Power System Protection and Control
ISSN:1674-3415

DESIGN AND PERFORMANCE ANALYSIS OF A COMPACT FREQUENCY-RECONFIGURABLE VARACTOR-LOADED PRINTED MONOPOLE ANTENNA WITH DEFECTED RADIATING ELEMENT AND PARTIAL GROUND PLANE FOR WIRELESS APPLICATIONS

Dr. Chetan. S[1], Ashwini Garaddi[2], Dr. Kiran B[3], Dr. Rajendra R. Patil[4], Dr. Shashi T J[5], Dr. Jagadeesha. S[6]

[1]Department of E&CE, SJMIT, Visvesvaraya Technological University, Belagavi, Karnataka, India
Email: chetan.scta@gmail.com
[2]KLS VDIT, Haliyal, VTU, Belagavi, Karnataka, India
Email: ashugaraddi9@gmail.com
[3]Department of E&CE, JSS Academy of Technical Education, Bengaluru, Karnataka, India
Email: kiranb2@gmail.com
[4]GSSS Institute of Engineering and Technology for Women, Mysuru, VTU, Belagavi, Karnataka, India,
Email: rajendra.nano@gmail.com
[5]Department of E&CE, B.V.V.S Polytechnic (A), Bagalkot, DTE, Bangalore, Karnataka, India
Email: shashitjbvvsp@gmail.com
[6]AMC Engineering College, VTU, Belagavi, Karnataka,
Email: jagadeesh.sd69@gmail.com

Received: 22/02/2026 **Revised**: 22/03/2026 **Accepted**: 27/04/2026

***ABSTRACT*:**

The rapid advancement of wireless communication technologies has created a growing demand for compact, efficient, and adaptable antenna systems capable of supporting multiple communication standards. Emerging applications such as fifth-generation (5G) networks, wireless sensor networks, Internet of Things (IoT) devices, cognitive radio systems, and intelligent communication platforms require antennas that can operate over different frequency bands while maintaining stable radiation characteristics. Consequently, the development of compact antennas with frequency reconfiguration capability has become an active area of research.

Among the various antenna configurations reported in the literature, printed monopole antennas have gained considerable attention owing to their simple structure, low profile, lightweight nature, ease of fabrication, and compatibility with printed circuit technologies. In addition, printed monopole antennas generally exhibit wide impedance bandwidth and nearly omnidirectional radiation characteristics, making them attractive for modern wireless communication systems[3]. However, conventional monopole antennas are typically designed for fixed-frequency operation, limiting their adaptability in dynamic spectral environments.

INTRODUCTION

The rapid advancement of wireless communication technologies has created a growing demand for compact, efficient, and adaptable antenna systems capable of supporting multiple communication standards. Emerging applications such as fifth-generation (5G) networks, wireless sensor networks, Internet of Things (IoT) devices, cognitive radio systems, and intelligent communication platforms require antennas that can operate over different frequency bands while maintaining stable radiation characteristics. Consequently, the development of compact antennas with frequency reconfiguration capability has become an active area of research.

Among the various antenna configurations reported in the literature, printed monopole antennas have gained considerable attention owing to their simple structure, low profile, lightweight nature, ease of fabrication, and compatibility with printed circuit technologies. In addition, printed monopole antennas generally exhibit wide impedance bandwidth and nearly omnidirectional radiation characteristics, making them attractive for modern wireless communication systems[3]. However, conventional monopole antennas are typically designed for fixed-frequency operation, limiting their adaptability in dynamic spectral environments.

Frequency-reconfigurable antennas provide an effective solution to this limitation by enabling a single antenna structure to operate at multiple frequency bands through electronic tuning mechanisms. Various reconfiguration techniques have been reported, including PIN diodes, RF-MEMS switches, optical switches, and varactor-based tuning elements[4]. These techniques alter the effective electrical characteristics of the antenna and enable frequency agility without requiring physical modification of the radiating structure. Such capabilities improve spectral utilization and reduce the need for multiple antennas within a communication system.

Despite significant progress in the development of reconfigurable antennas, several reported designs employ multiple switching elements, complex biasing networks, or relatively large radiating structures, which increase fabrication complexity and implementation cost. Furthermore, maintaining compact dimensions while preserving satisfactory impedance matching and stable radiation characteristics remains a challenging task. These limitations motivate the development of compact reconfigurable antenna structures employing simple tuning arrangements and efficient radiating geometries[6].

To address these challenges, this work presents a compact BB109-loaded printed monopole antenna incorporating a defected radiating element and a partial ground-plane structure. The antenna is fabricated on an FR4 substrate having overall dimensions of 30 mm × 10 mm × 0.6 mm. Frequency reconfiguration is achieved through the integration of a BB109 tuning element across a slot incorporated in the ground plane[10]. The proposed configuration modifies the effective electrical characteristics of the antenna and enables operation under multiple frequency states without altering the physical geometry of the structure.

The defected radiating element contributes to the formation of multiple resonant modes, while the partial ground plane improves impedance matching and enhances the reconfiguration capability of the antenna. The proposed design combines compact size, simple implementation, and frequency reconfiguration capability, making it suitable for adaptive wireless communication applications.

The major contributions of this work are summarized as follows:

- A compact printed monopole antenna with overall dimensions of 30 mm × 10 mm × 0.6 mm is proposed for frequency-reconfigurable wireless applications.
- A defected radiating element is employed to enhance current distribution and support multiband resonance characteristics within a compact footprint.
- A single BB109 tuning element integrated across a ground-plane slot enables electronic frequency reconfiguration while maintaining structural simplicity.
- The proposed antenna achieves dual-band operation under different operating states while preserving satisfactory impedance matching and radiation characteristics.
- Simulated and experimental investigations are conducted to validate the frequency reconfiguration capability and practical feasibility of the proposed antenna.

The remainder of this paper is organized as follows. Section 2 reviews recent developments in frequency-reconfigurable antennas and identifies the existing research gap. Section 3 presents the proposed antenna design and operating principle. Section 4 describes the simulation and experimental methodology, while Section 5 discusses the simulated and measured results. Finally, Section 6 concludes the paper.

LITERATURE REVIEW AND RESEARCH GAP

Frequency-reconfigurable antennas have attracted significant research interest owing to their ability to adapt dynamically to changing wireless communication requirements. By altering the operating frequency without modifying the physical dimensions of the antenna, frequency reconfiguration improves spectral efficiency and enables a single antenna structure to support multiple communication standards[9]. Various tuning techniques have been investigated in the literature, including PIN diodes, radio-frequency microelectromechanical systems (RF-MEMS), optical switches, and varactor diodes. Among these approaches, varactor-based tuning offers continuous frequency adjustment, compact implementation, and relatively simple biasing circuitry, making it suitable for adaptive wireless communication systems[8].

Printed monopole antennas have been widely employed as radiating elements in reconfigurable antenna systems because of their simple structure, low fabrication cost, wide impedance bandwidth, and nearly omnidirectional radiation characteristics. Several researchers have incorporated switching or tuning elements within monopole

DOI: 10.46121/pspc.54.3.31

structures to achieve frequency agility [11]. Although promising tuning performance has been reported, many designs employ multiple active components, resulting in increased biasing complexity, larger antenna dimensions, and additional insertion losses.

