Manipal Journal of Science and Technology

Volume 8 | Issue 2 Article 3

12-31-2023

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Recommended Citation

Varun Yadav, Dr. Manish; Pramith Fernandes, Lanston; and Varun Yadav, Dr Swati (2023) "Cutting-Edge: Four-Element Lumped Mirror Array mm-Wave Antenna for 5G Second Band, Satellite, and Defence Microwave Applications," *Manipal Journal of Science and Technology*: Vol. 8: Iss. 2, Article 3.
Available at: https://impressions.manipal.edu/mjst/vol8/iss2/3

Research Article

Cutting-Edge: Four-Element Lumped Mirror Array mm-Wave Antenna for 5G Second Band, Satellite, and Defence Microwave Applications

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Abstract

This article presents a Lumped Mirror Array mm-Wave Antenna designed for 5G second band, satellite, and defence Microwave applications. The performance of the Array Antenna has been rigorously validated through extensive simulations conducted using CST Microwave Studio, employing a 160 × 70 × 1.5 mm^3 FR-4 substrate. The proposed design incorporates unique features, showcasing an impressive impedance bandwidth of 70.4% and a notable return loss of -35 dBi. Operating within a frequency range of 4.7 to 67.63 GHz, this antenna consistently maintains its polarization patterns across the entire spectrum, ensuring reliable and efficient operation. With a remarkable gain of 3.85 dBi and an efficiency rating of 82.9%, the Array Antenna stands out for its adaptability, making it suitable for diverse applications such as C-band, X-band, Ku-band, K-band, Ka-band, and various other microwave applications.

Keywords: Antenna, Array Antenna, Microwave Application, mm-wave antenna

1. Introduction

The high-frequency UWB band radiator is a cutting-edge solution for multiple communication applications. This advanced antenna operates in the UWB band, which encompasses a high-frequency range, enabling seamless communication across various wireless technologies. The UWB band radiator boasts exceptional performance, offering superior data transfer rates, reduced latency, and enhanced capacity. With its innovative design and precise engineering, this radiator supports multiple communication protocols, making it ideal for next-generation wireless systems. Experience the power of high-frequency communication with the high-frequency UWB band radiator, an indispensable choice for diverse communication needs, from 5G and beyond. Embrace the future of wireless connectivity with this state-of-the-art radiator. Wireless communication extensively employs a compact size of antennas, each distinguished by its unique shapes and attributes. These antennas encompass a variety of designs such as semi-circular, rectangular slots, triangular, multi-slots, and U-shaped, as documented in various sources [1-7]. To enhance the capabilities of these antennas, researchers have explored numerous techniques aimed at boosting their performance.

One notable strategy involves manipulating the antenna's ground plane by in-corporating

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Manuscript received: 30-08-2023
Revision accepted: 28-09-2023

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How to cite this article: Manish Varun Yadav, Lanston Pramith Fernandes,Swati Varun Yadav, Lumped Mirror Array mm-Wave Antenna", *Manipal J. Sci. Tech.*, vol.8(2), 18-25, 2023.

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parasitic elements. This additional integration of elements has proven to enhance antenna performance significantly. Another avenue of exploration involves integrating small fractal components, which contribute to the overall improvement of antenna attributes. Circular and U-shaped slots have also been integrated into designs, affecting parameters like bandwidth and radiation patterns. The alteration of the circular patch's shape has been recognized as a means to achieve specific polar radiation patterns of interest [8-15]. Past research efforts have significantly advanced the capabilities of aerospace communication systems by extending their operational range. These advancements were made possible through innovative adaptations to antenna designs. For example, a pivotal breakthrough emerged when adjustments were introduced to a patch antenna known for its defective backside and incorporation of semi-circular slots [16-18]. Through careful modifications to these specific aspects of the antenna's structure, researchers successfully achieved a broadened bandwidth that aligns with the demands of aerospace communication. Furthermore, manipulating the antenna's backside by introducing modified slots has yielded intriguing results. This approach led to the creation of a patch element intentionally designed with a compromised plane, an unexpected characteristic that, counterintuitively, enhances the antenna's performance in certain contexts [19-20]. These findings underscore the intricate nature of antenna design, where unconventional alterations can lead to unforeseen advantages. Beyond these pivotal discoveries, studies have delved into alternative alternatives to antenna designs aimed at enhancing performance. One notable exploration avenue involves using a flexible antenna alongside a radiator shaped in a "dumbbell" configuration [21-22]. This innovative design highlights the diversity of creative solutions and underscores how unconventional geometries can contribute to desired outcomes in aerospace communication. Another proposed enhancement revolves around a long strip patch antenna strategically integrating rear-cut slots [23]. This design adaptation was conceived to optimize the flow of current within the antenna, ultimately resulting in improved performance characteristics. Such inventive design adjustments exemplify the iterative and forward-looking nature inherent to antenna engineering.

