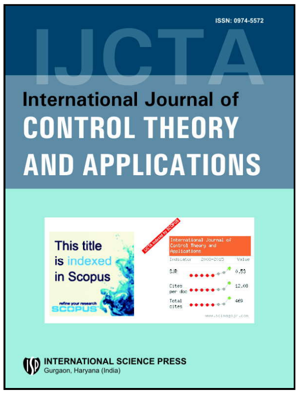

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 6 • 2017

A Slotted Microstrip Antenna with Fractal Design for X-Band based Surveillance Applications

Shailendra Kumar Dhakad[1], Umesh Dwivedi[2], Sudeep Baudha[3] and Tapesh Bhandari[4]

[1] *Department of Electrical & Electronics Engineering BITS Pilani K. K. Birla Goa Campus, Goa, India, Email: skdhakad@goa.bits-pilani.ac.in*
[2] *School of Engineering & Technology Amity University, Rajasthan, India, Email: ukdwivedi@jpr.amity.edu*
[3] *Department of Electrical & Electronics Engineering BITS Pilani K. K. Birla Goa Campus, Goa, India, Email: sudeepb@goa.bits-pilani.ac.in*
[4] *Department of Electrical & Electronics Engineering BITS Pilani K. K. Birla Goa Campus, Goa, India, Email: tapesh.bhandari@gmail.com*

Abstract: This paper proposes a unique micro-strip patch antenna with a hexagonal fractal pattern for ground based surveillance radar applications. To further optimize the functioning of the antenna, multiple slots have been added to the ground plane, and a stepped pattern has been implemented to increase the current density and the gain. A detailed study of the stages of development of the antenna has been made, illustrating the effect that various design elements have on the operating characteristics of the final design. There is specific emphasis on the use of slots in the ground plane. Variations in return loss, gain, VSWR, operating frequency and bandwidth with changes in the design of the ground plane have been documented. The antenna is designed to perform in the X-band, more specifically in between 8-9.5 GHz, making it well suited for short range search. The final iteration of the antenna design, including various stages of slotting in the ground plane, works at 8.7 GHz, which is well within the X-band range, and has a return loss of -29.84 dB.

Keywords: David Antenna, hexagonal, fractal, surveillance radar, return loss, Voltage Standing Wave Ratio (VSWR), X band.

1. INTRODUCTION

Microstrip antennas are becoming increasingly popular for various applications. These antennas are low profile, physically robust, and inexpensive to manufacture using modern printed-circuit technology. Additionally, these antennas are versatile in terms of resonant frequency, polarization pattern, and impedance matching, and are compatible with MMIC (Monolithic Microwave Integrated Circuit) designs [1]. These characteristics make them particularly useful in mechanically rugged and light weight subsystems, such as for radars demanding a low profile. The X band is a segment of the microwave region falling within the frequency range of 8.0 to 12.0

GHz, as per the IEEE. This band is used for a variety of applications like weather monitoring, defence and space communications, and high resolution imaging. A radar operating in the X band is well suited for high resolution search where light weight and mobility are prioritized over long range as described in [1]. Good target resolution is achieved through wide bandwidth and narrow beam width allocations as detailed in [2] and [3].

The term "fractal" has been coined by Mandelbrot, and is explained in [5]. Fractals are often used to model complex natural objects, and their applications to antenna engineering allow for implementing several new and innovative designs, as explained in [6]. Symmetric fractal patterns significantly increase the surface current path length compared to a conventional patch antenna of similar dimensions. The use of a fractal design allows us to achieve conformity and low profile with a compact size. Fractal antennas are implemented through the repetition of a shape over two or more scale sizes, or "iterations". The feed network of the proposed antenna contains two iterations of self-repeating hexagonal patterns.

A slot antenna consists of a flat metal surface with a hole or "slot" cut out. The slot mimics a dipole antenna in the way it radiates electromagnetic waves. The shape and size of the slot, as well as the driving frequency influence the radiation distribution pattern. Slotted antennas are useful when greater control of radiation pattern is required, and are thus widely used in radar antennas, where directivity is essential. As suggested in [7] and [8], slots have been added to the ground plane for optimizing the antenna, and their effect on the bandwidth and the gain, is also analyzed in this paper.

2. ANTENNA DESIGN

The size of the feed pattern and the antenna are estimated by approximating them to the length and width of a simple, rectangular patch antenna at the same frequency. While increasing the substrate thickness directly increases the operating frequency, it can also cause undesired radiation patterns. Thus, this trade-off between bandwidth and radiation pattern must be taken into consideration while sizing.

