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RESEARCH PAPER

Compact dual-band truncated patch antenna with fractal defected ground structure for wireless applications

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In this paper, a compact, dual-band patch antenna is proposed over Minkowski fractal defected ground structure (DGS) for bandwidth enhancement of global positioning system (GPS) applications. The proposed design combines the truncated dual L-shaped slits cut on diagonal corners of radiating patch and fractal defect on the metallic ground plane. This concept shifts the frequencies to lower bands with improvement in antenna radiation properties. By deploying symmetrical and asymmetrical boundaries to the structure for the fractal DGS on metallic ground plane, improvement in bandwidth and gain are obtained. Compact antenna size is achieved for dual-band GPS frequencies of L_1 (1.575 GHz) and L_2 (1.227 GHz). The measured results for antenna prototype are (1.2–1.245 GHz): L_2 band and (1.51–1.59 GHz): L_1 band for 10 dB return loss bandwidth with better pattern radiation. Gain value with and without DGS is observed for compact antenna overall volume of $0.32\lambda_o \times 0.32\lambda_o \times 0.024\lambda_o$.

Keywords: Defected ground structure, Spur lines, Minkowski fractal patch antenna, Gain and impedance bandwidth

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I. INTRODUCTION

Rapid progression is done in the field of wireless communication and radio frequency electronics with the benefit of meeting the requirement of miniaturization. Compact planar antennas are very promising candidates in satisfying the design consideration. Microstrip patch antenna covering more than one wireless communication band is considered a dual/multiband [1–3]. Challenge is to obtain enhanced bandwidth and better gain with the antenna designed to operate at dual bands. It is noted that majority of the earlier literature with different shaped slots and slits printed on the patches have drawn less attention due to less gain at low resonant frequencies. The use of defected ground structure (DGS) was explored earlier to miniaturize printed circuits, and this concept was adapted to the problem of antenna designs [4]. Metallic ground plane may be considered a dominant portion of the radiating structure [5]. Self-similar structure for the fractal shape and multiple scales of recurring geometry benefit the antenna to resonate at different frequency bands. Variety of simple DGS slots such as dumbbell shaped, arrow shaped dumbbell, circular shaped, and spiral shaped are available in the literature which increases the effective length on the ground plane [6–8]. Efficient size reduction of low-pass filters and broad bandwidth with patches is discussed using sierpinski fractal DGS [9].

Several techniques have been demonstrated using fractal elements and elevation of patches which are discussed in the available literature. Etching of a defect in the ground plane of patch antenna disturbs the current distribution and gives rise to increasing effective capacitance and inductance [10]. Hilbert fractal-shaped structures have been proposed to produce printed and microstrip dipole and monopole antennas with compact size and dual-band performance for different applications [11]. Concentric ring-shaped DGS [12] discusses about suppressing the harmonics in microstrip-based active antenna designs. Liu et al. presented a monopole antenna exciting tri-bands with DGS playing a major role [13]. Probe-fed broad band antenna with V-slot DGS [14] and Z-type DGS [15] for bandwidth enhancement are few latest models developed in current literature. H-shaped DGS slot antennas with CPW fed obtain high bandwidth for WLAN 2.4 GHz band with very low gain [16]. Circular ring-shaped DGS proposed for wideband application, but resonates at X-band frequency [17]. Polygonal DGS [18] is etched on the ground plane and is used for array applications for better gain value. The brief literature dealt about applying defect on the ground plane for multiple applications in enhancement of bandwidth and frequency shift property.

In the present design, it is observed that the slits truncated across diagonal corners on the radiating area, create additional resonant frequencies. Fractal DGS on the metallic ground would give rise to size reduction with lowering the frequencies. The size reduction property of the proposed antenna may be suitable for miniaturized planar and conformal

