DESIGN AND OPTIMIZATION OF SIERPINSKI CARPET FRACTAL ANTENNA USING ARTIFICIAL NEURAL NETWORK (ANN) AND HIGH FREQUENCY STRUCTURE SIMULATOR (HFSS) COMPUTATIONAL TECHNIQUES

Rakhee Patil[1]*, Dr. Kalpana Vanjerkhede[2]

Article History: **Received:** 10.08.2023 **Revised:** 29.09.2023 **Accepted:** 16.11.2023

Abstract:
In the realm of modern wireless communication systems, the demand for compact, efficient, and multifunctional antennas has led to the exploration of novel design paradigms. In the field of wireless communication with constantly evolving antenna technology the need for antennas with enhanced bandwidth, gain and low profile is tremendously increasing. Fractal antennas have garnered significant attention due to their unique characteristics that lead to improved performance and miniaturization with broadband/multiband characteristic in modern wireless communication systems. This paper presents the design and optimization of a Sierpinski Carpet fractal antenna using advanced computational techniques.
In this paper the design process which begins with the generation of the Sierpinski Carpet fractal structure by iteratively subdividing a square into smaller squares and removing specific portions following a predefined pattern. The novel approach is based on the Artificial Neural Network (ANN) and a High Frequency Structure Simulator (HFSS) as a computational tool in the designing of proposed antenna. These methods provide accurate simulations of the antenna radiation patterns, impedance characteristics, and resonant frequencies across multiple frequency bands. The optimization process aims to enhance parameters like bandwidth, gain, radiation efficiency, and impedance matching for the frequency band between 2 GHz and 8 GHz, thus providing multiband capabilities of Fractal antenna to be utilized for Wi-Fi & WiMAX systems..The findings of the design and optimization of the Sierpinski Carpet fractal antenna presented in this paper showcase the potential of combining intricate fractal geometries with computational techniques. In this work, Artificial Neural Networks prove to be the optimal choice for antenna design and optimization .This synergy leads to antennas with enhanced performance characteristics, making them valuable components in the ever-evolving field of wireless communication systems.

Keywords: Fractal, Sierpinski Carpet, Multiband, Artificial Neural Network, HFSS, Optimization

[1]*Assistant Professor, Department of E&CE, RYMEC, Ballari & Visvesvaraya Technological University,Belagavi-590018,Karnataka, India.
[2]Professor & Vice Principal, Department of E&IE, PDACEG, Kalaburagi, & Visvesvaraya Technological University,Belagavi-590018, Karnataka, India.

***Corresponding Author:** Rakhee Patil
*Assistant Professor, Department of E&CE, RYMEC, Ballari & Visvesvaraya Technological University,Belagavi-590018,Karnataka, India.

DOI: 10.53555/ecb/2023.12.11.77

I. Introduction:

Fractal antennas exhibit a unique quality, maintaining their shape through recursive transformations—a self-similarity inherent in various fractals [1, 2]. Despite being a singular antenna, the fractal antenna offers multiband capabilities, supporting multiple frequencies while simultaneously enhancing bandwidth and reducing size. Its standout feature lies in sustaining optimal performance even after undergoing miniaturization. In essence, the fractal antenna fulfills the criteria of diverse wireless communication systems, providing attributes like wideband, multiband, low profile, and compact size. Notably, the response of fractal antennas diverges significantly from conventional designs.

The integration of fractal shapes into antenna geometry facilitates the attainment of wideband and multiband capabilities. Fractal antennas can be categorized into different classes, such as Deterministic and Random antennas. Examples of deterministic fractal antennas include classic wideband antennas, Koch curves, Koch snowflakes, Sierpinski gasket, and Sierpinski carpet.

The Sierpinski carpet, a form of fractal antenna, adopts the structure of a square patch antenna, applying fractal concepts to the microstrip patch antenna and generating numerous elements. The recursive generation of the Sierpinski carpet yields an efficient radiation pattern, surpassing other fractal antennas in adaptive beam forming. The efficiency of resonant frequencies increases with higher iterative geometries. The number of antenna iterations not only aids in reducing metal usage but also contributes to achieving a favorable reflection coefficient, resulting in cost savings [3].

