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A HYBRID PREFRACTAL THREE-BAND ANTENNA FOR MULTI-STANDARD MOBILE WIRELESS APPLICATIONS

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A Hybrid Prefractal Three-Band Antenna for Multi-Standard Mobile Wireless Applications

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***Abstract*— In this letter, the synthesis of a miniaturized three-band planar antenna working in GSM and $WiFi$ frequency bands is described. The reference geometry for the synthesis of the antenna is a hybrid prefractal shape obtained by integrating a Sierpinski-like and a Meander-like structure. The synthesis of the geometrical parameters of the antenna has been performed by means of a customized Particle Swarm strategy to yield electrical parameters within given specifications. In order to show the effectiveness of the approach, some results from the numerical synthesis procedure are described and a comparison between simulations and experimental measurements is reported.**

***Index Terms*— Antennas Synthesis, Pre-Fractal Antennas, Multi-Band Antennas, Miniaturized Antennas, Hybrid Fractal Geometries, Particle Swarm Optimizer.**

I. INTRODUCTION

THE massive use of multiple wireless standards in a single devices often requires the integration of the related radiating systems in a single device, posing a very critical design task to the antenna designers. Such a task becomes even more challenging when, besides multi-band operations, an high degree of miniaturization is required, as well (e.g., next generation mobile wireless devices). Fractal shapes [1][2] have proved to be good candidates for the development of both miniaturized and multi-band antennas and several studies have been carried out to analyze/describe their radiating properties [3][4][5]. Moreover, it has been found that the addition of some degrees of freedom, obtained by perturbing a reference fractal shape, allows one to tune the locations of non-harmonic frequency bands [6][7]. Following such an idea and thus avoiding the insertion of lumped loads in the antenna structure, this letter presents the innovative design of a planar radiator able to work in three frequency bands under restrictive geometrical constraints. The reference antenna geometry has been obtained by combining two different fractal shapes in an unique hybrid structure. The one is aimed at tuning the highest resonances, the other to set the lowest frequency band keeping miniaturized dimensions. According to such a technique, the resulting reference hybrid shape turns out to be just defined by a set of descriptive parameters to be modified in order to fit the design requirements. Because of the complexity of the tuning procedure based on the variation of the descriptive parameters and aimed at fitting both geometrical and electrical constraints, the problem at hand has been faced in terms of an optimization one and a suitable implementation of an effective cooperative stochastic optimization algorithm [8][9][10] [i.e., the particle swarm optimizer (PSO)] has been adopted.

The outline of the letter is as follows. The synthesis process is illustrated by focusing on the achieved performances. The results of a numerical analysis devoted to show how the different aspects of the design establish the overall performance of the antenna are reported, as well. For completeness, a comparison between simulations and experimental data from an antenna prototype is reported to assess the reliability of the synthesis technique.

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II. ANTENNA DESCRIPTION AND PERFORMANCE ASSESSMENT

The antenna has been required to operate in the GSM and $WiFi$ frequency bands ($f_{GSM-L} = 925\,MHz$, $f_{GSM-H} = 1850\,MHz$, and $f_{WiFi} = 2440\,MHz$) according to the needs of an innovative mobile device able to exploit both wireless standards to provide at the same time GSM connectivity and Voice over IP (VoiP) operations (in the Wi-Fi band). Because of the mobile application, an hemispherical coverage is needed and the the main-lobe amplitude has been set as follows: $\theta_{-3\,dB} \geq 70^o$. As far as the geometrical constraints are concerned, the maximum extension of the antenna has been fixed to $4 \times 4\,cm^2$ on a low permittivity planar substrate (i.e., *Arlon* substrate of thickness $h = 0.8\,mm$ and dielectric characteristics $\varepsilon_r = 3.38$ and $tg\delta = 0.0025$ at $f = 10\,GHz$). It is worth to note that the linear extension of the resulting antenna turns out to be a reduction of about 50% of the size of a quarter-wave monopole that operates at the lowest GSM frequency band. Due to such a very hard constraint on the antenna size, the requirements on the electrical properties have been slightly slackened. Accordingly, a *Voltage Standing Wave Ratio* ($VSWR$) value lower than 3.5 has been required at the input port of the antenna,whatever the working frequency band.

