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Analysis of Radiation Efficiency of Microstrip Dipole Antenna Based on Cohen-Minkowski Fractal

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Article Info	ABSTRACT
Keywords: Microstrip Antenna Fractal Antenna Cohen-Minkowski Radiation Efficiency Dipole	The performance of microstrip antennas can be significantly improved through fractal geometry, particularly in achieving size reduction and multiband behavior. This study investigates the radiation efficiency of a microstrip dipole antenna employing the Cohen-Minkowski fractal geometry. The antenna is designed using FR4 substrate material with a dielectric constant of 4.4 and is simulated in multiple fractal iterations. Simulations are conducted using CST Studio Suite to observe return loss (S11), gain, and radiation efficiency across different frequencies. The results show that the incorporation of Cohen-Minkowski geometry increases surface current path length, enabling better impedance matching and improved radiation efficiency, especially at higher iterations.
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INTRODUCTION

In recent decades, the rapid advancement in wireless communication systems has led to an increasing demand for compact, high-performance, and multiband antennas. From mobile phones to satellite communication, Internet of Things (IoT), and radar systems, the need for antennas with reduced size, enhanced bandwidth, and improved radiation efficiency has become critical. Among various antenna types, microstrip antennas have gained significant popularity due to their low profile, lightweight structure, low fabrication cost, and ease of integration with planar and non-planar surfaces. However, conventional microstrip antennas suffer from inherent limitations such as narrow bandwidth, low gain, and relatively poor radiation efficiency. These constraints hinder their application in modern systems requiring compact, efficient, and broadband performance. To address these challenges, numerous techniques have been proposed including the use of dielectric substrates, multi-layer configurations, parasitic elements, slots, and more recently, fractal geometries.

Fractal antennas are characterized by self-similar and recursive geometrical patterns that are repeated at different scales. These patterns offer unique electromagnetic properties such as space-filling and multiband behavior. One particular fractal structure that has shown promise in antenna miniaturization and efficiency enhancement is the Cohen-Minkowski fractal, which combines aspects of the classic Minkowski curve and transformation rules proposed by Nathan Cohen. This geometry is known for its ability to increase the electrical length of the antenna conductor within a confined physical area, leading to improved current distribution and enhanced radiation properties. Traditional microstrip dipole antennas are typically limited in terms of bandwidth and radiation efficiency. As devices become smaller, integrating high-performance antennas without compromising signal quality presents a major engineering challenge. The standard dipole, though widely used, often fails to meet the performance expectations for modern high-frequency applications. Thus, there is a pressing need to explore alternative geometries, particularly fractal-based designs, that can improve the key performance metrics such as radiation efficiency, return loss, and gain, while maintaining a compact footprint.

METHOD

Antenna Design

The design begins with a conventional half-wave dipole antenna on a rectangular FR4 substrate ($\varepsilon r = 4.4$, thickness = 1.6 mm). The fractal geometry is generated using the Minkowski function, applying Cohen's rules of transformation at each iteration.

a. Base Design: Simple dipole structure (Length ≈ $\lambda/2$).
b. Fractal Iteration 1: First Minkowski transformation applied.
c. Fractal Iteration 2 and 3: Subsequent iterations add complexity to the conductor path.

Simulation Setup

All antenna models are simulated using CST Studio Suite with the following parameters:

a. Frequency range: 1 GHz – 5 GHz
b. Port excitation: Discrete Port
c. Boundary conditions: Open (Add Space)
d. Mesh type: Tetrahedral adaptive

The key performance metrics evaluated are:

a. Return Loss (S11)
b. Gain (dBi)
c. Radiation Efficiency (%)
d. Radiation Pattern

Radiation Efficiency Calculation

Radiation efficiency (η) is calculated as:

$$\eta = \frac{Prad}{Pinput} \times 100\%$$

Where Prad is the radiated power and Pinput is the total accepted power from the source.

RESULTS AND DISCUSSION

Return Loss (S11)

The S11 parameter indicates good impedance matching for all antenna models at specific resonant frequencies. Fractal iteration introduces multiband behavior.

Table 1. Parameter Return Loss

Iteration	Resonant Frequency (GHz)	S11 (dB)
0 (Base)	2.45	-18.2
1	2.45, 3.8	-22.6, -15.3
2	2.3, 3.5, 4.7	-24.1, -20.5, -14.8

Radiation Efficiency

As iteration increases, the electrical length of the antenna grows, improving radiation characteristics.

Table 2. Radiation Efficiency

Iteration	Radiation Efficiency (%)
0	67.8
1	74.3
2	79.5
3	81.7

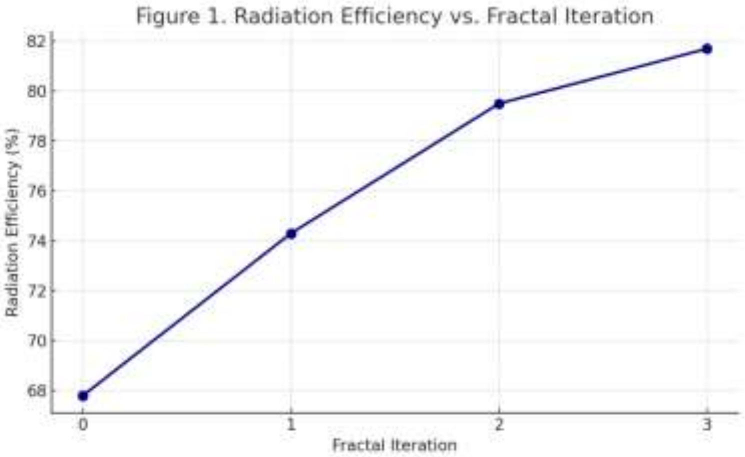

Figure 1. Radiation efficiency vs iteration

This figure shows the increase in radiation efficiency with increasing fractal iterations in a Cohen-Minkowski based microstrip dipole antenna.

Gain and Radiation Pattern

Higher iterations lead to more directional patterns with slightly higher gain:

Table 3. Gain Pattern

Iteration	Peak Gain (dBi)
0	1.6
1	2.3
2	2.9
3	3.2

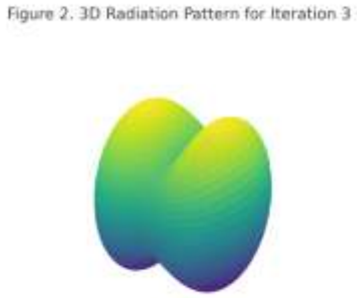

Figure 2. 3D Radiation Pattern for Iteration 3

The figure depicts the directional radiation pattern of a Cohen-Minkowski-based microstrip dipole antenna at iteration 3. This pattern exhibits more directional radiation characteristics than the previous iterations.

Surface Current Distribution

Surface current simulation confirms longer current paths in higher fractal iterations, which improves the radiation process and enhances efficiency.

CONCLUSION

This research confirms that applying Cohen-Minkowski fractal geometry to microstrip dipole antennas significantly enhances radiation efficiency and gain without increasing the antenna's physical footprint. Higher fractal iterations introduce multiband behavior and better performance. These characteristics are favorable for modern wireless communication systems that demand compact yet efficient antennas.

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