Performance Evaluation of Pasapalli and Modified Sierpinski Square Fractal Antennas in X-Band Spectrum

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Abstract. This paper presents the design and performance of two novel dual-band fractal antennas with wide bandwidths and good gain for various wireless applications. The first antenna operates in two frequency bands: 4.9 to 5.4 GHz and 7.5 to 10.3 GHz, while the second antenna operates in two frequency bands: 3.2 to 3.7 GHz and 4.2 to 5.7 GHz. Both antennas have a compact size of 40 mm x 45 mm and exhibit good gain across their respective frequency bands . . .

Keywords: Fractal,Pasapalli fractal,Modified Sierpinski Square Fractal,Bandwidth, Gain,Radiation patter,Rogers RO3010

1 Introduction

Fractal antennas, a concept introduced by Benoit Mandelbrot in 1983[1], revolutionized antenna design by leveraging the principles of fractal geometry[2]. Unlike traditional antennas, fractal antennas exhibit non-integer dimensions and possess unique properties that allow them to have an infinite length while fitting into a finite volume. This distinctive feature is harnessed to enhance the electrical length of antennas without increasing their physical size[3].

The key advantage of fractal antennas lies in their ability to achieve multiple resonant bands and increase bandwidth. Various designs, such as the Koch dipole[4], Koch monopole, Koch loop, Minkowski[5], Sierpinski[6], Cantor slot patch,star-shaped fractal[7] and fractal tree dipole, exemplify the versatility of fractal geometry in antenna engineering. Fractal antennas can either reduce the antenna size or broaden the bandwidth of each individual band, making them highly adaptable for different applications.

A notable example is the Von Koch fractal antenna, which involves iteratively replacing each line segment with four smaller segments, creating a self-replicating structure. This process continues indefinitely, resulting in a geometrically intricate antenna design. The fractal dimension of these antennas encapsulates information about their self-similarity and space-filling properties, highlighting their unique characteristics in the realm of electromagnetic radiators. The application of fractal geometry in antenna design opens up a rich spectrum of possibilities for achieving compact size, multiple resonant bands, and increased bandwidth, making fractal antennas a significant innovation in modern antenna technology.

Within antenna components, power dividers are pivotal for signal distribution. A numerical analysis on a Slinky 3 dB Power Divider[8] sheds light on its role in High-Speed RF Sensor Systems, offering valuable insights that complement the focus on fractal antennas and enhance understanding in advanced RF systems.

Fractal antennas[9], with inherent self-similarity, offer size reduction crucial for space-constrained applications like portable devices. Their multiband capabilities suit diverse communication needs, from wireless technologies to medical imaging, where compact size enhances innovation in wireless capsule endoscopy. Additionally, in radar systems and radio astronomy, fractal antennas excel in achieving precise beamforming and capturing celestial signals. Their adaptability, compact design, and versatile performance position fractal antennas as pivotal elements in advancing communication systems, wireless devices, and sensing applications.

2 Literature Review

The proposed Minkowski fractal antenna[11] with a square patch element on FR-4 substrate (dielectric constant 4.4, thickness 1.6mm) demonstrates multiband resonance in X-band and Ku-band frequencies (8-18 GHz). Utilizing CST MWS simulation, the study explores its resonant frequencies at 8.8 GHz, 10.8 GHz, 13.02 GHz, and 15.23 GHz, showcasing its suitability for Radio Location and Wireless Personal Area Network (WPAN) applications in the X-band, validated by analysis in Section III.

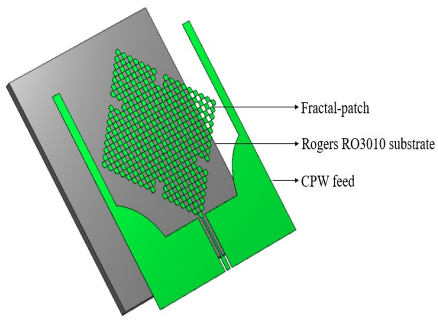
The study introduces a Modified Sierpinski Carpet Fractal Antenna[12] resonating across six frequencies (4.825-9.145 GHz) for C and X-band applications. Utilizing FR4 substrate and ANSYS/ANSOFT HFSS V13 simulation, it assesses radiation patterns, gain, VSWR, and return losses, validated through experimental testing. The antenna's simplicity, cost-effectiveness, and adaptability signify potential in telecommunications, satellite communication, radar, and space applications, aligning well with simulations.

