Design of a Combined Crown and Sierpinski Fractal Antenna

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Abstract
A new design of a combined crown and sierpinski fractal antenna has been presented in this paper as an alternative solution to improve the bandwidth of the conventional microstrip antenna. The space filling and self-similarity property of fractal geometries are used to design above said antenna. The proposed fractal antenna is designed on RT-DUROID substrate of thickness 1.6mm and relative permittivity of 2.2 and mounted above the ground plane at a height of 6mm. The proposed antenna design helps in reducing the metal usage, save cost and provide good reflection coefficient. Performance of proposed antenna has been analyzed in terms of return loss, VSWR, input impedance, gain, and bandwidth in the 1 GHz to 5 GHz frequency range. The proposed antenna provides an impedance bandwidth of 61% around the resonant frequency of 0.55 GHz. This antenna can be used for Ground Penetration Radar (GPR), which is found to be suitable for land mine detection.

Keyword
Fractal Antenna, Return Loss, VSWR, IE3D, Simulation

I. Introduction
Microstrip Antenna have always been a source of attraction for the researchers due to their low profile, low cost, low weight, ease of integration into arrays and conformal shapes [1]. However, their narrow bandwidth has always posed a major hindrance in their applications. Extensive research has been carried out to overcome this limitation .Some of the common techniques employed to enhance the bandwidth of conventional microstrip patch antenna are increasing the substrate thickness [2], use of low dielectric substrate, use of slot geometry, using different shaped patches, use of frequency selective surfaces [3], employing fractal geometries. Evolutionary research has been done in the field of fractal antenna and numerous researchers investigated several antenna designs. Sarin et al. proposed a wideband printed microstrip antenna, which represent bandwidth of 38% [4]. Large bandwidth results from an addition of a rectangular metal strip on a slotted square microstrip antenna. Deshmukh et al. realized a compact rectangular microstrip antenna in which they implanted the half U-Slot in the patch on the edges of the patch [5] .This arrangement has done to increase the Bandwidth and it becomes double than the conventional patch. Roy et al. proposed a V-Slot loaded, proximity coupled microstrip patch antenna [6]. This miniaturized microstrip antenna exhibits circularly polarized far field and has wide bandwidth in the frequency of WLAN with very good axial ratio bandwidth. Jahromi et al. suggested grounded coplanar waveguides (GCPW) to enhance antenna characteristics such as conventional sierpinski carpet antenna represents bandwidth within the frequencies 6.25-8.4 GHz, while modified sierpinski carpet antennas enhances the bandwidth throughout the frequency band 4.65-10.5 GHz. Their new feeding technique changes the behavior of the fractal elements from multiband to wideband [7]. Abdelaziz proposed a novel microstrip antenna with wide bandwidth. He demonstrated that a dual band microstrip antenna can be realized by connecting together two different radiating elements through a matched section and are embedded on a single layer structure [8]. Wide bandwidth of 9% has achieved by mapping two resonance frequencies of two elements. Puente et al. demonstrated the change in the behavior of sierpinski gasket fractal antenna by varying the flare angle and the validity of this experiment was assessed by comparing its predictions with measured data through an analytical model [9]. Mak et al. proposed a high gain and wideband microstrip patch antenna. To enhance the bandwidth they employed the L-probe parallel feeds and noticed the rise in gain by increasing the wide of the patch [10]. Wojciech et al. demonstrated a modified sierpinski gasket monopole antenna with small size and high efficiency [11]. This design was developed to radiate for both 2.4 and 5.2 GHz ISM-bands. Various other techniques that have been explored to enhance the bandwidth of conventional microstrip patch antenna include square ring slot antenna [12], a transmission line fed crescent patch antenna [13], a wideband sierpinski shaped slot antenna [14].

In the present work, a combined crown and sierpinski fractal antenna has been designed to operate between 0-5 GHz around the resonant frequency of 0.55 GHz. This novel design is not only representing the higher bandwidth but also high gain is achieved. To achieve a good value of gain is a big challenge in such type of fractal antennas because it is directly affected by the copper conducting patch area. IE3D Zeland simulation software is opted amongest many available electronic simulation software due to its effectiveness of producing results equivalent to the measured values.

