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Research paper

A super wideband circular-shaped fractal antenna loaded with concentric hexagonal slots

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Abstract

This article presents a super wideband (SWB) circular-shaped fourth iterative fractal antenna loaded with concentric hexagonal slots. A tapered microstrip feed and a partial ground plane is used. It has a total size of 40 × 27 × 1.6 mm3. Numerical results of the antenna show that it provides a bandwidth from 1.43 GHz to more than 40 GHz (percentage bandwidth greater than 186%) with a bandwidth ratio of approximately greater than 28:1 for S11 < -10 dB. A prototype of the proposed antenna has been fabricated and its performances are measured up to 15 GHz. A good agreement is achieved between the numerical and experimental reflection coefficient, VSWR and input impedance. Measured radiation patterns at different frequencies and simulated peak gain are presented and discussed. It has the advantages of super wide bandwidth and compact size. The developed antenna is suitable for various wireless communications such as GPS, GSM, UMTS, ISM and UWB.

Keywords: *Circular Radiating Patch; Fractal Antenna; Hexagonal Slot; Microstrip Feedline; SWB Applications; Tapered Feeding*.

1. Introduction

In addition to 3.1 to 10.6 GHz band of frequencies for UWB applications, the present day users of wireless systems are very much demanding for high data rate over a super wideband (SWB) of frequencies to accommodate both the short and long-range transmission for ubiquitous applications [1]. Antennas with ratio bandwidth greater than or equal to 10:1 are treated as SWB antennas [2], [3]. Some printed SWB antenna structures [1], [3-14] using fractal monopoles with defected ground plane for enhanced impedance bandwidth and compact size are reported in the open literature.

In this article, a novel compact circular-shaped fourth iterative SWB fractal antenna with concentric hexagonal slots is developed and presented. Bandwidth enhancement is achieved by using four iterations of the fractal geometry, linearly tapered microstrip feedline and defected ground plane. ANSYS High Frequency Structure Simulator (HFSS) which is based on finite element method (FEM) is used for the design, simulation and analysis of the antenna.

The designed antenna is appropriate for many applications such as GPS 1575 MHz, GSM 1800 MHz, UMTS 2000 MHz, ISM 2.4/5.2/5.8 GHz, UWB. The proposed antenna is simple and compact in size when compared to SWB antennas reported in the literature [1], [6], [12-13].

2. Antenna structure and design

The final structure and dimensions of the developed antenna is shown in Fig. 1. It is printed on a glass epoxy substrate (FR4) having thickness of 1.6 mm, εr=4.4 and tan δ=0.02. A microstrip feed with linear tapering and having feed length of Lf = 16.31 mm,

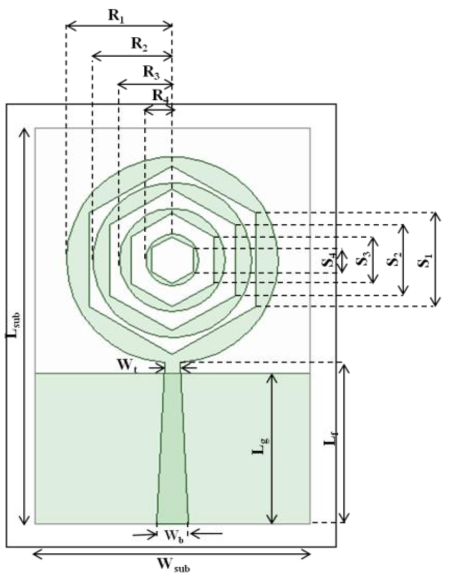

Fig. 1: Geometrical Structure of the Proposed Antenna. L_{sub} = Length of Substrate, W_{sub} = Width of Substrate, L_f = Length of Feed, L_g = Length of Ground, R = Radius of Circular Patch, S = Side Length of Hexagonal Slot, W_b = Bottom Width of Feed Line, W_t = Top Width of Feed Line.

Top width of W_t = 1.4 mm and bottom width of W_b = 3.2 mm is used for impedance conversion from 75 Ω at the radiating patch to 50 Ω at the input of microstrip line. Also, it enhances the impedance bandwidth. The radiator of the antenna consists of four concentric hexagonal slot-loaded fractal circular patches. A partial ground plane producing a capacitive effect is used to counteract the inductive nature of the circular radiator and hence resulting in

Table 1: Dimensions of Developed Antenna

Parameter	Value (mm)	Parameter	Value (mm)
W_{sub}	27	L_{sub}	40
W_b	3.2	W_t	1.4
L_f	16.31	L_g	15.4
R_1	10.4	S_1	9.5
R_2	7.8	S_2	7.125
R_3	5.2	S_3	4.75
R_4	2.6	S_4	2.375

(A) **(B)**

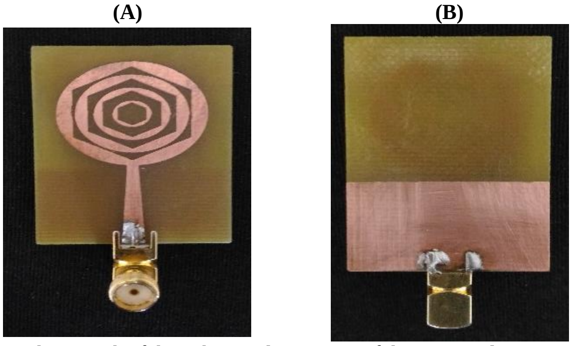

Fig. 2: Photograph of the Fabricated Prototype of the Proposed Antenna (A) Top View and (B) Bottom View Only Real Impedance.

