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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 its 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 straight 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.
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: \( L(r) = N \cdot r \). As the step size \( r \) goes to zero, \( L(r) \) approaches a finite limit, the length of the curves. But for fractals the product \( N \cdot r \) 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 \( N \cdot r^{D_H} \) stays finite. This critical exponent, \( D_H \), is called Hausdorff dimension. Equivalently, we have

\[
D_H = \lim_{r \to 0} \frac{\log N}{\log(1/r)}
\]

For \( n \)th 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,

\[
D_H = \frac{\log 4}{\log 3} = 1.26....
\]

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 \( \varepsilon \). 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.

![Fractal Antenna Applications](image)

**Fig. 5.**

The energy radiated in the far field:

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

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

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

and

$$f[n, \zeta] = \frac{\beta \Delta r - L}{\alpha v} , \quad \beta = \frac{v}{c} ,$$

Where \( h \) is the height of the detector \( \Delta r \) 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.
The antenna system can optionally include miniaturized antennas for wireless cellular services such as GSM900 (870-860 MHz), GSM1800 (1710-1880 MHz) and UMTS (1900-2170 MHz).

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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).
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](image)

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.](image)

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

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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).

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.

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 disperser. 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.
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.
Figure 23 shows 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.

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.
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 behavior, 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 TiO2, 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 SiO2).

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.
A fractal antenna is patterned out of a conductive layer (e.g., Cu, Au, ITO, etc.) and is provided between first and second opposing substrates of a vehicle windshield. A polymer inclusive interlayer function to both protect the fractal antenna(s) and laminate the opposing substrates to one another. In other embodiments, a multiband fractal antenna is provided which includes a first group of triangular shaped antenna portions, and a second triangular shaped antenna portion(s), wherein each of the triangular shaped antenna portions of the first group is located within a periphery of the second triangular shaped antenna portion. The first group of antenna portions transmits and/or receives at a first frequency band, while the second antenna portion(s) transmits and/or receives at a second frequency band different than the first band [18].

More particularly, one embodiment relates to a vehicle windshield including a fractal antenna(s). Another embodiment relates to a multiband fractal antenna. Yet another embodiment of this invention relates to an array of fractal antennas.

Generally speaking, antennas radiate and/or receive electromagnetic signals. Design of antennas involves balancing of parameters such as antenna size, antenna gain, bandwidth, and efficiency. Most conventional antennas are Euclidean design/geometry, where the closed antenna area is directly proportional to the antenna perimeter. Thus, for example, when the length of a Euclidean square is increased by a factor of three, the enclosed area of the antenna is increased by a factor of nine.

Unfortunately, Euclidean antennas are less than desirable as they are susceptible to high Q factors, and become inefficient as their size gets smaller.

Characteristics (e.g., gain, directivity, impedance, efficiency) of Euclidean antennas are a function of the antenna’s size to wavelength ratio.

Euclidean antennas are typically desired to operate within a narrow range (e.g., 10-40%) around a central frequency $f_c$ which in turn dictates the size of the antenna (e.g., half or quarter wavelength). When the size of a Euclidean antenna is made much smaller than the operating wavelength ($\lambda$), it becomes very inefficient because the antenna’s radiation
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A fractal antenna is patterned out of a conductive layer (e.g., Cu, Au, ITO, etc.) and is always having a substantially higher radiation resistance than a small Euclidean loop antenna of equal size. Accordingly, fractals are much more effective than Euclidean when small sizes are desired. Fractal geometry may be grouped into:
- Random fractals, which may be called chaotic or Brownian fractals and include a random noise component
- Deterministic or exact fractals. In deterministic fractal geometry, a self-similar structure results from the repetition of a design or motif (or generator) (i.e., self-similarity and structure at all scales). In deterministic or exact self similarity, fractal antennas may be constructed through recursive or iterative means. In other words, fractals are often composed of many copies of themselves at different scales, thereby allowing them to defy the classical antenna performance constraint which is size to wavelength ratio.

resistance decreases and becomes less than its ohmic resistance (i.e., it does not couple electromagnetic excitations efficiently to free space). Instead, it stores energy reactively within its vicinity (reactive impedance $X_r$).