Generally substrate relative dielectric constant lies in the range $2.2 \leq \varepsilon_r \leq 12$. Due to fringing effect [4] there is a change in the dielectric constant and the length of the substrate because some waves also travel through air. So effective dielectric constant εreff and effective length Leff are given by:

$$reff = \frac{r+1}{2} + \frac{r-1}{2}\left[1+12\frac{h}{W}\right]^{\frac{-1}{2}}$$

And $L_{eff} = L + 2\Delta L$

where h is the thickness of the substrate. Here, ΔL is given by:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)}$$

and the actual length L and width W can be calculated using

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}\ \mu_0\ \epsilon_0}} - 2\Delta L, \qquad W = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r + 1}}$$

c is the speed of light, f is the frequency and h is substrate thickness.

These formulae yield the dimensions of the substrate to be 44mm X 44mm. The design and dimensions are illustrated in the following section. The proposed antenna is shown in Fig. 1. The antenna is similar to the David antenna proposed in [8], where the fractals are made on the hexagonal patch design in order to increase the bandwidth of the antenna. Modifications to the design are inspiredfrom the configurations proposed in [9], [10], and [11]. It is etched on an economical FR4-epoxy substrate which has a thickness of 1.6mm, permittivity of 4.4, and a loss tangent of 0.002. An edge based rectangular feed line of 50Ω, with dimensions 22mm X 1.66mm, is used to feed the system. The dimensions of the proposed antenna, depicted in Table 1, ensure its working in the X-Band.

Table 1
Dimensions of the proposed antenna

Parameters	Subs. Length	Subs. Width	Hor. Slot Length	Hor. Slot Width	Ver. Slot Length	Ver. Slot Width	Step of Ladder	Hexagonal Length
Values(mm)	44	44	25.33	1.69	20.33	2.25	1	1.666

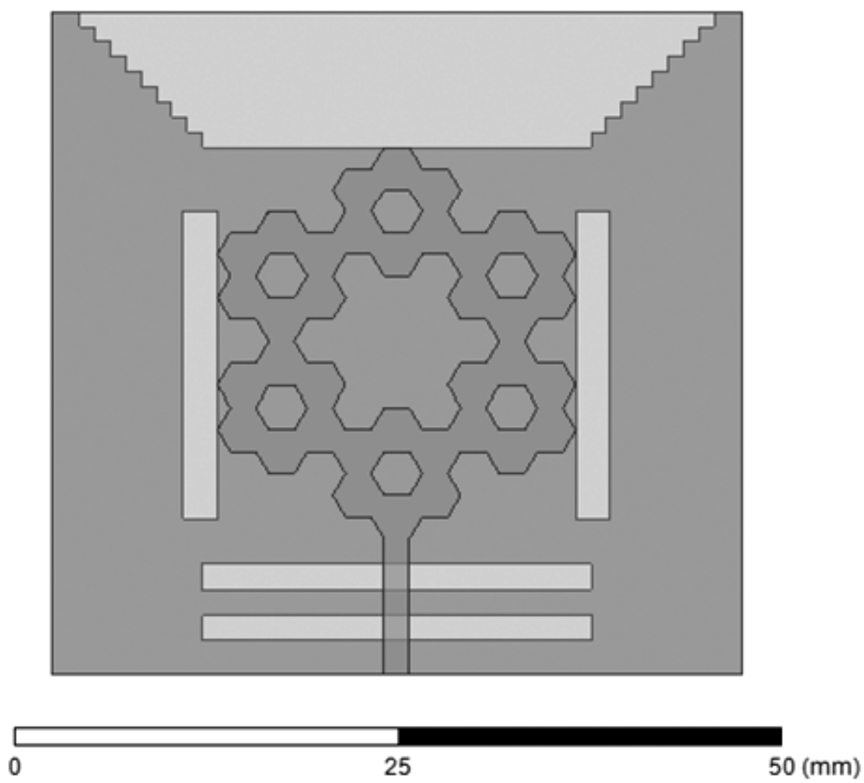

Figure 1: Proposed Antenna Design

3. DEVELOPMENTAL STAGES

The proposed slotted, hexagonal fractal microstrip patch antenna as shown in figure 1 has been simulated in Ansoft High Frequency Structure Simulator (HFSS v13.0). The work done previously in [16] has been taken as a base and further improvements have been done on the same design. The return loss, VSWR, gain and radiation patterns of the antenna are measured. To investigate the effects of different parameters of the proposed antenna, a parametric study has been done, and the S11 parameter rectangular plots of the designs have been shown.

