Microwave Review
July 2025, Vol. 31, No. 1, pp. 8-12
DOI: 10.18485/mtts_mr.2025.31.1.2

Design and Performance Analysis of a Frequency Reconfigurable Antenna for Wireless Applications

Prem Nath Suman[1], Gajendra Kant Mishra[2]

Abstract – **This research introduces an advanced frequency reconfigurable antenna utilizing PIN diodes to adjust resonant frequencies dynamically, ensuring versatile operation across a wide frequency range. The proposed design demonstrates impressive efficiency and performance in two operational states, validated through measured results. This study highlights the potential of integrating two PIN diodes for adaptive wireless communication systems, contributing to the advancement of frequency reconfigurable antenna designs resonating at six distinct resonating frequencies and maximum gain of up to eight dBi and their applications in future communication technologies.**

Keywords – **Frequency reconfigurable antennas, PIN diode, Spectrum, Wireless communication.**

I. Introduction

The growing demand for advanced wireless communication systems has increased the need for antennas that can operate across multiple frequency bands without the complexity of traditional designs [1-3]. In the past, separate antennas were required for each frequency band, resulting in larger and more intricate setups. Frequency-reconfigurable antennas provide a solution by allowing a single antenna to operate at various frequencies, making systems more efficient and reducing overall costs [3-8]. These antennas achieve flexibility through several techniques, including the use of elements like switches, tunable materials, and adjustable resonators [4]. These methods enable antennas to change their frequency response and adapt to different communication standards. This capability makes them suitable for multi-band operations, where frequency agility is essential, such as in systems that rely on frequency hopping or dynamic switching between bands [6].

To ensure optimal performance, key factors like the radiation pattern, gain, bandwidth, and efficiency must be carefully balanced across all operating frequencies [9]. Researchers are continually improving these designs to maintain compact size, minimize power consumption, and enhance durability in various environments [10]. The versatility of frequency reconfigurable antennas makes them highly applicable in various sectors.

Article history: Received August 01, 2024; Accepted October 31, 2024

[1]Prem Nath Suman is at faculty in the Department of Electrical and Electronics Engineering at Arka Jain University, Jamshedpur, India, E-mail: prem.pns@gmail.com.
[2]Gajendra Kant Mishra is a faculty in the Department of Electronics & Communication Engineering at Birla Institute of Technology, Mesra, Ranchi, India 835215, E-mail: gkantm@gmail.com.

