Resonant Frequency Analysis of Coaxial Feed Equilateral Triangular Microstrip Antenna Using Neural Network

Abhishek Tripathi[1*], P. K. Singhal[2], Vandana Vikas Thakare[3],

Department of Electronics, Madhav Institute of Technology and Science Gwalior, India
[1]abhishek5191@gmail.com
[2]pks_65@yahoo.com
[3]vandanavt_19@rediffmail.com

Abstract- **In this paper a novel technique is proposed for the estimation of resonant frequency of coaxial feed equilateral triangular microstrip patch antenna. The major advantage of the proposed approach is that, after proper training, proposed neural model completely bypasses the repeated use of complex iterative process for calculation of resonant frequency, thus resulting in an extremely fast solution with high accuracy. The Levenberg - Marquardt training algorithm of MLPFFBP-ANN (Multilayer Perceptron feed forward back propagation Artificial Neural Network) and RBF-ANN (Radial basis function Artificial Neural Network) have been used to implement the neural network model. For this purpose, the training and validation data is obtained by analysing the equilateral triangular microstrip antenna using Computer Simulation Technology Microwave Studio (CST MWS) Software. The results obtained using ANN models are found in agreement with the simulation findings, and also it is concluded that RBF network is more accurate and fast as compared to MLPFFBP network.**

Index Terms- **Artificial Neural Networks (ANN), Microstrip Antenna, Multilayer Feed Forward Networks, Resonant Frequency, and Radial Basis Function (RBF) Neural Networks.**

I. INTRODUCTION

Microstrip antennas due to their many attractive features have drawn attention of industries for an ultimate solution for wireless communication. The existing era of wireless communication has led to the design of an efficient, wide band, low cost and small volume antennas which can readily be incorporated into a broad spectrum of systems [1]. This needs very accurate calculation of various design parameters like resonant frequency in deciding the utility of an antenna.

ANN application to the field of microwaves is very recent. Artificial neural networks are parallel computational models, comprised of densely interconnected adaptive processing units [2]. These networks are fine-grained parallel implementations of nonlinear static or dynamic systems. A very important feature of these networks is their adaptive nature where "learning by example" replaces "programming" in solving problems. This feature makes such computational models very appealing in application domains where one has little or incomplete understanding of the problem to be solved, but where training data is available [3].

Accurate analysis of a microstrip line requires a cumbersome computational technique [4-9]. R. K. Mishra and A. Patnaik [10-11] had developed and tested an ANN model for predicting the design parameters (length and radius) of square and circular patch antenna using error back propagation algorithm for the training of a three-layer neural network. A.P. Singh and J. Singh [12] had also estimated the patch dimensions for the given values of the dielectric constant (ε_r) and substrate height (h) using feed forward neural network. D. Karaboga *et al* [13] had proposed neural computation of resonant frequency of electrically thin and thick rectangular microstrip antenna. A number of papers reported [14-18] preferably considering rectangular and circular geometry for the training of three-layer, feed forward back propagation (MLPFFBP) neural network.

In this paper, an attempt has been made to exploit the capability of artificial neural networks to calculate the resonating frequency of coaxial feed equilateral triangular microstrip patch antenna for specified range (10mm-30mm), using MLPFFBP with Levenberg-Marquardt training algorithm and RBF ANN.

II. DESIGN AND DATA GENERATION

The equilateral triangular microstrip patch antenna is made up of side length 'a' mm over a ground plane with substrate thickness 'h' mm having dielectric constant 'ε_r'.

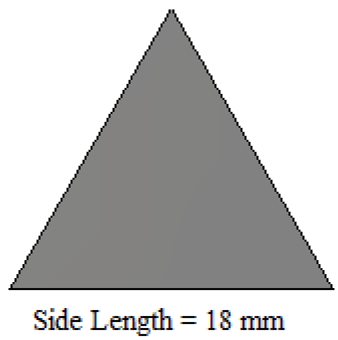

Figure 1: Equilateral triangular microstrip antenna

There are numerous substrates that can be used for the design of microstrip antennas and their dielectric constants are usually in the range of $2.2 < \varepsilon_r < 12$. Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound fields to minimize undesired radiation and coupling, and lead to smaller element [14]. The software used to model and simulate the proposed microstrip patch antenna is CST (Computer Simulation Technology) Microwave Studio Software [19].