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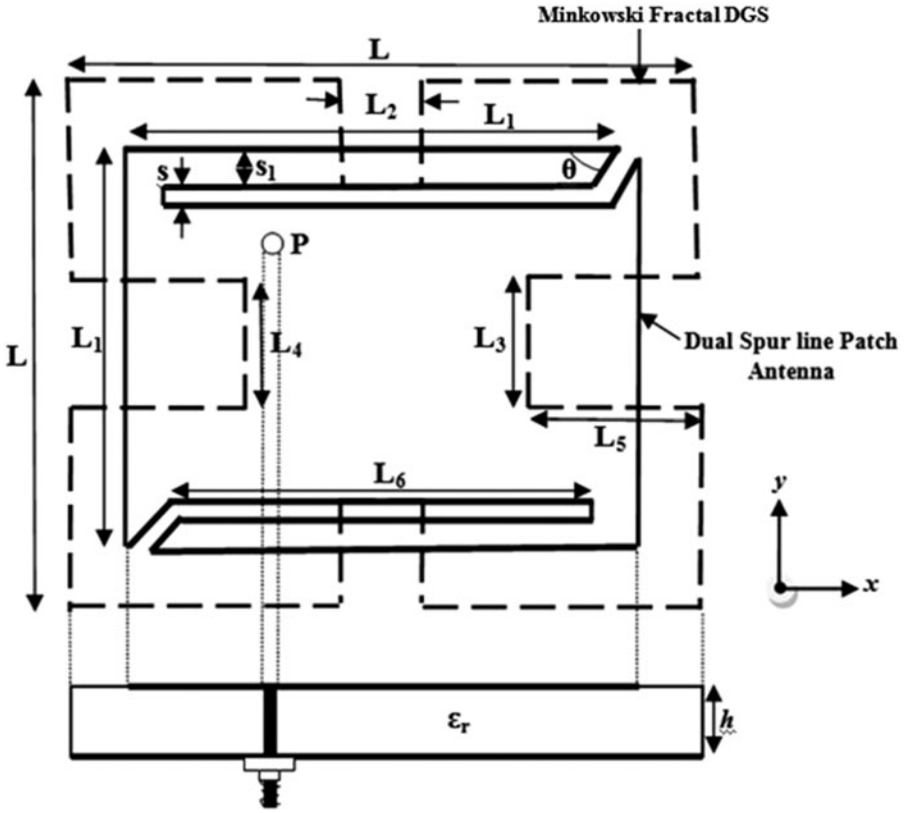

Fig. 1. Geometry of the proposed antenna (all dimensions in mm).

antenna arrays that are suitable for personal communication devices. The antenna resonates at frequencies of handheld devices. The antenna has to be further modified to be integrated on hand held device. The problem of back radiation due to defect on the ground plane can be reduced with the usage of absorbers without degrading the actual performance of the antenna in the form of bidirectional patterns [19].

In this paper, Minkowski shaped fractal geometrical element is adopted as optimum choice that allow both miniaturization and dual-band behavior. The optimal feed positions of iterative shapes of proposed antenna are same, which indicates that the feed position is insensitive to the variation in the spur-line length. Owing to the spur-line perturbation, the radiation pattern of the lower operating frequency has a relatively larger cross-polarization component than that of the higher resonant frequencies [20]. The embedded spur lines are normally placed at non-radiating edges of the patch and the design resonates at three bands. When the spur-line length is greater than about one-half of the patch side length ($L_6 > L_1/2$), the antenna can have a new resonant mode at a frequency less than the fundamental frequency. Furthermore, this new resonant mode and TM_{10} dominant mode can both be excited with good impedance matching using single probe feed located with (−8, 8) at point P.

II. ANTENNA DESIGN

The conventional square-shaped patch antenna with single coaxial probe feed is initially considered. Dual L-shaped slits are cut across the diagonal corners on the radiating portion along with minkowski shaped defective element on the metallic ground plane are as shown in Fig. 1. It is printed on a dielectric substrate of 3.175 mm thick with a relative permittivity of 2.33 and loss tangent of 0.0012. The radiating patch is completely covered by $36 \times 36 \times 3.175$ mm^3 dimensions on top.

The optimized dimensions of the top layer and bottom layer of antenna are displayed in Table 1. The purpose of metallization with fractal DGS on bottom layer is to shift the S_{11} response to a lower frequency without increasing the size of the radiating patch. Further, the impedance matching at obtained frequencies also needs to be maintained.

A) Design of DGS

Different techniques have already been used for the antenna size miniaturization such as using the substrate with high dielectric constant, edge shorted patch with shorting plates, slot loading, etc. The etching of a defect in the ground plane is also a unique technique for size reduction. This technique not only reduces the size, but also improves the antenna efficiency at low frequencies. Variety of slot geometries etched in the microstrip ground plane has been reported in the

Table 1. Optimized geometrical dimensions of the proposed structure.