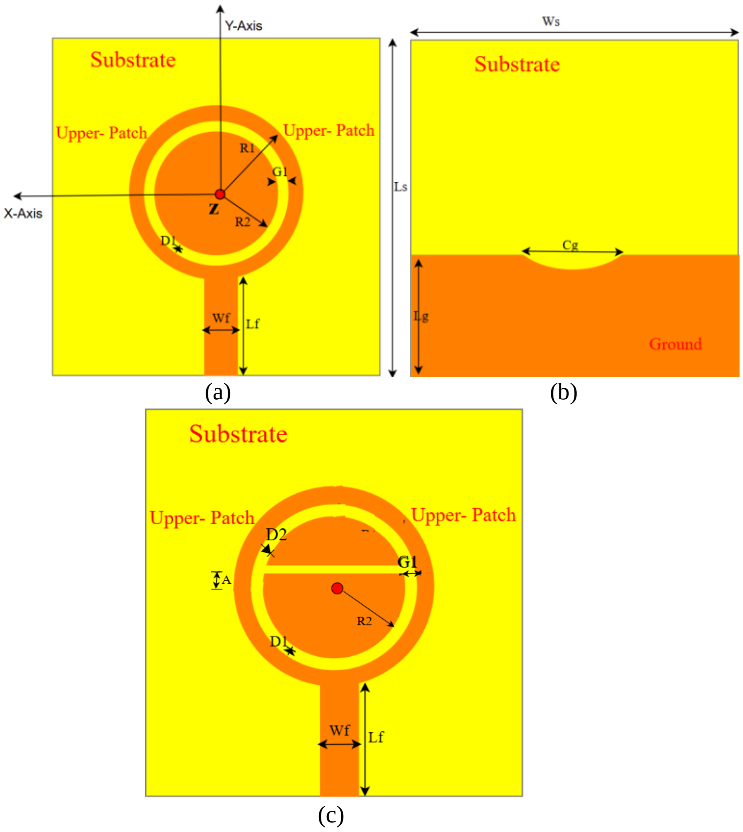


Fig.1. Proposed Structure of frequency reconfigurable antenna: (a) Antenna I (previous) top view [21], (b) Common ground bottom [21], (c) Antenna II proposed top view: R1=9mm, R2=7.25mm, G1=0.8mm, Wf=3.27mm, Lf=11.70mm, Ws=36mm, Ls=40mm, Lg=12mm, Cg=11.8mm, D1,D2 =diode

They play a vital role in wireless communication networks, such as mobile phone systems, WLANs, and satellite communications, where reliable performance across multiple frequency bands is critical. In addition, these antennas are essential in cognitive radio networks, where real-time spectrum allocation is required to maximize efficiency and minimize interference [8]. By offering the ability to dynamically adjust frequency bands, these antennas pave the way for more adaptive and intelligent communication systems in the future [11].

Recent research has introduced various innovative frequency reconfigurable antennas [12-22]. A differential antenna with dipoles and PIN diodes achieves dual-band operation at 3.5 GHz and 5.5 GHz [15], while a microstrip slot antenna covers six bands (2.2–4.75 GHz) with bent slots and integrated biasing [16]. A planar loop-monopole antenna achieves nona-band coverage for 2G/3G/4G with minimal space and a single diode [17]. Miniaturized patch antennas with aperture feeds and PIN diodes enable reconfigurability in the X-band [18]. Additionally, varactor-based monopole antennas provide tunable WiMAX bands [19], and compact loop antennas offer wide tunable bandwidths [20].

In [21], research presents the design, analysis, and performance evaluation of a frequency reconfigurable antenna that uses a circular ring configuration with a PIN diode for dynamic frequency tuning. The proposed design enables versatile operation across multiple frequency bands, eliminating the need for multiple antennas. By incorporating a reconfigurable element and a defective ground structure, the antenna achieves excellent performance with resonating frequencies of 3.02 GHz, 3.38 GHz, 3.66 GHz, 4.13 GHz, and 6.47 GHz, demonstrating bandwidth percentages of up to 40.68% and a maximum gain of 7.6 dBi. Limitations include a narrow tuning range, limited gain improvement, and higher insertion loss at reconfigured states also, the stopband of the reflection coefficient of the antenna is not clear.

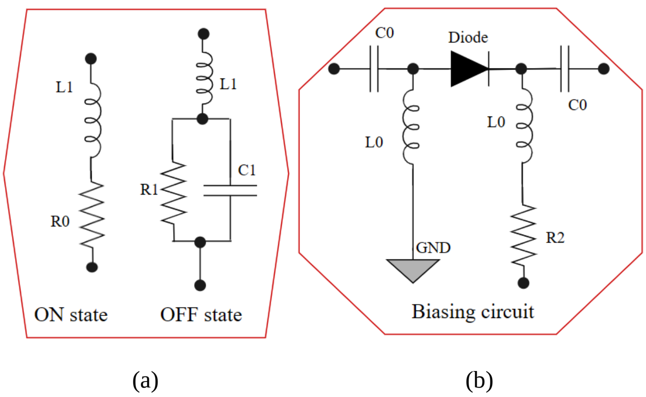


Fig. 2. (a) Equivalent circuit models of PIN diode at on and off state, (b) Biasing Circuit of the PIN diode [21]

This research successfully demonstrates a circular ring frequency reconfigurable antenna using PIN diodes for dynamic sharp tuning across multiple frequency bands with excellent stop band. The design exhibits efficient performance in both operational states, confirming its versatility for adaptive wireless communication. The findings contribute to advancements in reconfigurable antenna technology for future communication systems.

