1. Haouam Imane[1], 2. Beladgham Mohammed[2], 3.Bendjillali Ridha Ilyas[3]

Salhi Ahmed University Center, Naama, Algeria (1), Tahri Mohammed University, Bechar, Algeria (2), Nour el Bachir University center, El Bayadh, Algeria (3)

ORCID: 1. A-9605-2019; 2.R-8472-2016; 3. A-8835-2019

doi:10.15199/48.2024.09.48

Antenna design based on fractal geometry compact for several application on 33Ghz and 35 Ghz

***Abstract**. As communication technomogy has advanced in the past decade, there is an increasing demand for antenna thar are smaller in size, multiband and supporting wideband frequencies. Additionally, the saturation of the lower part of the microwave spectrum and the need for higher data transmission rates necessitate a shift to higher frequencies, to address these requirement, the use of fractal geometries in antenna design, has emerged as a promising solution through research and development. The objective of this work is to design and simulate a new antenna using the fractal structure, the proposed antenna design is founded on a circle with diameter 4.84mm, a square contained within this circle is systematically removed. This resulting shape is identified as the generator for the overall geometry, then this deletion process is iteratively applied five time with smaller dimensions. Through electromagnetic simulation of HFSS, the proposed antenna's pehavior is analyzed with the radiation pattern and the maximum gain, also the effect of substrate material on working frequencies is mentioned*

***Streszczenie.** Wraz z rozwojem technologii komunikacyjnej w ostatniej dekadzie wzrasta zapotrzebowanie na anteny o mniejszych rozmiarach, wielopasmowe i obsługujące częstotliwości szerokopasmowe. Ponadto nasycenie dolnej części widma mikrofalowego i potrzeba wyższych szybkości transmisji danych powodują konieczność przejścia na wyższe częstotliwości. Aby sprostać tym wymaganiom, wykorzystanie geometrii fraktalnej w projektowaniu anten okazało się obiecującym rozwiązaniem w wyniku badań i rozwój. Celem pracy jest zaprojektowanie i symulacja nowej anteny wykorzystującej strukturę fraktalną, proponowana konstrukcja anteny opiera się na okręgu o średnicy 4,84mm, kwadrat zawarty w tym okręgu jest systematycznie usuwany. Powstały kształt jest identyfikowany jako generator ogólnej geometrii, następnie proces usuwania jest stosowany iteracyjnie pięciokrotnie z mniejszymi wymiarami. Poprzez symulację elektromagnetyczną HFSS analizowane jest zachowanie proponowanej anteny z charakterystyką promieniowania i maksymalnym wzmocnieniem, wspomina się także o wpływie materiału podłoża na częstotliwości robocze (**Projekt anteny oparty na kompaktowej geometrii fraktalnej do różnych zastosowań na częstotliwościach 33 GHz i 35 GHz**)*

Keywords: Fractal geometry, microstrip antenna, multiband, millimeter waves, wideband frequencies.
Słowa kluczowe: Geometria fraktalna, antena mikropaskowa, wielopasmowość, fale milimetrowe, częstotliwości szerokopasmowe..

Introduction

In nature, there are shapes and objects that we cannot define with the help of the existing geometric shapes (circles, squares, triangles, rectangles. . .), because the latter reaches its limits when it comes to describing very irregular objects. This led scientists to invent new models to try to explain this irregularity of nature. This allowed the emergence of a new geometry called "fractal geometry", which is an extension of Euclidean geometry and allows to specify a large number of new shapes

Traditional antennas operate in a narrow frequency band, however, with the recent evolution of radio systems, more and more antennas can operate in several distinct frequency bands, these antennas are then called multi-band antennas.

The fractal antenna's distinctive feature lies in self-similaruty,enabling the achievement of multiband or wideband capabilities[1], and space filling properties that facilitate antenna miniaturization[2]. Consequently the primary objective in utilizing fractal antenna is to harness the electromagnetic properties inherent in their unique geometry[3][4]

This properties allows this small and differents structure antenna to radiate in many frequencies with large band of frequencies,which makes them suitable for application covering multiple bands[5]. due to their self-replicating patterns, this antenna can fill space efficiently.

