Fractal Structures for Electronics Applications

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Fractal – “broken, fragmented, irregular”

“I coined *fractal* from the Latin adjective *fractus*. The corresponding Latin verb *frangere* means "to break" to create irregular fragments. It is therefore sensible - and how appropriate for our need ! - that, in addition to "fragmented" (as in *fraction* or *refraction*), *fractus* should also mean "irregular", both meanings being preserved in *fragment*. ”

B. Mandelbrot :

The fractal Geometry of Nature, 1982

Fractals in nature

A naturally occurring fractal is one in which it's pattern is found somewhere in nature.

A few examples where these recursive images are seen are trees, ferns, fault patterns, river tributary networks, coastlines, stalagmite, lightning, mountains, clouds.

Several of the examples just listed are also structures that are mimicked in modern computer graphics.

http://classes.yale.edu/fractals/Panorama/Nature/NatFracGallery/Gallery/Stalagmite.gif

http://classes.yale.edu/fractals/Panorama/Nature/Rivers/Norway.gif

http://classes.yale.edu/fractals/Panorama/Nature/Rivers/Waterfall1.gif

Fractal geometry: the language of nature

- Euclid geometry: cold and dry
- Nature: complex, irregular, fragmented

"Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line."

Practical measurements

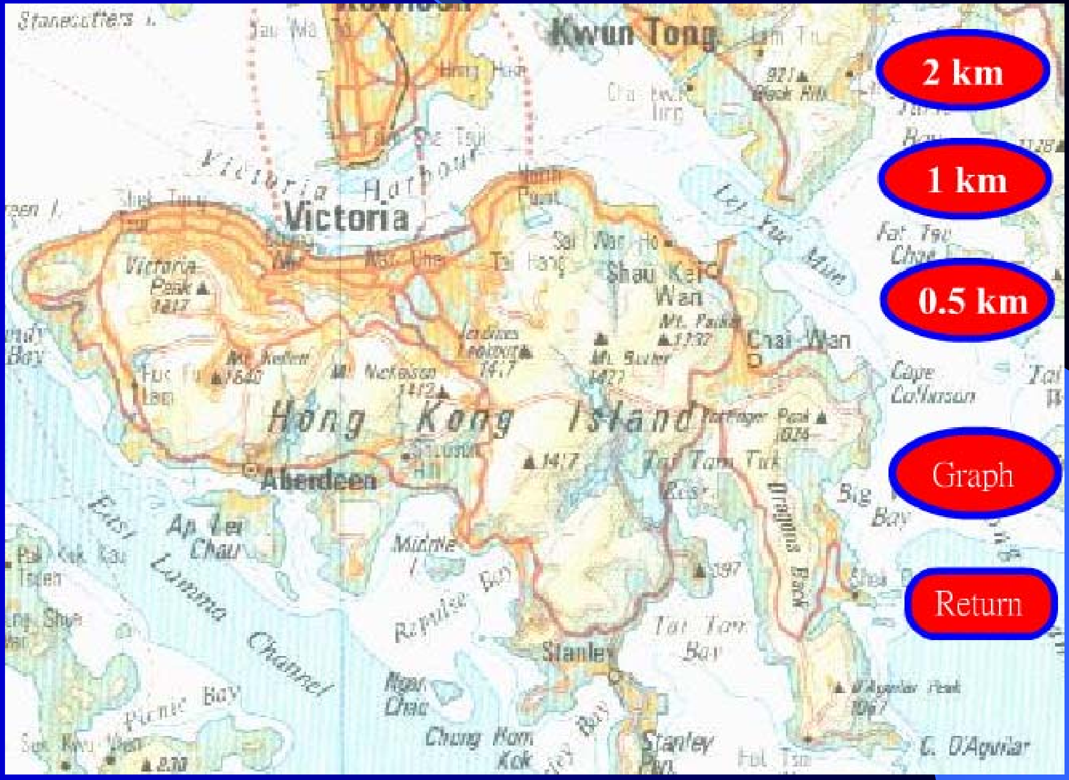
- There is no formula for coastlines, or defined construction process.
- The shape is the result of millions of years of tectonic activities and never stopping erosions, sedimentations, etc.

- In practice we measure on a geographical map.
- Measurement procedure:
  - Take a compass, set at a distance *s* (in true units).
  - Walk the compass along the coastline.
  - Count the number of steps *N*.
  - Note the scale of the map. For example, if the map is 1:1,000,000, then a compass step of 1cm corresponds to 10km. So, *s*=10km.
  - The coast length ≈ *sN*.

The Hong Kong coast

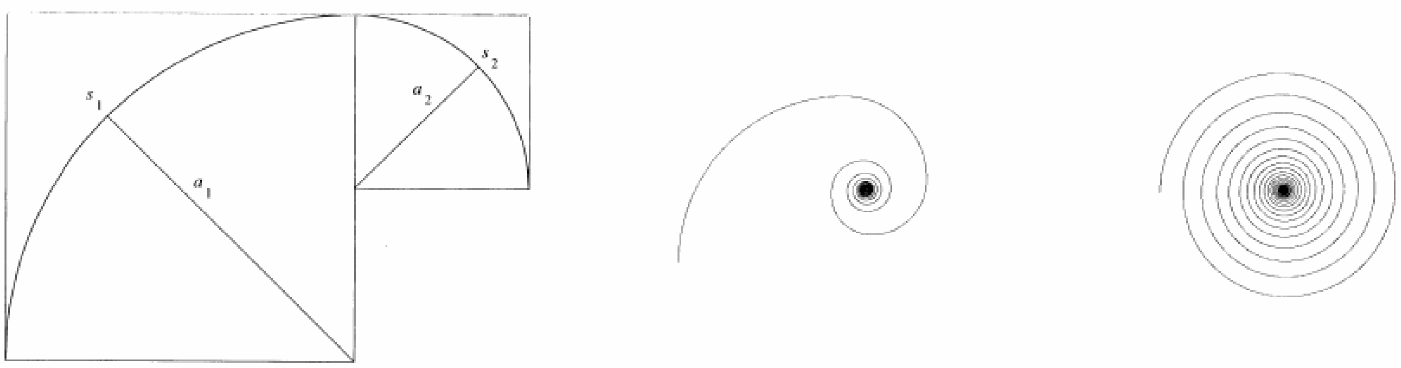
- Apply the procedure with different s.
- Results:
  - **The measured length increases with decreasing *s*.**

Compass step *s*	**Length *u***
2km	43.262km
1km	52.702km
0.5km	60.598km
0.1km	69.162km
0.02km	87.98km



Notion of length

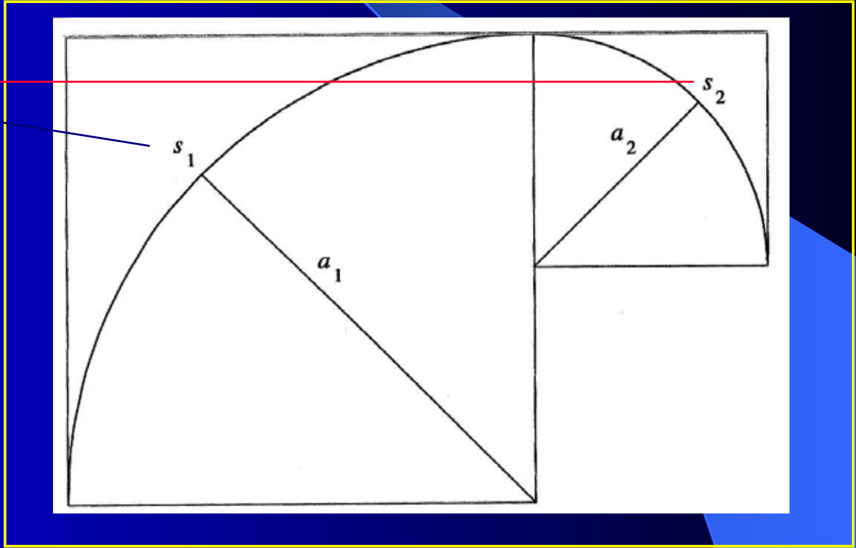
- **Fractal geometry generalizes ordinary notions of length, scale, and dimension in interesting and subtle ways.**
  - For length, classical example is coastline length of a given country or border.
    - Result depends on fineness of *scale* used—as scale goes down, length goes up.
    - Ratio of scale to length gives rise to new notions of dimension.
  - Spirals provide another excellent example countering intuition about length.
    - *Example:* Smooth polygonal spiral can have finite or infinite length depending on method of construction.



Construction Method — Infinite length ($a_k = 1/k$) — Finite length ($a_k = 0.95^{k-1}$)

Answer: A
Spiral 1 is infinitely long but Spiral 2 isn't.

- Quarter circles of progressively decreasing radius.
- $s_1 = \pi a_1/2$
- $s_2 = \pi a_2/2$



- Length = $\frac{\pi}{2}\sum_{i=1}^{\infty} a_i$

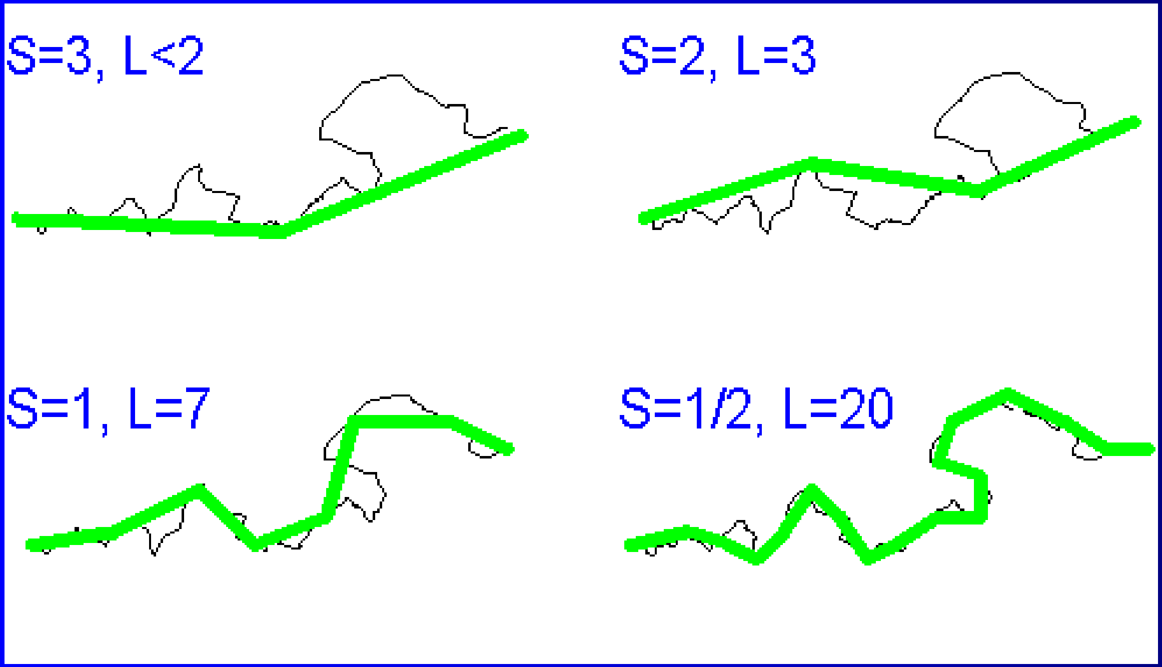
- If $a_i = 1, q, q^2, q^3, \ldots, q^{i-1}, \ldots$, then length is finite (right one, q=0.95).
- If $a_i = 1, 1/2, 1/3, 1/4, \ldots, 1/i, \ldots$, then length is infinite (left one).

Euclid dimension

- In Euclid geometry, dimensions of objects are defined by integer numbers.
- 0 - A point
- 1 - A curve or line
- 2 - Triangles, circles or surfaces
- 3 - Spheres, cubes and other solids

Length of the coastline of Britain

$$D = \frac{\ln(L_1)/\ln(L_2)}{\ln(S_1)/\ln(S_2)}$$



- For a square we have N^2 self-similar pieces for the magnification factor of N

dimension=log(number of self-similar pieces) /log(magnification factor)

$$=\log(N^2)/\log N=2$$

For a cube we have N^3 self-similar pieces

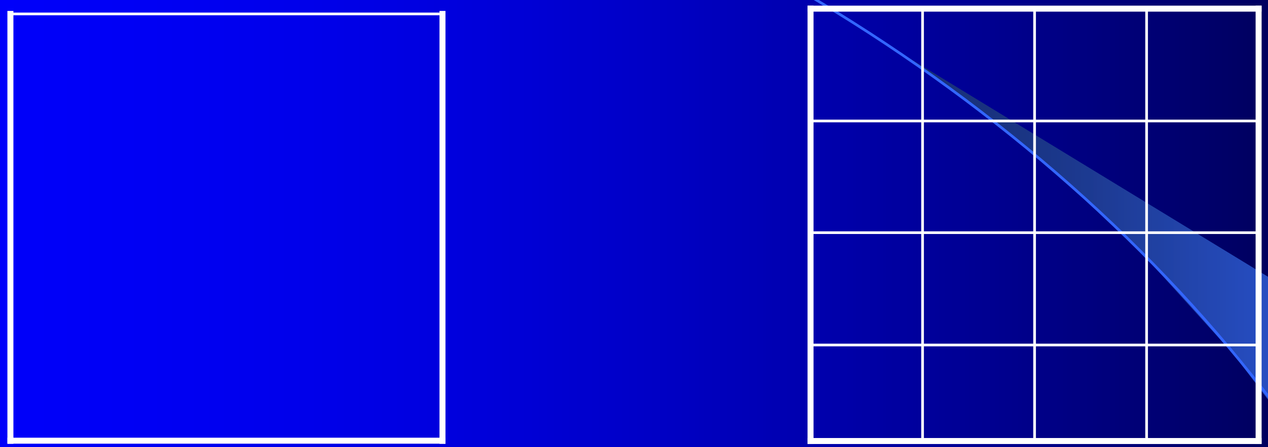
dimension=log(number of self-similar pieces) /log(magnification factor)

$$=\log(N^3)/\log N=3$$

Sierpinski triangle consists of three self-similar pieces with magnification factor 2 each

dimension=log3/log2=1.58

Dimension of a two dimensional sqaure



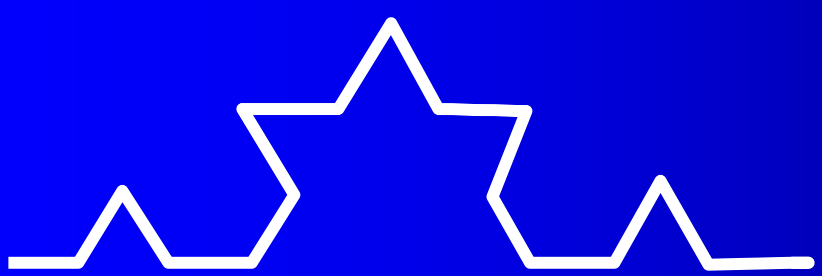
Fractal dimension

- Fractal dimension can be non-integers
- Intuitively, we can represent the fractal dimension as a measure of how much space the fractal occupies.

- Given a curve, we can transform it into 'n' parts (n actually represents the number of segments), and the whole being 's' times the length of each of the parts. The fractal dimension is then :

$$d = \log n / \log s$$

Scaling/dimension of the von Koch curve



- Scale by 3 – need four self-similar pieces
- D=log4/log3=1.26

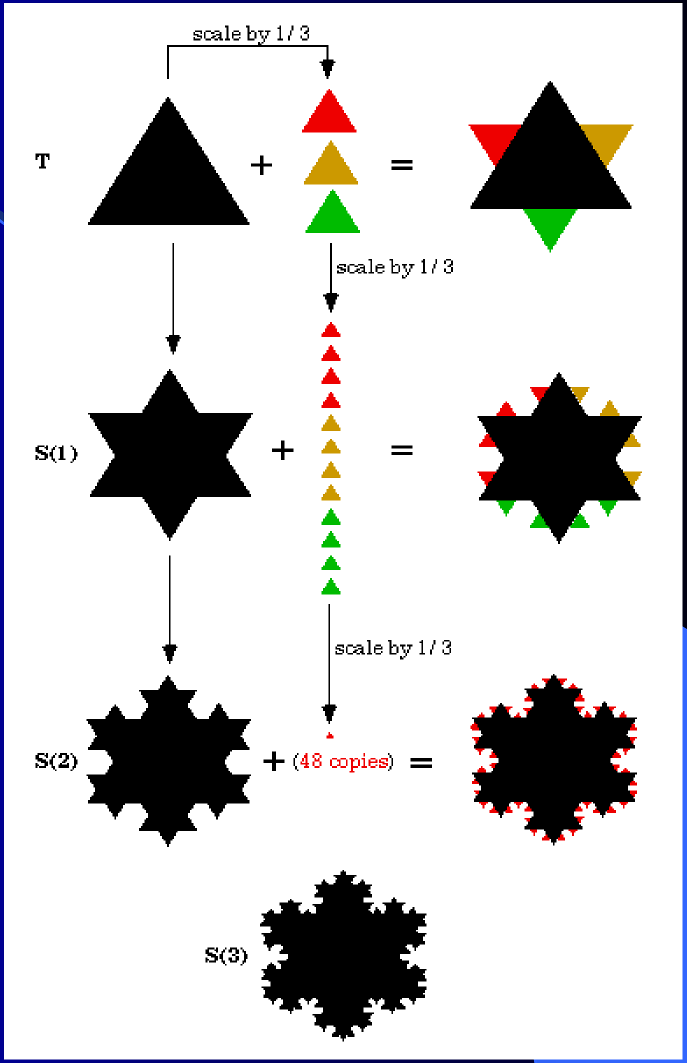
mathematical fractal: Konch Snowflake

- Step One.
  Start with a large equilateral triangle.
- Step Two.
  Make a Star.

1. Divide one side of the triangle into three parts and remove the middle section.
2. Replace it with two lines the same length as the section you removed.
3. Do this to all three sides of the triangle.

- Repeat this process infinitely.

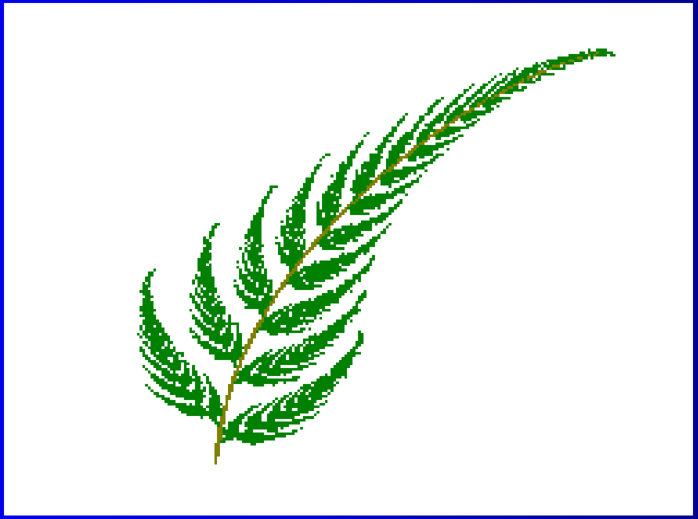
- The snowflake has a finite area bounded by a perimeter of infinite length!



Definition: Self-similarity

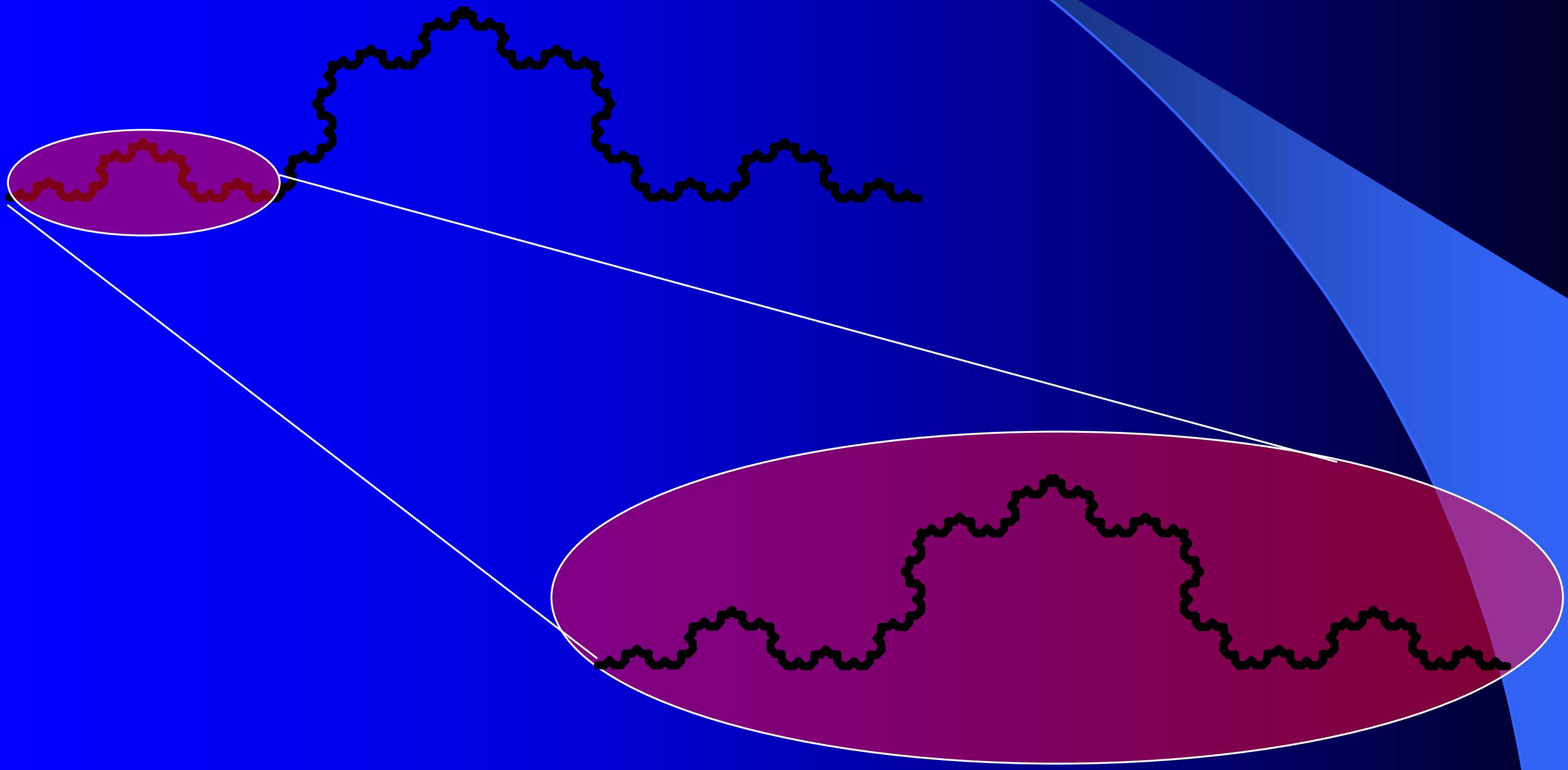
– A geometric shape that has the property of self-similarity, that is, each part of the shape is a smaller version of the whole shape.

