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Design and Optimization of PSI (Ψ) Slotted Fractal Antenna Using ANN and GA for Multiband Applications

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Abstract A novel design of PSI (Ψ) slotted fractal antenna that exhibits multiband operation has been used for optimization in this paper which enhanced its utilities for distinct bands. The empirical fact is that return loss is optimized after applying Artificial Neural Network and Genetic Algorithm. The proposed fractal antenna has been designed using substrate material of RT/Duroid having height of substrate 1.5 mm, dielectric constant 2.2 and loss tangent 0.0009 for the stage of iteration up to one. The simulated, optimized and experimental results are obtained by the use of Zeland IE3D software, MATLAB Software and Rohde and Schwarz ZVL Vector Network Analyzer respectively. The measured values of return loss which obtained after fabrication are −13.81, −19.88, −20.86, and −27.33 dB for the resonant frequencies 1.89, 2.78, 4.40, and 5.72 GHz and the values of their respective VSWR are 1.52, 1.25, 1.21 and 1.12. The output values obtained after simulation and fabrication have minute variations but are found to be a good candidate for applications in the bands of L, S and C.

Keywords Artificial Neural Network (ANN) · Fractal · Genetic Algorithm (GA) · Iteration · Optimization · PSI (Ψ) slotted geometry

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1 Introduction

The enthusiastic fact about the technology is that it follows the law of nature which changes continuously with time. From the twentieth to twenty first century, an incredible change in the technology exists. This abrupt change is due to the exponential growth in the field of technology. In the region of antennas, this drastic change occurred due to the evolution of fractal antennas. In the technophile era, researcher wants a single antenna which has characteristics of different kinds of antenna like low-profile, low cost, broadband and multiband. The repetition of analogous pattern in the next iteration stage by a certain iteration factor is the strategy behind the invention of fractal antenna [1, 2]. The important properties of the fractal antenna are size miniaturization, broadband and multiband operations which prove a fruitful technique to the wireless and communication technology [3, 4]. Koch Snowflake, Hilbert Curve, Sierpinski Gasket, Sierpinski Carpet, Minkowski Island and the hybrid combination of Koch and Sierpinski etc. are the fundamental geometries of fractal antennas [5–11].

Optimization is the process or the mechanism by the use of which, the maxima or minima of a function can be found. The different kinds of optimizing techniques can be adopted such as Artificial Neural Networks (ANN), Genetic Algorithm (GA), BAT Algorithm (BA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Bacterial Foraging Optimization (BFO) etc. for improving the output parameters [12–21]. In this paper, Artificial Neural Networks (ANN) and Genetic Algorithm (GA) have been used for the optimization of fractal antenna which deploys PSI (Ψ) Slotted geometry to enhance its applications for operations in different IEEE frequency bands. PSI (Ψ) is one of the letter of Greek alphabets and is investigated in [22–25] which exhibit broadband properties.

Section 1 of this paper gives a brief overview of properties of fractal antenna and different optimization techniques. Section 2 illustrates the geometry of PSI (Ψ) slotted fractal antenna (PSFA). Sections 3 and 4 gives the description of Artificial Neural Networks (ANN) and Genetic Algorithm (GA). A discussion about the simulated results, experimental results and their comparison is presented in Sect. 5 which subsequently followed by conclusion and the future applications of the product.

2 Fractal Antenna Deploying PSI (Ψ) Slotted Geometry

The PSI (Ψ) slotted fractal antenna (PSFA) has been designed by using the parametric values as mentioned in Table 1.

