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A New Approach in Realisation of DGS Microstrip Patch Antennas With Fractal Geometry

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ABSTRACT

A new approach in realization of Defected Ground Structure Microstrip Patch antennas with Fractal Slots cut in the ground plane has been presented. The presented approach resulted in miniaturization of radiating patches and avoidance of multiple resonances which are prime considerations in antennas for Wi-Fi applications. A rectangular Microstrip patch is taken as a basic radiating patch. In the ground plane, square and circular slots following Sierpinski Carpet Fractal Geometry are cut resulting in Defected Ground Structure (DGS) Microstrip Patch antenna. The antenna is designed to operate at 2.4 GHz and the performance characteristics have been simulated using HFSS software. The proto-type DGS Microstrip patch antenna with square fractal slots is fabricated and tested. The measured results are in good agreement with the simulation studies. The technique has also resulted in size reduction of radiating patch compared to the standard microstrip patch antenna operating at the same frequency.

Keywords: Defected Ground Structure (DGS); Fractal; Sierpinski carpet; Square slots; Circular slots; Microstrip patch antenna

NOMENCLATURE

W, L : Dimensional parameters of patch antenna
h : Height of substrate
c : Speed of light in free space,
f_r : Resonant frequency
$VSWR$: Voltage standing wave ratio
CPW : Compact coplanar waveguide
L_{eff} : Effective length of the patch

1. INTRODUCTION

There is an ever-increasing demand for miniaturized patch antennas for wireless communication applications in portable devices. A slot in proper shape cut in the ground plane of Microstrip patch antennas lowers the resonant frequency of the antenna and thus leads to size reduction. A wide variety of slot shapes such as Spiral heads, arrow head slot, interdigital DGS etc. are used in the realization of Defected Ground Structures[1]. A Defected Ground Structure (DGS) has been implemented for resonating frequency shift of an antenna by disturbing the current distribution with miniaturization up to 50% and other related studies are also reported[2-4]. A circular ring microstrip antenna with a defected ground having four circular rings with impedance bandwidth of about 1.33 GHz in the X-band with a significant gain is reported[5]. A multi-band semi-circle fractal antenna with U-shaped Slot DGS is reported[6] to achieve multi-band antenna performance. A Multiband Behavior of Wideband Sierpinski Fractal Bow-Tie Antenna is also proposed for wide band application[7]. A compact coplanar waveguide (CPW) monopole antenna comprising a fractal radiating patch embedded with folded T-shaped element (FTSE) operating over a frequency range of 2.94 -11.17 GHz with a fractional bandwidth of 117 percent for VSWR≤ 2 is reported[8]. An Inverted-L (IL) – shaped radiating element and a parasitic element in the ground plane are reported[9] to generate three resonant modes for triple band WLAN applications at 2.3/3.5/5.5 GHz WiMAX and 5.2/5.8 GHz. A novel compact multiband Broadside Coupled Split Ring Resonator (BC-SRR) loaded fractal antenna with Perturbed Sierpinski carpet fractal geometry for 4G and other wireless systems is reported[10].

In this paper, a new method of realization of Defected Ground Structures by introducing slots following Fractal geometry[11] in the ground plane of the microstrip patch antenna is presented. Two configurations viz. square and circular slots cut in the standard ground plane following the Sierpinski carpet of 1st, 2nd, and 3rd order fractal geometry are discussed. Simulation of Defected Ground Structure microstrip patch antenna in both these configurations operating at 2.4 GHz have been carried out using HFSS software. The third order fractal slot Defected Ground Structure microstrip patch antenna has been fabricated on RT Duroid (ε_r =2.2) and measured results are presented.

2. ANTENNA DESIGN

2.1 Radiating Patch

A Rectangular microstrip patch antenna with a Radiating

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Patch and a Ground plane is shown in Fig. 1. The antenna dimensional parameters length (L), width (W), substrate height (h), and dielectric constant (ε_r) are responsible for tuning the frequencies. The antenna is fed with an inset feed by considering Defected Ground Structure configuration. The following design equations[12] are used for the computation of dimensions of the rectangular microstrip patch antenna:

Effective dielectric constant:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{w})(1 + 12\frac{h}{w})^{-0.5} \quad (1)$$

where, `w' is width of patch and `h' is height of substrate.

