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Arrow Cross Shape Slotted Fractal Antenna with Enhanced Bandwidth for Wi-Fi/WiMAX/WLAN Applications

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Abstract—A fractal antenna with enhanced bandwidth (BW) from 2.62 GHz to 5.2 GHz is presented for Wi-Fi applications. The antenna is designed to achieve a wider BW, and it consists of a rectangular shape patch attached to a half circular disc. The antenna is fed by microstrip feed model. The ground plane of the antenna is maintained partial with a slot at centre. Double head arrow cross shaped slots are etched on the radiating element to form the proposed fractal antenna. While the centre slot is made to look like + symbol, the surrounding four fractal slots are made to look like × symbol. FR4 substrate with dielectric constant 4.4 with thickness 1.6 mm is used to design the antenna. The overall size of the antenna is maintained compact with dimensions 44 mm × 40 mm. The dimensions of the fractal slots are varied, and the operating band is tuned. The proposed antenna covers from 2.62 GHz to 5.2 GHz with BW 2.58 GHz. The step-by-step implementation of the fractal antenna and comparative analysis are presented with the help of reflection coefficient curves. While the proposed antenna covers wideband, it showed peak resonance at dual operating frequencies at 3.2 GHz and 4.8 GHz. The designed antenna-maintained gain of 2.96 dBi and 3.47 dBi at 3.2 GHz and 4.8 GHz frequencies, respectively. The proposed antenna performance is presented with the help of reflection coefficient, VSWR, gain, field distributions, and radiation pattern curves. The simulated and measured analysis comparison showed good agreement making the designed antenna a good candidate for wideband Wi-Fi applications.

1. INTRODUCTION

Antennas with wideband coverage have garnered much attention in recent times. Several antennas that exhibit multi-band capabilities or with high bandwidth capabilities are being developed to serve different kinds of applications. The advantage of having these kinds of antennas is that they can serve in low power transmission applications that require larger bandwidth to transfer with high data rate. These antennas need to be compact in size, so that they can fit into small scale communication device. While these antennas are developed, miniaturization of the antenna is important apart from enhancing the bandwidth and the performance of the antenna. Fractal's geometries are more often used due to their capabilities in achieving miniaturization of the antenna. They were first introduced by MandelBrot in 1977. These fractals can be of different shapes derived from nature [1]. Utilization of fractal geometry can help in overcoming the disadvantages of traditional microstrip antennas, and fractals can help in achieving the multi-band, gain, and BW enhancement, and size reduction [2–5].

In recent years, several types of fractal antennas have been developed to serve Wi-Fi, WiMAX, WLAN, and UWB applications. A novel multiband fractal antenna is designed using circle and triangle shaped slots for CDMA, LTE, WiMAX, and WLAN applications in [6]. In [7], a wideband monopole antenna is designed using a sector shaped fractal model for 5.8 GHz WLAN applications. Square shaped fractal geometry is used to load as metamaterial to implement BW enhanced antenna [8]. Fractal

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geometry along with meander shaped transmission line is utilized to design wideband antenna for L band in [9]. In [10], a wideband dielectric resonator antenna is designed by placing cylindrical shaped slabs in fractal model, to cover from 2.6 GHz to 4.34 GHz. In [11], Koch fractal geometry slots are made to designed wideband antenna to operate in frequency band 1.45 GHz–4.86 GHz. Optimized fractal antenna using + shaped geometry is designed with modified ground plane for wideband applications in [12]. In [13], a high gain hexagonal fractal antenna covering from 1.31 GHz to 6.81 GHz is designed. In [14], a modified Minkowski fractal antenna along with a circle-shaped split-ring resonator is designed to operate in three frequency bands at 2–2.7 GHz, 3.4–3.6 GHz, and 5.45–5.95 GHz. In [15], a star shaped fractal slot antenna with dual band operation cantered at 1.33 and 1.69 GHz is designed and implemented.

In this paper, cross arrow shaped slots are utilized to design the proposed fractal antenna. Five cross arrow slots are made on the patch element. At centre, a slot is made in + shape, and at four corners slots are made to look like ×. These slot dimensions are varied, and the optimal dimensions are taken after the parametric study. The proposed antenna covers from 2.62 GHz to 5.2 GHz with BW of 2.58 GHz. Reflection coefficient is good at two frequencies 3.2 GHz and 4.8 GHz. Field distribution, 3D & 2D radiation patterns are presented for these two frequencies.

2. ANTENNA CONFIGURATION

2.1. Antenna Model

The proposed wideband fractal antenna is presented in the following Figure 1. The antenna consists of a patch made of rectangle and half circle shaped combination, with a microstrip feed line. The fractal slots are made using cross arrow shape geometry. The + and × orientations are used to make the slots. The partial ground with a slot at centre is used for the proposed antenna. An FR4 substrate with dielectric constant 4.4 and loss tangent 0.02 is used for implementing the antenna. The overall size of the antenna is maintained compact with dimensions 44 mm × 40 mm × 1.6 mm. The EM simulation software ANSYS HFSS 18.0 is used to design and analyse the antenna parameters. The final dimensions of proposed fractal antenna after parametric study are listed in Table 1.

