Synthesizing Sierpinski Antenna by Genetic Algorithm and Swarm Optimization

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Abstract. *The paper discusses the synthesis of the Sierpinski antenna operating at three prescribed frequencies: 0.9 GHz, 1.8 GHz (both GSM) and 2.4 GHz (Bluetooth). In order to synthesize the antenna, a genetic algorithm and a particle swarm optimization were used. The numerical model of the antenna was developed in Zeland IE3D, optimization scripts were programmed in MATLAB. Results of both the optimization methods are compared and experimentally verified.*

Keywords

Fractal antenna, Sierpinski monopole, particle swarm optimization, genetic algorithm.

1. Introduction

Many branches of science are interested in fractal geometry, and the area of telecommunications is one of them. Among several applications, fractals have been studied for creating new shapes of antennas that allow to extend the antenna design and synthesis concepts beyond the Euclidean geometry [1]–[4].

A fractal antenna uses a self-similar design to maximize the length or the perimeter of the antenna structure within a given total surface area or volume.

In our study, the Sierpinski gasket is used as the investigated fractal geometry. The Sierpinski gasket can exhibit both the conventional self-similarity (the fractals are copies of the whole structure within the structure at different scales) and the self-affinity (the scale factor is different for different directions). The self-similarity and the self-affinity allow the multiband behavior of the antenna [2].

In the open literature, a relatively large number of papers dealing with the conventional Sierpinski antenna were published. Searching for a self-affined Sierpinski antenna, a single submission [5] was revealed in IEEExplore. No publication about the synthesis of self-affined Sierpinski antennas using global optimization methods was discovered. Our research was therefore concentrated on the exploitation of genetic algorithms and particle swarm optimization [6]–[11] to tuning the self-affined Sierpinski monopole in order to operate in prescribed frequency bands.

Both the Particle Swarm Optimization (PSO) and the Genetic Algorithm (GA) belong to the evolutionary algorithms approaching the optimum generation by generation. PSO and GA differ in the way a new population is generated from the present one, and in the way the members are represented within the algorithm. PSO and GA scripts were programmed in MATLAB.

The numerical model of the antenna was developed in Zeland IE3D, and was connected with optimization scripts to reach resonances at the frequencies 0.9 GHz, 1.8 GHz, and 2.4 GHz. The designed antenna was fabricated and measures to confirm simulation data.

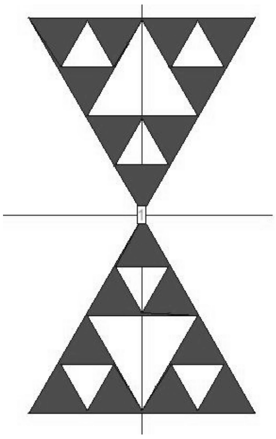

Fig. 1. Sierpinski dipole (two iterations).

The paper is organized as follows. Section 2 describes the development of the numerical model of the Sierpinski antenna in Zeland IE3D. Section 3 presents results of the antenna optimization by PSO, Section 4 shows results produced by GA, and Section 5 brings experimental results.

2. Numerical Modeling

The numerical model of the Sierpinski antenna was developed in Zeland IE3D. For the antenna fabrication, the substrate ARLON CuClad (the height h = 1.54 mm, the dielectric constant ε_r = 2.33, negligible losses) was chosen.

The bottom side of the substrate is not covered by any metallic film. In the upper side of the substrate, the synthesized Sierpinski layout from a good conductor (the assumed conductivity $4.9 \cdot 10^{+7}$ S/m) is etched.

The Sierpinski antenna was modeled as a symmetric dipole with a symmetric port between the arms. The arms were built as a set of triangles on metallic layers.

3. PSO Synthesis

PSO is a stochastic strategy that tries to imitate the social behavior of communities of organisms, such as bees or birds. This algorithm exploits the solution space by taking into account the experience of a single particle as well as that of the entire swarm. In PSO, each particle of the swarm flies in an n-dimensional space, and the position at a certain instant is identified by the vector of the coordinates X. Therefore, the *solution space* has to be defined in the first step. The particle is free to fly inside the n-dimensional space, and the fitness function is the tool used for deciding if one position is better than the other position. In each iteration, the velocity and the position of a particle are changed to approach the best position [6]–[8].

