CPW Fractal Antenna with Third Iteration of Pentagonal Sierpinski Gasket Island for 3.5 GHz WiMAX and 5.2 GHz WLAN Applications

Original Scientific Paper

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Abstract *– Nowadays, the compact and multiband antennas are typically required for personal communication devices in the continuously developing wireless communication industry. The fractal antenna with the third iteration of the pentagonal Sierpinski gasket island for WiMAX and WLAN applications is presented in this work. It starts with the fundamental design of the square patch (Antenna A1) and pentagonal patch (Antenna A2). This simulation work is done using CST Microwave Studio simulation studio by applying the concept of the zero, first, second and third fractal iteration. Then, it goes on to use the fractal geometry concept of the Sierpinski gasket island structure with three designs step. The designs consist of the first iteration (Antenna B1), second iteration (Antenna B2) and third iteration (Antenna B3) of fractal geometry. The simulation work of Antenna B3 is compared with the fabrication work of the same design. After that, the measurement of the Antenna B3 is done in laboratory with - 29.55 dB at 3.41 GHz and - 20.40 dB at 5.28 GHz for its operating frequencies with bandwidth of 3.52 GHz and 5.48 GHz, respectively. At targeting 3.5 GHz WiMAX, 5.2 GHz WLAN application and 7.24 GHz of Antenna B3, the antenna shows the – 17.78 dB, - 29.63 dB and – 22.73 dB, respectively, and this value is feasible for WiMAX and WLAN operation.*

Keywords*: Fractal Geometries, Patch Antenna, Sierpinski Gasket, Co-Planar Waveguide, Return Loss*

1. INTRODUCTION

In the rapidly expanding wireless communication world, compact and multiband antennas are typically needed for personal communication devices. To fulfill the enormous demand for contemporary wireless applications, multiband, miniaturized microstrip patch antennas are needed [1]. Due to its appealing qualities, including its straightforward design, low profile, high efficiency, affordable manufacturing, and acceptable radiation properties, planar monopole antennas with various configurations are regarded as the most common in this field [2].

The fractal geometry is a useful technique for building multi-band and low-profile antennas to reduce the interference caused by the presence of other adjacent communication systems [3].

The fundamental resonant mode in the microwave and millimetre frequency ranges is demonstrated by fractal geometry structures (FGS), whose geometrical structures influence the resonant frequency [4]. These requirements can be met by using fractals in the antenna design. For example, a Hayder-Koch fractal geometry structure is applied [5]. Besides that, a frequency-selective surface also used the same concept to improve its performance by adding this fractal geometry design. For example, it uses using Koch fractal hexagonal loop [6]. Therefore, this is utilized to calculate the multiband frequency of the antenna effect and is made up of several variations of a single fundamental form.

It has been demonstrated that fractal geometry is helpful in several fields. Fractal geometry is useful for designing tiny, multiband antenna arrays, and high-directive components in the field of antenna engineering. The fractal dimension, a complexity measure developed by Mandelbrot and based on his 1967 work on fractional dimensions, serves as the primary description of fractal sets [7]. Based on basic mathematical shapes, fractal structures can be divided into two categories. Firstly, it is a deterministic fractal structure with examples of the Sierpinski gasket [8-9], fern fractal [10], von-Koch snowflakes [11], and Minkowski [12]. Then, the creation of random fractal structures is random by natural phenomena such as dendrites and lightning bolts.

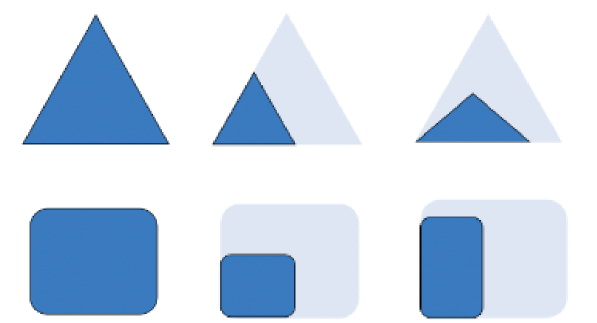
The self-similar structure of the fractal antenna was created by iterative design. Repeating the iteration endlessly results in a shape with a finite length but an infinite area within a limited border. Several studies have described novel fractal designs that provide a variety of geometry for lowering compact magnitudes, enlarging antennas, and maintaining the same radiating properties over the bandwidth [13].

Sets known as fractals display a repeating pattern at various scales. Table 1 shows an example of the similarity and not similarity of the first iteration from the zero iteration stage. Contraction decreases shapes, and it's possible that the shrinking is more significant in one direction than another, according to the inequality in the definition of a contraction [14].

