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FractalComs
IST-2001-33055

Conclusions of the FractalComs Project:
Exploring the Limits of Fractal Electrodynamics for the Future Telecommunication Technologies

J.M. Rius[1], J.M. González-Arbesú[1], J. Romeu[1], A. Cardama[1], A. Heldring[1], E. Úbeda[1], J.R. Mosig[2], E. Cabot[2], R. Gómez[3], A. Rubio[3], M. Fernández Pantoja[3], F. García Ruiz[3], M. Giona[4], P. Burghignoli[4], G. Bugeda[5], M. Riera[5], J. Parrón[6]

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The FractalComs Partners

2002-2003

Electromagnetics & Photonics Eng. Group
Polytechnic University of Catalonia (UPC)
Barcelona (Spain)

Project leader, experts on antennas and microwave devices design and simulation, and early developers of fractal multiband antennas.

Lab. of Electromagnetics & Acoustics
Federal Polytechnic Institute of Lausanne (EPFL)
Lausanne (Switzerland)

Experts on numerical analysis and miniaturization of printed antennas and microwave circuits.

Dept. of Electromagnetics and Physics of Matter
University of Granada (UGR)
Granada (Spain)

Experts on electromagnetic theory and on time domain modeling, with experience on simulation of fractal antennas.

Interuniversity Research Center for Disordered Systems and Fractals in Chemical Engineering and Dept. of Electronic Engineering
"La Sapienza" University of Rome
Rome (Italy)

Experts on vector calculus along fractal curves and surfaces.

International Center for Numerical Methods in Engineering (CIMNE)
Barcelona (Spain)

Experts on adaptive meshing for numerical simulation.

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The FractalComs Objectives

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- Increase the know-how in Fractal Electrodynamics Theory:
  - Understand better the behavior of EM fields in fractal domains
  - Acquire guidelines for the design of fractal antennas
- Can fractal antennas reach the fundamental miniaturization bandwidth limit?
- Develop a software tool for computer simulation to allow a later design and optimization
  - Time domain visualization
- Explore the impact of the technological limitations on the performance of fractal-shaped microwave devices
  - Minimum detail size and loss efficiency.

The FractalComs Objectives (2)

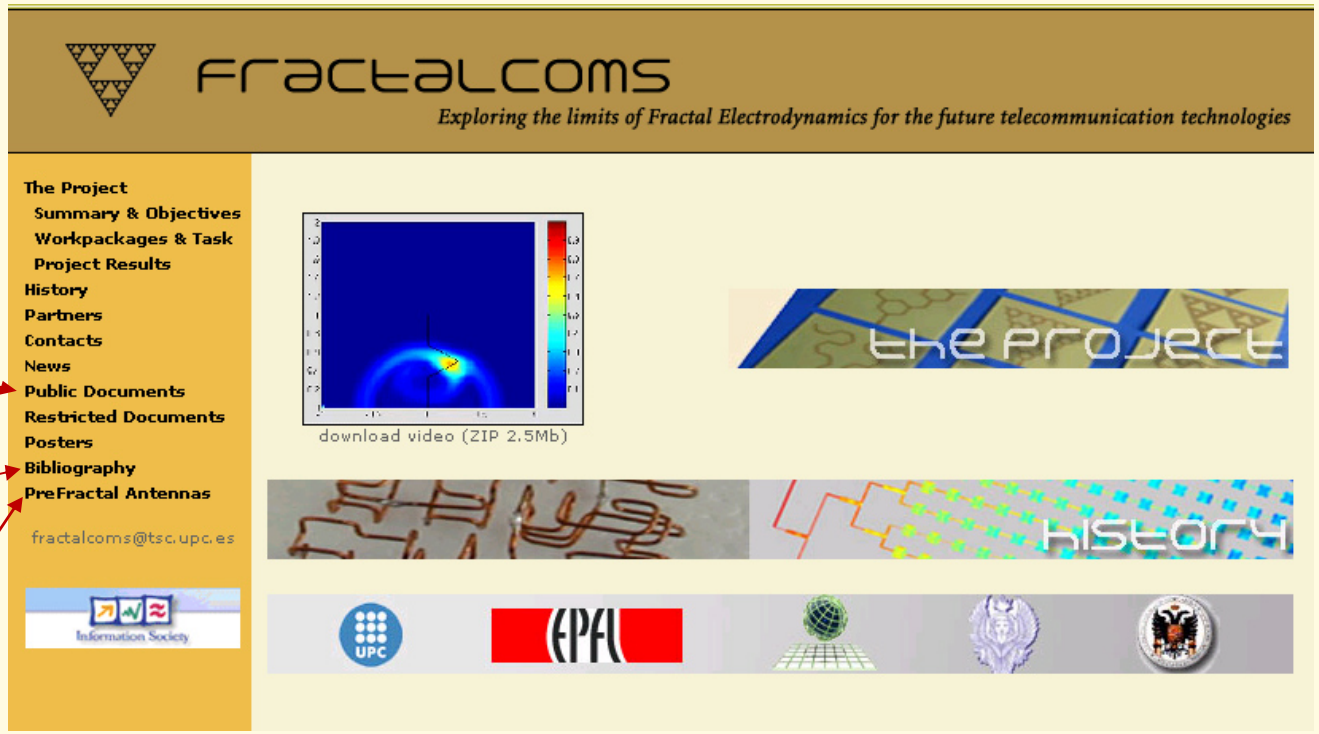
- It must be remarked that this is a FET project and therefore the main objective is an increase of knowledge. Fractal antennas are becoming increasingly popular and many European SMEs, driven by the need of offering up-to-date state-of-the-art products, may decide to tackle risks by including them in their production lines. This project should provide answers about the potential interest of fractal antennas, through a careful study of electrical performance vs. technological complexity trade-offs.

