Fractal Antenna Applications

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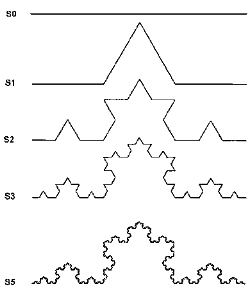
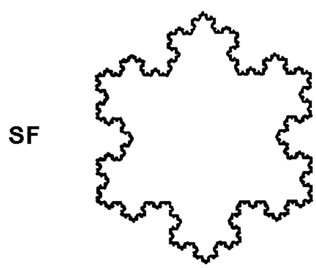
1. Introduction

Fractals are geometric shapes that repeat itself over a variety of scale sizes so the shape looks the same viewed at different scales. For such mathematical shapes B.Mandelbrot [1] introduced the term of "fractal curve". Such a name is used to describe a family of geometrical objects that are not defined in standard Euclidean geometry. One of the key properties of a fractal curve is his self-similarity. A self-similar object appears unchanged after increasing or shrinking its size. Similarity and scaling can be obtained using an algorithm. Repeating a given operation over and over again, on ever smaller or larger scales, culminates in a self-similar structure. Here the repetitive operation can be algebraic, symbolic, or geometric, proceeding on the path to perfect self-similarity.

The classical example of such repetitive construction is the Koch curve, proposed in 1904 by the Swedish mathematician Helge von Koch. Taking a segment of straight line (as *initiator*) and rise an equilateral triangle over its middle third, it results a so called *generator*. Note that the length of the generator is four-thirds the length of the initiator. Repeating once more the process of erecting equilateral triangles over the middle thirds of strait line results what is presented in figure (Figure 1). The length of the fractured line is now $(4/3)^2$. Iterating the process infinitely many times results in a "curve" of infinite length, which - although everywhere continuous - is *nowhere differentiable*. Following Mandelbrot, such nondifferentiable curves is a *fractal*.



Koch fractal
Fig. 1.



Koch snowflake
Fig. 2.

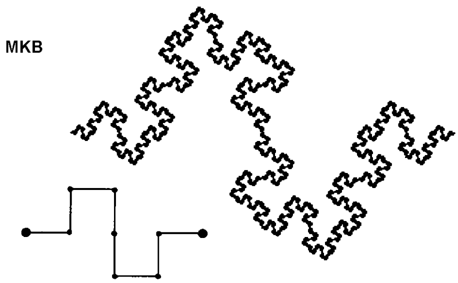


Fig. 3.

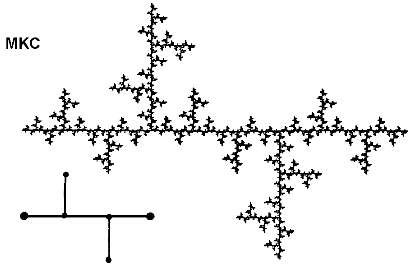


Fig. 4.

Applying the Koch generator to an equilateral triangle, after infinite iteration, converge to the Koch snowflake (Figure 2). The perimeter of the snowflake curve increase after *n* iteration $(4/3)^n$ -fold over the perimeter of the initial triangle. Thus, as *n* approaches infinity, the perimeter becomes infinite long! In the next two images there are some variations on the same theme (Figure 3 and figure 4).
For a smooth curve, an approximate length $L(r)$ is given by a product of the number N of straight-line segments of length r need to step along the curve from one end to the other end. The length will be: $L(r) = N.r$. As the step size r goes to zero, $L(r)$ approaches a finite limit, the length of the curves. But for fractals the product $N.r$ diverges to infinity because, as r goes to zero, the curve becomes more and more tortuous. Asymptotically this divergence behaves according to a well-define homogenous power law of r. There is some *critical exponent* D_H. >1 such that the product $N.r^{DH}$ stays finite. This critical exponent, $D_{H,}$, is called *Hausdorff dimension*. Equivalently, we have

$$D_H = \lim_{r->0} \frac{\log N}{\log(1/r)}$$

For nth generation in the construction of the Koch curve or snowflake, choosing $r = r_0/3^n$, the number of pieces N is proportional to 4^n. Thus,

$$D_H = (log4)/(log3) = 1.26....$$

For a smooth curve $D_H = 1$, for a smooth surface $D_H = 2$, and Koch or other fractals on the surface will have D_H between 1 and 2. Fractals are characterized by their dimension. It is the key structural parameter describing the fractal and is defined by partitioning the volume where the fractal lies into boxes of side ε. For a real curve that mimic a fractal there is only a finite range over which the above scaling law will apply [2]. So, correct speaking, real curve are not true mathematical fractals, but intermediate stages obtained by iteration that could be called "fractal-like curves". The fractal dimension will be an important parametrization for the fractal antennas that could be explore, and will impact significantly the intensity and spatial structure of the radiated pattern.

The fractal design of antennas and arrays results from applying the new fractal geometry in the context of electromagnetic theory. Fractals help in two ways. First, they can improve the performance of antenna or antenna arrays. Traditionally, in an array, the individual antennas are either randomly scattered or regularly spaced. But fractal arrangement can combine the robustness of a random array and the efficiency of a regular array, with a quarter of the number of elements. "Fractals bridge the gap because they have short-range disorder and long-range order" [3].

A fractal antenna could be considered as a non uniform distribution of radiating elements. Each of the elements contributes to the total radiated power density at a given point with a vectorial amplitude and phase. By spatially superposing these line radiators we can study the properties of simple fractal antennae.