The self similarity structure allow the antenna to exhibit a degree of redundancy, enhancing its robustness, this properties contributes to improved impedance matching and radiation characteristics.

The aim of using fractal antenna is to capitalize on teir special geometric properties to achieve advantages such as multiband and miniaturization, that make fractal antenna suitable for a variety of applications , uncluding wireless communication devices, RFID systems, and compact electronic systems.

For several research[6], the fractal antennas have been used in the lower bands for many application as microwave and different frequencies but in recent years, the increas of technology and a rapid developpement in many services imposed a rise of frequencies, that's lead the scientist to look for higher frequencies using fractal antenna in various fields such as medical imaging, military systems, and wireless communications.

For this reason, our work will be based on the different aspects of the printed fractal antennas with its novel structure comparing with the sierpinsky carpet fractal antenna

This paper presents the results of fractal antennas simulation of the sierpinsky carpet using the HFSS software. This software is the indispensable tool for antenna design.

Then, we will comment and discuss the different results that represent the parameter S11, the resonance frequencies and the visualization of the radiation diagram.

Related works

Y.K.Choukiker and al [7] proposed an hybrid fractal shape of planar antenna based on two structure integration of fractals: Minkowski and Koch curves. The results and measured impedance matching fractional bandwidths have been found around 1.6Ghz to 1.9Ghz and 2.68Ghz to 6.25Ghz

S.Singh and A.Singh [8] have studied a modified design of sierpinski fractal antenna using high frequency coaxial probe feed. The implemented antenna shows a broadband behavior in frequencies bands between 12.2-13.4Ghz and 21-30Ghz with gain between 8 to 22dB which it can be used in several application such as passive and active sensor

Alibakhshi-kenari M and al [9] proposed a novel single radiator card-type tag. The structure of this antenna is based on a series hillbert-curve loop and matched stub for high frequency, ultra-high frequency and dual band radio frequency, the results realized a broadband and circular polarization performance which is also easy to fabricate.

Syed S.Haider and al [10] presented a structure for a new fractal patch with rectangular slot etched in it to achieve dual band. This antenna provides polarization diversity with sual band characteristics with high broad side gain, stable radiation patterns and good port to port isolation wivh makes it a good competitor for 5G mobile communication

Amar tawfeeq.A and al [11] designed and configurated a novel antenna via five stage process, in every stage, they used the modified square patch with a half size that used previously to added to shape the dual fractal structure antenna. This experience had measured dual operating bands that meet the specification of the wi-fi and WiMAX applications

Bhatia S.S and al [12] designed a fractal antenna with eight element for multiband applications. the proposed antenna array operated on eight frequency band in the range of 3 to 10Ghz, this frequency can be used for the applications such as WiMAX, WLAN, x-band for satellite communication and point to point for high-speed wireless communications.

Wenpe Li and al [13] proposed a study of tree shaped fractal antenna, by increasing the number of iterations, optimizing the priority ground plane and the size of the dielectric substrate. The antenna gives a good result around frequency band 26 Ghz- 30.2Ghz and at the center of 28 Ghz

Harini.V and al [14] implemented an extended sierpinsky gasket fractal design, the designed antenna operates at frequencies from 24 to 61Ghz with a good reflection coefficient value which is radiate with the maximum electric field in all directions

Microstrip antenna

A microstrip antenna is a type of antenna that is constructed on a flat, planar substrate using microstrip transmission line technology. It serves as a passive component connected to a generator and the medium through which the waves propagate. Numerous techniques exist for designing and manufacturing antennas, each with unique characteristics tailored to specific applications [15]. Among these methods the printed circuit technology stands out as one of the most commonly used.it consist of radiating patch, a ground plane and a substrate.