These aspects of Euclidean antennas work together to make it difficult for small Euclidean antennas to couple or match to feeding or excitation circuitry, and cause them to have a high $Q$ factor (lower bandwidth). $Q$ (Quality) factor may be defined as approximately the ratio of input reactance to radiation resistance,

$$Q = \frac{X_{in}}{R_r}$$

The $Q$ factor may also be defined as the ratio of average stored electric energies (or magnetic energies stored) to the average radiated power. $Q$ can be shown to be inversely proportional to bandwidth. Thus, small Euclidean antennas have very small bandwidth, which is of course undesirable (e.g., tuning circuitry may be needed).

Many known Euclidean antennas are based upon closed-loop shapes. Unfortunately, when small in size, such loop-shaped antennas are undesirable because, as discussed above, e.g., radiation resistance decreases significantly when the antenna size/area is shortened/dropped. This is because the physical area $A$ contained within the loop-shaped antenna’s contour is related to the latter’s perimeter. Radiation resistance ($R_c$) of a circular (i.e., loop-shaped) Euclidean antenna is defined by,

$$R_c = \frac{2}{3}\pi k \frac{A}{\lambda^2} = 20\pi^2 \left(\frac{C}{\lambda}\right)^2$$

where $k$ is a constant.

Since ohmic resistance $R_c$ is only proportional to perimeter ($C$), then for $C<1$, the ohmic resistance $R_c$ is greater than the radiation resistance $R_r$ and the antenna is highly inefficient. This is generally true for any small circular Euclidean antenna.

A small-sized antenna will exhibit a relatively large ohmic resistance and a relatively small radiation resistance $R$, such that low efficiency defeats the use of the small antenna.

Fractal geometry is a non-Euclidean geometry which can be used to overcome the aforesaid problems with small Euclidean antennas. Radiation resistance $R_r$ of a fractal antenna decreases as a small power of the perimeter ($C$) compression, which a fractal loop or island always having a substantially higher radiation resistance than a small Euclidean loop antenna of equal size. According to, fractals are much more effective than Euclidean when small sizes are desired. Fractal geometry may be grouped into:
- Random fractals, which may be called chaotic or Brownian fractals and include a random noise component
- Deterministic or exact fractals. In deterministic fractal geometry, a self-similar structure results from the repetition of a design or motif (or generator) (i.e., self-similarity and structure at all scales). In deterministic or exact self similarity, fractal antennas may be constructed through recursive or iterative means. In other words, fractals are often composed of many copies of themselves at different scales, thereby allowing them to defy the classical antenna performance constraint which is size to wavelength ratio.

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Recent growth in technology such as the Internet, cellular telecommunications, and the like has led to personal users desiring wireless access for: Internet access, cell phones, pagers, personal digital assistants, etc., while competing types of wireless broadband such as TDMA (Time Division Multiple Access), CDMA (Code Division Multiple Access) and GSM are being pushed by wireless manufacturers. Unfortunately, current vehicle antenna systems do not have the capability of efficiently enabling such desired wireless access.

In view of the above, it will be apparent that there exists a need in the art for a vehicle antenna system that enables efficient access to the Internet, cell phones, pagers, personal digital assistants, radio, and/or the like. There also exists a need in the art for a multiband fractal antenna. These and other needs which will become apparent to the skilled artisan from a review of the instant application are achieved by the present antenna system.

Certain embodiments of this system relate to a fractal antenna printed on dielectric substrates (e.g., glass substrate or other suitable substrate). Other embodiments of this system relate to a vehicle windshield with fractal antenna(s) provided therein. Other embodiments of this system relate to a multiband fractal antenna.

Other embodiments of this system relate to an array of fractal antennas provided on a substrate.