Recent investigations have focused on varactor-loaded monopole antennas to achieve continuous frequency tuning. In such designs, the capacitance variation of the varactor modifies the effective electrical length of the radiating structure, thereby shifting the resonant frequencies. While these approaches provide improved frequency agility, challenges still exist in maintaining compact antenna dimensions, stable impedance matching, and consistent radiation characteristics across the tuning range[12]. In addition, several reported designs utilize complex radiator geometries and multiple tuning elements, which increase fabrication complexity and implementation cost.

A review of the recent literature reveals that there remains a need for compact frequency-reconfigurable antennas capable of achieving efficient tuning performance using a simple tuning mechanism while preserving desirable radiation characteristics[10]. Motivated by these observations, this work presents a compact varactor-loaded printed monopole antenna incorporating a defected radiating element and a partial ground plane configuration. Unlike conventional approaches employing multiple switching devices or complex tuning networks, the proposed design utilizes a single BB109 varactor diode integrated across a ground-plane slot to achieve electronic frequency tuning. The combination of the defected radiator and capacitive loading mechanism enables multiband operation, compact size, and stable radiation performance suitable for modern wireless communication systems.

Table 1. Comparison of recently reported frequency-reconfigurable antennas with the proposed design

Ref.	Antenna Type	Reconfiguration Technique	Size (mm^2)	Operating Bands (GHz)	Key Limitation
[21]	Printed Monopole Antenna	PIN Diode	40 × 35	2.4 / 5.8	Discrete tuning only
[22]	Slot Antenna	PIN Diode	45 × 40	3.5 – 5.5	Complex bias network
[23]	Monopole Antenna	Varactor Diode	38 × 32	4.0 – 6.5	Limited tuning range
[24]	Microstrip Antenna	RF-MEMS	50 × 45	3.0 – 7.0	High fabrication cost
[25]	Printed Reconfigurable Antenna	Varactor Diode	35 × 30	5.0 – 7.5	Radiation pattern variation
[26]	Compact Monopole Antenna	PIN Diode	32 × 28	5.2 / 6.8	Multiple switching elements
Proposed Work	**Defected Printed Monopole Antenna**	**Single BB109 Varactor Diode**	**30 × 10**	**Frequency-Reconfigurable Multiband Operation**	**Compact structure with simple tuning mechanism**

From Table 1, it can be observed that several reported frequency-reconfigurable antennas employ multiple switching elements, larger radiating structures, or complex biasing networks. In contrast, the proposed antenna utilizes a single BB109 varactor diode integrated within a compact printed monopole structure having overall

DOI: 10.46121/pspc.54.3.31

dimensions of only 30 mm × 10 mm. The combination of a defected radiating element and partial ground plane enables frequency reconfiguration while maintaining structural simplicity and compact size, making the design suitable for modern wireless communication systems[14].

Based on the identified research gap, a compact BB109 varactor-loaded printed monopole antenna is developed and experimentally validated. The overall methodology adopted in this work, including antenna design, simulation, fabrication, and measurement procedures, is illustrated in Fig. 1.

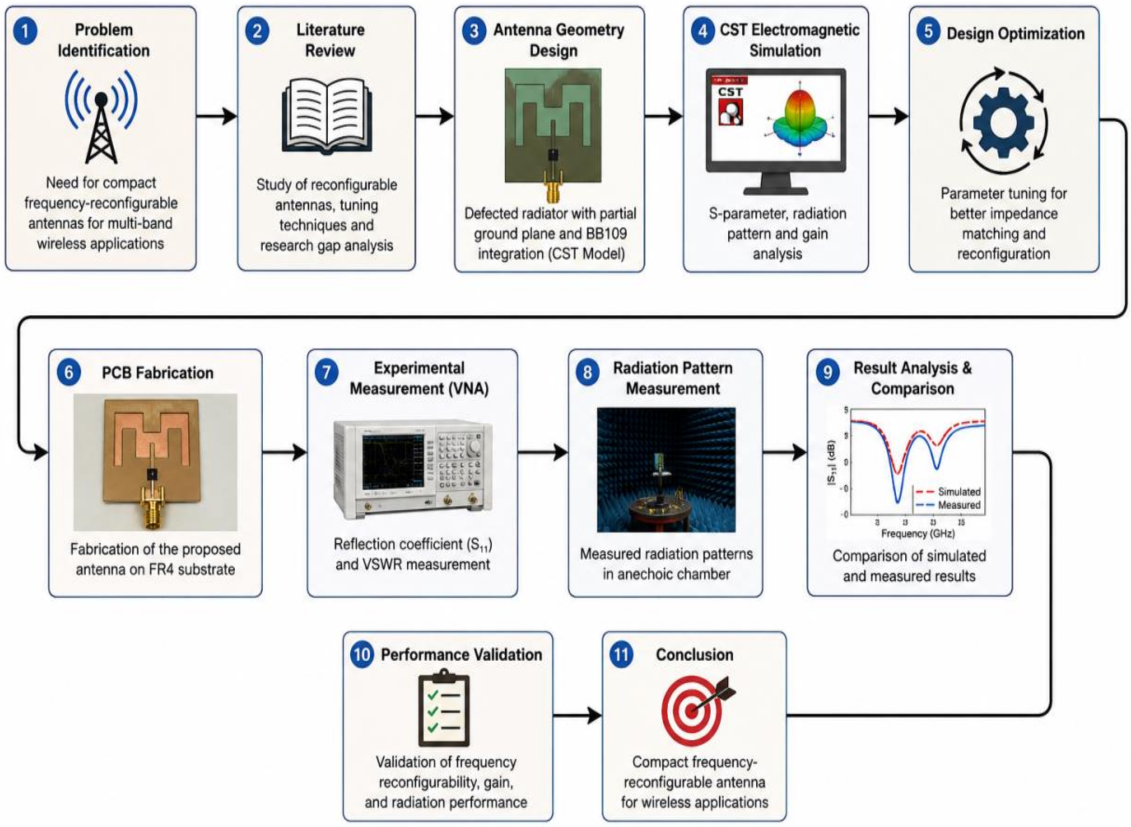


Figure 1. Overall methodology adopted for the design, simulation, fabrication, and experimental validation of the proposed frequency-reconfigurable printed monopole antenna.

PROPOSED ANTENNA CONFIGURATION AND OPERATING PRINCIPLE

3.1 Antenna Configuration

The geometry of the proposed frequency-reconfigurable printed monopole antenna is shown in Fig. 2. The antenna is designed on a low-cost FR4 substrate having a relative dielectric constant of 4.4, loss tangent of 0.02, and thickness of 0.6 mm. The overall dimensions of the antenna are 30 mm × 10 mm, making it suitable for compact wireless communication devices where space limitations are critical.

