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Bandwidth Enhanced Miniaturized Fractal Antenna Using Giuseppe Peano and Sierpinski Carpet for UWB and Satellite Applications

O. Mahri[1,*], N. Guebgoub[1], M. Benslama[2], T.A. Denidni[3]

[1] *Laboratoire des Télécommunications, Université 8 Mai 1945, 24000-B.401 Guelma, Algérie*
[2] *Laboratoire LET, Université Frères Mentouri Constantine 1, 25000 Constantine, Algérie*
[3] *CEMT – INRS, 800 Rue De La Gauchetière Ouest, Bureau 6900 Québec, H5A 1K6, Canada*

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In this paper, a new microstrip monopole compact antenna is designed by using two fractal structures: Giuseppe Peano and Sierpinski carpet for ultra-wideband (UWB) applications and satellite communications. It consists of a square patch with two steps, and a rectangular slot on the partial ground plane. The antenna is simulated using a microstrip feed line and an FR-4 dielectric substrate with $\varepsilon_r = 4.3$ and $\tan\delta = 0.025$. The first iteration of the Giuseppe Peano and two-level iterations of Sierpinski carpet fractals have been applied on the patch. The simulated results conducted by the CST Microwave Studio Simulator show reasonable agreement with the measured results. The frequency range obtained for $S_{11} < -10$ dB is 3.1-12.2 GHz, relatively 118.95 % with a bandwidth enhancement of approximately 63.51 % compared to the basic antenna. The stated antenna is also compared with the related literature reviews to differentiate its performance. The designed antenna exhibits omnidirectional radiation patterns and a good gain over the entire band with a peak of 5.2 dB at 12 GHz. The proposed antenna shows satisfactory radiation efficiency, compact size, and easiness to manufacture which makes it a strong candidate for practical UWB applications and satellite communications.

Keywords: Fractal antenna, Sierpinski carpet, Giuseppe Peano, UWB, Satellite communications.

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1. INTRODUCTION

In a communication system, the antenna itself is a component requiring particular study. While seeking to optimize the radio performance of the antenna, it is necessary to adapt it to the latest applications and meet the integration requirements in the terminal architecture. The emerging UWB radio communication technology which exploits the principle of very short carrier-free pulsed radio links offers interesting advantages over current information transmission techniques and could revolutionize the telecommunications field. For several years now, the deployment of these technologies, especially in mass-market applications, requires the use of high bandwidth miniature and low-cost performance antennas [1, 2]. Moreover, designing a low profile and compact size antenna with good characteristics is a challenging task for researchers. Nowadays, fractal structures are a good solution to achieve a compact, low-profile antenna with multi-band and/or broadband characteristics due to its two most common properties: self-similarity and space-filling [3]. The discontinuities due to the convoluted and jagged shape of fractal increase the bandwidth and effective radiation of the antenna. The self-similarity property of a fractal causes multi-band and/or broadband behavior, and the space-filling property leads to size reduction [4].

In this paper, a new microstrip monopole compact fractal antenna which is realized by a combination of Giuseppe Peano and Sierpinski carpet fractal geometries is proposed. The Giuseppe Peano fractal is applied along the edges of a square radiating patch and Sierpinski carpet fractal structure is etched on its surface. The antenna is fed through a microstrip line with a symmetrical slot on the upper edge of the partial ground plane. The simulations were done with CST simulator which is considered as the best software for the analysis and the design of planar and wired antennas.

2. ANTENNA DESIGN

The Sierpinski fractal structure was invented by the Polish mathematician Sierpinski. There are several variants of this geometry, among which is the Sierpinski carpet. The iterations of Sierpinski carpet geometry are shown in Fig. 1 [5, 6].

In 1890, Giuseppe Peano introduced a new fractal function for space filling property of a structure known as Giuseppe Peano [7]. This concept of fractal structure was introduced into antenna engineering for miniaturization purpose [8, 9]. The recursive procedure of the Giuseppe Peano fractal is applied along the edges of a square radiating patch up to the second iteration as depicted in Fig. 2 [10, 11].

