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A New Reduced Size Multiband Fractal Microstrip Patch Antenna for Microwave Applications

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Abstract. A new fractal structure of a circular microstrip patch antenna (CMPA) for multi-band frequencies is proposed. To obtain multi-band characteristics, several techniques can be applied such as fractal geometry, defected ground structure (DGS) and making a slot in the patch. Fractal is one of the methods used to reduce the size of the antenna due to is space-filling ability. The proposed antenna operates at different resonant frequencies, at 3.32 GHz, 4.12 GHz, 4.82 GHz, 5.45 GHz, 6.02 GHz, 6.52 GHz, 6.97 GHz, 7.4 GHz and 7.76 GHz, with the return loss of less than -10 dB, VSWR < 2. The relative permittivity of the substrate used in this model is 1.01, and the face medium of the patch is made up of a perfect electric conductor (PEC). The fractal antenna is designed and simulated using the FEKO comprehensive software version 7.0 that is based on a method of moment (MOM) for solving electromagnetic structures. The performance of the antenna shows good radiation characteristics that makes it suitable for the current wireless communication systems for the S-and C-band applications.

Keywords: patch, fractal, return loss, VSWR, gain, FEKO.

Pomanjšana krožna mikrotrakasta antena za uporabo v mikrovalovnih aplikacijah

V članku predstavljamo novo fraktalno strukturo za krožne mikrotrakaste antene v različnih pasovnih območjih.
Za dosego večpasovnih karakteristik smo uporabili geometrijo fraktalov, okvarjeno ozemljitveno strukturo in izdelano režo. Z uporabo fraktalov lahko zmanjšamo velikost anten zaradi njihove sposobnosti zapolnitve prostora. Predlagana antena deluje pri različnih resonančnih frekvencah pri 3,32 GHz, 4,12 GHz, 4,82 GHz, 5,45 GHz, 6,02 GHz, 6,52 GHz, 6,97 GHz, 7,4 GHz in 7,76 GHz, s povratno izgubo manj kot -10 dB, VSWR <2. Dielektrik v substratu ima relativno dielektričnost 1,01. Anteno smo načrtali in simulirali s programskim orodjem FEKO. Zmogljivost antene se izkazuje z dobrimi karakteristikami sevanja in eksperimentalni rezultati potrjujejo njeno uporabnost v brezžičnih komunikacijskih sistemih v območjih S in C.

1 INTRODUCTION

Microstrip patch antennas play an important role in the today's wireless communication due to their highly desirable characteristics such as light weight, low volume, multi-band support, reduced cost, high efficiency, ease of manufacturing, compact size, and easy integration with microwave integrated circuits (MICs) [1], [2]. These merits are suitable in a wide range of applications of the microstrip patch antennas like radar, satellite, multimedia, smart home and others. Fractal-shaped antennas show some of the interesting features that result from their inherent geometrical properties. Fractals are generally made up of multiple copies of themselves of various sizes based on self-similarity properties [3], [4]. By using the fractal's technique in an antenna, multiple benefits are achieved such as improved VSWR, miniaturization of the antenna and wide-band performance. There are many fractal geometries [5], such as Sierpinski's gasket, von Koch's snowflake, Cantor's comb, Mandelbrot's set, Lorenz's attractor, etc. [6]. The name 'Fractal' obtained from the Latin word "Fractus", meaning broken pieces, given by Benoit Mandelbrot [7] is based on his essay in 1975.

The size of an antenna is very important for most wireless communication systems. Many techniques are performed to reduce its size, such as the use of dielectric substrates with a high dielectric constant and increasing the electrical length of the antenna by improving its shape [8]. Conventionally, each antenna operates at a single frequency band, on the other hand; antennas are needed for various applications. Therefore, more space is required for different antennas. In order to solve this problem, a multi-band antenna should be used where a single antenna should operate at many frequency bands. A Multi-band behavior is performed by applying a fractal technique in the antenna. Many researchers are interested in designing and simulating antennas with multi-band frequencies by using different shapes of the fractal technique, which is the main goal of this paper [9] [10] [11] [12] [13].

