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38123 Povo – Trento (Italy), Via Sommarive 14
<http://www.disi.unitn.it>

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R. Azaro, D. Franceschini, L. Manica, and A. Massa

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A Miniaturization Process of an Antenna with Pre-Fractal Geometry by means of a Particle Swarm Optimization

Davide Franceschini*, Renzo Azaro, Luca Manica, and Andrea Massa

Department of Information and Communication Technologies,

University of Trento, Via Sommarive 14, I-38050 Trento, Italy.

E-mail: andrea.massa@ing.unitn.it, Web-page: <http://www.eledia.ing.unitn.it>

This work presents a synthesis procedure for designing miniaturized pre-fractal antennas for wireless applications. In order to minimize the linear dimensions of the antenna and to obtain Voltage Standing Wave Ratio values within specifications, the device configuration has been synthesized by defining a suitable building pre-fractal geometry tuned through a customized Particle Swarm Optimizer.

Introduction

The demand of wireless infrastructures able to support fixed and mobile access to high-speed broadband applications is continuously growing. In order to deliver services over a wireless communication network to last-mile end-users, particular attention has to be paid to the development of compact and portable devices. In such a context, the design of miniaturized radiators able to guarantee good efficiency and reliability are becoming mandatory. With such requirements, the use of fractal antennas seems to be a good choice for achieving reduced dimensions maintaining the desired radiation properties. In particular, fractal geometries that are built with a finite number of fractal iterations (pre-fractal antennas) are very useful to achieve a good miniaturization and to provide enhanced bandwidth [1]-[4]. In such a framework, this paper considers an optimization procedure for the synthesis of a pre-fractal Koch-like antenna able to fully exploit the degree of the geometry under test. Starting from a reference geometry and tuning its geometric descriptors through a numerical procedure based on a particle swarm optimizer (PSO) [5][6], the proposed method is aimed at fitting the project constraints in an effective fashion. In order to assess the effectiveness of the design process and of the arising features, a reference test case is taken into account and illustrative results are shown.

Design Procedure

Usually, the optimization of a radiator with a pre-fractal geometry is carried out by fixing suitable constraints in terms of maximal VSWR (\overline{VSWR}) at the input port in the working frequency band and size reduction compared to the length of a standard quarter-wave monopole antenna. Since the device has to be physically printed on a planar dielectric substrate, the fractal geometry and the widths and

lengths of each fractal segment are the parameters to be optimized in order to fit the project requirements.

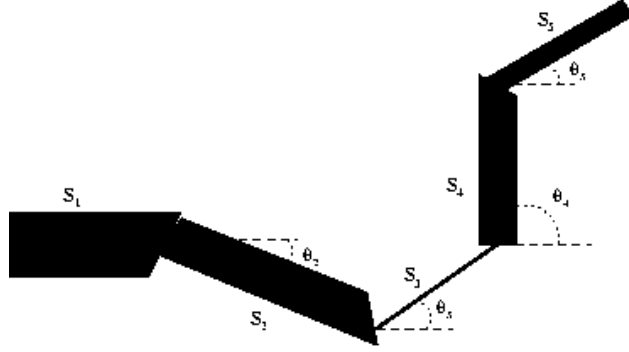


Figure 1. Geometry of the trapezoidal fractal generator ($I = 5, J = 3$).

By considering as building block the trapezoidal curve described in [4], the antenna structure is uniquely determined by the fractal iteration number N , the set of corresponding descriptive parameters $s_i^N, \theta_i^N, i = 1, \dots, I$ (Fig. 1 when $N = 1$), which define the affine transformations employed by the iterated function system (IFS) [4] for generating the pre-fractal antenna geometry, the projected length of the fractal structure denoted by L , and the widths of the fractal segments $w_j^N, j = 1, \dots, J$. Moreover, such a set of parameters has to satisfy the geometrical constraint described by the following relationship

$$\sum_{i=1}^I s_i^N \cos \theta_i^N = L \cap \sum_{i=1}^I s_i^N \sin \theta_i^N = 0 \quad (1)$$

being $\theta_1^N = 0^\circ$.

The design problem is then recast as the solution of the optimization problem where $\underline{u} = \{N, s_i^N, \theta_i^N, w_j^N; i = 1, \dots, I; j = 1, \dots, J\}$ is the parameters array and Φ defined as follows

$$\Phi(\underline{u}) = \sum_{i=0}^{I-1} \left\{ \max \left[0, \frac{\Lambda\{i\Delta f\} - \overline{VSWR}}{\overline{VSWR}} \right] \right\} \quad (2)$$

is the cost function to be minimized, Δf being the sampling frequency interval and $\Lambda\{i\Delta f\} = \Lambda(\underline{u})$ is the VSWR value at $f = i\Delta f$ when the antenna structure described by the array \underline{u} is considered. Furthermore, the generation of impractical solutions (due to their intricate and convoluted shapes) is avoided introducing some physical constraints on the antenna parameters and a penalty on those configurations that, even though not unfeasible, would be difficult to realize (e.g., higher fractal orders or large ratio between width and length of the fractal segment or longer than a standard linear antenna).

