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Design and Analysis of Microstrip Sierpinski Fractal Antenna for Wireless application

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ABSTRACT- This paper describes a novel design for a microstrip fractal antenna based on the Sierpinski triangle shape. It is built on a FR4 substrate and operates in the 5.5 GHz frequency range. The proposed antenna is designed and validated using ANSYS Electronic Desktop's High Frequency Structure Simulator (HFSS). The simulated results show good performance in terms of radiation pattern, gain and input impedance. This proposed antenna can be widely used in wireless communication equipment that is progressing towards miniaturization and high frequency. The antenna designed gives a return loss of -29 dB at 5.53GHz. It has a gain of 0.85 dB and directivity of 1.8dB.

Keywords: Fractal antenna, Sierpinski triangle, Microstrip patch, Gain, Return Loss.

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1. INTRODUCTION

A fractal is a self-similar object or structure on all length scales. Fractal patterns can be found in nature at all scales, from a single fern leaf that resembles the entire plant to clouds, snowflakes, blood vessels, and cauliflowers. The use of fractals in antenna elements enables the creation of smaller, resonant antennas that are multiband/broadband and can be optimized for gain. They do not require any additional loading components and are simple and inexpensive to manufacture.

A fractal antenna is an antenna that employs a fractal or similar design to maximize the effective length of a patch material having the capability of transmitting and receiving electromagnetic radiation or waves in a very specific total area, or to reinforce its environment. Fractal antennas have better parameters while performing better at different frequencies [9-11]. In today's world, communication plays the major role in the life of an individual. Nowadays wireless modes of communication are preferred by everyone due to the convenience of using it. In order to design a wireless mode, antenna plays a major role [1]. These antennas must be compact and be sufficient to radiate the required power. When it comes to size fractal antennas play a major role as the fractals provide high surface perimeter in a small area. The effective length of the fractal antenna is increased while the area remains constant. Depending on the design, fractals can take any shape.

Fractals have a basic shape which is a polygon [2-4]. This basic shape is repeated in a sequential order to obtain a self-similar design obtaining a pattern which is unique at each iteration. The key is the no of repetitions which scales the sizes at every iteration. Thus, the effective length of the antenna is maximized which means that the perimeter of the structure increases in a given area. Also, the area exposed remains same with increase in the curvature length thus maximizing the transmission or receiving power [5-8].

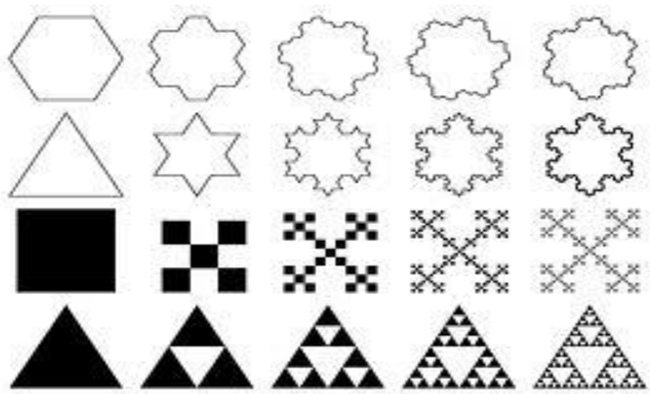

Figure 1. Different types of Fractal structures

Generally, fractal antennas are compact due to their efficiency in area. They could be made multi band making them work at various operating frequencies. This makes a difference with traditional antenna designs as they could give excellent results simultaneously at multiple frequencies. Other antennas are cut to work at particular frequency. Also, the size of the antenna could be decreased without the use of inductors or capacitors. The Sierpinski triangle was proposed by a mathematician named Sierpinski based on his studies in theory of number,

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functions, and topologies. This triangle is also called Sierpiński gasket or Sierpiński sieve. It is an attractive fractal shape with fixed set of equilateral triangles. Initially the self- similar sets start with the curve. The pattern is reproducible by any level of scaling like magnification or reducing the size. When the midpoints of the sides of an equilateral triangle are connected, smaller congruent equilateral triangles form inside the original triangle, forming the Sierpinski Triangle Pattern. This process is repeated indefinitely until the middle triangle is removed. In Earlier Days it was a decorational work but later found its origin in antennas [12-13]. *Figure 1* shows different types of fractal structures.