As shown in Fig. 3, the above two fractal geometries are applied on the radiating patch of the proposed antenna [12]. The geometry of the basic antenna is a planar square monopole antenna that is printed on the FR-4 substrate with a size of $30 \times 30 \times 1.5$ mm^3 ($Ws \times Ls \times h$). The permittivity of the substrate is $\varepsilon_r = 4.3$ and its loss tangent is 0.025. The dimensions of the patch are $Lp = Wp = 14$ mm. The partial ground plane has a reduced length of 12.5 mm (Lg) and the same width as the substrate. The microstrip feed line is designed to be of 50 Ohm with a width $Wf = 3$ mm.

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[*] mahri.omar@univ-guelma.dz
omarmahri@yahoo.fr

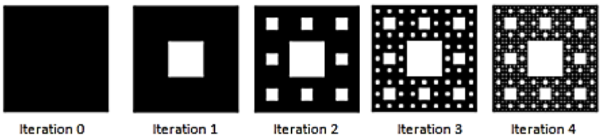


Fig. 1 – Four iterations of the Sierpinski carpet

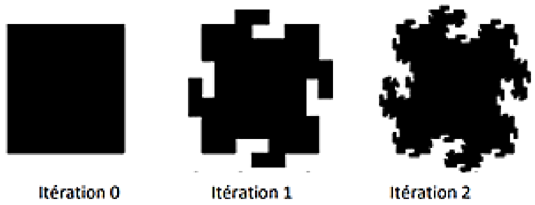


Fig. 2 – Giuseppe Peano fractal

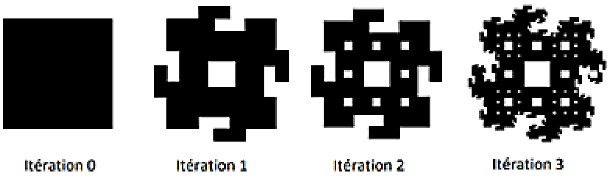


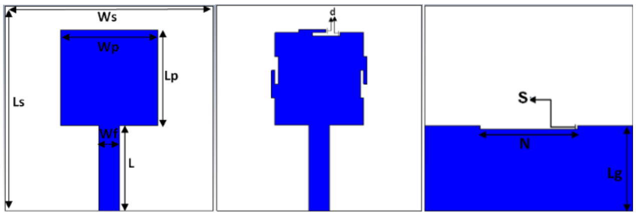
Fig. 3 – The proposed geometry

2.1 Application of the Giuseppe Peano Fractal

In this section, Giuseppe Peano fractal geometry will be applied to the edges of the square patch of the basic antenna. Furthermore, a symmetrical rectangular shape of dimensions (0.5 × 14) mm^2 ($N \times S$) will be removed from the middle of the upper edge of the ground plane, as shown in Fig. 4.

Fig. 5 clearly shows the effect of the inserted slot in the ground plane of the Peano antenna compared to the basic antenna. Consequently, a bandwidth of 3.28 GHz to 11.62 GHz is achieved.

To further improve the bandwidth at the entry, the lower end of the patch is clipped in a particular fashion on both sides to generate proper impedance steps having the dimensions $a_1 = 1$ mm, $a_2 = 4$ mm, $a_3 = 0.5$ mm, $b = 0.5$ mm, $c = 0.5$ mm, as seen in Fig. 6. Consequently, a bandwidth of 3.1 GHz to 12.1 GHz is achieved, as illustrated in Fig. 7 [13].



a b c

Fig. 4 – Basic antenna (a), Giuseppe Peano antenna (b), and ground plane with a slot (c)

2.2 Application of the Sierpinski carpet

Fig. 8 shows the first three iterations of Sierpinski carpet applied on the radiating Giuseppe Peano patch of the proposed antenna. It can be seen from Fig. 8 that the insertion of the first three iterations of the fractal does not significantly affect the antenna bandwidth.

