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Optimization of Swastika Slotted Fractal Antenna using Genetic Algorithm and Bat Algorithm for S-band Utilities

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Abstract A novel pattern of fractal antenna deploying Swastika slotted geometry up to second iteration is used for optimization in this paper which enhanced its utilities for S-band. Swastika Slotted Fractal Antenna has been designed and fabricated by the use of FR4 substrate material which has 1.6 mm as its substrate thickness, 4.4 as dielectric constant and 0.02 as loss tangent with help of Zeland IE3D software and MATLAB software. The comparison between Genetic Algorithm and Bat Algorithm revealed that results of BA are superior than GA for the designed geometry. The testing of proposed fabricated antenna has been done by using Rohde and Schwarz ZVL Vector Network Analyzer and obtained experimental results are in good agreement with optimized simulated results. Also, fabricated SSFA resonate at 2.49, 2.70, 2.96 and 3.96 GHz with corresponding values of S-parameter (S_{11}) as −16.78, −18.87, −28.66 and −11.48 dB respectively.

Keywords Bat algorithm (BA) · Fractals · Genetic algorithm (GA) · Iteration · Optimization · Swastika slotted fractal antenna (SSFA)

1 Introduction

The empirical fact of using different kinds of optimization techniques is that it gives superior solution to solve various kinds of problems, improve the results and reduces the error. Artificial Neural Networks (ANN), Particle Swarm Optimization (PSO), Genetic

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Algorithm (GA), Ant Colony Optimization (ACO), BAT Algorithm (BA) and Bacterial Foraging Optimization (BFO) etc. are the fundamental techniques used for optimization [1–10].

Fractals have distinct properties from other type of antennas. Idea of fractal came from the occurrence of natural processes like phenomenon of cloud formation, mountains, branches of tree, coastlines etc. [11, 12]. Also, these antennas were adopted due to their multiband and wideband applications [12–14]. Hilbert Curve, Koch Snowflake, Sierpinski Gasket, Minkowski Island, Sierpinski Carpet and the hybrid combination of Sierpinski and Koch etc. are the basic structures that exhibit properties of fractal antenna [15–21].

Basically, Swastika is the holistic symbol of auspiciousness related to Hindu religion and other communities also. It is made up from two straight lines which cross each other like plus sign and all the tips are bent at the angle of 90 degree [22].

The applications of S-band exist in the range from 2 to 4 GHz for short waves of microwave band. It has utilities in satellite communication, weather radar, microwave ovens, WLAN, ISM band, Bluetooth and WiMAX etc.

In this paper, Genetic Algorithm (GA) and Bat Algorithm (BA) are used for the optimization of Swastika Slotted Fractal Antenna (SSFA) which are nature inspired meta-heuristic algorithms. The comparison of both techniques showed that Bat Algorithm (BA) gave better results than Genetic Algorithm (GA) for the Swastika slotted fractal geometry.

The first section of this paper gives brief description of optimization techniques, fractal geometries, importance of Swastika symbol and S-band applications. Second section illustrates the geometry and comparison of different iteration stages of Swastika Slotted Fractal Antenna (SSFA). Genetic Algorithm (GA) and Bat Algorithm (BA) with their results of comparison are investigated in the third section. Simulated and experimental results are discussed in the fourth section, subsequently followed by conclusion.

2 Different Iteration Stages of SSFA with Comparison

The main parameters which are inevitable requirement for the design of SSFA are given in Table 1. SSFA is designed and simulated with the help of Zeland IE3D Software [23] up to the iteration factor two. Both length, L and width, W of square patch is 36 mm. The metal portion of square patch is reduced by inserting a slot of Swastika symbol in it (Fig. 1).

In the next iteration stages, similar pattern of Swastika slot is imitated in all the four quadrants by iteration factor (IF) as given below

$$\text{New width of Swastika slot} = a_1 \times \text{Previous width of Swastika slot} \qquad (1)$$

where, a_1 (iteration factor) = 1/3.

Table 1 Values of parameters for the design of SSFA

S. No.	Name of Parameter	Value
1.	Substrate thickness, h	1.6 mm
2.	Substrate material	FR4
3.	Loss tangent, tan δ	0.02
4.	Dielectric constant, ε_r	4.4