2. RELATED WORK

Zheng et al proposed a dual band fractal microstrip antenna that operates in both the WLAN and WiMAX bands. The centre frequency ranges between 2.4GHz and 2.7GHz, and the isolation near the centre frequency exceeds 15dB [1]. Jahanvi et al proposed a straightforward method for creating a Sierpinski triangular fractal antenna. These antennas are small and lightweight. This design is suitable for wireless applications and covers the S band [16]. Rizvi et al proposed a fractal geometry-based wideband antenna design for sub-6-GHz applications. Rogers TMM 4 thermoset microwave material was used to create a small antenna with an overall dimension of 30 mm 30 mm 1.524 mm. The radiator of the presented antenna was extracted from a conventional square patch, and then fractals were loaded to increase the antenna's bandwidth. The antenna has a measured wide bandwidth of 2.8 GHz with a frequency range of 2.97 - 5.77 GHz, which corresponds to 64% practical bandwidth covering the entire 5G sub-6-GHz band spectrum allocated globally [2]. Hussain et al. presented a 39 GHz wideband and high gain fractal antenna for 5G communication systems. The antenna is based on a Rogers RT/duroid 5880 and has a small footprint of 15 mm 15 mm 0.79 mm. The proposed antenna's low profile, broad bandwidth, high radiation gain and efficiency, simple design and ease of manufacture and low cost make it a viable candidate for 5G millimeter-wave's applications [3]. Rani et al proposed a modified Koch fractal antenna design and development. The presented antenna has more frequency bands and better impedance matching than traditional Koch curve antennas. Additionally, the bacterial foraging optimization (BFO) approach is used to increase the impedance bandwidth [5].

3. PROPOSED METHODOLOGY

In this paper, a Sierpinski triangular fractal antenna is proposed. The novelty of this proposed antenna lies in the fact that the number of iterations has been increased to 4 so that the better performance is visualized in terms of return loss and gain. Also, the proposed method focuses on improving gain and return loss as compared to previous works. These antennas are small and lightweight. This layout is appropriate for wireless applications. These Sierpinski triangles can be constructed using multiple ways. It can be done by removing or cutting the triangles out of the base triangle, by shrinking or duplication of the base triangle and by using the rule of pascal's triangle. For the sake of easy iteration and designing using basic shapes, the best opted method is the magnification. *Figure 2* shows the general Sierpinski configuration with 3 iterations.

Initial height of the triangle is h1=4.32 mm which is the base height. This triangle is iterated thrice to get the first iteration of height h2=8.65 mm. The result of the first iteration is obtained. Similarly, this is iterated thrice to get second iteration with h3=17.31 mm. For third iteration h4=34.6mm. The final height at iteration 4 is h5=69.28 mm. The scale factors of the proposed Sierpinski triangle are different (Δl =hl /h2, Δ2=h2/h3, and Δ3=h3/h4). As the size is doubled after each iteration, the obtained scale factor is 0.5. Sierpinski configuration is used in the antenna design. The substrate is FR4, with a thickness of 1.6 mm, a relative dielectric constant of 4.4, and a loss tangent of 0.025. The antenna is fed by a 50 Ohm microstrip line, and the entire circuit measures 80 mm x 70 mm. The design is implemented in ANSYS HFSS software version 2021 R1. This software is often utilized in the calculation of antenna parameters like S-parameters, gain, voltage wave ratio, radiation diagram, current and field distributions, antenna efficiency, impedance matching so on. It is user-friendly software. The results are typically viewed as either as tabular or graphical format. *Figure 3* shows the different iterations to create of Patch on Substrate.

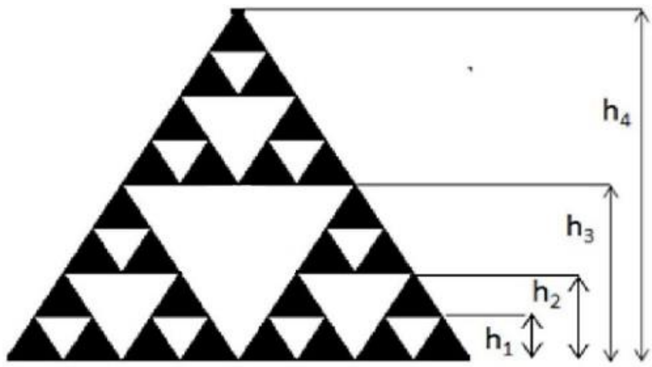

Figure 2. General Sierpinski configuration with 3 iterations

3.1. Design Procedure and Parameters

The proposed antenna is designed using the ANSYS HFSS software. The following is the procedure for designing the antenna:

- Insert a blank HFSS.
- Start with the substrate with the given parameters.
- Below the substrate place a ground plane for the given dimensions.
- Design the patch for the antenna starting with the base triangle and iterate it to get the final patch.
- Provide feed for the patch by creating a port for the given parameters.
- Draw a radiation box around the exiting design.
- Apply radiation box and electric fields to the patch and ground.
- Also apply electric field boundary. Provide electric field excitation.
- Setup the solution for analysis with proper sweep frequency and analyze the setup.

