



Design And Parametric Analysis Of A CPW-Fed Patch Antenna For Very Low Frequency (VLF) Wireless Communication With Nuclear Submarines

Anupam Kumar Yadav¹, Dr. Sandeep Kumar Singh², Dr. Pavan Kumar Shukla³, Dr. Achyuta Nand Mishra⁴, Dr. Vijay Kumar Gupta⁵

1, 3 Department of Electrical Electronics and Communication Engineering, NIET, greater Noida

2 Department of Electrical Electronics and Communication Engineering, Sharda University, greater Noida

4 Department of Electrical Electronics and Communication Engineering, Supaul College of Engineering, Bihar

5 Department of Electrical Electronics and Communication Engineering, Government Engineering College, West Champaran

Abstract

In this study, a compact patch antenna design is introduced, utilizing a coplanar waveguide (CPW) feed configuration. The antenna structure measures $35 \times 35 \times 1.35 \text{ mm}^3$ and employs an FR4 substrate with a dielectric constant of 4.4. A microstrip feedline is used to connect a coaxial cable to the antenna, ensuring impedance matching at 50Ω . The antenna demonstrates resonant behavior within the 12.46–15.00 GHz range (Ku-band) and the 16.25–19.00 GHz range (NATO K band), specifically at 13.20 GHz and 17.30 GHz. At these resonant frequencies, the voltage standing wave ratio (VSWR) is maintained below 2, achieving values of 1.04 and 1.06, respectively, which indicates excellent impedance matching and performance. The primary objective of this patch antenna design is to achieve a wide impedance bandwidth at the -10 dB return loss threshold, along with a low voltage standing wave ratio (VSWR) at each resonant frequency. Its dual-band operation makes it particularly suitable for wireless communication systems used in nuclear submarines. The proposed antenna demonstrates favorable performance characteristics, including adequate gain, low VSWR, acceptable return loss, and a stable radiation pattern—making it well-suited for high-frequency wireless applications. Parametric analysis confirms the antenna's effectiveness for operations in both the Ku-band and NATO K-band, highlighting its potential for reliable communication in maritime defense environments.

KEYWORDS: Patch, dual-band, Ku-band, Nato K-band.

1. INTRODUCTION

Over the past few decades, satellite and wireless communication systems have undergone substantial development, exerting a significant impact on modern life. Numerous applications, such as communication systems and local area networks (LANs), demand reliable solutions for the transmission and reception of electromagnetic waves. Owing to their structural simplicity, low profile, and ease of fabrication, microstrip patch antennas (MPAs) have emerged as a prominent choice for fulfilling these requirements. The inherent design flexibility of MPAs has led to the evolution of various configurations and techniques aimed at optimizing antenna performance across diverse frequency bands [1-5].

The increasing demand for compact mobile devices has driven the development of smaller and more efficient handsets. As the overall demand for mobile communication grows, the need for miniaturized components becomes more critical. Among these, antenna size plays a pivotal role in the design of portable communication systems. Microstrip patch antennas (MPAs) are frequently employed in such applications due to their low profile, light weight, and ease of integration with compact devices. The key design parameters of an MPA, such as the length and width of the radiating patch, primarily determine its resonant frequency and overall performance. With the advent of fifth-generation (5G) mobile networks, there is a need for antennas capable of supporting ultra-high data rates, minimal latency, and high reliability, making compact and efficient antenna designs increasingly essential [5-10].

The 5G New Radio (NR) interface is designed to meet the increasingly demanding requirements of a wide range of use cases anticipated for 2020 and beyond. These include substantial growth in user connectivity, traffic volume, and device density. To effectively support such diverse and high-performance communication scenarios, the availability of sufficient 5G spectrum across various frequency bands is essential. Spectrum resources must be efficiently managed and allocated to ensure that 5G networks can deliver enhanced capacity, ultra-low latency, and high reliability across different application domains [10-15].

