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A Modified Sierpinski Carpet Fractal Antenna for Multiband Applications

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Abstract The sudden growth in wireless communication area has increased the requirements of compact integrated antennas. This paper describes the design of Modified Sierpinski Carpet Fractal Antenna which resonates at six frequencies 4.825, 5.455, 6.265 GHz and 6.805, 8.02 and 9.145 GHz. Different performance parameters like radiation pattern, gain, Voltage Standing Wave Ratio, return losses are observed at all the frequencies. The FR4 glass epoxy with relative permittivity 4.4 and height 1.6 mm is used as substrate material. Antenna is fed by coaxial probe feed and simulated using ANSYS/ANSOFT HFSS V13 software. Proposed antenna has simple structure. Investigation is done between 1 and 10 GHz frequencies. The proposed antenna is fabricated and tested on the Vector Network Analyzer. The measured and simulated results of proposed antenna are compared and are found to be good agreement with each other.

Keywords Bandwidth · Gain · HFSS · Radiation pattern · Return loss · MSCFA · VSWR · VNA

1 Introduction

A microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side [1]. Microstrip patch antennas can be demonstrated in a first approximation as a cavity of electrically small height [2]. These antennas are popular

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for low profile applications at frequency above 100 MHz [3]. The patch may be square, rectangular, dipole, circular, triangular, circular ring, elliptical or any other configuration [4].

In the upcoming years, research work has been carried out for several antenna configurations based on fractal geometries. These are low profile antennas with moderate gain and can be operated at multiple frequency bands and hence are multifunctional [5]. Fractals were firstly defined by Benoit Mandelbrot. These geometries have been used to characterize unique occurrences in pattern of nature that were difficult to define with euclidean geometries like length of coastlines, the clouds density, and the tree's branches. It describes the class of complex geometries that are created through successive iteration of applying a geometric generator to a simple self-similar basis [6]. The term "fractal" means broken or irregular fragments. According to Mandelbrot, "a fractal is a shape made of parts similar to the whole in some way" [7]. Fractals are classified into two categories and these are deterministic and random fractals. Deterministic fractal antenna works on the principle of a 'motif'. The term deterministic means that there is no randomness involved i.e. it always produces the same original object after repetitive recursion and several scaling. Fractals defined by iterated function systems often display exact self similarity. Examples of fractals are classic wideband antennas, koch curves, koch snowflakes, sierpinski gasket, sierpinski carpet. Random fractals are quite similar and look like random walks. Random fractals were used to generate array configurations that were completely ordered and disordered and vice versa. Fractal arrays sierpinski fractal structures are designed for carrying out multiple iterations of a basic geometric shape such as triangle, circle or square [5].

Sivia et al. [8] applied concept of fractal to the geometry of rectangular microstrip patch antenna to obtain multi-band frequency operation. For the applications of multi-band in wireless communications and the environment like handhold radio devices, the antenna should be compact in size [9]. Fractal geometry has been useful in designing small antennas, multiband elements, and highly directive antennas [10]. Fractal geometries are used in radiating systems and microwave devices to provide further multiple properties [11].

Different feeds to define microstrip antenna are microstrip line, coaxial probe, aperture coupling and proximity coupling [12]. Many of these feeding techniques can improve the bandwidth, but provide asymmetry in radiation pattern. Mostly aperture and electromagnetic coupling methods of feeding are used in stacked configurations to avoid the spurious radiations from the feed. The coaxial probe feed is the most popular one for electrically thick substrates, but the inductance of the probe may create the impedance mismatch which can be compensated by cutting slots on the patch. Coaxial probe feed, slot on the patch provides in gain enhancement [13]. In this paper concept of fractal has been applied to rectangular patch to obtain a unique model of modified sierpinski carpet fractal antenna. Coaxial probe feed is used to feed the proposed antenna. Various parameters such as return loss, gain and VSWR are measured.

