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Research Article

Partial Substrate Removal Techniques for the Enhancement of Gain and Radiation Characteristics in Fractal Antenna

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Abstract: Gain is an important parameter of the antenna through which the performance of the antenna is determined. Generally to increase the gain of the antenna, array configuration will be used but the overall size of the antenna will be increased. A method to enhance gain of a fractal antenna is investigated by partially removing the substrate surrounding the patch. The partial substrate removal reduces the losses due to surface waves. The effects of substrate removal in different configurations on the gain of the antenna are studied numerically and simulated. Compared to a conventional patch antenna, the antennas with partial substrate removal can enhance gain, for example, up to 2.7 dB. Furthermore, it is observed that the enhancement of gain is more due to the loss reduction of surface waves and dielectric substrate than increased patch size when the effective dielectric constant of substrate is lowered. Such a technique can be applied on designs, operating at higher frequencies where by surface wave and substrate losses are more significant.

Keywords: Fractal antenna, gain enhancement, radiation characteristics, substrate removal

INTRODUCTION

Advanced telecommunication systems oblige antennas with more extensive transmission capacity i.e., wider bandwidth and smaller dimensions than ordinarily conceivable. Fractal antennas are very good solution to this problem. Scaling properties, fractional dimensions and self-similarity characterize these structures (Yeap and Chen, 2010; Jilani *et al*., 2013; Dholakiya *et al*., 2011; Ratnaratorn *et al*., 2013). Fractal radio wires are described by self-similarity and space filling properties which bring about impressive size diminishment and multiband operation as contrasted with expected microstrip antenna. However, surface wave loss, conductor loss and dielectric loss will inferior the patch antennas gain. Two losses i.e., dielectric loss and the conductor loss depend on the perfection of the materials being utilized like gold or copper and the substrate correspondingly. The thickness of substrate and the loss tangent of materials will decide the dielectric loss. In the same way materials permittivity and the thickness of the substrate will affect the surface wave loss. Therefore, the conductor and dielectric losses can be reduced by choosing the good conductor, substrate materials and hence increasing the antennas gain, the patch antenna gain could be increased additionally through the suppression of surface waves (Chen *et al*., 2009; Sukaimi *et al*., 2013; Kumar *et al*., 2007; Madhav *et al*., 2013). One of the simple methods is replacing the patch antennas substrate with air whose dielectric constant is equal to 1 or by a less dielectric constant material, which are well known to be suspended patch antennas. Spacing material such as foam will form an air gap which is required by the suspended patch for fabrication purposes or the respective patch will be supported by posts. These both types may not be suitable for mass production, because they can be breakable and not very durable at times. The antenna gain can be further improved by Electromagnetic band gap structures. The surface waves can be blocked by periodic structures from transmitting in a definite band gap. For obtaining the lower dielectric constant substrate we have to pierce the substrate or to create holes in the substrate. The partial removal of substrate i.e., the concept of producing a lower dielectric constant will be more practical for the ease of fabrication (Arivazhagan *et al*., 2013; Madhav *et al*., 2014a, b; Mirzapour and Hassani, 2008).

The effective simple way is explored in this study to enhance the gain of antenna, in which fractal microstrip patch antennas partial substrate removal effects are examined. The main objective is to enhance the fractal microstrip patch antennas gain through partial substrate removal surrounding the antenna through which surface waves and dielectric loss can be suppressed (Madhav *et al*., 2012). If the detached substrate is a large portion then it can be referred as