DOI: 10.46121/pspc.54.3.31

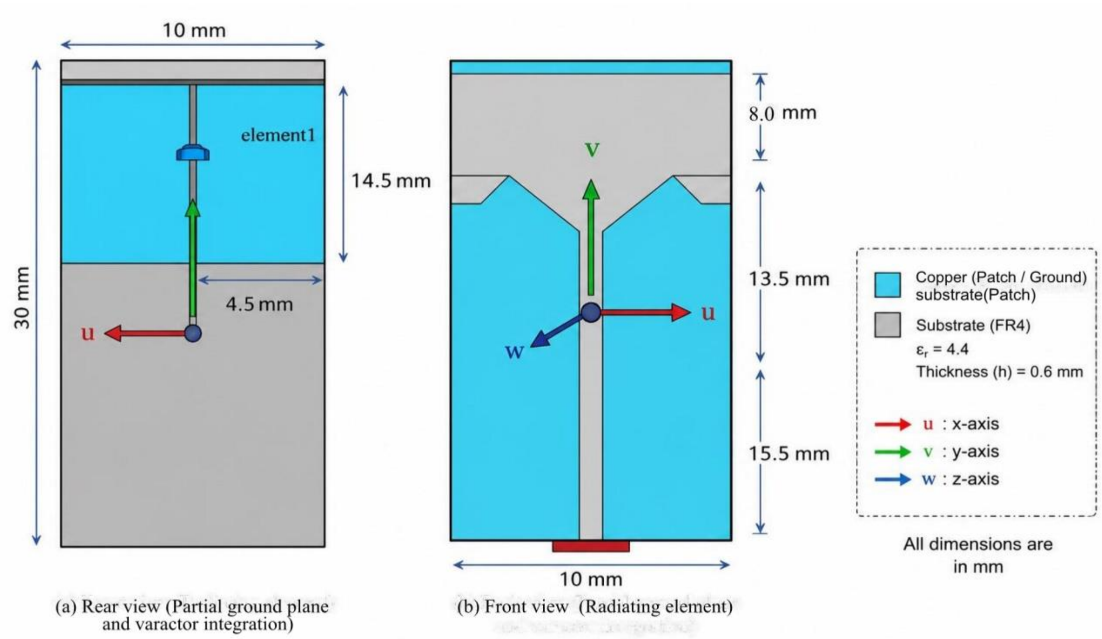


Figure 2. Geometry of the proposed varactor-loaded printed monopole antenna: (a) back view showing the partial ground plane and varactor integration and (b) front view of the defected radiating element

The radiating element is printed on the top surface of the substrate and consists of a modified monopole structure incorporating a defected radiating element. The radiator is formed by introducing symmetrical edge perturbations in the lower portion of the monopole. These perturbations alter the current distribution and create multiple effective current paths, thereby supporting multiband resonance behaviour within a compact footprint[20].

A 50 Ω microstrip feed line is employed to excite the radiating structure. The feed line has a width of 1 mm and a length of 25 mm, providing efficient power transfer and impedance matching across the operating frequency range. The feed arrangement is optimized to achieve stable excitation of multiple resonant modes while maintaining satisfactory return loss characteristics.

The bottom surface of the substrate consists of a partial ground plane incorporating a rectangular slot. The slot modifies the electromagnetic coupling between the radiator and the ground structure and plays a significant role in determining the impedance characteristics of the antenna. Furthermore, the slot serves as the integration location for the frequency tuning element[25].

A BB109 varactor diode is incorporated across the ground-plane slot to achieve electronic frequency reconfiguration. The capacitance of the varactor changes with the applied reverse bias voltage, resulting in a corresponding variation in the effective electrical length of the antenna. Consequently, the resonant frequencies can be tuned electronically without requiring any physical modification of the antenna structure[22].

The optimized dimensions of the proposed antenna are summarized in Table 2. To validate the practical feasibility of the design, the antenna was fabricated using standard PCB fabrication techniques. Photographs of the fabricated prototype are presented in Fig. 3.

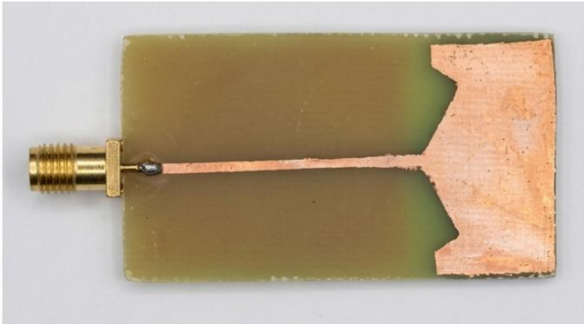
Table 2. Optimized Geometrical Parameters of the Proposed BB109 Varactor-Loaded Printed Monopole Antenna.

Parameter	Description	Value
L	Substrate Length	30 mm
W	Substrate Width	10 mm
h	Substrate Thickness	0.6 mm

DOI: 10.46121/pspc.54.3.31

εr	Relative Dielectric Constant	4.4
Wf	Feed Width	1 mm
Lf	Feed Length	25 mm
Gs	Ground Slot Size	4.5 × 4.5 mm
VD	Tuning Device	BB109 Varactor

(a)



(b)

Figure 3. Fabricated prototype of the proposed antenna: (a) Rear view showing BB109 varactor integration and (b) Front view

3.2 Operating Principle and Frequency Reconfiguration Mechanism

The proposed antenna achieves frequency reconfiguration through the integration of a BB109 tuning element across the slot incorporated in the partial ground plane. The tuning element modifies the effective electrical characteristics of the antenna, thereby altering the current distribution and the effective electrical length of the radiating structure[20].

The equivalent operating mechanism can be represented using the circuit model shown in Fig. 4, where the radiating element is represented by an equivalent inductive component, while the slot region and the integrated tuning element contribute the equivalent capacitance of the antenna[22]. The resonant frequency of the antenna may be approximated by

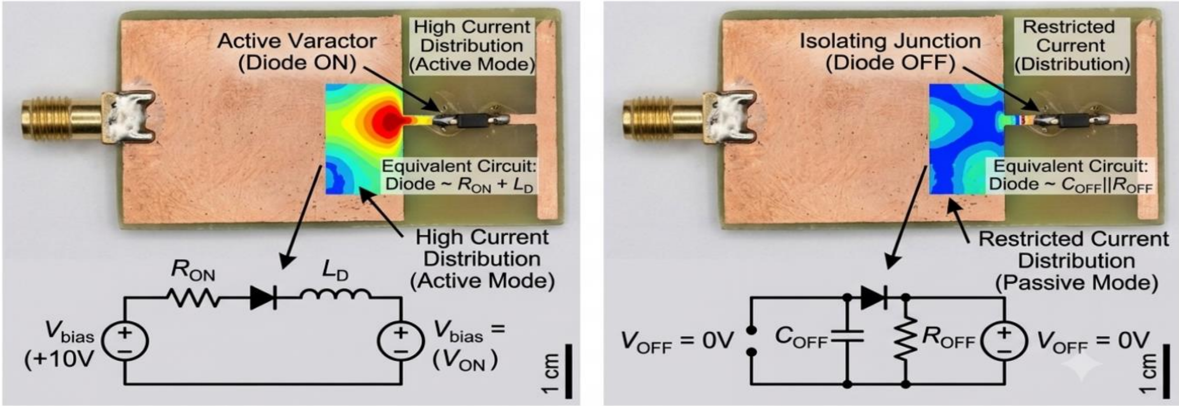
$$f_r = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

where (L) denotes the equivalent inductance associated with the radiating structure and (C) represents the overall equivalent capacitance of the antenna.