2 Design and Fabrication of Proposed Antenna

The basic idea is to increasing the electrical length of the antenna by optimizing its shape. Fractal shape has been useful for multiband applications.

Step 1 The design of MSCFA starts with rectangular patch which operates at resonant frequency of 2.4 GHz. By substituting the values of $\varepsilon_r = 4.4$, $f_0 = 2.4$ GHz, h = 1.6 mm and $C = 3 \times 10^8$ m/s in Eqs. (1)–(5) length and width of the rectangular patch are calculated as shown in Table 1.

Calculation of Width (W)

The width of the patch element (W) is calculated using equation as given in [4]

$$w = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

Effective dielectric constant ε_{eff} is calculated using following equation as given in [4]

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{1/2} \tag{2}$$

Effective length of patch is calculated using equation as given in [4]

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3}$$

Extension in length of patch is calculated using Eq. (4) as given in [4]

$$\Delta L = 0.412h\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$

The actual length (L) of patch is calculated using following equation as given in [4]

$$L = L_{eff} + 2\Delta L \tag{5}$$

Thus length and width of patch are found 29.44 and 38.04 mm respectively. Substrate width and length are taken 60 mm each. This geometry is known as base geometry as shown in Fig. 1a.

Step 2 Divide base geometry into 9 congruent sub-rectangles in a 3-by-3 grid, and remove one central rectangle from each outer grid as shown in Fig. 1b to get 1st iteration of MSCFA. Black part represents metal and white part represents substrate.

Step 3 Divide each metallic rectangle of 1st iteration geometry into 9 congruent sub-rectangles in a 3-by-3 grid, and remove one central rectangle from each this metallic rectangle to get 2nd iteration of MSCFA. Black part represents metal and white part represents substrate as shown in Fig. 1c.

Step 4 Similar process is repeated to get 3rd iteration geometry as shown in Fig. 1d.

Table 1 Antennas parameters

Dielectric substrate (FR4)	$\varepsilon_r = 4.4$
Substrate height (h)	1.6 mm
Patch width (Wp)	38.04 mm
Patch length (Lp)	29.44 mm
Substrate width (Ws)	60 mm
Substrate length (Ls)	60 mm
Feed location	(4,4,0)

