Progress In Electromagnetics Research C, Vol. 61, 139–147, 2016

A Compact Wideband Fractal-Based Planar Antenna with Meandered Transmission Line for L-Band Applications

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Abstract—In this paper, a development of compact wideband antenna for L-Band Applications is presented. The proposed antenna is developed based on Modified Sierpinski Based Fractal geometry for the antenna patch with additional meandered structure in the antenna transmission line. The designed antenna is printed on a 10×10 cm of substrate with a relative permittivity of 4.3 and thickness of 1.6 mm. The antenna is fed by a $50\,\Omega$ microstrip line. The proposed antenna is characterized both in numerical and experimental analysis. The antenna characteristics are analyzed in terms of return loss, bandwidth, antenna gain, radiation pattern and radiation efficiency. From the experimental analysis, the fabricated antenna exhibits reasonable agreement to numerical design. The proposed antenna has an operating frequency from 0.94 GHz to 2.25 GHz with the lowest return loss of -36 dB and maximum gain around 5.49 dBi, as well as radiation efficiency of 97%, approximately.

1. INTRODUCTION

In recent years, many researchers pay great attention to the development of wideband telecommunication technology operating at L-band frequency spectrum, such as radar tracking, mobile satellite, terrestrial technology, personal communications systems [1–3], medical diagnostic systems [4] and remote sensing [5]. This great attention to L-band technology occurs due to the resistance to rain attenuation while other technologies operating above frequency spectrum of L-band are suffered by rain.

Additionally, due to a mobility behavior of the service users at L-band technology, there has been great demand for the development of compact devices. Consequently, development of a compact antenna with wideband operating frequency and high gain is indispensable. Microstrip antennas become an alternative for such applications, as they have all of the aforementioned properties, along with low-cost fabrication.

In order to satisfy those requirements, there exist numerous antenna designs proposed for L-Band applications in the literatures. One of the well-known antenna designs to miniaturize antenna dimension and widen the operating frequency is slotted antenna [5–12]. In [6], Karmakar and Bialkowski proposed a slotted antenna with coupled aperture to obtain circular polarization operating at a frequency of 1.545 GHz to 1.661 GHz. However, this antenna employed multi-layering substrate which can increase a complexity in implementation, while the antenna operating frequency is not fully covered L-Band spectrum. An inverted-F antenna with U-shaped slot is also proposed by Sahu and Jyoti in [7] to achieve wideband frequency. The achieved gain of this proposed antenna is still low. In [9], Mobashsher and Abbosh proposed a three-dimensional folded dipole antenna with a slot-loaded to achieve wide fractional bandwidth and unidirectional radiation. Even though they can cover all of the frequency range at L-band, fabrication process of the proposed antennas has a potential drawback of complex implementation. An attempt to achieve high antenna gain is proposed in [10] by employing an array

Received 23 October 2015, Accepted 5 January 2016, Scheduled 14 January 2016
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antenna Coplanar-Waveguide (CPW) feeding slot. CPW-fed slot is used due to its simple integration with monolithic microwave integrated circuit (MMIC). By using this technique, the bandwidth can achieve up to 18% at the center frequency. However, the antenna dimension does not comply with the requirement of light-weight antenna.

Another technique to widen the operating bandwidth uses multi-resonance frequencies within -10 dB impedance bandwidth. This technique uses fractal geometry implemented to the antenna design. The main characteristic of fractal geometry is self-similarity shape when it is observed at a different scale. This property may produce multiband resonance frequencies. There are several fractal geometries in the literature, such as Sierpinski Gasket, Sierpinski Carpet, Hilbert Curve and Koch Snowflake [13]. Besides achieving multiband resonance frequencies, there are several advantages of this geometrical antenna design, such as high gain and wideband frequency band [14]. Conventional fractal antenna employs huge ground plane perpendicularly connected to radiation part of fractal antenna [14]. However, the installation of this design is not simple. Furthermore, in order to simplify the fractal antenna design, many researchers proposed a planar fractal antenna printed on microstrip material [15–19]. In [15], Hwang proposed a modified Sierpinski fractal antenna to reduce the antenna dimension and to achieve multiband frequency resonance. However, the operating frequency of the proposed antenna is still narrow with a bandwidth of 200 MHz for L-band spectrum. Coplanar-Waveguide (CPW) feeding line is proposed to be combined with Sierpinski based fractal antenna to obtain wideband and compact antenna [17–19]. However, the achievable gains of those proposed antenna designs are still low.