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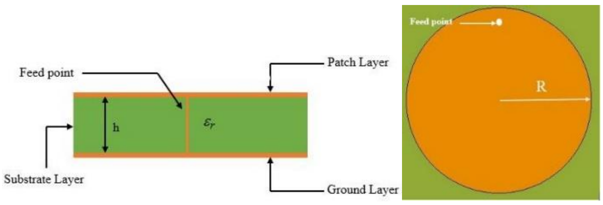
2 ANTENNA STRUCTURE AND SIMULATION RESULTS

2.1 Antenna Geometry

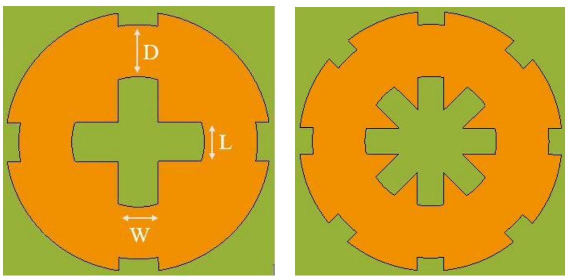
The basic configurations for the proposed antenna are a polystyrene foam-material substrate layer with a low dielectric constant of 1.01, which is a close similarity of the dielectric constants of air and thickness (h) of 5 mm, and the patch plane is printed on an infinite substrate as a perfect conductor with a radius of 50 mm (see Figures 1 a and b). This antenna is as a wide-band solution used in monolithic wireless communication applications that require multi-resonance frequencies.

The antenna fractal shape is constructed in four iterations. In the first iteration, two rectangular arms of the width of 15 mm and the length of 47.69 mm each are orthogonal to the another like the plus symbol and constructed from four arms with a width of the previous arms and short length placed on the edges of the patch in the same direction of the two preceding arms. These arms are subtracted from the proposed circular antenna (see Figure 2 a). The same procedure is repeated in the second iteration but the number of the arms in the middle is increased from two to three with similar angles, and the arms at the edges are still placed in the direction of the three arms (see Figure 2 b). The same process is continually in the third and fourth iteration but with more arms (see Figures 2 c and d). The proposed antenna is fed by a coaxial cable at the -43. 5 mm at x-and y-axes. This point remains constant in all iterations.

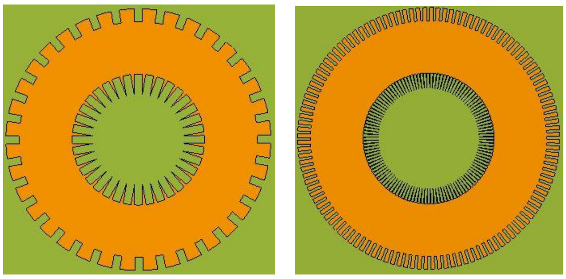


(a) (b)

Figure 1 . Conventional CMPA produced by FEKO, (a): Side view (b): Top view



(a) (b)



(c) (d)

Figure 2 . (a): 1st iteration of the fractal CMPA (b): 2nd iteration of the fractal CMPA (c): 3rd iteration of the fractal CMPA (d): 4th iteration of the fractal CMPA

The method of moments (MOM) is a numerical technique for linear-equation solutions. Many problems can be solved by this method such as integral and differential equations because of its accuracy and efficiency [14]. The surface is divided into triangular boundary edges (see Figure 3).

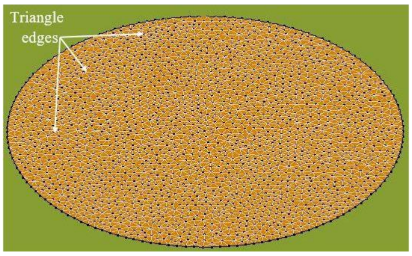


Figure 3 . Triangular boundary edges (mesh) produced by FEKO

The design parameters of the proposed fractal CMPA are given in Table 1.

Table 1. Parameter values of the proposed antenna

Symbol	Parameter values
R	50 mm
D	20.52 mm
W	15 mm
L	47.69 mm
h	5 mm
ε_r	1.01
(x. y) feed point	(-43. 5) mm

2.2 Simulation Results

The simulation is carried out in FEKO. In this design, different parameters such as Standing Wave Ratio (VSWR), S-parameter (S11), current distribution, impedance matching, and gain are obtained through simulation results produced by FEKO. The proposed antenna covers a range of frequencies from 3 GHz to 8 GHz. The simulation results are shown in Figures 4-9. The return loss is a significant parameter of an antenna.

It represents the extent matched between devices or lines in dB. The satisfactory value of the return loss is less than -10 dB. Figure 4 shows that the simulated return loss versus the frequency occurs at eight resonant frequencies in the third iteration and nine in the fourth iteration (multi-band) in addition to the single bands for the previous iterations (zero, first and second). It is well seem that the multi-fractal antennas are enhanced s-parameter characteristics as illustrated in Table 2. VSWR is a measure of the impedance mismatch between the antenna and the feed line. The minimum value of VSWR is unity. The fourth iteration of the fractal CMPA appears of the minimal VSWR value of 1.07 achieved at the 6.52 GHz frequency (see Figure 5 and Table 3).