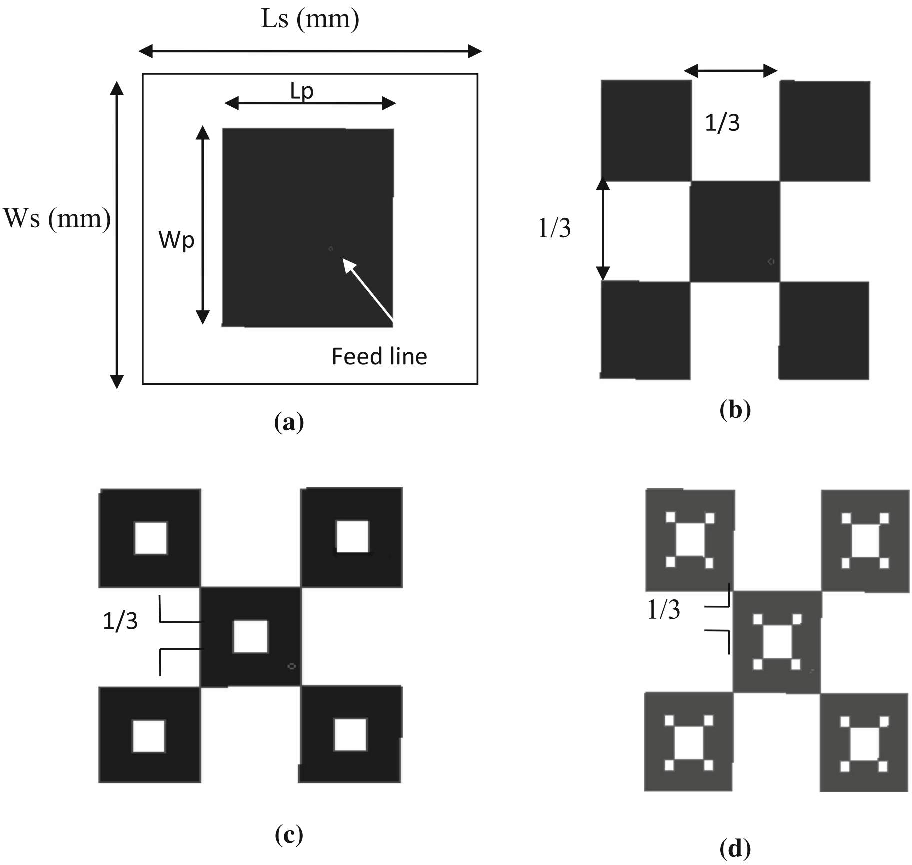

Fig. 1 Geometry of proposed Modified Sierpinski Carpet Antenna. **a** 0th iteration, **b** 1st iteration, **c** 2nd iteration, **d** 3rd iteration

The three iterations of the proposed antenna have been fabricated on FR4 glass epoxy and fabricated structures are shown in Fig. 2. Return losses of antenna are measured using Vector Network Analyzer (VNA). The VNA must be calibrated before making the

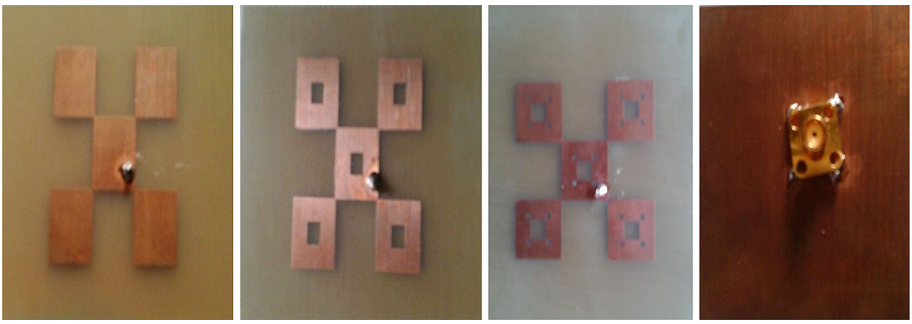

Fig. 2 Fabricated geometries of proposed Sierpinski Carpet Antenna

measurements [16]. The calibration is done by using the cal kit/calibration kit which has three ports open, short and load. The start and stop frequency of antenna is assigned before calibrating the VNA.

The antenna is connected to the port 1 of VNA after the completion of calibration. Select the S_{11} curve response and the number of traces from the response menu and trace menu respectively.

3 Simulated and Measured Results

Simulated and measured results of proposed antenna in terms of S parameter, VSWR and gain are given below:

3.1 S Parameter Characteristics

S_{11} is known as S parameter or reflection coefficient, signifies power reflected back at antenna port due to impedance mismatch between antenna and transmission line. $S_{11} = 20\log_{10}\left|\frac{E_r}{E_i}\right| = 10\log_{10}\left|\frac{E_r}{E_i}\right|^2 = 10\log_{10}\left(\frac{P_r}{P_i}\right)$. When antenna is connected to Vector Network Analyzer (VNA), then S_{11} signifies the amount of energy reflected to the VNA [14]. Small value of S_{11} means high amount of energy is delivered to antenna and small energy is reflected back to antenna port. S_{11} values are measured in dB and are –ve. There is minor difference between reflection coefficient S_{11} and Return Loss (RL). $RL = 10 \log_{10}(P_i/P_r)$, where P_i is incident and P_r is reflected powers respectively. So RL is positive. Measured and simulated S_{11} versus frequency plots of all the three iterations are shown in Figs. 3, 4 and 6 respectively. S_{11} of proposed antenna for 1st iteration are less than -10 dB at 5.32, 6.31 and 9.055 GHz frequencies. So, 1st iteration of proposed antenna works at these three frequencies. Similarly 2nd iteration works at three frequencies 5.275, 6.445 and 9.055 GHz whereas 3rd iteration works at six frequencies 4.825, 5.455,