The equations [26] for finding the length, L and width, W of the PSI (Ψ) slotted fractal antenna (PSFA) are given as:

Table 1 Parametric values for the design of PSI (Ψ) slotted fractal antenna (PSFA)

Name of parameter	Value
Substrate material	RT/Duroid
Substrate thickness, h	1.5 mm
Dielectric constant, ε_r	2.2
Loss tangent, tan δ	0.0009

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + (\epsilon_r - 1)\left[1 + 12\frac{W}{h}\right]^{-1/2} \tag{2}$$

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.2580)\left(\frac{W}{h} + 0.8\right)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}} \tag{4}$$

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

where ΔL is the length extension, ϵ_{reff} is the effective dielectric constant, L_{eff} is the effective length and c is the speed of light in vacuum (3×10^8 m/s).

For the resonant frequency, $f_o = 2.45$ GHz, substituting all parametric value in Eqs. (1)–(5), the length, L and width, W of rectangular patch antenna are calculated to be 40.52 and 48.40 mm respectively.

Zeland IE3D Simulator [27] is used to design the PSI (Ψ) slotted fractal antenna (PSFA). Basic geometry, first iteration stage and front view of Psi (Ψ) slotted fractal geometry is shown in Fig. 1. The basic geometry of PSFA of length, $L = 40.52$ mm and

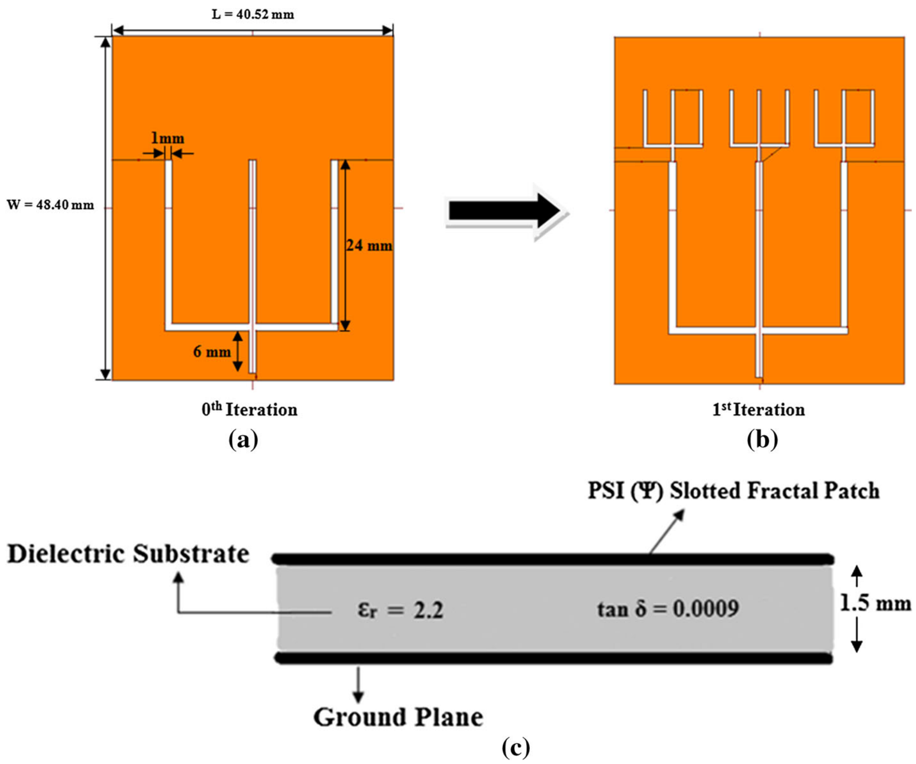

Fig. 1 **a** Zeroth iteration stage, **b** first iteration stage, **c** front view of PSI (Ψ) slotted fractal antenna (PSFA)

width, $W = 48.40$ mm is designed in IE3D by selecting a rectangular patch with given parametric values. Then, slots of Psi (Ψ) shape are inserted in it. The next stage of fractal antenna is generated by knowing the value of iteration factor (IF) and hence, new values of length and width are calculated as follows:

$$\text{New width of Psi}(\Psi)\text{slot for next stage} = a_1 \times \text{Preceding width of Psi}(\Psi)\text{slot} \quad (6)$$

where iteration factor, $a_1 = 1/3$.

$$\text{New length of Psi}(\Psi)\text{slot for next stage} = a_2 \times \text{Preceding length of Psi}(\Psi)\text{slot} \quad (7)$$

where iteration factor, $a_2 = 1/2$.

