a single band microstrip patch antenna at 60GHz millimeter wave for 5G applications" in 2017 international conference on Computer, Communications, and Electronics (Comptelix), IEEE Conference Publications, pages (227-230).

[14] Wonbin Hong, Kwang-hyunBaek, and SuengtaeKo, "Millimeter-wave 5G Antennas for Smartphones: Overview and Experimental Demonstration," IEEE Early Access Articles, 2017 IEEE Transaction on Antennas and Propagation, pages(1-1).

[15] 2016 IEEE International Symposium on Antennas and Propagation(APSURSI), Fajardo, PR, USA, Y. A. M. K. Hashem, O. M. Haraz, and E. D. M. El-Sayed, "6-Element 28/38 GHz dual-band MIMO PIFA for future 5G cellular systems," pp. 393-394.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[16] Paithane Ajay, PaithaneSakshi; Dambhare Sunil; ThigaleMadhav; Alagirisamy, "Implementing jerk free bldc position control using soc with fourth order trajectory planning" Journal of Theoretical and Applied Information Technology, Vol 101 Issue 14, 2023, pp. 5553-5565.

[17] Patil U. G., S. D. Shirbahadurkar, and A. N. Paithane. "Linear collaborative discriminant regression and Cepstra features for Hindi speech recognition." Journal of Engineering Research, (2019).