The structure of the Sierpinski carpet fractal antenna comprises basic microstrip patch antennas printed on a substrate with a feed line (transmission line). One side of the substrate features a radiating patch, while the other side has a ground plane, as illustrated in Figure 1. Here, 'h' represents the substrate thickness, and 't' signifies the conductor thickness. Table 1 provides detailed specifications of the proposed antenna.

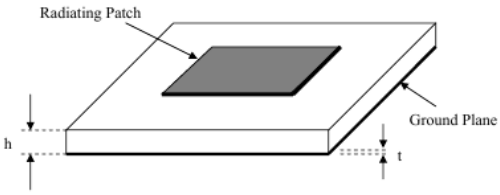


Figure 1 Structure of Sierpinski Carpet Antenna.

Sl. No	. Parameters	Value
1	Dielectric constant _	4.4
2	Substrate height	1.58mm
3	Loss tangent	0.0013
4	Square patch length	35.4mm
5	Square patch width	35.4mm
6	Ground plane length	70 mm
7	Ground plane width	70 mm

Table 1 Antenna Design Specifications

In this work, the microstrip line as a transmission line is used in the creation of a Sierpinski Fractal antenna. The microstrip, a prevalent form of strip line, comprises thin metal strips printed on a Printed Circuit Board (PCB). Essentially, it is a type of transmission line that is smaller and lighter than coaxial cables and waveguides. The proposed antenna design is simulated using the High Frequency Structure Simulator (HFSS) 15.0, a high-computing, full-wave electromagnetic (EM) field simulator for 3-D modeling of volumetric passive devices. HFSS provides insights into various 3-D electromagnetic problems, calculating matrix scattering parameters (S, Y, Z-Parameters), EM fields (near and far fields), and resonant frequency [4]. The microstrip Feeding Technique is employed, and a lumped port is used for excitation [5].

An artificial neural network (ANN) is a system modeled after the human brain [6, 7]. It comprises various types of simple, nonlinear functional blocks known as neurons, organized into layers interconnected by parallel synaptic weights. The ANN exhibits learning ability, where synaptic weights can be adjusted during the learning process to store information in the neural network. In the ANN model, a formula is not necessary for designing the microstrip antenna due to its empirical nature, relying on the observation of physical phenomena. In this work, an artificial neural network is developed for the design of a Sierpinski carpet fractal antenna. The obtained results are compared with simulation and experimental results, demonstrating that the ANN model is fast, accurate, efficient, and cost-effective for antenna modeling, simulation, and optimization.

II. Antenna Design using HFSS 15.0:

In the proposed design of the Sierpinski Fractal antenna, the chosen transmission line is the microstrip line, a prevalent type of strip line characterized by thin metal strips printed on a Printed Circuit Board (PCB). This form of transmission line is notably smaller and lighter in comparison to coaxial cables and waveguides.

The fundamental structure of the microstrip patch antenna feed line reveals that the microstrip patch antenna is imprinted on the substrate. This substrate includes a dielectric layer that separates the transmission line, a patch on one side, and a ground plane on the other side. The effective dielectric constant of the microstrip configuration typically ranges between 1 (air) and about 4 (substrate G-10 or FR-4), with the signal conductor exposed to air. The feeding system employs a microstrip transmission line where a microstrip patch directly connects with the strip line. The dimensions, specifically the length (L_{TX}) and width (W_{TX}), are meticulously calculated to ensure the impedance of the strip line matches that of the patch.

While various formulas describe the impact of altering the transmission line width or length, the ultimate priority lies in achieving optimal performance. Therefore, in the design process, the emphasis is on constructing a transmission line that yields favorable results within the desired frequency range. The width (Wi), length (Li), and effective constant (€e) of the microstrip line are determined by applying specific equations tailored to ensure the desired performance characteristics.

