Design of a Circularly Polarized Elliptical Patch Antenna using Artificial Neural Networks and Adaptive Neuro-Fuzzy Inference System

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Abstract—**In the present paper, a circularly polarized elliptical patch antenna is designed using artificial neural networks (ANN) and adaptive neuro-fuzzy inference system (ANFIS). The resonant frequency and gain are taken as the input while the radius of semi-major axis and heights of the substrate are taken as the outputs. From the numerical results, it is observed that the errors in the output parameters are less in case of an ANFIS model as compared to that of an ANN model. With ANFIS model, a parametric study with different types and numbers of membership functions is also presented.**

I. INTRODUCTION

The recent development in the wireless communication has given rise to the need of low weight, small size, cheap and easily installable antennas. Microstrip patch antennas fulfill all such requirements. They are low profile antennas and are suitable for planar as well as non-planar surfaces. Depending upon the resonant frequency and the excited mode, microstrip antennas are capable of providing linear as well as circular polarization. Circular polarization is preferred in many practical applications, such as radar, communication, navigation system, etc. Circular polarization may be obtained by using multiple feeds [1] or by altering the shape of microstrip patch antenna [2]. It is reported in the open literature [3] that, an elliptical patch antenna provides circular polarization with only a single feed. However, elliptical geometry is the least analyzed geometry, due to the involvement of complex Mathieu functions in the mathematical analysis. The conventional techniques for designing and analyzing elliptical microstrip antennas are difficult to implement and are time consuming. In order to avoid the complexity of the conventional techniques, two soft computing techniques viz. artificial neural networks [4] and adaptive neuro-fuzzy inference system [5] are proposed in the present paper.

In [6], the synthesis problem of an elliptical microstrip patch antenna is discussed, considering single material with resonant frequency as the output. The present work aims at the comparison of the results obtained using ANN and ANFIS for circularly polarized elliptical patch antenna. Moreover, for ANFIS, a study of effect of number of membership functions and type of membership functions is also carried out. Section II discusses the development of the CAD model and Section III presents the results and the analysis.

II. ELLIPTICAL PATCH ANTENNA

Figure 1 shows the geometry of the elliptical patch antenna under consideration, where a is the semi-major axis, b is the semi-minor axis and a_{eff} is the effective semi-major axis. In order to obtain circular polarization, the feed was located at 45° with respect to the major axis. By changing the feed location, the relative amplitudes of x directed and y directed electric fields is changed. When the feed is moved towards the major axis, it enhances the excitation of current flowing parallel to major axis and thus results in greater amplitude of E_x [7]. The elliptical antenna is inherently elliptical polarized antenna but when the antenna is coupled through a feed located at 45° azimuthal angle then circular polarization is obtained.

III. DEVELOPMENT OF THE CAD MODEL

In the present paper, for designing of elliptical patch antenna, two CAD models have been developed. The first model is based on ANN, while the second model is based on ANFIS concept. The results obtained using both the models are then compared.

As shown in Figure 2, the resonant frequency (f_r) and the gain (g) are taken as the input, while the radius of major-axis (a) and height of the substrate (h) are considered as the outputs.
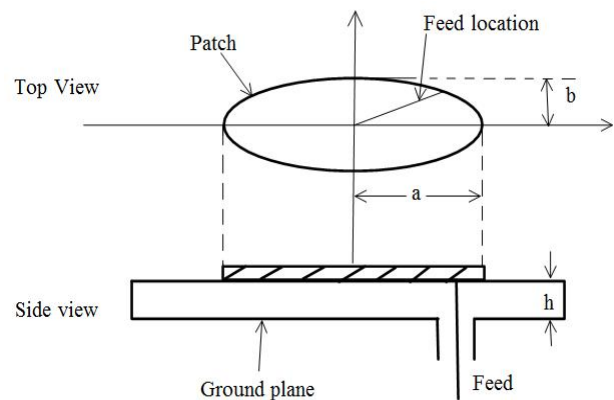

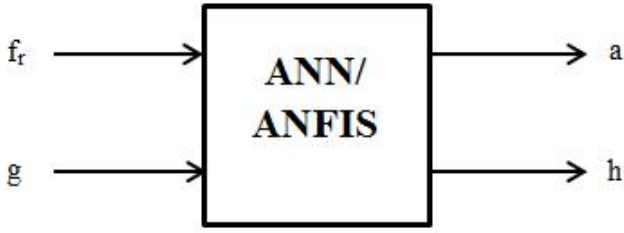Figure 1. Elliptical patch antenna geometry under consideration

Figure 2. CAD Model for design of Elliptical Patch Antenna

ANNs are non-linear mapping structures, which are principally based onthe functions of the human brain. It consists of simple computational units called neurons, which are highly interconnected.The connections between the neurons are called as links. Every link has a weight parameter associated with it. Each neuron receives stimulus from the neighboring neuron connected to it, process the information and produces an output. The structure of ANN consists of an input layer, an output layer and one or many hidden layer/s. The number of hidden layers and number of neurons therein does not follow any thumb rule. However, they should be chosen judiciously so that the network is neither under trained nor over-trained. In the present paper, radial basis function type artificial neural network (RBF-ANN) is used to obtain the geometrical parameters of elliptical patch antenna using spread constant = 1. Different values of spread constants were verified but the most appropriate was spread constant = 1.