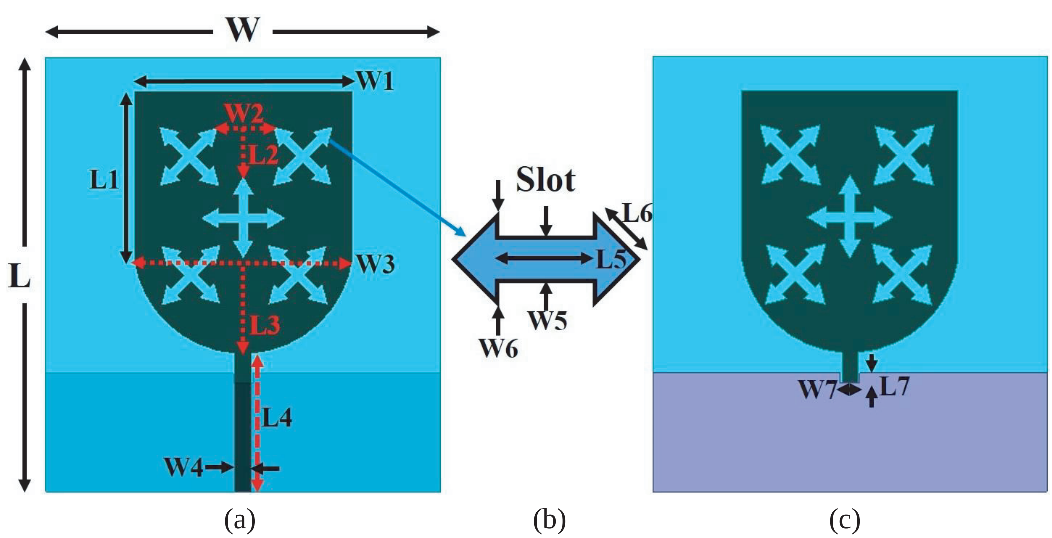


Figure 1. Proposed fractal antenna design: (a) Top view; (b) Fractal arrow slot dimensions & (c) Bottom view.

While most of the fractal geometries follow connected uniform or nonuniform slots, in this article the slots are selected based on periodic structured models. The lattice size of the periodic slots and the gap between them along with the actual periodic slot dimensions will contribute in changing the effective Inductance (L) and Capacitance (C) thus helping in tuning the resonant frequency f_r. Different

Table 1. The dimensions of the proposed wideband fractal antenna.

Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)	Parameter	Value (mm)
L	44	$L4$	14.03	W	40	$W4$	1.6
$L1$	17	$L5$	4.55	$W1$	22	$W5$	1
$L2$	5	$L6$	2.25	$W2$	0.45	$W6$	2.25
$L3$	9.55	$L7$	1	$W3$	22	$W7$	2

metamaterial inspired periodic slots including double headed arrow cross slots, and their significance in altering the operational band or enhancing the BW is explained clearly in [16, 17]. Orientation of these arrow slots while they are placed in the same position exhibits similar wide-band response, when being analysed. The center slot orientation is altered to 90 degrees as the slots are getting connected if being placed in the same orientation. The change of orientation for the center slot enabled the cause of different L and C combinations between the surrounding slots and the center slot, which helped in tuning the dimensions and achieving wider BW.

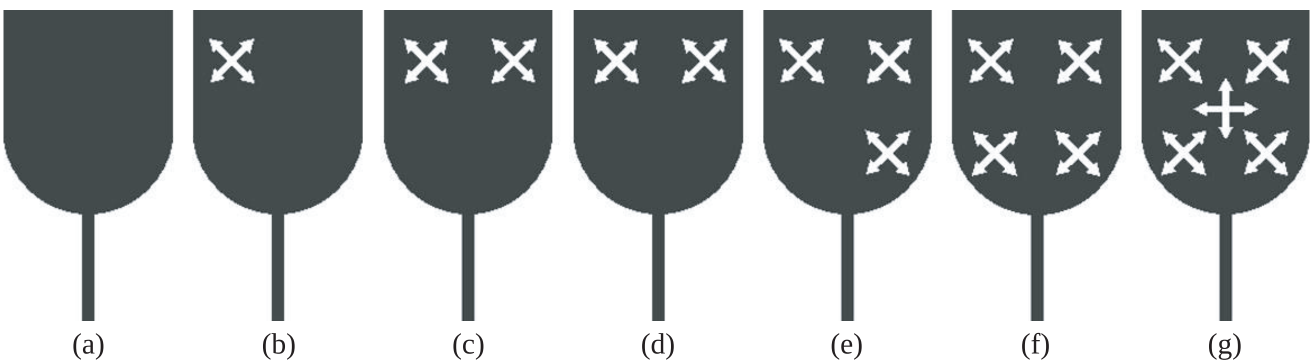


Figure 2. Evolution of proposed wideband fractal antenna: (a) Step-1; (b) Step-2; (c) Step-3; (d) Step-4; (e) Step-5; (f) Step-6; (g) Step-7.