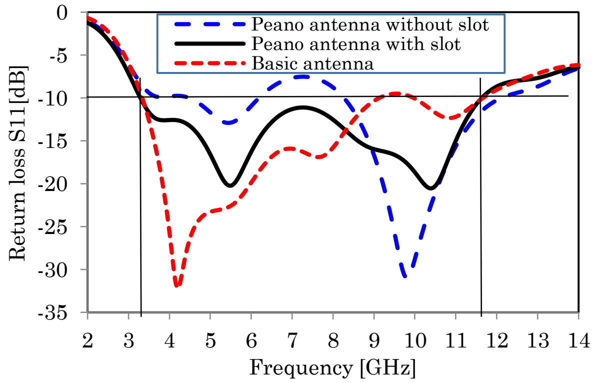


Fig. 5 – Effect of the inserted slot in the ground plane on the reflection coefficient S_{11} of the Peano antenna

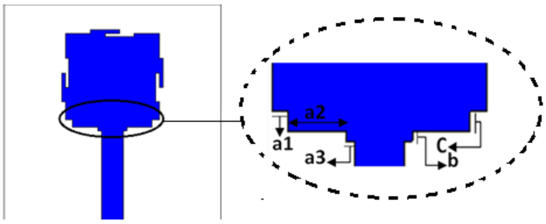


Fig. 6 – Giuseppe Peano antenna with steps

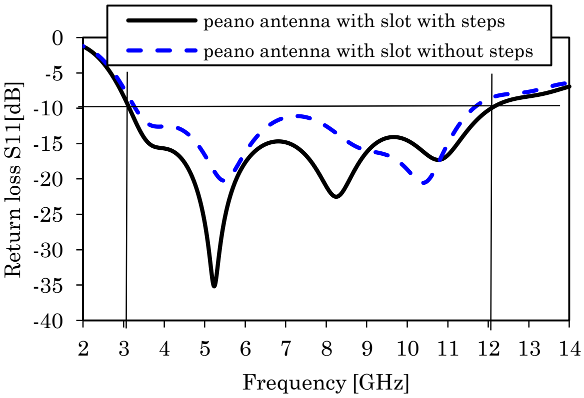
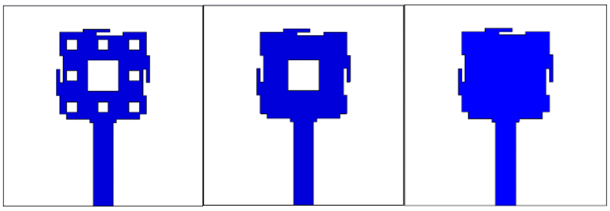


Fig. 7 – Effect of the impedance steps on the reflection coefficient S_{11} of the proposed Peano antenna with a slot in the ground plane



a b c

Fig. 8 – Giuseppe Peano and Sierpinski carpet antenna: Iteration 0 (a), Iteration 1 (b), Iteration 2 (c)

Therefore, the final configuration of the proposed antenna (Iteration 2) occupies about 9.1 GHz, relatively 118.95 %, covering the bandwidth ranging from 3.1 to 12.2 GHz compared to that of the basic antenna of 5.78 GHz extending from 3.34 to 9.12 GHz. The bandwidth has increased by approximately 63.51 %.