ANFIS is a very powerful soft-computing technique which combines the best features of Fuzzy Inference Systems (FISs) and ANN. By using a hybrid learning procedure, the ANFIS can construct an input-output mapping based on both human knowledge (in the form of fuzzy if-then rules) and stipulatedinput-output data pairs. Also ANFIS combines the gradient descent method and the least squares estimate (LSE) to identify its parameters. LSE is used in the forward pass while gradient descent is used in the backward pass.ANFIS structure consists of five different layers. The first layer is the input data which is fuzzified and the neuron values are represented by parameterized membership function. The second layer deals with calculation of activation of fuzzy rules via differentiable T-norms. The third layer realizes a normalization operation over the matching values of the rule. The fourth layer multiplies the normalized activation level and the output of the respective rule while the last and the fifth layer produce the output by an algebraic sum. Unlike ANN, ANFIS does not require selection of number of layers a priory. However, the only structural limitation is that, it should be feed-forward type. The present ANFIS model employed '*gbell*' type membership function. Also, five membership functions have been considered after rigorous simulations.

III. RESULTS AND DISCUSSION

For the purpose of training and testing, data set was generated by simulating elliptical patch antenna using full wave solver (FWS). For obtaining circular polarization,

eccentricity 'e' was kept constant as suggested in [7]. Out of the total generated data set, 70% data was utilized in training the networks, while remaining 30% data was used in testing the models.

Sample results for two different materials, Rogers3003 and FR4 for both ANN and ANFIS models are presented in Table I and Table II, respectively. In case of ANFIS model, the study of different membership functions (*gbell*, *gauss*, *pimf*) was also carried out and the results are summarized in Table III. Moreover, for ANFIS model, the effect of number of membership function on the result is summarized in Table IV.

The formula used for calculating the percentage error is:

$$\% \text{ Error} = \frac{\text{Approximate value} - \text{Actual value}}{\text{Actual value}} \times 100 \tag{1}$$

where, the value obtained from FWS is considered as actual value and that obtained from the CAD model (ANN and ANFIS) is considered as approximate value.

TABLE I
RESULTS OF RBF-ANN AND ANFIS MODEL FOR FR4 MATERIAL

Input		Output (FWS)		% Error (RBF-ANN)		% Error (ANFIS)	
f_r (GHz)	g (dBi)	a (mm)	h (mm)	a	h	a	h
1.14	0.04	36.5	0.762	0.05	0.65	0	0
1.19	0.03	35.0	0.762	0.20	0.52	0	0
1.69	1.33	24.5	1.524	0.36	0.91	0	0
1.22	2.44	34.0	1.524	0.64	0	0	0

TABLE II
RESULTS OF RBF-ANN AND ANFIS MODEL FOR ROGERS3003 MATERIAL

Input		Output (FWS)		% Error (RBF-ANN)		% Error (ANFIS)	
f_r (GHz)	g (dBi)	a (mm)	h (mm)	a	h	a	h
1.55	4.37	33	0.508	1.3	0.78	0	0
1.25	5.54	40	0.762	0.52	0.26	0.32	0
1.18	5.65	43	0.762	0.72	0.39	0.18	0.13
1.08	6.83	46	1.524	0.04	1.15	0.04	0.06

TABLE III
STUDY OF MEMBERSHIP FUNCTIONS IN ANFIS MODEL FOR INPUT-OUTPUT PAIRS OF TABLE II

% Error for '*gbell*'		% Error for '*gauss*'		% Error for '*pimf*'	
a	h	a	h	a	h
0	0	0	0	0	0
0.32	0	0.2	0	0.22	0
0.18	0.13	0.09	0	0.09	0.13
0.04	0.06	0	0.06	0.02	0.06

TABLE IV
EFFECT OF CHANGE IN NUMBER OF MEMBERSHIP FUNCTIONS IN ANFIS
MODEL FOR FR4 MATERIAL

Input		Output (FWS)		% Error for 3 membership functions		% Error for 5 membership functions	
f_r (GHz)	g (dBi)	a (mm)	h (mm)	a	h	a	h
1.14	0.04	36.5	0.76	0.11	0.45	0	0
1.19	0.03	35.0	0.76	0.03	0.35	0	0
1.69	1.33	24.5	1.52	0.03	0.18	0	0
1.22	2.44	34.0	1.52	0.03	0.07	0	0

IV. CONCLUSION

Comparison of results generated using RBF-ANN and ANFIS shows that the percentage error obtained in ANFIS model is less as compared to that obtained by RBF-ANN model. For the present design, '*gauss*' type of membership function gives relatively better results. Also, in case of ANFIS, as the number of membership function increases, the error reduces. The ANFIS model requires less time and is accurate in prediction. Thus, for antenna problems, ANFIS technique is simple, easy to apply, very useful and efficient once trained.

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