Parameters	(mm)	Parameters	(mm)
L	40	S_1	2
L_1	36	S	1
L_2	6	L_6	29
L_3	12	θ	30°
L_4	12	P	(−8.8)
L_5	13		

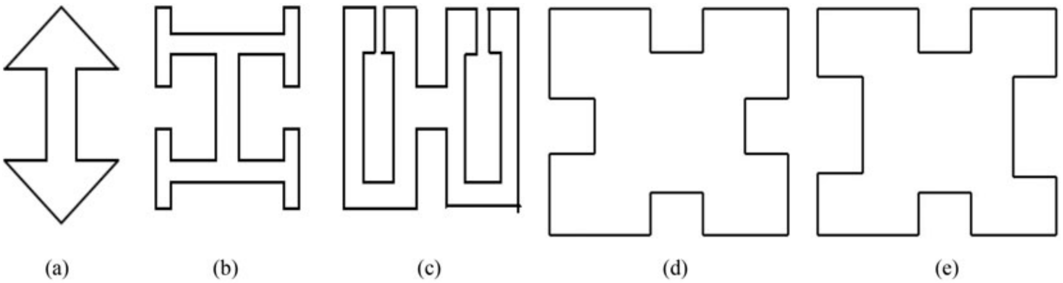

Fig. 2. (a) Arrow head, (b) H-shaped slot, (c) open-loop dumbbell, (d) symmetric fractal shape, and (e) asymmetric fractal shape.

literature [6]. The different geometries of slots are arrowhead slot, H-shaped slot, open loop dumbbell, and fractal slots as shown in Fig. 2.

Asymmetric minkowski fractal shaped cut on the metallic ground plane is chosen to increase the impedance bandwidth for dual-band compact. The difference in indentations on either side of the fractal DGS increase route length of current and hence, effective inductance, which gives rise to lower cut-off frequency. Selection of DGS structure placed on ground plane shows the impact of frequency tuning and improvement of the bandwidth and gain at resonant frequencies. The dimensions of the DGS slot are selected as part of design specifications such that modes change the position from higher frequency to lower frequency.

B) Design simulations

The design iterations of the model are as shown in Fig. 3 and the simulations are carried using Hyper Lynx IE3D tool. Representative S_{11} (in dB) characteristics with and without the fractal DGS compared with basic patch are presented in Fig. 4, to illustrate the significance of DGS. The ground plane is etched with minkowski fractal DGS configuration in order to achieve dual-band operation and resonates at lower frequencies. The asymmetry $(L_2 \neq L_3)$ and $(L_4 \neq L_6)$ lengths on the sides of the fractal DGS are tuned to obtain loading reactance values that reduces the resonant frequency of the TM_{mn} modes as desired. These design specifications are introduced to approach excitation of dual resonant modes accompanied with good impedance bandwidths over the operating bands for the proposed structure. The observations of gain and impedance bandwidth values from the simulations performed for all three design iterations are listed in Table 2.

The bandwidth is narrow operating at a frequency of 3.75 GHz for iteration of Fig. 3(a). Additional multi bands are generated for Fig. 3(b) (without DGS) with bandwidths maintained at all operated resonant frequencies. On the

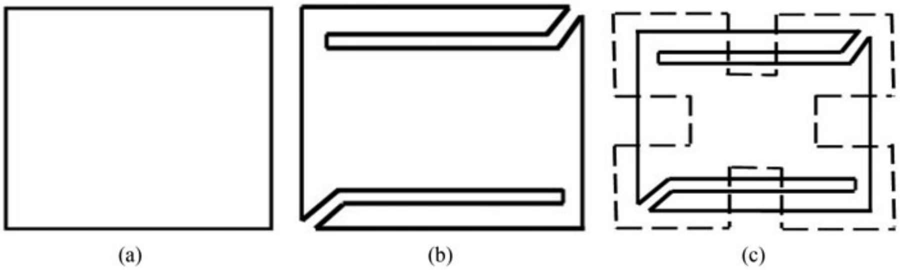

Fig. 3. Design iterations: (a) basic patch, (b) truncated L-shaped spur lines without DGS, and (c) truncated corners with Minkowski fractal DGS.