The organization of the research paper is summarized as follows. The Section II, III defines the fractal antenna, different geometries and advantages. Section IV illustrates the feeding technique. The basic concept behind the design of proposed antenna is described in Section V and Section VI presents the simulations results of fractal patch antenna. This section is then followed by conclusion.

II. Fractal Antenna
A fractal antenna can be described as an antenna that uses a fractal, self similar deign to maximise the length or increase the perimeter of material that can receive or transmit electromagnetic radiation within a given total surface area and volume [15-16]. The original inspiration for the development of fractal geometry came largely from an in-depth study of the patterns of nature. The unique features of fractals such as self-similarity and space filling properties enable the realization of antennas with interesting characteristics such as multi-band operation and miniaturization. A self-similar set is one that consists of scaled down copies of itself [17]. This property of self-similarity of the fractal geometry aids in the design of fractal antennas with multiband characteristics. The self-similar current distribution on these antennas is expected to cause its multiband characteristics. The space-filling property leads to curves those are electrically very long but fit into a compact physical space [17]. This property can lead to the miniaturization of antenna elements.

III. Fractal Geometries

There are many fractal geometries that have been found to be useful in developing new and innovative designs for antennas [16]. These geometries have been used to characterize structure in nature that was difficult to define with Euclidean Geometries. These fractal geometries are Minkowski, Sierpinski Carpet , Crown Square, Sierpinski Gasket, Hilbert Curve, Koch curve and so on.

A. Sierpinski Gasket

The most popular fractal antenna is Sierpinski gasket named after the Polish Mathematician Sierpinski who described some of the main properties of this fractal shape in 1916. Four important factors decide the shape of the Sierpinski gasket triangle, which are the height 'h' of the triangle, the flare angle 'α', the scaling factor ' Sf' and the number of iterations 'n'.

First, a triangle is taken in a plane. Then in next step, a central triangle is removed with vertices that are located at the midpoint of the sides of the triangle as shown in the fig.1. The process is then repeated for remaining triangles. The sierpinski gasket is formed by doing this iterative process infinite numbers of times. In fig.1 black triangular areas represents a metallic conductor where as the white triangle areas represent region where metal has been removed.

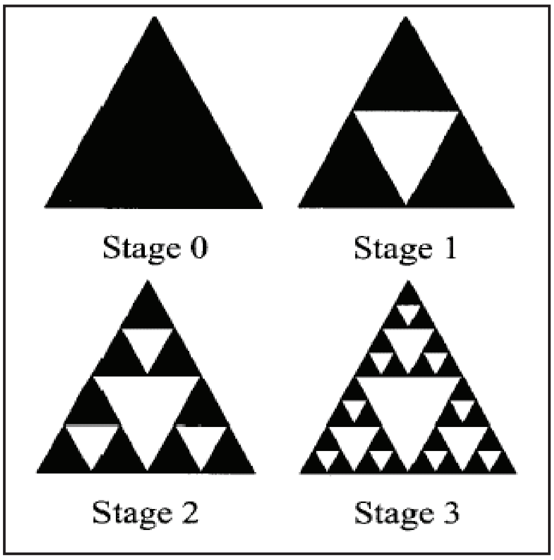

Fig. 1: Several stages in the construction of Sierpinski Gasket Fractal

B. Crown Square

As shown in figure, the base shape of a Crown Square fractal antenna is a nearly square from which a central 45^0 rotated half size nearly square is subtracted [18-19]. Then in the nth iteration a shape with scale of $1/2^{n2}$ is added to the $(n-1)^{th}$ iteration. Generally, only two iterations are considered since higher orders do not make significant affect on antenna properties.

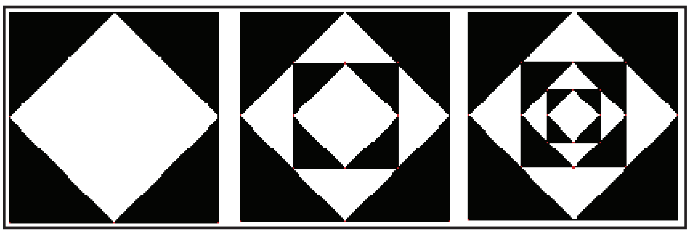

Fig. 2: First Few Stages in the construction of Crown Square Fractal

IV. Feeding Technique

Antenna performance depends upon the feeding technique and its suitable position. A feeding technique can be chosen based on factor power transformation between patch and feed point for proper impedance matching. In this work microstrip, line feed has been used because it is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. In microstrip line feed, a conducting strip is connected directly to the edge of the micro strip patch as shown in Fig. 3. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure [1].

