# A New Design of Dual Band Fractal Antenna for LEO Applications

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***Abstract*—In this paper, a new design of dual band printed antenna based on Minkowski fractal geometry has been presented. The antenna offers a very light weight, low profile, and very low coast, which satisfy the requirement of Low Earth Orbit (LEO) applications. Some techniques have been used to qualify the printed antenna for space applications. Simulation results show the advantage of Minkowski fractal geometry in terms of multiband and bandwidth enhancement. The proposed antenna operates in S and L, Ultra High Frequency (UHF) band efficiently, and has a small size, so it is useful for small satellite communication applications.**

***Keywords- printed antenna;dua lband;LEO;Minkowski fractal geometry; multiband.***

## I. INTRODUCTION

The modern space industry is focused on the small satellites manufacturing to reduce the cost of the mission. With this in mind, research engineers are concentrated on minimizing the mass and the sub-systems number on board satellite. The radio frequency subsystem requires the development of small size, low cost, lightweight, and compact antennas. Printed antennas are the best candidates to meet these requirements [1-5].

After using the high modes of resonance, printed antennas have the ability to operate in two or more bands simultaneously with very similar performance. The advantage of this option is to minimize the total number of antennas on board satellite. Due to the self-similarity nature of their geometry, fractal is used to design the printed antennas to obtain the multi-band property [6].

For space applications, the antenna must be very reliable, mechanically robust, and able of supporting both random vibration and shock at the launch. In orbit, the antenna must be able to survive in the harsh radiation environment, such as ionizing radiation, cosmic rays, and solar energetic particles. Therefore, the materials of the antennas manufacturing must be carefully chosen [7].

As applications, the European Student Earth Orbiter (ESEO) satellite communicates at 2.080 GHz, 2.260 GHz, and bears a total of six microstrip antennas for command and telemetry.

S-band patch antennas are used for communication by the commercial Surrey Satellite Technology Limited (SSTL) micro-satellite, the antenna has a 4.9 dBi gain, main lobe beamwidth equal to 80°, and it has been used for command uplink [8].

A dual-polarized broadband antenna array is presented in [9]. The operative bandwidth is from 3.15 to 3.25GHz, and the peak measured gain is approximately 19 dBi. The proposed antenna has potential applications in Synthetic Aperture Radar (SAR), remote sensing, and wireless communications.

The goal of this work is to use the Minkowski fractal geometry [21, 22]. to design a dual band antenna for LEO applications.

In Section 2, we formulate the concept of fractal geometry to design the proposed antenna. In Section 3, we describe the geometry of the dual band printed antenna, principle, and procedure. Finally, simulation results are shown in Section 4.

## II. FRACTAL GEOMETRY

Fractals are used in several areas: statistical analysis, modelling nature, coding, and compression. As they can affect fine structures, fractals have found a good place in art and architecture. In the last two decades, researchers have used fractals in the field of electromagnetism, especially in the antenna design [10].

Fractal, meaning broken or irregular fragments, was originally used by Mandelbrot to describe a family of complex shapes that possess an inherent self-similarity or self-affinity in their geometrical structure.

Generally, using fractal geometries in antennas tends to miniaturize their physical sizes and produce multiband response [11-13].

The first development of the antenna based on fractal geometry has been introduced by Cohen [14], who later founded the company Fractal Antennas Inc. Cohen tried to exploit the usefulness of different pre-fractal geometries empirically, namely Koch curves [10], the curve of Minkowski and Sierpinski carpet [21-22].

 

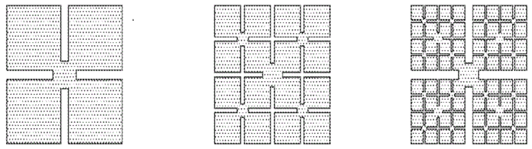


Figure 1. Generation of Minkowski fractal geometry.

In [15], a new microstrip fractal antenna for high impedance matching and bandwidth has been suggested. To improve the antenna performance, many authors proposed using the Defected Ground Structure (DGS) on microstrip antenna [16- 20].

