A NOVEL FRACTAL RECTANGULAR CURVE PRINTED MONOPOLE ANTENNA FOR PORTABLE TERMINALS

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Abstract: A novel fractal rectangular curve monopole antenna is introduced and its input impedance characteristics are examined based on simulation results. The investigated fractal rectangular curve resonates at 2.45 GHz ISM band occupying the smallest area as compared to previously published printed fractal monopole geometries. Moreover, this novel geometry exhibited a very wide bandwidth and a high input resistance notwithstanding its very compact size.

INTRODUCTION
The current upsurge in wireless communication systems has forced antenna engineering into facing new challenges, which include the need for small size, good performance and low-cost antennas. Miniature antennas are of prime importance due to the available space limitation on the user equipment and the oncoming deployment of diversity and MIMO (Multiple Input Multiple Output) systems. The basic antenna miniaturization techniques include lumped element loading, material loading, the use of ground planes, short circuits and antenna’s environment and geometry optimization [1]. Among these techniques, the latter has gained much interest lately, by the introduction of fractals in antenna engineering due to their inherent miniaturization ability.

In this paper a novel Fractal Rectangular Curve (FRC) printed monopole antenna is proposed. Initially, the iterative procedure to construct the fractal rectangular curve is described. The ability of the FRC to double its perimeter in every iteration was found triggering for examining its size reduction capability as a printed monopole antenna. The investigated FRC monopole resonates at the 2.45 GHz ISM (Industrial Scientific and Medical) band occupying the smallest area ($53 \text{ mm}^2 = \lambda_d/8 \times \lambda_d/36$), as compared to previously published fractal monopole geometries, such as the Koch and the Minkowski curve [2], [3]. Beyond its miniature size the FRC geometry proved to possess a very wide bandwidth and high input resistance as compared to other fractal geometries. The latter attribute makes it feasible for mounting at the center of the device’s ground plane without the need of a matching network, where a monopole traditionally sustains a substantial input resistance decrement. For this, the FRC monopole emerges as a good candidate for MIMO and multi-element antenna systems where multiple monopoles must be printed over a terminal device’s ground plane.

THE FRACTAL RECTANGULAR CURVE MONOPOLE ANTENNA
The shape of the proposed configuration stems from the “Squares Curve” [4], using a rectangular initiator instead of a square one and named after this as a Fractal Rectangular Curve (FRC). The FRC geometry was firstly proposed as a microstrip patch antenna radiator in [5]. It is constructed by applying a geometric transformation on the rectangle FRC-0 (Initiator) of Fig. 1a. By producing four more rectangles of a quarter of the area of FRC-0 and placing them at the four corners of the initiator as depicted in Fig. 1b, the pre-fractal FRC1 is obtained.

Figure 1. Construction of the fractal rectangular curve monopole antenna, a) FRC-0 (Initiator), b) FRC-1, c) FRC-2, d) FRC-3.
Repeating this adding procedure one more time at each rectangle placed at the four corners, results in the pre-fractal FRC2 (Fig.1c). The ideal fractal curve would be obtained by applying this iterative procedure an infinite number of times. However, for antenna applications a few iterations would suffice. The fractal rectangular curve monopole is constructed by following the trace of one side of the FRC as depicted in Fig. 1 (a)-(d).

**SIMULATED RESULTS**

The four antenna monopoles of Fig. 1 are printed on a dielectric over the device’s ground plane and placed at the edge of it, as depicted in Fig. 2. The dimensions of the ground plane are 45 mm wide and 90 mm long, which are typical for a portable terminal device. The monopoles use the ground plane, through current induction, to produce the other half of the dipole. The dimensions of the monopoles were chosen so as each of them to resonate at 2.45 GHz. The monopoles are printed on an 8 mils-thick substrate with relative permittivity $\varepsilon_r = 3.38$ and loss tangent, $\tan\delta = 0.0027$, having a 10 mils-trace (0.254 mm), while the thickness of the copper layers is 35 µm (1 ounce).

![Figure 2](image_url)  
Figure 2. Geometry and dimensions of the a) FRC-0, b) FRC-1, c) FRC-2 and d) FRC-3 monopole-ground plane system (not to scale).

The geometries of Fig.2 were simulated using the IE3D Method of Moments based electromagnetic field solver [6]. The computed input return losses (S11) of the investigated configurations are illustrated in Fig. 3a, where it can be seen that all monopoles resonate at 2.45 GHz ISM band. The reference impedance of the S11 parameters is different for every monopole, as depicted in the label of the Fig. 3a, since every monopole resonates at a different input resistance. The FRC-3 monopole occupies an area of $15.8 \times 3.4 = \lambda_d/8 \times \lambda_d/36 \approx 53 \text{ mm}^2$, which is the smallest area compared to previously published printed fractal monopoles, such as the Koch ($125 \text{ mm}^2$) [2] and the Minkowski ($64 \text{ mm}^2$) [3].

As a general principle antenna miniaturization is a compromise among volume, bandwidth and efficiency [1]. This can be viewed from Fig. 3b where the bandwidth and the input resistance at resonance are depicted as a function of the number of iterations. It can be seen that at the third iteration, the bandwidth and input resistance at resonance slightly decrease by 22 and 20 % respectively. Given that the efficiency of the above geometries is the same and independent of the iterations at a value of 94 %, it becomes clear that the size of the radiator is reduced at the cost of bandwidth. By comparing the FRC’s performance to previously published printed fractal monopoles such as the Koch and the Minkowski, two very important advantages arise. Firstly, the FRC-3 possesses a 770 MHz bandwidth, the widest reported as compared to the Koch and
the Minkowski, which have 490 and 280 MHz respectively. In addition, the input resistance of the FRC-3 at the corner of the ground plane is 84 Ω, whereas that of the Koch and Minkowski is 50 Ω [2], [3].

![Figure 3](image_url)

**Figure 3.** Computed results of the a) input return losses b) bandwidth and input resistance at resonance as a function of the number of iterations.

The inherent high input resistance of the FRC monopole makes it a good candidate for applications such as MIMO and multi-element antenna systems, where monopoles have to be printed at the center of the ground plane. It has been reported that as the monopole moves from the corner to the center of the ground plane, the input resistance of the monopole-ground plane system decreases substantially [2], [7], [8]. The FRC monopole, however, due to its inherent high input resistance can be fine-tuned at the center of the ground plane, where it exhibited an input resistance of 43 Ω and a 370 MHz BW, without the need of a matching network or ground plane corrugations.

**CONCLUSIONS**

A novel fractal rectangular curve monopole antenna was presented and its resonance characteristics were investigated based on simulated results. The fractal rectangular curve monopole proved to resonate at 2.45 GHz ISM band occupying the smallest area ($\lambda_0/8 \times \lambda_0/36 = 53 \text{ mm}^2$) as compared to previously published printed fractal monopole geometries. Furthermore, this novel geometry exhibited the ability to maintain a very wide bandwidth and high input resistance despite its miniature size. Its inherent high input resistance makes it a very good candidate for applications such as MIMO or multi-element antenna systems where monopoles have to be printed at the center of the ground plane.

**REFERENCES**