10.48047/jocaaa.2023.31.02.32

A Trophy Shaped Monopole SWB Antenna and AI Optimization Techniques

Pooja Naresh Bhatt[1, 2], Rashmi A. Pandhare[3], Saurabh Shukla[4]

[1]PhD Scholar, Department of Electronics & Telecommunication, Indian Institute of Information Technology (IIIT), Nagpur, India
[2]Assistant Professor, Department of Electrical & Electronics Engineering, IPS Academy, Institute of Engineering & Science, Indore
[3]Assistant Professor, Department of Electronics & Communication Engineering, Indian Institute of Information Technology (IIIT), Nagpur, India
[4] Scientist, Defense, Research & Development Organization (DRDO), New Delhi, India

ABSTRACT
A compact Trophy-Cup-shaped Microstrip patch antenna concerning super-wideband (SWB) administration is conferred in the aforementioned paper. The intended architecture is loaded with a boxlike 50-ohm feed-line. The fragmented ground plane helps in delivering a super wide band from 2.5 GHz to beyond 120 GHz meeting return loss below -10dB. The dimensions are 40 x 40 mm^2. RT Duroid 5880 with a thickness of 0.762 and dielectric constant of 2.2 is employed. The fractional bandwidth achieved is 192.62%. The simple design satisfies the requirements for the applications that involve the SWB spectrum. The paper also discusses miscellaneous artificial intelligence tactics that can be exercised to optimize various antenna parameters.

Keywords:
SWB, AI, Defected Ground, RT Duroid, microstrip, fractional bandwidth, Bandwidth Dimension Ratio, microstrip feed, AI Optimization Techniques

1. INTRODUCTION

As of present day, due to modernistic progression in 5G and wireless communication technology, it is seen to have ever-rising interest in high data rates, high speed, and secure wireless systems. These demands are being fulfilled by SWB antennas and hence the numerous researches and work is done in this area. Comprehensive research has been done to deliver novel designs that give wide bandwidth, better efficiency and high gain [1]. The major applications of SWB Antenna include ranging and monitoring systems for both military and civil operations, Doppler navigation aids, Industrial, Scientific and Medical(ISM) and Defense. Of late, the expeditiously sprouting drift of wireless communication is spanning the modern antenna designing towards artificial intelligence (AI). Antenna system performance can be magnificently cultivated using various AI algorithms and skills. Complicated issues of communication system design are solved and ingenious results are accomplished with dynamic AI tools.

In 2002, UWB antennas were in demand and frequently being used. The bandwidth approved by FCC for UWB is 3.1 to 10.6 GHz. However, with the rapid development in wireless communication technology, UWB band limitations created restrictions and hence SWB antennas started getting more weightage. The maximum transmitted power by UWB was not enough anymore for ISM or other major wireless applications [2]. Also the slow adaption rate of UWB and long signal acquisition time were becoming major constraint. SWB is basically an upgraded level of UWB technology availing all the features of UWB along with better bandwidth and improved resolution eliminating the UWB constraints. To acquire the super wide bandwidth, numerous bandwidth enhancement techniques are implemented such as use of suitable substrate, number of feeding techniques such as linear tapering, coplanar-waveguide. Modification in patch by creating slots and chamfering/blending edges and trimming has resulted in exponential growth in the bandwidth. Partial ground plane or defected ground surface (DGS) approach has harvested wide bandwidth for plentiful of antennas in the literature and introducing notch for WLAN band has been shown in [3, 4, 5]. SWB Antenna covers both short and long range transmissions for delivering universal services. Such an antenna is proposed in [5] by inlaying a fractal groove in the base along with an egg-shaped patch displaying WiMAX and LTE bands. The antenna proposed in [6] has almost omni-directional patterns and 6dBi gain. The frequency band is SWB starting with lower cut-off at 2.96 GHz to more than 120 GHz. Another unique fractal geometry is implemented in [7] for antenna to work for 1 GHz till 30 GHz. The design also has a defected ground to improve the matching of impedance. Importance of Bandwidth Dimension Ratio (BDR) and its effect on antenna characteristics is shown in [8] that has a simple semi-circular radiating patch with ground of a shape of trapezoid. The lower-rung frequency here is 1.30 GHz.