II. Antenna Geometry and Design

The frequency reconfigurable antenna presented in this study is an improved version of a prior design [21], utilizing an FR-4 substrate with a thickness of 1.6 mm. This updated Antenna II substrate has a dielectric constant (ε_r) of 4.4 and a loss tangent (δ) of 0.019. The overall dimensions of the antenna, as illustrated in Figure 1, are provided in millimeters. The earlier design includes a top patch incorporating a ring structure inked to the feed line, with a circular patch positioned within the ring. One PIN diode is strategically placed in the gap of G1 to tune the frequency. The performance of this antenna has been improved by adding a horizontal slot on the concentric solid circular patch at a specific distance above the centre. This improved antenna is proposed with two PIN diodes. The details of antenna I (previous antennas) [21] are illustrated in Fig. 1 (a) and (b), respectively, while antenna ii which is proposed antenna top view has been shown in Fig. 1 (c). The use of a circular patch in this research was chosen for its technical benefits, aligning with the study's objectives. Unlike rectangular patches, the circular geometry offers inherent symmetry, reducing edge effects and simplifying performance analysis. This leads to enhanced frequency response, broader bandwidth, and lower cross-polarization, crucial for maintaining signal purity. While rectangular patches are easier to fabricate, the circular design provides more uniform radiation patterns and improved performance across multiple frequency bands, making it ideal for frequency reconfigurable antennas in adaptive wireless communication systems, ensuring efficient and reliable operation.

To achieve a high bandwidth, a partially ground plane is employed. The ground plane features a defective ground structure with a round slot [21]. This choice enhances compactness, impedance matching, and controlled radiation pattern modification [22]. The round slot aids in smoother impedance matching and contributes to achieving the desired bandwidth and resonant frequency characteristics. The partial nature of the slot allows for targeted adjustments, optimizing the antenna's performance for specific criteria. This configuration helps widen the antenna's impedance bandwidth, ensuring efficient transmission and reception across multiple frequency bands [23].

This research presents a comprehensive study on the design, fabrication, and evaluation of a frequency reconfigurable antenna incorporating advanced features such as PIN diodes, a defective ground structure, and a circular slot. The design's performance was thoroughly analyzed using both simulation and experimental methods, with Ansys-HFSS software employed for precise simulation of the antenna's behavior. The comparison between measured and simulated data demonstrated an excellent match, validating the accuracy and effectiveness of the proposed design. Minor discrepancies observed were attributed to factors such as material imperfections, fabrication limitations, and measurement techniques, but these had minimal impact on the overall performance evaluation.

The antenna successfully achieved high gain and wide bandwidth across multiple frequency bands, demonstrating its suitability for dynamic wireless communication applications. Its frequency reconfigurability ensures versatility in various communication environments, while its efficient design enhances performance in terms of radiation patterns and impedance matching. This study advances the field of reconfigurable antennas by showing how integrating features like PIN diodes and defective ground structures can improve performance, making it a viable solution for future wireless technologies requiring adaptable and high-performing antennas.

III. Results and Discussions

The PIN diode from the BAP-65 family, capable of transitioning between on and off states, is optimal for our antenna. In the "on" state, it establishes electrical continuity between the outer ring and inner circle, enhancing surface current distribution and ensuring smooth signal transmission. The BAPS 65-02-115 datasheet provides exact values for the required components. Figure 2 (a) shows the comparable circuit diagram, while Fig. 2 (b) illustrates the biasing circuit with DC blocking capacitors and RF choke inductors.