In this paper, a compact wideband antenna for telecommunication services operating at L-band is proposed. The proposed antenna is designed by exploiting the advantages of fractal geometry and meandered transmission line to develop wideband antenna with light-weight antenna dimension. By using meandered transmission line, the antenna design has not only a low-profile property, but also simple implementation on MMIC [20, 21]. The designed antenna will be implemented on a substrate with relative permittivity of 4.3.

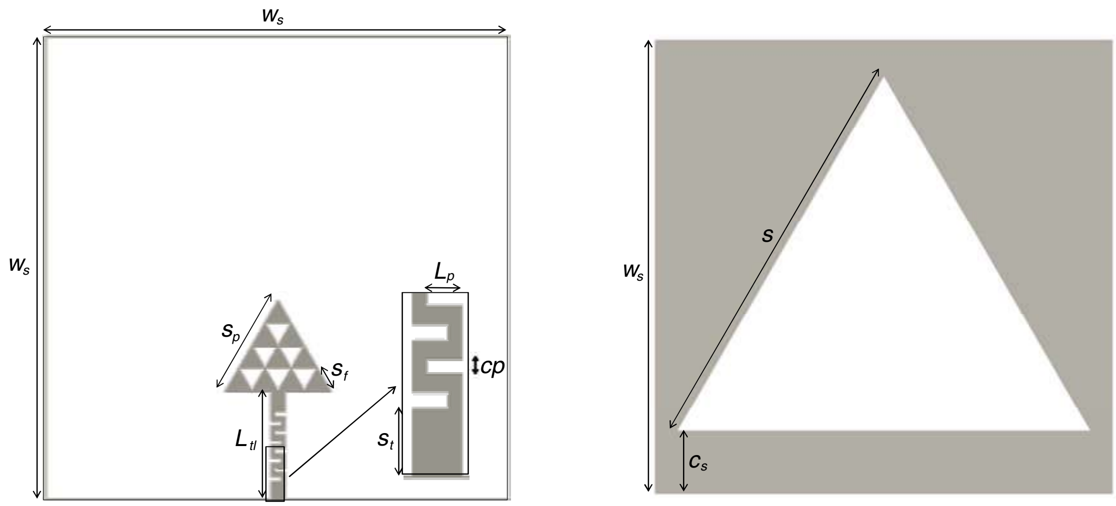
The rest contents of this paper are organized as follows. Section 2 describes structure configuration of the proposed antenna. The numerical and experimental investigations are described in Section 3 and Section 4, respectively. This paper ends with the conclusion in Section 5.

2. THE PROPOSED ANTENNA CONFIGURATION

This paper presents a development of compact antenna with the intended frequency operating at L-band spectrum. This antenna is developed by employing the advantages of fractal geometry and meandered-line to obtain wider -10 dB impedance bandwidth and lightweight antenna dimension, respectively. The proposed antenna is printed on both sides of an FR4 epoxy which has a relative permittivity of 4.3 and substrate thickness of 1.6 mm. The substrate of FR4 epoxy is chosen due to its inexpensive cost and availability in the local market.

The geometrical structure of the proposed antenna and its dimensions are shown in Figure 1. The overall dimension of the proposed antenna occupies 100 mm × 100 mm of substrate area. The antenna structure consists of two-stage iterative fractal geometry which is connected to modified transmission line with meandered-line. These structures are implemented on the top side of the antenna. Whilst, on the bottom side of the antenna, triangular slot is printed acting as a ground plane. The antenna is fed by 50 Ω microstrip line.

The fractal geometry chosen in this antenna is modified Sierpinski gaskets. Sierpinski geometry is derived from Pascal's triangle by deleting the grid nodes that are exactly divisible by certain prime number, p. An equilateral triangle with a length s_p of 22.5 mm is taken as a base to construct fractal geometry. This Sierpinski geometry shows favorable characteristics of radiation in terms of resonance, impedance, and directivity. Due to its self-similarity characteristic of the fractal geometry, -10 dB impedance bandwidth can be achieved. The transmission line which feeds the triangular fractal patch has a length l_{tl} of 18.75 mm. The meandered-line slot is also loaded to the transmission line in order to reduce the patch dimension [20, 21]. The meander-line has 6 fingers with finger space c_p of 1 mm and finger length l_p of 2.1375 mm.