The geometry of first iteration stage is obtained by inserting the analogous reduced pattern of original PSI (Ψ) slot at the tips. The value of iteration factor (IF) for the widthwise and lengthwise arm of Psi (Ψ) slot are 1/3 and 1/2 respectively. Hence, Psi (Ψ) slotted antenna comes into its fractal fashion shape. The coaxial probe feed is used to excite the PSI (Ψ) slotted fractal antenna (PSFA) due to easy installation and simplified use.

From the graph shown in Fig. 2, it is revealed that the results of return loss are more negative for the first iteration as compared to zeroth iteration and the resonant frequency is shifted towards left as the number of iteration is increased because of the insertion of fractal Psi (Ψ) slots in the basic geometry. Also, the number of resonant frequencies increased for the geometry of first iteration stage. Thus, the geometry of first iteration stage is chosen for the optimization and fabrication purpose.

3 Artificial Neural Networks (ANN) for PSFA

Artificial Neural Networks (ANN) can be exploited for training the data set. An artificial neuron is a computational model inspired from the phenomenon of natural neurons. Usually, the backpropagation algorithm which is the one of the kind of multilayer perceptron, enhance its utilities for layered feed-forward ANNs (Table 2).

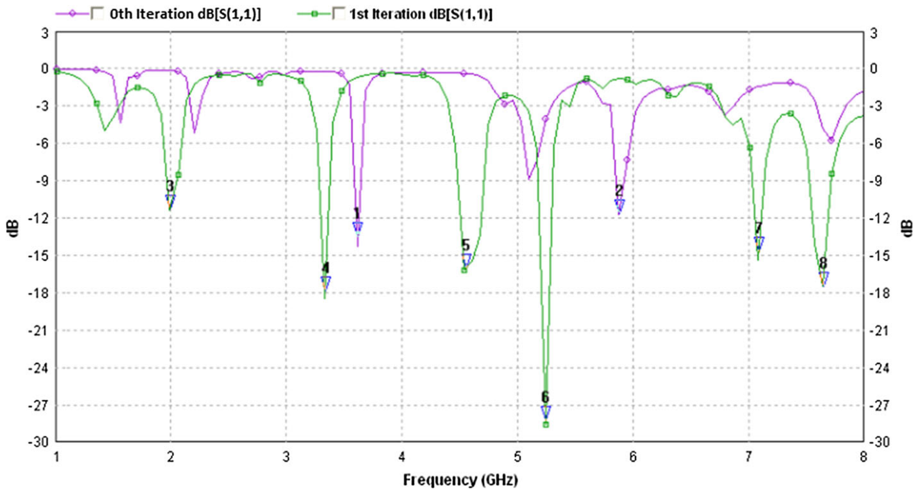

Fig. 2 Comparison of return loss for zeroth and first iteration stage of PSFA

Table 2 Parameters of ANN model for PSFA

Name of parameter	Value
Number of data samples	106
Number of neurons in the input layer	2
Number of neurons in the hidden layer, *n*	5
Number of neurons in the output layer	6
Type of training algorithm	Back propagation