Initially designed antenna structure consisting of a circular ring with an embedded circular patch. After optimization, a PIN diode was placed between the circular patch and the ring. The complete results and analysis of this configuration are discussed in the preceding sections of the chapter. To enhance the performance, a modification was introduced in the coaxial circular patch. Firstly, vertical slotting was applied to the circular patch, and two distinct PIN diodes were installed in the two separate portions of the slot.

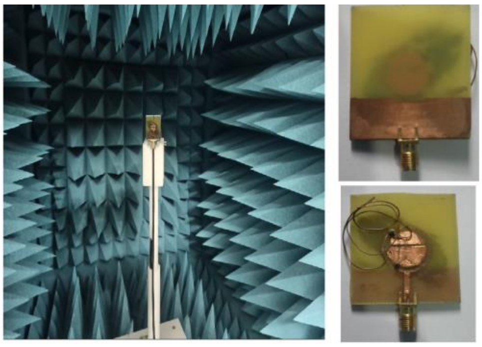


Fig.3.Measurement Setup and fabricated prototype of the Antenna II

These diodes connected the upper ring to the inner vertically slotted patch. While this structural alteration resulted in noticeable deviations in the performance, the outcomes were not entirely satisfactory. In the subsequent phase, the vertical slotting was replaced with horizontal slotting. Two PIN diodes were installed, one in the upper and one in the lower circularly slotted patch, connecting them to the outer ring. A detailed parametric study was conducted to determine the slot's optimal position above the circular patch's centre point, as illustrated in Fig. 4.

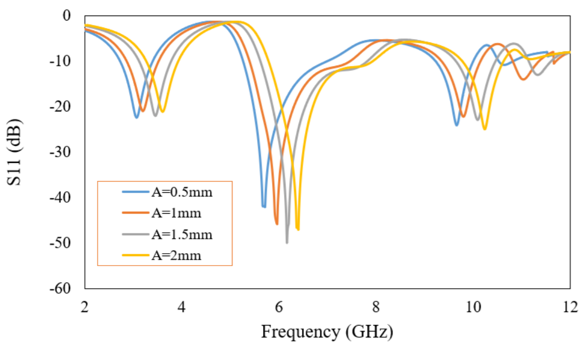


Fig. 4. Parametric study demonstrating the position of slot above centre point

This horizontal slotting approach aimed to improve the antenna's performance by better controlling the current distribution and enhancing the tuning capabilities of the structure. The parametric study helped identify the precise position of the slot that yielded the best performance outcomes, demonstrating a significant improvement over the previous vertical slotting configuration. Structural modification and the subsequent parametric analysis showcase the potential for achieving improved antenna performance through meticulous design and optimization. The study highlights the importance of slot orientation and diode placement in the gap for fine-tuning the antenna characteristics, paving the way for more efficient and effective designs.

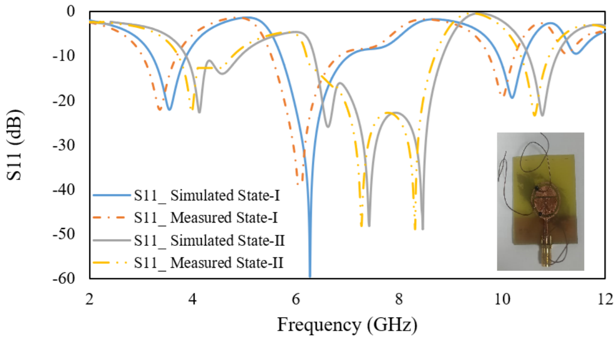


Fig. 5. Simulated and measured reflection coefficient of antenna II for state I and state II

In Fig. 1 (c), the installation of a PIN diode at two distinct positions is depicted, following the optimization process. Figure 5 illustrates the simulated and measured reflection coefficient of the antenna for two distinct state I and state II. State I, when D1 off and D2 on, the antenna resonates at 3.56 GHz, 6.27 GHz, and 10.20 GHz, covering three bands: 3.23-3.87 GHz, 5.73-6.95 GHz, and 9.95-10.51 GHz. The impedance bandwidths are 18%, 19.24%, and 5.47%, with corresponding gains of 5.05 dBi, 4.80 dBi, and 4.39 dBi.