The authors have proposed a compact double-Damru-shaped (pellet drum) antenna, which is fed by a coplanar waveguide (CPW) and constructed on an FR4 substrate with dimensions of $20 \times 10 \times 1.6 \text{ mm}^3$. This antenna operates in five separate frequency bands, with resonant frequencies at 18 GHz, 20.3 GHz, 21 GHz, 21.5 GHz, and 26.4 GHz. It offers penta-band functionality, providing impedance bandwidths with reflection coefficients less than -10 dB ($|S_{11}| \leq -10 \text{ dB}$) across different frequency ranges. Specifically, the bandwidths are 300 MHz (17.85–18.15 GHz) for the Ku-band, 300 MHz (20.2–20.5 GHz) for the lower K-band, 300 MHz (20.8–21.1 GHz) for the middle K-band, 200 MHz (21.4–21.6 GHz) for the higher K-band, and 500 MHz (26.2–26.7 GHz) for the 5G band, making it well-suited for penta-band applications [15-20].

The structure of this paper is organized to systematically present the development and analysis of the proposed antenna. Section II describes the design methodology, including the techniques and configurations adopted in constructing the antenna prototype. This section also outlines the specific materials and dimensions used to achieve the desired electrical characteristics. Section III is dedicated to the optimization process and the parametric studies conducted to fine-tune the antenna's performance. Various design parameters are varied and analyzed to observe their impact on key metrics such as return loss, gain, and bandwidth. In Section IV,

the simulated results are evaluated and benchmarked against previously reported designs in the literature. This section also highlights the strengths and limitations of the proposed antenna and suggests possible avenues for future enhancements and research.

II. GEOMETRY ANALYSIS

Figure 1 illustrates the development of asymmetric configurations of antenna that have been created and studied. The proposed antenna design, inner and outer curve has a diameter of 16.96 mm and 14.96 mm. Angular displacement between these two curves are 258.45 and 41.18 degrees as shown in Fig.1. The steps for calculating geometric design parameters are shown below.

Step 1: Calculation of the Width (W):

The width of the Microstrip patch antenna is given as:

$$W = \frac{C}{2fo\sqrt{\frac{\epsilon_r + 1}{2}}}$$

Step 2: Calculation of Effective dielectric constant (ϵ_{eff}):

The effective dielectric constant is:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{1 + 12 \frac{h}{w}}$$

Step 3: Calculation of the Effective length (L_{eff}):

The effective length is:

$$L_{eff} = \frac{c}{2fo\sqrt{\epsilon_{eff}}}$$

Step 4: Calculation of the length extension (ΔL):

The length extension is:

$$\Delta L = 0.412h \frac{(\epsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}$$

Step 5: Calculation of actual length of patch (L):

The actual length is obtained by:

$$L = L_{eff} - 2 \cdot \Delta L$$

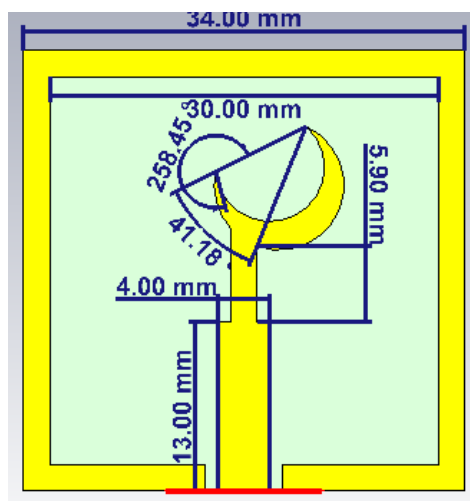


Fig.1 Proposed antenna design

2. PARAMETRIC RESULT ANALYSIS

The proposed antenna design was simulated using CST Studio Suite Version 17, an electromagnetic (EM) simulation software that utilizes the Finite Integration Technique (FIT) within the antenna template's transient solver mode. The simulation results confirm that the antenna performs well across various evaluation criteria. A strong correlation was observed between theoretical expectations and CST simulation outcomes in terms of return loss, voltage standing wave ratio (VSWR), impedance bandwidth (IBW), radiation pattern, directivity, and gain. The optimized electrical parameters obtained from the simulation are summarized in Table I.