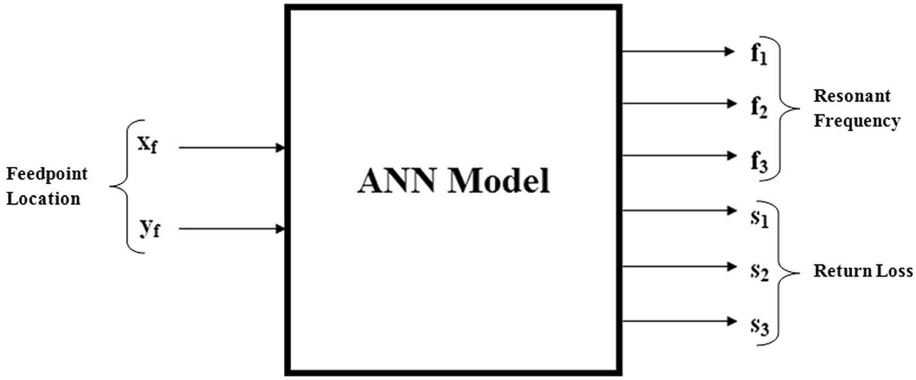

Fig. 3 ANN Model for PSI (Ψ) slotted fractal antenna (PSFA)

Feed location points (x_f, y_f) are the input parameters for the input layer. Similarly, resonant frequencies (f_1, f_2, f_3) and return loss (s_1, s_2, s_3) are the output parameters for output layer shown in Fig. 3 of ANN model. Five neurons are present in the hidden layer. The architecture of ANN Model for PSI (Ψ) slotted fractal antenna (PSFA) is indicated by Fig. 4. The data set of 106 samples is prepared by doing simulations for the training of neurons. The training of data has been done by the use of MATLAB software (Fig. 5).

4 Genetic Algorithm (GA) for PSFA

GA tool of MATLAB is used for the optimization of feedpoint location (x_f, y_f) of PSI (Ψ) slotted fractal antenna (PSFA).

The basic principle behind the process of Genetic Algorithm (GA) which is based on Darwinian theory of 'survival of the fittest' is fully illustrated in the flow chart shown in the Fig. 6. The procedural or fundamental steps for the Genetic Algorithm (GA) consists of chromosomes, genes, set of population, fitness function, cross-over, mutation, replacement etc. In the inception of GA, initial population was created and then the fitness of each individual was evaluated. Depending on fitness, the parents were selected. After that, new population with recombinations was created. If the results of new population are better than the previous one, then halt the process, otherwise start the process again from evaluation step. In this way, with the help of Genetic Algorithm (GA), best optimized results can be reached (Table 3).

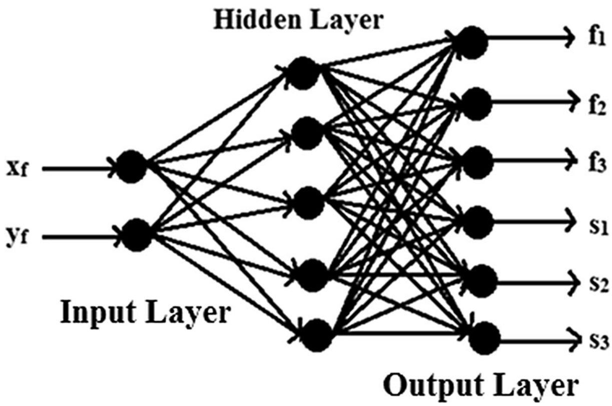

Fig. 4 Architecture of ANN Model for PSI (Ψ) slotted fractal antenna (PSFA)