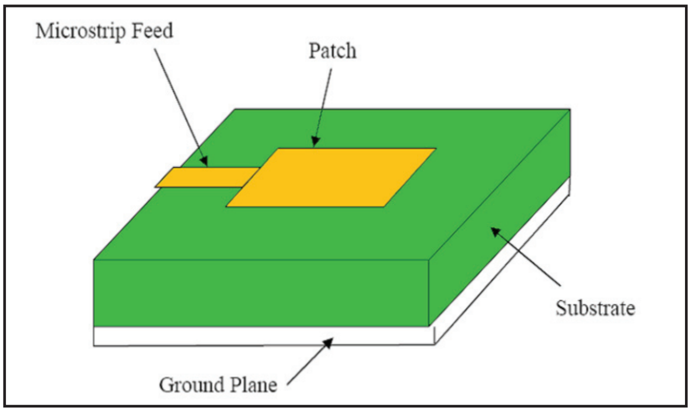

Fig. 3: Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna.

V. Description of Proposed Antenna Design

The proposed antenna has been designed using a RT- duroid substrate with a dielectric constant of 2.2 and with a substrate thickness of 1.6mm.The microstrip line feed is used to excite the antenna.IE3D simulation software has been used to simulate the proposed antenna design. The basic shape of the proposed antenna consist of square patch of each side length 30mm has been taken on the ground plane of length =30mm and width = 45mm.

Table 1: Parameters and Dimensions of Proposed Fractal Antenna

Antenna Parameters	Design Value
Dielectric Constant	2.2
Substrate Height(mm)	1.6
Loss Tangent	0.01
Length of Patch(mm)	30
Width of Patch(mm)	30
Length of Substrate (mm)	30
Width of Substrate (mm)	45
Feed Line Length (mm)	2
Feed Line Width(mm)	15

A. First Iteration of Proposed Antenna Design

It is achieved by cutting crown square fractal slot deploying sierpinski gasket geometry of each side length 8mm in the centre of the square patch as shown in fig.4. Return loss of -24.16 dB and VSWR of 1.12 is available at resonant frequency of 0.55 GHz.