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The FractalComs Project Web Page

- http://www.tsc.upc.es/fractalcoms/



Project results and guidelines for the design of small antennas.

Almost 600 references on pre-fractal antennas.

Backgound on pre-fractal antennas for beginners.

World-wide State-of-the-art

- **Small antennas:**
  - **New Q-factor fundamental limit based on sinusoidal current distribution by Thiele et al. [2003]**
    - **Much higher Q than Chu-McLean fundamental limit**
    - **The new limit fully agrees with FractalComs project results**
- **Performance of pre-fractal antennas:**
  - **Work of S.R. Best [2002-2003]**
    - **Same conclusion as FractalComs Project**

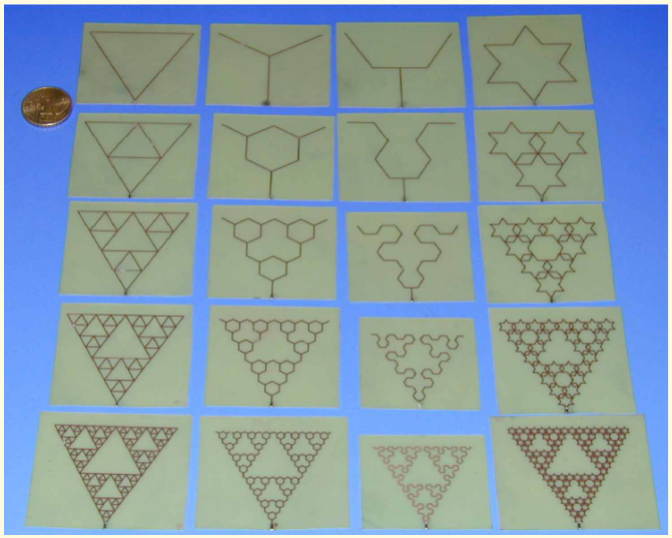
It is the topology of the antenna what determines the performance, regardless whether it is a conventional antenna or a pre-fractal one.

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Theory of Fractal Electrodynamics

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- **Influence of fractal dimension and topology on the antenna performance:**
  - Topology has a stronger influence than Fractal Dimension
  - Structures with or without loops show very different behaviour
  - More iterations: smaller electrical size, higher Q, lower efficiency