Certain other embodiments of this system relate to a method of making fractal antennas, or arrays thereof. While fractal antennas are illustrated and described herein as being used in the context of a vehicle windshield, the system is not limited as certain fractals (e.g., multiband fractal antennas) may be used in other contexts where appropriate and/or desired.

Figure 32 is a cross sectional view of a vehicle windshield, including a fractal antenna (3). The windshield (curved or flat) includes first glass substrate (5) on the exterior side of the windshield, second glass substrate (7) on the interior side of the windshield adjacent the vehicle interior, polymer interlayer (9) for laminating the substrates (5, 7) to one another, and fractal antenna(s) (3).

Polymer inclusive interlayer (9) may be of or include polyvinyl butyral (PVB), polyurethane(PU), PET, polyvinylchloride (PVC), or any other suitable material for laminating substrates (5) and (7) to one another.
Substrates (5) and (7) may be flat in certain embodiments, or bent/curved in other embodiments in the shape of a curved vehicle windshield. Substrates (5) and (7) are preferably of glass such as soda-lime-silica type glass, but may be of other materials (e.g., plastic, borosilicate glass, etc.) in other embodiments of this system.

As shown in Figure 32, the fractal antenna includes a conductive layer (3) provided on the interior surface of substrate (5). Fractal antenna layer (3) may be of or include opaque copper (Cu), gold (Au), substantially transparent indium-tin-oxide (ITO), or any other suitable conductive material in different embodiments of this system. Transparent conductive oxides (TCOs) are preferred for fractal antenna layer (3) in certain embodiments; example TCOs includes ITO, SnO, AlZnO, RuO, etc. Layer (3) is patterned into the shape of a fractal antenna.

The first major surface of fractal antenna layer (3) contacts insulative polymer inclusive interlayer (9). Interlayer (9) functions to both protect fractal antenna layer (3), and laminate the opposing substrates (5) and (7) to one another. Interlayer (9) is substantially transparent (i.e., at least about 80% transparent to visible light).

In the embodiment presented in Figure 32, fractal antenna (3) is shown as being located directly on the interior surface 5a of substrate 5. However, in other embodiments, the fractal antenna (3) may be located on substrate (5) with one or more additional layer(s) being provided there between.

In other embodiments, fractal antenna(s) may be printed on a PVB layer located between the substrates, or located on a polymer inclusive film located between the substrates. In all of these scenarios, antenna (3) is considered to be “on” and “supported by” substrate (5).

Because fractal antenna (3) herein may be printed on a substrate (e.g., glass substrate), the dielectric nature of the substrate may slightly change the effective dimension of the antenna by slowing electromagnetic waves passing there through. This may cause the antenna to look bigger than it actually is. However, it has been found that this effect can be compensated, for example, using the following equation,

$$\lambda_e = \frac{\lambda_0}{\sqrt{0.5(\varepsilon_r + 1)}}$$

Figure 33 is a plan view of a windshield. As shown, a single fractal antenna FA (3) may be located at an upper portion of the windshield (i.e., near where a rear view mirror is to be attached thereto) so that it is not located in a primary viewing area of the windshield.

Instead of a single fractal antenna, an array(s) of fractal antennas (3) may be provided on the windshield in any of the manners described herein.

One array may be provided at an upper portion of the windshield, and another array at a bottom portion of the windshield (one array for a first frequency band, and another array for the second frequency band). In other embodiments, only a single array may be provided either at the upper portion or the lower portion of the windshield.

In the Figure 34 is illustrated a base element (20) in the form of a straight line or trace (a curve could instead be used). A fractal motif or generator (21), V-shape, is inserted into the base element to form a first order iteration N=1, the second iteration N=2, and the third iteration N=3. The iteration may go on and on (N may increase up to 10, up to 100, up to 1000, etc.) in different embodiments. Preferable, fractal antenna (3) herein take the shape of any fractal iteration herein, of N=2 and higher.
Figure 35 illustrate a loop shaped Koch fractal antenna (3) and a loop shaped Euclidean antenna (28) overlaid with one another, where both take up about the same volume or extend.