Examples:



Self-similarity revisited

Self-similarity in the Koch curve

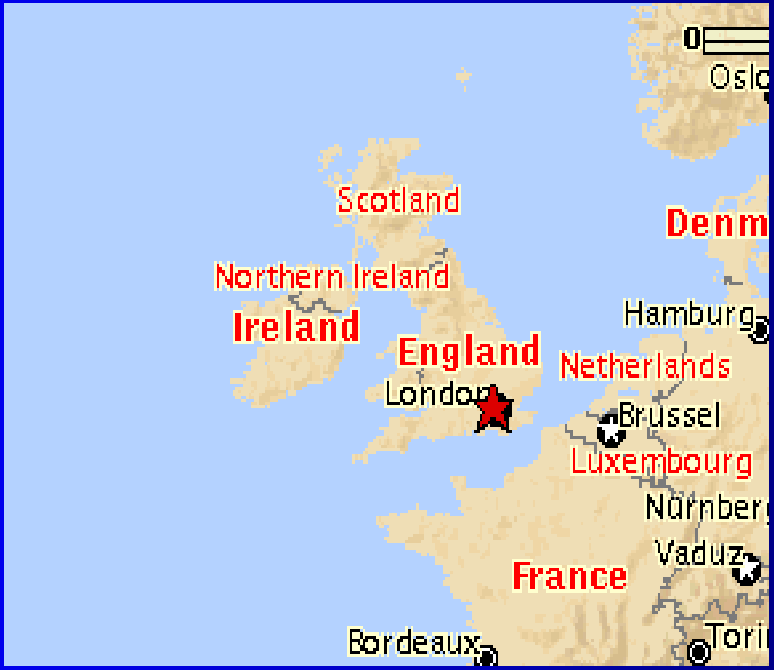


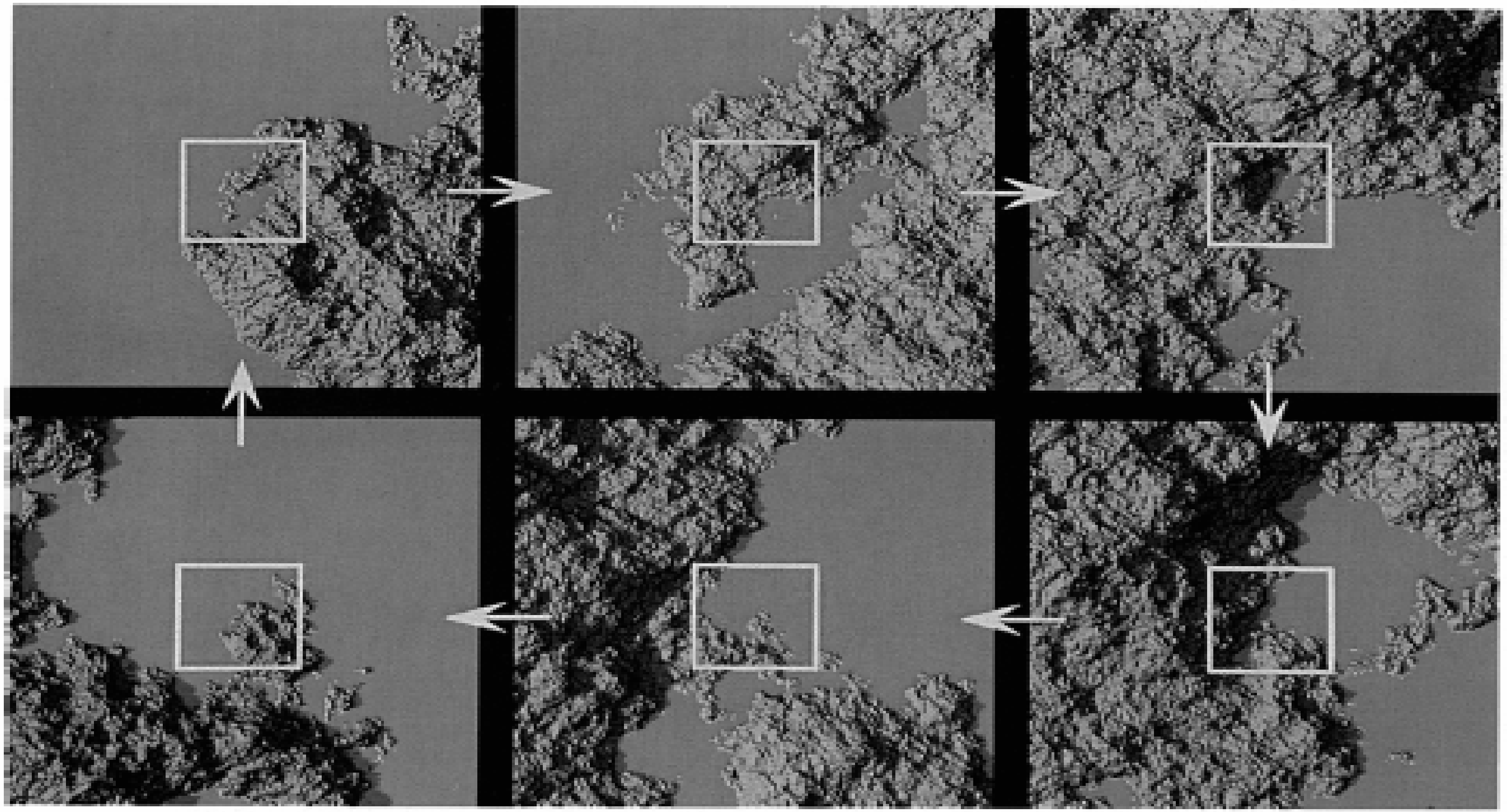
Real world fractals

A cloud, a mountain, a flower, a tree

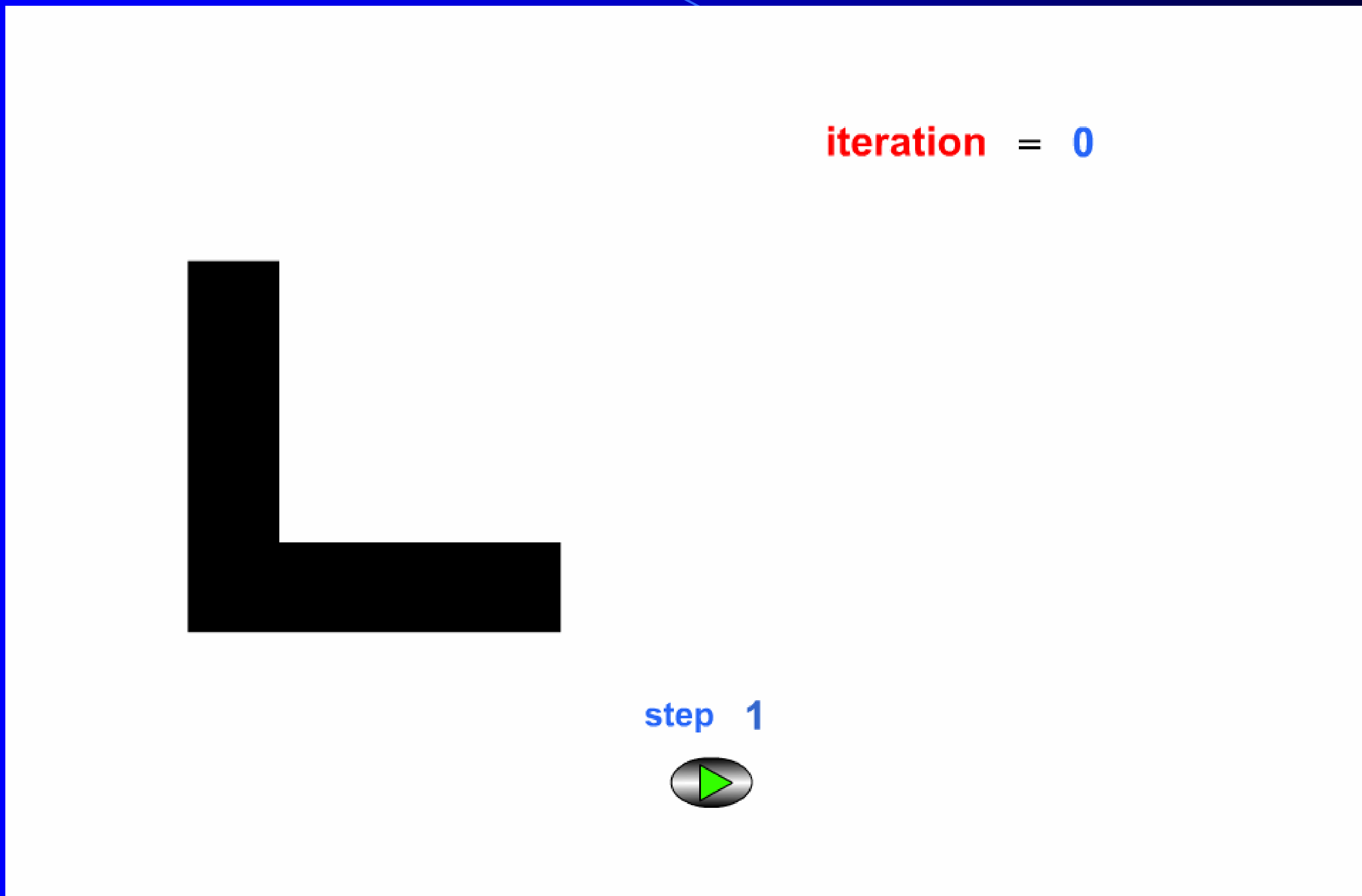
or a coastline…

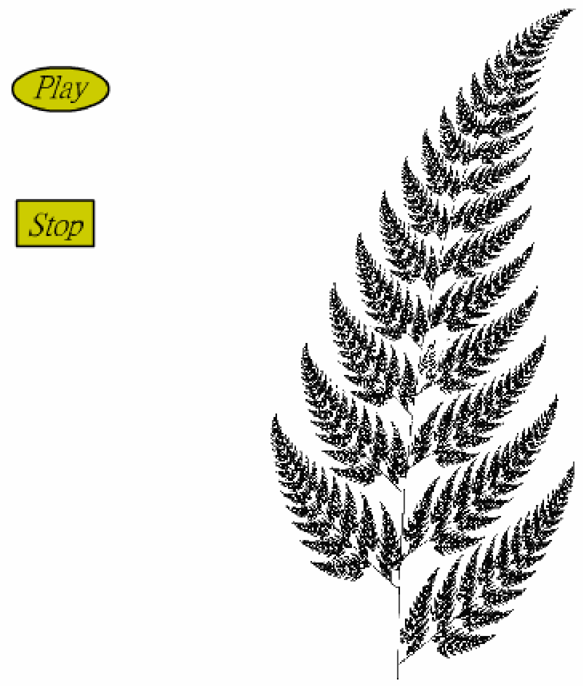
The coastline of Britain

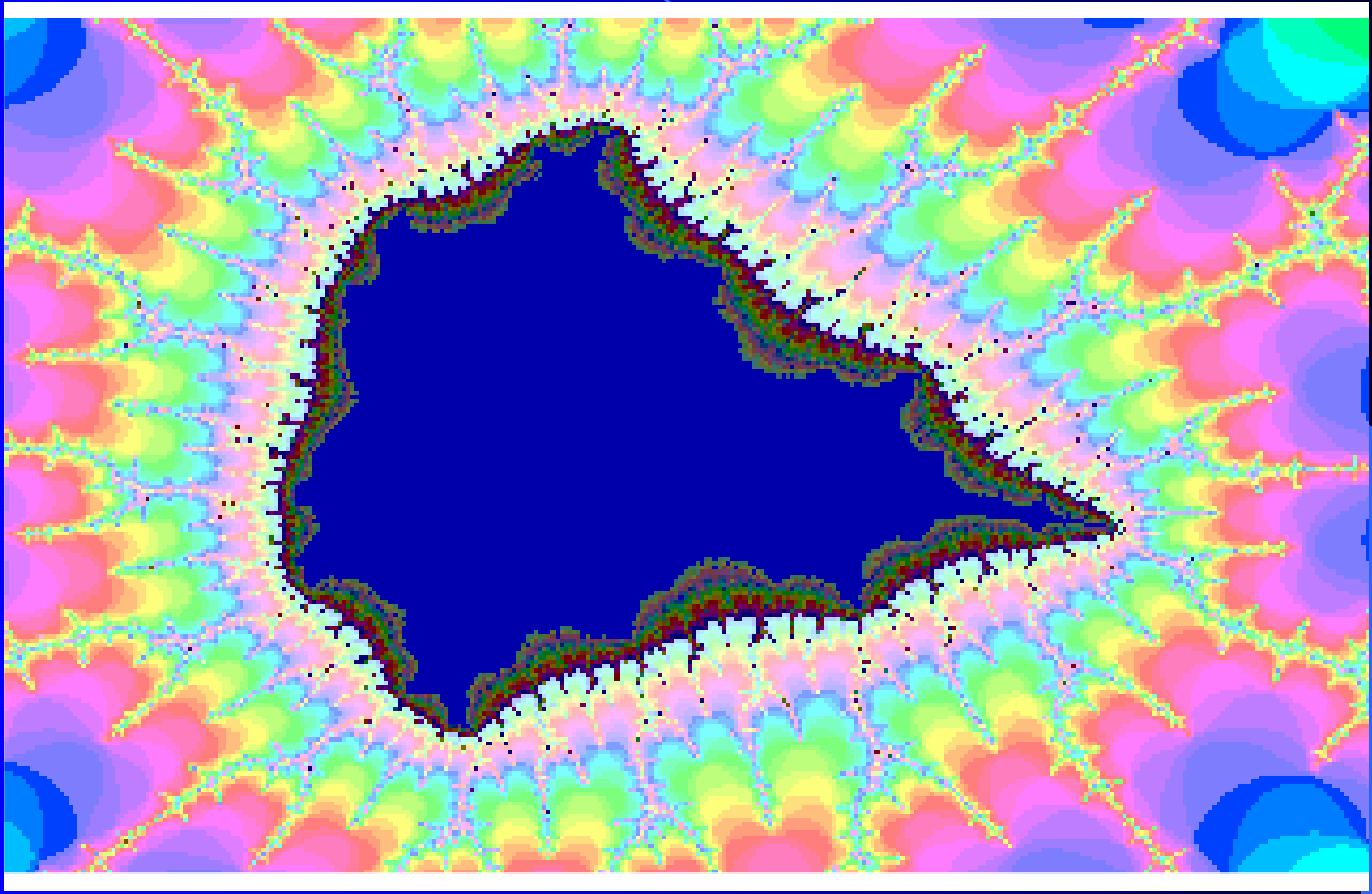




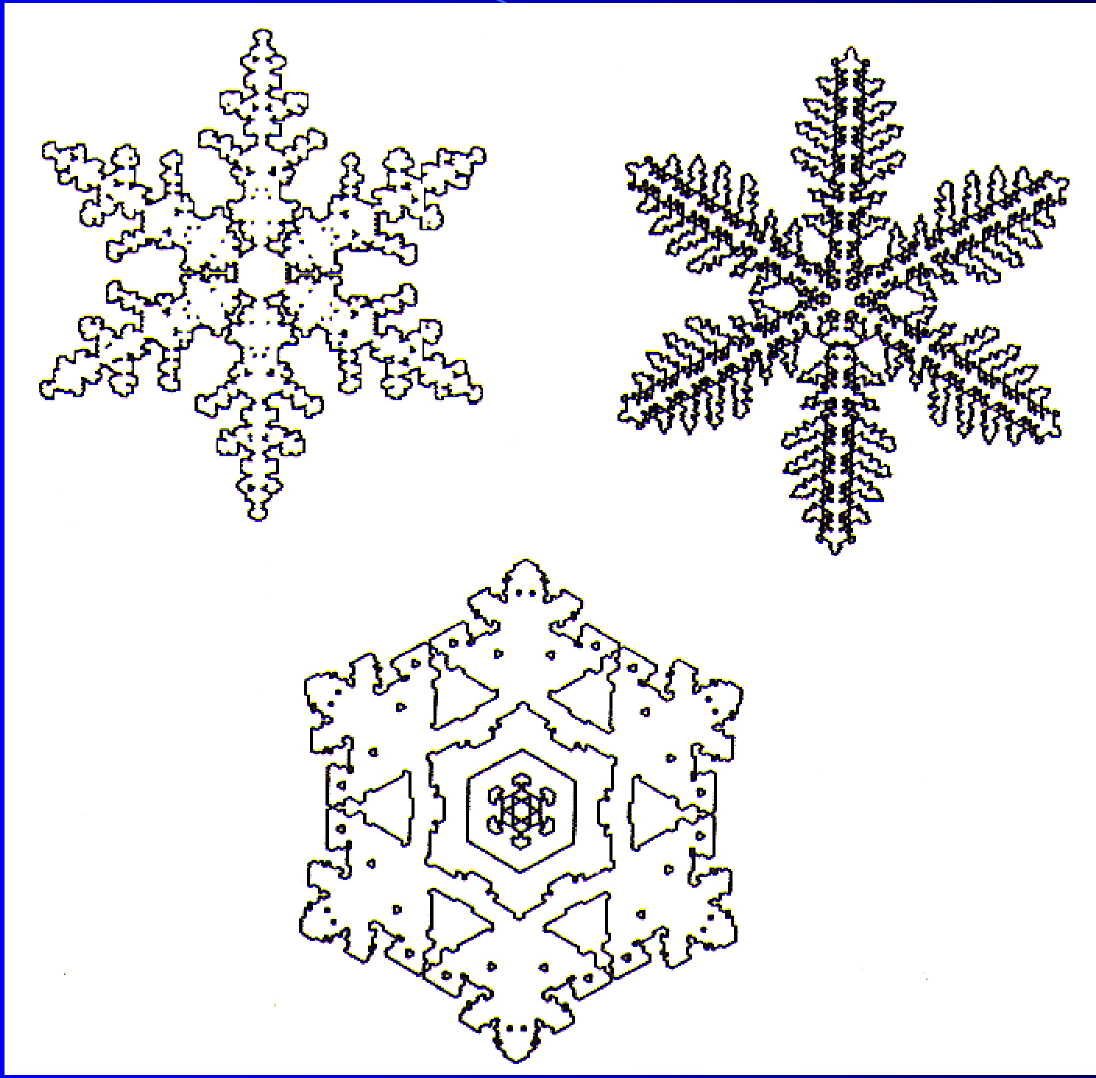
Fractal Coastline (6 magnifications)


iteration = 0
step 1


Play
Stop



In nature – snow-flakes



Another example: Cantor Set

- The oldest, simplest, most famous fractal

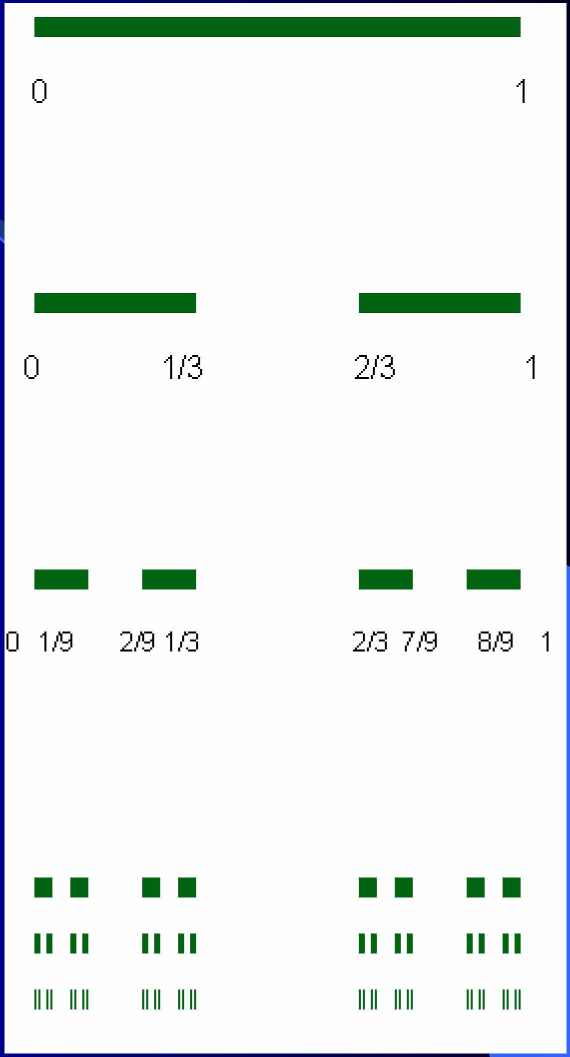
1 We begin with the closed interval [0,1].

2 Now we remove the open interval (1/3,2/3); leaving two closed intervals behind.

3 We repeat the procedure, removing the "open middle third" of each of these intervals

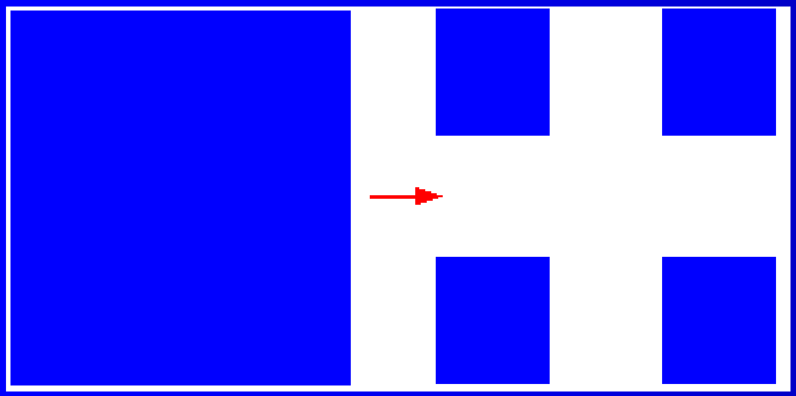
4 And continue infinitely.

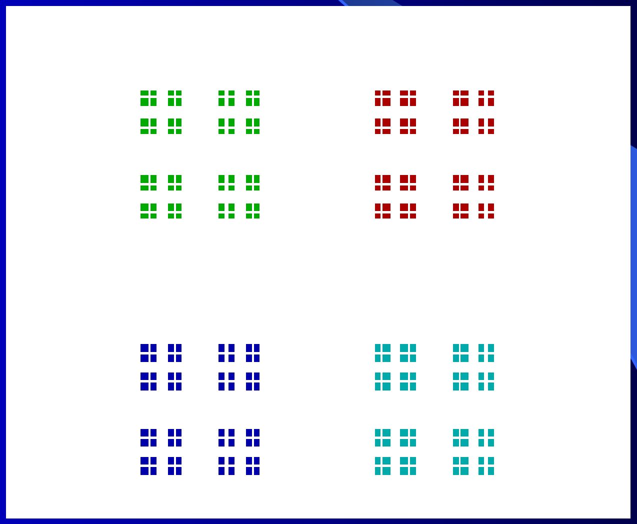
- Fractal dimension:
  D = log 2 / log 3 = 0.63…
- Uncountable points, zero length



Cantor square

- Fractal dimension: $d = \log 4 / \log 3 = 1.26$





Generating fractal geometic structures

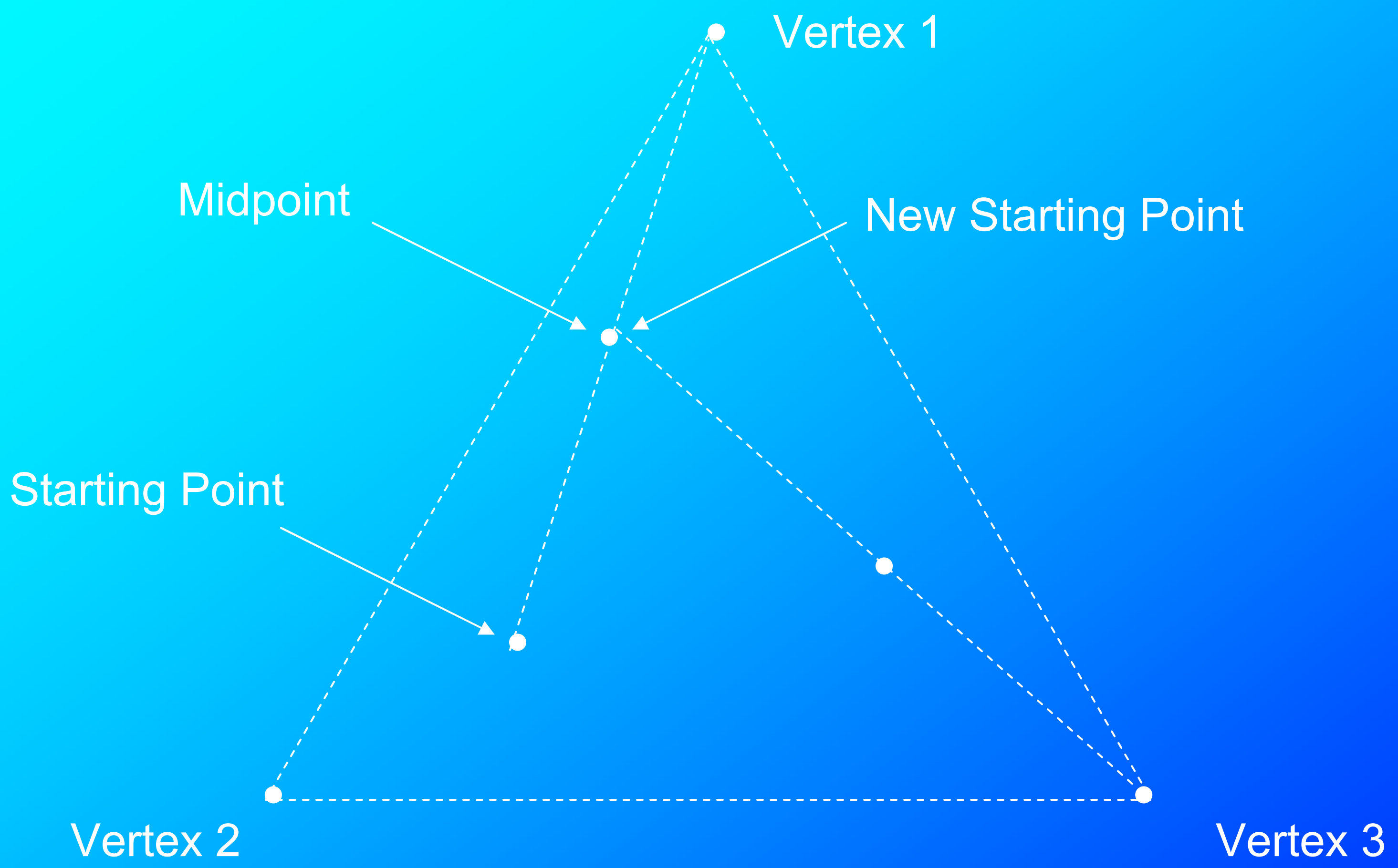
- Iterations
- IFS (affine transforms)
- Complex transforms (iterations)

Sierpiński Fractals

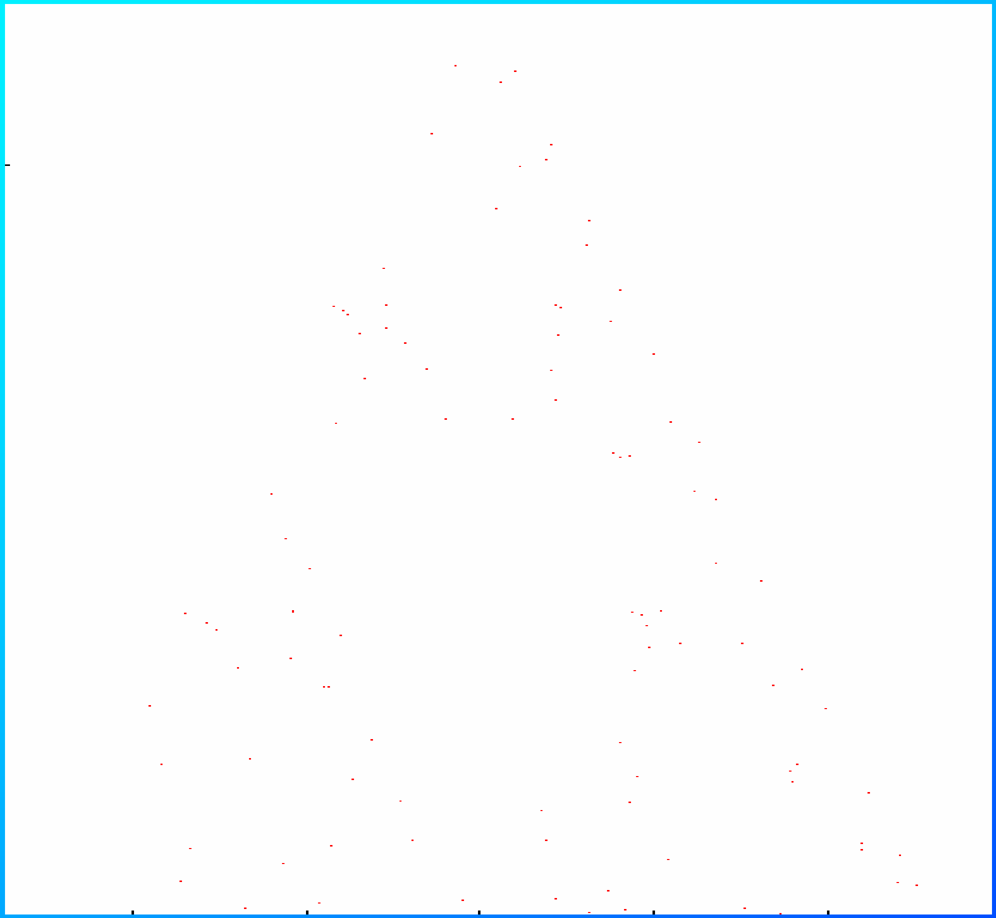
- Named for Polish mathematician Waclaw Sierpinski