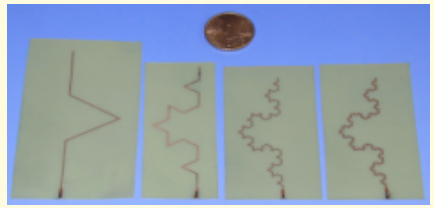


Delta Wired Sierpinski

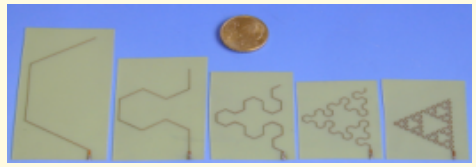
Y-Wired Sierpinski

Sierpinski Arrowhead

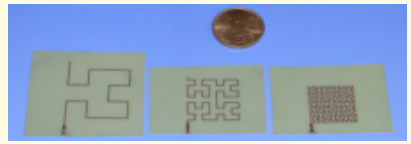
Koch-1 Wired Sierpinski



Koch



Sierpinski Arrowhead

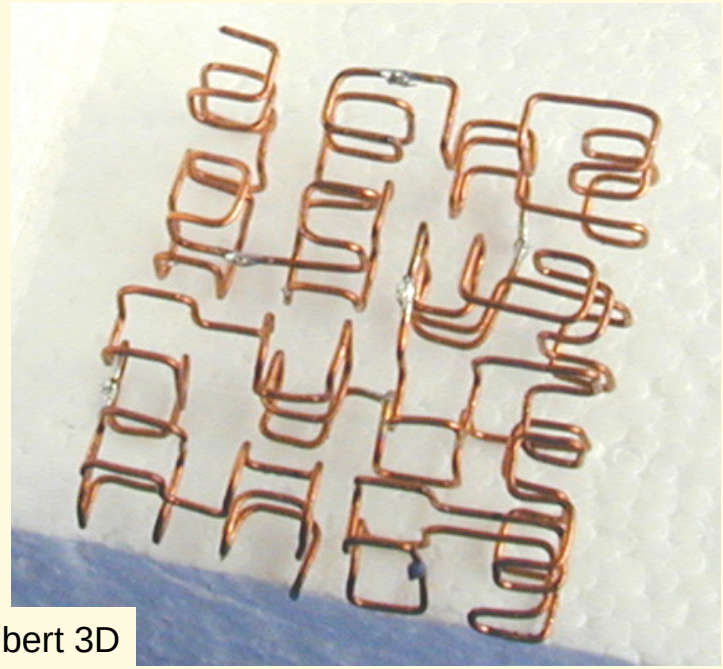


Hilbert

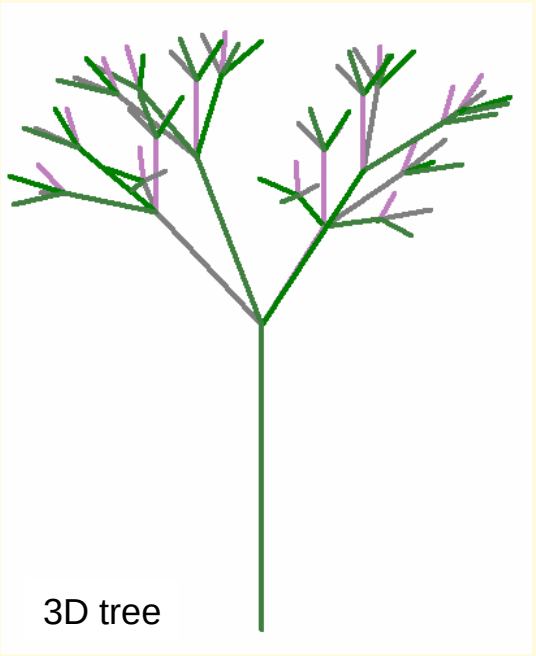
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Theory of Fractal Electrodynamics (2)

- **3D pre-fractals:**
  - **Do not provide further improvement in performance**
  - **Longer wire: higher Q-factor, lower efficiency ➡ unpractical**