The synthesis starts with a zero iteration antenna (a bowtie antenna), and triangles of higher iterations are sequentially added. New structure geometries produced by the PSO script in MATLAB are sent to Zeland IE3D in order to analyze the antenna. The position of a particle is composed from widths and heights of triangles of different iterations. Since Zeland IE3D operates with vertices, an additional script is developed to transform the dimensions of triangles to the vertices.

Since the input file of Zeland IE3D (the extension *geo*) is of the ASCII format, a reference antenna with the desired parameters is composed, and its dimensions (vertices) are changed just through the geometry file. This way, new antennas with the same shape and different dimensions can be obtained. Hence, a new script, which changes the geometry file of the reference antenna, sends the modified file into Zeland IE3D, and collects the results of the antenna analysis, has to be developed.

Once the geometry file is changed, we use the following code to begin the simulation in Zeland IE3D:

```
! C:\Program Files\Zeland\exe\zeland.exe &
! C:\Documents\bowtie\newfractal.sim
```

The first command is used to start the Zeland Manager from Matlab (the path of the installation of Zeland software, working in background). The second command is used to start the simulation of the antenna (the path of the simulation input, *sim* file). When setting up a simulation, the MGRID module saves the geometry into the *geo* file, and the input and control parameters into the *sim* file. Then, MGRID calls IE3D using the *sim* file as the command line argument. The *sim* file informs IE3D about the location of the *geo* file and output files. In order to perform an IE3D simulation, both the *sim* file and the *geo* file are needed [12]. After creating the reference antenna, we have to therefore save it and create the simulation file choosing the option *create .sim file only* in the simulation setup dialog. Once the simulation is finished, the results are collected from the *sp* file or from the *ipa* file.

The Sierpinski antenna is optimized to reach a satisfactory impedance matching in prescribed frequency bands. The objective function can be therefore formulated as follows:

$$F(\mathbf{x}) = \sum_{i=1}^{N} \left\{ \left[R(f_i,\mathbf{x}) - R_d(f_i)\right]^2 + \left[X(f_i,\mathbf{x}) - X_d(f_i)\right]^2 \right\} \quad (1)$$

Here, $R(f_i, \mathbf{x})$ and $X(f_i, \mathbf{x})$ are the input resistance and input reactance of the Sierpinski antenna computed by Zeland IE3D at the frequency f_i for the vector of state variables $\mathbf{x}$ (widths and heights of triangles). Next, $R_d(f_i)$ and $X_d(f_i)$ are the desired input resistance and input reactance of the Sierpinski antenna at the frequency f_i, and N is the number of frequency bands to be matched.

In the synthesis process, the major problems consist in creating and changing vertices of the polygons. I.e., the one-iteration antenna (Fig. 2) is constructed by 7 polygons (3 in the upper branch, 3 in the lower branch and 1 for the port). Therefore, we only need to keep 8 vertices corresponding to the polygons of the upper branch, due to the vertex of lower branch are symmetrical and the vertex of the port is always the same. Fig. 2 shows in detail the links among polygons to understand why 8 vertices appear. As shown in Fig. 2, the corner of an *empty* triangle does not reach the end of the closer polygon, and therefore, each corner is formed by two points.

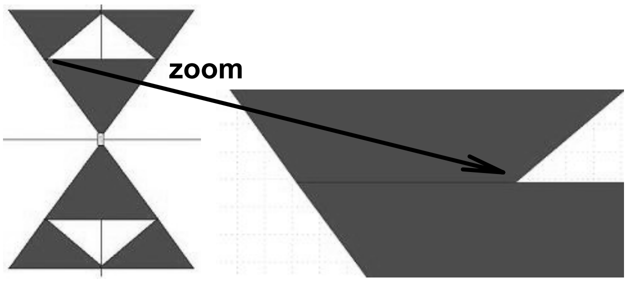

Fig. 2. One-iteration Sierpinski antenna (left). A detail of the Sierpinski antenna (right).

Each iteration of a fractal antenna (including the zero one) can generate one resonant frequency. In order to cover the required frequencies 0.9 GHz, 1.8 GHz and 2.4 GHz, at least a two-iteration Sierpinski antenna has to be designed. Our attention is therefore turned to a two-iteration Sierpinski antenna and a three-iteration one (Fig. 3).

Frequency response of the magnitude of the reflection coefficient of the two-iteration antenna is depicted in Fig. 4, and the response of the three-iteration antenna is shown in Fig. 5. Obviously, both the antennas show similar impedance matching.