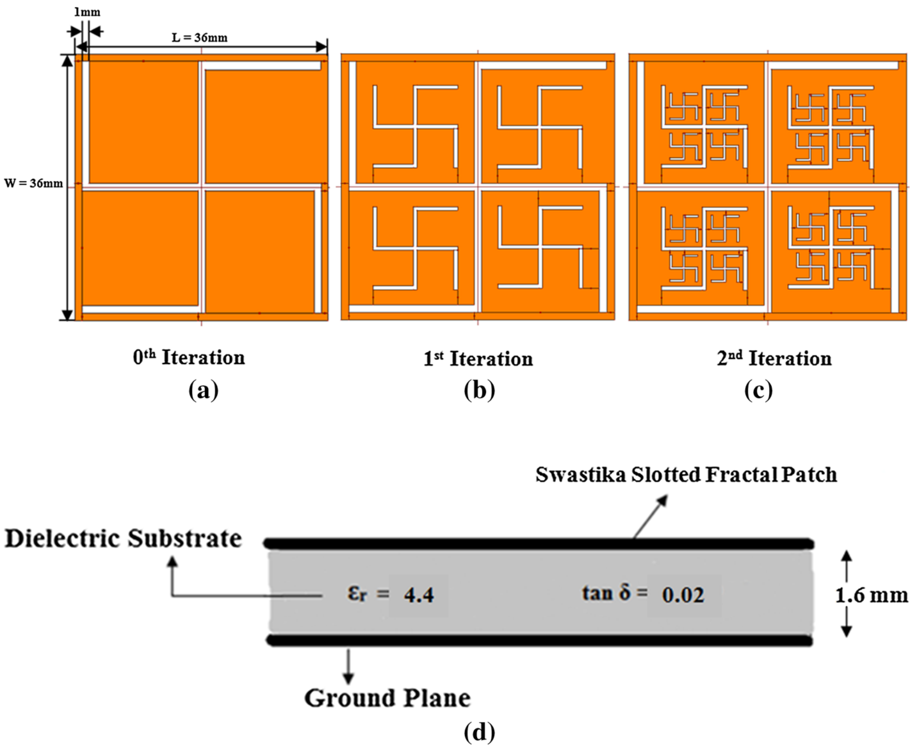

Fig. 1 SSFA with (a) 0th iteration (b) 1st iteration (c) 2nd iteration and (d) front view

$$\text{New length of Swastika slot} = a_2 \times \text{Previous length of Swastika slot} \tag{2}$$

where, a_2 (iteration factor) = 1/2.

Figure 2 depicts the comparison of return loss for zeroth, first and second iteration stage of SSFA. From the observation of this graph, important point to be noticed is that the number of resonant frequencies are increased and shifted towards the left as the iteration increased due to the insertion of Swastika shaped slot in the square patch. Also, the return loss values improved from zeroth to second iteration stage. Thus, geometry of second iteration stage has been chosen for the simulation and fabrication purpose.

3 GA and BA with Comparison Results

Artificial Neural Network (ANN) is used to train the prepared data set of 104 samples with the help of MATLAB Software. Feed points are the input parameter with return loss and resonant frequencies being the output parameters (Table 2).

3.1 Genetic Algorithm (GA) for SSFA

Genetic Algorithm (GA) is applied with help of GA tool in MATLAB to get the optimized values of feed point. ANN is provided as fitness function to GA. GA comprises of creation of initial population, evaluation, selection, cross-over, mutation and replacement.

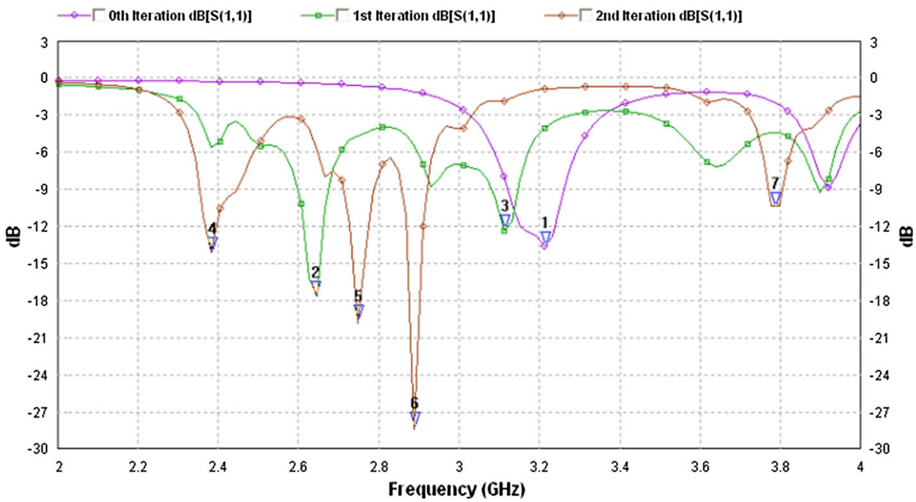

Fig. 2 Comparison of return loss for zeroth, first and second iteration stage of SSFA

Table 2 Values of various parameters of ANN for SSFA

S. No.	Name of Parameter	Value
1.	Number of neurons in the input layer	2
2.	Number of neurons in the output layer	6
3.	Number of neurons in the hidden layer, *n*	6
4.	Number of data samples	104

The obtained optimized values of feed point are 12.556 along x-axis and −14.25 along y-axis. Figure 3 shows the variation of fitness value with respect to number of generations for mean fitness and best fitness.