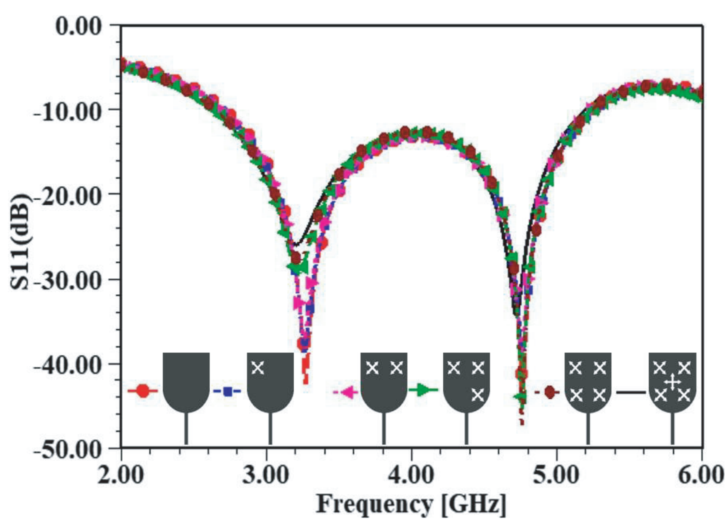


Figure 3. Reflection coefficient comparison for the design steps mentioned in Figure 2.

2.2. Antenna Step by Step Evolution

The proposed cross arrow slotted fractal antenna step by step evolution from basic antenna and the slots effect on the operating frequency is analysed and presented in Section 2.2. The steps involved in implementing the antenna from step-1 to step-7 are illustrated in the following Figure 2. The reflection coefficient comparison is presented in Figure 3.

Figure 3 data shows that the proposed designed antenna maintains its wideband coverage while the number of fractal slots is increased. The miniaturization of the antenna is maintained while the antenna operational bandwidth is maintained as the original base antenna. For the fifth slot at centre, we observe the operational band shifting towards the lower resonance compared to the remaining steps. While the impedance matching of the antenna is altering for each step, the operation bandwidth is maintained wider with overall good impedance matching. Slot dimensions are maintained in a way to avoid the antenna performance degradation. The slot dimensions and the gap between the fractal slots are tuned in consideration of maintaining the antenna actual performance while achieving the miniaturization of the antenna.

2.3. Parameter Study

To obtain the optimal dimensions of the antenna, all the dimensions of the proposed antenna geometry are varied, and the parametric analysis is performed. The final dimensions after the parametric study are listed in Table 1. Two parameters out of all dimensions are presented in Section 2.3. The dimensions that affect the antenna operation drastically are the length $L1$ and width $W1$ of the patch. The parameters ($L1$) and ($W1$) are varied, and the effects are compared and presented with the help of the reflection coefficient curves shown in Figure 4.

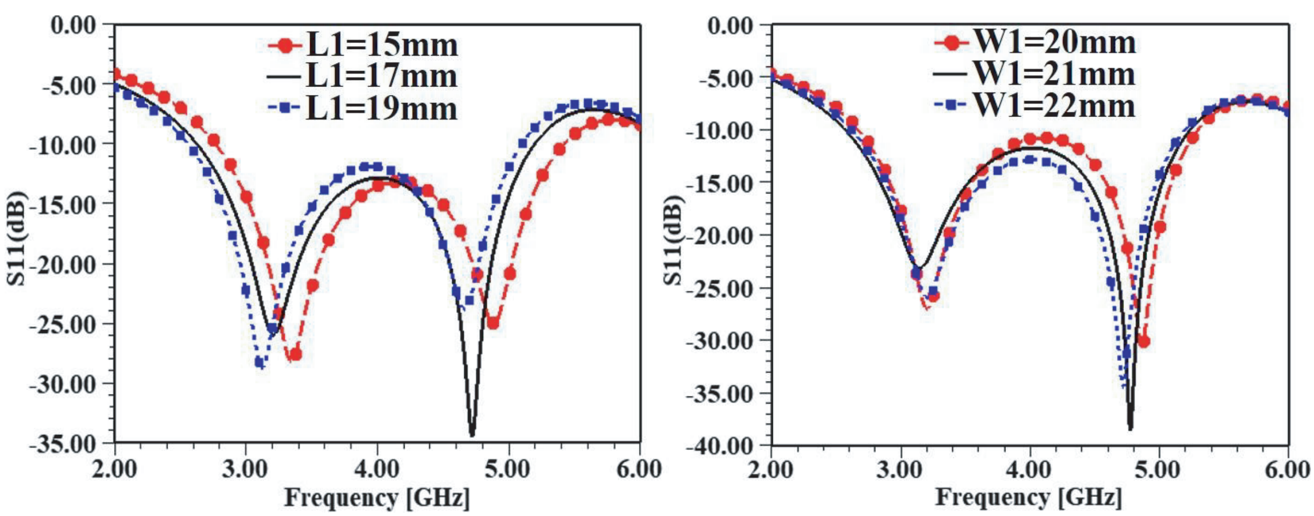


Figure 4. Reflection coefficient curves comparison for parametric study performed for parameters $L1$ and $W1$.