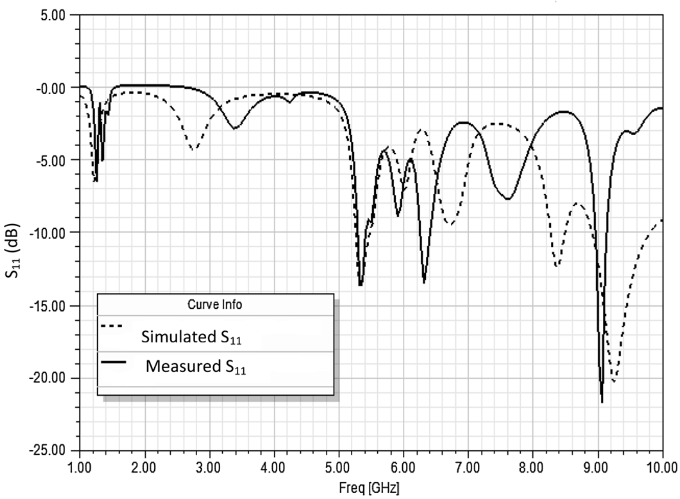

Fig. 3 S parameter characteristic for 1st iteration

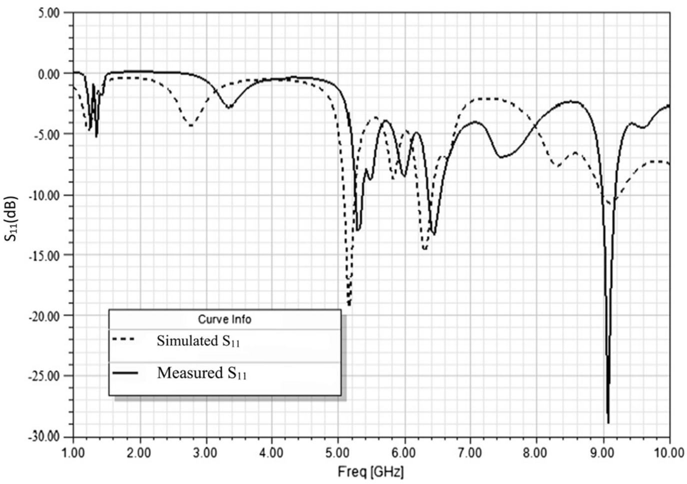

Fig. 4 S parameter characteristic for 2nd iteration

6.265 GHz and 6.805, 8.02 and 9.145 GHz. Simulated and measured results for S_{11}(dB) and VSWR of proposed antenna are also shown in Table 2. Experimental setup for measuring return loss of proposed antenna of 2nd iteration is shown in Fig. 5. It consists of VNA, proposed antenna and monitor of computer. S parameter characteristic for 2nd iteration is also shown on computer screen as shown in Fig. 5.

3.2 Radiation Pattern

Graphical representation of radiations of antenna as a function of direction is given the name radiation pattern. If radiations of antenna are expressed in terms of field strength E

Table 2 A comparison of simulated and measured S_{11} and VSWR at different frequencies

Iteration	Simulated resonant frequencies (GHz)	Simulated S_{11} (dB)	Simulated VSWR	Measured resonant frequencies (GHz)	Measured S_{11} (dB)	Measured VSWR
1st	5.33	−13.79	1.51	5.32	−13.28	1.55
	8.36	−12.38	1.63	6.31	−13.51	1.53
	9.25	−20.17	1.21	9.055	−21.64	1.18
2nd	5.16	−19.24	1.24	5.275	−12.77	1.59
	6.31	−14.66	1.45	6.445	−13.16	1.56
	9.11	−10.64	1.83	9.055	−28.87	1.07
3rd	4.85	−13.59	1.52	4.825	−18.56	1.26
	5.25	−20.63	1.20	5.455	−13.59	1.52
	6.09	−16.47	1.35	6.265	−18.10	1.28
	6.81	−12.24	1.64	6.805	−13.90	1.50
	8.44	−17.66	1.28	8.020	−13.00	1.57
	9.12	−19.77	1.22	9.145	−26.10	1.10