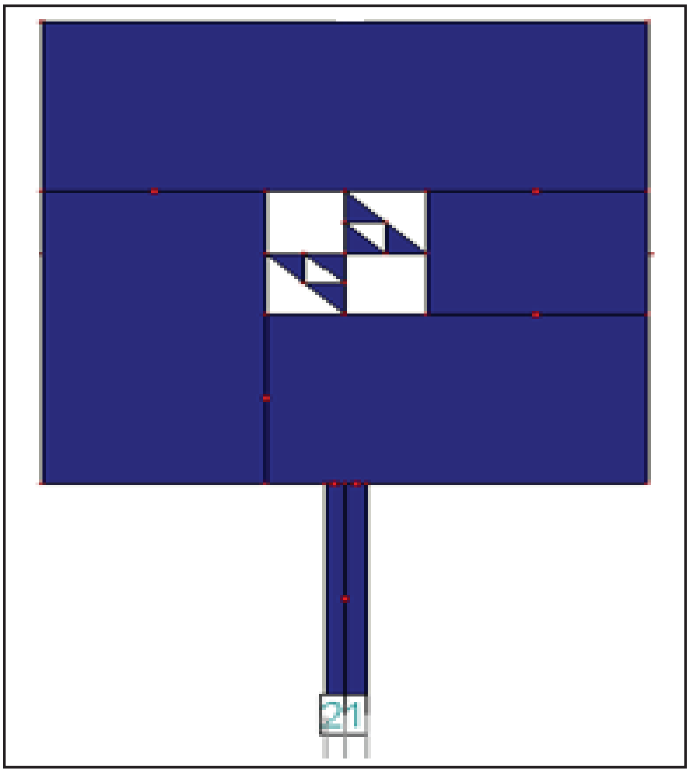

Fig. 4: Geometry of first iteration of proposed fractal antenna

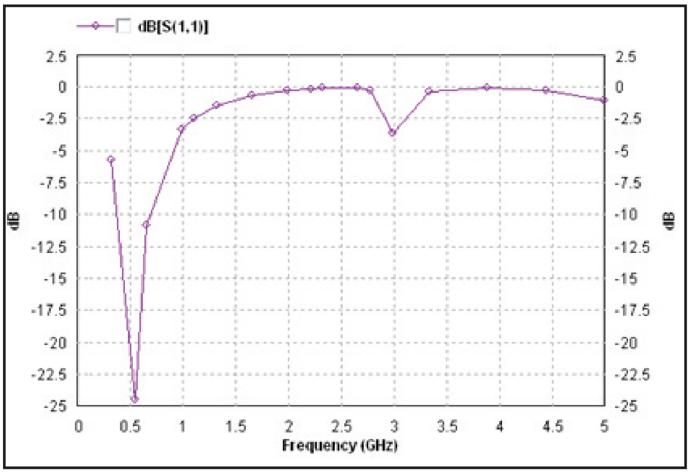

Fig. 5: Return Loss Versus Frequency Plot of First Iteration of Proposed Fractal Antenna

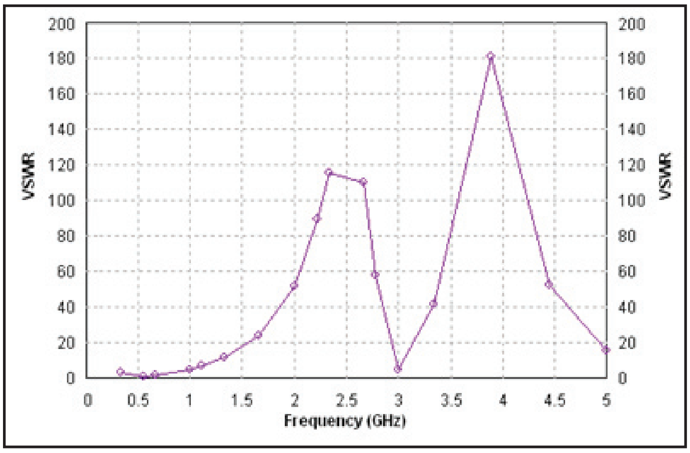

Fig. 6: VSWR Versus Frequency Plot of First Iteration of Proposed Fractal Antenna

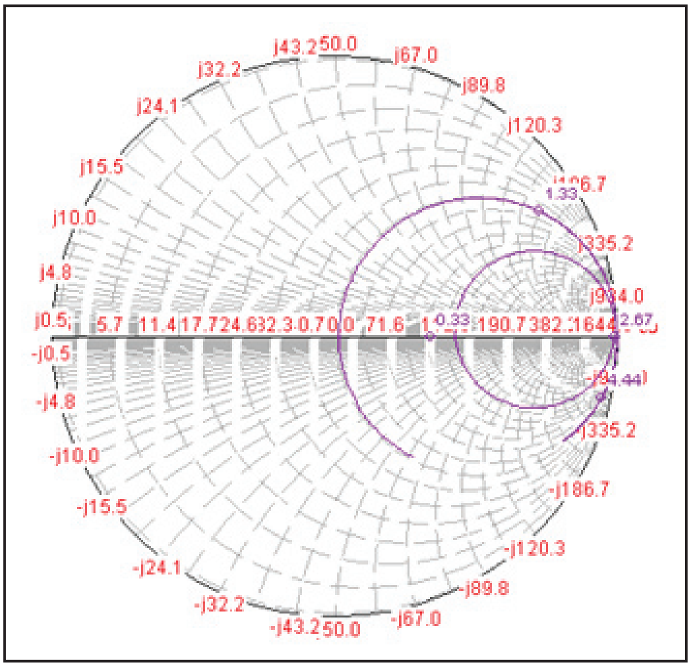

Fig. 7: Input Impedance LOCI Using Smith Chart of First Iteration of Proposed Fractal Antenna