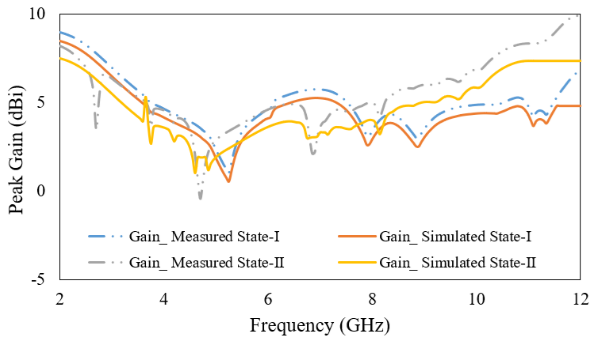


Fig. 6. Simulated and measured peak gain of antenna II for state I and state II

In State II, with D1 on and D2 off, the antenna demonstrates versatility by resonating at four distinct frequencies: 4.13 GHz, 7.42 GHz, 8.46 GHz, and 10.8 GHz. This state spans three bands: (3.9-4.9) GHz, (6.37-8.82) GHz (encompassing the second and third resonating frequencies), and (10.55-11.03) GHz. A peak gain of 8 dBi is reported at 10.8 GHz. For the other three frequencies, 4.13 GHz, 7.42 GHz, and 8.46 GHz, the simulated and measured gains are approximately 3.1 dBi, 3.58 dBi, and 4.58 dBi, respectively, These metrics are illustrated in Fig. 5 and 6, respectively. Due to several factors like fabrication tolerances, material property variations, parasitic effects, measurement environment factors, and unaccounted losses mismatch between measured and simulated results are noticed in the figures. These results highlight the antenna's capability to provide multiple resonant frequencies and broad impedance bandwidths under different states of the PIN diodes. The overall efficiency of the proposed reconfigurable antenna, exceeding 75%, is illustrated in Fig. 7. This demonstrates the antenna's effectiveness and adaptability for various applications, ensuring reliable performance across multiple frequency bands. The proposed antenna's radiation pattern for both E and H planes at 3.56 GHz and 6.27 GHz are shown graphically in Fig. 8. Figure 9 provides the reflection coefficient of the antenna E Plane and H plane at the resonating frequency at 4.13 GHz, 7.42 GHz, 8.46 GHz.