3.2 Bat Algorithm (BA) for SSFA

In 2010, BAT Algorithm (BA) was firstly coined by Xin-She Yang. The enthusiastic fact about this algorithm is that it is derived from the echolocation property of microbats [24–26]. Bats are one and the only mammals with wings which has unique feature of echolocation. Figure 4 illustrates the full mechanism behind the Bat algorithm. Fundamental step of this algorithm includes the initialization of bat population with random value of velocity, v_i at position, x_i. Fitness of each bat is evaluated and current best value to be found. When bats are on their mission of food search or prey, they continuously vary their loudness, A_i, frequency, f_i and pulse rate, r_i. The new solution is generated by updating the values of velocity, v_i at position, x_i if maximum number of iterations becomes greater than iteration, t.

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{3}$$

$$v_i^t = v_i^{t-1} + \left(x_i^{t-1} - x_*\right) f_i \tag{4}$$

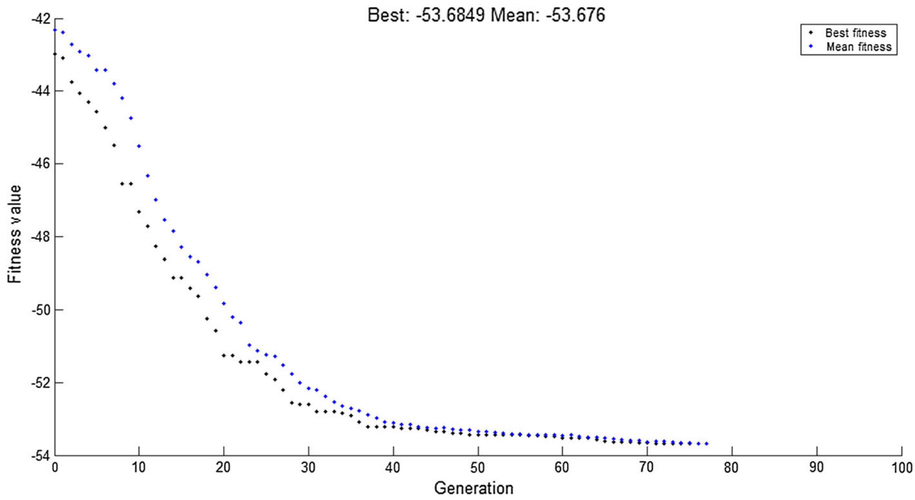

Fig. 3 Fitness value v/s generation for SSFA

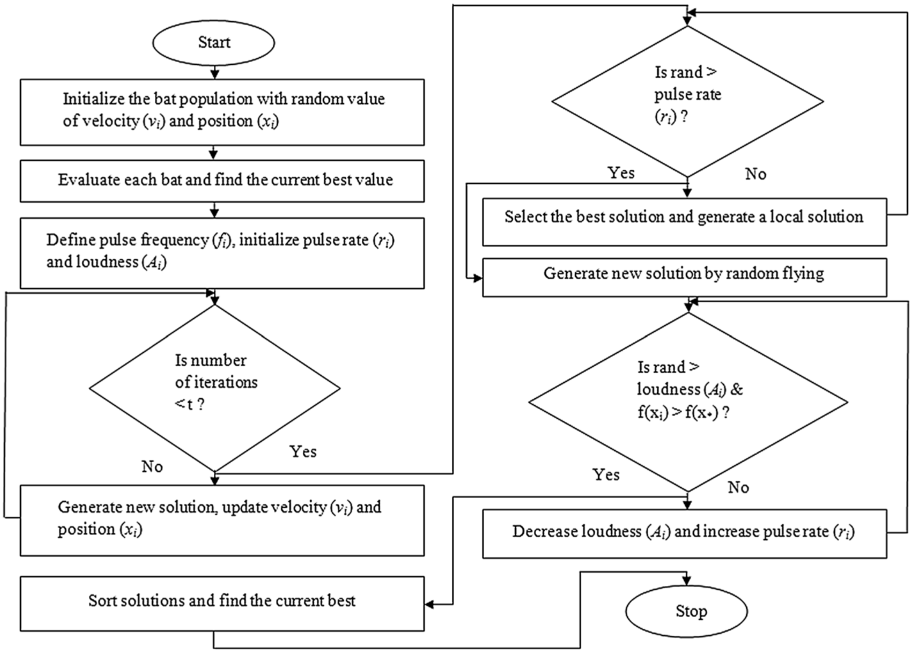

Fig. 4 Flow chart of BAT Algorithm (BA)

$$x_i^t = x_i^{t-1} + v_i^t \tag{5}$$

where β is the random vector and x_* is the current best solution .