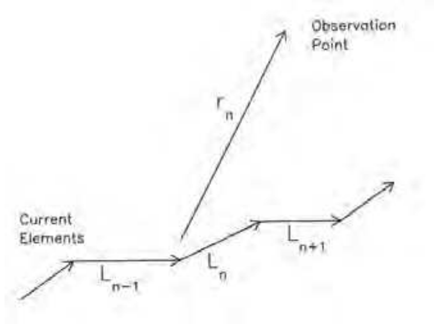


Fig. 5.

The energy radiated in the far field:

$$R(x, y, z,) \propto \int E^2 dt \ .$$

The array factor can be normalized by maximum in the array factor corresponding to the single dipole, i.e.

$$R_0 \approx \frac{\beta^2 I_0^2 A}{4(1-\beta a)^2 h^2} \quad \text{where} \quad A = \frac{3\varsigma^4 - \varsigma^2 f[\eta,\varsigma]}{2(4+5\varsigma^2+\varsigma^4)} \approx 1 \ ,$$

$$\text{and} \quad f[\eta,\varsigma] = \frac{\beta \Delta r - L}{\alpha v}, \quad \beta = v/c,$$

Where h is the height of the detector Δr is the difference in distance between the beginning and the end points of the dipole to the detector position, v is the speed of the current thought the wire.

In the following parts we will exemplify from many fractals applications one possible use, fractal antenna for terrestrial vehicles.

2. Integrated Multi-Service Car Antenna

The system relates a multi-service antenna integrated in a plastic cover fixed in the inner surface of the transparent windshield of a motor car [4].

The miniaturized antennas are for the basic services currently required in a car, namely, the radio reception, preferably within the AM and FM or DAB bands, the cellular telephony for transmitting and receiving in the GSM 900, GSM 1800 and UMTS bands and for instance the GPS navigation system.
The antenna shape and design are based on combined miniaturization techniques which permit a substantial size reduction of the antenna making possible its integration into a vehicle component such as, for instance, a rear-view mirror (Figure 6 – the components are numbered).

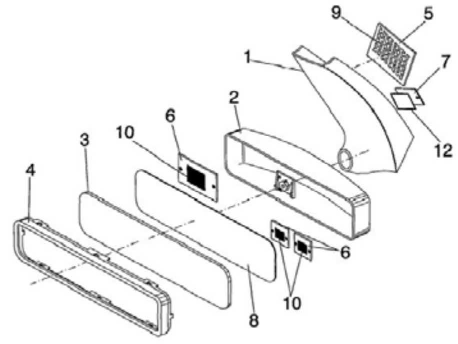


Fig. 6.

Until recently, the telecommunication services included in a automobile were limited to a few systems, mainly the analogical radio reception (AM/FM) bands). The most common solution for these systems is the typical whip antenna mounted on the car roof. The current tendency in the automotive sector is to reduce the aesthetic and aerodynamic impact of such whip antennas by embedding the antenna system in the vehicle structure. Also, a major integration of the several telecommunication services into a single antenna is especially attractive to reduce the manufacturing costs or the damages due to vandalism and car wash systems.
The antenna integration is becoming more and more necessary as we are assisting to a deep cultural change towards the information society. The internet has evoked an information age in which people around the globe expect, demand, and receive information. Car drivers expect to be able to drive safely while handling e-mails, telephone calls and obtaining directions, schedules, and other information accessible on the World Wide Web (www).
Telematic devices can be used to automatically notify authorities of an accident and guide rescuers to the car, track stolen vehicles, provide navigation assistance to drivers, call emergency roadside assistance and remote diagnostics of engine functions.
The inclusion of advanced telecom equipments and services in cars and other vehicles is very recent, and it was first thought for top-level, luxury cars. However, the fast reduction in both equipment and service costs are bringing telematic products into mid-priced automobiles. The massive introduction of a wide range of such new systems would generate a proliferation of antennas upon the bodywork of the car, in contradiction, unless an integrated solution for the antennas is used.

The patent PCT/EP00/00411 proposed a new family of small antennas based on the curves named as space-filling curves. An antenna is said to be a small antenna (a miniature antenna) when it can be fitted into a small space compared to the operating wavelength. It is known that a small antenna features are:
- A large input reactance (either capacitive or inductive) that usually has to be compensated with an external matching / loading circuit or structure.
- A small radiating resistance
- Small bandwidth
- Low efficiency

This is mean that is highly challenging to pack a resonant antenna onto a space which is small in terms of the wavelength at resonance. The space-filling curves introduces for the design and construction of small antennas improve the performance of other classical antennas described in the prior art (such as linear monopoles, dipoles and circular or rectangular loop)
The integration of antennas inside mirrors have been already proposed [5].
Patent US4123756 is one of the first to propose the utilisation of conducting sheets as antennas inside mirrors. Patent US5504478 proposed to use the metallic sides of a mirror as antenna for wireless car aperture [6]. Others configurations have been proposed to enclose wireless car aperture, garage opening or car alarm [7]. Obviously, these solutions proposed a specific solution for determinate systems, which generally require a very narrow bandwidth antenna, and did not offer a full integration of basic services antenna. Other solutions were proposed to integrate the AM/FM antenna in the thermal grid of the rear windshield [8].
However, this configuration requires an expensive electronic adaptation network, including RF amplifiers and filters to discriminate the radio signals from the DC source and is not adequate to the low antenna efficiency.
A main substantial innovation of the presented system consists in using a rear-view mirror to integrate all basic services required in a car: radio-broadcast, GPS and wireless access to cellular networks. The main advantages with respect to prior art are:
- Full antenna integration with no aesthetic or aerodynamic impact
- A full protection from accidental damage or vandalism
- Significant cost reduction.

