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Fractal Inspired Hybrid Microstrip Patch Antenna for Surveillance Drone Applications

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ABSTRACT

Drone based surveillance and communication systems are playing a vital role in modern days for both military and civilian applications. Antennas with low profile, smaller size, and light weight are essential for the realization of these systems. A novel fractal-inspired hybrid microstrip patch antenna realized with Sierpinski gasket fractal slots cut in the radiating patch along with corresponding ground structure simultaneously defected with Sierpinski carpet fractal slots is reported for the first time. The antenna resonates at 2.4 GHz with a measured return loss of 17 dB, gain of 7 dB and measured 3 dB beamwidth is of the order of 70°. The current approach leads to the size reduction of the antenna to the extent of 55 % in comparison to standard radiating patch antenna resonating at the same frequency. The fractal-inspired hybrid microstrip patch antenna is a promising candidate for drone-based surveillance and communication applications owing to its miniaturization and good directional radiation properties.

keywords: Defected Ground Structure (DGS); Fractal; Sierpinski carpet; Sierpinski gasket; Microstrip patch

NOMENCLATURE

L : Length of radiating patch
W : Width of radiating patch
L_s : Lengthof ground plane
h : Substrate height
c : Light velocity
f_r : Resonant frequency
$€_r$: Relative dielectric constant

1. INTRODUCTION

In recent times, drones are being used extensively to carry out myriad tasks for military applications[1-3] such as reconnaissance, surveillance, communication, data relay, patrolling, and demining. NATO has defined Unmanned Aerial Vehicle (UAV) categories and classes[4]. Accordingly Micro and Mini class of UAVs may be considered as drones to carry out surveillance and communication missions. The payloads for such surveillance drones impose stringent restrictions on Size, Weight and Power (SWaP) requirements.

The advancements in electronics and material technology pave the way towards realizing miniaturized electronic hardware for drones. On the other hand, antenna is another important sub-system in realization of this kind of lightweight SWaP optimised payloads. Antennas for drones need to be judiciously chosen by considering several salient factors like spatial coverage, gain, low profile, smaller size, light weight etc. The quality and efficiency of drone-based surveillance payloads largely depend on the efficient miniature antenna design. Antenna miniaturization techniques broadly include use of fractal geometry concept as a space-filling factor, use of high permittivity substrate, different shape of slots cut in the radiating patch, use of Defected Ground Structure, use of meta materials or a combination of the above techniques[5-15].

The foremost scholar in the field of fractals, Benoit Mandelbrot, realised fractals in 1975[5]. Fractal geometry[6] leads to a very simple process of iteration, and differs from classical geometry, which incorporates the formulation for shape definition. By applying the interesting repetition or self-similarity property of fractal geometry over two or more orders reduces the antenna dimensions. The space filling enhances the bandwidth by making closer multiple resonances. Thus, incorporating fractal geometry with EM theory in research of fractal antenna engineering[7] is leading to several new areas of research in antenna technology. Puente[8], *et al.* introduced the Sierpinski gasket-based monopole fractal antenna having multi-band performance. Sung[9] has proposed a wideband fractal slot antenna using Sierpinski fractal geometry in which the number of resonant bands depends upon the iterations of the Sierpinski square radiating elements. Cai[10], *et al.* presented a small-size antenna designed using fractal meta surface and fractal resonator for WiMAX band applications. A miniaturised circularly polarized antenna with wide beamwidth was reported in reference 11, which works on the GPS band of 1.575 GHz. It is formed using two pairs of printed monopoles which are orthogonally placed, coupled with inter-digital capacitors and grounding strip outer lines. A dual-band miniature monopole

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chip antenna having three substrates with four copper layers is reported in[12] for WLAN applications. Two metamaterial Minkowski fractal antennas one with a complete ground plane and the other using defective ground structure (DGS) with square split ring resonator (SSR) for 5G applications are reported in[13]. The self-similar Minkowski fractal antenna with circular DGS for multi-band applications is reported in reference 14. A rectangular microstrip patch antenna with fractal DGS for Wi-Fi applications is reported in reference 15.