3.1. Design 1

This is the basic design of the antenna without a ground plane, and with hexagonal fractal feed. Its corresponding rectangular plot is given below. The two major peaks in thegraph correspond to a return loss of -8 dB at 8.1 GHz and 21.95 dB at 9.5 GHz. Design and return loss in figure 2 and 3

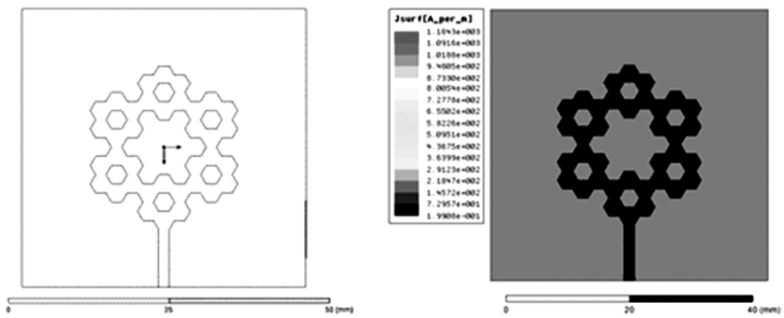

Figure 2: A hexagonal fractal antenna with no ground plane, and its corresponding current density distribution

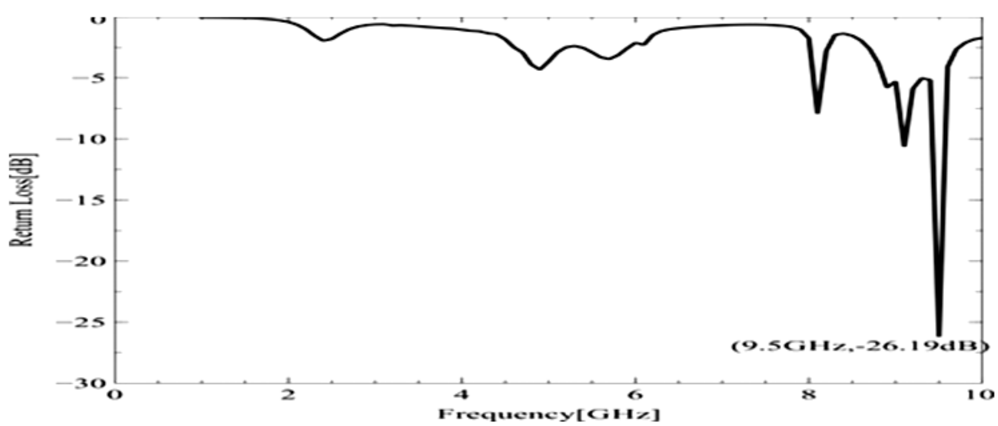

Figure 3: Return loss vs frequency

3.2. Design 2

This design contains the antenna with a regular square shaped ground plane of side 44mm, which is the same size of the substrate. It yields a return loss of -11.15 dB at 7.3 GHz as shown in figure 4 and 5.

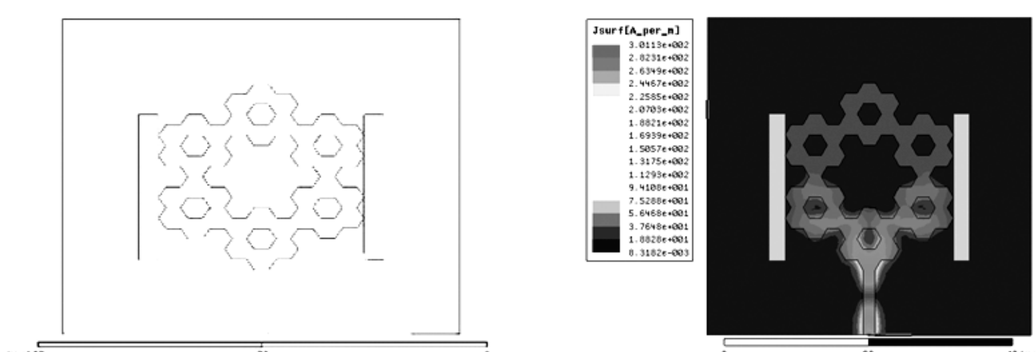

Figure 4: A hexagonal fractal antenna with vertical slots in ground plane, and its current density distribution

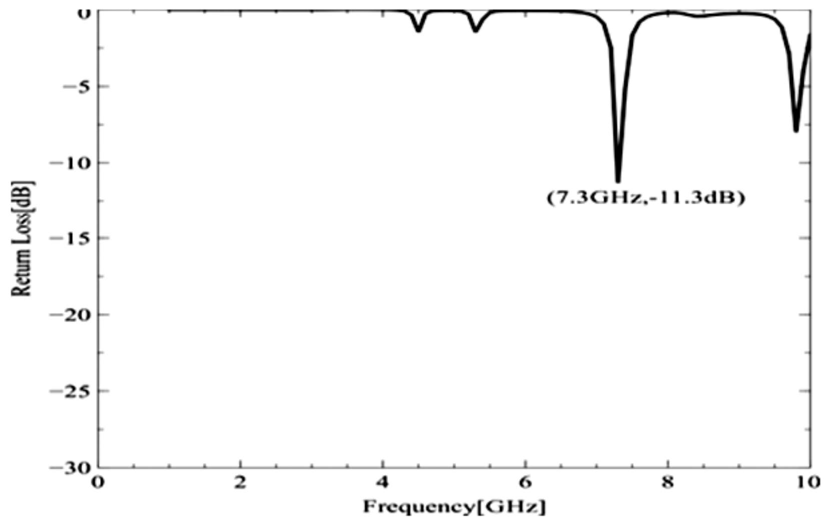

Figure 5: S11 Parameter Rectangular Plot

3.3. Design 3

This design is similar to Design 2, but contains vertical slots in the ground plane of dimensions 14mm × 1mm. The ensuing rectangular plot in figure 5 illustrates the effect these slots have on the return loss of the antenna.