The width W_i of the radiating edge

$$W = \frac{c[(\varepsilon_r + 1)/2]^{-1/2}}{2f_r}$$

The length L_i is slightly smaller than ½ of wavelength in the dielectric. To calculate an initial value of L_i, the equation used is:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_e}} - 2\Delta L$$

Where

$$\Delta L = 0.412h\frac{\varepsilon_e + 0.300W/h + 0.264}{\varepsilon_e - 0.258W/h + 0.813}$$

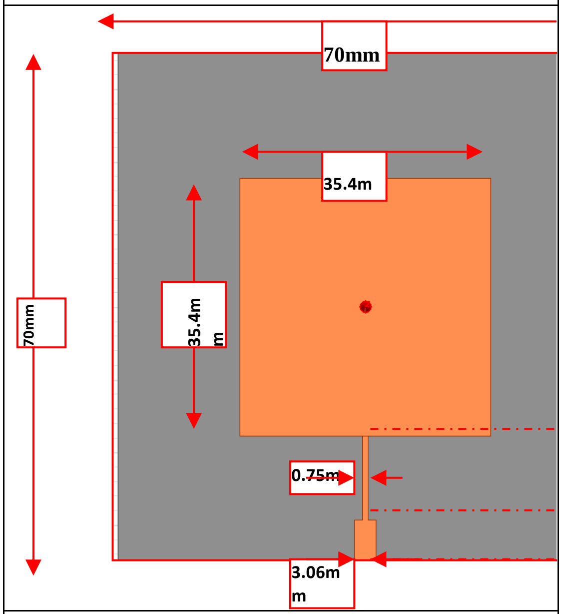
The effective constant of microstrip line is approximatedby

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\frac{1}{\sqrt{1 + 12h/W}}$$

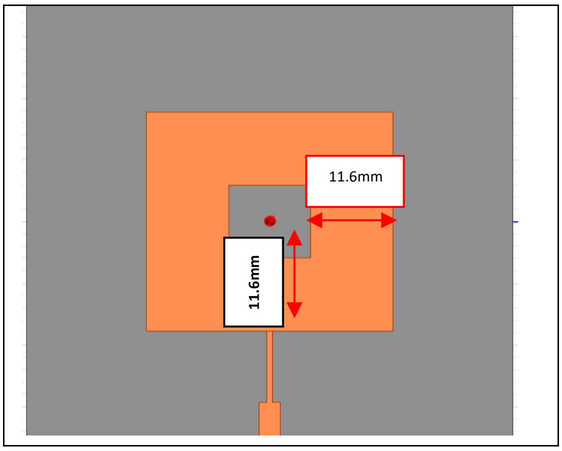
The proposed Sierpinski carpet patch antenna is designed to enhance the performance parameters and to reduce the size of the antenna .The Simulation of designed antenna is carried out using HFSS 15.0 software through the subsequent steps:

i. Primarily the substrate with dimensions of 70mm x 70mm is chosen, and then design of carpet antenna begin with square patch starting with base size of 35.4mm x 35.4 mm..The square patch of size 11.68mm x 11.68mm from the centre of base shape is removed to get the next iteration which results in dividing the base fractal antenna into a 3-by-3 grid. Since the size of the removed square is one third of base square further subdivide the remaining eight solid squares into nine equal squares and remove the center square of size 3.85mm x 3.85mm from each one to attain the next iteration. With the application of above process, the designed antenna is iterated for iteration zero, iteration one and iteration two illustrated in figure 2.1below
ii. Consequently the size of the antenna is reduced by due to fractal antennas by 10.22% in the first iteration and
iii. In the second iteration the antenna size is furtherreduced by approximately 22.11% resulting in furtherreduction of antenna size.
iv. Simulation results pertaining to Return loss(S_{11})&VSWRfor iterations zero, one & two are plotted as shown in figure 2.2 & 2.3

