Neural Network Model for Aperture Coupled Microstrip Antennas

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Abstract – **This paper presents a Neural Network model for the design of an Aperture Coupled Microstrip Antenna (ACMSA) for a desired frequency between 1.5 GHz to 8.9 GHz. The results obtained from the proposed method are compared with the results of IE3D and are found to be in good agreement The advantage of the proposed method lies with the fact that the various parameters required for the design of an ACMSA at a particular frequency of interest can be easily extracted without going into the rigorous time consuming, iterative design procedures using a costly software package.**

Keywords – **Neural Networks, Aperture Coupled Microstrip Antennas.**

I. INTRODUCTION

In response to the fast change in modern communication system due to the high requirement of compactness of antenna size, increase in bandwidth, reconfigurable antennas etc., antenna parameters keep on changing which makes designing of antenna difficult, cumbersome and time consuming as parameters have to be calculated using lengthy analysis and design cycles. Review of many papers shows that in present days neural network models are used extensively for wireless communication engineering, which eliminates the complex and time consuming mathematical procedures of designing antennas, like method of moments (MOM) [1-10].

Various ANN models are developed for determining resonant frequencies of microstrip patches of various shapes like rectangular, triangular etc. [2 – 3] and [8 – 9]. In [7, 10], several designs have been presented using ANN techniques. A comprehensive review of applications of ANN in microwave engineering and different types of methods to develop the ANN models is discussed in [10].

Many a times it is found that the design of an antenna at a desired frequency of interest is a cumbersome iterative process especially when the characteristics of the antenna depend on a large number of variable input parameters. As a test case, an Aperture Coupled Microstrip Antenna (ACMSA) is considered since it involves determination of several parameters and justifies the use of ANN for its design. As such this work develops an ANN model which gives all the parameters of an aperture coupled microstrip antenna for a desired frequency range between 1.5 GHz to 8.9 GHz.

This particular range of frequencies is chosen for designing this model, as most of the usable frequencies lie within this range.

An aperture-fed patch antenna was first proposed by Pozar [17] and allows the substrate height to be increased, which greatly enhances bandwidth. The use of reactive loading on microstrip patches was investigated by Davidson [18] among others, and has shown that dual resonances can be created with such a structure.

II. ANTENNA DESIGN

An ACMSA is shown in Fig. It consists of two substrates separated by a ground plane. The top substrate (ε_r^a) contains the radiating element, and the bottom substrate (ε_r^b) contains the microstrip feed line. A small aperture is cut in the ground plane to allow coupling from open circuited microstrip feedline to the radiating patch.

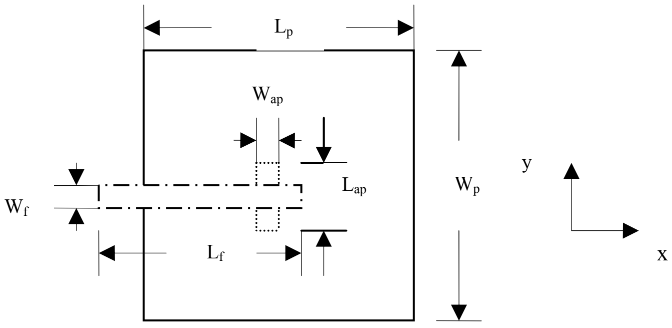

Fig.1. Aperture coupled patch antenna

The parameters on which resonant frequency of the antenna depends upon are shape and dimensions of the radiating element, dimensions of the ground plane, shape and size of the aperture, dimensions of feedline, position of feedline and the dielectric constants of the two substrates [11-16].

An ACMSA can be designed for different frequencies on a suitable dielectric substrate. The shape of radiating element and aperture are chosen to be rectangular. The output parameters determined during the design of an antenna are:

(a) Dimensions of ground plane (L_g, W_g)
(b) Dimensions of aperture (L_{ap}, W_{ap})
(c) Dimensions of radiating element (L_p, W_p)
(d) Dimensions of feed (L_f, W_f)
(e) Feed position (X, assuming Y=0)

III. DEVELOPMENT OF NEURAL NETWORK MODEL

The model developed has one input layer, one hidden layer and one output layer as shown in Fig.2. The model is trained with 831 training patterns of input/output data, which are obtained by interpolating 250 simulated data, where the input parameter is resonant frequency and the output parameters are L_g, W_g, L_{ap}, W_{ap}, L_p, W_p, L_f, W_f and X with Y=0

