SAR Level Reduction Based on Fractal Sausage Minkowski Square Patch Antenna

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Abstract —The research and development of fractal antenna led to produce good multiple wireless applications. Fractal Sausage Minkowski Square Patch Antenna is promising as one of the popular fractal square patch antenna in modern applications. Both of civil and military applications in telecommunication witnessed high demand on fractal antenna. In our work, the proposed fractal antennas were designed to operate in L- band 1.575 GHz for Global Positioning System (GPS) applications. We present 0th, 1st, 2nd and 3rd iteration of new fractal sausage Minkowski design and simulation to reduce SAR levels using CST software 2014. Roger TMM4 is used as substrate with εr of 4.5 and thickness of 1.6 mm. Radiating patch is formed of PEC and a thickness of 0.6 mm. SAR level is measured for fractal antenna where the level of SAR is reduced by factor of 19.51 for 1 g and 11.30 for 10 gs for human head tissue. Furthermore, our calculations indicate that the patch antenna size is miniaturized by factor of 2.53. According to our knowledge RF performance is very good for the size miniaturization and SAR reduction for the four models of iterations so, antenna is efficient and can be used as candidate for GPS applications.

Index Terms—Specific Absorbing Rate (SAR), Sausage Minkowski, Iteration Fractal Antenna, Square Patch Antenna (SPA), Gain

I. Introduction

Fractal geometries have been employed in antenna structure to enhance some antenna parameters. Fractal geometries have two prosperities, first is space filling and second is self-similarity. The characteristics of Microstrip patch antenna (MPA) have attracted large attention as a consequence of its features. Square patch became one of the attractive devices in the world of modern telecommunication system [1]. Fractal Sausage Minkowskihas the priority in wire lees application due to tiny size, low profile, multiple band operation, high gain and easy to manufacture and installation. These advantages make Sausage Minkowski technology is very promising from an application perspective. Several antennas were implemented using a technique of fractal Minkowski. Some of these antennas have designed and simulated by changing thickness or relative permittivity of the substrate. Other are simulated using different material in both of substrate and the patch [2]. Other kinds of antennas like Sierpinkski gasket fractal antenna are implemented for applications of WLAN, RFID ISM band was proposed in [1]. Compact and cheap structure of tag based on short circuit patch antenna was introduced for RFID [2]. The details of fabrication on RO4003C substrate for circularly polarized square shaped radiating structure was explained in [3]. Integration of two fractal geometries where the first is the first iterations of Giusepe Peano built in the edges of a square patch and the second is a Sierpinski Carpet fractal were combined to perform compact antenna was suggested by [4]. A Sausage Minkowski with 1st and 2nd iteration was design and simulated in L band for GPS applications [5]. While in [6] SAR levels are determined over mass of head tissues for human with respect to the IEEE and ICNIRP standards for head safety. The inclination angle is taken to be 0 degree. The evaluation of the presented antenna is carried out when the distance is adjusted to 5 cm between body of human and microwave device at frequency of the evolution of SAR values is carried out for adult human, and the head tissues is consisted of three layer (skin, skull and brain). Study, analysis and comparison for various types of fractal antenna based on aperture couple feeding method was introduced in [7]. In addition, a miniaturized dual band radiating structure operate at ISM band is simulated by modifying the antenna configuration by technique of a fractal structure [8]. There are kinds of Sierpinski such as Sierpinski gasket [9] and Sierpinski carpet [10]. Good review and discussion with details for different algorithms and methods which it used for RFID antenna are showed in [11]. A unique element radiating structure which, it can be etched on a piece of aluminum using for HF applications [12]. The using of FR4 substrate with relative permittivity of 4.5 is used in design and simulation of Sierpinski carpet [13].

Specific Absorption Rate (SAR) is defined as how much amount of transmitted power will be absorbed by human body tissue. SAR is a function of the electrical conductivity (σ) which is measured in mho/m, electric field intensity (E) which is measured in v/m and tissue mass density (ρ) which is measured in unit of kg/m3:

$$SAR = \int_{sample} \frac{\sigma(r)|E(r)|^2}{\rho(r)}\, dr$$

SAR is measured in unit of W/kg or mw/g. When SAR is high that means transmitted power is high and the location of antenna is critical, therefore the antenna parameters must be changed or to change the antenna

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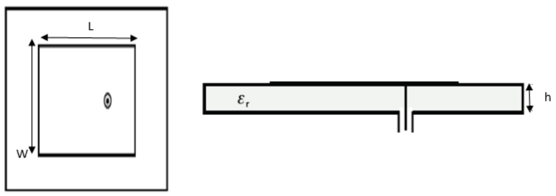
itself [14]. SAR level is decreased to investigate the criteria of international safety standards (ICNIRP&IEEE). Measurements of the absorbed power by predicting the induced SAR in the human head tissue was reported [15], [16]. Simulation by change the position of antenna to calculate the perfect location for SAR level reduction was introduced by [17].