- Involve basic geometric polygons

Sierpinski Chaos Game

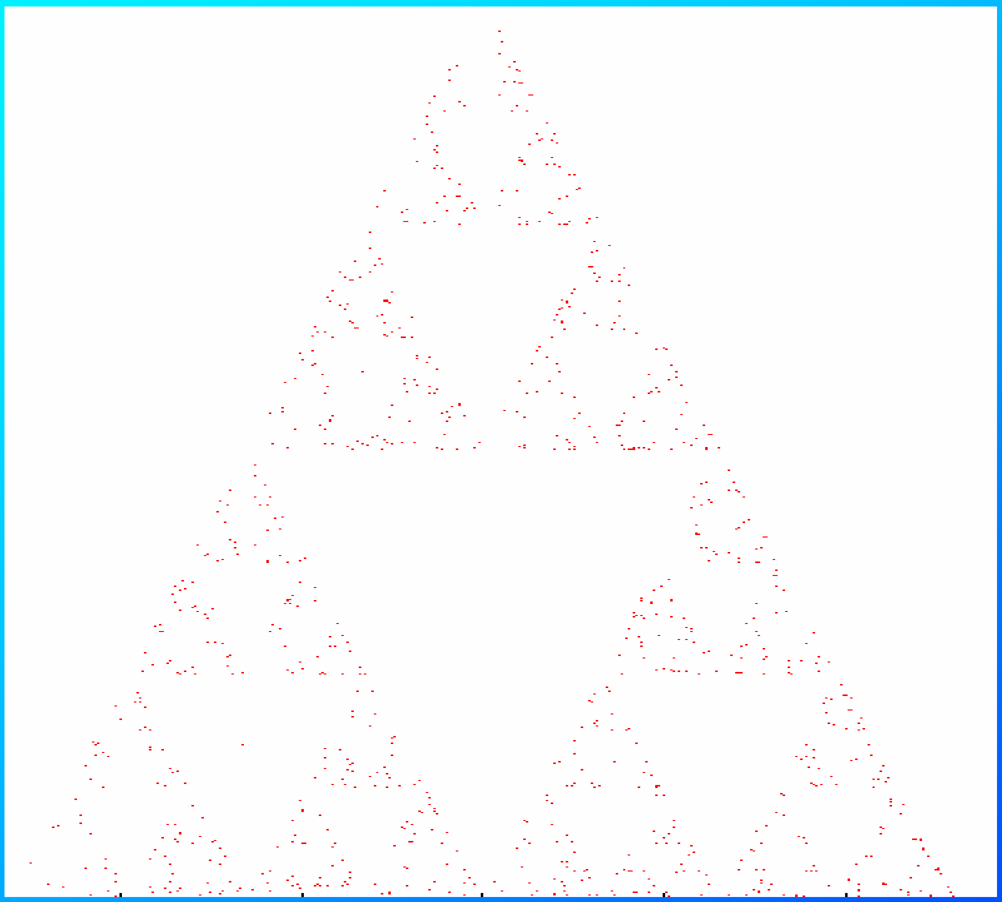


Sierpinski Chaos Game



100 pts

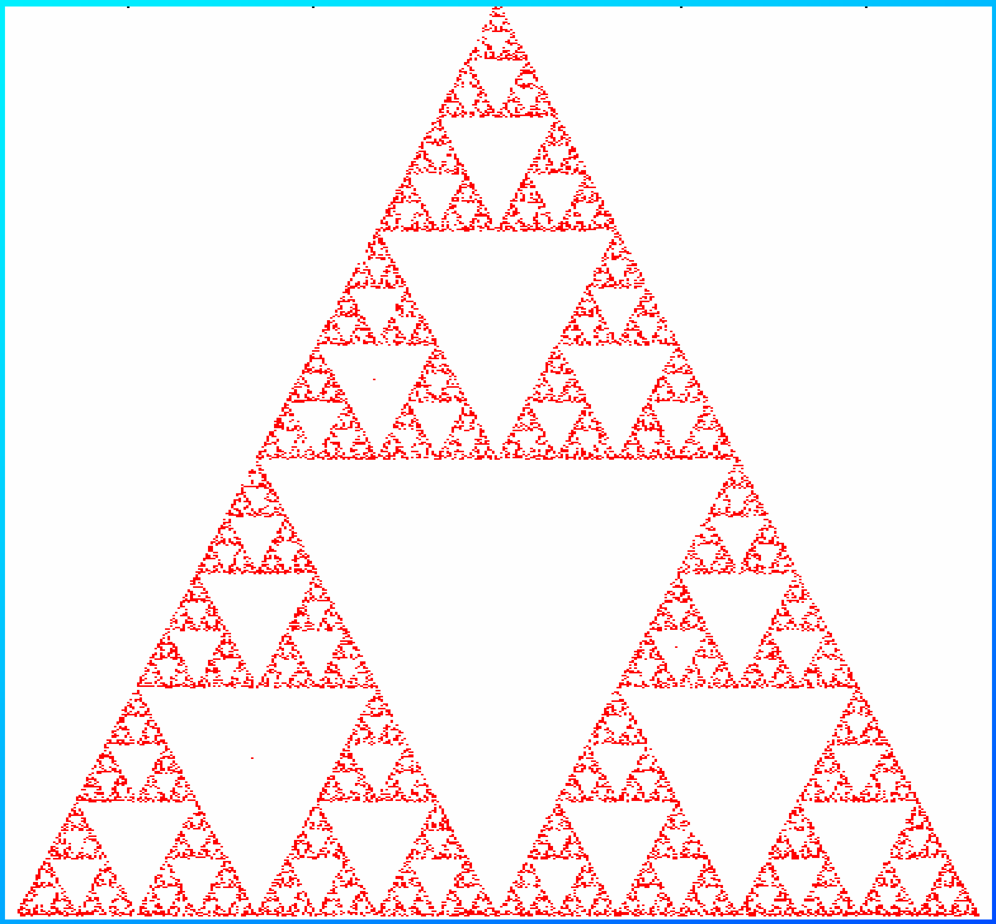
Sierpinski Chaos Game



- 1000 pts

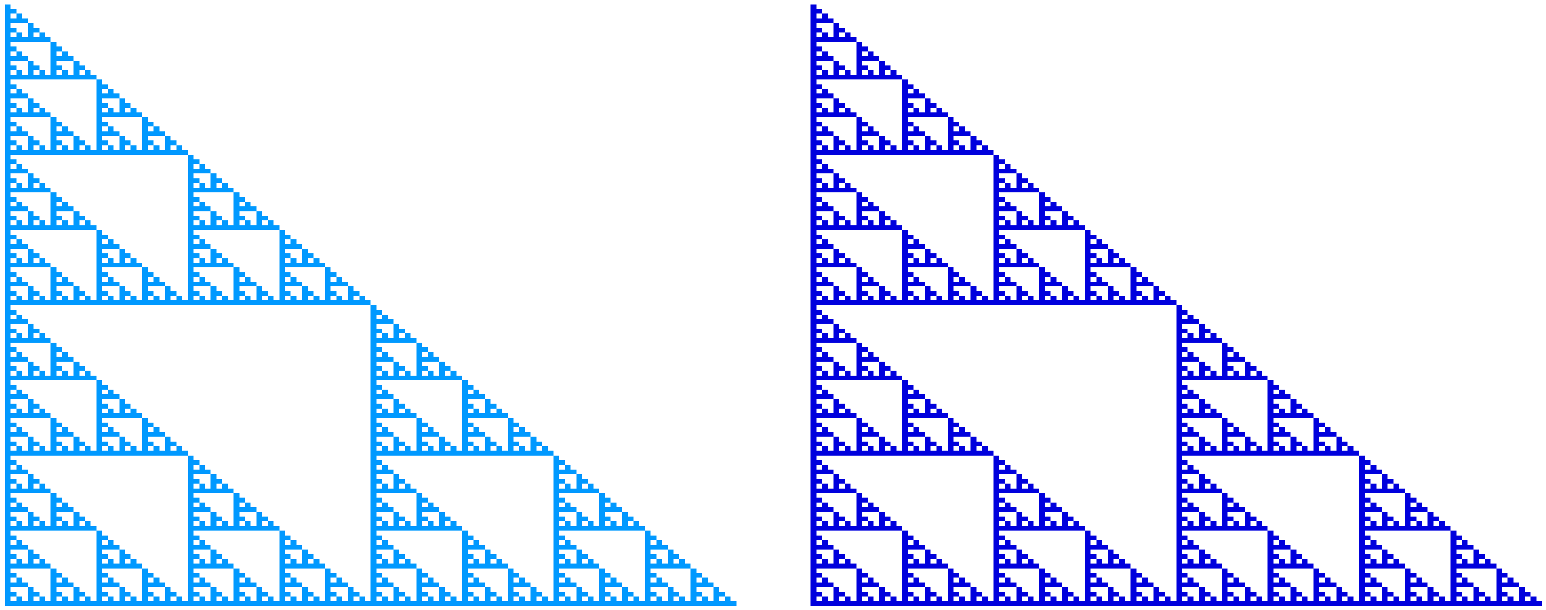
Sierpinski Chaos Game

Fractal dimension = 1.8175…

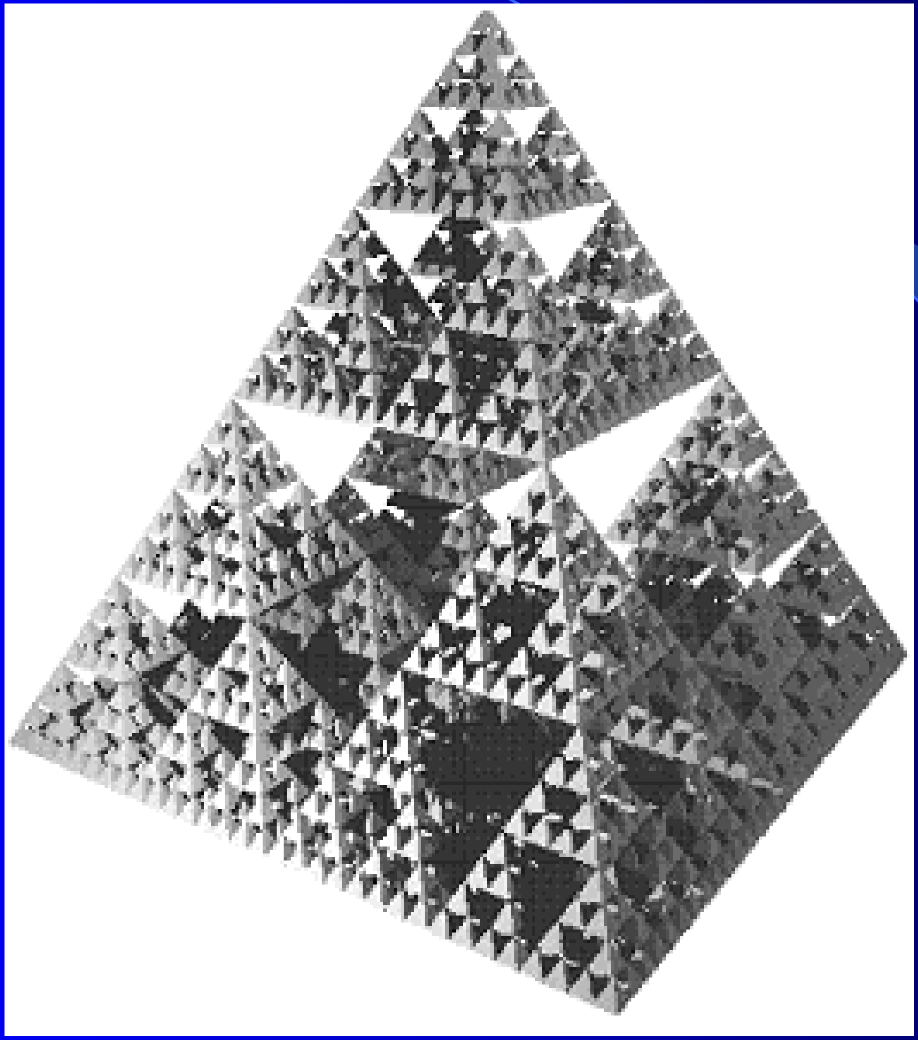


- 20000 pts

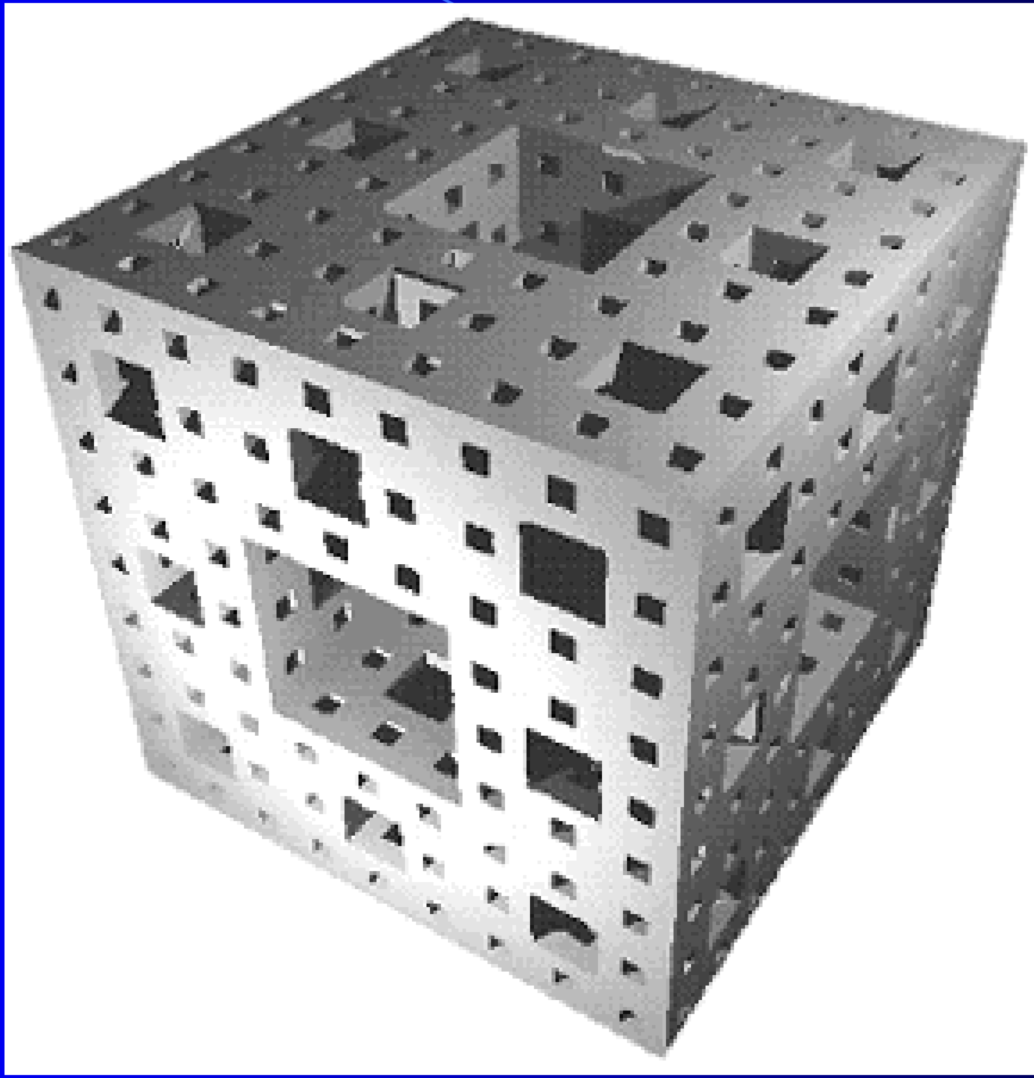
Sierpinski gasket/carpet



r	s	θ	φ	e	f
1.0	1.0	0	0	0.0	0.0



Menger's sponge



IFS (Iterated Function Systems)

$$\begin{bmatrix} x \\ y \end{bmatrix} \rightarrow \begin{bmatrix} r\cos(\theta) & -s\sin(\varphi) \\ r\sin(\theta) & s\cos(\varphi) \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix}$$

Here, (x,y) is a point on the image,

(r,s) tells you how to scale and reflect the image at the various points,

(theta,phi) tells you how to rotate,

(e,f) tells you how to translate the image.

Various Fractal Images are produced by differences in these values, or by several different groups of values.

IFS (continued)

Remember that matrix from the previous slide? Lets rewrite it as a system of two equations :

x` = rcos(theta)x – ssin(phi)y + e
y` = rsin(theta)x + scos(phi)y + f

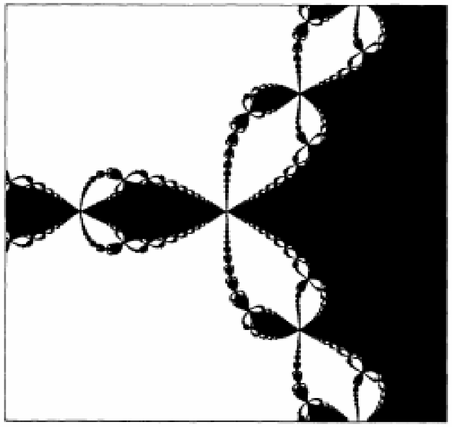
(x,y) being the pair we are transforming, and (x`,y`) being the point in the plane where the old (x,y) will be transformed to.

EVERY Transformation follow this pattern. So for file transmission, all we need
to include would be the constants from above : r,s,theta,phi,e,f, x,y
This greatly simplifies the Task parsing.

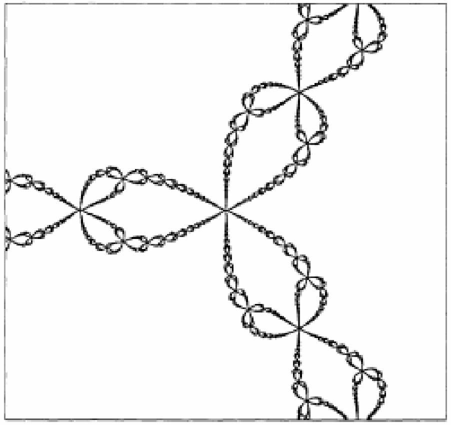
On return you would only need to include the (x,y)->(x`,y`)

Julia set

- Defined as boundary between bounded and unbounded sequences in complex plane for the nonlinear maps $z^n + c$ ($z, c \in \mathbf{C}$, n usually 2).
- Sets are either totally connected or disconnected (latter called *dust*).
- Manifest themselves in such contexts as familiar *Newton-Raphson* algorithm for complex case — e.g. $z^3 - 1 = 0$:



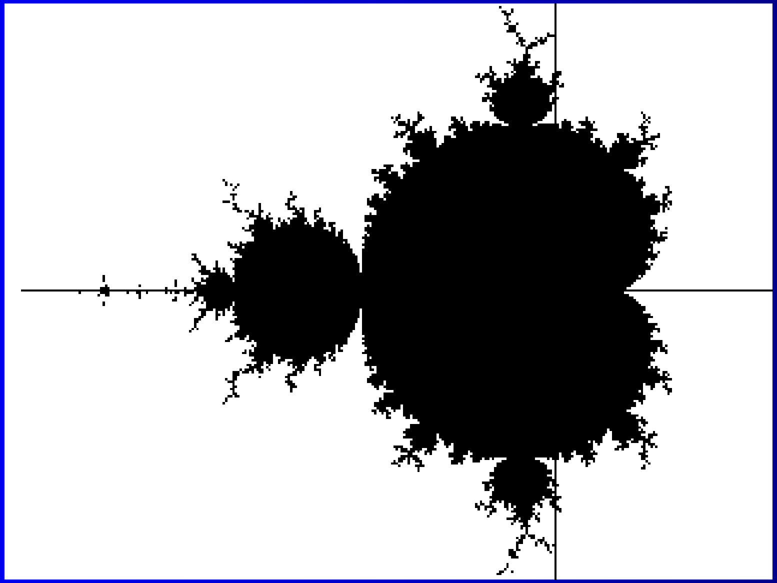
Basin of attraction for $z = 1$ solution.



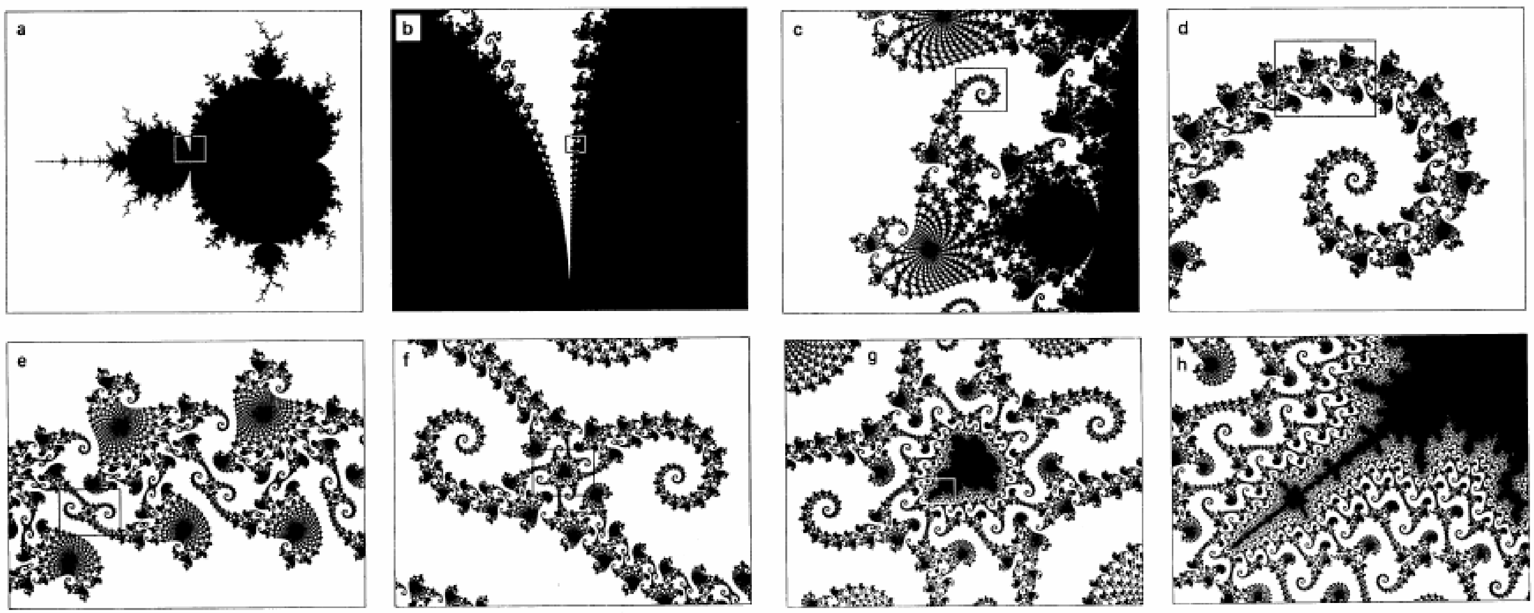
Basin boundaries.