### A. *The geometry of Minkowski*

The process of generating fractal geometry is simple, starting with an initial geometric shape called 'initiator' or 'generator', the process is iterative. As a first iteration, each part of the initiator is replaced by a reduced form of the initiator, that is to say, one proceeds to a decrease of scale [21].

For the fractal geometry of Minkowski, from a square, a rectangle of dimension w1 (slot width) × w2 (indentation width) is cut down from the middle of the edge of each side of the square, the generation process of Minkowski pre-fractal geometry is shown in Fig. 1.

Therefore, the circumference (p), increasing with the number of iterations, is given by [23]:

$$p_n = (1 + 2a_2).p_{n-1} \qquad (1)$$

$$a_1 = w_1/L_0$$

With; $a_2=w_2/L_0$ ; $2(0.5(1-a_1))^D+2a_2^D+a_1^D=1$

$p_n$: the circumference according to the order of iteration.
*$a_1$: side ratio.*
*$a_2$: aspect ratio.*
*$w_1$: slot width.*
*$w_2$: indentation width.*
*$L_0$: the length of the side.*
*D: the fractal dimension*

(a). Front view ( b). Top view

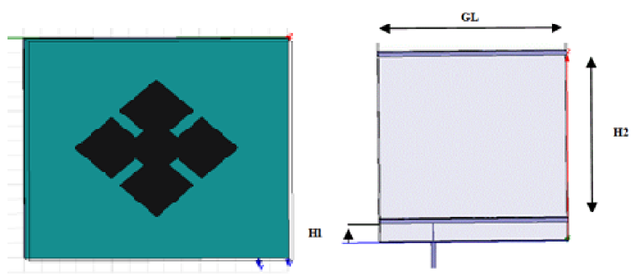


Figure 2. HFSS model of the 1st iteration Minkowski pre-fractal antenna

TABLE I. PHYSIC CHARACTERISTIC OF ROGER RT/DOUROID 5870

| Variable | $\varepsilon_r$ | tan(δ) | TML (%) | CVCM (%) |
|---|---|---|---|---|
| Roger RT/douroid 5870 | 2.33 | 0.012 | 0.05 | 0 |

### B. *Sizing:*

Sizing of the rectangular patch antennas are based on the transmission line model. For the circular patch antennas, the sizing is based on the cavity model. To obtain the antenna dimension values (L,W) of rectangular and circular patch antennas, we use MATLAB for the simulation purposes. The program input are the physical characteristics and material values of the antenna, the dielectric substrate, the thickness of the substrate in mm, the conductivity of the radiating element metal, the loss tangent of the dielectric substrate, and also, the operating frequency [22].

## III. ANTENNA DESCRIPTION

For the proposed models, we used the substrate Roger RT / douroid 5870, permittivity $\varepsilon_r$ = 2.33, and insertion loss tan (δ) = 0.012. The physical characteristics of this material are shown in Table 1. These characteristics indicate that the Roger RT / douroid 5870 can be used in the spatial domain, the Total Mass Loss (TML) is equal to 0.05% (less than 1%), and Collected Volatile Condensable Materials (CVCM) is 0% (lower than 0.1%). These values satisfy the National Aeronautics and Space Administration (NASA) requirements for the use of materials in space [14].

The geometry of the proposed antenna is shown in Fig. 2 (the simulation model of the first iteration Minkowski pre-fractal antenna), where a diamond patch of length $L_0$ = 32.95 mm, is placed coplanar with a finite ground plane, which has a square shape of length $G_L$=75mm.

To obtain circular polarization, the patch was fed by two microstrip lines with orthogonal phase shift of 900. The microstrip lines are printed on the substrate and connected by a 50 Ω coaxial cable. The dielectric substrate used is type Roger RT / duroid with relative permittivity $\varepsilon_r$ =2.33 and thickness t = 1.6 mm.

To increase the gain, a parasitic element is used as a patch director; also, upper layer substrate similar to the primary layer was created to the parasite patch [23].

In order to achieve the spreading of the bandwidth, the thickness of the substrates is increased by putting an air layers ($\varepsilon_r$ = 1), one between the ground plane, the substrate, the other between the substrate and the substrate whose heights H1=7.1mm and H2 = 63mm, respectively.

The technique of dual power supply by microstrip will be used in order to obtain the circular polarization.