The utilization of micro-strip antennas is already known in mobile telephony handsets [9], especially in the configuration denoted as PIFA (Planar Inverted F Antennas).
The reason of the utilization of micro-strip PIFA antennas reside in their low profile, their low fabrication costs and an easy integration within the hand-set structure.
One of the miniaturization techniques used in this antenna system are based on spacefilling curves. In some particular case of antenna configuration system, the antenna shape could be also described as a multi-level structure.
Multi-level technique has been already proposed to reduce the physical dimensions of micro-strip antennas.
The present integrated multi-service antenna system for vehicle comprising the following parts and features:
- The antenna includes a conducting strip or wire shaped by a space-filling curve, composed by at least two-hundred connected segments forming a substantially right angle with each

adjacent segment smaller than a hundredth of the free-space operating wavelength. This antenna is used for AM or DAB radio broadcast signal reception.
- The antenna system can optionally include miniaturized antenna, for wireless cellular services such as GSM900 (870-860 MHz), GSM1800 (1710-1880 MHz) and UMTS (1900-2170 MHz).
- The antenna system can include a miniaturized antenna for GPS reception (1575 MHz).
- The Antenna set is integrated within a plastic or dielectric cover fixed on the inner surface of the transparent windshield of a motor vehicle.

One of the preferred embodiments for the plastic cover enclosing the multi-service antenna system is the housing of the inside rear view mirror. This position ensures an optimised antenna behaviour, a good impedance matching, a substantially omnidirectional radiation pattern in the horizontal plane for covering terrestrial communication systems (like radio or cellular telephony), and a wide coverage in elevation for the case of satellite communication system (GPS).

The important reduction size of such antennas system is obtained by using space-filling geometries.

A space-filling curve can be described as a curve that is large in terms of physical length but small in terms of the area in which the curve can be included. More precisely, the following definition is taken for a general space-filling curve: a curve composed by at least ten segments forming an angle with each adjacent segment.

Whatever, the design of such space-filling curve is, it can never intersect with itself at any point except the initial and final point (that is, the whole curve can be arranged as a closed curve or loop, but none of the parts of the curve can become a closed loop).

A space-filling curve can be fitted over a flat or curved surface, and due to the angles between segments, the physical length of the curve is always larger than that of any straight line that can be fitted in the same area (surface).

Additionally, to properly shape the structure of a miniature antenna, the segments of the space-filling curves must be shorter than a tenth of the free-space operating wavelength.

The antenna is fed with a two conductor structure such as a coaxial cable, with one of the conductors connected to the lower tip of the multilevel structure and the other conductor connected to the metallic structure of the car which acts as a ground counterpoise.

This antenna type features a significant size reduction below a 20% than the typical size of a conventional external quarter-wave whip antenna; this feature together with the small profile of the antenna which can be printed in a low cost dielectric substrate, allows a simple and compact integration of the antenna structure.

Besides the key reduction of the antenna element covering the radio broadcast services, another important aspect for the integration of the antenna system into a small package or car component is reducing the size of the radiating elements covering the wireless cellular services. This can be achieved by using a Planar Inverted F Antenna (PIFA) configuration, consisting on connecting two parallel conducting sheets, separated either by air or a dielectric, magnetic or magnetodielectric material.

The sheets are connected through a conducting strip near a one of the sheets corners and orthogonally mounted to both sheets.

The antenna is fed through a coaxial cable, having its outer conductor connected to first sheet, being the second shit coupled either by direct contact or capacitive to inner conductor of the coaxial cable.

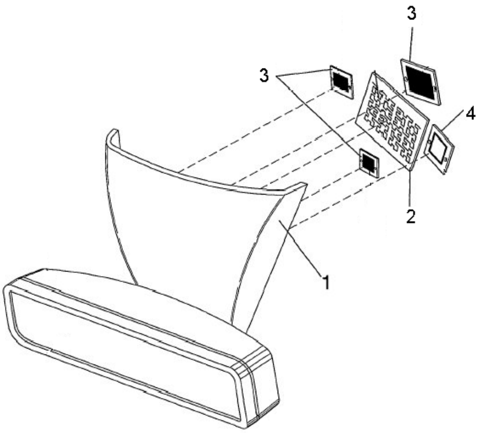


Fig. 7.

In the Figure 7 is shown another preferred embodiment of the present antenna system. The rear view mirror base support (1) to be fixed on the front windshield includes, a space-filling antenna for AM/FM reception (2), a set of miniature antennas (3) for wireless cellular system telephony transmitting or receiving GSM900 (870-960 MHz), GSM1800 (1710-1880 MHz) and UMTS (1900-2170 MHz) signals, and a GPS antenna (4).
In the Figure 8 is shown a detail of the space-filling structure antenna for reception of AM/FM bands. The antenna (1) is fed (2) as a monopole and is placed inside a rear view mirror support. The antenna can be easily adapted for DAB system by scaling it proportionally to the wavelength reduction.
In Figure 9 is presented a set of miniature antennas for cellular telephony system for transmitting GSM900, GSM1800 and UMTS. In this configuration, the antennas are composed by two planar conducting sheets, the first one being shorter than a quarter of the operation wavelength (1), and the second one being the ground counterpoise (2).

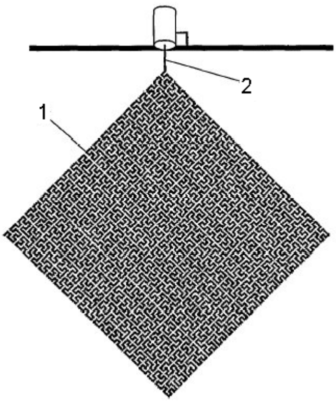


Fig. 8.

