Performance Improvement of Fractal Microstrip Antenna with Metamaterial

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ABSTRACT:
This study was carried out to design, simulate, and develop an ultra wideband (UWB) fractal microstrip patch antenna (MPA). The antenna designed for broadband telecommunications had smaller dimensions, omnidirectional pattern, and good gain/return loss. The miniaturization was realized through a metamaterial transmission line and antenna power supply by an electromagnetic coupling system. In order to cover the desired frequency bandwidth, a new fractal was designed and combined with the circular polarization of disturbances in certain parts of the fractal structure. Furthermore, the quality of antenna bandwidth was improved deforming the ground plane. Finally, the results of the development, simulation, and measurement of input return losses and radiation patterns were explored. The results demonstrated that the proposed model involves a compact, simple fractal MPA that provides ideal bandwidth and impedance matching.

KEYWORDS: Fractal Microstrip, Metamaterial, Circular polarization.

1. INTRODUCTION

Since antenna size is a limitation to frequency band, it is crucial to downsize the antennas so as to adjust their effect on frequency range. Moreover, frequency-independent antennas are designed in a way to avoid the characteristic size because any antenna entailing several characteristic sizes will be able to transmit multiple wavelengths [1].

Therefore, self-similar fractal structures entail frequency-independent nature and a great deal of heterogeneity as a result of their unspecific size. This can facilitate the design and miniaturization of antennas. In fact, MPAs with fractal and quasi-fractal geometry provide the best option to meet the requirements of broadband systems [2-22].

In this study, an antenna was designed and powered through symmetric circular radiation and an electromagnetic coupling system. The miniaturization of antenna was implemented through the metamaterial line and the desired frequency bandwidth coverage combined with the new fractal structure. This entails several desirable features in terms of size, bandwidth, gain, and radiation pattern Additionally, input impedance matching and lower input losses were evident in the newly designed model [3-11].

Another idea behind the new design was improvement in bandwidth quality by deforming the ground plane. Finally, the results revealed that the newly proposed model involved a compact, simple antenna that meets numerous conventional standards concerning the design of antennas and the UWB system.

2. ANTENNA DESIGN

2.1. Radiation Element of the Antenna

The new antenna consists of a substrate made of FR-4. Table (1) shows the permittivity, loss tangent, and dimensions of the proposed antenna.

Table 1. Specifications and dimensions of the newly proposed antenna.

Iteration	Parameter/ Values(mm)	Iteration	Parameter/ Values(mm)
1	r1=8	8	Ws2=Ws3=2.58
2	R2=r2=7	9	Lg=7.5
3	r3=6	10	Ls1=2.28
4	r4=5	11	Ls2=0.58
5	r5=4	12	Ls3=0.58
6	r6=3	13	Wf=1.8
7	Ws1=2.5	14	W=20

The microstrip supply line in the new design involved a coupling electromagnetic supply system and substrates from the microstrip line end, so as to enhance the bandwidth and minimize any unwanted radiation.

For this purpose, the lower layer was made of Rogers RT/Duroid5880 with permittivity of ε_r =2.2, while the upper layer was made of FR-4. Table (2) shows the specifications of fractal iteration and the newly designed antenna [13]. One of the ideas behind the design of this antenna was to create a slot in the ground, so as to enhance the bandwidth. With a slot designed on the ground place, the surface current intensifies at high frequencies, thus bringing about resonance, increased impedance bandwidth, and proper matching.

Table 2. Specifications of fractal iteration in the newly designed antenna.

