JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. 16 No 4, 04032(4pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том 16 № 4, 04032(4cc) (2024)

OPEN ACCESS

REGULAR ARTICLE

Circularly Polarized Exotic Tri-Shakti Shaped Patch Antenna for 5G Millimeter Wave Communication Systems

Akanksha Gupta[1,*], Pranav Saxena[1,†], Komal Sharma[2], Manish Kumar[3], Dheeraj Bhardwaj[4]

[1] *JECRC University, 303905 Jaipur, India*
[2] *Swami Keshvanand Institute of Technology Management and Gramothan, 302017 Jaipur, India*
[3] *Maharishi International University, Fairfield, IA 52557, The United States*
[4] *Birla Institute of Technology, Mesra, Jaipur Campus, 302017 Jaipur, India*

(Received 15 April 2024; revised manuscript received 10 August 2024; published online 27 August 2024)

A circular polarization (CP) compact single-layer millimeter-wave antenna is proposed for 5G communication systems. The antenna is excited by a microstrip line. Its design is inspired by the Exotic Tri Shakti shape (L = 35.44 mm, W = 45.65 mm), which combines three different shapes: Trishul, Om and Swastik. The primary objective of this research is to design a CP antenna. The antenna is designed using RT/Duroid 5880 (ε_r = 2.2) substrate material, The choice of this substrate material is crucial in achieving the desired antenna performance. The proposed antenna shows multiple resonant frequencies with the max gain produced by the antenna are 15.03 dBi, 14.51 dBi, and 14.27 dBi at frequencies 40.42 GHz, 41.38 GHz and 53.43 GHz respectively and the max efficiency of 99 % at the frequency 30.41 GHz (VSWR ≤ 2). The max impedance bandwidth is 3.05 GHz for the frequency range (25 GHz-60 GHz) and the Axial ratio bandwidths are 60 MHz and 13 MHz at frequencies 40.42 GHz and 57.19 GHz respectively.

Keywords: Microstrip Antenna, Dielectric constant (ε_r), Defected ground structure, Wideband, Circular polarization (CP), Axial ratio beam width (ARBW).

DOI: 10.21272/jnep.16(4).04032 PACS number: 84.40.Ba

1. INTRODUCTION

More than ever, there is an increasing need for mobile communication. Researchers and developers nationwide are actively involved in the advancement of the next generation of communication technology utilizing millimeter waves, commonly referred to as 5G [1-3]. This new generation aims to significantly enhance the performance of existing communication networks in terms of baud rate and transmission speed [4], for which several feeding tech. among these the microstrip line feed [5-8] because of its quality of being easy to understand and to design. The design includes the shape of the patch which definitely impacts on the result of the antenna parameters. In 5G applications, a coaxially-fed circular antenna was studied in [9]. At 28 GHz, the studied configuration outperforms a circular strip-fed antenna in bandwidth and beam width, though with lower gain. Rectangular patches at 28 GHz were favored as mentioned in [10]. This aligns with [11], which highlighted the ability to control patch size using a shunt inductive load. It emphasizes the preference for rectangular shapes in this scenario.

Researchers explored a low-profile circularly polarized antenna in [12], and [13] introduced a novel design enhancing circularly polarized radiation gain through shorting pin loading, both contributing to circular polarization advancements. Researchers focused on biomedical applications in [14], a domain that could benefit from circular polarization and ground radiation. A CP asymmetric microstrip antenna [15] for global navigation introduced, emphasizing wide beam and improved bandwidth, which aligns with the concerns addressed by [16] regarding better parametric calculation for bandwidth and return loss. In summary, these studies form a comprehensive landscape of microstrip antenna research, collectively advancing various aspects of design, polarization, and applications. Swastika and rectangular microstrip antennas comparison has been done [17] with highlighting Swastika's directional pattern and superior performance. The modified rectangular antenna proved suitable for indoor applications. Following a similar approach, [18] adapted the Swastika patch antenna for space applications with a three-stage optimized design. A microstrip antenna with a swastika slot for UWB applications has been designed in [19]. [20] introduced a ψ-shape patch microstrip antenna with a wide 55 % impedance bandwidth, suitable for base station applications. However, at 7 GHz, it experienced increased cross-polarizations and reduced gain. [21] designed a Trishul-shaped microstrip antenna that is versatile for various frequency bands and applications, owing to its wideband characteristics. It is applicable for L, S, C, and X frequency bands, the antenna finds applications in IMT, Bluetooth, WLAN, WiMAX, GSM 1800, GSM 1900, and satellite communication due to its wideband characteristics.