From Figure 4 data it can be observed that when $L1$ is increased the antenna operational band shifts towards the lower resonance. For $L1 = 17$ mm, the antenna impedance matching is good at 4.8 GHz and less at 3.2 GHz than the remaining variations. For $L = 17$ mm, the antenna covers 5 GHz band with good impedance matching. Similarly, for $W1 = 21$ mm, the antenna shows good impedance matching at higher resonance compared to other variations.

2.4. Simulated Analysis

The fractal slots are made to achieve the miniaturization of the antenna without affecting the antenna performance. The antenna performance is compared between the basic antenna and proposed fractal

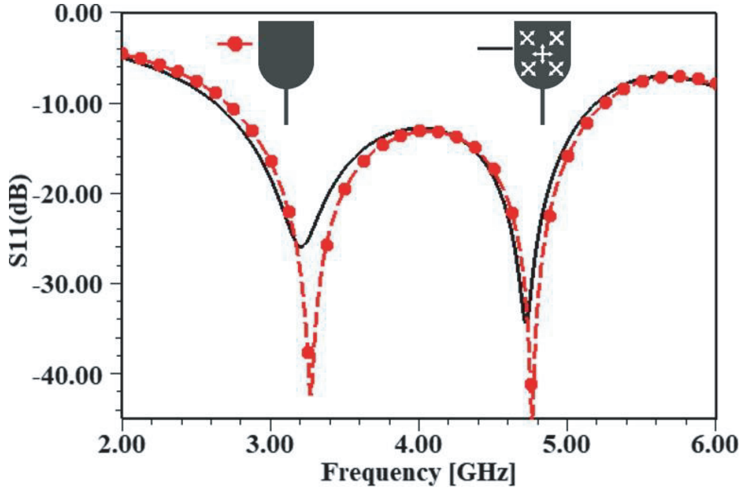


Figure 5. Reflection coefficient comparison between the basic antenna model and the proposed wideband fractal antenna.

