Bandwidth enhanced deltoid leaf fractal antenna for 5.8 GHz WLAN applications

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ABSTRACT

A wideband deltoid leaf fractal antenna is proposed for 5.8 GHz commonly used in industrial scientific and medical (ISM) and wireless local area networks (WLAN) applications. A microstrip patch antennas is designed with leaf shape radiating element. Using a leaf shape, it is possible to increase the perimeter of a design and thus reduce the overall dimensions of the antenna. A circular ring slot is made on the leaf shaped radiator, in a way that a circular disc is loaded at centre. Triangular fractal slots are made inside the circular disc to make it miniaturized. A partial ground is maintained with slot at centre. The antenna is fed by micro-strip feed. The locality and measurements of the fractal slots are varied to make the antenna radiate at 5.8 GHz with wider bandwidth (BW) of (2.26 GHz). The complete size of the antenna is 40 mm^3 × 40 mm^3 × 1.6 mm^3. The step-by-step implementation of the antenna and the effects of its dimensions are compared and presented using the reflection coefficient curve. The measured reflections coefficient |S11|<-10 dB maintained the operational band from (5.36 GHz – 7.62 GHz), with gain 4.2 dBi. The proposed antenna is planned and simulated using high frequency structure simulator (HFSS). The simulated and measured comparison showed good agreement, the designed antenna is suitable for 5.8 GHz WLAN applications with wider bandwidth requirements.

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1. INTRODUCTION

Nowadays, wireless communication systems capable of serving wider band frequency coverage garnered much attention. These wireless communications systems require, antennas that provide enough wider coverage in terms of frequency range, while maintaining the low profile, low weight and compact size. Fractal models and loop models are frequently used to attain the miniaturization of the antenna. Fractal models are introduced to create different kinds of innovative designs to achieve multiple advantages in antenna size and performances [1]. Several kinds of fractal models have been introduced over the years to achieve antenna miniaturization [2]-[4]. These fractals can be similarly positioned, could have decremental iterations or similar iterations to achieve the miniaturization of the antenna.

In the past years, many researchers have done many researches on improving the bandwidth of the antenna for different applications. 5.8 GHz frequency is one of the most commonly used frequency and it have good scope for improving the bandwidth to have wide range of coverage. Different approaches are utilised to enhance the bandwidth of antenna. Some of the commonly used methods are using slots, fractals and metamaterial inspired structures. In [5], sectoral based fractal model is used to develop wideband monopole antenna at 5.8 GHz. In [6] a dielectric resonator antenna (DRA), with two segments DRA model is used to design miniaturized antenna with enhanced bandwidth to operate at 5.8 GHZ wireless local area networks (WLAN) applications. L shaped antenna which operates at 5.8 GHz is designed, the parasitic elements are utilised to upgrade the bandwidth of the antenna [7]. Step impedance resonator (SIR) based periodic structures are etched on radiator and ground plane to achieve the multi band antenna to operate at 2.4 GHz / 5.2 GHz and 5.8 GHz [8].

Fractal based models also helps in achieving the wideband antennas. In recent times several fractal antennas are designed with wider bandwidth, some ultra wide-band antennas width band rejection characteristics or with enhanced ultra wide band (UWB) coverage are designed using fractal geometry designs. While incorporating the fractal models the selection of the radiator play vital role in achieving the wider bandwidth ratio easily [9]. Square shaped fractal model is used as metamaterial loaded antenna to achieve the bandwidth (BW) enhancement in [10]. Fractal antenna model along with meander line transmission line is used to achieve wider bandwidth for L band applications in [11]. Cylindrical shaped DRA's are used to position them as fractal model to design wideband fractal antenna that covers from 2.6 GHz – 4.34 GHz in [12]. In [13], Koch fractals are used as metasurface slots to designed wideband antenna that covers from 1.45 GHz – 4.86 GHz. In [14], hexagonal fractal antenna with Koch is used to achieve the UWB coverage. Smiley shaped fractal model is used to design UWB antenna in [15]. Hexagonal shaped fractal geometry is used to design radiator and the defective ground surface is used along with the radiator to develop high gain wideband antenna [16].