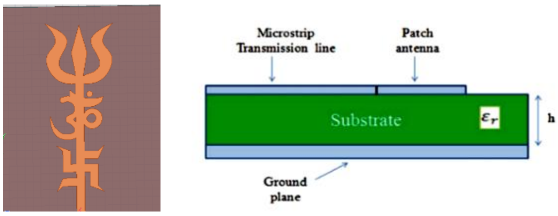
* Correspondence e-mail: guptaakku1994@gmail.com
† hod.physics@jecrcu.edu.in

Cite this article as: A. Gupta et al., *J. Nano- Electron. Phys.* 16 No 4, 04032 (2024) https://doi.org/10.21272/jnep.16(4).04032

On the basis of number of research work as outlined above, This paper centers on the design and performance of an exotic shape Tri-shakti microstrip antenna, a sequential combination of Tri-shul, Om, and Swastik shapes. Utilizing Ansys HFSS software and dielectric RT/Duroid 5880 as the substrate material, a circularly polarized antenna is designed with microstrip line feeding. The simulation explores key parameters including return loss, gain, efficiency, VSWR, and axial ratio. Further details are discussed in the following sections.

2. TRI-SHAKTI MICROSTRIP PATCH ANTENNA DESIGN

Fig 1 illustrates the front view of a Tri Shakti-shaped microstrip patch antenna, specifically designed as a circularly polarized antenna with high gain. The antenna dimensions are 35.44 mm × 45.65 mm of rectangular patches covering a wide frequency range of 25-60 GHz supporting numerous applications. The dielectric material employed is RT/Duroid 5880 ($\varepsilon_r = 2.2$, $\tan\delta = 0.0009$), with $h = 1.6$ mm. Due to its low permittivity, it is particularly favored for high-frequency applications, as it facilitates high gain and maximum radiation efficiency (Circuit A., 2010). To excite the radiating patch, a 50-ohm microstrip line is utilized, as depicted in Fig. 1.



(a) (b)

Fig. 1 – (a) Front view (b) side view of the Designed antenna

The specific dimensions of the Tri-Shakti patch antenna are provided in Table 1.

Table 1 – Dimensions for antenna parameters

Antenna parameter	Dimension (mm)
Length of Patch (L_p)	35.44
Width of Patch (W_p)	45.65
Length of Ground (L_g)	41.84
Length of Substrate (L_S)	41.84
Width of Substrate (W_S)	52.05
Hight of Substrate (h)	1.6

3. RESULT AND DISCUSSION

For this Tri-shakti microstrip patch antenna design, a rigorous simulation has been carried out to study various antenna parameters. An in-depth parametric analysis was performed on various dimensional variables of the antenna to optimize and achieve the specific desired performance characteristics. The analysis has been discussed in the following way.

The designed antenna, depicted in Figures 2 to 7, showcases impressive performance characteristics. It exhibits resonances at multiple frequencies (VSWR ≤ 2) with minimum return losses, achieving – 56.78 dB, – 44.43 dB, and – 39.27 dB at 56.07 GHz, 33.89 GHz, and 46.58 GHz. The gain peaks at 15.03 dBi, 14.51 dBi, and 14.27 dBi at 40.42 GHz, 41.38 GHz, and 53.43 GHz, respectively, while the directivity reaches a maximum of 17.27 dBi at 41.39 GHz. The antenna efficiency is approximately 99.08 %, and the simulated axial ratio (AR) demonstrates circularly polarized EM wave radiation with Axial ratio bandwidths 60 MHz and 13 MHz at frequencies 40.42 GHz and 57.19 GHz respectively.