Since the multi-band antenna prototype has to satisfy very challenging geometrical requirements for a suitable integration in the hosting mobile device, a Meander-like structure has been added to the Sierpinski-like shape (see Fig. 1) in order to obtain an electrical length of the whole structure compliant with the lowest GSM frequency. As a matter of fact, the Sierpinski-like structure allows a good trade-off between electrical properties and antenna dimensions at the highest frequencies [1][5][6], while Meander-like shapes

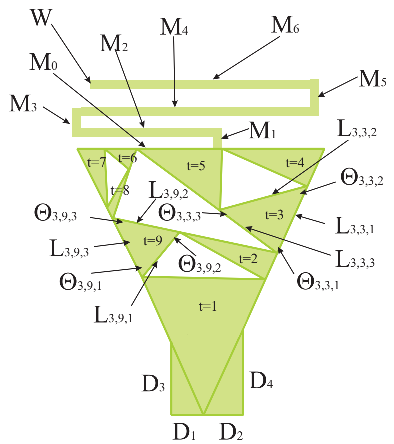
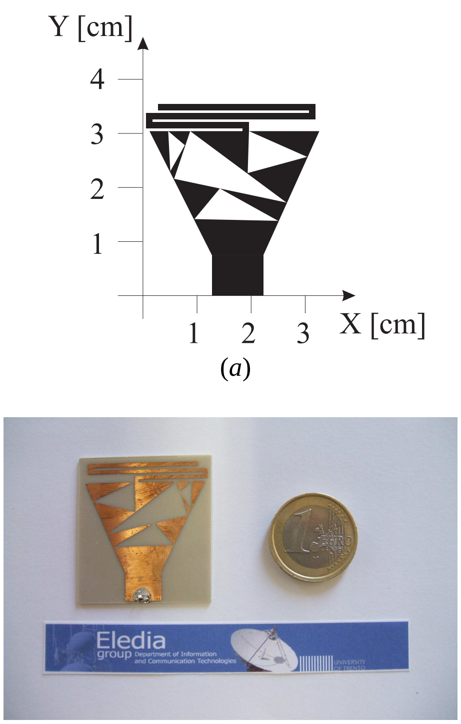


Fig. 1. Geometry of the reference antenna shape.



(*b*)

Fig. 2. *Three-band hybrid prefractal antenna* - (*a*) Synthesized antenna geometry and (*b*) photograph of the antenna prototype.

[1] guarantee a size miniaturization at the lowest frequency. Starting from such a hybrid reference structure, the synthesis problem has been recast as an optimization one then solved by means of the PSO [10][13]. Towards this end, the PSO has been integrated with a hybrid prefractal shape generator and a Method-of-Moments (MoM) [14] electromagnetic simulator as in [7]. In particular, the following set of PSO parameters has been used: $P = 6$ (P being the dimension of the swarm), $\eta = 10^{-3}$ (η being the convergence threshold), and $K = 200$ (K being the maximum number of iterations of the iterative optimization).

The synthesized antenna geometry [Fig. 2(*a*)] has the following dimensions: $34.8\,[mm]$ along the x-axis and $36.1\,[mm]$ along the y-axis (i.e., a reduction of about 55.5% along the y-axis when compared with a standard quarter-wave monopole with a resonance at f_{GSM-L}). In order to assess the reliability of the synthesis process, a prototype of the antenna has been built [Fig. 2(*b*)] and its electrical performances evaluated through a set of experimental measurements. The $VSWR$ values have been collected by considering a reference finite ground plane of size $90 \times 140\,cm^2$ and with a scalar network analyzer in a controlled environment. The measured data have been compared with those from the numerical simulations and the result is shown in Figure 3 . As it can be observed, there is a good agreement between experimental and numerical data. More in detail, as regards to the minimum and average *VSWR*s, it turns out that: (*a*) $VSWR_{min}^{(sim)} = 2.4$ vs. $VSWR_{min}^{(meas)} = 2.5$ and $VSWR_{av}^{(sim)} = 3.1$ vs. $VSWR_{av}^{(meas)} = 3.8$ [*GSM-L* frequency band]; (*b*) $VSWR_{min}^{(sim)} = 1.3$ vs. $VSWR_{min}^{(meas)} = 1.7$ and $VSWR_{av}^{(sim)} = 1.5$ vs. $VSWR_{av}^{(meas)} = 1.9$ [*GSM-H* frequency band]; (*c*) $VSWR_{min}^{(sim)} = 3.2$ vs. $VSWR_{min}^{(meas)} = 3.3$ and $VSWR_{av}^{(sim)} = 3.4$ vs. $VSWR_{av}^{(meas)} = 3.6$ [$WiFi$ frequency band].