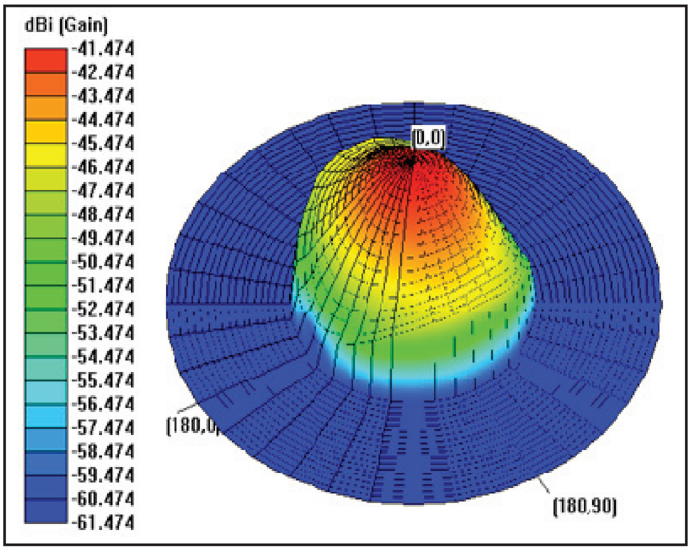

Fig. 8: Gain of First Iteration of Proposed Fractal Antenna

B. Second Iteration of Proposed Antenna Design

Fig. 5 shows the second iteration of the proposed fractal antenna. In the centre one crown square fractal slot deploying sierpinski gasket geometry each of side length 8mm is taken and similar four slots each of side length 4mm are taken on each corner of the central slot. A VSWR of 1.09 and return loss of -26.39 are available at the resonant frequency.

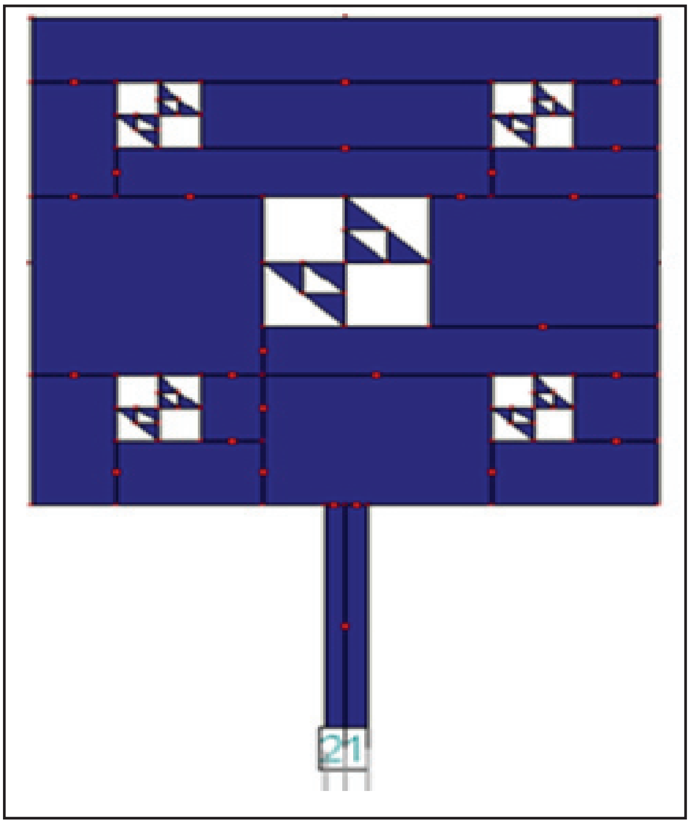

Fig. 9: Geometry of Second Iteration of Proposed Fractal Antenna

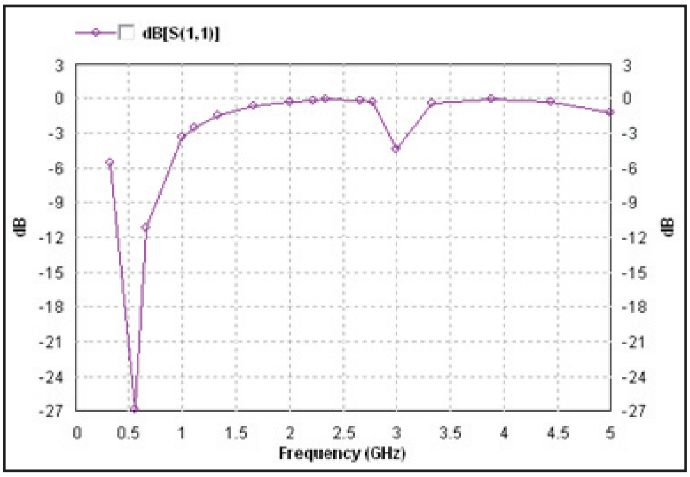

Fig. 10: Return Loss Versus Frequency Plot of Second Iteration of Proposed Fractal Antenna