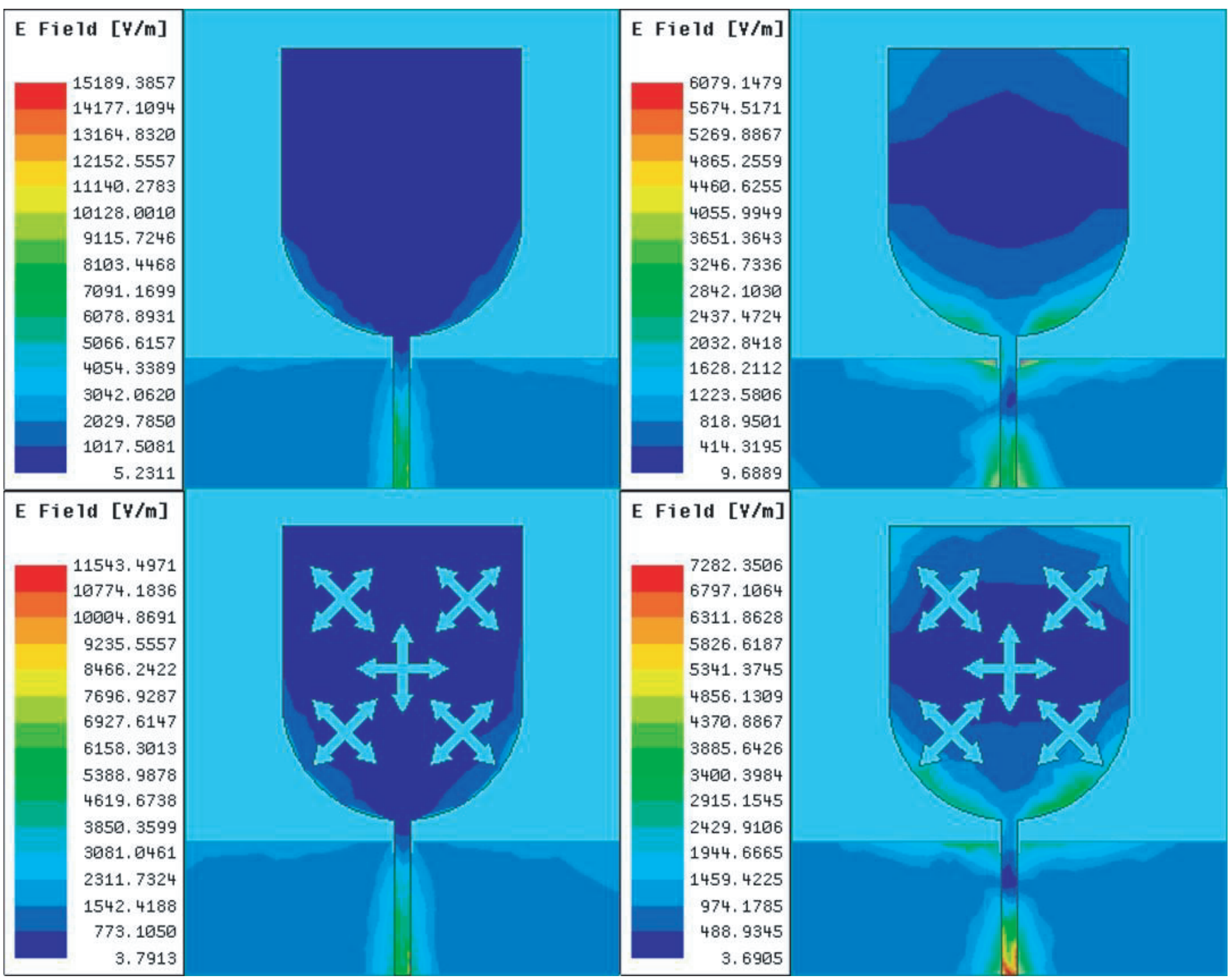


Figure 6. E-field distribution comparison between the basic antenna model and the proposed wideband fractal antenna.

antenna to highlight the fractals incorporation. The reflection coefficient comparison between the basic antenna and proposed fractal antenna is presented in the following Figure 5. From Figure 5 it can be seen that for the basic antenna the impedance matching is better while the proposed fractal slotted antenna is able to maintain the performance. The slotted antenna operation is shifted towards lower resonance with improved bandwidth. The basic antenna covers from 2.7 GHz to 5.25 GHz maintaining BW of 2.25 GHz, whereas fractal slotted antenna operational band covers from 2.62 GHz to 5.2 GHz with BW of 2.28 GHz.

The designed fractal antenna displays good reflection coefficient at dual frequencies 3.2 GHz and 4.8 GHz. The E-field distribution at these frequencies for basic antenna and the fractal antenna are compared and presented in the following Figure 6. The distribution comparison in Figure 6 shows that at centre part of the patch the filed distribution is significantly less for the basic antenna at both the frequencies 3.2 GHz and 4.8 GHz. utilizing this as advantages the fractal slots are made in these areas to achieve miniaturization without affecting the antenna actual performance.

Similarly, the comparison of 3D radiation pattern curves between the basic antenna and proposed wideband fractal antenna at frequencies 3.2 GHz and 4.8 GHz is presented in Figure 7. From Figure 7 it can be seen that at 3.2 GHz the maximum gains of the basic antenna and fractal antenna are maintained same as 2.7 dBi. At frequency 4.8 GHz, the basic antenna maintains maximum gain at 4 dBi, whereas for fractal antenna it is improved to 4.2 dBi. The orientation of the radiation pattern and coverage are maintained similar for the proposed fractal antenna to its original base antenna.