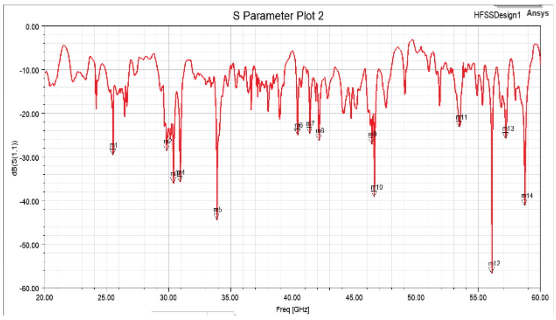


Fig. 2 – Return loss v/s frequency

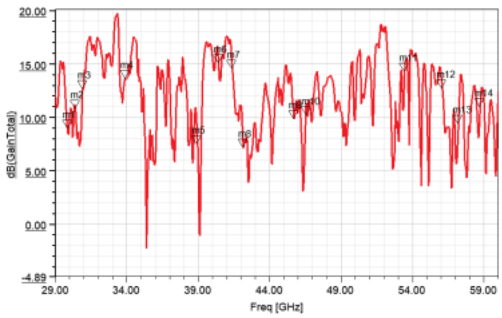


Fig. 3 – Total field gain v/s frequency

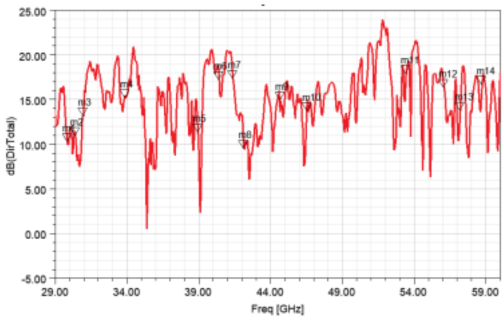


Fig. 4 – Directivity v/s frequency

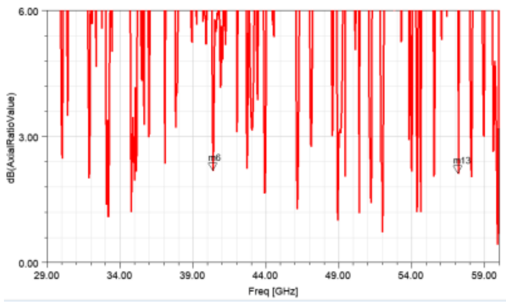


Fig. 5 – Axial ratio v/s frequency

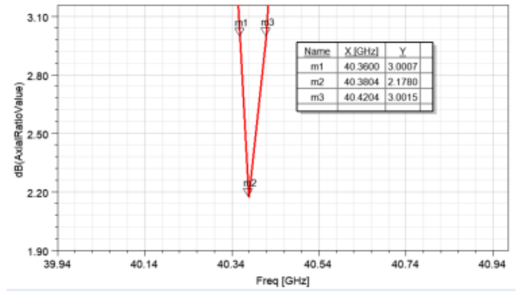


Fig. 5a – Magnified axial ratio v/s frequency at 40.42 GHz

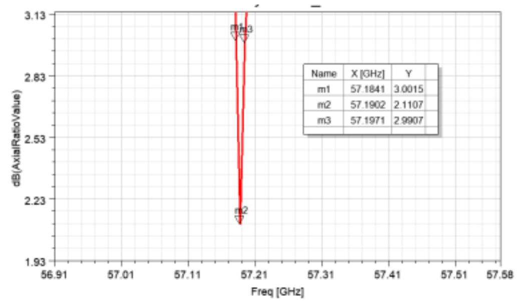


Fig. 5b – Magnified axial ratio v/s frequency at 57.19 GHz

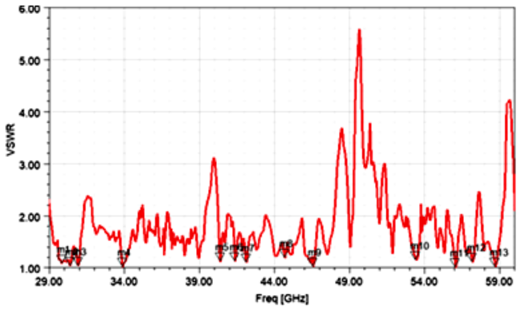
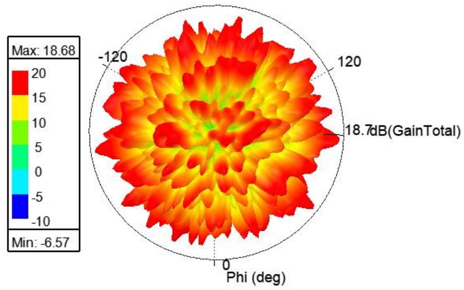
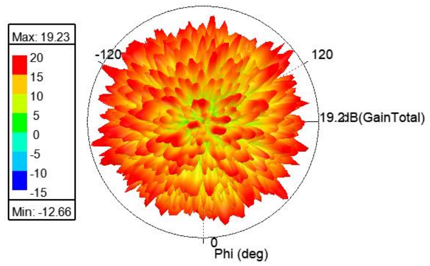