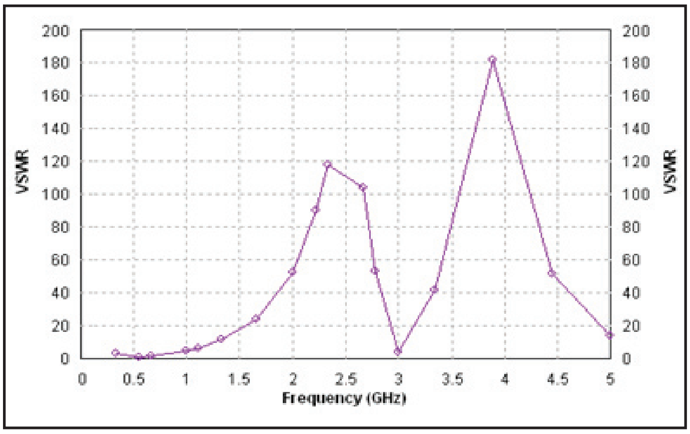

Fig. 11: VSWR vs. Frequency Plot of Second Iteration of Proposed Fractal Antenna

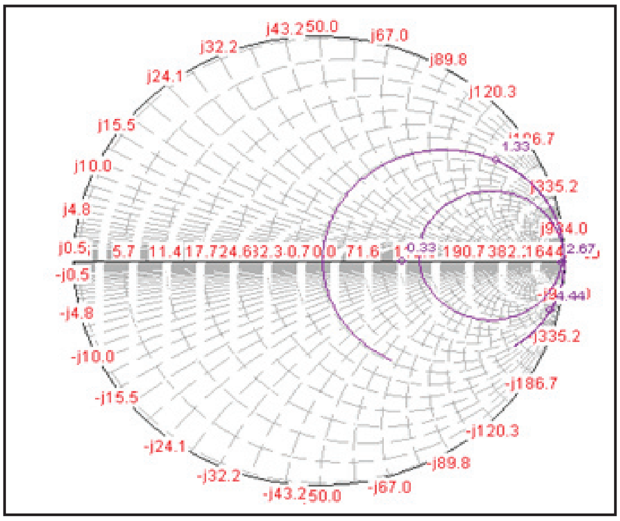

Fig. 12: Input Impedance LOCI Using Smith Chart of Second Iteration of Proposed Fractal Antenna

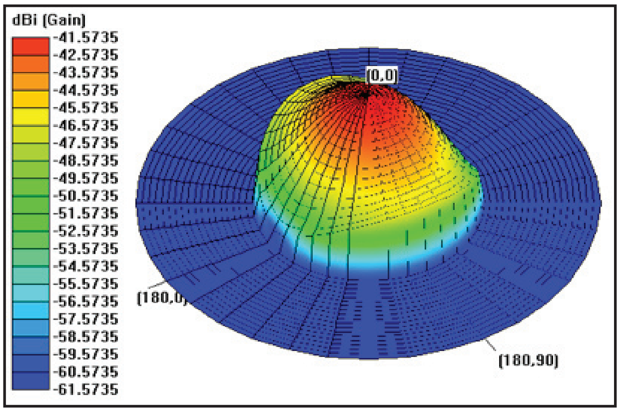

Fig. 13: Gain of Second Iteration of Proposed Fractal Antenna

C. Third Iteration of Proposed Antenna Design

Fig.14 shows the third iteration of the proposed fractal antenna. In this one central crown square fractal slot deploying sierpinski gasket geometry is cut and twenty similar structured fractal slot are taken on each corner of the central slot with reduction in their sizes . These fractal slots have dimension of each side equals L_1=8mm, L_2=4mm, L_3=2mm.