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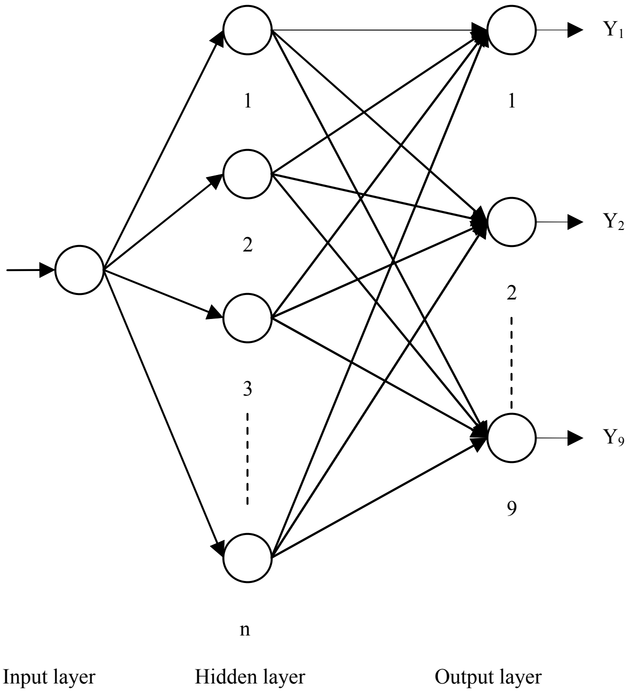

Fig.2. Feed Forward Network

The training procedure consists of the following steps:

- Developing training patterns: Using the IE3D software which is based on moment of methods, the structure is analyzed for various resonant frequencies which form the input parameter and corresponding computed parameters (dimensions of the patch, dimensions of ground plane etc.) form the output targets. An input pattern and an output target give a training pattern together. All the training patterns form the training set.
- Formation of neural network model: We create a neural network consisting of an estimated number of layers and of an estimated number of neurons in the layers. The number of resonant frequencies for which the network is trained gives the number of neurons in the input layer and the number of computed parameters determines the number of neurons in the output layer. The number of hidden layers and hidden neurons has to be estimated. Initial synaptic weights and biases are set randomly.
- Training neural network model: During the training, input patterns are successively introduced into the inputs of the neural network, and synaptic weights are changed to reach desired output responses. The training is completed when the network reacts properly to all input patterns from the training set.
- Verifying neural model: We introduce such patterns to the inputs of the neural model, which differ from the input patterns of the training set. Exploiting the numerical model, correctness of the response of the network is verified. If the response is incorrect, additional training patterns have to be prepared, and training is repeated over a larger training set.
- Using neural model. The trained neural network produces output responses with a sufficient accuracy both for training patterns and for interlaying input patterns. Therefore, the neural network can replace the numerical model.

The trained neural network provides a special approximation where the exact results of the numerical analysis, which are hidden in the training patterns, are used for neural computation and give us directly all the required design parameters of an antenna for a desired frequency. In this way, a computationally modest neural network model can replace a numerical analysis for parameters differing from training patterns.

Here, when the network is ready after training, it is used to determine the output parameters of an ACMSA at a desired resonant frequency. The output parameters achieved from the network can be used for designing the aperture coupled microstrip antenna. The performance of the prepared model is discussed below.

V. RESULTS AND DISCUSSION

The model developed is trained with data, which are collected from IE3D simulation software, a commercial simulator, based on Method of Moments. Keeping the dielectric constants of both the substrate fixed at 4.4, the model is developed using feed forward Back Propagation algorithm [7 -8]. The purpose of selection of FR4 dielectric material lies with its low cost and easy availability.

The network is trained with back propagation algorithm, which has one hidden layer with 1000 neurons whose performance goal was taken as 10^{-5} and number of epochs 1200 and 1800. For 831 input/ output training samples, the network requires almost 1hr for training and % Error is found to lie within 0.4% to 4.6 %. Where % Error is calculated by the following formula:

$$\%Error = \frac{Simulated\ \ Value - ANN\ Value}{Simulated\ \ Value} \cdot 100$$

The network is tested for 16 random frequencies. Those input frequencies are compared with the resonant frequencies obtained from IE3D software for the corresponding output parameters given by the network. The results are tabulated in Table 1 for all the parameters, which also compare the simulated value with the one obtained from the ANN model. From Table 1 one can estimate that the prepared network or model is accurate enough for determining the various design parameters of an ACMSA operating between 1.5 GHz and 8.9 GHz. The above mentioned characteristics of the ACMSA obtained from the ANN model are found to be acceptable within the error limit. Finally with the help of data obtained from ANN model, a prototype model of the ACMSA is fabricated and tested. The test results are then compared with the results obtained from the IE3D for one particular set of data. The results obtained from NN model, IE3D and experiment are found to be in good agreement with each other as shown in Table 2. The fabricated antenna is finally tested using Vector Network Analyzer and the return loss characteristic is compared with the simulated value in Figure 3. From Figure 3, it is concluded that the prepared model can be used for wideband applications. As such error ranging from 0.4 % - 4.6% will not create problem while designing. Thus this model can be very well used for design of ACMSA for a dielectric constant of the substrates as 4.4.