Iteration	Parameter	Iteration	Parameter
1	rq1=rq2=rq	6	Θg=π
2	0< rq <1	7	K=0.5
3	Θq1=Θq2=Θq3	8	FR-4
4	Θq=0	9	Er=4.3
5	-q to q qє N	10	1<q<4

2.2. Description of The Proposed Fractal Geometry Style

The basic structure of the newly proposed antenna is a fractal circle [12- 24]. Figures (1), (2), and (3) illustrate the first and second iterations for the circular fractal. This section compares the miniaturization features of the circular fractal antenna in the first iteration against a simple circular antenna. The iteration of fractal circles serves to improve the antenna bandwidth. In fact, the circles were arranged in a series of symmetrical loops within the main antenna. The radii of the fractal circles were r_1=6 mm, r_2=5 mm, and r_3=6 mm. A series of asymmetric arcs were employed to build an electrical connection. These arcs connect the inner and outer loops, thus creating a modified fractal Sierpinski triangle in the newly designed antenna [22].

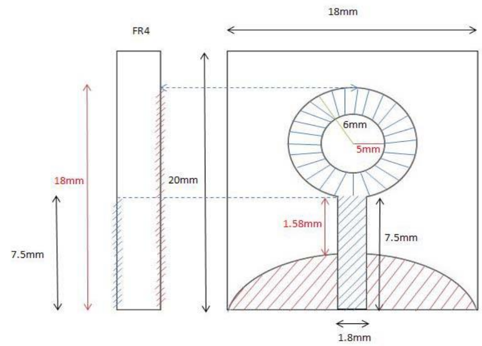
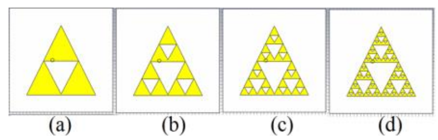


Fig. 1. Illustration of the newly proposed antenna's basic structure.



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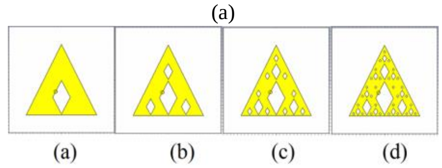

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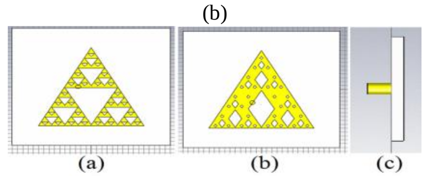


(c)

Fig. 2. (a) Fractal Sierpinski triangle design (b) Modified fractal Sierpinski triangle(c) coax feed with the FR-4 substrate [6,22].

2.3. Design and Simulation Of The Antenna Radiation Element

The new antenna has a substrate made of FR-4, powered through an electromagnetic microstrip line. Both substrates were selected from the microstrip line, so as to enhance the bandwidth and minimize any unwanted radiation. The lower layer was made of RT with permittivity of $\varepsilon_r = 2.2$, loss tangent of 0.0009, and thickness of 1.524 mm, while the upper layer was made of FR-4 with permittivity of $\varepsilon_r = 4.4$, loss tangent of 0.24, and dimensions of 18×20×0.5 mm^3. The selected loops were 1 mm wide and arranged at distances based on the inner radius. Moreover, the loops were connected through a series of asymmetric arcs.

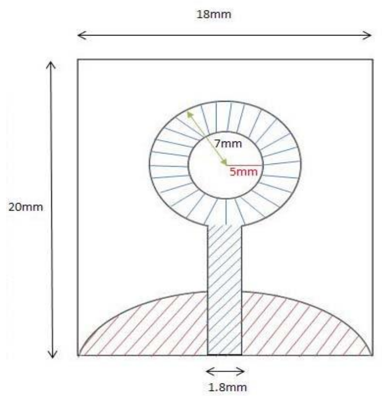
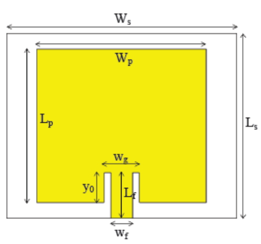


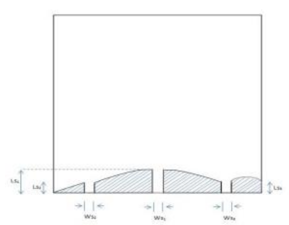
Fig. 3. The initial view of the new antenna.