Ensuring balanced radiation patterns holds immense significance within the realm of antenna design. The achievement of equilibrium in radiation patterns guarantees uniform emission of signals across various directions, a fundamental prerequisite for effective communication. A noteworthy approach proposed to confront this challenge revolves around a deliberate adjustment to the antenna's rear side. This involves the strategic introduction of meticulously trimmed circular holes [24-25]. This meticulous modification aims to exert control over signal propagation dynamics, culminating in a more consistent radiation pattern and elevated antenna performance.

Addressing the challenge of impedance matching, which is crucial for efficient power transfer between the antenna and transmission line, has led to integrating multi-slots within the antenna's structure [26]. Similarly, adopting the L-shaped design has proven instrumental in alleviating band resonance issues, thereby enhancing the antenna's proficiency within a desired frequency spectrum [27]. To expand the operational bandwidth, certain studies have explored the truncation of the antenna's ground plane [28]. This technique brings about alterations in signal propagation characteristics, empowering the antenna to cover a broader range of frequencies. In addition, researchers have directed their focus toward modifying the primary patch of the antenna to achieve heightened gain [29]. This adjustment entails reshaping the core element to optimize signal concentration and radiation efficiency, significantly contributing to overall performance enhancements.

2. Geometry and Design Structure

Figure 1 shows a visual representation that covers the basic design steps of the proposed array antenna and the main components discussed in this article. The tested and tailor-made array antenna has 160 × 70 × 1.5 mm^3 dimensions and is built on an FR4 substrate. Copper was chosen as the antenna material and annealed to improve its permittivity and electrical conductivity. FR4 substrate, with a measured dielectric constant of 4.3, serves as the base material for the array antenna. Simulations are performed using the CST simulator to evaluate the array antenna performance accurately. The array antenna laboratory uses traditional chemical etching techniques in the manufacturing process. Subsequent tests and measurements will take place in an anechoic chamber, supported by a vector network analyzer (VNA). The development of this compact array mm-wave antenna suitable for 5G-II band, satellite, and defence microwave applications is of great importance to the development of wireless communication systems. The selected dimensions, substrate materials, and manufacturing techniques underline the careful approach to array antenna design. Evaluation through simulations and field testing underscores the commitment to ensuring optimal performance in real-world communications scenarios.

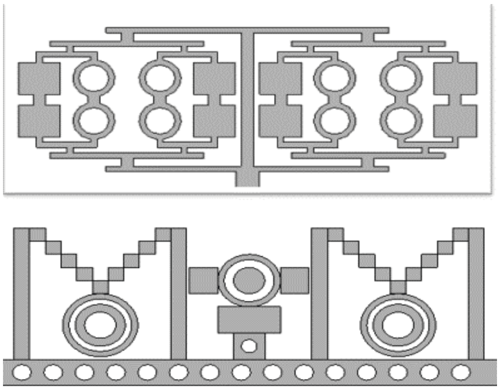
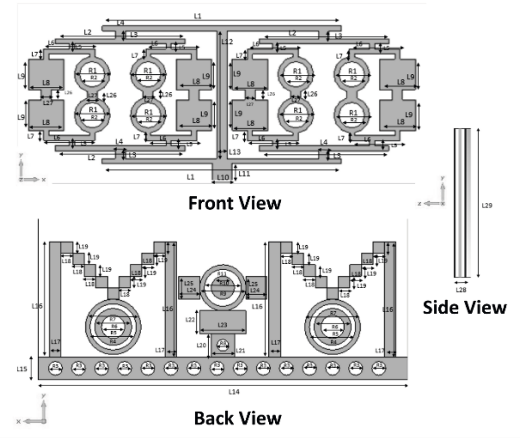


Figure 1. Visual representation of the proposed array antenna

Figure 2 provides a visual representation of the basic geometry and concept behind the network design. The board is characterized by a compact but complex structure that includes a variety of front and rear elements. On the frontal aspect, the design integrates a lumped structure of two rectangles and two circles which are connected in parallel to each other. These two lumped structures on the left side are mirrored on the right side and are separated with a rectangular patch of 38 x 4 mm3. The four lumped structures are interlinked, receiving their central feed through a 50-ohm strip line, thereby influencing the lower boundary oscillation of the array. Proceeding to the rear of the antenna, a unique M-shaped arrangement is created on the ground plane with 15 slots that are 3 x 3 mm in size. Additionally, the antenna's resonance properties are greatly improved, especially at higher frequencies, by carefully placing parasitic circular elements between the M-shaped structures.