The fractal antenna's subsequent phases are generated by the seed antenna. The initial frequency of the Sierpinski antenna is determined by the seed antenna's size. The development of the fractal is determined by the desired number of bands [15].

Table 1. Example of the similarity and not similarity of the first iteration from the zero iteration stage

Zero iteration	First iteration	
	Apply a similarity	Not apply a similarity



Fractal geometry structures have some benefits, including small size, improved input impedance, wideband/multiband support for numerous applications, consistent performance over a broad frequency range, and—not least—the ability to add inductance and capacitance without the need for additional components. Furthermore, low-side lobes arrays, under-sampled arrays, and high-directivity elements can be made using mass fractals and boundary fractals [16].

Waclaw Sierpinski discovered the Sierpinski fractal geometry in 1915, and Sierpinski gaskets have been thoroughly studied for monopole and dipole antenna layouts. Over the last two decades, researchers have investigated a variety of fractal geometries. However, since its introduction in 1998 by Puente-Baliarda, the Sierpinski gasket fractal antenna geometry has been studied more than any other geometry [17].

There is several research on the Sierpinski gasket fractal antenna have been done. Kaur [18] introduces a complementary Sierpinski gasket fractal antenna array for wireless MIMO portable devices with 8.2 % bandwidth at the center frequency of 4.94 GHz (4.74 GHz - 5.15 GHz. In another work, Ramli [19] designed a Sierpinski Gasket Fractal Antenna (SGFA) with slits for multiband applications at 2.4 GHz and 5.0 GHz [19]. In other work, Chaouche had been introduced a modified Sierpinski gasket fractal antenna for tri-band applications with a bandwidth range between 1.6 GHz to 2.05 GHz, 4.88 GHz to 6.13 GHz, and 9.86 GHz to 10.34 GHz [20]. Other works also are shown to use the Sierpinski gasket fractal in their antenna design [21-23].

The fractal antenna is designed in this work with the third iteration of the pentagonal Sierpinski gasket island for 3.5 GHz WiMAX and 5.2 GHz WLAN applications. CST Microwave Studio is the simulation software used for this experiment to define the wanted design. Then, the fabricating work of the same design is contrasted with the simulation work of the suggested antenna. The proposed antenna is then measured in a laboratory for return loss, resonance frequency, and gain.

2. ANTENNA DESIGN

The antenna is designed to step by step, starting with the basic design antenna patch. Antenna A, which has a design of a basic patch of rectangular shape (Antenna $A1$) and pentagonal shape (Antenna $A2$), had been done. Then it moves to the next design of Antenna B, consisting of three different sub-shaped iterations – Antenna $B1$, Antenna $B2$ and Antenna $B3$.

2.1. SIERPINSKI GASKET FRACTAL ITERATION CONCEPT

In this work, the Sierpinski gasket fractal is designed in the iteration stage. It starts with the zero iteration concept designed in a pentagonal shape. Then, it goes to the first iteration fractal with a Sierpinski gasket island shape. Fig. 1 represents the Sierpinski gasket fractal iteration concept from zero to the third iteration stage.

(a) (b) (c) (d)

Fig. 1. Sierpinski gasket fractal iteration concept, (a) zero iteration, (b) first iteration, (c) second iteration, (d) third iteration

Next, a similar shape with a reduced size of the Sierpinski gasket island shape is added to become a second iteration fractal. Lastly, the step is repeated with a third iteration fractal step consisting of three Sierpinski gasket islands of different sizes.

2.2. ANTENNA A

The first part of the design is the Antenna *A1*, which is made of copper that is 0.035 mm thick and is mounted on an FR4 substrate that is 1.6 mm thick and has a dielectric constant of 4.3. It has a substrate, a co-planar waveguide (CPW) structure, a patch with a pentagonal shape, and a feeding line that connects to the antenna source (waveguide). This rectangular patch is the basic structure design, then it follows as the pentagonal patch structure design.

It shows that Antenna *A1* measured 22.0 mm in width and 22.0 mm in length, respectively. While the other design of Antenna *A2* has a dimension of 25.2 mm width and 25.1 mm length. Besides that, the width of a pentagonal island line is 1.26 mm The fundamental square and pentagonal antenna structure of Antenna *A1* and Antenna *A2* is shown in Fig. 2.