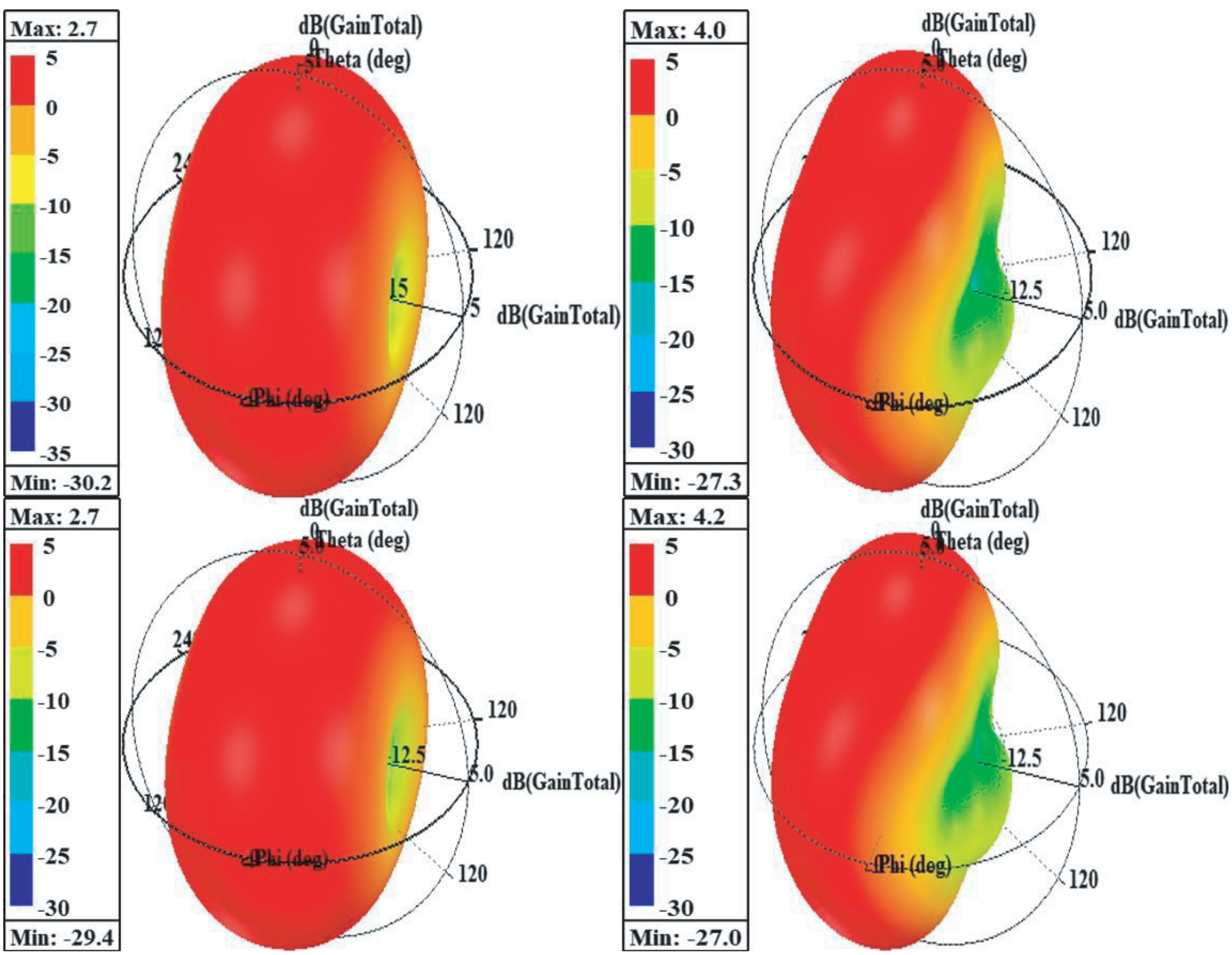
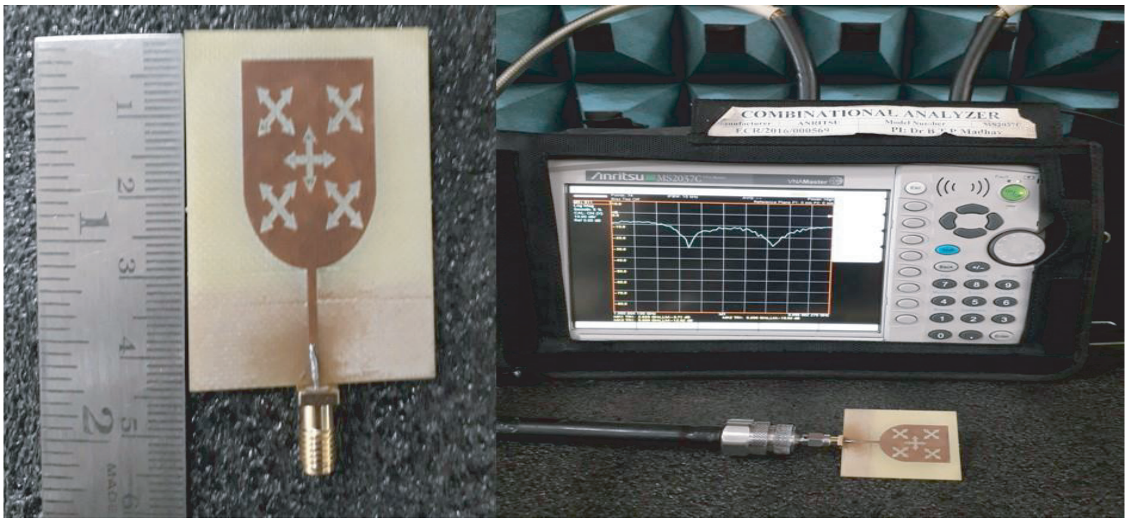


Figure 7. 3D radiation pattern comparison between the basic antenna model and the proposed wideband fractal antenna.

3. RESULTS AND DISCUSSION

As per the optimal dimensions listed in Table 1, the proposed wideband fractal antenna is successfully fabricated and tested. The prototyped of the fabricated wideband fractal antenna is illustrated in the below Figure 8(a), and the S-parameters measurement setup inside the anechoic chamber is presented in Figure 8(b).

