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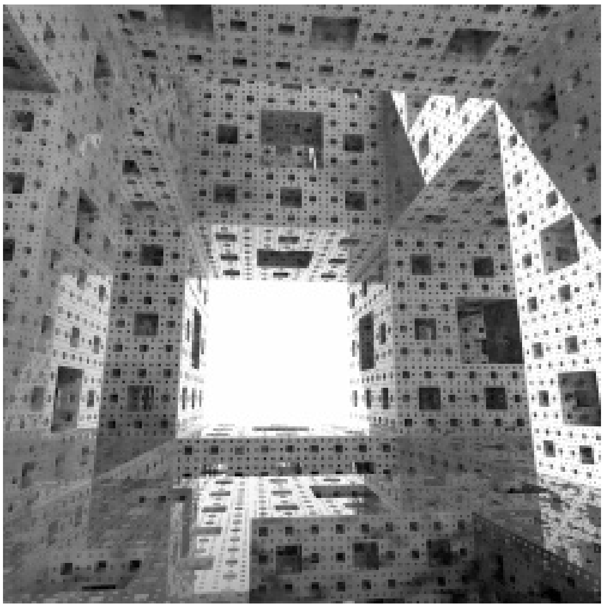
FRACTAL MINIATURIZATION IN RF AND MICROWAVE NETWORKS

Fractal Technology in the Wireless World

Fractals are bringing forth a new generation of miniature RF and microwave passive networks for wireless devices. Any wireless system relies on an RF front-end which includes matching networks, filters, diplexers, along with other passive elements such as capacitors, inductors and resistors. No matter whether the system is as powerful as a cellular base-station, as sensitive as a super conducting satellite receiver or as small as a system-on-chip wireless device, the miniaturization and integration of such a front-end becomes always a key issue in terms of performance, robustness, packaging and cost.



Fractals are reaching every corner of the wireless world

Fractal technology has been already applied in the miniaturization of another essential part of the wireless front-end: the antenna. Miniature Fractal Antennas® for handsets, PDAs, cellular base-stations and cars are allowing multimedia, high-speed data applications to be introduced in every small corner of the wireless world. The size compression and multiband capabilities of fractals allows efficient, broadband and multipurpose devices to be packed in places that were at length inaccessible due to size, weight, or appearance constraints. Based on an analogous principle to the antenna miniaturization capabilities, fractal technology has been recently proven to become the most efficient way in packaging RF and microwave networks as well.

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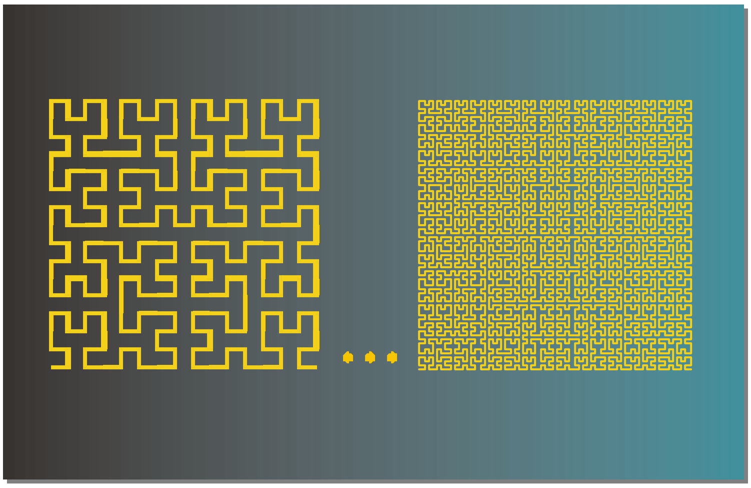
Fractal Miniaturization of Passive Networks

The bottleneck in the miniaturization of reactive components such as filters and resonators comes from a very well know geometric principle. Any high quality factor (Q) resonating structure needs to keep a certain size relative to the working wavelength. In most wireless and RF applications, such as cellular systems (GSM900, PCS, UMTS), satellite applications (GPS) and WLAN/PAN systems (Bluetooth™, HiperLAN/2, IEEE802.11), the wavelength range from 30 cm to 5 cm entails the need of too much space for the new generation of ever shrinking wireless devices.

Some basic notions such as size and dimension must be looked at from a completely different perspective when dealing with fractal geometry. Infinite length objects that fit any small surface and fractional dimension structures that fill the space in a more efficient way are common examples of the amazing capabilities of fractal objects and geometries. It is precisely due to those capabilities that long wavelengths can be fitted in small spaces.



The Hilbert curve – Two different iterations. The curve growths exponentially at each iteration and completely fills up a squared surface. There is not a better way to package the same length in a smaller surface.