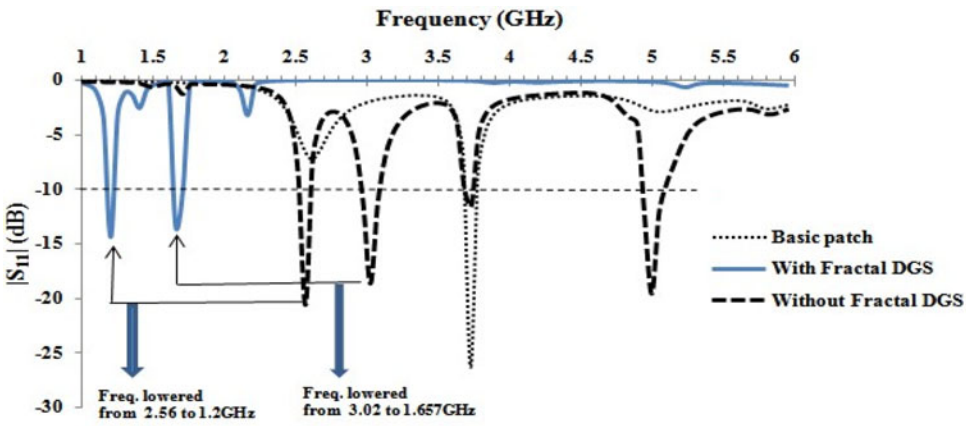

Fig. 4. Simulated return loss curves for design iterations.

Table 2. Simulated results of antenna design iterations.

Structure	Freq (GHz)	Impedance BW (MHz)	% BW	Gain (dBi)
Basic patch	3.75	70	1.87	4.52
Without fractal DGS	2.56	60	2.34	6.63
	3.02	160	5.29	6.71
	3.710	60	1.62	4.63
	4.985	170	33.41	2.49
With fractal DGS	1.205	50	4.15	2.95
	1.685	94	5.58	−2.53

other hand, Fig. 3(c) (with DGS) provides higher bandwidth over generated dual bands at lower frequencies, when compared with previous two designs. The simulated values of S_{11} show impedance bandwidth of 50 and 90 MHz for the operating bands of 1.202 and 1.685 GHz, respectively. From the observations, it shows that frequency is lowered from 2.56 to 1.2 GHz for first band and from 3.02 to 1.657 GHz for second band, respectively, for the third design iteration as indicated in Fig. 4. Simulated gain values at these resonant frequencies are listed in Table 2. From the generated text values, it indicates that gain value is compromised, especially at lower frequencies with the applied DGS.

C) Surface current distribution

The relationship between the excited surface waves and the cut off frequency (f_c) representing the existence of TE/TM modes is expressed by,

$$f_c = \frac{n}{4h\sqrt{\varepsilon_o\mu_o}\sqrt{\varepsilon_r\mu_r - 1}}, \qquad (1)$$

where $n = 0, 2, 4, \ldots$ for TM modes and $n = 1, 3, 5, \ldots$ for TE modes, h, the thickness of the dielectric; ε_r and μ_r are relative permittivity and permeability of the substrate; ε_o and μ_o are free space permittivity and permeability. Owing to high dielectric thickness ($h = 3.175$) for proposed antenna design, high energy is coupled to surface waves, thus increasing the surface waves. However, this results in increase in the antenna bandwidth and antenna efficiency. To decrease the resonant frequency of the antenna for a given surface area,

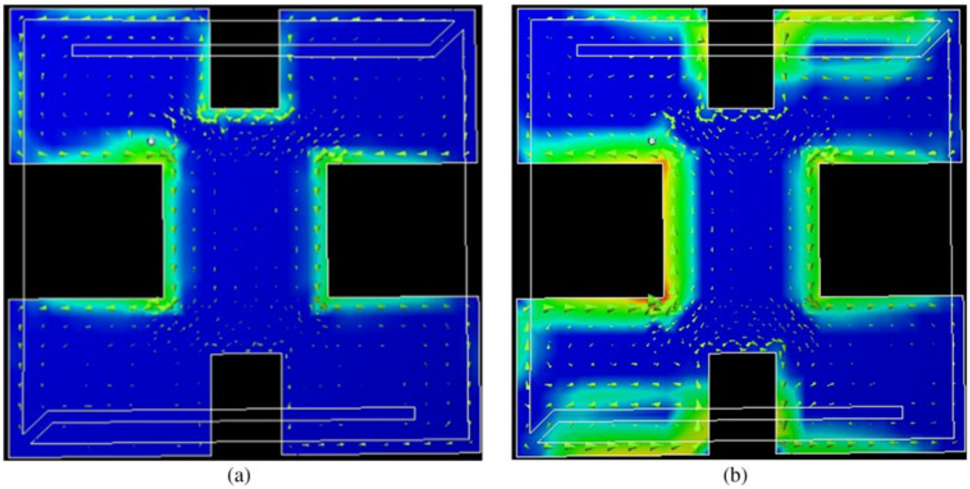
(a) (b)

Fig. 5. Average and vector current distributions at: (a) 1.202 GHz and (b) 1.657 GHz.