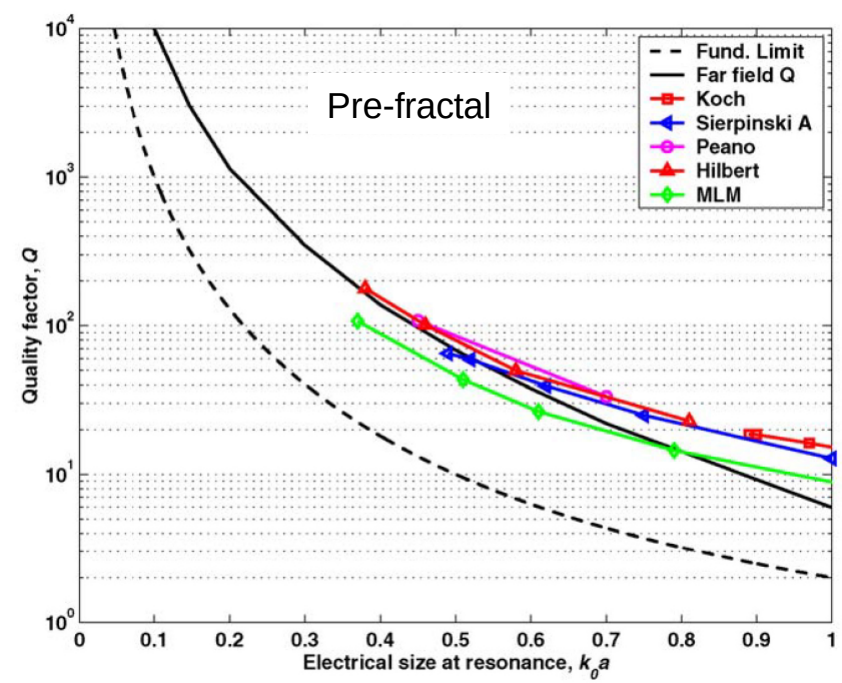
Hilbert 3D

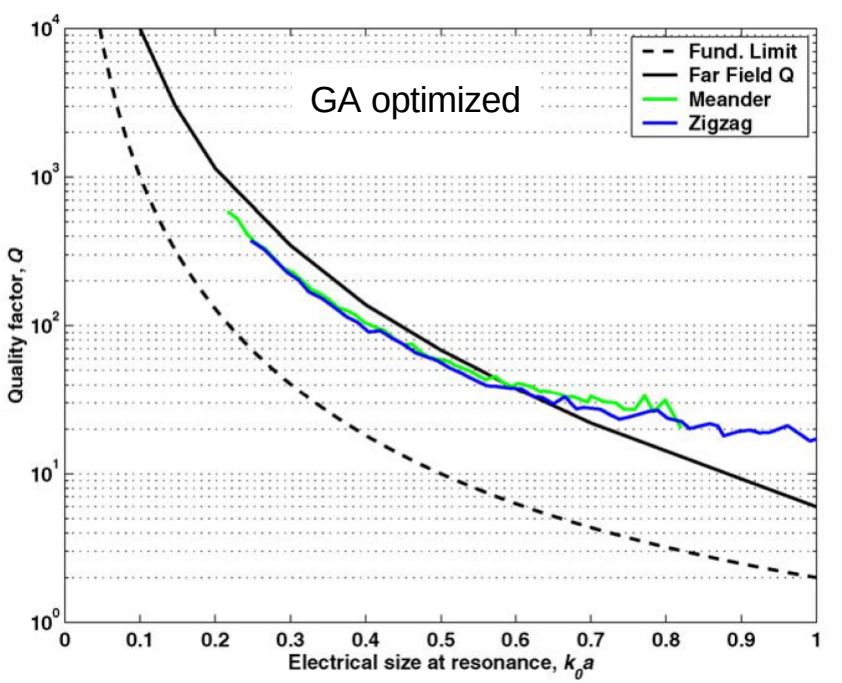


3D tree

Theory of Fractal Electrodynamics (3)

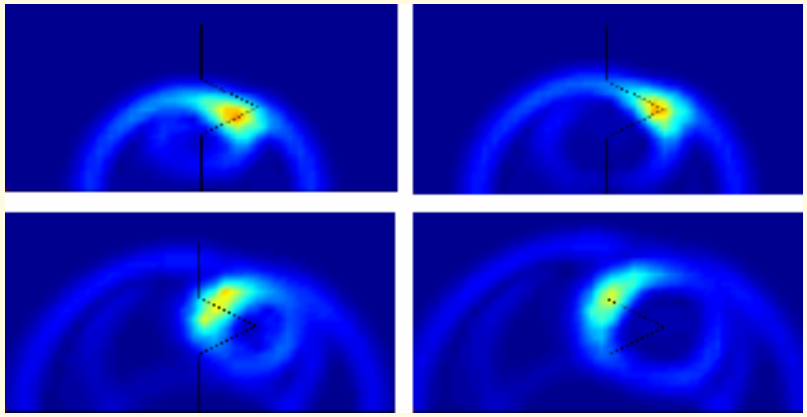
- **Fundamental bandwidth limit:**
  - **The new bandwidth limit formulation of Thiele et al. [2003] based on a sinusoidal current distribution along a wire antenna agrees very well with the results of the project**

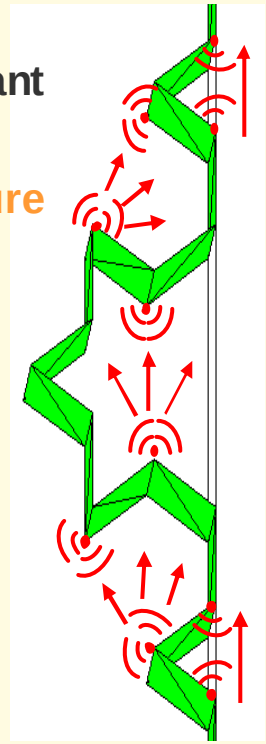




Theory of Fractal Electrodynamics (4)