Sierpinski Carpet Fractal antenna dimension for Iteration Zero



Sierpinski Carpet Fractal antenna dimension for Iteration One



Sierpinski Carpet Fractal antenna dimension for Iteration Two

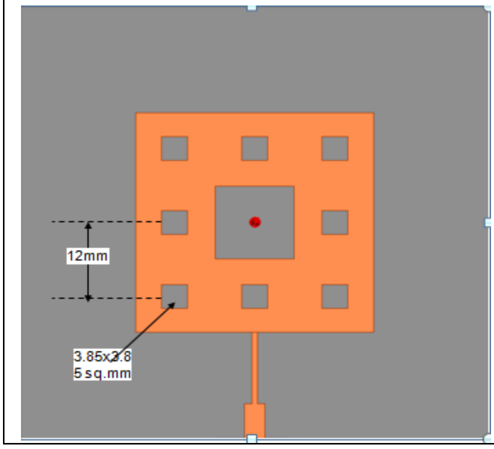


Figure 2.1 Sierpinski Carpet Fractal Antenna dimension for Various Iterations

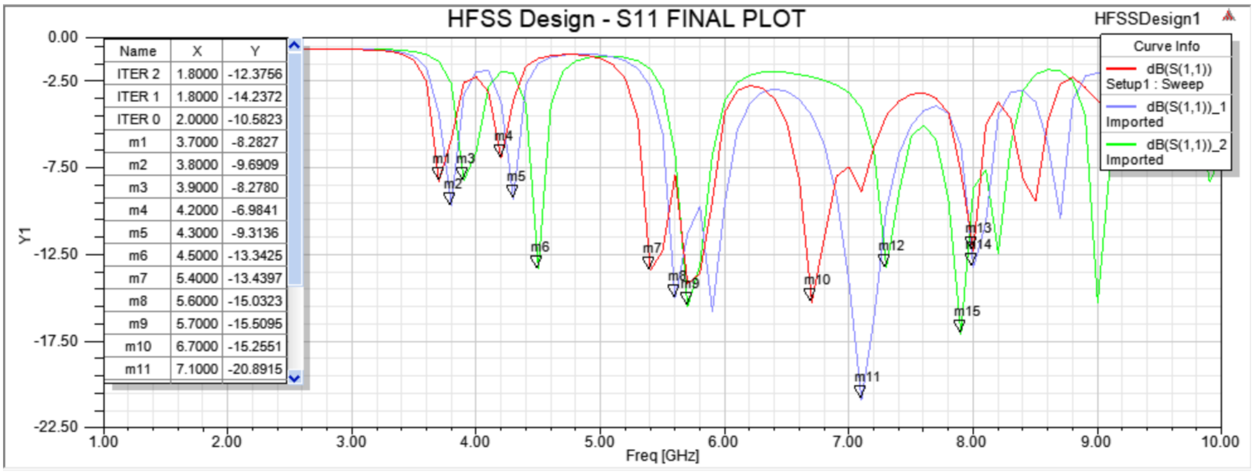


Figure 2,2 Consolidated Graph of S_{11} Vs Frequency up to 8 GHz for Iteration, Zero, One & Two of Sierpinski Carpet Fractal Antenna using HFSS 15.0