This work presented new design and simulation of fractal Sausage Minkowski based on 0th, 1st, 2nd and 3rd iteration to reduce SAR levels for GPS applications. Also, we discussed and compared antennas characteristics in terms of radiation pattern, SWR, return loss and volume.

II. Methodology and Materials

A. Fractal Sausage Minkowski Geometry

First of all, a fractal is defined as a geometrical configuration that seems to have the same structure of the original structure in spite of how far you zoom out. Sausage Minkowski can be constructed either deterministic or random algorithm. However, deterministic is widely used rather than the other algorithm. In the world of wireless communication large efforts are focused to develop new types of antennas which are suitable for the applications in range of frequency from 1 to 6 GHz [18]. These antennas became a candidate for GPS application because of their proper weight and size compared to conventional kinds of antennas. Good features of square patch made it desirable for space application [19]. However, square patch radiator is used high relative permittivity of dielectric materials to reduce the profile so, it widely used in mobile communication. Usually, GPS antenna is made by fractal technology as result of these properties. In our work, the length of square patch L is as a rule the $L< \lambda gi / 2$, where λgi expresses the guide wavelength on the dielectric material. Two criteria are met to gain good efficiency with wider bandwidth that the thickness of dielectric substrate must be thick with low relative permittivity and vice versa [20]. Assume width of the proposed antenna W_{pi} at vertical axis (y), length L_{pi} at horizontal axis (x), the thickness of a substrate h_{si} along z- axis as shown in Fig. 1 [21].



(a) (b)

Fig. 1. SPA (a) top view, (b) side view

The condition to work in the fundamental mode that the patch's dimension must smaller than $\lambda_{di}/2$.Where $\lambda_{di}= \lambda_0 / \sqrt{\varepsilon_{reff}}$, λ_{di} denotes the wavelength propagation in substrate material, λ_0 denotes the free space wavelength and $\varepsilon_{reff}$is the effective relative permittivity.

According to equations 1 and 3 W_{pi} and L_{pi} are calculated as [21]:

$$wpi = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (1)$$

According to equation 2, height of the dielectric substrate can be calculated as [22]:

$$hsi = \frac{0.3c}{2\pi f_r\sqrt{\varepsilon_r}} \quad , \quad hsi \leq 0.06\,\frac{\lambda di}{\sqrt{\varepsilon_r}} \quad (2)$$

Applying equation 3, the real length can be expressed as:

$$Lpi=L_{eff}-2\Delta Lpi \quad (3)$$

Length extension (ΔLpi) can be determined using equation 4.

$$\Delta Lpi = 0.412hsi\,\frac{(\varepsilon_{reff}+0.3)\left[\frac{wpi}{hsi}+0.264\right]}{(\varepsilon_{reff}-0.258)\left[\frac{wpi}{hsi}+0.8\right]} \quad (4)$$

Effective relative permittivity (ε_{reff}) is denoted in equation 5 [23].

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\,\frac{hsi}{wpi}\right]^{\frac{-1}{2}} \quad (5)$$

and

$$Lp_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \quad (6)$$

where Lp_{eff} is the effective length of the patch.

Equations 7&8 give the width (WGi) and the length (LGi) of the ground plane [24]:

$$WGi=6hsi+Wpi \quad (7)$$

$$LGi=6hsi+Lpi \quad (8)$$

Two conditions are met to make the antenna will be operated in all the ranges of frequency [25]. First, the symmetrical configuration about certain point and second, the individual antenna must have the same original shape in spite of fractal process.

In fact, the fractal geometry is employed widely in satellite, mobile and wireless communication system to miniaturize the size of radiator device which operates in wide dynamic range resonant frequencies [26], [27]. Fundamental of fractal geometry work based on iterative mathematical process, which is explained by an iterative function system (IFS) algorithm.

In our work, fractal Sausage Minkowski is determined as illustrated in Fig. 2.