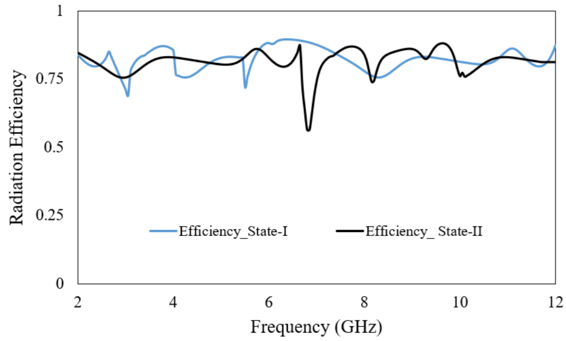


Fig. 7. Simulated radiation efficiency of antenna II for state I and state II

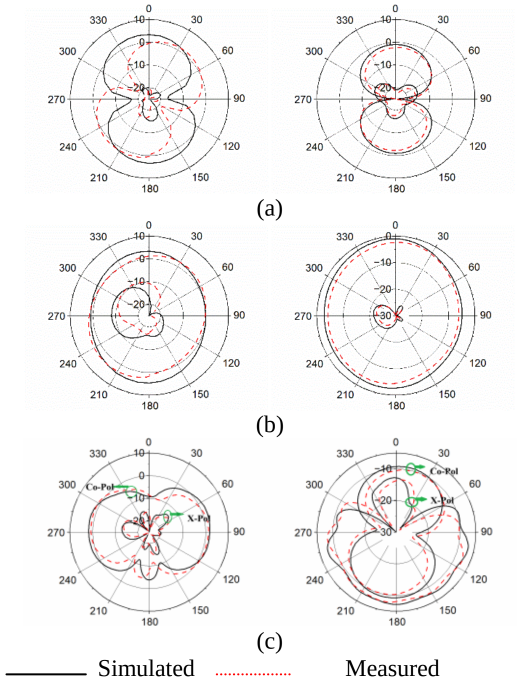
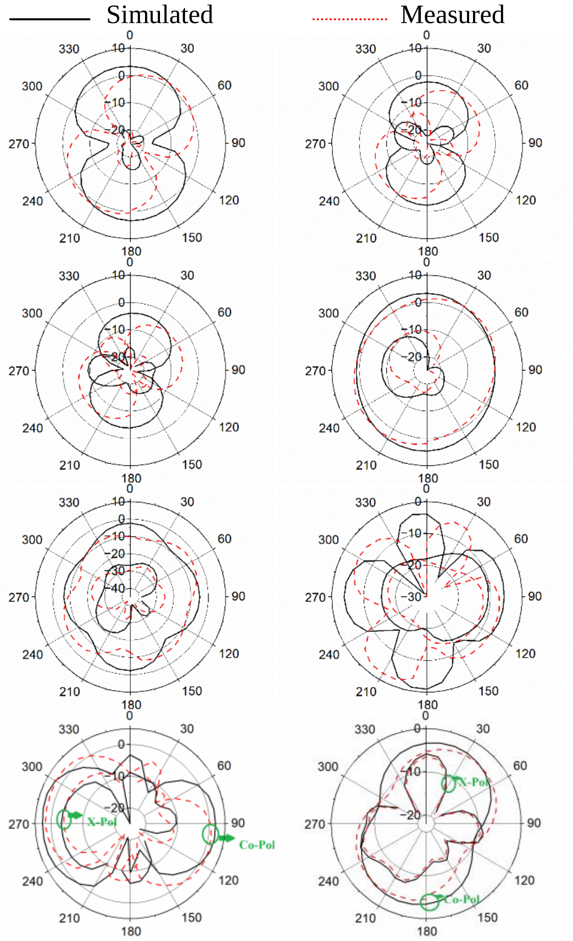


Fig. 8. Graphical representation of reflection coefficient of: (a) E-plane 3.56 GHz, H-plane 3.56 GHz, (b) E-plane 6.27 GHz, H-plane 6.27 GHz, (c) H-plane 10.20 GHz, H-plane 10.20 GHz

IV. Conclusion

The analysis of the reconfigurable antenna with a PIN diode demonstrates its ability to switch resonant frequencies dynamically, enabling flexible operation. Measured results confirm efficient performance in both states, with bandwidth percentages indicating optimal spectrum utilization. This versatility enhances its suitability for wireless applications requiring adaptive frequency control. The proposed reconfigurable antenna exhibits impressive versatility and performance across States I and II. In State I, with D1 off and D2 on, the antenna resonates at 3.56 GHz, 6.27 GHz, and 10.20 GHz, covering three bands with impedance bandwidths of 18%, 19.24%, and 5.47%, and gains of 5.05 dBi, 4.80 dBi, and 4.39 dBi, respectively. In State II, with D1 on and D2 off, it resonates at 4.13 GHz, 7.42 GHz, 8.46 GHz, and 10.8 GHz, spanning bands with impedance bandwidths and gains of up to 8.0 dBi. The findings contribute to the advancement of frequency reconfigurable antenna designs, showcasing the potential of using PIN diodes for adaptive wireless communication systems.