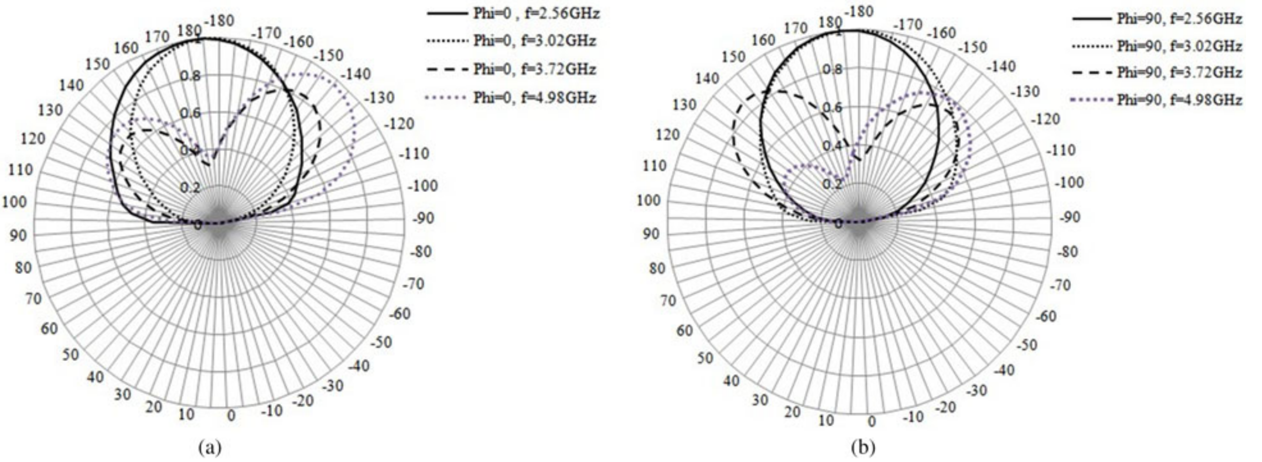

Fig. 6. Simulated E-plane radiation patterns for (a) phi = 0° and (b) phi = 90° at resonant frequencies of 2.56, 3.02, 3.72, and 4.98 GHz (y–z plane) (without DGS).

Fig. 7. Photograph of the proposed antenna working for L_1 and L_2 bands: (a) top view and (b) bottom view.

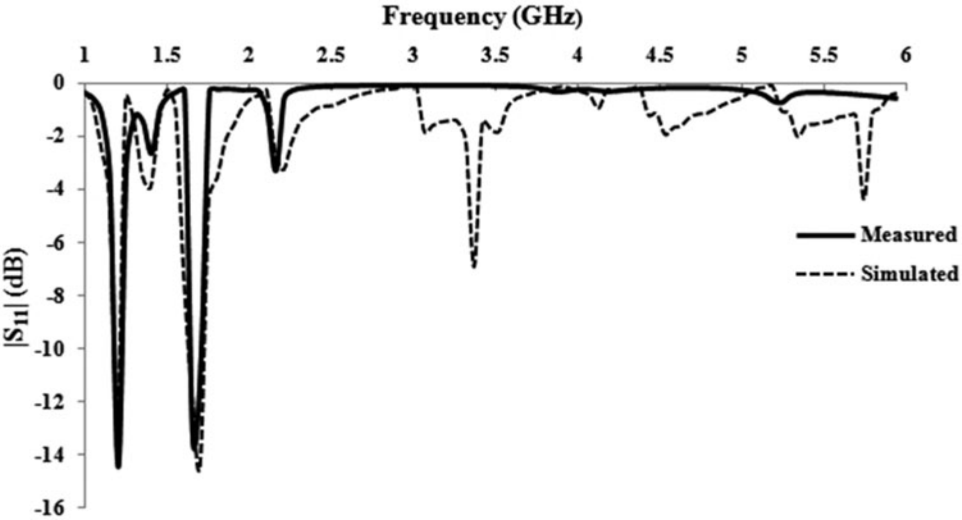

Fig. 8. Simulated and measured return loss curve for the proposed antenna.

the current path must be maximized with in the area. The key to reduce the size of the antenna is to maximize the current patch of the printed antenna. It is found that Minkowski fractal DGS with probe feed achieves a significant reduction in size of antenna using frequency shift and also shown that bandwidth is enhanced.