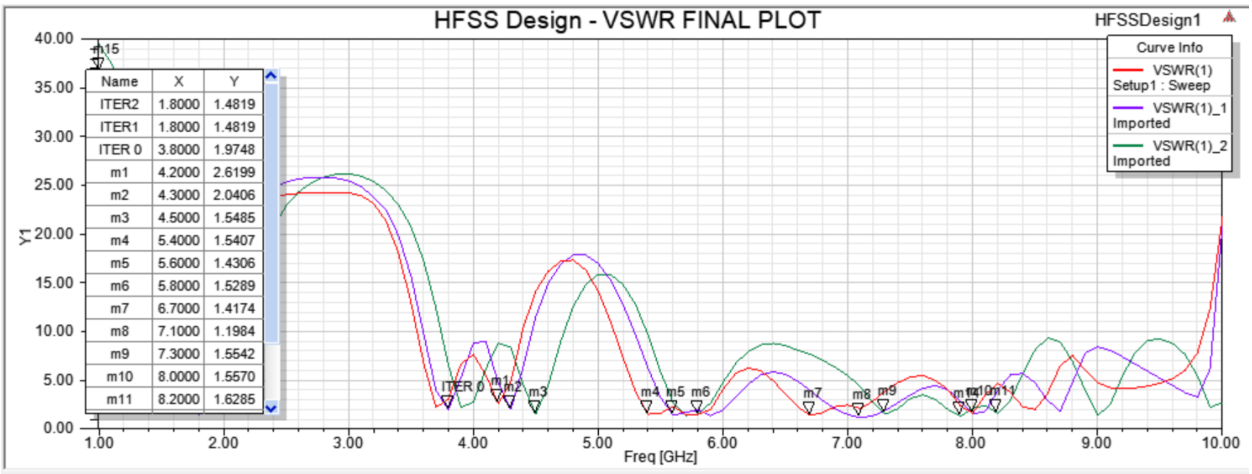


Figure 2.3 Consolidated Graph of VSWR up to 8 GHz for Iteration, Zero, One & Two of Sierpinski Carpet Fractal Antenna using HFSS 15.0

III. Antenna Design using Neural Network Model:

The neural network has become a widely recognized mathematical structure, forming the foundation of data-driven models [8-10]. These networks, inspired by the human brain, are a category of machine learning models characterized by interconnected nodes called neurons, organized into layers. Each neuron receives input, processes it through an activation function, and produces an output passed to the next layer.

Artificial Neural Networks (ANNs) can be trained from specific inputs to targets, adjusting parameters like the number of hidden layers, neurons in each layer, and the training algorithm. Weights and biases are automatically adjusted during training to minimize the error between the desired output and the network output. The initial step in the ANN technique involves generating a database of samples, a crucial aspect of Artificial Intelligence for effectively handling nonlinear data [11-13].

ANN architectures typically feature three logic layers: the input layer, hidden layer(s), and the output layer. Hidden layers, containing one or more neurons lie between the input and output layers. While different applications dictate specific configurations, most models include two or three hidden layers for estimating various mathematical functions. The model's performance relies on factors such as data collection, learning algorithm, weight initialization, and activation function. In antenna design, data is collected through simulations or experimental measurements, extending slightly beyond the model's operational range [15-17].

In the initial step, data samples are categorized into training (approximately 70%), testing (15%), and validation (15%) sets. The percentage allocation may vary based on specific application requirements [18-20]. Subsequently, the network size is determined, specifying the number of hidden layers and neurons in each layer. In the proposed ANN model, training occurs over 300 epochs with a batch size of 32. Weights and biases are updated using back propagation and gradient descent during training to achieve minimum mean squared error. Data for this work is collected by simulating a Sierpinski carpet antenna using HFSS software, leading to the selection of the best combination for the proposed model.

The model comprises a feed forward neural network with four layers: the first layer is a dense layer with 128 neurons, followed by two dense layers with 256 neurons each, and a final dense layer with 1 neuron. A Rectified Linear Unit (ReLU) activation function is applied to the first, second, and third layers, while no activation functions are used for the fourth and final layer. Activation functions play a crucial role in stimulating hidden nodes to produce a desirable output. In this implementation, the neural network predicts significant parameters, such as S_{11} dB and VSWR values, based on frequency (Freq [GHz]). The flow and structure of the neural network model are depicted in Figures 3a and 3b.

The design steps encompass loading the dataset, splitting it into input and output variables, normalizing the input data, splitting the dataset into training and test sets, defining the neural network model, compiling the model, training it on the training set, and evaluating the model on the test set.