Table 1: Result Analysis

Antenna Geometry (mm ³)	VSWR (< 2)	Resonance frequency (f_r) in GHz	Antenna Bandwidth (GHz)	S ₁₁ Parameter (- dB)	Number of Bands
34×34×1.35 mm ³	1.04	13.20	12.46-15.00	42	Dual
	1.06	17.30	16.25-19.00	27	

The voltage standing wave ratio (VSWR) of the proposed patch antenna is presented in Fig. 2. Fig. 3 shows the return loss characteristics of the antenna. The directivity and antenna gain are depicted in Figs. 4 and 5, respectively. Finally, the radiation pattern of the antenna is shown in Fig. 6.

3.1 VSWR

The Voltage Standing Wave Ratio (VSWR) represents the ratio of transmitted to reflected voltage standing waves in a radio frequency (RF) transmission system. It is a key parameter used to evaluate the efficiency of power transfer from the source, through the transmission line, and into the load. As illustrated in Fig. 2, the

VSWR at the resonance frequencies of 13.20 GHz and 17.30 GHz are 1.04 and 1.06, respectively, indicating excellent impedance matching at both frequencies.

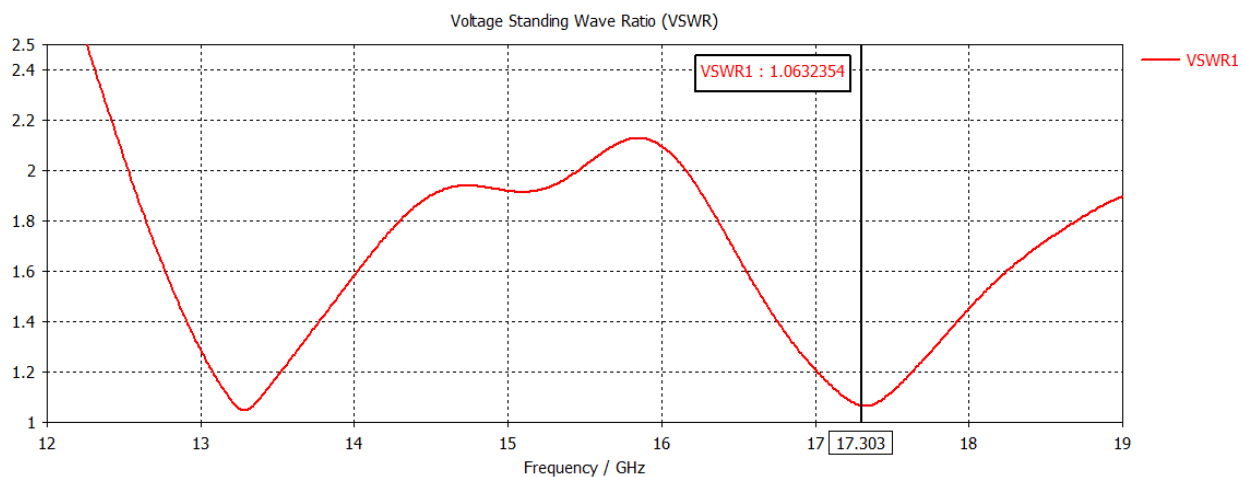


Fig. 2

VSWR of the proposed antenna

3.2 Return Loss

Return loss is the ratio of reflected power to incident power, measured in decibels (dB). For resonance frequencies of 13.20 GHz, 17.30 GHz and 23.88 GHz the return loss is -40 dB, -26 dB and -15 dB respectively as shown in Fig. 3.