Fig. 5 Syntax for Artificial Neural Networks (ANN) training

```
net = newff(input,target,n);
[net,tr] = train(net,input,target);
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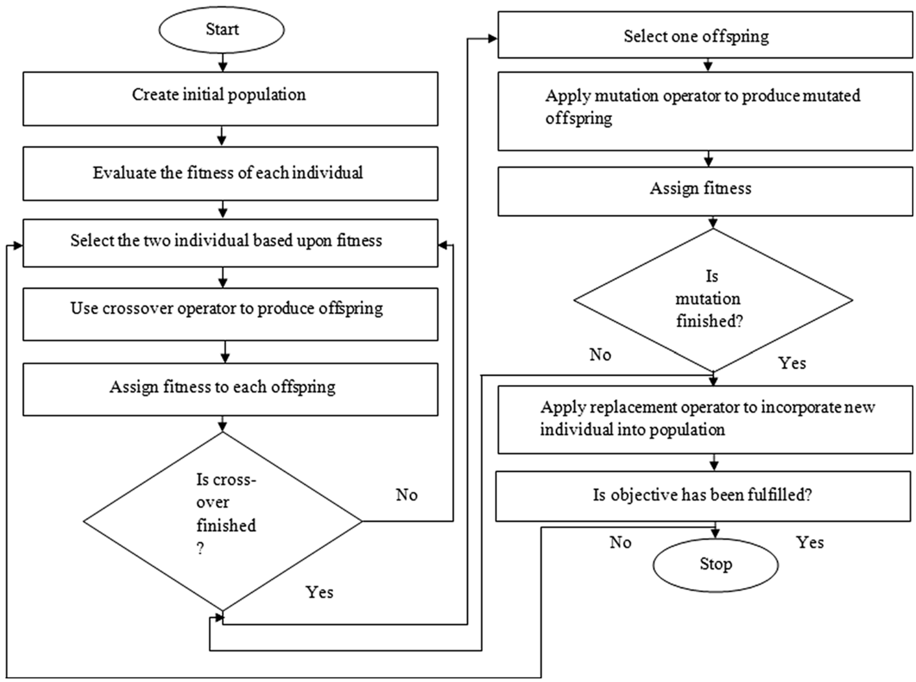

Fig. 6 Standard flow chart of Genetic Algorithm (GA)

Next, the geometry of first iteration of PSFA was simulated with obtained optimized values of feedpoint location (x_f, y_f) and the simulation result of optimized return loss was analyzed by using IE3D simulator. The final simulated results were verified by their comparison with Table 4.

Table 3 Optimized value of feed location after applying GA

Feed location	Optimized value after applying GA
x_f	0.9
y_f	15.345

Table 4 Optimized value of parameters by GA in MATLAB

Resonant frequency (f_r)	Optimized value of return loss by GA (in MATLAB)
1.89	−11.38
3.10	−20.27
4.85	−14.81

5 Simulated and Experimental Results After Applying Genetic Algorithm (GA)

5.1 Simulation Results of Optimized PSFA After Applying GA

The Fig. 7 illustrates that PSFA resonates at frequencies 1.99, 3.34, 4.55, 5.24, 7.08 and 7.58 GHz with corresponding values of simulated optimized return loss −11.59, −20.05, −16.56, −30.69, −12.65 and −24.75 dB respectively. The obtained values of VSWR are 1.72, 1.33, 1.35, 1.08, 1.63 and 1.13 at resonant frequencies 1.99, 3.34, 4.55, 5.24, 7.08 and 7.58 GHz respectively. These outputs values are in agreement to the values shown in Table 4. The total bandwidth covered by PSFA is 696.24 MHz (Fig. 8).

5.2 Fabrication and Experimental Results of Optimized PSFA After Applying GA

After achieving the optimized simulation results, a prototype of the PSI (Ψ) slotted fractal antenna (PSFA) is fabricated for testing and comparing the simulation and experimental

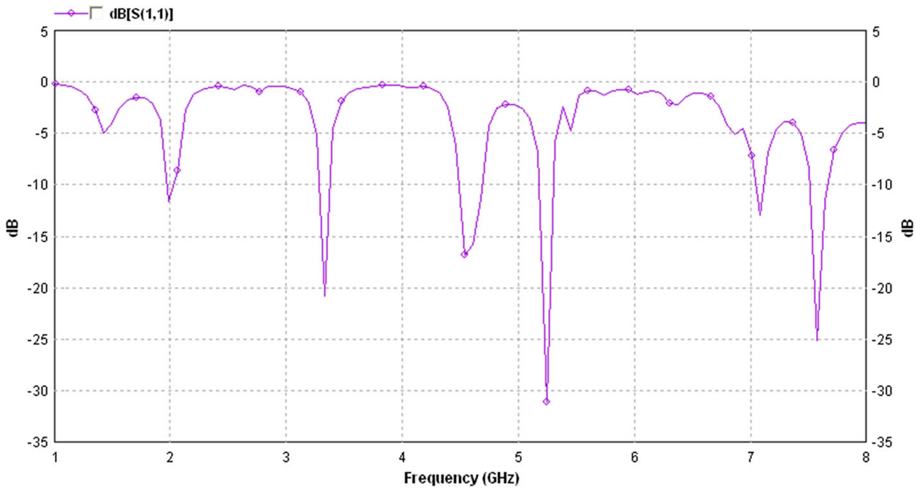

Fig. 7 Simulated optimized return loss after applying GA

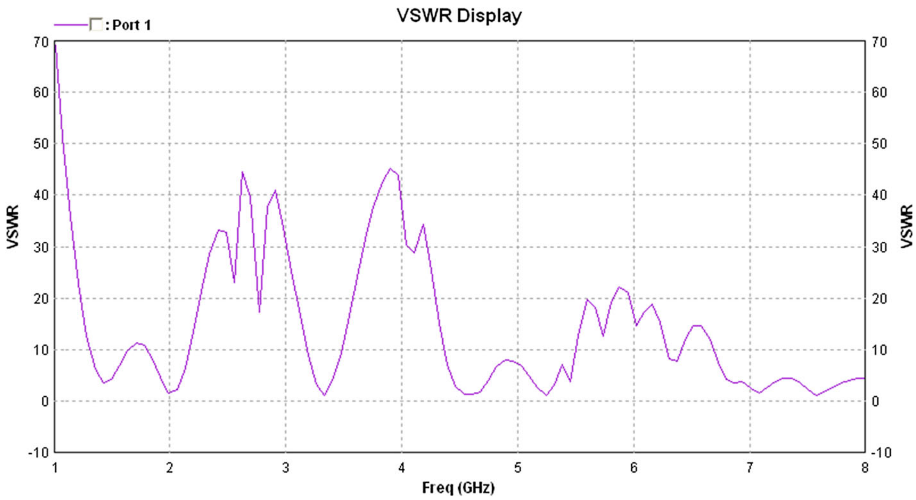

Fig. 8 Simulated VSWR after applying GA

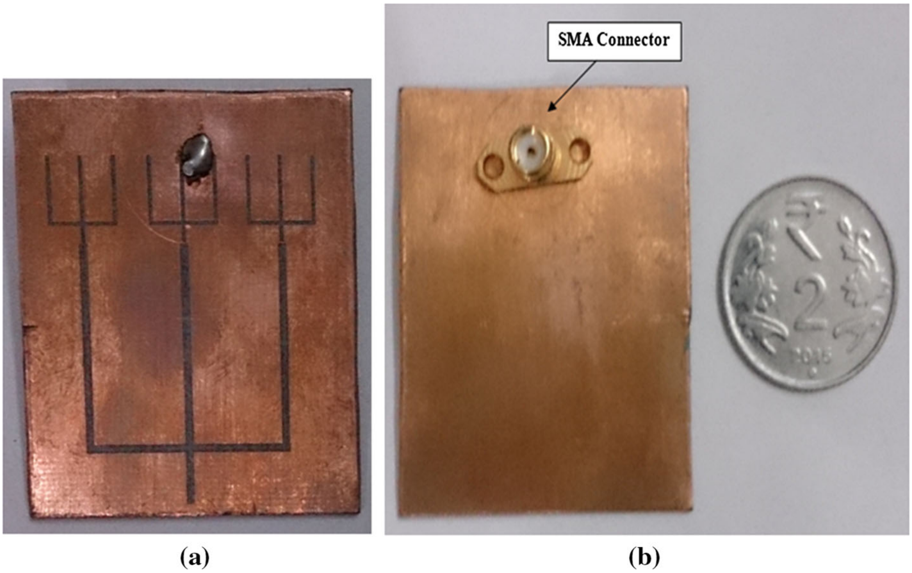

Fig. 9 **a** Front view, **b** back view of fabricated PSFA with feed connector

results. Figure 9 depicts the prototype of PSFA with SMA connector which is used for providing the coaxial feed. Also, Fig. 10 illustrates all the measurement setup of Rohde & Schwarz ZVL Vector Network Analyzer for testing the fabricated PSFA up to 6 GHz as per the availability range of VNA.