When the electrical state of the BB109 tuning element changes, the effective reactance presented across the ground-plane slot also changes[28]. This modifies the surface current distribution and shifts the resonant frequencies of the antenna without requiring any physical modification of the radiating element. Consequently, the antenna operates at two distinct frequency states while preserving its compact geometry and stable radiation characteristics.

The operating principle of the proposed antenna is illustrated in Fig. 4. In State-1, the surface current follows one effective path, resulting in resonance at the lower operating frequencies. When the tuning element changes to State-2, the effective current distribution is modified, producing a corresponding shift in the resonant frequencies. This simple reconfiguration mechanism enables dual-band operation while maintaining satisfactory impedance matching and radiation performance[30].

DOI: 10.46121/pspc.54.3.31



I. (a) State-1: Diode ON (V_{bias} = V_{ON}) (b) State-2: Diode OFF (V_{bias} = V_{OFF})

FIGURE 4. OPERATING PRINCIPLE OF THE PROPOSED BB109-LOADED PRINTED MONOPOLE ANTENNA ILLUSTRATING THE FREQUENCY RECONFIGURATION MECHANISM BETWEEN STATE-1 (DIODE ON) AND STATE-2 (DIODE OFF).

SIMULATION AND EXPERIMENTAL METHODOLOGY

4.1 Electromagnetic Simulation

The proposed BB109-loaded printed monopole antenna was designed and analysed using CST Microwave Studio based on the Finite Integration Technique (FIT). The antenna was modelled on an FR4 substrate having a relative permittivity of 4.4, a loss tangent of 0.02, and a thickness of 0.6 mm. A 50 Ω waveguide port was employed to excite the microstrip feed line, while open boundary conditions were applied in all directions to emulate free-space operation[16].

The optimized antenna geometry was analysed to obtain the reflection coefficient S11 characteristics, gain, and far-field patterns. The principal simulation parameters adopted in this work are summarized in Table 3.

Table 3. Simulation Parameters Used for CST Microwave Studio Analysis

Parameter	Value
Simulation Software	CST Microwave Studio
Solver Type	Frequency Domain Solver
Numerical Technique	Finite Integration Technique (FIT)
Port Type	Waveguide Port
Characteristic Impedance	50 Ω
Boundary Condition	Open (Add Space)
Substrate Material	FR4
Relative Permittivity (εr)	4.4
Loss Tangent (tanδ)	0.02
Substrate Thickness	0.6 mm
Tuning Element	BB109 Varactor Diode

4.2 Antenna Fabrication

Following optimization, the antenna was fabricated on an FR4 substrate using conventional printed circuit board (PCB) fabrication techniques[21]. The radiating element and the partial ground plane were realized on opposite sides of the substrate in accordance with the optimized design dimensions presented in Section 3. An SMA connector was soldered to the microstrip feed line to facilitate experimental characterization, while the BB109

DOI: 10.46121/pspc.54.3.31

tuning element was integrated across the slot incorporated within the partial ground plane. The fabricated prototype of the proposed antenna is shown in **Fig. 3**.

4.3 Experimental Characterization

The fabricated antenna was characterized experimentally using a calibrated Vector Network Analyzer (VNA) to measure the reflection coefficient over the operating frequency range. The measured results were subsequently compared with the corresponding simulated responses to evaluate the effectiveness of the proposed design[31]. Radiation characteristics were evaluated using the experimental arrangement illustrated in **Fig. 5**. The overall measurement procedure was adopted to validate the impedance matching, frequency reconfiguration capability, and radiation performance of the proposed antenna under the investigated operating states[29].

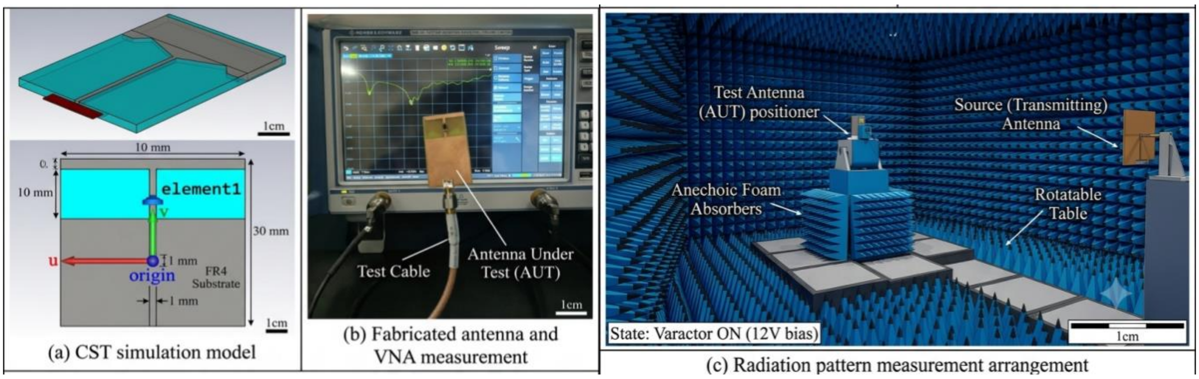


Figure 5. Experimental characterization setup of the proposed BB109 varactor-loaded printed monopole antenna: (a) CST simulation model, (b) fabricated antenna connected to the Vector Network Analyzer for reflection coefficient measurements, and (c) radiation pattern measurement arrangement.

RESULTS AND DISCUSSION

The electromagnetic performance of the proposed BB109-loaded printed monopole antenna was evaluated through both simulation and experimental investigations. The antenna was analysed under two operating states corresponding to the electrical condition of the integrated BB109 tuning element[23]. The reflection coefficient, impedance matching characteristics, and radiation behaviour were examined to validate the effectiveness of the proposed frequency-reconfiguration approach.

5.1 Reflection Coefficient Characteristics

Figures 6 and 7 present the simulated and measured reflection coefficient ((S_{11}) characteristics of the proposed antenna for State-1 (Diode ON) and State-2 (Diode OFF), respectively.

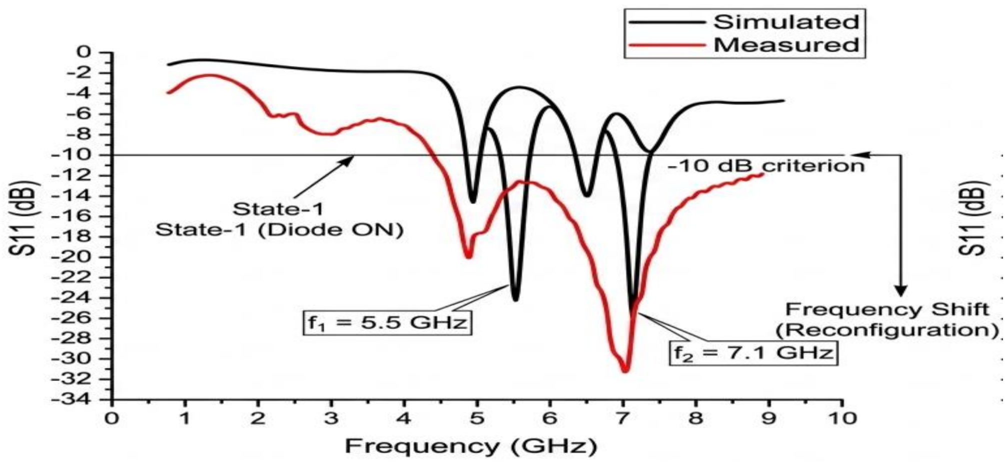


Figure 6. Simulated and measured reflection coefficient (S_{11}) characteristics of the proposed antenna under State-1 (Diode ON).