Printed antennas are created by depositing conductive materials on a substrate, called radiating patch [15]. The shape and dimension of the radiating patch determine the antenna’s resonant frequency and radiation pattern, this performance affected also by the choice of substrate material.The substrate material can be a dielectric material like fiberglass-reinforced epoxy, Teflon…etc

Feeding mechanism

Microstrip antennas are typically fed using a microstrip transmission line, the cavity model or a full wave analysis [16-18]. the transmission line model is the simplest, providing a good deal of physical insight, it represents as two slots of microstrip antenna each of width W and height h separated by a transmission line of length L. the microstrip is essentially non-uniform line consisting of two dielectrics, typically the substrate and air[19], the most of electric field lines reside within the substrate and also distributed into the air, by following the formulation of transmission line model, The dimensions of antenna are calculated.

The expression of the effective dielectric constant is provided by balanis [20][21]:

$$\text{(1)} \quad \varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt[2]{1+12(\frac{h}{W})}} - 0.04(1-\frac{W}{h})^2\right]$$

The width of the antenna is obtained from:

$$\text{(2)} \quad W = \frac{V_0}{2F_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

Where $\mathcal{E}_r$, V_0 and F_r are the dielectric constant of the substrate, the speed of light in vaccum and the resonant frequency

The length L of the patch is given by:

$$\text{(3)} \quad L = \frac{C}{2f_o\sqrt{\varepsilon_r eff}} - 0.834h\left(\frac{(\varepsilon_r eff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r eff-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

The fringing effect causes the length of the patch at each end to be extended by distance ΔL :

Where

$$\text{(4)} \quad 0.412h\left(\frac{(\varepsilon_r eff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r eff-0.258)\left(\frac{W}{h}+0.8\right)}\right) = \Delta L$$

The esential parameters for the design of a patch antenna are the resonnant frequency F_r, the dielectric constant of the substrate $\mathcal{E}_r$, and the thickeness of the substrate h

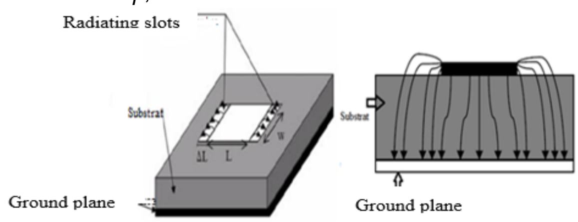

Fig.1. transmission line model

Feeding type

The most feeding technique implemented in practice, namely the microstrip transmission line and coaxial probe according to their simplicity and they are easy to fabricate and design. In this study, coaxial feeding is used. In this method the inner conductor of the coaxial is attached to the radiation patch of the antenna while the outer conductor is connected to the ground plane[21].

The main advantage of this feeding method is that the coaxial probe can be placed and adjusted to fine-tune the antenna’s performance, and to match its input impedance, also it is easy to manufacture and exhibit low stray radiation. However, it has disadvantages in terms of producing cross polarization radiation[18]

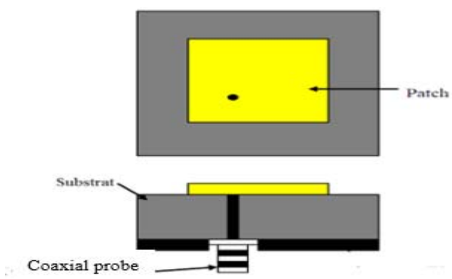

Fig.2. coaxial feeding technique

Fractal antenna

fractal antenna uses fractal geometry, which is generated by a theoretically infinite iteration process, the details are not identical where the reduced base pattern of a certain factor is found at all levels of observation, due to their self-similarity structure

According to their complex and self-replicating patterns at various scales, fractal antenna can operate over a wide range of frequencies while maintaining a good performance

The dimension of fractal constitutes a generalization of the dimension concept used in Euclidean geometry. The fractal dimension D is the number that quantifies the degree of irregularity and fragmentation of geometric object. The fractal dimension is given by:

(5) $$D=\left(\frac{\log N}{\log\frac{1}{S}}\right)$$

Where N is the number of self-similar copies, and S is the reduction ration

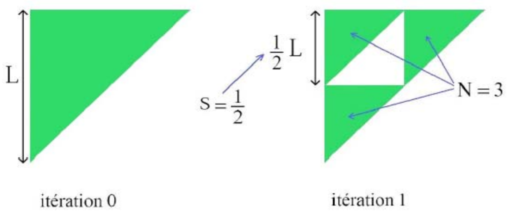

Fig.3. The calcul of fractal dimension

Proposed antenna

The use of thin substrates with high permittivity (1 <εr<12) is recommended for microwaves and millimeter waves circuits as it minimize surface waves, unwanted radiation and antenna volume. Recently, fractal antenna has been proposed to achieve these properties, besides a size miniaturization and multiband antenna architectures [22].

for this work the commonly found materials for substrate is FR4-epoxy and benzocyclobutene with relative permittivity of 4.4 and 2.6 respectively, the substrate tallness (h) of 1.6mm

The purpose of using fractal antenna is to take advantage of the electromagnetic characteristics of its special geometry to have multi-frequency character. the adaptation of the antenna within all frequencies of a band is defined by a reflection coefficient

The objective is to guarantee transmission or reception at a specific frequency with the best adaptation which is imposed according to the standards, it must be less than -10 db, showing a good adaptation to the resonance frequency of the valid band

Antenna simulation results

In this paper, a little size fractal antenna design is suggested, based on a circular initiator with a diameter of 4.84 mm, a square in the center of this circle is deleted to obtain the generator form of this shape. At each iteration the generator form is repeated with a dimension so that the diameter of the new circle is the side of the square, this process is repeated five times until achieving a shape with a good reflection coefficient and resonance condition. To simulate and optimize the proposed antenna model, the HFSS simulation software is used

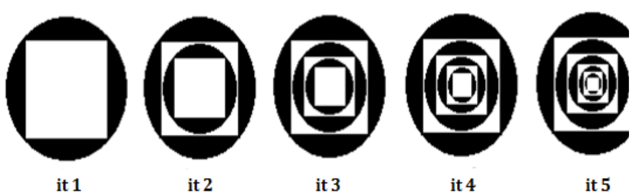

Fig.4. The proposed fractal structure dimension

The developed antenna parameters in this work are given by:

Table 1. The proposed antenna characteristics

parameter	Value
Substrate dimension	12*12mm
height	1.6mm
material	FR4-epoxy
permittivity	4.4
Characteristic impedance	50Ω
Feeding type	Coaxial probe
Feed material	pec

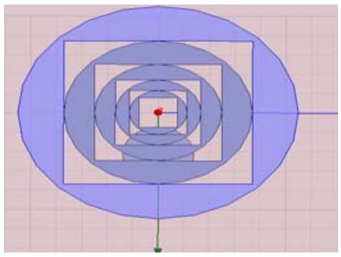

Fig.5. The proposed antenna design on simulator

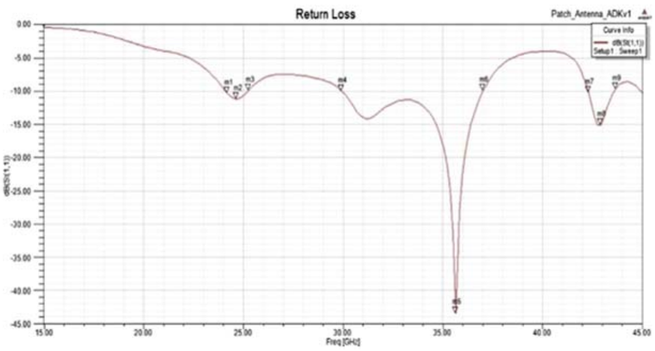

Fig.6. S11 curve of the antenna

The fig 6 shows the return loss curve of the fifth order of this proposed fractal antenna, using as substrate material the Fr4-epoxy. As can be seen from the figure, the antenna has many resonances point with different loss coefficient, the remarqued point, at 35.65 Ghz with corresponding return loss -43.35 dB and bandwidth is 30Ghz-37Ghz

From figures 7,8 and 9, the two-dimensional gain curve of the center frequency with the three-dimensional gain pattern of the antenna at 24.64Ghz, 35.65Ghz and 42.88Ghz respectively, to see the difference between gain in the resonance points