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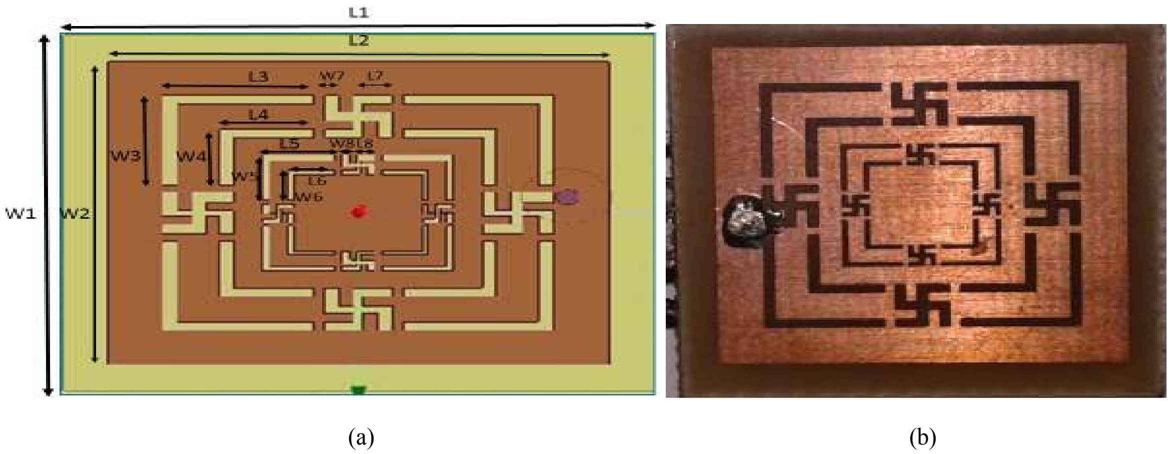


Fig. 1: Swasthik fractal antenna model (a) HFSS designed model, (b) Prototyped model

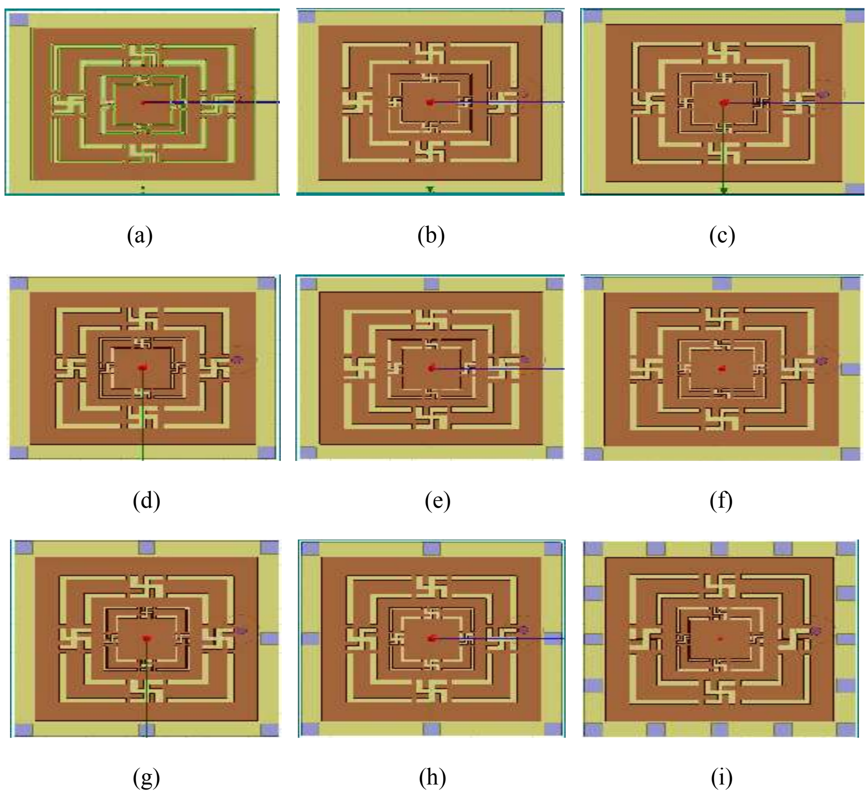


Fig. 2: Substrate removal iterations, (a) substrate removed on top left corner, (b) substrate removed on both the top corners, (c) substrate removed on both the top corners and lower right corner, (d) substrate removed on both the top corners and lower corners, (e) substrate removed on both the top corners, middle top and lower corners, (f) substrate removed on both the top corners, middle top and lower corners, right side middle edge, (g) substrate removed on both the top corners, middle top and lower corners, middle and right side edge, (h) substrate removed on all the corners and middle edges, (i) substrate removed on all the corners and edges

open air cavity method. The different substrate removals are designed, calculated and presented in this study.