Otherwise, randomness is compared with the pulse emission rate, r_i. The new solution is generated with random flying if randomness is greater than pulse emission rate, r_i. Otherwise, best solution is to be selected and local solution is generated accordingly.

Table 3 Values of different parameters of BA for SSFA

S. No.	Name of Parameter	Value
1.	Population size, m	20
2.	Loudness, A_i	0.25
3.	Pulse emission rate, r_i	0.5
4.	Minimum frequency, f_{min}	0
5.	Maximum frequency, f_{max}	2
6.	Maximum number of iterations	2000

Sorting of solutions and finding the current best value has to be done if best results are obtained, otherwise, the value of loudness, A_i is decreased, and the value of pulse emission rate, r_i is increased.

$$A_i^{t+1} = \alpha A_i^t \tag{6}$$

$$r_i^{t+1} = r_i^0[1 - exp(-\gamma t)] \tag{7}$$

where α and γ are constants.

The process is to be terminated if target is met with good optimized results. Bat algorithm gives efficient results as compared to the other optimization techniques. This algorithm has tremendous applications to solve the inverse problems, in data mining, clustering, fuzzy logic and image processing etc. Table 3 highlights the value of important parameters used in the Bat algorithm for SSFA. The obtained optimized values of feed point are 13.9593 along x-axis and 6.3495 along y-axis. The convergence curve for SSFA is shown in Fig. 5 which ends at 2000 generations.

Figure 6 depicts the comparison of return loss between Genetic Algorithm (GA) and Bat Algorithm (BA) for SSFA (Table 4).

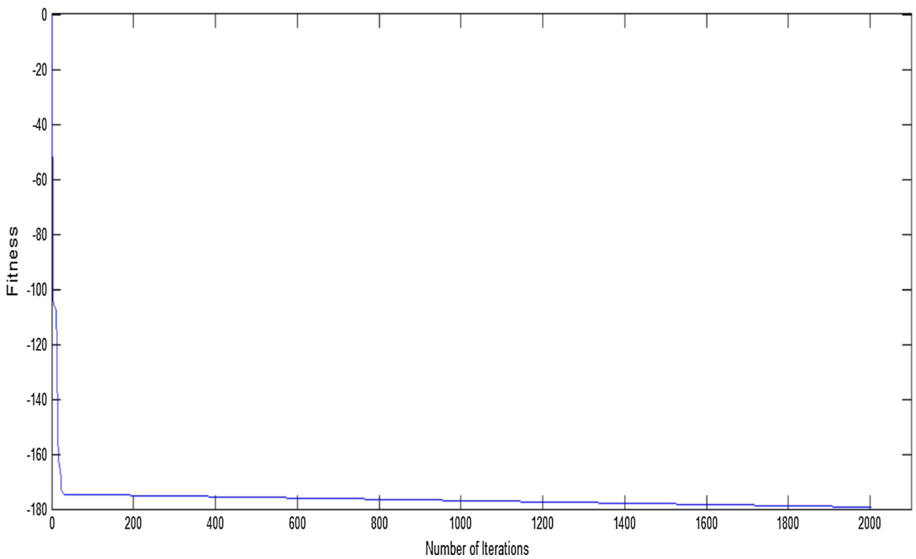

Fig. 5 Graph of convergence curve for SSFA

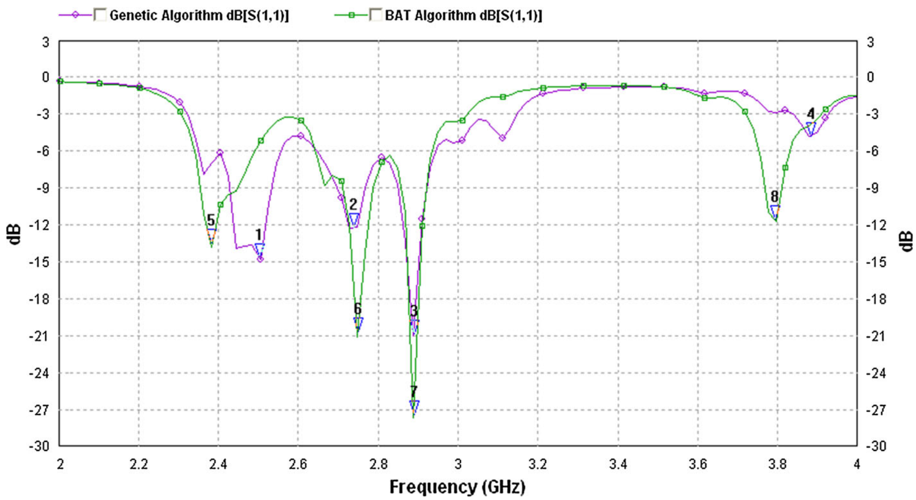

Fig. 6 Comparison graph of return loss for Genetic Algorithm (GA) and Bat Algorithm (BA) of SSFA

This graph clearly indicates that return loss for BA is more negative as compare to GA. Hence, with help of BA, superior results are obtained than GA.