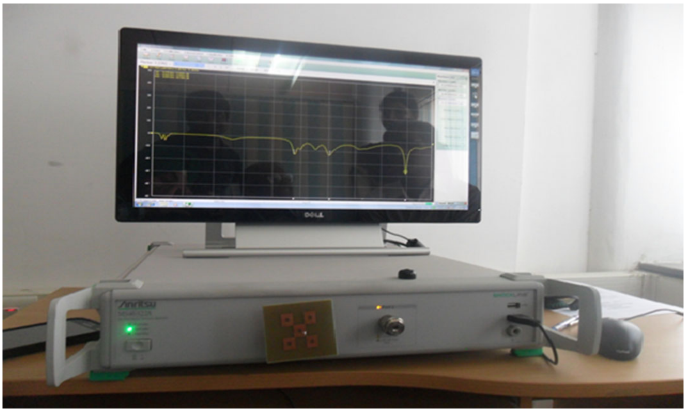

Fig. 5 Experimental setup for measuring S_{11} of 2nd iteration of proposed antenna

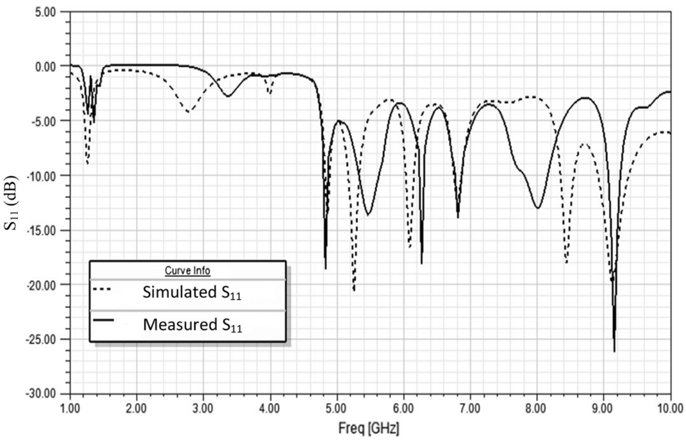

Fig. 6 S parameter characteristic for 3rd iteration

(volt/meter), the radiation pattern is called field strength pattern. 2D Radiation patterns of the antenna are plotted in far-field range by keeping the proposed antenna at a height of 2 m from the ground with a separation distance of 5 m between transmitting and receiving antennas. The simulated and measured radiation pattern in E plane and H plane of all the three iterations at center frequencies for all iterations are shown in Figs. 7, 8 and 9 respectively. The simulated and measured radiation patterns for XZ and YZ planes for $\Phi = 0$ and $\Phi = 90$ are used. Short dash lines show the simulated results and solid lines show the measured results for all iterations at XZ and YZ planes. MSCFA shows omni-direction characteristics in $\Phi = 0$ and $\Phi = 90$ at lower frequencies for 0th, 1st and 2nd iterations. In 3rd iteration, radiation patterns is distorted at frequency 9.12 GHz due to change in nature of current due to edge reflection resulting from standing waves lower frequencies to a travelling wave at higher frequencies.