In this paper, a fractal inspired hybrid microstrip patch antenna is realized by employing a novel concept of fractal slots cut both in the radiating patch and the ground plane. The antenna resonant frequency (f_r) is chosen at 2.4 GHz of ISM band which is widely used for drone-based surveillance and wireless communication applications. The concept can be extended to any frequency band of interest by following the proposed scheme with proportionate dimensional scaling. The realized antenna has considerable size reduction with same resonating frequency and also possesses good gain and directional radiation characteristics which are the prime features for antenna to address the drone-based surveillance applications.

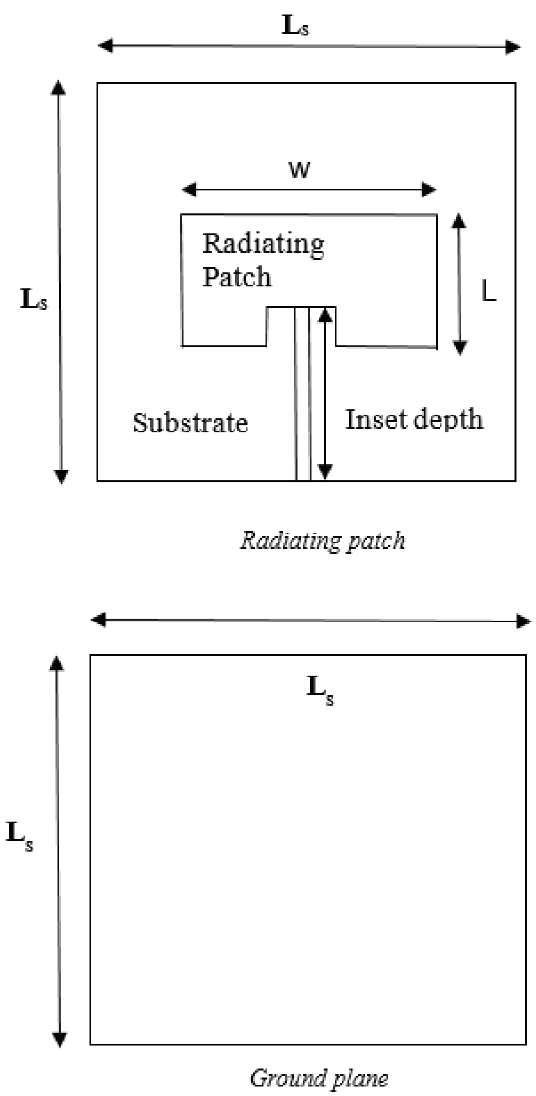


Figure 1. Microstrip patch antenna with inset feed.

2. ANTENNA CONFIGURATION AND DESIGN

The antenna configuration is derived by following the following steps:

2.1 Standard Microstrip Patch Antenna With Inset Feed

A standard rectangular microstrip patch antenna with inset feed is considered, the parameters of which are shown in Fig. 1. The standard antenna dimensional parameters are responsible for tuning the frequencies. The inset feed is used to fed antenna by considering configuration of Defected Ground Structure. The design equations[16] are used for the computation of dimensions of the antenna operating at 2.4 GHz to realize on a PTFE substrate (€r = 2.2 and h=1/16”). The computed dimensional details of the standard microstrip patch antenna[17] are given in Table 1.

Table 1. Dimensional details of standard microstrip patch antenna

Parameter	Dimension (mm)
Patch length (L)	41.19
Patch width (W)	49.15
Inset depth	12.63
Ground plane length (L_s)	92.28
Ground plane width (L_s)	92.28

2.2 Radiating Patch Cut With Sierpinski Gasket Fractal Slots

Sierpinski gasket fractal slots are cut at all the four corners of the radiating patch as shown in Fig. 2. It is important to note that, in the process of cutting fractal inspired slots in the radiating patch, the position and orientation of Sirepinski gasket need to be properly chosen at each corner of the radiating patch without disturbing the basic fractal gasket geometry. In a similar fashion, slots following different other fractal geometries can also be introduced in the radiating patch by maintaining fractal self-similarity properties.