In order to minimize (2) and according to the guidelines given in [6], a suitable implementation (i.e., dealing with variable-length unknown arrays) of the PSO [7] is used in conjunction with an IFS generating software and a method-of-moments (MoM) simulator [8]. The IFS generates the corresponding pre-fractal antenna structure starting from each of the trial arrays $\underline{u}_m^{(k)}, m = 1, \dots, M, k = 1, \dots, K$ (m and

k being the trial array index and the iteration index, respectively) defined by the PSO. The corresponding VSWR value is computed by means of the MoM simulator, which takes into account the presence of the dielectric slab and of the reference ground plane assumed of infinite extent. The iterative process continues until $k = K_{\max}$ or $\Phi_{opt} \leq \phi_{th}$, ϕ_{th} being the convergence threshold and $\Phi^{opt} = \min_{k,m} \left\{ \Phi \left[\underline{u}_m^{(k)} \right] \right\}$.

Numerical Assessment

In order to preliminarily validate the proposed design procedure, the optimization of a pre-fractal Koch-like monopole antenna for Wi-Max applications in the 3.4 – 3.6 GHz band will be considered. As far as the project guidelines are concerned, the European Standard ETSI EN 302 085 V1.2.2 (2003-08) requires that the antenna presents a Voltage Standing Wave Ratio lower than $\overline{VSWR} = 1.8$ in the 3.4 – 3.6 GHz frequency range. Moreover, let us consider as geometrical constraints that: (1) a size reduction of more than 20 % compared to a standard quarter-wave resonant monopole is required and (2) the antenna has to be physically printed on a planar dielectric substrate of dimensions $L_{\max} = 16$ [mm] \times $H_{\max} = 10$ [mm].

In order to meet such design requirements, the proposed approach has been used. In particular, the PSO algorithm has been employed considering a population of $M = 15$ trial solutions, a threshold $\phi_{th} = 10^{-3}$, and a maximum number of iterations equal to $K_{\max} = 500$. Moreover, the other PSO parameters have been set as in [7] and according to the reference literature [6].

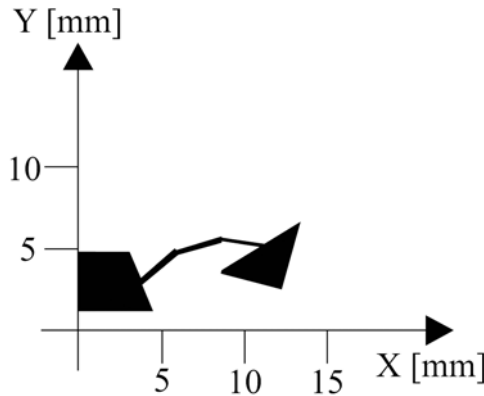


Figure 2. Geometry of the fractal monopole at the convergence iteration ($k = K_{conv}$) of the optimization procedure.

The geometry of the antenna structure synthesized after the optimization process (i.e., the best solution $\underline{u}_{opt}^{(k=k_{opt})} = \arg(\min_m \left\{ \Phi \left[\underline{u}_m^{(k=k_{opt})} \right] \right\})$) is shown in Fig. 2 and in order to give some indications on the iterative optimization process the evolution of the VSWR function at different steps is reported in Fig. 3. The plots highlight that starting from a mismatched design solution ($k = 0$), the antenna geometry improves to the final shape ($k = K_{conv}$) that fits the requested specification in terms of both VSWR and overall dimensions (Fig. 2). In more detail, the

transversal and longitudinal linear dimensions of the synthesized structure are equal to $L_{opt} = 13.39$ [mm] along the x -axis and $H_{opt} = 5.42$ [mm] along the y -axis, respectively. Moreover, the projected length L_{opt} turns out to be smaller than that of the resonant monopole printed on FR4 substrate, with a reduction of 24.77% .

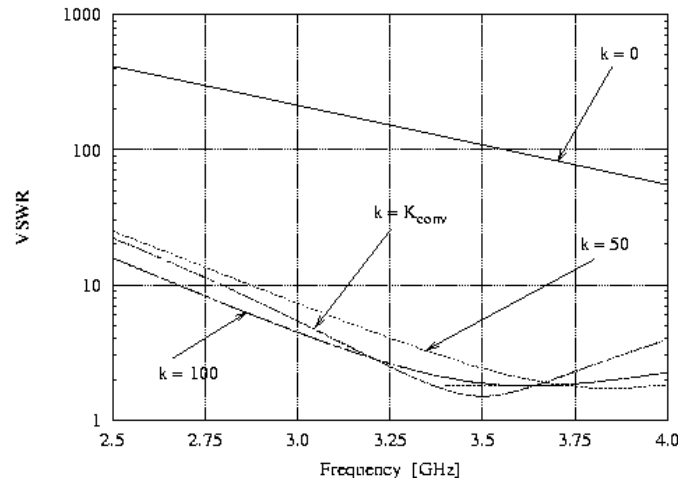


Figure 2. Simulated VSWR values at the input port at different iteration steps of the optimization procedure.

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