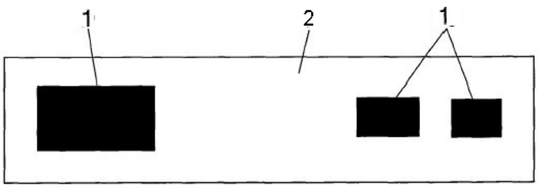


Fig. 9.

Both conducting sheet (1) and counterpoise are connected through a conducting strip. Each conducting sheet is fed by a separate pin.

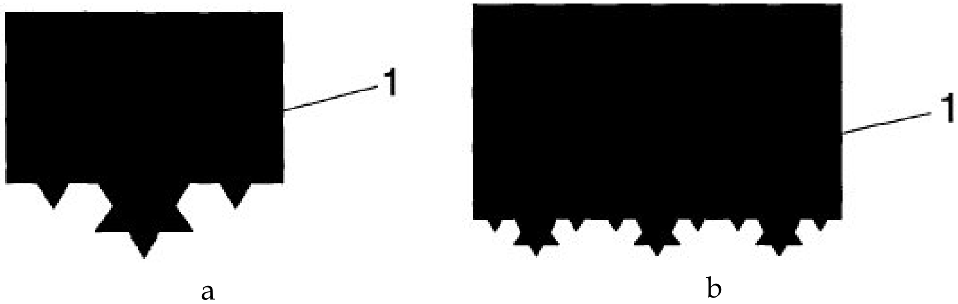


Fig. 10.a, b

In the Figures 10a,b is presented two examples of space-filling perimeter of the conducting sheet (1) to achieve an optimised miniaturization of the mobile telephony antenna.
In the Figure 11 are presented four examples of miniaturization of the satellite GPS patch antenna using a space-filling or multilevel antenna technique.

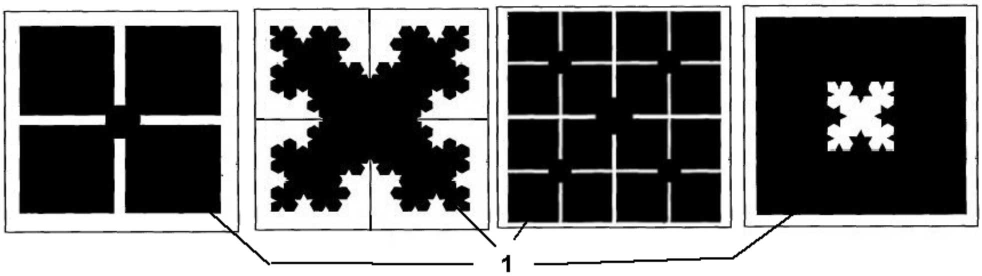


Fig. 11.

The GPS antenna is formed by two parallel conducting sheets spaced by a high permittivity dielectric material, forming a micro-strip antenna with circular polarisation. The circular polarization is obtained either by means of a two feeder schema or by perturbing the perimeter of the patch. The superior conducting sheet (1) perimeter is increased by confining it in space filling curve.
In the Figure 12 is presented another preferred embodiment wherein at least two space-filling antennas are supported by the same surface, one space-filling antenna for receiving radio broadcasted signals, preferably within the AM and FM or DAB bands, and the other second space-filling antennas for transmitting and receiving in the cellular telephony bands such as for GSM.
All the space-filling antennas (3) are connected at one end to one of the wires of a two conductor transmission line such as a coaxial cable (1, 2), being the other conductor of transmission line connected to the metallic car structure (1).

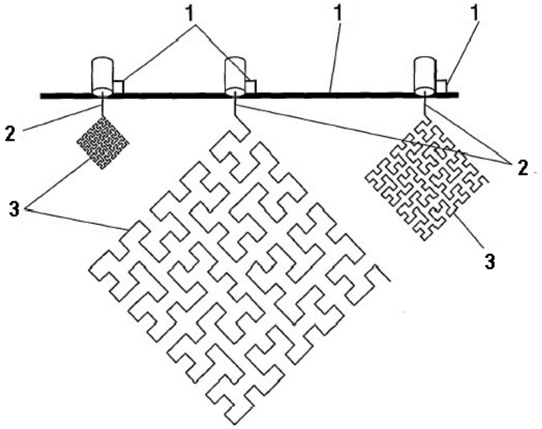


Fig. 12.

In the Figure 13 is presented an alternative position of GPS antenna (1). The antenna is placed in a horizontal position, inside the external housing (2) of an external rear view mirror.

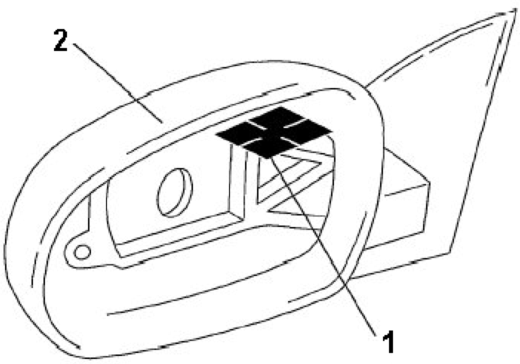


Fig. 13.

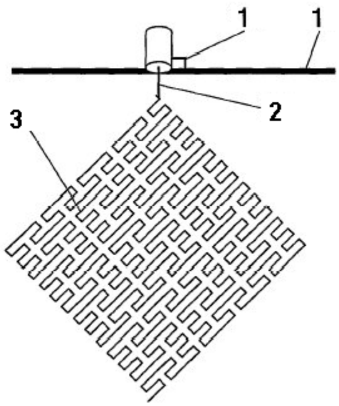


Fig. 14.

