Experiences on Monopoles with the Same Fractal Dimension and Different Topology

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The effective use of the radian sphere surrounding an antenna improves its bandwidth.

Fundamental limit for antennas:

\[ Q = \frac{1}{ka} + \frac{1}{(ka)^3} \]

\( a \): radius of the smallest sphere that surrounds the antenna;
\( k \): wave number at the operating frequency.

Fractals are supposed useful for designing better small antennas thanks to

- their Fractal Dimension \( D (> D_{\text{straight monopoles}} = 1) \)
- and the space-filling ability of some fractal geometries.
Introduction (ii)

- Fractals are generated by an infinite iterative algorithm. Fractals are the attractors of these algorithms.

- ... but we are limited to the use of prefractals.
Introduction (iii)

Generating fractals:

- **Initiator**
- **Generator**
- **Prefractal**
- **Fractal**

**Multiple Reduction Copy Machine (MRCM)**

**Iterative Function System (IFS)**

\[ A_n = W[A_{n-1}] \]
\[ W[A] = w_1[A] \cup w_2[A] \cup \ldots \cup w_N[A] \]

\[ w_i[A] : \text{affine transformation} \]

scale - rotation - translation

\[ \lim_{n \to \infty} A_n = \lim_{n \to \infty} W[A_{n-1}] = A_\infty \]

IFS attractor indep. of \( A_0 \)
Fractals built with MRCM and IFS are self-similar curves.

A useful definition of fractal dimension $D$ for this kind of structures is the self-similarity dimension:

$$
\sum_{i=1}^{M} N_i \left( \frac{1}{s_i} \right)^D = 1
$$

$s_i$: scale of transformation.

$N_i$: number of copies of the initiator scaled with the same factor $s_i$.

$M$: number of scales (diff.)

$D$ of prefractals is considered to be the same that the $D$ of the fractal.
**Introduction**

- Changing the generator leads to different fractals although their $D$ could be the same.

- Moreover, different initiators lead to the same fractal. Each prefractal has the same $D$. 

![Fractal Images]
Introduction (vi)

- If prefractals are used to fabricate (wire) antennas, segments have different (wire) lengths and orientations among them.

- Expected EM behavior is not the same for these different structures.

- Expected performances are not the same in terms of radiation efficiency $\eta$, quality factor $Q$ and electric size $k_0a$ of the structures.

$a$: radius of the smallest sphere that surrounds the antenna;
Do *initiator* or *generator* influence the performance of an antenna even when the fractal has the same $D$?

If yes,

- it remarks the scarce influence of $D$ on the radiation performance of antennas
- it remarks the influence of topology on the effective design of antennas
In this Work... (i)

- We assess the influence of topology, more than $D$, on the behavior of prefractal antennas through simulations and measurements.

- Planar self-resonant wire monopoles selected.
  - easy fabrication procedures
  - no need for external compensation
  - analized with standard software
  - no need of baluns

- Comparison with some Euclidean monopoles to reach further conclusions.
In this Work... (ii)

- Prefractals generated using IFS algorithms.

- Analysis of prefractals with $D=1.58$ and $D=2.00$.
  - $D=1.58$ : Prefractals based on the Sierpinski gasket with different initiators
    - Delta Wired Sierpinski (DWS)
    - Y-Wired Sierpinski (YWS)
    - Koch-1 Sierpinski (K1S)
    - Sierpinski Arrowhead (SA)
In this Work... (iii)

- Simulated prefractals with D=1.58

- Delta Wired Sierpinski

- Y-Wired Sierpinski

- Koch-1 Sierpinski

- Sierpinski Arrowhead

\[ \frac{\lambda}{4} \sim 1.2 \text{ GHz} \]
In this Work... (iv)

- $D=2.00$ : Prefractals with the same $D$ and built with different generators
  - Peano curve (P)
    - 9 transformations
  - Peano variant 2 (Pv2)
    - 9 transformations avoiding crossings
  - Peano variant 3 (Pv3)
    - Networked IFS, 9 transformations
  - Hilbert (H)
    - Networked IFS, 4 transformations
In this Work... (v)

- Simulated prefractals with $D=2$

$\lambda/4 \sim 0.8$ GHz

Hilbert monopoles

Peano monopoles

Peano var.2 monopoles

Peano var.3 monopoles

$\lambda/4 \sim 1.2$ GHz
In this Work... (vi)

- Euclidean one-dimensional structures:
  - \( \lambda/4 \) monopole
  - Rhomb monopole
  - Triangular monopole
Simulations (i)

- Monopoles of $D=1.58$ and Peano monopole are made resonant at $\sim 1200$ MHz.
- Monopoles of $D=2$ made resonant at $\sim 800$ MHz.
- Copper wire, radius: 0.06 mm.
- Method of Moments software: NEC.
  - $0.5 \text{ GHz} \leq f \leq 1.5 \text{ GHz}$
  - $0.001 \leq \Delta/\lambda \leq 0.01$  $2.5 \leq \Delta/b$
  - Extended Thin Wire Kernel

- Computation of
  - Radiation efficiency
    \[ \eta = \frac{R_r}{R_r + R_\Omega} \]
  - Lossless quality factor
    \[ Q = \frac{\omega}{2R_r} \left( \frac{dX_{in}}{d\omega} + \left| \frac{X_{in}}{\omega} \right| \right) \]
Simulations (ii)

- Performance of prefractals with $D=1.58$
Simulations (iii)

- Performance of prefractals with D=2

lossless Q
Measurements (i)

- Fabricated structures using standard PCB techniques.
- FR4 substrate, 0.25 mm thick, 35 µm etching, 0.35 mm strips width.
- 80 cm x 80 cm ground plane and SMA connector.
- Wheeler cap method used to measure the radiation resistance of the monopoles (cylindrical cap).
- VNA used to measure impedances:
  - electrical delay
  - adjusting measurements to RLC model (McKinzie method)
Measurements (ii)

- Expected differences between measurements and simulations: wires/strips, dielectric substrate, freq. shift, real conductivity of copper, soldering losses, no connector/connector, finite ground plane, contact between cap and ground plane, NEC limitations when segments are close together and at bends.
Measurements (iii)

- Prefractal monopoles $D=1.58$
Measurements (iv)

- Prefractal monopoles $D=2$
  - Peano monopoles
  - Peano var. 2 monopoles
  - Peano var. 3 monopoles
  - Hilbert monopoles
Measurements

- Designed Euclidean monopoles

![Diagram of monopole designs](image_url)
Measurements (vi)

- Performance of prefractals with D=1.58

![Graphs showing performance of prefractals with D=1.58]
Measurements (vii)

- Performance of prefractals with D=2
Conclusion (i)

- Prefractals built with loops achieve lower $Q$ and higher $\eta$.
- Stagnation of performances of highly iterated prefractals built with loops show their trend to behave as certain Euclidean antennas.
- Prefractals built with a continuous wire achieve higher miniaturization ratios (lower $k_0a$) though worst $Q$ and $\eta$ values.
- Highly iterated prefractals built with a continuous wire reach unpractical performances (very low and very high $Q$).
Conclusion (ii)

- Compromise among loop and open wire structures is achieved with YWS (equal performance than \(\lambda/4\) monopole, size reduction: \(\sim 70\%\)).

- As expected, topology affects antenna performance \((k_0a, Q, \text{ and } \eta)\) more than \(D\).
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