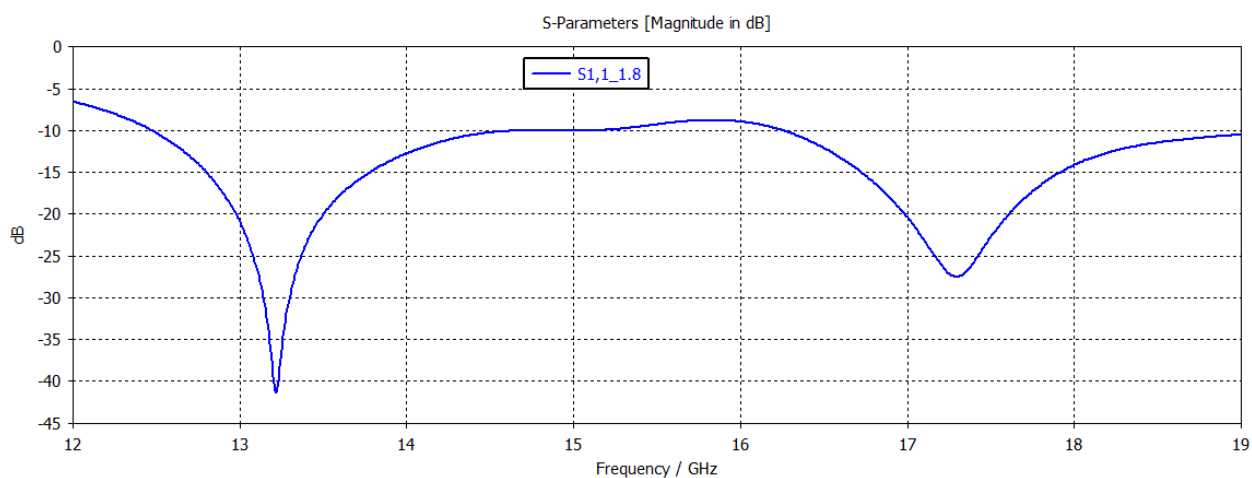


Fig. 3 Return loss of the proposed antenna

3.3 Directivity

It is measured in relation to the concentration of energy emitted in a certain direction by the transmitting antenna. The primary lobe's directivity magnitude at 13.20 GHz is 2.42 dBi. According to Fig. 4, the major lobe magnitude of directivity is 5.82 and 5.81 dBi, respectively, for resonance frequencies of 17.30 GHz.

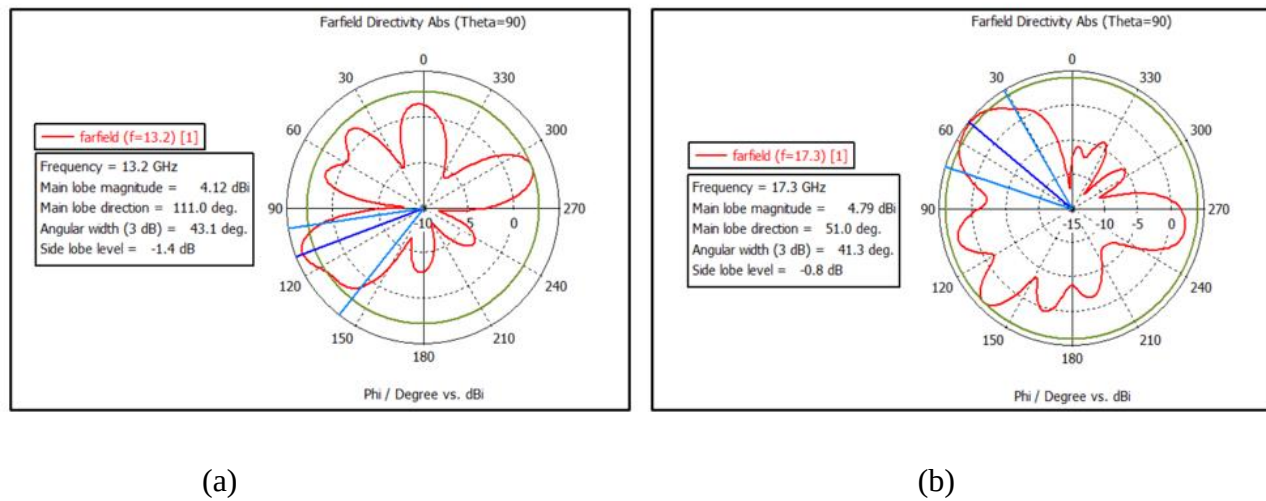


Fig.4 Directivity of proposed antenna at resonance frequencies of (a) 13.20 GHz (b) 17.30GHz

3.4 Gain

The amount of power that is transmitted from an isotropic source to the direction of the peak radiation is referred to as antenna gain. As shown in Fig. 5, the gain is 3 dB and 4.9 dB at resonance frequencies of 13.20 GHz, and 17.30GHz , respectively.

