Design of a Dual Band Antenna for Wireless Communications Utilizing the Sierpinski Carpet Fractal

Sanae Attioui[1,⋆], *Asma* Khabba[1], *Saida* Ibnyaich[1], and *Abdelouhab* Zeroual[1]

[1] *I2SP Research Team, Department of physics, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakech, Morocco*

Abstract. This study is focused on the design and presentation of a unique dual band fractal antenna that incorporates the Sierpinski carpet onto the fundamental rectangular patch antenna. The versatility of this fractal antenna lies in its innovative design, which makes it suitable for the applications that operate in the C-band and X-band. The process of producing the Sierpinski carpet involves cutting three squares of different sizes within the given patch area. The fractal antenna that is suggested is placed on a substrate composed of FR-4 material, which possesses a dielectric constant of 4.4. Additionally, the antenna has dimensions $35 \times 30 \times 1.6\ mm^3$. The antenna that is being proposed for use has been designed and developed through the utilization of the High-Frequency Structure Simulator (HFSS). According to the simulation results, it can be observed that the fractal antenna demonstrates the capability of resonating at three distinct frequencies. The frequencies of 4.88 GHz (-19.88 dB), 9.62 GHz (-15.07 dB), and 10.03 GHz (-26.65 dB) are all characterized by a radiation behavior that is considered appropriate for the intended application.
Keywords : Fractal antenna, Dual band, Sierpinski Carpet, Wireless communication.

1 Introduction

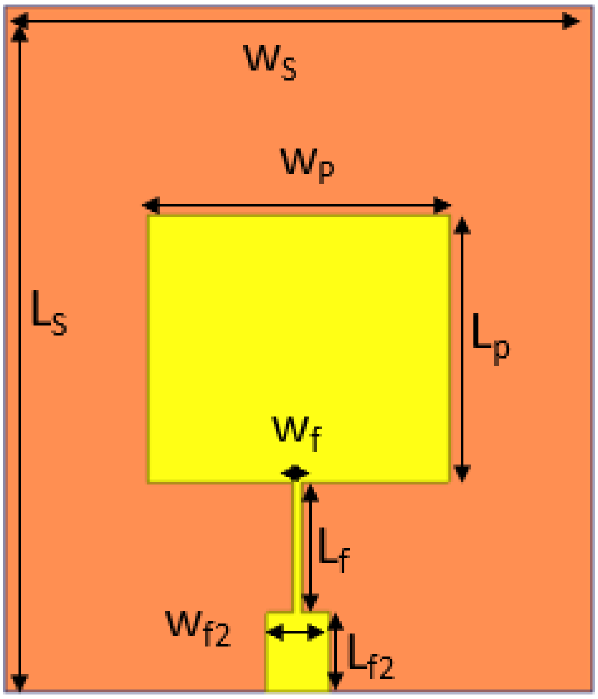
The progress achieved in wireless communication and antenna technology has led to the emergence of fractal antennas as an effective solution to meet the demand for antenna structures that are compact, efficient, and flexible[1, 2]. The innovative antennas present a pioneering methodology to address the difficulties presented by the progressively growing need for high-speed data transmission[3], smooth connectivity, and the abundance of wireless devices[4].
Due to their limited adaptability to emerging communication standards, traditional antennas, which are usually designed for specific frequency bands, often face challenges in meeting the requirements of modern wireless systems[5]. However, fractal antennas provide a remarkable solution through the utilization of the inherent self-similarity and intricate geometrical patterns found in fractals[6].
Fractal antennas are the ideal solution for space-limited applications because their self-similar structures allow them to be scaled down to miniature sizes without any loss of performance[7, 8]. Additionally, they present decreased electromagnetic interference and heightened signal reception, elevating the overall quality of wireless communication[9]. Fundamentally, fractal antennas represent an innovation in antenna technology[10], expertly addressing the multifaceted challenges of modern wireless communication with elegance and efficiency[11–13].
The paper presents a new miniature dual band fractal antenna that features a Sierpinski Carpet design. An FR-4 substrate with dimensions of $35 \times 30 \times 1.6\ mm_3$ is used for printing the design. The suggested fractal antenna demonstrates resonance at three distinct frequencies, namely 4.88 GHz, 9.62 GHz, and 10.03 GHz. The proposed antenna is discussed in detail in the following sections, with the first section focusing on its geometry. Continuing with the discussion, the following section examines the findings pertaining to the reflection coefficient, input impedance, surface current distribution, gain, and other crucial metrics. In the last section, the study reaches its conclusion.