One of the most appealing examples of a space-filling fractal geometry is the Hilbert curve. With a fractal dimension D=2, the curve ideally features an infinite length and fills up every corner in a bounded squared surface. Still preserving its properties as a curve, the object is no longer one-dimensional but approaches a two-dimensional surface. Such an amazing kind of space-filling property is common to most fractal shapes; in fact, nature has been using such properties

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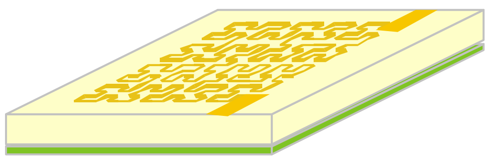
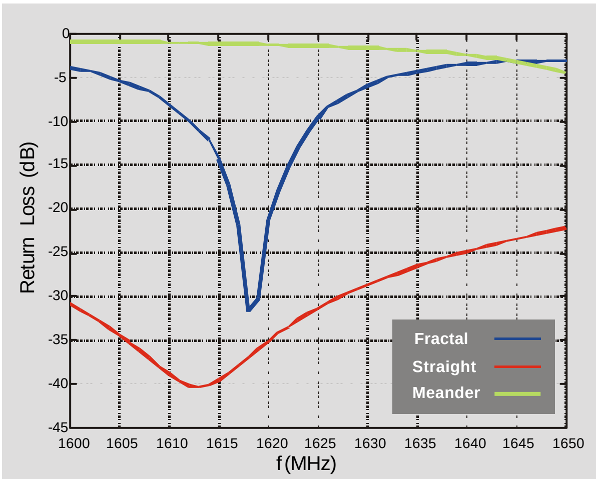
for millions of years to optimise the energy transportation in living organisms and many mathematical fractal shapes find their close relatives in natural forms. This is why fractals are The Technology of Nature®. It is also due to those properties that such a technology provides the maximum shrinking capabilities for planar microwave filters, resonators and passive devices, no matter whether the device is integrated inside a microwave integrated circuit (MMIC), a surface mount device (SMD), or a miniature, low-cost high-temperature super conducting device (HTS).



The planar Hilbert Resonator is a high Q microstrip filter. Patent WO0154221.



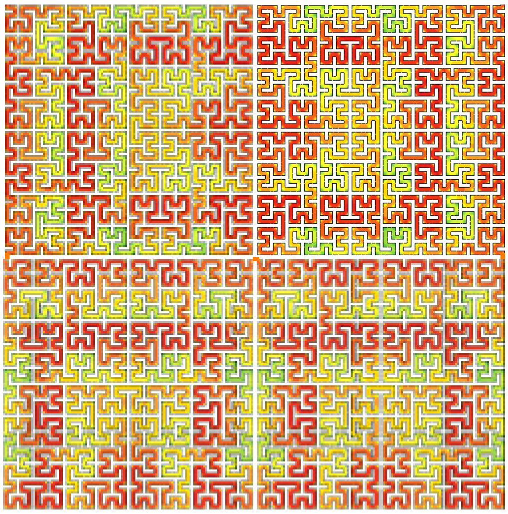
Comparison between a conventional half-wavelength resonator, a meander line resonator and a Hilbert fractal resonator.

Miniature Fractal Filters and Resonators

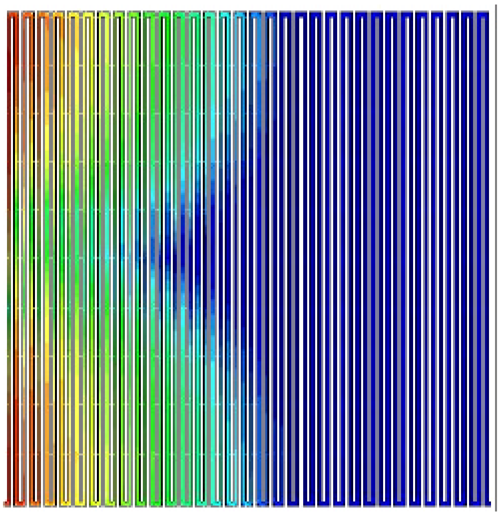
One of the critical issues in the performance of a reactive component is the Quality Factor (Q). The highest the Q, the better the component. In filtering applications, the Q is directly related to sharpness of the pass-band to reject-band transition, to the minimum bandwidth and to the insertion loss of the filter. The Q is degraded by ohmic losses, but enhanced with storage of reactive energy. In general terms, the performance of a small filter is related to the ability of the resonating structures of the filter in storing as much reactive energy as possible in the available volume.