The developed antenna dimensions are shown in Table 1 and the fabricated prototype is depicted in Fig. 2.

3. Results and discussion

The simulated and measured reflection coefficient of the proposed antenna is presented in Fig. 3. The numerical results of proposed antenna show that the antenna impedance bandwidth ranges from 1.43 GHz to more than 40 GHz with a ratio bandwidth of approximately greater than 28:1 for S11 < -10 dB and percentage bandwidth of more than 186%. The experimental results of the developed antenna are measured using Anritsu Master MS2037C Vector Network Analyzer (5 kHz to 15 GHz). The experimental results show that the developed antenna operates from 1.45 GHz to 15 GHz (Maximum limit of network analyzer used for the measurement). As the experimental result shows a downtrend at 15 GHz, it is expected that the developed antenna will operate beyond 15 GHz as well. The experimental results are in good agreement with simulation results. There is a slight discrepancy between the simulation and measurement mainly due to the effect of SMA connector and some unavoidable processing errors. The SMA connector is not accounted in the simulation but used in the

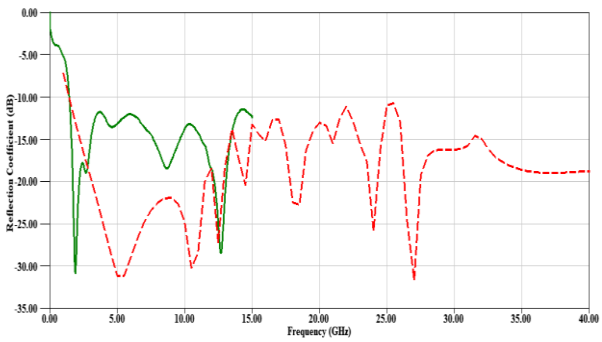

Fig. 3: Reflection Coefficient Plot of the Proposed Antenna. (Solid Curve Represents Measured and Dashed Curve Represents Simulated).

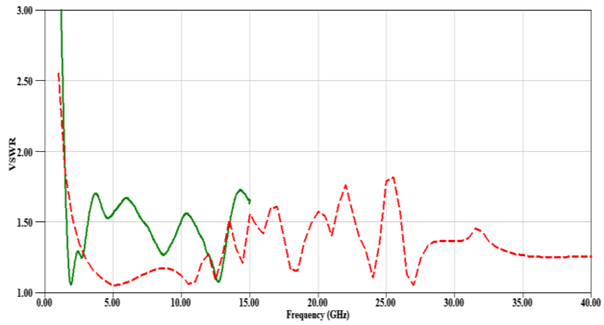

Fig. 4: VSWR Plot of the Proposed Antenna. (Solid Curve Represents Measured and Dashed Curve Represents Simulated).

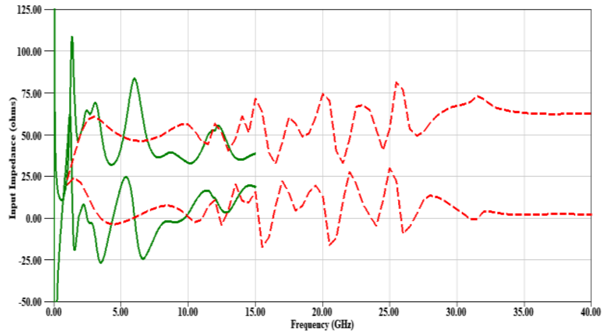

Fig. 5: Input Impedance Plot of the Proposed Antenna. (Solid Curve Represents Measured and Dashed Curve Represents Simulated).

Measurement, so that a varying reactance is loaded, leading to the movement of resonant points. Also, the mismatch in the results is observed due to fabrication tolerance and substrate losses.

The simulated and measured VSWR is presented in Fig. 4 and the experimental result shows a downtrend at 15 GHz, therefore, it is expected again that the developed structure will operate beyond 15 GHz also as an antenna. Fig. 5 shows the simulated and measured input impedance of the proposed antenna and it is evident from the plot that the average resistive part is around 50 Ω and average reactive part is around 0 Ω for both simulation and measurement.

Fig. 6 shows the variation of simulated peak gain which varies approximately from -2.53 dB to 42.76 dB over the frequency of interest. The simulated surface current density of the proposed antenna at few selected frequencies is shown in Fig. 7. The current is uniformly distributed over the surface of the feed line, patch and ground plane. A high current density is observed along the feedline, at the connecting edge of the feed and circular patch and at the top edge of the defected ground plane. Fig. 8 shows the measured radiation pattern in both E-Plane and H-Plane at 5 GHz, 12 GHz and 15 GHz respectively.