Parameters	L1	L2	L3	L4	L5	L6	R1	R2	R3	R4	R5	L7	L8	R6	R7
Values	94	52	4	4	2	20	7	5	3	10	5	4	14	8	12
Parameters	**R8**	**R9**	**R10**	**R11**	**L9**	**L10**	**L11**	**L12**	**L13**	**L14**	**L15**	**L16**	**L17**	**L18**	**L19**
Values	2.5	10	8	5	12	7.8	8	48	4	160	10	50	10	5	5
Parameters	**L20**	**L21**	**L22**	**L23**	**L24**	**L25**	**L26**	**L27**	**L28**	**L29**					
Values	10	10	10	20	9	10	4	5	1.5	70					

Figure 2. Graphical view summarizing of radiator antenna

The dimensions of the array, namely its length, height, and width, are represented as 'L14,' 'L29,' and 'L28,' respectively, as indicated in the design's detailed parameter values presented in Figure 2. This section goes into detail regarding the creation of a unique arrangement that incorporates a lumped structure between two rectangles with dimensions of 'L8' and 'L9' and two cylinders with radii of 'R1' and 'R2.' By connecting these structures with a rectangular element of dimensions 'L27' and 'L28,' performance is further improved, especially in lower-order bands. The complex interaction between these elements results in the array's

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distinctive appearance and enhanced performance over a range of frequency ranges. This lumped element is firmly attached to the primary microstrip and is characterized by dimensions denoted as 'L10 x L11'. In the pursuit of enhancing performance within the lower band, a strategic addition is made with the incorporation of a rectangular strip characterized by dimensions 'L12 x L13.' This strip serves a dual purpose by acting as a separator, distinctly partitioning the left section from the right section of the array. Notably, this separation results in the creation of a mirrored image of the lumped structure, adding symmetry to the overall design. Venturing to the rear side of the array, a noteworthy feature unfolds—an M-shaped structure. This distinctive configuration assumes a pivotal role in the antenna's functionality, specifically contributing to higher-order resonance. The deliberate integration of these structural elements demonstrates a meticulous approach to the design, aiming for a comprehensive optimization of the array's performance across different frequency bands.

The manufacturing procedure for this proposed array design incorporated the utilization of a well-established and highly precise chemical etching technique. Rigorous efforts were invested in refining the fabrication process to ensure the highest level of precision and repeatability. Following the completion of fabrication, thorough inspection protocols were systematically implemented to scrutinize the array meticulously, identifying and addressing any potential manufacturing defects or irregularities. The previously mentioned cutting-edge approach illustrates a comprehensive and intricate strategy aimed at elevating the performance of the antenna. This is achieved through meticulous design choices, advanced fabrication methodologies, and stringent quality control procedures. This methodology represents a significant advancement in the field of antenna engineering, pushing the boundaries of achievable precision, efficiency, and dependability.

3. Design Evolution of the Proposed Array

The visual representation of the design evolution for the proposed array is presented in Figure 3, showcasing the step-by-step development catering to the 5G-II band, satellite, and defence microwave applications. This evolutionary process unfolds across four clearly defined phases.

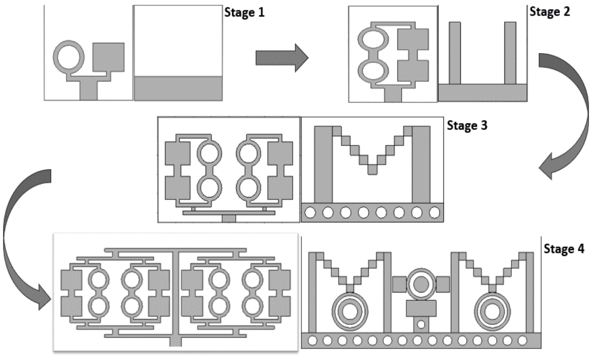

Figure 3. Radiator Evolution

In the initial step (Step 1), the process is inaugurated by establishing a foundational cylindrical and rectangular patch, along with a well-defined ground plane radiator. Advancing to Step 2, the design evolves as an additional cylindrical and rectangular patch is introduced above the existing structure, transforming it into a lumped-shaped patch. This phase also incorporates two rectangular strips on the rear side.