In the Figure 14 is shown another example of space-filling antenna, based of a fractal curve, for AM/FM reception. The antenna is fed as a monopole and is placed inside a rear view mirror support.

3. Anti-radar fractals and/or multilevel chaff dispersers

Chaff was one in the forms of countermeasure employed against radar. It usually consists of a large number of electromagnetic dispersers and reflectors, normally arranged in form of strips of metal foil packed in a bundle. When they are released by an aircraft or distributed by rockets launched by a ship, most of the strips of foil which constitute the chaff bale are dispersed by the effect of the wind and become highly reflective clouds. Its vertical descent is determined by the force of gravity and for the properties to resist advance presented by the strips of individual leaves.

Chaff is usually employed to foil or to confuse surveillance and tracking radar.

Miscellaneous reference information on radar chaff can be found in [10], or in other patented publications [11].

Nevertheless, little attention has been paid to the design of the shape of the dispersers which form the cloud. Here are presented new geometry of the dispersers or reflectors which improve the properties of radar chaff [12]. Some of the geometries presented here of the dispersers or reflectors are related with some forms expounded for antennas. Multilevel and fractal structures antennas are distinguished in being of reduced size and having a multi-band behaviour, as has been expounded already in patent publications [13].

The main electrical characteristic of a radar chaff disperser is its radar cross-section (RCS) which is related with the reflective capability of the disperser. The new geometries facilitates a large RCS compared with dispersers presented in previous patents having the same size, surprisingly the RCS is equivalent to that of conventional dispersers of greater size.

Instead of using conventional rectilinear forms, multilevel and fractal geometries are introduced. Due to this geometric design, the properties of the clouds of radar chaff are improved mainly in two aspects: radar cross-section (RCD) and mean time of suspension.

A fractal curve for a chaff disperser is defined as a curve comprising at least ten segments which are connected so that each element forms an angle with its neighbours, no pair of these segments defines a longer straight segment, these segments being smaller than a tenth part of the resonant wavelength in free space of the entire structure of the dispenser. In many of the configuration presented, the size of the entire disperser is smaller than a quarter of the lowest operating wavelength.

The space-filling curves (or fractal curves) can be characterized by:

1. They are long in terms of physical length but small in terms of area in which the curve can be included. The disperser with a fractal form are long electrically but can be included in a very small surface area. This means it is possible to obtain a smaller packaging and a denser chaff cloud using this technique.

2. Frequency response: Their complex geometry provides a spectrally richer signature when compared with rectilinear dispersers known in the stat of the art.

Depending on the process of the form and of the geometry of the curve, some spacefilling curves (SFC) can be designed theoretically to characterise a larger Haussdorf dimension than their topological dimensions. These infinite theoretical curves cannot be constructed physically, but they can be approximated with SFC design.

The fractal structure properties of disperser not only introduce an advantage in terms of reflected radar signal response, but also in terms of aerodynamic profile of dispersers. It is known that a surface offers greater resistance to air than a line or a one-dimensional form. Therefore, giving a fractal form to the dispersers with a dimension greater than unity ($D>1$), increase resistance to the air and improve the time of suspension.

Multi-level structures are a geometry related with fractal structures. In that case of radar chaff a multi-level structure is defined as structure which includes a set of polygons, which are characterized in having the same number of sides, wherein these polygons are electro-

magnetically coupled either by means of capacitive coupling, or by means of an ohmic contact. The region of contact between the directly connected polygons is smaller than 50% of the perimeter of the polygons mentioned in at least 75% of the polygons that constitute the defined multilevel structure.
A multilevel structure provides both:
- A reduction in the size of dispensers and an enhancement of their frequency response, and
- Can resonate in a non-harmonic way, and can even cover simultaneously and with the same relative bandwidth at least a portion of numerous bands.
The fractal structure (SFC) are preferred when a reduction in size is required, while multilevel structures are preferred when it is required that the most important considerations be given to the spectral response of radar chaff.
The main advantages for configuring the form of the chaff dispersers are:
1. The dispersers are small; consequently more disperser can be encapsulated in a same cartridge, rocket or launch vehicle.
2. The disperser are also lighter, therefore they can remain more time floating in the air than the conventional chaff.
3. Due to the smaller size of the chaff dispersers, the launching devices (cartridges, rockets, etc.) can be smaller with regard to chaff systems in the state of the art providing the same RCS.
4. Due to lighter weight of the chaff dispersers, the launching devices can shot the packages of chaff father from the launching devices and locations.
5. Chaff constituted by multilevel and fractal structures provide larger RCS at longer wavelengths than conventional chaff dispersers of the same size.
6. The dispersers with long wavelengths can be configured and printed on light dielectric supports having a non-aerodynamic form and opposing a greater resistance to the air and thereby having a longer time of suspension.
7. The dispersers provide a better frequency response with regard to dispersers of the state of the art.
To complete the description being made and with the object of assisting in a better understanding of the characteristics of fractals and multilevel structures, a set of drawings are represented.
In the following images such size compression structures based on fractal curves are presented.
Figure 15 show examples of SZ fractal curves which can be used to configure a chaff disperser.
Figure 17 shows several examples oh Hilbert fractal curves (with increasing iteration order) which can be used to configure the chaff disperser. Figure 18 shows various examples of ZZ fractal curves (with increasing iteration order) which provide a size compression ratio. Figure 19 shows several examples of Peano fractal curves (with increasing iteration order) which can be used to configure chaff disperser. These provide a size compression ratio. Figure 19 show two examples of fractal curves which define a loop which can be used to configure chaff dispersers.
Figure 21 shows several examples of multilevel structures built by joining various types of triangle.
Figure 22 shows several examples of multilevel structures built by joining various types of square.