In literature [9], concept of 2 ground planes (top and bottom), top being used for matching impedance at lower frequencies is implemented giving SWB bandwidth with ratio of 66.6:1. A circular-base rectangular monopole antenna is shown in [10] achieving super wide bandwidth and to increase the BDR with ellipse shaped ground plane. Trimming the

10.48047/jocaaa.2023.31.02.32

patches has always been author's first choice towards achieving SW Bandwidth. A unique crescent shaped patch with slots in ground plane is introduced in [11] to get bandwidth beyond UWB. Concept of providing notches to get multiple bands is also liked by many literatures'. One of which is investigated in [12] that has dual band providing WiMAX and WLAN application based bands. Use of Split Ring Resonating Structure is done to obtain band rejection characteristics. One more fractal geometrical figurine is seen in the literature of [13] that is circular-hexagonal style in a circular patch to achieve bandwidth of 2.18 GHz till 44.5 GHz. Author of [14] proposes a trapezoidal monopole antenna to procure a super extensive bandwidth of 1.4 GHz to 90 GHz. Ring resonators are applied here to eliminate X band in SWB range. A creative staircase fractal structure is employed in [15] on a wide-slot antenna to attain SWB with ratio of 20:1. Authors of [16] have used an inscribed fractal structure to achieve the bandwidth of 2.3 to 105.5 GHz.

The review of [17] displays a study and comparison of varied methodologies of AI, machine learning (ML) and deep learning (DL) that has been adopted in literature to hone the diapason. The literature in [18] presents concise perks and flaws of AI methods to apply to an antenna design. It also shows some feasible applications to the domain. ANN Model applied to design a microstrip antenna is shown in [19]. AI technology has also been applied to reconfigurable antenna arrays and delivered optimum results with ease [20]. A leaf-shaped patch antenna that has utilized 4 different hybrid AI network is designed in [21] for X-band. AI based computational technology is adopted in [22] to achieve accuracy in the parameter findings of an antenna. A combination of two methods viz. Simulated Annealing (SA) and direction set in multi dimensions is proffered in [23].

2. PROPOSED DESIGN

2.1 Architecture

The composition of proposed Compact Trophy-Cup shaped antenna is depicted in Figure 1. The dimensions are 40 × 40 mm^2 (L_s x W_s) with thickness of substrate (RT Duroid 5880) being 0.762 mm (h_s) with dielectric constant of 2.2 (ε_r) and loss tangent 0.009 (δ). The first figure (1A) shows the front view that is the radiating patch and the 50 ohm feed line and the latter (1B) shows the back view that is the partial ground plane with the dimensions of 14.7 × 40 mm^2 (L_g x W_g). The borders of ground are blended to improvise the bandwidth. The compact Trophy-cup shaped patch has dimensions 24.5 × 25 mm^2 (L_p x W_p) with chamfered and blended corners. The optimized dimensions of transmission feed line to achieve impedance matching are 14.95 mm (L_f) and 1.5 mm (W_f) respectively. Figure 1(C) displays the perspective view of the proposed antenna.