Moving on to Stage 3, the evolution continues with the mirroring of the lumped patch on the front side and the creation of square patches that connect the two rectangular patches on the rear side. In the final stage (Stage 4), the lumped structure undergoes mirroring, resulting in the creation of four distinct lumped structures separated by a rectangular path in the middle. On the rear side, the design is further refined by mirroring the M-shaped patch and adding two cylindrical parasitic patches below the M-shaped structure. This modification significantly contributes to elevating the overall performance, culminating in the development of the final product.

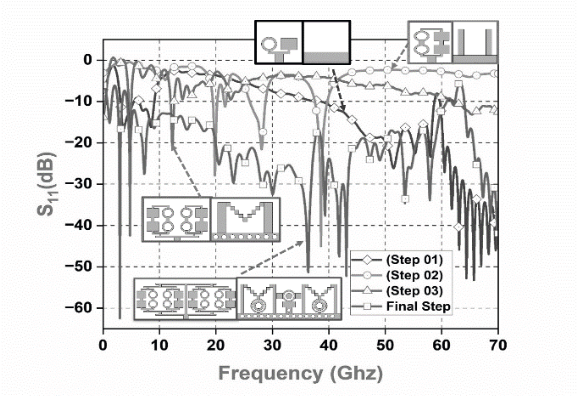

Figure 4. All stages S_{11} parameter

In Figure 4A, the reflection coefficient of the proposed radiator, representing the magnitude of S11, is evident. These illustrations systematically capture the progression of the lumped array design. Commencing with Step 01, the initial configuration features a cylindrical and rectangular patch situated over a well-established ground plane. The cylindrical element, characterized by a 7 mm outer diameter and 5 mm inner diameter, and the rectangular element, measuring 14 mm in breadth and 12 mm in length, are intricately interconnected through a microstrip line with dimensions of 8 x 7.8 mm. The rear structure, characterized by dimensions of 40 x 10 mm, induces a resonance that encompasses a single band, extending from 3.1 to 9 GHz, as visually depicted in Figure 4A.

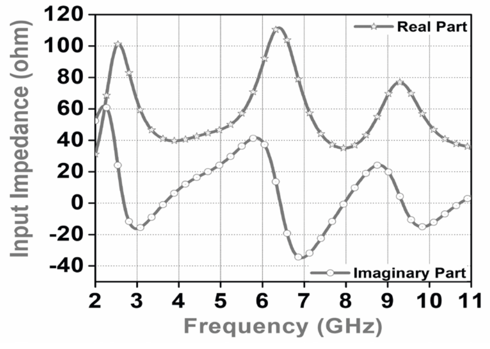

Figure 5. Input Impedance

Figure 5, shows a visual representation of the relationship between frequency and input impedance, offering valuable insights into the antenna's electrical characteristics. The graph shows that the behaviour is primarily inductive within the 2-2.8 GHz frequency range, as indicated by a positive polarity in the curve. This suggests that at these frequencies, the antenna exhibits characteristics associated with inductance, where the impedance tends to resist changes in current. However, as the frequency increases beyond this range, there is a transition to a capacitive behaviour, marked by a negative polarity in the curve. In this capacitive regime, the antenna's impedance begins to favour the storage and release of electrical energy. It is important to note that the impedance values are normalized to 50Ω, providing a standardized reference point for evaluating the antenna's performance across this frequency spectrum.

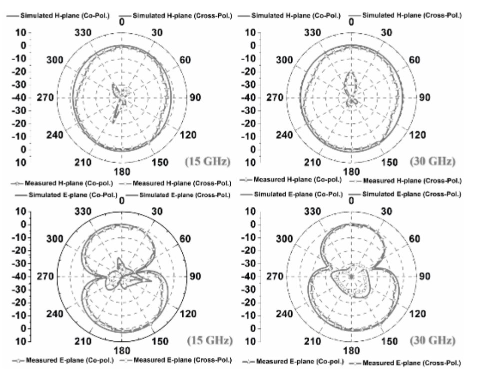

Figure 6. Co and Cross-Polarization radiation patterns

Figure 6 offers an insightful visual representation of the Co (co-polarization) and Cross-polarization patterns at specific frequencies, notably 15 and 30 GHz. The radiation pattern display is presented in two orthogonal planes, providing a comprehensive understanding of the antenna's behaviour. Specifically, the 'H' plane is situated at 0^0 in the XoZ plane, and the 'E' Plane is at 90^0 in the YoZ plane. These radiation patterns are notable for their stability and uniformity, strongly indicating the antenna's pronounced efficiency. Examining the radiation patterns in both orthogonal planes facilitate a clearer comprehension of the antenna's directional characteristics at the specific frequencies.