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## IV. SIMULATION RESULTS

The particular geometry of the fractal antenna and electromagnetic characteristics gives self-similarity that may be used for obtaining the multiband fractal antenna. Due to their geometric complexity, it is very difficult to predict the required performance by using numerical methods. All these methods are based on solving discrete forms of Maxwell field equations.

In this work, we opted for the simulator Ansoft High Frequency Structure Simulator (HFSS) 13.0. The technique used by the software is based on the finite element method. Ansoft HFSS can be used to calculate parameters, such as S-Parameters, Resonant Frequency and Fields. Apart from the normal view design, it provides a 3D view, which is an added advantage.

To investigate the effect of the fractal geometry on the multiplicity of bands, we represent in each case:

- The return loss by taking the maximum value equal to -10 dB.
- The Voltage Standing Wave Ratio (VSWR) to determine the operating frequency taking the maximum value of less than 2 dB.

Fig. 3 shows the variations of the return loss (S11) and the VSWR of the first iteration Minkowski fractal antenna versus frequency. It is noted that the antenna operates in two different frequencies. For VSWR<2, the first frequency is f1=2.0602 GHz corresponds to VSWR1=0.4397, and the second frequency is f2=3.4135 GHz corresponds to VSWR2=0.323.

The radiation pattern of the first iteration Minkowski fractal antenna, for the two angles phi=0° and phi=90°, is shown in Fig. 4. It is observed that, for the two plans of the electric field E (phi=0°) and the magnetic field H (phi=90°), the antenna aperture is about 60°, which gives a quasi-hemispherical radiation pattern.

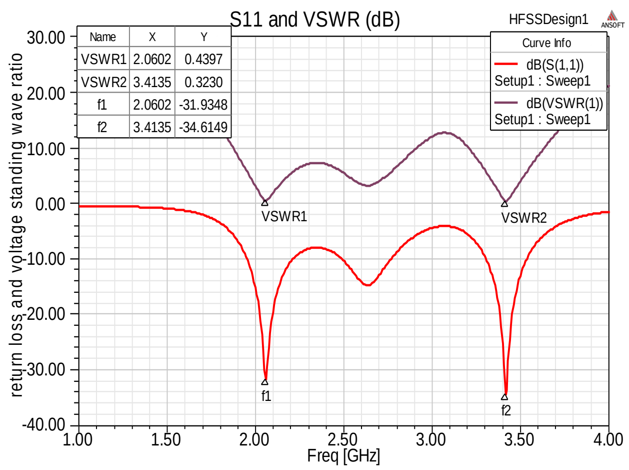


Figure 3. Variations of return loss and voltage standing wave ratio of the first iteration Minkowski fractal antenna

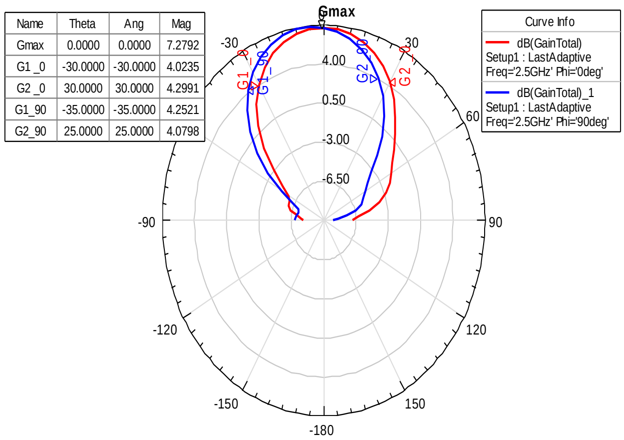


Figure 4. Radiation pattern of the first iteration Minkowski pre-fractal antenna.

Fig. 5 shows the 3D gain variation pattern of the first iteration Minkowski antenna. It is noticed that the maximum gain of the antenna is Gmax=7.357dB in the Z axis direction (phi=0°).