(a) (b)

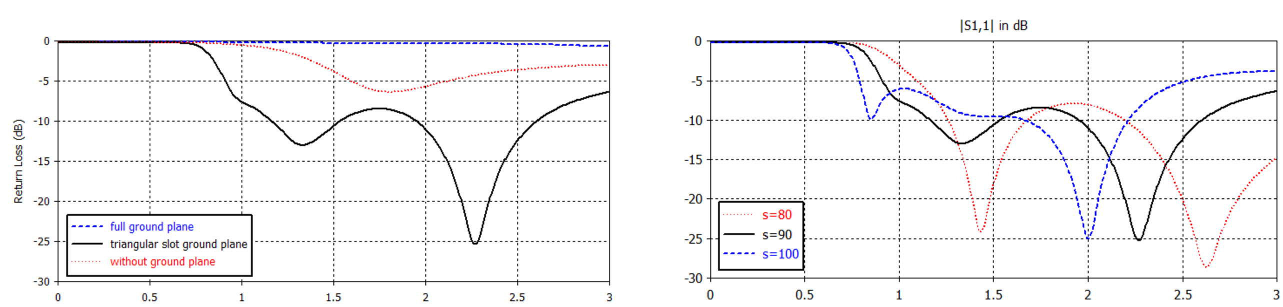
Figure 1. Geometry of the proposed antenna (a) top side and (b) bottom side.

3. NUMERICAL ANALYSIS

After designing the structure of the proposed antenna, numerical analysis is conducted by using an Electromagnetic CAD Software to achieve the best characteristic of the designed antenna. The characteristics of the proposed antenna are first numerically investigated in terms of return loss, bandwidth, radiation pattern, as well as antenna gain and radiation efficiency.

The best characteristic of the proposed antenna is obtained by investigating the effect of antenna dimension changes to the antenna characteristic through several parametrical analyses with different values of each antenna dimension. The results of these numerical analyses are shown in Figure 2 to Figure 4. Figure 2 shows the influence of ground plane on the designed antenna. There exists a great difference to the antenna characteristic in terms of return loss when using ground plane. Besides that, the resonant frequency will shift to the higher frequency band when the dimension of triangular slot ground plane is reduced. This might result in a larger radiating surface proportional to the operating frequency of the antenna.

Moreover, the effects of Sierpinski based triangular fractal and meander line structures on the antenna characteristic are depicted in Figure 3 and Figure 4, respectively. From Figure 3, it can be affirmed that there is a bit different antenna characteristic in terms of return loss at the higher frequency band by changing the iterative stage of fractal structure. Whilst, there are many influences



(a) (b)

Figure 2. Effect of ground plane in terms of (a) ground plane shape and (b) ground plane size.

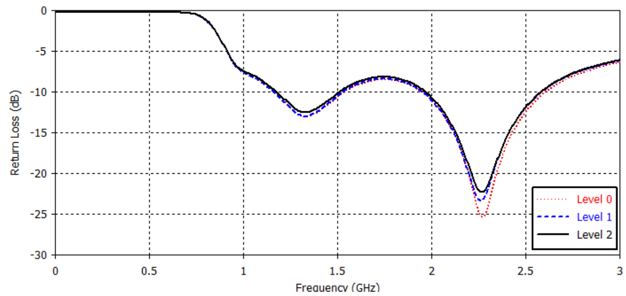


Figure 3. Effect of fractal iteration.