The Mandelbrot Set

- The Mandelbrot set is a connected set of points in the complex plane
- Calculate: $Z_1 = Z_0^2 + Z_0$, $Z_2 = Z_1^2 + Z_0$, $Z_3 = Z_2^2 + Z_0$
- If the sequence Z_0, Z_1, Z_2, Z_3, ... remains within a distance of 2 of the origin forever, then the point Z_0 is said to be in the Mandelbrot set.
- If the sequence diverges from the origin, then the point is not in the set

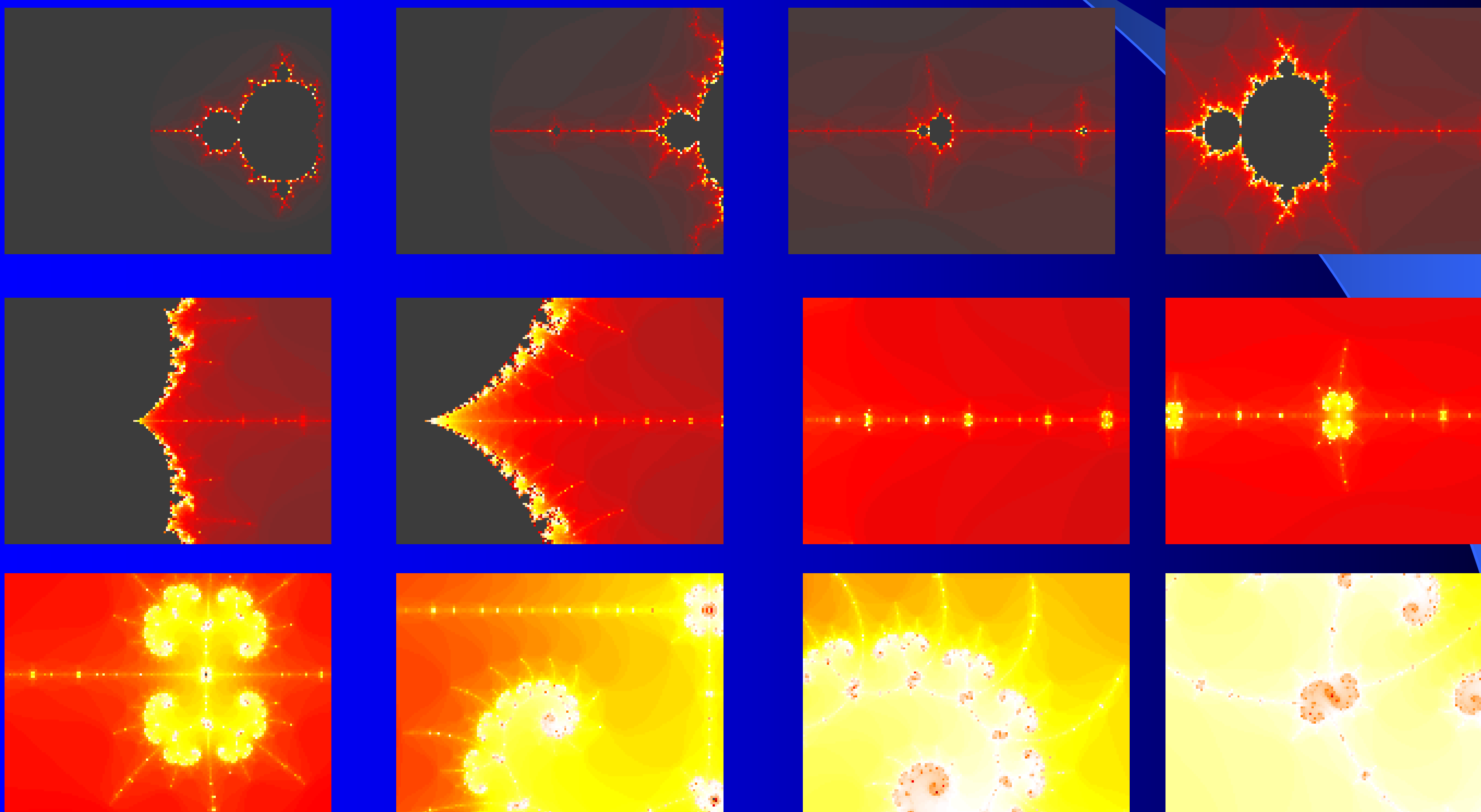


- Most popular and complex object of contemporary mathematics.
- Constructed via simple recipe $\{c \in \mathbf{C} : c^2 + c \not\to \infty\}$, called *prisoner set*.
- Zoom views of set:

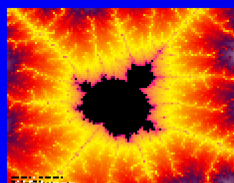
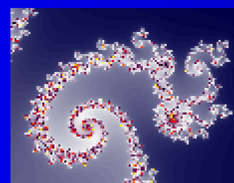
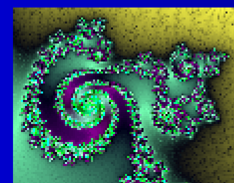
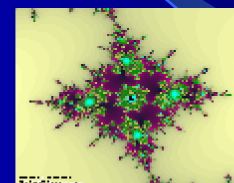
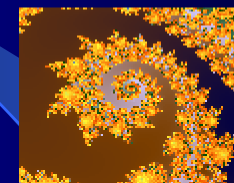
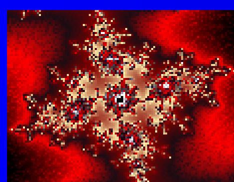
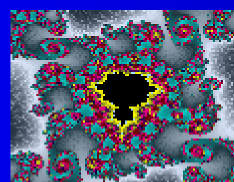
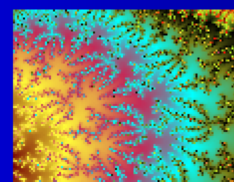
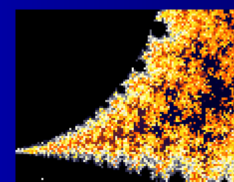
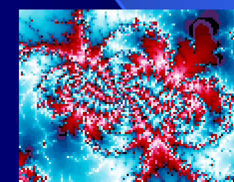
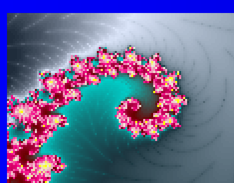
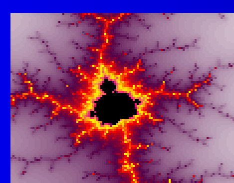
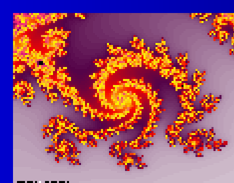
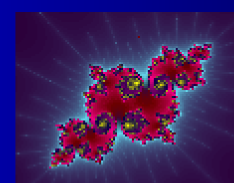
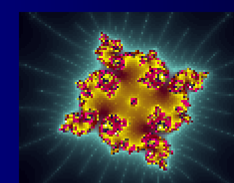


Colored Mandelbrot Set

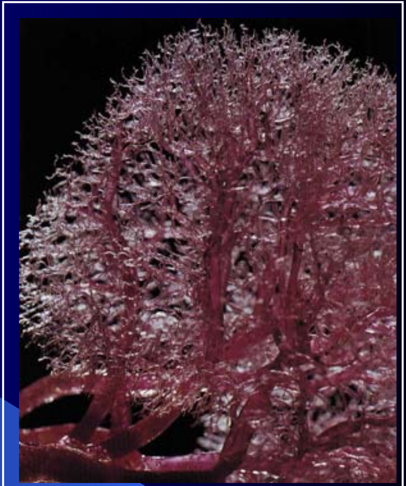
- The colors are added to the points that are not inside the set. Then we just zoom in on it



$$z_{n+1} = z_n^2 + c$$

Are organisms fractal?



child lung

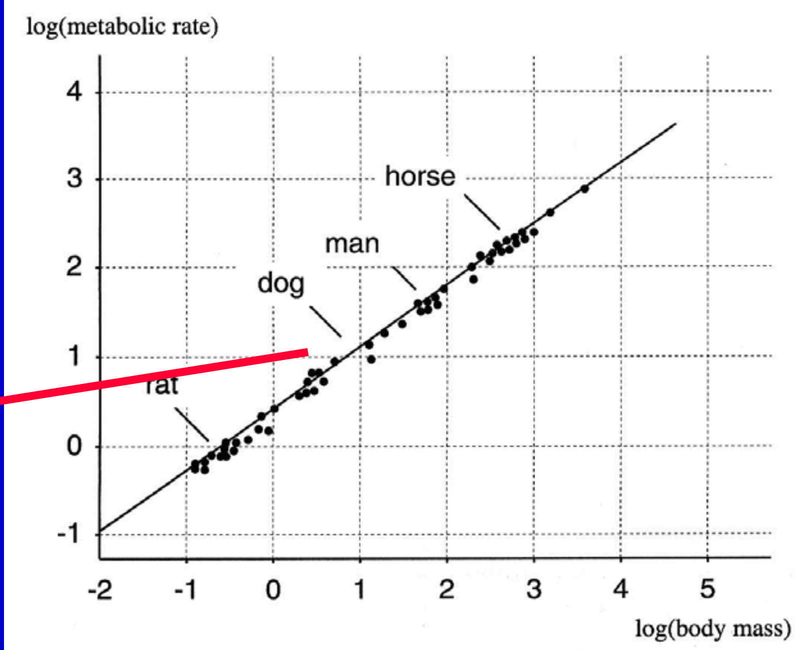
- M. Sernetz *et al.* (1985 paper in J. Theoretical Biology)
- Contrary to common belief, metabolic rate is not proportional to body weight. Instead, it fits in a power law relationship.

- $m = cw^{\alpha}$

Metabolic rate

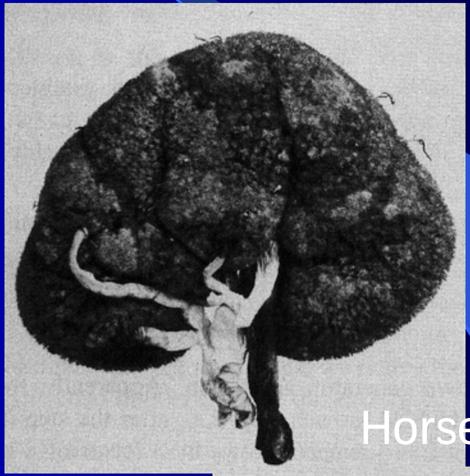
Body weight

Slope $\alpha \approx 0.75$



Dimension of organisms

- We can deduce the fractal dimension from $\alpha \approx 0.75$.
- Suppose r is the scaling factor (like *s*). Since weight is r^3, the power law can be modified to $m = cr^{3\alpha}$.
- Thus, $D = 3\alpha \approx 2.25$.
- **The body is not a solid volume, it is rather a fractal (highly convoluted surface) of dimension 2.25!**
  - **Would the dimension change when an organ malfunctions?**
  - **Is the dimension different for different animals?**



Horse kidney

Fractals in biology

Plate 3: Broccoli Romanesco.

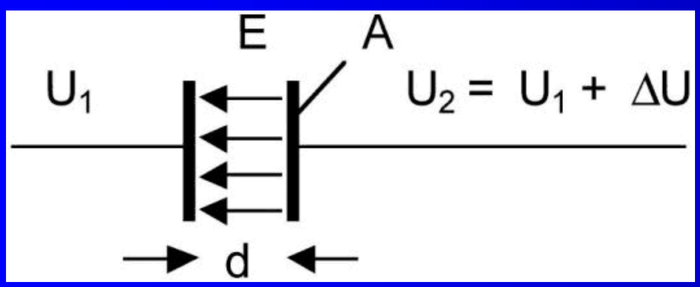
Plate 5: Broccoli Romanesco, detail.

Essential properties for applications:

- Finite area – infinite perimeter !
- Self-similarity (same properties and shapes at different scales)

Physical relations for capacitors

Both electrodes have a surface A (in m^2) separated by distance d (in m). The applied voltage ΔU (in Volt) creates an electric field $E = \Delta U/d$ storing the electrical energy. Capacitance C in Farad (F) and stored energy J in Ws is:



$$C = \varepsilon_0 \cdot \varepsilon_r \frac{A}{d} \qquad J = \tfrac{1}{2} C \cdot \Delta U^2$$

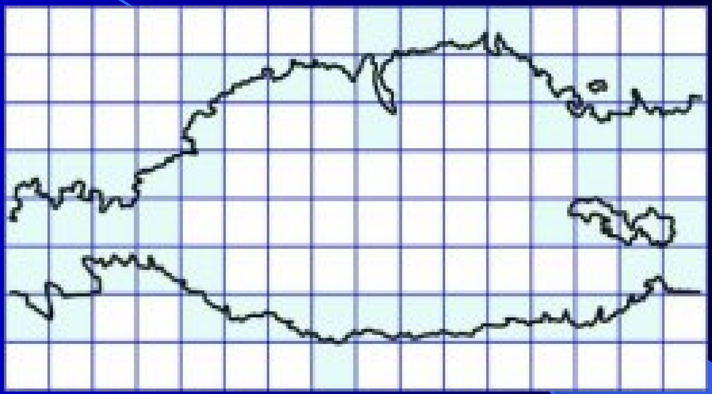
where ε_r (e.g. 1 for vacuum or 81 for water) is the relative dielectric constant which depends on the material placed between the two electrodes and $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m is a fundamental constant.

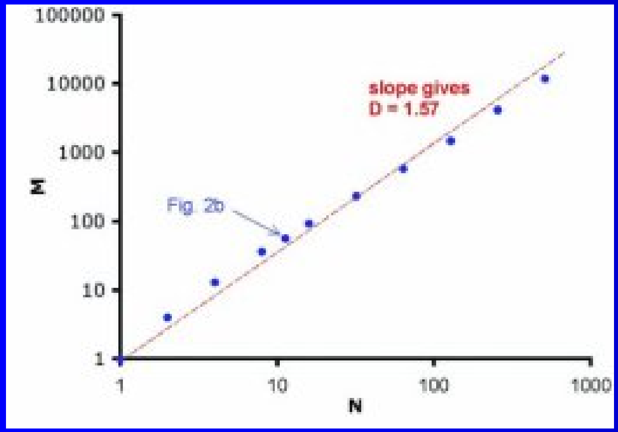
Capacitance in Farad	1000	$1 \cdot 10^{-3}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-9}$	$1 \cdot 10^{-12}$
Example	 supercapacitor with 1500 F, max. 2.5 V (positive electrode left)	 electrolyte capacitor with 1000 mF, max. 25 V (positive electrode left)	 electrolyte capacitor with 10 mF, max. 35 V (bent wire is positive electrode)	 rolled capacitor with 51 nF, max. 63 V	 plate capacitors with 50 pF. Left: an element from an old vacuum-tube radio in the form of two plates rolled to a cylinder, max. 450 V. Right: modern ceramic element, max. 100 V)
Energy Stored	Watt hours (Wh)	several Ws (Ws)	milli-Ws = 10^{-3} Ws (mWs)	milli-Ws = 10^{-3} Ws (mWs)	micro-Ws = 10^{-6} Ws (mWs)
Applications	Novel applications in power electronics: e.g. in cars, for replacing batteries in consumer electronics	Power supply units	Low frequency technology: general electronics, e.g. audio amplifiers	Low frequency technology: general electronics, e.g. audio amplifiers	High frequency technology: e.g. radio, TV, PC

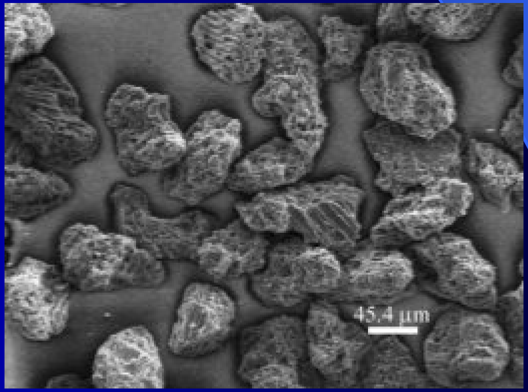
How to create capacitors with larger C?

- Create capacitors with very large areas A – technologies to create fractal-type surfaces
- Use designs taking advantage of lateral capacitance in integrated circuits

Electrochemically modified glassy carbon is a promising material to be used in electrochemical capacitors. Oxidation of the surface of a glassy carbon electrode results in a porous layer with very large capacitance and fairly low internal resistance when using an aqueous electrolyte.

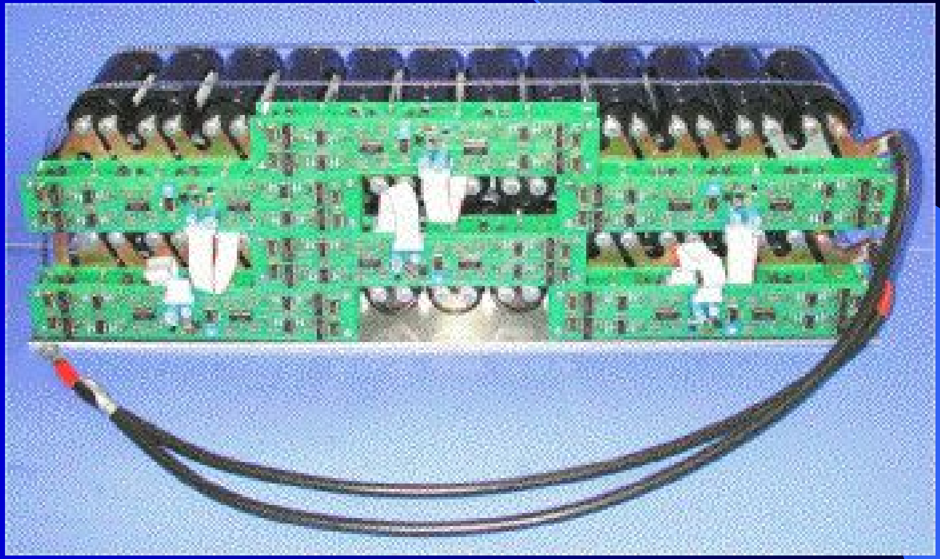






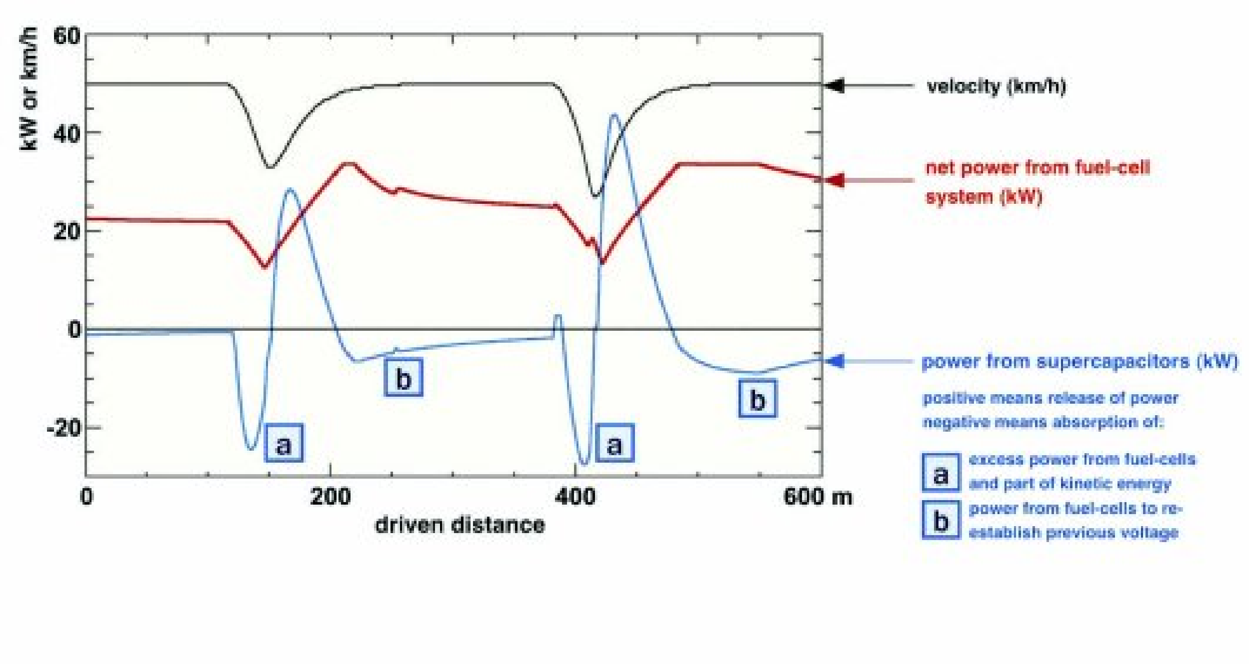
- Paul Scherrer Institute in Villigen, Switzerland - Rüdiger Kötz and his group have developed an electrode in collaboration with the Swiss company *Montena* (*Maxwell*).

- **a) Micrograph of a cross section through a supercapacitor electrode.The white stripe is a part of the 30 μm thick metallic carrier-foil (total foil is 0.1 m wide, 2 m long). On both sides carbon particles provide a complex fractal surface responsible for the high capacity.The space taken by the green resin used to fix the delicate carbon structure before cutting and to provide a good contrast for imaging is normally filled with the electrolyte (an organic solvent containing salt ions).**
  b) Borderline of the cross section through the electrode surface in (a) to be analyzed by the box-counting procedure, illustrated for a tiling with 128 squares:M = 56 squares (filled with light blue colour) are necessary to cover the borderline.Their side lengths are N = 11.3 (square root of 128) times smaller than the length scale of the whole picture.
  c) The box-counting procedure is repeated with a computer program for different N.The average fractal dimension of the borderline is the gradient of the straight line approximating the measured points in this Log(M) over Log(N) plot, giving D   1.6.This same dimension was measured in the lengthinterval covering nearly 3 decades between 0.6 mm (length of micrograph in Figs 2a, b) and about 1 μm (fine structure in Fig. 2d).
  d) Carbon particles as seen with an electron microscope show roughness also in the 1 μm scale. It is assumed that the above indicated fractal dimension D holds over the entire range of 8 decades between the macroscopic scale (i.e. the geometric size of the order of 0.1 m) and the microscopic scale (i.e. the micropores in the order of 1 nm = $1 \cdot 10^{-9}$ m).The electrode surface is therefore multiplied by $10^{8*0.6}$ or about 60’000 when compared to the normal two-dimensional surface of 0.2 m^2.



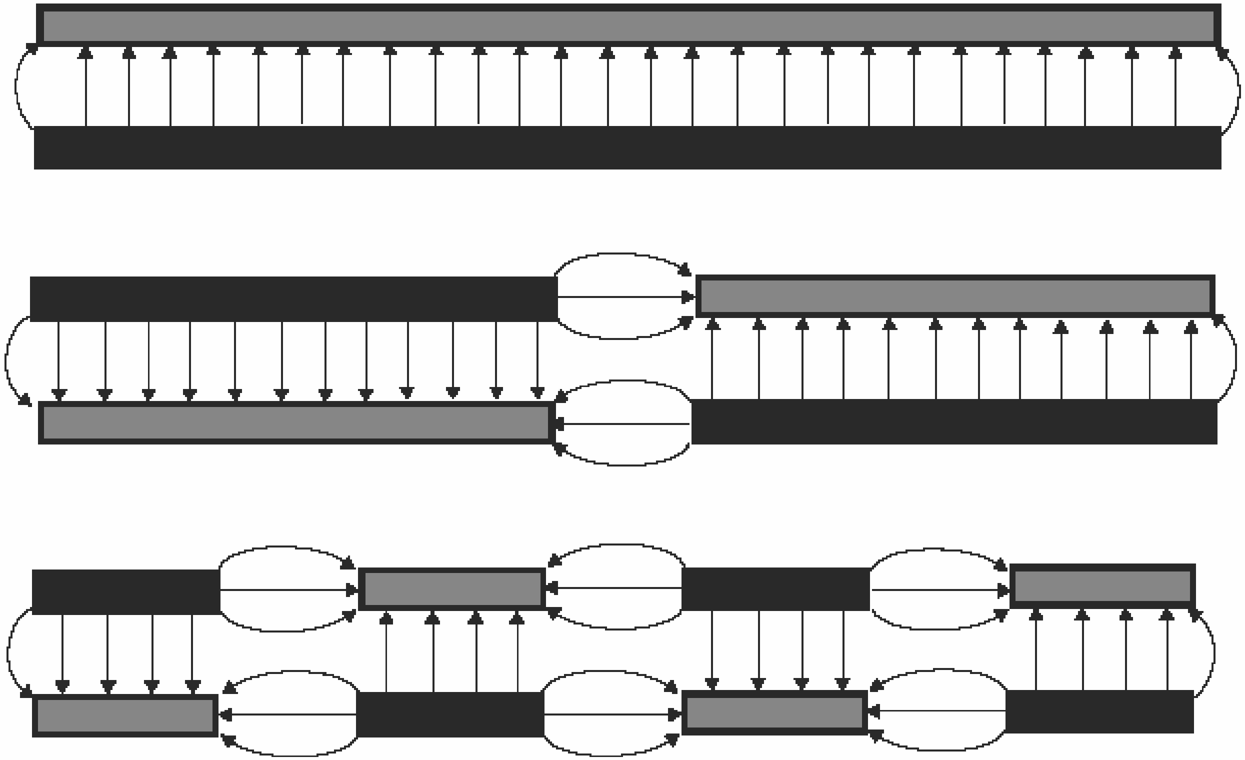
- *800 F boostcap by montena SA utilizing PSI electrode.*
- *Capacitor module with 2 x 24 capacitors resulting in 60 V , 60 F with an overall internal resistance of < 20 mOhm.*

- Supercapacitor module for HY-LIGHT.
  Capacitance: 29 F
  Power: 30 - 45 kW for 20 - 15 sec ; Weight: 53 kg
- HY-LIGHT accelerates to 100km/h in 12 seconds


kW or km/h
60
40
20
0
-20
0
200
400
600 m
driven distance
velocity (km/h)
net power from fuel-cell system (kW)
power from supercapacitors (kW)
positive means release of power
negative means absorption of:
a
excess power from fuel-cells and part of kinetic energy
b
power from fuel-cells to re-establish previous voltage

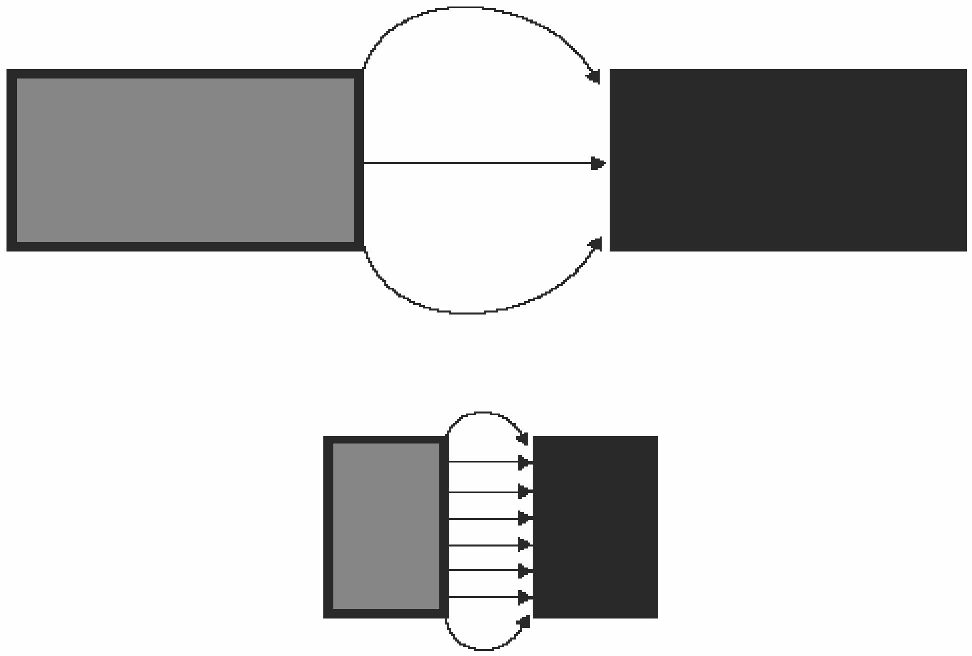
Vertical vs. Lateral Flux

- Lateral flux increases the total amount of capacitance.