- **Influence of couplings in the resonant frequency:**
  - **There is no use in increasing the number of IFS iterations beyond a limit given by the amount of coupling.**
  - **Capacitive coupling (or shortcuts) limit the decrease of resonant frequency with increasing wire length.**
  - **In order to avoid coupling, guidelines for the design of miniature wire monopoles have been derived.**





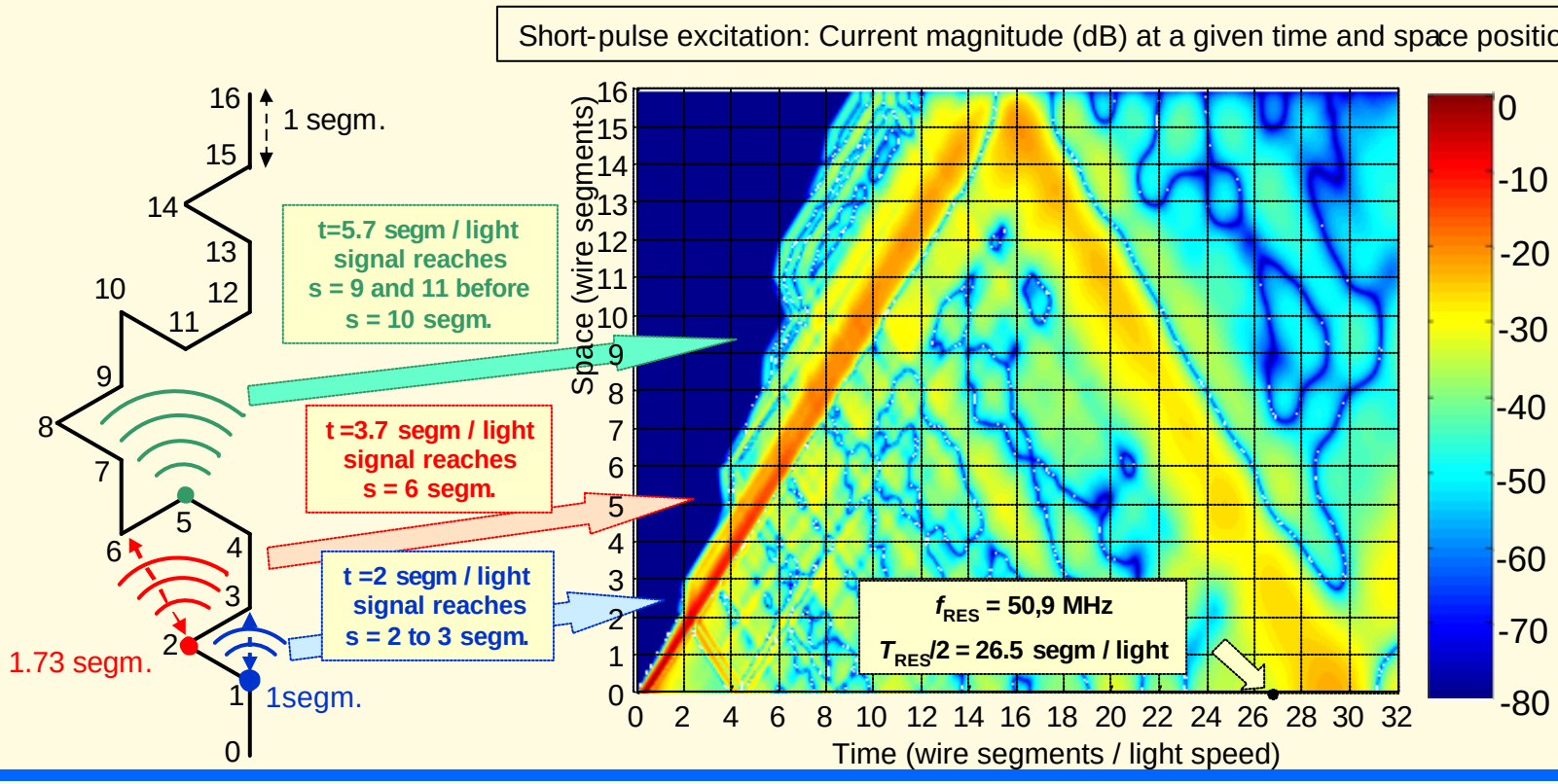
Software Simulation Tools

- Simulations in the frequency and time domains.
  - FIESTA-3D code optimisation (MoM + acceleration):
    - Acceleration of the MoM + MLMDA solution for certain structures generated by an IFS
    - CPU time and memory storage reduced one order of magnitude.
  - Thin-wire models with reduced kernel are useful for analysing low order pre-fractals:
    - NEC is useful for the simulation of such structures.
    - DOTIG is also useful for analysing low-order pre-fractal geometries.