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3.1.1 Feed system
In this proposed work, inset Feed is used.
In order to set the inset feed
- Draw rectangle for Feed Lines with the length = 4.32 mm and width =1.6 mm.
- Assign the lumped port for Excitation.
- Assign Perfect E boundary to the ground plane
- Assign Perfect E boundary to patch.

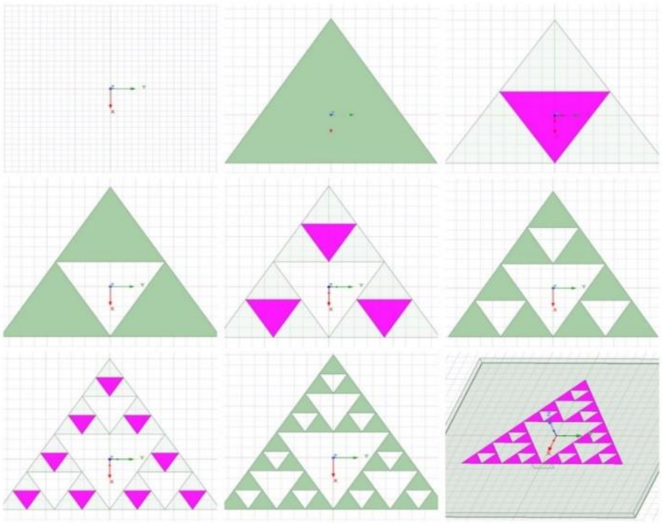

Figure 3. Different iterations to create of Patch on Substrate

Table 1. Design Parameters

Parameters	Values
Substrate	
Length	80 mm
Width	70 mm
Thickness	1.6 mm
Material	FR4 EPROXY
Ground	
Length	80 mm
Width	70 mm
Material	Regular

Parameters	Values
Patch	
Length of base triangle	69.28 mm
Length Of Each Triangle	4.32 mm
No of triangles cut from the base triangle	40
No of triangles in the patch	81
Distance from centroid to vertex	20 mm
No of iterations	4
Material of the patch	Regular

4. RESULTS AND DISCUSSIONS
Figure 5 shows the return loss of proposed antenna. The simulated results of rectangular patch antenna show that it resonates at 5.53GHz. It is clearly seen that there is a linear dip at the frequency of 5.53GHz in accordance with the designed frequency. The fractal shape of the antenna enables it to achieve a wide bandwidth, which is essential for accommodating the frequency range required for wireless communication at 5.5 GHz. The antenna designed gives a return loss of -29 dB at 5.53 FHz. Figure 6 shows the gain plot of proposed antenna. From the results it is observed that the designed antenna lies in the affordable range of return loss. The antenna exhibits good performances at, 5.53GHz. The antenna is inexpensive, compact, and has a moderate gain and stable radiation pattern, making it ideal for wireless applications. The fractal design helps in improving the radiation pattern of the antenna, ensuring that it radiates efficiently in the desired direction, thus enhancing its overall performance. The fractal geometry of the Sierpinski triangle allows for a highly compact antenna design. This compact size is crucial for applications requiring miniaturization, such as in small wireless devices. The entire area of this antenna is 70 x 80 mm^2 and has been validated in simulation using Ansys Electronic Desktop. It has a gain of 0.85 dB and directivity of 1.8dB. *Figure 7* shows the directivity of proposed antenna.

Figure 5. Return Loss of Sierpinski Fractal antenna

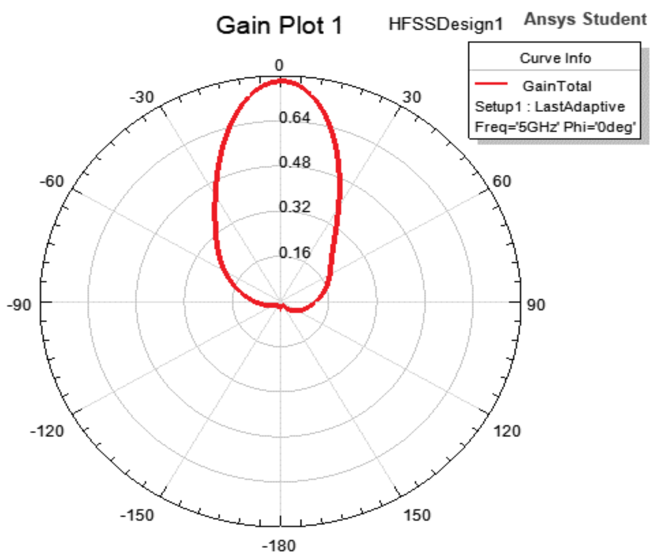

Figure 6. Gain plot of Sierpinski Fractal antenna

The Voltage Standing Wave Ratio measures feeder loss due to mismatch. It normally ranges from 0 to infinity. When the value is less than 2, the antenna is said to be matched. At 5.53GHz, the proposed antenna has a VSWR of about 1. *Figure 8* depicts the VSWR of the proposed antenna.