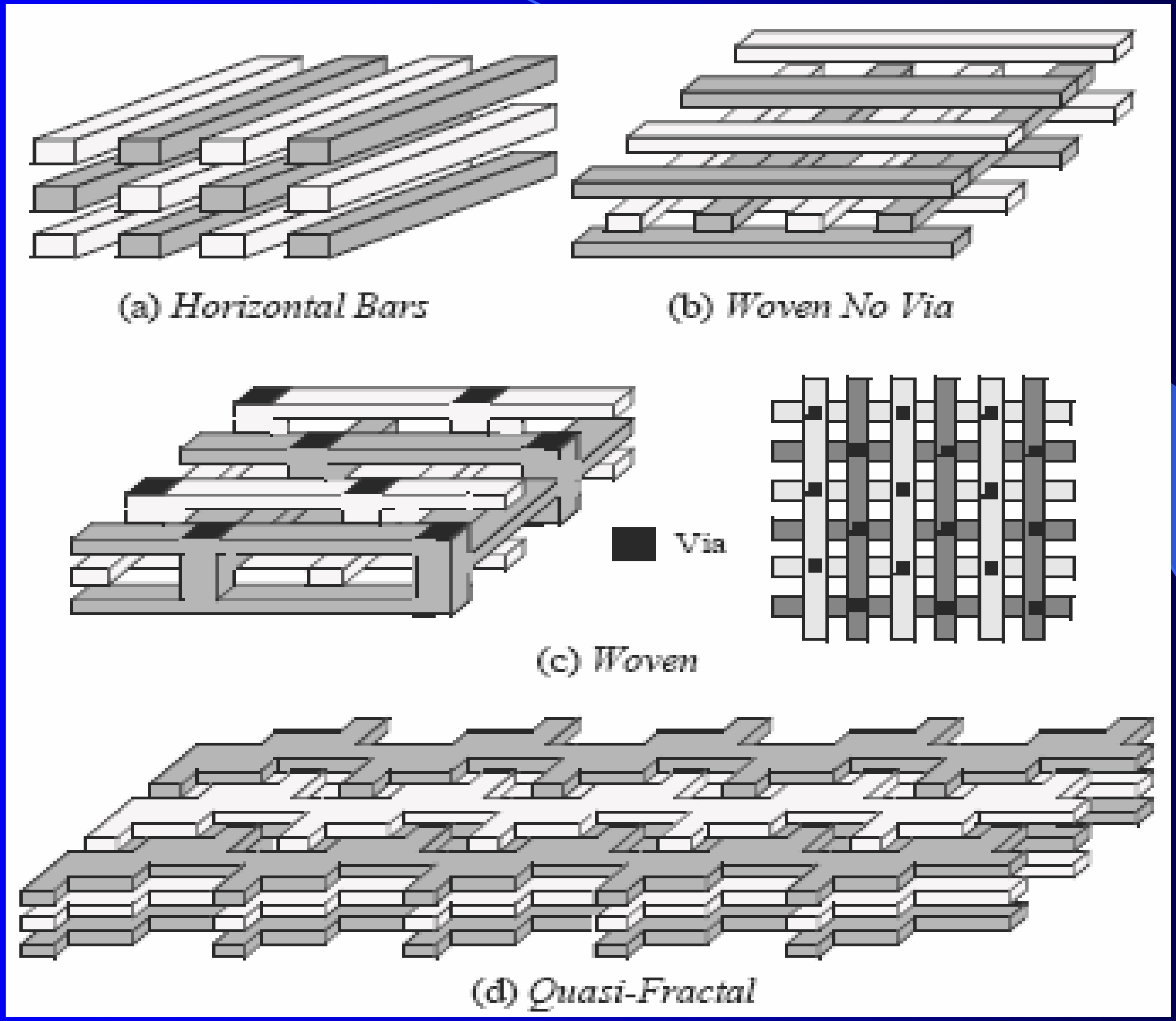


Scaling

- Unlike conventional parallel-plate structures, the capacitance per unit area increases as the process technologies scale.

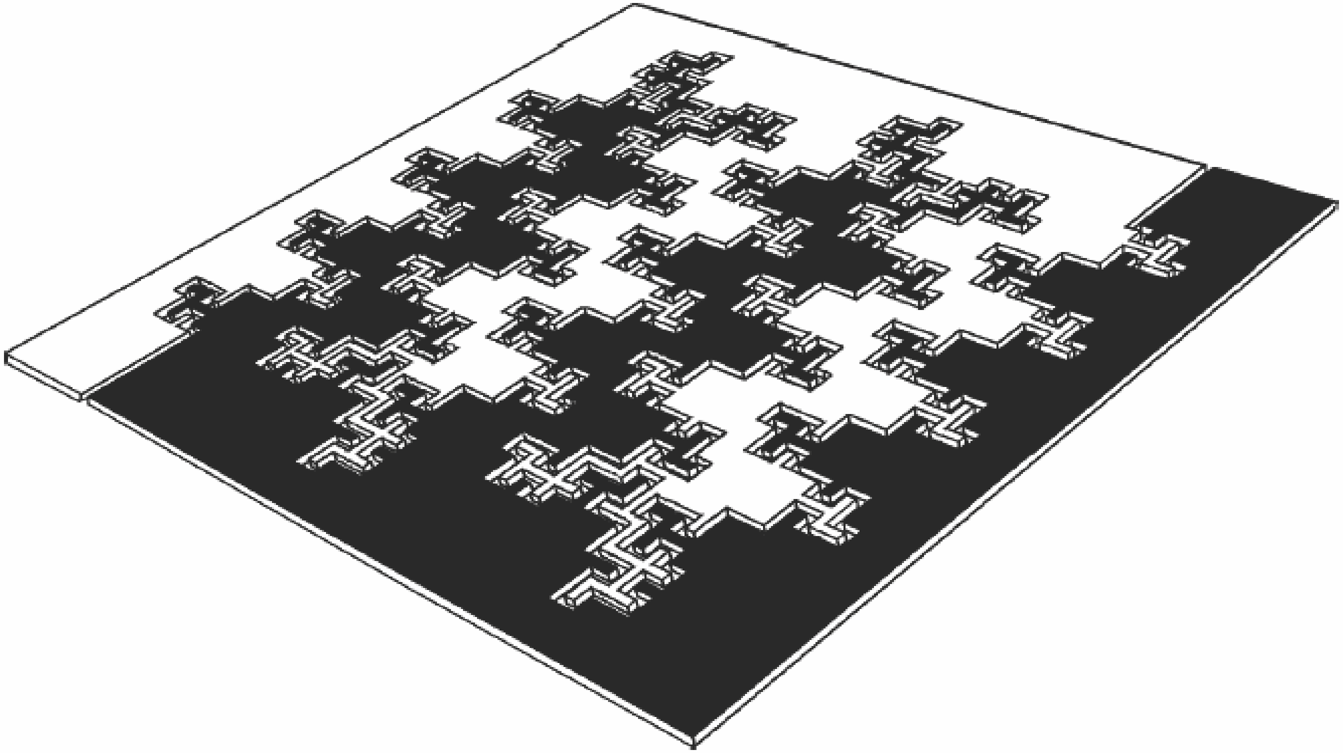


Manhattan capacitor structures



Fractal Capacitor

- Quasi fractal geometries can be utilized to increase capacitance per unit area.



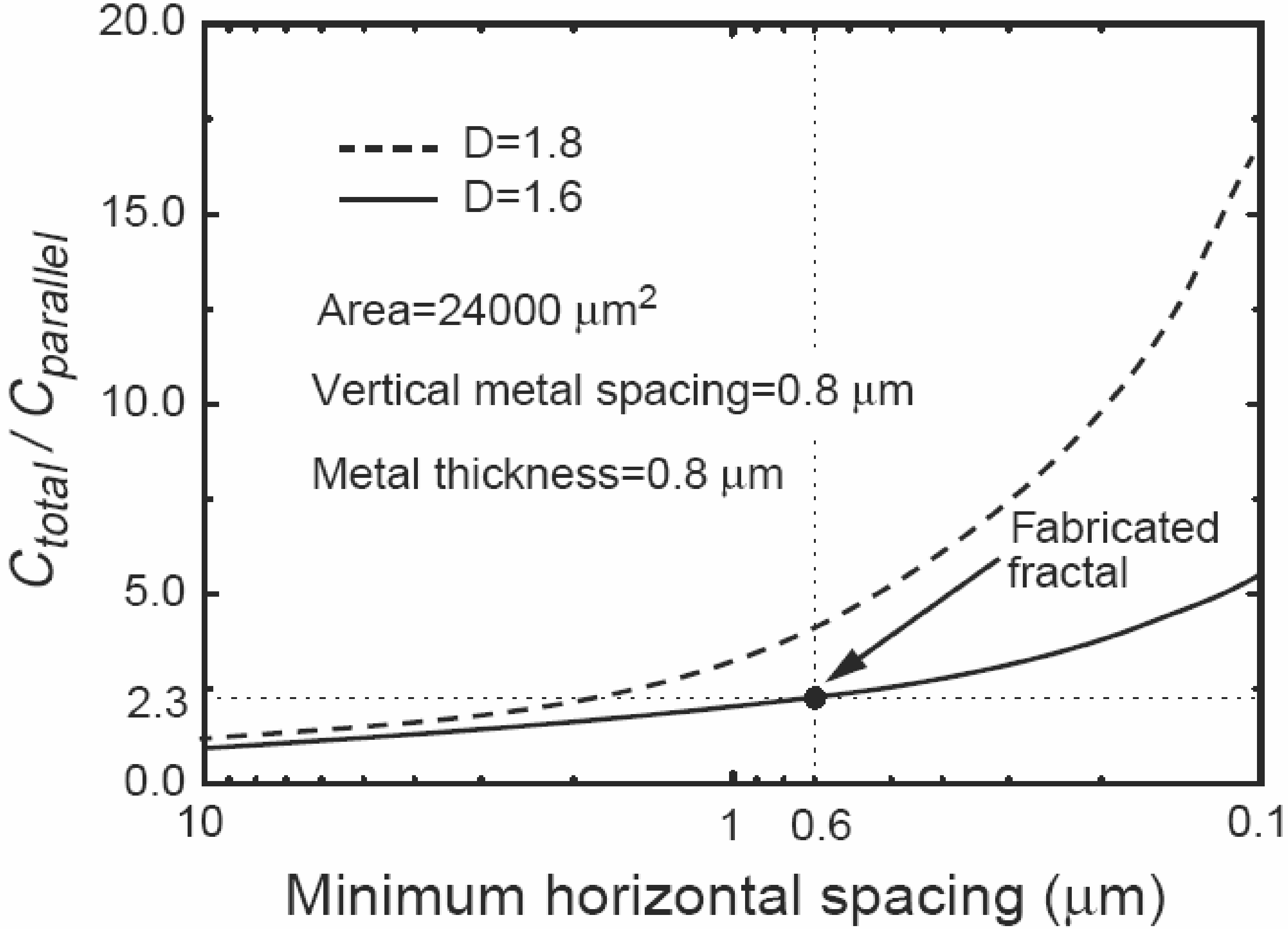
3-D representation of a fractal capacitor using a single metal layer.

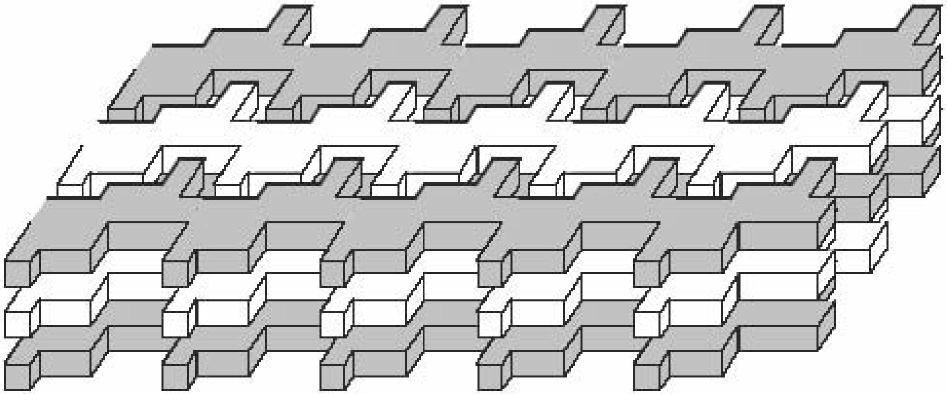
Capacitance Estimation

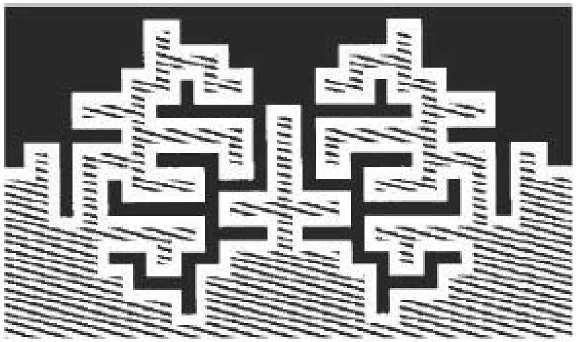
$$C_{lateral} = K \frac{(\sqrt{A})^{D}}{(w+s)^{D-1}} \times t$$

- w: Minimum width of the metal.
- s: Minimum spacing between two adjacent strips.
- A: Area of the fractal capacitance.
- t: Thickness of the metal layers.
- K: Proportionality factor that depends on the family of fractals being used.
- D: Fractal dimension.

Boost Factor *vs.* Lateral Spacing



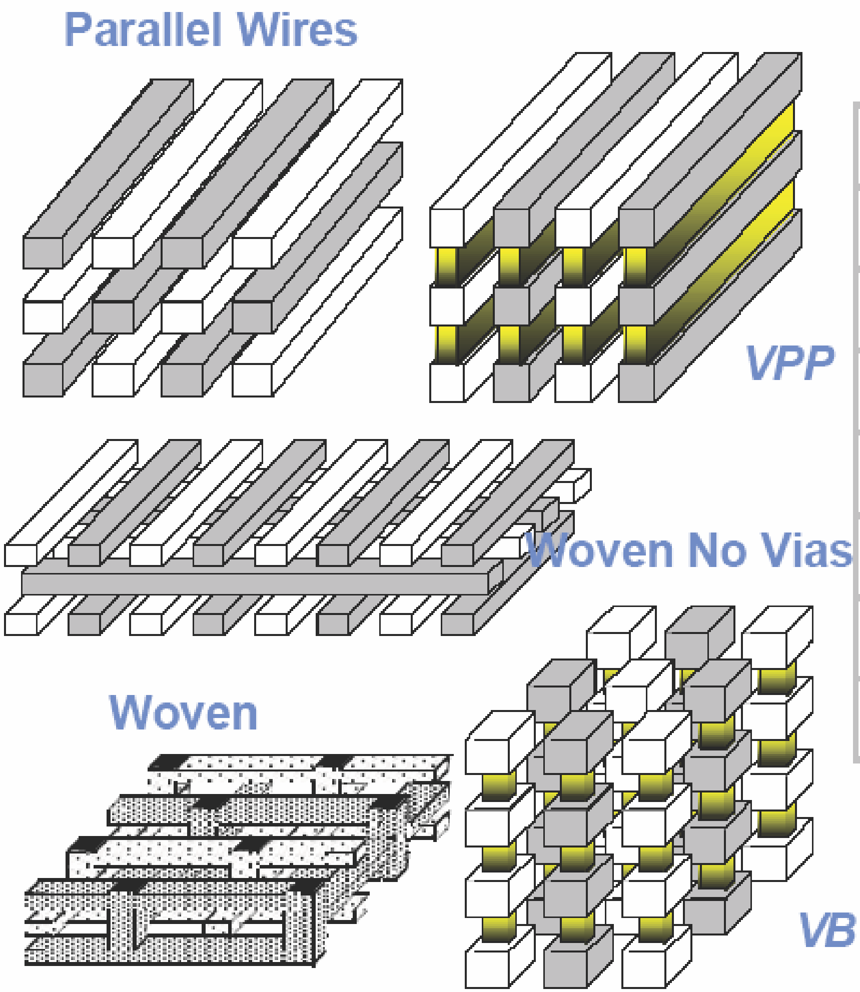




- Quasi-fractal structures maximize periphery to increase field usage,
- Have strong vertical *and* lateral components,
- Time consuming to generate and simulate,
- Look beautiful !

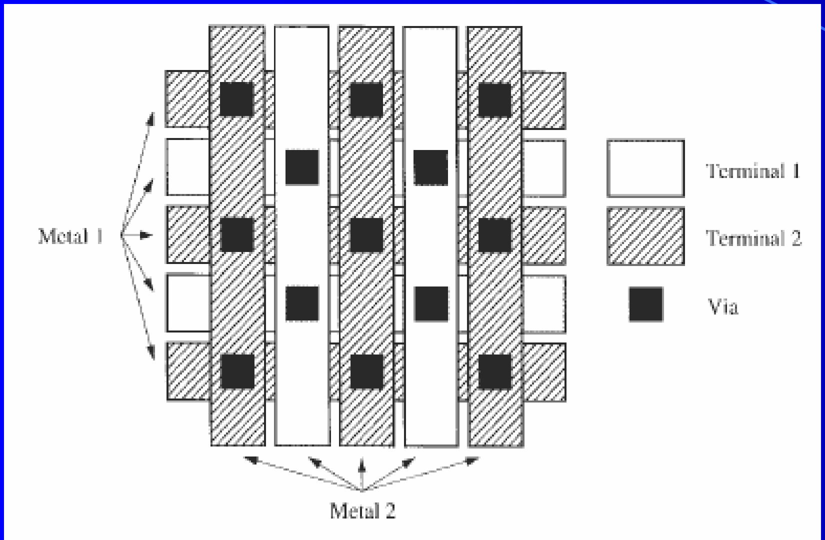
[Samavati, Hajimiri, Shahani, Nasserbakht, and Lee, ISSCC 1998]

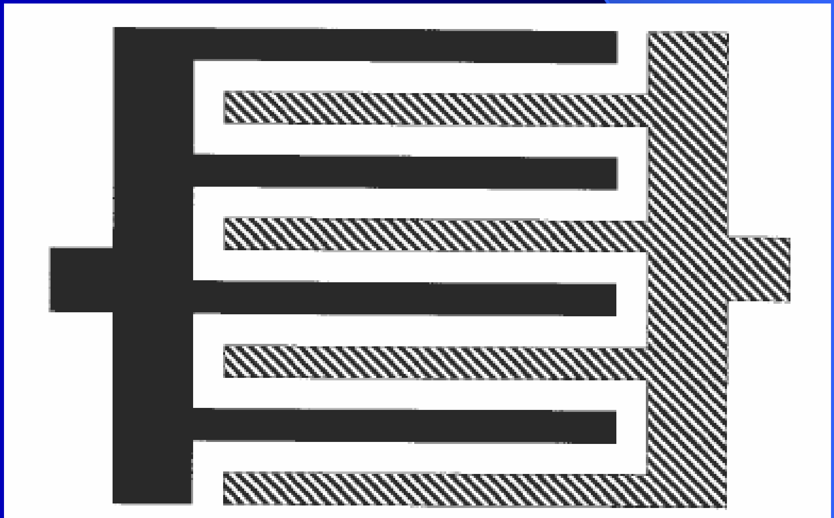
Capacitance density comparison



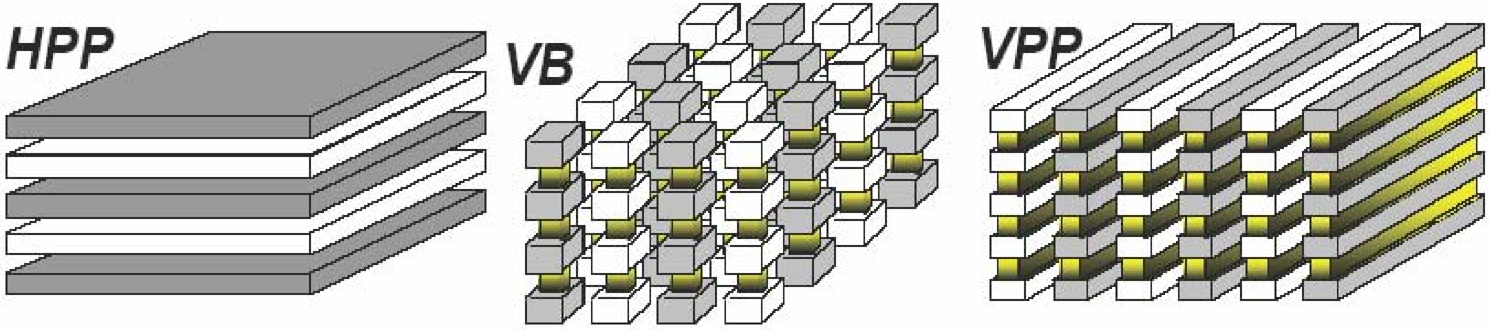
	% TL1	% TL2
Woven	37.0%	52.7%
Woven no Vias	28.3%	40.3%
Parallel Wires	28.3%	40.3%
Quasi-Fractal	17.9%	25.5%
Horizontal PP	0.8%	1.1%
Vertical PP	49.6%	70.7%
Vertical Bars	63.7%	90.8%

[Aparicio and Hajimiri, JSSC March 2002]

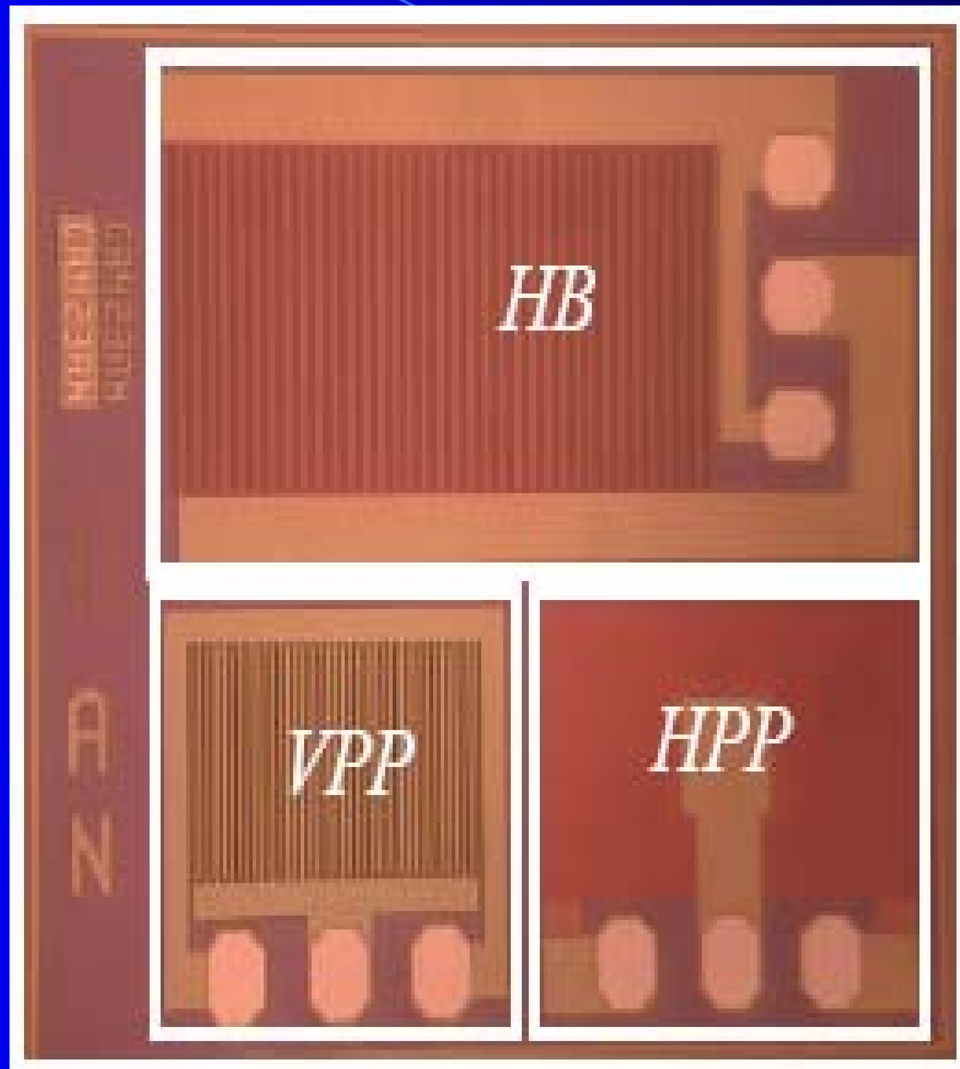

Metal 1
Terminal 1
Terminal 2
Via
Metal 2

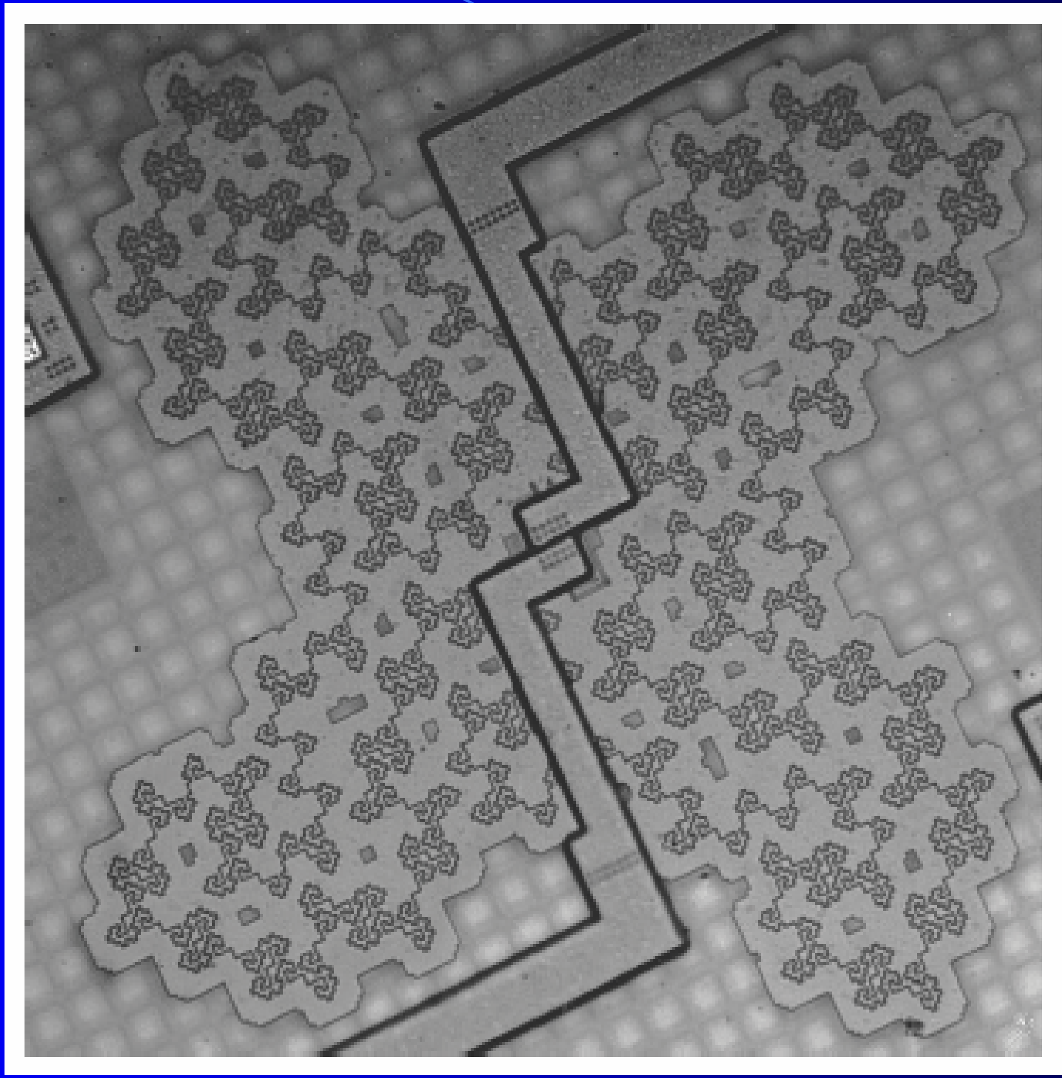


Measurement Summary



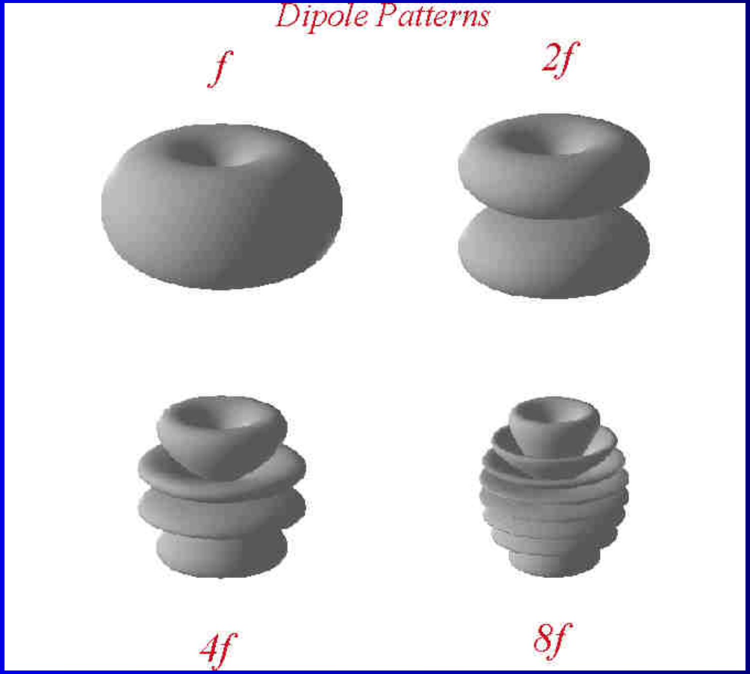
	HPP	VB	VPP	MIM 0.18μ
Average Cap. [pF]	1.095	1.076	1.013	1.057
Cap. Density [aF/μm^2]	203.6	1281.3	1512.2	1100
Cap. Enhancement	1	6.29	7.43	5.40
f_{res} [GHz]	21	37.1	40 <	11
Q (Measured) @1GHz	63.8	48.7	83.2	95