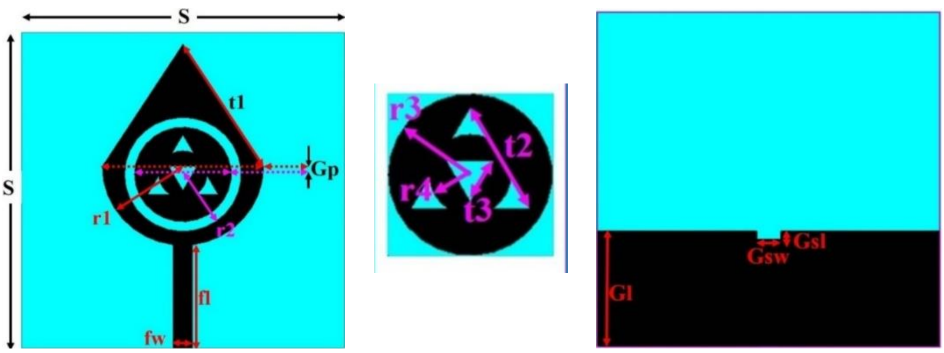
To improve the gain and wide impedance bandwidth properties of the antenna, hexagonal rings and triangular elements have been incorporated to create a fractal nature fed with a triangular slotted symmetrical defective ground structure with a rectangular slit at the center [17]. In [18] a printed monopole antenna with open mouth flower patch followed by a hard surface (HS) array provide an omni directional antenna along with the stability in the radiation pattern over the frequency band from 2.4 GHz to 10 GHz. A reconfigurable meta surface layers enhances the gain of microstrip antennas, PIN diodes are used to reconfigure the antenna structure, and a meta surface pattern of layers suggested to increase its gain [19]. By incorporating geometry of radiating patch dependent on the Sierpinski triangle fractal of a copper triangular layer, it was possible to achieve excellent reduction in mutual coupling among the antenna elements of a monopole antenna array for the multiple-input multiple-output (MIMO) applications [20]. In [21] an inverted lambda (λ) shaped diploe attached to printed reflector and an inverted L-ground plane of a microstrip patch anteena is used to realize a bandwidth enhancement. As a result of the reflector structure, a frequency resonance occurs at 1.1 GHz, 2.5 GHz and other band from 3.5 GHz to 6 GHz. The split-ring resonators (SRR) array improved the antenna matching and tuned to the frequency range 3 GHz up to 7.45 GHz and a complete boresight gain around 7 dBi over that frequency band. An electromagnatic band gap lens is in corporated into circular truncated slotted square patch antennas to enhance antenna gain, bandwidth, impedance matching, and resonance frequency [22]. In [23] a castor leaf-shaped quasi-self-complementary antenna with double band rejection characteristics is presented for the broadband applications. The fractal-based star-shaped antenna design with a wide operating bandwidth can be effective for S-band applications [24]. In [25] a bio inspired linden leaf shaped antenna between the operating frequency 1.6 GHz and 2.6 GHz for energy harvesting.

In this paper, leaf model antenna is considered due to its capabilities of achieving wider bandwidth. Circular ring along with triangular shaped fractals are etched in patch element to achieve the wideband fractal antenna which operates at 5.8 GHz. The designed antenna covers from 5.36 GHz to 7.62 GHz. Tuning the dimensions of the fractal slots helped in achieving the required frequency of operation and enhanced BW. The fabricated antenna showed good agreement in reflection coefficient comparison with simulated data. It maintained gain 4.2 dBi at operating frequency 5.8 GHz.

2. ANTENNA CONFIGURATION

2.1. Antenna model

Figure 1 illustrates the proposed fractal antenna architecture. Antenna is designed based on leaf antenna model. It contains a circular ring slot and at centre triangular fractal slots are made. The fractals are followed as first a circular ring slot is made on the leaf radiator where its leaves a circular disc at centre. A triangular slot is made inside the circular disc. Another circular disc with less radius than the first iteration circular disc is made inside the triangular slot. The 2nd iteration circular disc is maintained in a it connects to the 1st iteration circular disc leaving three triangular shaped slots. Similarly, another triangular slot is made inside the 2nd circular disc to realize the ultimate model of the proposed antenna. FR-4 substrate with a relative permittivity of 4.4 and loss tangent of 0.02 of size 40 mm^3× 40 mm^3 × 1.6 mm^3 is used as a substrate. The ultimate dimensions of the antenna shown in Figure1 after the parametric study are listed in the Table 1.