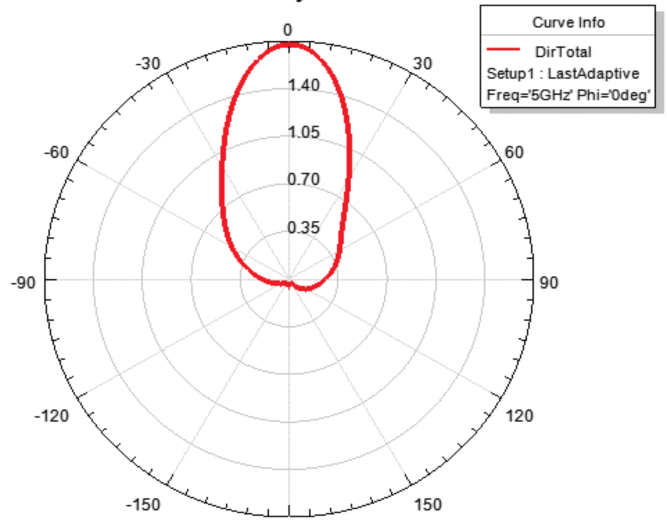

Figure 7. Directivity of proposed antenna

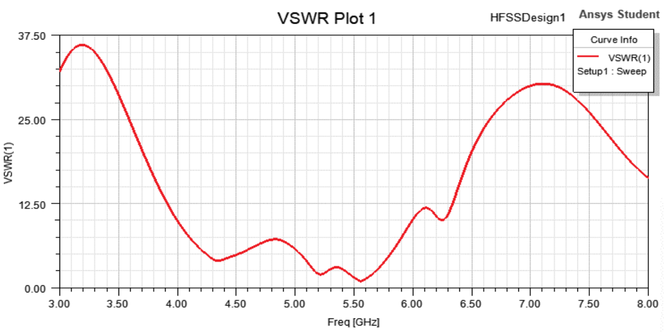

Figure 8. VSWR of proposed antenna

The scientific reasoning behind using a Sierpinski fractal for a 5.5 GHz application lies in the fractal's ability to create multiple resonant paths within a compact structure. At 5.5 GHz, the wavelength is relatively small, making it challenging to design an antenna with the desired performance characteristics. By using a Sierpinski fractal, which is a self-similar structure, the antenna is able to create multiple resonances at different scales, allowing it to efficiently radiate at the desired frequency. Additionally, the fractal geometry helps in reducing the overall size of the antenna, making it suitable for compact and portable applications. *Table 2* shows the analysis of Sierpinski fractal antenna for different iterations. From the table, it can be inferred that as the number of iteration increases, there is improvement in gain, return loss, VSWR, Directivity and operating bandwidth. This would enable the designed antenna suitable for wireless application. *Table 3* represents the analysis of proposed antenna by varying the sides of triangle. From the analysis, it can be inferred that the maximum return loss achieved at 5.53 GHz with side of triangle as 35 mm. In this way, the gain and return loss values are optimized to achieve better performance.

Table 2. Analysis of Sierpinski fractal antenna for different iterations

Iteration	Return Loss (dB)	Gain (dBi)	Directivity (dBi)	VSWR	Operating Bandwidth (GHz)	Input Impedance (Ohms)
1	-15	-2.5	1	<1.5	0.1	50
2	-19	-1.5	1.3	<1.3	0.1	50
3	-25	-0.52	1.4	<1.2	0.15	50
4	-29	0.85	1.8	<1.1	0.25	50

Table 3. Dimensionality Analysis

Side of the Triangle (mm)	Return Loss (dB)	Resonating Frequency (GHz)
25	-23	6.9250
31	-24	6.2875
35	-29	5.5375
38	-21	4.9500
42	-19	4.6000

5. CONCLUSION

The proposed microstrip fractal antenna based on the Sierpinski triangle shape demonstrates excellent performance in the 5.5 GHz frequency range, offering a return loss of -29 dB, gain of 0.85 dB, and directivity of 1.8 dB. These results indicate its suitability for wireless communication equipment requiring miniaturization and high frequency operation. To enhance its performance further, future iterations could focus on increasing the number of iterations to improve power radiation and potentially increase the number of sides of the base shape for more efficient fractal design utilization. As the antenna is compact and fits well into electronic devices, it holds promise for future antenna designs in various applications.

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