HB
VPP
HPP



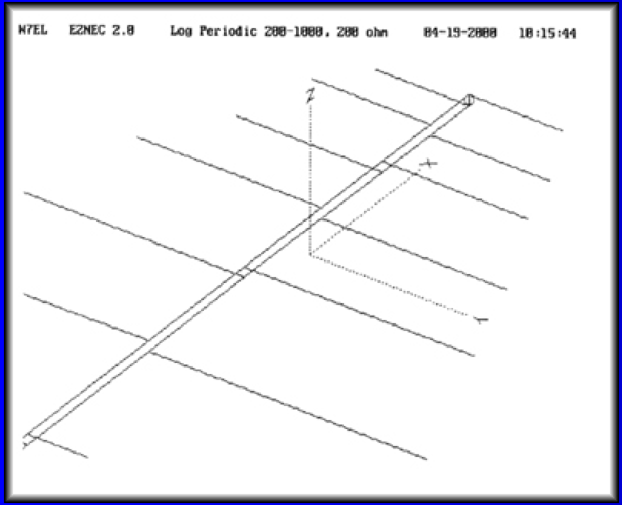
Antenna properties

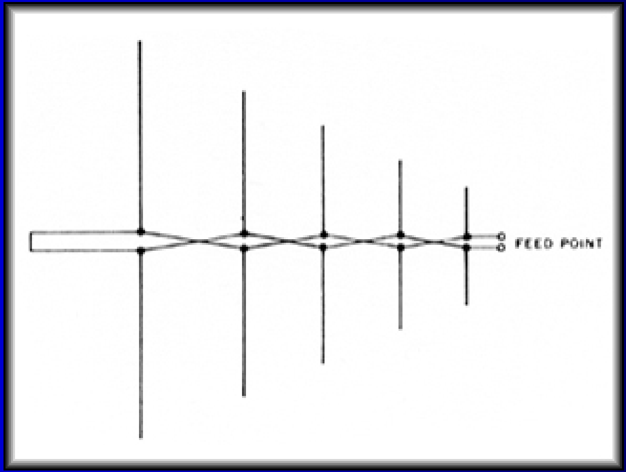
- Radiation pattern variation for a linear antenna with changing frequency – antennas are narrow-band devices!

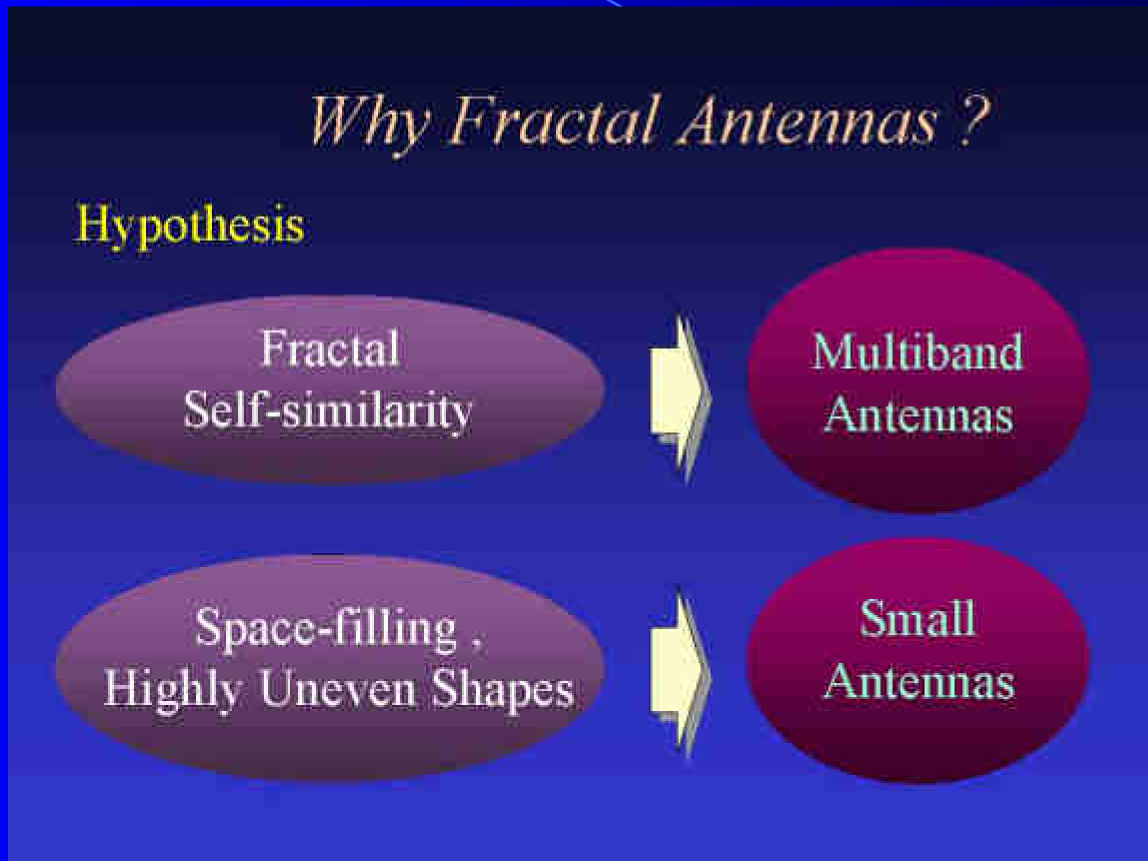


fractal antenna is an antenna that uses a self-similar design to maximize the length, or increase the perimeter (on inside sections or the outer structure), of material that can receive or transmit electromagnetic signals within a given total surface area. For this reason, fractal antennas are very compact, are multiband or wideband, and have useful applications in cellular telephone and microwave communications. Fractal antenna response differs markedly from traditional antenna designs, in that it is capable of operating optimally at many different frequencies simultaneously. Normally standard antennae have to be "cut" for the frequency for which they are to be used—and thus the standard antennae only optimally work at that frequency. This makes the fractal antenna an excellent design for wideband applications.

- The first fractal antennas were arrays, and not recognized initially as having self similarity as their attribute. Log-periodic antennas are arrays, around since the 1950's (invented by Isbell and DuHamel), that are such fractal antennas. They are a common form used in TV antennas, and are arrow-head in shape. Antenna elements made from self similar shapes were first done by Nathan Cohen, a professor at Boston University, in 1988. Most allusions to fractal antennas make reference to these 'fractal element antennas'.


N7EL EZNEC 2.0 Log Periodic 200-1000, 200 ohm 04-19-2000 10:15:44


FEED POINT

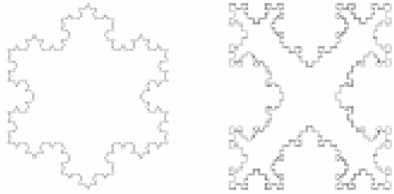

Why Fractal Antennas ?
Hypothesis
Fractal
Self-similarity
Multiband
Antennas
Space-filling ,
Highly Uneven Shapes
Small
Antennas

Which Fractals and Why?

Loops

Minimize Size

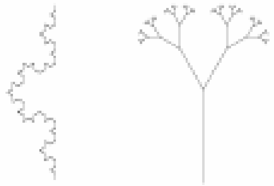
Increase Input Impedance



Dipoles

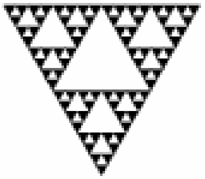
Minimize Heights

Increase Input Impedance



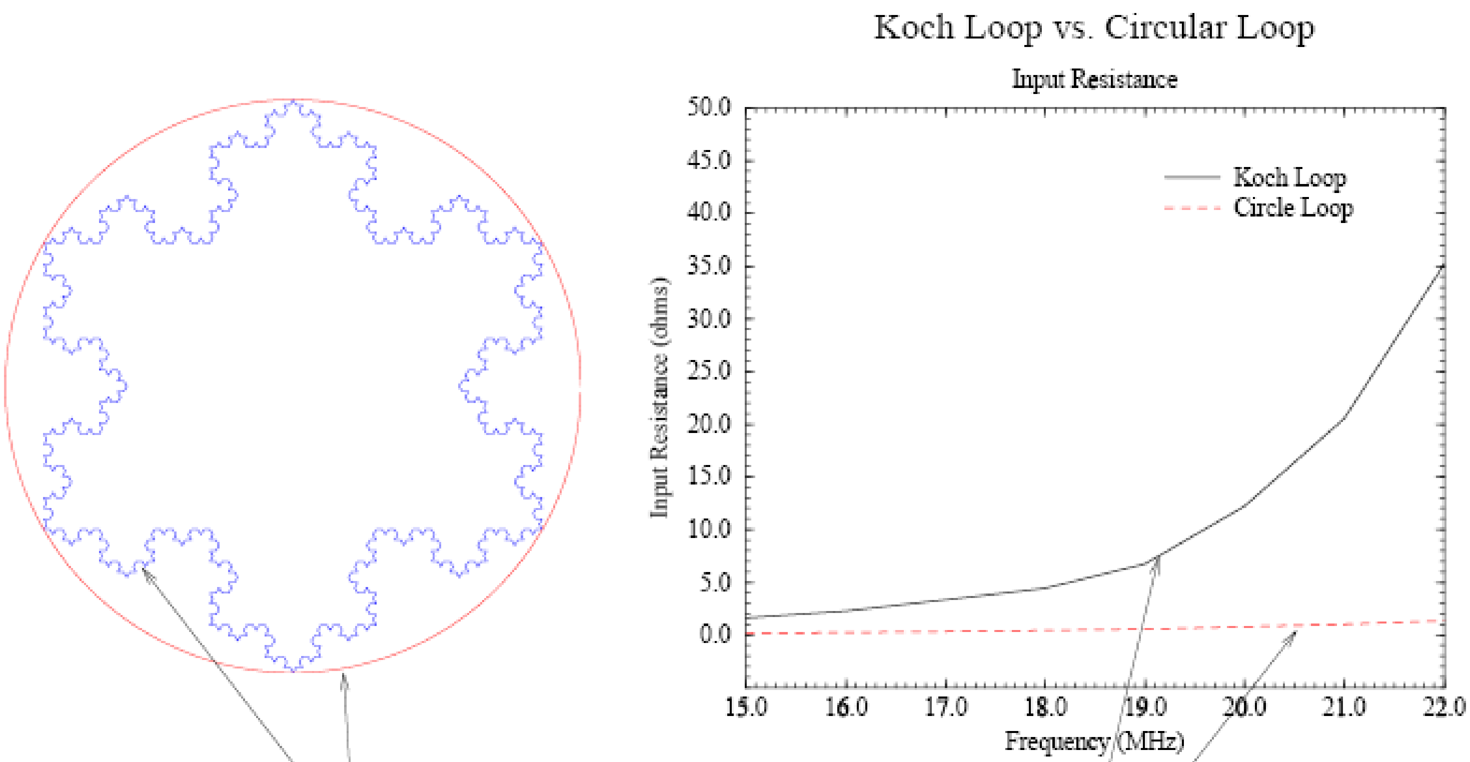
Dipoles

Multiband



Small Fractal Loop Antennas

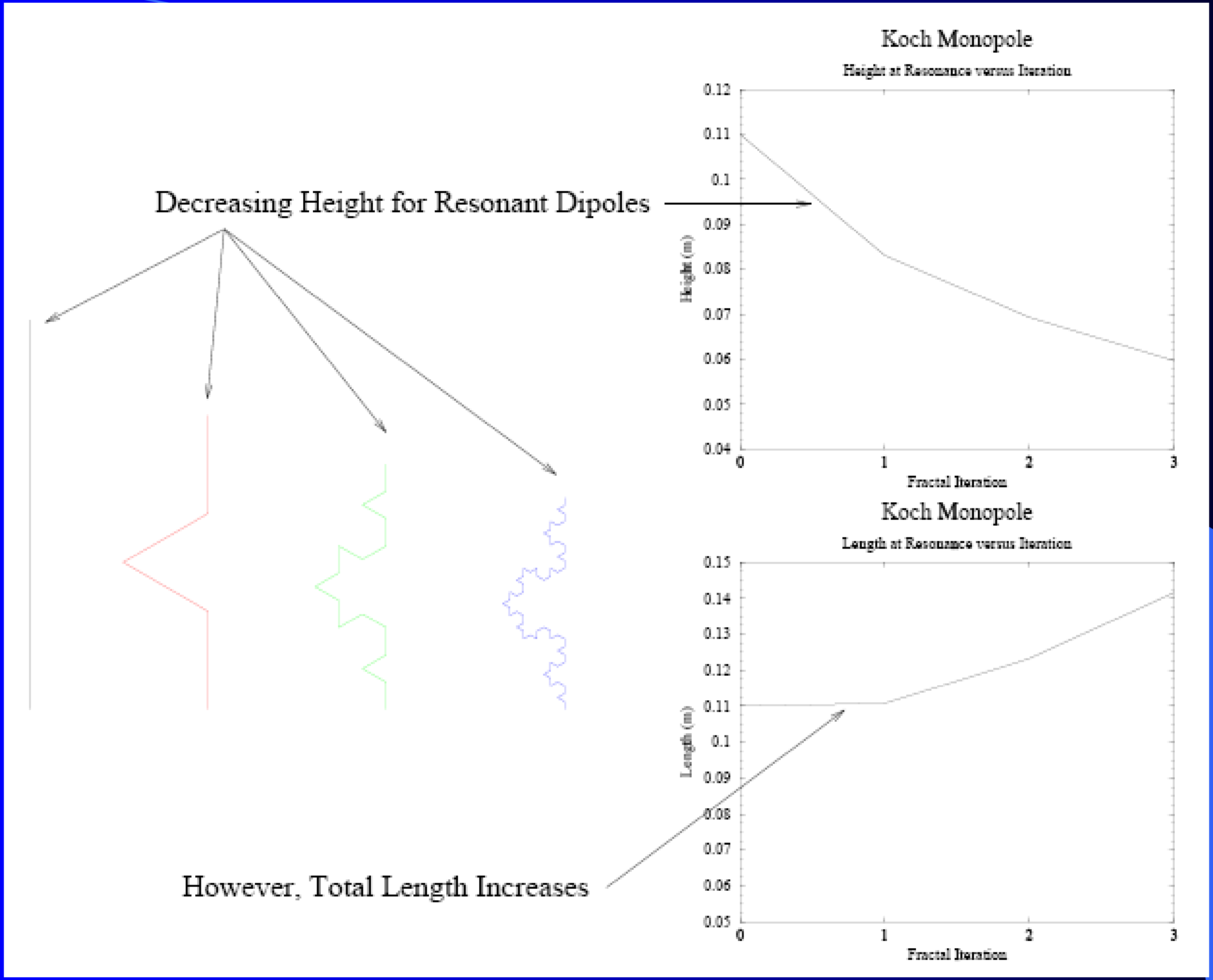
Main Benefit: Increased Input Impedance



Both loops take up the same volume

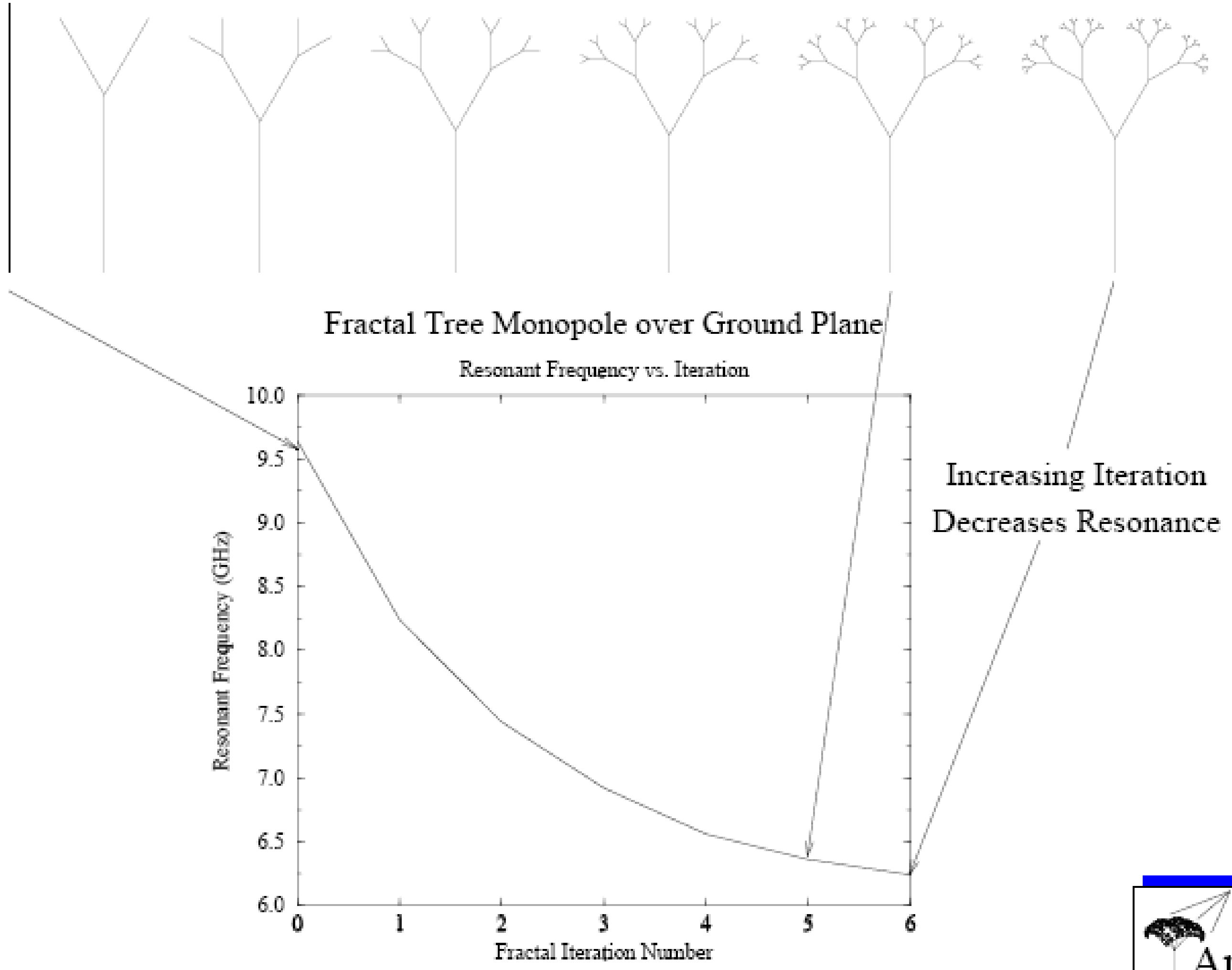
But, the input impedance of the fractal loop is higher

Fractal Antennas



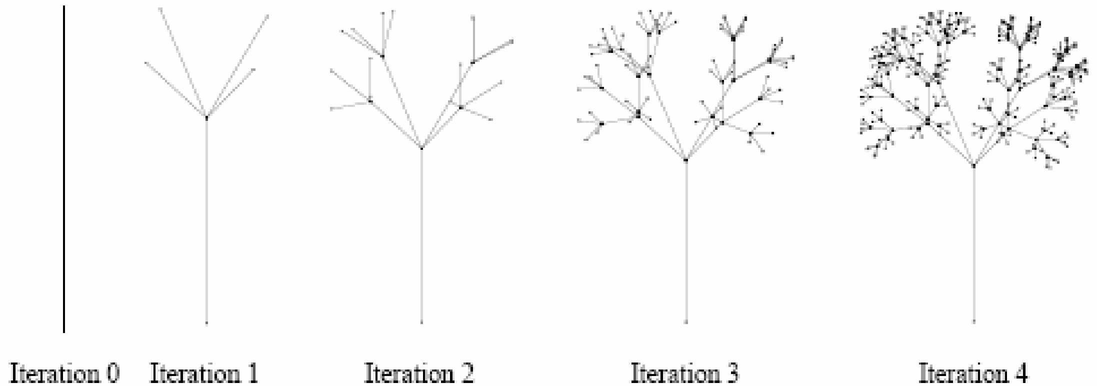
Decreasing Height for Resonant Dipoles
However, Total Length Increases
Koch Monopole
Height at Resonance versus Iteration
Height (m)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0
1
2
3
Fractal Iteration
Koch Monopole
Length at Resonance versus Iteration
Length (m)
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0
1
2
3
Fractal Iteration

Main Benefit: Decreased Resonant Frequency



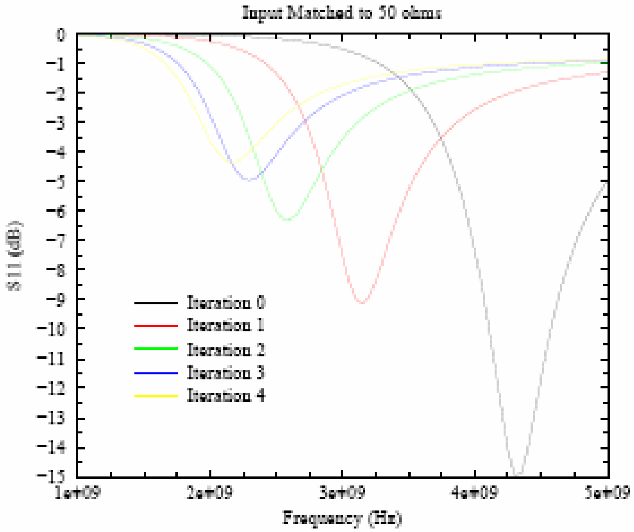
Fractal Antennas

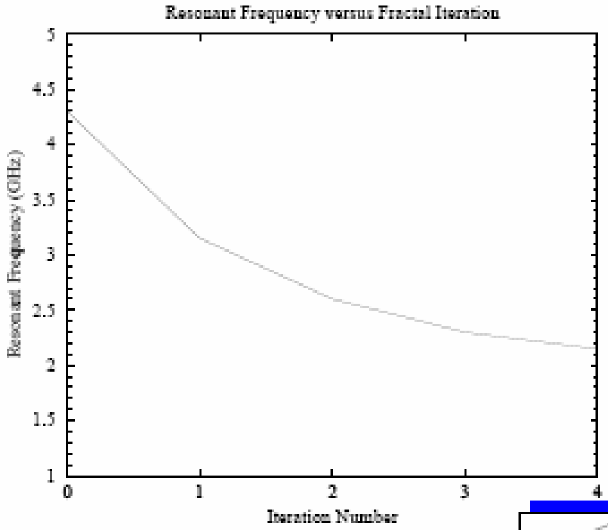
Main Benefit: Decreased Resonant Frequency