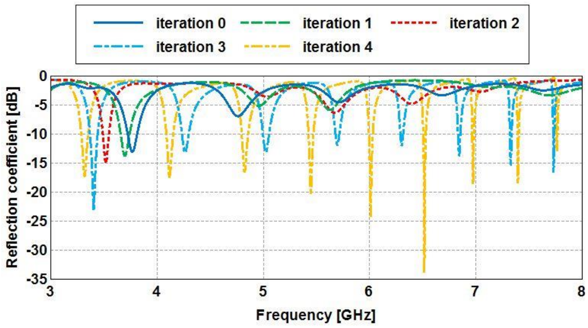


Figure 4 . Reflection coefficient (return losses) results at different iterations of the fractal CMPA produced by FEKO

Table 2. Reflection coefficient results

No. of iteration	Resonant frequency (GHz)	Reflection coefficient (dB)
Iteration 0	3.77	-13.04
Iteration 1	3.7	-13.69
Iteration 2	3.52	-14.6
Iteration 3	3.41	-21.72
	4.27	-13.12
	5.03	-13
	5.7	-11.4
	6.3	-11.9
	6.85	-11.92
	7.33	-12.5
	7.73	-14.4
Iteration 4	3.32	-16.72
	4.12	-17.09
	4.82	-16.5
	5.45	-19.6
	6.02	-18
	6.52	-32.1
	6.97	-18.6
	7.4	-13.8
	7.76	-10.73

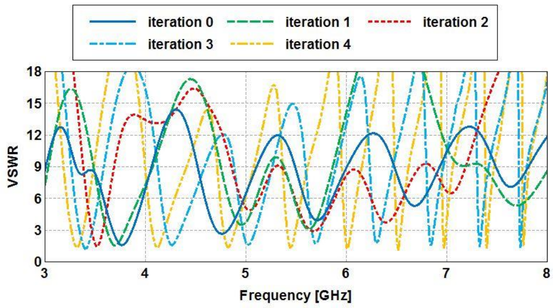


Figure 5 . VSWR results at different iterations of the fractal CMPA produced by FEKO

Table 3. VSWR results

No. of iteration	Resonant frequency (GHz)	VSWR
Iteration 0	3.77	1.582
Iteration 1	3.7	1.557
Iteration 2	3.52	1.493
Iteration 3	3.41	1.261
	4.27	1.577
	5.03	1.65
	5.7	1.79
	6.3	1.82
	6.85	1.704
	7.33	1.66
	7.73	1.43
Iteration 4	3.32	1.38
	4.12	1.34
	4.82	1.37
	5.45	1.39
	6.02	1.3
	6.52	1.07
	6.97	1.47
	7.4	1.52
	7.76	2.28

The gain is defined as the radiation intensity in a given direction divided by the radiation intensity that is obtained (see Figure 6). In this paper, the maximum gain of 4.17 dBi is realized at 4.27 GHz for the third iteration (see Figure 7). The current distribution on the patch surface in the fourth iteration is obtained as shown in Figure 8. It can be observed that the current does not accurately pass through the edges, but slightly follows a route curved. Hence, the higher iteration number means that an addition of further edges in the patch without increasing the electrical length just reduces the patch area. The current distribution and the impedance matching results for each iteration are presented in Figures 9 and 10, respectively.

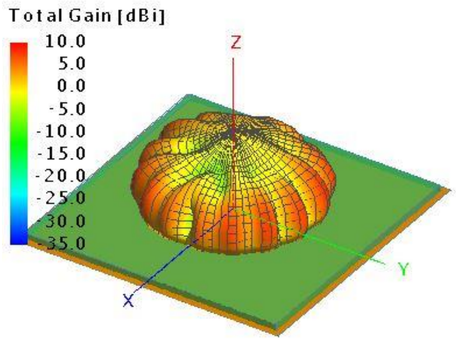


Figure 6 . 3-D total gain result for the fractal CMPA with the fourth iteration produced by FEKO in the x-y plane