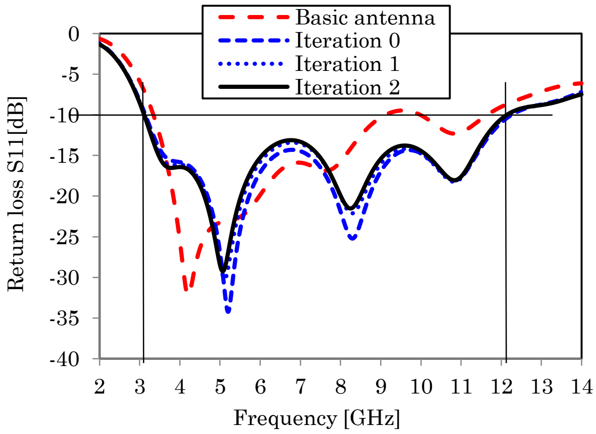


Fig. 9 – Reflection coefficient of the given iterations of the Giuseppe Peano and Sierpinski carpet antenna

3. RESULTS AND DISCUSSION

The proposed fractal UWB antenna prototype is fabricated with standardized technologies based on mechanical gravure using a LPKF ProtoMat Circuit Board Plotter. The input reflection coefficient of the fabricated prototype was measured using a vector network analyzer (Rohde & Schwarz R & S®ZNB20) (VNA) with a range of 100 KHz to 20 GHz. The comparison of the simulated and the measured return loss characteristics is illustrated in Fig. 10. It shows a very good accuracy between them. The little discrepancy may be due to manufacturing error and poor soldering effect. The measured and the simulated VSWR is plotted to prove that the antenna covers a wide bandwidth for VSWR < 2, as shown in Fig. 11. The simulated and the measured VSWR are in good agreement.

3.1 Radiation Patterns

The radiation patterns represent the relative intensity of the antenna in different radiation and reception directions. The co-polarization and cross-polarization far field radiation patterns of the proposed antenna in the *H*- and *E*-planes at 4.7, 8 and 10 GHz are shown in Fig. 12.