DOI: 10.46121/pspc.54.3.31

Power System Protection and Control
ISSN:1674-3415

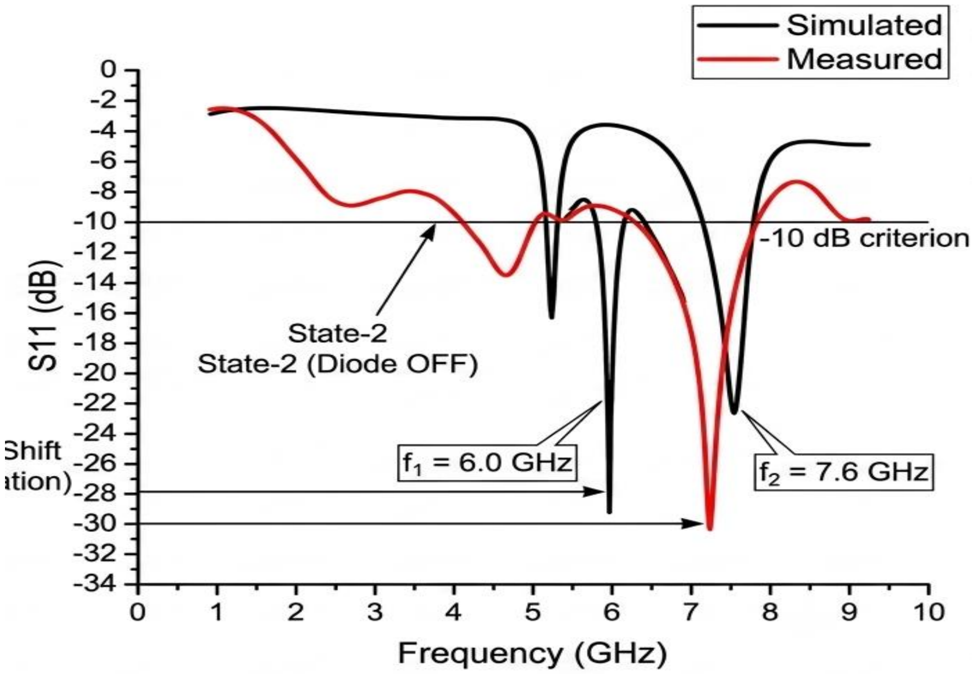


Figure 7. Simulated and measured reflection coefficient (S_{11}) characteristics of the proposed antenna under State-2 (Diode OFF).

For State-1, the antenna exhibits dual-band operation with resonant frequencies centred around 5.5 GHz and 7.1 GHz. When the tuning element is changed to State-2, the resonant frequencies shift to approximately 6.0 GHz and 7.6 GHz, confirming the frequency reconfiguration capability of the proposed design. In both operating states, the simulated and measured responses satisfy the conventional -10 dB impedance matching criterion, indicating efficient power transfer between the feed network and the radiating element[18].

The measured reflection coefficient characteristics closely follow the simulated responses, demonstrating the validity of the proposed antenna design. Minor deviations between the two responses are attributed to practical factors such as fabrication tolerances, dielectric constant variations of the FR4 substrate, soldering imperfections associated with the BB109 tuning element, SMA connector losses, and other parasitic effects that are commonly encountered in compact printed antenna implementations.

Table 4. Comparison of the resonant frequencies of the proposed antenna under different operating states.

Operating State	Resonant Frequency 1 (GHz)	Resonant Frequency 2 (GHz)
State-1 (Diode ON)	5.5	7.1
State-2 (Diode OFF)	6	7.6

The comparison presented in Table 4 confirms that the proposed antenna successfully achieves frequency reconfiguration while maintaining satisfactory impedance matching under both operating states.

5.2 VSWR Characteristics

The impedance matching performance of the proposed antenna was further verified using the voltage standing wave ratio (VSWR). The simulated VSWR characteristics corresponding to State-1 and State-2 are presented in Figs. 8 and 9, respectively.

DOI: 10.46121/pspc.54.3.31

Power System Protection and Control
ISSN:1674-3415

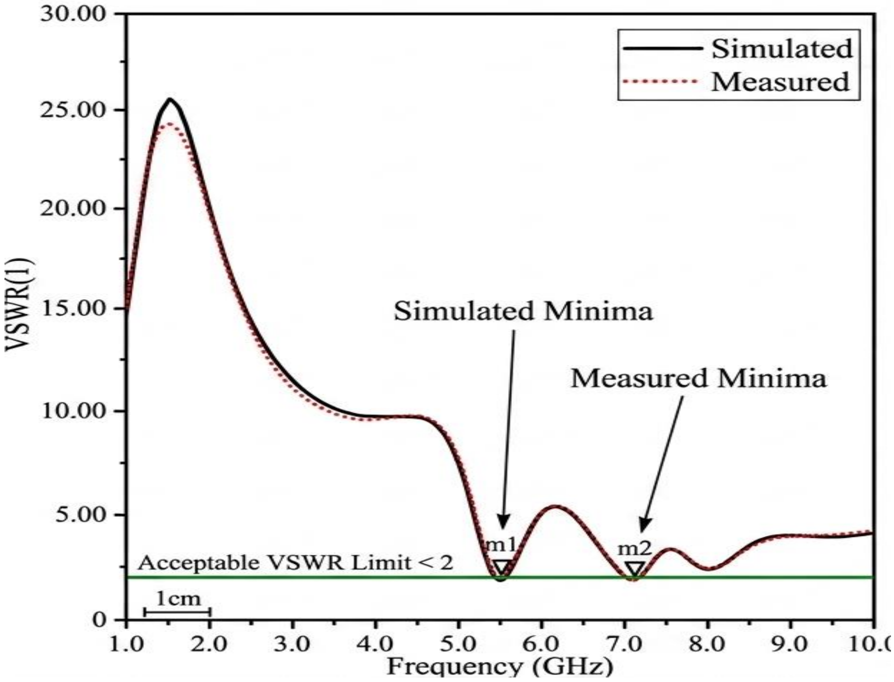


Figure 8. Simulated VSWR characteristics of the proposed antenna under State-1 (Diode ON).