As an example a coaxial feed equilateral triangular microstrip antenna of side length a=18 mm is simulated using CST Software which is resonating at 8.6207 GHz frequency. The dielectric substrate FR4 (Lossy) is used with dielectric constant (ε_r) = 4.3, and substrate thickness (h) =1.6 mm on a ground plane. Figure 1 shows the geometry of coaxial feed equilateral triangular microstrip antenna. By varying length of this geometry the training data for range (10mm-30mm) and test data for MLPFFBP and RBF- ANN has been generated. Figure 2 shows the return loss (S_{11}) vs. frequency curve for the example antenna.

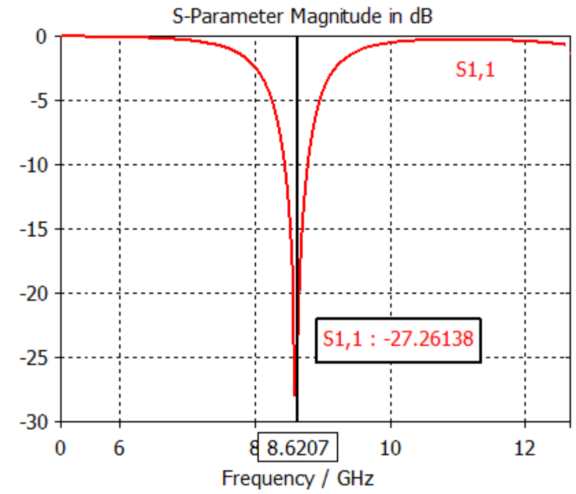

Figure 2: The return loss (S_{11}) in dB verses resonating frequency of the microstrip patch antenna

III. ANN MODEL FOR ANALYSIS OF MICROSTRIP PATCH ANTENNA

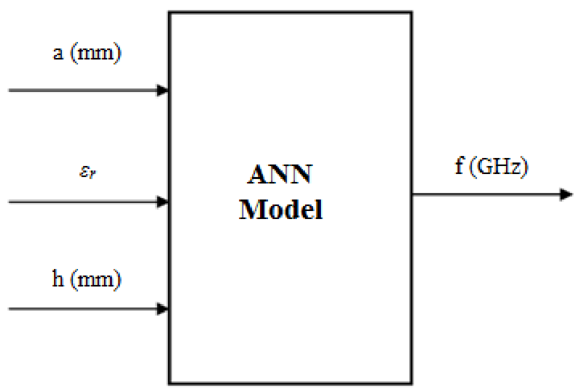

Figure 3: Analysis ANN Model [16].

The artificial neural network model has been developed for triangular microstrip patch antenna as shown in Figure 3. The feed forward network has been utilized to calculate the resonant frequency of the patch by inputting length of the patch 'a' (mm), substrate dielectric constant 'ε_r' and substrate height 'h'. This is defined as analysis ANN model. So by giving the side length of the equilateral triangular patch at input of the ANN model keeping all other parameters constant, resonating frequency of the patch is obtained at the output accurately, without doing complex calculations using empirical formulas.

IV. NETWORK ARCHITECTURE AND TRAINING OF MLPFFBP NEURAL NETWORK

MLP networks are feed forward networks trained with the standard back propagation algorithms to achieve the required degree of accuracy as shown in Figure 4. For the present work the multilayer perceptron feed forward back propagation neural network (MLPFFBP) [2, 3] is used with Levenberg-Marquardt training algorithm having two hidden layers. This network can be used as a general function approximator. It can approximate any function with a finite number of discontinuities, arbitrarily well given sufficient neurons in the hidden layer [20].