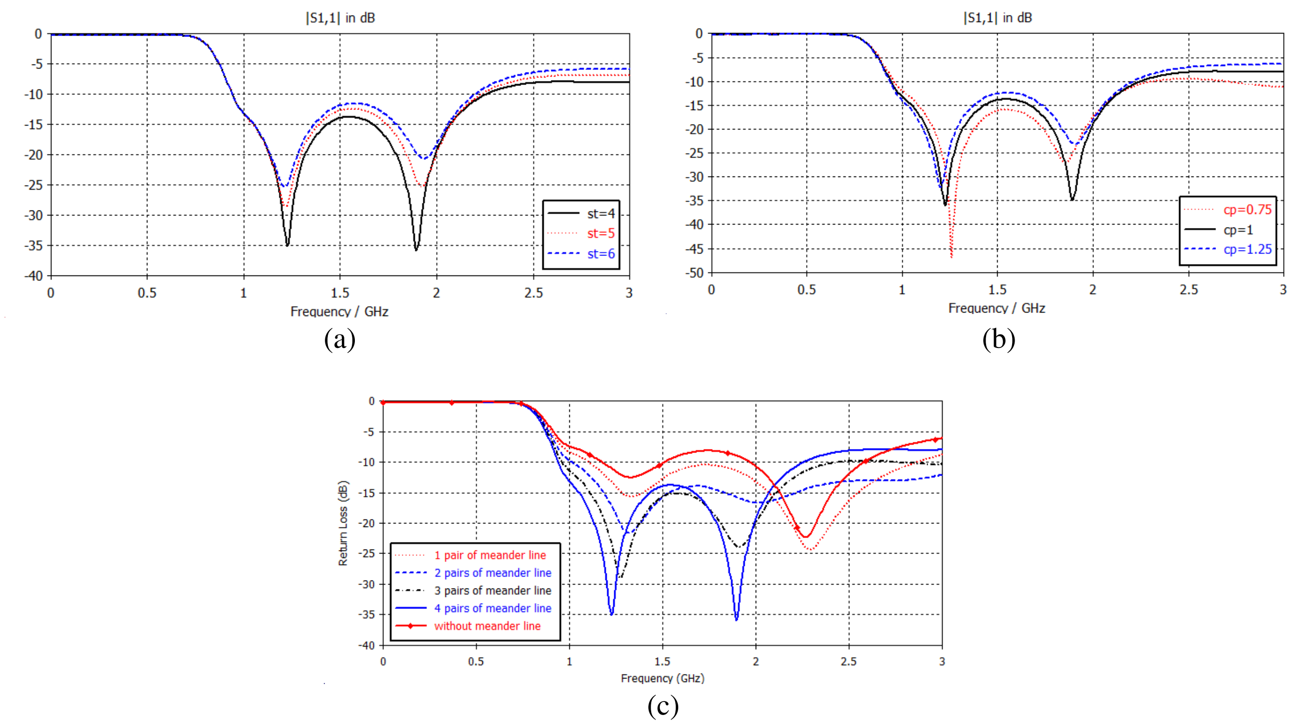


Figure 4. Effect of meander-line (a) position, (b) finger space and (c) number of fingers.

of the meander line structure on the antenna characteristic, both in return loss and operating frequency bandwidth, as depicted in Figure 4. By reducing the meander line position from the connector, the return loss value of the proposed antenna becomes better than the large position (see Figure 4(a)). Meanwhile, the return loss of the proposed antenna is also affected by the changes of the space between fingers (see Figure 4(a)). However, from Figure 4(c), we can see that many different characteristics both in terms of return loss and operating frequency bandwidth occur when the number of meander-line fingers is changed. When the number of meander line fingers is increased, the antenna return loss becomes smaller, and the operating frequency bandwidth becomes wider. Besides that, by changing the number of meander-line fingers, the operating frequency of the designed antenna is also shifted to the higher band.

Based on the aforementioned parametrical analysis, the final characteristic of the proposed antenna can be obtained. In order to obtain the antenna characteristic in terms of resonant frequency and bandwidth, the return loss parameter of the proposed antenna is numerically analyzed by observing the area below -10 dB of return loss. Figure 5 presents the bandwidth of the designed antenna which can operate from the frequency of 0.93996–2.2451 GHz (bandwidth of 1.3 GHz) with the lowest return loss about -36 dB,.

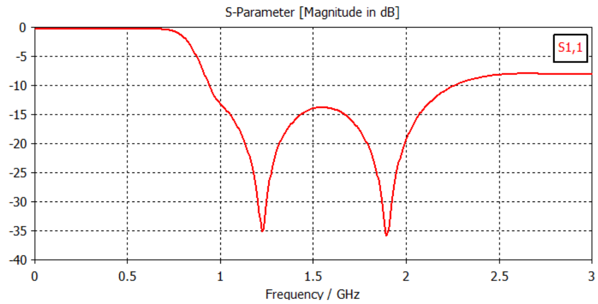


Figure 5. Return loss of the proposed antenna.