2.4 Deforming The MPA Ground Structure

The frequency band required within UWB systems falls between 1.6 and 3.1 GHz [5, 12]. In this study, several measures were taken to improve the antenna's bandwidth. For instance, the main idea behind designing this type of antenna was to deform the ground plane aimed at improving its performance, particularly offsetting the bandwidth and return loss.

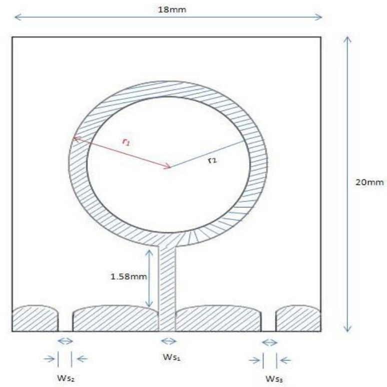
The ground plane was designed based on a slotted ground structure. For this purpose, a rectangular slot was inserted beneath the microstrip supply line (Ws1) in addition to two other small slots (Ws2) around the ground plane. Figures (4) and (5) illustrate how the slotted ground structure was designed. By creating this type of slots in the ground plane, in addition to a few resonances within the bandwidth, there will be greater impedance bandwidth. Moreover, the slotted ground structure enhances the surface current at higher frequencies, eventually increasing the antenna bandwidth.





(a) (b)

Fig. 4. (a, b) The slot inserted in the oval ground plane to improve the antenna bandwidth.



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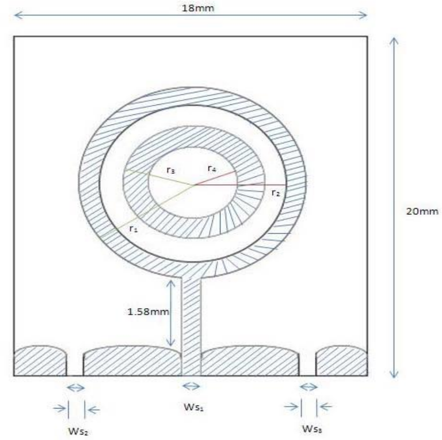

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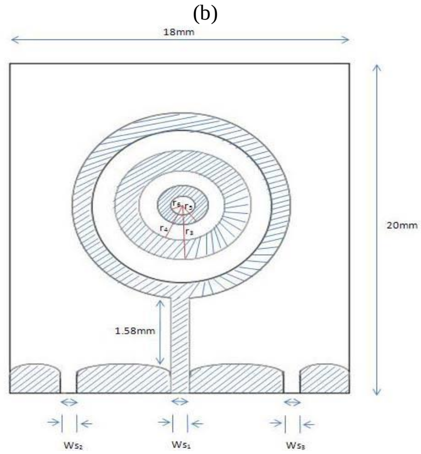

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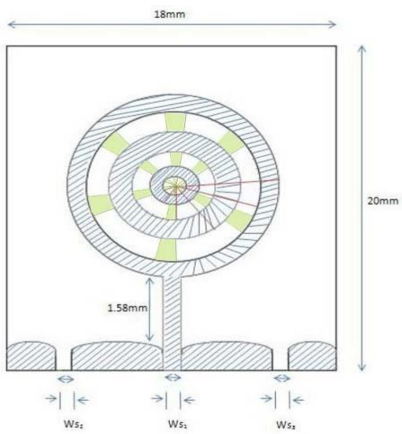

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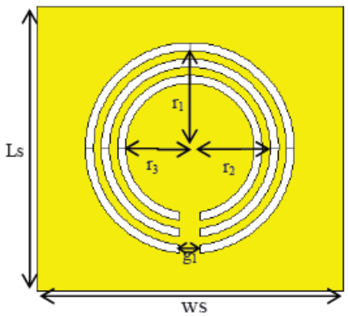
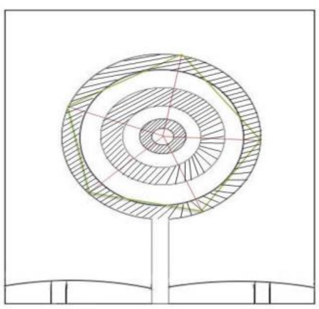


(e)

Fig. 5. Design process: (a) step one (b)step two(c)step three (d)step four(e) Circular ring [25].