(a) (b) (c)

Figure1. Proposed antenna model: (a) top view, (b) fractal part enhanced view, and (c) back view

Table 1. The measurements of the proposed fractal antenna

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
S	40	$r1$	10	Gp	1	Gl	13.8
$t1$	18.455	$r2$	7.211	fl	13.0722	Gsl	1
$t2$	8.66	$r3$	6	fw	2.4	Gsw	2.8
$t3$	3.464	$r4$	3				

2.2. Antenna analysis

The step-by-step design procedure of the fractal antenna is presented in the Figure 2. In step 1 a leaf model is taken as radiator. In step-2, a circular slot is made at centre. In step-3, another circular disc is placed at centre with less radius than the, circular slot made in step-2. In step 4, a triangular slot is made inside the circular disc positioned at centre in step-3. In step-5 another circular disc with triangular slot is added at centre.

Figure 2. Step by Step evolution of wider band fractal antenna

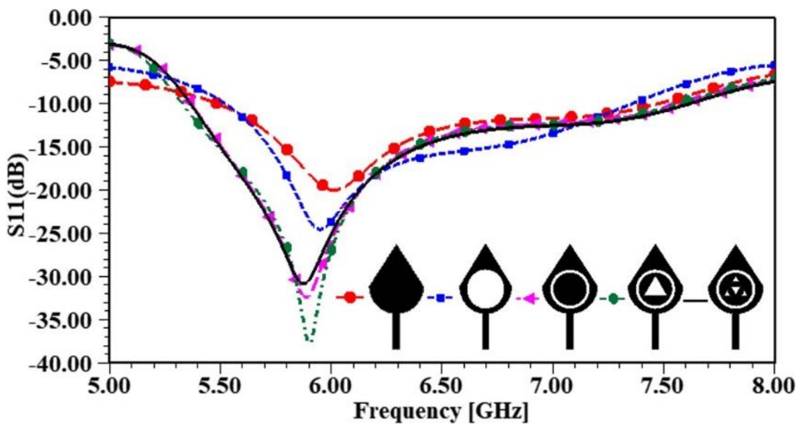
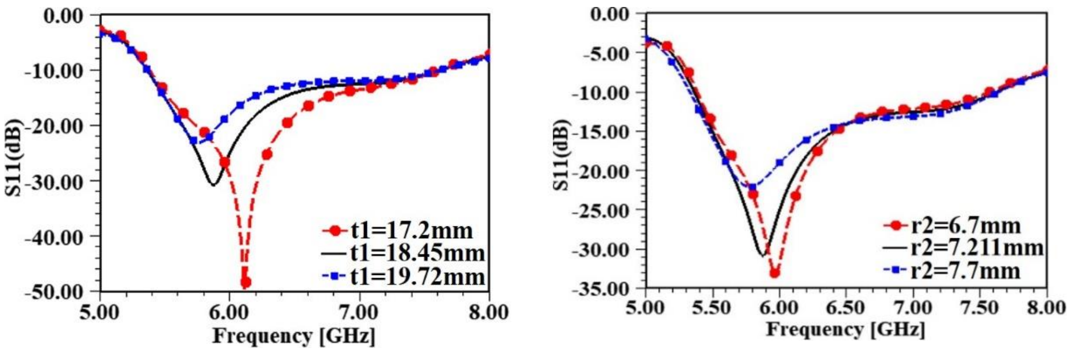


Figure 3. Reflection coefficient comparison of the antenna design steps

The proposed antenna is fed by the centre positioned microstrip feed line. The antenna performance comparison for the step-by-step evaluation is presented using the reflection coefficient (S_{11}) vs frequency curve is presented in the following Figure 3. For the step-1 and 2 reflection curve showed poor impedance matching and less operation band and the frequency of operation is away from the intended 5.8 GHz frequency. For steps 3 to 5 the operation bandwidth is almost maintained similar, but when compared for step 5 the operation band is maintained higher and also the operating frequency is at 5.8 GHz. Step 5 is more miniaturized and achieved higher band width with required operating frequency 5.8 GHz.