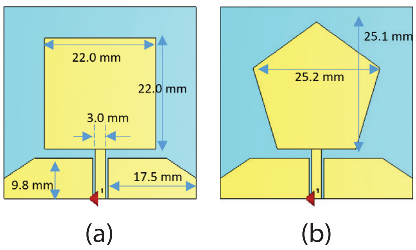


Fig. 2. Basic antenna design with CPW of Antenna *A*, (a) Antenna *A1* – square (b) Antenna *A2* – pentagonal

2.3. ANTENNA B

Then, it goes to the second part of Antenna *B*, which applies the fractal concept. It follows with Antenna *B1*, Antenna *B2* and Antenna *B3* with the first iteration, second iteration and third iteration step of the Sierpinski Gasket Island fractal. Fig. 3 shows the proposed design with CPW of Antenna *B*. Each iteration had an addition of a similar shape but with reduced dimension sizes of pentagonal island ring-shaped from one, two and three depending on the iteration number steps.

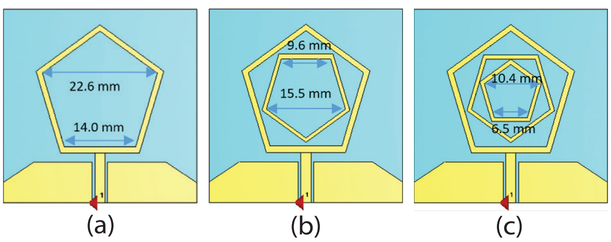


Fig. 3. Proposed design with CPW of Antenna *B*, (a) Antenna *B1* – first iteration, (b) Antenna *B2* - second iteration, (c) Antenna *B3* – the third iteration

3. RESULTS

The desired effect performance result of the microstrip patch antenna design with fractal geometric structure is supported by several notable findings. The key conclusions are bandwidth in GHz, return loss in GHz (dB versus frequency), antenna gain in GHz (dB versus frequency), and antenna radiation pattern. For resonance frequency, this antenna must transmit and receive at least 90 % of the signal. Besides that, the antenna's suitable result for antenna gain must be greater than 1 dB.

Antenna A1 performance result is shown in Fig. 4. It shows the return loss at the first resonant frequency point of 3.35 GHz with – 12.45 dB, and it was found that this antenna's gain and bandwidth range performance were 2.00 dB and 2.96 GHz – 3.73 GHz, respectively. It goes to the second stage of Antenna *A2* at two different resonant frequencies of 3.52 GHz and 5.99 GHz with – 20.69 dB and – 24.77 dB of return loss. The antenna's gain shows are 5.04 dB. Besides that, the bandwidth of 1.61 GHz and 2.69 GHz for the first and second resonant frequencies of Antenna *A2*. Table 2 represents the performance results of Antenna *A1* and *A2*.

Table 2. Performance results of Antenna *A*

Ant	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (GHz), f_{High} - f_{Low} (GHz)	Gain (dB)
A1	3.35	- 12.45	0.77, 2.96 – 3.73	2.00
A2	3.52	- 20.69	1.61, 2.66 – 4.27	2.18
	5.99	- 24.77	2.69, 4.97 – 7.66	5.04

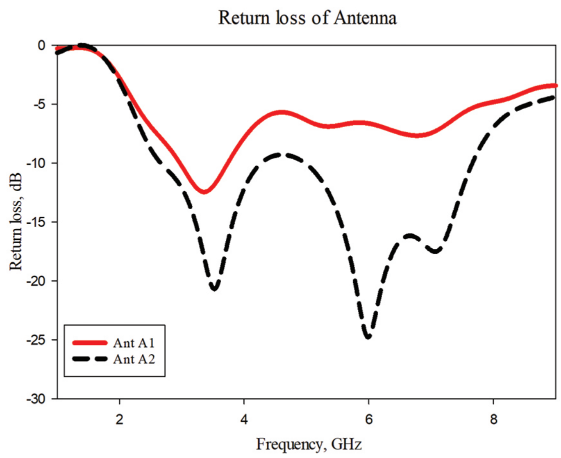


Fig. 4. Return loss of basic antenna design with CPW of Antenna *A*, (a) Antenna *A1* - rectangular, (b) Antenna *A2* – pentagonal

Fig. 5 and also Table 3 represent the performance results of Antenna *B*. It shows performance between several antennas of *B1*, *B2*, and *B3* with the first, second and iteration structure of the Sierpinski gasket fractal. Antenna *B1* effects of operating at two resonant frequencies of 2.34 GHz and 5.45 GHz with a return loss of – 12.28 dB and – 20.59 dB. It shows the bandwidth of 0.38 GHz and

1.92 GHz for the first and second resonant frequencies. Next, it goes to the Antenna *B2*, which operates at two different resonant frequencies of 2.26 GHz and 5.23 GHz with a return loss of - 11.15 dB and - 30.79 dB, respectively. It displays the 0.16 GHz and 0.79 GHz bandwidths for the first and second resonant frequencies, respectively.