MATERIALS AND METHODS

A novel swasthik slot fractal aperture coaxial fed micro strip antenna is designed and shown in Fig. 1. The dimensional characteristics are presented in Table 1 and the total dimension of the antenna is 26×26×1.5 mm is prototyped on substrate with dielectric constant of 4.4. Different slots are arranged on the aperture with swasthik slots in between them. The fractal based geometry is designed with modified geometrical calculations, rather than going for conventional geometrical calculation.

Table 1: Antenna dimensions

Length (mm)	Width (mm)
L1 = 26	W1 = 26
L2 = 4.00	W2 = 4.00
L3 = 6.50	W3 = 6.50
L4 = 4.10	W4 = 4.10
L5 = 3.25	W5 = 3.25
L6 = 2.05	W6 = 2.05
L7 = 1.20	W7 = 0.60
L8 = 0.60	W8 = 0.30

The basic model is modified by removing substrate material at the corners of four sides as shown in Fig. 2. Figure 2a, squares-shaped lattice of dimension 2×2×1.5 mm is removed from the left corner of the substrate material. Figure 2b, two edges of the top side are removed with same dimensions considered for previous case. Figure 2c, substrate removed on both the top corners and lower right corner. Figure 2d to 2i shows that removal of square lattice at different positions on the substrate.

RESULTS AND DISCUSSION

Figure 3 shows the simulated |S11| for the designs for all the iterations. The simulation is carried out with the help of Finite element method based High Frequency Structure Simulator (HFSS-15). From the simulation results, it is observed that antenna is resonating at multiband with resonating frequencies of 2.7, 5.9, 9.2, 10.7, 13.6 and 19 GHz, respectively. From Iteration 1 to 9, The impedance bandwidth is improving at least by an average of 3% and it is observed that that Iteration1 is having minimum loss at fundamental resonant frequency and iteration 9 having minimum loss at a Centre frequency of total bands.

Figure 4 shows the VSWR Vs Frequency of all the models. It is noted that at the entire resonating frequencies VSWR 2:1 ratio is maintained by the antenna for all the Iterations.