Figures 36a,b,c illustrate another way in which vehicle windows may be made according to certain embodiments. In the upper Figure, one or more fractal antenna(s) (3) are printed on polymer (PET) film (40). Polymer inclusive film (40) also supports adhesive layer (41) and backing/release layer (42). If many antennae (3) are printed on film (40) via silkscreen printing, or any other suitable technique, then the coated article may be cut into a plurality of different pieces as shown by cutting line (45). After cutting (which is optional), release layer (42) is removed (peeled off), and film (40) with fractal antenna (3) printed thereon is adhered to substrate (5) via exposed adhesive layer (41) (see Figure 36b).
The structure (Figure 36b) is laminated to the other substrate (7) via PVB interlayer (9). In such a manner, fractal (3) can be more easily formed in the resulting vehicle window that is shown in Figure 36c.

6. Multilevel and Space-Filling Ground-Planes for Miniature and Multi-Band Antennas

A new family of antenna ground-planes of reduced size and enhanced performance based on an innovative set of geometries. These new geometries are known as multilevel and space-filling structures, which had been previously used in the design of multiband and miniature antennas. A throughout description of such multilevel or space-filling structures can be found in [19].

One of the key issues of the present antenna system is considering the ground-plane of an antenna as an integral part of the antenna that mainly contributes to its radiation and impedance performance (impedance level, resonant frequency, and bandwidth). A new set of geometries are disclosed here, such a set allowing to adapt the geometry and size of the ground-plane to the ones required by any application (base station antennas, handheld terminals, cars, and other motor-vehicles), yet improving the performance in terms of, for instance, bandwidth, VSWR (Voltage Standing Wave Ratio), or multiband behaviour.

The use of multilevel and space-filling structures to enhance the frequency range an antenna can work within was well described in patent publications [19]. Such an increased range is obtained either through an enhancement of the antenna bandwidth, with an increase in the number of frequency bands, or with a combination of both effects.

The multilevel and space-filling structures are advantageously used in the ground plane of the antenna obtaining this way a better return loss or VSWR, a better bandwidth, a multiband behaviour, or a combination of all these effects. The technique can be seen as well as a means of reducing the size of the ground-plane and therefore the size of the overall antenna.

A first attempt to improve the bandwidth of micro-strip antennas using the ground plane was described in [20, 21]. There, a particular case of a ground-plane composed by three rectangles with a capacitive electromagnetic coupling between them was used. Some of the geometries described here are inspired in the geometries already studied in 19th century by several mathematicians such as Giuseppe Peano and David Hilbert.

In all these cases the curves were studied from the mathematical point of view but were never used for any practical engineering application. Such mathematical abstraction can be approached in a practical design by means of the general space-filling curves described for this antenna system. It is interesting to notice that in some cases, such space-filling curves can be used to approach ideal fractal shapes as well.

The key point of the present antenna system is shaping the ground-plane of an antenna in such a way that the combined effect of the ground-plane and the radiating element enhances the performance and characteristics of the whole antenna device, either in terms of bandwidth, VSWR, multiband behaviour, efficiency, size, or gain.
Instead of using the conventional solid geometry for ground-planes as commonly described in the prior art, here are introduced a new set of geometries that forces the currents on the ground-plane to flow and radiate in a way that enhances the whole antenna behaviour.

The basis of this new system consists of breaking the solid surface of a conventional ground-plane into a number of conducting surfaces (at least two of them), which are electromagnetically coupled either by the capacitive effect between the edges of the several conducting surfaces, or by a direct contact provided by a conducting strip, or a combination of both effects.

The resulting geometry is no longer a solid, conventional ground-plane, but a groundplane with a multilevel or space-filling geometry, at least in a portion of ground-plane.

A multilevel geometry for a ground-plane consists of a conducting structure including a set of polygons, featuring the same number of sides, electromagnetically coupled either by means of a capacitive coupling or ohmic contact. The contact region between directly connected polygons is narrower than 50% of the perimeter of polygons in at least 75% of polygons defining conducting ground-plane.