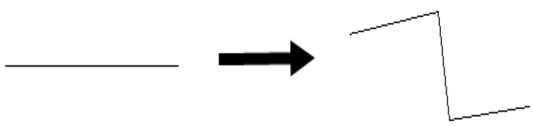


Fig. 2. Fractal Sausage Minkowski polygons

The generated fractal by replacing each dimension of the square with the broken line is shown in Fig. 2 and repeating this step sequentially on the generating polygons [5], [6]. The length of each side is determined as shown in equation 9:

$$lsi = \left(\frac{1}{\sqrt{5}}\right)^{ni} * LPi \quad (9)$$

where lsi denotes the length of side, ni denotes number of iteration and LPi is the side length.

B. Fractal Sausage Minkowski Based on Square Patch Microstrip Antenna

- **Essential Square patch antenna with 0th iteration**
  The details of Square Patch Antenna (SPA) design is depicted in Fig. 3a. Feeding is done using Coaxial cable which is widely used in feeding technique for transporting energy in antenna devices. The dimensions of square patch are calculated using equations (1-8) at the operating frequency 1.575GHz. The proposed antenna structure is composed from Rogers
  TMM4 as a substrate which has dielectric constant (εr) equals to 4.5 with thickness (h) equals to 1.6 mm. For both ground plane and square patch, the material is PCE material with thickness is 0.6 mm. The design is taking on account that the size of coaxial cable is determined according to the 50 Ω antenna impedance.
- **1st iteration Fractal Sausage Minkowski Square Patch antenna**
  To implement 1st iteration Fractal Sausage Minkowski Square patch antenna (F1), the length of each side will be $1/\sqrt{5}$ *LPi. The total number of segments in 1st iteration is twelve segments. The dimensions of F1 are illustrated in Fig. 3b and listed in Table I.
- **2nd iteration Fractal Sausage Minkowski Square patch antenna**
  The procedure which was implemented in F1, the same steps are repeated again in 2nd iteration Fractal Sausage Minkowski (F2) on square shaped. The side length is equal to $(1/\sqrt{5})^2$ *LPi. The total generated segments of 2nd equals to 36. The dimensions resulted from 2nd iteration of (F2) is depicted in Fig. 3c. Table I list the dimensions of F2.
- **3rd Fractal Sausage Minkowski Square Patch antenna**
  To calculate the 3rditeration Fractal Sausage Minkowski (F3), the same steps are repeated again which was used for calculating F1 and F2 on square shaped. The side length is equal to $(1/\sqrt{5})^3$ *LPi. The total generated segments of 3rdequals to 108. The dimensions resulted from 3rditeration of (F3) is depicted in Fig. 3d. Table I list the dimensions of F3.

TABLE I: GEOMETRICAL CONFIGURATION OF SPA

Length of side (mm)	Types of Fractal			
	0th iteration	1st iteration	2nd iteration	3rd iteration
Lpi	43	35.25	32.25	27
Wpi	43	35.25	32.25	27
LGi	86	86	86	86
WGi	86	86	86	86
hsi	1.6	1.6	1.6	1.6
tpi	0.6	0.6	0.6	0.6

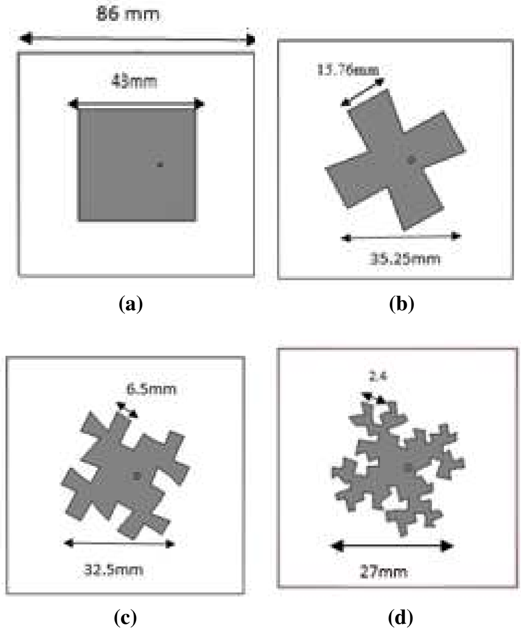


Fig.3. Fractal Sausage Minkowski SPA(a) 0 iteration, (b) 1st iteration, (c) 2nd iteration, (d) 3rd iteration

III. RESULTS AND DISCUSSION

This section depicts the results of the four iterations for fractal Sausage Minkowski geometry applied on square patch antenna. The results are presented in CST software version 2014 for the various iterations to use in applications of GPS. Simulated reflection coefficient, gain, VSWR and the area of the patch are shown in Table II. The simulated resonance frequency occurs at 1.575 GHz as shown in Fig. 4, Fig. 6, Fig. 8 and Fig. 10. From the observations for the Figures (4, 6, 8, 10), it is clear that the values of reflection coefficient will be decreased from -18dB at the 0th iteration to -25 at 3rd iteration. Radiation pattern is plotted in polar and 3D as shown in Fig. 5, Fig. 7, Fig. 9 and Fig. 11. It can be observed that the radiation pattern is semi Omni direction.