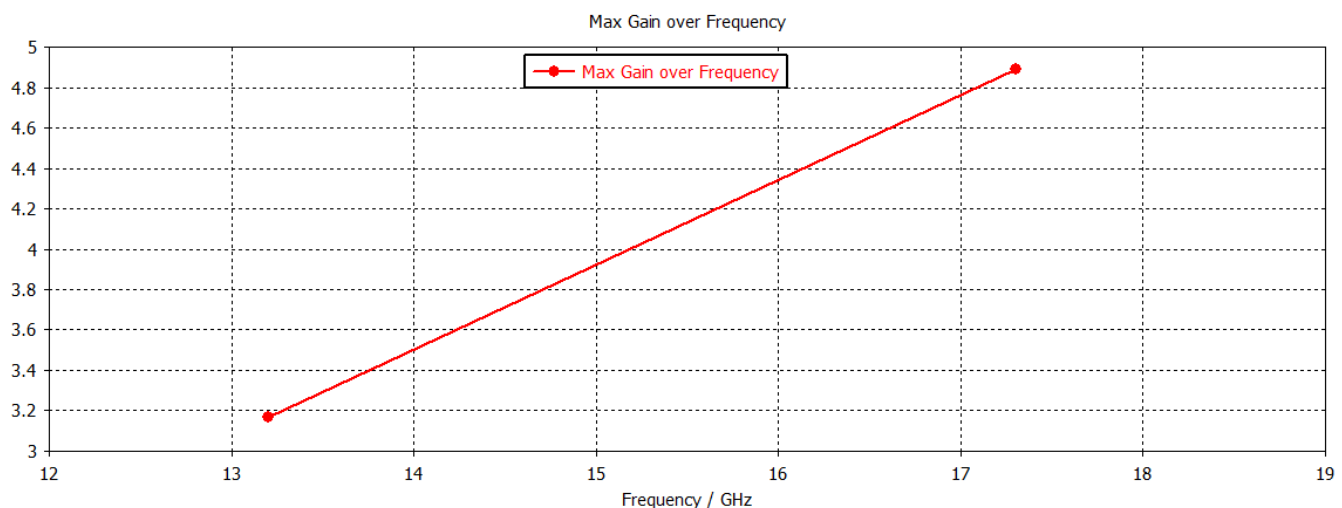


Fig. 5 Gain of the Proposed antenna

3.5 Radiation Pattern

Voltage and electric field are related; a higher E-field striking an antenna will result in a greater voltage differential between the antenna's terminals. As shown in Fig. 6, the major lobe magnitude of the E-field is 17.7 dB (V/m), 19.7 dB (V/m) at resonance frequencies of 13.20 GHz, and 17.30 GHz, respectively.