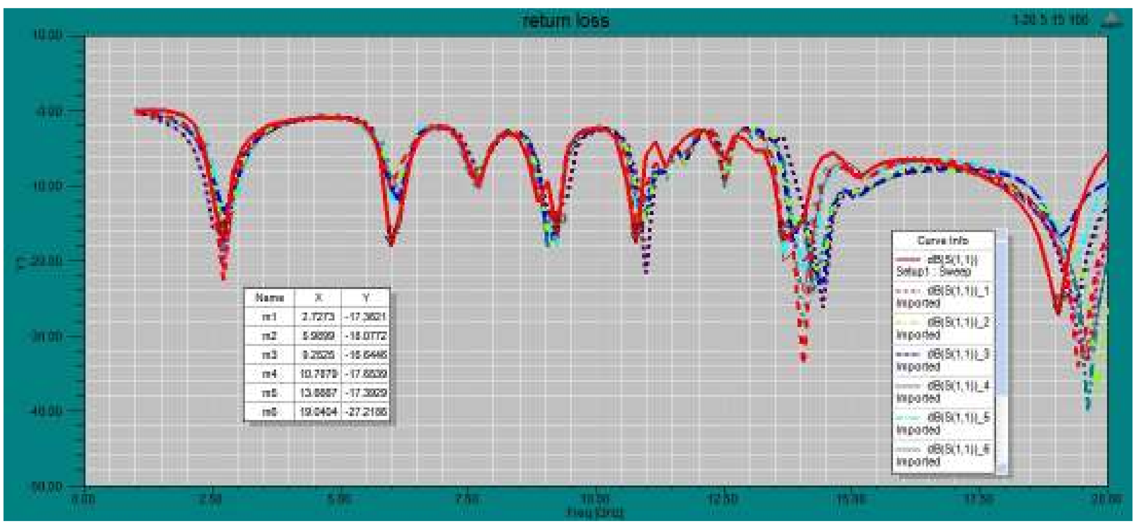


Fig. 3: Return loss vs. frequency

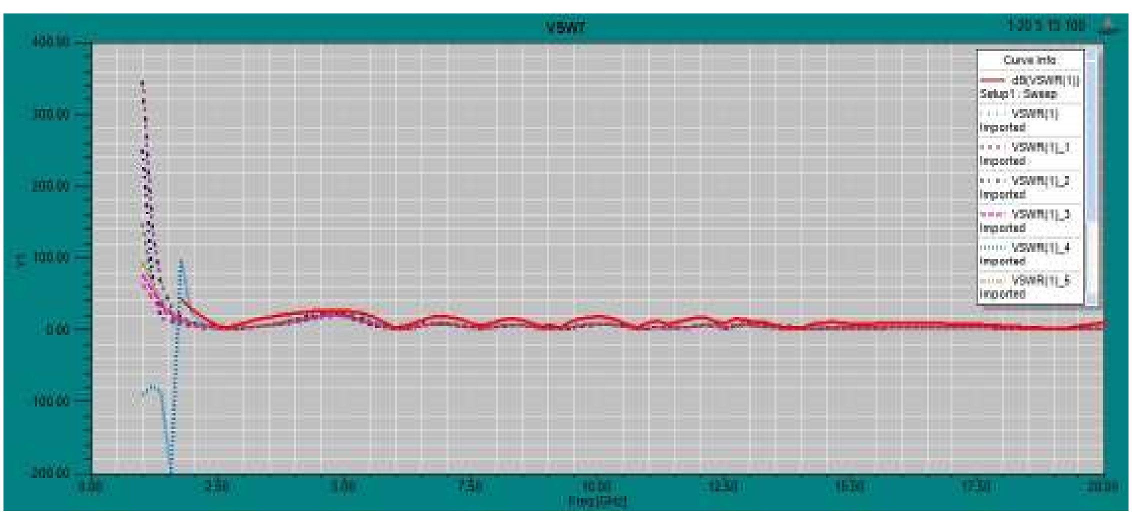