3.4. Design 4

This design contains horizontal slots in the ground plane instead of vertical slots. The slots have dimensions 25.33mm × 1mm each, and are symmetrical, as shown inthe following figures 6.

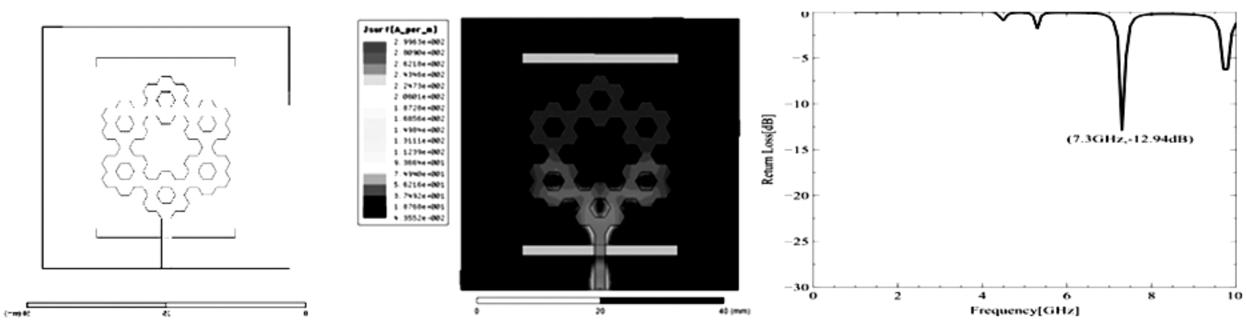

Figure 6: A hexagonal fractal antenna with horizontal slots in ground plane, and its current density distribution and return loss Parameter Rectangular Plot

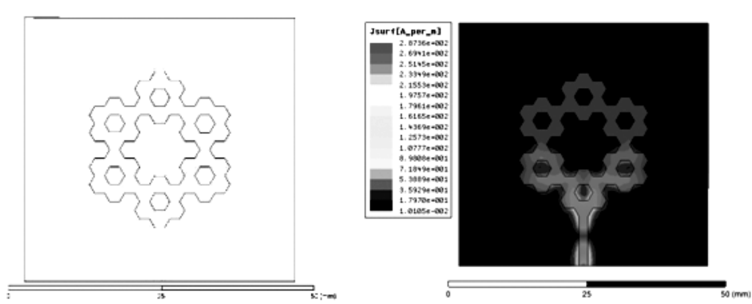

Figure 7: A hexagonal fractal antenna with ground plane, and its corresponding current density distribution

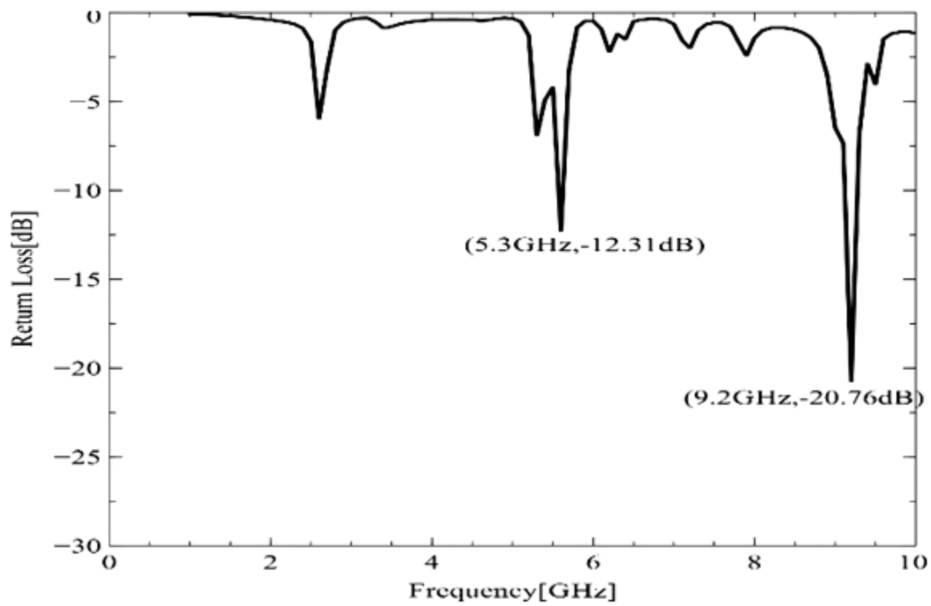

Figure 8: S11 Parameter Rectangular Plot

3.5. Design 5

In this iteration, the previous design has been modified keeping current density gains in mind. The upper slot has been extended iteratively to form a stepped pattern, keeping the lower slot intact. The step size is 1mm, and the length of each consecutive slot in the stepped design increases by 2mm. Figure 7and 8 shows the design and results. This design generates a favorable result, as has been concluded in [16].