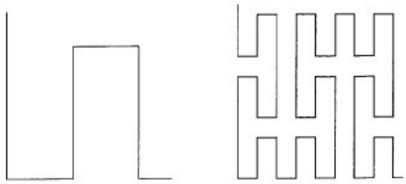


Fig. 15.

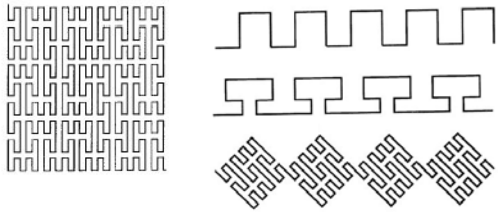


Fig. 16.

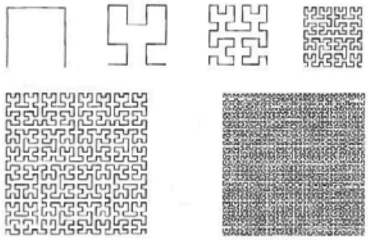


Fig. 17.

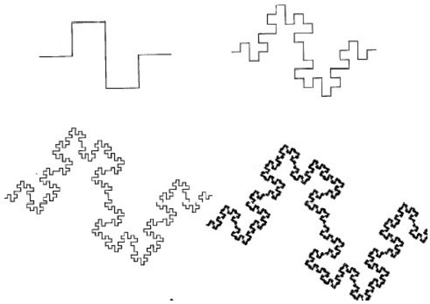


Fig. 18.

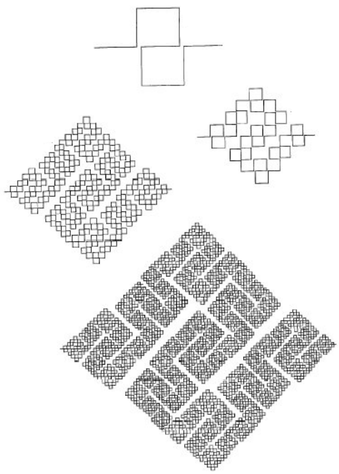


Fig. 19.

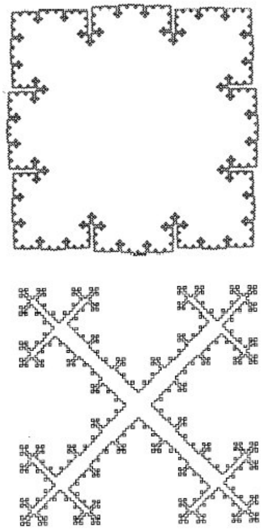


Fig. 20.

Figure 23 show some fractal dispersers forming a cloud of radar chaff. The disperser is formed by conducting, super-conducting or semi-conducting material configuring a fractal structure which is supported by a leaf of dielectric material.

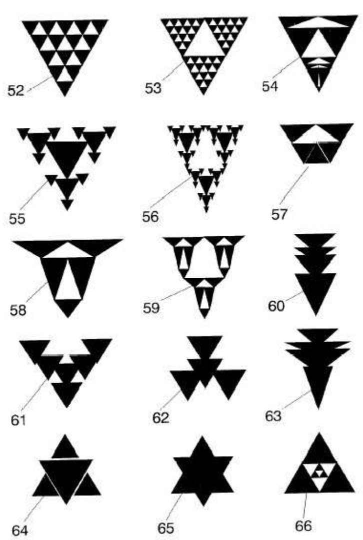


Fig. 21.

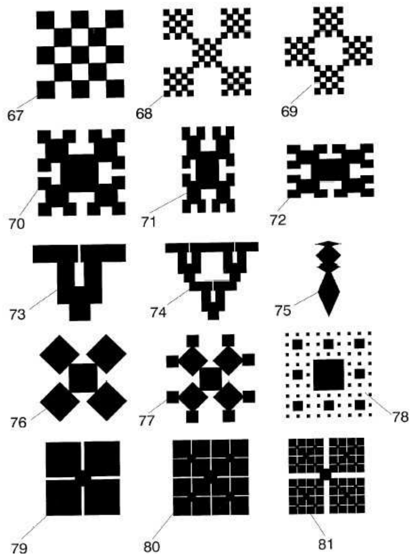


Fig. 22.

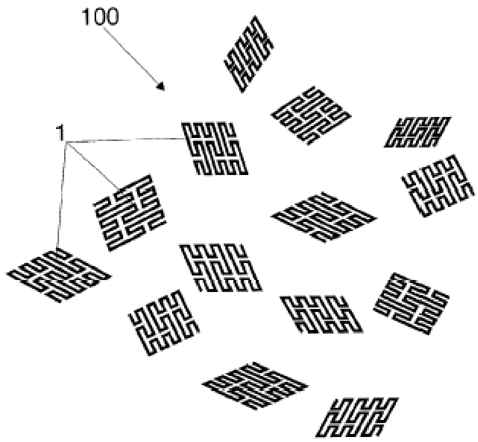


Fig. 23.