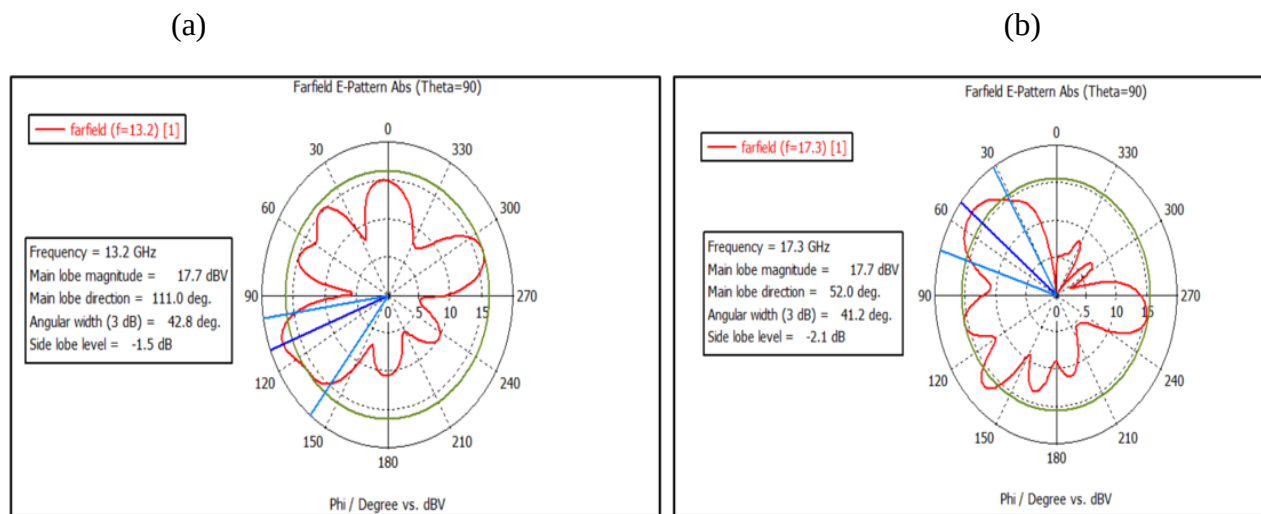


Fig. 6 Radiation pattern of proposed antenna (a) 13.20 GHz, (b) 17.30GHz

3. CONCLUSION

A novel and efficient CPW-fed patch antenna has been designed to achieve the required performance specifications. The proposed antenna is compact and supports dual-band operation, with resonant frequencies at 13.20 GHz and 17.30 GHz. This design is ideal for Ku-band and NATO K-band communication, specifically for Very Low Frequency (VLF) wireless communication in nuclear submarines. The antenna design provides excellent performance for a wide range of wireless applications.

The antenna operates over two frequency bands: 12.46–15.00 GHz (Ku-band) and 16.25–19.00 GHz (NATO K-band), with resonant frequencies of 13.20 GHz and 17.30 GHz, respectively. By reducing the antenna's physical size and utilizing materials with different dielectric properties, the frequency bandwidth can be expanded. This approach allows for an extended range of resonance frequencies, enabling the antenna to be used in emerging wireless applications at higher frequency bands.

REFERENCES

1. Anupam Kumar Yadav, Awadhesh Dwivedi” Result Comparison between I and + Sign Slotted Micro Strip Patch Antennas for Wi-Max applications”-International Journal of Innovative Research in Technology, ISSN: 2349-6002 Volume-8, Issue-5, (Oct 2021), PP 679-682
2. Anupam Kumar Yadav, Awadhesh Dwivedi, Namrata Yadav” Performance comparison between I slotted and U slotted shaped microstrip patch antennas”- Journal of Engineering Science, ISSN: 0377-9254 Volume-11, Issue-5, (May 2020), PP 329-332,
3. Anupam Kumar Yadav, Awadhesh Dwivedi, “Result Comparison of Slotted I Sign Shaped Microstrip Patch Antenna with Rectangular Patch Antenna for Wi-Max Frequency” IJESR/June 2019/ Vol-9/Issue-6/18-22, 2019.
4. Anupam Kumar Yadav, Vijay Kumar 'L-Shaped Micro stripped Patch Antenna for Frequency Range of 3 - 3.5 GHz" IJESR/ICRIT 2018/ Special Issue/Article No-57/356-361, 2018.
5. Anupam Kumar Yadav, Suaib Mohammad 'Design of H Shape Slotted Micro Strip Patch Antenna for Wi-Max Applications" IJESR/ICRIT-IV/ Special Issue/ Article No-40/219-222, 2018.
6. Anupam Kumar Yadav, “Design of Slotted I Sign Shaped Microstrip Patch Antenna for Wi-Max Frequency of 3.5 GHz” IJESR/ICRIT-IV/ Special Issue/ Article No-39/213-218 ', 2018.
7. Anupam Kumar Yadav, “A Review of Genetic And K- Means (GAK) Algorithm for Data Clustering” IJESR/ICRIT 2018/ Special Issue/Article No-7/29-34
8. Anupam Kumar Yadav, “Design of U-slotted microstrip patch antenna for wi-max Frequency range of 3 to 3.5ghz, IJESR/ICRIT 2018/ Special Issue/Article No-53/330-334
9. Anupam Kumar Yadav, V.K. Pandey “Slotted Dumbbell Shaped Microstrip Patch Antenna for Wi-Max Frequency band of 3.4-3.69GHZ”-International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249-8958 Volume-2, Issue-6, (August 2013), PP 170-172, www.ijeat.org.
10. Anupam Kumar Yadav, Sabyasachi Mukherjee “Collision Avoidance Approach for Performance Optimization in Packet Switched Network” International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Issue 3, Volume 2 (March 2015).
11. Anupam Kumar Yadav, Sabyasachi Mukhopadhyay, Pradip Kumar Yadava “Performance Comparison between U Slotted and Dumbbell Slotted Shaped Rectangular Patch Antenna” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (An ISO 3297: 2007 Certified Organization) Vol. 4, Issue 4, April 2015.
12. Anupam Kumar Yadav, Sandeep Singh and Suman Lata, “Design and Investigation of a Double-Damru (Pellet Drum)-Shaped CPW-Fed Microstrip Patch Antenna for 5G Wireless Communications” Journal of electronics Materials (JEM)-Scopus Indexed DOI:10.1007/s11664-023-10413-x
13. Anupam Kumar Yadav, Sandeep Singh and Suman Lata “Investigating the |S11| Parameter of CPW-Fed Antennas for Wi-MAX and WLAN Applications” Journal of electronics Materials (JEM)-Scopus