In this definition of multilevel geometry, circles and ellipses are included as well, since they can be understood as polygons with infinite number of sides.

A Space-Filling Curve (hereafter SFC) is 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 in this document for a space-filling curve:

A curve composed by at least ten segments which are connected in such a way that each segment forms an angle with their neighbours, that is, no pair of adjacent segments define a larger straight segment, and wherein the curve can be optionally periodic along a fixed straight direction of space if, and only if, the period is defined by a non-periodic curve composed by at least ten connected segments and no pair of adjacent and connected segments defines a straight longer segment.

Also, whatever the design of such SFC 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 ground-plane, the segments of the SFC curves included in the ground-plane must be shorter than a tenth of the free-space operating wavelength.

Fig. 37.
Depending on the shaping procedure and curve geometry, some infinite length SFC can be theoretically designed to feature a Haussdorf dimension larger than their topological-dimension (see Figure 37).

That is, in terms of the classical Euclidean geometry, it is usually understood that a curve is always a one-dimension object; however when the curve is highly convoluted and its physical length is very large, the curve tends to fill parts of the surface which supports it. In that case, the Haussdorf dimension can be computed over the curve (or at least an approximation of it by means of the box-counting algorithm) resulting in a number larger than unity. The curves shown in the Figure 37 are some examples of such SFC, in particular drawings 11,13,14 and 18 show some examples of SFC curves that approach an ideal infinite curve featuring a dimension \( D = 2 \).

From an initial curve (8), other curves (9), (10), and (11) are formed (called Hilbert Curves). Likewise, other set of SFC curves can be formed, such as set (12), (13), (14), called SZ curves; set (15) and (16), known as ZZ curves; set (17), (18) and (19), called Hilbert ZZ curves; set (20) Peanodec curve, and set (21) based on the Giusepe Peano curve.

Depending on the application, there are several ways for establishing the required multilevel and space-filling metallic pattern according to the present antenna system. Due to the special geometry of multilevel and space-filling structure, the current distributes over the ground-plane in such a way that it enhances the antenna performance and features in terms of:

- Reduced size compared to antennas with a solid ground-plane
- Enhanced bandwidth compared to antennas with a solid ground-plane
- Multi-frequency performance
- Better VSWR feature at the operating band or bands
- Better radiation efficiency
- Enhanced gain

Figure 38 shows a new configuration (27) for a PIFA (Planar Inverted F Antenna), formed by an antenna element (30), a feed point (29), a short-circuit (28), and a particular example of a new ground-plane structure (31) formed by both multilevel and space-filling geometries.

Figure 39 shows an improved monopole antenna (36) configuration (35) where the ground-plane (37) is composed by multilevel and space-filling structures.
Figure 40 shows an improved antenna patch system composed by a radiating element (42) and a multilevel and space-filling ground-plane (43).

Figure 41 shows several examples of different contour shaped for multilevel groundplanes, such as rectangular (44), (45), and (46); and circular (47), (48), and (49). In this case, circles and ellipses are taken as polygons with infinite number of sides.

Figure 42 shows alternative schemes of multilevel ground-planes. The ones being showed in the drawings (68) to (76) are being formed from rectangular structure, but any other shape could have been used.
Figure 40 shows an improved antenna patch system composed by a radiating element (42) and a multilevel and space-filling ground-plane (43). Figure 41 shows several examples of different contour shaped for multilevel groundplanes, such as rectangular (44), (45), and (46); and circular (47), (48), and (49). In this case, circles and ellipses are taken as polygons with infinite number of sides.

Figure 42 shows alternative schemes of multilevel ground-planes. The ones being showed in the drawings (68) to (76) are being formed from rectangular structure, but any other shape could have been used.

Figure 43 shows examples (77) and (78) of two conducting surfaces (5) and (6) being connected by one (10) or two (9) and (10) SFC connecting strips.