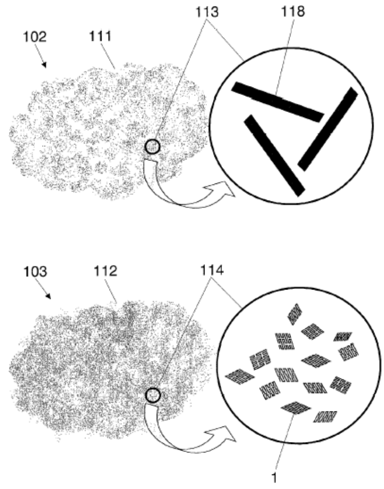


Fig. 24.

Figure 24 shows a comparison between a conventional chaff cloud with regard to a fractal or multilevel structure chaff cloud. Conventional chaff is formed substantially by linear or straight strip dispersers of a length determined by the wavelength of the radar. The fractal chaff are smaller for the same operating frequency, therefore a fractal chaff cloud can be made denser than a conventional one, providing a larger radar cross-section (RCS) and remaining floating in the air for a long time.

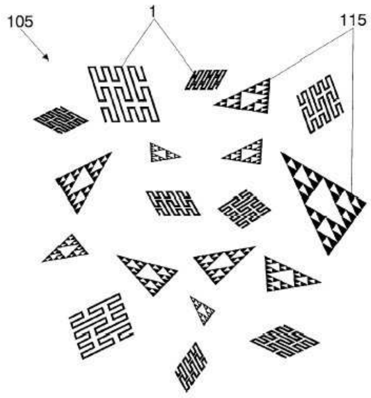


Fig. 25.

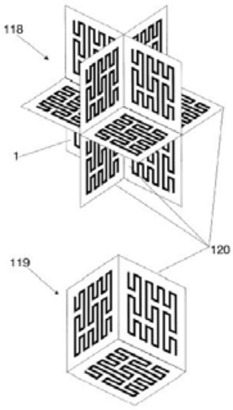


Fig. 26.

Figure 25 shows a mix of multilevel and fractal structures with diverse sizes forming a radar cloud. The sizes and geometries of the structures can be made to design the frequency signature for the whole chaff cloud.
Figure 26 shows a trihedron reflector with a fractal disperser on each side of the trihedron. The 3D disperser is constituted by up to 8 trihedrons. This type of reflector improves the backward dispersion in mono-static radar.

4. Multilevel Advanced Antennas for Motor Vehicles

This application relates to an antenna for a motor vehicle, having the following parts and characteristics [14], Figure 27:
- A transparent windshield covered with a transparent, optically conductive plate on at least one side of any of the window material plates,
- A multilevel structure printed on the conductive plate. The multilevel structure consists of a set of polygonal elements pertaining to one same class, preferably triangles or squares.
- A transmission line powering two conductors
- A similar impedance in the power supply point and a horizontal radiation diagram in at least three frequencies within three bands.

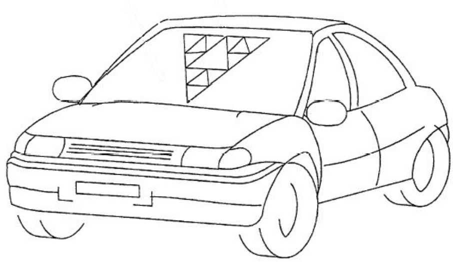


Fig. 27.

The main advantage of this advanced antenna system lies in the multi-band and multi-service performance of the antenna. This enables convenient and easy connection of a simple antenna for most communication systems of the vehicle.
The antenna is formed by a set of polygonal elements, supported by transparent conductive layer coated on the transparent window of motor vehicle.
The particular shape and design of the polygonal elements, preferably triangular or square, enhances the behaviour of the antenna to operate simultaneously at several bands.
The multi service antenna will be connected to most of the principal equipments available in a motor vehicle such as radio (AM/FM), Digital Audio and Video Broadcasting (DAB or DVB), Tire pressure control, Wireless car aperture, Terrestrial Trunked Radio (TETRA), mobile telephony (GSM 900 – GSM 1800 – UMTS), Global Positioning System (GPS), Bluetooth and wireless LAN (Local Area Network) access.
Until recently, telecommunication systems available in a automobile were limited to a few services, mainly the analogical radio reception (AM/FM bands).
The most common solution for these systems is the typical whip antenna mounted on the car roof. The current tendency in the automotive sector is to reduce the aesthetic and aerodynamic impact due to these antennas by embedding them in the vehicle structure. Also, a major integration of the several telecommunication services into a single antenna would help to reduce the manufacturing costs or the damages due to vandalism and car wash equipments.
The antenna integration is becoming more and more necessary as we are assisting to a profound change in telecommunication habits. The internet has evoked an information age in which people around the globe expect, demand, and receive information. Car drivers expect to be able to drive safely while handlings e-mail a telephone calls and obtaining directions, schedules, and other information accessible on the WWW.
Telematic devices can be used to automatically notify authorities of an accident and guide rescuers to the car, track stolen vehicles, provide navigation assistance to drivers, call emergency roadside assistance and remote diagnostics of engine functions.
High equipments and services have been available on some cars for very few years. The high costs of these equipments initially limited them to luxury cars.
However, rapid declines in both equipment and services prices are bringing telematic products into mid-priced automobiles.
The massive introduction of new systems will generate a proliferation of new car antennas, in contradiction with the aesthetic and aerodynamic requirements of integrated antenna.
Antennas are essentially narrowband devices. Their behaviour is highly dependent on the antenna size to the operating wavelength ratio.
The use of fractal-shaped multi-band antennas was first proposed in 1995 (Patent No. 9501019). The main advantages addressed by these antennas featured similar parameters (input impedance, radiation pattern) at several bands maintaining their performance, compared with conventional antennas. Also, fractal-shapes permit to obtain antenna of reduced dimensions compared to other conventional antenna, as well. In 1999, multilevel antennas [15] resolved some practical problems encountered with the practical applications of fractal antennas.
Fractal auto-similar objects are, in strict mathematical sense, composed by an infinite number of scaled iterations, impossible to achieve in practice. Also, for practical