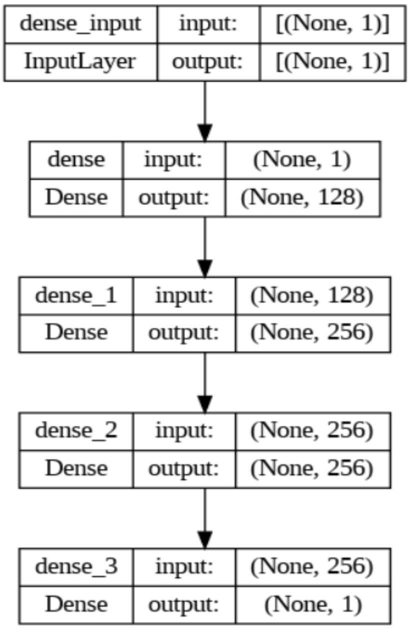


Figure 3a Neural Network Model Flow

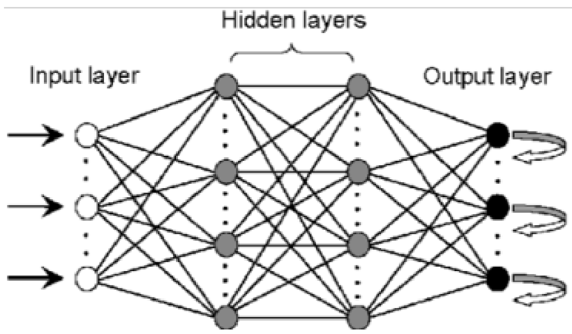


Figure 3b Neural Network Model

IV. Results & Discussion:

The S_{11} and VSWR values obtained through HFSS 15.0 software align closely with those from the Neural Network model, indicating effective optimization of the antenna dimensions using NN.

The proposed technique employs a Multilayer Feed Forward Artificial Neural Network as an approximate model for determining various antenna parameters. The results of the current study are highly convincing, demonstrating the suitability of the proposed technique in implementing neural models to predict accurate design parameters under specific conditions.

The S_{11} (Return Loss) and VSWR values of the Sierpinski carpet fractal antenna obtained through ANNs exhibit excellent agreement with the simulated values, as presented in Table 4a and 4b. This close correspondence between simulated and ANN results reinforces the validity of the proposed model.

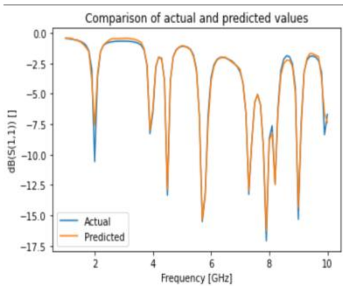


Figure 4a Graph of S11 Vs Frequency for Iteration Zero

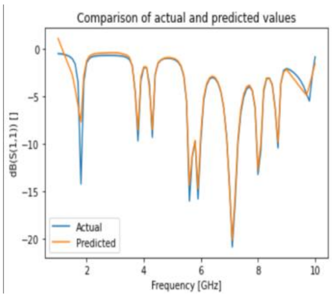


Figure 4b Graph of S_{11} Vs Frequency for Iteration One

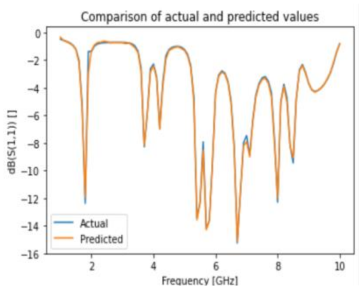


Figure 4c Graph of S_{11} Vs Frequency for Iteration Two

Sl. No	Iteration-0 S11 (dB)			Iteration-1 S11 (dB)			Iteration-2 S11 (dB)		
	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)
1.	2.0	-10.58	-9.63	1.8	-14.23	-9.70	1.8	-12.37	-11.92
2.	3.9	-8.27	-8.99	3.8	-9.69	-8.56	3.8	-8.28	-8.16
3.	4.5	-13.34	-12.86	4.3	-9.31	-8.52	4.3	-6.98	-6.98
4.	5.7	-15.50	-15.38	5.6	-11.32	-11.16	5.4	-14.19	-14.29
5.	7.3	-13.27	-12.98	7.1	-16.22	-15.37	7.1	-11.67	-11.53
6.	7.9	-17.09	-16.24	8.0	-13.23	-12.73	8.0	-12.29	-11.98

Table 4a: Simulated results for three iterations from the Plot for S_{11} (dB)