4 Simulated and Measured Results With BA

4.1 Optimized Simulation Results of SSFA

The geometry of second iteration stage of SSFA is resonated at 2.39, 2.75, 2.89 and 3.79 GHz with corresponding values of S-parameter (S_{11}) are −13.22, −20.62, −27.43 and −11.62 dB respectively. The total bandwidth of SSFA is 215.98 MHz (Fig. 7).

Voltage Standing Wave Ratio (VSWR) is another important parameter which states that how well matching takes place between the antenna and transmission line. Here, VSWR is 1.52 at 2.39 GHz, 1.21 at 2.75 GHz, 1.09 at 2.89 GHz and 1.71 at 3.79 GHz (Fig. 8).

Figure 9 indicates that total field directivity of optimized SSFA is 6.79, 4.60, 7.83 and 7.53 dBi at resonant frequencies 2.39, 2.75, 2.89 and 3.79 GHz respectively.

Table 4 Comparison between GA and BA for SSFA

Genetic Algorithm (GA)			Bat Algorithm (BA)	
S. No.	Resonant frequency, f_r (in GHz)	Return Loss (in dB)	Resonant frequency, f_r (in GHz)	Return Loss (in dB)
1.	2.50	−14.67	2.39	−13.22
2.	2.74	−12.22	2.75	−20.62
3.	2.89	−20.08	2.89	−27.43
4.	3.88	−4.79	3.79	−11.62

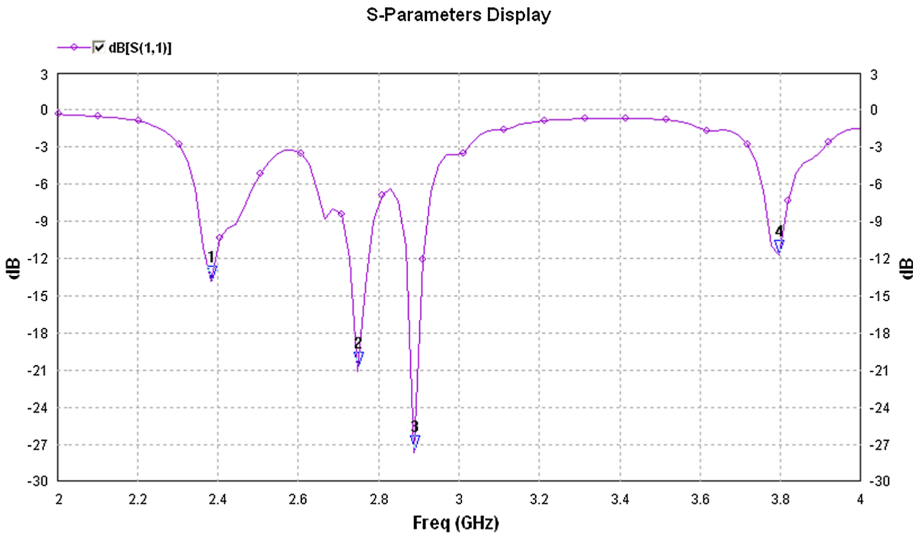

Fig. 7 Simulated optimized S-parameter (S_{11}) graph after applying BA

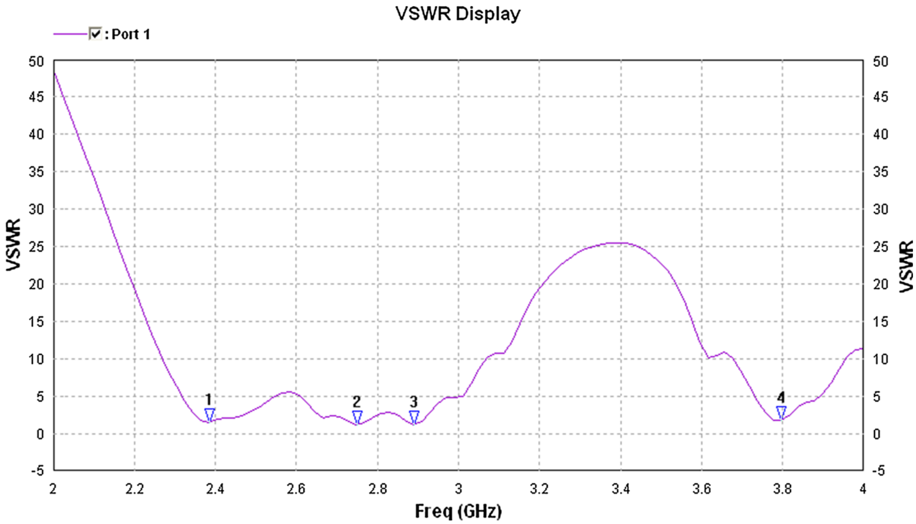

Fig. 8 Simulated optimized VSWR graph after applying BA

4.2 Fabrication and Optimized Measured Results of SSFA

After obtaining the simulated results, optimized SSFA for second iteration is fabricated by using FR4 as its substrate material. Simple co-axial feeding technique is adopted to excite SSFA by using SMA connector. To perform testing of fabricated SSFA, Rohde & Schwarz ZVL Vector Network Analyzer (VNA) is used (Figs. 10, 11, 12 and 13).