Figure 44 shows examples of antennas wherein the radiating element has substantially the same shape as the ground-plane, thereby obtaining a symmetrical or quasy-symmetrical configuration, and where the radiating element is placed parallel (drawing (127) or orthogonal, drawing (128) to ground-plane.

7. Miniature Broadband Ring-Like Micro-strip Patch Antenna

A miniature broadband stacked micro-strip patch antenna formed by two patches, an active and a parasitic patches, where at least one of them is defined by a Ring-Like Space-Filling Surface (RSFS) is presented [22], Figure 45.
By means of this new technique, the size of the antenna can be reduced with respect to prior art, or alternatively, given a fixed size the antenna can operate at a lower frequency with respect to a conventional microstrip patch antenna of the same size and with an enhanced bandwidth. Also, the antennas feature a high gain when operated at a high order mode. An antenna is said to be small antenna (a miniature antenna) when it can be fitted in a space which is small compared to the operating wavelength. More precisely, the radian-sphere is taken as the reference for classifying an antenna as being small. The radian-sphere is an imaginary sphere of radius equal to the operating wavelength divided by two times $\pi$. 

An antenna is said to be small in terms of wavelength when it can be fitted inside a radian-sphere. 

The fundamental limits of small antennas where theoretically established by H.Wheeler and L.J.Chu in the middle 1940’s. They basically stated that a small antenna has a high quality factor (Q) because of the large reactive energy stored in the antenna vicinity compared to the radiated power. Such a high quality factor yields a narrow bandwidth. In fact, the fundamental limit derived in such theory imposes a maximum bandwidth given a specific size of a small antenna. Other characteristics of a small antenna are its small radiating resistance and its low efficiency. 

According to [23], the performance of a small antenna depends on its ability to efficiently use the small available space inside the imaginary radian-sphere surrounding the antenna. In the antenna system presented here, a novel set of geometries named ring-like spacefilling surfaces (RSFS) are introduced for the design and construction of small antennas that improve the performance of other classical microstrip patch antennas described in the prior art. 

A general configuration for microstrip antennas (also known as microstrip patch antennas) is well known for those skilled in the art and can be found in [24]. 

The advantages such antennas compared to other antenna configurations are:
- Its low, flat profile (such as the antenna can be conformally adapted to the surface of a vehicle, for instance),
- Its convenient fabrication technique (an arbitrary shaped patch can be printed over virtually any printed circuit board substrate),
- And low cost.

A major drawback of this kind of antennas is its narrow bandwidth, which is further reduced when the antenna size is smaller than a half-wavelength.

A common technique for enlarging the bandwidth of microstrip antennas is by means of a parasitic patch (a second patch placed on top of the microstrip antenna with no feeding mechanism except for the proximity coupling with the active patch) which enhances the radiation mechanism [25].

A common disadvantage for such a stacked patch configuration is the size of whole structure.