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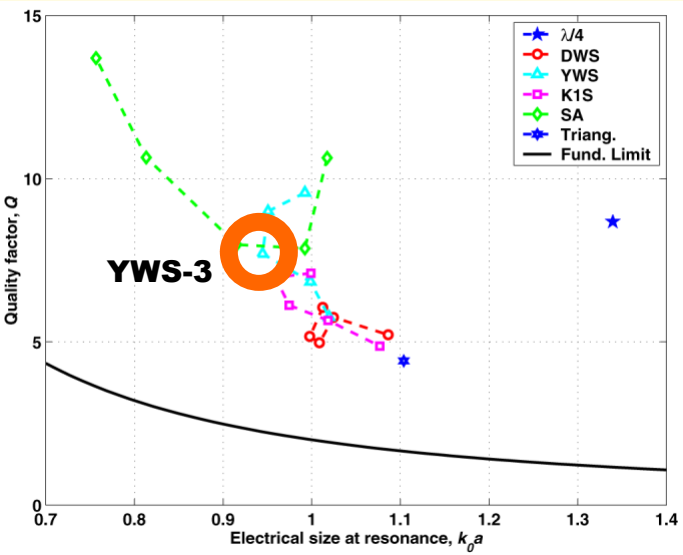
Software Simulation Tools (2)

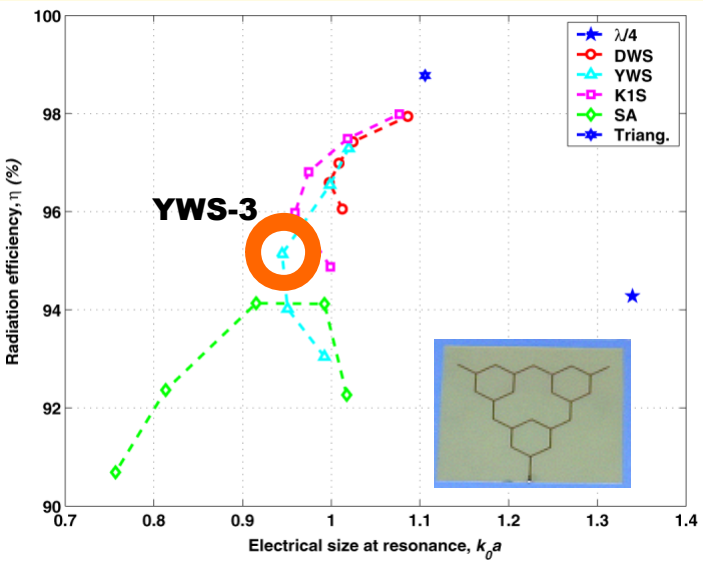
- **Many conclusions derived thanks to time domain animations and/or space-time diagrams.**



Fractal Devices Development

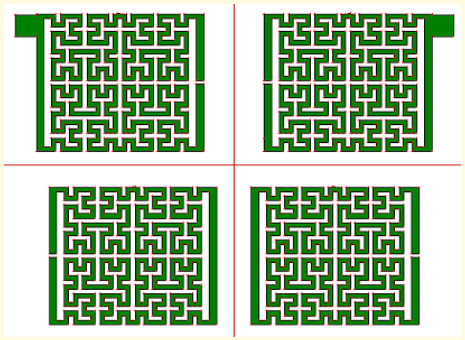
- **Several families of self-resonant pre-fractal monopoles have been designed and measured.**
  - **An optimum design among the Sierpinski family is a Y-wired Sierpinski (68% the size of a $\lambda/4$ monopole)**