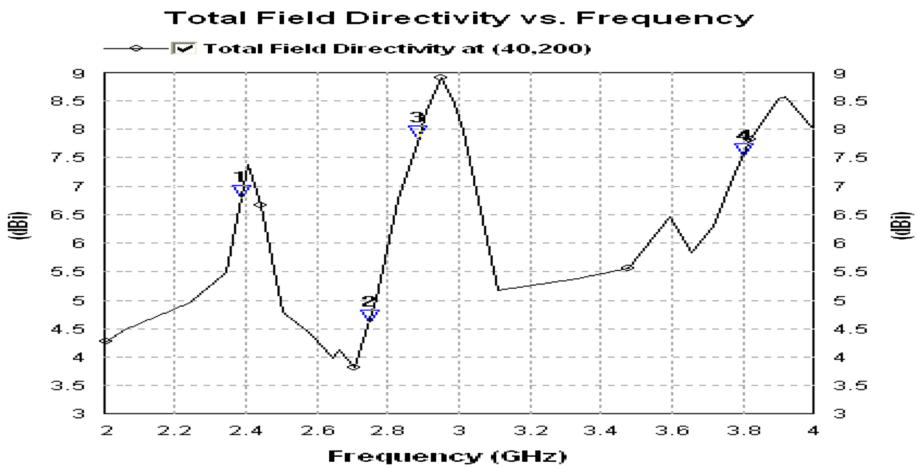

Fig. 9 Simulated optimized total field directivity graph after applying BA

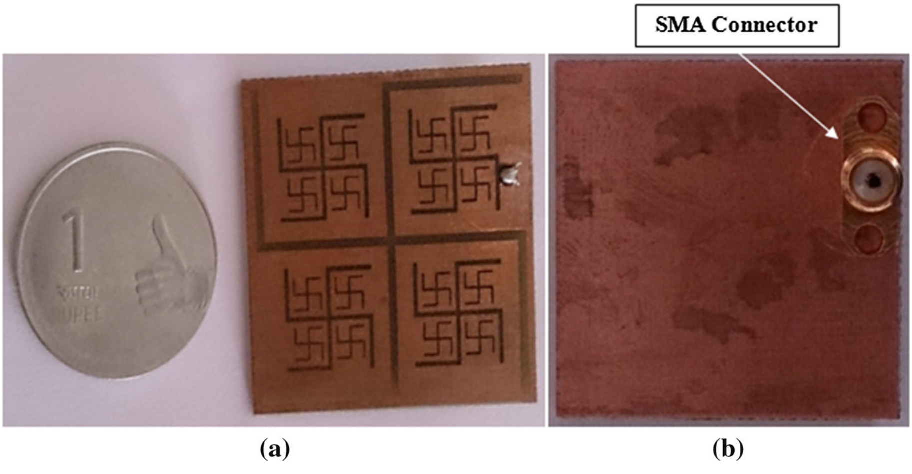

Fig. 10 Fabricated SSFA (a) front view and (b) back view

Fabricated optimized SSFA has values of S-parameter (S_{11}) and VSWR as −16.78, −18.87, −28.66, −11.48 dB and 1.33, 1.27, 1.08, 1.73 at resonant frequencies 2.49, 2.70, 2.96 and 3.96 GHz respectively.