The advantage of this new antenna system is obtaining a microstrip patch antenna of a reduced size when compared to the classical patch antennas, yet performing with a large bandwidth. The proposed antenna system is based on a stacked patch configuration composed by a first conducting surface (the active patch) substantially parallel to a conducting ground counterpoise or ground-plane, and a second conducting surface (the parasitic patch) placed parallel over such active patch.
Such parasitic patch is placed above the active patch so the active patch is placed between parasitic patch and the ground-plane.
One or more feeding source can be used to excite the active patch. The feeding element of the active patch can be any of the well-known feeding element described in the prior art (such as for instance a coaxial probe, a co-planar micro-strip line, a capacitive coupling or an aperture at the ground-plane) for other micro-strip patch antennas.
The essential part of the antenna system is the particular geometry of either the active or the parasitic patches (or both).
The RSFS geometry consists on a ring, with an outer perimeter enclosing the patch and an inner perimeter defining a region within the patch with no conducting material.
The characteristic feature of the antenna system is the shape of either the inner or outer perimeter of the ring, either on the active or parasitic patches (or in both of them).
The ring perimeter is shaped as a space-filling curve (SFC), i.e., a curve that is large in terms of physical length but small in terms of the area can be included.
More precisely, the following definition is taken in this presentation for a space-filling curve: A curve composed by at least ten segments which are connected in such a way that each segment forms an angle with their neighbours, i.e., no pair of adjacent segments define a larger straight segment, and wherein the curve can be optionally periodic along a fixed straight direction of space if and only if the period is defined by a non-periodic curve composed by at least ten connected segments and no pair or adjacent and connected segments define a straight longer segment.
Also, whatever the design of such SFC is, it never intersects with itself at any point except the initial and final points (that is, the whole curve is arranged as a closed loop defining either the inner or outer perimeter of one patch within the antenna configuration).
Due to the angle between segments, the physical length of space-filling curve is always larger than that of any straight line than can be fitted in the same area (surface) as space-filling curve. Additionally, to properly shape the structure of the miniature patch antenna, the segments of the SFC curves must be shorter than a tenth of the free space operating wavelength.
The function of the parasitic patch is to enhance the bandwidth of the whole antenna system. Depending on the thickness and size constrain and the particular application, a further size reduction is achieved by using the same essential configuration for the parasitic patch placed on top of the active patch.
It is precisely due to the particular SFC shape of the inner or outer (or both) perimeters of the ring on either the active or parasitic patches that the antenna features a low resonant frequency, and therefore the antenna size can be reduced compared to a conventional antenna. Due to such a particular geometry of the ring shape, the antenna system is named Micro-strip Space-Filling Ring antenna (also MSFR antenna).
The advantage of using the MSFR configuration disclosed in this presentation is threefold:
1. Given a particular operating frequency or wavelength, the MSFR antenna has a reduced electrical size with respect to prior art.
2. Given the physical size of the MSFR antenna, the antenna operates at a lower frequency (a longer wavelength) than prior art.
3. Given a particular operating frequency or wavelength, the MSFR antenna has a larger impedance bandwidth with respect to prior art.
Also, it is observed that when these antennas are operated at higher order frequency modes, they feature a narrow beam pattern, which makes the antenna suitable for high gain applications.

As it will be readily notice by those skilled in the art, other features such as crosspolarisation or circular or elliptical polarization can be obtained applying to the newly disclosed configurations the same conventional techniques described in the prior art.

Figure 46 shows three preferred embodiments for a MSFR antenna. The top one describes an antenna formed by an active patch (3) over a ground plane (6) and a parasitic patch (4) placed over active patch.

At least one of the patches is a RSFS (e.g. top) both patches are a RSFS, only the parasitic patch is a RSFR (middle) and only the active patch is a RSFS (bottom).

Active and parasitic patches can be implemented by means of any of the well-known techniques for micro-strip antennas already available in the state of the art. For instance, the patches can be printed over a dielectric substrate (7) and (8) or can be conformed through a laser cut process upon a metallic layer.

The medium (9) between the active (3) and parasitic patch (4) can be air, foam or any standard radio frequency and microwave substrate.

The dimension of the parasitic patch is not necessarily the same than the active patch.

Those dimensions can be adjusted to obtain resonant frequencies substantially similar with a difference less than a 20% when comparing the resonance of the active and parasitic elements.

Figure 47 shows another preferred embodiment where the centre of active (3) and parasitic patches (4) are not aligned on the same perpendicular axis to the groundplane (7). This misalignment is useful to control the beam width of radiation pattern.

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To illustrate several modification either on the active patch or the parasitic patch, several examples are presented.

Figure 48 and 49 described some RSFS either for the active or the parasitic patches where the inner (1) and outer perimeters (2) are based on the same SFC.

To illustrate some examples where the centre of the removed part is not the same than the centre of patch, in Figure 50 are presented other preferred embodiments with several combinations: centre misalignments where the outer (1) and inner perimeter of the RSFC are based on different SFC.

The centre displacement is especially useful to place the feeding point on the active patch to match the MSFR antenna to specific reference impedance. In this way they can features input impedance above 5 Ohms.