The IE3D simulated surface current distributions at the frequencies of 1.202 and 1.657 GHz are illustrated in Fig. 5. It can be clearly seen that the current distributions are different for dual bands. L-shaped spur lines and fractal DGS modify the

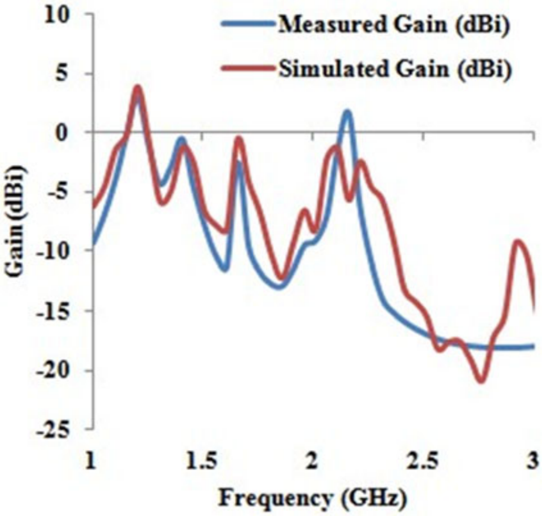

Fig. 9. Measured and simulated gain response of the proposed antenna.

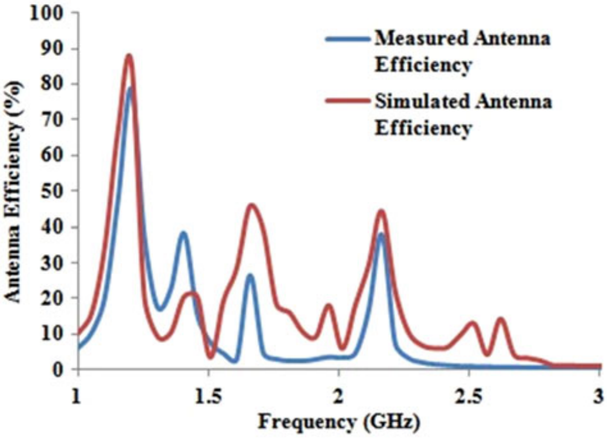

Fig. 10. Measured and simulated antenna efficiency for the proposed antenna.

current distribution for exciting the antenna at both frequencies. Most of the current flow is at the edges of the patch at 1.202 GHz as given in Fig. 5(a), whereas the surface current at 1.657 GHz is mainly concentrated around asymmetrical boundaries of fractal DGS indicating the presence of resonance as drawn in Fig. 5(b). This implies that for the high resonant band, significant improvement in the bandwidth is observed due to the placement of fractal DGS. Enhanced impedance bandwidth is achieved with dual L-shaped slit antenna loaded with fractal DGS by optimizing the dimensions to adjust its different resonances.

D) Simulated radiation patterns

The simulated *E*-plane radiation patterns are represented as shown in Fig. 6 for operating frequencies of 2.56, 3.02, 3.72, and 4.98 GHz, respectively, for the antenna without DGS. It is found that poor radiation characteristics are observed at high resonant modes. This is due to back propagation of the ground plane.

III. EXPERIMENTAL RESULTS AND DISCUSSION

To validate the hypothesis made pertaining to the proposed antenna experimentally the antenna is fabricated and tested. Top view and bottom view of the proposed antenna shown in Fig. 7 is measured using Agilent E5071C vector network analyzer. The simulated and measured return loss curve for the antenna is presented in Fig. 8.