2.3. Parameter study

In order to get the optimal antenna measurements and also the parameters of the lead antenna, leaf side triangle edge length $(t1)$, first circular slot radius $(r2)$ are varied, analysed and the comparative analysis is shown in the following Figure 4 using S_{11} vs frequency curves. From Figure 4(a) it can be seen that, when $t1$ dimension is increasing the reflection coefficient response shifting towards the lower resonance and the impedance matching is getting poorer, after the parametric study at $t1$ = 18.45 mm, the proposed antenna is maintaining the intended frequency of operation at 5.8 GHz with good impedance matching. From Figure 4(b) it can be observed that, similar to t1 when $r2$ is increased the operating frequency is shifting towards the lower resonance, at $r2$ = 7.211 mm it maintained the intended operating frequency 5.8 GHz. Similarly other antenna dimensions are also tuned and the optimal values after the parametric study are listed in the Table1.



(a) (b)

Figure 4. Parametric study comparison using reflection coeffcient for (a) dimension $t1$ and (b) dimension $r2$

2.4. Simulated analysis

In order to highlight the usage of the slots to achieve the better performance of the antenna. The antenna performance is compared in the Figure 5 for the original leaf model and the proposed model. From Figure 5 it can be clearly seen that the leaf model at base step with the same dimensions operates at 6 GHz with return loss -20 dB and maintained operation band below -10 dB from 5.5 GHz to 7.5 GHz. For the proposed design after the slots are made it operated at 5.8 GHz with return loss -30 dB and maintained operational band below -10 dB from 5.4 GHz to 7.7 GHz.

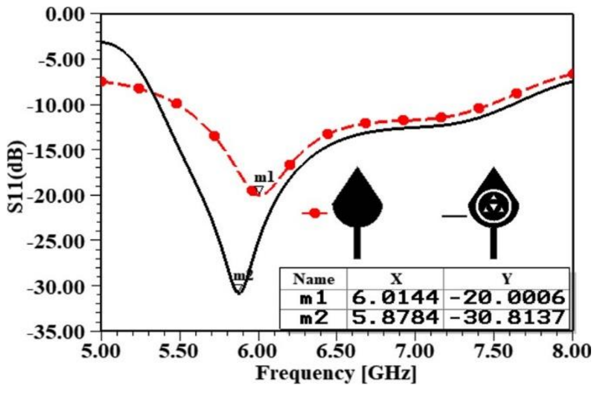
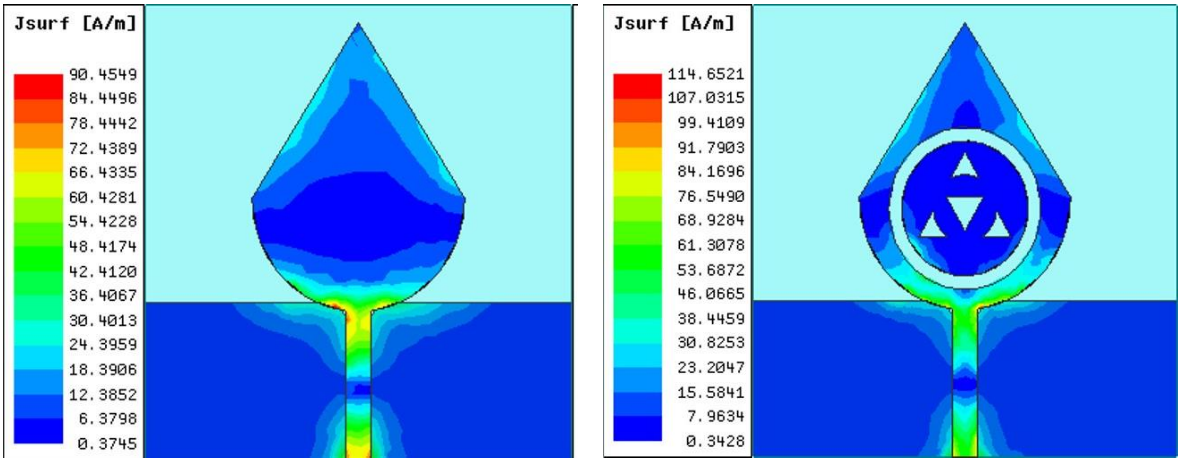