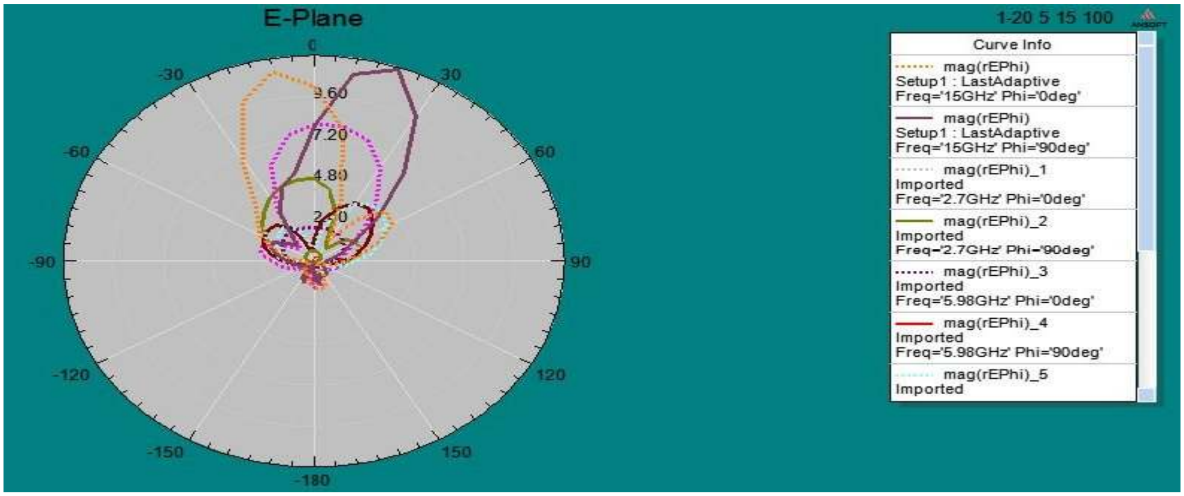
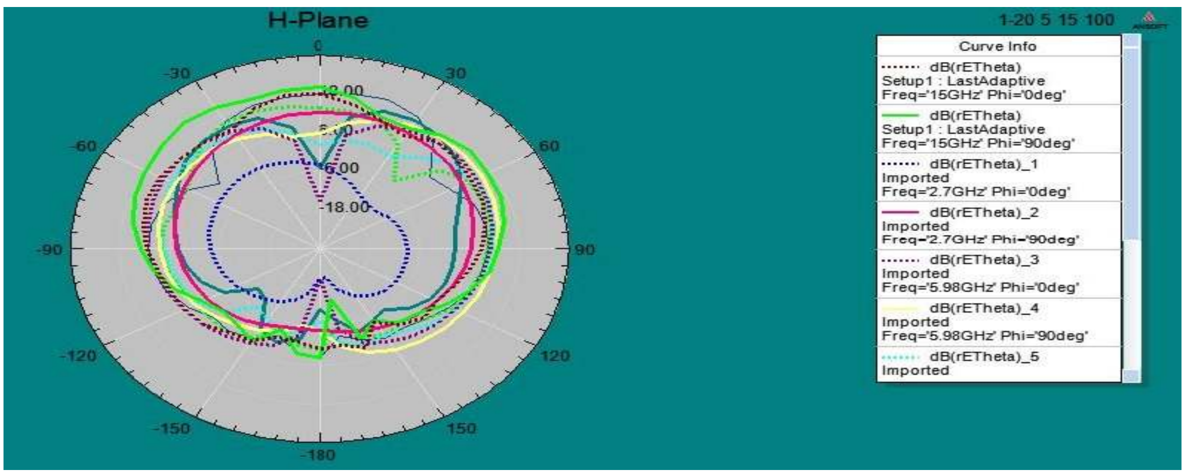


