On the design of small thin-wire antennas using GA

M. Fernández Pantoja*, F. García Ruiz*, A. Rubio Bretones*, S. González García*, R. Gómez Martín*,
J. M. González Abersú**, J. Romeu**, J. M. Rius**, P. L. Werner*** and D. H. Werner***
* Dpt. de Electromagnetismo. Univ.Granada, Granada, Spain
** Dpt. Teoría del Senyal i Comunicacions, Univ.. Politecnica Catalunya (UPC), Barcelona, Spain.
***Dpt. of Electrical Engineering, The Pennsylvania State University, University Park, USA

Abstract— **A new set of genetically generated electrically small antennas with a better performance than that of several families of Sierpinsky prefractal monopoles of the same electrical size at resonance is presented.**

I. Introduction

As is well known, electrically small antennas are inherently highly reactive and inefficient radiators and they present a very narrow bandwidth when they are tuned to resonance. Hence, in designing these kinds of antennas, it is necessary to seek a compromise between parameters such as resonance frequency, bandwidth and efficiency. In a previous work [1] a multi-objective Genetic Algorithm (GA) in conjunction with the numerical electromagnetic code (NEC) [2] was applied to the optimization of electrically small wire antennas in search of such a compromise. As a result, for a given overall wire length and antenna size, it was shown that genetically optimized antennas with zigzag or meander geometries behaved better than genetically optimized prefractal geometries such as generalized Koch antennas.

Further numerical experiments and measurements using other prefractal wire monopole antennas such as those with Peano and Hilbert geometries [3-4] confirmed the superior performance of genetically optimized zigzag and meander antennas [5]. One common feature of all these antennas is that they do not include in their geometry any closed-loop shapes. Nevertheless, for other prefractal families of wire antennas which do include closed-loop shapes in their geometry, such as the Delta, Y and Koch Sierpinsky types (see Figure 1), improvement was not possible using zig-zag or meander designs.

Subsequently, the option of including closed loops in the GA code was allowed when seeking the best possible structure instead of the restriction to exclusively zigzag and meander geometries. The result was that the new set of genetically optimized antennas performed better than all the prefractal antennas plotted in Figure 1. In this paper these results are presented and discussed.

II. Genetically optimized antennas including loops

With a similar procedure to the one described in [1], a multi-objective (Pareto) GA code [6] was used to design genetically optimized small monopole antennas with better performance than that of the prefractal antennas shown in Figure 1. Thus, instead of limiting the search to only zigzag and meander geometries, the possibility of generating structures including closed-loop was allowed. This new family was formed filling an equilateral triangle of height $h = 6.22$ cm using as building blocks the basic shapes plotted on the right side of Figure 2. To this end the main triangle was subdivided into 16 equilateral subtriangles, which were randomly replaced by one of the basic shapes.

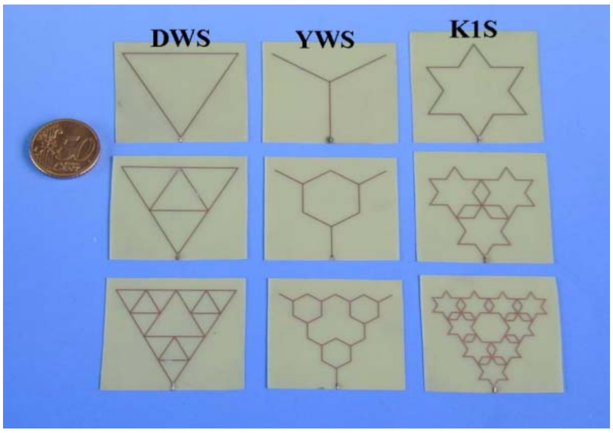

Fig. 1. From left to right, three iterations of: Delta wire Sierpinski, Y Wire Sierpinski and Koch Sierpinski.

To generate the genetically optimized antennas a set of monopole antennas, which constituted the initial generation, were randomly formed and encoded into chromosomes using fixed-point decimal coding [6]. The population was composed of 20 chromosomes, each comprising a set of $N = 16$ genes which represent coded versions of the individual characteristics. Figure 2 indicates the genes associated with each of the basic shapes utilized. The antennas were made of 0.1 mm radius copper wires, and fed at their base. Their efficiency, input impedance, and resonance frequency were calculated applying the frequency-domain method-of-moments-based NEC code. As our aim was to evolve towards small individuals with the lowest possible Q factor and the highest possible efficiency, e, the three following fitness functions were evaluated for each individual:

$$
\begin{aligned}
F^1 &= 1 - \frac{f_r}{f_r^s} \\
F^2 &= e \\
F^3 &= \frac{1}{Q}
\end{aligned}
\qquad (1)
$$

where f_r is the resonance frequency corresponding to any generated antenna and f_r^s is the first resonance frequency of a straight monopole of length $1cm$.