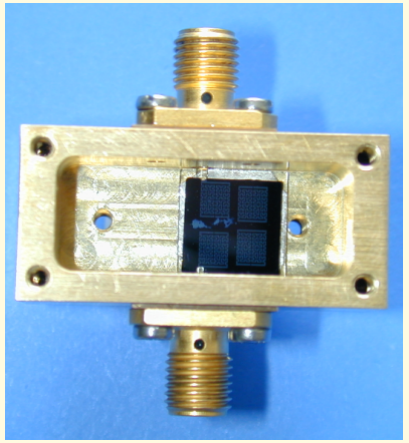


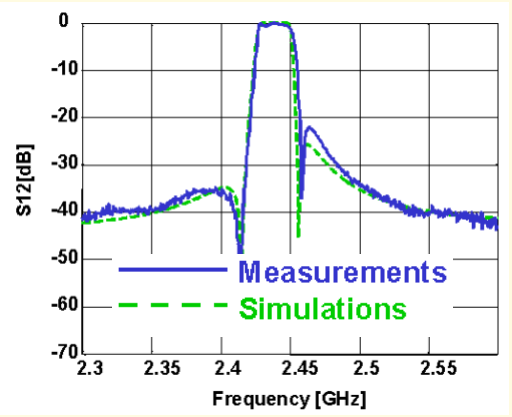


Fractal Devices Development (2)

- **Superconductor resonators and filters: small size, high Q, and low losses.**
  - **Quasi elliptical four poles filter at 2.45 GHz**





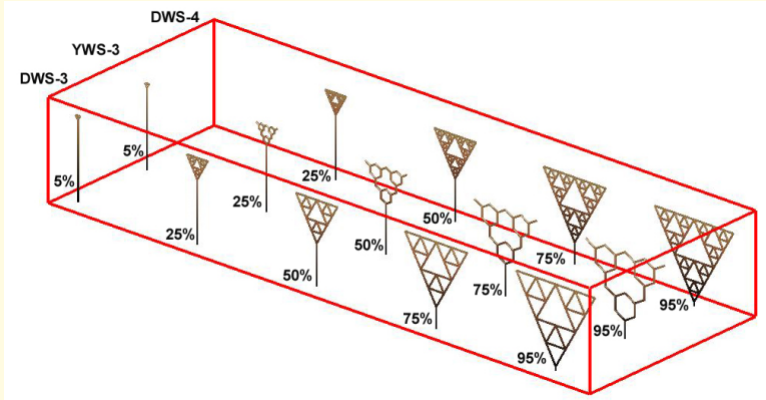


@ f_0=2.45 GHz BW= 20 MHz

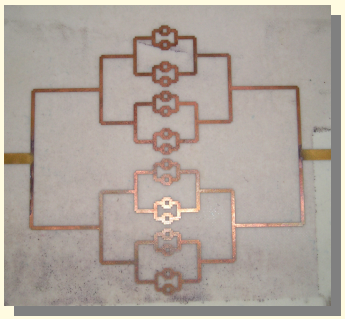
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Fractal Devices Development (3)

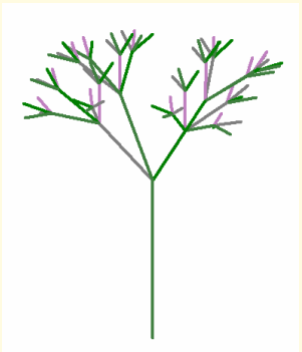
- **Pre-fractal loading of monopoles, genetically designed pre-fractal monopoles, pre-fractal trees, and capillary filters**