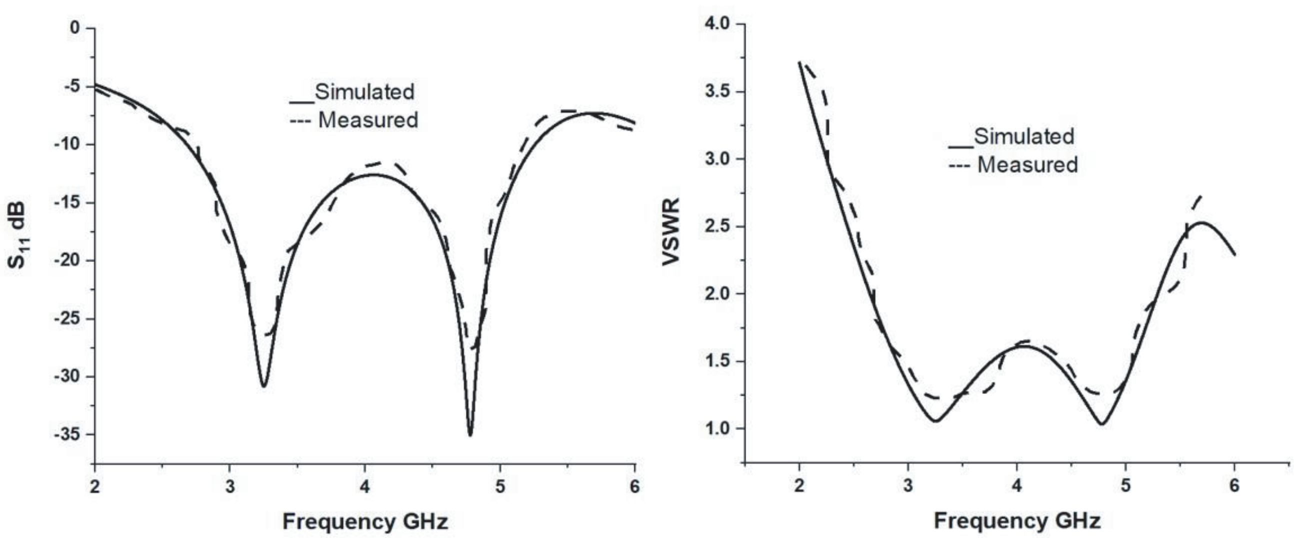


(a) (b)

Figure 8. Proposed wideband fractal antenna: (a) Prototype; (b) S_{11} measurement setup.

The simulated and measured comparative analysis with the help of reflection coefficient curves, VSWR curves, radiation pattern curves, and the gain vs frequency curves are presented in this Section 3.

Figure 9 represents the simulated and measured comparison for S_{11} and VSWR curves. The comparison shows good agreement between the simulation and measurement, and the operational band is maintained similar to the simulated data. The small deviation between the simulation and measurement



(a) (b)

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

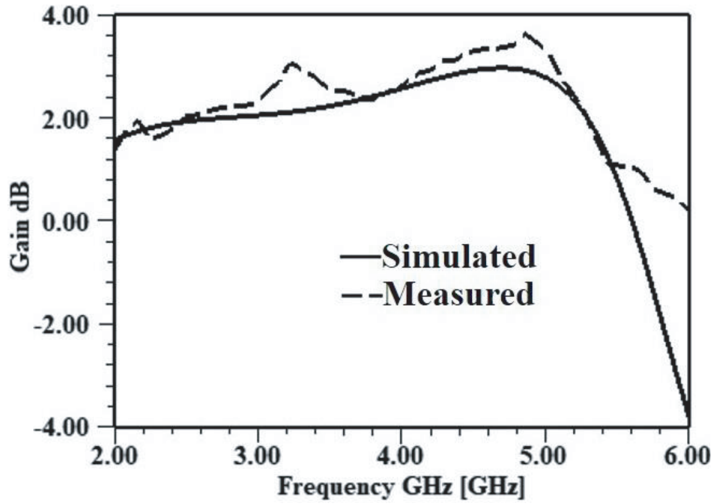


Figure 10. Simulated and measured comparison for gain vs frequency.

