A New Compact Triple-Band Micro-strip Monopole Antenna Based on Minkowski Fractal Geometry

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Abstract

Wireless communication systems have reached significant advances in size reduction; however, antenna terminals still the main current challenge facing system compatibility. Thus, most industrial research is devoted toward antenna miniaturization in wireless systems. Therefore, a novel compact Triple-Band Fractal (TBF) antenna is suggested in this work using three coupling fractal patches with different iteration levels of Minkowski geometry to provide three resonant bands. The antenna substrate of a dielectric constant of 10.8 with a thickness of 1.27 mm is used in the antenna design inside CST Microwave studio environment. It is found that the zero iteration patch resonator is responsible for the upper band while the 2nd iteration resonator administered the lower band; therefore, this antenna is more flexible in tuning its band. The size of proposed antenna is 31×12 mm2 that shows more miniaturization in comparison to another published antenna designs in the literature.

Keywords: Microstrip antenna; Triple band antenna; Monopole antenna; Minkowski fractal geometry.

المستخلص

قد وصلت انظمة الاتصالات اللاسلكية الى مستويات متقدمة في صغر الحجم, و مع ذلك, تبقى حجم الهوائيات هي التحدي الكبير. نتيجة الى ذلك معظم البحوث متكرسة لتصغير حجم الهوائي في الانظمة اللاسلكية. لذلك هوائي شريحي جديد صغير الحجم احادي القطب ثلاثي الحزم قد اقترح في هذه الورقة باستخدام ثلاث بقع جزيئية مقترنة مع خط النقل, كل بقعة تكون بمستوى مختلف من التكرار لــ الشكل الهندسي منكويسكي للحصول على ثلاث حزم رنينية. ثابت العزل لوسادة الهوائي يساوي 10.8, علما ان سمك الوسادة يساوي 1.27ملم. هذه الوسادة استخدمت لتصميم الهوائي داخل برنامج الــ CST. و قد وجده بان المرنان مع مستوى تكرار صفري يكون هو المسؤل عن الحزمة العليا بينما المرنان مع مستوى التكرار الثاني هو المسؤل عن الحزمة السفلى و بذلك فان هذا الهوائي يكون مرن في ضبط التردد المركزي لجميع الحزم. حجم الهوائي المقترح هو 31×12 ملم2, و بذلك فان هذا الهوائي يكون صغير مقارنة ببقية الهوائيات المذكورة في المراجعة.

الكلمات المفتاحية: هوائي شريحي; هوائي ثلاثي الحزم; هوائي احادي القطب; الشكل الهندسي الجزيئي منكويسكي

Introduction

The design interest for multi-band microwave devices including antennas has been increased recently to satisfy multi applications of compact systems [Fuqiang, *et al.*, 2010].Therefore, the fields of design multiband antennas and filters were attacked through several publications as in [Sami, *et al.,* 2013]-[14].For example in [Fuqiang, *et al.,* 2010], a triple-band microstrip antenna for WLAN application was made up of two one-quarter wavelength resonators. Another rectangular tri-band patch antenna loading by slots and shorting pins was proposed [Sami, *et al.,* 2013]. For WLAN and wireless sensor applications, a triple band microstrip patch antenna based on U-slot reported in [Meena, *et al.,* 2015].E-shaped technique backed by E-shaped ground plane used to design triple band microstrip antenna [Deshmukh, *et al.*, 2016].However, antenna size reduction was considered one of the most challenges in any compacted systems. One of the suggested solutions is investigating meander and spiral lines as in [Ibrahim, *et al.,* 2012] and [Elwi, *et al.,* 2011] for size reductions.

Nevertheless, Vivaldi antennas of different geometries were introduced for multi-wideband applications [Azeez, *et al.,* 2016] and [Elwi, *et al.,* 2015]. Embedded patch antennas with metamaterial structures were developed in [Elwi, *et al.*, 2014] and [Elwi, *et al.*, 2014] for different frequency bands systems. Minkowski-Like and Peano fractal geometry, with different iteration levels and lengths, coupled to the feeding transmission line were suggested to design multi-band band stop filters [Ahmed, *et al.*, 2016]-[Ahmed, *et al.*, 2017].