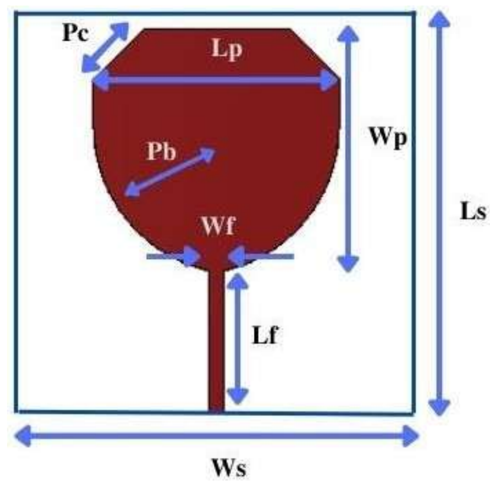

Figure 1(A). Front View

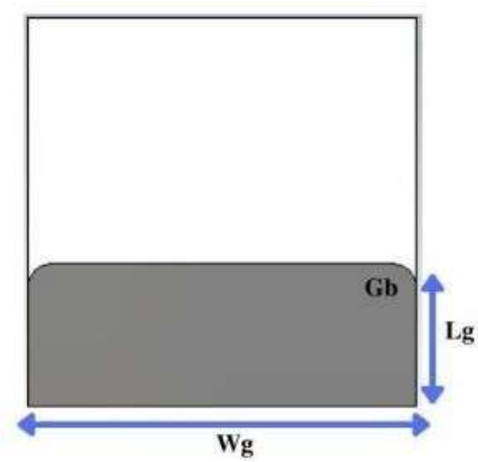

Figure 1(B). Back View

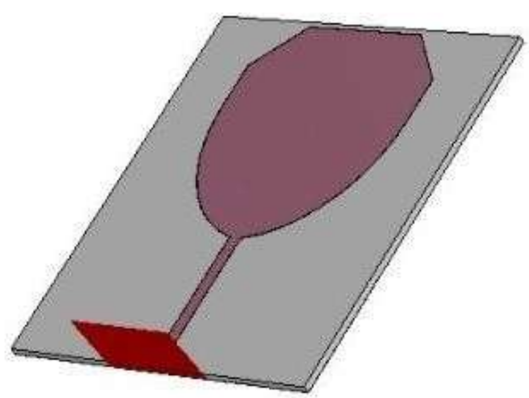

Figure 1(C). Perspective View of the proposed design.

10.48047/jocaaa.2023.31.02.32

2.2 Analysis

2.2.1 Parameter Calculations

The parameters are refined suitably to earn the best results. The feed-line and the patch dimensions are computed using fundamental equations [24]

$$L_f = \frac{\lambda_g}{4} \quad [1]$$

where $\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}}$

$$W_f = \frac{7.48 \times h_s}{e^{z_0\left(\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - 1.25 \times h_p \quad [2]$$

ε_{reff} is the effective dielectric constant.
λ_g is the guided wavelength.

$$w_p = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad [3]$$

$$l_p = l_{eff} - 2\Delta l \quad [4]$$

where, $l_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}}$

$$\Delta l = 0.412 h_s \frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h_s}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h_s}+0.8\right)} \quad [5]$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12 h_s}{w_p}\right]^{-\frac{1}{2}} \quad [6]$$

c being the velocity of light.
f being the center frequency.

The substrate dimensions hence are obtained by applying following equations:

$$l_g = l_p + 6h' \quad [7]$$

$$w_g = w_p + 6h' \quad [8]$$

where $h' = \frac{0.0606\lambda}{\sqrt{\varepsilon_r}}$

All the above mentions equations are the standard globally used formulae for determination of different antenna parameters to avail the best optimized values.

2.2.2 Bandwidth Enhancement

The intent of implementing an SWB Antenna is to encompass the extensive spectrum of frequencies [8]. Literature shows millions of creative ways to procure as large bandwidth as possible. Truncations, slot creations, modifications on joints and many more techniques have yielded surprising enlargement of bandwidths.

The proposed design cater to impedance matching from 2.5 GHz to above 120 GHz that cases a sustained territory of resonating frequencies depicted by S_{11} and VSWR graphs in Figures 2A and 2B. The radiating patch is blended from the bottom depicting a cup. The narrow bottom delivers high resonant frequencies. The upper edges of the patch are chamfered to deliver the lower resonant frequencies.

The next very important part of the structure is the ground plane. The blending of top edges of ground is implemented to inculcate the lower frequency that is depending on the prolonged current path. The length of the ground is optimized to get the umbrella of the bandwidth presented here. The simulation is advocated using Computer Simulation Technology (CST) software. The geometrical values are indexed in the table 1.

Table 1: Optimized statistics of various parameters

Nomenclature	Parameter	Values
W_s	Width of Substrate	40
L_s	Length of Substrate	40
h_s	Height/Thickness of Substrate	0.762
W_g	Width of Ground	40
L_g	Length of Ground	14.7
W_p	Width of Patch	25
L_p	Length of Patch	24.5
h_p	Height/Thickness of Patch/Ground	0.02
W_f	Width of Feed line	1.5
L_f	Length of Feed line	14.95
W_s	Width of Substrate	40
L_s	Length of Substrate	40

2.2.3 Bandwidth Dimension Ratio (BDR)

Every SWB Antenna has to display wide bandwidth along with stipulated structure. To analyze the different architecture available in literary work in relation to bandwidth and dimensionality, antenna engineers came up with a model terminology called Bandwidth Dimension Ratio (BDR). Its technical definition implies the operating bandwidth that can be expressed per unit electrical area, given by following formula:

$$\frac{\%\,BW}{\lambda_{length} \times \lambda_{width}} \quad [9]$$

λ is the lower cut-off frequency of the operating bandwidth.