In order to show how the different geometrical elements contribute to establish the overall performance of the synthesized antenna, the simulated VSWR values in correspondence with "intermediate" geometries (Fig. 4) have been analyzed and the results are summarized in Fig. 5. Each intermediate geometry contains a sub-set of the geometrical features of the antenna prototype. With reference to Fig. 4, the following shapes have been considered: (*a*) the Sierpinski-like pre-fractal truncated at the first ($i = 1$) fractal iteration [5][6] (i.e., the bow-tie-like shape), (*b*) the same geometry with the Meander-like section added, (*c*) the shape (*b*) with the Sierpinski-like pre-fractal at the second ($i = 2$) iteration, (*d*) the model (*b*) with the Sierpinski-like pre-fractal profile at the $i = 3$ iteration (i.e., the optimized antenna shape). Moreover, the antennas in (*e*) and (*f*) have been obtained by adding to the model (*c*) one and two of the triangular elements at the $i = 3$ iteration of the Sierpinski generation. Furthermore, the sample (*g*) has been defined by narrowing the two triangular elements of (*e*). By comparing the VSWR plots of (*a*) and (*b*) (Fig. 5), it can be observed that the addition of the Meander-like element to the

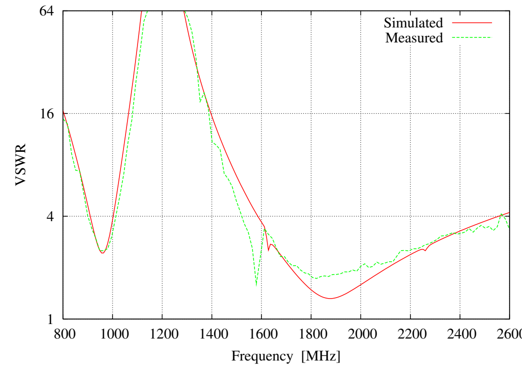


Fig. 3. *Three-band hybrid prefractal antenna* - Comparison between measured and simulated *VSWR* values.

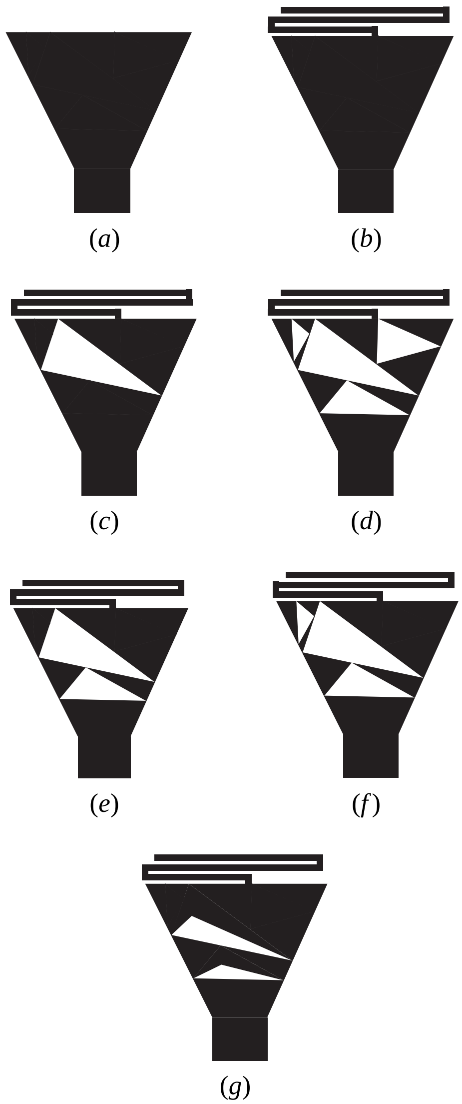


Fig. 4. *Three-band hybrid prefractal antenna* - Intermediate geometries.