The measured values of S_{11} show a bandwidth of 6.3% (1.17–1.25 GHz) and 4.6% (1.5–1.65 GHz) at lower and upper bands, respectively. It is also found that the measured

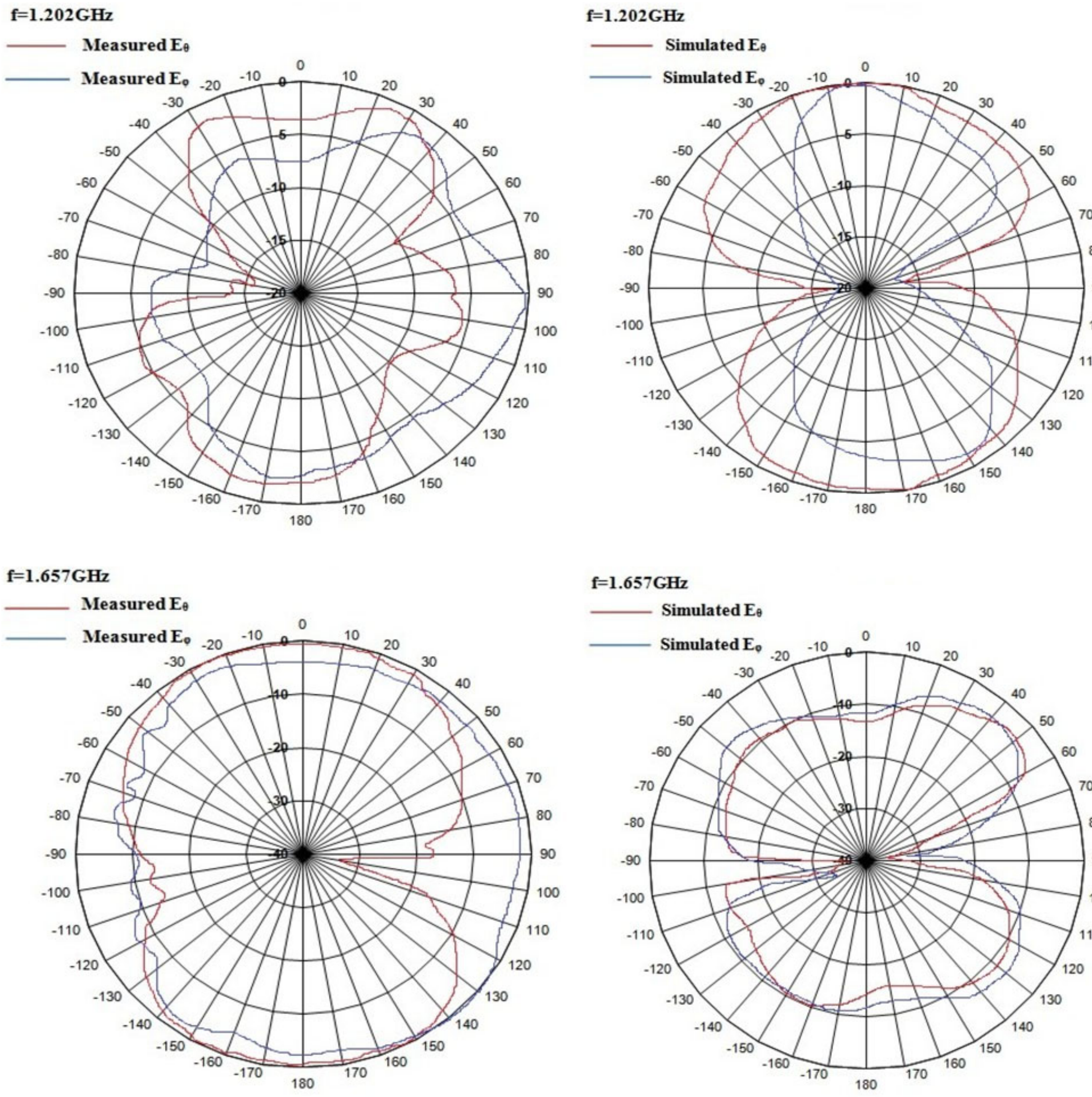

Fig. 11. Measured and simulated radiation patterns in the *y*–*z* plane at 1.202 and 1.657 GHz.

Table 3. Simulated results of antenna design iterations.