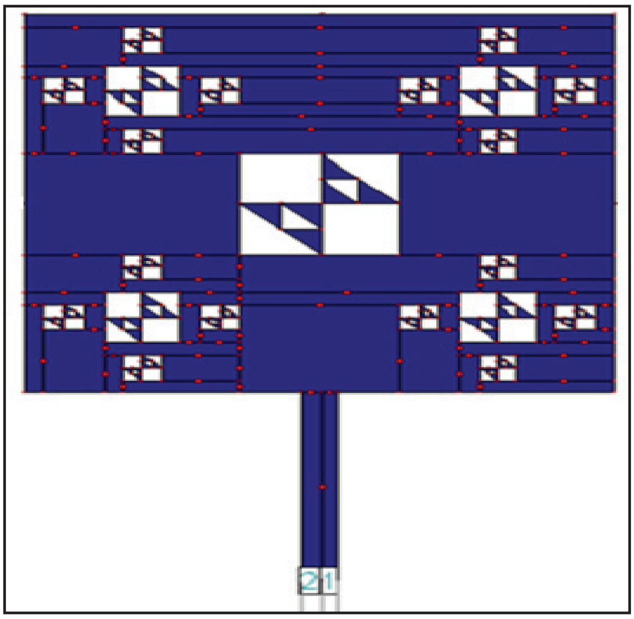

Figure 14: Geometry of Third Iteration of Proposed Fractal Antenna

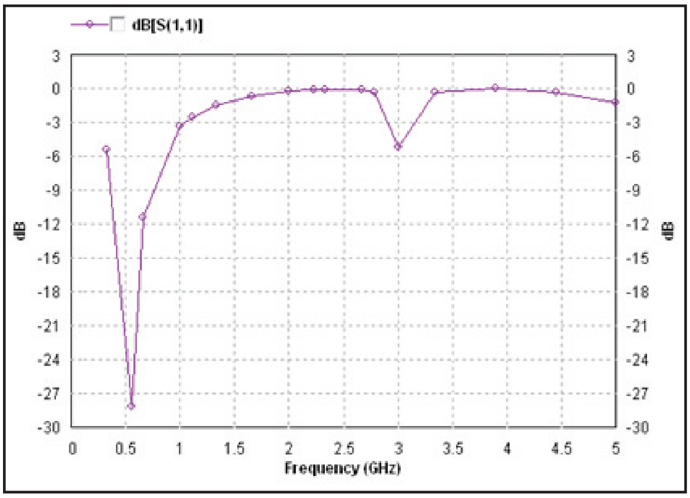

Fig. 15: Return Loss Versus Frequency Plot of Third Iteration of Proposed Fractal Antenna

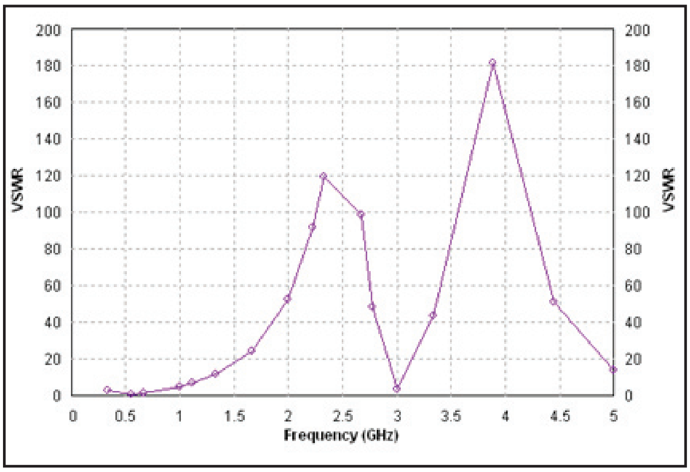

Fig. 16: VSWR Versus Frequency Plot of Third Iteration of Proposed Fractal Antenna