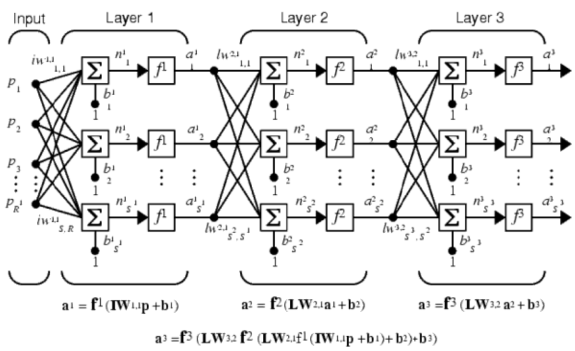

Figure 4: Three layer MLPFFBP network architecture [14]

In the present work input to the network is side length 'a' of patch antenna and output of the network is resonant frequency. In order to evaluate the performance of proposed MLPFFBP-ANN based model for the design of equilateral triangular microstrip antenna, simulation results are obtained using CST Software. 81 training patterns and 20 test patterns were generated to validate the model. The network has been trained for a specified range (10mm - 30mm).

During the training process the neural network automatically adjusts its weights and threshold values such that the error between predicted and sampled outputs is minimized [21, 22]. The adjustments are computed by the back propagation algorithm. The error goal is 1e-5 and learning rate is 0.1. The transfer function preferred is tansig and purelin in the architecture.

In Table 1 resonant frequencies obtained using CST Software and using L-M Algorithm for different test patterns are compared and the Mean Square Error has been calculated.

Table 1: Comparison of results obtained using CST and MLPFFBP-ANN using Levenberg-Marquardt Algorithm for the analysis of Resonant Frequency of Triangular Microstrip Antenna.

Side Length (mm)	f (GHz) CST	f (GHz) L-M ANN	Absolute Error	MSE
12.125	13.18	13.0223	0.1577	0.0249
13.125	12.14	12.2572	-0.1172	0.0137
14.125	11.32	11.4063	-0.0863	0.0074
15.125	10.7	10.6837	0.0163	0.0003
16.125	10.08	10.2395	-0.1595	0.0254
17.125	9.52	9.5821	-0.0621	0.0039
18.125	9	8.8574	0.1426	0.0203
19.125	8.52	8.4905	0.0295	0.0009
20.125	8.12	8.0292	0.0908	0.0082
20.825	7.86	7.877	-0.017	0.0003
21.125	7.76	7.7129	0.0471	0.0022
22.125	7.42	7.1038	0.3162	0.1
23.125	7.13	7.2693	-0.1393	0.0194
24.125	6.86	6.8545	0.0055	0
25.125	6.49	6.482	0.008	0.0001
26.125	6.25	6.2268	0.0232	0.0005
27.125	6.02	6.0076	0.0124	0.0002
28.125	5.83	5.8585	-0.0285	0.0008
28.825	5.68	5.6978	-0.0178	0.0003
29.125	5.62	5.6048	0.0152	0.0002

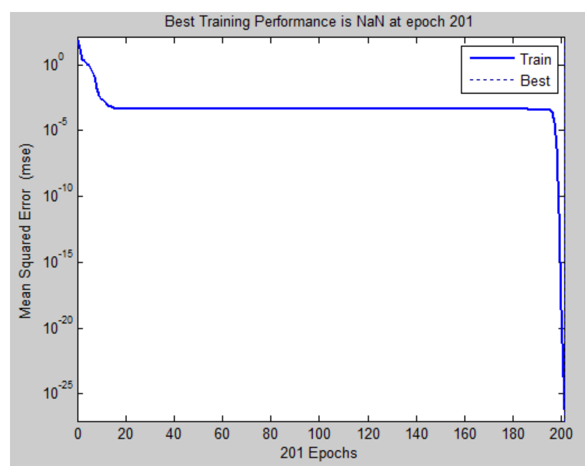

Figure 5: Number of epochs to achieve minimum mean square error level in case of MLPFFBP with LM as training algorithm.

Figure 5 shows the training performance of the developed neural model for proposed antenna using L-M training Algorithm. There are 80 input neurons in the input layer, 5 neurons in the first hidden layer and one output neuron in the output layer. Model is trained in 201 epochs and the training time was 26 sec.