Other, non-regular (or mathematical generated fractal) curves was investigated for fractal antenna use in automotive industry and other applications like in RFID tags, with good results [26, 27]. The field is in rapid change, the potential of fractal antenna applications being far to be fully explored.
8. References

1. B.B. Mandelbrot, *The Fractal Geometry of Nature*, W.H. Freeman and Company, 1983; Mandelbrot, B.B., How long is the coast of Britain? Statistical self-similarity and fractional dimension, *Science* **156**, (1967) 636-638.

2. F.J. Falkoner, *The geometry of fractal sets*, Cambridge Univ. Press, 1990

3. D. Jaggrad, [http://pender.ee.upenn.edu/facu5.htm](http://pender.ee.upenn.edu/facu5.htm), D. Werner [http://www.psu.edu](http://www.psu.edu)

4. Balanis, Constantine A., *Antenna Theory Analysis and Design*, Second Edition, John Wiley & Sons, Inc., 1997

5. Puente Balliarda Carles, Rozan Edouard, Fractus-Ficosa International U.T.E, Patent, International Publication Number WO 02/35646 A1, 02.05.2002

6. Patent US4123756

7. Patent US5504478

8. Patent US5798688

9. Patent WO 95/11530

10. Virga K., Rahmat-Samii Y., “Low-Profile Enhanced-Bandwidth PIFA Antennas for Wireless Communications Packaging”, IEEE Trans. On Microwave Theory and Techniques, October 1997.

11. Skolnik M.I, “Introduction to Radar Systems”, Mc. Graw Hill, London, 1981

12. European Patent Application EP 1317018 A2 / 27.11.2002

13. Patent WO 0154225, Patent WO 0122528

14. Patent EP 1313166 A1

15. Patent PCT/ES/00296

16. Patent WO 95/11530

17. Patent JP-UM-49-1562; Patent US 445884; US Patent 5355144; US Patent 5255002

18. Patent WO 03017421 A2

19. Patent WO 03/023900 A1; Patent WO 01/22528; Patent WO 01/54225

20. Chiou T., Wong K., „Design of Compact Microstrip Antennas with a Slotted Ground Plane” IEEE-APS Symposium, Boston, 8-12 July, 2001

21. Patent US No. 5,703,600

22. Patent WO 02/063714 A1

23. Hansen R.C., “Fundamental limitations on Antennas”, Proc.IEEE, vol.69, no.2, February 1981

24. Pozar D., “The Analysis and Design of Microstrip Antennas and Arrays”, IEEE Press, Piscataway, NJ 08855-1331

25. Zurcher J.F., Gardiol F.E., “Broadband Patch Antennas”, Artech House 1995

26. M. Rusu, R. Baican, Adam Opel AG, Patent 01P09679, “Antenne mit einer fraktalen Struktur”, die auf der Erfindungsmeldung 01M-4890 “Fractal Antenna for Automotive Applications” basiert, 18 Okt. 2001.

27. M.V. Rusu, M. Hirvonen, H. Rahimi, P. Enoksson, C. Rusu, N. Pesonen, O. Vermesan, H. Rustad, “Minkowski Fractal Microstrip Antenna for RFID Tags”, *Proc. EuMW2008 Symposium*, Amsterdam, October, 2008; Rahimi H., Rusu M., Enoksson P., Sandström D., Rusu C., Small Patch Antenna Based on Fractal Design for Wireless Sensors, *MME07, 18th Workshop on Micromachining, Micromechanics, and Microsystems*, 16-18 Sept. 2007, Portugal.
The book deals with modern developments in microwave and millimeter wave technologies, presenting a wide selection of different topics within this interesting area. From a description of the evolution of technological processes for the design of passive functions in millimetre-wave frequency range, to different applications and different materials evaluation, the book offers an extensive view of the current trends in the field. Hopefully the book will attract more interest in microwave and millimeter wave technologies and simulate new ideas on this fascinating subject.

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