Fringing factor:

$$\triangle L = 0.412h \frac{(\varepsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \quad (2)$$

where, `w' is width of patch, `h' is height of substrate

Calculation of Length:

$$L = L_{eff} - 2\triangle L \quad (3)$$

$$L_{eff} = \frac{c}{2Lf_0\sqrt{\varepsilon_{reff}}} \quad (4)$$

where, `L' is length of patch,`ΔL' is extension in length due to fringing.

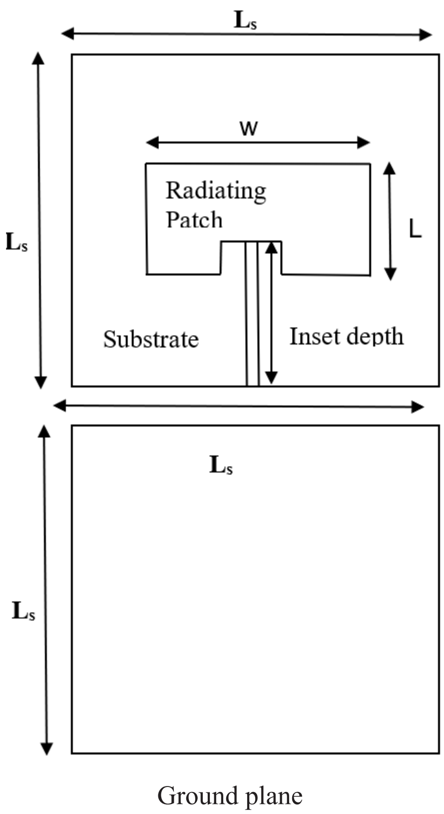


Figure 1. Microstrip patch antenna.

Calculation of width:

$$W = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (5)$$

Where, `c' is the speed of light in free space, *fr* is the resonant frequency.

Calculation of ground plane dimension:

Table 1. Dimension details of basic rectangular microstrip patch antenna

Parameter	Dimension (cm)
Patch Length (L)	4.119
Patch Width (W)	4.915
Inset Depth	1.263
Ground Plane Length (L_s)	9.228
Ground Plane Width (L_s)	9.228

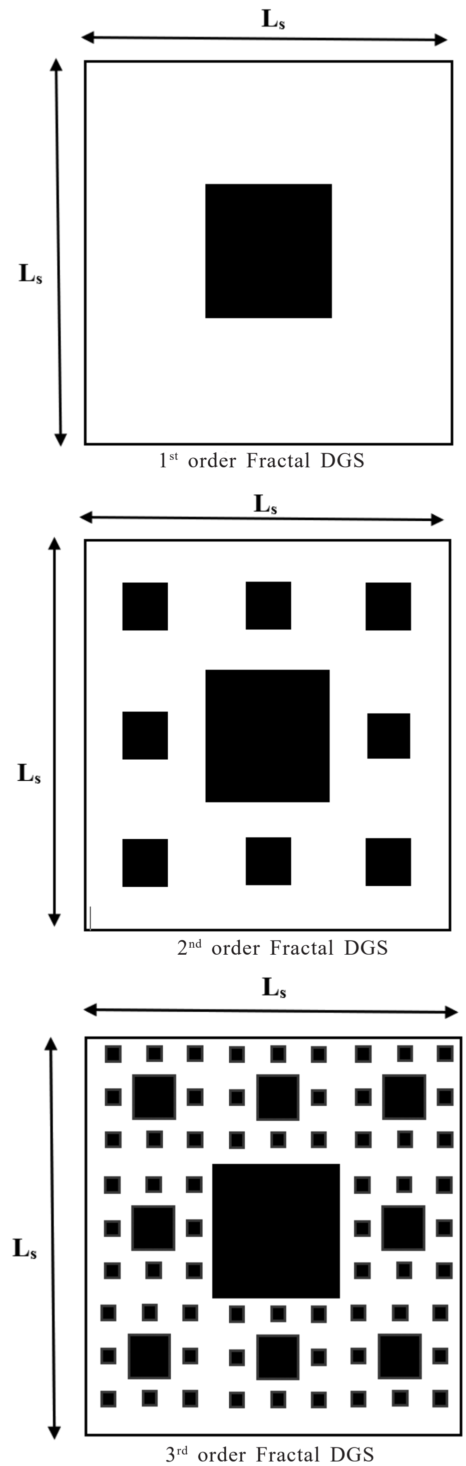


Figure 2. DGS with square fractal slots.