IV. RBF NETWORKS

Radial basis function network is a feed forward neural network with a single hidden layer that uses radial basis activation functions for hidden neurons. RBF networks are applied for various microwave modelling purposes. The RBF neural network has both a supervised and unsupervised component to its learning. It consists of three layers of neurons - Input, hidden and output. The hidden layer neuron represents a series of centres in the input data space. Each of these centres has an activation function, typically Gaussian. The activation depends on the distance between the presented input vector and the centre. The farther the vector is from the centre, the lower is the activation and vice versa [14]. The generation of the centres and their widths is done using an unsupervised k-means clustering algorithm. The centres and widths created by this algorithm then form the weights and biases of the hidden layer, which remain unchanged once the clustering has been done [3]. A typical RBF network structure is given in Figure 6. The parameters c_{ij} and ε_{ij} are centres and standard deviations of radial basis activation functions. Commonly used radial basis activation functions are Gaussian and Multiquadratic.

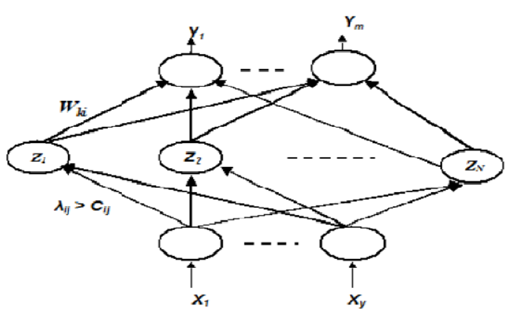

Figure 6: RBF network architecture [12]

Given the input x, the total input to the i[th] hidden neuron γ_i is given by-

$$\gamma_i = \sqrt{\sum_{j=1}^{n}\left(\frac{x_j - c_{ij}}{\lambda_{ij}}\right)} \quad ;\ i=1, 2, 3,\ldots\ldots, N$$

Where N is the number of hidden neurons. The output value of the i[th] hidden neuron is $z_{ij}=\sigma(\gamma_i)$ where $\sigma(\gamma_i)$ is a radial basis function. Finally, the output of the RBF network are computed from hidden neuron is given by-

$$y_k = \sum_{i=0}^{N} w_{ki} z_{ki}$$

Where w_{ki} is the weight of the link between the i[th] neuron of the hidden layer and the k[th] neuron of the output layer. Training parameters w of the RBF network include w_{k0}, w_{ki}, c_{ij}, λ_{ij}, k=1,2,....,m, i=1,2.....,N, j=1,2,....,n.

In the RBF network, the spread constant was chosen as 1.0, which gives the best accuracy. The network was trained with 81 samples and tested with 20 samples. In the structure there is 1 input and 1 output was used for the analysis ANN. RBF networks are more fast and effective as compared to MLPFFBP for proposed antenna design. The RBF network automatically adjusts the number of processing elements in the hidden layer till the defined accuracy is reached. The training algorithm is unsupervised k-means clustering algorithm.

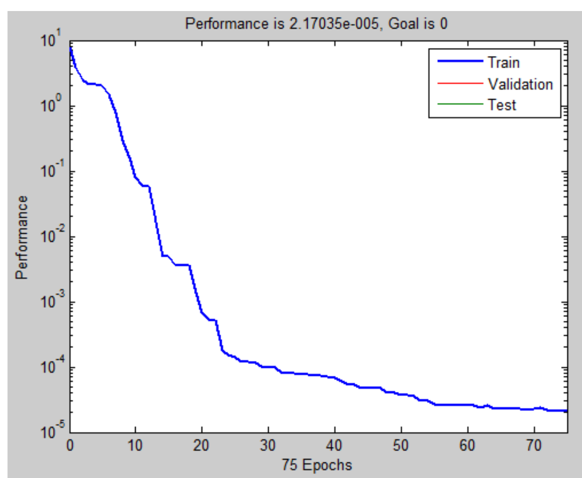

Figure 7: Number of epochs to achieve minimum mean square error level in case of RBF Network.

Figure 7 shows the training performance of the developed neural model using RBF Network. Model is trained in 75 epochs. It is clear that RBF Network is much faster than feed forward networks since RBF network is trained in fewer epochs than feed forward network (201 epochs) using L-M Algorithm.

Table 2: Comparison of results obtained using CST and RBF-ANN Algorithm for the analysis of Resonant Frequency of Triangular Microstrip Antenna.