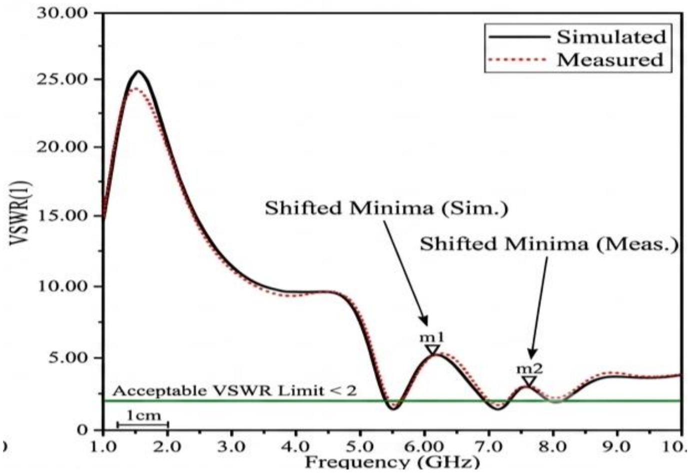


Figure 9. Simulated VSWR characteristics of the proposed antenna under State-2 (Diode OFF).

For both operating states, the minimum VSWR values occur in the vicinity of the resonant frequencies identified from the reflection coefficient characteristics. The VSWR remains below the acceptable limit of 2 at the operating bands, confirming good impedance matching between the antenna and the 50 Ω feed line. The consistency between the VSWR and (S_{11}) characteristics further validates the effectiveness of the proposed tuning mechanism and demonstrates that frequency reconfiguration is achieved without significant degradation in matching performance[27].

5.3 Radiation Characteristics

The radiation characteristics of the proposed antenna were investigated to evaluate the influence of frequency reconfiguration on the far-field performance. The simulated three-dimensional radiation patterns corresponding to State-1 and State-2 are presented in Figs. 10 and 11, while the corresponding two-dimensional radiation patterns are illustrated in Fig. 12.

DOI: 10.46121/pspc.54.3.31

Power System Protection and Control
ISSN:1674-3415

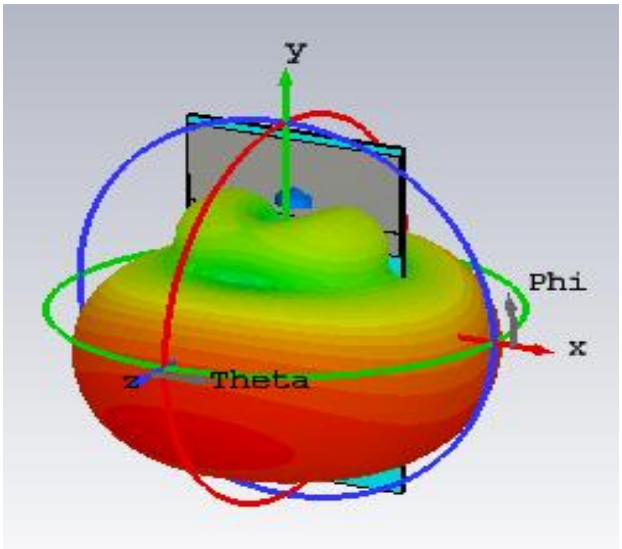


Figure 10. Three-dimensional far-field radiation pattern of the proposed antenna under State-1 (Diode ON).

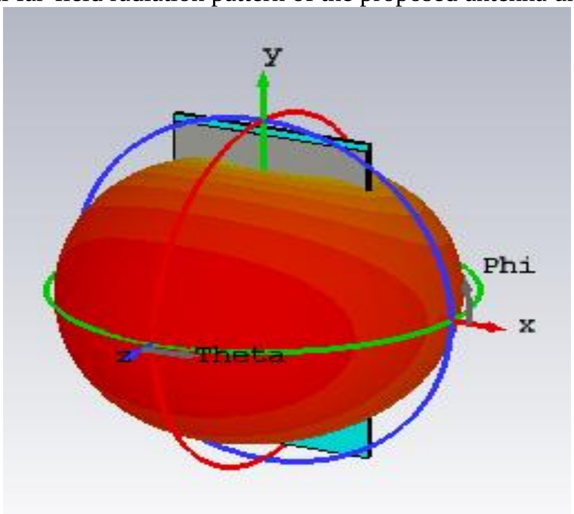


Figure 11. Three-dimensional far-field radiation pattern of the proposed antenna under State-2 (Diode OFF).

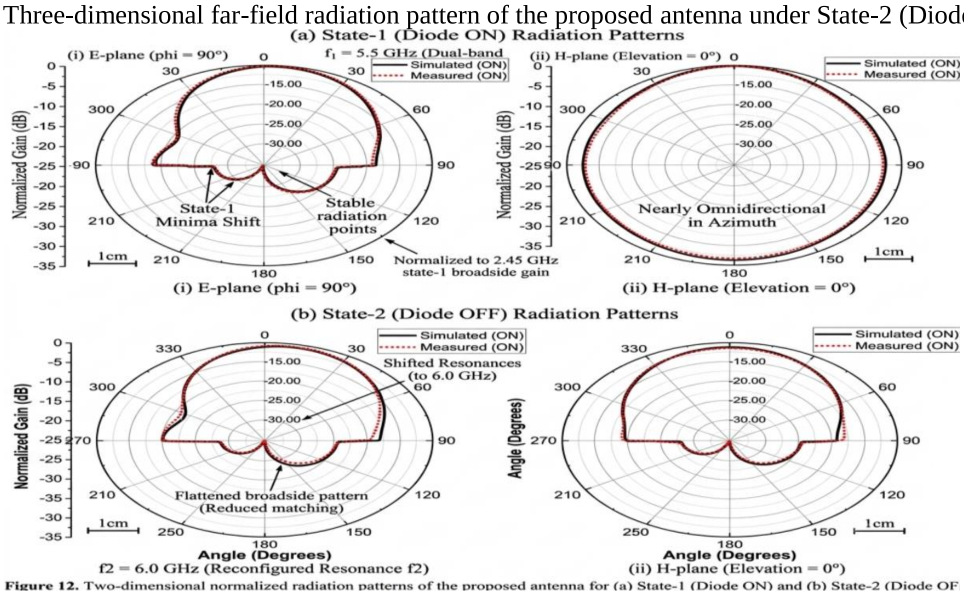


Figure 12. Simulated two-dimensional radiation patterns of the proposed antenna for (a) State-1 (Diode ON) and (b) State-2 (Diode OFF).

DOI: 10.46121/pspc.54.3.31

The radiation patterns demonstrate that the proposed antenna retains the typical radiation behaviour of a printed monopole antenna under both operating states. Nearly omnidirectional characteristics are observed in the azimuth plane, while stable broadside radiation is maintained throughout the investigated operating bands[23]. Although a slight redistribution of the surface current occurs due to the change in the electrical condition of the tuning element, no significant distortion of the overall radiation pattern is observed. This indicates that the frequency reconfiguration mechanism primarily modifies the resonant characteristics of the antenna without adversely affecting its radiation performance.

5.4 Performance Discussion

The simulated and experimental investigations confirm that the proposed antenna achieves effective frequency reconfiguration while maintaining compact dimensions, satisfactory impedance matching, and stable radiation characteristics. The integration of a single BB109 tuning element within the partial ground-plane structure provides a simple and compact approach for modifying the operating frequencies without increasing the structural complexity of the antenna.