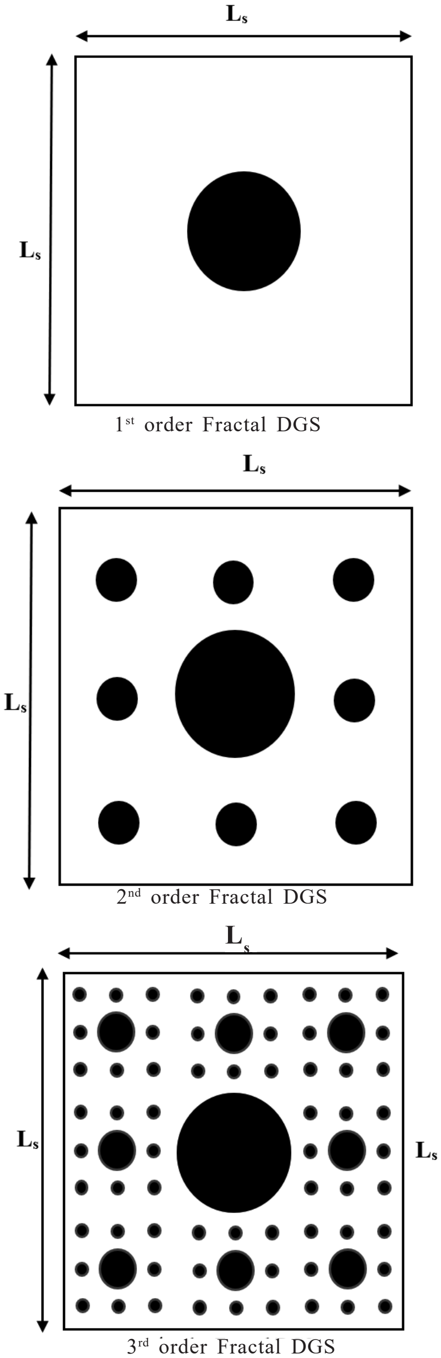


Figure 3. DGS with circular fractal slots.

$$L_g = 6h + L, W_g = W + 6h \quad (6)$$

where, `h' is the height of substrate. `L' is length of patch. `W' is width of patch. The calculated dimensions of the basic radiating patch antenna resonating at 2.4 GHz are given in Table 1.

2.2 Defected Ground Structure

The standard ground plane of the microstrip fractal patch antenna of size (Ls x Ls) is defected by cutting slots in the ground plane. The Defected Ground Structure has been applied to the designed antenna. The Defected Ground Structure starts with applying slots cut in the ground plane as per Sierpinski Carpet Fractal Geometry. The 1st iteration has been obtained