Side Length (mm)	f (GHz) CST	f (GHz) RBF ANN	Absolute Error	MSE
12.125	13.18	13.2027	-0.0227	0.0005
13.125	12.14	12.1368	0.0032	0
14.125	11.32	11.3295	-0.0095	0.0001
15.125	10.7	10.6625	0.0375	0.0014
16.125	10.08	10.0655	0.0145	0.0002
17.125	9.52	9.5975	-0.0775	0.006
18.125	9	9.0229	-0.0229	0.0005
19.125	8.52	8.5487	-0.0287	0.0008
20.125	8.12	8.1322	-0.0122	0.0001
20.825	7.86	7.8567	0.0033	0
21.125	7.76	7.7506	0.0094	0.0001
22.125	7.42	7.4176	0.0024	0
23.125	7.13	7.1006	0.0294	0.0009
24.125	6.86	6.8496	0.0104	0.0001
25.125	6.49	6.4993	-0.0093	0.0001
26.125	6.25	6.2478	0.0022	0
27.125	6.02	5.9965	0.0235	0.0006
28.125	5.83	5.8214	0.0086	0.0001
28.825	5.68	5.6815	-0.0015	0
29.125	5.62	5.6264	-0.0064	0

In Table 2 resonant frequencies obtained using CST Software and using RBF Network for different test patterns are compared and the Mean Square Error has been calculated, which is almost zero for all the test patterns.

V. RESULTS

It has been established from Table 1 that the Levenberg-Marquardt algorithm is the optimal model to achieve desirable values of speed of convergence. It has been observed that 201 epochs are needed to reduce MSE level to a low value of 10^{-25} for three layers MLPFFBP with Levenberg-Marquaradt (LM) training algorithm and transig as a transfer function. Achievement of such a low value of performance goal (MSE) indicates that trained ANN model is an accurate model for designing the microstrip patch antenna. It is observed that tansig is most suitable transfer function for the present work.

As the work signifies RBF ANN is also used to model the coaxial feed triangular microstrip patch antenna. It is established from Table 2 that RBF is giving results not only more accurate but fast also, the presented RBF network has performed training in less epochs than in MLPFFBP. So it is concluded that RBF architecture is better from MLPFFBP and its accuracy is up to 99.92%.

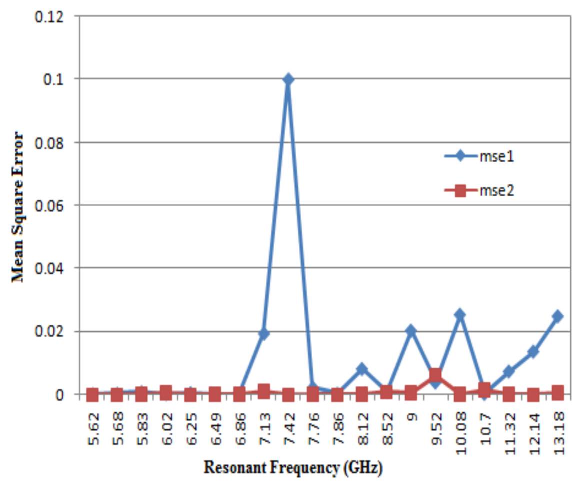

Figure 8: Graph showing variation of Mean Square Error with Frequency (GHz) for Levenberg-Marquardt Algorithm (mse1) and RBF ANN Algorithm (mse2)

Comparison of Mean Square Error (mse1) Using L-M Algorithm given in Table 1 and Mean Square Error (mse2) using RBF-ANN Algorithm given in Table 2 for the analysis of Resonant Frequency of Triangular Microstrip Antenna is shown in graph (Figure 8). It is clear from the graph that accuracy achieved using RBF Networks is much better than the accuracy achieved using Levenberg-Marquardt training Algorithm of MLPFFBP Networks.

VI. CONCLUSION

In this paper, coaxial feed equilateral triangular microstrip patch antenna using MLPFFBP and RBF-ANN has been modelled. The results obtained with the present technique are closer to the experimental results generated by simulating a large no of triangular antennas using CST software on the FR4 (Lossy) substrate. The paper concludes that results obtained using present ANN techniques are quite satisfactory and followed the experimental trend and also that RBF is giving the best approximation to the design as compared to MLPFFBP.