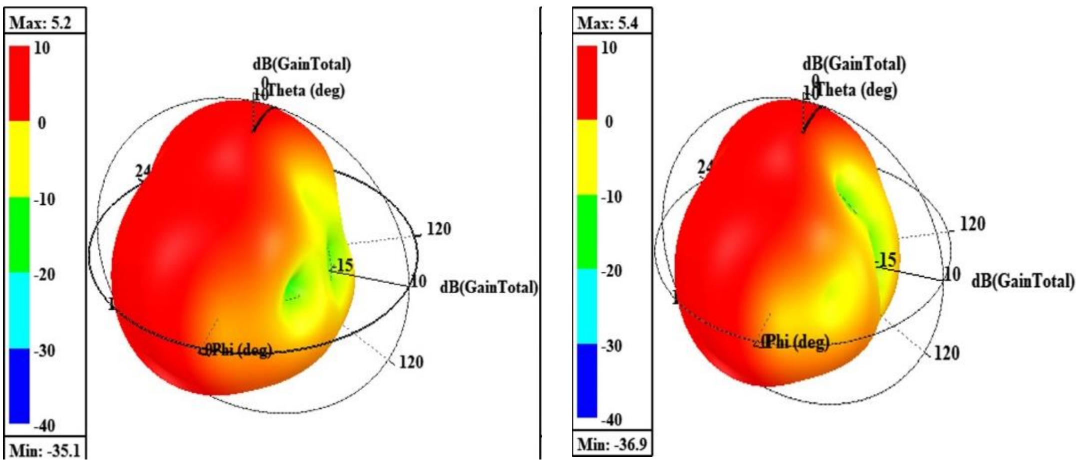
Figure 5. Reflection coefficient comparison between the basic leaf model and the proposed fractal model

Similarly, in Figure 6(a) compares the reflection coefficient of the antenna design steps and Figure 6(b) presents comparision interms of axial ratio. Figure 7(a) and Figure 7(b) represents 3D radiation plots compared and presented for leaf model and the proposed fractal model. From Figure 6(a) it can be observed that, the current distribution is weak at center, where the slots are made as shown in Figure 1. This helped in altering the current distribution and achieving the miniaturized fractal antenna with enhanced bandwidth. From Figure 7 it can be seen that, the leaf antenna maintained utmost gain 5.2 dBi where as for the proposed fractal model the maximum gain is improved to 5.4 dBi.



(a) (b)

Figure 6. Surface current distribution: (a) basic leaf model and (b) proposed fractal model



(a) (b)

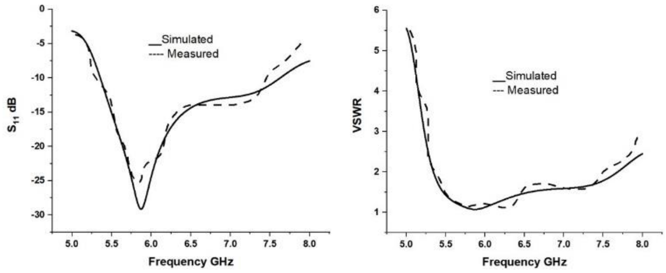
Figure7. 3D radiation plots: (a) basic leaf model and (b) proposed fractal model

3. RESULTS AND DISCUSSION

According to the dimensions listed in Table 1, the fractal antenna is successfully designed and measured. The fractal antenna fabricated prototype model is presented in the Figure 8(a). The S-parameters measurement setup inside the anechoic chamber is illustrated in the Figure 8(b). Figure 9(a) shows the simulated and measured comparison for the S_{11} and Figure 9(b) shows VSWR comparison. The comparison showed that, the fractal antenna maintained quality agreement between the simulated and the measured analysis. The slight deviation could be caused by the unavoidable fabrication issues.