The study investigates the efficiency of fractal antennas[13] compared to Euclidean-shaped counterparts, highlighting the enhanced space-filling capacity of fractals. It emphasizes how fractal structures nearing theoretical limits benefit applications, notably in mobile terminals, by enabling efficient performance within reduced volumes. The research explores the behavior of the Koch monopole, revealing that increasing iterations approach the theoretical limit for small antennas, addressing the challenge of maximizing antenna efficiency within limited space.

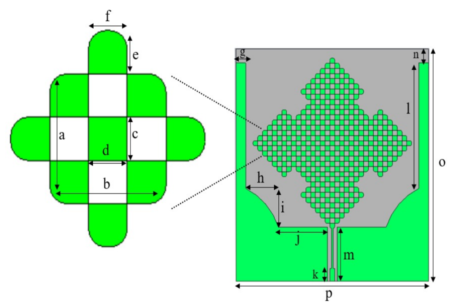
The research presents a modified bow-tie slot antenna[14] fed by asymmetric coplanar waveguides, achieving a 6.0 dBi flat gain between 12.6-13 GHz for X-band and C-band applications. Through HFSS software analysis, the antenna demonstrates efficient dual-band operation at 3GHz, 5.2GHz, 7.6GHz, 9.2GHz, 11GHz, and 12.8GHz, offering gains of 4.48 dBi and 6.04 dBi at 12.6 GHz and 12.8 GHz, suitable for military, radar, and satellite systems.

3 Antenna design

3.1 Pasapalli Fractal



(a)



(b)

Fig. 1: This is the caption of the figure displaying a white eagle and a white horse on a snow field

Our research introduces a novel fractal antenna design, drawing inspiration from the intricate Pasapalli pattern. Leveraging the inherent self-similar and space-filling properties of the Pasapalli motif, a single unit cell of this pattern is meticulously replicated across multiple iterations to formulate our antenna structure. Crucially, Rogers RO3010 substrate, known for its exceptional dielectric properties and stability, serves as the foundational material with a thickness of 1.28mm. The choice of Rogers RO3010 substrate is pivotal in achieving the desired performance metrics due to its low loss tangent and consistent dielectric constant, which contribute significantly to enhanced signal propagation and antenna efficiency.

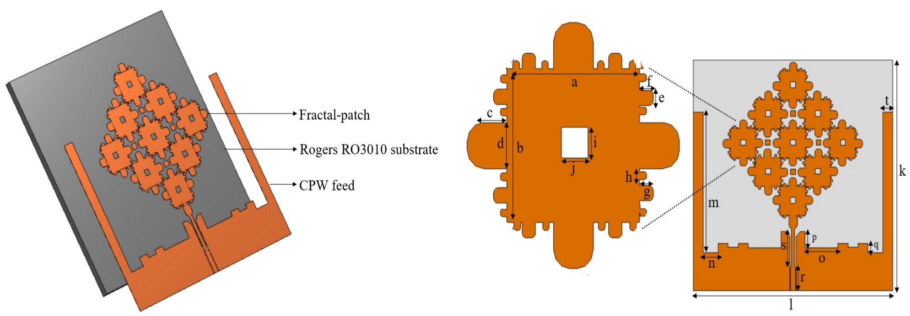
Table 1: This is the example table taken out of *The TEXbook,* p. 246

Parameter(mm)	a	b	c=d=e=f	g	h	i	j	k	l	m	n	o	p
Value(mm)	5	5	1.67	2	8	8.5	10.2	2.5	24.3	2.5	2.7	45	40

3.2 Modified Sierpinski Square Fractal

diving into the world of antennas with a fascinating exploration of a Modified Sierpinski Square design. Imagine adding smaller squares within the antenna structure to see how it affects its performance! using Rogers RO3010 as substrate—it's known for keeping our signals strong and steady.setting up the antenna with a Coplanar Waveguide (CPW) feed, which helps match everything up smoothly.

The objective of this design is to meticulously examine the influence of these alterations – specifically, the introduction of smaller squares – on significant antenna characteristics. We're talking about things like how it tunes in to frequencies,Bandwidth and the strength of the signal it can produce. By really digging into these details, we're aiming to uncover some really helpful insights. Ultimately, this research could give us a better handle on designing antennas for the future of communication systems!