In this paper, a novel compacted triple-band fractal antenna introduced by applying fractal geometry on coupled patches resonators.

The Proposed Triple-band Antenna Design

In the recent decade, many of researchers in different science fields applying the fractal geometries in their works to take its advantages. One famous of fractal geometry is Minkowski. The original Minkowski fractal geometry couldn't use in antenna design because the arms of it intersected. Therefore; the closed form to Minkowski has been using in a designing process, shown in Figure 1 and called Minkowski-Like pre-fractal geometry [Ali, 2008].

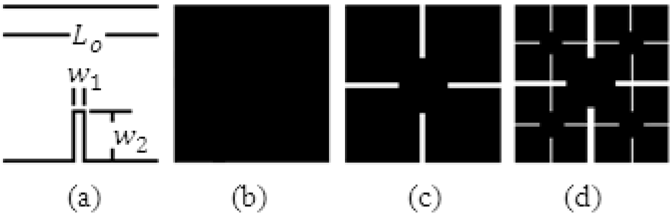
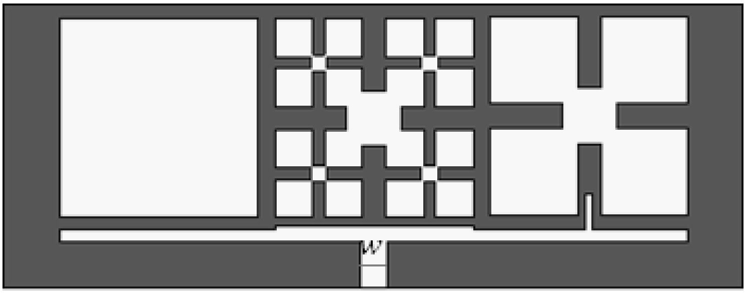


Figure 1: The steps of growth of Minkowski-Like fractal geometry: (a) the generator, (b) the square ring, (c) the 1st iteration, and (d) the 2nd iteration [Ali, 2008].

where L_o is siding length of the patch, while w_1 and w_2 are widths and deeps of the grooves that construct the Minkowski-Like, respectively. The ratio of w_2 and w_1 is equal to 1/3. Perimeters can calculate by using the following equation [Ahmed, *et al.*, 2016]:

$$P_n = \left(1 + 2\frac{w_2}{L_o}\right)P_{n-1} \tag{1}$$

The configuration of the proposed antenna consists of three coupled patches with different Minkowski-Like fractal geometry iterations, center open stub (COS) and right side open stub (RSOS) as shown in Figure 2.



(a)

(b)

Figure 2: The triple-band antenna configuration, (a) Top view, (b) Bottom view.

where w is the width of the transmission line feed. The substrate with dielectric constant 10.8 and thickness 1.27 mm has been used to design the suggested antenna. The feeding transmission line with the width equal to 1.15 mm used to match the antenna with input port 50Ω.All the patches have same dimensions (8.35×8.35) mm^2, but each one has different perimeter because distinct iteration levels applied on each one that have been calculate by equation 1. The different borders result in different current path lengths for patches, therefore; each patch is answerable for one band [Ahmed, *et al.*, 2016]. The 0thiteration patch results in an upper band while 2^{nd} iteration patch produces a lower band. The antenna configuration with only three patches doesn't have the suitable response, therefore; the COS and the RSOS have been installed to the structure to increase the coupling [Hong, J.-S., 2011]-[Choudhury, 2016], as shown in Figure 3, t and d are the dimensions of the open stubs. The dimensions of the COS are t = 0.1 mm and d = 8.35 mm, while dimensions of the RSOS are t = 0.3 mm and d = 1.5 mm.