The return loss (S11) of the two Minkowski antennas for the first and the second iteration are presented in Fig. 6. For | S11 | < -10 dB, the second iteration Minkowski antenna operates for four frequencies in two bands: L band for the frequency $f_1$ = 1.8722 GHz: | S11 | = -20 dB, and S band for $f_2$ = 2.2632 GHz: | S11 | = -13.36 dB, $f_3$ = 2.4962 GHz: | S11 | = -24.35 dB, and $f_4$=2.9323 GHz: | S11 | = -20.26 dB.

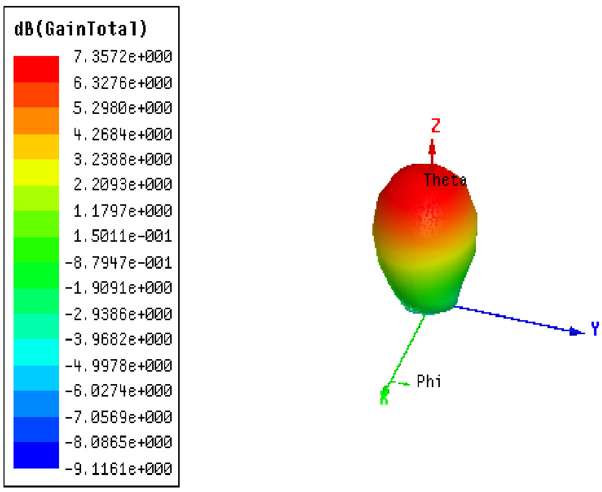


Figure 5. 3D gain variation pattern.

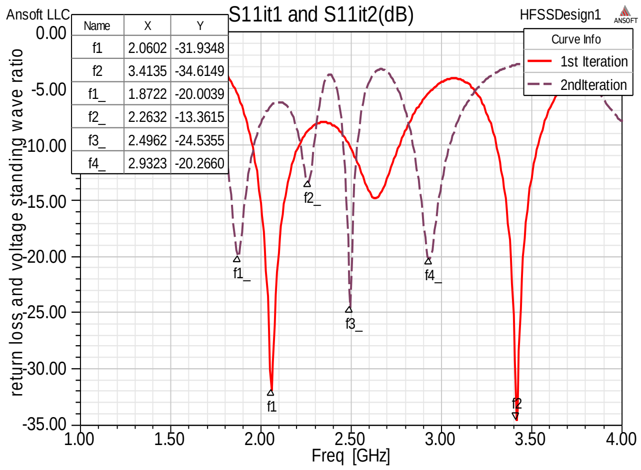


Figure 6. S11 of the first and the second iteration Minkowski fractal antennas

By comparison with the first iteration Minkowski antenna, we notice the appearance of two new frequencies.

For the condition VSWR<2, the frequency f2 = 2.2632 GHz (VSWR2=3.78) does not present a resonance frequency, we can thus conclude that the second iteration Minkowski antenna presents three resonances frequencies (Fig. 7).

Fig. 8 represents the model of the third iteration Minkowski fractal antenna using HFSS (the relative axis is tilted by 45° compared to the principal axis).

However, the gain decreases when the iteration number increases. This is justified by the increasing of the antenna input impedance, which leads to antenna and microstrip line mismatch.

The radiation pattern of three iterations for phi=90° and phi=0°, is shown in Fig. 9 and Fig. 10, respectively.