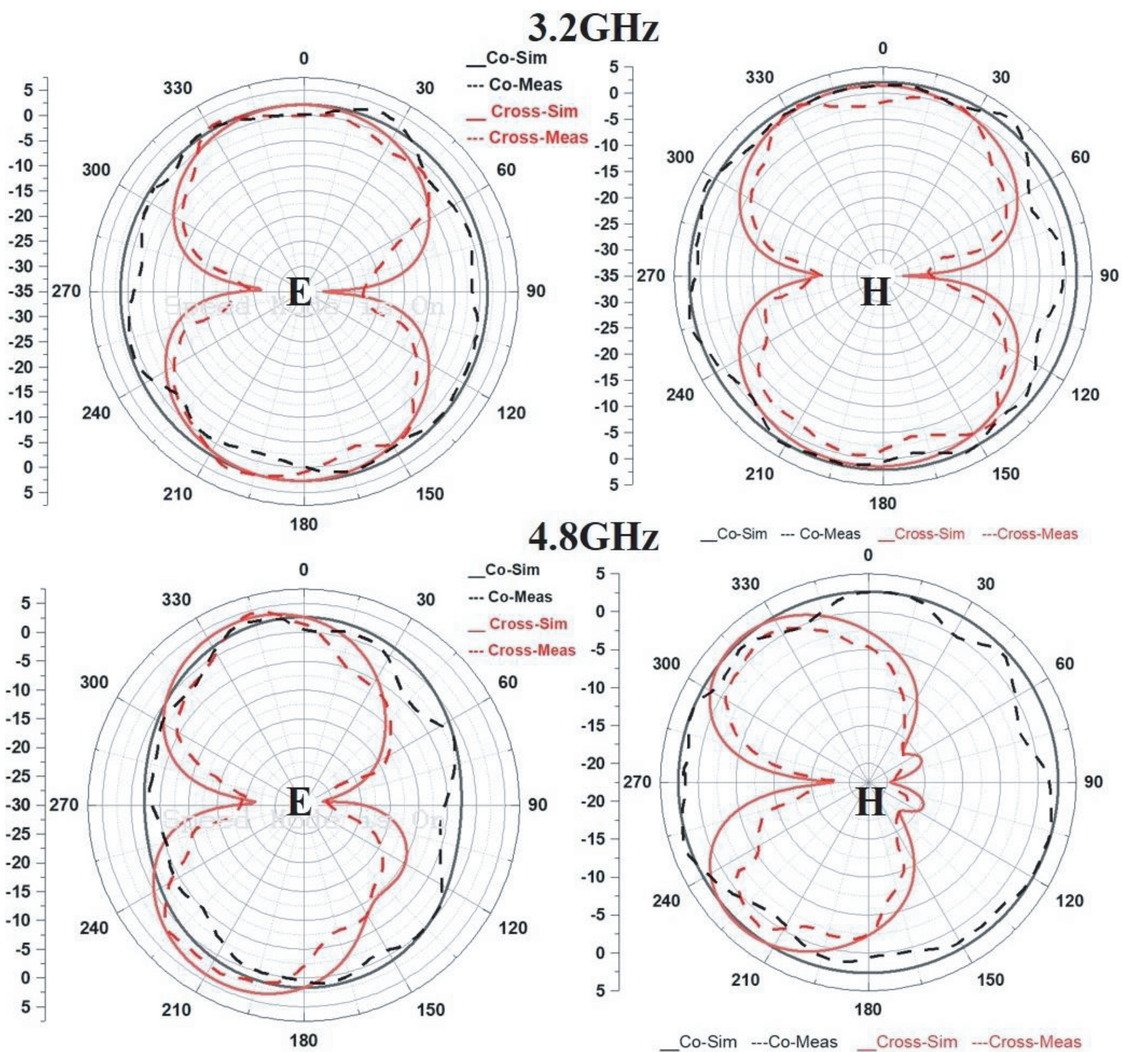


Figure 11. Simulated and measured 2-D radiation patterns comparison for the proposed wideband fractal antenna at 3.2 GHz. and 4.8 GHz in E & H-planes.

could be caused by unavoidable errors like fabrication issues, connector faults, etc. The VSWR curve is maintained between 1 and 2 for the intended operational band for both simulated and measured analysis. The gain vs frequency curve, shown in Figure 10, shows that measurements of the proposed antenna exhibit gains 2.96 dBi and 3.47 dBi at 3.2 GHz and 4.8 GHz, respectively.

Similarly, the radiation pattern comparison between simulation and measurement in E and H planes for co- and cross-polarizations at 3.2 GHz and 4.8 GHz frequencies is presented in Figure 11. The co-polarized patterns are mostly omnidirectional for all cases. For cross-polarization at 3.2 GHz, the patterns are in 8-shape for E and H planes, and at 4.8 GHz the patterns are maintained in 8 shapes while showing some shift towards the left side.

Table 2 shows the comparison between proposed antenna and reported antennas. It shows that utilization of the cross-arrow fractal slots helps in reducing the size of the proposed antenna significantly while maintaining the BW, compared to other antennas.

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

Antenna Design	Operating Frequency (GHz)	Dimensions (mm)	Coverage (GHz)	BW (GHz)	Gain (dBi)
Proposed Work	3.2, 4.8	$44 \times 40 \times 1.6$	2.62–5.2	2.58	2.96, 3.47
[13]	3.79,5.5	$45 \times 40 \times 1.6$	1.31–6.81	5.5	6.1
[12]	-	$45 \times 44.92 \times 1.6$	3–5.48	2.48	5.1
[11]	-	$120 \times 120 \times 1.6$	1.45–4.86	3.41	-
[10]	3, 3.6, 4.2	102 radius, 1.6 thickness	2.6–4.34	1.74	-
[9]	1.45, 1.5, 1.95, 2	$100 \times 100 \times 1.6$	0.94–2.35	1.41	4.42, 4.42, 6.2, 6.52

4. CONCLUSION

This paper presents the implementation of miniaturized wideband fractal antenna for Wi-Fi/WiMAX/WLAN applications. The proposed fractal antennas used cross arrows fractal slots to achieve the miniaturization of the antenna. The designed antenna size was 44 mm × 40 mm × 1.6 mm. The presented wideband fractal antenna showed good reflection coefficient at 3.2 GHz and 4.8 GHz frequencies. At these frequencies it maintained measured gain at 2.96 dBi and 3.47 dBi, respectively. It showed wideband width for both simulated and measured analysis covering from 2.62 GHz to 5.2 GHz with BW of 2.58 GHz. The simulation and measurement comparison for S_{11}, VSWR, radiation patterns, and gain vs frequency curves showed good agreement making the designed wideband fractal antenna a good candidate for wideband applications.

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