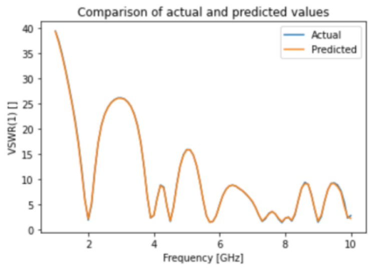


Figure 4d Graph of VSWR Vs Frequency for Iteration Zero

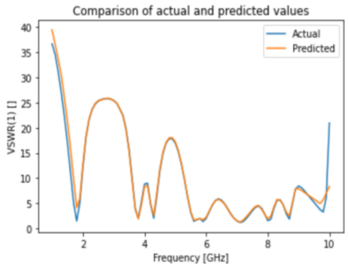


Figure 4e Graph of VSWR Vs Frequency for Iteration One

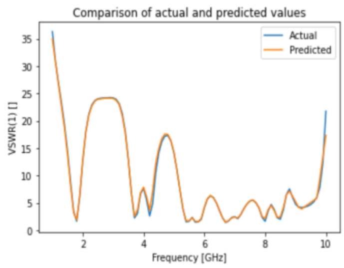


Figure 4f Graph of VSWR Vs Frequency for Iteration Two

Sl. No.	Iteration-0 VSWR			Iteration-1 VSWR			Iteration-2 VSWR		
	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)	Freq (GHz)	HFSS Result (Actual)	NN Result (Predicted)
1.	2.0	1.83	2.02	1.8	1.48	2.11	1.8	1.63	1.89
2.	3.9	2.25	2.07	3.8	1.97	1.95	3.8	2.25	2.28
3.	4.5	1.54	1.66	4.3	2.04	2.08	4.3	2.61	2.67
4.	5.7	1.40	1.41	5.6	1.74	1.77	5.4	1.48	1.64
5.	7.3	1.55	1.66	7.1	1.36	1.61	7.1	1.71	1.77
6.	7.9	1.32	1.50	8.0	1.55	1.92	8.0	1.64	2.06

Table 4b Simulated results for three iterations from the Plot for VSWR

V. Conclusion:

A compact multiband Sierpinski carpet fractal antenna, designed for operation between 2 GHz and 8 GHz using FR4 epoxy (er=4.4, dielectric loss tangent=0.02, substrate height=1.58mm) and excited with a 50Ω microstrip line, was modeled and simulated to enhance performance parameters. The results indicate that as iterations increase, the antenna size is reduced by 10.22% in the first iteration and 22.11% in the second iteration, making it the smallest for the chosen frequency bands. After the second iteration, the antenna size is approximately 33% smaller compared to the basic patch, with S_{11} parameter/return losses below -10 dB & optimized VSWR values for all iterations, achieving multiband properties.

In conclusion, Artificial Neural Networks prove to be the optimal choice for antenna design and optimization. The computational efficiency of Neural Network models surpasses traditional techniques such as Finite Element Method, Method of Moments, HFSS, CST Microwave Studio, etc. Once learning data is available through electromagnetic simulation or measurement, the neural model enables accurate and efficient optimization. Additionally, the design can be obtained within the training region. Thus, for antenna modeling, simulation, and optimization, Artificial Neural Networks emerge as a fast, accurate, and cost-effective solution.

References:

[1] B.B. Mandelbrot. 1983. „The Fractal Geometry of Nature", San Francisco

[2] W.L. Chen and G. M. Wang.. Small size edge-fed Sierpinski carpet microstrip patch antenna. PIERS C, Vol.3. 2008

[3] B.T.P.Madhav, D. Ujwala, J. Ravindranath Chowdary.,A. Siva Nagendra Reddy, Ch. Kranthi, Sachin Kumar Bidichandani, Design andanalysis of New Sierpinski Carpet Fractal antenna, Volume 2, No.3, May – June 2013, International Journal of Microwaves Applications, ISSN 2320 2599

[4] C.A.Balanis, "Antenna Theory - Analysis and Design", 2nd edition , John Wiley & Sons Inc., 1997.