3D Fractal Tree

3D Fractal Tree

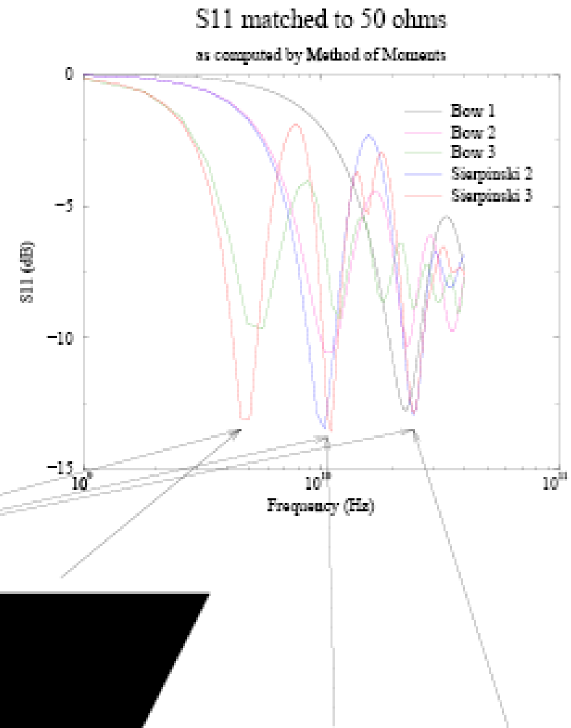




Fractal Antennas

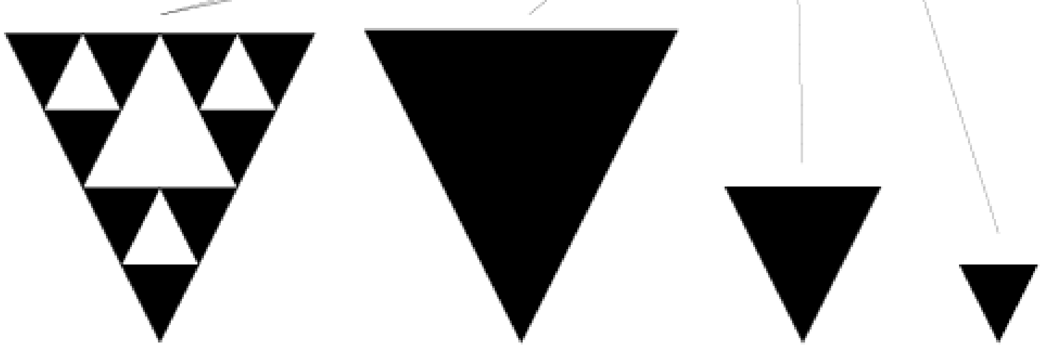
Sierpinski Sieve Dipole Antennas

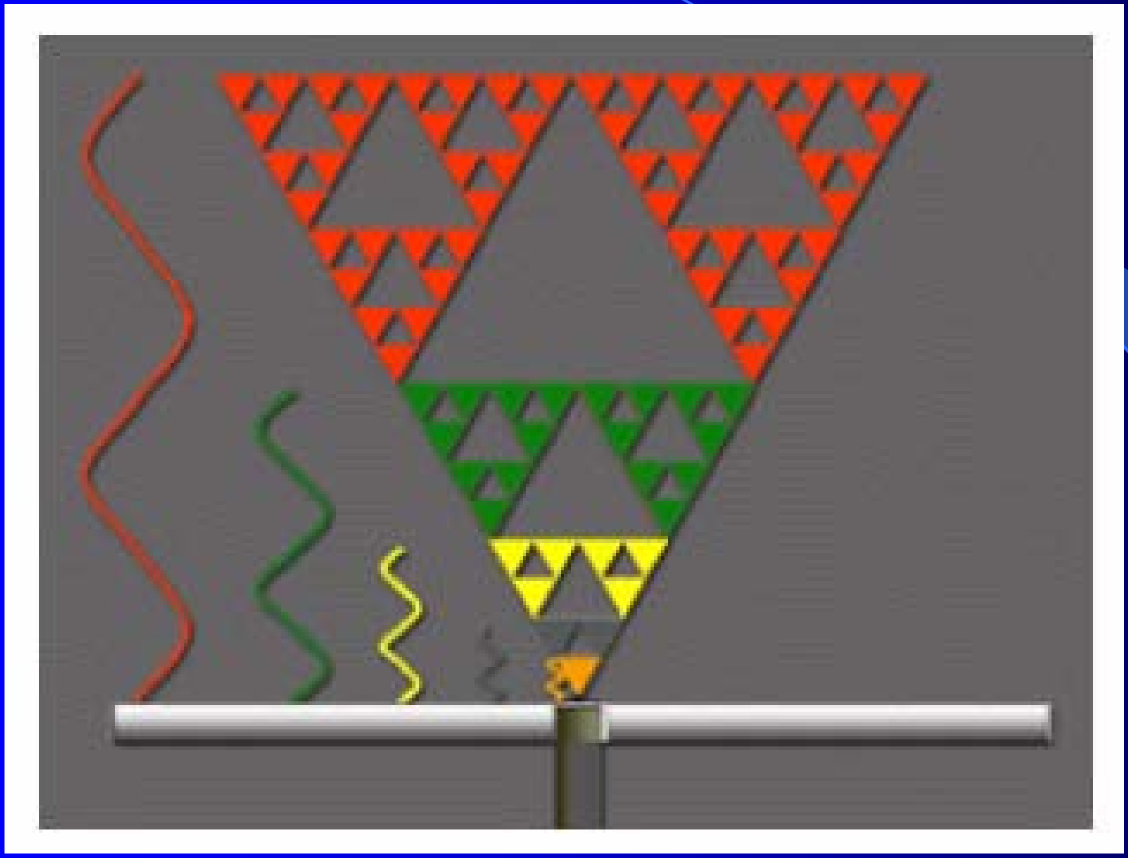
Main Benefit: Multiband



The 3 bands matched by 3 different bowtie dipoles

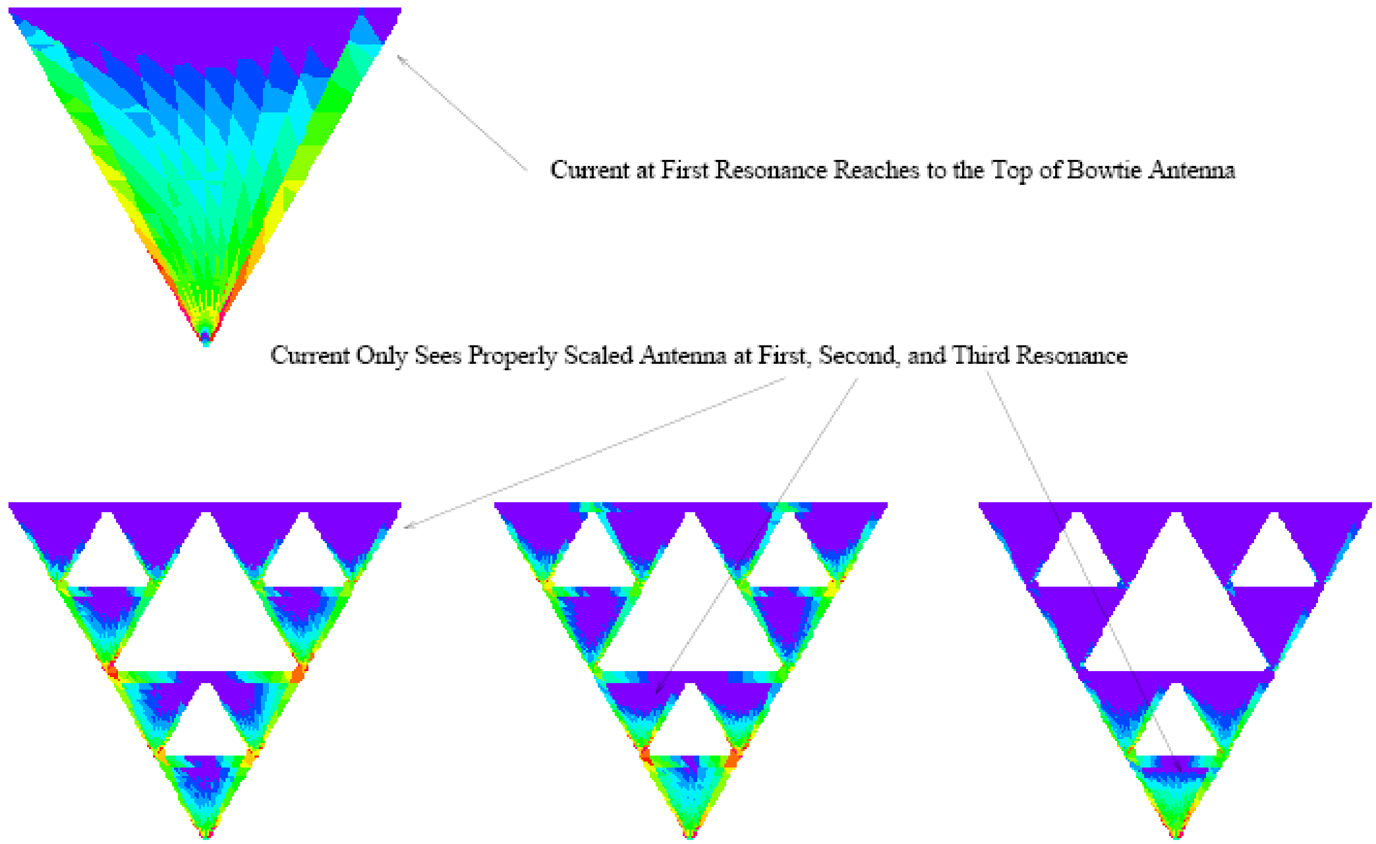
Are matched by 1 sierpinski dipole

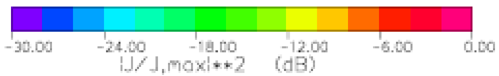




Surface Currents Computed by Method of Moments

Surface Currents Clearly Show Multiband Behavior





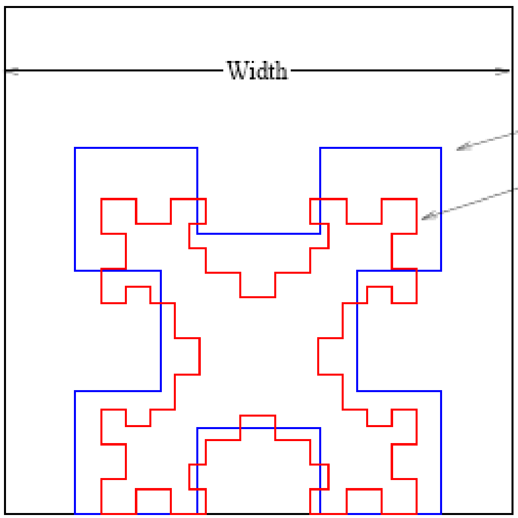
Fractal Antennas

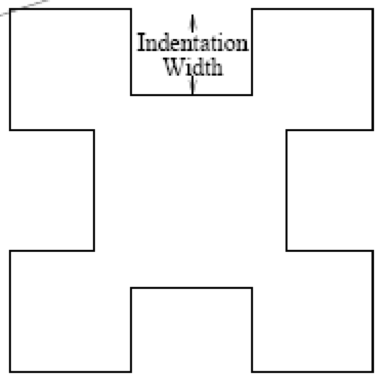
Fractal Square Loop Antennas

Main Benefit: Decreased Size

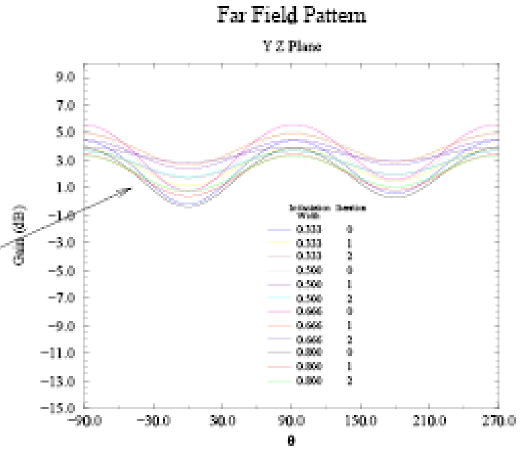
Decreased Antenna Width
Accompanies Increases in Iteration

For Second and Third Iteration





Far Field Pattern
Remains Similar
even with
Smaller Area



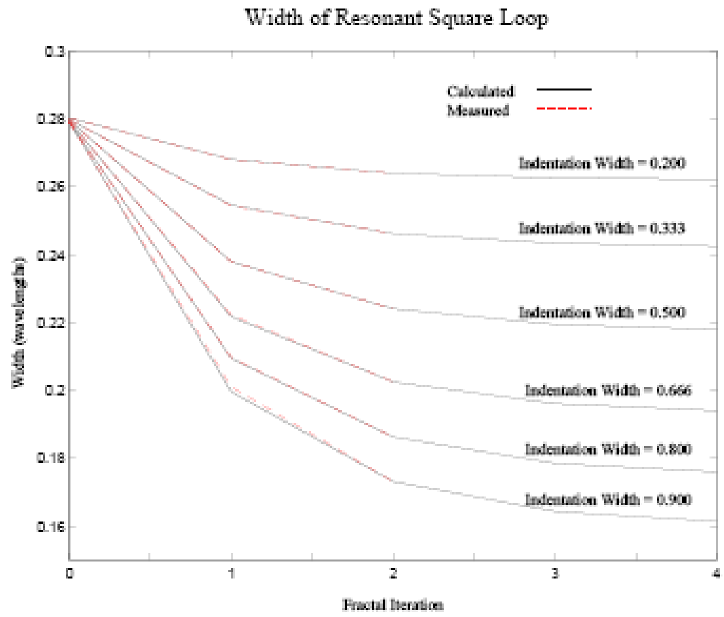
Fractal Antennas

Fractal Square Loop Antenna Design Curves

The Antenna can be Fabricated for a Given Iteration

$$Width = \frac{C}{e^{2*1.1}-1}$$

For a given indentation width, resonant loops can be designed using the above equation, where C is found empirically.

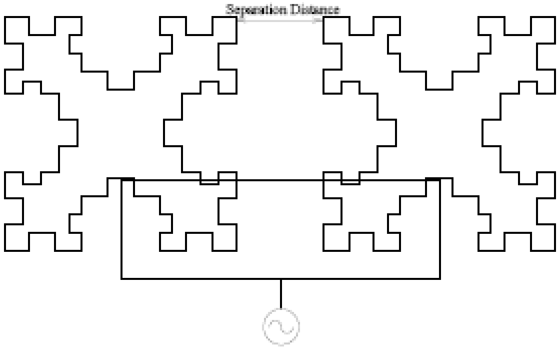


Fractal Antennas

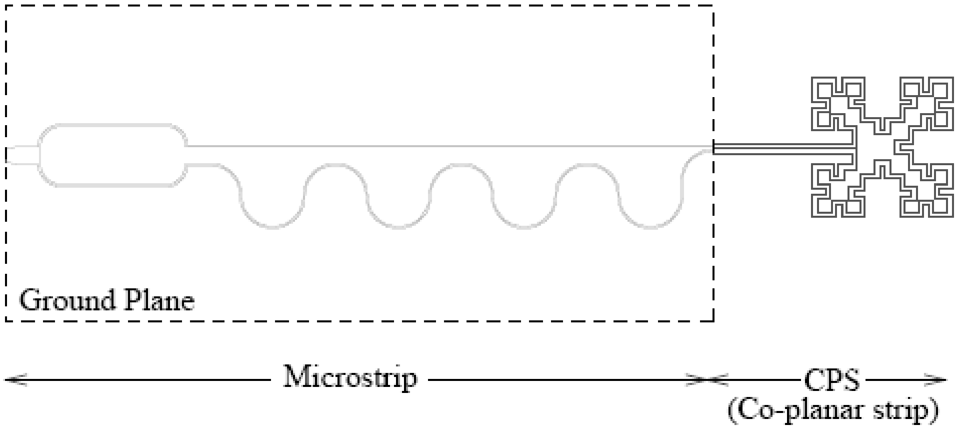
Arrays with Fractal Elements

Main Benefit: Decreases Mutual Coupling between Elements

Separation Distance can be Maximized Using Fractal Elements



Thin Feeding Network for Fractal Array Elements

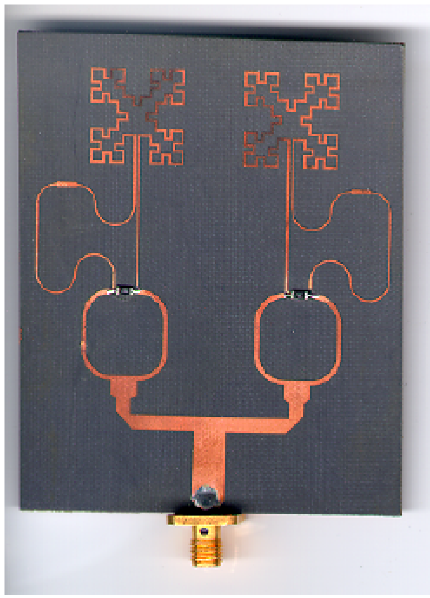


Fractal Antennas

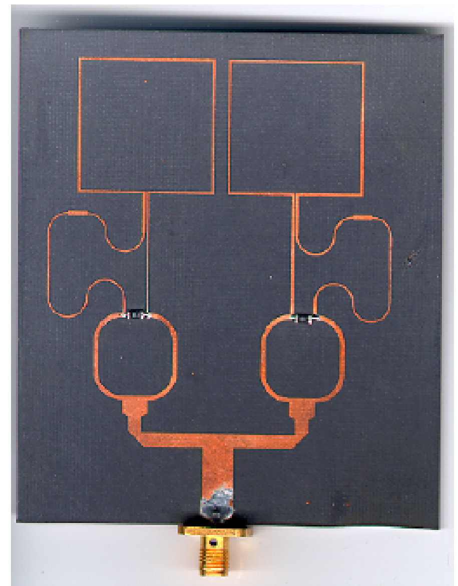
John Gianvittorio - UCLA

Fabricated Fractal Array Antennas

Decreased inter-element coupling for fixed spacing
Increased packing ability with smaller fractal elements



Fractal Array

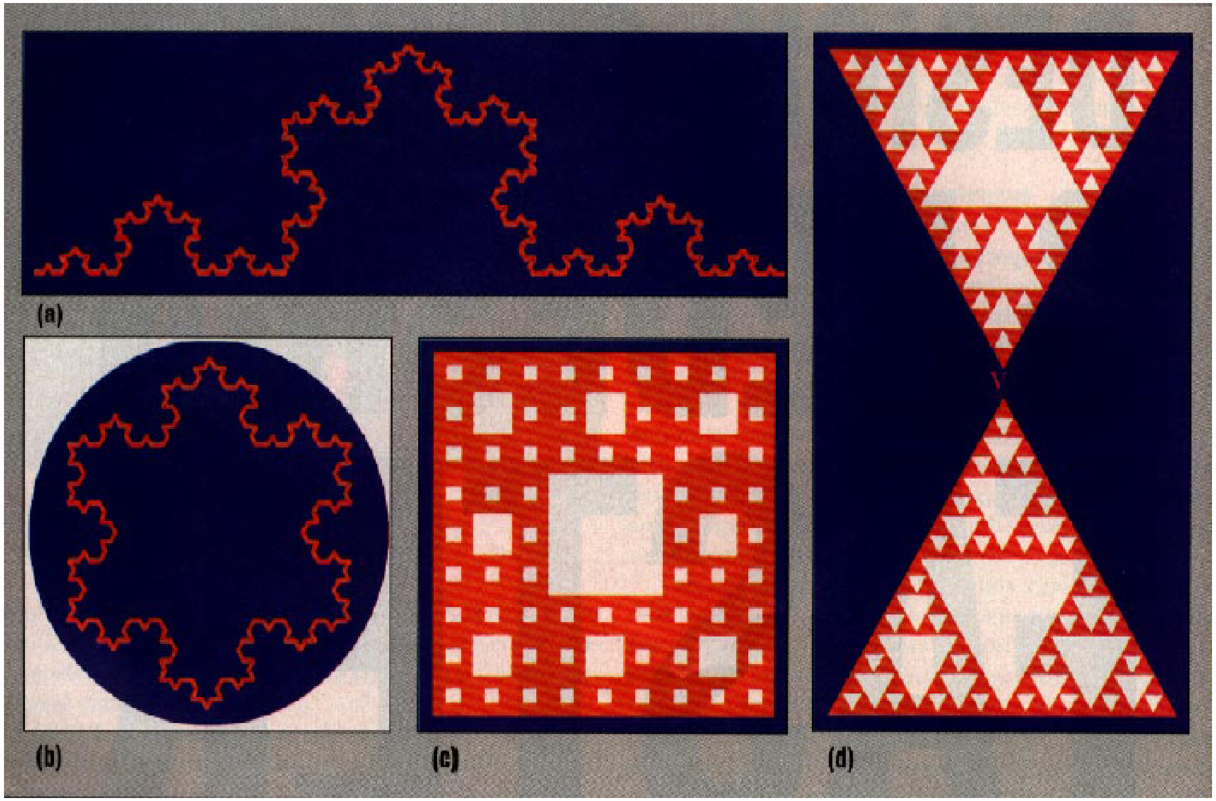


Standard Array

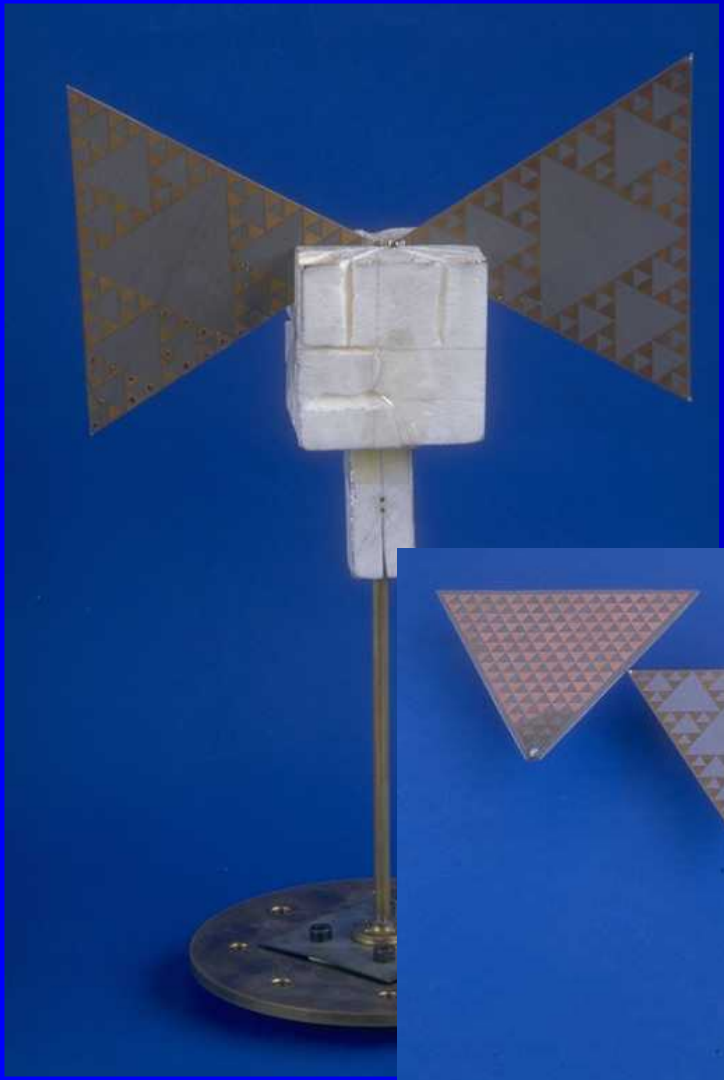
Fractal Antennas

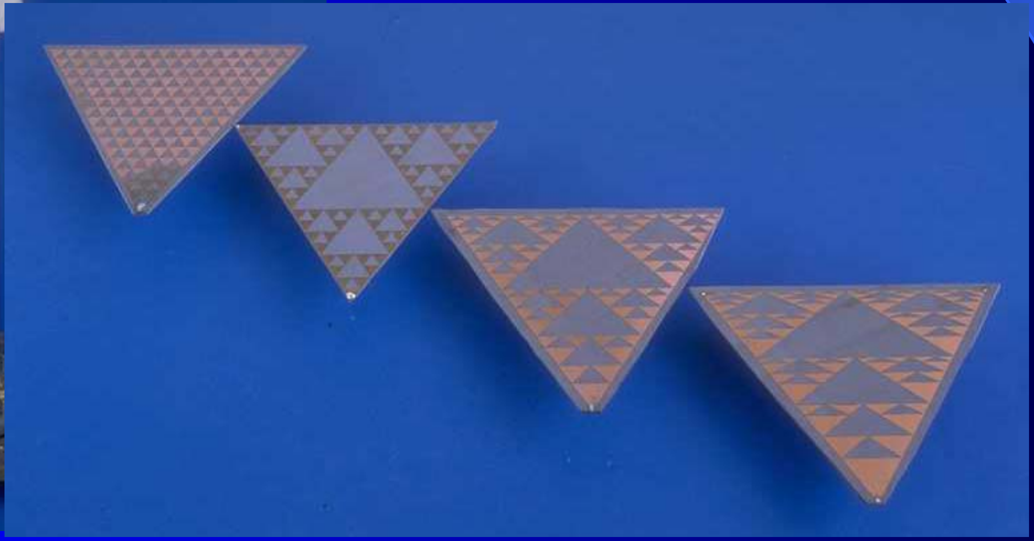
Fractal antenna design

- Sample fractal antenna elements:



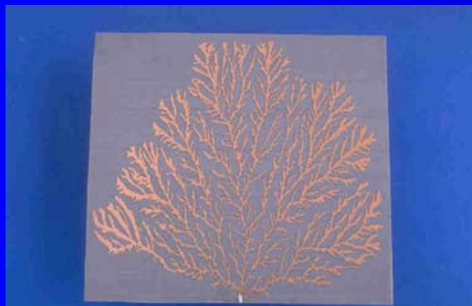
(a) Koch dipole (b) Koch loop (c) Cantor slot patch (d) Sierpinski dipole