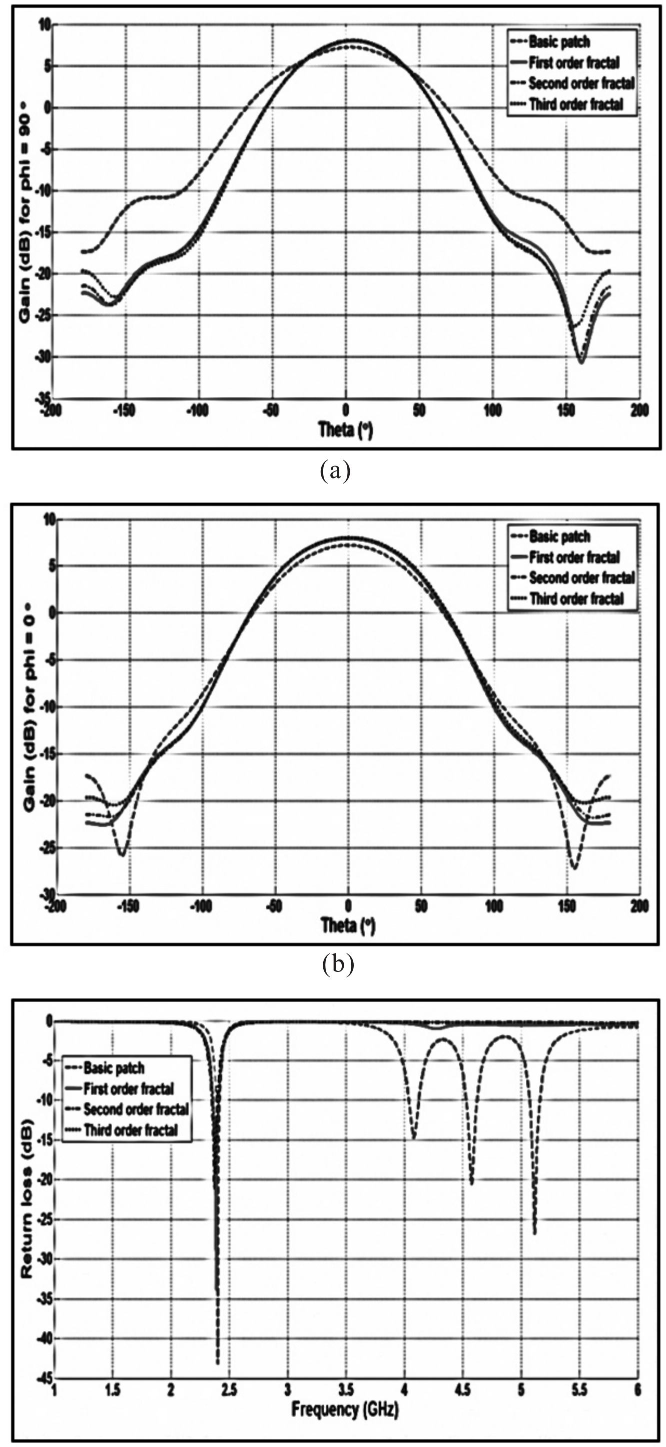
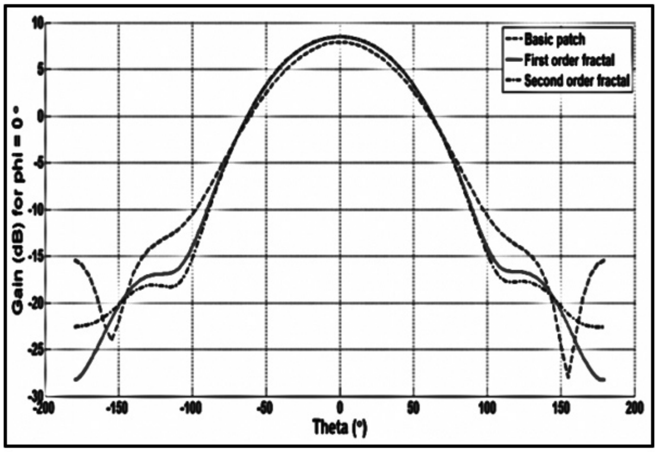


Figure 4. Gain and return loss comparison plots of standard patch and distorted ground structure with sierpinski fractal square slots. (a) Gain plot at Ø = 0° (b) Gain plot at Ø = 90° (c) Return loss plot.

by removing a Square Slot followed by iteration done by removing eight squares with scaling factor of one third. Same procedure is applied for subsequent iterations with the same scaling factor. A typical scheme of fractal slots for 1st, 2nd, and 3rd order square slots is indicated in Fig. 2.