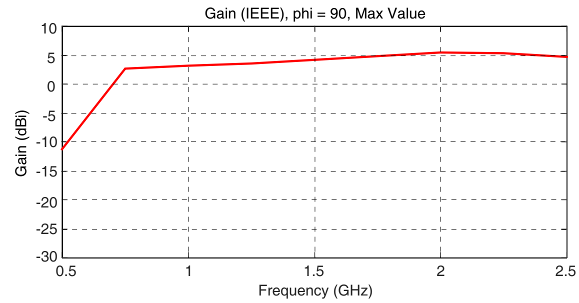
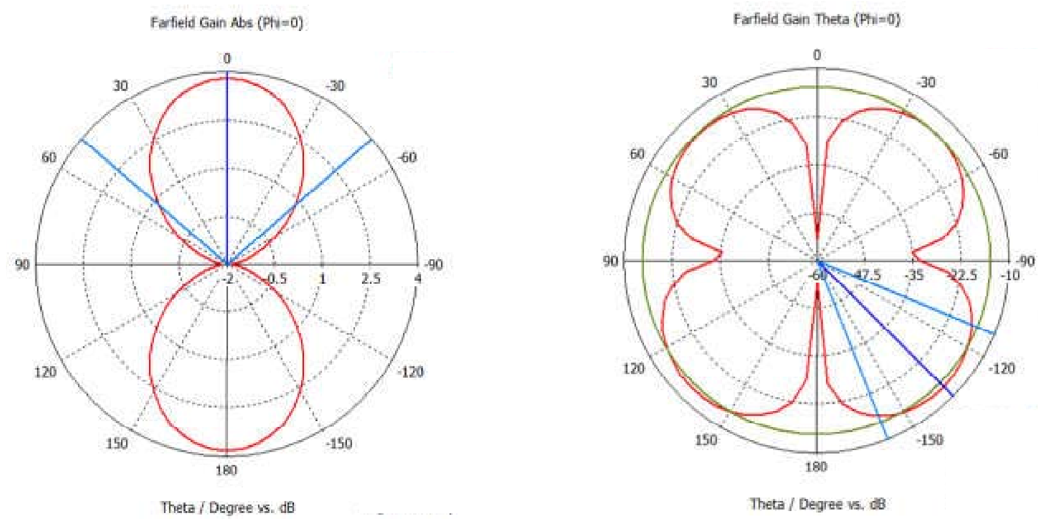


Figure 6. Gain of the proposed antenna.



(a) (b)

Figure 7. Radiation pattern of the proposed antenna (a) E-plane and (b) H-plane.

Beside the analysis of return loss parameter, the final characteristics of the proposed antenna are also analyzed in terms of antenna gain and radiation pattern, as depicted in Figure 6 and Figure 7. Figure 6 shows the maximum antenna gain over the operating antenna frequencies. The maximum and minimum antenna gains are achieved approximately at the operating frequency of 1.75 GHz and 1 GHz, respectively. As presented in Figure 7, the radiation pattern of the proposed antenna shows a bidirectional pattern in E-plane direction and almost broadside pattern in H-plane direction. This radiation pattern of the proposed antenna is suitable for the applications which need directive radiation. For further development of directive antenna, there exist several adequate techniques, such as electromagnetic band-gap (EBG) [22, 23]. By using EBG, a back radiation of the antenna can be reduced. Additionally, numerical radiation efficiency of the proposed antenna achieves 97%, approximately.

4. EXPERIMENTAL ANALYSIS

After obtaining the optimum characteristic, the designed antenna is prototyped for further experimental analysis. The fabricated antenna is presented in Figure 8. The fabricated antenna is experimentally analyzed in terms of return loss, bandwidth, antenna gain, radiation pattern and radiation efficiency. Figure 9 illustrates the measured return loss of the designed antenna which can be observed has almost reasonable agreement with the numerical results. A bit discrepancies between the numerical and experimental return losses occur because the Electromagnetic CAD Software uses an ideal dipole source to excite the antenna, whereas the actual measurement uses a finite-length coaxial cable, beside