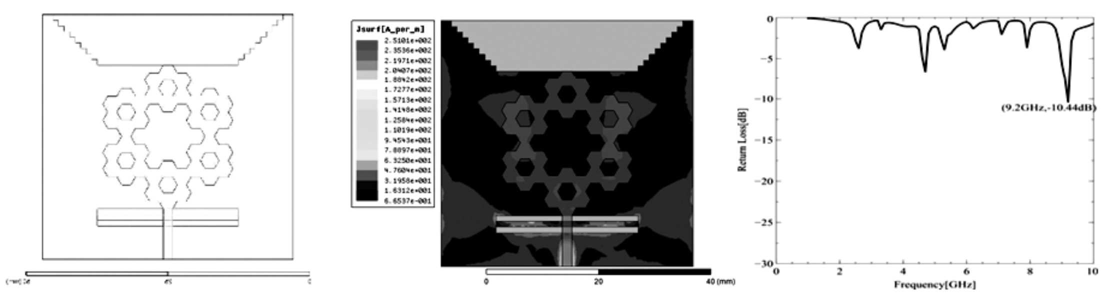

Figure 9: A hexagonal fractal antenna with two horizontal slots and stepped pattern in ground plane, and its current density distributionand S11 Parameter Rectangular Plot

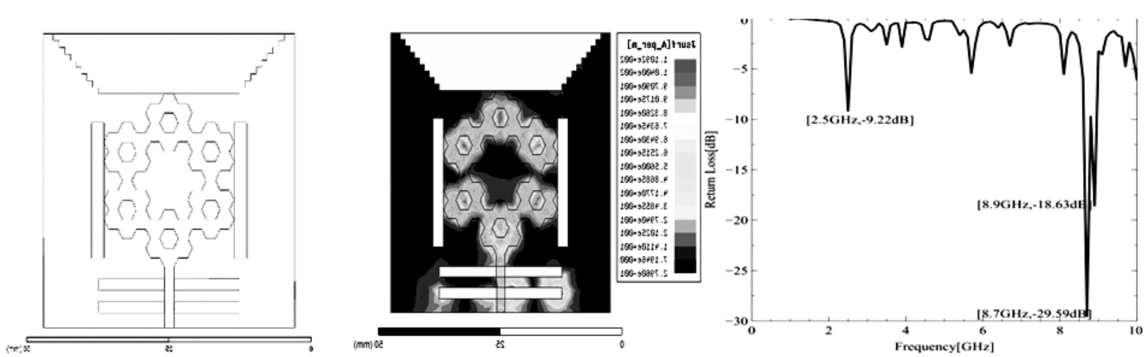

Figure 10: A hexagonal fractal antenna with horizontal slots in ground plane, and its current density distribution and S11 Parameter Rectangular Plot

3.6. Design 6

This design incrementally improves upon the previous design by adding two horizontal slots towards the bottom of the ground plane, keeping the stepped pattern as it is. This increases the current density around both the bottom slots and improves upon the results of the previous design. Plots have been shown in figure 9.

3.7. Design 7

This is the finalized design of the proposed antenna. The vertical slots seen in Design 3 are added back to the ground plane, but their dimensions have been tweaked to obtain an optimum operating frequency in the X-Band. The obtained results have been included thereafter in figure 10.

4. ANALYSIS OF RESULTS

A detailed report of the final design results has been compiled below.