In the case of circular slots fractal configuration, the maximum size of the circle which can be inscribed inside a



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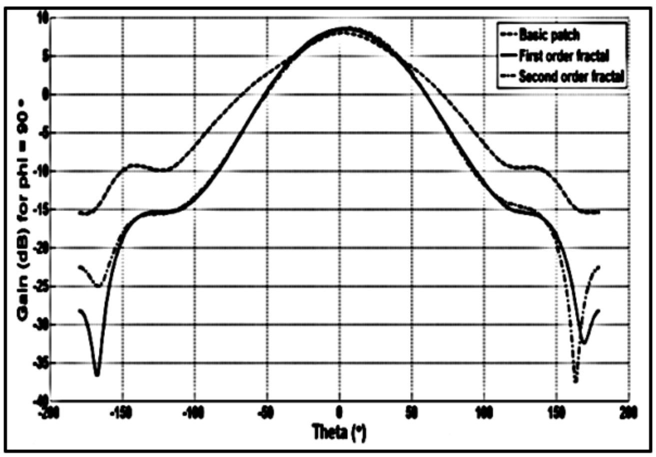

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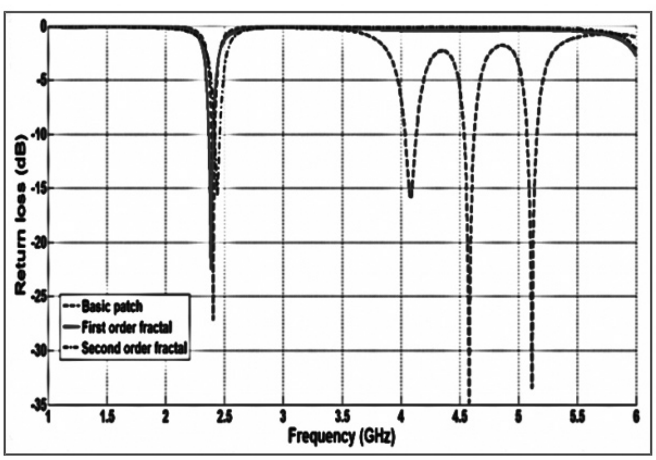
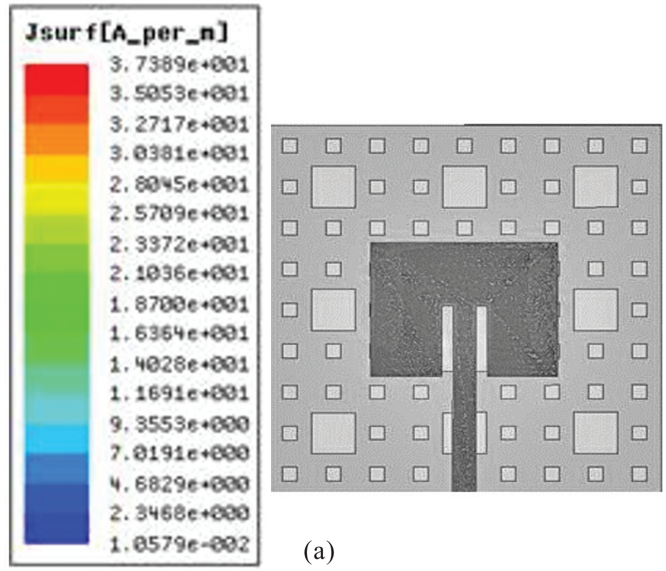


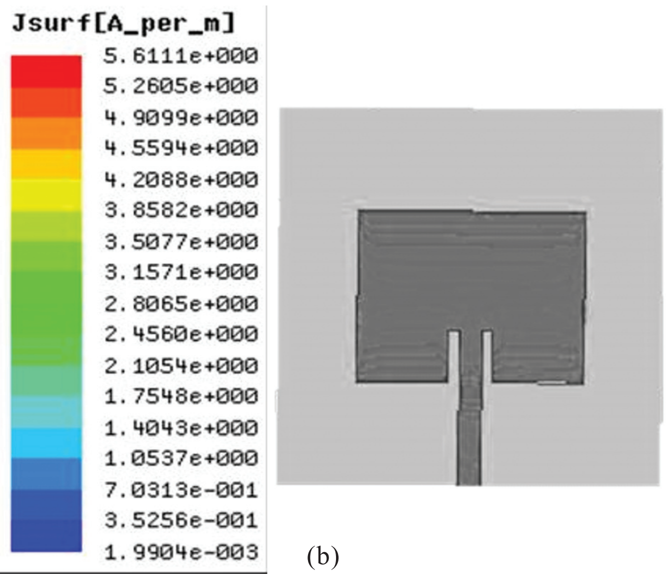
(c)