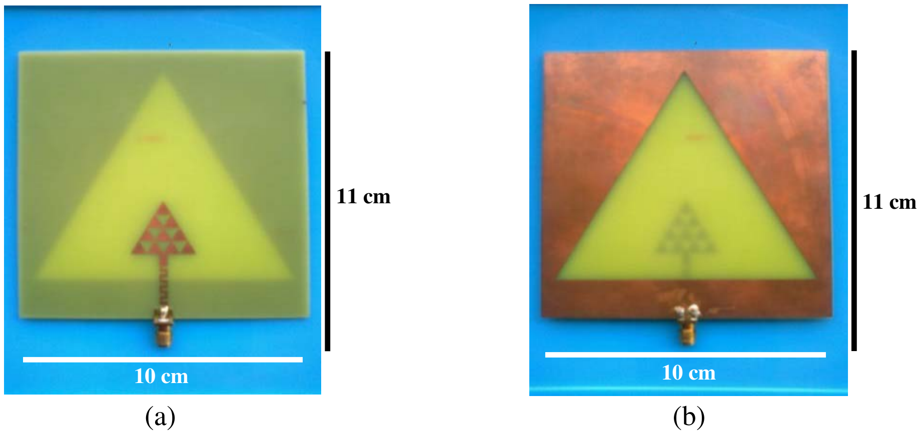


Figure 8. Prototype of the proposed antenna (a) top side and (b) bottom side.

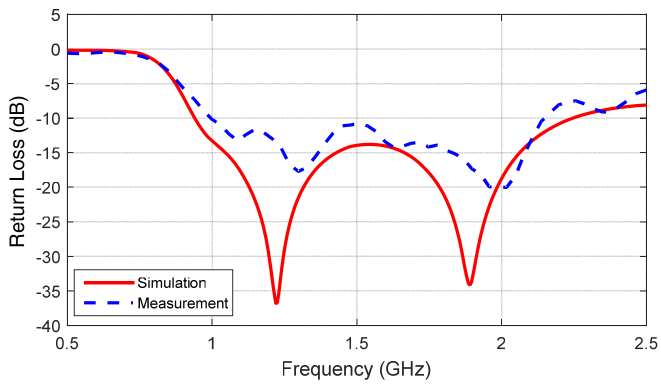


Figure 9. Experimental characteristic of return loss and its comparison to the numerical results.

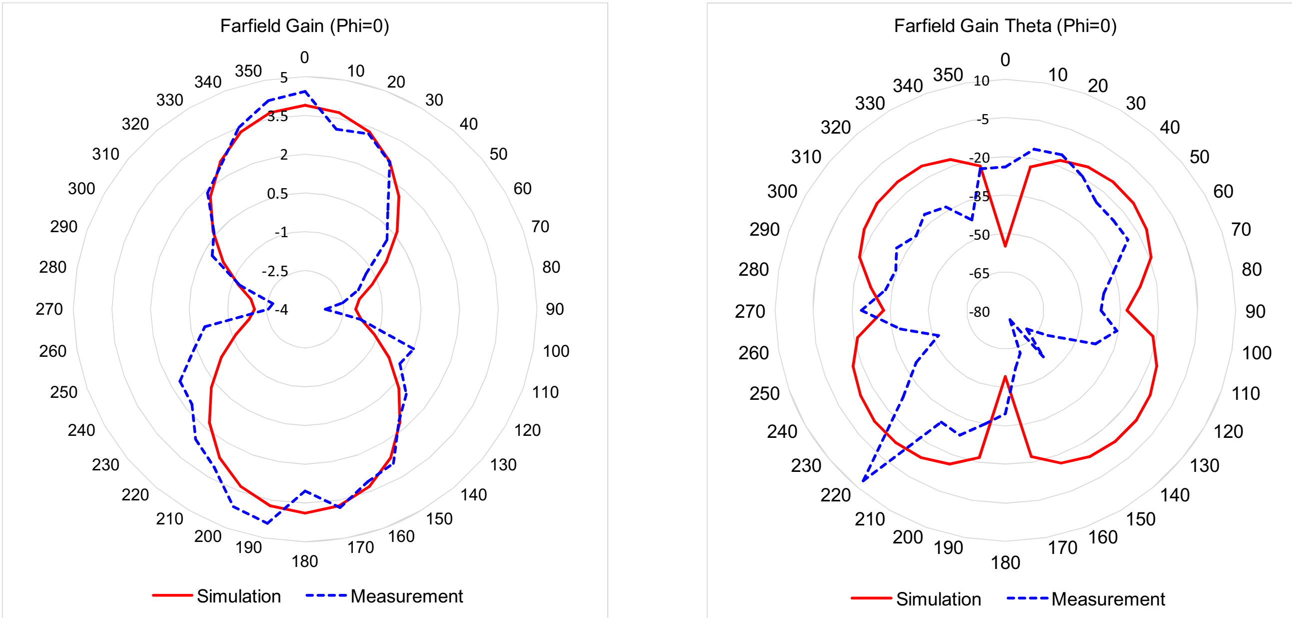
Table 1. Comparison between numerical and experimental analysis.