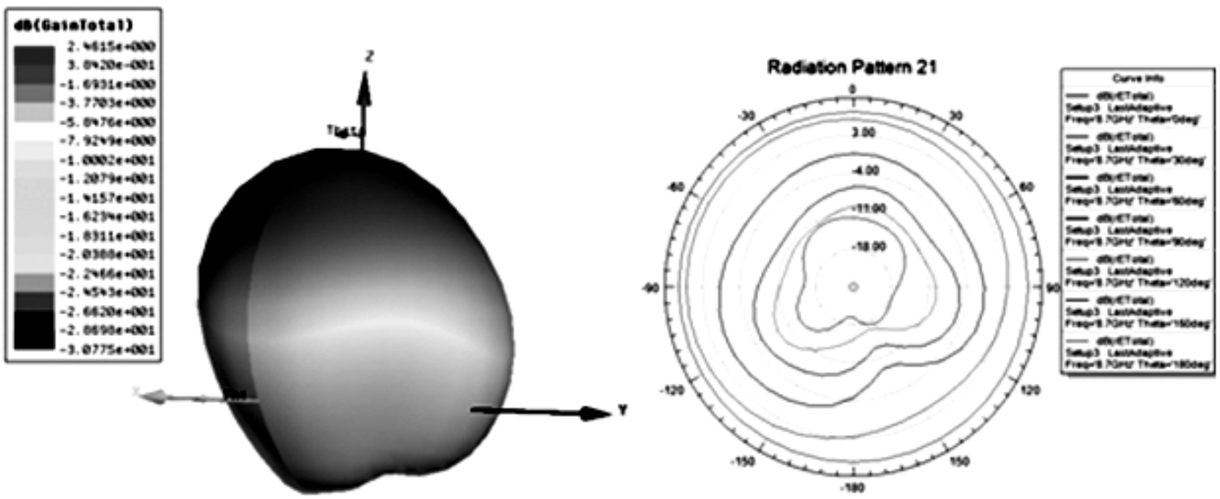

Figure 11: 3D Polar Plot – Antenna Gain and Radiation Efficiency Pattern

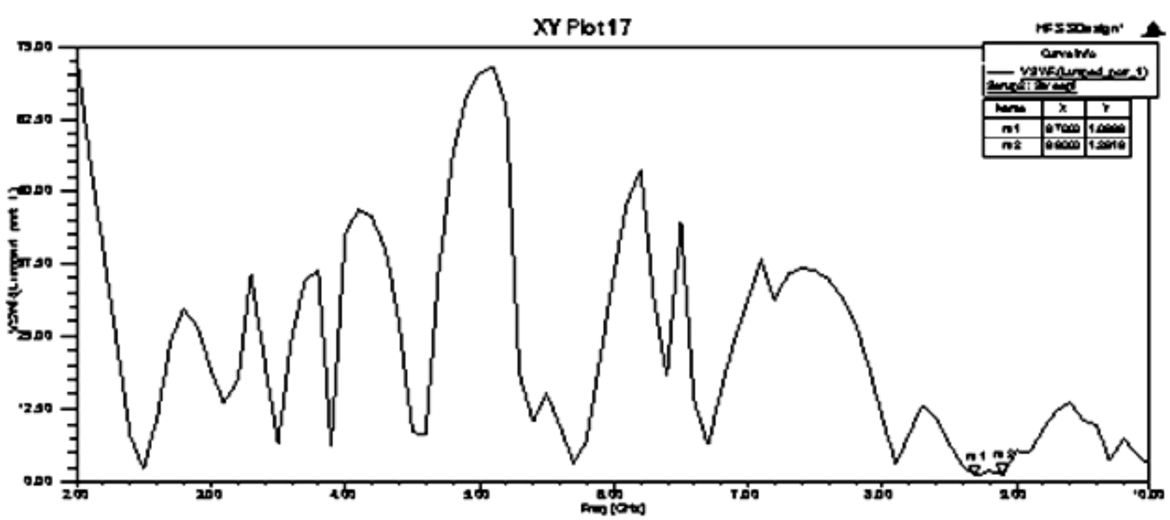

Figure 12: Rectangular plot - VSWR Parameter

As seen from the above comparisons, we can see that Design 7 yields a highly desirable gain when compared to other designs. Moreover, it also offers a high 10dB bandwidth of nearly 340 MHz (8.62 GHz to 8.96 GHz), with the optimum operating frequency of 8.7 GHz. This behavior is well suited for applications in the X-Band. The maximum gain at the operating frequency is -29.56 dB. The high surface current density distribution depicted in Fig. 10 shows the efficiency of the design. However, for optimum use in radar applications the radiation efficiency pattern of an antenna is also an important parameter. The radiation pattern must be fairly widespread [3] in order to be able to detect objects in the immediate surroundings of the antenna. High directivity is undesirable. Keeping this in mind, a 3D polar plot of the antenna gain has been plotted in Fig. 11.A step by step compilation of the various parameters obtained from analyzing the various designs has been presented in Table 2. In Fig. 13, a cumulative parametric analysis of the return loss of the various designs has been presented as a colour coded graph, enabling easier comparison. This will illustrate the effect of various design elements on the result.