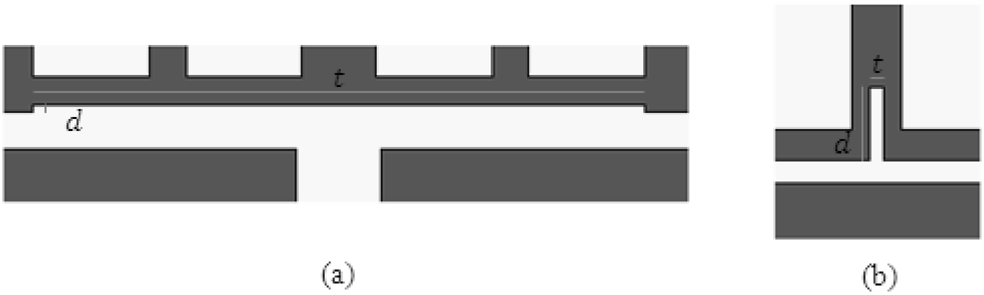


Figure 3: Zooming view of open stubs, (a) The center open stub, and (b) The right side open stub.

The Antenna Simulation Results

To inquiry the idea that explains in the design section, the suggested antenna structure has been implemented by using microwave studio in CST software package simulator. The scattering parameter, S_{11}, of the antenna is shown in Figure 4.

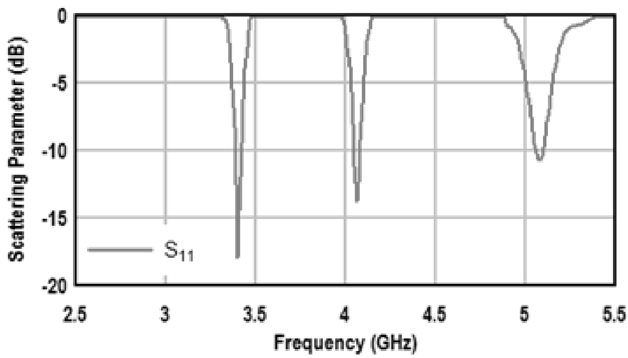


Figure 4: The Scattering parameter, S11, response of the proposed antenna.

The center bands of the triple-band antenna are at f_o = 3.5 GHz, f_1 = 4.05 GHz and f_2 = 5.00 GHz, as shown in Figure 4.

In terms of the corresponding guided wavelength λg, the side length of the ring resonators represent about 0.253 λ_g [Ahmed, *et al.,* 2016]:

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}} \quad \textbf{(2)}$$

where ε_{eff} is the effective dielectric constant that can be calculated by empirical expressions r. However, most of the commercially available EM simulators can perform a direct calculation of both λ_g and ε_{eff}, for given substrate parameters and the operating frequency. For the present case, λ_g has been found at the design frequency to be 33 mm.

Figure 5 shows radiation patterns (E-field and H-field) of the proposed antenna at 3.5 GHz, 4.05 GHz, and 5 GHz. The maximum radiation at 3.5 GHz, 4.05 GHz, and 5 GHz are at $\theta_o = 42^{\circ}$, $\theta_1 = 74^{\circ}$ and $\theta_2 = 75^{\circ}$ respectively.