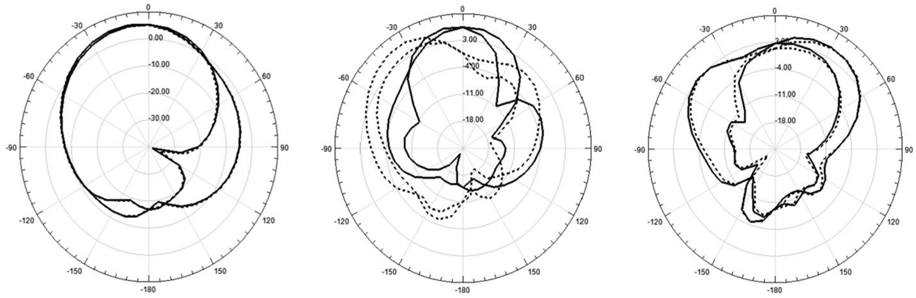

Fig. 7 Simulated and measured radiation pattern for 1st iteration

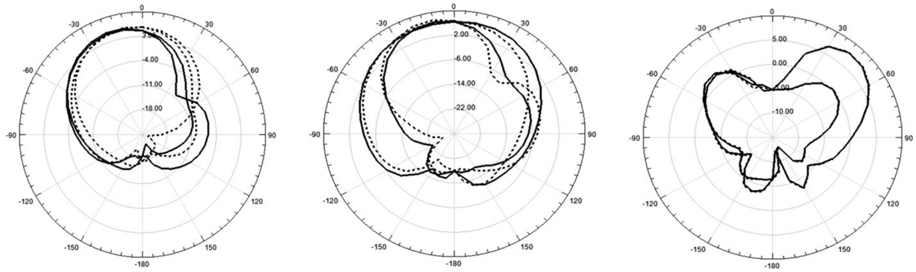

Fig. 8 Simulated and measured radiation pattern for 2nd iteration

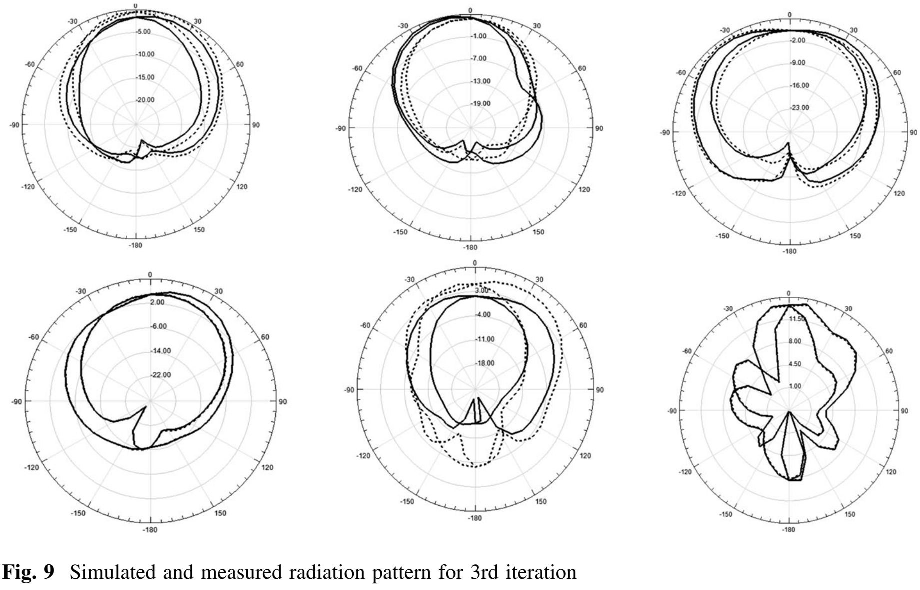

Fig. 9 Simulated and measured radiation pattern for 3rd iteration

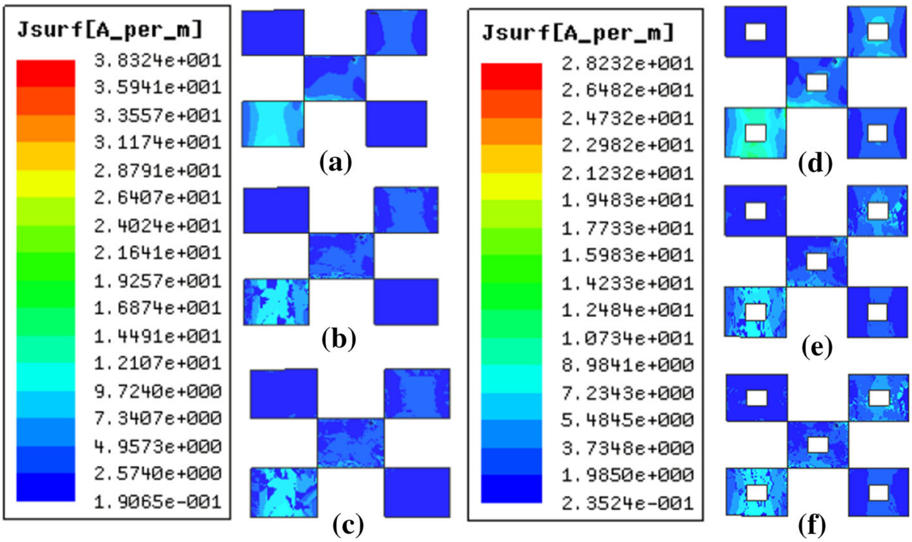

Fig. 10 Current distribution of 1st iteration of proposed antenna at **a** 5.33 GHz **b** 8.36 GHz **c** 9.25 GHz and current distribution 2nd iteration of proposed antenna at **d** 5.16 GHz **e** 6.31 GHz **f** 9.11 GHz

3.3 Current Distribution

The current distribution gives the distribution of current over the patch of antenna. Current distributions of proposed antenna at frequencies are 5.33, 8.36 and 9.25 GHz for 1st iteration