applications, the scale factor between each iteration and the spacing between the bands do not have to correspond to the same number.
Multilevel antennas introduced a higher flexibility to design multi-service antennas for real applications, extending the theoretical capabilities of ideal fractal antennas to practical, commercial antennas.
Several solutions were proposed to integrate the AM/FM antenna in the vehicle structure. A possible configuration is to use the thermal grid on the rear windshield [16]. However, this configuration requires an expensive electronic adaptation network, including RF amplifiers and filters to discriminate the radio signals from the DC source. Moreover, to reduce costs, the AM band antenna often comes apart from the heating grid limiting the area of the heating grid.
Other configuration is based on the utilization of a transparent conducting layer.
This layer is coated on the vehicle windshield is introduce to avoid an excessive heating of the vehicle interior by reflecting IR radiations.
The utilization of this layer as reception antenna for AM or FM band has been already proposed with several antenna shapes [17].
Obviously all these antenna configurations can only operate at a determinate frequency band in reason of the frequency dependence of the antenna parameter and are not suitable for a multi-service operation.
One of the main substantial innovations of the antenna system presented here consists in using a single antenna element, maintaining the same behaviour for several applications, and to keep the IR protection.
The advantages reside in full antenna integration with no aesthetic or aerodynamic impact, a full protection from vandalism, and a manufacturing cost reduction.
The main advantage of this system is the multi-band and multi-service behaviour of the antenna. This permits a convenient and easy connection to a single antenna for the majority of communication systems of the vehicle.
The typical frequency bands of the different applications are the following:

- FM (80 - 110 MHz)
- DAB (205 - 230 MHz)
- TETRA (350 - 450 MHz)
- Wireless Car Aperture (433 MHz, 868 MHz)
- Tire Pressure Control (433 MHz)
- DVB (470 - 862 MHz)
- GSM 900 / AMP (820 - 970 MHz)
- GSM 1800 / DCS / PCS / DECT (1700 - 1950 MHz)
- UMTS (1920 - 2200 MHz)
- Bluetooth (2400 - 2500 MHz)
- WLAN (4,5 - 6,0 GHz)

This multi-band behaviour is obtained by a multilevel structure composed by a set of polygonal elements of the same class (the same number of sides), electro-magnetically coupled either by means of an ohmic contact or a capacitive or inductive coupling mechanism. The structure can be composed by whatever class of polygonal elements.
However, a preference is given to triangles or squares elements, being these structures more efficient to obtain an omni-directional pattern in the horizontal plane.

To assure an easy identification of each element composing the entire structure and the proper multiband behaviour, the contact region between each element has to be in at least the 75% of the elements, always shorter than 50% of the perimeters of polygonal structures.
The other main advantage of this antenna system resides in the utilization of a transparent conductive layer as support for the antenna.
Being transparent, this antenna can be coated in the windshield screen of a motor vehicle. Other possible positions are the side windows or the rear windows.
The most common material used is ITO (Indium Tin Oxide), although other materials may be used (like for instance TiO_2, SnO or ZnO), by sputtering vacuum deposition process. An additional passive layer can be added to protect the conducting layer from external aggression (for instance SiO_2).
Other advantage of the multi-band antenna is to reduce the total weight of the antenna comparing with classical whip. Together with the costs, the component weight reduction is one of the major priorities in the automotive sector. The cost and weight reductions are also improved by the utilization of only single cable to feed the multi-service antenna.

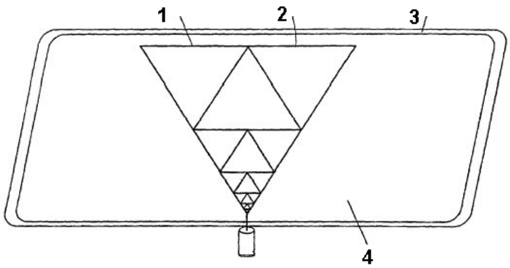
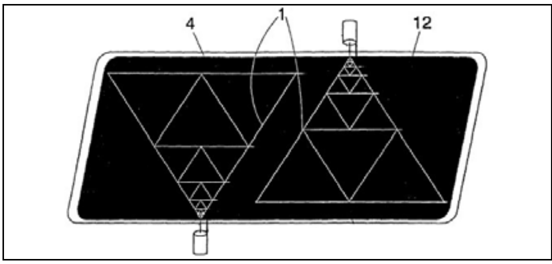


Fig. 28.

In Figure 28 is show a possible configuration for the multi-band antenna which support is an optically transparent conducting layer: A triangular multilevel structure (2) fed as a monopole and with the transparent conducting layer (1) filling the inside area of the polygonal elements and wherein the rest of the windows surface (4) is not coated with conducting layer.
In figure 29 is show an example of how several multilevel structures (1) can be printed at the same time using the same procedure and scheme described above.



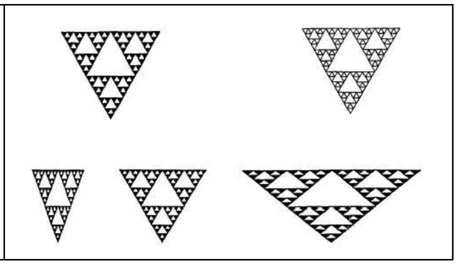


Fig 29. Fig. 30.