[5] Ansys HFSS for Antenna Simulation, https://www.ansys.com/en-in/resource-center/application-brief/ansys-hfss-for-antenna-simulation

[6] Jagtar Singh Sivia, Amarpartap Singh,Tara Singh Kamal Design of Sierpinski Carpet Fractal Antenna using Artificial Neural Networks International Journal of Computer Applications (0975 – 8887) Volume 68– No.8, April 2013

[7] Jagtar Singh Sivia, Amar Partap Singh Pharwaha, and Tara Singh Kamal, Analysis and Design of Circular Fractal Antenna Using Artificial Neural Networks Progress In Electromagnetics Research B, Vol. 56, 251{267} , 2013

[8]Vandana Vikas Thakare, Pramod Singhal, Microstrip Antenna Design Using Artificial Neural Networks International Journal of RF and Microwave Computer-Aided

Engineering/Vol. 20, No. 1, January 2010, VC 2009 Wiley Periodicals, Inc. Int J RF and Microwave CAE 20:76– 86, 2010.

[9] Lahcen Aguni,SamiraChabaa, SaidaIbnyaich, Abdelouhab Zeroual, WLAN/WIMAX patch antenna design using artificial neural networks ,Cadi Ayyad University

[10] Samira Chabaa · Saida Ibnyaich Abdelouhab Zeroual, Design of a Symmetric CPW- Fed Patch Antenna for WLAN/WIMAX Applications Using ANN Lahcen Aguni · Abdessalam El Yassini © Springer Science+ Business Media, LLC, part of Springer Nature 2020

[11] L. Y. Xiao, W. Shao, F. L. Jin, and B. Z. Wang, \Multiparamete rmodeling with ANN for antenna design", *IEEE Trans. OnAntenna.and Propag.*, vol. 66, no. 7, pp. 3718{3723, 2018(DOI: 10.1109/TAP.2018.2823775).

[12] A. Landi, P. Piaggi, M. Laurino, and D. Menicucci, \Arti_cial neuralnetworks for nonlinear regression and classi_cation", in*Proc. of10th In. Conf. on Intell. Syst. Design and Appl.*, Cairo, Egypt, 2010,pp. 115{120 (DOI: 10.1109/ISDA.2010.5687280).

[13] S. Lek *et al*., \Application of neural networks to modelling nonlinear relationships in ecology", *Ecological Modell.*, vol. 90, no. 1,1996,pp. 39{52 (DOI: 10.1016/0304-3800(95)00142-5).

[14]. Wang, J. R., W. J. Liu, and M. S. Tong, "An artificial neural network based design of triple-band microstrip patch antenna for WLAN applications," 2020 IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO), 1-4, 2020.

[15] C. G. Christodoulou and A. Patnaik, \Neural networks for antennas", in *Morden Antenna Handbook*, C. A. Balanis, Ed. Wiley,2008,pp. 1625{1657 (ISBN: 9780470036341).

[16] M. Kayri, \Predictive abilities of Bayesian regularization and Levenberg-Marquardt algorithms in arti_cial neural networks:A comparative empirical study on social data", *Mathem. and Com-put. Appl.*, vol. 21, no. 2, 2016 (DOI:10.3390/mca21020020).

[17] V. S. Kushwah and G. S. Tomar, \Design and analysis of microstrip patch antennas using artifcial neural network", in *Trends in Research on Microstrip Antennas*, S. Chattopadhyay, Ed. Rijeka: IntechOpen,2017 (DOI: 10.5772/intechopen.69522).

[18] Vandana Vikas Thakare , Pramod Singhal, Artificial Intelligence in the Estimation of Patch Dimensions of Rectangular Microstrip Antennas Circuits and Systems, 2011, 2, 330-337

[19] Sukhdeep Kaur, Rajesh Khanna, Pooja Sahni, Naveen Kumar, Design and Optimization of Microstrip Patch Antenna using Artificial Neural Networks, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8, Issue-9S, July 2019

[20] Anuradha , Shweta Rani , Sushil Kakkar,,AN Ann Solution For Generalized Sierpinski Fractal Antenna, MATEC Web of Conferences DOI:10.1051/ 57, 01024 (2016) matec 57 conf/2016 01024 ICAET 2016