A good example of the energy-storing capabilities of fractals is the Hilbert resonator. Due to the unique space-filling properties of fractals, a very long but small resonator can be efficiently packed into the same space as a conventional half-wavelength resonator yet featuring a Q factor which is about **10 times larger** (see figure above).

Again, this behavior can be linked to unique geometrical features of fractals and their space-filling properties. Due to the very long length of the strip, electromagnetic waves are bouncing back and forth and travelling for a longer time inside the resonator which results in a much higher stored energy. It is interesting noticing that a meander structure with the same length and area as the Hilbert resonator is not resonating at the same frequency. The reason is that the coupling between turns in a meander structure is much higher due to the longer length of the turns, while in the fractal structure the size of the turns is reduced at the same rate as the length of the curve increases. In terms of geometry, the Hilbert curve is a self-avoiding curve that maximizes the distance with itself at each fractal iteration while the meander line tends to lose its linear curve properties when trying to fill the same bounded region.



The Hilbert resonator operating at a high-order, high-Q mode. It maximizes the stored reactive energy in the available space. Patent WO0154221.



A meander resonator with the same length, stripline width and operating at the same-frequency as the Hilbert resonator on the left. Due to multi-turn coupling the structure is not resonating.

Beyond the high Q performance of the fractal resonator, one of the most astonishing features is its shrinkage capability. For instance, when operated at

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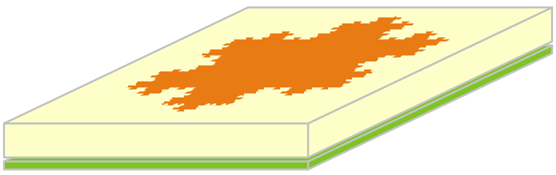
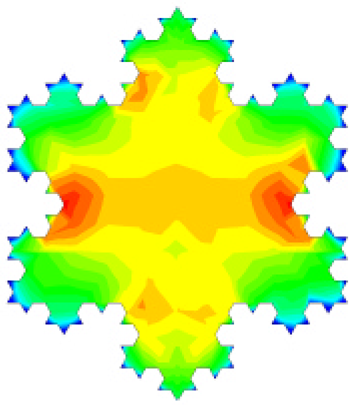
the fundamental mode, the microstrip resonator can be packed in an area which is smaller than **1/10.000th** of the squared wavelength. Also, the resonator can be packed in a linear space which is **30 times shorter** than the equivalent straight half-wavelength resonator printed over the same substrate.

Of course, these and other related fractal geometries can be used to shape other components such as transmission lines, matching stubs, delay lines and alike. In general, in any application where the wavelength is large and a high-density package integration is convenient, fractals provide the optimum packaging technology.

Another example where fractal geometry improves the performance of conventional resonating structures is the microstrip cavity or microstrip patch resonator. In this case, the fractal structure is the boundary enclosing the patch. Again, when comparing the resonator with a conventional circular patch built in the same substrate and operating at the same resonant frequency, a patch like the Koch fractal (see figure below) features a **60% surface reduction** with at least a **30% increase in the quality factor**.



The Koch island patch resonator (left). Patent WO0154221.



Fundamental resonant mode on the Koch island patch resonator.

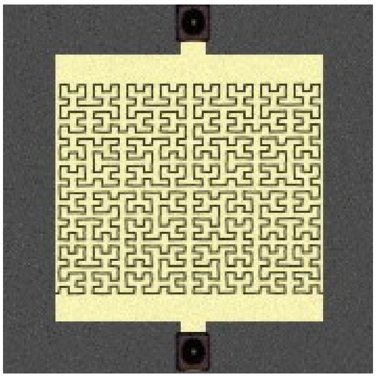
Such a surface reduction and Q factor increase is linked to a phenomenon called Localization, which is typically observed in fractal resonators. By means of this phenomenon, most of the stored energy is trapped in the boundary of the resonator, which features a high storing capability due to the particular geometrical characteristics of the fractal boundary. These features are of most interest in those high-tech applications where the cost of the substrate material is a key limiting factor (such as HTS filters) and where the best performance is required.

Miniature Fractal Integrated Passives

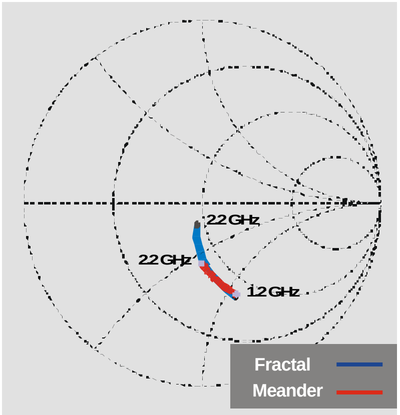
Beyond the miniaturization and integration of filters and resonators, the benefits of fractal technology extend to many other passive devices. Integrated passive components such as capacitors, inductors and resistors, in the form of SMD, flip-chip (chip arrays) or as building blocks in MMICs, are improved in terms of package density and performance.