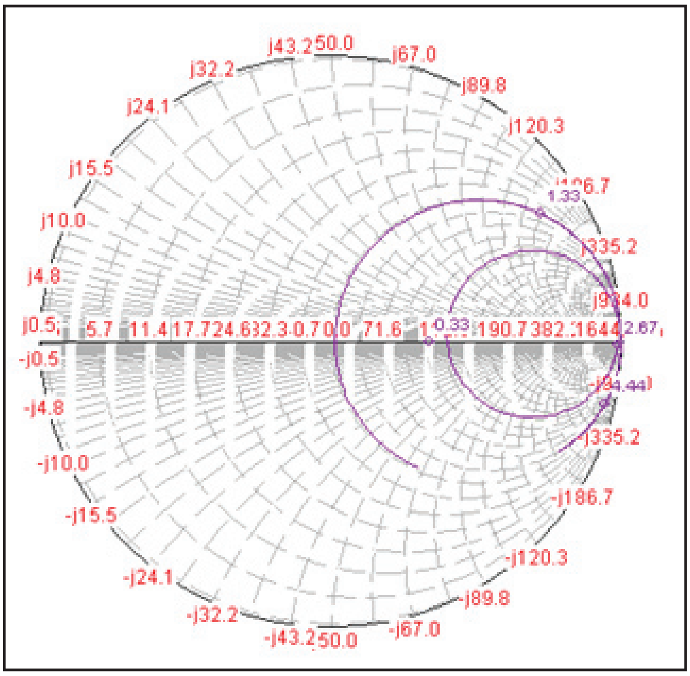

Fig. 17: Input Impedance LOCI Using Smith Chart of Third Iteration of Proposed Fractal Antenna

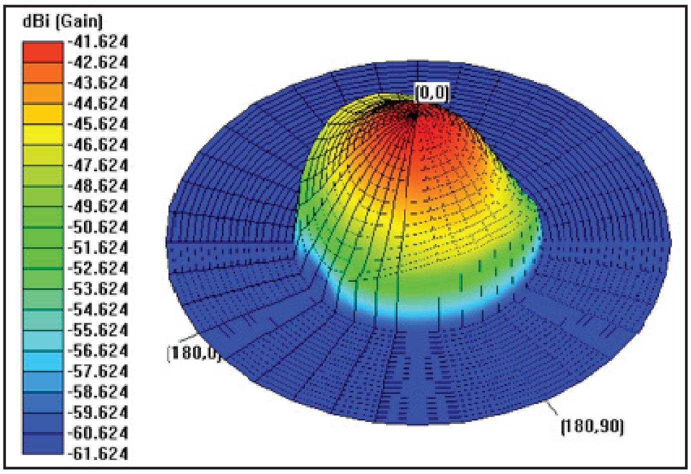

Fig. 18: Gain of Third Iteration of Proposed Fractal Antenna

VI. Result and Discussion

The proposed antenna design has been simulated using IE3D commercial software. IE3D, from Zeland software Inc. is an electromagnetic simulation and optimization software useful for circuit and antenna design [20]. The proposed antenna is designed up to 3rd iteration. Simulations of proposed antenna has been carried out in terms of return loss, VSWR, gain, and bandwidth at 0.55 GHz. The return loss is the parameter, which indicates the amount of power that is lost to the load and does not return as a reflection. VSWR is another important input parameter, which must be taken into consideration while analyzing the antenna .Input impedance matching is necessary in case of antenna. When an antenna and feed line do not have matching impedances, some of the electrical energy cannot be transferred from the feed line to the antenna. Energy not transferred to the antenna is reflected back towards the transmitter. It is the interaction of these reflected waves with forward waves causes standing wave patterns, which reduce the amount of acceptable signal. It is always desirable for VSWR to be always less than 2.

Table 2: Comparison b/w Various Parameters of the Three Proposed Geometries

Iteration	1	2	3
Resonant Frequency(GHz)	0.55	0.55	0.55
Return Loss(dB)	-24.16	-26.39	-28.14
VSWR	1.12	1.09	1.10
Bandwidth (%)	54.18	56.54	61.27

VII. Conclusion

In this work, a novel fractal antenna has been designed to overcome the constraint of narrow bandwidth of conventional patch antenna. This technique has achieved much better results in terms of bandwidth enhancement, VSWR, return loss and gain as compared to other geometries. The bandwidth and return loss comparison for the three geometries are described in Table 2. The proposed antenna has an impedance bandwidth of 61.27 % around the resonant frequency of 0.55 GHz. This antenna has VSWR of 1.10 and a return loss of -28.14, which are significant results and used for GPR, which is found to be suitable for land mine detection with 1 meter of Penetration depth. Antenna is designed to operate at center frequency of approximate 0.55GHz with 50Ω microstrip line feed. This antenna is suitable for both kinds Anti tank and Anti personnel land mine detection.

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