Table 1demonstrates a contrast between antennas that have been previously documented. After evaluating multiple parameters, it has been established through our analysis that the design we propose is smaller in dimensions and displays enhanced characteristics compared to the antennas previously documented.

Table 1. Comparison of published planar antennas

References	**Band obtained (GHz)**	**Peak Gain (dBi)**	**Fractional B/W (%)**	**Peak (η) (%)**	**Overall volume (in λ)**
[2]	3.1-22	1.7	150%	NA	$.28\lambda*.25\lambda*.016\lambda$
[7]	3.9-14	3.5	142%	75%	$.26\lambda*.26\lambda*.019\lambda$
[9]	2-9	4.5	127%	62%	$.33\ \lambda*.22\lambda*0.1\ \lambda$
[13]	3.5-19	3.2	145%	81%	$.23\lambda*.23\lambda*.015\lambda$
[16]	3.1-11	2	109%	60%	$.55\lambda*.41\lambda*.022\lambda$
[18]	2.9-16	5.2	139%	87%	$.33\lambda*.24\lambda*.014\lambda$
[24]	2.8-12	2.79	122%	72%	$.18\lambda\ *.14\lambda\ *.15\lambda$
[27]	2.7-7.3	2.3	108%	78.3%	$.32\lambda*.2\lambda*.014\lambda$
[28]	3.1-11	2.2	110%	69%	$.14\lambda*.18\lambda*.015\lambda$
[29]	2.3-11	2.1	129%	70%	$.2\lambda*.3\lambda*.014\lambda$
Presented	**4.7-67**	**3.85**	**70.4%**	**82.9%**	**.16λ x .09λ x .019λ**

Conclusion

This article introduces a novel Lumped-Mirror Array mm-Wave Antenna tailored for 5G second band, satellite, and defence microwave applications. The antenna's performance has been meticulously assessed through extensive simulations utilizing CST Microwave Studio, employing a 160 × 70 × 1.5 mm^3 FR-4 substrate. With distinctive characteristics, including an impressive impedance bandwidth of 70.4% and a notable return loss of -35 dBi, the proposed design operates effectively within a wide frequency range from 4.7 to 67.63 GHz. It consistently maintains polarization patterns across this spectrum, ensuring dependable performance. With a gain of 3.85 dBi and an efficiency rating of 82.9%, the Array Antenna exhibits versatility suitable for various applications spanning C-band, X-band, Ku-band, K-band, Ka-band, and numerous other microwave applications. This antenna design represents a significant advancement in mm-wave technology, offering a promising solution for diverse communication and defence needs.

References

1. Mishra, Brijesh, et al. "A review on microstrip patch antenna parameters of different geometry and bandwidth enhancement techniques." International Journal of Microwave and Wireless Technologies 14.5 (2022): 652-673.
2. Baudha, Sudeep, and Manish V. Yadav. "A novel design of a planar antenna with modified patch and defective ground plane for ultra-wideband applications." Microwave and Optical Technology Letters 61.5 (2019): 1320-1327.
3. Yash, B, and S. Baudha. "A compact mace shaped ground plane modified circular patch antenna for ultra-wideband applications." Telecommunications and Radio Engineering 79.5 (2020).
4. Khidre, Ahmed, et al. "Wide band dual-beam U-slot microstrip antenna." IEEE transactions on antennas and propagation 61.3 (2013): 1415-1418.
5. Baudha, Sudeep, and Manish V. Yadav. "A novel design of a planar antenna with modified patch and defective ground plane for ultra-wideband applications." Microwave and Optical Technology Letters 61.5 (2019): 1320-1327.
6. Baudha, Sudeep, Manish Varun Yadav, and Ishita Srivastava. "A Novel Approach for Compact Antenna with Parasitic Elements Aimed at Ultra-Wideband Applications." 2020 14th European Conference on Antennas and Propagation (EuCAP). IEEE, 2020.