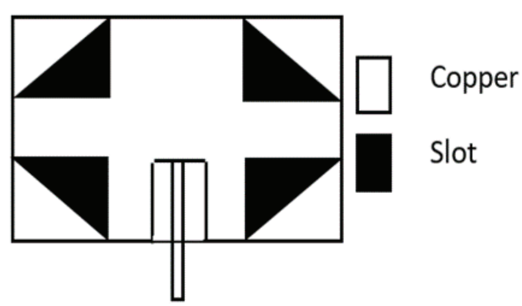


Figure 2. Radiating patch cut with sierpinskigasket fractal slots.

2.3 Defected Ground Structure

The defected ground structure is obtained by cutting square slots in the ground plane as per Sierpinski Carpet Fractal Geometry. The first order is obtained by cutting a single square slot in the ground plane and the second order obtained by removing eight squares with one third scaling. The realized DGS with 1st order and 2nd order Sierpinski carpet fractal slots is shown in Fig.3. The same procedure can be applied for any subsequent higher order iterations by maintaining proper fractal self-similarity properties. Any other shape of slots such circular slots[17] can also be employed in realization of defected ground structure.

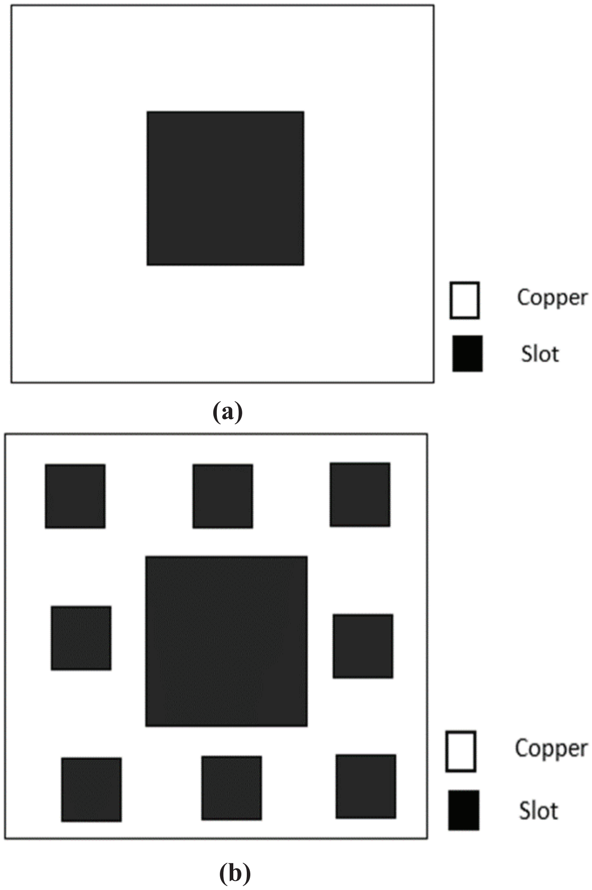


Figure 3. Defected ground structure with 1st and 2nd order sierpinski carpet fractal slots: (a) 1st order DGS, and (b) 2nd order DGS.