Any SWB antenna demands to uphold the minimum BDR of 10:1 [1, 3, 5, and 7]. The corresponding figures of the prospected architecture and formerly articulated designs are shown in table 2.

10.48047/jocaaa.2023.31.02.32

Ref. No.	Dimensions	Frequency Range	FBW%
[3]	40 × 45	1.6 – 47.5	186.0
[4]	52.25 × 42	0.96 – 10.9	167.2
[6]	35 × 49	2.5 – 20	155.5
[7]	52 × 46	0.95 – 13.8	173.9
[8]	52 × 42	1.30 – 20	175.6
[9]	80 × 80	0.3 – 20	187.6
[10]	52 × 42	0.96 – 13.98	174.3
[11]	62 × 64	1.68 – 26	175.7
[12]	60 × 60	10 – 50	133.0
[14]	40 × 50	2.5 – 110	191.0
[15]	60 × 60	3 – 60	180.9
Proposed	**40 × 40**	**2.5-120**	**192.62**

Table 2: Comparative Analysis of literature on SWB

From the above table, it is ascertained that prospective structure is concise and delivers considerably better values of SWB frequency ranging from 2.5 till 120 GHz and more with fractional bandwidth of 192.62%.

3. Results & Discussions

The reformed and polished results are achieved by using commercial CST Software. The proposed antenna covers the impedance bandwidth of 117.51 GHz within the frequency territory of 2.5 GHz to over and above 120 GHz.

The final simulated results are shown in Figures 2(A) and 2(B). The annotations clearly shows maximum return loss of -49.18 dB that is to be seen at 93.46 GHz.

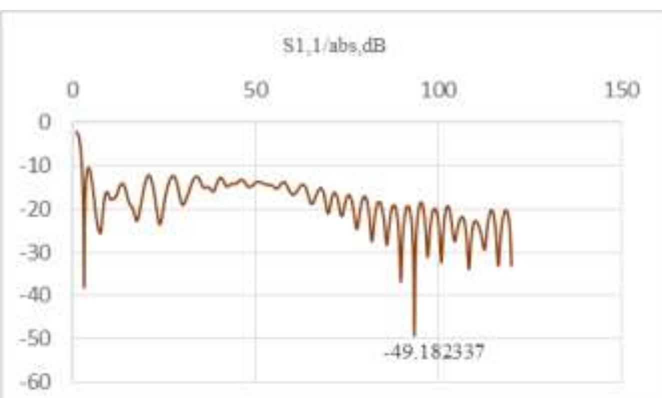

Figure 2(A). S_{11} v/s Frequency

The above results show for the entire range of SWB frequency the values of S_{11} is less than -10 dB as eligible requirement of an SWB antenna. The minimum S_{11} achieved is -49.18 dB at 93.5 GHz.

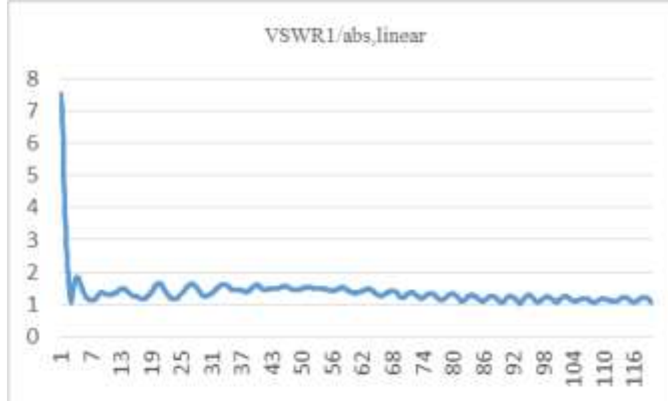

Figure 2(B). VSWR v/s Frequency

The above simulated results show that for the entire SWB range, VSWR is less than 2. Another important parameter being the apex gain of the considered design comes out to be 9.53 dB as shown in Figure 2(C).