7. Shagar, Arumugam Chellamuthu, and Shaik Davood Wahidabanu. "Novel wideband slot antenna having notch-band function for 2.4 GHz WLAN and UWB applications." International Journal of Microwave and Wireless Technologies 3.4 (2011): 451-458.
8. Baudha, Sudeep, Kannan Kapoor, and Manish Varun Yadav. "U-shaped microstrip patch antenna with partial ground plane for mobile satellite services (MSS)." 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC). IEEE, 2019.
9. Kurniawan, Adit, and Salik Mukhlishin. "Wideband antenna design and fabrication for modern wireless communications systems." Procedia Technology 11 (2013): 348-353.
10. Ghosh, Abhijyoti, et al. "Improved polarization purity for circular microstrip antenna with defected patch surface." International Journal of Microwave and Wireless Technologies 8.1 (2016): 89-94.
11. Baudha, Sudeep, and Manish Varun Yadav. "A compact ultra-wide band planar antenna with corrugated ladder ground plane for multiple applications." Microwave and Optical Technology Letters 61.5 (2019): 1341-1348.
12. Abdelraheem, Ahmed M., and Mahmoud A. Abdalla. "Compact curved half circular disc-monopole UWB antenna." International Journal of Microwave and Wireless Technologies 8.2 (2016): 283-290.
13. Shivani Gupta, and Manish Varun Yadav. "Parasitic rectangular patch antenna with variable shape ground plane for satellite and defence communication." 2019 URSI Asia-Pacific Radio Science Conference (AP-RASC). IEEE, 2019.
14. Awad, Noor M., and Mohamed K. Abdelazeez. "Multislot microstrip antenna for ultra-wide band applications." Journal of King Saud University-Engineering Sciences 30.1 (2018): 38-45.
15. Baudha, Sudeep, et al. "A compact planar antenna with extended patch and truncated ground plane for ultrawide band application." Microwave and optical technology letters 62.1 (2020): 200-209.
16. Yadav, Manish Varun, and Sudeep Baudha. "A miniaturized printed antenna with extended circular patch and partial ground plane for UWB applications." Wireless Personal Communications 116 (2021): 311-323.
17. Deshmukh, Amit A., et al. "Broadband slot cut rectangular microstrip antenna." Procedia Computer Science 93 (2016): 53-59.
18. Hota, Satyabrat, et al. "Miniaturized planar ultra-wideband patch antenna with semi-circular slot partial ground plane." 2019 IEEE Indian Conference on Antennas and Propagation (InCAP). IEEE, 2019.
19. Baudha, Sudeep, and Manish V. Yadav. "A novel design of a planar antenna with modified patch and defective ground plane for ultra-wideband applications." Microwave and Optical Technology Letters 61.5 (2019): 1320-1327.
20. Harshit Garg, and Manish Varun Yadav. "Dumbbell shaped microstrip broadband antenna." Journal of Microwaves, Optoelectronics and Electromagnetic Applications 18 (2019): 33-42.
21. Kumar, Dash S, et al. "A cutting-edge S/C/X band antenna for 5G and beyond application." AIP Advances 13.10 (2023).
22. Hota, Satyabrat, et al. "A novel compact planar antenna for ultra-wideband application." Journal of Electromagnetic Waves and Applications 34.1 (2020): 116-128.
23. Mangaraj, B, et al. "A compact, ultrawide band planar antenna with modified circular patch and a defective ground plane for multiple applications." Microwave and Optical Technology Letters 61.9 (2019): 2088-2097.
24. Golait, Manohar, et al. "A compact ultra-wideband square and circular slot ground plane planar antenna with a modified circular patch." International Journal of Microwave and Wireless Technologies 14.8 (2022): 989-994.
25. Yadav, Manish Varun, Sudeep Baudha, and Vaibhav Sanghi. "A 5G rotated frame radiator for ultra wideband microwave communication." International Journal of

Microwave and Wireless Technologies (2023): 1-9.

26. Mazinani, S. Maryam, and Hamid Reza Hassani. "A novel broadband plate-loaded planar monopole antenna." IEEE Antennas and Wireless Propagation Letters 8 (2009): 1123-1126.

27. Shivani, Thukral. "A Compact Hammer Shaped Printed Antenna With Parasitic Elements For Defense And Mobile Satellite Applications." 2021 IEEE Indian Conference on Antennas and Propagation (InCAP). IEEE, 2021.

28. Baudha, S., M. V. Yadav, and Yash Bansal. "A compact slot antenna for ultra-wideband applications." Telecommunications and Radio Engineering 79.3 (2020).

29. Kim, Gyeong-Ho, and Tae-Yeoul Yun. "Compact ultrawideband monopole antenna with an inverted-L-shaped coupled strip." IEEE Antennas and Wireless Propagation Letters 12 (2013): 1291-1294.