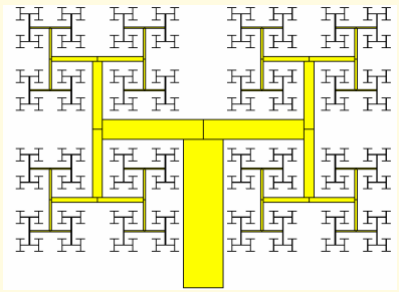
Pre-fractal loading of monopoles



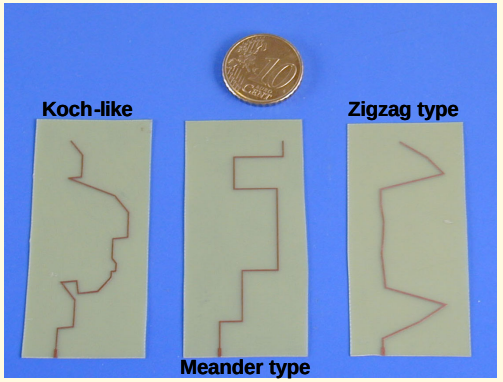
Capillary filters



3D pre-fractal tree



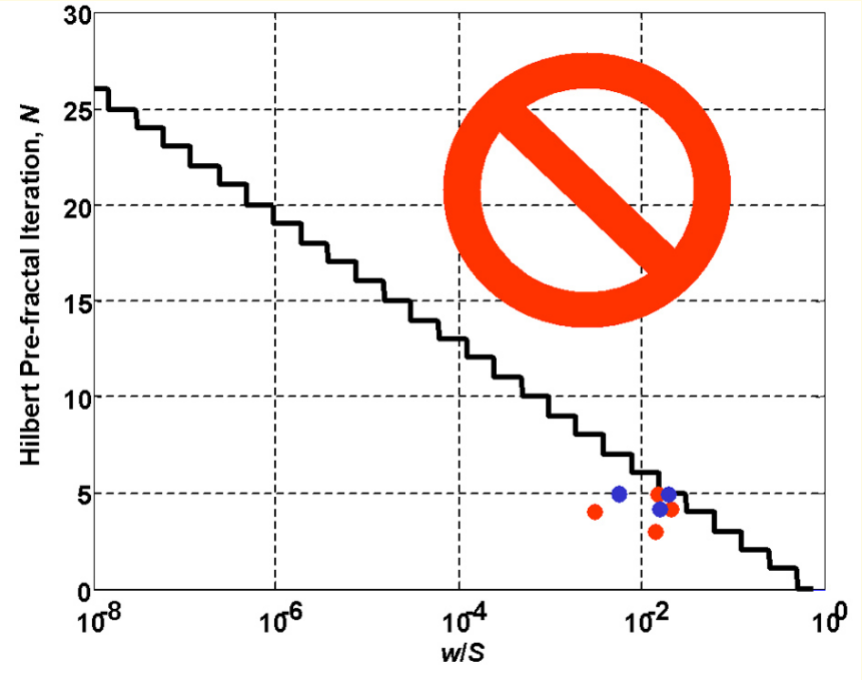
Pre-fractal H-tree



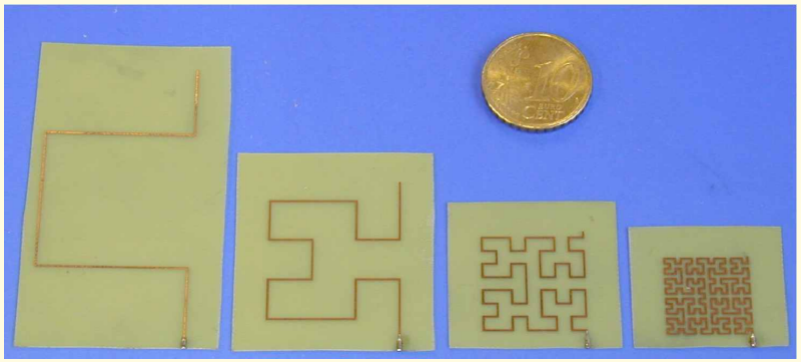
GA designs

Fractal Devices Development (4)

- **Technological limitations when fabricating pre-fractal devices**



measured simulated



Hilbert pre-fractal

$$N \leq \left\lfloor -\frac{\log \frac{w}{S}}{\log 2} \right\rfloor$$

N: maximum attainable iteration;
w: strip width or wire diameter;
l: segment length;
S: square size that encloses the Hilbert pre-fractal;

General Conclusions

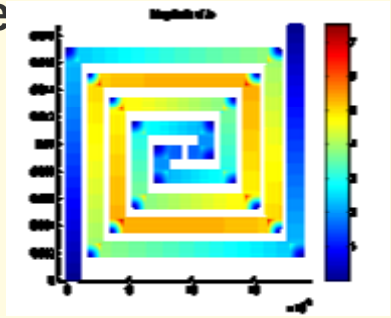
- The knowledge gained in understanding the behaviour of small pre-fractal wire antennas can be applied in using pre-fractal geometries to other EM devices
  - For instance, superconductive filter resonators
- The numerical analysis tools developed for the study of small wire pre-fractal antennas are able to analyse complex structures having:
  - a very large number of unknowns
  - very bad condition number

  and thus can be used with advantage in the analysis of complex high-detailed small near-resonance structures, such as PBG, metamaterials, etc.

General Conclusions (2)

- **The conclusions derived from the behaviour of small wire pre-fractal antennas lead to useful design criteria for better small wire antennas.**

  - **Following these criteria, the two-arm square Archimedean spiral antenna achieves the highest degree of miniaturization with respect to the resonant frequency for a planar antenna fitted in a square**



General Conclusions (3)

- **Pre-fractal IFS provide a systematic algorithm to pack a long wire into a small space Þ miniature devices**
  - **High Q Þ bad for antennas but very good for resonators**
  - **High losses Þ use superconductive materials**

Very selective miniature filters with pre-fractal resonators

- **Details: http://www.tsc.upc.es/fractalcoms/**

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