TABLE II: THE CHARACTERISTICS OF FRACTAL SAUSAGE MINKOWSKI SQUARE PATCH ANTENNA

Characteristics	Types of Fractal			
	0th iteration	1st iteration	2nd iteration	3rd iteration
Reflection coefficient (dB)	-17	-24	-25	-25
Gain (dB)	4.5	4.54	4.61	4.85
VSWR	1.6	1.4	1.2	1.2
Area of patch (mm^2)	1849	1242.5625	1056.25	729

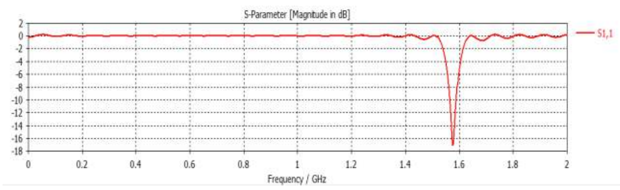
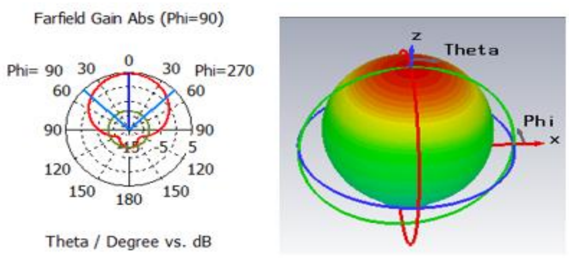


Fig. 4. 0th iteration Reflection coefficient at 1.575 GHz



(a) (b)

Fig. 5. 0th iteration Radiation pattern (gain), (a) polar, (b) 3D

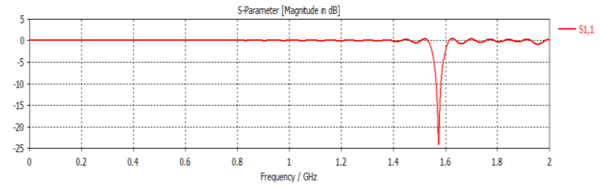
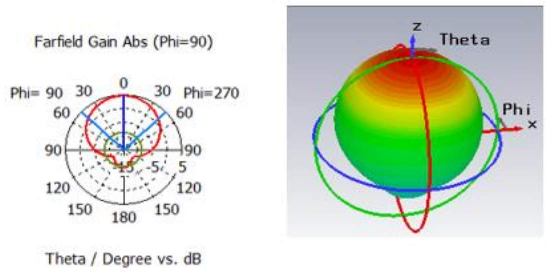


Fig. 6. 1st iteration Reflection coefficient at 1.575 GHz



(a) (b)

Fig. 7. 1st iteration Radiation pattern (gain) (a) polar (b) 3D

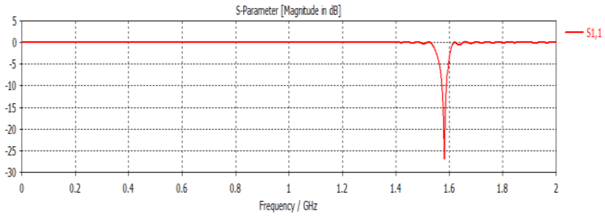
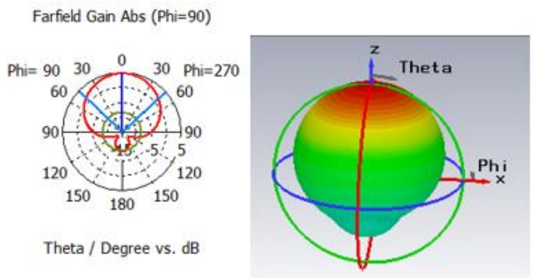


Fig. 8. 2nd iteration Reflection coefficient at 1.575 GHz



(a) (b)