By increasing the number of training patterns and the hidden layers of the network, the network can be made more accurate. In the proposed work a simple interpolation technique is used to add up more number of training data by interpolating more number of points lying between 250 simulated data obtained from the IE3D simulation, to get 831 data for training.

VI. CONCLUSION

The trained networks are very useful as they give all the design parameters of the ACMSA for any desired resonant frequency. A distinct advantage of neural computation is that, after proper training, a neural network completely bypasses repeated use of complex iterative processes for new design presented to it. This work can be further extended for variable dielectric constants and for different shapes of the radiating patch.

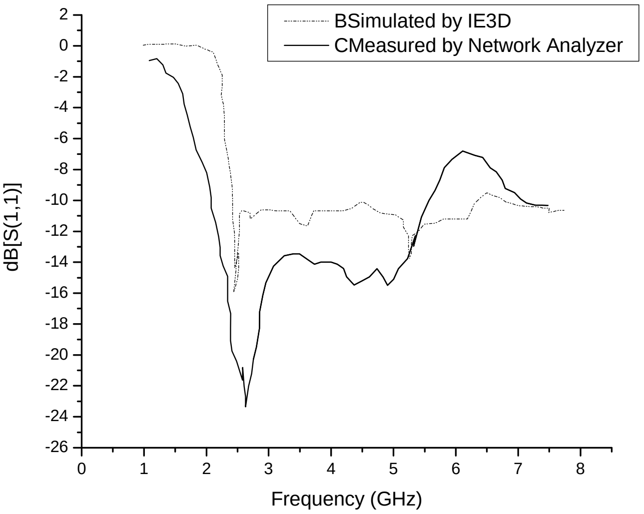

Fig.3 Measured and simulated result of the designed antenna using Vector Network Analyzer and IE3D software simultaneously.

TABLE1. ERROR MEASUREMENT FOR THE SIMULATED f_r FROM IE3D AND THE NN MODEL USING BACK PROPAGATION ALGORITHM FOR 1200 EPOCHS

S.N.	Input Parameters									Output Parameters		
	L_g (mm)	W_g (mm)	L_{ap} (mm)	W_{ap} (mm)	L_p (mm)	W_p (mm)	L_f (mm)	W_f (mm)	X (mm)	f_r (GHz) (IE3D)	f_r (GHz) (NN)	% Error
1.	43.4444	43.5523	1.3743	1.6447	19.6988	19.7474	21.7156	3.3951	-9.0053	1.50667	1.5	0.4426
2.	36.3539	35.9003	1.0639	1.5597	4.5883	5.2139	17.6200	3.1327	-6.2377	1.77000	1.8	-1.6882
3.	25.5028	25.8656	1.6807	0.6492	4.6640	4.8845	14.5795	3.4049	-4.1872	2.424	2.44	0.6600
4.	25.0828	25.0128	1.8692	1.3025	4.6732	5.0847	13.9366	3.0301	-5.0788	2.47600	2.5	-0.9691
5.	21.3062	22.9408	2.4865	0.9889	5.5733	5.2514	12.7635	2.6159	-4.9215	2.84000	2.8	1.4085
6.	18.5387	18.7397	1.5849	1.6178	5.1194	4.5159	9.8822	2.5889	-3.7573	3.17400	3.18	1.8903
7.	16.3207	16.4964	1.2620	1.1059	4.8519	4.7399	9.5730	3.3382	-3.9479	3.54600	3.5	1.2972
8.	12.8473	12.8384	1.3717	2.1552	4.5900	3.7139	5.0183	2.2293	-2.5430	4.18200	4.2	-0.4304
9.	10.4488	9.2082	1.5683	0.7888	3.9768	4.9156	4.5180	2.1308	-2.1509	4.96667	5.2	4.6979
10.	7.6665	7.9438	0.6035	0.6635	5.0888	5.2486	4.8196	3.3441	-1.4489	6.23000	6.2	0.4815

TABLE2. COMPARISON SHOWING RESONANT FREQUENCIES OBTAINED FROM DIFFERENT METHODS

S.N	Frequency Obtained From ANN Model (GHz)	Frequency Obtained From IE3D (GHz)	Frequency Obtained From Prototype Model Fabricated (GHz)
1.	2.44	2.424	2.46

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