(a) (b)

Fig. 9. Graphical representation of reflection coefficient of: (a) E-plane 4.13 GHz, 7.42 GHz, 8.46GHz, (b) H-plane 4.13 GHz, 7.42 GHz, 8.46GHz

References

[1] J. K., "A Survey on Frequency Reconfigurable Antenna for Wireless Applications", *International Journal of Psychosocial Rehabilitation*, vol. 24, no. 5, pp. 5734–5744, Apr. 2020, DOI: 10.37200/ijpr/v24i5/pr2020281

[2] P. N. Suman, R. K. Chandan and G. K. Mishra, "A Study of Different 5G Reconfigurable Antennas for Communication", *Handbook of Research on Technological Advances of Library and Information Science in Industry 5.0*, pp. 178–195, Oct. 2022, DOI: 10.4018/978-1-6684-4755-0.ch010

[3] I. Nazir, F. Mukhtar and I. E. Rana, "A Miniaturized

Frequency Reconfigurable Substrate Integrated Waveguide Antenna for Frequency Jamming Applications", *IEEE Access*, vol. 12, pp. 127805–127824, DOI: 10.1109/access.2024.3454515

[4] P. N. Suman and G. K. Mishra, "Linear to Left-Hand and Right-Hand circularly polarized reconfigurable square patch antenna", *AEU - International Journal of Electronics and Communications*, vol. 184, p. 155421, Sep. 2024, DOI: 10.1016/j.aeue.2024.155421

[5] S. Gaya, A. Hamza, O. Sokunbi, S. I. M. Sheikh and H. Attia, "Electronically Switchable Frequency and Pattern Reconfigurable Segmented Patch Antenna for Internet of Vehicles", *IEEE Internet of Things Journal*, vol. 11, no. 10, pp. 17840-17851, 15 May, 2024, DOI: 10.1109/JIOT.2024.3362906

[6] P. N. Suman, P. N. Suman, J. Kumari, A. Kiran, M. Shanmugam, A. Rai, S. Debarmma, S. Kumar, M. K. Ojha, V. Nath, G. K. Mishra, "Design and Development of Metamaterial Absorber for IoT Applications", *IETE Journal of Research*, pp. 1–10, Jan. 2024, DOI: 10.1080/03772063.2024.2307426

[7] T. Raikwar, P. N. Suman, R. Chandan, G. K. Mishra and R. K. Rusia, "The Road Ahead of 6G: Exploring the Future of Wireless Connectivity", *Microwave Review*, vol. 29, no. 2, pp. 62-71, Dec. 2023, DOI: 10.18485/mtts_mr.2023.29.2.8

[8] P. N. Suman and G. K. Mishra, "Antenna for Cognitive Radio Applications-A Review", *Microwave Review*, vol. 29, no. 2, pp. 53-61, Dec. 2023, DOI: 10.18485/mtts_mr.2023.29.2.7

[9] P. N. Suman and G. K. Mishra, "An Aperture Fed Frequency Reconfigurable Patch Antenna for X-Band Applications", *2nd International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies (ICAECT),* Bhilai, India, 2022, pp. 1-3, DOI: 10.1109/ICAECT54875.2022.9808075

[10] J. Utkarsh, A. K. Lall, D. K. Upadhyay and G. K. Mishra, "Frequency Reconfigurable Bandpass Filter for IMT-A Applications", *2nd International Conference on Computing and Communications Technologies (ICCCT),* Feb. 2017, DOI: 10.1109/iccct2.2017.7972242

[11] S. Shankar and D. K. Upadhyay, "A Compact Maple Leaf and Triangular Hybrid Fractal Shaped UWB Frequency Reconfigurable Antenna with Wide Continuous Tunable Band Notch", *Iranian Journal of Science and Technology, Transactions of Electrical Engineering,* vol. 47, no. 1, pp. 301–316, Aug. 2022, DOI: 10.1007/s40998-022-00536-y