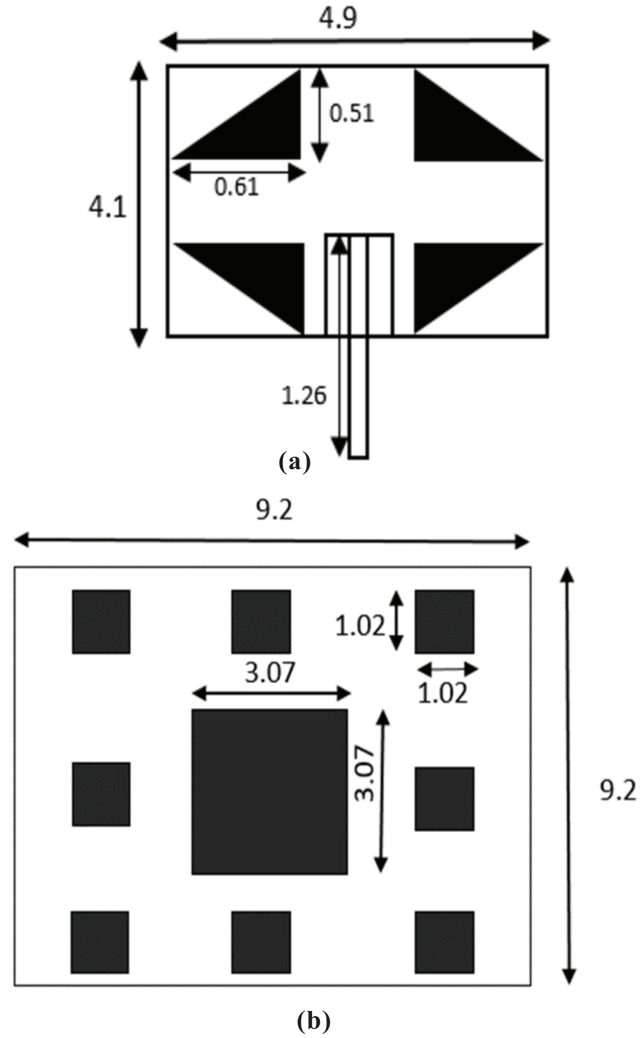
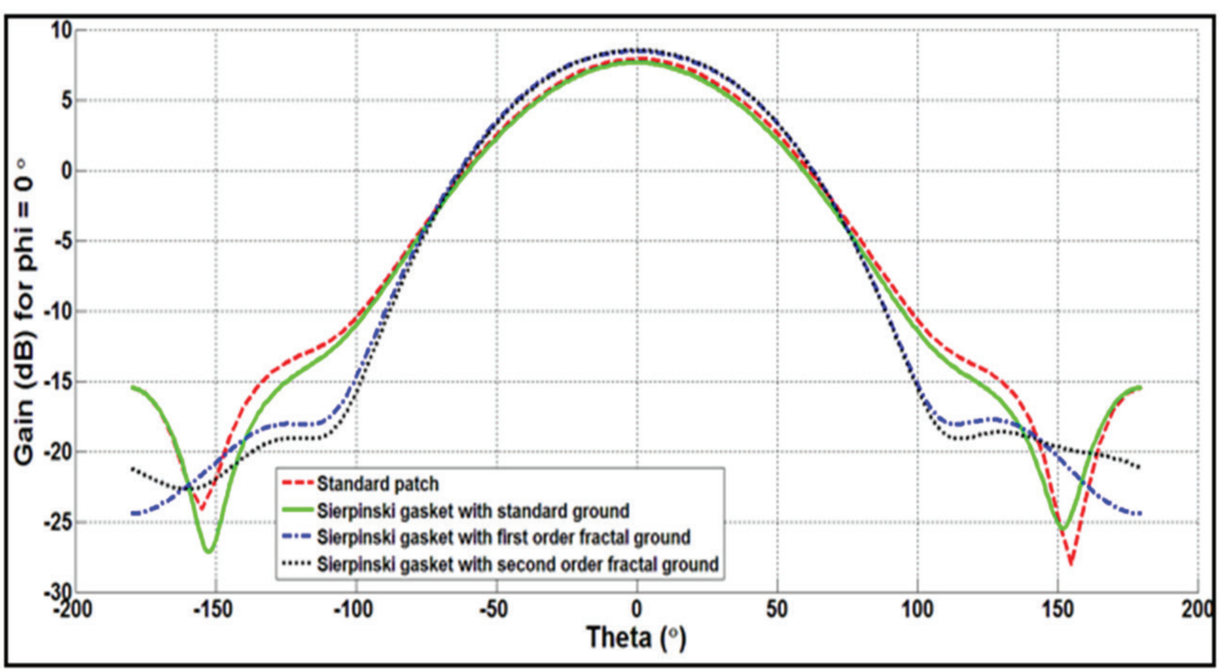