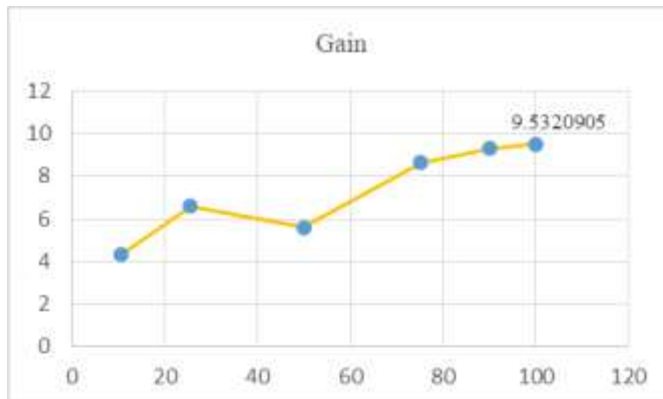

Figure 2(C). Gain v/s Frequency

Good values S_{11} and VSWR particularly describes how intimately the antenna impedance is coordinating alongside transmission line and eventually outlines the comprehensive attainment of an antenna design.

To technically explain the radiation pattern, it is illustration of energy that is radiated by any antenna. It's a mathematical function of the far-field.

Radiation Patterns are displayed for frequencies at 6.95 GHz, 18.85 GHz, 30.75 GHz, 66.45 GHz, 96.2GHz and 120.0 GHz in the complete frequency range in Figure 4. The patterns on the left side represent Elevation (Vertical) Plane for the corresponding frequencies. Similarly, the patterns on the right side represent the Azimuthal (Horizontal) Plane.

10.48047/jocaaa.2023.31.02.32

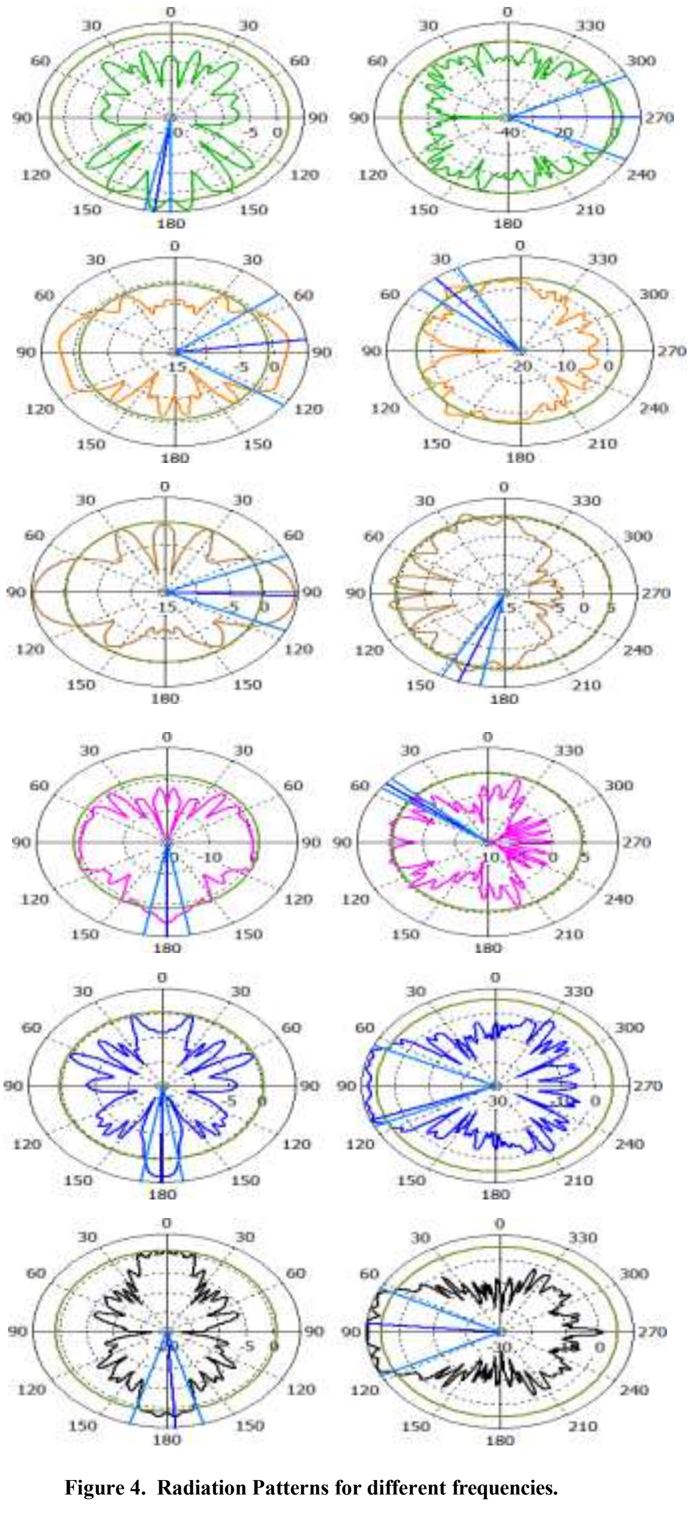

Figure 4. Radiation Patterns for different frequencies.