(a) (b)

Fig. 2: (a)stack view of modified Sierpinski Square Fractal(b)Dimenisions

Table 2: This is the example table taken out of *The TEXbook,* p. 246

Parameter(mm)	a=b	c=d	e=f	g=h	i=j	k=l	m	n	o	p	q	r	s	t	u
Value(mm)	5	1.5	0.5	0.25	1	40	24.4	3.05	6.6	2.85	1.6	4.1	6.7	2	9

4 Results

4.1 Results of Pasapalli Fractal

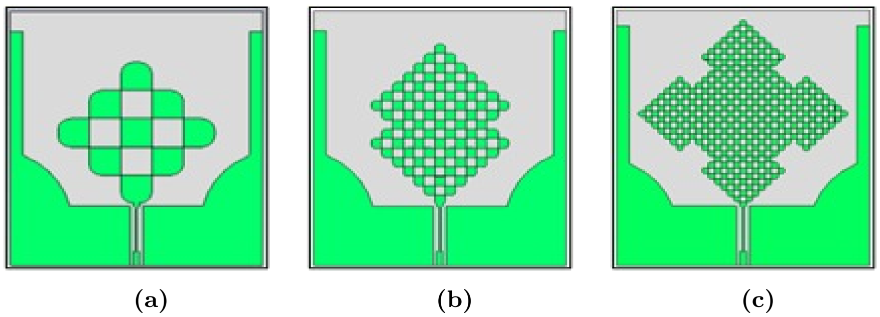


Fig. 3: Iterations within the Pasapalli fractal(a)Iteration 1(b)Iteration 2(c)Iteration 3

In its initial iteration, the Pasapalli fractal exhibits three distinct resonating bands. At 5.681, an S-parameter of -37.513 accompanies a bandwidth spanning 230 MHz. Another resonance at 6.914 showcases an S-parameter of -21.460, featuring a bandwidth of 132 MHz. Additionally, at 10.712, the fractal resonates with an S-parameter of -21.997, encompassing a bandwidth of 122 MHz. The

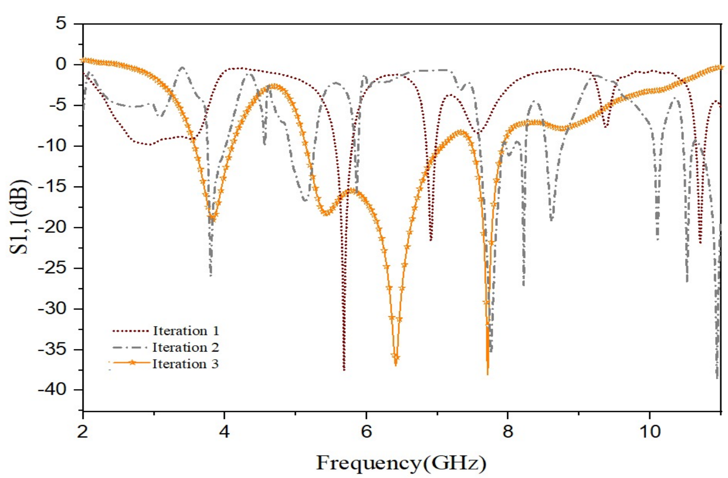


Fig. 4: S-parameter analysis across various iterations of the Pasapalli fractal.

Pasapalli fractal exhibits resonance at seven distinct frequencies during the second iteration. These frequencies are 3.8GHz, 5.132GHz, 7.76GHz, 8.219GHz, 8.624GHz, 10.109GHz, and 10.523GHz. The corresponding S-parameter values at these frequencies are -25.97dB, -16.65dB, -35.51dB, -27.06dB, -18.94dB, -21.41dB, and -26.64dB, respectively. These findings demonstrate the Pasapalli fractal's multifrequency resonance characteristics in its evolved state.

As observed from the previous iterations, the Pasapalli fractal has demonstrated a multiband nature, yet it presented limitations in terms of narrow bandwidth. In response to this characteristic, an additional iteration has been conducted to address and enhance the fractal's bandwidth performance.

In the third iteration, significant improvements were achieved in the bandwidth of the Pasapalli fractal. It now displays three distinct resonating bands at frequencies of 5.421GHz, 7.43GHz, and 8.438GHz.