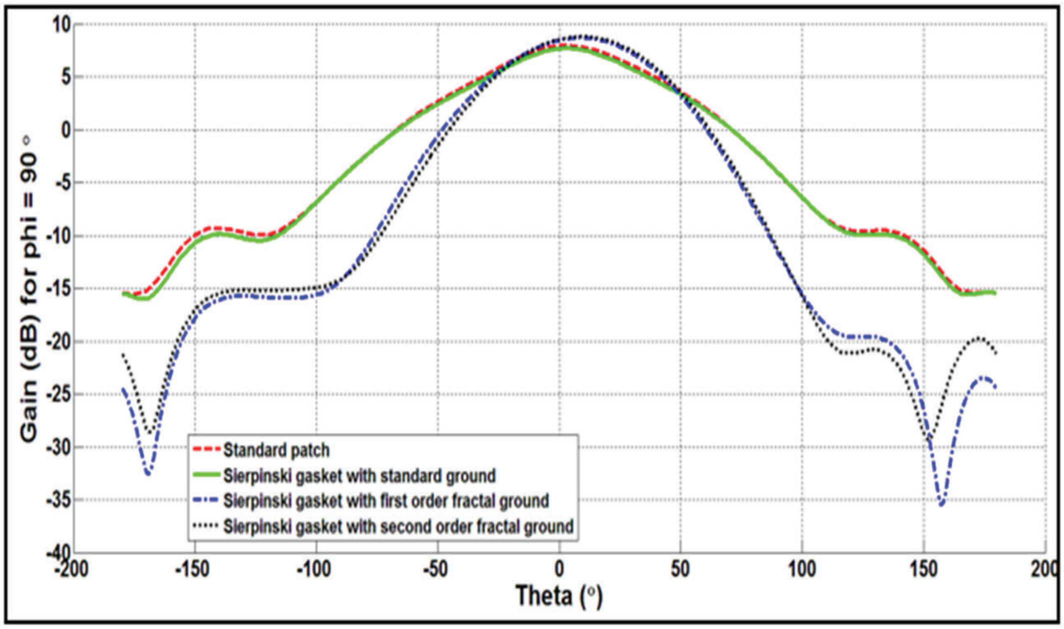