Figure 5. Gain and return loss comparison plots of standard patch and distorted ground structure with sierpinski fractal circular slots. (a) Gain plot at Ø = 0° (b) Gain plot at Ø = 90° (c) Return loss plot.

unit square cell of Sierpinski Carpet Geometry has been taken in the 1st order, and thereafter the same geometry in scale-down version is followed in higher orders. The Defected Ground Structure with 1st, 2nd, and 3rd order Fractal circular slots are shown in Fig. 3. The selection retains the fractal properties of the antenna, and the design is generic and modular for the realization of higher-order antennas following the same fractal geometry.



(a)



(b)

Figure 6. Current density distribution plots: (a) 3rd order DGS square fractal slot microstrip patch antenna, and (b) Basic microstrip patch antenna.

The DGS fractal antenna is simulated using HFSS 15 tool. With application of the Sierpinski fractal slots to the ground plane, reduction in size of radiating patch is obtained in comparison to a standard patch antenna at the frequency of operation of 2.4 GHz.

3. SIMULATION STUDIES AND DISCUSSIONS

Simulation studies using HFSS tool for both square and circular slot DGS configurations have been done. The comparison plots of gain and return loss plots of Distorted Ground Structure fractal slot antennas for both the configurations to that of standard rectangular microstrip patch antenna are presented in Fig. 4 - Fig. 5.

From the return loss plots, it is evident that the antenna without DGS resonates at 2.4 GHz and also at further harmonics. Microstrip patch antenna with fractal Defected Ground Structures resonates only at required frequency of 2.4

Table 2. Microstrip patch antenna with DGS of square fractal slots

Configuration	Patch dimensions (cm)	Area (cm^2)	Size reduction	Resonant freq. (GHz)	Return loss @ Resonant frequency	Peak Gain (dB)	3 dB beam width for phi =0°	3 dB beam width for phi = 90°
Basic patch	Length: 4.119 Width: 4.915	20.25	---	2.4043	27.11	7.94	74° approx.	72° approx.
First order DGS	Length: 3.447 Width: 4.113	14.18	29.97 %	2.398	14.72	8.64	80° approx.	65° approx.
Second order DGS	Length:3.374 Width: 4.026	13.58	32.90 %	2.4095	26.45	8.71	75° approx.	65° approx.
Third order DGS	Length: 3.987 Width: 3.341	13.32	34.20 %	2.4053	24.74	8.69	75° approx.	65° approx.

Table 3. Microstrip patch antenna with DGS of circular fractal slots

Configuration	Patch dimensions (cm)	Area (cm^2)	Size reduction	Resonant freq. (GHz)	Return loss @ Resonant frequency	Peak Gain (dB)	3 dB beam width for phi =0°	3 dB beam width for phi = 90°
Basic patch	Length: 4.119 Width: 4.915	20.25	---	2.4043	27.11	7.96	74° approx	70° approx
First order DGS	Length: 3.291 Width: 3.927	12.92	36.16 %	2.3843	22.41	8.49	78° approx	66° approx
Second order DGS	Length:3.217 Width: 3.838	12.34	39.01 %	2.4376	15.56	8.6	78° approx	64° approx

GHz, and all the higher harmonic frequencies are suppressed due to the disturbing current distribution at harmonics, so that the antenna resonates only in fundamental mode. A comparison of the surface-current density distribution plots of the basic rectangular microstrip patch antenna and the 3rd order DGS Square Fractal Slot microstrip patch antenna is shown in Fig. 6.