Fig. 4: VSWR vs. frequency



(a)



(b)

Fig. 5: (a) E-plane radiation pattern, (b) H-plane radiation pattern

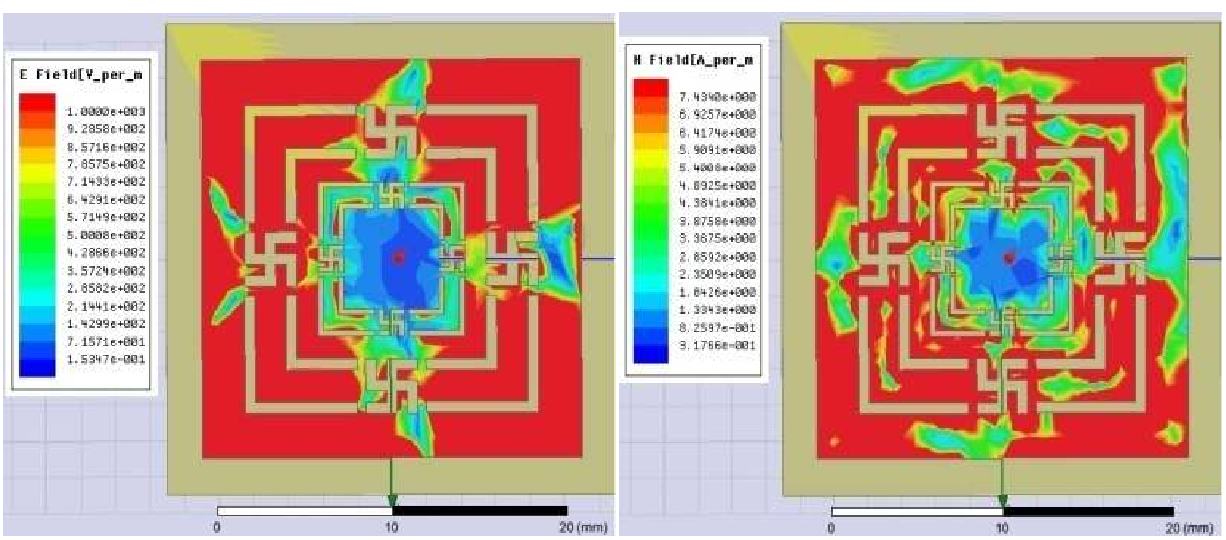


Fig. 6: E-field and H-field at 5.98 GHz

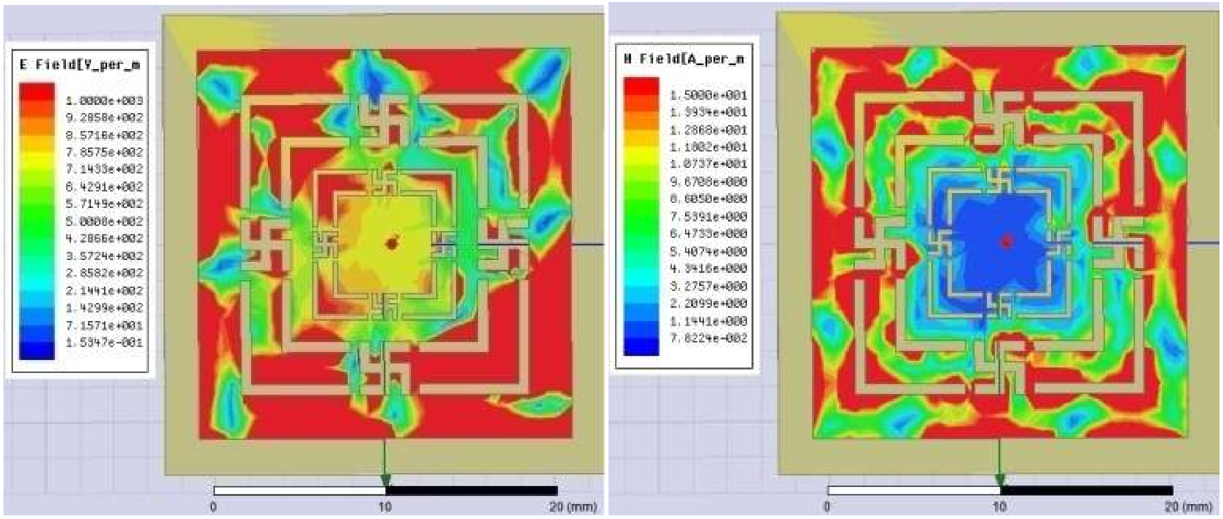


Fig. 7: E-field and H-field at 9.25 GHz

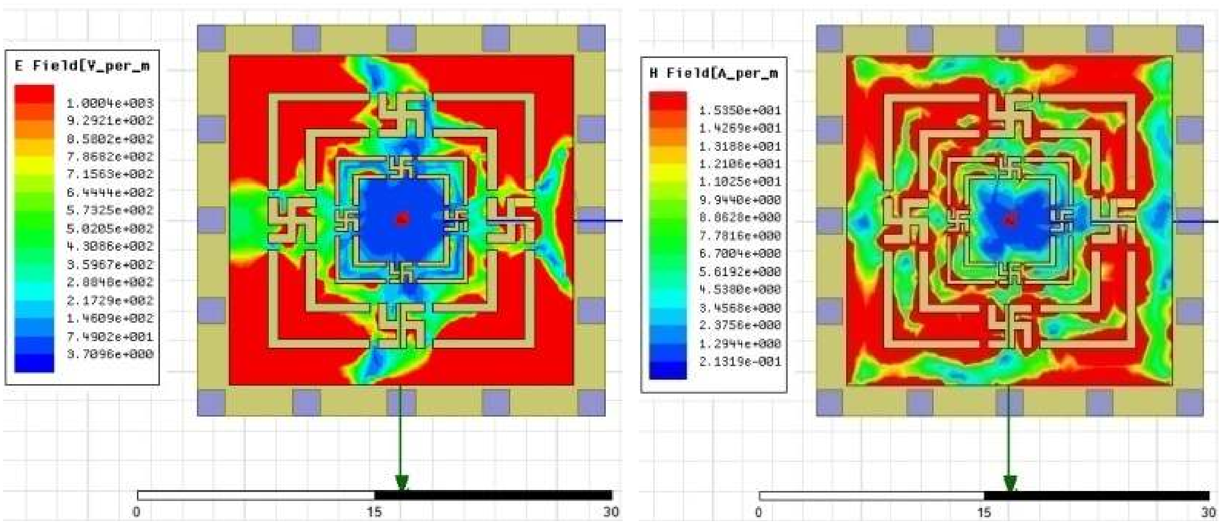


Fig. 8: Proposed model E-field and H-field at 5.98 GHz

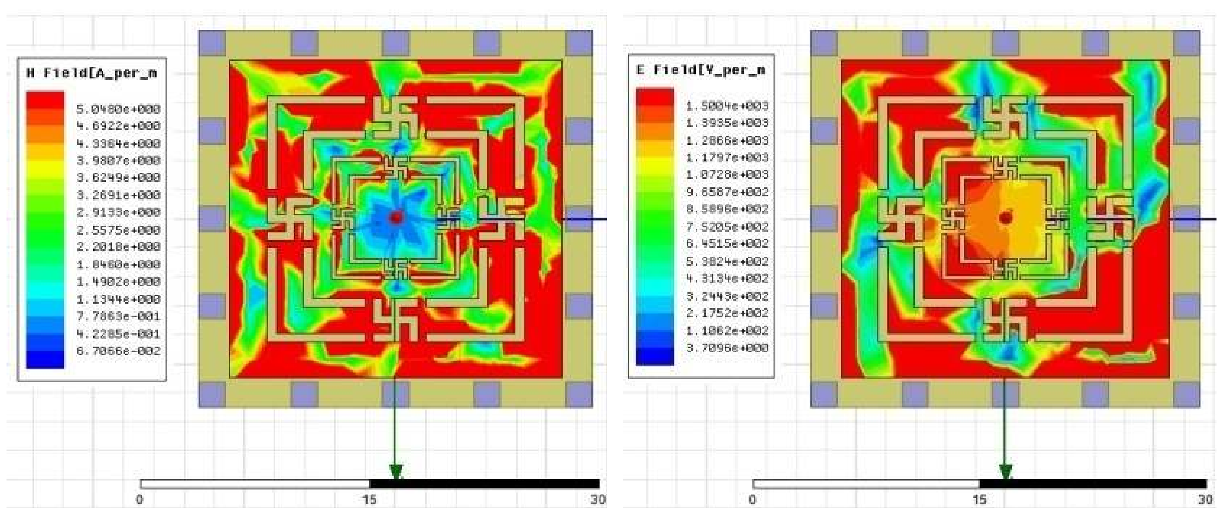


Fig. 9: Proposed model E-field and H-field at 9.25 GHz

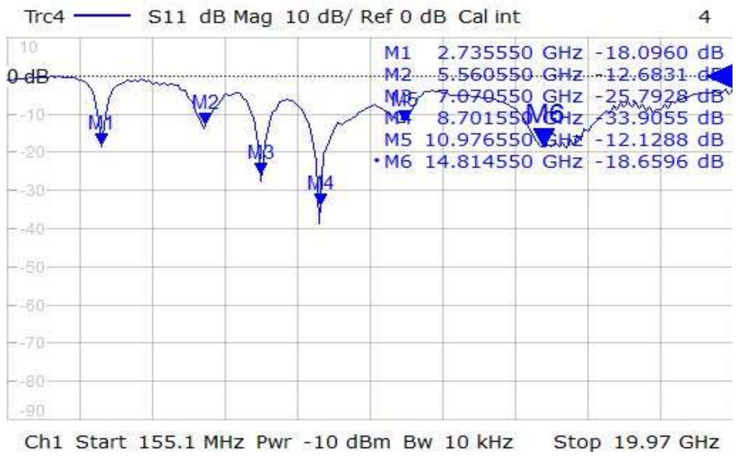


Fig. 10: Measured $|S_{11}|$ parameter for the proposed model

Fig. 11: VSWR vs. frequency of the proposed model

Table 2: Antenna impedance values at resonant frequencies

	Impedance in ohms	
Frequency in GHz	Re	Im
2.73	47	13.49
5.56	32	10.72
7.07	45	3.36
8.70	65	8.27
10.90	40	26.60
14.80	37.5	11.97

Figure 5a and b shows the radiation patterns for the designs at their respective resonant frequencies in the E and H planes. The cross polarization levels are less than -18 db for iterations 1, 4, 6 and 8, respectively and have narrow beam widths in both E-plane and H-plane for remaining iterations. The radiation efficiency is more at 10.78 GHz for basic model with high Gain and directivity of 6.3 and 3.85 db, respectively. Figure 6 and 7 illustrates the electric field and magnetic field distributions at 5.9 and 9.2 GHz along the plane of the patch for final