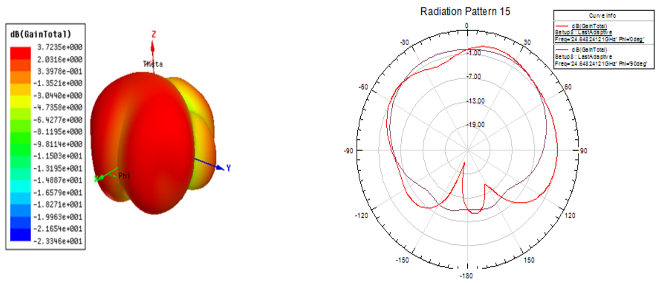

Fig.7. 2D and 3D radiation pattern of frequency =24.64Ghz

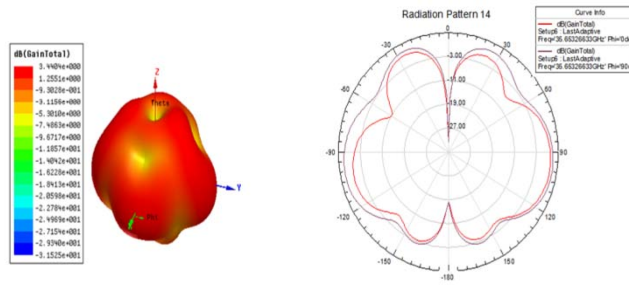

Fig.8. 2D and 3D radiation pattern of frequency =35.65Ghz

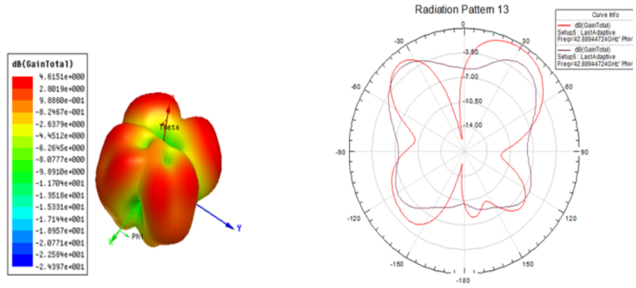

Fig.9. 2D and 3D radiation pattern of frequency =42.88Ghz

The following table summarizes the characteristics found for each frequency in terms of S11 coefficient, gain and bandwidth

Table 2. the results for the resonance frequencies

Resonance frequency (Ghz)	S11(dB)	Gain(dB)	bandwidth	
			Ghz	%
24.64	-11.24	3.72	1.06	4.30
35.65	-43.35	3.44	7.08	19.87
42.88	-15.11	4.61	1.36	3.17

Results of material effects

In this part, the effect of the type of substrate material on the antenna behavior is analyzed, the suggested antenna will be simulated with the benzocyclobuten as a substrate material.

The antenna geometry used in this simulation is the same with 5 iterations. The table below show the characteristics used for this experience including the substrate dimension, the relative dielectric constant and the feeding type.

Table 3. The proposed antenna characteristics

Parameters	Value
Substrate dimension	15*12mm
height	1.6mm
material	benzocyclobuten
permittivity	2.6
Characteristic impedance	50Ω
Feeding type	Coaxial probe
Feed material	pec

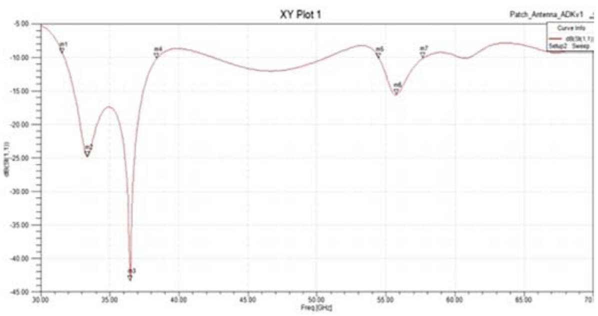

Fig.10. S11 curve of the antenna

The fig shows the return loss curve by the reflection coefficient S11, the antenna's loss coefficient at 33.4 Ghz and 36.5Ghz is -20.10dB and -34.28dB respectively, with corresponding bandwidth from 31.7Ghz- 36.5Ghz