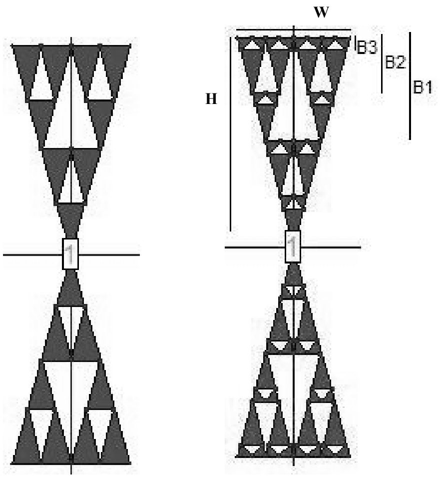

Fig. 3. Sierpinski antenna. Two iterations (left), three iterations (right).

The algorithm ran for 10 iterations with 20 particles. Obviously, further tuning should be performed to reach the matching limit –10 dB at least.

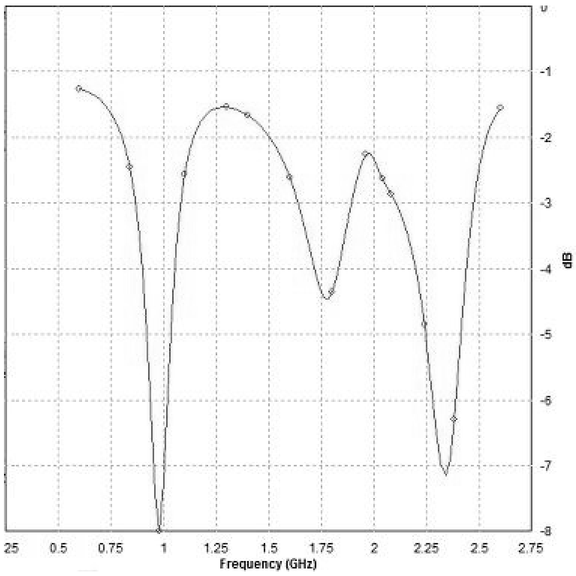

Fig. 4. Frequency response of the magnitude of the reflection coefficient at the input of the two-iteration Sierpinski antenna synthesized by PSO.

4. GA Synthesis

GA is a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. The evolution usually starts from a population of randomly generated individuals (a generation). In each generation, the individuals are decoded and evaluated according to a fitness function set for a given problem. Then, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and mutated) to form a new population. The new population is used then in the next iteration of the algorithm. GA operates on coded parameters. The coding is a mapping from the parameter space to the chromosome space. The coded parameters represented by genes in the chromosome, enable GA to proceed in a manner that is independent on the parameters themselves. Typically, a binary coding is utilized, but any encoding from binary to continuous, floating-point number representations of parameters can be used [9]–[11].

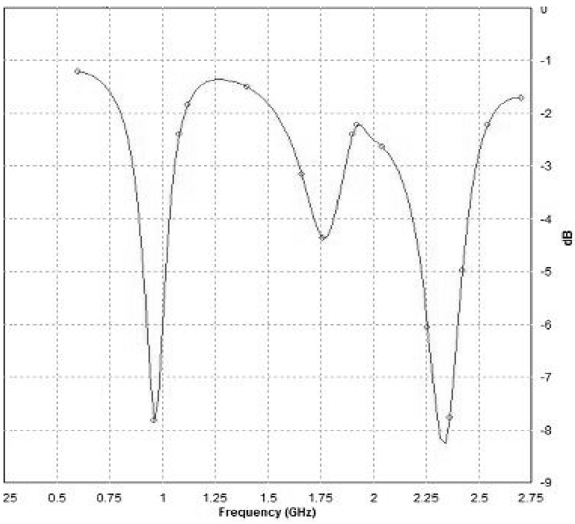

Fig. 5. Frequency response of the magnitude of the reflection coefficient at the input of the three-iteration Sierpinski antenna synthesized by PSO.

In our optimization, we set a crossover probability to 0.8, and a mutation probability equal to 0.05. The widths and the heights of the triangles were binary coded, and were checked to eliminate their potential overlapping. GA ran for $G = 10$ generations, and $I = 20$ individuals. GA worked with elitism and tournament selection. Impedance matching of the antenna (Fig. 6) is slightly better compared to the results obtained by PSO.