4. INFLUENCE OF ARTIFICIAL INTELLIGENCE ON ANTENNA DESIGNING

Before studying the various AI techniques used in literature, it is imperative to understand the urge to use these trending technologies for the scheming of any antenna. Generally, a designer uses hit and trial method to achieve the goal of specific values of the antenna parameters (like gain, efficiency, S_{11}, VSWR etc.) for the optimum result. These time-consuming ways might be simple for crafting antennas of limited use however, are found to be tedious when the requirement of antenna is very specific. Collectively, possibility of error in general is very high when values are found in a general manner.

To surmount the mentioned hitches in designing a to-be perfect antenna for huge wireless applications like SWB, there is definitely an obligation to the developers to come up with innovative technological solutions and that is when purpose of AI, ML and DL fulfills. The upcoming study displays diverse comprehensive reviews in literature towards gravitating technology of AI. Distinguished applications of Artificial Intelligence in Antenna designing and optimizations are following:

4.1 Wireless Localization

This is a low-cost and high accuracy mechanism. The goal is to find the location of pertinent targets and inspect them for monitoring and navigation [17, 23]. The general approaches are triangulation and proximity detection.

4.2 Beam Forming

It is a prevalent method used in smart antennas. Here, arrays of an antenna are made to transmit radio signals in a set direction and that collective signal is controlled by number of small antennas by balancing the phase/magnitude of signals ultimately resulting in a targeted beam [17, 22, 23].

4.3 Adaptive Nulling

This arrangement is ought to have a digital beam forming (DGF) design and an ML algorithm to enhance the Signal to Interference Ratio (SIR). This is a cost effective technique and is potent to noise in multipath environment.

These are some of the AI techniques that give a brief idea about the kind of approach that can be expected to fit required outcome. Use of ANN Modeling in [19] and hybrid methods in [21] to achieve most favorable values to articulate an antenna clearly demonstrates the aid to utilize AI based methods.

5. CONCLUSION

A simple and compact Trophy-Cup shaped SWB Antenna is proposed in this paper. The truncated edges and DGS is employed resulting in the broad bandwidth making the structure suitable for wide range of SWB applications. The design has simulated excellent results of bandwidth of 2.5 GHz to beyond 120 GHz attaining the return loss lower than -10 dB. Dimensions of corners and blended edges are properly optimized to ensure as minimum as possible mismatching among several application bands. Simple design and configuration can be deployed in a single device without any interference.

The dominance of cutting-edge AI technology can be seen in the paper. Harmony of AI approach to antenna design is seen to be very fruitful and is helping the designers to accustom as many methodologies as possible to get the desired and optimum conclusions.