The table below resume the result of the frequency on resonant point

Table 4. the results for the resonance frequencies

Resonance frequency(Ghz)	**S11 (dB)**	**Gain (dB)**	**bandwidth**	
			Ghz	**%**
33.4	-20.1	8.04	7.1	21.2

The radiation patterns of the proposed antenna for the frequencies found are represented respectively by the figures bellow

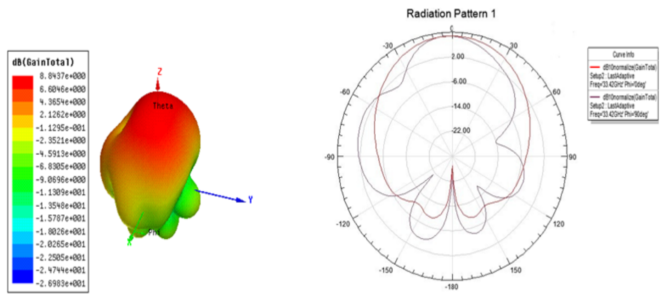

Fig.10. 2D and 3D radiation pattern of frequency =33Ghz

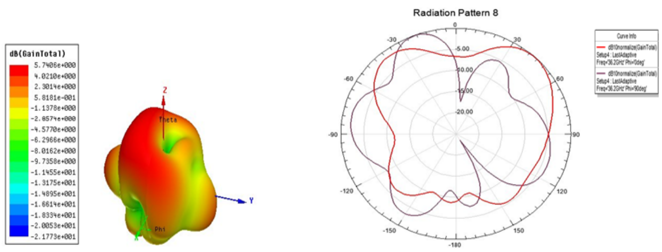

Fig.12. 2D and 3D radiation pattern of frequency =36Ghz

The radiation diagram is almost directive with a significant gain.

Conclusion

In this paper, a self-similarity and space filling characteristics of the fractal structure are used to design a new fractal antenna. by increasing the number of iterations of the initial form, changing the type of material, optimizing the size of the ground plane and also the size of dielectric substrate.

The proposed antenna can operate with a good radiation at several frequencies, at 24.64Ghz, 35.65Ghz and 42.88Ghz when using FR4-epoxy as substrate material and at 33.4 Ghz and 36.5Ghz when using the benzocyclobuten. The antenna's working gain is 4 dB and 8 dB which can be used in several millimeter waves application such as 5G communication.

Authors

1- Dr. Haouam Imane, Department of electrical engineering, University Center Salhi Ahmed Naama, Algeria haouam.imane@cuniv-naama.dz

2-Beladgham Mohammed, Department of electrical engineering, Tahri Mohammed University, Bechar, Algeria Beladgham.mohammed@cuniv-bechar.dz

3- Bendijallali Ilyas Ridha, Technologie department University center nour bachir, El Bayadh, Algeria r.bendjillali@cu-elbayadh.dz

REFERENCES

[1] D. H. Werner and S. Ganguly, "An overview of fractal antenna engineering research," in IEEE Antennas and Propagation Magazine, vol. 45, no. 1, pp. 38-57, Feb. 2003.

[2] J. Pourahmadazar, C. Ghobadi and J. Nourinia, "Novel Modified Pythagorean Tree Fractal Monopole Antennas for UWB Applications," in IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 484-487, 2011

[3] H. Oraizi and S. Hedayati, “miniaturized UWB monopole microstrip antenna design by the combination of giusepe peano and sierpinski carpet fratals”, IEEE antennas and wireless propagation letters, vol 10, 2011 pp67-70

[4] J.P. Gianvittorio, and Y. R Sami, “fractal antennas: a novel antenna miniaturization technique and applications, “ IEEE antennas and propagation magazine, vol 44, No1, Feb 2002.

[5] C. milias, R.B. Andersen, P.I.Mazaridis, Z.D. Zaharis, B. Muhammad, J.T. Kristensen, A.Mihovska, D.D.Hermansen “Matematerials-inspired Antennas: A Review of the State of the Art and Future Design Challenges”, vol 9, IEEE Access,2021.