are shown in Fig. 10a–c respectively. The maximum current density magnitude indicates the highest coupling effect while the minimum magnitude indicates the lowest one [15]. Similarly current distributions of proposed antenna for 2nd iteration at 5.16, 6.31

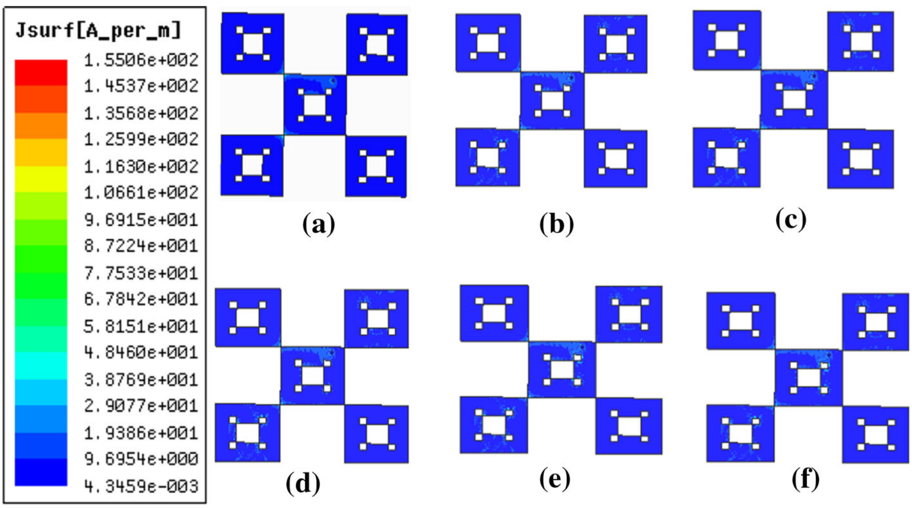

Fig. 11 Current distribution of 3rd iteration of proposed antenna at **a** 4.85 GHz **b** 5.25 GHz **c** 6.09 GHz **d** 6.81 GHz **e** 8.44 GHz **f** 9.11 GHz

and 9.11 GHz and for 3rd iterations at frequencies 4.85, 5.25, 6.09 GHz and 6.81, 8.44 and 9.12 GHz are shown in Figs. 10d–f and 11 respectively. From Fig. 11 it is clear that current distribution is almost uniform at all central frequencies of 3rd iteration. Current density has maximum value at slots and edges as shown in Fig. 10d–f.