Fig. 11 Rohde & Schwarz ZVL Vector Network Analyzer for testing SSFA

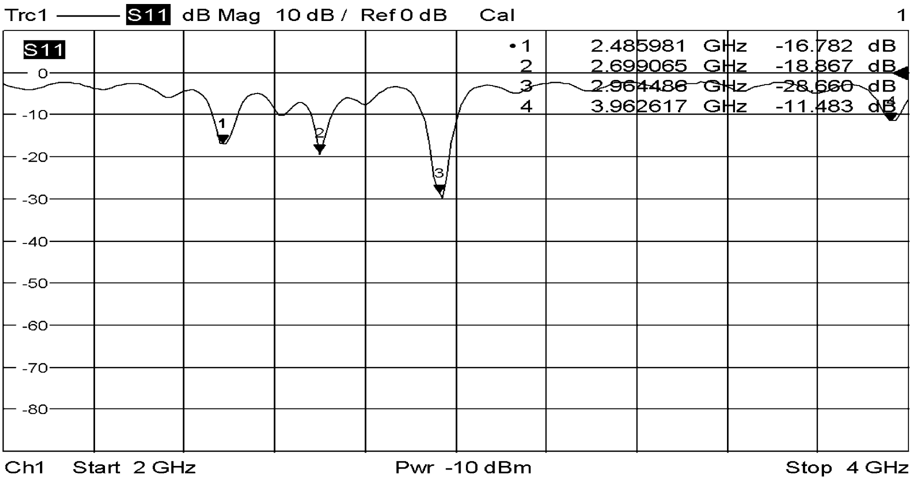

Fig. 12 Measured optimized S-parameter (S_{11}) graph for SSFA

The comparison between optimized simulated and experimental results of SSFA as shown in Table 5 reveal the existence of slight variations between both results due to the imperfection during fabrication or environmental changes. But overall, they are in good agreement with each other.

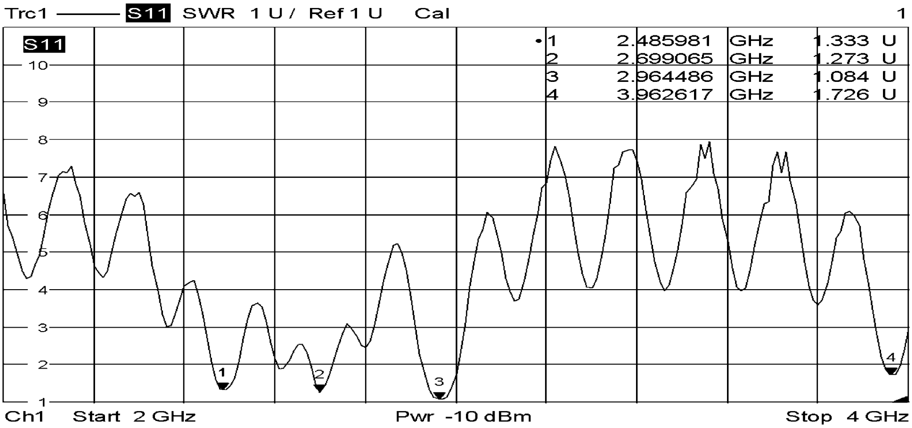

Fig. 13 Measured optimized VSWR graph for SSFA

Table 5 Comparison between optimized simulated and experimental results of SSFA

Optimized Simulated Results			Optimized Experimental Results		
Resonant frequency, f_r (in GHz)	S_{11} (in dB)	VSWR	Resonant frequency, f_r (in GHz)	S_{11} (in dB)	VSWR
2.39	−13.22	1.52	2.49	−16.78	1.33
2.75	−20.62	1.21	2.70	−18.87	1.27
2.89	−27.43	1.09	2.96	−28.66	1.08
3.79	−11.62	1.71	3.96	−11.48	1.73

5 Conclusion

Two optimization methods for the optimization of Swastika Slotted Fractal Antenna are reported in this paper which employed its utilities for S-band. On investigation of the results of Genetic Algorithm and Bat Algorithm, it is realized that BA gives more efficient results as compared to GA. Also, BA is less time consuming than other algorithms. SSFA resonates at 2.49, 2.70, 2.96 and 3.96 GHz experimentally. Insertion of Swastika slot in the square patch results in the metal reduction by 39.09%. Simple co-axial feeding technique is used in this research work, but other techniques can also be applied. Also, the frequency is shifted towards left as iteration stage increased from zeroth to second. Overall, the proposed antenna is good candidate for the multiband operations. Different kinds of optimization methods can be applied to same patch of SSFA and iteration stage can also be increased in future. More metal can be evicted by increasing the size of Swastika slot. Structure of SSFA can be modified by making it an array.