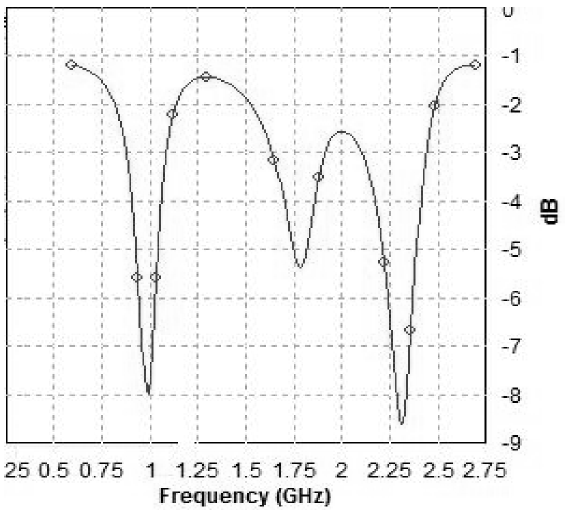

Fig. 6. Frequency response of the magnitude of the reflection coefficient at the input of the three-iteration Sierpinski antenna synthesized by GA.

Tab. 1 shows the dimensions of the three-iteration Sierpinski antenna synthesized by PSO and GA. Here *W* is the width and *H* is the height of the basic bowtie antenna, and B_i is the height of the triangle corresponding to the (i+1) iteration. Widths of triangles are of the homogeneous scale.

	PSO	GA
W [mm]	100	95
H [mm]	180	177
B_1 [mm]	91	88
B_2 [mm]	50	46
B_3 [mm]	5	3

Tab. 1. Optimum dimensions of the three-iteration Sierpinski antenna obtained by PSO and GA. Symbols *W*, *H*, and B_i are depicted in Fig. 3.

Obviously, the dimensions are very similar.

Finally, the four-iteration Sierpinski antenna synthesized by the GA was chosen to be experimentally verified.

5. Experiments

The fractal antenna was fabricated from the ARLON CuClad (ε_r = 2.33, h = 1.54 mm). The antenna prototype is shown in Fig. 7.

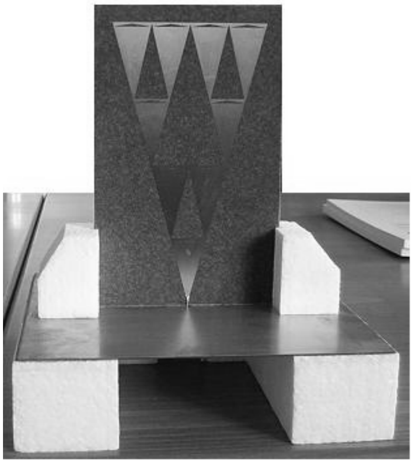

Fig. 7. The fabricated multiband fractal antenna.

The measurement experiment was carried out by a scalar analyzer Anritsu 54147A. The measurement was performed with 401 sweep data points evaluated from 0.8 GHz to 2.5 GHz. The measured response is shown in Fig. 8.

Comparing Fig. 6 and Fig. 8, a quite good agreement can be observed. Values of the impedance matching of the fabricated antenna are better on one hand, but the resonant frequency of the lowest frequency band is shifted to higher frequencies on the other hand. Such difference might be caused by the different geometry of the model (infinite ground plane) and the fabricated antenna (finite ground plane).

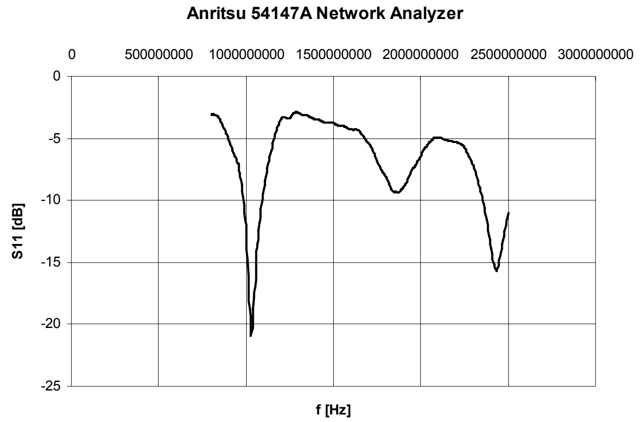

Fig. 8. Frequency response of the magnitude of the reflection coefficient of the fabricated fractal antenna measured by a scalar analyzer.

6. Conclusion and Future Work

The research described in the paper is focused on the investigation of the self-affine Sierpinski antennas, which are rarely discussed in the open literature. In the next step, the general numerical model of the self-affine Sierpinski antenna is associated with global optimization scripts to perform the automatic synthesis of these antennas with respect to the multiband impedance matching. Functionality of developed techniques was experimentally verified.