(a) (b)

Figure 8. Proposed fractal antenna:
(a) prototype and (b) S_{11} measurement setup



(a) (b)

Figure 9. Simulated and measured comparative analysis:
(a) S_{11}vs Frequency and (b) VSWR

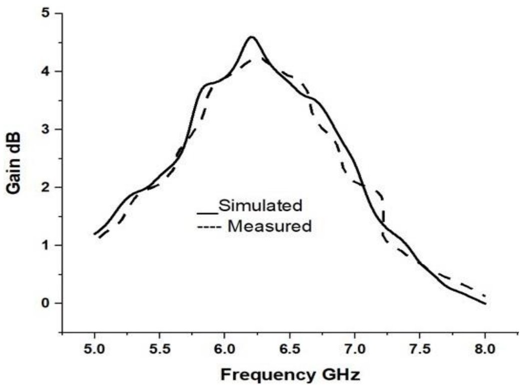
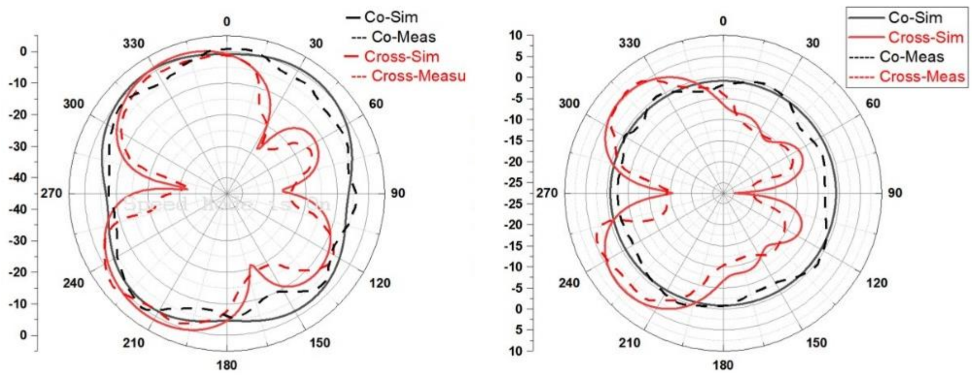


Figure 10. Simulated and measured comparison for gain vs frequency

Similarly, the simulated and measured comparison of the gain vs frequency curve is presented in the following Figure 10. It can be seen that the antenna gain measurement maintained as per expectations in the intended operation band. The proposed antenna radiation pattern comparison for simulated and measured in e-plane and h plane for the co and cross polarization are illustrated in the following Figure 11. The patterns maintained mostly omni shape at 5.8 GHz. For the better understanding of working performance of the designed antenna, comparison with previous existing models is listed in the following Table 2.



(a) (b)

Figure 11. 2D radiation patterns: (a) E-plane radiation pattern of the fractal antenna at 5.8 GHz and
(b) H-plane radiation pattern

Table 2. Performance comparison between the proposed antenna and previous work

Antenna design	Operating frequency (GHz)	Dimensions (mm)	Band width (GHz)	Gain (dBi)
Proposed work	5.8	40×40×1.6	5.36 – 7.62	4.2
[7]	5.8	50×50×1	5.7 – 6.08	–
[6]	5.8	30×40×0.8	5.5 – 6.2	–
[5]	6.15	27×35×1.6	3.22 – 6.55	4.35

4. CONCLUSION

This paper presents, a compact wideband fractal antenna is designed and presented for 5.8 GHz WLAN applications. The design is based on leaf radiator. A circular ring along with triangular fractal slots are made to achieve the wideband with frequency of operation at 5.8 GHz. The ground of this antenna is maintained partial with slot at centre to improve band width further. The antenna maintained the return loss below -10 dB from 5.36 GHz to 7.62 GHz maintaining bandwidth of 2.26 GHz. The fabricated prototypes showed good agreement with simulated data when measured. The designed antenna-maintained gain around 4.2 dBi at 5.8 GHz. The proposed wideband antenna is good for 5.8 GHz WLAN applications. Leaf designed microstrip patch antenna layout technique is used for the further improvent of the engineered antennas for the wireless communication applications.

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