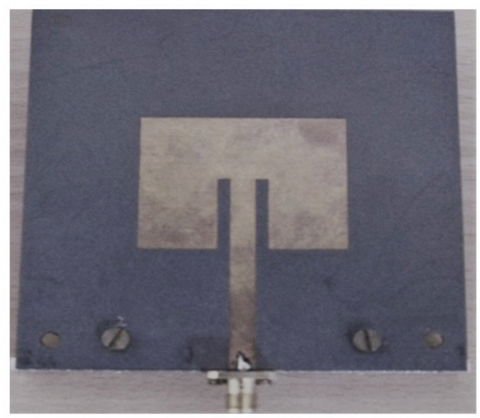
The reduction in size of the radiating patch is obtained with incorporation of Sierpinski carpet fractal Defected Ground Structure slot up to an extent of 40% relative to the basic microstrip patch antenna and the reduction is more in case of circular slots compared to the square slots. The performance comparison of DGS microstrip patch Antennas to that of the basic rectangular microstrip patch are indicated in Tables 2 & 3 for square & circular DGS Fractal slot configurations respectively.

4. FABRICATED ANTENNA AND MEASURED RESULTS

Patch Antenna with Defected Ground Structure of square fractal slots in 3rd order has been realized on RT Duroid material (ε_r = 2.2, substrate height = 1/16") and tested. The photograph of the fabricated antenna is given in Fig. 7.

The measured return loss plot of the fabricated proto-type antenna is presented in Fig 8. The return loss plot reveals that the antenna resonates at the designed frequency of 2.4 GHz. The measured radiation patterns of the fabricated antenna in both vertical and horizontal polarizations are presented in Fig. 9, and the radiation patterns of the antenna are in good agreement with the simulation results.

The antenna has a typical 3 dB beamwidth of 70 deg., and the measured gain of the antenna at the resonant frequency



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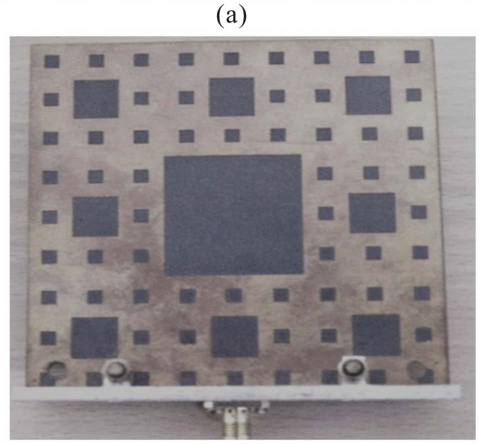


(b)

Figure 7. Fabricated antenna proto-type with distorted ground structure of square fractal slots: (a) Top view and (b) Bottom view.

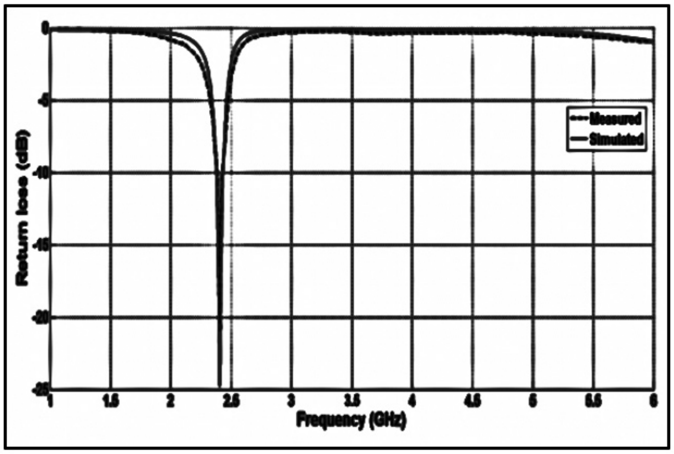


Figure 8. Measured return loss of defected ground structure patch antenna with 3rd order sierpinski fractal square slots.

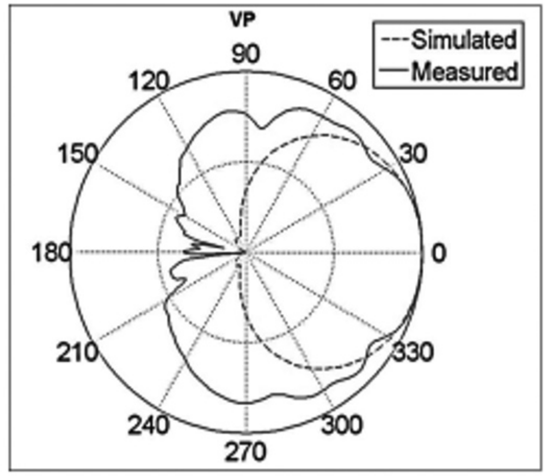
of 2.4 GHz is about 8 dB. As per the radiation patterns, it is clear that the DGS fractal slot microstrip patch antenna retains its pattern purity as that of a patch antenna which is the main feature for wireless applications.