VII. REFERENCES

[1] Balanis, C. A., *Antenna Theory*, John Wiley & Sons, Inc., 1997.
[2] Haykin, S., *Neural Networks*, 2nd edition, pHI, 2003.
[3] Hassoun, M. H., *Fundamentals of Artificial Neural Networks*, Chapter 8, New Delhi, Prentice Hall of India, 1999.
[4] R. Garg, and S. A. Long, "Resonant frequency of electrically thick rectangular microstrip antennas", *Electron. Lett.*, vol. 23, no. 21, pp. 1149-1151, 1987.
[5] J. P. Damiano and A. Papiernik, "A simple and accurate model for the resonant frequency and the input impedance of printed anrennas, *Int. J. Microwave. Millimeter-Wave Comp. Aided Eng.*, vol. 3, no. 4, pp. 350-361, 1993.
[6] M. Kara, "The resonant frequency of rectangular microstrip antenna elements with various substrate thicknesses", *Microw. Opt. Technol. Lett.*, vol. 11, no. 2, pp. 55-59, 1996.
[7] M. D. Deshpande and M. C. Bailey, "Input impedance of microstrip antennas", *IEEE Trans. on Antennas Propagation,* vol. 30, no. 4, pp. 645-650, 1982.
[8] W. F. Richards, Y. T. Lo and D. D. Harrison, "An improved theory for microstrip antennas and applications", *IEEE Trans. on Antennas Propagation,* vol. 29, no. 1, pp. 38-46, 1981.
[9] S. F. Peik, G. Coutts and R. R. Mansour, "Application of neural networks in microwave circuit modelling", *IEEE Canadian Conference*, vol. 2, pp. 928-931, 1998.
[10] R. K. Mishra and A. Patnaik, "Neural network-based CAD model for the design of square patch antennas", *IEEE Trans. on Antennas and Propagation,* vol. 46, no. 12, pp. 1890-1891, 1998.
[11] R. K. Mishra and A. Patnaik, "Design of circular microstrip antenna using neural network", *Inst. Electron Telecommun. (IETE) Eng. J. Res*., vol. 44, no. 1&2, pp. 35-39, 1998.
[12] A. P. Singh and J. Singh, "On the design of a rectangular microstrip antenna using artificial neural network", *IE (I) Journal-ET*, vol. 90, pp. 20-25, 2009.
[13] D. Karaboga, K. Guney, S. Sagiroglu and M. Erler, "Neural computation of resonant frequency of electrically thin and thick rectangular microstrip antenna", *Microwaves, Antennas and Propagation, IEEE Proc.* Vol. 146, no. 2, pp. 155-156, 1999.
[14] Thakare V. V., Singhal P. K., "Bandwidth Analysis by introducing slots in microstrip antenna design using ANN", *Progress In Electromagnetic Research M*., vol. 9, 107-122, 2009.
[15] Zhang, Q. J. and K. C. Gupta, *Neural Networks for RF and Microwave Design*, Artech House Publishers, 2000.
[16] Qi-Jun Zhang, *Senior Member, IEEE*, Kuldip C. Gupta, *Fellow, IEEE,* and Vijay K. Devabhaktuni, *Student Member, IEEE* "Artificial Neural Networks for RF and Microwave Design—From Theory to Practice", *IEEE Transaction on Microwave Theory and Techniques*, vol. 51, no. 4, April 2003.
[17] Lukasz Sorokosz, Wlodzimierz Zieniutycz, "Artificial Neural Networks in Microwave Components and Circuit Modelling", *Przeglad Elektrotechniczny (Electrical Review),* ISSN 0033-2097, R. 88 NR 6/2012.
[18] M.Naser-Moghaddasi, Pouya Derakhshan Barjoei, Alireza Naghsh, "A Heuristic Artificial Neural Network for Analyzing and synthesizing Rectangular Microstrip Antenna", *International Journal of Computer Science and Network Security*, vol. 7, no.12, pp. 278-281, Dec. 2007.
[19] CST (Computer Simulation Technology) Microwave Studio Suit Software 2010.
[20] S. Rajasekaran, G. A. Vijayalakshmi Pai, "Neural Networks, Fuzzy Logic, and Genetic Algorithms: Synthesis and Application", Prentice Hall of India Limited, New Delhi, 2006.
[21] MATLAB Software, version 7.8.0, user manual.
[22] Rudra Pratap, "Getting started with MATLAB 7", Oxford, 2005.