The last stage shows the Antenna *B3* with three locations of the resonant frequencies at 3.46 GHz, 5.19 GHz, and 7.24 GHz with return loss shown as - 23.43 dB, - 30.27 dB and - 22.72 dB, respectively.

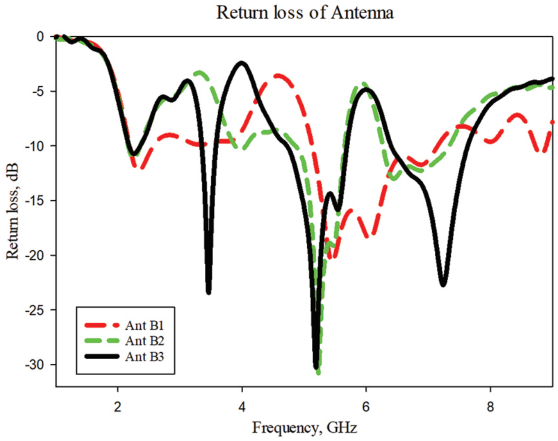


Fig. 5. Return loss of proposed design with CPW of Antenna *B*

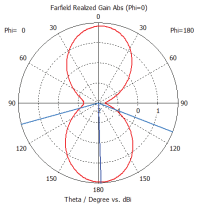
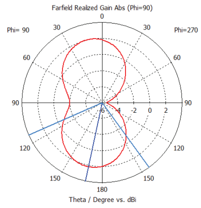
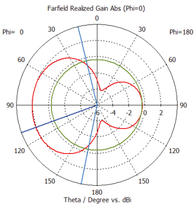
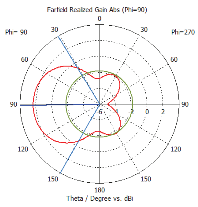
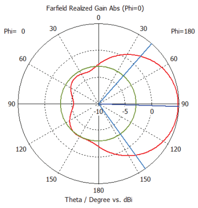
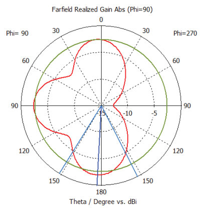
Table 3. Several performance results of Antenna *B*

Ant	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (GHz), f_{High} - f_{Low} (GHz)	Gain (dB)
B1	2.34	- 12.28	0.38, 2.19 – 2.57	1.72
	5.45	- 20.59	1.92, 5.23 – 7.15	2.76
B2	2.26	- 11.15	0.16, 2.16 – 2.32	1.50
	5.23	- 30.79	0.79, 4.86 – 5.65	3.31
B3	3.46	- 23.43	0.23, 3.35 – 3.58	2.04
	5.19	- 30.27	0.06, 4.72 – 5.68	4.05
	7.24	- 22.72	1.24, 6.40 – 7.64	5.06

Table 4 shows that phi = 0° and phi = 90° display the radiation pattern of the microstrip patch antenna from Antenna *B3*, where the radiation pattern symbolizes the distribution of electromagnetic power in free space. At phi = 0° and phi = 90° of 3.5 GHz, it displays an eight-shaped pattern for the first resonant frequency, with some lobes facing forward in the 00 direction and others facing toward the 180° direction.

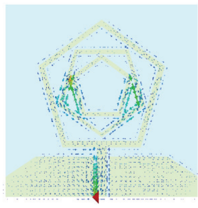
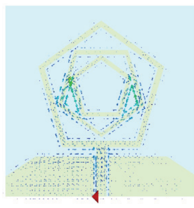
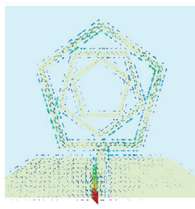
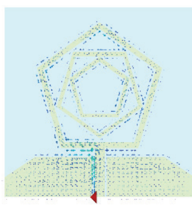
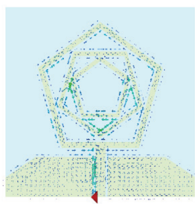
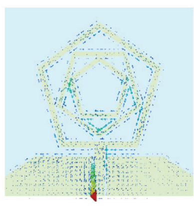
For 5.2 GHz, it shows the right direction major lobes and left path minor lobes are visible. In contrast to phi = 90°, it shows nearly the same as 0°. The right direction main lobes and left path minor lobes are evident for 7.24 GHz of phi = 0°. On the other hand, the phi = 90° shows three locations of lobes at 0°, 90° and 180°.