Figure 4. Fractal inspired hybrid microstrip patch antenna, (b) Bottom view (Dimensions in cm).



(a)



(b)

Figure 5. Simulated gain plots, (a) Top view (Dimensions in cm)a) Gain Plot φ=0°; and (b) Gain Plot φ=90°.

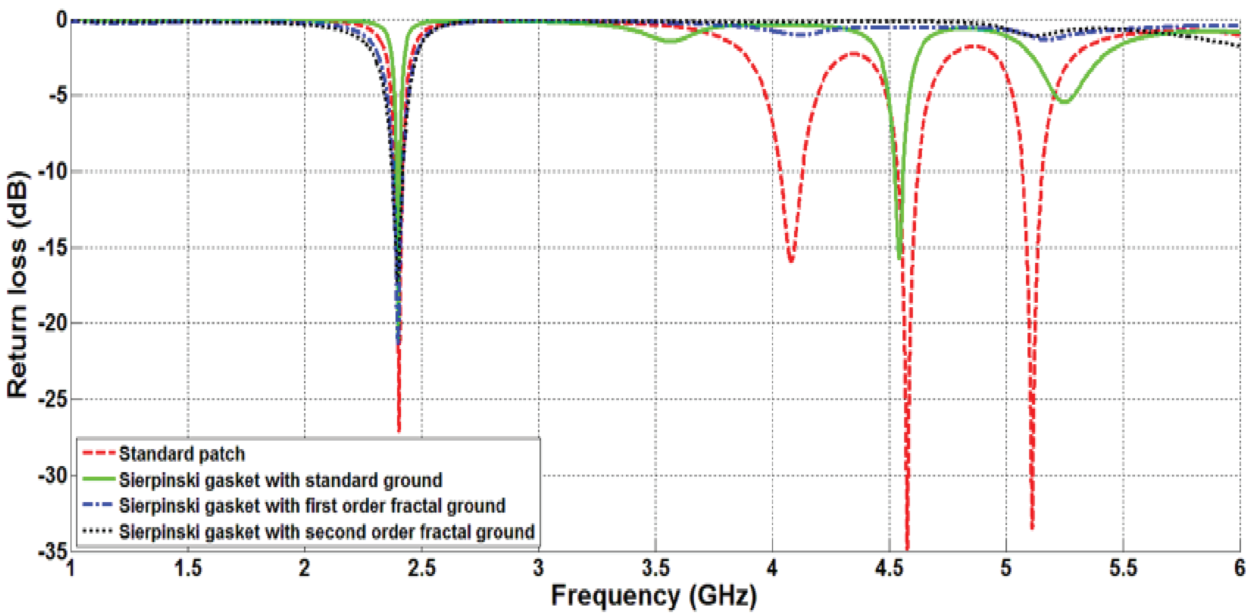


Figure 6. Simulated return loss plots.

2.4 Final Antenna Configuration

The final configuration of the proposed fractal inspired hybrid microstrip patch antenna indicating the dimensional details is given in Fig. 4.

3. SIMULATION STUDIES

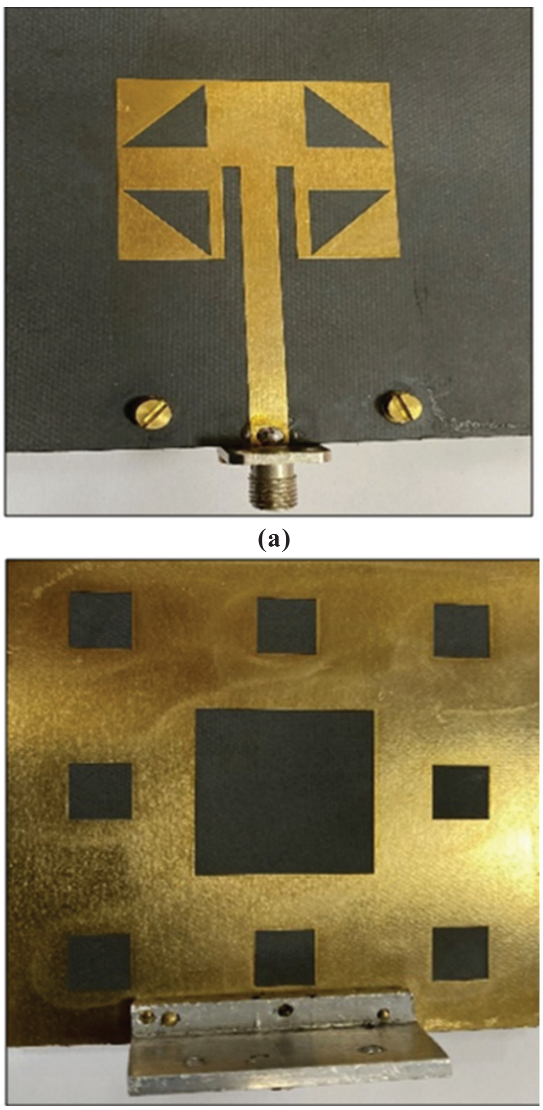
The fractal inspired hybrid microstrip patch antenna is simulated using HFSS tool. For comparison purpose, standard microstrip patch antenna, radiating patch cut with Sierpinski gasket slots, defective ground structures generated with first and second order Sierpinski carpet geometries are also simulated. The comparative gain and return loss plots are presented in Figs. 5-6. From these plots, it is observed that the proposed hybrid microstrip patch antenna resonates at the designed frequency of 2.4 GHz, and other higher order harmonic frequencies are suppressed due to the current distribution disturbances at these harmonics. Further, size reduction of the radiating patch to the extent of 55 % relative to the standard antenna is observed. The antenna parameter comparison in different configurations is indicated in Table 2.