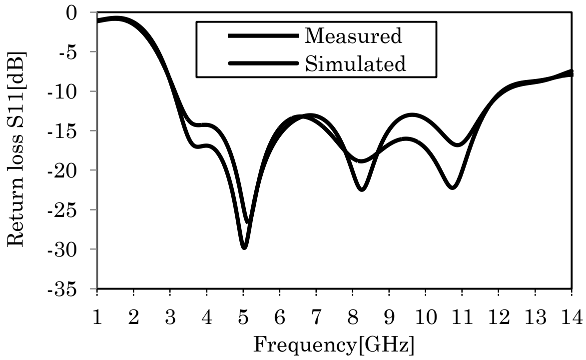


Fig. 10 – Measured and simulated return loss of the proposed antenna

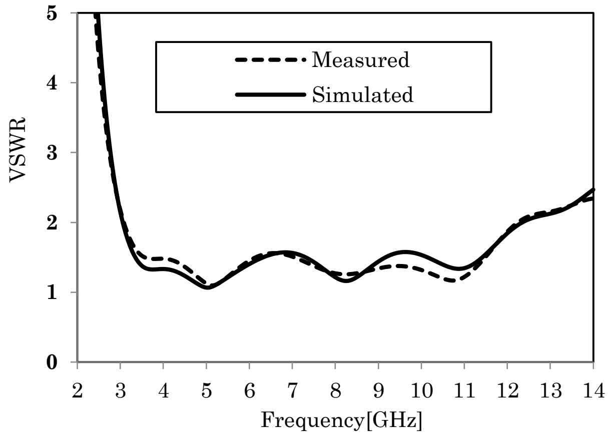


Fig. 11 – Measured and simulated VSWR of the proposed antenna

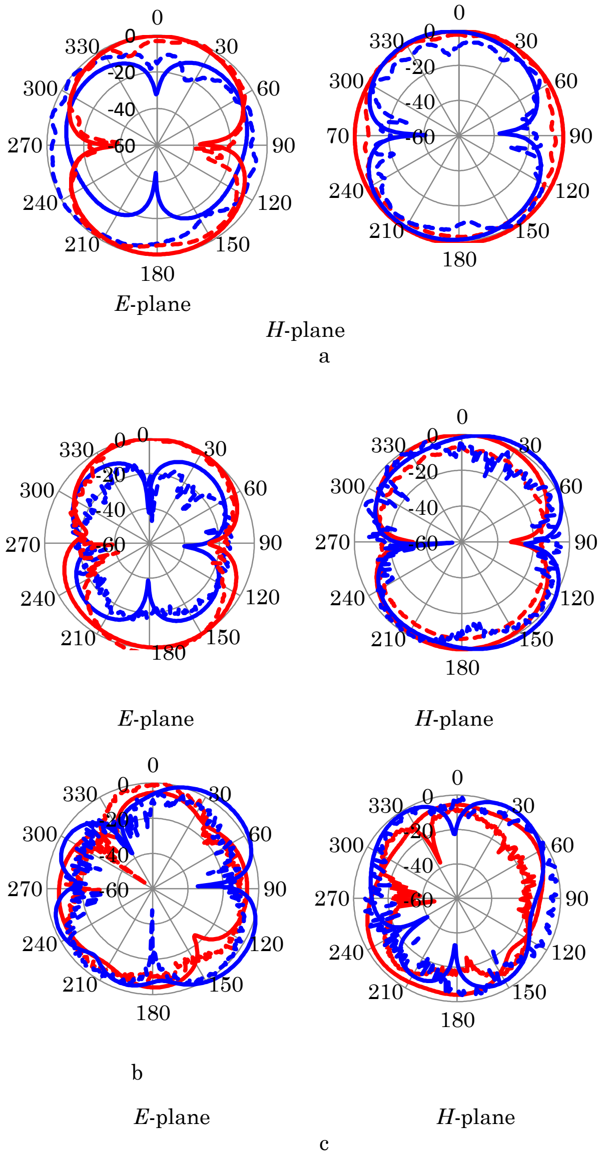


Fig. 12 – Simulated (solid line) and measured (dash line) far field radiation patterns in the *E*- and *H*-planes (red line indicates co-polarization and blue line indicates cross-polarization) of the proposed antenna at 5.1 GHz (a), 8 GHz (b), 10 GHz (c)

Table 1 – Description of the special paragraph styles

Ref.	Antenna size (mm × mm)	Bandwidth (GHz)	Bandwidth (%)	Peak gain (dB)	Efficiency (%)
[14]	34 × 43	[3.1-10.6]	120	5.5 dB at 10.6 GHz	–
[15]	41 × 50	[3-11.4]	116.66	5.27 dB at 10 GHz	–
[16]	45 × 45	[2.7-10.9]	120	7.5 dB at 10 GHz	95 % at 9 GHz
[17]	30 × 35	[6.75-11.69]	53.58	2.37 dBi	–
[18]	72 × 72	[1.27–4.67]	11.44	5.7 dB at 3.5 GHz	–
This work	30 × 30	[3.1-12.2]	118.95	5.2 dB at 12 GHz	85 % at 6.2 GHz

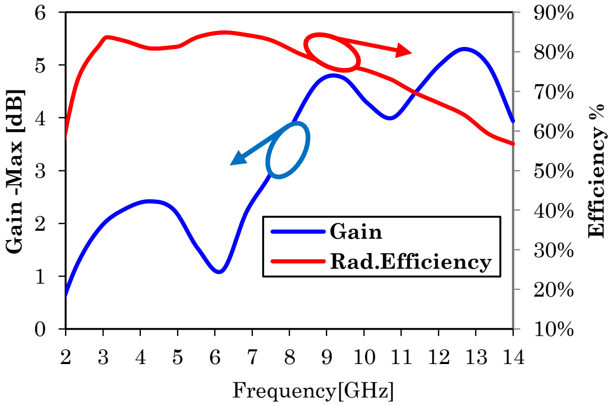


Fig. 13 – Simulated gain and radiation efficiency of the proposed antenna

The radiation characteristics of the antenna are measured in an anechoic chamber with broadband standard gain horn antennas.

In general, it can be noted that the proposed antenna exhibits an omnidirectional radiation with a great stability for low frequencies and a slight deterioration for high frequencies.