Table 2
Performance Comparison of various designs

Name	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7
Frequency(GHz)	9.5	7.3	7.3	7.3	9.2	9.2	8.7
Gain(dB)	-26.2	-11.16	-11.3	-12.94	-20.75	-10.94	-20.96
VSWR	1.18	2.10	1.26	1.17	1.12	1.21	1.07

In addition, the Voltage Standing Wave Ratio (VSWR) of the antenna's emission pattern gives us valuable insight into how well the antenna is impedance matched to the surveillance radar system it is connected to, and is an important metric in measuring the radiation efficiency of the antenna at a particular frequency. For an ideal antenna with perfect impedance matching, the value of VSWR is 1. The rectangular plot in Fig. 12 of the VSWR

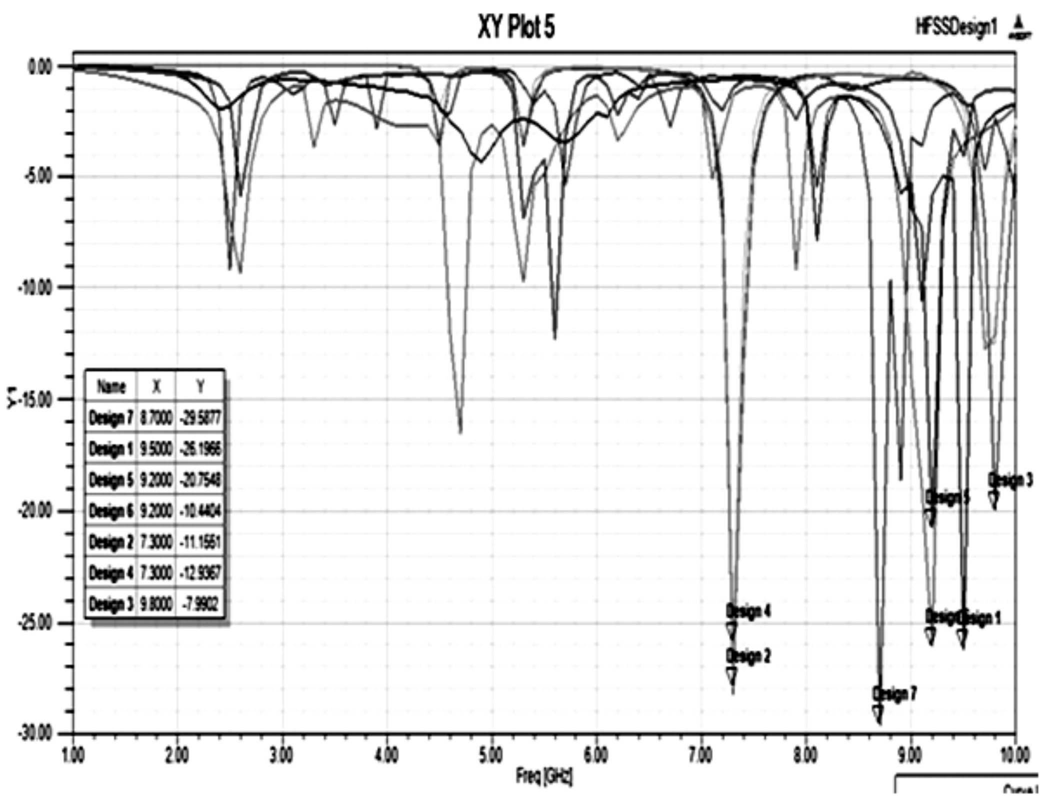

Figure 13: S11 Parameters Rectangular Plots of various designs

of the proposed antenna shows a desirable VSWR of 1.067 at the operating frequency of 8.7 GHz (marked as m1), and 1.26 at 8.9 GHz (marked as m2), making it an acceptable operating point. As calculated above, this analysis of VSWR parameters concurs with the bandwidth of 340 MHz.

From the exhaustive study completed above, the following trends can be inferred with respect to the addition of slots in the ground plane:

- *Addingslots lowers the fundamental resonant frequency.*

  This is observed in comparing Design 2, Design 3, and Design 4, although the effect is more pronounced in the subsidiary lobes. Designs 5, and 6 show a drastic shift in the operating frequency, which is primarily due to the stepped pattern, which is equivalent to multiple slots.

- *Adding horizontal slots increases the gain.*

  The addition of horizontal slots in Design 3 boosts the gain by about 2 dB. The increase for Designs 5 and 7, which have multiple horizontal slots, is manifold. However, adding slots very close to each other, as in Design 6 decreases gain, possibly due to interference of radiation patterns.

- *Increasing slot width increases current density.*

  This trend is visible in the transition from Designs 5 and 6 to Design 7. An increase in the thickness of the slots increases the surface current density distribution around the slots and the fractal design feed element. This leads to a net increase in gain.

- *The range of the radar improves with insertion of slots.*

  Upon adding slots, the range of the antenna broadens, and we are able to detect targets in a more diverse range, hence improving our application in surveillance radar technology.

- *The VSWR value 1 as slots are introduced.*

  As the slots in the ground plane increase, the VSWR successively decreases to reach a desirable value of close to 1. This denotes that the impedance of the radio and transmission line is well matched to the antenna's impedance.