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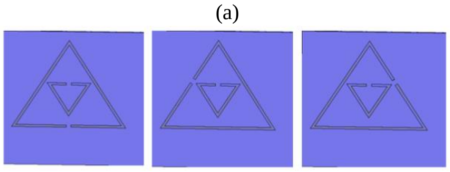
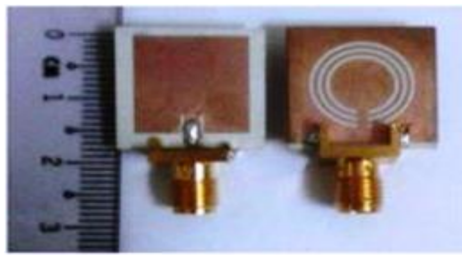


(b)

Fig. 6. (a) An overview of the fractal triangle built within the newly proposed antenna (b) Fractal Sierpinski triangle design.

3. DEVELOPMENT OF THE PROPOSED FRACTAL ANTENNA

Figures (6) and (7) illustrate the structure of the proposed antenna that is a combination of a few fractal antennae, and concentric truncated arcs. The antenna was powered through an electromagnetic microstrip line. Moreover, the substrate parameters were selected exactly from the microstrip end line, so as to enhance the antenna bandwidth and curtail any unwanted radiation. The circular polarization was achieved by selecting the length of perpendicular fractal edges (s_1, s_2) in a way that the two orthogonal modes were stimulated at a 90-degree phase difference. Having designed and completed the new antenna, the SAM was connected to the supply line. Finally, the developed antenna was tested in the antenna room. The techniques adopted for enhancing the bandwidth included: a) Increasing the number of radiation elements used in the antenna design. b) Deformation of the antenna structure and creating a series of symmetrical grooves around the supply line. c) Adding to the number of fractal iterations. The next section explored the values of each parameter and the development stages.



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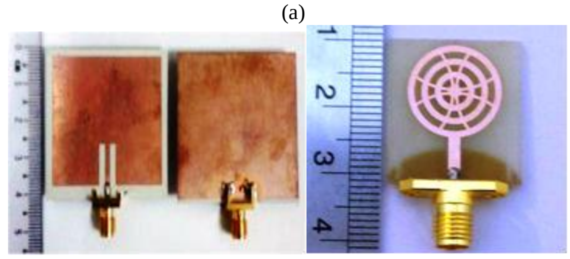
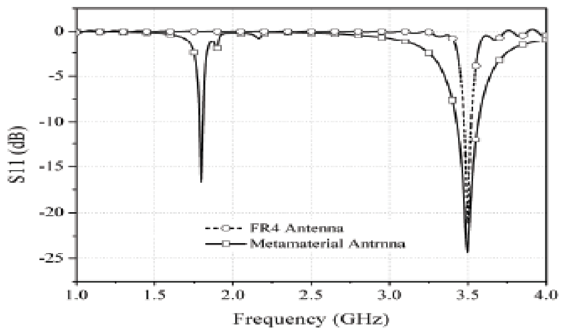


(b) (c)

Fig. 7.A view of the newly designed and developed antenna.