Table 4. Performance results of the radiation pattern of Antenna B3

GHz	Phi = 0°	Phi = 90°
3.5		
5.2		
7.24		

Then, it goes to Table 5 of surface current for the Antenna B3 at three different resonant frequencies at phi = 0° and phi = 90°. The observation shows that the 3.5 GHz is more concentrated at the second ring, 5.2 GHz at the first ring and the 7.24 GHz effect at the third ring.

Table 5. Surface Current of the Antenna B3

GHz	0°	90°
3.5		
5.2		
7.24		

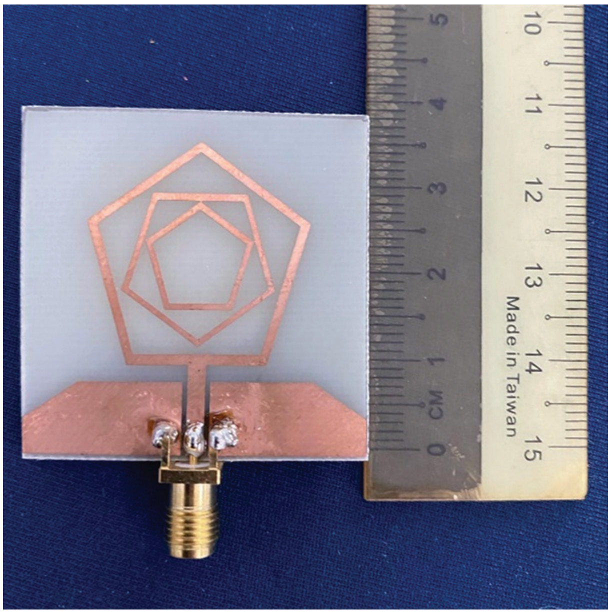


Fig. 6. Fabricated Antenna *B3*

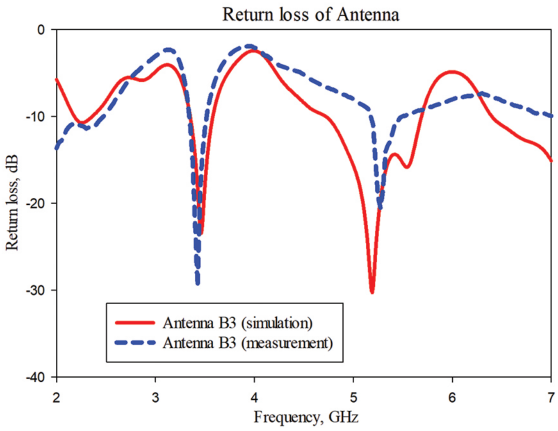


Fig. 7. Return loss of proposed design with CPW of Antenna *B3* (simulation and measurement)

Table 6. Several performance results of Antenna *B3* (simulation and measurement)

Ant	Resonant frequency, f_r (GHz)	Return loss (dB)	Bandwidth (GHz), f_{High} - f_{Low} (GHz)	Gain (dB)
B3 sim	3.46	- 23.43	0.23, 3.35 –3.58	2.04
	5.19	- 30.27	0.06, 4.72 –5.68	4.05
B3 meas	3.41	- 29.55	0.16, 3.36 –3.52	1.98
	5.28	- 20.40	0.31, 5.17 –5.48	3.89

4. CONCLUSION

This work presents various pentagonal microstrip patch antenna designs with several advancement techniques of fractal iteration. Antenna *A1* and *A2* are the first and second basic square and pentagonal patch antenna shapes. Then the Sierpinski gasket island fractal structure's first, second and third iterations are applied into three parts of Antenna *B1*, Antenna *B2* and Antenna *B3*. As a result of the antenna's designs, the performance of the return loss, gain, and the first, second and third Sierspinski gasket iterations impacted the radiation pattern. For measurement performance, it indicates that - 29.55 dB at 3.41 GHz and - 20.40 dB at 5.28 GHz for its operating frequencies with bandwidth of 3.52 GHz and 5.48 GHz, respectively. The Antenna B3 shows - 17.78 dB and - 29.63 dB in the targeted applications of 3.5 GHz WiMAX and 5.2 GHz WLAN, respectively. The Antenna B3 exhibits - 17.78 dB, - 29.63 dB, and - 22.73 dB for 3.5 GHz WiMAX, 5.2 GHz WLAN application, and 7.24 GHz, respectively. These values are practical for WiMAX and WLAN operation that can be apply to the future research with other types of novelty fractal antenna design. This antenna also can be applied to the complete communication system.

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