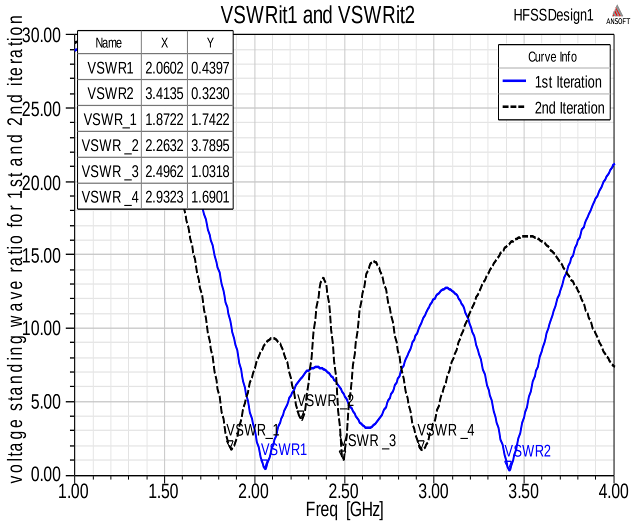


Figure 7. VSWR of the first and the second iteration Minkowski fractal antennas

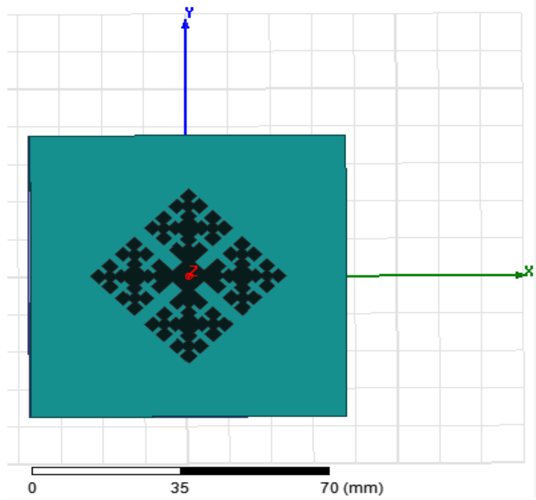


Figure 8. HFSS model of the third iteration Minkowski fractal antenna

According to Fig. 10, it is observed that the antenna aperture increases relatively with the iteration number; this shows the advantage of using the fractal geometry.

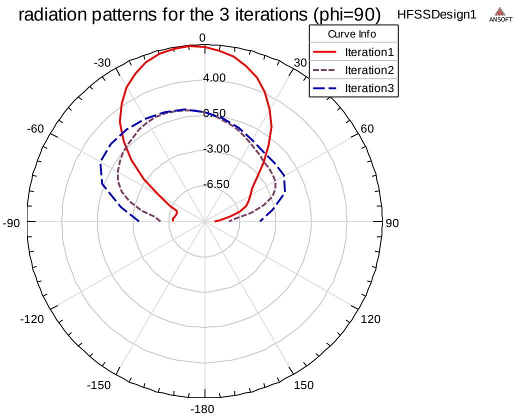


Figure 9. The radiation pattern of three iterations for phi=90°

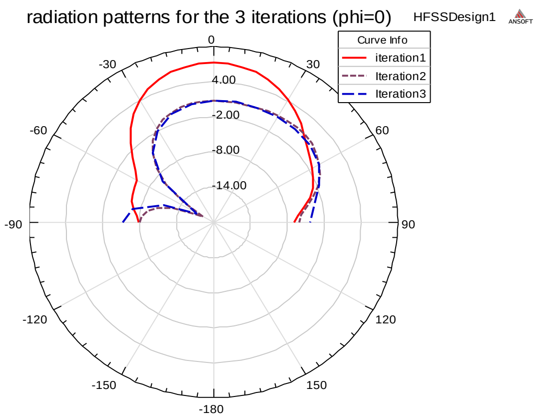


Figure 10. The radiation pattern of three iterations for phi=0°

## V. CONCLUSION AND FUTURE WORK

In this paper, a new structure of printed antenna based on the Minkowski fractal geometry has been presented. The suggested structure is made up of two layers of substrate and a parasitic element of patch in order to increase the gain. A separation by layers of airs is done to increase the antenna bandwidth.

A fractal geometry study effect on the printed antennas is done; a comparative study was drawn up to conclude that the use of fractal geometry has several advantages, such as the multiplicity of band, and the increase in the antenna bandwidth.

The proposed antenna is characterized by reduced size, low cost, low profile, and rigid structure.

The third iteration Minkowski pre-fractal antenna operates in S and L bands, presents a moderate gain, and a quasi-hemispherical radiation pattern. This antenna can be used in telemetry, tracking, and control for satellite Earth observation.

Finally, we may conclude that the space parameters and structural of the antenna are very affected on the RF performance of the printed antenna. The advantage of the fractal geometry is the property multi-band, but this is limited by the structural performance of the antenna, and then by the form of the radiating element.

As future work, we can extend this work to VHF/UHF bands, a large number of potential applications arise. The low input resistance for the antenna using fractal geometry can be improved by feeding the antenna suitably. The suggested antenna presented in this work needs an optimization algorithm for radiation study.

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