Antenna/year	Description	Freq. (GHz)	Size reduction (based on low resonant freq.)	10 dB return loss BW (%)	Volume (mm^3)	Gain (dBi)	Applications
[5]	Fractal DGS for Planar Circuits	3.76 5.75	20%	–	13 × 13 × 0.762	NIL	RF Low-pass filters
[11]	Modified Sierpinski Fractal	0.9 1.8 2.4	NIL	22 54.3	100 × 53.7 × 0.8	0.34 4.11 2.75	GSM/PCS/DCS
[15]	Broadband antenna with V-slot DGS	5.8	NIL	45	NIL	NIL	Array applications for low XP
[17]	CPW-fed H-shaped DGS	2.4	10%	8.3	38 × 22 × 1.59	1	WLAN
[16]	Z-type DGS for BW enhancement	10 With DGS	45%	2.8 12.1	32 × 32 × 1.59	NIL 8.7	X-band operations
[18]	Wideband DGS Circular ring	11.8	NIL	8	50 × 50 × 1.59	4.42	X-band application
[19]	Polygonal defect	9.5	22%		10 × 7.5 × 0.75	2.5	Planar arrays
[Proposed work] Minkowski DGS	Truncated antenna with DGS	1.202 1.657	80% 64%	6.3 4.6	40 × 40 × 3.1 75	3.9 −0.5	GPS wireless receivers, Iridium
	Spur-line antenna without DGS	2.56 3.02 3.725 5.01	19% NIL NIL NIL	5.8 4.2 3.04 2.15	36 × 36 × 3.1 75	6.4 6.2 4.9 3	WLAN/WiMAX applns

values are in good agreement with the simulated values. Figure 9 demonstrates the measured and simulated gain of the antenna versus frequency for antenna with DGS. The measured gain for the resonant frequencies is 3.9 and −0.5 dBi for L_1 and L_2 bands, respectively. As long as receiver is assumed to be near to the transmitter, negative gain can be acceptable. The gain in the upper band is about −0.5 dBi and the negative gain value is due to the low antenna efficiency at that band and the antenna designed is likely to be used for handheld devices up to −2 dBi. There is a reduction in gain predicted by the simulation which actually does not exist as given by the measurement. This reduction in gain shown by simulation may be due to limited number of grid points considered during simulation which may be affecting the results for the case of defected ground structure. Owing to the aforementioned reason, a difference of measured and simulated gain value is observed with maintained efficiency at 2.2 GHz. It is evident that the results obtained for the frequencies of operation smaller than 2 GHz via simulation approximate the respective measurements. Considering antenna performance requirements and the tradeoffs associated with operation over dual frequency bands, size constraint is typically required for handheld devices. The measured radiation efficiency of about 79 and 38% at lower and upper resonance frequencies, respectively, as shown in Fig. 10.

The measured and simulated radiation characteristics at the y–z plane of the antenna at 1.2 GHz (L_1 band for GPS receiver) and 1.65 GHz (L_2 band and Iridium), respectively, are presented in Fig. 11.

Table 3 gives the performance of the proposed antenna when compared with current existing models. From the observed results, the improved −10 dB impedance bandwidth and ~72% of average size reduction of antenna are obtained.

The size reduction effect has been calculated by comparing a traditional square patch antenna's first resonant frequency with that of the proposed DGS-based antenna. For example, a regular square patch antenna for 1.2 GHz required a length and width of 80 mm. The proposed antenna resonates at the same frequency with a size of $36 \times 36\ \text{mm}^2$. Thus, the obtained size reduction is 79.75% and calculation is performed $[1-(36 \times 36\ \text{mm}^2/80 \times 80\ \text{mm}^2) \times 100]$. This concept defines the size reduction property for the designed antenna. With reference to the resonant bands, the average size reduction is calculated for both bands. ~80% size reduction for first band and ~64% for the second band. Overall size reduction is nearly ~72%. The proposed antenna has to be modified further to be integrated on handheld device and placing reflectors at a distance of $\lambda_g/4$ of antenna produce unidirectional patterns. In handheld devices, the designed dual-band antenna can redirect the back radiation by proper selective dimensions of defect on back side metal of the patch without degrading the antenna performance. Typical frequencies in L_1 and L_2 bands generated are used for linearly polarized (LP) GPS receiver applications and they are unique to each application which can be placed onboard aircraft, ships, submarines, cars, and trucks. Iridium phone antenna is used for handheld telephone services works at 1.6 GHz.

VI. CONCLUSION

Minkowski fractal DGS-based truncated slit antenna is designed, fabricated, and tested for dual-band applications. Frequency shift property of DGS structure makes the proposed antenna to resonate at lower frequencies. Overall size reduction of 72% is achieved with this DGS-based antenna. Good agreement is found between the measured and simulated results of the operating antenna. The results show acceptable gain value at both LP frequency bands. Different wireless applications will be benefited with the designed single-layered fractal DGS antenna.

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