After the testing of fabricated PSFA, it is revealed that antenna resonates at frequencies 1.89, 2.76, 4.40 and 5.71 GHz with optimized return loss values at −13.82, −19.88, −20.86 and −27.33 dB respectively. Similarly, their corresponding values of VSWR are 1.52, 1.23, 1.21 and 1.12.

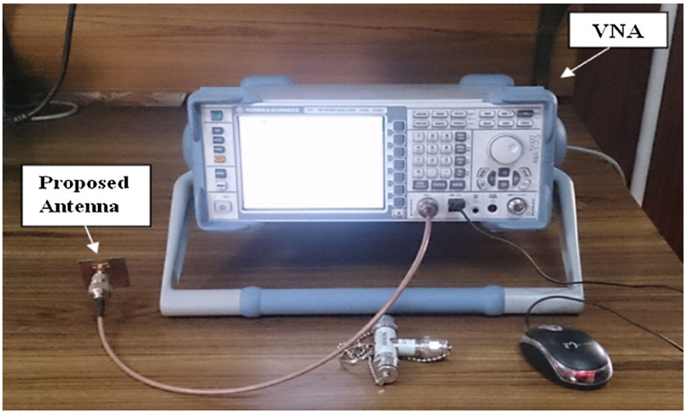

Fig. 10 Setup of VNA for testing the fabricated PSI (Ψ) slotted fractal antenna (PSFA)

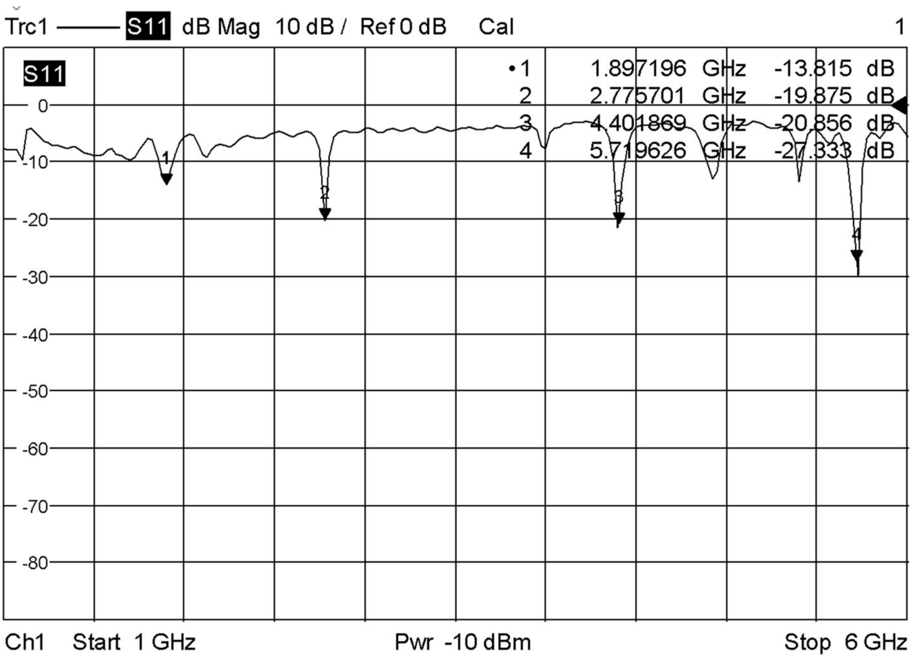

Fig. 11 Measured optimized return loss after applying GA

When simulated and measured results are investigated, it is concluded that the minute variation has been observed due to the environmental changes and due to imperfections in fabrication. Overall, both results have good agreement over the operational range (Figs. 11, 12; Table 5).

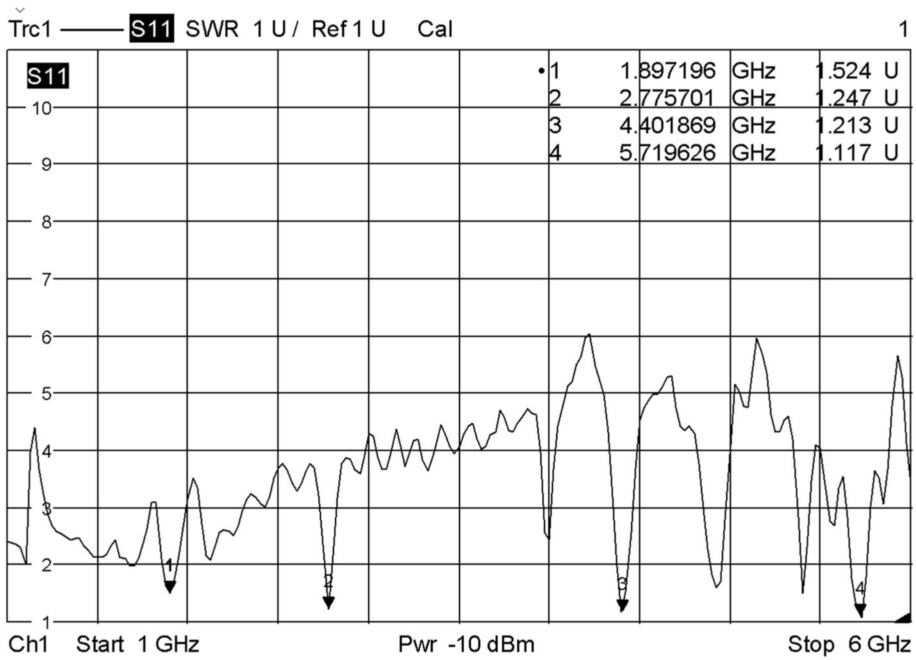

Fig. 12 Measured VSWR after applying GA

Table 5 Comparison between optimized simulated and measured results of PSFA

Optimized simulated results			Optimized measured results		
Resonant frequency, f_r (in GHz)	Return loss (in dB)	VSWR	Resonant frequency, f_r (in GHz)	Return loss (in dB)	VSWR
1.99	−11.59	1.72	1.89	−13.82	1.52
3.34	−20.05	1.33	2.78	−19.88	1.25
4.55	−16.56	1.35	4.40	−20.86	1.21
5.24	−30.69	1.08	5.71	−27.33	1.12

6 Conclusion

The design and optimization of multiband PSI (Ψ) slotted fractal antenna (PSFA) by the use of Artificial Neural Networks (ANN) and Genetic Algorithm (GA) with help of Zeland IE3D and MATLAB software is the recapitulation of this paper which exhibits tremendous applications for L, S, and C band. The reported GA method of optimization is the simple strategy to obtain minimum return loss and easy to understand. The gist of the proposed research work is that optimized measured return loss is found to be −13.82, −19.88, −20.86 and −27.33 dB at resonant frequencies 1.89, 2.78, 4.40 and 5.71 GHz with VSWR 1.52, 1.25, 1.21 and 1.12 respectively. As the number of iterations went up, the resonant frequency shifted towards left. The eviction of PSI (Ψ) slots from the patch results in the reduction of metal by 18.13%. In nutshell, PSI (Ψ) slotted fractal antenna (PSFA) is best suited for broadband and multiband operations. In future, more reduction of metal can be done by increasing size of PSI (Ψ) slots. The number of iterations can be surged and other optimization techniques can also be applied.

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