[12] P. N. Suman and G. K. Mishra, "A CPW Fed Hexagonal Patch Frequency Reconfigurable Antenna for Multiple Applications", *3rd International Conference on Advances in Electrical, Computing, Communication and Sustainable Technologies*, Jan. 2023, DOI: 10.1109/icaect57570.2023.10118197

[13] A. Al-Zoubi, F. Yang and A. Kishk, "A Broadband Center-Fed Circular Patch-Ring Antenna With a Monopole Like Radiation Pattern", *IEEE Transactions on Antennas and Propagation*, vol. 57, no. 3, pp. 789–792, Mar. 2009, DOI: 10.1109/tap.2008.2011406

[14] N. A. Kumar and A. S. Gandhi, "A Compact Novel Three-Port Integrated Wide and Narrow Band Antennas System for Cognitive Radio Applications", *International Journal of Antennas and Propagation, vol.*, pp. 1–14, 2016, DOI: 10.1155/2016/2829357

[15] G. Jin, C. Deng, Y. Xu, J. Yang, and S. Liao, "Differential Frequency-Reconfigurable Antenna Based on Dipoles for Sub-6 GHz 5G and WLAN Applications", *IEEE Antennas and Wireless Propagation Letters,* vol. 19, no. 3, pp. 472–476, Mar. 2020, DOI: 10.1109/lawp.2020.2966861

[16] H. A. Majid, M. K. A. Rahim, M. R. Hamid and M. F. Ismail, "A Compact Frequency-Reconfigurable Narrowband Microstrip Slot Antenna", *IEEE Antennas and Wireless Propagation Letters,* vol. 11, pp. 616–619, 2012, DOI: 10.1109/lawp.2012.2202869

[17] Y. Liu, P. Liu, Z. Meng, L. Wang and Y. Li, "A Planar Printed Nona-Band Loop-Monopole Reconfigurable Antenna for Mobile Handsets", *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 8, pp. 1575–1579, Aug. 2018, DOI: 10.1109/lawp.2018.2856459

[18] W. Lin and H. Wong, "A Polariztion Reconfigurable Aperture-Fed Patch Antenna Array", *IEEE International Conference on Computational Electromagnetics (ICCEM),* Feb. 2016, DOI: 10.1109/compem.2016.7588472

[19] X. L. Sun, S. W. Cheung and T. I. Yuk, "Frequency-Reconfigurable Dual-Band Monopole Antenna for WiMAX Wireless Devices", *Microwave and Optical Technology Letters*, vol. 56, no. 1, pp. 49–55, Nov. 2013, DOI: 10.1002/mop.28032

[20] S. Subbaraj, M. Kanagasabai, M. G. N. Alsath, S. K. Palaniswamy, S. Kingsly and I. Kulandhaisamy, "A Compact Frequency-Reconfigurable Antenna with Independent Tuning for Hand-Held Wireless Devices", *IEEE Transactions on Antennas and Propagation,* vol. 68, no. 2, pp. 1151–1154, Feb. 2020, DOI: 10.1109/tap.2019.2938668

[21] P. N. Suman and G. K. Mishra, "Adaptive Antennas for the Wireless Future: Design, Analysis, and Performance Evaluation of Frequency Reconfigurable", *Microwave Review*, vol. 30, no. 1, pp. 49–54, 2024, DOI: 10.18485/mtts_mr.2024.30.1.7

[22] P. Kumar, R. Sinha, A. Choubey and S. K. Mahto, "DGS Based Miniaturized Wideband MIMO Antenna with Efficient Isolation for C Band Applications", *Frequenz,* vol. 77, no. 3–4, pp. 163–172, July 2022, DOI: 10.1515/freq-2022-0029

[23] K. K. So and K. W. Leung, "Bandwidth Enhancement and Frequency Tuning of the Dielectric Resonator Antenna Using a Parasitic Slot in the Ground Plane", *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 12, pp. 4169–4172, Dec. 2005, DOI: 10.1109/tap.2005.860002