The comparison of fabricated DGS microstrip patch antenna of 3rd order Sierpinski Fractal square slots performance characteristics against other typical DGS microstrip antennas reported in the literature is indicated in Table 4.

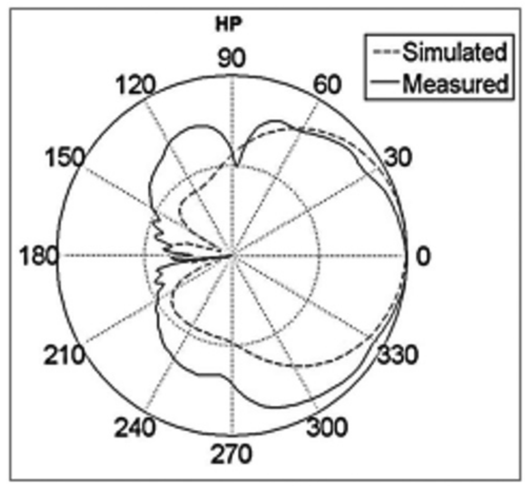
The comparison reveals that the proposed approach has resulted in the reduction of antenna size without compromising the gain and back radiation features, and there are no multiple resonances in the realized antenna.

5. CONCLUSIONS

Microstrip patch Antennas with Defected Ground Structure of Sierpinski Carpet Fractal Slots in square and circular shapes have been discussed in the paper. The fabricated prototype antenna's measured results are in close agreement with the simulation values. The proposed approach of Fractal DGS Microstrip patch antennas is attractive in achieving antenna miniaturization without compromising on Gain and back radiation problems. There are no multiple resonances in these antennas and are suitable for wireless applications without getting affected by unwanted interferences from other unintended frequencies.



(a)



(b)

Figure 9. Measured radiation patterns of defected ground structure patch antenna with 3rd order sierpinski fractal square slots in horizontal and vertical planes.

Table 4. Comparison with reported DGS

Reference	Resonant frequency	Size reduction	Gain	Observations
H. Elftouhetc.[2]	3 GHz	50 %	2 dB	• Low Gain • High back radiation.
Alper, C. etc.[4]	0.9 GHz	% of size reduction not reported	2.5 dB	• Multi-Band operation, • Low Gain • High back radiation
	1.8 GHz		1.4 dB	
	2.4 GHz		3.8 dB	
I. B. Issa etc.[7]	2.48-3.35 GHz	% of size reduction not reported	3.8 dB Max.	• Multi-Band operation • Low Gain
	5.91 GHz			
	6.76-8.33 GHz			
	13.73-16.1 GHz			
Realized 3rd order DGS microstrip patch antenna with Sierpinski square fractal slots	2.4 GHz	34 %	8 dB	• No gain reduction • No back radiation.

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CONTRIBUTORS

Mr R.V. Hara Prasad obtained his M.E. (ECE with Spl. Microwave & Radar Engineering) degrees from Osmania University, Hyderabad. Under his guidance, ground based EW systems for Army; airborne EW systems for Tri-services and passive seekers for missile application have been executed. He assumed the charge of Director, Defence Laboratory, Jodhpur on 1st July 2022.
In the present work, he has worked out configuration of Defected Ground Structure Microstrip Patch Antennas with Fractal Slots cut in the ground plane and carried out simulation, prototype antenna fabrication and measurements. He has drafted the manuscript.

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 professor at the National Institute of Technology and 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.

Dr M. Chakravarthy obtained his PhD (ECE) from Andhra University, Visakhapatnam. He is working as Additional Director at Defence Electronics Research Laboratory, Hyderabad. His areas of interest are in 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.