After applying the GA operators [6] of the tournament method, one-point crossover and a Gaussian-probability-distribution mutation, the multi-objective GA procedure renders a 3D graph of $k_0 h$, e and Q corresponding to each individual after each generation, where k_0 is the wavenumber corresponding to f_r. The envelope of this graph evolves to an optimal set of solutions called the Pareto front [6], [7], from which the designer can choose the individual that best fits the design requirements. The procedure is applied by means of domination schemes using triangular sharing functions to guarantee diversity in the final set of optimal solutions. The specific GA adopted in this work employs both a crossover operator and a mutation operator with probabilities of 80% and 5%, respectively.

Figure 3 plots two projections of the Pareto surface corresponding to the results after 7000 generations. To compare the characteristics of the same set of specific individuals, we first projected the Pareto surface onto the efficiency-Q plane, then selected the individuals with the lowest Q and plotted both their efficiency and their Q factor versus their electrical size (see Figure 3). Note that there is now consistently a GA design with a better performance, higher efficiency and lower Q, than that of any prefractal Sierpinsky antenna of the same electrical size at resonance.

Among all the GA-designed antennas, the four shown in Figure 4 have been selected to construct and compare with the prefractal Sierpinski antennas of Figure 1. Note that the Sierpinski antennas are considered only up to the third iteration, so that the maximun wire length of the GA individuals coincides with that of the prefractal monopoles, and the comparison is made under the same conditions. To facilitate the measurements, all the antennas were scaled from their original height to have the same size (56.9 mm high). The antennas have been printed on a 0.25 mm thick fiberglass substrate using standard techniques for printed circuit-board manufacturing. They were made 0.3 mm wide with 35 μm etch strips. The dimensions of the strip were chosen so that the actual geometry where the current flowed in the strip had the same surface area in cross section as that in the original wire [8]. Once constructed, the antennas were mounted on a 3 mm thick ground plane of 80 cm x 80 cm and fed through their base with a SMA connector. The antennas were raised 2.2 mm (the length of the connector central pin) from the ground plane,.

Radiation efficiency of the antennas was measured at resonance with the Wheeler Cap Method [9]. An almost cylindrical metal bowl was used as a cap, its size being enough to fulfill the radianlength criterion for the minimum spacing between the antennas and the cap walls. The resonant frequencies of the cap were also checked to be out of the frequency range of the antennas being tested [10]. The Wheeler method for the radiation-efficiency determination is based on the measurement of the input resistance of the antenna when radiating in its usual environment and when surrounded by a metal shield. The input resistance measured in the usual environment gives the radiation and the ohmic resistance of the antenna. When the antenna is measured with a properly designed cap that prevents radiation, the input resistance accounts for only the ohmic losses of the antenna. From these two measurements the radiation resistance of the antenna was inferred and, from its standard definition, the radiation efficiency was computed. Once the radiation resistance at resonance and the input reactance in a frequency range around the resonance were known, the quality factor without losses was also estimated using the relationship in [11]. The input resistance and the reactance of the antennas, with and without the cap, were mesuared with a calibrated vector network analyzer inside an anechoic chamber. The shift between the reference (calibration) plane and the ground plane was compensated for using the electrical delay of the analyzer.

Figure 5 and 6 show, respectively, the values of efficiency and Q measured for the GA designed antennas and for those shown in Figure 1, confirming that the non-fractal antennas perform better than do the fractal designs. In Figure 5, the fundamental limit for the Q factor [11] was included as a reference. Figures 5 and 6 also include the results corresponding to a monopole, named PM5, built by removing from the PM4 antenna the detached triangle located in its upper right corner. It can be seen that PM4 and PM5 elements behave identically. Measured efficiencies, quality factors, and electrical sizes at resonance agree reasonably well with the expected values from simulations plotted in Figure 3, and both reveal the GA capability of designing monopoles with slightly better performance than prefractals for almost the same electrical sizes. The slight differences between simulations and measurements are due to the scaling factor used in order to have antennas with the same height as well as the presence of a substrate that supports the strips [12]. Both shift the resonant frequencies towards lower frequencies from the expected values and add losses to the antennas.

III. Conclusions

A multi-objective genetic algorithm has been applied to generate a new family of electrically small, thin wire antennas that perform better than do several families of prefractal Sierpinsky antennas in terms of resonance frequency, efficiency, and Q factor. For this aim it was necessary to allow the GA procedure to take into account geometries which also include closed-loop shapes instead of only seeking for zigzag and meander designs. The measurements confirmed the results.