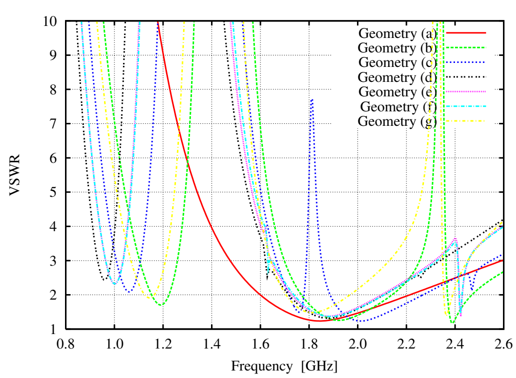


Fig. 5. *Three-band hybrid prefractal antenna* - VSWR values in correspondence with the geometries in Fig. 4.

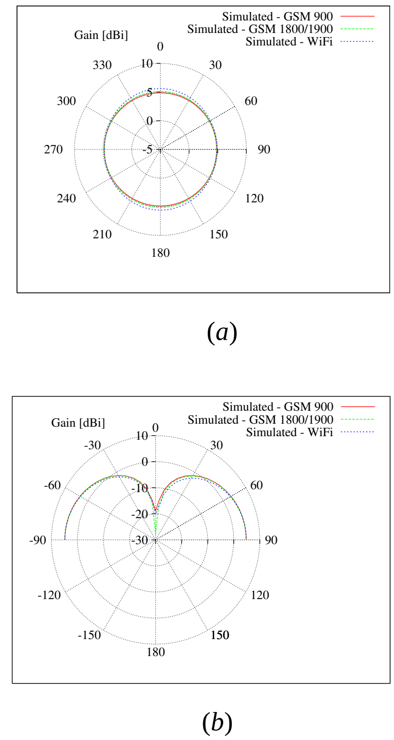


Fig. 6. *Three-band hybrid prefractal antenna* - Behavior of the gain function along the horizontal plane [(*a*) - $\theta = 90^o$] and the vertical plane [(*b*) - $\phi = 0^o$], respectively.

bow-tie antenna (operating around $1.6\,GHz$) provides a new resonance at a lower frequency value. The successive insertion of the pre-fractal details [$i = 2$ - (*c*) and $i = 3$ - (*d*)] allows a fine tuning of the working frequencies in both the higher frequency band and the GSM 900 MHz band.

Now, let us consider the plots of the shapes in (*c*), at two intermediate geometries [i.,e., (*e*) and (*f*)], and for the prototype geometry (*d*). The tuning effect caused by the addition of the triangular elements of the Sierpinski iteration $i = 3$ is clearly pointed out in Fig. 5. As a matter of fact, the value of the lower resonance frequency reduces, while the higher one increases. On the other hand, the VSWR response with only the two central triangles, where the height of each triangle is significantly diminished [i.e., the shape (*g*)], turns out to be far from the project requirements.

Finally, to point out the compliance of the prototype also with the pattern requirements, Figure 6 shows the beam patterns calculated along the H-plane [Fig. 6(*a*)] and in the E-plane [Fig. 6(*b*)], respectively.

III. Conclusion

The design of a three-band antenna working in GSM and $WiFi$ frequency bands has been presented. In order to fit the hard geometrical requirements, an suitable and innovative hybrid fractal shape has been used. Such a reference geometry has been obtained by integrating a Sierpinski-like prefractal and a Meander-like shape. Successively, the descriptive parameters of the antenna have been tuned thanks to an optimization process based on the PSO. Then, starting from the result of the numerical simulations, a prototype of the antenna has been built. The comparison between measurements and simulations has assessed the reliability of the synthesis procedure as well as the effectiveness of the designed antenna. Moreover, the operation of the antenna and the importance of different aspects of the design to establish the overall performance have been analyzed to point out how the fractal concepts and their integration is useful in the design process.

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