4 Conclusion

In present paper the effect of fractal geometry on rectangular microstrip patch antenna has been analyzed. The experimental results are in concord with the simulation results. The key features of this antenna is its simplicity in construction using fractal geometry, works at six frequencies (4.825, 5.455, 6.265 GHz and 6.805, 8.02 and 9.145 GHz) and low cost to get improved performance for multi band (C and X) applications. This geometry offers numerous variations in dimension and design, hence gives wide scope for various commercial applications. Proposed antenna can be used for long distance radio telecommunications in C band as well as satellite communication, radar, space communications in X band.

References

1. Panwar, S., & Sharma, B. S. (2013). Dual U-slot mmicrostrip patch antenna with enhanced bandwidth. *International Journal of Science and Research (IJSR), 2*(8), 145–147.
2. Borja, C., & Romeu, J. (2003). On the behavior of koch island fractal boundary microstrip patch antenna. *IEEE Transactions on Antennas and Propagation, 51*(6), 1281–1291.
3. Sivia, J. S., Singh, A., & Kamal, T. S. (2013). Neurocomputational approach for feed-position estimation in circular micro-strip Antenna. *International Journal of Computer Applications, 75*(6), 33–38.
4. Balanis, C. A. (1997). *Antenna theory*. London: Wiley.
5. Roopa, R., Jayadevat, S., Manassarkar & Kumarswamy, Y. S. (2013). Design of sierpinski carpet sierpinski fractal antenna by improving the performance parameters and reducing the antenna size, In *IEEE Conference on Information & Communication Technologies* (pp. 70–73). IEEE.
6. Dalsania, P., Shah, B. & Dwivedi, V. V. (2012). Analysis of multiband behaviour on square patch fractal antenna, In *International Conference on Communication Systems and Network Technologies* (pp. 76–78). IEEE.
7. Sagne, D. S., Batra, R. S. & Zade, P. L. (2012). Design of modified geometry sierpinski carpet fractal antenna array for wireless communication, In *3rd IEEE International Advance Computing Conference (IACC)*, pp. 435–439.
8. Sivia, J. S., Singh, A., & Kamal, T. S. (2013). Design of sierpinski carpet fractal antenna using artificial neural networks. *International Journal of Computer Applications, 68*(8), 5–10.
9. Chowdar, P. S. R., Prasad, A. M. & Rao, P. M. (2014). Design of modified sierpinski antenna for WLAN applications, In *International Conference on Electronics and Communication System.*
10. Jahromi, M. N., Falahati, A., & Edwards, R. M. (2011). Bandwidth and impedance-matching enhancement of fractal monopole antennas using compact grounded coplanar waveguide. *IEEE Transactions on Antennas and Propagation, 59*(7), 2480–2487.
11. Oraizi, H., & Hedayati, S. (2012). Circularly polarized multiband microstrip antenna using the square and giuseppe peano fractals. *IEEE Transactions on Antennas and Propagation, 60*(7), 3466–3470.
12. Singh. J., Singh, A. P., & Kamal, T. S. (2011). On the design of triangular microstrip antenna for wireless communication, In *International Journal of Computer Applications*, pp. 103–106.
13. Kushwaha, R. S., Srivastava, D. K., & Saini, J. P. (2012). A design of H-shape slot loaded wideband microstrip patch antenna. *International Journal of Electronics and Computer Science Engineering, 1*(2), 533–537.
14. Bird, T. S. (2009). Definition and misuse of return loss. *IEEE antenna and propagation magazine, 51*(2), 166–167.

15. Mezaalab, Y. S., Alib, J. K., & Eyyuboglua, H. T. (2015). Miniaturised microstrip bandpass filters based on moore fractal geometry. *International Journal of Electronics, 102*(8), 1306–1319.
16. Bhatia, S. S., & Sivia, J. S. (2016). A novel design of circular monopole antenna for wireless applications. *Wireless Personal Communication, International Journal*, *91*(3), 1153–1161.

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