IV. References

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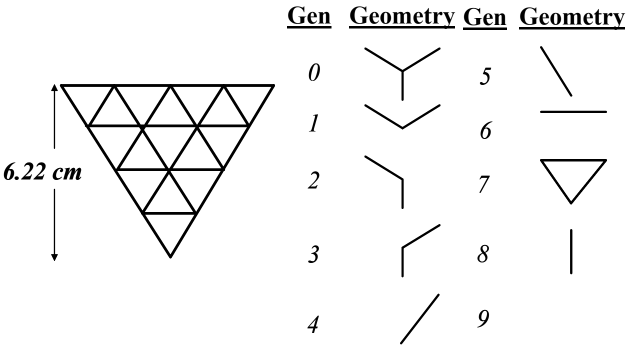

Fig. 2. Area to be filled and building blocks to replace the subtriangles. The equilateral triangle has the same height, $h = 6.22$ cm, than the Sierpinski antennas in Figure 1.

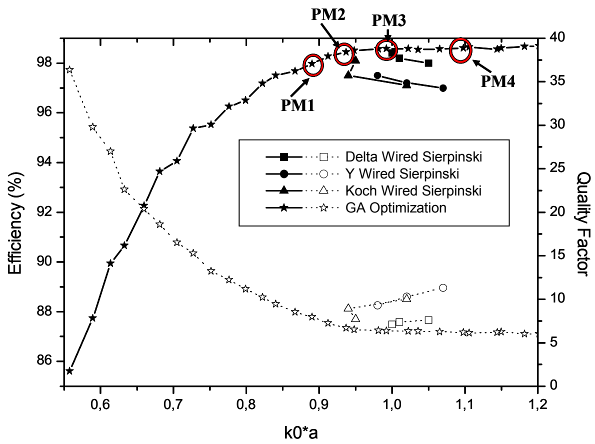

Fig. 3. Efficiency and Q factor of the individuals designed with GA and of the prefractal antennas in Figure 1. The filled symbols represent the efficiency while the non-filled symbols represent the Q-factor

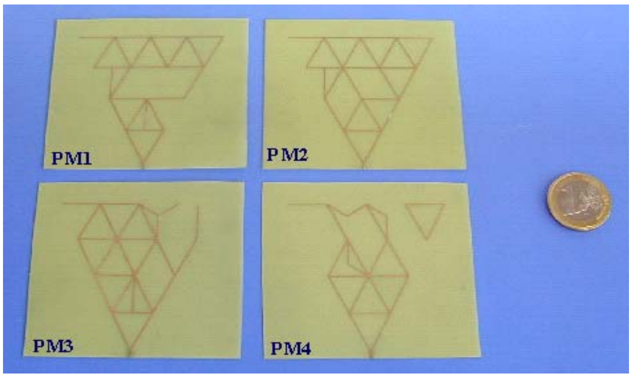

Fig. 4. Example of several optimized GA antennas.

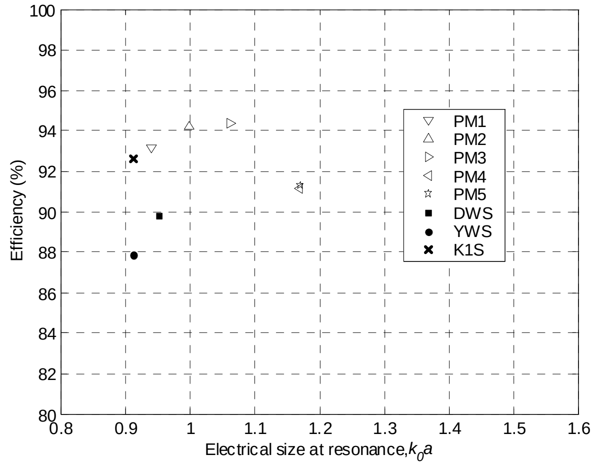

Fig. 5. Meassured efficiency of the antennas in Figure 4 and in Figure 1

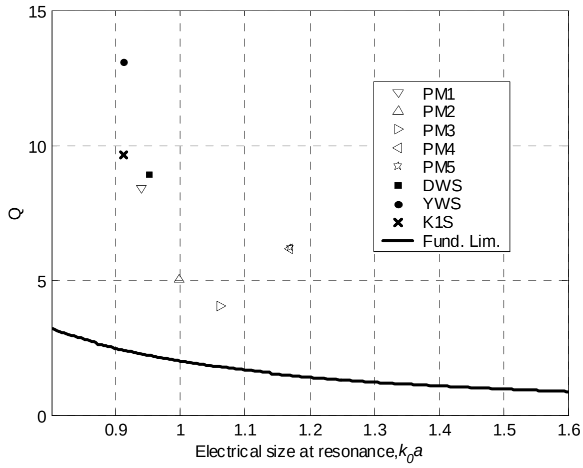

Fig. 6. Meassured Q-factor of the antennas in Figure 4 and in Figure 1.

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