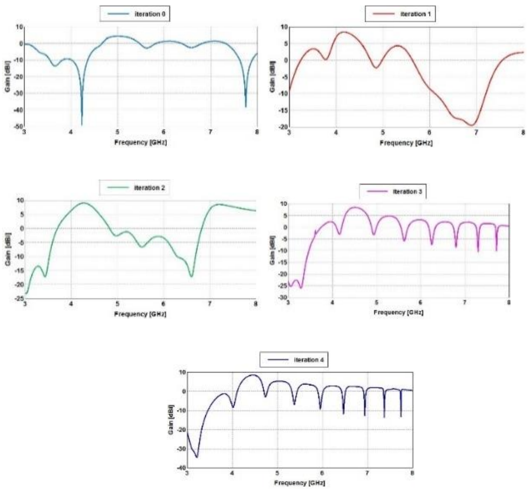
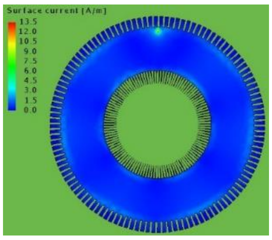
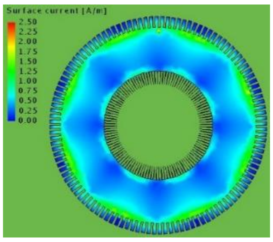


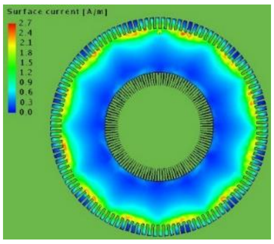
Figure 7 . Cartesian graphs of the gain at all resonant frequencies for each iteration



(a)



(b)



(c)

Figure 8 . 3-D Current distribution result for the fractal CMPA with the fourth iteration produced by FEKO at (a): 3.44 GHz (b): 4.02 GHz (c): 5.388 GHz

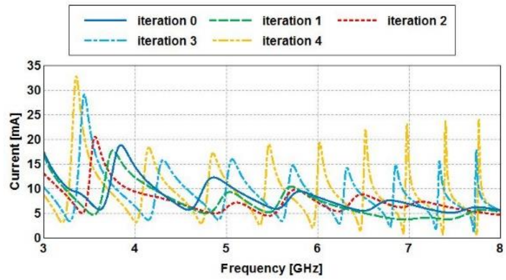


Figure 9 . Current distribution results at different iterations of the fractal CMPA produced by FEKO

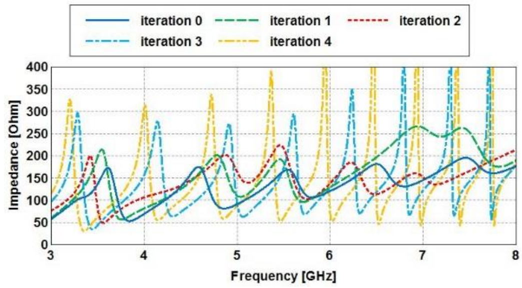


Figure 10 . Impedance matching results at different iterations of the fractal CMPA produced by FEKO

Table 4. Impedance, current and gain results

No. of iteration	Resonant frequency (GHz)	Impedance (Ω)	Current (mA)	Gain (dBi)
Iteration 0	3.77	65.2	15.34	-11
Iteration 1	3.7	65.5	15.34	1.24
Iteration 2	3.52	57.9	17.27	-10.14
Iteration 3	3.41	42.764	23.4	-13.72
	4.27	70.124	14.26	4.17
	5.03	68.3	14.6	1.75
	5.7	71.9	13.9	-0.66
	6.3	75	13.3	-1.92
	6.85	67.48	14.82	-0.86
	7.33	64.6	15.5	-1.40
	7.73	57.3	17.5	-2.15
Iteration 4	3.32	38.269	26.16	-20.2
	4.12	60.471	16.54	0.72
	4.82	65.5	15.3	2.77
	5.45	56.7	17.7	-2.16
	6.02	52.8	19.1	0.55
	6.52	47.9	20.9	0.47
	6.97	43.6	23	0.19
	7.4	46.3	23.4	-0.18
	7.76	52.76	20.71	1.02

3 Conclusion

The Fractal antenna is considered as a promising field due to its space filling and self-repetitive properties. In this paper, a symmetrical fractal antenna designed and analyzed by using the FEKO simulator software is proposed. The antenna shows acceptable results in terms of the return loss, VSWR and its decreased size. Its main benefit are: (i) considerable size reduction (the best size reduction is obtained in the fourth iteration), (ii) multi-band properties, (iii) better return loss and VSWR results up to 32.1 dB and 1.07, respectively. The antenna is used in the WLAN and WiMAX wireless and other microwave applications.

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