Fig. 6 – VSWR v/s frequency

The total gain along with 3-Dimensional radiation pattern of the proposed antenna is presented in Fig. 7 (a and b) both resonating frequencies at which antenna is circularly polarized, undoubtedly indicates that the maximum peak gains within resonating frequencies were 18.68dB (at 40.42GHz) and 19.23 dB (at 57.19 GHz).



a



b

Fig. 7 – 3D Radiation Pattern at (a) 40.42 GHz and (b) 57.19 GHz

Table 2 – The variation of antenna parameters with respect to resonant frequencies

Marker No	Resonant freq. (GHz)	Return loss (dB)	Impedance band width %	Gain (dBi)	Directivity (dBi)	Efficiency %	Axial ratio Beam Width (MHz)
m1	25.52	– 29.64	7.46	6.75	7.62	89	–
m2	29.84	– 28.68	7.13	8.91	10.18	88	–
m3	30.41	– 30.08	7.13	10.79	10.89	99	–
m4	33.89	– 44.43	9.12	13.59	13	90	–
m5	38.93	– 21.45	6.26	7.49	11.29	66	–
m6	40.42	– 26.93	1.40	15.03	17.15	88	60
m7	41.39	– 24.03	5.32	14.51	17.27	85	–
m8	42.13	– 27.13	5.32	7.12	9.44	75	–
m9	44.7	– 21.35	5.1	12.75	14.82	86	–
m10	46.58	– 39.27	2.32	10.05	14.08	71	–
m11	53.44	– 23.45	1.79	14.27	17.81	80	–
m12	56.07	– 56.78	1.44	12.7	16.25	78	–
m13	57.19	– 25.81	1.65	9.35	13.71	68	13
m14	58.7	– 36.65	2.25	10.97	16.62	66	–

4. CONCLUSION

A compact circular polarized Tri Shakti patch antenna has been presented in this paper using RT/Duroid 5880 substrate material and strip line feed technique. The proposed antennas demonstrate excellent impedance matching and achieve high gain across all operating frequency bands and 3-dB AR bandwidth. This antenna shows too many resonant frequencies with the max gain produced by the antenna is 15.03 dBi, 14.51 dBi, 14.27 dBi at frequency 40.42 GHz, 41.38 GHz and 53.43 GHz respectively and the max efficiency 99 % at the frequency 30.41 GHz

(VSWR ≤ 2). The max impedance bandwidth is 3.05 GHz within the frequency range (25 GHz-60 GHz) and the 3-dB AR bandwidth are 60 MHz and 13 MHz at frequency 40.42 GHz and 57.19 GHz respectively. The summary of the results in Table 2 reveals that the designed antenna frequency range (25 to 60 GHz) is useful for Space applications and future fifth-generation (5G) mobile phones application. However, it is important to validate the performance of the antenna in space communication scenarios through fabrication. This aspect will be considered in future work, which will also include additional analyses such as stability assessment and beamforming capabilities.

ACKNOWLEDGEMENT

Grateful acknowledgment to supervisors Dr. Komal Sharma, Dr. Pranav Saxena, and Dr. Manish Kumar for their guidance and support in shaping the research project. Appreciation to Dr. Dheeraj Bhardwaj and Birla Institute of Technology, Mesra, Jaipur Campus, for providing resources and enabling the study.