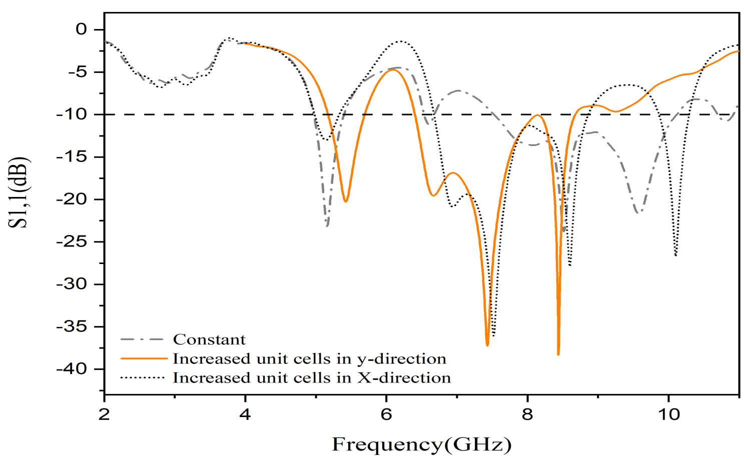
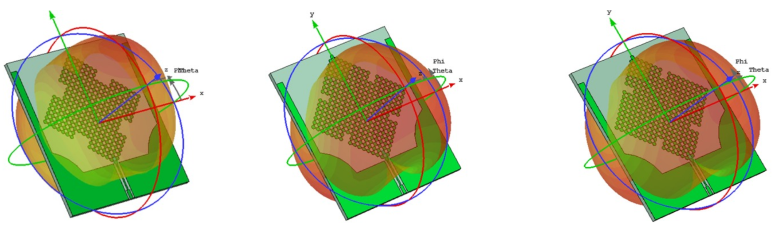


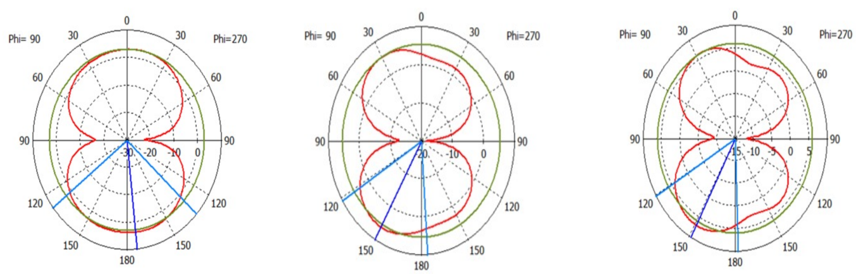
Fig. 5: Analyzing S-parameter changes during the increment of unit cells

4.2 Radiation pattern



(a) (b) (c)

Fig. 6: Radiation pattern in 3D according to the increment of cells(a)Constant(b)increment in X-direction(c)increment in Y-direction



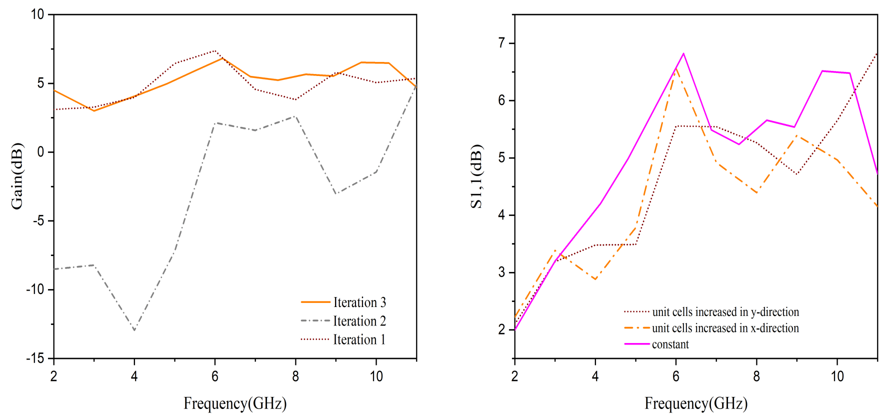
(a) (b) (c)

Fig. 7: Radiation pattern in 2D according to the increment of cells(a)Constant(b)increment in X-direction(c)increment in Y-direction

The figures presented depict the radiation pattern, both in 2D and 3D, of the Pasapalli fractal as the number of unit cells increases along the x-direction, y-direction, and when kept constant. These visual representations offer a comprehensive understanding of how the radiation pattern evolves concerning variations in the number of unit cells in different directions. Analyzing these patterns aids in grasping the antenna's behavior as it scales in different dimensions.

4.3 Gain

The presented figures illustrate the gain behavior of the Pasapalli fractal under two distinct analyses. One analysis focuses on uniformly increasing the number of unit cells in all directions to enhance both bandwidth and gain.