Results obtained can be considered as preliminary ones: the synthesis should be conceived as a multi-objective one in order to cover radiation properties, gain, polarization and other aspects important for proper antenna functionality. Moreover, the global optimization methods should be completed by local tuning algorithms to reach the optima more accurately.

Therefore, the antenna obtained in this work was not analyzed in depth. The study was focused to optimize impedance matching of the antenna only. The continuation of this work should increase the number of optimized parameters in order to obtain more complete and useful antenna in prescribed frequency bands.

Since the global synthesis is relatively CPU-time consuming (numerical analysis of 200 antennas involve around 24 hours), parallel processing or other techniques reducing CPU-time requirements should be adopted in order to run the analysis for more than 10 generations in a reasonable time. Results obtained show, that such a number of iterations is not sufficient to obtain satisfactorily accurate results.

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References

[1] MANDELBROT, B.B. *The Fractal Geometry of Nature*. New York: W.H. Freeman and Company, 1982.

[2] HAZDRA, P. *Compact Fractal Antenna Structures*. Technical Thesis. Prague: Czech Technical University, 2005.

[3] PUENTE, C., ROMEU, J., POUS, R., CARDAMA, A. On the behavior of the Sierpinski multiband antenna. *IEEE Transactions on Antennas and Propagation*, 1998, vol. 46, no. 4, p. 517–524.

[4] MONTOYA, A. *Fractal Antennas (Antenas Fractales: un paso en la evolución de las Telecomunicaciones)*. Mendellín-Colombia: Universidad de Antioquía. (In Spanish)

[5] SIAH, E. S., OOI, B. L., KOOI, P. S., XHOU, X. D. Experimental investigation of several novel fractal antennas-variants of the Sierpinski Gasket and introducing fractal FSS screens. In *Proceedings of the 1999 Asia Pacific Microwave Conference*, vol. 1, p. 170 – 173, 1999.

[6] ROBINSON, J., RAHMAT-SAMII, Y. Particle swarm optimization in electromagnetics. *IEEE Transactions on Antennas and Propagation*, 2004, vol. 52, no. 2, p. 397–407.

[7] GARCIA, J. M., ALBA E., LUQUE G. J. *Algoritmos Basados en Cúmulos de Partículas Para la Resolución de Problemas Complejos.* 2006. (In Spanish.)

[8] PEREZ LOPEZ, J. R. *Contribución a los métodos de optimización basados en procesos naturales y su aplicación a las medidas de campo próximo*. Santander: Universidad de Santander, 2005. (In Spanish.)

[9] TOWNSEND, A.A.R. *Genetic Algorithm – A Tutorial* [online]. Av.: www-course.cs.york.ac.uk/evo/SupportingDocs/TutorialGAs.pdf

[10] MICHAEL JOHNSON, J., RAHMAT-SAMII, Y. Genetic algorithms in engineering electromagnetics. *IEEE Antennas and Propagation Magazine*, 1997, vol. 39, no. 4. p. 7–21.

[11] LARRAÑAGA, P., INZA, I. Genetic Algorithms *(Algoritmos Genéticos)*. Leioa: Universidad del País Vasco. (In Spanish.)

[12] *IE3D User's Manual*. Fremont: Zeland Software, Inc., 2006.

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Beatriz María VIDAL was born in 1981. She is a student of the University of Cantabria of Telecommunication Engineering (Spain). She received the bachelor's degree in electronic systems in telecommunications in 2005 from the University of Cantabria. In 2008, she is going to finish her studies working in her master's thesis in a project at the Brno University of Technology.

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Prof. Raida has authored or coautored more than 80 papers in scientific journals and conference proceedings. His research has been focused on numerical modeling and optimization of electromagnetic structures, application of neural networks to modeling and design of microwave structures, and on adaptive antennas. In 1999, he received the Young Scientist Award of URSI General Assembly in Toronto, Canada.

Prof. Raida is a member of the IEEE Microwave Theory and Techniques Society. From 2001 to 2003, he chaired the MTT/AP/ED joint section of the Czech-Slovak chapter of IEEE. In 2003, he became the Senior Member of IEEE. Since 2001, Prof. Raida is editor-in-chief of the Radioengineering journal (publication of Czech and Slovak Technical Universities and URSI committees).