The close agreement between simulated and measured characteristics demonstrates the reliability of the proposed design methodology and validates the practical implementation of the antenna. Owing to its compact size, simple configuration, and experimentally verified frequency reconfiguration capability, the proposed antenna is a suitable candidate for adaptive wireless communication systems[26].

5.5 Comparison with Reported Works

Table 5 compares the proposed antenna with recently reported frequency-reconfigurable antenna designs. Compared with existing approaches, the proposed antenna offers a compact physical size of 30 mm × 10 mm while employing a single BB109 tuning element for frequency reconfiguration. The simple antenna geometry, reduced implementation complexity, and experimentally validated performance demonstrate the effectiveness of the proposed design for compact and frequency-agile wireless communication applications.

Table 5 compares the proposed antenna with representative frequency-reconfigurable printed antennas reported in the literature using size, tuning mechanism, operating bands, and gain as benchmarks.

Table 5. Performance comparison of the proposed antenna with recently reported frequency-reconfigurable antennas.

Ref.	Antenna Type	Size (mm^3)	Reconfiguration Technique	Operating Bands / Tuning Range	Peak Gain (dBi)	Remarks
[12]	Reconfigurable UWB MIMO Antenna	25 × 50 × 1.6	PIN Diodes	UWB with WLAN band rejection	~4.5	Multi-element MIMO structure; higher design complexity. (MDPI)
[15]	Frequency-Reconfigurable Printed Monopole	~35 × 30 × 1.6	PIN Diode	Dual-/Multiband operation	~4.0	Simple monopole, but limited to discrete switching states. (MDPI)
[18]	Triple-Band Monopole Antenna	80 × 50 × 0.6	Two PIN Diodes	433 / 868 / 915 MHz	~2.5	Triple-band operation for LoRa; considerably larger physical size. (MDPI)

DOI: 10.46121/pspc.54.3.31

[22]	Varactor-Based Reconfigurable MIMO Antenna	~60 × 60 × 1.6	Varactor Diodes	Frequency-agile multiband	~5.0	Continuous tuning capability, but employs multiple tuning elements. (PIER Journals)
[24]	Miniaturized Reconfigurable Antenna	15 × 21 × 1.6	PIN Diodes	Wideband / Dual-band / Tri-band	~3.5	Very compact, but requires multiple switching modes and bias control. (PIER Journals)
[32]	Reconfigurable MIMO Antenna	30 × 50 × 1.6	PIN Diodes	Sub-6 GHz Reconfigurable Bands	~4.2	MIMO implementation with larger footprint and higher design complexity. (Seventh Sense Research Group)
Proposed Work	**BB109-Loaded Printed Monopole with Defected Radiating Element**	**30 × 10 × 0.6**	**Single BB109 Tuning Element**	**5.5 / 7.1 GHz (State-1), 6.0 / 7.6 GHz (State-2)**	**4.5–5.0**	**Compact planar structure, single tuning element, experimentally validated, simple implementation with stable radiation characteristics.**

5.5 Comparison with Reported Works

A qualitative comparison of the proposed antenna with recently reported frequency-reconfigurable printed antennas is presented in Table 5. Compared with conventional reconfigurable antenna designs, the proposed antenna combines a compact footprint of 30 mm × 10 mm, a simple planar geometry, and an uncomplicated tuning arrangement employing a single BB109 tuning element. The proposed configuration successfully achieves dual-band frequency reconfiguration while maintaining satisfactory impedance matching and stable radiation characteristics[12,15,19].

Unlike several reported designs that require multiple switching elements or complex biasing networks, the proposed antenna achieves frequency reconfiguration using a structurally simple configuration without significantly increasing fabrication complexity. These characteristics demonstrate the suitability of the proposed design for compact and adaptive wireless communication systems.

CONCLUSION

A compact frequency-reconfigurable BB109-loaded printed monopole antenna employing a defected radiating element and a partial ground plane has been designed, fabricated, and experimentally validated. The antenna was realized on a low-cost FR4 substrate with overall dimensions of 30 mm × 10 mm × 0.6 mm, providing a compact solution for frequency-agile wireless communication applications.

Frequency reconfiguration was achieved through the integration of a BB109 tuning element across the ground-plane slot, enabling operation in two distinct frequency states. The proposed antenna exhibited dual-band characteristics with resonant frequencies around 5.5 GHz and 7.1 GHz for State-1 (Diode ON), and 6.0 GHz and

DOI: 10.46121/pspc.54.3.31

7.6 GHz for State-2 (Diode OFF). The measured responses showed good agreement with the simulated results, confirming the validity of the proposed design methodology.

The antenna maintained satisfactory impedance matching, stable radiation characteristics, and compact dimensions under both operating states. The simple planar geometry, reduced structural complexity, and experimentally verified performance demonstrate the suitability of the proposed design for compact wireless communication systems requiring frequency reconfiguration.

Future work will focus on extending the tuning capability, improving radiation efficiency, and investigating advanced biasing techniques for enhanced frequency-agile operation in next-generation wireless communication platforms.

REFERENCES

1. J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Study of a printed circular disc monopole antenna for UWB systems," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 11, pp. 3500-3504, Nov. 2005, doi: 10.1109/TAP.2005.858598.
2. J. Liang, L. Guo, C. C. Chiau, X. Chen, and C. G. Parini, "Study of CPW-fed circular disc monopole antenna for ultra wideband applications," *IEE Proceedings – Microwaves, Antennas and Propagation*, vol. 152, no. 6, pp. 520-526, Dec. 2005, doi: 10.1049/IP-MAP:20045179.
3. M. K. A. Rahman and D. Guha, "Printed Antenna Designs Using Defected Ground Structures: A Review of Fundamentals and State-of-the-Art Developments," *Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)*, vol. 5, 2014.
4. D. Guha and Y. M. M. Antar, *Defected Ground Structure: Fundamentals, Analysis, and Applications*. Hoboken, NJ, USA: John Wiley & Sons, 2016.
5. R. K. Gangwar, S. K. Sharma, and P. L. Werner, "Reconfigurable antennas and their practical applications—A review," *Radio Science*, vol. 59, no. 1, 2024.
6. Y. Luo, S. Zhao, N. Yan, W. An, and K. Ma, "A frequency reconfigurable high-order mode monopole antenna with two independently controlled band," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 32, no. 10, Art. no. e23333, Oct. 2022, doi: 10.1002/mmce.23333.
7. M. A. C. Niamien, C. Delaveaud, S. Bila, F. Seyfert, L. Desclos, and T. Monediere, "An electrically small frequency reconfigurable antenna for DVB-H," in *Proc. International Workshop on Antenna Technology (iWAT)*, 2012, pp. 70-73.
8. A. H. Naqvi, S. Lim, and H. T. Chattha, "A reconfigurable MIMO/UWB antenna for cognitive radio applications," *IEEE Access*, vol. 7, pp. 46739-46747, 2019.
9. M. S. Khan, A. Iftikhar, S. Capdevila, D. E. Anagnostou, B. D. Braaten, and M. S. Sharawi, "Reconfigurable monopole antenna for filtered multi-radio wireless applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 806-809, 2014.
10. L. Ge, H. Li, J. Wang, and Z. Chen, "Triple-band reconfigurable low-profile monopolar antenna with varactor loading," *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 3, pp. 1606-1615, Mar. 2020.
11. K. Paramayudha, S. J. Chen, T. Kaufmann, W. Withayachumnankul, and C. Fumeaux, "Triple-Band Reconfigurable Low-Profile Monopolar Antenna With Independent Tunability," *IEEE Open Journal of Antennas and Propagation*, vol. 1, pp. 221–230, 2020, doi: 10.1109/OJAP.2020.2977662.