2 Antenna design procedure

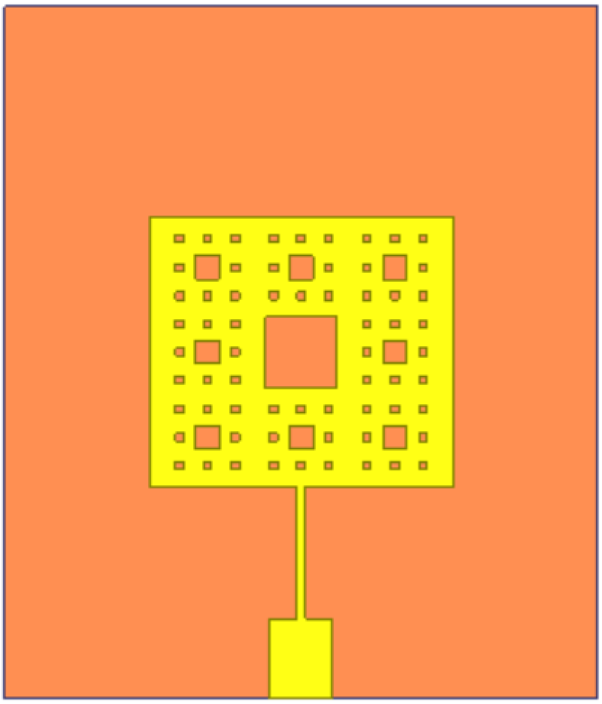
The suggested antenna design is simulated utilizing the High Frequency Simulator Structure (HFSS) on a cost-effective FR-4 substrate material ($\epsilon_r = 4.4$), with dimensions of $35 \times 30 \times 1.6 mm^3$. The structure is backed by a full ground plane. The design initially uses a conventional patch antenna that comes with a quarter wave transformer feed line fed through 50Ω. In order to minimize the size of the conventional antenna, the proposed design employs the Sierpinski square carpet fractal and involves the cutting of three rectangular forms. The Sierpinski carpet design process commences with the removal of a square, with an edge dimension of 3.6 mm, from the radiating patch center. The next procedure is to cut eight squares with an edge dimension of 1.2 mm around the primary square that was cut. To create the Sierpinski Carpet, the process requires the cutting of eight additional squares with an edge dimension of 0.4 mm around the squares from the previous step.

⋆e-mail: sanae.attioui@ced.uca..ma

The initial design is depicted in Fig. 1a, whereas the design of the suggested antenna incorporating the Sierpinski carpet is showcased in Fig. 1b, with the corresponding dimensions provided in Table 1.



(a)



(b)

Figure 1: Geometric structure of the proffered fractal antenna (a) Conventional antenna (b) Proposed antenna.

Table 1: Suggested fractal antenna parameters

Dimension	Value (mm)
W_S	30
L_S	35
W_g	30
L_g	35
W_p	15.4
L_p	13.6
W_f	0.5
L_f	6.7
W_{f2}	3.24
L_{f2}	4

3 Results and discussions

The simulation conducted on the designed antenna has yielded significant findings, which are presented in detail in this paper. The analysis encompasses important aspects like the reflection coefficient, surface current distribution, input impedance, and gain.

3.1 Reflection coefficient

The recommended fractal antenna is created by first designing a basic rectangular patch antenna, which is then modified through the use of the Sierpinski Carpet to minimize its size. Fig. 2 provides an illustration of the reflection coefficient of the fractal antenna proposed. Based on the analysis, the dual band antenna resonates at three separate frequencies. These frequencies are 4.88 GHz (-19.88 dB), 9.62 GHz (-15.07 dB), and 10.03 GHz (-26.65 dB). The fractal antenna that has been proposed showcases an impressive capability of consistently maintaining a reflection coefficient value below -10 dB across all resonance frequencies. This undeniably showcases its remarkable suitability for various applications.

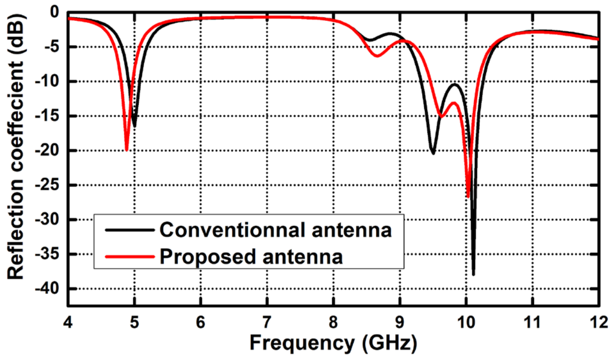


Figure 2: Simulated reflection coefficient of the proffered fractal antenna

3.2 Input impedance

Fig. 3) illustrates the input impedance of the dual band antenna, showcasing both the real and imaginary components. The close proximity of the imaginary part to 50 Ω and the near-zero value of the real part indicate a favorable behavior in the input impedance.

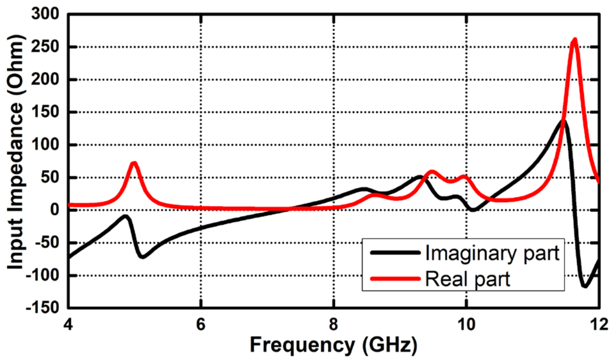
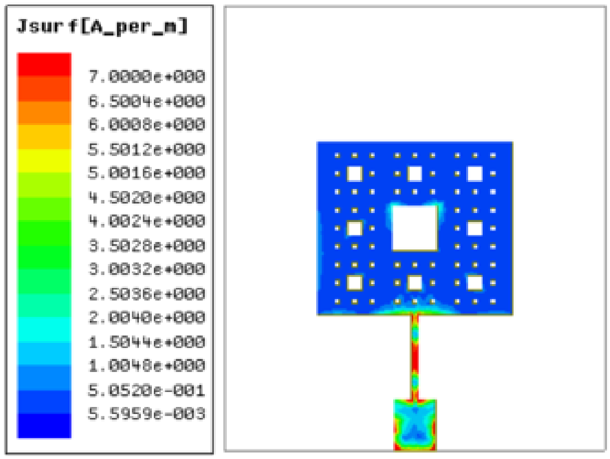