Indexed. DOI: 10.1007/s11664-023-10413-x

14. Anupam Kumar Yadav, Sandeep Singh and Suman Lata “Design and Parametric Analysis of a Triple Band Waxing Crescent Moon Shaped Slotted Microstrip Patch Antenna for 5G Wireless Communications” International Journal of Scientific Research in Engineering and Management. ISSN: 2582-3930. Volume: 06 Issue: 11 | November – 2022.
15. Anupam Kumar Yadav, Sandeep Singh and Suman Lata Dhar “Tri-Shul Shaped microstrip patch antenna for X-band wireless applications” International Journal of Scientific Research in Engineering and Management, ISSN: 2582-3930, Volume: 06 Issue: 09 | September – 2022. DOI:10.55041/IJSREM16299,
16. Anupam Kumar Yadav, Sandeep Singh and Suman Lata “Design and Analysis of CPW-Fed Antenna for Quad-Band Wireless Applications” Journal of electronics Materials (JEM)- Scopus Indexed. DOI: 10.1007/s11664-023-10413-x
17. A. K. Yadav, S. K. Singh, P. K. Shukla, A. N. Mishra, A. P. Singh and Sharmila, "Comparative Analysis of Dielectric Substrate Materials on the Performance of CPW-Fed Patch Antenna with a Variable Feed Line Width for Extremely High Frequency (EHF) Wireless Applications such as 5G/6G," *2024 International Conference on Emerging Technologies and Innovation for Sustainability (EmergIN)*, Greater Noida, India, 2024, pp. 656-661, doi: 10.1109/EmergIN63207.2024.10961790.
18. A. K. Yadav, S. K. Singh, P. K. Shukla, A. N. Mishra, N. K. Gupta and P. Ponde, "Development and Evaluation of a Multiband Om-Shaped Om Slotted CPW Fed Patch Antenna for 5G Wireless Uses," *2024 International Conference on Emerging Technologies and Innovation for Sustainability (EmergIN)*, Greater Noida, India, 2024, pp. 339-345, doi: 10.1109/EmergIN63207.2024.10960986.
19. Yadav, A.K., Lata, S. & Singh, S.K. Design and Investigation of a Double-Damru (Pellet Drum)-Shaped CPW-Fed Microstrip Patch Antenna for 5G Wireless Communications. *J. Electron. Mater.* **52**, 4400–4412 (2023). <https://doi.org/10.1007/s11664-023-10414-w>
20. Yadav, A.K., Lata, S., Singh, S.K. *et al.* Investigating the $|S_{11}|$ Parameter of CPW-Fed Antennas for WiMAX and WLAN Applications. *J. Electron. Mater.* **52**, 4359–4368 (2023). <https://doi.org/10.1007/s11664-023-10361-6>