3.2 Gain and Efficiency

Fig. 13 presents the simulated results of the proposed UWB fractal antenna in terms of gain and radiation efficiency. In the lower frequency band (of the UWB range), the antenna gain varies from 1.1 to 2.41 dB, which is acceptable due to the very small antenna size. Thus, it is clear that the gain is higher at higher frequencies, as opposed to a lower frequency range. A gain of more than 2.41 dB is obtained and the peak is near 5.2 dB at 12 GHz. The radiation efficiency varies between 67 and 84.9 % in the UWB frequency range. In general, the results still show satisfactory agreement for the proposed antenna for UWB operation and satellite communications.

3.3 Comparison of the Proposed Antenna with Some Existing Similar Antennas

A comparative study of the proposed antenna with other planar antennas in terms of size, operation band, peak gain and efficiency is summarized in Table 2. The comparative result reveals that the proposed fractal antenna with a small size is a better device for UWB applications with a good gain and excellent efficiency.

4. CONCLUSIONS

In this paper, the combination of two fractal geometries – Giuseppe Peano and Sierpinski Carpet – is designed to achieve the miniaturized size of a printed monopole antenna. By using the steps on the square patch and a single slot on the partial ground plane, the width of the band is improved. The proposed antenna is numerically studied and optimized by CST Microwave Studio. The obtained results indicate that the miniaturized antenna demonstrates a stretched bandwidth from 3.1 to 12.2 GHz with a bandwidth improvement of approximately 63.51 % compared to the basic antenna. A prototype is fabricated and subjected to a series of measurements. Good agreement between simulation and measurement results is obtained. The proposed antenna has an omnidirectional radiation pattern, good gain, and high efficiency. In conclusion, all these characteristics make the proposed antenna suitable for UWB applications and satellite communications.

ACKNOWLEDGEMENTS

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Мініатюрна фрактальна антена з розширеною пропускною здатністю з використанням фракталів Джузеппе Пеано та килима Серпінського для UWB та супутникових додатків

O. Mahri[1], N. Guebgoub[1], M. Benslama[2], T.A. Denidni[3]

[1] *Laboratoire des Télécommunications, Université 8 Mai 1945, 24000-B.401 Guelma, Algérie*
[2] *Laboratoire LET, Université Frères Mentouri Constantine 1, 25000 Constantine, Algérie*
[3] *CEMT – INRS, 800 Rue De La Gauchetière Ouest, Bureau 6900 Québec, H5A 1K6, Canada*

У роботі нова мікросмужкова монопольна компактна антена розроблена з використанням двох фрактальних структур: Джузеппе Пеано і килима Серпінського для надширокосмугових (UWB) додатків та супутникового зв'язку. Вона складається з квадратного патчу з двома сходинками та прямокутної щілини на площині заземлення. Антена моделюється за допомогою мікросмужкової лінії живлення та діелектричної підкладки FR-4 з $\varepsilon_r = 4,3$ та $\tan\delta = 0.025$. Перша ітерація фракталу Джузеппе Пеано та дворівневі ітерації фракталів килима Серпінського були застосовані до патчу. Змодельовані результати, проведені CST Microwave Studio Simulator, показують розумне узгодження з результатами вимірювань. Діапазон частот, отриманий для $S_{11} < -10$ дБ, становить 3,1-12,2 ГГц або 118,95 % із розширенням смуги пропускання приблизно на 63,51 % порівняно з основною антеною. Сконструйована антена демонструє діаграми спрямованості в усіх напрямах та гарне підсилення по всьому діапазону з піком 5,2 дБ на частоті 12 ГГц, задовільну ефективність випромінювання, компактні розміри та простоту виготовлення, що дозволяє її широко застосовувати UWB та супутникового зв'язку.

Ключові слова: Фрактальна антена, Килим Серпінського, Джузеппе Пеано, UWB, Супутниковий зв'язок.