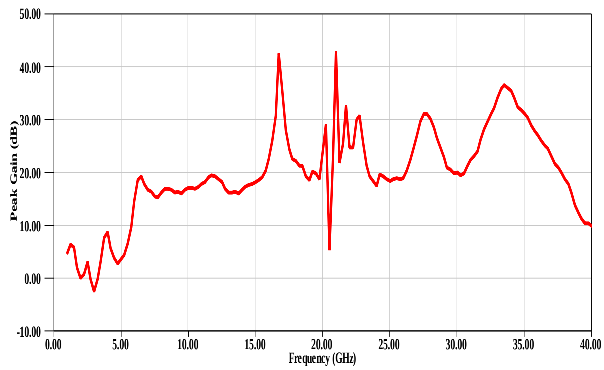

Fig. 6: Simulated Peak Gain versus Frequency of the Proposed Antenna.

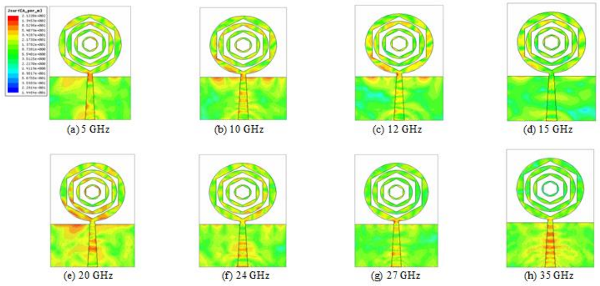

Fig. 7: Simulated Surface Current Density of the Proposed Antenna at Few Selected Frequencies.

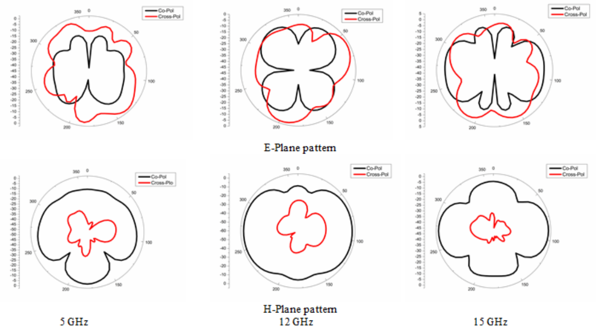

Fig. 8: Measured Radiation Patterns of the Proposed Antenna at Different Frequencies both in E-Plane and H-Plane.

Table 2: Comparison of Functional Characteristics of the Proposed Antenna with Existing Antennas

Antenna	Frequency Bandwidth (GHz)	Electrical Dimension (L × W, in mm^2)	10 dB BW (%)	Bandwidth Dimension Ratio (BDR)	Peak Gain
Chen K R et al [1]	1.44 – 18.8	0.37 λ × 0.17 λ 77 × 35	171.54	2735	7 dBi*
Gorai A et al [6]	3 - 35	0.55 λ × 0.38 λ 55 × 38	168.42	805.84	6 dBi#
Singhal S et al [12]	3.5 – 37.2	0.2785 λ × 0.234 λ 22 × 18.5	165.6	2541.12	13.7 dB#
Okas P et al [13]	0.96 – 13.98	0.1664 λ × 0.1344 λ 52 × 42	174.29	7468.51	5.8 dBi*
Proposed	1.43 - 40	0.191 λ × 0.1287 λ 40 × 27	186	7566.6	42.76 dB*

* - Simulated # - Measured

A comparison between previously reported and proposed SWB antennas is presented in Table 2 in terms of electrical dimension, percentage bandwidth, bandwidth dimension ratio (BDR), and peak gain. BDR indicates how much bandwidth (in %) is provided by the antenna per unit area that is defined as:

$$BDR = \frac{Bandwidth\%}{\lambda_{length} \times \lambda_{width}} \quad (1)$$

Where, λ is the wavelength at lower cut-off frequency of the operating bandwidth. From the BDR expression, it can be observed that the larger BDR indicates the design of the antenna is compact and has a wider frequency band.

The proposed antenna has higher frequency bandwidth, moderate electrical dimension, higher percentage bandwidth, and higher BDR of 7566.6 among the referenced antennas. Also, the simulated peak gain of the proposed antenna is higher than the peak gain of the existing antennas.

4. Conclusion

A super wideband circular-shaped fractal antenna loaded with four concentric hexagonal slots is developed and investigated. A tapered microstrip feed and a partial ground plane are used to improve the impedance bandwidth. It has a total size of 40 × 27 × 1.6 mm3. Besides higher BDR (7566.6), the proposed antenna has higher ratio BW (28:1), percentage BW (186%), and compact size when compared with the antennas found in the literature. Thus, the proposed antenna is novel in respect of structure and its functional characteristics. The developed antenna is simple, small size and easy to fabricate. For the developed antenna, the radiation pattern characteristics are relatively omnidirectional in the H-Plane. The developed antenna is also suitable for various applications like S, C, and X bands' operations.

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