4. MEASURED RESULTS

The fractal inspired hybrid microstrip patch antenna is fabricated using RT Duroid material ($\varepsilon_r = 2.2$, substrate height= 1/16") and tested. The photograph of the same is given in Fig.7. The measured return loss plot of the fabricated prototype antenna is shown in Fig 8. The antenna is resonating at 2.4 GHz as designed. The measured radiation patterns

Table 2. Simulated performance comparison of proposed fractal inspired hybrid microstrip patch antenna with other antenna configurations

Configuration	Patch dimensions (cm)	Area (cm^2)	Reduction in size (%)	Resonant freq. (GHz)	Return loss at Resonant frequency	Peak Gain (dB)	HPBW at phi = 0 °	HPBW at phi = 90°
Standard microstrip Patch Antenna	Length: 4.11 Width: 4.92	20.22	---	2.4043	27.11	7.9	74°	70°
Radiating patch with Sierpinski gasket slots and standard ground plane	Length: 3.43 Width: 4.22	14.47	28.4	2.4008	21.17	7.16	74° .	71°
Radiating patch with Sierpinski gasket slots and 1st order fractal DGS generated with Sierpinski carpet slots	Length: 3.14 Width: 3.63	11.40	43.6	2.4009	21.47	7.06	80°	64°
Radiating patch with Sierpinski gasket slots and 2nd order fractal DGS generated with Sierpinski carpet slots (Hybrid microstrip patch Antenna)	Length: 2.84 Width: 3.22	9.14	54.79	2.3980	17.23	7.12	78°	74°



(a)

(b)

Figure 7. Photograph of fractal inspired hybrid microstrip patch; (a) Top view showing the Sirpinski gasket Fractal slots cut in the radiating patch; and (b) Bottom view showing the Defected Ground Structure generated with second order Sirpinski carpet fractal slots.

in both vertical and horizontal polarizations are shown in Fig. 9, which shows good agreement with the simulated patterns. The typical 3 dB beamwidth of antenna is 76° in both planes and the measured gain is 7 dB at the resonant frequency of 2.4 GHz. The measured radiation patterns indicate the pattern purity of hybrid microstrip patch antenna which is the prime requirement for surveillance applications. The proposed approach has resulted in the antenna size reduction with no compromise in the gain and back radiation features, and no multiple resonances observed.

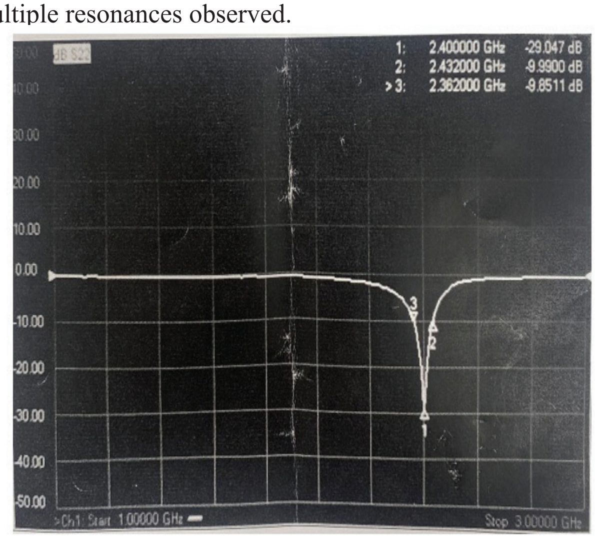
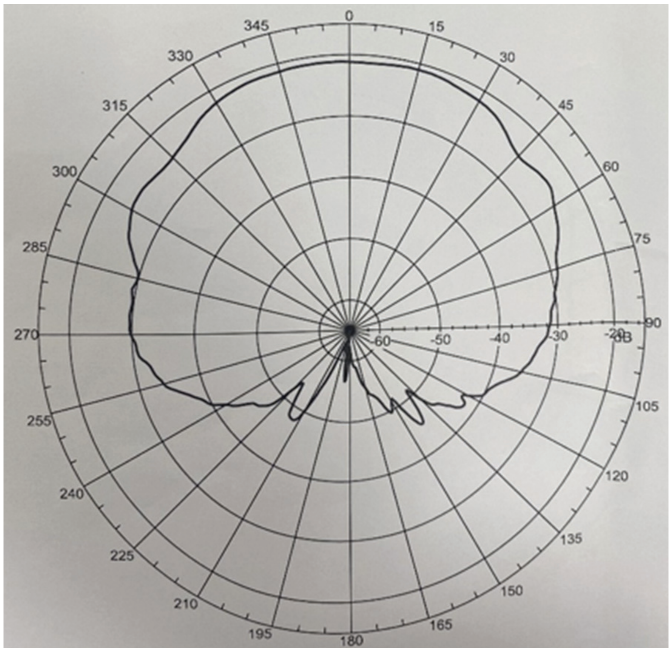