4. SIMULATION AND COMPARISON

Development process, the new antenna was tested in a specific room to evaluate the condition-bound differences and the impact of SAM dimensions on antenna radiation. It should be noted that the absorbents applied for covering SAM curtailed to a large extent the impact of dimensions. Figure (8) shows the return loss in the initial mode, with an antenna on slotted ground structure and electromagnetic supply line. Figure (8.a) Return loss in the initial mode, antenna FR-4 on slotted ground structure and Metamaterial antenna of electromagnetic supply line in 1.6 and 3.1 GHz [13] and (8.b) Return loss in Design process: step one, step two, step three, step four. Figure (9) shows the antenna's radiation pattern on Planes E and H. The antenna's gain falls between 2 and 13 GHz as shown in Figure (10), where circular polarization covers the band range. Table (3) shows comparison of the new method with previous proposed methods.



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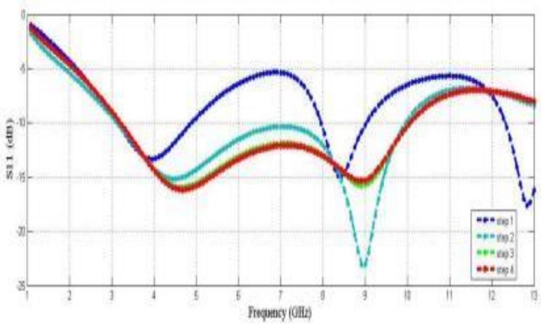

(b)

Fig. 8. (a) Return loss in the initial mode, antenna FR-4 on slotted ground structure and Metamaterial antenna of electromagnetic supply line [13], (b) Return loss in design process: step one, step two, step three, step four.

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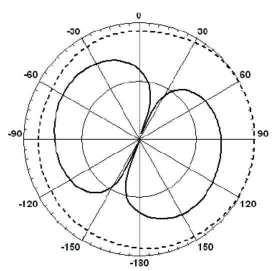

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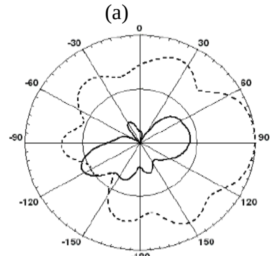

(b)

Fig. 9. Antenna radiation pattern for 5-cell in the pages of E (line) and H in resonance frequency a) fr =5.83, b) fr =7.48.

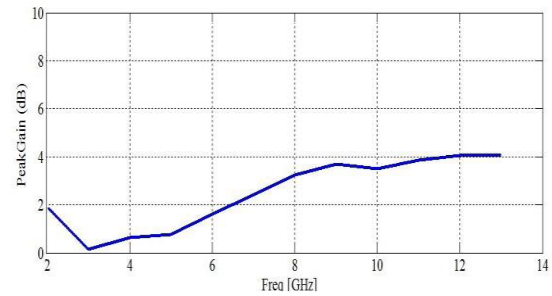

Fig. 10. Antenna's gain within 2-13 GHz.

Table 3. Comparison of the new method with previous proposed methods.

parameter	Prototype model	Ref [22]	Ref [23,26]	Ref [24,25]
Bandwidth	2-13 GHz	3.4-8GHz	1.5-11 GHz	6-15 GHz
Gain(dB)	2-13	6-13	3-12.5	6.5-16
Efficiency	75-95.6%	---------	-----------	94-98%
Size(mm)	18×20×0.5	40×80×1	70×140×3	48×110×0.78

5. CONCLUSION

In this study, an MPA was designed and developed so as to cover several frequency bands. With its smaller dimensions, the newly proposed antenna can enhance gain and radiation pattern. This is facilitated through modifications in the ground plane and supply line.

The major drawback in MPAs is the diminished gain through miniaturization at lower frequencies, which was to a great extent, resolved by the newly proposed antenna. Moreover, the return loss required by UWB systems was designed, implemented and tested through a radiation pattern, VSWR, and desirable gain.

The results showed that the newly proposed antenna was sufficiently compact and provided good bandwidth and impedance matching.

Given the ideal bandwidth delivered to UWB systems through the fractal antenna design, the new model can serve as an efficient platform for designing MPAs through appropriate matching and supply of one or more bands.

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