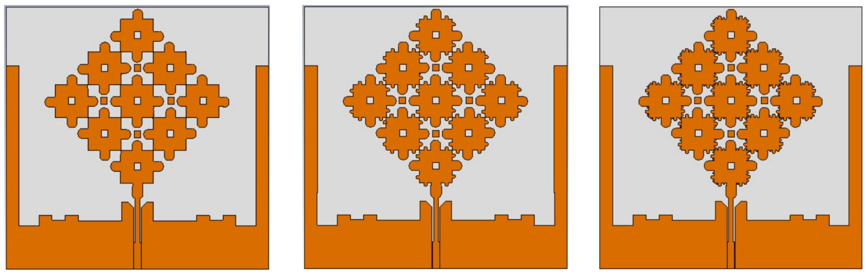
(a) **(b)**

Fig. 8: (a)Graph illustrating the comparison between iterations of the Pasapalli fractal (b)Graph depicting the contrast observed while incrementing unit cells within the Pasapalli fractal.

The second analysis involves augmenting cells specifically in chosen directions to investigate potential alterations in frequency shift, multiband behavior, and bandwidth. These comparative analyses provide valuable insights into the fractal's performance characteristics, delineating the impact of uniform versus directional adjustments in unit cells on the antenna's gain, bandwidth, and multiband capabilities.

5 Results of Modified Sierpinski Square Fractal

5.1 s-parameters



(a) **(b)** **(c)**

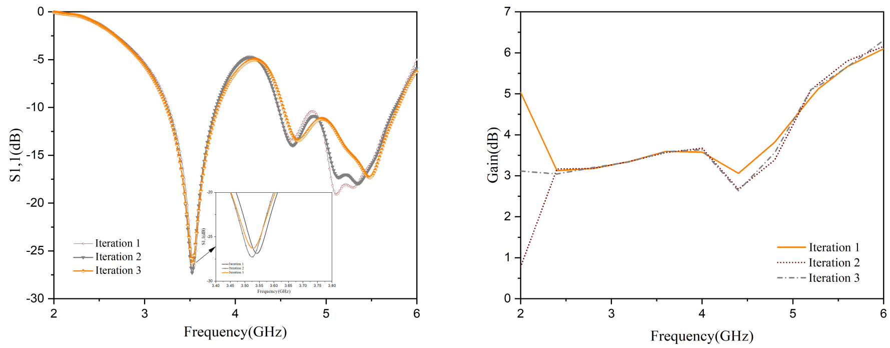
Fig. 9: Iterations of Modified Sierpinski Square Fractal(a)Iteration 1 (b)Iteration 2 (b)Iteration 3

Thia design analysis is to explore the effect of incorporating smaller squares within iterations of the Modified Sierpinski Square fractal, aiming to understand their influence on S-parameters and bandwidth.

Across the three iterations of the Modified Sierpinski Square fractal, the introduction of smaller squares in each iteration, progressively diminishing in size compared to the preceding ones, yielded minimal observable changes in both the S-parameters and the overall bandwidth. Despite the incorporation of these intricately smaller repetitive structures, the anticipated alterations in the fractal's performance metrics, particularly the S-parameters and bandwidth, were not significantly pronounced. This observation suggests that the introduction of these diminutive repetitive elements did not yield substantial variations in the specified parameters, indicating a consistent behavior or limited influence on the fractal's characteristics throughout its iterations.

5.2 Gain

The gain graph of the Modified Sierpinski Square Fractal, as depicted in the provided figure, notably demonstrates consistent behavior despite the insertion of smaller squares within its structure. Remarkably, the inclusion of these smaller elements within the fractal's design did not significantly affect the gain output. The graph illustrates a remarkable stability in gain, suggesting that the introduction of these intricate smaller squares did not induce substantial deviations or enhancements in the fractal's gain characteristics.



(a) **(b)**

Fig. 10: (a)S-parameter of Modified Sierpinski Square fractal (b)Gain at different Iterations

6 Conclusion

The Pasapalli fractal demonstrated promising improvements in gain, S-parameters, and bandwidth as the number of iterations increased, showcasing its potential for enhanced performance. In contrast, the Modified Sierpinski Square Fractal showed intriguing stability, as even with the insertion of smaller squares, the system's S-parameters, gain, and bandwidth exhibited minimal alteration. These observations underscore the adaptability of Pasapalli iterations in optimizing antenna characteristics, while the consistent behavior of the Modified Sierpinski Square fractal highlights its resilience to structural modifications. Together, these findings provide valuable insights into the distinct behaviors and potential applications of iterative fractal antenna designs in communication systems.

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