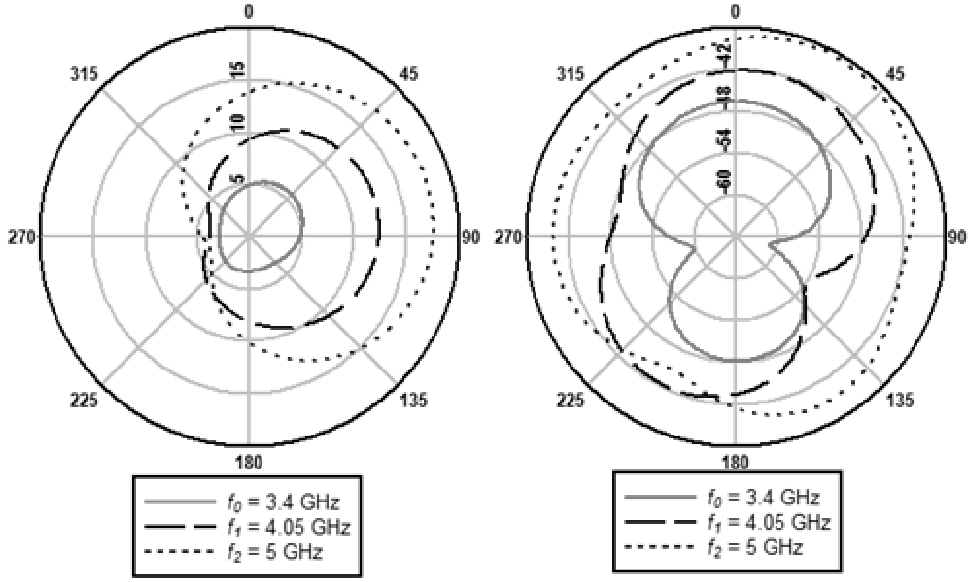


Figure 5: The simulated Antenna's radiation patterns, (a) E-filed, (b) H-filed.

The simulated gain of the suggested antenna is displayed in Figure 6. The gain of the antenna at the center of the third band (5 GHz) is above 0 dB, but the antenna gains at the centers of the first and the second bands (3.4 GHz and 4.05 GHz) are below 0 dB; gain enhancement at these bands has been required.

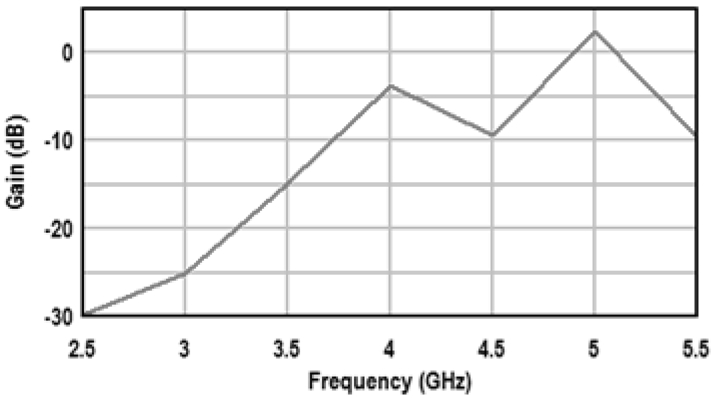


Figure 6: The simulated triple-band antenna gain.

To clear the size of the proposed antenna the comparison with other work has been done as shown in table 1.

Table 1 the comparison between the proposed antenna and other works.

Works	Band 1 (GHz)	Band 2 (GHz)	Band 3 (GHz)	Patch Size
[K. Fuqiang, et al., 2010]	2.4	5.2	5.8	$0.44\lambda_g \times 0.189\lambda_g$
[G. Sami, et al., 2013]	2.4	3.5	5.7	$0.399\lambda_g \times 0.542\lambda_g$
[D. Meena, et al., 2015]	5.59	6.1	6.8	$1.156\lambda_g \times 0.884\lambda_g$
[A. A. Deshmukh, et al., 2016]	0.896	1.43	1.71	$0.542\lambda_g \times 0.65\lambda_g$
Proposed work	3.4	4.05	5	$0.253\lambda_g \times 0.253\lambda_g$

Conclusion

A novel compacted triple-band fractal antenna is presented in this paper.The proposed structure consists of three square patches; each is modified by applying Minkowski-like fractal geometry with different iteration levels. Center Open Stub (COS) and Right Side Open Stub (RSOS).The patches are coupled using open stubs and to enhance the antenna response.To simulate the resulting antenna structure, a substrate with dielectric constant 10.8 and thickness 1.27 mm is used to implement the antenna.The proposed antenna can excite a triple band response within the swept frequency range. These bands are centered at f_o = 3.4 GHz, f_1 = 4.05 GHz and f_2 = 5.00 GHz. Each resonant band is attributed by a specified patch so that the tuning of a particular band is possible without affecting the other bands. However, it is planned to enhance the gain realized by each band because the gain at lower band is higher than those of the other two bands.

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