References

1. Werner, D., Gregory, M., Jiang, Z. H., & Brocker, D. E. (2015). Optimization methods in antenna engineering. In Z. N. Chen (Ed.), *Handbook of antenna technologies* (pp. 1–47). Springer. https://link.springer.com/referenceworkentry/10.1007/978-981-4560-75-7_15-1.
2. Dhaliwal, B. S., & Pattnaik, S. S. (2013). *Artificial neural network analysis of Sierpinski Gasket fractal antenna: A low cost alternative to experimentation. Advances in artificial neural systems* (pp. 1–7). Cairo: Hindawi Publishing Corporation.
3. Kaur, R., & Rattan, M. (2014). Optimization of return loss of differentially fed microstrip patch antenna using ANN and firefly algorithm. *Wireless Personal Communications, 80*(4), 1547–1556.
4. Ozkaya, U., & Seyfi, L. (2015). Dimension optimization of microstrip patch antenna in X/Ku band via artificial neural network. *Procedia-Social and Behavioral Sciences, World Conference on Technology, Innovation and Entrepreneurship, 195,* 2520–2526.
5. Lukes, Z., & Raida, Z. (2005). Multi-objective optimization of wire antennas: Genetic algorithms versus particle swarm optimization. *Radioengineering, 14*(4), 91–97.
6. Herscovici, N., Osorio, M. F., & Peixeiro, C. (2002). Miniaturization of rectangular microstrip patches using genetic algorithms. *IEEE Antennas and Wireless Propagation Letters, 1*(1), 94–97.
7. Neyestanak, A. A. L., Kashani, F. H., & Barkeshli, K. (2007). W-shaped enhanced-bandwidth patch antenna for wireless communication. *Wireless Personal Communications, 43*(4), 1257–1265.
8. Primson, K. P. R. C., & Anita, R. (2014). Antenna design for wimax applications using Artificial Bee Colony algorithm. *Journal of Theoretical and Applied Information Technology, 68*(3), 493–503.
9. Kumari, U. R., Rao, P. M., & Raju, G. S. N. (2016). Generation of optimized beams from concentric circular antenna array with dipole elements using BAT Algorithm. *Microelectronics, Electromagnetics and Telecommunications, Lecture Notes in Electrical Engineering, 372,* 547–552.
10. Kumar, K. A., Ashwath, R., Kumar, D. S., & Malmathanraj, R. (2010) Optimization of multislotted rectangular microstrip patch antenna using ANN and Bacterial Foraging Optimization. In: *IEEE Asia-Pacific International Symposium on Electromagnetic Compatibility, Beijing, China* (pp. 449–452).
11. Mandelbrot, B. B. (1983). *The fractal geometry of nature*. New York: Freeman.
12. Gianvittorio, J. P., & Samii, Y. R. (2002). Fractal antennas: A novel antenna miniaturization technique, and applications. *IEEE Antennas Propagation Magazine, 44*(1), 20–36.
13. Werner, D. H., Haup, R. L., & Werner, P. L. (1999). Fractal antenna engineering: The theory and design of fractal antenna arrays. *IEEE Antennas and Propagation Magazine, 41*(5), 37–58.
14. Werner, D. H., & Ganguly, S. (2003). An overview of fractal Antenna engineering research. *IEEE Antennas and Propagation Magazine, 45*(1), 38–57.
15. Li, J., Jiang, T., Cheng, C., & Wang, C. (2013). Hilbert fractal antenna for UHF detection of partial discharges in transformers. *IEEE Transactions on Dielectrics and Electrical Insulation, 20*(6), 2017–2024.
16. Baliarda, C. P., Romeu, J., & Cardama, A. (2000). The Koch monopole: A small fractal antenna. *IEEE Transaction on Antennas and Propagation, 48*(11), 1773–1781.
17. Kim, I. W., Yoo, T., Yook, J., & Park, H. (2001). The Koch Island fractal microstrip patch antenna. In: *IEEE Antennas and Propagation Society International Symposium, Boston, MA, USA* (vol. 2, pp. 736–739).
18. Puente, C., Romeu, J., Pous, R., & Cardama, A. (1998). On the behavior of the Sierpinski multiband fractal antenna. *IEEE Transaction on Antennas and Propagation, 46*(4), 517–524.
19. Chowdary, P. S. R., Prasad, A. M., Rao, P. M., & Anguera, J. (2015). Design and performance study of Sierpinski fractal based patch antennas for multiband and miniaturization characteristics. *Wireless Personal Communications, 83*(2), 1713–1730.
20. M.K. A. Rahim, N. Abdullah, and M. Z. A. A. Aziz (2005) Microstrip Sierpinski carpet antenna design. IEEE Asia-Pacific Conference on Applied Electromagnetics (pp. 58-61).
21. Chen, W. L., Wang, G. M., & Zhang, C. X. (2008). Small-size microstrip patch antennas combining Koch and Sierpinski fractal shapes. *IEEE Antennas and Wireless Propagation Letters, 7,* 738–741.
22. Sharma, A., & Vishwakarma, R. K. (2014). Microstrip antenna with Swastik slot for UWB applications. In: *IEEE Students' Conference on Electrical, Electronics and Computer Science, Bhopal* (pp. 1–5).
23. IE3D version 14.0, Zeland Software Inc., Fremont, CA, 2008.
24. Yang, X. S., & Gandomi, A. H. (2012). Bat algorithm: a novel approach for global engineering optimization. *Engineering Computations, 29*(5), 464–483.
25. Tsai, P. W., Pan, J. S., Liao, B. Y., Tsai, M. J., & Istanda, V. (2012). Bat Algorithm inspired algorithm for solving numerical optimization problems. *Applied Mechanics and Materials, 148–149,* 134–137.
26. Yang, X. S. (2013). Bat algorithm: literature review and applications. *International Journal of Bio-Inspired Computation, 5*(3), 141–149.

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