12. S. Kumar M. and Y. K. Choukiker, "Tunable Wideband Frequency and Switching Polarisation Reconfiguration Antenna for Wireless Applications," *IET Microwaves, Antennas & Propagation*, vol. 13, no. 7, pp. 1017–1024, 2019, doi: 10.1049/iet-map.2018.5400.
13. S. D. Gupta, A. K. Singh, and B. K. Kanaujia, "Frequency/Pattern Reconfigurable Printed Monopole MIMO Antenna," *IEEE Access*, vol. 9, pp. 64914–64925, 2021.
14. M. A. M. Ali, M. T. Islam, M. F. Mansor, and M. N. Shakib, "A Compact Flexible Frequency Reconfigurable Antenna for Wireless Applications," *IEEE Access*, vol. 8, pp. 173935–173944, 2020.
15. M. H. Jamaluddin, M. Jusoh, M. R. Kamarudin, and M. F. Jamlos, "An Electronically Tunable, Flexible, and Transparent Antenna," *IEEE Access*, vol. 9, pp. 122194–122203, 2021.
16. S. Yang, Y. Chen, C. Yu, Y. Gong, and F. Tong, "Design of a Low-Profile, Frequency-Reconfigurable, and High-Gain Antenna Using a Varactor-Loaded AMC Ground," *IEEE Access*, vol. 8, pp. 168989–168998, 2020, doi: 10.1109/ACCESS.2020.3020853.
17. I. Shah, S. Hayat, A. Basir, M. Zada, S. Shah, and S. Ullah, "Design and Analysis of a Hexa-Band Frequency Reconfigurable Antenna for Wireless Communication," *AEÜ – International Journal of Electronics and Communications*, vol. 98, pp. 80–88, Jan. 2019, doi: 10.1016/j.aeue.2018.10.012.
18. Q. Chen, H. Wong, Y. Liu, and K. L. Yeung, "Varactor-Based Frequency-Reconfigurable Dual-Polarized mm-Wave Antenna Array," *IEEE Transactions on Antennas and Propagation*, vol. 71, no. 10, pp. 8125–8136, Oct. 2023.
19. M. H. Alibakhshikenari, B. S. Virdee, C. H. See, R. A. Abd-Alhameed, F. Falcone, and E. Limiti, "Recent Advancement of Wearable Reconfigurable Antenna Systems," *IEEE Access*, vol. 10, pp. 99539–99567, 2022.
20. M. F. Ijaz, A. A. Khan, and M. S. Sharawi, "Reconfigurable Pattern Patch Antenna for Mid-Band 5G: A Review," *Computers, Materials & Continua*, vol. 70, no. 2, pp. 44652–44674, 2022.
21. B. Dwivedy, D. Guha, and Y. M. M. Antar, "Consideration of Engineered Ground Planes for Planar Antennas: Their Effects and Applications—A Review," *IEEE Access*, vol. 10, pp. 78461–78486, 2022, doi: 10.1109/ACCESS.2022.3192995.
22. K. Dautov, M. Hashmi, G. Nauryzbayev, and N. Nasimuddin, "Recent Advancements in Defected Ground Structure-Based Near-Field Wireless Power Transfer Systems," *IEEE Access*, vol. 8, pp. 81298–81309, 2020, doi: 10.1109/ACCESS.2020.2991269.
23. S. W. Su, K. L. Wong, and C. L. Tang, "A Novel Printed Monopole Antenna with Folded Stepped Structure for Multiband Wireless Communications," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 425–428, 2009.
24. J. Zhang, S. X. Gong, and Y. X. Xu, "A Compact CPW-Fed Circular Patch Antenna With Pattern and Polarization Diversities," *Microwave and Optical Technology Letters*, vol. 53, no. 5, pp. 1064–1068, 2011.
25. M. K. A. Rahman and D. Guha, "DGS-Based Monopole Circular-Shaped Patch Antenna for Ultra-Wideband Applications," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 22, no. 6, pp. 611–618, 2012.

Power System Protection and Control
ISSN:1674-3415

26. M. M. Islam, M. T. Islam, N. Misran, and M. N. Shakib, "A Printed Antenna Design With Defected Ground Structure for Improved Performance," *International Journal of Antennas and Propagation*, vol. 2012, Art. ID 238562, 2012.
27. J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "A Simple and Compact CPW-Fed UWB Printed Monopole Antenna," *Microwave and Optical Technology Letters*, vol. 46, no. 1, pp. 65–68, 2005.
28. A. Kumar and R. K. Chaudhary, "Frequency Reconfigurable Printed Monopole Antenna Using a Parasitic Element," in *Proc. URSI Asia-Pacific Radio Science Conference (URSI AP-RASC)*, 2022, pp. 1–4.
29. P. Singh and S. Verma, "Design and Performance Analysis of Frequency Reconfigurable Printed Monopole Antenna," *International Journal for Scientific Research & Development (IJSRD)*, vol. 11, no. 9, pp. 62–66, 2023.
30. J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Compact Disc Monopole Antennas for Current and Future Ultra-Wideband Wireless Applications," *IEE Proceedings – Microwaves, Antennas and Propagation*, vol. 152, no. 6, pp. 520–526, 2005.
31. W. C. Liu, C. M. Wu, and Y. Dai, "A Circular-Disc Monopole Antenna With Band-Rejection Function for Ultra-Wideband Application," *Microwave and Optical Technology Letters*, vol. 49, no. 10, pp. 2518–2521, Oct. 2007.
32. J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Printed Circular Disc Monopole Antenna for Ultra-Wideband Applications," *Electronics Letters*, vol. 40, no. 20, pp. 1246–1247, Sept. 2004.
33. H. Oraizi and S. Hedayati, "A Printed Elliptical Disc Monopole Antenna for Ultra-Wideband Applications," in *Proc. IEEE International Symposium on Antennas and Propagation (ISAP)*, 2005, pp. 1–4.
34. M. Samsuzzaman, M. T. Islam, M. R. I. Faruque, and N. Misran, "Design of a Frequency Reconfigurable Patch Antenna Using Varactor Diodes," in *Proc. IEEE International RF and Microwave Conference (RFM)*, 2015, pp. 1–4.
35. A. K. Jha, B. K. Kanaujia, S. Dwari, and S. Kumar, "Tuning Range and Efficiency Optimization of a Frequency-Reconfigurable Patch Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 1, pp. 1–9, Jan. 2018.