Fractal Planar Capacitor

High-density planar capacitors are an example of how fractal geometry can be used advantageously in the field of passive integrated elements. In a planar capacitor, capacitance is limited by the width and length of the gap that spaces two co-planar conducting surfaces. Therefore, planar capacitors always feature a lower capacitance than parallel plate capacitors due to its linear geometry as opposed to the surface geometry of the later. Using two-dimensional fractal curves, the gaps tend to approach the surface behavior maximizing the capacitance per unit of surface that can be obtained in such planar configuration. In other words, an arbitrarily large gap-length can be packed in an arbitrarily small area, with the only limitation of the resolution in the manufacturing procedure. Studies comparing a fractal planar capacitor versus a conventional interdigital capacitor, with the same element size, gap length and width, illustrate some of the benefits of the fractal capacitor. As it can be observed in the Smith Chart, the capacitance



A fractal planar capacitor that approaches a surface capacitor. Patent WO0154221



Comparison between fractal and interdigited capacitor performance

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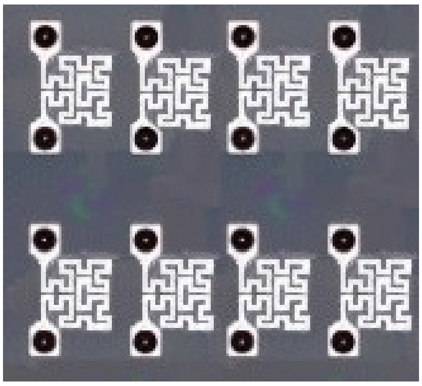
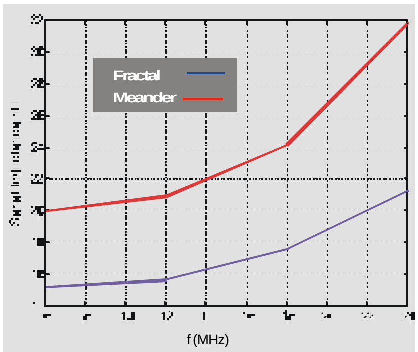
value of the fractal design is higher than for the traditional interdigital element in a wide frequency range.

Fractal Resistors

The same space-filling properties that provide a high capacitance in the case of planar capacitors are also in the base of the low-Q, high value fractal resistors. Since an arbitrarily large length of resistive material can be packed in an arbitrarily small area (with the only limitation of the manufacturing resolution), resistance per unit surface is maximized. At the same time, the parasitic serial inductance is minimized due to the ability of the fractal shape of filling space while maximizing the distance with itself due to its self-avoiding geometrical property. As per the case of the capacitors, the design of microwave resistors based on fractal geometries shows the mentioned advantages comparing to the state-of-the-art geometries. Again, a fractal shaped resistor is compared to a conventional resistor, showing a smaller parasitic serial inductance (right). It is important to stress that this result is obtained with exactly the same length and width (resolution) of resistive material packed in the same area.



A Hilbert resistor array in a flip-chip package. Patent WO0154221



Parasitic serial inductance: comparison of fractal and conventional resistors. Both features the same resistor length and area, but the fractal one introduces lower parasitic inductance.

Miniature filters and high Q resonators, high value capacitors and low parasitic resistors. These are just some few examples of the benefits of using a cutting-edge technology in the design of passive network elements and components. And there is much more: miniature matching transmission lines and networks, compact delay lines, single turn inductors, miniature ring resonators. Where ever there is a requirement in improving passive components, fractals provide the most advanced solution.

The Technology of Nature®

Fractal technology opens a new scope of opportunities in the miniaturization of passive RF and microwave components. In the frame of the next generation of wireless devices where miniaturization and performance will make the difference, fractal technology is ready to provide with the most competitive solution. Miniature filters, resonators, inductors, capacitors, resistors and related passive devices are now getting benefit from such a cutting edge technology inspired in nature.

Fractus is a cutting-edge technology company in the field of miniature and multiservice passive microwave devices. We were the pioneers in introducing fractal technology in the wireless market through our Fractal Antennas® products for cellular networks and terminals, and we own a solid and broad patent portfolio to ensure the maximum competitive advantage of our custommers. Fractus consistently led the way in creativity and we know exactly what is needed: innovation, performance, flexibility, support, quality, and teamwork. Your company believes in honouring these commitments. And so do we at Fractus.

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