[6] Choo, H. Antenna Design for Microwave and Millimeter Wave Applications: Latest Advances and Prospects. Appl. Sci. 2021, 11, 5556. https://doi.org/10.3390/app11125556

[7] Y. K. Choukiker, S. K. Sharma, and S. K. Behera ,”Hybrid Fractal Shape Planar Monopole Antenna Covering Multiband Wireless Communications With MIMO Implementation for Handheld Mobile Devices”, Antenna and Propagation, IEEE Transaction, Vol. 62, No. 3; pp 1483-1488, 2014.

[8] A. Singh and S. Singh, “A Novel CPW – Fed wideband printed monopole antenna with DGS”, International Journal of Electronics and Communications (AEU), Vol. 69, pp.299-306 , 2015, DOI: 10.1016/j.aeue.2014.09.016

[9] Alibakhshi-Kenari M, Naser-Moghadasi M, Ali Sadeghzadeh R,Virdee BS and Limiti E (2016) Dual-band RFID tag antenna based on the Hilbert-curve fractal for HF and UHF applications. IET Circuits, Devices & Systems 10, 140–146.

S. S. Haider, M. R. Wali, F. A. Tahir and M. U. Khan, "A fractal dual-band polarization diversity antenna for 5G applications," *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, San Diego, CA, USA, 2017, pp. 763-764, doi: 10.1109/APUSNCURSINRSM.2017.8072424

[10] Abed, Amer & Singh, Mandeep & Islam, Mohammad. (2018). Compact Fractal Antenna Circularly Polarized Radiation for Wi-Fi and WiMAX Communications. IET Microwaves Antennas & Propagation. Article. 10.1049/iet-map.2018.5213.

[11] Bhatia, S.S, Sivia, J.S. On the Design of Fractal Antenna Array for Multiband Applications. J. Inst. Eng. India Ser. B **100**, 471–476 (2019). https://doi.org/10.1007/s40031-019-00409-9

[12] Wenpe Li, wei he, Zhongrong Lai and Siyu Liu. Study of a 28Ghz tree shaped fractal millimeter waves antenna. 2nd international conference on oil & gaz engineering and geological sciences, (2020) *IOP Conf. Ser.: Earth Environ. Sci.* 558 052026

[13] Harini, V., Sairam, M.V.S. & Madhu, R. Performance Analysis of an Extended Sierpinski Gasket Fractal Antenna for Millimeter-wave Femtocells Applications. Wireless Pers Commun 119, 1437–1468 (2021). https://doi.org/10.1007/s11277-021-08289-3

[14] Jacob du.P, Saurabh.S, “ millimeter wave antennas: configuartions and applications”, springer international publishing switzerland, signals and communication technology, ISBN 978-3-319-35067-7, DOI 10.1007/978-3-319-35068-4, 2016

[15] W.Richards, Y.Lo, An improved theory and experiment on microstrip antennas. Antennas Propag. Soc. It Symp 17(1),1979

[16] D. Sengupta, the transmission line model for rectangular patch antennas. Antennas and propag. Soc. Int. Symp. 21,158-161 (1983).

[17] K. Carver, J.Mink, Mictrostrip antenna technology. IEEE Trans. Antennas propag. 29 (1), 2-24 (1981)

[18] Sika.S, Seong Ro.L, Dong-Ypi.C, “a neww fractal based miniaturized dual band patch antenna for RF energy harvesting”, international journal of antenna and propagation, vol2014, http://dx.doi.org/10.1155/2014/805052.

[19] Pozar.M.D, transmission line and wave guides, microwaves engineering,4th edn. John wiley and Spns Inc, Dedham, Massachussets, 1979

[20] Balanis.A.C, antenna theory analysis and design, John wiley and Sons, New york, NY, USA, 3rd edition, 2005

[22] Vijayalakshmi.C, Naveen.S.B.N, “design and analysis of fractal antenna for millimeter wave application”, internatinal journal of advance scientific research and engineering trends, vol6, june 2021