10.48047/jocaaa.2023.31.02.32

REFERENCES

1. W. Balani et al., “Design techniques of super-wideband antenna–existing and future prospective,” IEEE Access, vol. 7, pp. 141241–141257, 2019.
2. F. A. Tahir and A. H. Naqvi, “A compact hut-shaped printed antenna for super-wideband applications,” Microw. Opt. Technol. Lett., vol. 57, no. 11, pp. 2645–2649, 2015.
3. W. Balani et al., “Design of SWB Antenna with Triple Band Notch Characteristics for Multipurpose Wireless Applications,” Applied Sciences, vol. 11, no. 2, p. 711, Jan. 2021, doi: 10.3390/app11020711.
4. P. Okas, A. Sharma, G. Das, and R. K. Gangwar, “Elliptical slot loaded partially segmented circular monopole antenna for super wideband application,” Int. J. Electron. Commun., vol. 88, pp. 63–69, 2018.
5. K.-R. Chen, C.-Y.-D. Sim, and J.-S. Row, “A Compact Monopole Antenna for Super Wideband Applications,” IEEE Antennas Wirel. Propag. Lett., vol. 10, pp. 488–491, 2011.
6. B. T. Ahmed, D. C. Carreras, and E. G. Marin, “Design and implementation of super wide band triple band-notched MIMO antennas,” Wirel. Pers. Commun., vol. 121, no. 4, pp. 2757–2778, 2021.
7. P. Okas, A. Sharma, and R. K. Gangwar, “Super-wideband CPW fed modified square monopole antenna with stabilized radiation characteristics,” Microw. Opt. Technol. Lett., vol. 60, no. 3, pp. 568–575, 2018.
8. M. Samsuzzaman and M. T. Islam, “A semicircular shaped super wideband patch antenna with high bandwidth dimension ratio,” Microw. Opt. Technol. Lett., vol. 57, no. 2, pp. 445–452, 2015.
9. U. Rafique and S. Ud Din, “Beveled-shaped super-wideband planar antenna,” TURK. J. OF ELECTR. ENG. COMPUT. SCI., vol. 26, no. 5, pp. 2417–2425, 2018.
10. P. Okas, A. Sharma, and R. K. Gangwar, “Circular base loaded modified rectangular monopole radiator for super wideband application: OKAS et al,” Microw. Opt. Technol. Lett., vol. 59, no. 10, pp. 2421–2428, 2017.
11. C. Á. Figueroa-Torres, J. L. Medina-Monroy, H. Lobato-Morales, R. A. Chávez-Pérez, and A. Calvillo-Téllez, “A novel fractal antenna based on the Sierpinski structure for super wide-band applications,” Microw. Opt. Technol. Lett., vol. 59, no. 5, pp. 1148–1153, 2017.
12. A. Azari, “A New Super Wideband Fractal Microstrip Antenna,” IEEE Trans. Antennas Propag., vol. 59, no. 5, pp. 1724–1727, 2011.
13. M. A. Dorostkar, M. T. Islam, and R. Azim, “Design of a novel super wide band circular-hexagonal fractal antenna,” Electromagn. Waves (Camb.), vol. 139, pp. 229–245, 2013.
14. A. Seyfollahi and J. Bornemann, “Printed-Circuit Monopole Antenna for Super-Wideband Applications,” in 12th European Conference on Antennas and Propagation (EuCAP 2018), 2018.
15. S.Das, S. Bhattacharjee, and S.R. Bhadra Chaudhari, “Fractal loaded hexagonal wide slot antenna for super wide band application,” in 2018 IEEE Indian Conference on Antennas and Propagation (InCAP), 2018.
16. D. Sagne and R. A. Pandhare, “Design and analysis of inscribed fractal super wideband antenna for microwave applications,” Prog. Electromagn. Res. C Pier C., vol. 121, pp. 49–63, 2022.
17. T. Gayatri, G. Srinivasu, D. M. K. Chaitanya, and V. K. Sharma, “A review on optimization techniques of antennas using AI and ML / DL algorithms,” International Journal of Advances in Microwave Technology, vol. 07, no. 02, pp. 288–295, 2022.
18. S. K. Goudos, P. D. Diamantoulakis, M. A. Matin, P. Sarigiannidis, S. Wan, and G. K. Karagiannidis, “Design of antennas through artificial intelligence: State of the art and challenges,” IEEE Commun. Mag., vol. 60, no. 12, pp. 96–102, 2022.
19. R. K. Thenua, V. V. Thakare, and P. Singhal, “Artificial intelligence in design of microstrip antenna,” 2009.
20. F. Zardi, P. Nayeri, P. Rocca, and R. Haupt, “Artificial intelligence for adaptive and reconfigurable antenna arrays: A review,” IEEE Antennas Propag. Mag., vol. 63, no. 3, pp. 28–38, 2021.
21. U. Ozkaya and L. Seyfi, “A comparative study on parameters of leaf-shaped patch antenna using hybrid artificial intelligence network models,” Neural Comput. Appl., vol. 29, no. 8, pp. 35–45, 2018.
22. M. C. D. Melo, P. B. Santos, E. Faustino, C. J. A. Bastos-Filho, and A. Cerqueira Sodre, “Computational intelligence-based methodology for antenna development,” IEEE Access, vol. 10, pp. 1860–1870, 2022.
23. S. Ledesma, J. Ruiz-Pinales, G. Cerda-Villafana, and M. G. Garcia-Hernandez, “A Hybrid Method to Design Wire Antennas: Design and optimization of antennas using artificial intelligence,” IEEE Antennas Propag. Mag., vol. 57, no. 4, pp. 23–31, 2015.
24. C.A. Balanis, Antenna theory: Analysis and design. Wiley-Interscience, 2014.