Fig. 9. 2nd iteration Radiation pattern (gain) (a) polar, (b) 3D

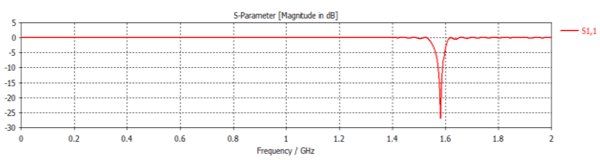
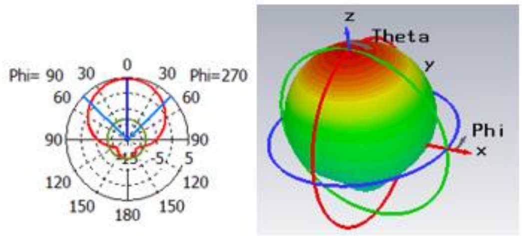


Fig. 10. 3rd iteration Reflection coefficient at 1.575 GHz

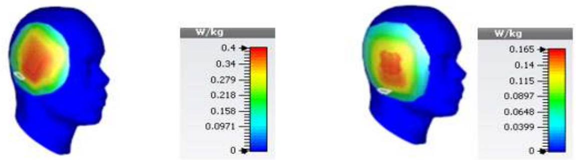
The SAR value is calculated for human head tissue model. The structure of human head tissue model consists of three layers' brain, skull and skin. The proposed antenna is positioned at a distance about 5mm from the human head. Fig. 12, Fig. 13, Fig. 14 and Fig. 15 show that the SAR simulation results for the proposed antennas and these results are shown in Table III where the SAR value is improved gradually with increasing the number of iteration. The red color indicates the region of brain tissue which absorbed electromagnetic fields radiations transmitted from the simulated antenna.



(a) (b)

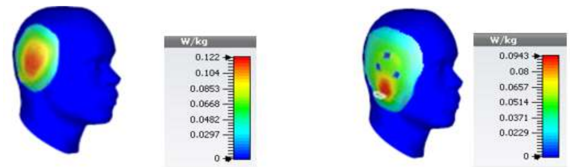
Fig. 11. 3rd iteration Radiation pattern (gain) (a) polar, (b) 3D

From Table III, the low SAR value at all the resonance frequencies is noticed to satisfy the international safety standards (FCC & ICNIPR) at (1 g & 10 g). The proposed 3rd iteration of the fractal antenna has a very low SAR value.



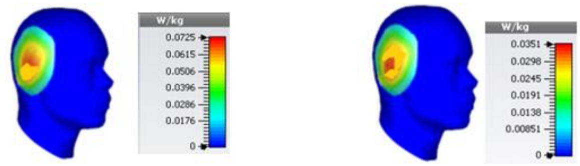
(a) (b)

Fig. 12. Specific absorbing rate (SAR) for SPA with 0 iteration, (a)1g, (b) 10g



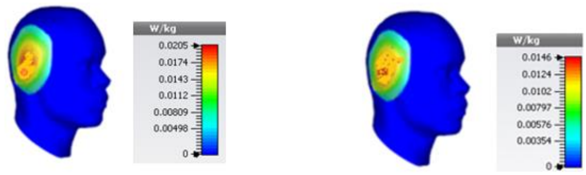
(a) (b)

Fig. 13. Specific absorbing rate (SAR) for SPA with 1stiteration, (a)1g, (b) 10g



(a) (b)

Fig. 14. Specific absorbing rate (SAR) for SPA with 2nd iteration, (a)1g, (b) 10g



(a) (b)

Fig. 15. Specific absorbing rate (SAR) for SPA with 3rd iteration, (a)1g, (b) 10g

TABLE III. SAR SIMULATION RESULTS

Iteration of Fractal	SAR (W/Kg)	
	1g	10g
0^{th}	0.4	0.165
1^{st}	0.122	0.0943
2^{nd}	0.0725	0.0351
3^{rd}	0.0205	0.0146

IV. CONCLUSIONS

A new and compact Fractal Sausage Minkowski patch antenna has been investigated. The proposed micro strip antenna works in 1.575 GHz for navigation system. Because of the high demand for new types of antenna for modern communication applications and attached to human body, SAR is considered an important factor and must be taken on account and enhanced. Therefore, another design is introduced and fabricated to enhance the SAR value A novel design and simulation show that the characteristics of the antenna will be enhanced in parallel with the increasing the number of fractal iteration like gain, directivity, radiation pattern, SWVR and return loss. In addition, the reducible values of SAR for 1st, 2nd and 3rd iteration indicate that SAR levels will be decreased with increasing the number of iteration. The results are compatible with the yearly reports limits of the two standards (ICNIRP&IEEE). As a result, the investigation of compact, low profile and cheap antenna using simple technique, SAR is reduced and the proposed antenna can be used for navigation purpose. We concluded that reducible values for low SAR level of radiator device (antenna) for human head will never degrade the RF performance of antenna.

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