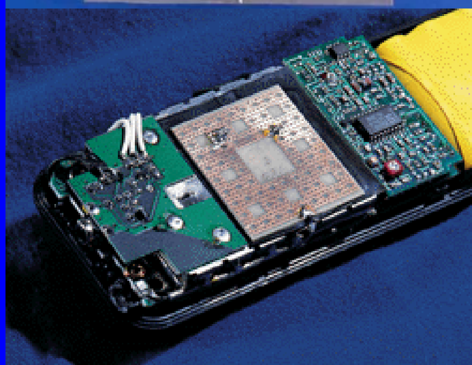


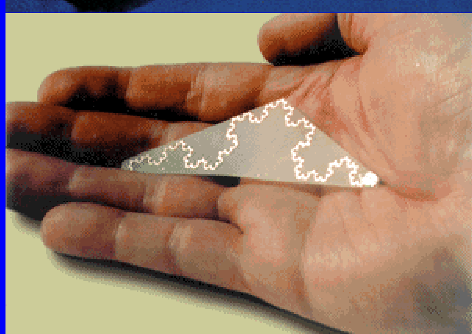



GSM
TETRA
GPS
AM/FM

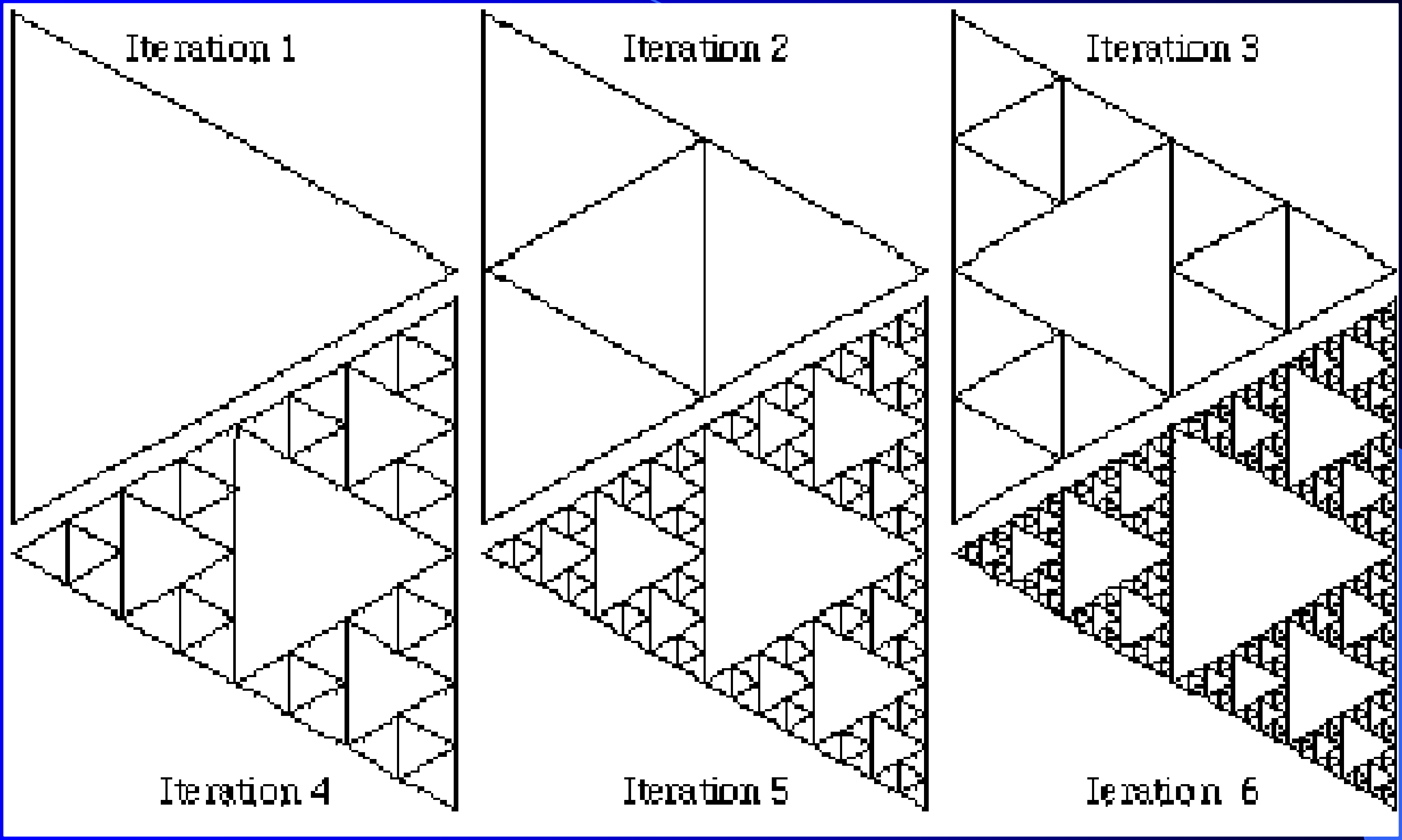

ITEM NO.:GS-205
Frequency: GPS 1575MHz ±3MHz
Band Width ±5 MHz
Impedance: 50ohms
SWI: 1.5:1
Gain: >3dBi
Cable: RG-174
Frequency: GSM 890-960MHz
1710-1990MHz
Impedance: 50 ohms
SWI: <2
Gain: 2.15dbi
Cable: RG-174
Frequency: 76-110MHz(FM)
525-1700KHz(AM)
Gain: +20db(FM)
+5db(AM)
Impedance: 75 ohms
Cable: 3C-2V
Voltage:10-14V
Cable length: 8"
Dia of installation hole: Φ15mm
Fit VW, GM, Audi, BWM, Peugeot

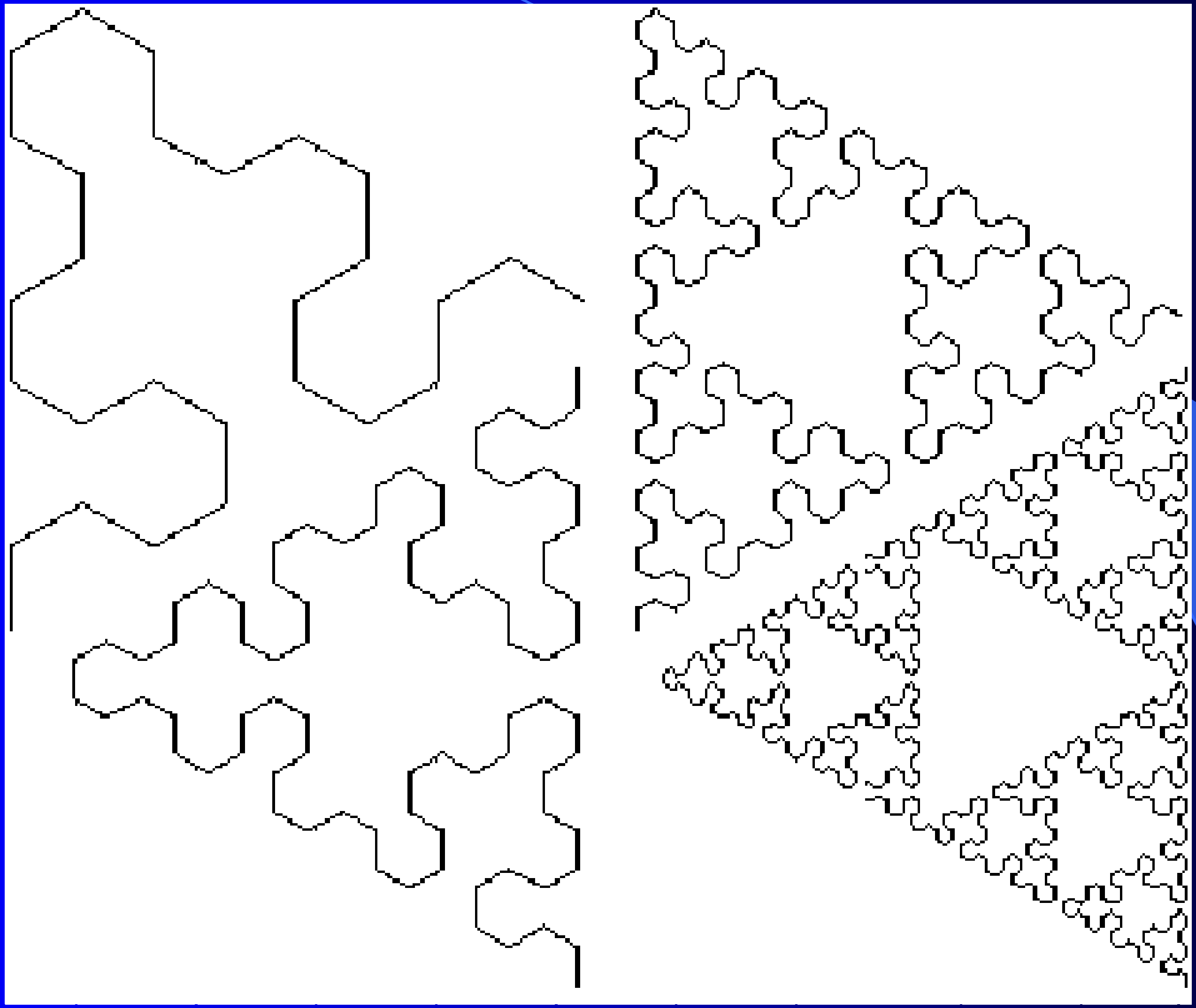


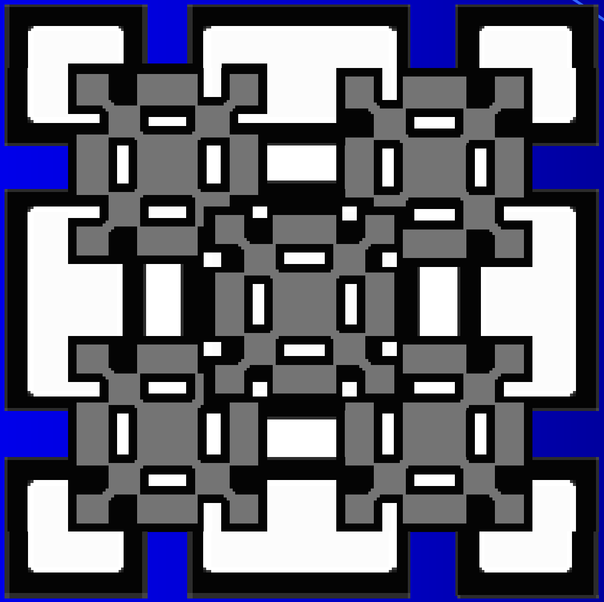


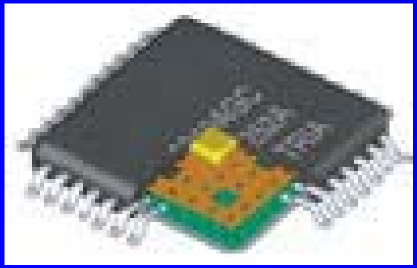


- Fractal antennas have superior multiband performance and are typically two-to-four times smaller than traditional aerials.
- Fractal antennas are the unique wideband enabler—one antenna replaces many.
- Multiband performance is at non-harmonic frequencies, and at higher frequencies the FEA is naturally broadband. Polarization and phasing of FEAs also are possible. Fractal Antenna
- Practical shrinkage of 2-4 times are realizable for acceptable performance.
- Smaller, but even better performance


Iteration 1
Iteration 2
Iteration 3
Iteration 4
Iteration 5
Ieration 6







Visualization of antenna (the brown layer) integrated on a package substrate

AiP integrated on Bluetooth® adapter

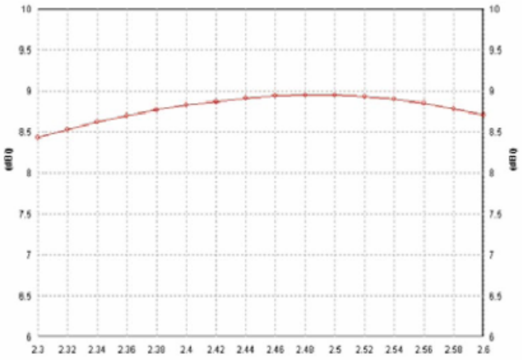
Fractus® Julia-12 ISM 2.4 GHz VPol — P/N: FR03-02-N-0-002

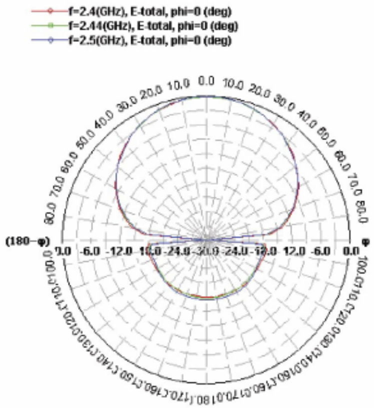
The **JULIA-12 ISM 2.4 GHz panel antenna** is a cost effective solution with an excellent broad coverage in a tiny package. The antenna features an internal Fractal shaped element and is suitable for both indoor and outdoor aplications.

Frequency Range	2.4 - 2.5 GHz
Directivity/Gain	9.6 dBi / 8.8 dBi
Impedance	50 Ω
Polarisation	VPOL
F/B Ratio	> 18 dB
VSWR	< 1.5 : 1
Vertical Beamwith	65°
Horizontal Beamwith	70°
Connector (Pig Tail)	RP-TNC or RP-SMA
Radome	ABS
Dimensions	10 x 10 x 3 cm

Measured results from a standard

Patent Pending: WO0154225, WO0122528, PCT/EP01/10589, PCT/EP02/07837, US60/613394, US60/627653 and PCT/EP02/07836





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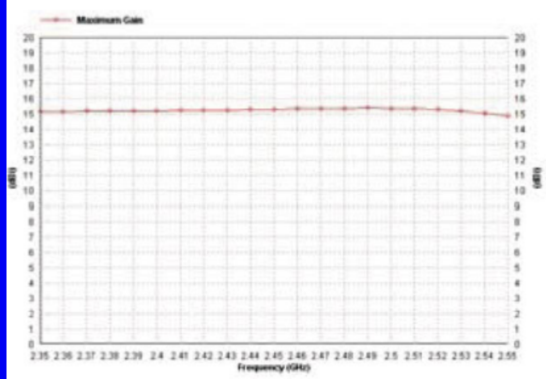
Fractus® Julia-10b ISM 2.4 GHz VPol   P/N: FR03-02-N-0-003

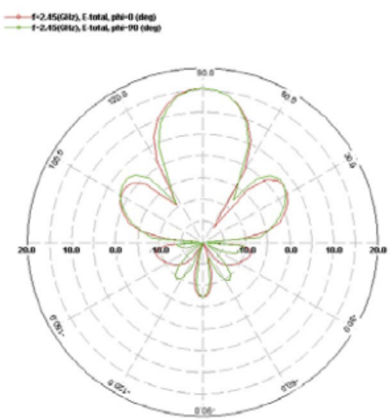
The **JULIA-10 ISM 2.4 GHz panel antenna** offers a superior gain to size ratio thanks to the Fractus' patented "Super Directive" patch design. JULIA-10 is the ideal choice to get extra range capacity in a tiny package.

Frequency Range	2.4 - 2.5 GHz
Directivity/Gain	16 dBi / 15 dBi
Impedance	50 Ω
Polarisation	VPOL
F/B Ratio	> 20 dB
VSWR	< 1.5 : 1
Vertical Beamwith	30°
Horizontal Beamwith	35°
Connector (Pig Tail)	RP-TNC or RP-SMA
Radome	ABS
Dimensions	21 x 21 x 3 cm

Measured results from a standard

Patent Pending: WO0154225, WO0122528, PCT/EP01/10589, PCT/EP02/07837, US60/613394, US60/627653 and PCT/EP02/07836





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Fractal Geofind™ GPS Slim Chip Antenna

P/N: FR05-S1-E-0-103

The **Fractal Geofind** is an slim chip antenna engineered specifically for consumer electronic devices operating with GPS system where low-cost and robust performance is mandatory.

Taking advantage of the space-filling properties of fractals, this **small planar monopole** antenna is ideal for use low-cost consumer electronic devices to add personal location functionalities. The **Fractal Geofind GPS Slim Chip Antenna** speeds your time-to-market by allowing you to integrate it within your industrial design easily (SMD mounting) and efficiently.

10 x 10 x 0.9 mm (image karger than actual size)

Front Back

Patent Pending: WO0154225, WO0122528, PCT/EP01/10589, PCT/EP02/07837, US60/613394, US60/627653 and PCT/EP02/07836

Product Benefits

High performance/price ratio

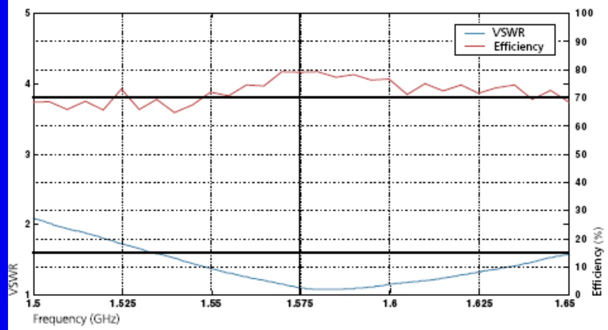
Raises your device's competitiveness by increasing satellite sensitivity and decreasing your device's BoM cost.

Omnidirectional pattern

Optimises device usage due to a uniform radiation pattern.

Small Volume

Allows integration into space limited areas easily and efficiently.



Frequency Range	1575 MHz
Efficiency	> 70 %
Peak Gain	> 1 dBi
VSWR	< 1.6:1
Weight	0.20 g
Temperature	-40 to +85 °C
Impedance	50 Ω unbalanced
Dimensions	10 x 10 x 0.9 mm

Measured results from a standard PCB of 70x30 mm

Please contact your sales representative at Richardson Electronics to obtain additional information on recommended configurations for different UWB devices.
Richardson Electronics: **www.rell.com** Fractus: **wireless@fractus.com** Reference: **DS_FR05-S1-E-0-103_v01**

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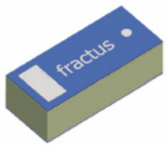
Fractus® Compact Reach Xtend™ Chip Antenna — P/N: FR05-S1-N-0-102

The **Fractus Compact Reach Xtend Chip Antenna** for Bluetooth® and 802.11 b/g WLAN is a tiny rectangular 3D-shaped antenna suitable for headset, compact flash (CF), secure digital (SD) and other small PCB devices operating at 2.4 GHz where high performance and low-cost are mandatory. Its broad bandwidth ensures high quality signal reception and transmission across wireless devices and different plastic housing designs.

Taking advantage of the space-filling properties of fractals, this **small monopole** antenna is ideal for use within indoor (highly scattered) environments. The **Fractus Compact Reach Xtend Chip Antenna** speeds your time to market by allowing you to easily integrate it within your industrial design (SMD mounting).

7 x 3 x 2 mm (image larger than actual size)



Front

Back

Patent Pending: WO0154225, WO0122528, PCT/EP01/10589, PCT/EP02/07837, US60/613394, US60/627653 and PCT/EP02/07836

Product Benefits

Small form factor

Allows integration into space limited areas easily and efficiently with minimum clearance area.

Broad bandwidth

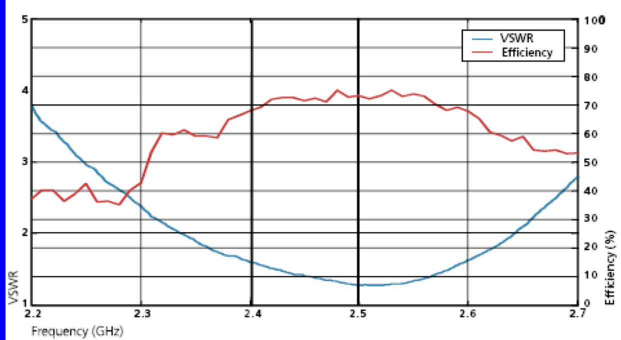
Ensures robust performance when considering different plastic housing and close body proximity.

Omnidirectional pattern

Optimises device usage due to a uniform radiation pattern.

Multi-mode support

Works for Bluetooth, and Wi-Fi 802.11b and g standards.



Frequency Range	2.4 - 2.5 GHz
Efficiency	> 70 %
Peak Gain	> 1 dBi
VSWR	< 2:1
Weight	0.20 g
Temperature	-40 to +85 °C
Impedance	50 Ω unbalanced
Dimensions	10 x 10 x 0.8 mm

Measured results from a standard PCB of 47x23 mm

Please contact your sales representative at Richardson Electronics to obtain additional information on recommended configurations for different UWB devices.
Richardson Electronics: **www.rell.com** Fractus: **wireless@fractus.com** Reference: **DS_FR05-S1-N-0-102_v01**

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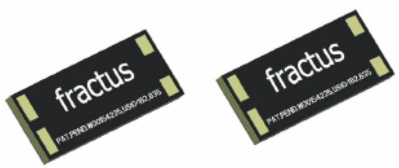
Fractus® EZConnect™ Zigbee™ Chip Antenna   P/N: FR05-S1-R-0-105

The Fractus **EZConnect Zigbee Chip Antenna** is a compact rectangular antenna suitable for smart home, security and other industrial devices using the 915 MHz ISM band, where low power consumption and cost are top of mind.Taking advantage of the space-filling properties of fractals, this **compact monopole** antenna is ideal for use within indoor (highly scattered) as well as outdoor environments.

The **Fractus EZConnect Zigbee Chip Antenna** speeds your time to market by allowing you to easily integrate it within your industrial design (SMD mounting).

18 x 7,3 x 1 mm (image larger than actual size)



Front   **Back**

Patent Pending: WO0154225, WO0122528, PCT/EP01/10589, PCT/EP02/07837, US60/613394, US60/627653 and PCT/EP02/07836

Product Benefits

Small form factor

Allows integration into space limited areas easily and effectively.

Broad bandwidth

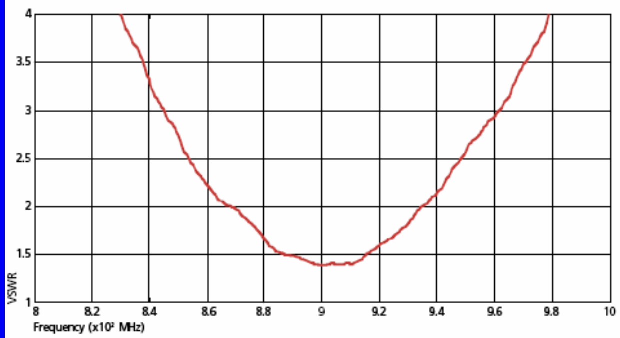
Ensures robust performance in different PCB dimensions and plastic housing, without the need for a matching network.

High performance

Optimises power consumption and increases device range.

Omnidirectional pattern

Increases device robustness due to a uniform radiation pattern.



Frequency Range	902 - 928 MHz
Efficiency	> 40 %
Peak Gain	> 0 dBi
VSWR	< 2:1
Weight	0.20 g
Temperature	-40 to +85 °C
Impedance	50 Ω unbalanced
Dimensions	18 x 7,3 x 1 mm

Measured results from a standard PCB of 120x65 mm

Please contact your sales representative at Richardson Electronics to obtain additional information on recommended configurations for different UWB devices.
Richardson Electronics: **www.rell.com**   Fractus: **wireless@fractus.com**   Reference: **DS_FR05-S1-E-0-105_v01**

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Customised Mobile Handset Antenna
Pat. Pending: WO012258, VS2002140615,
WO0154225, VS10/182,635

Fractus Compact Dual-Band Reach XtendTM
WLAM 802.11 a/b/g/j/n Chip Antenna 2.4 & 5GHz

FRACTAL ANTENNA SYSTEMS INC

Electronic Warfare

UAB™ Antenna

Extreme wideband and omnidirectional performance with superior gain. Operates with or without a ground plane over a 25:1 frequency range, from VHF to microwave. Compact form factor packaged in a 7.7 inch-diameter, 10 inch-high radome weighing 4.8 pounds. Up to 250W input power. VSWR less than 2:1.

UAD™ Antenna

Extreme wideband performance with up to 250W power handling and superior gain. Operates over UHF to microwave. Low profile of 5.7 inches and easily concealable in a 7.7 inch-diameter radome. VSWR less than 2:1.

UGS™ Antenna

Single antenna integrated with an unattended ground sensor (UGS) providing superior omnidirectional long-range performance. Operates over high HF through VHF. Innovative raised phase center design minimizes ground losses, while improving radiation pattern and launch angle. Easily deployed in a compact, lightweight package measuring 2.5 inches in diameter and 3 feet in height.

RFsabre™

With outstanding lower frequency gain and less than 3:1 VSWR over a very wide frequency range, the RFsabre antenna delivers great performance in a distinctly compact form factor. The vehicle-mounted version can survive impacts with solid objects at speeds up to 25 MPH. Geared for security, communications, signal gathering, and high power transmit applications. New hanging or tripod mounted versions available.

TRANZTENNA™

Breakthrough performance in a wideband antenna from the fractal antenna innovators

Fractal antenna technology, implemented in transparent conductive film, makes covert capability possible with a mission-capable antenna system that operates over a huge frequency range.

- Outstanding gain
- Transparent
- Conformable
- Only 13 x 18 inches
- VSWR less than 3:1
- Inherently 50 Ohms
- Optional frequency lowering panels

Signal intelligence warfighters face a difficult challenge — the need to monitor communications over a very wide frequency range while remaining clandestine. Current electronic surveillance systems employ multiple antennas that are either large or noisy. Covertness and high performance are united in the Tranztenna™ optically transparent antenna: an extremely wideband antenna designed for vehicle or building window placement. This conformable, rugged, compact antenna is easy to transport and install in field operations. New missions to intercept and monitor enemy communications are possible with this breakthrough in transparent antenna technology.

Feature	Advantage	Benefit
Transparent	Visually unobtrusive	Covert use of antenna in vehicle or building window
Good Gain	Superior to ITO films	Excellent signal-to-noise ratio
Wideband	Operation over very wide frequency range	Instantaneously access most spectrum of interest
Compact Size	Effective use of small window apertures	Access to lower frequencies
Conformable	Flexible sheet	Easy transport and deployment

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