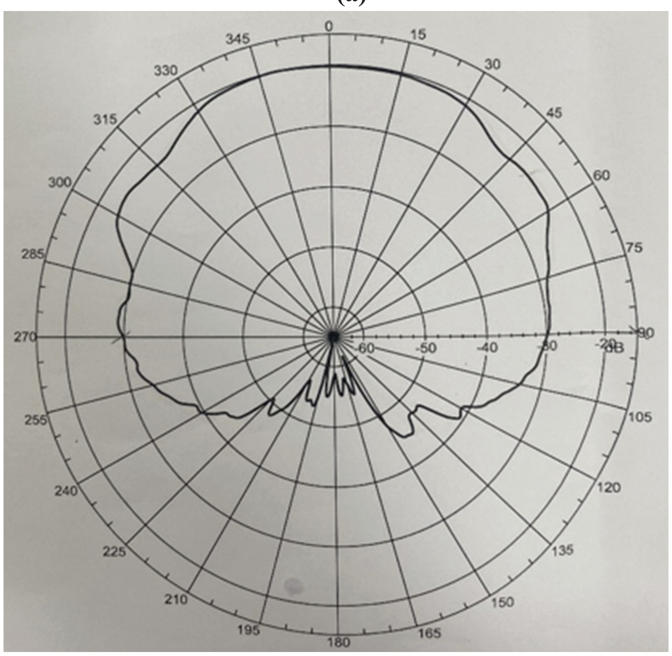
Figure 8. Measured return loss plot of fractal inspired hybrid microstrip patch antenna.

5. CONCLUSIONS

A new type of Fractal inspired Hybrid Microstrip patch antenna is proposed in the paper. The measurement results of the fabricated prototype antenna are in close agreement with the simulation. The proposed approach resulted in antenna miniaturization to the extent of 55 % as compared with the standard patch antennaoperating at the same resonant frequency. There are no multiple resonances observed and the proposed antenna is an attractive candidate for drone-based surveillance applications owing to its low profile, miniature size, pattern purity and good gain characteristics.



(a)



(b)

Figure 9. Measured radiation plots of fractal inspired hybrid microstrip patch antenna, (a) Horizontal polarization; and (b) Vertical polarization.

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In the present work, he has contributed in evolving the Fractal inspired hybrid microstrip patch antenna configuration for surveillance drone applications and carried out simulation , antenna fabrications and measurements.

Dr D. Vakula obtained her PhD degree in Fault Diagnostics of Antenna Arrays from the National Institute of Technology, Warangal, India. She is working as a Professor at the National Institute of Technology. Her areas of interest include: Phase array antennas, ultra wideband antennas, multiband antennas, fault diagnostics, neural networks, and metamaterials.
In the present work, she has reviewed the simulation results and test results and provided overall guidance in evolving the novel approach in the realization of proposed antenna.

Dr M. Chakravarthy obtained his PhD (ECE) from Andhra University, Visakhapatnam. Presently, he is a Senior Scientist working at DRDO-DLRL, Hyderabad. His areas of interest include: Broadband HF/VHF/UHF/MW/MMW Antennas & Arrays and computational electromagnetics.
In the present work, he has reviewed the design methodology and prototype antenna evaluation results.