proposed model. Similarity is observed for the case of H-field from Fig. 7. From Fig. 8, we observed that magnetic field distribution at the edges of the patch is less compared to H-field in the Fig. 9. The electric field distribution at the four corners in the Fig. 8 is more compared to Fig. 9.

R and S ZNB 20 VNA is used to measure the S-parameters of the fabricated model. Figure 10 shows the measured $|S_{11}|$ parameter for the proposed model. There is a frequency shift in the measured values compared to the simulated results because of the mismatch in the connector used at the port. The impedance matching is little bit poor with the connector used in the prototype model. The smith chart values in the Table 2 shows the evidence for this non coherence at the respective frequencies. Figure 11 shows the VSWR curve for the proposed model in the real time measurement from fabricated design. It has been observed from the results that, antenna is maintaining VSWR<2 at the resonant frequencies.

Table 3 shows the antenna parameters for the basic fractal antenna at different resonant frequencies. Maximum directivity of 6.3 dB and peak gain of 3.8 dB is attained at 10.78 GHz.

Table 3: Antenna parameters for basic fractal design

Quantity	2.7 Ghz	5.98 Ghz	9.25 Ghz	10.78 Ghz	15 Ghz
Max U	0.0244755 (W/sr)	0.0461356 (W/sr)	0.0781758 (W/sr)	0.258819 (W/sr)	0.184455 (W/sr)