Parameters	Simulation	Measurement
Operating Frequency	0.93996–2.2451 GHz	0.99543–2.1481 GHz
Bandwidth	1.30514 GHz	1.15267 GHz
Fractional Bandwidth	87.01%	76.85%

Table 2. Antenna gain comparison between numerical and experimental analysis.

Frequency (GHz)	Antenna Gain (dBi)	
	Simulation	Measurement
1.45	4.02	4.42
1.50	4.14	4.42
1.95	5.37	6.20
2.00	5.49	6.52

a roughness error of etching process. Meanwhile, the operating bandwidth of the fabricated antenna is narrower around 0.99543–2.1481 GHz. However, this difference can be neglected since the intended operating frequency at L-band is still covered. The numeric comparison between numerical and experimental analyses is presented in Table 1.



(a) (b)

Figure 10. Measured radiation pattern of the proposed antenna (a) E-plane and (b) H-plane.

Table 3. Comparison of the proposed antenna and other antennas design.

Design	Structure	Dimension (mm)	Band (GHz)	Gain (dBi)
[5]	Cross-slot aperture couple	$88 \times 65 \times 17$	1.15–1.35	-
[6]	Aperture couple	$80 \times 80 \times 4.57$	1.545–1.559 1.646–1.661	9
[7]	U-slot PIFA	$80 \times 58 \times 10$	1.18; 1.5; 2.49	2.74
[8]	Tapered-slot	$130 \times 70 \times 1.5$	3.8–6	
[10]	slot antenna array	$220 \times 220 \times 1.6$	1.15–1.9	8
[9]	Slot-Loaded Folded Dipole	$72 \times 30 \times 15$	1–1.8 GHz	3
[11]	Coplanar parasitic ring slot	$110 \times 110 \times 28$	1.45–1.9	8.5
[12]	Square slot	$100 \times 60 \times 57$	0.99–2.12	7.6
[13]	Modified Sierpinski Fractal	$101.67 \times 78.5 \times 1.6$	1.7–1.9	3.87
[14]	Sierpinski Fractal	$800 \times 800 \times 800$	1.32–1.60	9.9
[15]	Modified Sierpinski	$100 \times 53.7 \times 0.8$	0.8–1.0; 1.581–2.76	3.77
[16]	Sierpinski with line feeding	$220 \times 100 \times 0.5$	1.45–1.6	6.2
[17]	Sierpinski with CPW	$91 \times 106 \times 0.78$	0.94	-
[18]	Sierpinski with CPW	$83.5 \times 50.5 \times 1.524$	1.0–1.2	2.1
[19]	Sierpinski CPW	$96 \times 72 \times 1.5$	3.29–4.4	2.4
proposed	Modified Sierpinski with meandered line	$100 \times 100 \times 1.6$	0.94–2.25	~ 5.49

Moreover, Table 2 presents the comparison of antenna gain between numerical design and fabricated antenna. From the table, it is observed that antenna gain of the fabricated antenna is slightly higher than the numerical design. Additionally, the radiation efficiency is measured around 95% with the experimental radiation pattern shown in Figure 10.

5. CONCLUSION

The development of compact wideband antenna based on modified Sierpinski and meander-line structure has been described. The developed antenna has been implemented on both sides of a substrate with relative permittivity and thickness of 4.3 and 1.6 mm, respectively. The proposed antenna has an overall antenna dimension of 10×10 cm. The proposed antenna is numerically and experimentally characterized in terms of return loss, bandwidth, antenna gain and radiation pattern as well as radiation efficiency. The numerical analysis shows that the designed antenna can operate from 0.94 GHz to 2.25 GHz with the lowest return loss of -36 dB and maximum gain around 5.49 dBi with the radiation efficiency about 97%. The experimental characteristic exhibits that the fabricated antenna has a operating frequency close to the numerical design.

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