REFERENCES

1. T.S. Rappaport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G.N. Wong, J.K. Schulz, M. Samimi, F. Gutierrez, *IEEE Access* **1**, 335 (2013).
2. N. Ashraf, O. Haraz, *Information and Communication Technology Research (ICTRC)* (2015).
3. T.S. Rappaport, J.N. Murdock, F. Gutierrez, *Proc. IEEE* **99** No 8, 1390 (2011).
4. X. Li, A. Gani, R. Salleh, O. Zakaria, *International Conference on Communication Software and Networks*, 554 (2009).
5. A. Elfatimi, S. Bri, A. Saadi, *2018 International Conference on Intelligent Systems and Computer Vision (ISCV)* (2018).
6. V.S. Rathor, J.P. Saini, *J. Electromagn. Anal. Appl.* **6** No 3, 31 (2014)
7. M. Kamran, M.I. Khattak, J. Nebhen, *Alexandria Eng. J.* **61** No 1, 29 (2022).
8. C.A. Balanis, *Antenna Theory: Analysis and Design, 3rd Ed.* (Wiley: Hoboken, NJ, USA: 2005).
9. S. Alam, I. Surjati, L. Sari, Y.K. Ningsih, *Int. J. Sci. Technol. Res.* **9** No 6, 861 (2020).
10. X. Zhang, L. Zhu, *IEEE Trans. Antennas Propag.* **64** No 6, 2172 (2016).
11. S. Kumar, A. Kumar, *International Conference on Innovations in Electronics, Signal Processing, and Communication (IESC)*, 287 (2019).
12. Y. Shi, J. Liu, *IEEE Trans. Anten. Propag.* **66** No 4, 2073 (2018).
13. X. Zhang, L. Zhu, N.W. Liu, *IEEE Trans. Anten. Propag.* **65** No 2, 521 (2017).
14. W. Lei, H. Chu, Y.X. Guo, *IEEE Trans. Anten. Propag.* **64** No 6, 2535 (2016).
15. Nasimuddin, Y.S. Anjani, A. Alphones, *IEEE Trans. Anten. Propag.* **63** No 8, 3764 (2015).
16. V. Jain, J.K. Singh, *Int. J. Res. Technol.* **1** No 1, 11 (2011).
17. S. Burlakoti, R. Prakash, *Kathford Journal of Engineering and Management* **1** No 1, 11 (2018).
18. D. Kaushal, T. Shanmuganantham, *International Conference on Emerging Technological Trends (ICETT)* (2016).
19. A. Sharma, K. Vishwakarma, Rajesh, *IEEE Students' Conference on Electrical, Electronics, and Computer Science* (2014).
20. S.K. Sharma, L. Shafai, *IEEE Antennas Wireless Propag. Lett.* **8**, 468 (2009).
21. A. Kaur, J. Kaur, N. Kumar, *International Journal of Engineering and Advanced Technology (IJEAT)* **8** No 5, (2019).

Патч-антена у формі три-Шакті з круговою поляризацією для систем зв'язку 5G міліметрових хвиль

Akanksha Gupta[1], Pranav Saxena[1], Komal Sharma[2], Manish Kumar[3], Dheeraj Bhardwaj[4]

[1] *JECRC University, 303905 Jaipur, India*
[2] *Swami Keshvanand Institute of Technology Management and Gramothan, 302017 Jaipur, India*
[3] *Maharishi International University, Fairfield, IA 52557, The United States*
[4] *Birla Institute of Technology, Mesra, Jaipur Campus, 302017 Jaipur, India*

Для систем зв'язку 5G пропонується компактна одношарова антена міліметрового діапазону з круговою поляризацією (CP). Антена збуджується мікросмужковою лінією. Його дизайн подібний до форми Exotic Tri Shakti (L = 35,44 мм, W = 45,65 мм), яка поєднує в собі три різні форми: Трішул, Ом і Свастик. Основною метою цього дослідження є розробка CP-антени. Антена розроблена з використанням матеріалу підкладки RT/Duroid 5880 (ε_r = 2,2). Вибір цього матеріалу підкладки має вирішальне значення для досягнення бажаних характеристик антени. Запропонована антена демонструє кілька резонансних частот із максимальним посиленням, створюваним антеною, 15,03 дБі, 14,51 дБі та 14,27 дБі на частотах 40,42 ГГц, 41,38 ГГц та 53,43 ГГц відповідно та максимальною ефективністю 99 % на частоті 30,41 ГГц (КСВН ≤ 2). Максимальна смуга пропускання імпедансу становить 3,05 ГГц для діапазону частот (25 ГГц-60 ГГц), а ширина смуги осьового відношення становить 60 МГц і 13 МГц на частотах 40,42 ГГц і 57,19 ГГц відповідно.

Ключові слова: Мікросмужкова антена, Діелектрична проникність (ε_r), Дефектна основа, Широкосмугова кругова поляризація (CP), Осьова ширина променя (ARBW).