Peak directivity	2.4127400	2.8708900	5.2981500	6.306860	5.940890
Peak gain	1.0807600	0.5902580	0.9900540	3.857940	2.402220
Peak realized gain	0.3075750	0.5797710	0.9824090	3.252490	2.317980
Radiated power	0.1274790 (W)	0.2019480 (W)	0.1854250 (W)	0.515706 (W)	0.390174 (W)
Accepted power	0.2845910 (W)	0.9822320 (W)	0.9922780 (W)	0.843062 (W)	0.964935 (W)
Incident power	1 (W)	1 (W)	1 (W)	1 (W)	1 (W)
Radiation efficiency	0.4479390	0.2056010	0.1868680	0.611706	0.404353
Front to back ratio	56.301500	18.773300	70.373200	45.35530	81.15470

CONCLUSION

A total of ten models including the basic fractal model, performance evaluation is presented in this study with partial substrate removal technique. The performance parameter like Gain, Bandwidth and Directivity are considered for the evaluation. It is observed that when compared with basic fractal geometry, the surface waves were suppressed and dielectric losses are reduced when partial substrate removal methods are applied. The gain is improved by 2.3 to 2.5 db. When the substrate surrounding the radiating edges of the patch antenna has been partially removed. The bandwidth improvement is also attained from this investigation. Therefore with partial substrate removal method, the Gain and Bandwidth parameters are significantly improved by decreasing dielectric losses.

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