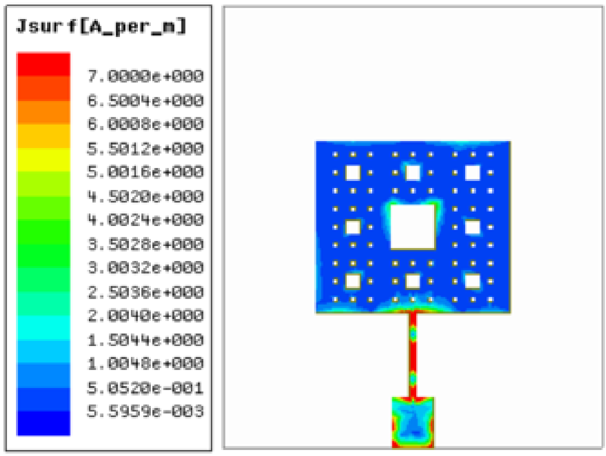
Figure 3: Simulated input impedance of the prposed fractal antenna

3.3 Surface current distribution

The illustration provided in Fig. 4 showcases the distribution of surface current at two separate frequencies, specifically 4.88 GHz and 10.03 GHz. The analysis of the figure indicates that there is a concentration of current at the feed line, and this concentration plays a crucial role in achieving a dual band.



(a)



(b)

Figure 4: Simulated surface current distribution of the proposed fractal antenna at (a) 4.88 GHz (b) 10.03 GHz.

3.4 Gain

The antenna gain plays a crucial role in both its coverage area and directional characteristics. The radiation patterns of the recommended antenna at a frequency of 4.5 GHz are depicted in polar plot format in Fig. 5. The patterns are shown separately in the E-plane ($\phi = 0deg$) and the H-plane ($\phi = 90deg$), which is identified as a directional plane.
Although the fractal antenna size is reduced by the Sierpinski carpet's many slots, this has the undesirable consequence of degrading the antenna's performance. However, the analysis of the proposed antenna indicates that it has a significant gain of 3.27 dB at 4.5 GHz.

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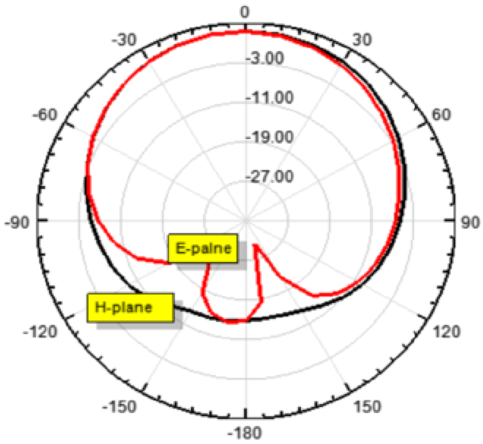
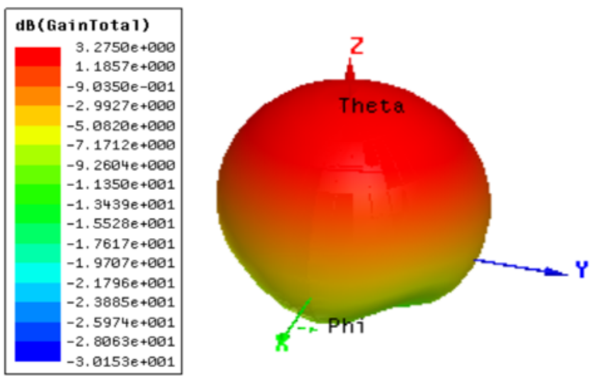


(a)



(b)

Figure 5: Simulated gain at 4.5GHz (a) Radiation patterns (b) 3D gain.

4 Conclusion

This study focused on investigating A dual band antenna design based on fractal geometry. The antenna was based on the Sierpinski carpet fractal and was intended for use in wireless applications. Specifically, it was designed for use in both C-band and X-band applications. The simulation of the proposed antenna is carried out using the High-Frequency Structure Simulator (HFSS). In light of the simulation outcomes, it has been demonstrated that the fractal antenna has the capability to resonate at three distinct frequencies specifically, 4.88 GHz at -19.88 dB, 9.62 GHz at -15.07 dB, and 10.03 GHz at -26.65 dB, all of which display a radiation behavior that is appropriate for the intended application.

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