- *Fractal design increases surface current density.*

  This is visible in Design 2, where there is an increase in the current density distribution around the fractal design feed element. The increase is appreciable when compared to a simple patch antenna of similar dimensions.

As the slots in the ground plane increase, the VSWR successively decreases to reach a desirable value of close to 1. This denotes that the impedance of the radio and transmission line is well matched to the antenna's impedance.

5. CONCLUSION

The use of a fractal based antenna design to increase bandwidth has been receiving much interest in recent times. In this paper, an application for such a design in an X-band surveillance radar has been proposed. The design is further optimized by the addition of slots. The suitability of the design for the proposed application is systematically proved by analyzing its gain, radiation pattern, VSWR values and operating bandwidth.

The importance of introducing slots in an antenna's ground plane is not unknown. It has been well documented in [12], [11], and [13]. Here, we have drawn a comparison of an antenna in various stages of development when introduction of slots modifies its existing characteristics. With slots in the picture, we are able to obtain a smoother S-Parameter curve with a wide range, and the resonating frequency at 9.2 GHz.

A detailed comparison with the various other design stages obtained during development has been made, showing the inherent benefits of one design over the other. This helps us obtain some general trends while designing, which have been documented herewith, and would be helpful for further research in this area.

VI. REFERENCES

[1] M. Micovic, A. Kurdoghlian, H. Moyer, P. Hashimoto, A. Schmitz,I. Milosavjevic, P.Willadesn,W.-S.Wong, J. Duvall, M. Hu, M. Delaney and D. Chow, "*Ka-band MMIC power amplifier in GaN HFET technology*," in Microwave Symposium Digest, 2004 IEEE MTT-S International, vol. 3, June 2004, pp. 1653–1656

[2] Merrill Skolnik, "Radar Handbook-Third Edition", 1970

[3] I. Immoreev and D. V. Fedotov, "Ultra wideband radar systems: advantages and disadvantages" in IEEE Conference on Ultra Wideband Systems and Technologies (UWBWST) Dig. Tech. Papers, May 2002, pp. 201–205.

[4] FCC, Washington, DC, USA, "First report and order on ultra-wideband technology", 2002.

[5] B. B. Mandelbrot, "The Fractal Geometry of Nature", New York, W. H. Freeman, 1983.

[6] Douglas H. Werner and SumanGanguly, "An Overview of Fractal Antenna Engineering Research", IEEE, 2003

[7] Majidzadeh, Maryam, ChangizGhobadi, JavadNourinia, and JavadPoorahmadazar. "*Small monopole antenna with modified slot ground plane for UWB applications*", 20th Iranian Conference on Electrical Engineering (ICEE2012), 2012.

[8] H.-R. Chuang. "A 3-8-GHz broadband planar triangular sleeve monopole antenna for UWB communication", 2007 IEEE Antennas and Propagation International Symposium, 06/2007

[9] Jacob Abraham and Thomaskutty Mathew "*David Fractal Antenna for Multiband Wireless Communication*" IEEE, Malaysia, 2014.

[10] Kumar, Ramavath Ashok, Yogesh Kumar Choukiker, and S K Behera. "Design of hybrid fractal antenna for UWB application", 2012 International Conference on Computing Electronics and Electrical Technologies (ICCEET), 2012.

[11] C.-C. Lin, Y.-C. Kan, L.-C. Kuo, and H.-R. Chuang, "A planar triangular monopole antenna for UWB communication," IEEE Microwave and Wireless Components Letters, vol.15, no.10, pp.624-626, Oct. 2005.

[12] Ojaroudi, M.; Yazdanifard, S.; Ojaroudi, N.; Naser-Moghaddasi, M, "Small Square Monopole Antenna With Enhanced Bandwidth by Using Inverted T-Shaped Slot and Conductor-Backed Plane," Antennas and Propagation, IEEE Transactions on, vol. 59, no.2, pp.670-674, Feb. 2011.

[13] K. Chung, S. Hong, and J. Choi, "Ultrawide-band printed Monopole antenna with band-notch filters," Microw. Antennas Propagation, vol. 1, no. 2, pp. 518–522, Apr. 2007.

[14] Pengcheng Li; Jianxin Liang; Xiaodong Chen, "*Study of printed elliptical/circular slot antennas for ultrawideband applications,*" Antennas and Propagation, IEEE Transactions on, vol 54, no.6, pp. 1670- 1675, June 2006.

[15] C. A.Balanis, "*Microstrip antennas*," in Antenna Theory, Analysis and Design, 3rd Edition, 2005

[16] Shailendra Kumar Dhakad; Neeraj Kumar Yadav; Ashwani Kumar; Shashank Verma, "*A Novel Single Band Microstrip Antenna with Hexagonal Fractal for Surveillance and Radar Application*", International Conference on soft computing for problem solving, Dec. 2015.